2. Small Signal Amplifiers

2.1 Introduction

In order to predict the behavior of a small-signal transistor amplifier, it is important to know its operating characteristics e.g., input impedance, output impedance, voltage gain etc. These characteristics were determined by using β and circuit resistance values. This method of analysis has two principal advantages. Firstly, the values of circuit components are readily available and secondly the procedure followed is easily understood. However, the major drawback of this method is that accurate results cannot be obtained. It is because the input and output circuits of a transistor amplifier are not completely independent. For example, output current I_c is affected by the value of load resistance rather than being constant at the value βI_b. Similarly, output voltage has an effect on the input circuit so that changes in the output cause changes in the input.

One of the methods that takes into account all the effects in a transistor amplifier is the hybrid parameter approach. In this method, four parameters (one measured in ohm, one in mho, two dimensionless) of a transistor are measured experimentally. These are called *hybrid* or *h parameters* of the transistor. Once these parameters for a transistor are known, formulas can be developed for input impedance, voltage gain etc in terms of *h* parameters. There are two main reasons for using *h* parameter method in describing the characteristics of a transistor;

(i) It yields exact results because the inter-effects of input and output circuits are taken into account.
(ii) These parameters can be measured very easily.

To begin with, we shall apply *h* parameter approach to general circuits and then extend it to transistor amplifiers.

2.2 Hybrid Parameters

Every linear circuit (a linear circuit is one in which resistances, inductances and capacitances remain fixed when voltage across them changes) having input and output terminals can be analysed by four parameters (one measured in ohm, one in mho and two dimensionless) called *hybrid* or *h Parameters*.

Hybrid means "mixed". Since these parameters have mixed dimensions, they are called hybrid parameters. Consider a linear circuit shown in Fig. 2.1. This circuit has input voltage and current labeled v_1 and i_1, respectively. This circuit also has output voltage and current labeled v_2 and i_2, respectively. Note that both input and output current (i_1 and i_2) are assumed to flow into the box whereas the input and output voltages (v_1 and v_2) are assumed positive from the upper to the lower terminals. These are standard conventions and do not necessarily correspond to the actual directions and polarities. When we analyse circuits in which the voltages are of opposite polarity or where the currents flow out of the box, we simply treat these voltages and currents as negative quantities.

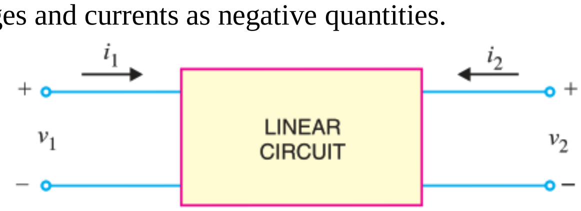


Fig. 2.1

It can be proved by advanced circuit theory that voltages and currents in Fig. 2.1 can be related by the following set of equations:

$$v_1 = h_{11}i_1 + h_{12}v_2 \quad (1)$$
$$i_2 = h_{21}i_1 + h_{22}v_2 \quad (2)$$

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 equations (1) and (2) to find the voltages and currents in the circuit. If we look at eq. (1), it is clear that h_{11} has the dimension of ohm and h_{12} is dimensionless. Similarly, from eq. (2), h_{21} is dimensionless and h_{22} has the dimension of mho. The following points may be noted about *h* parameters:

(i) Every linear circuit has four *h* parameters; one having dimension of ohm, one having dimension of mho and two dimensionless.

(ii) The *h* parameters of a given circuit are constant. If we change the circuit, *h* parameters would also change.

(iii) Suppose that in a particular linear circuit, voltages and currents are related as under:

$$v_1 = 10i_1 + 6v_2$$
$$i_2 = 4i_1 + 3v_2$$

Here we can say that the circuit has *h* parameters given by; $h_{11} = 10\ \Omega$; $h_{12} = 6$; $h_{21} = 4$ and $h_{22} = 3$ mho.

2.3 Determination of *h* Parameters

The major reason for the use of *h* parameters is the relative ease with which they can be measured. The *h* parameters of a circuit shown in Fig. 2.1 can be found out as under:

(i) If we short-circuit the output terminals (See Fig. 2.2), we can say that output voltage $v_2 = 0$. Putting $v_2 = 0$ in equations (1) and (2), we get;

$$v_1 = h_{11}i_1 + h_{12} \times 0$$
$$i_2 = h_{21}i_1 + h_{22} \times 0$$

Therefore;

$$h_{11} = \frac{v_1}{i_1} \quad \text{for } v_2 = 0 \text{ i.e output shorted}$$

and

$$h_{21} = \frac{i_2}{i_1} \quad \text{for } v_2 = 0 \text{ i.e output shorted}$$

Let us now turn to the physical meaning of h_{11} and h_{21}. Since h_{11} is a ratio of voltage and current (i.e. v_1/i_1), it is an impedance and is called "*input impedance with output shorted*". Similarly, h_{21} is the ratio of output and input current (i.e., i_2/i_1), it will be dimensionless and is called "*current gain with output shorted*."

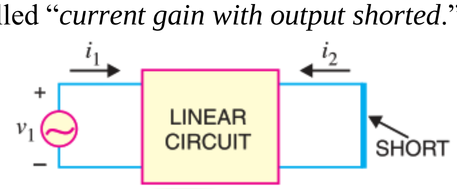


Fig. 2.2

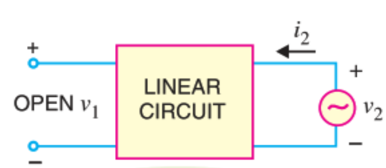


Fig. 2.3

(ii) The other two *h* parameters (viz h_{12} and h_{22}) can be found by making $i_1 = 0$. This can be done by the arrangement shown in Fig. 2.3. Here, we drive the output terminals with voltage v_2, keeping the input terminals open. With this set up, $i_1 = 0$ and the equations become:

$$v_1 = h_{11} \times 0 + h_{12} v_2$$
$$i_2 = h_{21} \times 0 + h_{22} v_2$$

Therefore;

$$h_{12} = \frac{v_1}{v_2} \quad \text{for } i_1 = 0 \text{ i.e input open}$$

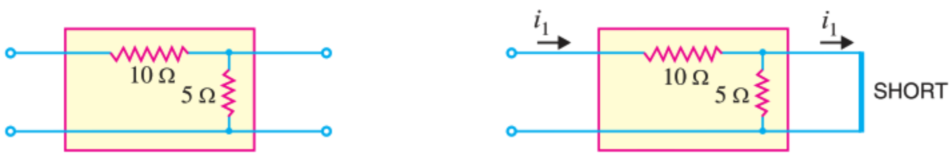
and

$$h_{22} = \frac{i_2}{v_2} \quad \text{for } i_1 = 0 \text{ i.e input open}$$

Since h_{12} is a ratio of input and output voltages (i.e. v_1/v_2), it is dimensionless and is called "*voltage feedback ratio with input terminals open*". Similarly, h_{22} is a ratio of output current and output voltage (i.e. i_2/v_2),), it will be admittance and is called "*output admittance with input terminals open.*"

Example 2.1

Find the *h* parameters of the circuit shown in Fig. 2.4(i).



(i) (ii)

Fig. 2.4

Solution

To find h_{11} and h_{21}, short-circuit the output terminals as shown in Fig. 2.4 (ii). It is clear that input impedance of the circuit is 10 Ω because 5 Ω resistance is shorted out.

Therefore;

$$h_{11} = 10\ \Omega$$

Now current i_1 flowing into the box will flow through 10 Ω resistor and then through the shorted path as shown. It may be noted that in our discussion, i_2 is the output current flowing into the box. Since output current in Fig. 2.4 (ii) is actually flowing out of the box, i_2 is negative i.e.,

$$i_2 = -i_1$$

Therefore;

$$h_{21} = \frac{i_2}{i_1} = \frac{-i_1}{i_1} = -1$$

To find h_{12} and h_{22}, make the arrangement as shown in Fig. 2.4 (iii). Here we are driving the output terminals with a voltage v_2. This sets up a current i_2. Note that input terminals are open. Under this condition, there will be no current in 10 Ω resistor i.e $i_1 = 0$ and, therefore, there can be no voltage drop across it. Consequently, all the voltage appears across input terminals i.e,

$$v_1 = v_2$$

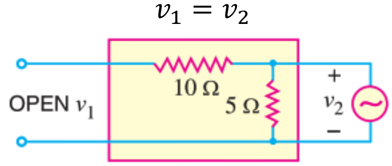


Fig. 2.4 (iii)

$$h_{12} = \frac{v_1}{v_2} = \frac{v_2}{v_2} = 1$$

Now the output impedance looking into the output terminals with input terminals open is simply 5 Ω. Then h_{22} will be the reciprocal of it because h_{22} is the output admittance with input terminals open, i.e,

$$h_{22} = 1/5 = 0.2 \text{ mho}$$

Thus, the *h* parameters of the circuit are;

$$h_{11} = 10\,\Omega \quad ; \quad h_{21} = -1$$
$$h_{12} = 1 \quad ; \quad h_{22} = 0.2 \text{ mho}$$

It may be mentioned here that in practice, dimensions are not written with *h* parameters. It is because it is understood that h_{11} is always in ohms, h_{12} and h_{21} are dimensionless and h_{22} is in mhos.

Exercise

Find the *h* parameters of the circuit shown in Fig. 2.5.

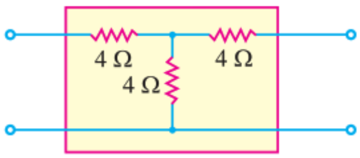
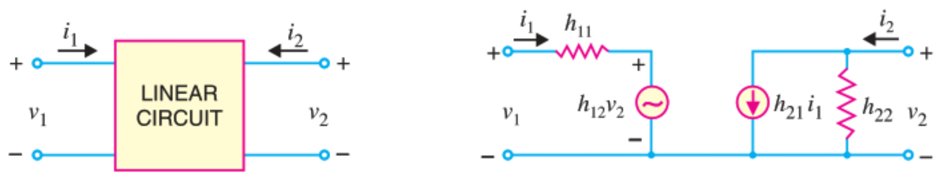


Fig. 2.5

2.4 *h* Parameter Equivalent Circuit

Fig. 2.6 (i) shows a linear circuit. It is required to draw the *h* parameter equivalent circuit of Fig. 2.6 (i). We know that voltages and currents of the circuit in Fig. 2.6 (i) can be expressed in terms of *h* parameters as restated below:

$$v_1 = h_{11}i_1 + h_{12}v_2 \tag{1}$$
$$i_2 = h_{21}i_1 + h_{22}v_2 \tag{2}$$



(i) (ii)

Fig. 2.6

Fig. 2.6 (ii) shows the *h* parameter equivalent circuit of Fig. 2.6 (i) and is derived from equations (1) and (2). The input circuit appears as a resistance h_{11} in series with a voltage generator $h_{12}v_2$. This circuit is derived from equation (1). The output circuit involves two components; a current generator $h_{21}i_1$ and shunt resistance h_{22} and is derived from equation (2). The following points are worth noting about the *h* parameter equivalent circuit [See Fig. 2.6 (ii)];

(i) This circuit is called hybrid equivalent because its input portion is a Thevenin equivalent, or voltage generator with series resistance, while output side is Norton equivalent, or current generator with shunt resistance. Thus it is a mixture or a hybrid. The symbol '*h*' is simply the abbreviation of the word hybrid (hybrid means "mixed").

(ii) The different hybrid parameters are distinguished by different number subscripts. The notation shown in Fig. 2.6 is used in general circuit analysis. The first number designates the circuit in which the effect takes place and the second number designates the circuit from which the effect comes. For instance, h_{21} is the "short-circuit forward current gain" or the ratio of the current in the output (circuit 2) to the current in the input (circuit 1).

(iii) The equivalent circuit of Fig. 2.6 (ii) is extremely useful for two main reasons;

a) 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 the output voltage v_2. Similarly, the effect of input upon output is represented by current generator $h_{21}i_1$ and its value depends upon the input current i_1.

b) Secondly, the two parts of the circuit are in a form which makes it simple to take into account source and load circuits.

2.5 Performance of a Linear Circuit in *h* Parameters

We have already seen that any linear circuit with input and output has a set of *h* parameters. We shall now develop formulas for input impedance, current gain, voltage gain and output impedance of a linear circuit in terms of *h* parameters.

2.5.1 Input Impedance

Consider a linear circuit with a load resistance r_L across its terminals as shown in Fig. 2.7. The input impedance Z_{in} of this circuit is the ratio of input voltage to input current i.e.

$$\begin{aligned} Z_{in} &= \frac{v_1}{i_1} \\ &= \frac{h_{11}i_1 + h_{12}v_2}{i_1} = h_{11} + \frac{h_{12}v_2}{i_1} \end{aligned} \qquad (3)$$

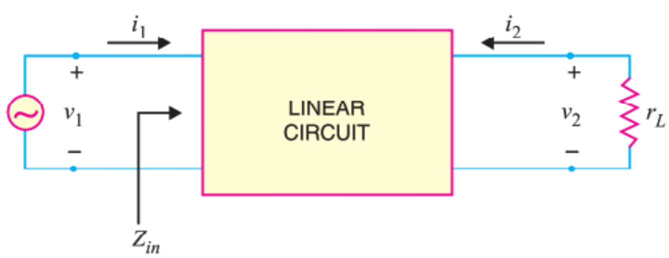


Fig. 2.7

Also from Fig. 2.7;

$$i_2 = -\frac{v_2}{r_L}$$

The minus sign is used here because the actual load current is opposite to the direction of i_2.

$$h_{21}i_1 + h_{22}v_2 = -\frac{v_2}{r_L}$$

$$-h_{21}i_1 = h_{22}v_2 + \frac{v_2}{r_L} = v_2\left(h_{22} + \frac{1}{r_L}\right)$$

Therefore;

$$\frac{v_2}{i_1} = \frac{-h_{21}}{h_{22} + \frac{1}{r_L}} \qquad (4)$$

Substituting the value of v_2/i_1 from exp. (4) into exp. (3), we get;

$$Z_{in} = h_{11} - \frac{h_{12}h_{21}}{h_{22} + \frac{1}{r_L}} \qquad (5)$$

This is the expression for input impedance of a linear circuit in terms of *h* parameters and load connected to the output terminal. If either h_{12} or r_L is very small, the second term in exp. (5) can be neglected and input impedance becomes:

$$Z_{in} \approx h_{11}$$

2.5.2 Current Gain

Referring to Fig. 2.7, the current gain A_i of the circuit is given by:

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

where

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

and

$$v_2 = -i_2 r_L$$

$$\Rightarrow i_2 = h_{21}i_1 - h_{22}i_2 r_L$$

$$\Rightarrow i_2(1 + h_{22}r_L) = h_{21}i_1$$

$$\Rightarrow \frac{i_2}{i_1} = \frac{h_{21}}{1 + h_{22}r_L}$$

$$A_i = \frac{h_{21}}{1 + h_{22}r_L}$$

If $h_{22}r_L \ll 1$, then $A_i \approx h_{21}$.

The expression $A_i \approx h_{21}$ is often useful. To say that $h_{22}r_L \ll 1$ is the same as saying that $r_L \ll 1/h_{22}$. This occurs when r_L is much smaller than the output resistance $(1/h_{22})$, shunting $h_{21}i_1$ generator. Under such condition, most of the generator current bypasses the circuit output resistance in favour of r_L. This means that $i_2 \approx h_{21}i_1$ or $i_2/i_1 \approx h_{21}$.

2.5.3 Voltage Gain

Referring back to Fig. 2.7, the voltage gain of the circuit is given by:

$$A_v = \frac{v_2}{v_1}$$

$$= \frac{v_2}{i_1 Z_{in}} \qquad (6)$$

While developing expression for input impedance, we found that:

$$\frac{v_2}{i_1} = \frac{-h_{21}}{h_{22} + \frac{1}{r_L}}$$

Substituting the value of v_2/i_1 in exp. (6);

$$A_v = \frac{-h_{21}}{Z_{in}\left(h_{22} + \frac{1}{r_L}\right)}$$

2.5.4 Output Impedance

In order to find the output impedance, remove the load r_L, set the signal voltage v_1 to zero (short-circuit the input) and connect a generator of voltage v_2 at the output terminals. Then, the h parameter equivalent circuit becomes as shown in Fig. 2.8. By definition, the output impedance Z_{out} is;

$$Z_{out} = \frac{v_2}{i_2}$$

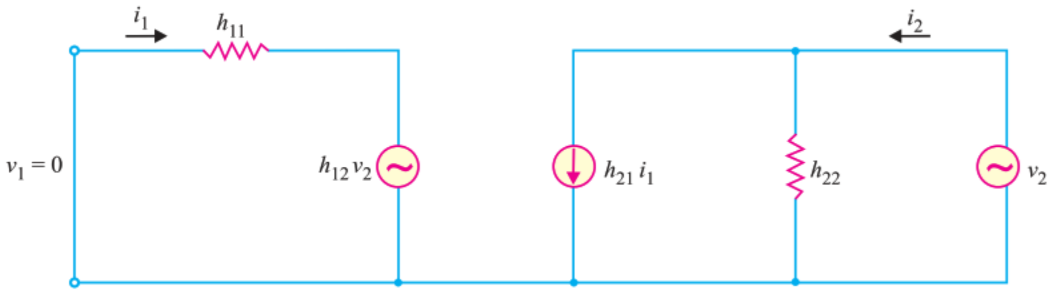


Fig. 2.8

With $v_1 = 0$ and applying Kirchhoff's voltage law to the input circuit, we have;

$$0 = h_{11}i_1 + h_{12}v_2$$

$$\Rightarrow i_1 = -\frac{h_{12}v_2}{h_{11}}$$

Also;

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

Putting the value of $i_1(= -h_{12}v_2/h_{11})$ in the above eq. we get;

$$i_2 = h_{21}\left(-\frac{h_{12}v_2}{h_{11}}\right) + h_{22}v_2$$

$$\Rightarrow i_2 = -\frac{h_{21}h_{12}v_2}{h_{11}} + h_{22}v_2$$

Dividing throughout by v_2, we have;

$$\frac{i_2}{v_2} = -\frac{h_{21}h_{12}}{h_{11}} + h_{22}$$

$$\Rightarrow Z_{out} = \frac{1}{h_{22} - \frac{h_{21}h_{12}}{h_{11}}}$$

Example 2.2

For the circuit shown in Fig. 2.9, determine;

(i) The input impedance

(ii) The voltage gain.

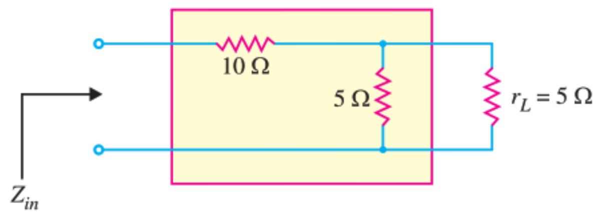


Fig. 2.9

Solution

The h parameters of the circuit inside the box are the same as those calculated in example 2.1 i.e.

$$h_{11} = 10 \quad ; \qquad h_{21} = -1$$

$$h_{12} = 1 \quad ; \quad h_{22} = 0.2$$

(i) Input impedance is given by;

$$Z_{in} = h_{11} - \frac{h_{12}h_{21}}{h_{22} + \frac{1}{r_L}} = 10 - \frac{1 \times -1}{0.2 + \frac{1}{5}}$$

$$= 10 + 2.5 = \mathbf{12.5\ \Omega}$$

By inspection, we can see that input impedance is equal to 10 Ω plus two 5 Ω resistances in parallel i.e. $Z_{in} = 10 + 5\ \Omega \| 5\ \Omega$.

(ii) Voltage gain

$$A_v = \frac{-h_{21}}{Z_{in}\left(h_{22} + \frac{1}{r_L}\right)}$$

$$= \frac{-(-1)}{12.5\left(0.2 + \frac{1}{5}\right)} = \frac{1}{5}$$

It means that output voltage is one-fifth of the input voltage. This can be readily established by inspection of Fig. 2.9. The two 5 Ω resistors in parallel give a net resistance of 2.5 Ω. Therefore, we have a voltage divider consisting of 10 Ω resistor in series with 2.5 Ω resistor.

2.6 The *h* Parameters of a Transistor

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

Fig. 2.10 shows the transistor amplifier circuit. There are four quantities required to describe the external behavior of the transistor amplifier. These are v_1, i_1, v_2 and i_2 as shown on the diagram of Fig. 2.10. These voltages and currents are related by the following sets of equations:

$$v_1 = h_{11} i_1 + h_{12} v_2$$
$$i_2 = h_{21} i_1 + h_{22} v_2$$

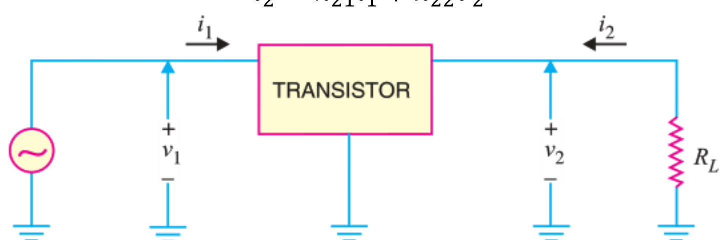


Fig. 2.10

The following points are worth noting while considering the behavior of a transistor in terms of *h* parameters;

(i) For small a.c. signals, a transistor behaves as a linear circuit. Therefore, its a.c. 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. For instance, a transistor used in *CB* arrangement may have $h_{11} = 20\ \Omega$. If we use the same transistor in *CE* arrangement, h_{11} will have a different value. Same is the case with other *h* parameters.

(iii) The expressions for input impedance, current gain, voltage gain and output impedance derived in section 2.4 are also applicable to transistor amplifier except that r_L is the a.c. load seen by the transistor i.e.

$$r_L = R_C \| R_L$$

(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 the transistor is used. Thus for *CE* arrangement,

$$v_1 = V_{be} \quad ; \quad i_1 = I_b \quad ; \quad v_2 = V_{ce} \quad ; \quad i_2 = I_c$$

Here, V_{be}, I_b, V_{ce} and I_c are the R.M.S values.

2.7 Nomenclature for Transistor *h* Parameters

The numerical subscript notation for h parameters (viz. h_{11}, h_{21}, h_{12} 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 h parameters of a transistor are represented by the following notation:

(i) The numerical subscripts are replaced by letter subscripts.

(ii) The first letter in the double subscript notation indicates the nature of parameter.

(iii) The second letter in the double subscript notation indicates the circuit arrangement (i.e. *CB*, *CE* or *CC*) used.

Table 2.1 below shows the h parameter nomenclature of a transistor:

Table 2.1 h parameter nomenclature of a transistor

S.No.	*h* parameter	Notation in CB	Notation in CE	Notation 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}

Note that the first letter i, r, f or o indicates the nature of parameter. Thus h_{11} indicates input impedance and this parameter is designated by the subscript i. Similarly, letters r, f and o respectively indicate reverse voltage feedback ratio, forward current transfer ratio and output admittance. The second letters *b*, *e* and *c* respectively indicate *CB*, *CE* and *CC* arrangement.

2.8 Transistor Circuit Performance in *h* Parameters

The expressions for input impedance, current gain, voltage gain and output impedance in terms of h parameters derived in section 2.4 for general circuit analysis apply equally for transistor analysis. However, it is profitable to rewrite them in standard transistor h parameter nomenclature.

2.8.1 Input Impedance

The general expression for input impedance is;

$$Z_{in} = h_{11} - \frac{h_{12}h_{21}}{h_{22} + \frac{1}{r_L}}$$

Using standard h parameter nomenclature for transistor, its value for *CE* arrangement will be:

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

Similarly, expressions for input impedance in *CB* and *CC* arrangements can be written. It may be noted that r_L is the a.c. load seen by the transistor.

2.8.2 Current Gain

The general expression for current gain is;

$$A_i = \frac{h_{21}}{1 + h_{22}r_L}$$

Using standard transistor *h* parameter nomenclature, its value for *CE* arrangement is;

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

Similarly, the expressions for current gain for *CB* and *CC* arrangements can easily be written down.

2.8.3 Voltage Gain

The general expression for voltage gain is;

$$A_v = \frac{-h_{21}}{Z_{in}\left(h_{22} + \frac{1}{r_L}\right)}$$

Using standard transistor *h* parameter nomenclature, its value for *CE* arrangement is;

$$A_v = \frac{-h_{fe}}{Z_{in}\left(h_{oe} + \frac{1}{r_L}\right)}$$

Similarly, the expressions for voltage gain for *CB* and *CC* arrangements can easily be written down.

2.8.4 Output Impedance

The general expression for output impedance is;

$$Z_{out} = \frac{1}{h_{22} - \frac{h_{12}h_{21}}{h_{11}}}$$

Using standard transistor *h* parameter nomenclature, its value for *CE* arrangement is;

$$Z_{out} = \frac{1}{h_{oe} - \frac{h_{re}h_{fe}}{h_{ie}}}$$

In the same way, the expressions for output impedance in *CB* and *CC* arrangements can be written.

The above expression for Z_{out} is for the transistor. If the transistor is connected in a circuit to form a single stage amplifier, then output impedance of the stage = $Z_{out} \| r_L$ where $r_L = R_C \| R_L$.

Example 2.3

A transistor used in *CE* arrangement has the following set of *h* parameters when the d.c. operating point is $V_{CE} = 10$ V and $I_C = 1$ mA:

$$h_{ie} = 2000\ \Omega; \quad h_{oe} = 10^{-4} \text{ mho}; \quad h_{re} = 10^{-3}; \quad h_{fe} = 50$$

If the a.c. load seen by the transistor is $r_L = 600\ \Omega$, determine;

(i) The input impedance

(ii) The current gain

(iii) The voltage gain.

What will be approximate values using reasonable approximations?

Solution:

(i) Input impedance, Z_{in} is given by;

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

$$= 2000 - \frac{10^{-3} \times 50}{10^{-4} + \frac{1}{600}} \qquad (\star)$$

$$= 2000 - 28$$

$$Z_{in} = \mathbf{1972\ \Omega}$$

The second term in eq. ($\star$) is quite small as compared to the first.

Therefore, $Z_{in} \approx h_{ie} = \mathbf{2000\ \Omega}$

(ii) Current gain, A_i is given by;

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

$$= \frac{50}{1 + (10^{-4} \times 600)}$$

$$A_i = \mathbf{47}$$

As $h_{oe}r_L \ll 1$, $A_i \approx h_{fe} = \mathbf{50}$

(iii) Voltage gain, A_v is given by;

$$A_v = \frac{-h_{fe}}{Z_{in}\left(h_{oe} + \frac{1}{r_L}\right)}$$

$$= \frac{-50}{1972\left(10^{-4} + \frac{1}{600}\right)}$$

$$A_v = \mathbf{-14.4}$$

The negative sign indicates that there is 180° phase shift between input and output. The magnitude of gain is 14.4. In other words, the output signal is 14.4 times greater than the input and it is 180° out of phase with the input.

Example 2.4

Fig. 2.11 shows a transistor amplifier in *CE* arrangement. The *h* parameters of transistor are as under:

$$h_{ie} = 1500\ \Omega; \quad h_{fe} = 50; \quad h_{re} = 4 \times 10^{-4}\ ; \quad h_{oe} = 5 \times 10^{-5}\ \text{mho}$$

Find;

(i) The a.c. input impedance of the amplifier
(ii) The voltage gain
(iii) The output impedance of the amplifier.

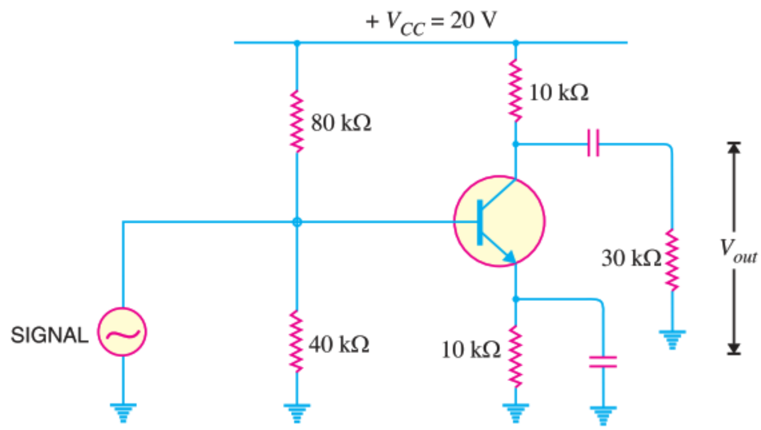


Fig. 2.11

Solution

The a.c. load r_L seen by the transistor is equivalent of the parallel combination of $R_C(= 10\ \text{k}\Omega)$ and $R_C(= 30\ \text{k}\Omega)$ i.e.

$$r_L = \frac{R_C R_L}{R_C + R_L} = \frac{10 \times 30 \times 10^6}{(10 + 30) \times 10^3} = 7.5\ \text{k}\Omega = 7500\ \Omega$$

(i) The input impedance looking into the base of transistor is given by:

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

$$= 1500 - \frac{4 \times 10^{-4} \times 50}{5 \times 10^{-5} + \frac{1}{7500}}$$

$$Z_{in} = 1390\ \Omega$$

This is only the input impedance looking into the base of transistor. The a.c. input impedance of the entire stage of the amplifier will be Z_{in} in parallel with bias resistors i.e.

$$\text{Input impedance of stage} = 80 \times 10^3 \| 40 \times 10^3 \| 1390 = \mathbf{1320\ \Omega}$$

(ii) Voltage gain, A_v is given by;

$$A_v = \frac{-h_{fe}}{Z_{in}\left(h_{oe} + \frac{1}{r_L}\right)}$$

$$= \frac{-50}{1390\left(5 \times 10^{-5} + \frac{1}{7500}\right)}$$

$$A_v = \mathbf{-196}$$

(iii) Output impedance of the transistor is;

$$Z_{out} = \frac{1}{h_{oe} - \frac{h_{fe} h_{re}}{h_{ie}}}$$

$$= \frac{1}{5 \times 10^{-5} - \frac{50 \times 4 \times 10^{-4}}{1500}}$$

$$Z_{out} = 27270\ \Omega \quad \text{or} \quad 27.27\ \text{k}\Omega$$

Therefore, output impedance of the stage of the amplifier $= Z_{out} \| R_C \| R_L$

$$= 27.27\ \text{k}\Omega \| 30\ \text{k}\Omega \| 10\ \text{k}\Omega = \mathbf{5.88\ k\Omega}$$

Exercise

1. A transistor used in *CE* arrangement has the following set of *h* parameters when the d.c. operating point is $V_{CE} = 10$ V and $I_C = 1$ mA:

   $$h_{ie} = 1700\ \Omega; \quad h_{re} = 1.3 \times 10^{-4}; \quad h_{fe} = 38; \quad h_{oe} = 6 \times 10^{-6}\ \text{mho}$$

   If the a.c. load seen by the transistor is $r_L = 2\ \text{k}\Omega$, determine;
   (i) The input impedance
   (ii) The current gain
   (iii) The voltage gain.
2. The *h* parameter values of the transistor in Fig. 2.12 are given alongside the figure. Determine;
   (i) The current gain
   (ii) Output impedance of the amplifier

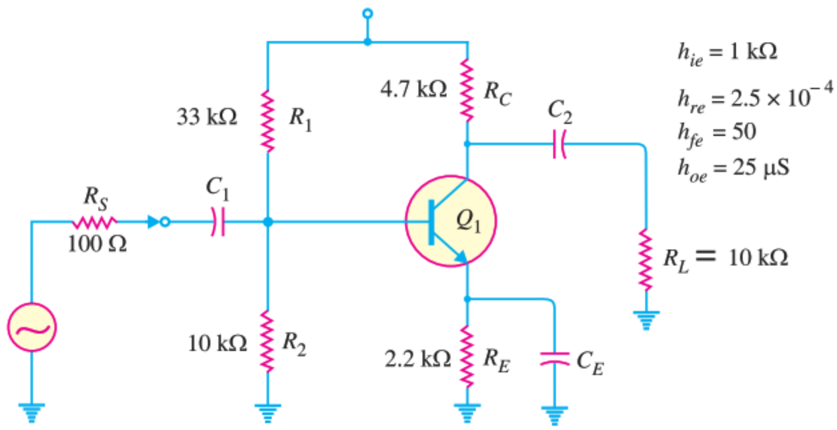


Fig. 2.12

2.9 Approximate Hybrid Formulas for Transistor Amplifier

The *h* parameter formulas (*CE* configuration) covered in section 2.8 can be approximated to a form that is easier to handle. While these approximate formulas will not give results that are as accurate as the original formulas, they can be used for many applications.

2.9.1 Input Impedance

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

In actual practice, the second term in this expression is very small as compared to the first term. Therefore, the *approximate formula* for the input impedance is given by;

$$Z_{in} = h_{ie}$$

2.9.2 Current Gain

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

In actual practice, $h_{oe} r_L$ is very small compared to 1.
Therefore, the *approximate formula* for the current gain is given by;

$$A_i = h_{fe}$$

2.9.3 Voltage Gain

$$A_v = \frac{-h_{fe}}{Z_{in}\left(h_{oe} + \frac{1}{r_L}\right)}$$

$$= \frac{-h_{fe} r_L}{Z_{in}(h_{oe} r_L + 1)}$$

Now approximate formula for Z_{in} is h_{ie}. Also $h_{oe} r_L$ is very small as compared to 1.
Therefore, the *approximate formula* for the voltage gain is given by;

$$A_v = -\frac{h_{fe} r_L}{h_{ie}}$$

2.9.4 Output Impedance

The output impedance of the transistor is;

$$Z_{out} = \frac{1}{h_{oe} - \frac{h_{fe} h_{re}}{h_{ie}}}$$

The second term in the denominator is very small as compared to h_{oe}.
Therefore, the *approximate formula* for the voltage gain is given by;

$$Z_{out} = \frac{1}{h_{oe}}$$

The output impedance of the amplifier is;

$$= Z_{out} \| r_L$$

$$= Z_{out} \| R_C \| R_L$$

Example 2.5

For the circuit shown in Fig. 2.13, the *h* parameters of the transistor are $h_{ie} = 1.94\ \text{k}\Omega$ and $h_{fe} = 71$. Use the *approximate hybrid formulas* to determine;

(i) The input impedance
(ii) The voltage gain.

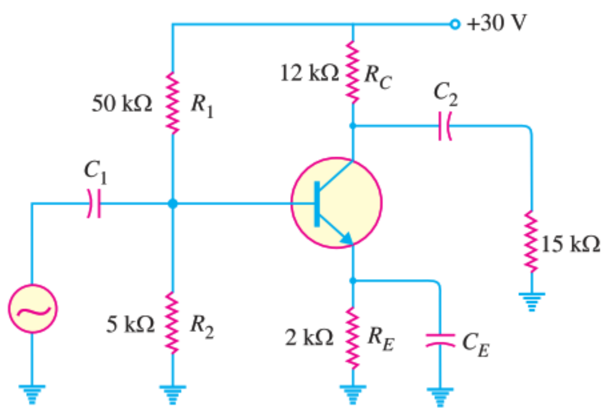


Fig. 2.13

Solution

$$\text{a.c. collector load}, r_L = R_C \| R_L$$

$$= 12\ \text{k}\Omega \| 15\ \text{k}\Omega = 6.67\ \text{k}\Omega$$

(i) Transistor input impedance

$$Z_{in(base)} = h_{ie} = 1.94 \text{ k}\Omega$$

Therefore, circuit input impedance is given by;

$$= Z_{in(base)} \| R_1 \| R_2$$
$$= 1.94 \text{ k}\Omega \| 50 \text{ k}\Omega \| 5 \text{ k}\Omega$$
$$= \mathbf{1.35\ k\Omega}$$

(ii) Voltage gain, A_v is given by;

$$A_v = -\frac{h_{fe} r_L}{h_{ie}}$$
$$= -\frac{71 \times 6.67 \text{ k}\Omega}{1.94 \text{ k}\Omega}$$
$$A_v = \mathbf{244}$$

Exercise

A transistor used in an amplifier has *h* parameter values of $h_{ie} = 600\ \Omega$ to $800\ \Omega$ and $h_{fe} = 110$ to 140. The a.c. collector load, $r_L = 460\ \Omega$. Using the *approximate hybrid formula*, determine the voltage gain of the circuit.

2.10 Limitations of *h* Parameters

The *h* parameter approach provides accurate information regarding the input impedance, current gain, voltage gain and output impedance of a transistor amplifier. However, there are two major limitations on the use of these parameters.

(i) It is very difficult to get the exact values of *h* parameters for a particular transistor. It is because these parameters are subject to considerable variation such as unit to unit variation, variation due to change in temperature and variation due to change in operating point. In predicting an amplifier performance, care must be taken to use *h* parameter values that are correct for the operating point being considered.

(ii) The *h* parameter approach gives correct answers for small a.c. signals only. It is because a transistor behaves as a linear device for small signals only.

Review Questions

1. What do you understand by hybrid parameters? What are their dimensions?
2. How will you measure *h* parameters of a linear circuit?
3. Draw the *h* parameter equivalent circuit of a linear circuit.
4. What is the physical meaning of *h* parameters?
5. Derive, in terms of *h* parameters and the load, the general formula for:
   (i) Input impedance,
   (ii) Current gain,
   (iii) Voltage gain
6. What are the notations for *h* parameters of a transistor when used in;
   (i) *CB*,
   (ii) *CE*,
   (iii) *CC* arrangement?
7. What are the drawbacks of *h* parameter approach in the design of a transistor amplifier?