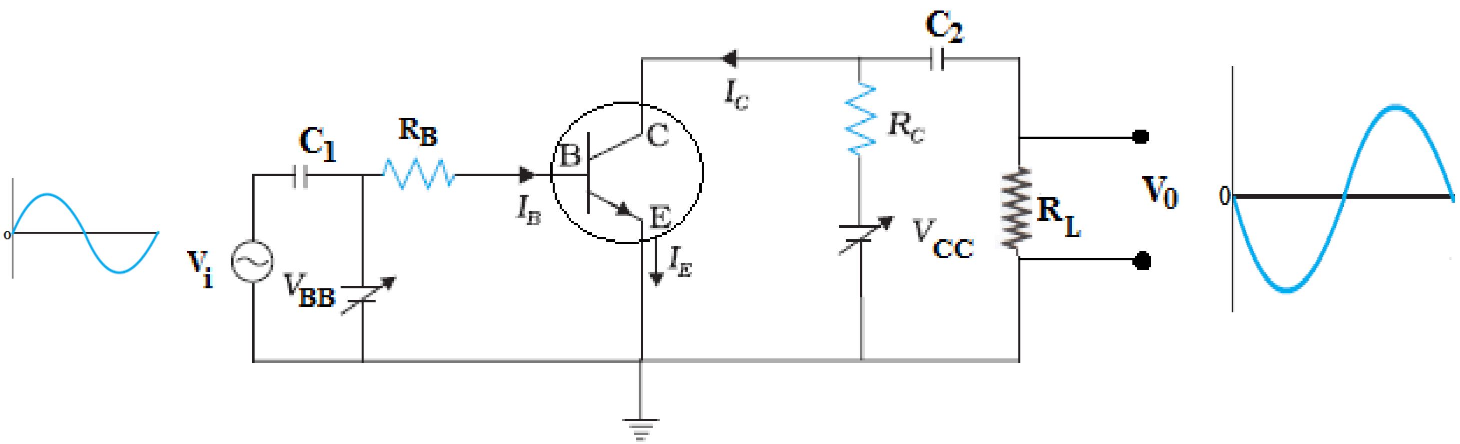
Transistor as an amplifier:

An amplifier is a device that increases the voltage, current or power of an input signal with the help of transistor by supplying the additional power from a separate source. The circuit details using an n-p-n transistor as a common emitter amplifier is shown in figure.



The input signal to be amplified is applied across the input circuit (base-emitter circuit). The input circuit is forward biased using a battery of e.m.f. V_{BB} volt. The amplified output signal is taken across the load resistance R_L in the output circuit (collector-emitter circuit). The output circuit is reverse biased using a battery of e.m,f. V_{CC} volt. According to Kirchhoff's junction law, emitter current (I_E), base current (I_B), and collector current (I_C) are related as

$$I_E = I_B + I_C \qquad \text{---- (1)}$$

When current (I_C) flows through the load resistance (R_L) then,

Output or collector voltage (V_0) = Applied voltage (V_{CE}) - Voltage drop across R_L

i.e. $$V_0 = V_{CC} - I_C R_L \qquad \text{----- (2)}$$

During positive half cycle of input signal, the forward bias of emitter-base junction increases. Due to increased forward bias, emitter current (I_E) increases and hence according to equation (1), collector current (I_C) also increases. Therefore, the voltage drop across R_L (=$I_C R_L$) increases. According to equation (2), the collector voltage or output voltage (V_0) decreases. Since collector is connected to the positive terminal of the battery (V_{CE}) so decrease in V_0 means that the collector voltage becomes less positive. In other words, amplified negative signal is obtained across the output.

Similarly, during negative half cycle of input signal, the forward bias of emitter-base junction decreases. As a result of this, emitter current (I_E) and hence collector current (I_C) decreases. Therefore, the voltage drop across R_L (=$I_C R_L$) also decreases. Hence according to equation (2), the output or collector voltage (V_0) increases. Since collector is connected to the positive terminal of the battery (V_{CE}) so increase in V_0 means that the collector voltage becomes more positive. Thus, an amplified positive signal is obtained across the output.

Since, in common-emitter amplifier, the output voltage decreases with increasing input signal and increases with decreasing input signal, so both input and output signals are out of phase i.e. there is a phase difference of π between input and output signals.

Current amplification factor (β):

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

$$\beta = \frac{\Delta I_C}{\Delta I_B}, \text{ at constant } V_{CE}$$

Voltage gain (A_V):

The ratio of change in the output voltage (ΔV_0) to the change in the input voltage (ΔV_i) is called voltage gain i.e.

$$A_V = \frac{\Delta V_0}{\Delta V_i} = \frac{\Delta I_C \Delta R_0}{\Delta I_B \Delta R_i} = \beta \times \frac{\Delta R_0}{\Delta R_i} = \beta \times \text{Resistance gain}$$

Power gain (P_V):

The ratio of change in the output power (ΔP_0) to the change in the input power (ΔP_i) is called power gain i.e.

$$P_V = \frac{\Delta P_0}{\Delta P_i} = \frac{\Delta I_C^2 \Delta R_0}{\Delta I_B^2 \Delta R_i} = \beta^2 \times \frac{\Delta R_0}{\Delta R_i} = \beta^2 \times \text{Resistance gain}$$

Transconductance (g_m):

The ratio of change in the output current (ΔI_0) to the change in the input voltage (ΔV_i), at constant output voltage (V_0) is called transconductance i.e.

$$g_m = \frac{\Delta I_0}{\Delta V_i}, \text{ at constant } V_0$$

$$\Rightarrow g_m = \frac{\Delta I_C}{\Delta V_{BB}}, \text{ at constant } V_{CC}$$

$$\Rightarrow g_m = \frac{\Delta I_C}{\Delta I_B} \times \frac{\Delta I_B}{\Delta V_{BB}}$$

$$\Rightarrow g_m = \beta \times \frac{1}{R_i}$$

$$\therefore \quad g_m = \frac{\beta}{R_i}$$

Its unit is Ω^{-1} or siemen.

37.1 Transistor Biasing

A transistor is used as an amplifier. For faithful amplification, the following three conditions must be satisfied :

(*i*) the emitter-base junction should be forward biased.

(*ii*) the collector-base junction should be reverse biased, and

(*iii*) there should be proper zero signal collector current.

The proper flow of zero signal collector current (proper operating point of a transistor) and the maintenance of proper collector-emitter voltage during the passage of signal is known as transistor biasing.

When a transistor is not properly biased, it works inefficiently and produces distortion in the output signal.

Requirements of biasing circuit

Following are the requirements of proper biasing a circuit :

1. **Proper zero signal collector current :** The collector current in the absence of the signal must be as least equal to the maximum collector current due to signal alone *i.e.*, zero signal collector current $\geq$ max. collector current due to signal alone. If this is not so, the output wave form obtained will be deformed.
2. **Minimum proper base-emitter junction voltage at any instant :** The base emitter voltage should be greater than cut-in voltage (V_γ= 0.3 V for Ge and 0.7 V for Si) *i.e.*, for faithful amplification, the potential barrier at emitter junction must be overcome by applying potential equal to cut-in voltage.
3. **Minimum proper collector-emitter junction voltage at any instant :** V_{CE} should be kept above (0.5 V for Ge and 1 V for Si) this is called knee voltages. If V_{CE} is too low, then collector-emitter junction is not properly reverse biased.

The condition (1) and (2) ensure that base-emitter junction shall remain properly forward biased and condition (3) ensure that collector emitter junction shall remain properly reverse biased in entire duration of the signal.

So, the proper flow of zero signal collector current and the maintenance of proper collector-emitter voltage during the passage of signal is known as transistor biasing. Thus, we may not operate the transistor any where in the active region. We must choose the operating point on the output characteristics such that above conditions are satisfied.

Stability Factor. The transistor parameters β, I_{C0} and V_{BE} are functions of temperature. Among these, the change in I_{C0} with temperature is more significant than other changes.

The stability factor S is defined as the rate of change of collector current I_C with respect to the reverse saturation current I_{C0} keeping β and V_{BE} constant, *i.e.*,

$$S = \frac{\partial I_C}{\partial I_{C0}} \approx \frac{\Delta I_C}{\Delta I_{C0}}$$

This expression shows that smaller is the value of S, higher is the stability. So the stability factor S should be kept as small as possible. The lowest value of S, that can be obtained is unity since I_C must include I_{C0}. Closer is the value of S to unity, lesser will be the variation of operating point with temperature.

I 3.12 : What do you mean by inherent variations of transistor parameters ? Define stabilisation and stability factor.

Inherent variations of transistor parameters

It is found that, the transistor parameters such as β, V_{BE}, I_C are not same for every transistor even of the same type. *e.g.*, BC147 is a silicon *n-p-n* transistor with β varying from 100 to 600 *i.e.* β may be 100 for one transistor and may be 600 for the other, although both of them are BC147. This variation in parameters is a characteristic of transistor. The major reason for these variations is difference in manufacturing techniques *e.g.*, it is not possible to control the base width, due to which a large change in transistor parameters occurs such as β, V_{BE} etc., even in the same type of the transistor .

The inherent variations of transistor parameter may change the operating point, resulting in unfaithful amplification. So, for getting faithful amplification operating point should be independent of inherent variations of transistor parameters.

Stabilisation

The collector current in a transistor changes rapidly when

(*i*) the temperature of collector junction changes

(*ii*) the transistor is replaced by another one of the same type. This is due to the inherent variations of transistor parameter.

When the temperature of collector junction changes or the transistor is replaced, the operating point (*i.e.*, zero signal I_C and V_{CE}) also changes. However, for faithful amplification, it is essential that operating point should remain fixed. So, *the process of making operating point independent of temperature changes or variations in transistor parameters is known as stabilisation.*

Therefore, stabilisation of the operating point is necessary due to following reasons :

1. Temperature dependence of I_C
2. Individual variations.
3. Thermal runway

1. **Temperature dependence of I_C :** The reverse saturation current I_{CO} changes greatly with temperature of collector junction. A rise of 10°C in temperature doubles the collector current I_{CO}. This fact may cause considerable practical difficulty in using a transistor as a circuit element.
   In order to compare the relative effectiveness of various circuits in reducing the temperature effect on I_C, a stability factor S is defined as *the ratio of the change in collector current to the change in reverse saturation current keeping β and V_{BE} constant.*

   or $$S = \frac{\partial I_C}{\partial I_{CO}}$$

   The larger the value of S, the circuit is more likely to exhibit *thermal instability.*
2. **Individual variations :** The value of β and V_{BE} are not exactly the same for any two transistors even of the same type.
3. **Thermal runaway :** The collector current for a C.E. configuration is given by

$$I_C = (\beta + 1) I_{CO} + \beta I_B \quad \text{.......(1)}$$

We know that I_{CO} is strongly dependent on temperature of collector junction, therefore if I_{CO} increases, the collector current I_C also increases by $(\beta + 1)I_{CO}$. The increased I_C will increase temperature of the transistor, which in turn will cause I_{CO} to increase. From these comulative events, the device burn out. Hence, *the self destruction of an unstablised transistor is known as thermal runaway.*

Differentiating equation (1) with respect to I_C

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

or $$1 = \frac{(\beta + 1)}{S} + \beta \frac{\partial I_B}{\partial I_C}$$

or $$\frac{(\beta + 1)}{S} = 1 - \beta \frac{\partial I_B}{\partial I_C}$$

or $$S = \frac{\beta + 1}{1 - \beta \dfrac{\partial I_B}{\partial I_C}} \quad \text{.......(2)}$$

It is the expression for calculating the *stability factor S* for any biasing arrangement. There are different bias stabilisation techniques which reduce to the value of S.

Types of transistor biasing:

There are three types of transistor biasing techniques:

1. Self Bias or Voltage Divider Bias or Emitter Resistance Bias Method..
2. Fixed Bias or Bas Resistor Method.
3. Collector – Base feedback resistor or biasing with feedback resistor method.

Self Bias or Emitter Bias (Voltage-Divider bias)

Self bias or emitter bias is the most widely used method of providing biasing and stabilisation to a transistor. The self bias or emitter bias circuit is shown in fig. 3.33. The forward bias of emitter base junction and reverse bias of the collector-base junction are provided by the supply voltage V_{CC} through the resistance R_1, R_2, and R_E respectively. In this method resistance R_1 and R_2 provides biasing and the emitter resistance R_E provides stabilisation. If R_I is zero then we use this self biasing for getting better

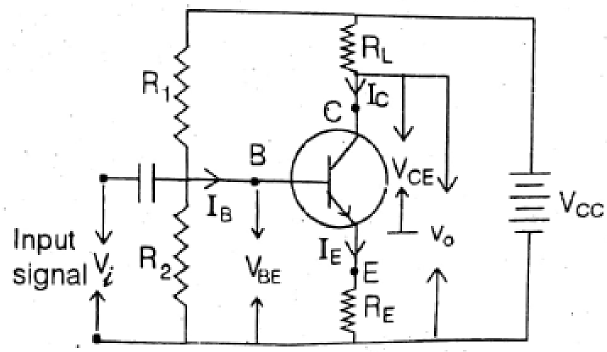


Fig. 3.33

stabilisation. The current in R_E causes voltage drop across it which is in the direction to reverse bias the emitter junction (and hence keeps a control over increase in I_C). The name voltage divider comes from the voltage divider formed by R_1 and R_2. The voltage drop across R_2 forward biases the base emitter junction. This causes the base current and hence collector current to flow in the zero signal conditions.

Stabilisation

If I_C tends to increase (let I_{CO} has risen due to rise in temperature or transistor has been replaced by another of larger β), then current in R_E increases. As a result the increased voltage drop across R_E increases the reverse bias across base emitter junction, so base current decreases. Hence, the reduced value of I_B tends to restore I_C to its original value.

Stability Factor

Suppose that the current flowing through R_1 is I_1. As base current is very small, the current flowing through R_2 is also I_1,

$$\therefore \quad I_1 = \frac{V_{CC}}{R_1 + R_2}$$

and voltage drop across R_2,

$$V_2 = \frac{V_{CC}\,R_2}{(R_1 + R_2)} \qquad [I_1 \cdot R_2]$$

Applying K.V.L. to the collector circuit,

$$V_{CC} = I_C R_L + V_{CE} + I_E R_E$$

$$= I_C R_L + V_{CE} + (I_C + I_B) R_E \qquad [\because I_E = I_C + I_B]$$

Applying K.V.L. to the base circuit,

$$V_2 = I_B R_T + V_{BE} + R_E I_E = I_B R_T + V_{BE} + (I_B + I_C)R_E \qquad ....(1)$$

where R_T is the effective resistance seen looking back from the base terminal and given by,

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

Differentiating equation (1) w.r.t. I_C

$$0 = \frac{\partial I_B}{\partial I_C} R_T + 0 + \frac{\partial I_B}{\partial I_C} R_E + R_E \qquad [\because V_{BE} \text{ is independent of } I_C]$$

or $$\frac{\partial I_B}{\partial I_C}(R_E + R_T) = -R_E$$

or $$\frac{\partial I_B}{\partial I_C} = \frac{-R_E}{R_E + R_T}$$

Now, the stability factor S is given by,

$$S = \frac{\beta + 1}{1 - \beta\left(\frac{\partial I_B}{\partial I_C}\right)}$$

Putting the value of$(\partial I_B/\partial I_C)$

$$\therefore \qquad S = \frac{\beta + 1}{1 + \beta\left(\frac{R_E}{R_E + R_T}\right)}$$

or $$S = \frac{(\beta + 1)(R_T + R_E)}{R_E + R_T + \beta R_E} = (\beta + 1) \times \frac{\left(1 + \frac{R_T}{R_E}\right)}{(\beta + 1) + \frac{R_T}{R_E}}$$

If $\frac{R_T}{R_E}$ is very small, then

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

Its is the smallest possible value of stability factor and leads to the maximum possible thermal stability.

and if $\frac{R_T}{R_E} \to \infty$, then $S = \beta + 1$

So, *the stability factor lies between* 1 *and* $\beta + 1$. Smaller is the value of R_T, better is the stabilisation. If R_T tends to zero but the value of S cannot be reduced below unity. Low value of R_T can be obtained by taking R_2 very small. But with low value of R_2, current drawn from V_{CC} will be large. Due to this, restriction, R_T can not become very small. Now, if we take R_E much large then it requires greater V_{CC} in order to maintain the same value of zero signal collector current. Therefore, the ratio R_T/R_E cannot be made very small from design point of view.

Fixed bias method

Fig. 3.31 shows the fixed bias arrangement for an *n-p-n* transistor operating in the C.E. configuration. The single source of voltage V_{CC} makes the emitter base junction forward biased and the collector base junction reverse biased.

In this biasing, a high resistance R_B (of the order of $M\Omega$) is connected between base and +ve end of V_{CC} for *n-p-n* transistor (-ve end of V_{CC} for *p-n-p* transistor). The required zero signal base current is provided by V_{CC} and it flows through R_B, because base is +ve w.r.t. to emitter *i.e.*, base emitter junction is forward biased.

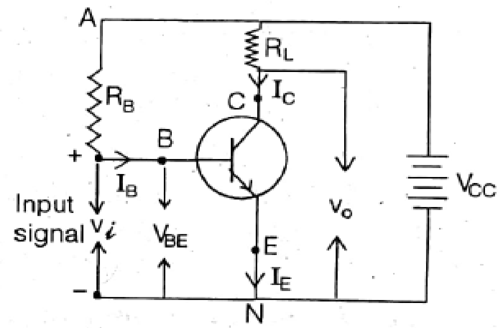


Fig. 3.31

Considering the closed circuit *ABENA* and applying Kirchoff's Voltage Law,

$$V_{CC} = I_B R_B + V_{BE}$$

or
$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

The voltage V_{BE} across forward biased emitter junction is 0.3 V for Ge and 0.7 V for Si transistor (given in the manual).

Since $V_{BE} << V_{CC}$ so, $$I_B \approx \frac{V_{CC}}{R_B}$$

or
$$R_B \approx \frac{V_{CC}}{I_B}$$

As the current I_B is approximately constant (V_{CC} and R_B are fixed), so this method is called fixed bias method.

Stability factor

The stability factor is given by,

$$S = \frac{\beta + 1}{1 - \beta\left(\frac{\partial I_B}{\partial I_C}\right)}$$

In fixed bias, I_B is independent of I_C

So,
$$\frac{\partial I_B}{\partial I_C} = 0$$

Thus, $S = \beta + 1$. It means that I_C changes $(\beta + 1)$ times I_{CO}. If $\beta = 50$, then $S = 51$ and I_C changes 51 times change in I_{CO}. Large value of S in this bias indicates that it has poor thermal stability. In this method, there is no means to stop increase in I_C due to rise in temperature of collector junction. So, this me.hod provides poor stabilization. Therefore, there are strong chances of thermal runaway.

Advantages

1. This biasing circuit is very simple as only one resistance R_B is required.
2. Biasing conditions can easily be set and the calculations are simple.
3. There is no loading of the source by the biasing circuit since no resistor is employed across base-emitter junction.

Disadvantages

1. This method provides poor stabilisation.
2. The stability factor is very high. Therefore, there are strong chances of thermal runaway.
   Due to these disadvantages, this method of biasing is rarely used.

Collector to base bias method or feed back resistor

To improve the stability of the fixed bias the resistance R_B is connected to collector junction rather than battery terminal (Fig. 3.32). Here required zero signal base current is determined by collector base bias V_{CB}. V_{CB} forward biases the base emitter junction and hence base current I_B flows through R_B. This causes zero signal collector current to flow in the circuit.

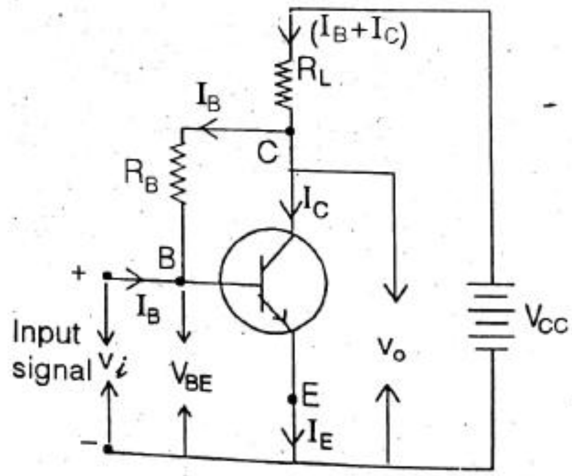


Fig. 3.32

To calculate stability factor (Actually it is instability factor, as greater S, greater instability) applying K.V.L. to figure 3.32, we get

$$V_{CC} = (I_B + I_C)R_L + I_B R_B + V_{BE} \quad ....(1)$$

or

$$I_B = \frac{V_{CC} - V_{BE} - I_C R_L}{(R_B + R_L)}$$

$$\frac{\partial I_B}{\partial I_C} = -\frac{R_L}{R_B + R_L}$$

Thus,

$$S = \frac{\beta + 1}{1 + \beta \frac{R_L}{R_B + R_L}} \quad ....(3)$$

for any value of R_L and R_B

$$S < (\beta + 1)$$

Therefore, this method gives better stability than the fixed bias. In this method feed back is provided from output to input terminal through R_B, so this method is also known as feed back resistor method.

Stability

The stability of the collector to base arrangement can be understood physically as follows. If I_C tends to increase (either because of rise in temperature or because the transistor has been replaced by another of larger β), then V_{CE} decreases due to greater drop across R_L ($\because$ $V_{CE} = V_{CC} - I_C R_L$) and hence V_{CB} decreases ($\because V_{CE} = V_{BE} + V_{CB}$) and I_B also decreases So, I_C is not allowed to increase.

Thus, the circuit tends to counter balance an increase of I_C and stabilize the quiescent point.

Advantages

1. It is a simple method as it requires only one resistance R_B.
2. This circuit provides some stabilisation, as we have

   $$V_{CE} = V_{BE} + V_{CB}$$

   Let the temperature of collector junction increases. This will increase the collector leakage current and the total collector current. But as soon as collector current increases, V_{CE} decreases due to greater voltage drop across R_L. This results in decreased V_{CB} *i.e.*, lower voltage is available across R_B. Hence, the base current I_B decreases. The smaller I_B tends to decrease the collector current to original value.

Disadvantages

1. The circuit does not provide good stabilisation because stability factor is fairly high, though it is smaller than that of fixed bias.
2. This circuit provides a negative feedback which reduces gain of the amplifier.
3. If R_L is small, then there is no improvement in stabilisation in collector to base bias methou than fixed bias

Hybrid Parameter

38.1 Two-port Representation of a Transistor

A transistor having three terminals is an active device and can be used in any of the three configuration, *CB*, *CE* and *CC*. In these configurations one of the terminals in common to the input and output circuits. Hence a transistor acts as a two port network, input port and the out port (Fig. 38.1).

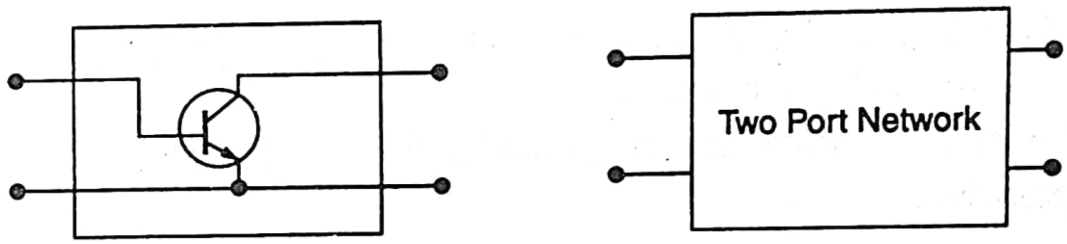


Fig. 38.1

For amplification purposes, the alternating currents, voltages to be amplified (called signals) are applied to the input port (pair of terminals) and the amplified signal is taken from output port (pair of output terminals). Then the performance of the amplifier is obtained by considering the transistor as a 'black box'.

38.2 The Hybrid Equivalent Circuit

To analyse the performance of transistors, they are conveniently represented by an equivalent circuit. The hybrid equivalent or the *h-parameter equivalent circuit* is widely used for small signal low frequency applications because of the following reasons.

(*i*) The *h*-parameters can be measured easily.

(*ii*) They are more independent of each other and other variables like frequency and operating point etc.

(*iii*) The value of *h*-parameters nearly corresponds to actual values of input and output impedances and current gain for many applications.

(*iv*) The *h*-parameters are real numbers at audio frequencies.

(*v*) They are particularly suitable for circuit analysis and design and are specified by the transistor manufacturers.

Hybrid Parameters. A four terminal network or a two port network can be treated as a Black Box with two input terminals and two output terminals (Fig. 38.2).

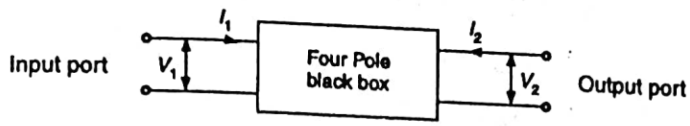


Fig. 38.2.

For each pair of terminals, there are two variables, the current I and voltage V. These four variables can be related by the following equations :

$$V_1 = h_{11} I_1 + h_{12} V_2 \quad \ldots(1)$$

$$I_2 = h_{21} I_1 + h_{22} V_2 \quad \ldots(2)$$

The parameters h_{11}, h_{12}, h_{21}, and h_{22}, which relate the four variables of the two port system, are called *h-parameters*. They may be defined by first putting $V_2 = 0$ (output terminals short circuited) and then $I_1 = 0$ (Input terminals open circuited) in the above equations. Thus

$$h_{11} = \left|\frac{V_1}{I_1}\right|_{V_2 = 0} = \text{Input impedance (with output shorted)} = h_i$$

$$h_{21} = \left|\frac{I_2}{I_1}\right|_{V_2 = 0} = \text{Forward current ratio (with output shorted)} = h_f$$

$$h_{12} = \left|\frac{V_1}{V_2}\right|_{I_1 = 0} = \text{Reverse voltage ratio (with input open)} = h_r$$

$$h_{22} = \left|\frac{I_2}{V_2}\right|_{I_1 = 0} = \text{Output admittance (with input open)} = h_0$$

h_{11} and h_{22} (*i.e.*, h_i and h_0) have dimensions of impedance and admittance respectively. h_{12} and h_{21} (*i.e.*, h_r and h_f) have no units. Hence the name hybrid parameters. Another subscript (*b* for Base, *e* for Emitter and *c* for Collector) is added to designate the configuration of the transistor.

Thus, h_{ib}, h_{rb}, h_{fb} and h_{0b} describe the *CB* configuration, h_{ie}, h_{re}, h_{fe} h_{0e} and h_{ic}, h_{rc}, h_{fc} and h_{0c} describe respectively the *CE* and *CC* configu-

3.9 : Define h-parameters. Describe the h-parameter equivalent circuit of a transistor.

h-Parameters

The performance of a transistor depends on its input and output impedance, voltage gain and current gain etc. To determine the response of a transistor circuit, its equivalent circuit is drawn replacing the transistor with the combination of circuit elements properly chosen that best approximates the actual behaviour of the device under specific conditions. For a particular operating point suitable d.c. values of voltage and currents, alternating voltage and currents (signals) are applied to input terminals (port) of the transistor amplifier. The amplified signal appears at output terminals (port). The behaviour of such a four terminal (two port) devices is usually determined by four variables *i.e.*, two voltage v_1 and v_2 (input and output voltages) and two currents i_1 and i_2 (input and output current) as shown in fig. 3.26. As v_1, i_1 and v_2, i_2 are external quantities for a transistor. Any pair of these quantities may be arbitrarily chosen as independent variables and remaining two dependent variable.

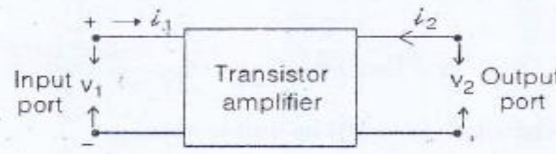


Fig. 3.26

If we assume v_2 and i_1 as independent variables and v_1 and i_2 are dependent variables, then

$$v_1 = f(i_1, v_2) \quad \text{.......(1)}$$

$$i_2 = f(i_1, v_2) \quad \text{.......(2)}$$

Taking the total differential of equation (1) and (2), we have

$$dv_1 = \left(\frac{\partial v_1}{\partial i_1}\right)_{v_2} di_1 + \left(\frac{\partial v_1}{\partial v_2}\right)_{i_1} dv_2 \quad \text{.......(3)}$$

$$di_2 = \left(\frac{\partial i_2}{\partial i_1}\right)_{v_2} di_1 + \left(\frac{\partial i_2}{\partial v_2}\right)_{i_1} dv_2 \quad \text{.......(4)}$$

Since, we are interested in developing only a.c. equivalent circuit, then $\Delta(\partial)$ quantities may be replaced by the symbols for instantaneous value of these variable quantities, thus

$$\Delta v_1 = v_1 = \left(\frac{\partial v_1}{\partial i_1}\right)_{v_2} di_1 + \left(\frac{\partial v_1}{\partial v_2}\right)_{i_1} dv_2$$

or
$$v_1 = h_{11} i_1 + h_{12} v_2 \quad \text{.......(5)}$$

and
$$\Delta i_2 = i_2 = \left(\frac{\partial i_2}{\partial i_1}\right)_{v_2} di_1 + \left(\frac{\partial i_2}{\partial v_2}\right)_{i_1} dv_2$$

or
$$i_2 = h_{21} i_1 + h_{22} v_2 \quad \text{.......(6)}$$

Equation (5) and (6) can be written as

$$\begin{bmatrix} v_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} i_1 \\ v_2 \end{bmatrix} \quad \text{.......(7)}$$

The quantities h_{11}, h_{12}, h_{21}, h_{22} are fixed constant for a given circuit and are called as *h-parameters*. These parameters are used to analyse a transistor or linear circuit having input and output terminals. These *h*-parameter may be defined as

$h_i = h_{11} = \left(\frac{\partial v_1}{\partial i_1}\right)_{v_2} = \frac{v_1}{i_1}$ = short circuited input impedance *i.e.*, input impedance with output short circuited ($v_2 = 0$). Its unit is ohm.

$h_r = h_{12} = \left(\frac{\partial v_1}{\partial v_2}\right)_{i_1} = \frac{v_1}{v_2}$ = open circuited reverse transfer voltage gain *i.e.*, reverse voltage gain with input open circuited. ($i_1 = 0$). It has no units.

$h_f = h_{21} = \left(\frac{\partial i_2}{\partial i_1}\right)_{v_2} = \frac{i_2}{i_1}$ = short circuited forward current gain *i.e.*, current gain with output short

$$h_0 = h_{22} = \left(\frac{\partial i_2}{\partial v_2}\right)_{i_1} = \frac{i_2}{v_2}$$ = open circuited output admittance *i.e.*, output admittance with input open circuited ($i_1 = 0$). Its unit is mho.

Since, these parameters does not have the same units or dimensions, (some have different dimensions and some are dimensionless) so, these parameters are called hybrid (mixed) parameters. At audio frequencies, *h*-parameters are real numbers and are easy to measure.

Hybrid h-Parameter Equivalent Circuit

The *h*-parameter equivalent circuit is derived from equation (5) and (6). The voltage v_1 is due to the flow of current i_1 through h_{11} in addition to a voltage generator $h_{12}v_2$. Similarly, we may conclude that output circuit is derived with the help of equation (6), it involves a current generator $h_{21}\, i_1$ and a shunt admittance h_{22}. The *h*-parameter equivalent circuit is shown in fig. 3.27.

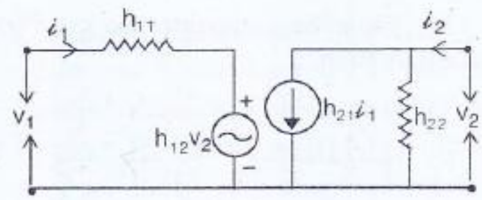


Fig. 3.27

39.1 Hybrid Equivalent Circuit of Common Emitter Amplifier

Fig. 39.1 shows the common-emitter *NPN* transistor amplifier circuit. R_g is the output resistance of input signal and R_L is the load resistance.

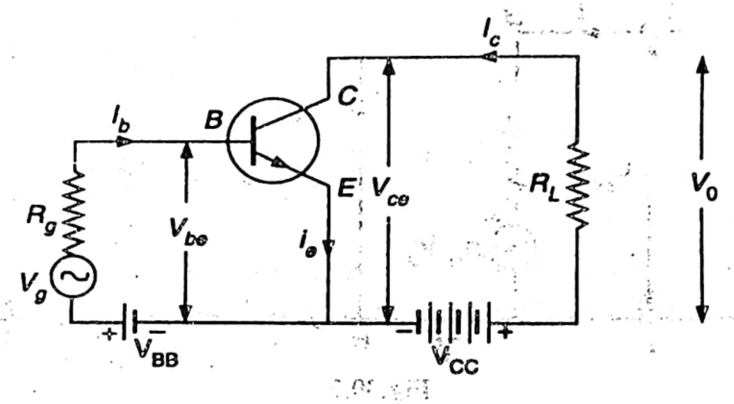


Fig. 39.1.

The general *h*-parameter expressions become,

$$V_i = V_{be} = h_{ie} I_b + h_{re} V_0 \quad ...(1)$$

$$I_c = h_{fe} I_b + h_{0e} V_0 \quad ...(2)$$

where $V_0 = V_{ce}$.

From Eq. (1), we get

$$I_b = \frac{V_i - h_{re} V_0}{h_{ie}} \quad ...(3)$$

The d.c. voltage of the collector with respect to the emitter is given by

$$V_{ce} = V_{cc} - I_c R_L$$

$$\therefore \quad dV_{ce} = -R_L\, dI_c \quad (\because V_{cc} \text{ is constant})$$

or

$$V_{ce} = -R_L\, i_c$$

In terms of usual notations, we can write

$$V_{ce} = -R_L I_c$$

or

$$V_0 = -R_L I_c$$

Substituting the value of V_0 in Eq. (2), we have

$$I_c = h_{fe} I_b - h_{0e} R_L I_c$$

or

$$h_{fe} I_b = h_{0e} R_L I_c + I_c$$

$$= \frac{I_c R_L}{1/h_{0e}} + \frac{I_C R_L}{R_L} \quad \ldots(4)$$

Equation (3) indicates that the base-emitter circuit is equivalent to a.c. voltage source of $h_{re} V_0$ which opposes the a.c. input voltage V_i and is connected in series with the input resistance h_{ie}.

Equation (4) indicates that the collector-emitter circuit is equivalent to current source which supplies a current $h_{fe} I_b$ and in parallel of which are

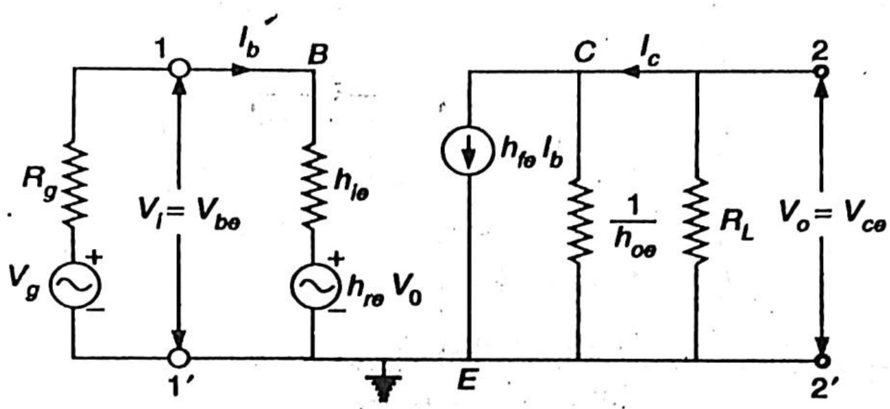


Fig.39.2.

connected the output resistance $1/h_{0e}$ and load resistance R_L.

Accordingly, the equivalent circuit is drawn in Fig. 39.2. Here the a.c. voltage source h_{re} V_0, which acts in opposition to the input signal V_i, represents the 'feedback' of the output voltage to the input circuit. The current source of magnitude h_{fe} I_b may be looked as if the input current I_b is amplified and appears as h_{fe} I_b in the output circuit. Thus $h_{fe} = \beta$, the current amplification factor.

39.2 Analysis of a Transistor *CE* Amplifier using *h*-parameters

Figure 39.2 shows the *h*-parameters equivalent circuit of a common emitter transistor amplifier. Here,

h_{ie} = input impedance,

h_{0e} = output admittance,

h_{fe} = forward current gain,

h_{re} = reverse voltage transfer ratio of the transistor.

The signal source V_g is across the input port along with its source impedance R_g. The load resistance R_L appears across the output port.

V_i and V_0 are the input and output signals respectively. The input and output currents are taken to be positive, while flowing inward. This circuit is an *a.c.* equivalent circuit and *d.c.* values do not appear in the circuit. I_b and I_c are the input and output currents, with the presence of the source and load.

We will now derive expressions for current gain, voltage gain, input impedance, output impedance and power gain.

(*i*) **Current Gain.** Let Z be the equivalent impedance of $1/h_{0e}$ and R_L in parallel. Then,

$$\frac{1}{Z} = 1/\frac{1}{h_{0e}} + \frac{1}{R_L} = h_{0e} + \frac{1}{R_L}$$

or

$$Z = \frac{R_L}{1 + h_{0e} R_L}$$

Voltage across R_L = voltage across Z

or

$$I_c R_L = h_{fe} I_b (Z) = h_{fe} I_b \left(\frac{R_L}{1 + h_{0e} R_L}\right)$$

or

$$\frac{I_c}{I_b} = \frac{h_{fe}}{1 + h_{0e} R_L}$$

$$\text{Current Gain } A_{ie} = \frac{\text{Output Current}}{\text{Input Current}}$$

$$\therefore \quad A_{ie} = \frac{I_c}{I_b} = \frac{h_{fe}}{1 + h_{oe} R_L} \quad \ldots(1)$$

(*ii*) **Input impedance.** The input impedance Z_{ie} of the transistor is the impedance at the input terminals 1 and 1′.

$$\text{Input impedance } Z_{ie} = \frac{\text{Input Voltage}}{\text{Input Current}} = \frac{V_i}{I_b}$$

But

$$V_i = h_{ie} I_b + h_{re} V_0$$

$$= h_{ie} I_b + h_{re}(-I_c R_L) \quad (\because V_0 = -I_c R_L)$$

$$Z_{ie} = \frac{V_i}{I_b} = h_{ie} - h_{re} R_L \left(\frac{I_c}{I_b}\right)$$

$$\therefore \quad Z_{ie} = h_{ie} - h_{re} R_L A_{ie} = h_{ie} - \frac{h_{re} \cdot h_{fe} \cdot R_L}{(1 + h_{0e} \cdot R_L)} \quad \ldots(2)$$

(*iii*) **Voltage gain**

$$\text{Voltage gain } A_{ve} = \frac{\text{Output Voltage } (V_0)}{\text{Input Voltage } (V_i)}$$

But $$V_0 = -I_c R_L$$

$$A_{ve} = -\frac{I_c R_L}{V_i} = -\left(\frac{I_c}{I_b}\right)\left(\frac{I_b}{V_i}\right) R_L$$

$$= -A_{ie}\left(\frac{1}{Z_c}\right) R_L = -\frac{A_{ie} R_L}{Z_i} \qquad \ldots(3)$$

Substituting the value of $Z_i = Z_{ie} = h_{ie} - h_{re} R_L A_{ie}$ from Eq. (2)

$$A_{ve} = -\frac{A_{ie} R_L}{h_{ie} - h_{re} R_L A_{ie}} = \frac{R_L}{\dfrac{h_{ie}}{A_{ie}} - h_{re} R_L}$$

Substituting $A_{ie} = \dfrac{h_{fe}}{1 + h_{0e} R_L}$ from Eq. (1), we get

$$A_{ve} = -\frac{R_L}{\dfrac{h_{ie}(1 + h_{0e} R_L)}{h_{fe}} - h_{re} R_L}$$

$$= -\frac{h_{fe} R_L}{h_{ie}(1 + h_{0e} R_L) - h_{fe} h_{re} R_L}$$

$$= -\frac{h_{fe} R_L}{h_{ie} + (h_{ie} h_{0e} - h_{fe} h_{re}) R_L}$$

$$= -\frac{h_{fe} R_L}{h_{ie} + R_L \Delta h} \qquad \ldots(4)$$

where $\Delta h = h_{ie} h_{0e} - h_{fe} h_{re}$

The negative sign shows that the input and the output are 180° out of phase.

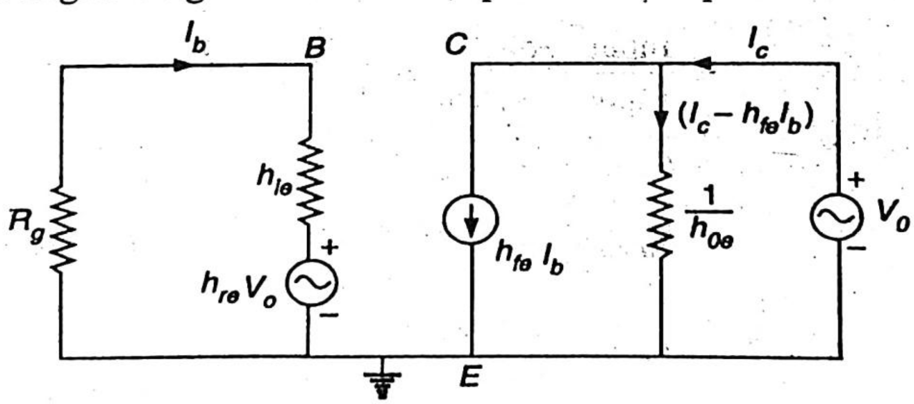


Fig. 39.3

(*iv*) **Output impedance.** The output impedance Z_0 of an amplifier is defined as the ratio of the output voltage to the output current with the input signal generator V_g reduced to zero and replaced by its internal resistance R_g and an a.c. voltage source V_0 (rms) applied to the output terminals as shown in Fig. 39.3. Thus

$$Z_{0e} = \frac{V_0}{I_c}$$

where I_c is the current sent by the applied source.

Since the current through the output resistance $1/h_{oe}$ is $I_c - h_{fe} I_b$, the output voltage V_0 is given by

$$V_0 = (I_c - h_{fe} I_b) \frac{1}{h_{oe}}$$

or $$h_{oe} V_0 = I_c - h_{fe} I_b \quad \ldots(5)$$

But the base current I_b is given by

$$I_b = -\frac{h_{re} V_0}{h_{ie} + R_g}$$

Substituting the value of I_b in Eq. (5), we get

$$h_{0e} V_0 = I_c + \frac{h_{fe} h_{re}}{h_{ie} + R_g} V_0$$

or $$V_0 \left(h_{0e} - \frac{h_{fe} h_{re}}{h_{ie} + R_g} \right) = I_c$$

or $$Z_{0e} = \frac{V_0}{I_c} = \frac{1}{h_{0e} - \dfrac{h_{fe} h_{re}}{h_{ie} + R_g}}$$

∴ $$Z_{0e} = \frac{h_{ie} + R_g}{h_{0e}(h_{ie} + R_g) - h_{fe} h_{re}} \quad \ldots(6)$$

(*v*) **Power gain.** Power gain of the amplifier is the product of current gain and voltage gain. Thus power gain

$$A_{pe} = |A_{ve}| \times |A_{ie}|$$

Substituting the values of A_{ve} and A_{ie} from Eqs. (4) and (1), we get

$$A_{pe} = \left(\frac{h_{fe} R_L}{h_{ie} + R_L \Delta h} \right) \left(\frac{h_{fe}}{1 + h_{0e} R_L} \right)$$

$$= \frac{h_{fe}^2 R_L}{(1 + h_{0e} R_L)(h_{ie} + R_L \Delta h)} \quad \ldots(7)$$

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

In actual practice, h_{oe}, h_{re} are very small quantities. $h_{oe} < 1$ and $R_L \Delta h < h_{ie}$.

∴ $$A_{pe} = \frac{h_{fe}^2 R_L}{h_{ie}}.$$