B.SC PHYSICS

SEMESTER IV

PHYCC203

# UNIT 3(A): AMPLIFIERS

BY

DR KAVITA VERMA

ASSISTANT PROFESSOR

DEPARTMENT OF PHYSICS

## **HYBRID PARAMETERS**

In general, any circuit can be looked at as a two-port network. We will consider a black box. We call this as a black box because we are not interested in the details of the circuit inside but we know that this has got several components may be transistors and resistors and we have an input port and an output port. You have two terminals here corresponding to the input port and you have other two terminals at the output port. This is a simple two port network and now we can apply a voltage here and measure the current and we can measure here the output current, output voltage, etc. Hybrid parameters are also known as h- parameters. as they use impedance parameters, admittance parameters, voltage ratio, and current ratios to represent the relationship between voltage and current in a two port network. Hybrid means mixed. Every linear circuit having input and output terminals can be analysed by four parameters one in ohm, one in mho, and two dimensionless called hybrid parameters.


**h parameters** are useful in describing the input-output characteristics of circuits where it is hard to measure impedance or admittance parameters such as a transistor parameter encapsulate all the important linear characteristics of the circuit, so they are very useful for simulation purposes. The circuit has input voltage and current labelled $\mathbf{V_1}$ and $\mathbf{I_1}$ corresponds to the input, $\mathbf{V_2}$ and $\mathbf{I_2}$ corresponds to the output voltage and current. We can always choose two of them as independent variables and two others as the dependent variables. So, we can have enough combination of these things. The current $I_1$ and $I_2$ are assumed to flow into the box and voltage $\mathbf{V_1}$ and $V_2$ are assumed positive from upper to lower

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terminals. These are standard conventions. The relationship between voltages and current in **h parameters** can be represented as:

$V_1 = h_{11}I_1 + h_{12}V_2$ (input side) ............(i)

$I_2 = h_{21}I_1 + h_{22}V_2$ (output side) ............(ii)

**$h_{11}$** has the dimension of ohm.

**$h_{12}$** has no dimension .(dimensionless)

**$h_{21}$** has no dimension .(dimensionless)

**$h_{22}$** has the dimension of mho.

This can be represented in matrix form as:

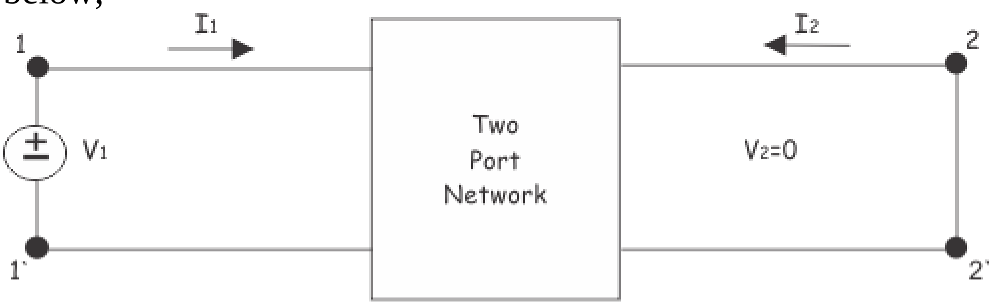
$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

**<u>Determining h parameters</u>**

The major reason for the use of h parameter is relative ease with which they can be measured.

**(i) $V_2 = 0$ (short circuit the output terminals)**

Let us short circuit the output port or terminal of a two port network as shown below,




Putting $V_2 = 0$ in equation (i) and (ii) we get

$h_{11} == \frac{V1}{I1}$ (for $V_2 = 0$, output shorted)

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Now, ratio of input voltage to input current, at short circuited output port is:

$$\left.\frac{V_1}{I_1}\right|_{V_2=0} = h_{11}$$

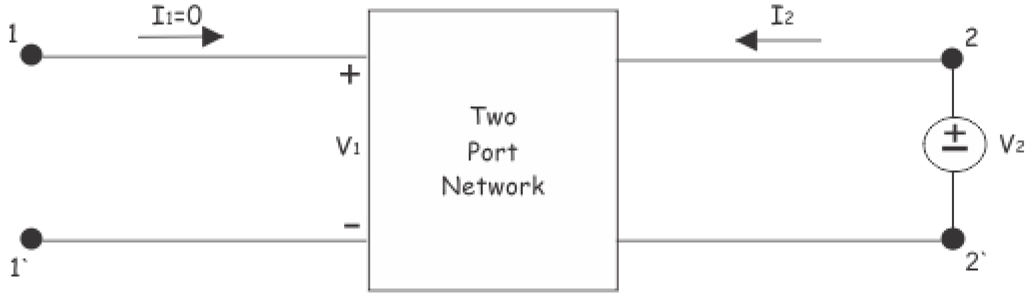
This is referred to as the short circuit input impedance (ohm). Now, the ratio of the output current to input current at the short-circuited output port is:

$$\left.\frac{I_2}{I_1}\right|_{V_2=0} = h_{21}$$

This is called short-circuit current gain of the network (dimensionless).

**(ii) $I_1$=0 (open circuit the input terminals)**

Now, let us open circuit the port 1. At that condition, there will be no input current ($I_1$=0) but open circuit voltage $V_1$ appears across the port 1, as shown below:




Putting $I_1$ =0 in equation (i) and (ii) we get

$$h_{12} == \frac{V1}{V2} \text{ (for } I_1 = 0\text{, input open)}$$

Now, ratio of input voltage to output voltage, at open circuited input port is:

$$\left.\frac{V_1}{V_2}\right|_{I_1=0} = h_{12} = \text{open circuit reverse voltage gain}$$

This is referred as reverse voltage gain or voltage feedback ratio because this is the ratio of input voltage to the output voltage of the network(dimensionless), but voltage gain is defined as the ratio of output voltage to the input voltage of a network.

Now:

$$\left.\frac{I_2}{V_2}\right|_{I_1=0} = h_{21}$$

It is referred as open circuit output admittance (mho)

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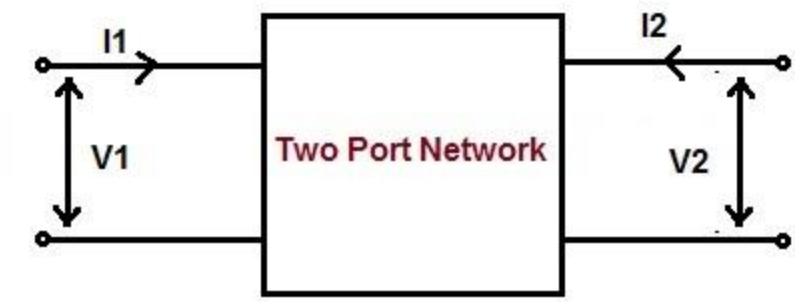
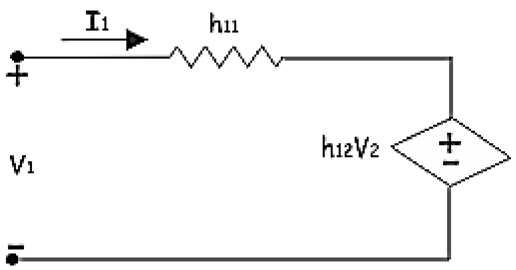
**h Parameter Equivalent Network of Two Port Network**

To draw **h parameter** equivalent network of a two port network , first we have to write the equation of voltages and currents using h- parameters. These are:

$$V_1 = h_{11}I_1 + h_{12}V_2 \cdots\cdots\cdots\cdots\cdots (i)$$
$$I_2 = h_{21}I_1 + h_{22}V_2 \cdots\cdots\cdots\cdots\cdots (ii)$$

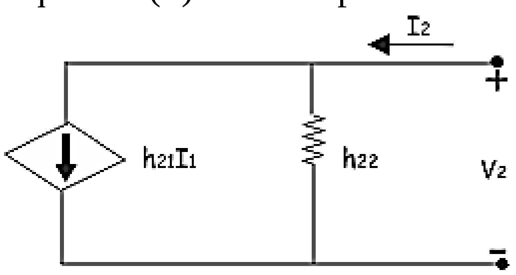
Equation (i) can be represented as a circuit based on Kirchhoff voltage Law:




(input side)

Equation (ii) can be represented as a circuit based on Kirchhoff current law:




(output side)

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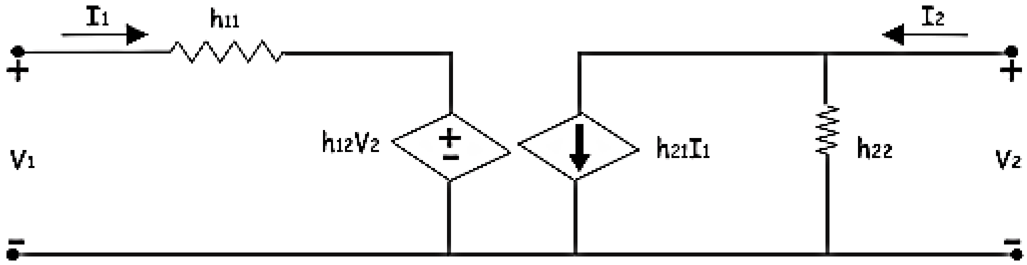
Combining these two parts of the network we get:



The h parameters equivalent network of a two port network

i) The input circuit appears as a resistance $h_{11}$ in series with a voltage generator $h_{12}V_2$. (derived from equation (i)).

ii) The output circuit involves current $h_{21}I_1$ and shunt resistance $h_{22}$. ( derived from equation (ii)).

iii) The input portion is a Thevenin equivalent or voltage generator with series resistance.

iv) The output is Norton equivalent or current generator with shunt resistance.

v) The first number in a subscript indicates the circuit in which the effect takes place and second number indicates the circuit from which the effect comes e.g. $h_{21}$ indicates ratio of current in the output to the current input (circuit 1)

vi) The equivalent circuit isolates the input and output circuit $h_{12}V_2$ indicates the effect if output upon input and value depends on output voltage $V_2$.

vii) The effect of input upon output represented by current generator $h_{21}I_1$ and its value depend upon input current.

viii) The equivalent circuit are in two parts which makes it simple to take into account source and load circuit.

ix) The h parameters are used to analysing Bipolar Junction Transistor or BJT.

**h- parameters of Transistor**

Transistor can be represented as two port networks by making anyone terminal common between input and output. There are three possible configurations in which a transistor can be used, there is a change in terminal voltage and current for different transistor configurations.

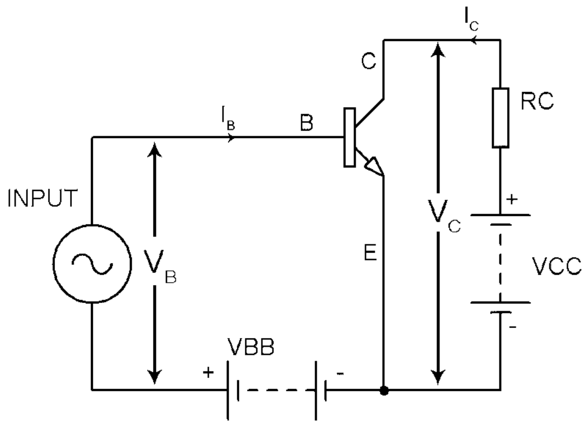



Figure 1: Basic CE Amplifier

To designate the type of configuration another subscript is added to h-parameters.

Nomenclature for transistor h-parameter:

$h_{11}$ , $h_{12}$ , $h_{21}$ , $h_{22}$ are general circuit notation.

h- parameters of Transistors are

i) The number subscript are replaced by letter subscripts.
ii) The first letter in double subscript indicates the nature of parameters.
iii) The second letter indicates the circuit arrangement.

| **PARAMETERS** | **h-parameter** | **CB** | **CE** | **CC** |
|---|---|---|---|---|
| Input resistance | $h_{11}$ | $h_{ib}$ | $h_{ie}$ | $h_{ic}$ |
| Reverse voltage gain | $h_{12}$ | $h_{rb}$ | $h_{re}$ | $h_{re}$ |
| Forward transfer current gain | $h_{21}$ | $h_{fb}$ | $h_{fe}$ | $h_{fe}$ |
| Output admittance | $h_{22}$ | $h_{cb}$ | $h_{oe}$ | $h_{oc}$ |

**i = input impedance** **r = reverse voltage feedback ratio**

**f = forward current transfer ratio** **o = output admittance**

**Equivalent circuit for Transistor:**

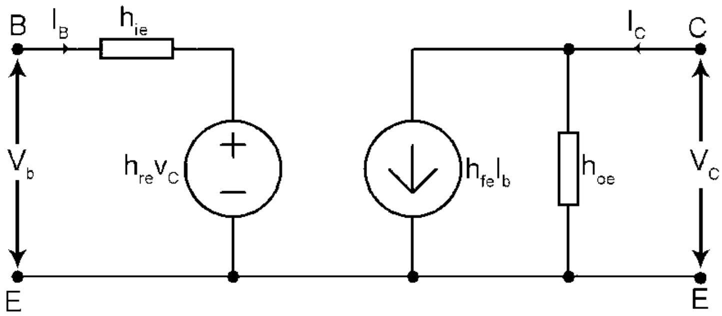



Figure 2: Hybrid model for CE amplifier

The circuit and equations are valid for either NPN or PNP transistor and are independent of the type of load or method of biasing.

- For small ac signal transistor behaves as linear transistor circuit. Therefore its ac operation can be described in terms of h-parameters.
- The notation $V_1$, $I_1$, $V_2$, $I_2$ is used for general circuit analysis. In transistor the notation depends upon the configuration.
- For CE arrangement $V_1 = V_{BE}$ , $I_1 = I_B$ , $V_2 = V_{CE}$ , $I_2 = I_C$

  These ($V_{BE}$, $I_B$ , $V_{CE}$ , $I_C$ are the RMS value).

  **Performance of Linear circuit in h parameters**

  Formula for input impedance, current gain, voltage gain, etc of a linear circuit in terms of h parameters.

  (i) **Input impedance**: Consider a linear circuit with a load resistance $r_L$ across its terminals (output terminal). The impedance Zin of this circuit is the ratio of input voltage to input current i.e

$$Zin = \frac{V1}{I1}$$

Now V1 $=h_{11}I_1 + h_{12}V_2$ in terms of h parameters. Substituting the value of V1 in the above equation we get

$$Zin = \frac{h11I1 + h12V2}{I1} = h_{11} + \frac{h12V2}{I1} \quad \text{.............(i)}$$

Now $I_2 = h_{21}I_1 + h_{22}V_2$ in terms of h parameters. But

$I_2 = -V_2/r_L$. The minus sign is used here because the actual load current is opposite to the direction of $I_2$.

$$-V_2/r_L = h_{21}I_1 + h_{22}V_2 \qquad [\therefore I2 = -V2/rL]$$

$$-h_{21}I_1 = h_{22}V_2 + V_2/r_L = V_2(h_{22} + 1/r_L)$$

$$V_2/I_1 = \frac{-h21}{h22 + 1/rL} \quad \text{..............(ii)}$$

Substituting the value of $V_2/I_1$ from equation (ii) into (i)

$$Zin = h_{11} - \frac{h12\,h21}{h22 + 1/rL} \quad \text{.....................................(iii)}$$

This is the expression for input impedance of a linear circuit in terms of h parameters and load connected to the output terminals. If either h12 or rL is very small ,the second term in the exp.(iii) can be neglected and input impedance becomes $Zin \approx h_{11}$.

(ii) **Current gain** : The current gain Ai is given by

$$Ai = I_2/I_1$$

Now, $I_2 = h_{21}I_1 + h_{22}V_2$

and $V_2 = -I_2r_L$

$\therefore$ $I_2 = h_{21}I_1 - h_{22}I_2r_L$

or $I_2(1 + h_{22}r_L) = h_{21}I_1$

or $I_2/I_1 = \frac{h21}{1 + h22\,rL}$

But ,

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$I_2/I_1$ = Ai, the current gain of the circuit

$$Ai = \frac{h21}{1+ h22\ rL}$$

If ,

$h_{22}\ r_L << 1$ then $Ai \approx h_{21}$ .

(iii) **Voltage Gain** : The voltage gain of the cicuit is given by

$$A_V = V_2/ V_1$$

$$= \frac{V2}{I1Zin} \quad (\therefore V_1 = I_1Zin)……………(iv)$$

But from (ii) we have

$$V_2 / I_1 = \frac{-h21}{h22+ 1/ rL}$$

Substituting in (iv) we get

$$A_V = \frac{-h21}{Zin(h22+rL)}$$

**Transistor Circuit Performance in h parameters**

The expression for input impedance , voltage, gain etc in terms of h parameters for general circuit analysis apply equally for transistor analysis.

**(i) Input impedance:**

$$Zin = h_{11} - \frac{h12\ h21}{h22+ 1/ rL} \quad \text{( For general circuit)}$$

$$Zin = h_{ie} - \frac{hre\ hfe}{hoe+ 1/ rL} \quad \text{(For Transistor in CE arrangement)}$$

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Similarly for CB and CC arrangement.

(ii) **Current gain**: The general expression for current gain is:

$$Ai = \frac{h21}{1+ h22\ rL}$$

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

$$Ai = \frac{hfe}{1+ hoe\ rL}$$

Similarly for CB and CC arrangement.

(iii) **Voltage gain**: The general expression for current gain is:

$$A_V = \frac{-h21}{Zin(h22+rL)}$$

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

$$A_V = \frac{-hfe}{Zin(hoe+rL)}$$

Similarly for CB and CC arrangement.

DR KAVITA VERMA
DEPARTMENT OF PHYSICS
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