Electronic Circuit Analysis

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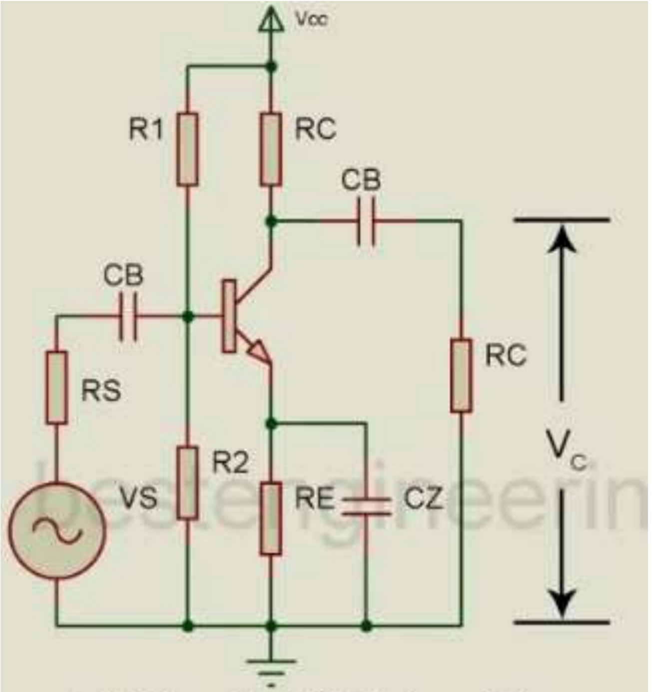
UNIT – I

BJT at low frequency: Transistor Hybrid model, Determination of h-parameters from characteristics, Analysis of transistor amplifier using h-parameter model, Emitter follower, Millers theorem and its dual, Cascading transistor amplifiers, Simplified CE & CC Hybrid models, CE Amplifier with an Emitter Resistance, High Input Resistance Transistor Circuits – Darlington pair, Boot strapped Darlington pair.

FET at low frequency: FET Small signal model, Common Source and Common Drain configurations at low frequencies.

Analysis of Common Emitter Amplifier using H Parameter



(a) Circuit of CE Amplifier

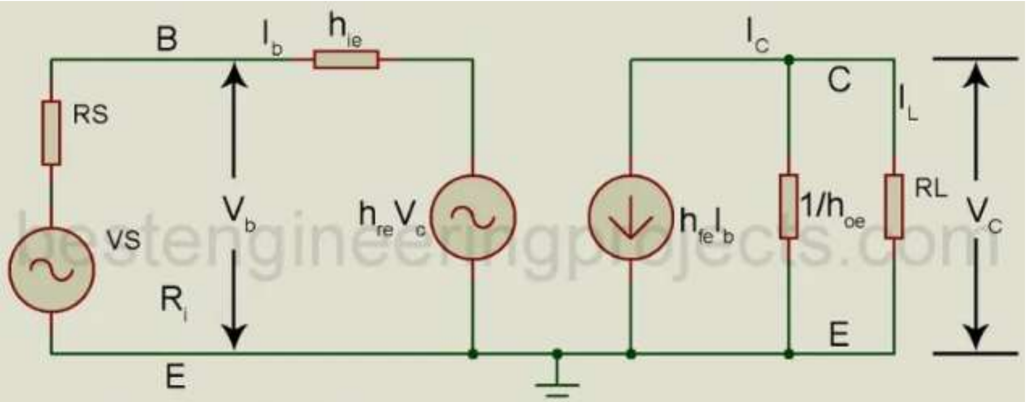


Figure 2: Equivalent Circuit of CE amplifier using h-model

For analysis, we replace the transistor with its small-signal two generator h-parameter model. This results in the equivalent circuit of Figure 2. We assume sinusoidal input.

Current Gain or Current Amplification:

Current gain is defined as the ratio of the load current I_1 to the input current I_b. Thus,

Current Gain $A_I = \frac{I_L}{I_b} = -\frac{I_c}{I_b}$ .....(1)

But from figure 2, $I_c = h_{fe} \times I_b + h_{oe} \times V_c$ .....(2)

Also $V_c = I_L \times R_L = -I_c \times R_L$ .....(3)

Combining Equation (2) and (3) we get,

$$I_c = h_{fe} I_b - h_{oe} \times I_c \times R_L or (1 + h_{oe} \times R_L) I_c = h_{fe} \times I_b$$

Hence current gain $A_I = -\frac{I_c}{I_b} = -\frac{h_{fe}}{1 + h_{oe} \times R_L}$ .....(4)

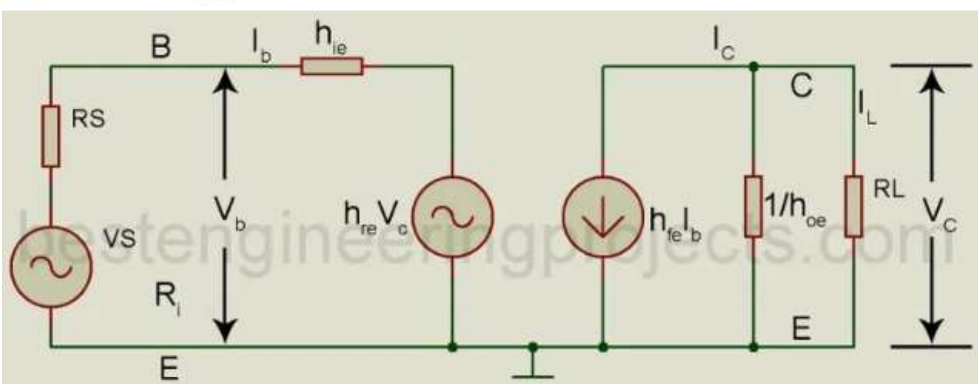


Figure 2: Equivalent Circuit of CE amplifier using h-model

Input Impedance R_i:

This is the impedance between the input terminals B and E looking into the amplifier as shown in Figure 2 and is, therefore, given by,

$$R_i = \frac{V_b}{I_b} \quad \text{......(5)}$$

From figure 2 $V_b = h_{ie} \times I_b + h_{re} \times V_c$ .....(6)

But $V_c = -I_c \times R_L = A_I I_b R_L$ .....(7)

Substituting the value of V_c from Equation (7) into Equation (6) we get,

$$V_b = h_i e \times +h_{re} A_I I_b R_L \quad \text{.....(8)}$$

Hence input impedance $R_i = \frac{V_b}{I_b} = h_{ie} + h_{re} A_I R_L$ .....(9)

$$= h_{ie} - \frac{h_{fe} h_{re}}{h_{oe} + Y_L} \quad \text{.....(10)}$$

Where $Y_L = \frac{1}{R_L}$

From Equation (10) we find that the input impedance R_i is also a function of load resistance R_L.

Voltage Gain or Voltage Amplification | Analysis of Common Emitter Amplifier using H Parameter:

It is the ratio of the output voltage V_c to the input voltage V_b. Thus,

Voltage Gain $A_v = \frac{V_c}{V_b} = -\frac{I_c R_L}{I_b R_i} = \frac{A_I R_L}{R_i}$ .....(11)

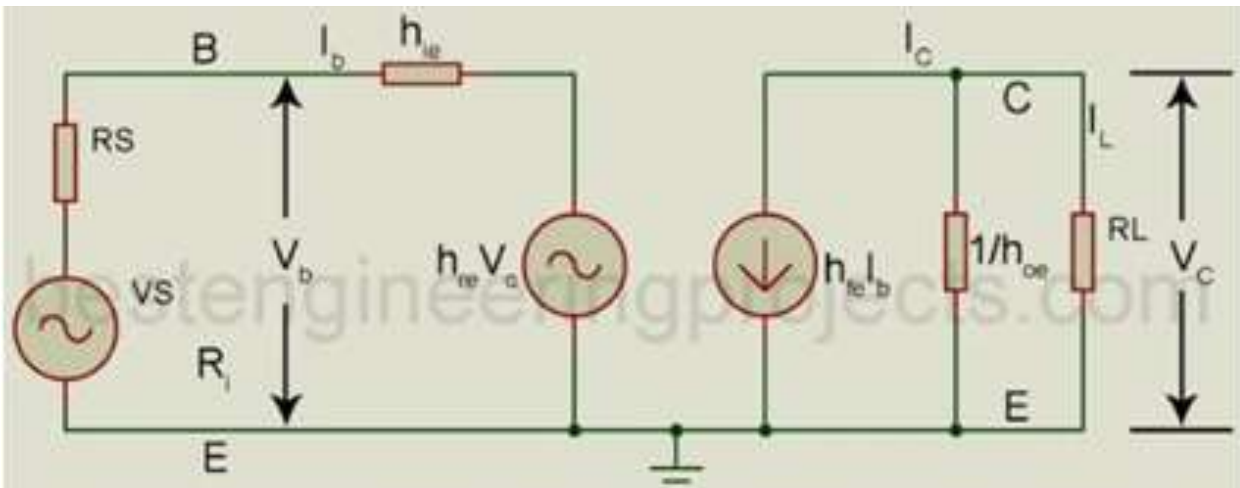


Figure 2: Equivalent Circuit of CE amplifier using h-model

Output Admittance Y_0:

It is the ratio of the output current I_c to the output voltage V_c with $V_s = 0$. Hence

$Y_0 = \frac{I_c}{V_c}$ with $V_S = 0$ ......(12)

On substituting the value of I_c from Equation (2) into Equation (12) we get,

$Y_0 = h_{fe} \times \frac{I_b}{V_c} + h_{oe}$ .....(13)

But with $V_s = 0$, Figure 2 gives $(R_s + h_{ie})\, I_b + h_{re}\, V_c = 0$

Or $\frac{I_b}{V_c} = -\frac{h_{re}}{h_{ie} + R_s}$ ......(14)

Combining Equation (13) and (14) we get, $Y_0 = h_{oe} - \frac{h_{fe} \times hre}{h_{ie} + R_s}$ ......(15)

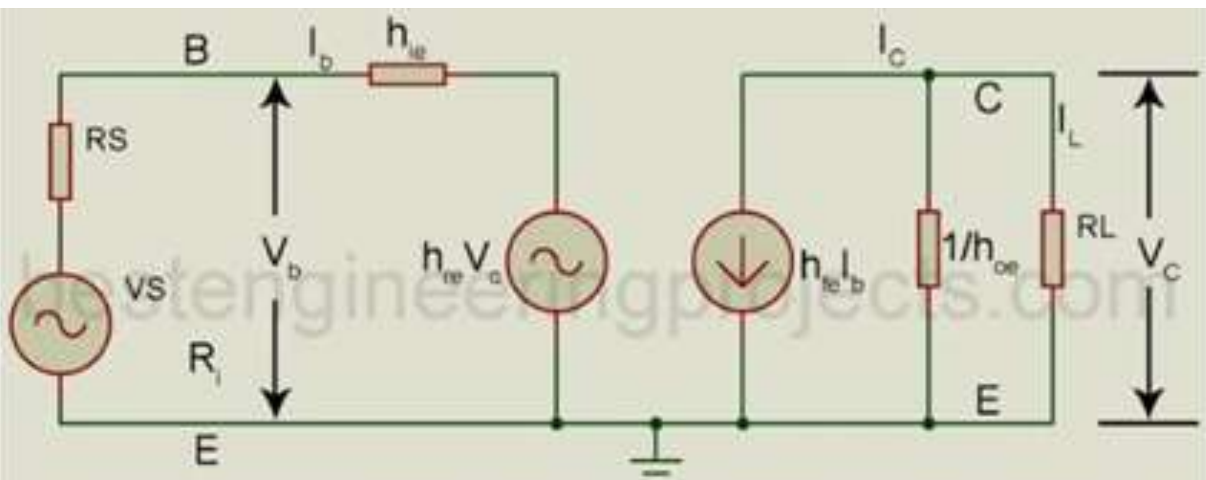


Figure 2: Equivalent Circuit of CE amplifier using h-model

Equation (15) shows that the output admittance Y_0 is a function of source resistance R_S. If the source impedance is purely resistive, then the output impedance Y_0 is real i.e. purely conductive.

Output impedance $R_0 = \frac{1}{Y_0}$ .....(16)

In the calculation of Y_0, R_L has been considered external to the amplifier. If we include R_L in parallel with R_0, we get the output terminal impedance Z_t given by,

$$Z < sub > t < /sub > = \frac{R_0 R_L}{R_0 + R_L}$$ .....(17)

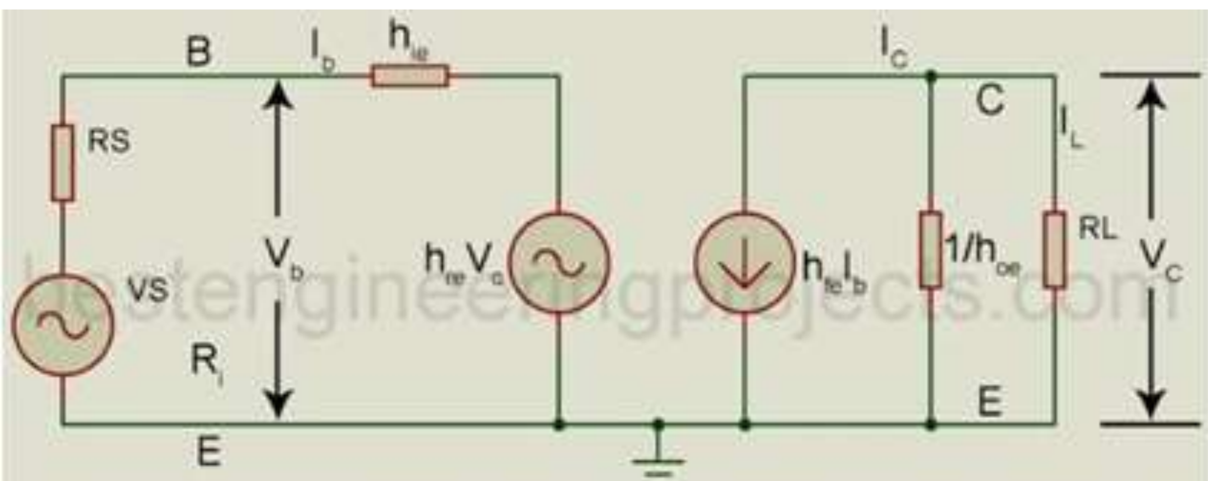


Figure 2: Equivalent Circuit of CE amplifier using h-model

Overall Voltage Gain Considering R_S:

Source voltage V_s applied at the input of an amplifier results in voltage V_b between bae and emitter terminals (input terminals) of the transistor and voltage V_c at the output. Then the overall voltage gain considering the source resistance is given by

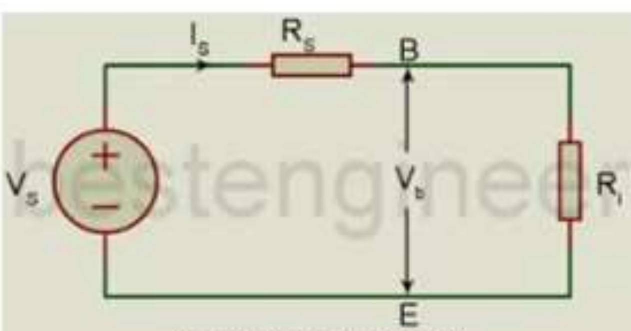
$$A_{VS} = \frac{V_c}{V_s} = \frac{V_c}{V_b} \times \frac{V_b}{V_s} = A_V \quad \frac{V_b}{V_s} \qquad \text{......(18)}$$

Figure 3(a) given the driven voltage source V_s with source resistance R_s in series. This form of an equivalent circuit for the energy source is known as Thevenin's equivalent source. This energy source then drives the amplifier represented by its input resistance R_i.

Then $$V_b = V_s \times \frac{R_i}{R_i + R_s} \qquad \text{......(19)}$$

Hence overall voltage gain $$A_{VS} = A_v \times \frac{R_i}{R_i + R_s} \qquad \text{.....(20)}$$

If $R_s = 0$, then $A_{VS} = A_V$. Thus, A_V forms a special care of A_{VS} with $R_s = 0$.

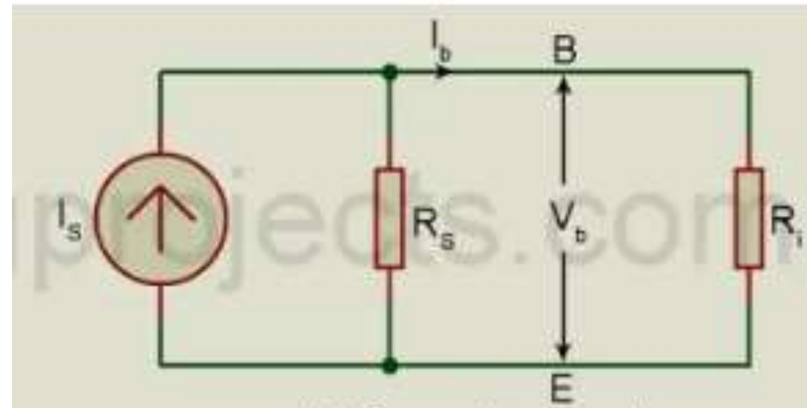


(a) Voltage Source V_s

Overall Current Gain Considering R_S:

We may replace the voltage source V_s with series source resistance R_s by what is known as Norton's equivalent source shown in Figure 3(b), consisting of current source I_s with source resistance R_s in the shunt. This current source drives the amplifier resulting in I_b at the input terminals of the amplifier and current I_L through the load impedance. Then the overall current gain A_{Is} is given by:

$$A_{Is} = \frac{I_L}{I_s} = \frac{-I_C}{I_b} \times \frac{I_b}{I_s} = A_I \times \frac{I_b}{I_s} \qquad .....(21)$$



(b) Current source I_s

From Figure 3(b), $I_b = I_s \dfrac{R_s}{R_s + R_i}$ .....(22)

Hence overall current gain $A_{IS} = A_I \dfrac{R_s}{R_s + R_i}$ .....(23)

From Equations (20) and Equation (23) we get, $A_{VS} = A_{IS} \times \dfrac{R_i}{R_s}$ .....(24)

Equation (24) is true provided that the voltage source V_s and the current source I_s have the same source resistance R_s.

Table 1: Result of small single analysis of low frequency ce amplifier

$A_I = -\frac{h_{fe}}{1 + h_{oe} \times R_L}$	$A_V = \frac{A_I \times R_L}{R_i}$
$R_i = h_{ie} + h_{re} \times A_I \times R_L$	$A_{VS} = \frac{A_V R_i}{R_i + R_s}$
$Y_0 = h_{oe} - \frac{h_{re} h_{fe}}{h_{ie} + R_s} = \frac{1}{Z_0}$	$A_{IS} = \frac{A_I R_s}{R_i + R_s}$

Ex: 1. The transistor is connected as CE amplifier with h-parameters $h_{ie} = 1100\Omega$, $h_{re} = 2.5 \times 10^{-4}$, $h_{fe} = 50$ and $h_{oe} = 24\ \mu A/V$. If $R_L = 10K\Omega$ and $R_S = 1K\Omega$, find the various gains and the i/p and o/p impedances.

Solution:

$$A_I = -\frac{h_{fe}}{1+h_{oe}R_L} = -\frac{50}{1+25 \times 10^{-6} \times 10^4} = -40.0$$

$$(Z_i = R_i) = h_{ie} + h_{re} A_I R_L = 1100 - 2.5 \times 10^{-4} \times 40 \times 10^4 = 1000\Omega.$$

$$A_V = \frac{A_I R_L}{R_i} = \frac{(-40) \times 10 \times 10^3}{1000} = -400$$

$$A_{Vs} = \frac{A_V \cdot R_i}{R_i + R_s} = \frac{(-400)(1000)}{1000+1000} = -200$$

$$A_{Is} = \frac{A_I R_s}{R_i + R_s} = \frac{(-40)(1000)}{1000+1000} = -20$$

$$Y_o = h_{oe} - \frac{h_{fe} h_{re}}{h_{ie} + R_s} = 25 \times 10^{-6} - \frac{50 \times 2.5 \times 10^{-4}}{1100+1000} = 19 \times 10^{-6}\ \mho$$

$$= 19\ \mu A/V.$$

$$Z_o = \frac{1}{Y_o} = \frac{1}{19 \times 10^{-6}} = \frac{10^6}{19}\ \Omega = 52.6\ K\Omega$$

Analysis of EMITTER FOLLOWER using h-parameter model

Common Collector Amplifier or the Emitter Follower: Figure 1(a) gives the basic circuit of a common collector amplifier, popularly called emitter follower. Its voltage gain is close to unity (one) and, therefore, any increment in the input voltage i.e. the base voltage appears as an equal increment in the output voltage across the load resistor in the emitter circuit. Thus, the emitter may be said to follow the input signal and hence the name emitter follower.

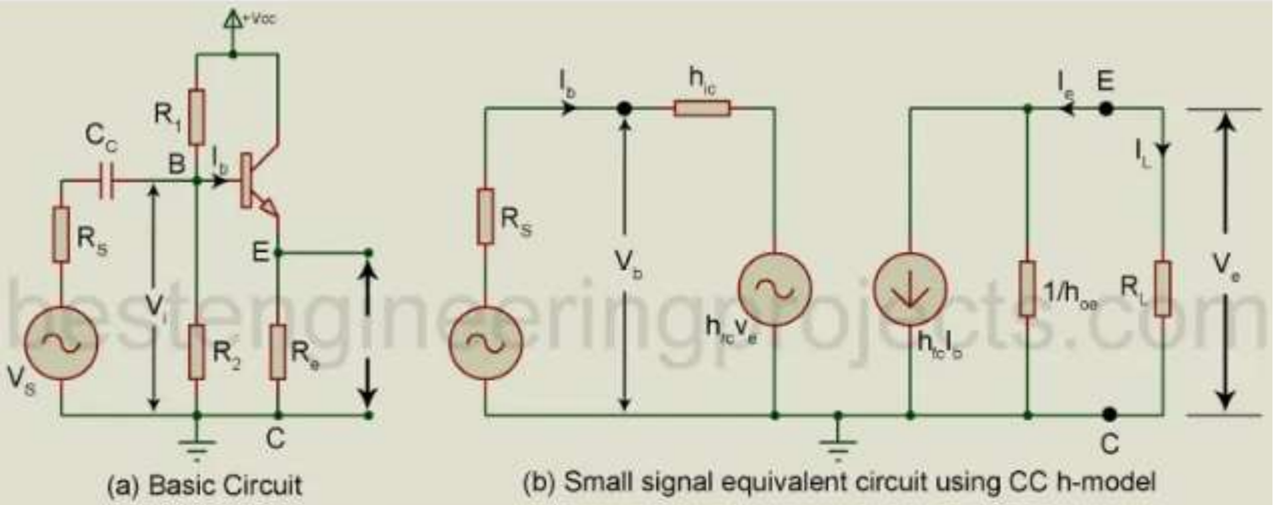
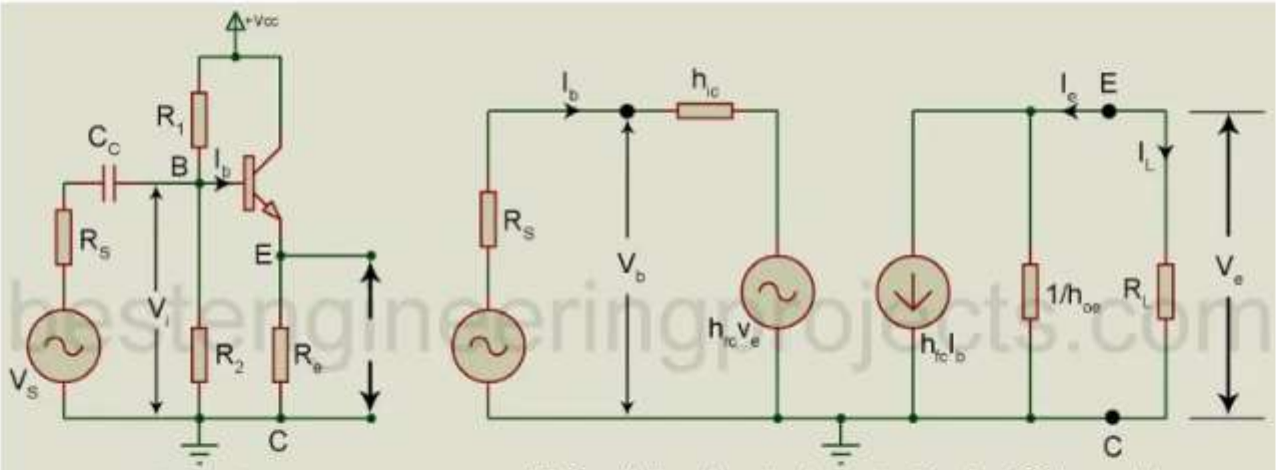


Figure 1: CC amplifier or emitter follower

The equivalent circuit of figure 1(a) is similar to that of CE amplifier of Figure 2. Hence the analysis procedure is exactly the same. The expression of A_I, R_i, A_V, A_{IS}, A_{VS} and Y_0 are, therefore, the same as of CE amplifier except that h-parameters of CC configuration are used. We may make use of Table 1 and simultaneously use conversion Table 2 to get the expression for A_I, R_i, A_V and R_0.



(a) Basic Circuit (b) Small signal equivalent circuit using CC h-model

Figure 1: CC amplifier or emitter follower

Table 1: Result of small single analysis of low frequency ce amplifier

$A_I = -\frac{h_{fe}}{1 + h_{oe} \times R_L}$	$A_V = \frac{A_I \times R_L}{R_i}$
$R_i = h_{ie} + h_{re} \times A_I \times R_L$	$A_{VS} = \frac{A_V R_i}{R_i + R_s}$
$Y_0 = h_{oe} - \frac{h_{re} h_{fe}}{h_{ie} + R_s} = \frac{1}{Z_0}$	$A_{IS} = \frac{A_I R_s}{R_i + R_s}$

Table

From CB to CE	*From CE to CB*	*From CE to CC*
$h_{ie}\ \ \frac{h_{ib}}{1\ \ h_{fb}}$	$h_{ie}\ \ \frac{h_{ie}}{1\ \ h_{fe}}$	$h_{ic} = h_{ic}$
$h_{oe}\ \ \frac{h_{ob}}{1\ \ h_{fb}}$	$h_{ob}\ \ \frac{h_{oe}}{1\ \ h_{fe}}$	$h_{oc} = h_{oe}$
$h_{fe}\ \ \frac{h_{fb}}{1\ \ h_{fb}}$	$h_{fb}\ \ \frac{h_{fe}}{1\ \ h_{fe}}$	$h_{fc} = -(1 + h_{fe})$
$h_{re}\ \ \frac{h_{ib} h_{ob}}{1\ \ h_{fb}}\ \ h_{rb}$	$h_{rb}\ \ \frac{h_{ie} h_{oe}}{1\ \ h_{fe}}\ \ h_{re}$	$h_{rc} = 1 - h_{re} \cong 1$

Thus, from Table 1 and Table 2,

Current gain $A_I = -\frac{I_e}{I_b} = -\frac{h_{fc}}{1 + h_{oc} \times R_L} = \frac{1 + h_{fe}}{1 + h_{oe} \times R_L}$ .....(1)

Input resistance $R_i = \frac{V_i}{I_b} = h_{ic} + h_{rc} \times A_I \times R_L = h_{ie} + A_I \times R_L$ .....(2)

Voltage gain $A_V = \frac{V_e}{V_i} = \frac{A_I \times R_L}{R_i}$ .....(3)

But from equation (2) $A_I \times R_L = R_i - h_{ie}$

Hence $A_V = \frac{R_i - h_{ie}}{R_i} = 1 - \frac{h_{ie}}{R_i}$ .....(4)

Overall voltage gain $A_{VS} = \frac{A_V \times R_i}{R_i + R_s}$ .....(5)

Overall current gain $A_{IS} = \frac{A_I \times R_s}{R_i + R_s}$ .....(6)

Output admittance $Y_0 = h_{oc} - \frac{h_{fc} \times h_{rc}}{h_{ic} + R_s} = h_{oe} + \frac{1 + h_{fe}}{h_{ie} + R_s}$ ......(7)

For reference

Table

From CB to CE	From CE to CB	From CE to CC
h_{ie} $\frac{h_{ib}}{1\ h_{fb}}$	h_{ie} $\frac{h_{ie}}{1\ h_{fe}}$	$h_{ic} = h_{ic}$
h_{oe} $\frac{h_{ob}}{1\ h_{fb}}$	h_{ob} $\frac{h_{oe}}{1\ h_{fe}}$	$h_{oc} = h_{oe}$
h_{fe} $\frac{h_{fb}}{1\ h_{fb}}$	h_{fb} $\frac{h_{fe}}{1\ h_{fe}}$	$h_{fe} = -(1 + h_{fe})$
h_{re} $\frac{h_{ib} h_{ob}}{1\ h_{fb}}$ h_{rb}	h_{rb} $\frac{h_{ie} h_{oe}}{1\ h_{fe}}$ h_{re}	$h_{re} = 1 - h_{re} \cong 1$

Summary

$$A_I = -\frac{I_e}{I_b} = \frac{-h_{fc}}{1+h_{oc}R_L} = \frac{1+h_{fe}}{1+h_{oe}R_L} \quad \text{—(1)} \quad \because h_{fc} = -(1+h_{fe}) \quad (14)$$

$$R_i = \frac{V_i}{I_b} = h_{ic} + h_{rc} A_I R_L = h_{ie} + A_I R_L \quad \text{—(2)} \quad \because h_{ic} = h_{ie}, \; h_{rc} \approx 1$$

$$A_V = \frac{V_o}{V_i} = \frac{A_I R_L}{R_i} = \frac{R_i - h_{ie}}{R_i} = 1 - \frac{h_{ie}}{R_i} \quad \text{—(3)} \quad \because A_I R_L = R_i - h_{ie} \text{ from eq (2)}$$

$$Y_o = h_{oc} - \frac{h_{fc} h_{rc}}{h_{ic}+R_s} = h_{oe} + \frac{1+h_{fe}}{h_{ie}+R_s} \quad \text{—(4)} \quad \because h_{fc} = -(1+h_{fe}), \; h_{rc} \approx 1, \; h_{ic} = h_{ie}, \; h_{oc} = h_{oe}$$

Ex 2: The emitter follower (CC amplifier) has the following h-parameters: $h_{ie} = 1100\,\Omega$, $h_{re} = 2.5 \times 10^{-4}$, $h_{fe} = 50$ and $h_{oe} = 24\,\mu A/V$. If $R_L = 10\,k\Omega$ and $R_S = 1\,k\Omega$, find the A_I, R_i, A_v and Y_o.

Solution:

$$A_I = \frac{1 + h_{fe}}{1 + h_{oe} R_L} = 40.75$$

$$R_i = h_{ie} + A_I R_L = 409\,k\Omega$$

$$A_v = 1 - \frac{h_{ie}}{R_i} = 0.997$$

$$R_o = \frac{1}{Y_o} = \frac{1}{\left(h_{oe} + \frac{1 + h_{fe}}{h_{ie} + R_s}\right)} = 41.2\,\Omega$$

$$A_{vs} = \frac{A_v R_i}{R_i + R_s} = 0.997 \times \frac{409}{410} = 0.995$$