SEC1205 - ELECTRONIC CIRCUITS - I

UNIT 2 - TRANSISTOR BIASING CIRCUITS ANS SMALL SIGNAL ANALYSIS OF BJT AMPLIFIERS.

Biasing- Types of biasing- DC equivalent circuit of BJT- Load Line-DC and AC Load Line Analysis – Hybrid Model of BJT- Hybrid Model Analysis of CE, CB, CC - Calculation of Input Impedance, Output Impedance, Voltage Gain, Current Gain using hybrid model- Approximate Model of BJT- CE, CB and CC Analysis- Small signal equivalent circuit of BJT- Small Signal Analysis of CE, CB and CC.

2.1 Introduction

The transistor can be operated in three regions : cut-off, active and saturation by applying proper biasing conditions as shown in the Table 1.1

Region of Operation	Emitter Base Junction	Collector Base Junction
Cut-off	Reverse biased	Reverse biased
Active	Forward biased	Reverse biased
Saturation	Forward biased	Forward biased

Table 1.1 Operating regions and bias conditions

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 nothing but the biasing of the transistor. Because d.c. voltages are used to bias the transistor, biasing is known as **d.c.** biasing of the transistor.

The process of forcing the transistor into the active region is called biasing.

When we bias a transistor we establish a certain current and voltage conditions for the transistor. These conditions are known as operating conditions or **d.c. operating point** or **quiescent point**. 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.

2.1.1 Q point and maximum undistorted output

It has been observed that under certain input signal conditions, the location of Q point on the load line may cause some portion of the output signal to be clipped and shown in figure 1.1(a), 1.1 (b) and undistorted output is shown in figure 1.1 (c).

2.1.2 Factors affecting stability of Q point

1. *Inherent variations of transistor parameters.* We know that the collector current for a common-emitter transistor amplifier is given by the relation,

$$I_C = \beta \cdot I_B + (I + \beta) \cdot I_{CO}$$

where β = Common-emitter current gain,

I_B = Base-current and

I_{CO} = Reverse saturation current.

2. *Variation in parameter values of transistors of the same type.*

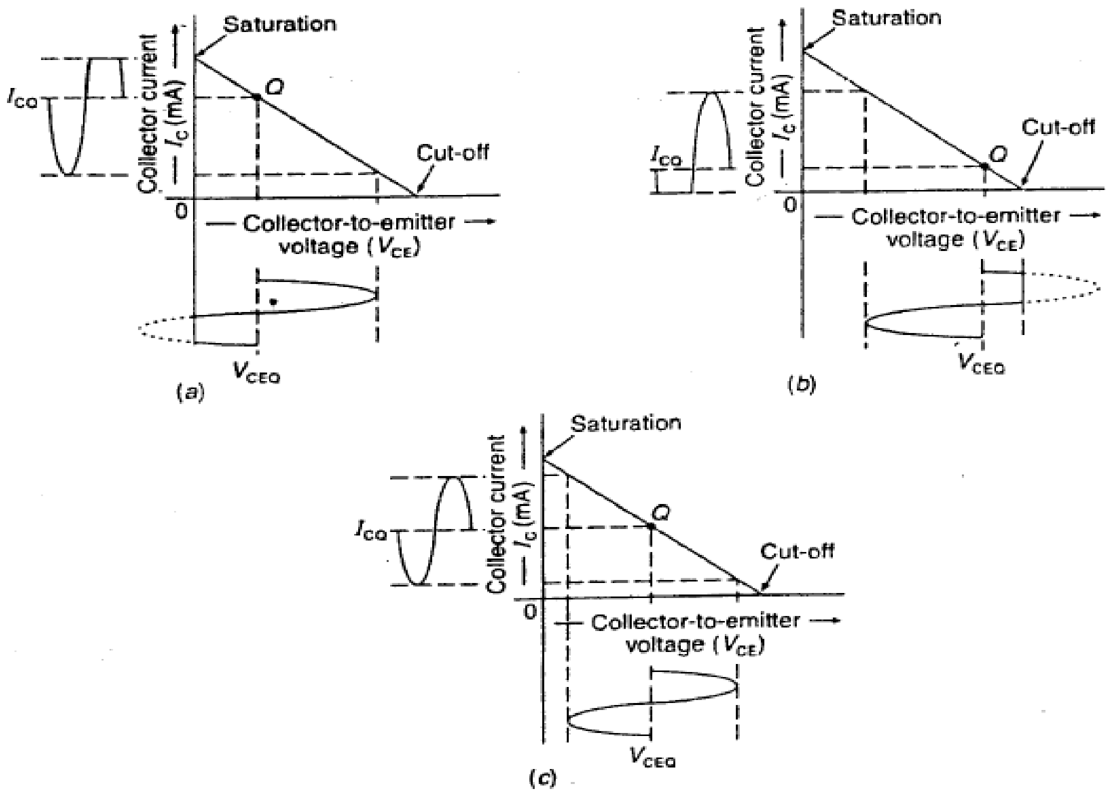


Fig. 1.1 Q point and maximum undistorted output

2.2 Need for biasing

- To fix the operating point at the middle of active region.
- Stabilize the collector current against temperature variations.
- Operating point independent of transistor parameters

2.2.1 Conditions for Proper Biasing of a Transistor

- Proper dc value of the collector current.
- Proper value of V_{BE} (0.7 V for silicon and 0.3 V for germanium) at any instant.
- Proper value of V_{CE} (1 V for silicon and 0.5 V for germanium) at any instant.

The conditions 1 and 2 make sure that base-emitter junction of a transistor shall remain forward biased, during all parts of the signal. The condition 3 makes sure that collector-base junction of input a transistor shall remain reverse biased at all instants.

2.3 Stability Factor

The stability factor may be defined as the rate of change of collector current with respect to the reverse saturation current keeping the common-emitter current gain (β) and base current (I_B) as constant. Mathematically, the stability factor,

$$S = \frac{dI_C}{dI_{CO}}$$

The stability factor is a measure of *bias stability* of a transistor circuit. It will be interesting to know that a *higher value of stability factor indicates poor stability, whereas a lower value indicates good stability.*

The stability factor may also be expressed alternatively by using the relationship between base current (I_B), collector current (I_C) and reverse saturation current (I_{CO}). We know that the value of collector current in a transistor is given by the relation,

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

Differentiating the above expression with respect to I_C,

$$1 = \frac{d(\beta \cdot I_B)}{dI_C} + \frac{d(1+\beta)\, I_{CO}}{dI_C}$$

$$= \beta \times \frac{dI_B}{dI_C} + (1+\beta)\frac{dI_{CO}}{dI_C} \qquad \text{... (Assuming } \beta \text{ as constant)}$$

$$= \beta \times \frac{dI_B}{dI_C} + (1+\beta)\frac{1}{S} \qquad \text{...} \left(\because\ S = \frac{dI_C}{dI_{CO}} \right)$$

$$\therefore \quad S = \frac{1+\beta}{1-\beta\left(\dfrac{dI_B}{dI_C}\right)} \qquad \text{... }(i)$$

The above expression is a general expression, which is very useful for determining the stability factor (S) of any biasing circuit. It can be done first by finding the relationship between the base current and collector current and then using the above equation to determine the value of stability factor.

2.3.1 Additional stability factors

However, there are two other factors, which affect the stability of the d.c. biasing circuit, namely *variation in the base current (I_B) and the current gain (β)* with *temperature*. The stabilities, due to these two quantities, are measured by the stability factors S' and S'' respectively.

The stability factor S' may be defined as *the rate of change of collector current (I_C) with respect to the base current (I_B) keeping the common-emitter current gain (β) and reverse saturation current (I_{CO}) as constant.* Mathematically, the stability factor,

$$S' = \frac{dI_C}{dI_B}$$

Therefore it is more convenient to define the stability factor S' as the rate of change of collector current with respect to the base-to-emitter voltage *i.e.*,

$$S' = \frac{dI_C}{dV_{BE}}$$

Similarly, the stability factor, S'' may be defined as *the rate of change of collector current (I_C) with respect to current gain (β) keeping the base current (I_B) and reverse saturation current (I_{CO}) as constant*. Mathematically, the stability factor,

$$S'' = \frac{dI_C}{d\beta}$$

2.4 Methods of Transistor Biasing

Following are the most commonly used methods for biasing the transistors.

1. Base bias (also called fixed bias).
2. Base bias with emitter feedback (also called emitter feedback bias).
3. Base bias with collector feedback (also called collector feedback bias).
4. Voltage divider bias (also called self bias).
5. Emitter bias.

2.4.1 Base Bias

Figure 1.2 (*a*) shows a base bias circuit for a NPN transistor. The base bias circuit is also known as fixed bias circuit. In this case, the circuit uses two d.c. supplies namely V_{BB} and V_{CC}. But a more practical method is to use a single d.c. supply (V_{CC}) as shown in Fig. 1.2 (*b*). In this case, both the base and collector resistance are connected to the positive side of the V_{CC} supply. To simplify the circuit diagram, we may omit the battery symbol and replace it by a line termination with a voltage indicated as shown in Fig. 1.2 (*c*).

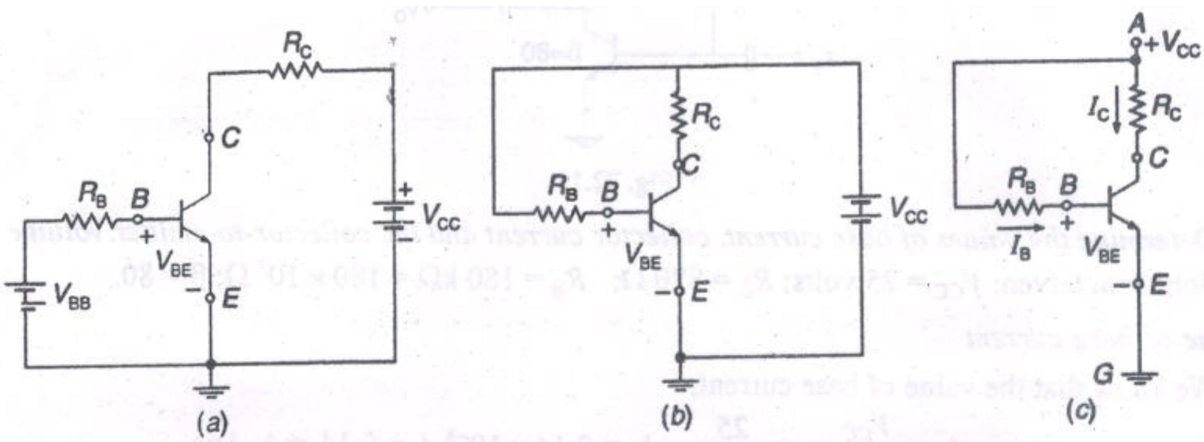


Fig. 1.2 Base bias circuit.

Now we shall determine the d.c. bias currents and voltages in the base and collector of the transistor. First of all, consider the base-emitter circuit loop (AFBEGA) in the base bias circuit. Applying Kirchoff's Voltage Law for the given loop,

$$I_B \cdot R_B + V_{BE} - V_{CC} = 0$$

or the base current, $$I_B = \frac{V_{CC} - V_{BE}}{R_B} \quad \text{... } (i)$$

Since the supply voltage V_{CC} and the base-emitter voltage (V_{BE}) have fixed values of voltage, the selection of base bias resistor (R_B) fixes the value of the base current. The equation (*i*) may be simplified, if we neglect the value of base-emitter voltage, because it is usually very small as compared to the value of V_{CC}. Thus the approximate value of base current,

$$I_B = \frac{V_{CC}}{R_B} \quad \text{... } (\because V_{CC} >> V_{BE})$$

Now consider the collector-emitter circuit loop (AFCEGA) in the base bias circuit. Applying Kirchoff's Voltage Law for this loop,

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

$$\therefore \quad V_{CE} = V_{CC} - I_C \cdot R_C \quad \text{... } (ii)$$

The above equation gives the voltage drop across the collector-emitter terminals of the transistor. The value of collector current is given by the relation,

$$I_C = \beta \cdot \frac{V_{CC}}{R_B} = \frac{V_{CC}}{R_B/\beta} \quad \text{... } (iii)$$

The above relation shows that the collector current is β times greater than the base current and is not at all dependent on the resistance of the collector circuit.

It may be noted from the equations (*ii*) and (*iii*) that the values of collector current (I_C) and collector-to-emitter voltage (V_{CE}) are dependent on β. But β is strongly dependent upon temperature. It means that collector current and collector-to-emitter voltage of a base bias circuit (which sets the *Q*-points of a transistor) will vary with the change in value of β due to variation in temperature. It means that it is impossible to obtain a stable *Q*-point in a base-bias circuit. Because of this fact, the base bias is never used in amplifier circuits. However, it is used in digital circuits, where the transistor is used as a switch between saturation and cut-off-regions.

2.4.1.1 Stability Factor of Base-Bias Circuit

We have already discussed in chapter on transistors that the collector current of a transistor in common emitter configuration is given by the relation,

$$I_C = \beta \cdot I_B + (1 + \beta) I_{CO}$$

Differentiating this equation with respect to I_{CO}

$$\frac{dI_C}{dI_{CO}} = 0 + (1 + \beta)$$

$$\therefore \quad S = 1 + \beta$$

Example . *Figure 22.11 shows a fixed bias circuit using an NPN transistor circuit.*

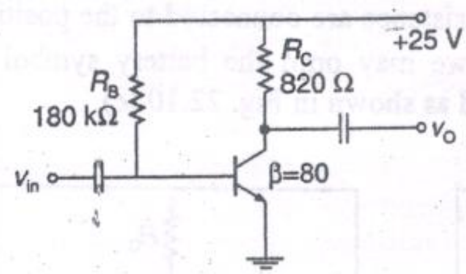


Fig. 22.11.

Determine the values of base current, collector current and the collector-to-emitter voltage.

Solution. Given: $V_{CC} = 25$ volts; $R_C = 820\ \Omega$; $R_B = 180\ k\Omega = 180 \times 10^3\ \Omega$; $\beta = 80$.

Value of base current

We know that the value of base current,

$$I_B = \frac{V_{CC}}{R_B} = \frac{25}{180 \times 10^3}\ A = 0.14 \times 10^{-3}\ A = 0.14\ mA\ \textbf{Ans.}$$

Value of collector current

We know that the value of collector current,

$$I_C = \beta \cdot I_B = 80 \times 0.14 \times 10^{-3} = 11.2 \times 10^{-3}\ A$$
$$= 11.2\ mA\ \textbf{Ans.}$$

Value of collector-to-emitter voltage

We know that the value of collector-to-emitter voltage,

$$V_{CE} = V_{CC} - I_C \cdot R_C = 25 - (11.2 \times 10^{-3}) \times 820\ V$$
$$= 25 - 9.2 = 15.8\ V\ \textbf{Ans.}$$

2.4.2 Base Bias with Emitter Feedback

Fig 1.3 shows the circuit of a base bias with emitter resistor. The emitter resistor provides better bias stability than the base bias circuit, as discussed in Art. 1.2 .

When the current gain (β) increases (say due to temperature), the collector currents in the circuit also increases. It produces more voltage across the emitter resistor (R_E), which reduces the voltage drop across the base resistor. This causes the base current to decrease. As a result of this, the collector current also decreases. Thus the increase in collector current, due the increase in value of current gain, is compensated.

It is evident from the above discussion that the emitter resistor provides compensation for the variation in the value of current gain (β) by reducing the base current. Thus the emitter resistor is called emitter feedback resistor.

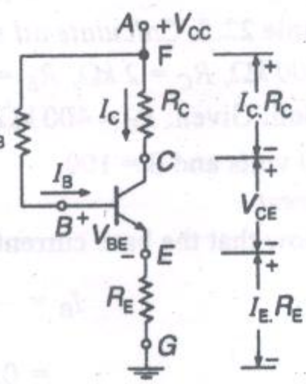


Fig. 1.3 . Base bias with emitter feedback.

The emitter feedback circuit is effective only if the emitter resistor is as large as possible. But in actual practice, it is not possible because the emitter resistor is kept relatively small to avoid the transistor to operate in saturation.

Let us now determine the d.c. bias currents and voltages in the base, collector and emitter of the transistor. First of all, consider the base-emitter circuit loop (AFBEGA) in the d.c. bias circuit. Applying Kirchoff's Voltage Law to the base-emitter circuit loop,

$$V_{BE} + I_E \cdot R_E - V_{CC} + I_B \cdot R_B = 0$$

Substituting I_E equal to $(\beta + 1)\, I_B$ in the above equation, and solving it for the base current,

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \frac{V_{CC} - V_{BE}}{R_B + \beta \cdot R_E} \quad \text{... (Taking } \beta + 1 \approx \beta)$$

$\therefore$ Collector current,

$$I_C = \beta \cdot I_B = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta} = \frac{V_{CC}}{R_E + R_B/\beta} \quad \text{... } (\because V_{CC} >> V_{BE})$$

It is evident from the above equation that if the value of emitter resistor (R_E) is made very large as compared to the value of (R_B/β), the bias circuit is independent of variations in current gain (β). But in actual practice, it is not possible to make the emitter resistor large enough to compensate for the effects of current gain (β) without saturating the transistor. Thus some compromise will have to be made between the bias stability and the performance of the circuit. Now consider the collector-emitter circuit loop (AFCEGA) in the d.c. bias circuit. Applying Kirchoff's Voltage Law to this loop.

$$V_{CE} + I_E \cdot R_E - V_{CC} + I_C \cdot R_C = 0$$

Replacing I_E with I_C in the above equation and solving it for the voltage across collector-emitter of a transistor,

$$V_{CE} = V_{CC} - I_C\,(R_C + R_E) \quad \text{... } (i)$$

The voltage measured from emitter to ground,

$$V_E = I_E \cdot R_E = R_C \cdot R_C \quad \text{... } (\because I_E \approx I_C)$$

The voltage measured from collector to ground,

$$V_C = V_{CC} - I_C \cdot R_C$$

Notes: 1. The voltage, at which the transistor is biased, may also be calculated by the relation,

$$V_{CE} = V_C - V_E$$

2. The saturation value of collector current may be obtained by using the equation (i) and its value is given by the relation,

$$I_{C\,(sat)} = \frac{V_{CC} - V_{CE}}{R_C + R_E} = \frac{V_{CC}}{R_C + R_E} \quad \text{... (if } V_{CC} >> V_{CE})$$

2.4.2.1 Stability Factor of Base Bias with Emitter Feedback

We have already discussed in the last article that if we apply Kirchoff's Voltage Law to the base-emitter circuit loop shown in Fig. 1.3, then we get

$$V_{BE} + I_E \cdot R_E - V_{CC} + I_B \cdot R_B = 0$$

Replacing I_E with $I_B + I_C$ in the equation and solving it for base current,

$$I_B = \frac{V_{CC} - V_{BE} - I_C \cdot R_E}{R_E + R_B}$$

Differentiating the above expression with respect to I_C,

$$\frac{dI_B}{dI_C} = \frac{0 - 0 - 1 \cdot R_E}{R_E + R_B} = -\frac{R_E}{R_E + R_B}$$

Substituting the value of dI_B/dI_C in the general expression for stability factor,

$$S = \frac{1+\beta}{1 - \beta\left(\frac{dI_B}{dI_C}\right)} = \frac{1+\beta}{1 - \beta\left(-\frac{R_E}{R_E + R_B}\right)} = \frac{1+\beta}{1 + \beta \cdot \frac{R_E}{R_E + R_B}}$$

Example *Figure shows the base-bias with emitter feedback resistor circuit. The transistor has a current gain (β) of 80. Determine the value of collector current, collector-to-emitter voltage and stability factor. Assume V_{BE} = 0.7 V.*

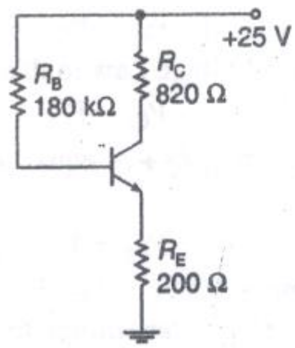


Fig.

Solution. Given: $\beta = 80$; $V_{BE} = 0.7$ volt; $V_{CC} = 25$ volts; $R_C = 820\ \Omega$; $R_B = 180\ \text{k}\Omega = 180 \times 10^3\ \Omega$ and $R_E = 200\ \Omega$.

Value of collector current

We know that the value of collector current,

$$I_C = \frac{V_{CC} - V_{BE}}{R_E + \frac{R_B}{\beta}} = \frac{25 - 0.7}{200 + \frac{180 \times 10^3}{80}}\ \text{A}$$

$$= 9.9 \times 10^{-3}\ \text{A or } 9.9\ \text{mA}\ \textbf{Ans.}$$

Value of collector-to-emitter voltage

We also know that the value of collector-to-emitter (or ground) voltage,

$$V_{CE} = V_{CC} - I_C \cdot R_C = 25 - (9.9 \times 10^{-3}) \times 820\ \text{V}$$

$$= 25 - 8.12 = 16.88\ \text{V}\ \textbf{Ans.}$$

2.4.3 Base Bias with Collector Feedback

Figure 1.4 shows a d.c. bias circuit in which the base resistor (R_B) is connected to the collector terminal of a transistor rather than to the V_{CC} supply as in a base bias circuit. Here, the collector voltage provides the bias-emitter junction. The resistor R_B acts as a feedback resistor. It provides a very stable Q-point by reducing the effect of variations in current gain (β).

Let us now determine the d.c. bias currents and voltages in the base and collector of the transistor. First of all, consider the base-emitter circuit loop (AFBEGA) in the d.c. bias circuit. Applying Kirchoff's Voltage Law to the base-emitter circuit loop,

$$V_{BE} - V_{CC} + (I_B + I_C)R_C + I_B \cdot R_B = 0$$

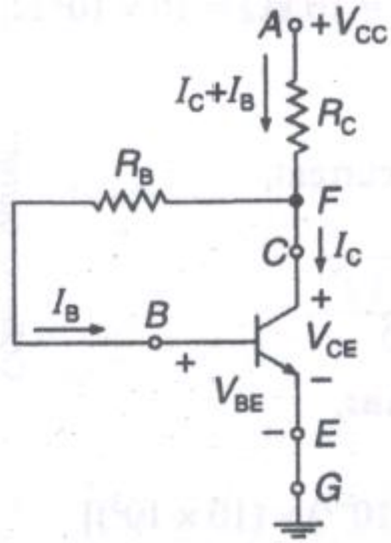


Fig. 1.4 . Base bias with collector feedback.

Substituting I_C equal to $\beta \cdot I_B$ in the above equation and solving for the base current,

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_C} = \frac{V_{CC} - V_{BE}}{R_B + \beta \cdot R_C} \quad \text{... (Taking } \beta + 1 = \beta\text{)}$$

and the collector current,

$$I_C = \beta \cdot I_B = \frac{V_{CC} - V_{BE}}{R_C + R_B/\beta} = \frac{V_{CC}}{R_C + R_B/\beta} \quad \text{... } (\because V_{CC} >> V_{BE})$$

Now consider the collector-emitter circuit loop (*i.e.*, AFCEGA) in d.c. bias circuit. Applying Kirchoff's Voltage Law to this loop,

$$V_{CE} - V_{CC} + (I_C + I_B)R_C = 0$$

Substituting $I_C + I_B$ equal to I_C in the above equation and solving it for collector-to-emitter voltage,

$$V_{CE} = V_{CC} - I_C \cdot R_C$$

2.4.3.1 Stability factor of Base Bias with Collector Feedback

We have already discussed in the last article that if we apply Kirchoff's Voltage Law to the base-emitter circuit shown in Fig. 1.4, then we get

$$V_{BE} - V_{CC} + (I_B + I_C)R_C + I_B \cdot R_B = 0$$

Rearranging the above equation and solving for base current,

$$I_B = \frac{V_{CC} - V_{BE} - I_C \cdot R_C}{R_C + R_B}$$

Differentiating the above expression with respect to I_C,

$$\frac{dI_B}{dI_C} = \frac{0 - 0 - 1 \cdot R_C}{R_C + R_B} = -\frac{R_C}{R_C + R_B}$$

Substituting the value of dI_B/dI_C in the general expression for stability factor,

$$S = \frac{1+\beta}{1-\beta\left(\dfrac{dI_B}{dI_C}\right)} = \frac{1+\beta}{1-\beta\left(-\dfrac{R_C}{R_C+R_B}\right)} = \frac{1+\beta}{1+\beta\times\dfrac{R_C}{R_C+R_B}}$$

It is evident from the above expression that the stability factor (S) of a collector feedback bias is smaller than ($1 + \beta$). Therefore the biasing arrangement of collector feedback resistor is certainly an improvement over the fixed bias circuit.

Example *. Determine the d.c. bias current and voltage for the d.c. bias circuit shown in Fig.*

Also determine the stability factor of the bias circuit. Assume $V_{BE} = 0.7$ V.

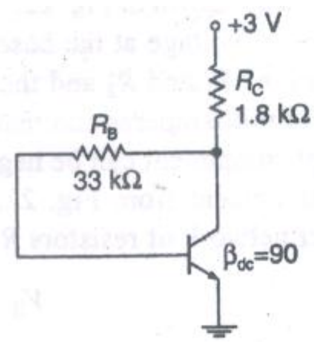


Fig.

Solution. Given: $V_{CC} = 3$ volts; $R_C = 1.8\ k\Omega = 1.8 \times 10^3\ \Omega$; $R_B = 33\ k\Omega = 33 \times 10^3\ \Omega$; $\beta = 90$ and $V_{BE} = 0.7$ volt

D.C bias current and voltage

We know that the base current,

$$I_B = \frac{V_{CC}-V_{BE}}{R_B+\beta\cdot R_C} = \frac{3-0.7}{(33\times10^3)+90(1.8\times10^3)}\ \text{A}$$
$$= 0.0118 \times 10^{-3}\ \text{A} = 0.0118\ \text{mA}$$

and the collector current,

$$I_C = \beta\cdot I_B = 90\times0.0118 = 1.06\ \text{mA}\ \textbf{Ans.}$$

∴ Collector-to-emitter voltage,

$$V_{CE} = V_{CC} - I_C\cdot R_C = 3-(1.06\times10^{-3})\times(1.8\times10^3)\ \text{V}$$
$$= 3 - 1.9 = 1.1\ \text{V}\ \textbf{Ans.}$$

Stability factor

We also know that stability factor,

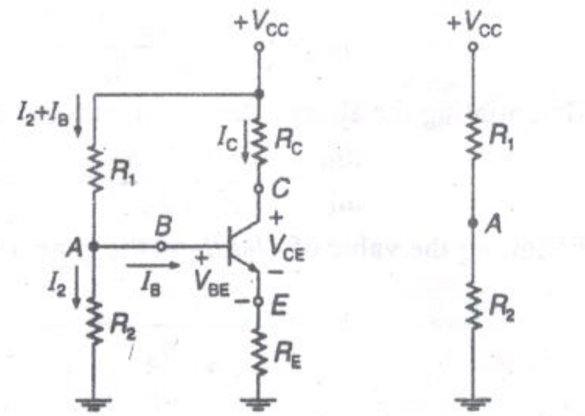
$$S = \frac{1+\beta}{1+\beta\times\dfrac{R_C}{R_C+R_B}} = \frac{1+90}{1+90\times\dfrac{1.8\times10^3}{(1.8\times10^3)+(33\times10^3)}}$$
$$= \frac{91}{5.65} = 16.1\ \textbf{Ans.}$$

2.4.4 Voltage Divider Bias

In all the d.c. bias circuits, discussed in the previous articles, we have found that the values of d.c. bias current and voltage of the collector depends upon the current gain (β) of the transistor. But we know that the value of current gain (β) is temperature sensitive especially for silicon transistors. Since the nominal value of current gain (β) is not well defined, therefore it would be desirable to provide a d.c. bias circuit which is independent of the transistor current gain (β). The d.c. bias circuit shown in Fig. 1.5 (a) meets this condition and is thus a very popular bias circuit. It is commonly known as *voltage divider bias* or *self bias circuit*.

The name voltage divider is derived from the fact that resistors R_1 an R_2 form a potential divider across the V_{CC} supply. The voltage drop across resistor R_2 forward biases the base-emitter junction of a transistor. The emitter resistor (R_E) providers the d.c. stability.

Now let us analyse the base-emitter loop of the voltage divider bias circuit. A basic assumption is that the resistance looking into the base is much larger than that of the resistor R_2. If this is so, then the current through resistor R_1 flows almost completely into resistor R_2 and the two resistors may be considered effectively



(a) Voltage divide bias circuit. (b) Voltage divider.

Fig. 1.5

in series as shown in Fig. (*b*). The voltage at the junction of the resistor (*i.e.*, point *A*), which is also the voltage at the base of the transistor, is then determined simple by the voltage divider network of R_1 and R_2 and the supply voltage. If the current through resistors R_1 and R_2 is of the order of milliamperes and that through the base is of the order of the microamperes, then the base current component can be neglected.

It is evident from Fig. 1.5 (*b*), that the voltage at the transistor base (due to the voltage divider network of resistors R_1 and R_2)

$$V_B = V_{CC} \times \frac{R_2}{R_1 + R_2}$$

Since the voltage drop across the base-emitter junction (V_{BE}) when forward biased is very small, as compared to the voltage at the base (V_B), therefore the voltage at the emitter is almost equal to the voltage at the base *i.e.*,

$$V_E = V_B \qquad \text{... (Neglecting } V_{BE}\text{)}$$

∴ Value of emitter current,

$$I_E = \frac{V_E}{R_E}$$

and the value of collector current,

$$I_C \approx I_E$$

The voltage drop across the collector resistor,

$$V_{R_C} = I_C \cdot R_C$$

and the voltage at the collector (measured with respect to the ground)

$$V_C = V_{CC} - V_{R_C} = V_{CC} - I_C \cdot R_C$$

The voltage from collector-to-emitter,

$$V_{CE} = V_C - V_E = V_{CC} - I_C \cdot R_C - I_E \cdot R_E$$

$$= V_{CC} - I_E (R_C + R_E) \qquad \text{... } (\because I_C = I_E)$$

Note. The values of d.c. bias voltages and currents obtained above are only approximate. The more accurate values of these quantities will be obtained in the next article.

2.4.4.1 Stability of Voltage Divider Bias

Consider again the voltage divider bias circuit shown in Fig. 1.5 (*a*). Looking out from the base terminal, the bias circuit can be redrawn as shown in Fig. 1.6 (*a*).

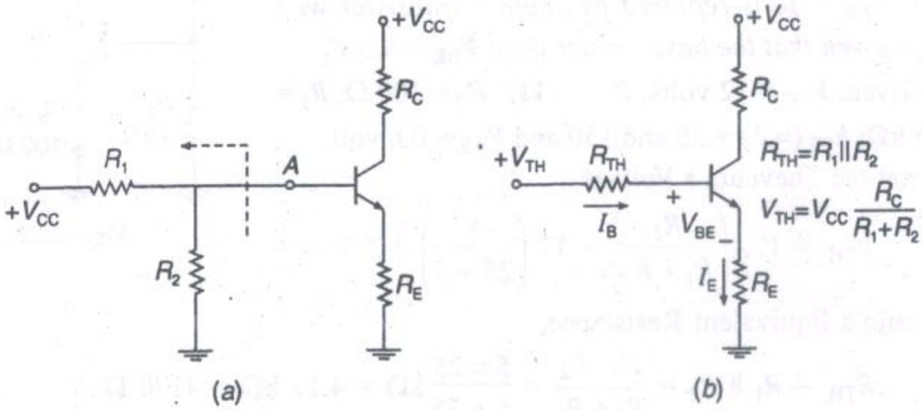


Fig. 1.6 Thevenizing the voltage divider bias circuit.

Now applying the Thevenin's Theorem to the circuit lying on the left of the point *A*, we get the Thevenin's Voltage,

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC}$$

and the Thevenin's Equivalent Resistance

$$R_{TH} = R_1 \parallel R_2 = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

We know that the Thevenin's Voltage (V_{TH}) is a voltage drop across resistor R_2. As a matter of fact, it is the voltage at the base (V_B) measured with respect to the ground. Figure 1.6 (*b*) shows the voltage divider bias circuit in which the series combination of resistors R_1 and R_2 is replaced by a Thevenin's equivalent circuit. Applying, Kirchoff's Voltage Law to the base-emitter loop of this circuit,

$$I_B \cdot R_{TH} + V_{BE} + I_E \cdot R_E - V_{TH} = 0$$

Replacing I_B with I_E / β (equal to I_C/β) in the above relation and solving for emitter current,

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + \dfrac{R_{TH}}{\beta}} \quad \text{...}(i)$$

$$= \frac{V_{TH} - V_{BE}}{R_E} \quad \text{... } (R_E >> R_{TH}/\beta)$$

It is evident from the above relation that *the emitter current is independent of current gain* (β). In actual practice, it is achieved by making the emitter resistor 10 times greater than R_{TH}/β. Mathematically, emitter resistance,

$$R_E \geq 10\ R_{TH}/\beta$$

or $$R_{TH} \leq 0.1\ \beta \cdot R_E \quad \text{... }(ii)$$

Usually, the value of resistor R_2 is smaller than the value of resistor R_1. Therefore the Thevenin's equivalent resistance R_{TH} (equal to $R_1 \parallel R_2$) is approximately equal to R_2. In that case, the (equation *ii*) may be written as

$$R_2 \leq 0.1\ \beta \cdot R_E \quad \text{... }(iii)$$

2.4.4.2 Stability factor of Voltage Divider Bias

We have already discussed in the last article that if we apply Kirchoff's Voltage Law to the base-emitter loop of the voltage divider bias circuit shown in Fig. 1.6 (*b*), we get,

$$I_B \cdot R_{TH} + V_{BE} + I_E \cdot R_E - V_{TH} = 0 \quad \text{... }(i)$$

Substituting the value of I_E (equal to $I_B + I_C$) in the above equation and solving it for base current,

$$I_B = \frac{V_{TH} - V_{BE} - I_C \cdot R_E}{R_E + R_{TH}}$$

Differentiating the above expression with respect to I_C,

$$\frac{dI_B}{dI_C} = \frac{0 - 0 - 1 \cdot R_E}{R_E + R_{TH}} = -\frac{R_E}{R_E + R_{TH}}$$

Substituting the above value of dI_B/dI_C in the general expression for stability factor,

$$S = \frac{1+\beta}{1-\beta\left(\dfrac{dI_B}{dI_C}\right)} = \frac{1+\beta}{1-\beta\left(-\dfrac{R_E}{R_E+R_{TH}}\right)} = \frac{1+\beta}{1+\beta\left(\dfrac{R_E}{R_E+R_{TH}}\right)}$$

Rearranging the above expression,

$$S = \frac{(1+\beta)\left(1+\dfrac{R_{TH}}{R_E}\right)}{1+\beta+\dfrac{R_{TH}}{R_E}}$$

Substituting the value of R_{TH} equal to $\dfrac{R_1 \cdot R_2}{(R_1 + R_2)}$ in the above expression and rearranging,

$$S = \frac{R_E\,(R_1 + R_2) + R_1 \cdot R_2}{R_E\,(R_1 + R_2) + R_1 \cdot R_2\,(1-\alpha)}$$

Example _ *Figure shows that d.c. bias circuit of a common emitter transistor amplifier.*

Find the percentage change in collector current, if the transistor with h_{FE} = 50 is replaced by another transistor with h_{FE} = 150. It is given that the base emitter drop V_{BE} = 0.6 V.

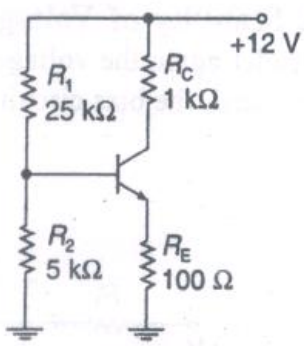


Fig. ____

Solution. Given: V_{CC} = 12 volts; R_C = 1 kΩ: R_E = 100 Ω; R_1 = 25 kΩ; R_2 = 5 kΩ; h_{FE} (= β) = 50 and 150 and V_{BE} = 0.6 volt.

We know that the Thevenin's Voltage,

$$V_{TH} = V_{CC}\left(\frac{R_2}{R_1+R_2}\right) = 12\left(\frac{5}{25+5}\right) = 2 \text{ V}$$

and the Thevenin's Equivalent Resistance,

$$R_{TH} = R_1 \parallel R_2 = \frac{R_1 \cdot R_2}{R_1+R_2} = \frac{5\times 25}{5+25}\text{ k}\Omega = 4.17 \text{ k}\Omega = 4170\ \Omega$$

We also know that the emitter current,

$$I_E = \frac{V_{TH}-V_{BE}}{R_E + \dfrac{R_{TH}}{\beta}}$$

For β = 50, the emitter current,

$$I_E = \frac{2-0.6}{100+\dfrac{4170}{50}} = 7.63\times 10^{-3}\text{ A} = 7.63 \text{ mA}$$

and for β = 150, the emitter current,

$$I_E = \frac{2-0.6}{100+\dfrac{4170}{150}} = 10.95\times 10^{-3}\text{ A} = 10.95 \text{ mA}$$

∴ Change in the collector current, when the transistor with h_{FE} equal to 50 is changed with another transistor with h_{FE} equal to 150,

$$\frac{10.95-7.63}{7.63} = 0.435 = 43.5\% \quad \textbf{Ans.}$$

2.5 D.C. And A.C. Equivalent Circuits

In a transistor amplifier, both dc and ac conditions prevail. The dc sources set up dc currents and voltages whereas the ac source (*i.e*. signal) produces fluctuations in the transistor currents and voltages. Therefore, a simple way to analyze the action of a transistor is to split the analysis into two parts *viz.* a dc analysis and an a.c. analysis. In the dc analysis, we consider all the dc sources at the same time and work out the dc currents and voltages in the circuit. On the other hand, for ac analysis, we consider all the ac sources at the same time and work out the ac currents and voltages. By adding the dc and ac currents and voltages, we get the total currents and voltages in the circuit. For example, consider the amplifier circuit shown in Fig. 1.7. This circuit can be easily analyzed by splitting it into dc equivalent circuit and ac equivalent circuit.

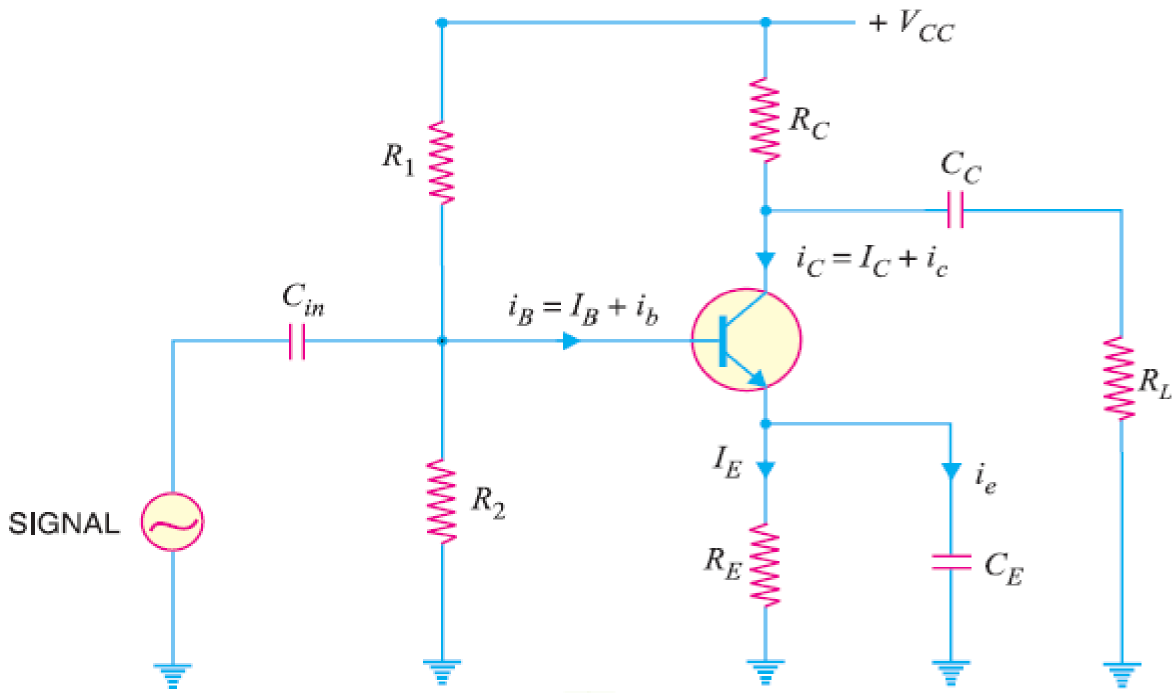


Fig. 1.7

(i) **D. C. equivalent circuit.** In the d.c. equivalent circuit of a transistor amplifier, only d.c. conditions are to be considered *i.e.* it is presumed that no signal is applied. As direct current cannot flow through a capacitor, therefore, *all the capacitors look like open circuits in the d.c. equivalent circuit.* It follows, therefore, that in order to draw the equivalent d.c. circuit, the following two steps are applied to the transistor circuit :

(a) Reduce all a.c. sources to zero.

(b) Open all the capacitors.

Applying these two steps to the circuit shown in Fig. 1.7, we get the d.c. equivalent circuit shown in Fig. 1.8. We can easily calculate the d.c. currents and voltages from this circuit.

(ii) **A.C. equivalent circuit.** In the a.c. equivalent circuit of a transistor amplifier, only a.c. conditions are to be considered. Obviously, the d.c. voltage is not important for such a circuit and may be considered zero. The capacitors are generally used to couple or bypass the a.c. signal. The designer intentionally selects capacitors that are large enough to appear as *short* circuits to the a.c. signal. It follows, therefore, that in order to draw the a.c. equivalent circuit, the following two steps are applied to the transistor circuit :

(a) Reduce all d.c. sources to zero (*i.e.* $V_{CC} = 0$).

(b) Short all the capacitors.

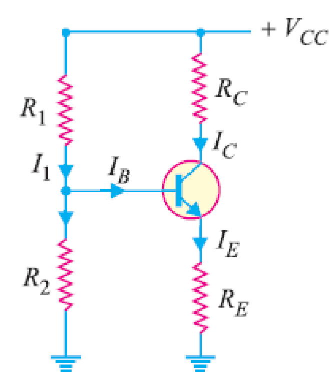


Fig. 1.8

Applying these two steps to the circuit shown in Fig.1.7 , we get the a.c. *equivalent circuit shown in Fig.1.9 . We can easily calculate the a.c. currents and voltages from this circuit.

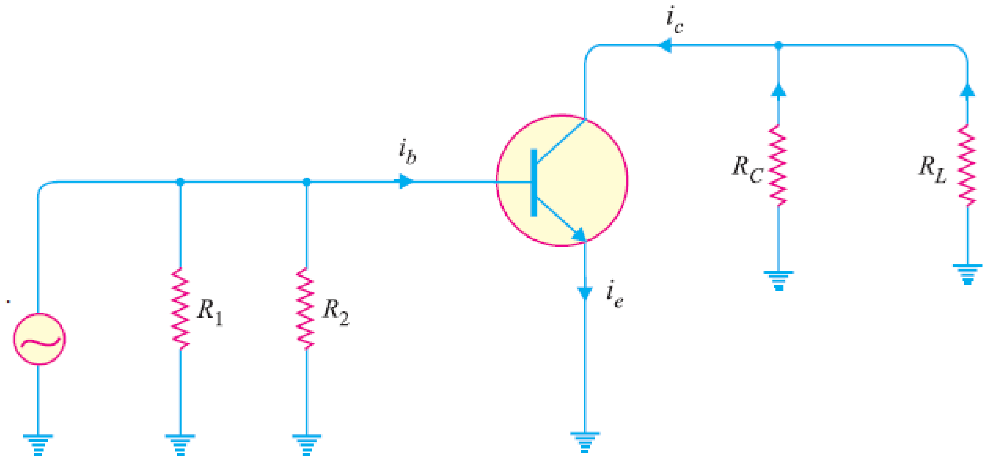


Fig. 1.9

It may be seen that total current in any branch is the sum of d.c. and a.c. currents through that branch. Similarly, the total voltage across any branch is the sum of d.c. and a.c. voltages across that branch.

2.6 Load Line analysis

The output characteristics are determined experimentally and indicate the relation between V_{CE} and I_C. However, the same information can be obtained in a much simpler way by representing the mathematical relation between I_C and V_{CE} graphically. As discussed before, the relationship between V_{CE} and I_C is linear so that it can be represented by a straight line on the output characteristics. This is known as a load line. The points lying on the load line give the possible values of V_{CE} and I_C in the output circuit. As in a transistor circuit both dc and ac conditions exist, therefore, there are two types of load lines, namely; dc load line and ac load line. The former determines the locus of I_C and V_{CE} in the zero signal conditions and the latter shows these values when the signal is applied.

(i) d.c. load line. It is the line on the output characteristics of a transistor circuit which gives the values of I_C and V_{CE} corresponding to zero signal or dc conditions.

Consider the transistor amplifier shown in Fig. 1.10 . In the absence of signal, d.c. conditions prevail in the circuit as shown in Fig. 1.11 (*i*). Referring to this circuit and applying Kirchhoff's voltage law,

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

or

$$V_{CE} = V_{CC} - I_C (R_C + R_E) \quad ...(i)$$

$$(\because I_E \simeq I_C)$$

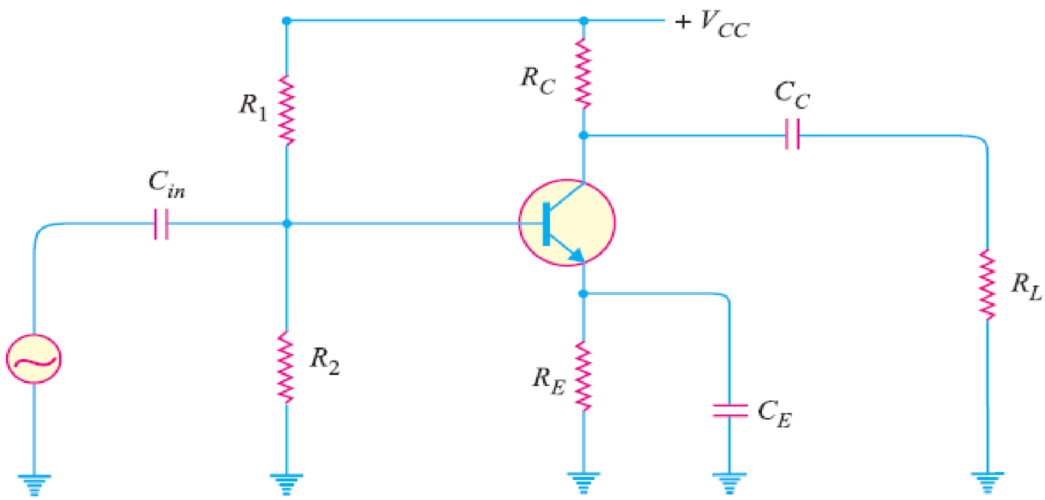


Fig. 1.10

As for a given circuit, V_{CC} and $(R_C + R_E)$ are constant, therefore, it is a first degree *equation and can be represented by a straight line on the output characteristics. This is known as *d.c. load line* and determines the loci of V_{CE} and I_C points in the zero signal conditions. The d.c. load line can be readily plotted by locating two *end points* of the straight line.

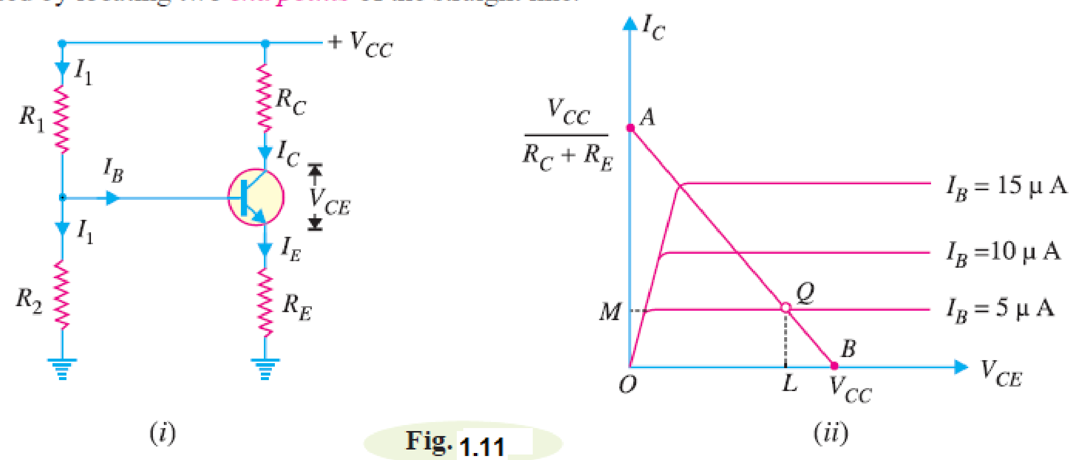


Fig. 1.11

The value of V_{CE} will be maximum when $I_C = 0$. Therefore, by putting $I_C = 0$ in exp. (*i*), we get,

$$\text{Max. } V_{CE} = V_{CC}$$

This locates the first point B $(OB = V_{CC})$ of the d.c. load line.

* This equation is known as **load line equation** since it relates the collector-emitter voltage (V_{CE}) to the collector current (I_C) flowing through the load.

The value of I_C will be maximum when $V_{CE} = 0$.

$$\therefore \qquad \text{Max. } I_C = \frac{V_{CC}}{R_C + R_E}$$

This locates the second point A $(OA = V_{CC}/R_C + R_E)$ of the d.c. load line. By joining points A and B, d.c. load line AB is constructed [See Fig. 1.11 (*ii*)].

Alternatively. The two end points of the d.c. load line can also be determined in another way.

$$V_{CE} + I_C\,(R_C + R_E) = V_{CC}$$

Dividing throughout by V_{CC}, we have,

$$\frac{V_{CE}}{V_{CC}} + \frac{I_C}{(V_{CC} / R_C + R_E)} = 1 \qquad ...(i)$$

The equation of a line having intercepts a and b on x-axis and y-axis respectively is given by ;

$$\frac{x}{a} + \frac{y}{b} = 1 \qquad ...(ii)$$

Comparing eqs. (*i*) and (*ii*), we have,

$$\text{Intercept on } x\text{-axis} = V_{CC}$$

$$\text{Intercept on } y\text{-axis} = \frac{V_{CC}}{R_C + R_E}$$

With the construction of d.c. load line on the output characteristics, we get the complete information about the output circuit of transistor amplifier in the zero signal conditions. All the points showing zero signal I_C and V_{CE} will obviously lie on the d.c. load line. At the same time I_C and V_{CE} conditions in the circuit are also represented by the output characteristics. Therefore, actual operating conditions in the circuit will be represented by the point where d.c. load line intersects the base current curve under study. Thus, referring to Fig. 1.11 (*ii*), if $I_B = 5\ \mu$A is set by the biasing circuit, then Q (*i.e.* intersection of 5 μA curve and load line) is the operating point.

(*ii*) a.c. load line. *This is the line on the output characteristics of a transistor circuit which gives the values of i_C and v_{CE} when signal is applied.*

Referring back to the transistor amplifier shown in Fig. 1.10 , its a.c. equivalent circuit as far as output circuit is concerned is as shown in Fig. 1.12 (*i*). To add a.c. load line to the output characteristics, we again require two end points–one maximum collector-emitter voltage point and the other maximum collector current point. Under the application of a.c. signal, these values are

Max. collector-emitter voltage $= V_{CE} + I_C R_{AC}$. This locates the point C of the a.c. load line on the collector-emitter voltage axis.

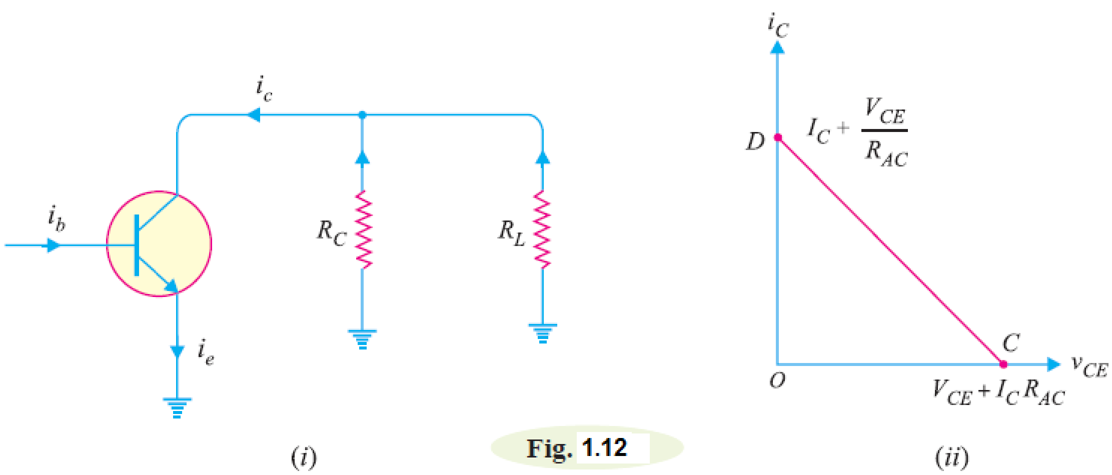


Fig. 1.12

$$\text{Maximum collector current} = I_C + \frac{V_{CE}}{R_{AC}}$$

where $$R_{AC} = R_C \parallel R_L = \frac{R_C\,R_L}{R_C + R_L}$$

This locates the point D of a.c. load line on the collector-current axis. By joining points C and D, the a.c.load line CD is constructed [See Fig. 1.12 (*ii*)].

Example . *For the transistor amplifier shown in Fig. 10.15, R_1 = 10 kΩ, R_2 = 5 kΩ, R_C = 1 kΩ, R_E = 2 kΩ and R_L = 1 kΩ.*

(i) Draw d.c. load line (ii) Determine the operating point (iii) Draw a.c. load line. Assume V_{BE} = 0.7 V.

Solution. (*i*) d.c. load line :

To draw d.c. load line, we require two end points *viz* maximum V_{CE} point and maximum I_C point.

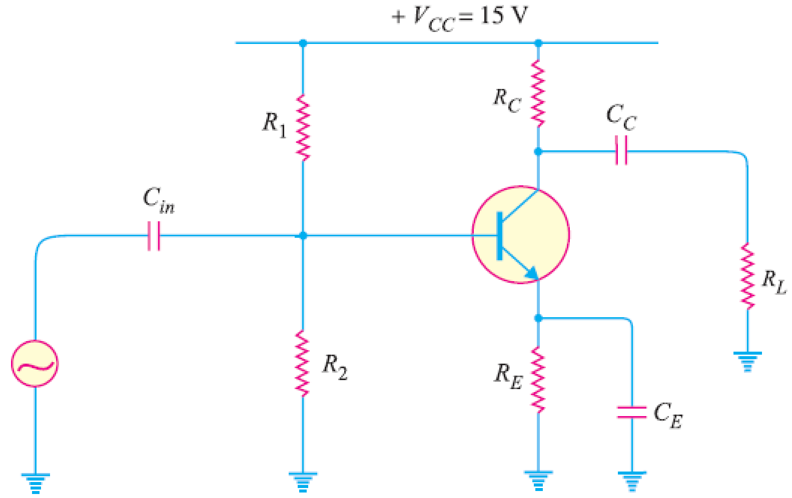


Fig.

$$\text{Maximum } V_{CE} = V_{CC} = 15 \text{ V}$$

This locates the point B (OB=15 V) of the d.c. load line.

$$\text{Maximum } I_C = \frac{V_{CC}}{R_C + R_E} = \frac{15\ V}{(1+2)\ \text{k}\Omega} = 5 \text{ mA}$$

This locates the point A (OA = 5 mA) of the d.c. load line. Fig. (*i*) shows the d.c. load line AB.

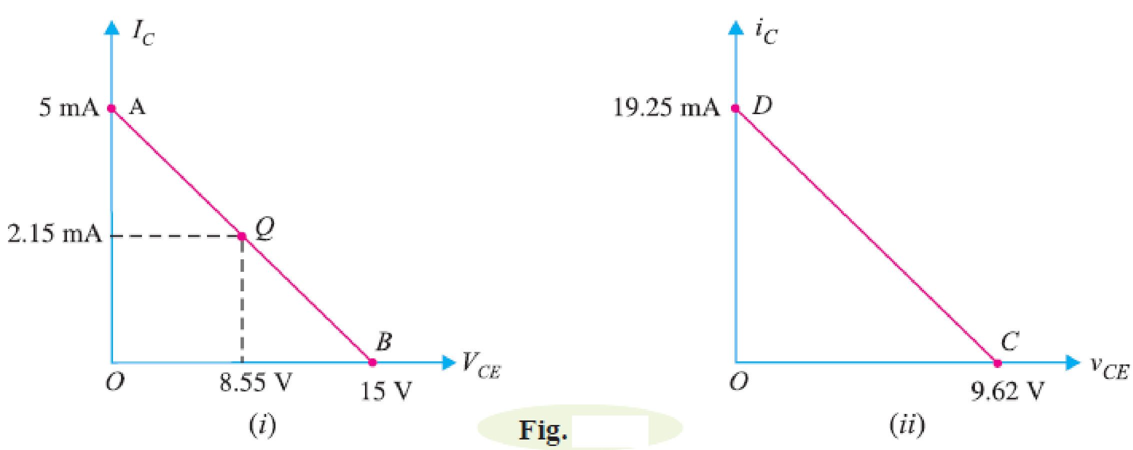


Fig.

(*ii*) **Operating point Q.** The voltage across R_2 (= 5 kΩ) is *5 V *i.e.* $V_2 = 5$ V.

$$\text{Now} \quad V_2 = V_{BE} + I_E R_E$$

$$\therefore \quad I_E = \frac{V_2 - V_{BE}}{R_E} = \frac{(5-0.7)\,V}{2\text{ k}\Omega} = 2.15 \text{ mA}$$

$$\therefore \quad I_C = I_E = 2.15 \text{ mA}$$

$$\text{Now} \quad V_{CE} = V_{CC} - I_C\,(R_C + R_E) = 15 - 2.15 \text{ mA} \times 3 \text{ k}\Omega$$

$$= 8.55 \text{ V}$$

∴ Operating point Q is **8.55 V, 2.15 mA.** This is shown on the d.c. load line.

(*iii*) **a.c. load line.** To draw a.c. load line, we require two end points *viz.* maximum collector-emitter voltage point and maximum collector current point when signal is applied.

$$\text{a.c. load, } R_{AC} = R_C \,||\, R_L = \frac{1\times 1}{1+1} = 0.5 \text{ k}\Omega$$

∴ Maximum collector-emitter voltage

$$= V_{CE} + I_C R_{AC}$$

$$= 8.55 + 2.15 \text{ mA} \times 0.5 \text{ k}\Omega = 9.62 \text{ volts}$$

This locates the point C ($OC = 9.62$ V) on the v_{CE} axis.

$$\text{Maximum collector current} = I_C + V_{CE}/R_{AC}$$

$$= 2.15 + (8.55 \text{ V}/0.5 \text{ k}\Omega) = 19.25 \text{ mA}$$

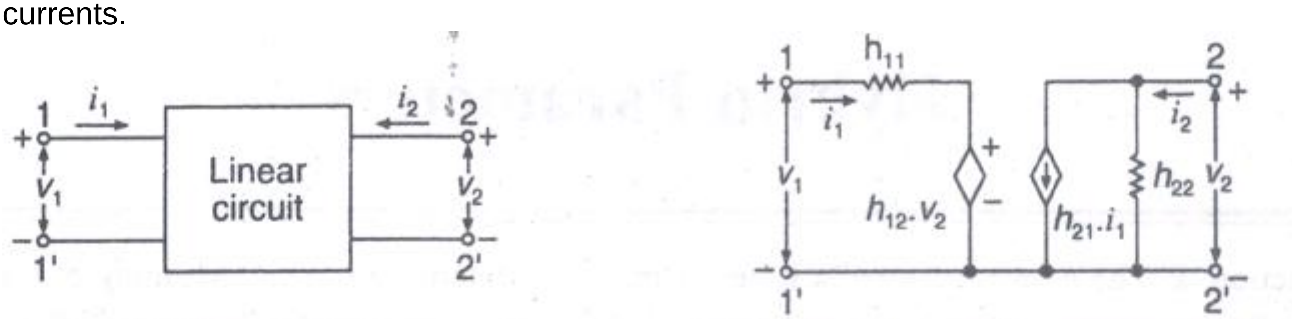
This locates the point D ($OD = 19.25$mA) on the i_C axis. By joining points C and D, a.c. load line CD is constructed [See Fig. (*ii*)].

2.7 Hybrid Parameters

The hybrid parameters are commonly known as 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.

2.7.1 The h-parameters of a Linear Circuit

Figure 1.13 *(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.



(*a*) Linear circuit. (*b*) Hybrid model for a linear circuit.

Fig. 1.13 .

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 polarity of voltages and direction of currents may be carefully noted. The polarity of voltage is such that the upper terminal is positive and the lower terminal is negative. Both the input an output currents are assumed to flow into the box. It is a standard convention for representing currents and voltages and do not correspond with the actual polarity of voltages and direction of currents. Thus if in any circuit, the voltages are of opposite polarity and currents are flowing out of the box; then these voltages and currents are taken as negative quantities.

The linear circuit may be replaced by an equivalent circuit as shown in Figure 1.13 (*b*). The equivalent circuit is called hybrid model of a linear circuit. In such a circuit, the input and output voltages and the input and output currents (called variables) may be related by the set of the following two equations:

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

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

where v_1 = Input voltage, v_2 = Output voltage,

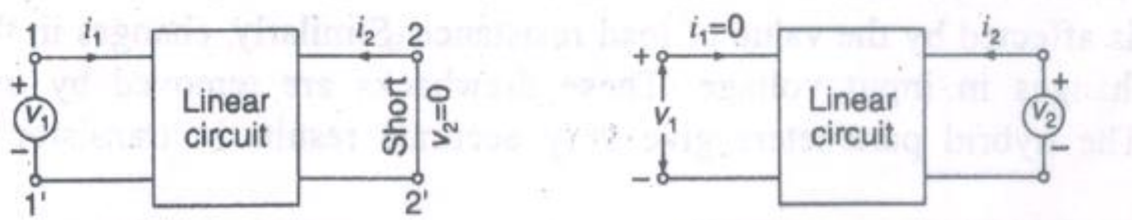
i_1 = Input current, i_2 = Output current, and

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. Thus a linear circuit has a set of four parameters namely h_{11}, h_{12}, h_{21} and h_{22}. These parameters completely describe the behaviour of the circuit and are constant for a given circuit. They are expressed in different units. The parameter h_{11} is expressed in ohms (Ω), h_{12} and h_{21} are dimensionless and h_{22} is expressed in mhos (Ω) or (*S*). Since these parameters have mixed units, therefore these are called hybrid (means mixed) or h-parameters.

2.7.2 Determination and Meaning of h-parameters

We have already discussed in the last article that every linear circuit may be represented by a set of four h-parameters namely h_{11}, h_{12}, h_{21} and h_{22}. The parameters h_{11} and h_{21} may be determined by short-circuiting the output terminals of a given circuit. On the other hand, h_{12} and h_{22} may be determined by open-circuiting the input terminals of the given circuits.



(*a*) Output short-circuited. (*b*) Input open-circuited.

Fig. 1.14

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 1.14 (*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 v_2 (equal to zero) in the above equation, the input voltage,

$$v_1 = h_{11} \cdot i_1 \text{ or } h_{11} = v_1/i_1$$

Thus h_{11} may be determined from the ratio v_1/i_1. The value of i_1 is obtained by applying a voltage at the input and then measuring the value of input current (i_1). Since h_{11} is the ratio of voltage to current, therefore it has the units of ohms *i.e.*, the same unit as that of a resistance. Because of this fact, h_{11} is also called input resistance of the circuit with output short-circuited. Similarly, we know that the output current is given by the relation,

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

Again substituting the value of v_2 (equal to zero) in the above equation, the output current,

$$i_2 = h_{21} \cdot i_1 \text{ or } h_{21} = i_2/i_1$$

Thus h_{21} may be determined from the ratio i_2/i_1. The values of i_1 and i_2 may be obtained by applying a voltage at the input and then measuring the input current (i_1) and output current (i_2). Since h_{21} is the ratio of currents, therefore it has no units. The parameter h_{21} is called the forward current gain of the circuit with output short-circuited.

2. *Determination of h_{12} and h_{22}.* These are determined by open circuiting the input terminals of a given circuit as shown in Fig. 1.14 (*b*). An open circuit, at the input terminals, makes the 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 i_1 (equal to zero) in the above equation, the input voltage,

$$v_1 = h_{12} \cdot v_2 \text{ or } h_{12} = v_1/v_2$$

Thus h_{12} may be determined from the ratio v_1/v_2. The value of v_1 may be obtained by applying a voltage v_2 at the output and then measuring the input voltage (v_1). Since, h_{12} is a ratio of voltages, therefore it has no units. As h_{12} is the ratio of input voltage (v_1) to the output voltage (v_2), therefore, its value is known as the reverse voltage gain in order to distinguish it from to forward voltage gain, whose value is equal to v_2/v_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 i_1 (equal to zero) in the above equation, the output current,

$$i_2 = h_{22} \cdot v_2 \qquad \text{or} \qquad h_{22} = i_2/v_2$$

Thus h_{22} may be determined from the ratio i_2/v_2. The value of current (i_2) may be obtained by applying a voltage at the output (v_2) and then measuring the output current with input open. Since h_{22} is the ratio of current to voltage, therefore it has the units of mhos (Ω) or Siemens (*S*). The parameter h_{22} is also called output conductance with input open.

2.7.3 Another Representation for h-parameters

Table 1.2 summaries the meaning of each h-parameter and the required condition.

Table 1.2 *h*-parameters

No.	*Parameter*	*Meaning*	*Condition*
1.	h_{11}	Input resistance	Output shorted
2.	h_{12}	Reverse voltage gain	Input open
3.	h_{21}	Forward current gain	Output shorted
4.	h_{22}	Output conductance	Input open

It will be interesting to know that the parameters h_{11} and h_{21} are called forward parameters h_{12} and h_{22} are called reverse parameters. The forward and reverse parameters indicate the way they represent themselves. For example, h_{12} is a reverse parameter because it is a voltage gain of v_1/v_2 (and not a forward gain v_2/v_1). Similarly, h_{22} is a reverse parameter because it is an output conductance. Sometimes, it is more convenient to represent the parameters h_{11}, h_{12} and h_{22} as h_i, h_r, h_f and h_o respectively. In other words,

$h_i = h_{11}$ = Input resistance with output shorted,

$h_r = h_{12}$ = Reverse voltage gain with input open,

$h_f = h_{21}$ = Forward current gain with output shorted, and

$h_o = h_{22}$ = Output conductance with input open.

These notations for *h*-parameters may be easy to remember by knowing the meaning of *i*, *r*, *f* and 0, which are given as below:

i = Input $\quad$ r = Reverse

f = Forward $\quad$ o = Output

2.7.4 The h-parameter Notations for Transistors

The h-parameters of a transistor depend upon the types of the connection (or configuration) used *i.e.*, common-emitter (CE), common-collector (CC) or common-base (CB). Because of this, each of the four h-parameters carries a second subscript letter *e*, *b* or *c*. The letter '*e*' is used to designate common-emitter; '*c*' for common collector and '*b*' for common base configuration. Table 1.3 shows the notations commonly used for transistor *h*-parameters.

Table 1.3

S. No.	*General Parameter*	*Transistor configuration*		
		Common emitter	*Common base*	*Common collector*
1.	h_{11}	h_{ie}	h_{ib}	h_{ic}
2.	h_{12}	h_{re}	h_{rb}	h_{rc}
3.	h_{21}	h_{fe}	h_{fb}	h_{fc}
4.	h_{22}	h_{oe}	h_{ob}	h_{oc}

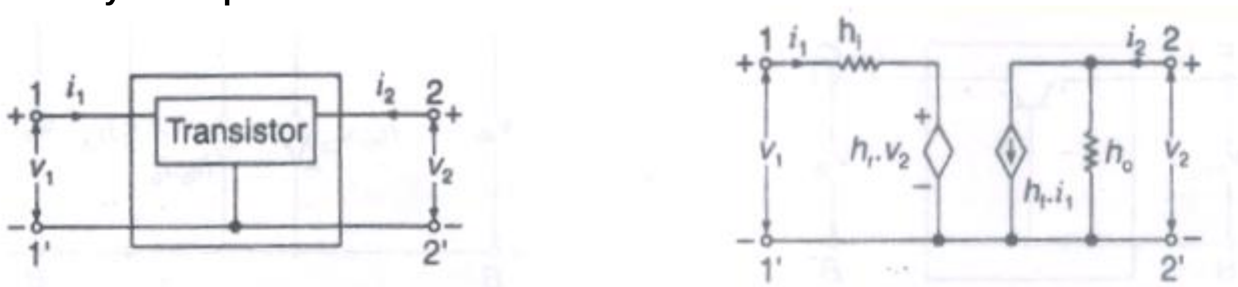
2.7.5 h-parameters of a Transistor

It has been observed that for small signal operation, the behaviour of a transistor is like a linear device (*i.e.*, a device whose output is directly proportional to the input and varies continuously with the input signal). Thus for small signal operation, every transistor has a set of four h-parameters. The values of these parameters depend upon the following factors:

1. Transistor type.
2. Transistor configuration.
3. Operating point.
4. Frequency.
5. Temperature.

The values of h-parameters may be obtained experimentally or graphically from the transistor characteristics. The procedure for determining h-parameters will be discussed later in this chapter.

2.7.6 Hybrid Equivalent Circuit of a Transistor



(*a*) Transistor.

(*b*) Hybrid equivalent circuit of a transistor.

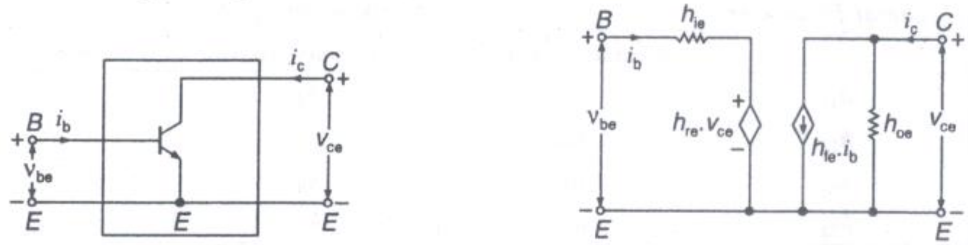
Fig. 1.15

Figure 1.15 (*a*) shows the transistor with its input and output terminals. The amplifier can be formed by connecting a signal source at its input terminals and a load resistance at its output terminals. Here the transistor represents in any one of the three possible configurations. Figure 1.15 (*b*) shows the general form of a h-parameter equivalent circuit of such a transistor. The equivalent circuit is known as small-signal low-frequency hybrid model of a transistor.

It may be noted in Fig. 1.15 (*b*) that the input resistance of a transistor (h_i) appears in series at the input. The reverse voltage gain (h_r) is multiplied by the output voltage to produce an equivalent voltage source (equal to $h_r \cdot v_2$) in series with the input. The equivalent voltage source indicates that in a practical transistor, some of the output voltage is fedback to the input. This represents an unavoidable interaction between the input and output circuits. The forward current gain (h_f) is multiplied by the input current and appears as an equivalent current source ($h_f \cdot i_1$) in the output. The output resistance (*i.e.*, reverse of output conductance, which is equal to $1/h_0$) appears across the output terminals. Since the transistor can be connected in any one of the three different ways namely common emitter, common base and common collector, therefore there are three hybrid equivalent circuits, which will be discussed in the following pages.

2.7.7 Hybrid Equivalent Circuit for Common Emitter Transistor

Figure 1.16 (*a*) shows the transistor connected in common-emitter (CE) configuration and Fig. 1.16 (*b*) shows the hybrid equivalent circuit of such a transistor.



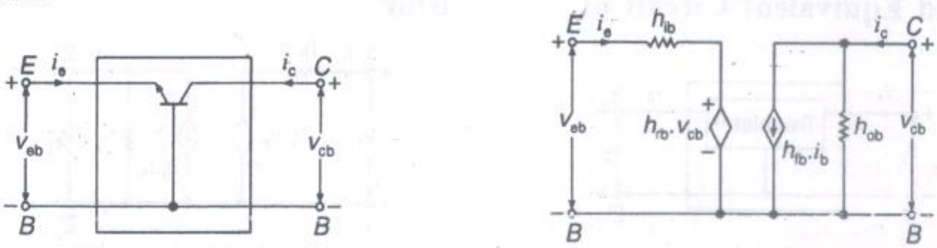
(*a*) Common emitter transistor. **Fig. 1.16** (*b*) Hybrid equivalent circuit of a common emitter transistor.

In a common emitter transistor configuration, the input signal is applied between the base and emitter terminals of a transistor and output appears between the collector and emitter terminals. The input voltage (v_{be}) and the output current (i_c) are given by the following equation:

$$v_{be} = h_{ie} \cdot i_b + h_{re} \cdot v_{ce}$$
$$i_c = h_{fe} \cdot i_b + v_{ce}$$

2.7.8 Hybrid Equivalent Circuit for Common Base Transistor

Figure 1.17 (*a*) shows the transistor connected in a common-base (CB) configuration and Figure 1.17 (*b*) shows its hybrid equivalent circuit. In a common-base configuration, the input signal is applied between emitter and base terminals and output appears between collector and base terminals.

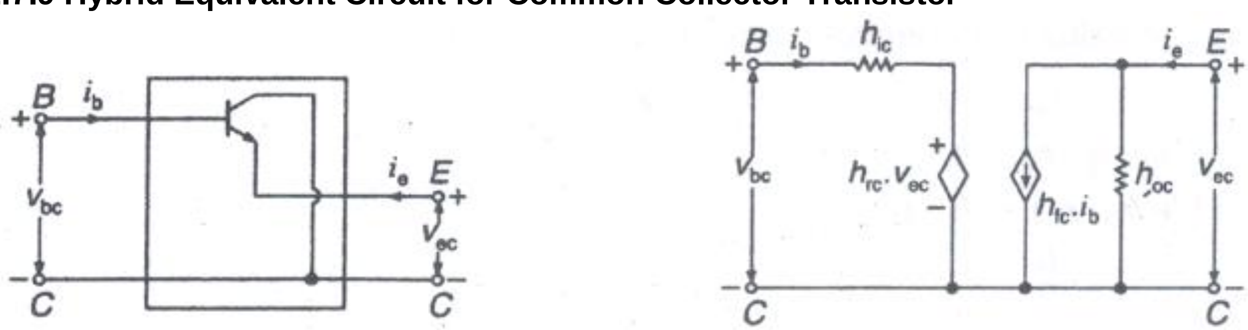


(*a*) Common emitter transistor. **Fig. 1.17** (*b*) Hybrid equivalent circuit of a common emitter transistor.

The input voltage (v_{eb}) and the output current (i_c) are given by the following equations:

$$v_{eb} = h_{ib} \cdot i_e + h_{rb} \cdot v_{cb}$$
$$i_e = h_{fb} \cdot i_c + h_{ob} \cdot v_{cb}$$

2.7.9 Hybrid Equivalent Circuit for Common Collector Transistor



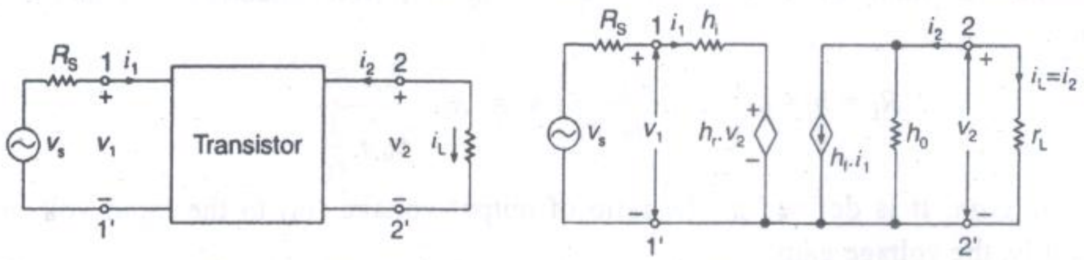
(*a*) Common collector transistor. **Fig. 1.18** (*b*) Hybrid equivalent circuit of a common collector transistor.

Figure 1.18 (a) shows the transistor connected in common-collector (CC) configuration and Figure 1.18 (b) shows its hybrid equivalent circuit. In a common-collector configuration, the input signal is applied between base and collector terminals and the output appears between emitter and collector terminals. The input voltage (v_{bc}) and the output current (i_e) are given by the following equations:

$$v_{bc} = h_{ic} \cdot i_b + h_{rc} \cdot v_{ec}$$
$$i_e = h_{fc} \cdot i_b + h_{oc} \cdot v_{ec}$$

2.8 Amplifier Expressions

Figure 1.19 (a) shows a general amplifier circuit. In this circuit, a transistor is connected in any one of the three possible configurations (*i.e.*, common emitter, common base or common collector) to a voltage source (v_s) and load resistance (r_L). The voltage source has an internal resistance (R_s) as shown in the figure. The load resistance (r_L) is the effective or a.c. load resistance seen by the transistor at its output. Figure 1.19 (b) shows the hybrid equivalent circuit of a general transistor amplifier circuit. Now we shall derive the expressions (called hybrid formulas) for input resistance, output resistance, current gain and voltage gain of a transistor.



(a) General amplifier circuit. (b) Hybrid equivalent circuit.

Fig. 1.19

The expressions for transistor amplifier input and output resistances, voltage and current gains may be obtained from the relations:

$$v_1 = h_i \cdot i_1 + h_r \cdot v_2 \quad \text{... } (i)$$
$$i_2 = h_f \cdot i_1 + h_o \cdot v_2 \quad \text{... } (ii)$$

It may be noted that the voltage drop across load resistance (r_L) is equal to the voltage across the output terminals of a transistor. Thus

$$v_2 = i_L \cdot r_L = - i_2 \cdot r_L \quad \text{... } (\because i_2 = - i_L)$$

(a) *Current gain.* It is the ratio of output current (i_L) to input currents (i_1). Mathematically, the current gain,

$$A_i = \frac{i_L}{i_1} = - \frac{i_2}{i_1}$$

Substituting the value of v_2 (equal to $- i_2 \cdot r_L$) in equation (ii),

$$i_2 = h_f \cdot i_1 + h_o (- i_2 \cdot r_L) = h_f \cdot i_1 - h_o \cdot i_2 \cdot r_L$$
$$i_2 + h_o \cdot i_2 \cdot r_L = h_f \cdot i_1$$
$$i_2 (1 + h_o \cdot r_L) = h_f \cdot i_1$$

$$\frac{i_2}{i_1} = \frac{h_f}{1 + h_0 \cdot r_L}$$

$$\therefore \qquad A_i = -\frac{i_2}{i_1} = -\frac{h_f}{1 + h_0 \cdot r_L} \qquad \text{... } (iii)$$

(*b*) *Input resistance.* The resistance, which we see looking into the amplifier input terminals (1, 1′) is called the amplifier input resistance. It is also known as the input resistance looking into the base of a transistor for common emitter and common collector amplifier and is designated by R_i. Its value is given by the ratio of input voltage (v_1) to the input current (i_1). Mathematically, the input resistance looking into the input terminals,

$$R_i = \frac{v_1}{i_1}$$

Again substituting the value of v_2 (equal to $-i_2 \cdot r_L$) in equation (i)

$$\begin{aligned} v_1 &= h_i \cdot i_1 + h_r(-i_2 \cdot r_L) \\ &= h_i \cdot i_1 - h_r \cdot i_2 \cdot r_L \end{aligned}$$

Dividing the above equation by i_1 on both sides,

$$\frac{v_1}{i_1} = \frac{h_i \cdot i_1 - h_r \cdot i_2 \cdot r_L}{i_1} = h_i - h_r\left(\frac{i_2}{i_1}\right) r_L$$

Replacing v_1/i_1 with R_i and i_2/i_1 by $-A_i$ in the above expression,

$$R_i = h_i - h_r(-A_i) \cdot r_L = h_i + h_r \cdot A_i \cdot r_L \qquad \text{... } (iv)$$

Substituting the value of A_i equal to $-h_f/(1 + h_0 \cdot r_L)$ from equation (iii) in the above expression,

Substituting the value of A_i equal to $-h_f/(1 + h_0 \cdot r_L)$ from equation (iii) in the above expression,

$$R_i = h_i + h_r\left(-\frac{h_f}{1 + h_0 \cdot r_L}\right) r_L = h_i - \frac{h_r \cdot h_f}{h_0 + \dfrac{1}{r_L}} \qquad \text{... } (v)$$

(*c*) *Voltage gain.* It is defined as the ratio of output voltage (v_2) to the input voltage (v_1). Mathematically, the voltage gain,

$$A_v = \frac{v_2}{v_1} = -\frac{i_2 \cdot r_L}{v_1} \qquad \text{... } (\because v_2 = -i_2 \cdot r_L)$$

Substituting the value of i_2 (equal to $-A_i \cdot i_1$) from equation (iii) the above expression,

$$A_v = \frac{A_i \cdot i_1 \cdot r_L}{v_1} = A_i \cdot r_L\left(\frac{i_1}{v_1}\right)$$

Replacing i_1/v_1 by R_i in the above expression,

$$A_v = \frac{A_i \cdot r_L}{R_i}$$

Substituting the value of A_i (equal to $-h_f/(1 + h_0 \cdot r_L)$) and R_i (equal to $\dfrac{h_i - h_r \cdot h_f}{(h_0 + 1/r_L)}$) in the above expression and rearranging,

$$A_v = -\frac{h_f \cdot r_L}{h_i + (h_i \cdot h_0 - h_r \cdot h_f)\, r_L}$$

If we replace $(h_i \cdot h_0 - h_r \cdot h_f = \Delta h)$ in the above expression, then the voltage gain,

$$A_v = -\frac{h_f \cdot r_L}{h_i + \Delta h \cdot r_L}$$

(*d*) *Output resistance.* It is obtained by setting the source voltage (V_S) to zero and the load resistance (r_L) to infinity and by driving the output terminals from a generators v_2 as shown in Fig.

Then output resistance is the ratio of voltage (v_2) to the current drawn from the voltage source (i_2). Mathematically, the output resistance,

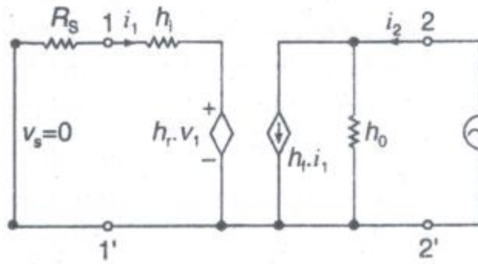


Fig. Hybrid equivalent circuit of a general transistor amplifier with voltage source connected across output terminals.

$$R_0 = \frac{v_2}{i_2} = \frac{v_2}{h_f \cdot i_1 + h_0 \cdot v_2} \qquad \text{... } (vi)$$

The value of current (i_1) may be obtained by applying Kirchoff's Voltage Law to the input side of transistor amplifier circuit. Thus

$$R_s \cdot i_1 + h_r \cdot v_2 = 0$$

$$\therefore \qquad i_1 = -\frac{h_r \cdot v_2}{R_s + h_i}$$

Substituting this value of i_1 in equation (vi),

$$R_0 = \frac{v_2}{h_f\left(-\dfrac{h_r \cdot v_2}{R_s + h_i}\right) + h_0 \cdot v_2}$$

$$= \frac{v_2}{-\dfrac{h_f \cdot h_i \cdot v_2}{R_s + h_i} + h_0 \cdot v_2}$$

Rearranging the above equation,

$$R_0 = \frac{R_s + h_i}{(R_s + h_i)\, h_0 - h_f \cdot h_i} = \frac{R_s + h_i}{R_s \cdot h_0 + (h_i \cdot h_0 - h_f \cdot h_r)}$$

$$= \frac{R_s + h_i}{R_s \cdot h_0 + \Delta h}$$

It may be noted from the above relation that if source resistance (R_s) is zero, then output resistance,

$$R_0 = \frac{h_i}{\Delta h}$$

(*e*) *Power gain.* It is defined as the product of voltage gain (A_v) and the current gain (A_i). Mathematically, the power gain,

$$\Delta P = A_v \cdot A_i$$

Notes: 1. The input resistance (R_i) of a transistor is the value of resistance looking directly into the transistor from the input terminals. It does not include the values of resistor connected externally for the biasing purpose. The input resistance, which takes into account the biasing resistors, is called resistance of the stage (or stage input resistance) and is designated by R_{is}. For a fixed bias current, the value of stage input resistance,

$$R_{is} = R_i \,||\, R_B$$

and for voltage divider bias circuit,

$$R_{is} = R_i \,||\, (R_1 \,||\, R_2)$$

2. The output resistance (R_o) of a transistor is the resistance looking directly into the transistor from the output terminals. It does not include the value of collector resistance (R_C) and load resistance (R_L). The output resistance, which includes the effect of R_C and R_L, is called output resistance of a stage (or stage output resistance) and is designated by R_{os}. Its value is given by the relation,

$$R_{os} = R_o \,||\, (R_C \,||\, R_L) = R_o \,||\, r_L \qquad \ldots (\because r_L = R_C \,||\, R_L)$$

3. In the expressions for output resistance, current and voltage gains, we require the value of a.c load resistance (*i.e.*, r_L). The value of r_L depends upon the type of connection used for transistor. For common emitter and common base connections, the a.c. load resistance,

$$r_L = R_C \qquad \ldots (\text{If } R_L \text{ is not connected})$$

$$= R_C \,||\, R_L \qquad \ldots (\text{If } R_L \text{ is connected})$$

However, for a common collector (or emitter follower connection) the value of a.c. load resistance,

$$r_L = R_E \qquad \ldots (\text{If } R_L \text{ is not connected})$$

$$= R_E \,||\, R_L \qquad \ldots (\text{If } R_L \text{ is connected})$$

2.8.1 Effect of Source Resistance on Voltage and Current Gains

We have already discussed in the last article the current and voltage gains of a transistor amplifier. The expressions for current and voltage gains derived there are from the amplifier input terminals (1, 1′) to the output terminal (2, 2′). In other words, these values do not take into consideration the source resistance (R_s). However, it is important to take into account the source resistance (R_s), while calculating the voltage and current gains of the transistor amplifier. In this case, the voltage and current gains are known as overall gains or stage gains.

The overall gains of the transistor amplifier is the ratio of output voltage (v_2) to the source voltage (v_s). Mathematically, the overall voltage gain,

$$A_{vs} = \frac{v_2}{v_s}$$

Multiplying and dividing the right hand side of the above equation by v_1,

$$A_{vs} = \frac{v_2}{v_s} \times \frac{v_1}{v_1} = \frac{v_2}{v_1} \times \frac{v_1}{v_s} = A_v \times \frac{v_1}{v_s}$$

where A_v (equal to v_2/v_1) is the voltage gain of amplifier from the input terminals (1, 1′) to the output terminals (2, 2′). In order to determine the voltage ratio (v_1/v_s), consider the circuit shown in Fig. 1.20 (*a*).

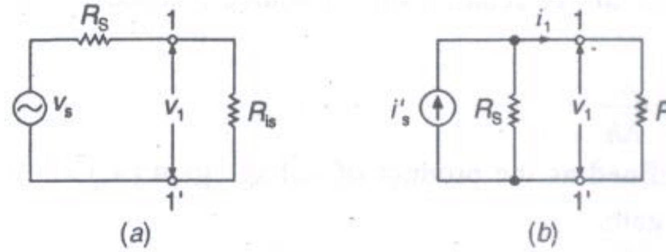


Fig. 1.20 . Effect of source resistance on amplifier voltage and current gains.

In this figure, the resistance R_{is} represents the amplifier input resistance. It is evident from this figure that the voltage drop across input resistance,

$$v_1 = v_s \times \frac{R_{is}}{R_s + R_{is}}$$

$$\therefore \quad \frac{v_1}{v_s} = \frac{R_{is}}{R_s + R_{is}}$$

and $$A_{vs} = A_v \times \frac{R_{is}}{R_s + R_{is}}$$

Similarly, the overall current gain of the transistor amplifier is the ratio of output current (i_L) to the current delivered by the source (i_s). Mathematically, the overall current gain,

$$A_{is} = \frac{i_L}{i_s} = -\frac{i_2}{i_s} \qquad \ldots (\because i_L = -i_2)$$

Multiplying and dividing the right hand side of the above equation by i,

$$A_{is} = -\frac{i_2}{i_s} \times \frac{i_1}{i_1} = -\frac{i_2}{i_1} \times \frac{i_1}{i_s} = -A_i \times \frac{i_1}{i_s}$$

where A_i (equal to (i_2/i_1) is the current gain of the amplifier from the input terminals (1, 1′) to the output terminals (2, 2′). In order to determine the current ratio, consider the circuit shown in Fig. 25.11 (b). Here the voltage source has been replaced by its equivalent current source. It may be noted that the current through the amplifier input resistance,

$$i_1 = i_s \times \frac{R_s}{R_s \times R_{is}}$$

$$\therefore \quad \frac{i_1}{i_s} = \frac{R_s}{R_s + R_{is}}$$

and $$A_{is} = A_i \times \frac{i_1}{i_s} = A_i \times \frac{R_s}{R_s + R_{is}}$$

2.8.2 Hybrid Formulas for Common Emitter Amplifier

These formulas may be obtained from the general hybrid formulas derived in Art. 2.8 by adding a second subscript letter 'e' (which stands for common emitter) with the h-parameters and are as discussed below:

(*a*) *Current gain.* It is given by the relation,

$$A_i = -\frac{h_{fe}}{1 + h_{oe} \cdot r_L}$$

where r_L is the a.c. load resistance. Its value is equal to the parallel combination of resistances R_C and R_L. Since h_{fe} of a transistor is a positive number, therefore A_i of a common emitter amplifier is negative.

(*b*) *Input resistance.* The resistance looking into the amplifier input terminals (*i.e.*, base of a transistor) is given by the relation,

$$R_i = h_{ie} + h_{re} \cdot A_i \cdot r_L$$

$$= h_{ie} - \frac{h_{re} \cdot h_{fe}}{h_{oe} + \frac{1}{r_L}}$$

The input resistance of the amplifier stage (called stage input resistance R_{is}) depends upon the biasing arrangement. For a fixed bias circuit, the stage input resistance,

$$R_{is} = R_i \parallel R_B$$

If the circuit has no biasing resistances, then $R_{is} = R_i$.

(*c*) *Voltage gain.* It is given by the relation,

$$A_v = \frac{A_i \cdot r_L}{R_i}$$

Since the current gain (A_i) of a common emitter amplifier is negative, therefore the voltage gain (A_v) is also negative. It means that there is a phase difference of 180° between the input and output. In other words, the input signal is inverted at the output of a common emitter amplifier. The voltage gain, in terms of h-parameters, is given by the relation,

$$A_v = -\frac{h_{fe} \cdot r_L}{h_{ie} + \Delta h \cdot r_L}$$

where $\Delta h = h_{ie} \cdot h_{oe} - h_{re} \cdot h_{fe}$

(*d*) *Output resistance.* The resistance looking into the amplifier output terminals is given by the relation,

$$R_0 = \frac{R_s + h_{ie}}{R_s \cdot h_{oe} + \Delta h}$$

where R_s = Resistance of the source, and

$$\Delta h = h_{ie} \cdot h_{oe} - h_{re} \cdot h_{fe}$$

The output resistance of the stage,

$$R_{os} = R_o \parallel r_L$$

(*e*) *Overall voltage gain.* It is given by the relation,

$$A_v = \frac{A_v \cdot R_{is}}{R_s + R_{is}}$$

(*f*) *Overall current gain.* It is given by relation,

$$A_{is} = \frac{A_i \cdot R_s}{R_s + R_{is}}$$

Example *The h-parameters of a transistor used in a common emitter circuit are $h_{ie} = 1.0\ k\Omega$, $h_{re} = 10 \times 10^{-4}$, $h_{fe} = 50$ and $h_{oe} = 100\ \mu$ mhos. The load resistor for the transistor is 1 kΩ in the collector circuit. The transistor is supplied from a signal source of resistance 1000 Ω. Determine the value of input and output impedances (or resistances), voltage and current gains in the amplifier stage.*

Solution. Given: $h_{ie} = 1.0\ k\Omega = 1000\ \Omega$; $h_{re} = 1.0 \times 10^{-4}$; $h_{oe} = 100\ \mu$ mhos $= 100 \times 10^{-6}$ mhos; $R_C = 1\ k\Omega = 1000\ \Omega$ and $R_s = 1000\ \Omega$.

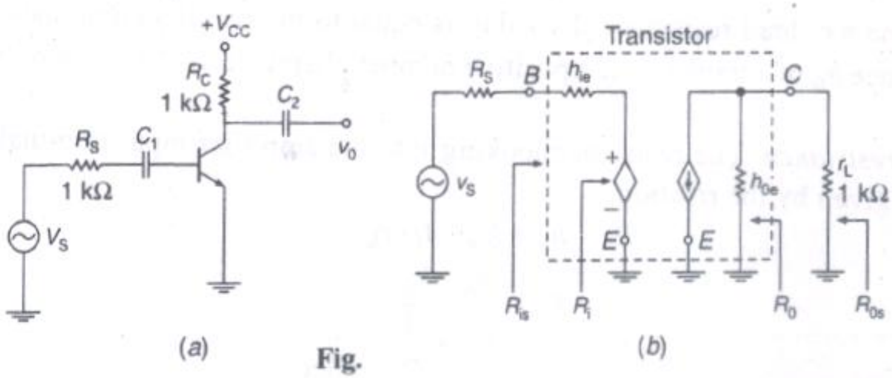


Fig.

Fig.(*a*) shows the common emitter transistor amplifier circuit and (*b*) shows its hybrid equivalent circuit.

(*a*) *Input resistance of the amplifier stage*

We know that there is no load connected at the output of the amplifier (*i.e.*, $R_L = 0$), therefore the value of a.c. load resistance,

$$r_L = R_C = 1000\ \Omega$$

We also know that current gain of a transistor,

$$A_i = \frac{h_{fe}}{1 + h_{oe} \cdot r_L} = -\frac{50}{1 + (100 \times 10^{-6}) \times 1000} = -45.5$$

and the input resistance of a transistor, looking directly into the base,

$$R_i = h_{ie} + h_{re} \cdot A_i \cdot r_L$$

$$= 1000 + [(1.0 \times 10^{-4}) \times (-45.5) \times 1000]\ \Omega$$

$$= 995\ \Omega$$

∴ Input resistance of the amplifier stage,

$$R_{is} = R_i = 995\ \Omega\ \textbf{Ans.}$$

(*b*) *Output resistance of amplifier stage*

We know that

$$\Delta h = h_{ie} \cdot h_{oe} - h_{re} \cdot h_{fe}$$

$$= [1000 \times (100 \times 10^{-6})] - (1.0 \times 10^{-4}) \times 50$$

$$= 95 \times 10^{-3} = 0.095$$

$\therefore$ Output resistance of the transistor looking directly into collector,

$$R_0 = \frac{R_s + h_{is}}{R_s \cdot h_{oe} + \Delta h}$$

$$= \frac{1000 + 1000}{[1000 \times (100 \times 10^{-6})] + 0.095}\ \Omega$$

$$= \frac{2000}{0.1 + 0.095} = 10.256\ \Omega$$

and output resistance of the amplifier stage,

$$R_{os} = R_o \parallel r_L = 10256 \parallel 1000 = 911\ \Omega \textbf{ Ans.}$$

(c) *Current gain of amplifier stage*

We know that the current gain of amplifier stage,

$$A_{is} = \frac{A_i \cdot R_s}{R_s + R_{is}} = \frac{(-45.5) \times (1000)}{1000 + 995} = -22.8 \textbf{ Ans.}$$

(d) *Voltage gain of amplifier stage*

We know that voltage gain of a transistor,

$$A_v = \frac{A_i \cdot r_L}{R_i} = \frac{(-45.5) \times (1000)}{995} = -45.7$$

$\therefore$ Voltage gain of amplifier stage,

$$A_{vs} = \frac{A_v \cdot R_{is}}{R_s + R_{is}} = \frac{(-45.7) \times 995}{1000 + 995} = -22.8 \textbf{ Ans.}$$

2.8.3 Hybrid Formulas for Common Base Amplifier

These formulas may be obtained from the general hybrid formulas derived in Art. 2.8 by adding a second subscript letter 'b' (which stands for common base) with h-parameters and are as discussed below:

(a) *Current gain.* It is given by the relation,

$$A_i = -\frac{h_{fb}}{1 + h_{ob} \cdot r_L}$$

where r_L is the a.c. load resistance. Its value is equal to the parallel combination of resistances R_C and R_L. Since h_{fb} of a transistor is a negative number, therefore the value of current gain (A_i) of a common base amplifier is positive.

(b) *Input resistance.* The resistance looking into the input terminals (*i.e.*, emitter of a transistor) is given by the relation,

$$R_i = h_{ib} + h_{rb} \cdot A_i \cdot r_L$$

$$= h_{ib} - \frac{h_{rb} \cdot h_{fb}}{h_{ob} + \dfrac{1}{r_L}}$$

The input resistance of the amplifier stage (called stage input resistance) R_{is} depends upon the biasing arrangement. If the amplifier circuits has no biasing resistance, then $R_{is} = R_i$

(*c*) *Voltage gain.* It is given by the relation,

$$A_v = \frac{A_i \cdot r_L}{R_i}$$

Since current gain (A_i) of a common base amplifier is positive, therefore the voltage gain (A_v) is also positive. It means that there is no phase difference between the input and output signals of a common base amplifier. The voltage gain, in terms of *h*-parameters, is given by the relation,

$$A_v = -\frac{h_{fb} \cdot r_L}{h_{ib} + \Delta h \cdot r_L}$$

where $\Delta h = h_{ib} \cdot h_{ob} - h_{rb} \cdot h_{fb}$

(*d*) *Output resistance.* The resistance looking into the amplifier output terminals is given by the relation,

$$R_0 = \frac{R_s + h_{ib}}{R_s \cdot h_{ob} + \Delta h}$$

where R_s = Resistance of the source, and

$$\Delta h = h_{ib} \cdot h_{ob} - h_{rb} \cdot h_{fb}$$

The output resistance of the amplifier stage,

$$R_{os} = R_o \,||\, r_L$$

(*e*) *Overall voltage gain.* It is given by the relation,

$$A_{vs} = \frac{A_v \cdot R_{is}}{R_s + R_{is}}$$

(*f*) *Overall current gain.* It is given by the relation,

$$A_{is} = \frac{A_i \cdot R_s}{R_s + R_{is}}$$

2.8.4 Hybrid Formulas for Common Collector Amplifier

These formulas may be obtained from the general hybrid formulas derived in Art. 2.8 by adding a second subscript letter '*c*' (which stands for common collector) with *h*-parameters and are as discussed below:

(*a*) *Current gain.* It is given by the relation,

$$A_i = -\frac{h_{fc}}{1 + h_{oc} \cdot r_L}$$

where r_L is the a.c. load resistance. Its value is equal to the parallel combination of resistancs R_E and R_L. Since h_{fc} of a transistor is a negative number, therefore current gain A_i is positive.

(*b*) *Input resistance.* The resistance looking into the amplifier input terminals (*i.e.*, base of a transistor) is given by the relation,

$$R_i = h_{ic} + h_{rc} \cdot A_i \cdot r_L$$
$$= h_{ic} - \frac{h_{rc} \cdot h_{fc}}{h_{oc} + \frac{1}{r_L}}$$

The input resistance of the amplifier stage R_{is} (called stage input resistance) depends upon the biasing arrangement, if the amplifier circuit has no biasing resistance, then $R_{is} = R_s$.

(*c*) *Voltage gain*. It is given by the relation,

$$A_v = \frac{A_i \cdot r_L}{R_i}$$

Since current gain (A_i) of a common collector amplifier is positive, therefore the voltage gain (A_v) is also positive. It means that there is no phase difference between the input and output signals of a common collector amplifier. The voltage gain, in terms of h-parameters, is given by the relation,

$$A_v = -\frac{h_{fc} \cdot r_L}{h_{ic} + \Delta h \cdot r_L}$$

where $\Delta h = h_{ic} \cdot h_{oc} - h_{rc} \cdot h_{fc}$

(*d*) *Output resistance*. The resistance looking into the amplifier output terminals is given by the relation,

$$R_0 = \frac{R_s + h_{ic}}{R_s \cdot h_{oc} + \Delta h}$$

where R_s = Resistance of the source, and

$$\Delta h = h_{ic} \cdot h_{oc} - h_{rc} \cdot h_{fc}$$

(*e*) *Overall voltage gain*. It is given by the relation,

$$A_{vs} = \frac{A_v \cdot R_{is}}{R_s + R_{is}}$$

(*f*) *Overall current gain*. It is given by the relation,

$$A_{is} = \frac{A_i + R_s}{R_i + R_{is}}$$

Table 1.4. Approximate hybrid formulas for common emitter, common base and common collector amplifiers

S. No.	*Item*	*Symbol*	*Common emitter*	*Common base*	*Common collector*
1.	Input resistance	R_i	h_{ie}	h_{ib}	$h_{ic} + h_{fc} \cdot r_L$
2.	Output resistance	R_o	$\frac{1}{h_{oe}}$	$\frac{1}{h_{ob}}$	$\frac{R_s + h_{ic}}{h_{fc}}$
3.	Current gain	A_i	$-h_{fe}$	$h_{fb} = 1$	h_{fc}
4.	Voltage gain	A_v	$\frac{h_{fe} \cdot r_L}{h_{ie}}$	$\frac{h_{fb} \cdot r_L}{h_{ib}}$	1

2.9 Introduction to amplifiers

The process of increasing the power of an ac signal is called amplification. The circuits used to perform this function are called amplifiers.

2.9.1 Classification of Amplifiers

The linear amplifiers may be classified according to their mode of operation *i.e.,* the way they operate on the predetermined set of values. Their descriptions are based on the following factors:

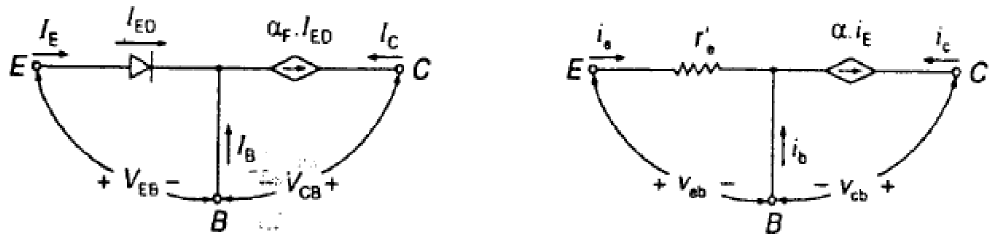
1. As based on the input
   (a) Small-signal amplifier
2. As based on the output
   (a) Voltage amplifier
3. As based on transistor configuration
   (a) Common-emitter (CE) amplifier (b) Common-base (CB) amplifier
   (c) Common-collector (CC) amplifier
4. As based on biasing conditions
   (a) Class-A (b) Class-B
5. As based on nature of load resistance
   (a) Untuned amplifiers (Wide-band amplifier)
   (b) Tuned amplifier (Narrow-band amplifier)
6. As based on frequency response
   (a) Direct coupled (DC) amplifier (b) Audio frequency (RF) amplifier
   (c) Radio frequency (RF) amplifier
   (d) Ultra high frequency (UHF) and microwave frequency amplifier
7. As based on number of stages
   (a) Single-stage amplifier (b) Multistage amplifier
8. As based on the method of coupling between the stages
   (a) DC (direct coupled) amplifier (b) R-C coupled amplifier
   (c) Transformer coupled amplifier

2.9.1.1 Small signal models of BJT

These are also called a.c. equivalent circuits of a transistor. The models, which we shall discuss here are linear. It may be noted that the transistor is not a linear device. But when we are interested in determining small changes about a quiescent operating point, linear models can be accurate. We know that signals can be represented by small changes. Thus linear models can be used in the analysis of small signal circuits for a variety of amplifier applications. It has been observed that the behaviour of transistor is different for low-frequencies and high-frequencies. Therefore we shall discuss the small signal models of a transistor under the following two heads:

1. Low-frequency small signal model.
2. High-frequency small signal model.

A low frequency small signal model can be obtained from the Ebers-Moll model of a transistor as shown in Figure (*a*). Since in the normal operation of a transistor, the emitter-base junction is forward biased and collector-base junction is reverse biased, therefore the Ebers-Moll model shown in Figure (*a*), can be reduced to a circuit as shown in Figure (*a*)



(*a*) Ebers-Moll model.
(*b*) Small signal model.

Fig. NPN transistor.

From this circuit, we can obtain a small signal model of a transistor as shown in Fig. (*b*).

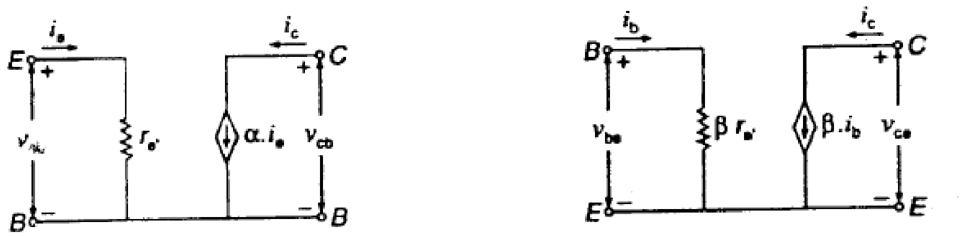
1. The emitter diode is replaced by an a.c. resistance r'_e. The resistance r'_e represents the a.c. resistance (or dynamic resistance) of a forward-biased emitter base junction. Its value is given by the relation,

$$r'_e = \frac{25}{I_E}$$

where I_E is the d.c. or quiescent operating current in milliamperes.

2. All currents and voltages of a transistor are indicated by lower case letter i and v respectively.
3. The diode current is represented by i_e instead of i_{ed}, as it does not make any difference. Similarly, α_F is shown as α.

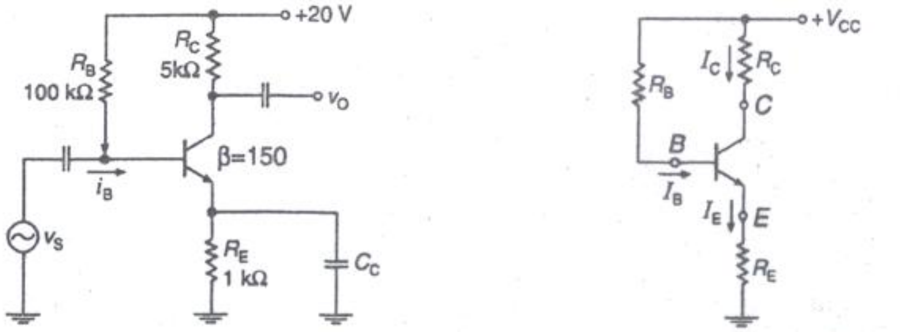
It may be noted that in a common emitter model, the a.c. resistance of a base-emitter junction is represented by $\beta \cdot r'_e$. The current of a controlled source is indicated by $\beta \cdot i_b$. The small signal models for an NPN transistor in a common base and common emitter configurations are shown in Fig.



(*a*) For a **NPN** transistor in common base configuration.
For a NPN transistor in common emitter configuration.

Fig. Low frequency small signal model.

2.9.2 Analysis of Common Emitter Amplifier



(*a*) Common emitter amplifier with emitter bypass capacitor. (*b*) D.C. equivalent circuit of common emitter amplifier.

Fig. 1.21

Figure 1.21 (*a*) shows the circuit of a simple common emitter amplifier with a base-bias (or fixed-bias) arrangement. The analysis of this amplifier can be done by splitting the circuit into two parts *i.e.,* d.c. equivalent circuit and a.c. equivalent circuit.

(*a*) *D.C. equivalent circuit.* It may be obtained from the amplifier circuit by opening (or disconnecting) the capacitors. The d.c. equivalent circuit is shown in Figure 1.21(*b*). We have already discussed in chapter on transistor biasing that base current in a base-bias circuit is given by the relation,

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{V_{CC}}{R_B} \quad \ldots (\because V_{CC} >> V_{BE})$$

and the collector current,

$$I_C = \beta \cdot I_\beta$$

$\therefore$ Emitter current,

$$I_E \approx I_C \approx \beta \cdot I_B$$

(*b*) *A.C. equivalent circuit.* It may be obtained from the amplifier circuit by replacing the d.c. supply (V_{CC}) by a ground and short-circuiting the capacitors. The a.c. equivalent circuit is shown in Figure 1.22 ·

We shall use d.c. and a.c. equivalent circuits to determine the amplifier parameters in the next article.

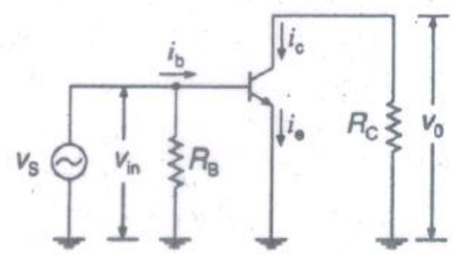


Fig. 1.22 . A.C. equivalent circuit.

2.9.2.1 Common Emitter Amplifier Parameters

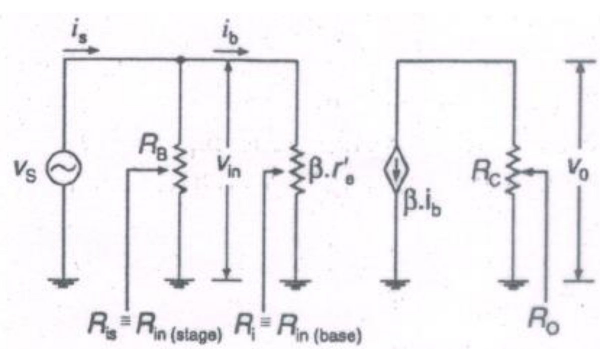


Fig. 1.23 . Detailed a.c. equivalent circuit of common emitter.

We have already discussed in the last article a simple a.c. equivalent circuit of a common emitter amplifier with base-bias. A more detailed a.c. equivalent circuit may be obtained by replacing NPN transistor with a small-signal model as discussed in the last chapter. Figure 1.23 shows such an a.c. equivalent circuit. This circuit is used to determine amplifier parameters such as input resistance (R_i), output resistance (R_o), current gain (A_i), voltage gain (A_v) and power gain (A_p). It may be noted that we have not shown the signal source resistance R_s in the figure. Therefore we shall take resistance R_s as zero. The effect of signal source resistance shall be discussed later in this chapter.

It may be noted from Figure 1.23 that $\beta \cdot r'_e$ represents the a.c. resistance of the emitter-base junction as seen by the input signal. It is known as input resistance, looking directly into the base and is designated by R_i or R_{in} (base). Here β is common emitter d.c. current gain (or h_{FE}) of a transistor. The input resistance, (R_i) does not include the effect of external biasing resistors connected to the base. The input resistance, which does include this is called an input resistance of amplifier stage. It is designated by R_{is} or R_{in} (stage). It may be noted that in the absence of signal source resistance (R_s), all the source voltage appears as the input voltage across the base-emitter junction. Another important point is that since $\beta \cdot r'_e$ is mucn smaller than resistance R_B, therefore a major part of source current (i_s) passes through $\beta r'_e$ and a negligible part through the resistance R_B. Following parameters of a common emitter amplifier are important from the subject point of view:

1. *Input resistance.* It is the resistance looking directly into the base and is given by the ratio of base voltage to base current. Thus input resistance,

$$R_i = \frac{v_b}{i_b} = \frac{v_{in}}{i_b}$$

Since $v_{in} = \beta \cdot r'_e \cdot i_b$, therefore, input resistance,

$$R_i = \frac{\beta \cdot r'_e \cdot i_b}{i_b} = \beta \cdot r'_e$$

and the input resistance of the amplifier stage,

$$R_{is} = R_B \,||\, (\beta \cdot r'_e)$$

Since $R_B >> \beta \cdot r'_e$, therefore,

$$R_{is} = \beta \cdot r'_e = R_i$$

2. *Output resistance.* It is the resistance, looking into collector, and is approximately equal to the collector resistance (R_c). Mathematically the output resistance,

$$R_0 = R_C$$

3. *Current gain.* It is the ratio of collector current (i_c) to the base current (i_b). Mathematically, the current gain,

$$A_i = \frac{i_c}{i_b} = \beta$$

4. *Voltage gain.* It is the ratio of output voltage (v_0) to the input voltage (v_{in}). Since the output voltage is the same as collector voltage and input voltage is the same as base voltage, therefore it is also known as voltage gain from base to collector. Mathematically the voltage gain,

$$A_v = \frac{v_0}{v_{in}}$$

We also know that the input voltage,

$$v_{in} = i_b \cdot \beta \cdot r'_e$$

and the output voltage,

$$v_0 = i_e \cdot R_C = \beta \cdot i_b \cdot R_C \qquad \ldots (\because (i_e = \beta \cdot i_b))$$

$\therefore$ Voltage gain,

$$A_v = \frac{\beta \cdot i_b \cdot R_C}{i_b \cdot \beta\, r'_e} = \frac{R_C}{r'_e}$$

5. *Power gain.* It is the product of current gain (A_i) and voltage gain (A_v). Mathematically, the power gain,

$$A_p = A_i \cdot A_v = \beta \cdot R_C / r'_e$$

and the power gain in decibels,

$$G_p = 10 \log_{10} A_p$$

Example *Figure (i) shows a common emitter amplifier with a base-bias arrangement.*

Determine the values of (a) input resistance looking into the base; (b) input resistance of the stage; (c) output resistance; and (d) voltage gain.

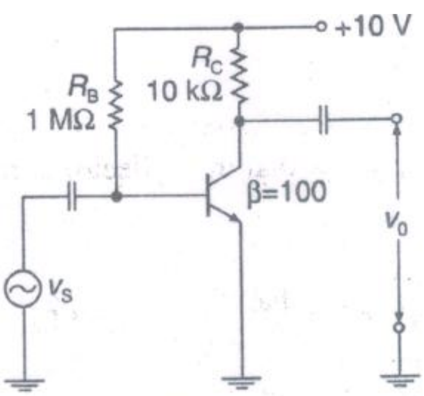


Fig. (i)

Solution. Given: V_{CC} = 10 volts; R_C = 10 kΩ = 10×10^3 Ω; R_B = 1 MΩ = 1×10^6 Ω and β = 100.

Figure (ii) shows the d.c. equivalent circuit for the common emitter amplifier.

(*a*) *Input resistance looking into the base*

We know that the base current,

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{10 - 0.7}{1 \times 10^6} = 9.3 \times 10^{-6} \text{ A}$$

$$= 9.3\ \mu\text{A}$$

and the collector current,

$$I_C = \beta \cdot I_B = 100 \times (9.3 \times 10^{-6})$$

$$= 0.93 \times 10^{-3} \text{ A} = 0.93 \text{ mA}$$

$\therefore$ Emitter current,

$$I_E \approx I_C = 0.93 \text{ mA}$$

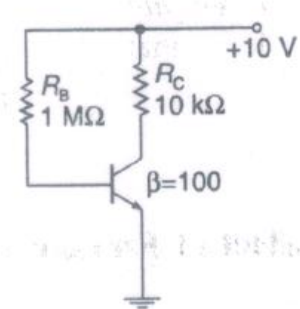


Fig. (ii)

and a.c. resistance of emitter diode,

$$r'_e = \frac{25}{I_E} = \frac{25}{0.93} = 26.9\ \Omega$$

∴ Input resistance looking directly into the base,

$$R_i = \beta \cdot r'_e = 100 \times 26.9 = 2690\ \Omega = 2.69\ k\Omega \textbf{ Ans.}$$

(*b*) *Stage input resistance*

We know that stage input resistance,

$$R_{is} = R_B \,||\, (\beta \cdot r_e') = (1 \times 10^6) \,||\, (2.69 \times 10^3)$$

$$= \frac{(1 \times 10^6) \times (2.69 \times 10^3)}{(1 \times 10^6 + 2.69 \times 10^3)} = 2.69\ k\Omega \textbf{ Ans.}$$

(*c*) *Output resistance*

We know that the output resistance,

$$R_0 = R_C = 10\ k\Omega \textbf{ Ans.}$$

(*d*) *Voltage gain*

We also know that the voltage gain,

$$A_v = \frac{R_c}{r'_e} = \frac{10 \times 10^3}{26.9} = 372 \textbf{ Ans.}$$

Example *A common emitter amplifier has an input resistance $R_i = 2.5\ k\Omega$ and a voltage gain of 200. If the input signal voltage is 5 mV, find (a) the base current (b) the collector current (c) the power gain, and (d) dB power gain. Take $\beta = 50$.*

Solution. Given: $R_i = 2.5\ k\Omega = 2.5 \times 10^3\ \Omega$; $A_v = 200$; $V_s = 5$ mV $= 5 \times 10^{-3}$ V and $\beta = 50$.

(*a*) *Base current*

Let i_b = Base current.

We know that the input resistance (R_i),

$$2.5 \times 10^3 = \frac{V_s}{i_b} = \frac{5 \times 10^{-3}}{i_b}$$

∴ $i_b = 2 \times 10^{-6}$ A $= 2\ \mu$A **Ans.**

(*b*) *Collector current*

We know that the collector current,

$$i_c = \beta \cdot i_b = 50 \times 2 = 100\ \mu A \textbf{ Ans.}$$

(*c*) *Power gain*

We know that the current gain,

$$A_i = \beta = 50$$

and power gain,

$$A_p = A_i \cdot A_v = 50 \times 200 = 10{,}000 \textbf{ Ans.}$$

(*d*) *dB Power gain*

We also know that *dB* power gain,

$$G_p = 10 \log_{10} A_p = 10 \log_{10} 10000$$
$$= 10 \log 10^3 = 40 \text{ dB. } \textbf{Ans.}$$

2.9.2.2 Characteristics and uses of Common Emitter Amplifier

A common emitter amplifier has the following important characteristics:

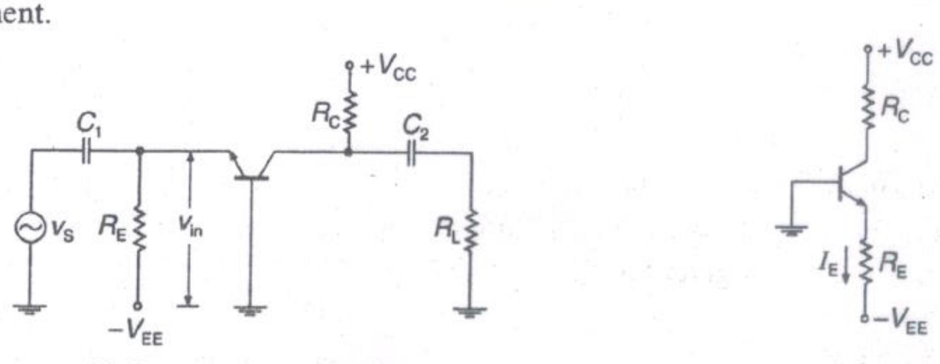
1. Its input resistance is in the range of 1 kΩ to 2 kΩ, which is considered to be moderately low.
2. Its output resistance is about 50 kΩ and is considered to be moderately large.
3. Its current gain (β) is very high and is in the range of 50 to 300.
4. Its voltage gain is of the order of 1500.
5. It produces very large power gain and is of the order of 10,000 (equal to 40 dB) or so.
6. It produces phase reversal of the input signal *i.e.*, output is 180° out of phase with respect to the input signal.

The common emitter amplifier is the most widely used amplifier in actual practice because of its large voltage and power gains. In addition to this, its input and output resistances are suitable for most of the applications.

2.9.3 Analysis of a Common Base Amplifier

Figure 1.24 shows a simple common base amplifier with a emitter-bias arrangement and connected to an external load resistance (R_L). The analysis of this amplifier circuit can be done by splitting it into two parts namely d.c. equivalent circuit and a.c. equivalent circuit. Both the d.c. and a.c. equivalent circuits may be obtained exactly in the same way as discussed for a common emitter amplifier.

Figure 1.24 (*b*) shows the d.c. equivalent circuit of the common base amplifier. We have already discussed in chapter on transistor bias that such a circuit is called emitter-bias arrangement.



(*a*) Common base amplifier. **Fig. 1.24** (*b*) D.C. equivalent circuit.

The emitter current in such a circuit is given by the relation,

$$I_E = \frac{V_{EE} - V_{BE}}{R_E}$$

and the collector current,

$$I_C = I_E$$

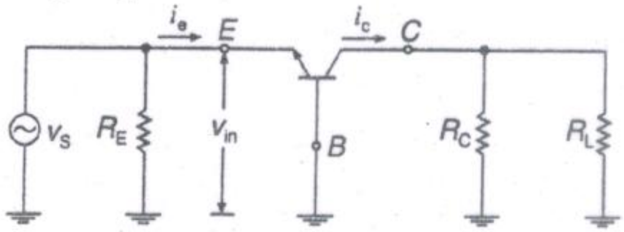


Fig. 1.25 . A simple a.c. equivalent circuit for CB amplifier.

Figure 1.25 shows a simple a.c. equivalent circuit for a common base amplifier. The input signal drives the emitter terminal and the output is taken from the collector.

2.9.3.1 Common Base Amplifier Parameters

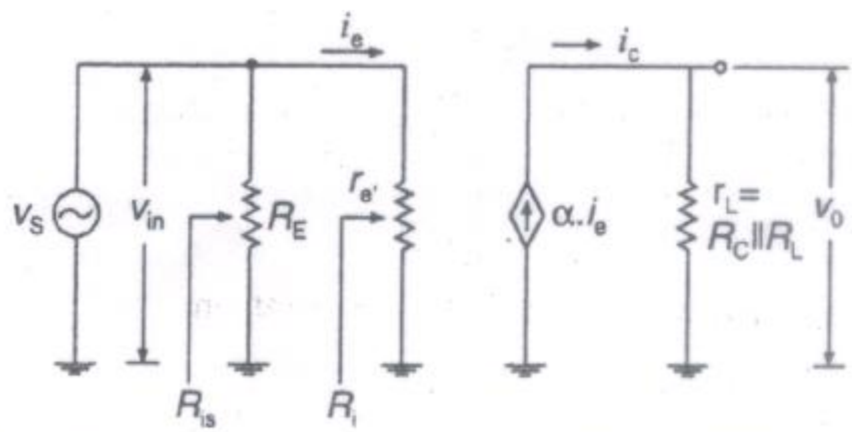


Fig. 1.26 . Detailed a.c. equivalent circuit of a common base amplifier.

Figure 1.26 shows a more detailed a.c. equivalent circuit of a common-base amplifier as compared to that discussed in the last article. In this circuit, the NPN transistor has been replaced by its small signal equivalent circuit. This circuit is used to determine the amplifier parameters.

It may be noted from the figure, that the signal source has no resistance *i.e.*, R_s is equal to zero. Therefore all of the signal voltage appears as the input voltage (*i.e.*, $v_{in} = v_s$). Now we shall determine the voltage of amplifier parameters in terms of circuit components.

1. *Input resistance*. The input resistance, looking directly into the emitter, is given by the relation,

$$R_i = r'_e$$

and the input resistance of the stage,

$$R_{is} = R_E \,\|\, r'_e = r'_e \qquad \text{... (if } R_E >> r'_e\text{)}$$

where r'_e is the a.c. resistance of the emitter diode (*i.e.*, emitter-base junction). It means that input resistance of a common base amplifier is just equal to r'_e. Since, the value of r'_e is usually very small, therefore the input resistance is also very small.

2. *Output resistance.* It is given by the relation,

$$R_0 = r_L$$

where r_L is the a.c. load resistance and its value is equal to the parallel combination of the resistances R_C and R_L (*i.e.*, $r_L = R_C \| R_L$). However, if R_L is not connected

$$R_0 = R_C$$

3. *Current gain.* It is given by the ratio of output current to the input current or the ratio of collector current to the emitter current. Mathematically the current gain,

$$A_i = \frac{i_c}{i_e} = \alpha$$

4. *Voltage gain.* It is given by the ratio of output voltage to the input voltage. Mathematically, the voltage gain.

$$A_v = \frac{v_0}{v_{in}} \qquad \text{.. } (i)$$

We know that the input voltage,

$$v_{in} = i_e \cdot r'_e$$

and the output voltage,

$$v_0 = i_c \cdot r_L = i_e \cdot r_L \qquad \text{... } (\because i_c = i_e)$$

Substituting the values of v_{in} and v_0 in equation (*i*) the voltage gain,

$$A_v = \frac{i_e \cdot r_L}{i_e \cdot r'_e} = \frac{r_L}{r'_e}$$

It indicates that voltage gain of a common-base amplifier is the ratio of a.c. load resistance to the a.c. resistance of emitter diode. It is also called the voltage gain from emitter to collector.

5. *Power gain.* It is given by the product of voltage gain and current gain. Mathematically, the power gain,

$$A_p = A_v \cdot A_i$$

The power gain, in decibels, is given by the relation,

$$G_p = 10 \log_{10} A_p$$

$\therefore$ Voltage gain of the amplifier stage,

$$A_{vs} = \frac{v_0}{v_{in}} = \frac{r_L}{R_s + r'_e} \approx \frac{r_L}{R_s} \qquad \text{... (If } R_s >> r'_e\text{)}$$

Example *For the single-stage common base amplifier shown in Figure , find the values of (a) input resistance, (b) current gain, (c) voltage gain and (d) power gain.*

What would be the r.m.s. value of the signal voltage across the load, if the input signal voltage is 10 mV? Assume the transistor to be made of silicon with current gain = 0.98.

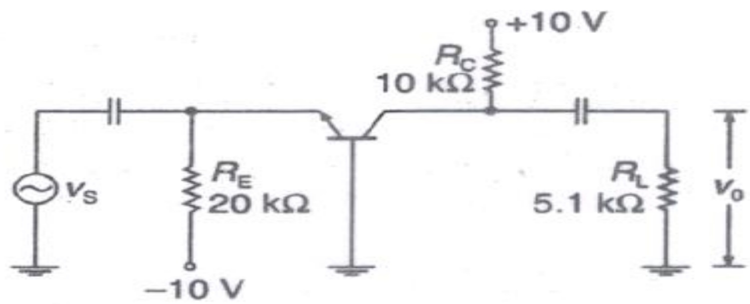


Fig.

Solution. Given: $V_S = 10$ mV; $\alpha = 0.98$; V_{BE} (for silicon transistor) = 0.7 volt; $V_{CC} = 10$ volts; $R_C = 10$ kΩ; $R_L = 5.1$ kΩ; $R_E = 20$ kΩ $= 20 \times 10^3$ Ω and $V_{EE} = 10$ volts.

Input resistance

We know that the value of emitter current,

$$I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{10 - 0.7}{20 \times 10^3} = 0.465 \times 10^3 \text{ A} = 0.465 \text{ mA}$$

and the value of a.c. emitter resistance,

$$r'_e = \frac{25}{I_E} = \frac{25}{0.465} = 53.8 \ \Omega$$

∴ Value of input resistance, looking directly into the emitter,

$$R_i = r'_e = 53.8 \ \Omega$$

and the input resistance of the stage,

$$R_{is} = R_E \parallel r'_e = (20 \times 10^3) \parallel 53.8 = 53.8 \ \Omega \ \textbf{Ans.}$$

Current gain

We know that the value of current gain,

$$A_i = \alpha = 0.98 \ \textbf{Ans.}$$

Voltage gain

We know that the value of a.c. load resistance,

$$r_L = R_C \parallel R_L = 10 \parallel 5.1 = 3.38 \text{ k}\Omega = 3.38 \times 10^3 \ \Omega$$

∴ Voltage gain,

$$A_v = \frac{r_L}{r'_e} = \frac{3.38 \times 10^3}{53.8} = 62.8 \ \textbf{Ans.}$$

Power gain

We know that the value of power gain,

$$A_p = A_v \cdot A_i = 62.8 \times 0.98 = 61.5 \ \textbf{Ans.}$$

and the power gain in decibels,

$$G_p = 10 \log_{10} A_p = 10 \log_{10} 61.5 = 17.9 \ dB \ \textbf{Ans.}$$

Output voltage

We know that the value of input voltage,

$$v_{in} = v_S = 10 \text{ mV} \qquad \ldots (R_s = 0)$$

∴ Value of output voltage,

$$V_0 = A_v \times v_{in} = 62.8 \times 10 = 628 \text{ mV} \ \textbf{Ans.}$$

Example *Consider the common base amplifier circuit as shown in* above *Example* *Assuming, the signal sources resistance (R_S) = 50 Ω, find (a) the voltage gain from source to output, (b) the voltage gain from emitter to output, and (c) approximate value of v_{in}.*

Solution. Given: $R_S = 50\ \Omega$.

We have already obtained the following in above Example

$I_E = 0.465$ mA; $r'_e = 53.8\ \Omega$; $R_i = 53.8\ \Omega$; $R_{is} = 52.4\ \Omega$ and $R_L = 3.38$ kΩ. Now we shall use the above values in this example.

(*a*) *Voltage gain from source to output*

We know that the voltage gain from source to output (called stage gain) is given by the relation,

$$A_{vs} = \frac{r_L}{R_s + r'_e} = \frac{3.38 \times 10^3}{50 + 53.8} = 32.6 \text{ **Ans.**}$$

(*b*) *Voltage gain from emitter to output*

We know that voltage gain from emitter to output,

$$A_v = \frac{r_L}{r'_e} = \frac{3.38 \times 10^3}{53.8} = 62.8 \text{ **Ans.**}$$

(*c*) *Value of v_{in}*

We know that the voltage gain from source to output, (A_{vs}),

$$32.6 = \frac{v_0}{v_s} = \frac{v_0}{10}$$

$$\therefore \quad v_0 = 32.6 \times 10 = 326 \text{ mV}$$

We also know that the voltage gain from emitter to collector (A_v),

$$62.8 = \frac{v_0}{v_{in}} = \frac{326}{v_{in}}$$

$$\therefore \quad v_{in} = 326/62.8 = 5.2 \text{ mV } \textbf{Ans.}$$

2.9.3.2 Characteristics and Uses of Common Base Amplifier

A common base amplifier has the following important characteristics:

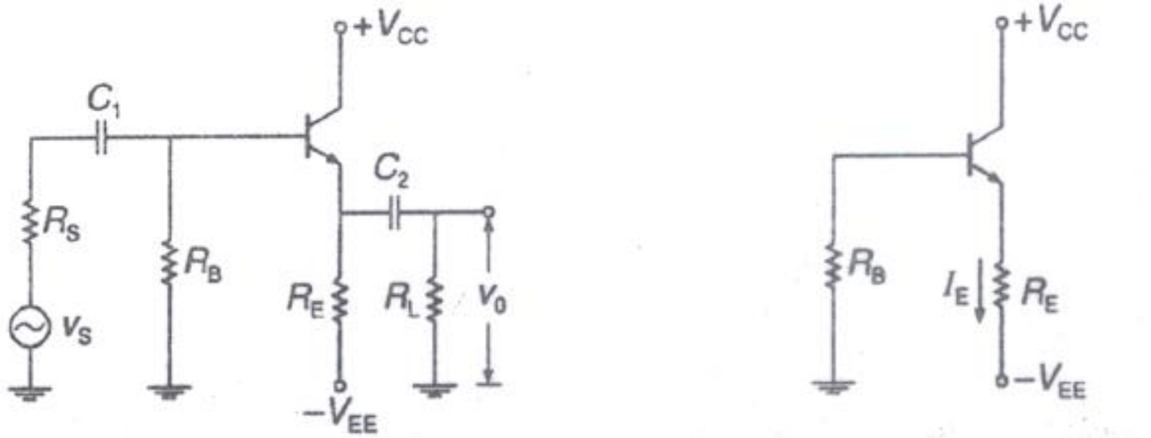
1. It has very low input resistance and is of the order of 30 to 150 ohms.
2. It has very high output resistance and is of the order of 500 kΩ.
3. Its current gain (α) is less than unity.
4. Its voltage gain is of the order of 1500.
5. Its power gain is of the order of 30 dB.
6. Its input and output are in phase with each other *i.e.*, there is no phase reversal between the input and output signals.

A common base amplifier has a very important application as it is used for matching circuits with low output resistance to those with a high input resistance.

2.9.4 Analysis of Common Collector Amplifier

Figure 1.27 (a) shows a simple common collector amplifier with a base-bias arrangement. The amplifier is connected to a load resistance (R_L). The d.c. equivalent circuit for the given amplifier is as shown in Figure 1.27 (b). The value of emitter current for such a circuit is given by the relation,

$$I_E = \frac{V_{EE} - V_{BE}}{R_E - R_B/\beta} \approx \frac{V_{EE}}{R_E + R_B/\beta}$$



(a) Common collector amplifier. (b) D.C. equivalent circuit.

Fig. 1.27

Figure 1.28 shows a simple a.c. equivalent circuit for a common collector amplifier. The input signal drives the base terminal and the output is taken from the emitter.

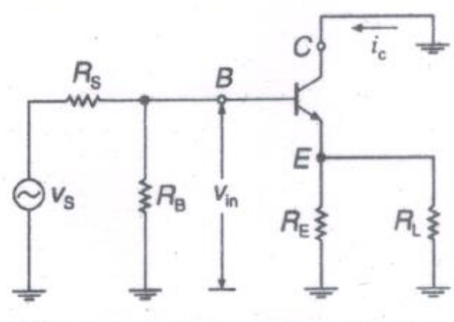


Fig. 1.28. A.C. equivalent circuit.

2.9.4.1 Common Collector Amplifier Parameters

Figure 1.29 shows a more detailed a.c. equivalent circuit of a common collector amplifier as compared to that of Figure 1.28 . In this circuit, an *NPN* transistor is replaced by its small-signals equivalent circuit. This circuit is used to determine input and output resistances, current gain, voltage gain and power gain of common collector amplifier.

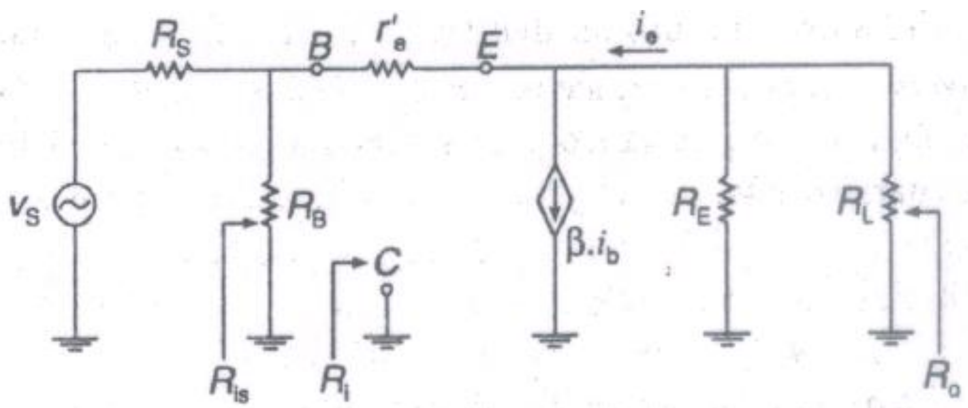


Fig. 1.29 . Detailed a.c. equivalent circuit of a common collector amplifier.

1. *Input resistance.* The input resistance of the stage is given by the parallel combination of R_E and R_i. Now R_i is the input resistance looking into the base. Its value is equal to $\beta\,(r'_e + r_L) \approx \beta \cdot r_L \cdot$ *i.e.,* β times the a.c. load resistance seen by the emitter.

$$\therefore \quad R_{is} = R_B \,\|\, \beta\,(r'_e + r_L)$$
$$\approx \beta\,(r'_e + r_L) \quad \text{... [If } R_B >> \beta\,(r'_e + r_L)]$$
$$\approx \beta \cdot r_L \quad \text{... (If } r_L >> r'_e)$$
$$= \beta \cdot R_E \quad \text{(If } R_L \text{ is equal to zero)}$$

2. *Output resistance.* Its value is given by the relation,

$$R_O = r_L \,\|\, \left(r'_e + \frac{R_B \,\|\, R_S}{\beta}\right)$$
$$= r'_e + \frac{R_B \,\|\, R_S}{\beta} \quad \text{... (If } r_L >> r'_e)$$

3. *Current gain.* It is given by the ratio of output current to input current *i.e.*, the ratio of emitter current to base current. Thus current gain,

$$A_i = \frac{i_c}{i_b} \approx \frac{i_e + i_b}{i_b} = 1 + \frac{i_c}{i_b} = 1 + \beta \approx \beta$$

4. *Voltage gain.* It is given by the ratio of output voltage to the input voltage. Thus voltage gain

$$A_v = v_O / v_{in}$$

We know that input voltage,

$$v_{in} = i_b \cdot R_i = i_b \cdot \beta\,(r'_e + r_L)$$

and output voltage,

$$v_O = i_e \cdot r_L = \beta \cdot i_b \cdot r_L$$

$$\therefore \quad A_v = \frac{\beta \cdot i_b \cdot r_L}{i_b \cdot \beta\,(r'_e + r_L)} = \frac{r_L}{r'_e + r_L} \approx \frac{r_L}{r_L} = 1 \quad \text{(If } r'_e << r_L)$$

It means that output signal from the emitter has the same magnitude as the input signal at the base.

5. *Power gain.* It is given by the product of voltage and current gain. Mathematically, the power gain.

$$A_p = A_v \times A_i = 1 \times \beta = \beta$$

and the power gain in decibels,

$$G_p = 10 \log_{10} A_p \text{ dB}$$

It is evident from the above discussion that the voltage gain of emitter follower is unity and current gain is β. However, input resistance is β times greater than the output resistance. It means that emitter follower steps up the resistance level of the output to a much higher value at its input. It is the most useful characteristic of an emitter follower (or common collector amplifier). This characteristic makes the emitter follower very useful as a resistance matching device *i.e.*, it is used to match circuits with high output resistance to those with low input resistance.

Example *Figure shows the circuit of an emitter follower. The transistor used in the circuit has current gain (β) of 50 and $V_{BE} = 0.7$ V*

Determine the values of input resistance, and the exact voltage gain.

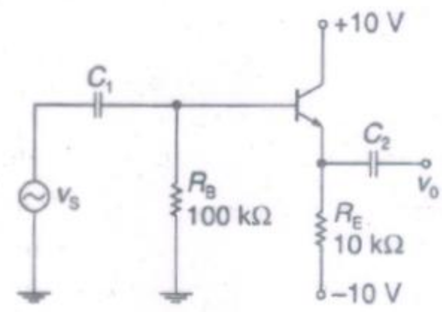


Fig.

Solution. Given: $V_{EE} = 10$ volts ; $R_E = 10$ kΩ $= 10 \times 10^3$ Ω; $R_B = 100$ kΩ $= 100 \times 10^3$ Ω; $\beta = 50$ and $V_{BE} = 0.7$ volt.

Input resistance

We know that the value of emitter current,

$$I_E = \frac{V_{EE} - V_{BE}}{R_E + \dfrac{R_B}{\beta}} = \frac{10 - 0.7}{(10 \times 10^3) + \dfrac{100 \times 10^3}{50}} = 0.775 \times 10^{-3} \text{ A} = 0.775 \text{ mA}$$

and a.c. resistance of emitter diode,

$$r'_e = \frac{25}{I_E} = \frac{25}{0.775} = 32.3 \ \Omega$$

∴ Input resistance looking directly into the base,

$$R_i = \beta (R_E + r'_e) = 50 [(10 \times 10^3) + 32.3] = 501.6 \text{ k}\Omega \textbf{ Ans.}$$

and input resistance of the stage,

$$R_{is} = R_B \parallel R_i = 100 \parallel 501.6 = 83.4 \text{ k}\Omega \textbf{ Ans.}$$

Output resistance

We know that the output resistance,

$$R_0 = r'_e + \frac{R_B \parallel R_S}{\beta} = r'_e = 32.3 \ \Omega \textbf{ Ans.} \qquad \ldots (\because R_s = 0)$$

Voltage gain

We also know that the voltage gain,

$$A_v = \frac{R_E}{r'_e + R_E} = \frac{10 \times 10^3}{32.3 + (10 \times 10^3)} = 0.997 \text{ Ans.}$$

2.9.4.2 Characteristics and Uses of Common Collector Amplifier

A common collector (or emitter follower) has the following important characteristics:

1. It has a high input resistance, which is of the order of 20 to 500 kΩ.
2. It has a low input resistance, which is of the order of 50 to 1000 Ω.
3. It has a high current gain. Its value depends upon the current gain (β) of the transistor, which is in the range of 50 to 500.
4. Its voltage gain is less than unity.
5. Its power gain is much smaller than that of common emitter and common base amplifiers.
6. Its output signal is in phase with the input signal.

The main application of common collector amplifier is for resistance matching. It is used to transfer energy from a high output resistance circuit to that of a low input resistance circuit. The common collector amplifier can also be used as a two-way amplifier, because it can pass a signal in either direction.

2.9.5 Comparison of Three Amplifier Configurations

Table 1.5 show the comparison of important characteristics of three amplifier configurations, namely common emitter, common base and common collector.

Table 1.5. Comparison of three amplifier configurations.

S. No.	*Characteristic*	*Type of configuration*		
		Common Emitter	*Common Base*	*Common Collector*
1.	Input resistance (R_i)	$\beta \cdot r'_e$ (Moderate)	r'_e (Lowest)	$\beta \cdot R_E$ (Highest)
2.	Output resistance (R_0)	R_c (Moderate)	R_c (Highest)	$\approx r'_e$ (Lowest)
3.	Current gain (A_i)	β (High)	≈ 1 (Lowest)	1 + β (Highest)
4.	Voltage gain (A_v)	r_L/r'_e (Highest)	r_L/r'_e (High)	≈ 1
5.	Power gain (A_p)	Highest	Moderate	Lowest
6.	Phase reversal	Yes	No	No