Dr. Avradip Pradhan,
Assistant Professor,
Department of Physics,
Narajole Raj College, Narajole.

C10T (Analog Systems and Apllications)

Topic – Amplifiers (Part – 1)

Sub Topic – Amplifiers

Introduction:

The basic function of transistor is to do amplification (i.e. to act as an amplifier). The weak signal is given to the base of the transistor and amplified output is obtained in the collector circuit. One important requirement during amplification is that only the magnitude of the signal should increase and there should be no change in signal shape. This increase in magnitude of the signal without any change in shape is known as *faithful amplification*. In order to achieve this, different techniques are provided to ensure that input circuit (i.e. base-emitter junction) of the transistor remains forward biased and output circuit (i.e. collector-base junction) always remains reverse biased during all parts of the signal. This is known as *transistor biasing*.

Transistor Biasing:

It is observed that for faithful amplification, a transistor amplifier must satisfy three basic conditions, namely: (i) proper *zero signal collector current* (I_C), (ii) proper *base-emitter voltage* (V_{BE}) at any instant and (iii) proper *collector-emitter voltage* (V_{CE}) at any instant. 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.

The basic purpose of transistor biasing is to keep the base-emitter junction properly forward biased and collector-base junction properly reverse biased during the application of signal. This can be achieved with a bias battery or associating a circuit with a transistor. The latter method is more efficient and is frequently employed. The circuit which provides transistor biasing is known as *biasing circuit*. It may be noted that transistor biasing is very essential for the proper operation of transistor in any circuit. In this e-report, two types of transistor biasing methods will be discussed, viz. *Fixed Bias Method* and *Voltage Divider Bias Method*.

Example: Suppose a signal applied to the base of a transistor gives a peak collector current of 1 mA. Then zero signal collector current must be atleast equal to 1 mA so that even during the peak of negative half-cycle of the signal, there is no cut off as shown in Fig. 1(*i*). If zero signal collector current is less, say 0.5 mA as shown in Fig. 1(*ii*), then some part (shaded portion) of the negative half-cycle of signal will be clipped off in the output.

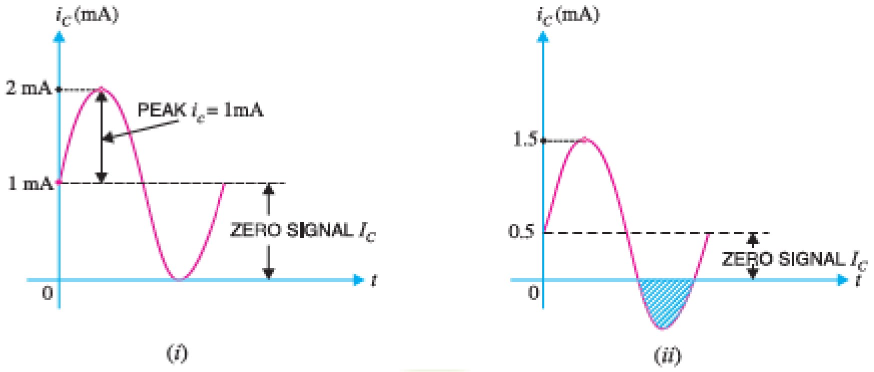

Fig. 1

Circuit Stabilization:

The collector current in a transistor changes rapidly when, (i) the temperature (T) changes and (ii) the transistor is replaced by another of the same type. This is due to the inherent variations of transistor parameters.

When the temperature changes or the transistor is replaced, the *operating point* (i.e. (I_C, V_{CE}) for zero signal) also changes. However, for faithful amplification, it is essential that operating point remains fixed. This necessitates making the operating point independent of these variations. This is known as stabilization.

Stabilization of the operating point is necessary due to the following reasons:

(i) Temperature dependence of I_C

(ii) Individual variations

(iii) Thermal runaway

Stability Factor:

The rate of change of collector current I_C with the collector leakage current I_{CO} at constant β and base current I_B is called the *stability factor* (S). Therefore,

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

The general expression of stability factor for a CE (common emitter) configuration can be obtained using the following equation

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

Differentiating with respect to I_C we obtain

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

Therefore, we finally obtain $S = \frac{\beta+1}{1-\beta\frac{dI_B}{dI_C}}$.

Fixed Bias Method:

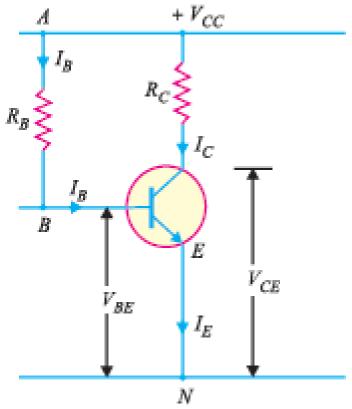

Fig. 2

In this method, a high resistance R_B (several hundred kΩ) is connected between the base and fixed positive end of supply for npn transistor (base and negative end of supply for pnp transistor, see Fig. 2). Here, the required zero signal base current is provided by V_{CC} and it flows through R_B. It is because now base is positive with respect to emitter i.e. base-emitter junction is forward biased. The required value of zero signal base current I_B (and hence $I_C = \beta I_B$) can be made to flow by selecting the proper value of base resistor R_B.

Circuit Analysis. Considering the closed circuit $ABENA$ and applying Kirchhoff 's voltage law, we get,

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

since V_{BE} is generally negligible in comparison to V_{CC}. So, R_B can always be found directly from the known values of V_{CC} and I_B.

Stability Factor. Since in fixed bias method I_B is independent of I_C, $\frac{dI_B}{dI_C} = 0$. Therefore, the stability factor (S) will be equal to $\frac{\beta+1}{1-0} = \beta + 1$. Due to such a large value of S in a fixed bias circuit, it has poor thermal stability.

Voltage Divider Bias Method:

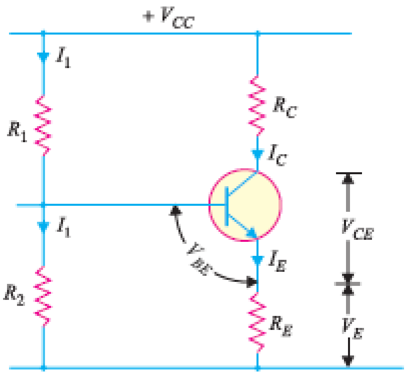

Fig. 3

This is the most widely used method of providing biasing and stabilization to a transistor. In this method, two resistances R_1 and R_2 are connected across the supply voltage V_{CC} (shown in Fig. 3) and provide biasing. The emitter resistance R_E provides stabilization. The word “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-flow in the zero signal conditions.

Circuit Analysis. Let us suppose that the current flowing through resistance R_1 is I_1. As the base current I_B is very small, therefore, it can be assumed with reasonable accuracy that current flowing through R_2 is also I_1 (shown in Fig. 3).

Voltage across resistance R_2 is $V_2 = I_1 R_2 = \frac{V_{CC}}{R_1+R_2} R_2$.

But according to Kirchhoff 's voltage law to the base circuit $V_2 = V_{BE} + V_E = V_{BE} + I_E R_E$. Therefore, $I_E = \frac{V_2 - V_{BE}}{R_E} \approx I_C$.

Though I_C depends upon V_{BE} but in practice $V_2 \gg V_{BE}$ so that I_C is practically independent of V_{BE}. Thus I_C in this circuit is almost independent of transistor parameters and hence good stabilization is ensured.

Now using Kirchhoff 's voltage law to the collector side $V_{CC} = I_C R_C + V_{CE} + I_E R_E \approx I_C R_C + V_{CE} + I_C R_E = I_C(R_C + R_E) + V_{CE}$.

So, $V_{CE} = V_{CC} - I_C(R_C + R_E)$.

Stability Factor. In this circuit, excellent stabilization is provided by R_E. It can be shown mathematically that stability factor of this circuit is given by

$$S = \frac{(\beta+1)(R_{\parallel}+R_E)}{R_{\parallel}+R_E+\beta R_E} \text{ where } R_{\parallel} = R_1 \parallel R_2$$

If $R_{\parallel} \ll R_E$, then S can be approximated as $\approx \frac{(\beta+1)R_E}{R_E+\beta R_E} = 1$.

Hybrid (or *h*) Parameters:

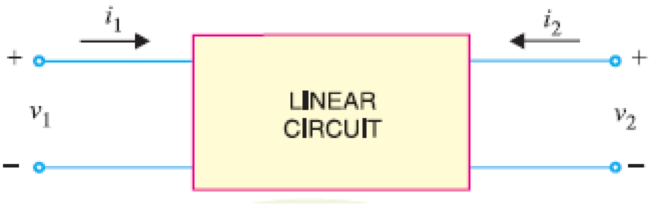

Fig. 4

Every linear circuit having input and output terminals can be analyzed by four parameters (one measured in Ω, one in Ω^{-1} (or mho) and two dimensionless) called hybrid or h parameters. Hybrid means “mixed”. Since these parameters have mixed dimensions, the word hybrid comes into play. Let us consider a linear circuit shown in Fig. 4. This circuit has input voltage and current labelled v_1 and i_1. This circuit also has output voltage and current labelled v_2 and i_2. It is crucial to note that both input and output currents (i_1 and i_2) are assumed to flow into the box; input and output voltages (v_1 and v_2) are assumed positive from the upper to the lower terminals.

It can be proved by advanced circuit theory that voltages and currents in Fig. 4 can be related by the following sets of equations:

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

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

In these equations, the hs are fixed constants for a given circuit and are called h parameters. Once these parameters are known, we can use these equations to find the voltages and currents in the circuit. It is clear that h_{11} has the dimension of Ω and h_{12} is dimensionless. Similarly h_{21} is dimensionless and h_{22} has the dimension of Ω^{-1}.

Determination of *h* Parameters:

The major reason for the use of h parameters is the relative ease with which they can be measured. Let us now try to get the physical meaning of these parameters.

For $v_2 = 0$ or a short-circuited output, we get $h_{11} = \frac{v_1}{i_1}$ and $h_{21} = \frac{i_2}{i_1}$.

Now for $i_1 = 0$ or an open-ended input, we get $h_{12} = \frac{v_1}{v_2}$ and $h_{22} = \frac{i_2}{v_2}$.

Therefore h_{11} is called as the *input impedance with the output shorted*, h_{12} is called as the *voltage feedback ratio with input open*, h_{21} is called as the *current* *gain with the output shorted* and h_{22} is called as the *output admittance with the input open*.

h Parameter Equivalent Circuit:

Fig. 5(*i*) shows a linear circuit. It is required to draw the h parameter equivalent circuit of Fig. 5(*i*).

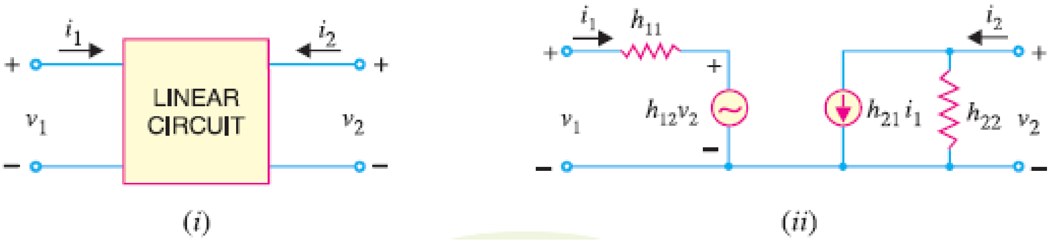

Fig. 5

Fig. 5(*ii*) shows h parameter equivalent circuit of Fig. 5(*i*) and is derived from the initial two equations. The *input circuit* appears as an impedance h_{11} in series with a voltage generator $h_{12}v_2$. This circuit is derived from the 1st equation. The *output circuit* involves two components; a current generator $h_{21}i_1$ and shunt admittance h_{22} and is derived from the 2nd equation.

The equivalent circuit of Fig. 5(*ii*) is extremely useful for two main reasons. Firstly, it isolates the input and output circuits, their interaction being accounted for by the two controlled sources. Thus, the effect of output upon input is represented by the equivalent voltage generator $h_{12}v_2$ and its value depends upon output voltage. Similarly, the effect of input upon output is represented by current generator $h_{21}i_1$ and its value depends upon input current. Secondly, the two parts of the circuit are in a form which makes it simple to take into account source and load circuits.

h Parameters of a Transistor:

It has been seen that every linear circuit is associated with h parameters. When this linear circuit is terminated by load r_L, we can find input impedance, current gain, voltage gain, etc. in terms of h parameters. Fortunately, for small AC signals, the transistor behaves as a linear device because the output AC signal is directly proportional to the input AC signal. Under such circumstances, the AC operation of the transistor can also be described in terms of h parameters. The expressions derived for input impedance, voltage gain etc. shall hold good for transistor amplifier except that here r_L is the AC load seen by the transistor. Fig. 6 shows the transistor amplifier circuit.

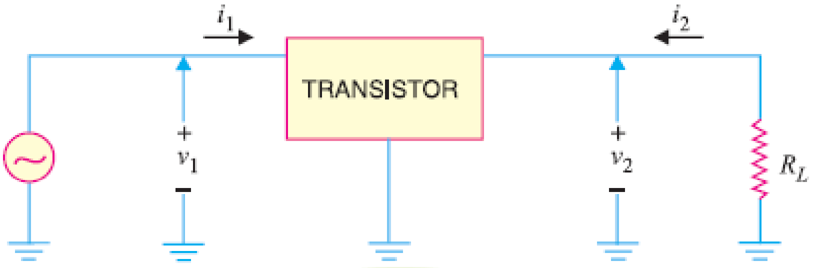

Fig. 6

The following points are worth noting while considering the behaviour of a transistor in terms of h parameters:

(i) For small AC signals, a transistor behaves as a linear circuit. Therefore, its AC operation can be described in terms of h parameters.

(ii) The value of h parameters of a transistor will depend upon the transistor connection (i.e. CB, CE or CC) used.

(iii) The expressions for input impedance, voltage gain etc. remain same to transistor amplifier except that r_L is the AC load seen by the transistor i.e. $r_L = R_C \parallel R_L$.

(iv) The values of h parameters depend upon the operating point. If the operating point is changed, parameter values are also changed.

(v) The notations v_1, i_1, v_2 and i_2 are used for general circuit analysis. In a transistor amplifier, we use the notation depending upon the configuration in which transistor is used. Thus for CE arrangement, $v_1 = V_{be}$, $i_1 = I_b$, $v_2 = V_{ce}$, $i_2 = I_c$. Here V_{be}, I_b, V_{ce} and I_c are all the RMS values.

Nomenclature for Transistor *h* Parameters:

The numerical subscript notation for h parameters (viz. h_{11}, h_{12}, h_{21} and h_{22}) is used in general circuit analysis. However, this nomenclature has been modified for a transistor to indicate the nature of parameter and the transistor configuration used. The table below shows the h parameter nomenclature of a transistor.

Serial No.	h parameter	in CB	in CE	in CC
1.	h_{11}	h_{ib}	h_{ie}	h_{ic}
2.	h_{12}	h_{rb}	h_{re}	h_{rc}
3.	h_{21}	h_{fb}	h_{fe}	h_{fc}
4.	h_{22}	h_{ob}	h_{oe}	h_{oc}

Here the first letter indicates the nature of parameter. For example, letters i, r, f and o indicate input impedance, reverse voltage feedback ratio, forward current transfer ratio and output admittance respectively. The second letters b, e and c respectively indicate CB, CE and CC arrangement.

This concludes part 1 of this e-report.

The discussion will be continuing in the part 2 of this e-report.

Reference:

Principles of Electronics, V.K. Mehta & Rohit Mehta, S. Chand & Company

(All the figures have been collected from the above mentioned reference)