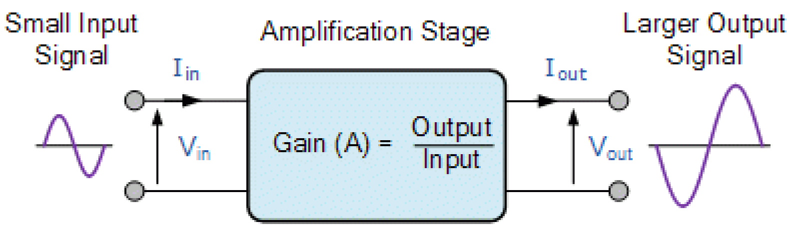
Introduction to the Amplifier

An amplifier is an electronic device or circuit which is used to increase the magnitude of the signal applied to its input



Amplifier is the generic term used to describe a circuit which produces an increased version of its input signal. Amplifier circuits are different and they are classified according to their circuit configurations and modes of operation.

Generally, amplifiers can be sub-divided into two distinct types depending upon their power or voltage gain. One type is called the **Small Signal Amplifier** which include pre-amplifiers, instrumentation amplifiers etc. Small signal amplifies are designed to amplify very small signal voltage levels of only a few micro-volts (μV) from sensors or audio signals.

The other type are called **Large Signal Amplifiers** such as audio power amplifiers or power switching amplifiers. Large signal amplifiers are designed to amplify large input voltage signals or switch heavy load currents as you would find driving loudspeakers.

In general the classification of an amplifier depends upon the size of the signal, large or small, its physical configuration and how it processes the input signal

The type or classification of an Amplifier is given in the following table.

Classification of Signal Amplifier

Type of Signal	Type of configuration	Classification	Frequency of operation
Small	Commom Emitter	Class A	DC Current
Large	Commom Base	Class B	Audio frequency(AF)
	Commoncollector	Class AB	Radio frequency(RF)
	---do-----	Class C	HF,UHF &SHF

Important Points to remember:

An ideal signal amplifier will have three main properties: Input Resistance or (R_{IN}), Output Resistance or (R_{OUT}) and of course amplification known commonly as Gain or (A).

Voltage Amplifier Gain

$$Voltage\,Gain\,(A_v) = \frac{Output\ Voltage}{Input\ Voltage} = \frac{V\,out}{V\,in}$$

Current Amplifier Gain

$$Current\,Gain\,(A_i) = \frac{Output\ Current}{Input\ Current} = \frac{Iout}{Iin}$$

Power Amplifier Gain

$$Power\,Gain\,(A_p) = A_v\ x\ A_i$$

Note that for the Power Gain you can also divide the power obtained at the output with the power obtained at the input. Also when calculating the gain of an amplifier, the subscripts v, i and p are used to denote the type of signal gain being used.

The power gain (Ap) or power level of the amplifier can also be expressed in **Decibels**, (**dB**). The Bel (B) is a logarithmic unit (base 10) of measurement that has no units. Since the Bel is too large a unit of measure, it is prefixed with *deci* making it **Decibels** instead with one decibel being one tenth (1/10th) of a Bel. To calculate the gain of the amplifier in Decibels or dB, we can use the following expressions.

- Voltage Gain in dB: a_v = 20*log(Av)
- Current Gain in dB: a_i = 20*log(Ai)
- Power Gain in dB: a_p = 10*log(Ap)

Note that the DC power gain of an amplifier is equal to ten times the common log of the output to input ratio, where as voltage and current gains are 20 times the common log of the ratio. Note however, that 20dB is not twice as much power as 10dB because of the log scale.

Amplifier Example

Determine the Voltage, Current and Power Gain of an amplifier that has an input signal of 1mA at 10mV and a corresponding output signal of 10mA at 1V. Also, express all three gains in decibels, (dB).

The Various Amplifier Gains:

$$A_V = \frac{\text{Output Voltage}}{\text{Input Voltage}} = \frac{1}{0.01} = 100$$

$$A_i = \frac{\text{Output Current}}{\text{Input Current}} = \frac{10}{1} = 10$$

$$A_p = A_V \times A_i = 100 \times 10 = 1,000$$

Amplifier Gains given in Decibels (dB):

$$a_v = 20\log A_v = 20\log 100 = 40\,dB$$

$$a_i = 20\log A_i = 20\log 10 = 20\,dB$$

$$a_p = 10\log A_p = 10\log 1000 = 30\,dB$$

Then the amplifier has a Voltage Gain, (Av) of 100, a Current Gain, (Ai) of 10 and a Power Gain, (Ap) of 1,000

Ideal Amplifier

We can know specify the characteristics for an ideal amplifier from our discussion above with regards to its **Gain**, meaning voltage gain:

- The amplifiers gain, (A) should remain constant for varying values of input signal.
- Gain is not be affected by frequency. Signals of all frequencies must be amplified by exactly the same amount.
- The amplifiers gain must not add noise to the output signal. It should remove any noise that is already exists in the input signal.
- The amplifiers gain should not be affected by changes in temperature giving good temperature stability.
- The gain of the amplifier must remain stable over long periods of time.

Definition and distinction or details of class of amplifiers.

- Amplifier classification takes into account the portion of the input signal in which the output transistor conducts as well as determining both the efficiency and the amount of power that the switching transistor both consumes and dissipates in the form of wasted heat.

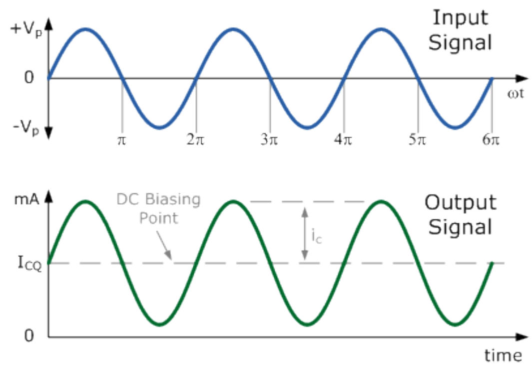
The most commonly used being:

- Class A Amplifier – has low efficiency of less than 40% but good signal reproduction and linearity.
- Class B Amplifier – is twice as efficient as class A amplifiers with a maximum theoretical efficiency of about 70% because the amplifying device only conducts (and uses power) for half of the input signal.
- Class AB Amplifier – has an efficiency rating between that of Class A and Class B but poorer signal reproduction than Class A amplifiers.
- Class C Amplifier – is the most efficient amplifier class but distortion is very high as only a small portion of the input signal is amplified therefore the output signal bears very little resemblance to the input signal. Class C amplifiers have the worst signal reproduction.

Class A Amplifier Operation

Class A Amplifier operation is where the entire input signal waveform is faithfully reproduced as the transistor is perfectly biased within its active region. This means that the switching transistor is never driven into its cut-off or saturation regions. The result is that the AC input signal is perfectly "centred" between the amplifiers upper and lower signal limits as shown below.

Class A Amplifier Output Waveform



A Class-A amplifier configuration uses the same switching transistor for both halves of the output waveform and due to its central biasing arrangement, the output transistor always has a constant DC biasing current, (I_{CQ}) flowing through it, even if there is no input signal present. In other words the output transistors never turns "OFF" and is in a permenant state of idle. hence it requires a heat sink as DC is lost as heat.

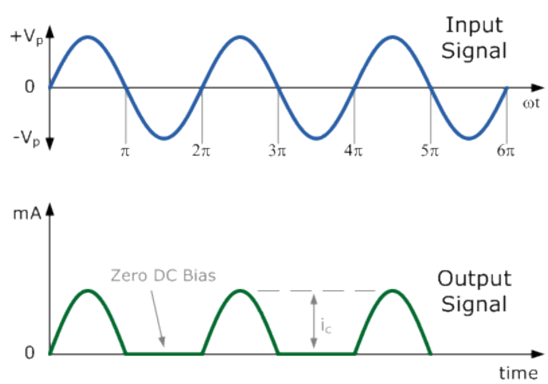
Class B Amplifier Operation

The **Class-B Amplifier** uses two complimentary transistors (either an NPN and a PNP or a NMOS and a PMOS) to amplify each half of the output waveform.

One transistor conducts for only one-half of the signal waveform while the other conducts for the other or opposite half of the signal waveform. This means that each transistor spends half of its time in the active region and half its time in the cut-off region thereby amplifying only 50% of the input signal.

Therefore with zero input signal there is zero output. As only half the input signal is presented at the amplifiers output this improves the amplifier efficiency over the previous Class-A configuration as shown below.

Class B Amplifier Output Waveform



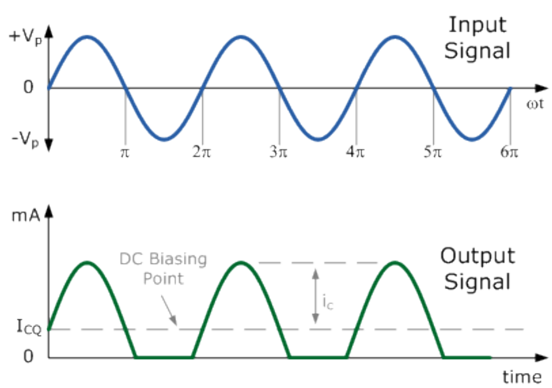
Class AB Amplifier Operation

The **Class-AB Amplifier** is a compromise between the Class-A and the Class-B configurations above. While Class-AB operation still uses two complementary transistors in its output stage a very small biasing voltage is applied to the Base of each transistor to bias them close to their cut-off region when no input signal is present.

An input signal will cause the transistor to operate as normal within its active region, eliminating any crossover distortion which is always present in the class-B configuration. A small biasing Collector current (I_{CQ}) will flow through the transistor when there is no input signal present, but generally it is much less than that for the Class-A amplifier configuration.

Thus each transistor is conducting, “ON” for a little more than half a cycle of the input waveform. The small biasing of the Class-AB amplifier configuration improves both the efficiency and linearity of the amplifier circuit compared to a pure Class-A configuration above.

Class AB Amplifier Output Waveform



Here we can make a comparison between the most common types of amplifier classifications in the following table.

Power Amplifier Classes

Class	A	B	C	AB
Conduction Angle	360°	180°	Less than 90°	180 to 360°
Position of the Q-point	Centre Point of the Load Line	Exactly on the X-axis	Below the X-axis	In between the X-axis and the Centre Load Line

Overall Efficiency	Poor 25 to 30%	Better 70 to 80%	Higher than 80%	Better than A but less than B 50 to 70%
Signal Distortion	None if Correctly Biased	At the X-axis Crossover Point	Large Amounts	Small Amounts

OPTIONAL(Badly designed amplifiers especially the Class “A” types may also require larger power transistors, more expensive heat sinks, cooling fans, or even an increase in the size of the power supply required to deliver the extra wasted power required by the amplifier. Power converted into heat from transistors, resistors or any other component for that matter, makes any electronic circuit inefficient and will result in the premature failure of the device.

So why use a Class A amplifier if its efficiency is less than 40% compared to a Class B amplifier that has a higher efficiency rating of over 70%. Basically, a Class A amplifier gives a much more linear output meaning that it has, **Linearity** over a larger frequency response even if it does consume large amounts of DC power.)

In this **Introduction to the Amplifier** tutorial, we have seen that there are different types of amplifier circuit each with its own advantages and disadvantages. In the next tutorial about amplifiers, we will look at the most commonly connected type of transistor amplifier circuit, the common emitter amplifier. Most transistor amplifiers are of the Common Emitter or CE type circuit due to their large gains in voltage, current and power as well as their excellent input/output characteristics.

UNIT III

BJT AMPLIFIERS

BJT h-parameter model

Analysis of transistor amplifier using h-parameter model

CB, CE and CC amplifiers

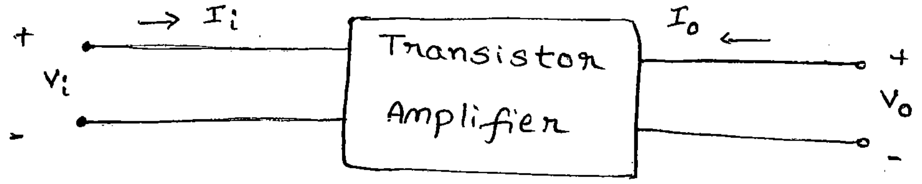
Comparison of CB, CE and CC configurations

Simplified h-parameter model

BJT AMPLIFIERS

H-Parameter Representation of a Transistor

A transistor can be treated as a two-port Network



Here I_i = Input current to the Amplifier

V_i = Input voltage to the Amplifier

I_o = Output current of the Amplifier

V_o = Output voltage of the Amplifier

Transistor is a current operated device.

Here input voltage V_i and output current I_o are the dependent variables.

Input current I_i and output voltage V_o are Independent variables.

$$V_i = f_1(I_1, V_o)$$

$$I_o = f_2(I_i, V_o)$$

This can be written in the equation form as follows

$$V_i = h_{11} I_i + h_{12} V_o$$

$$I_o = h_{21} I_i + h_{22} V_o$$

The above equation can also be written using alphabetic Notations

$$V_i = h_i I_i + h_r V_o$$

$$I_o = h_f I_i + h_o V_o$$

Definitions of h-parameter:

The parameters in the above equation are defined as follows

$h_{11} = h_i = \left.\frac{V_i}{I_i}\right|_{V_o=0}$ = Input resistance with output short circuited.

$h_{12} = h_r = \left.\frac{V_i}{I_o}\right|_{I_i=0}$ = Reverse voltage transfer ratio with input open circuited.

$h_{21} = h_f = \left.\frac{I_o}{I_i}\right|_{V_o=0}$ = Short circuit forward current gain with output short circuited.

$h_{22} = h_o = \left.\frac{I_o}{V_o}\right|_{I_i=0}$ = output Admittance with input open circuited.

BJT H-parameter Model:

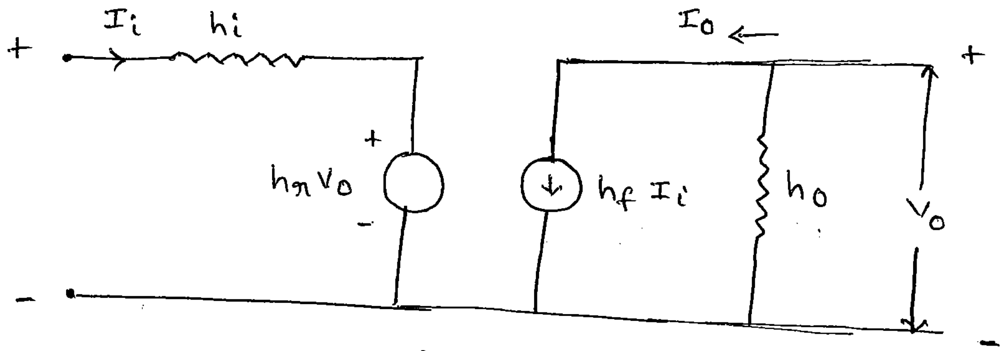
Based on the definition of hybrid parameters the mathematical model for two port networks known as h-parameter model (Hybrid Parameter model) can be developed.

The two equations of a transistor is given by

$$V_i = h_i I_i + h_r V_o$$

$$I_o = h_f I_i + h_o V_o$$

Based on above two equations the equivalent circuit or Hybrid Model for transistor can be drawn.



<u>Advantages</u> (or) <u>Benifits</u> of <u>h- parameters</u>

1) Real numbers at audio frequencies
2) Easy to measure
3) Can be obtained from the transistor static characteristic curves.
4) convinient to use in circuit analysis and design.
5) Easily convertable from one configuration to other
6) Most of the transistor manufacturers sepecify the h-parameters.

<u>H parameter Model for CE Configuration</u>

Let us consider the common emitter configuration shown in figure below. the Variables I_b, I_c, V_b and V_c represent total instantaneous corrents and Voltages.

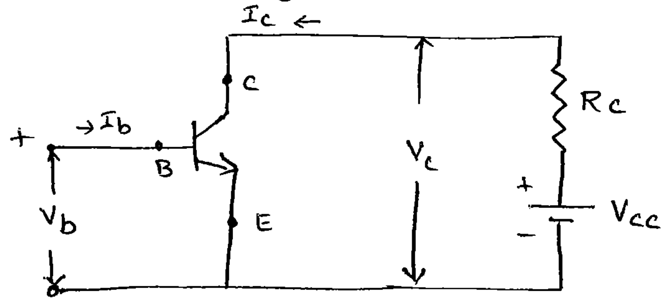
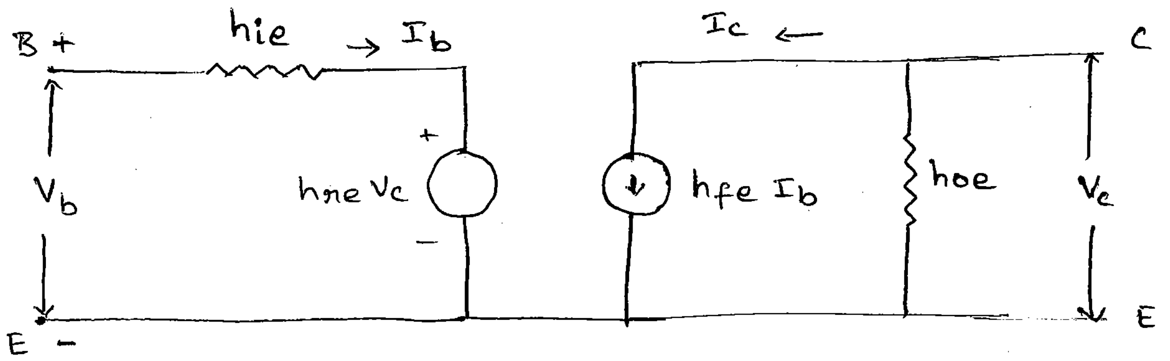


Fig: simple common emitter configuration

Here I_b - Input current V_b - Input voltage

I_c - output current V_c - output voltage

h- parameter model for common emitter configuration is shown in figure below.



$$V_b = h_{ie} I_b + h_{re} V_c$$

$$I_c = h_{fe} I_b + h_{oe} V_c$$

where

$$h_{ie} = \left.\frac{\Delta V_B}{\Delta I_B}\right|_{V_c = \text{constant}} = \left.\frac{V_b}{i_b}\right|_{V_c = \text{constant}}$$

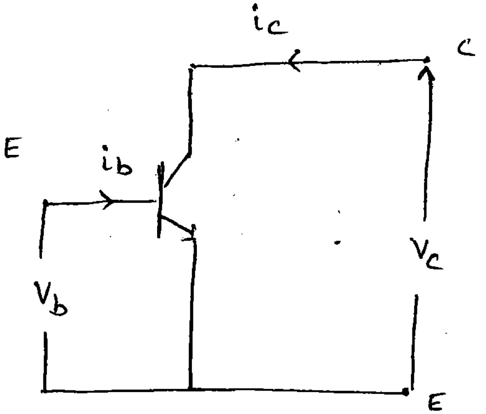
$$h_{re} = \left.\frac{\Delta V_B}{\Delta V_c}\right|_{I_B = \text{constant}} = \left.\frac{V_b}{V_c}\right|_{i_b = \text{constant}}$$

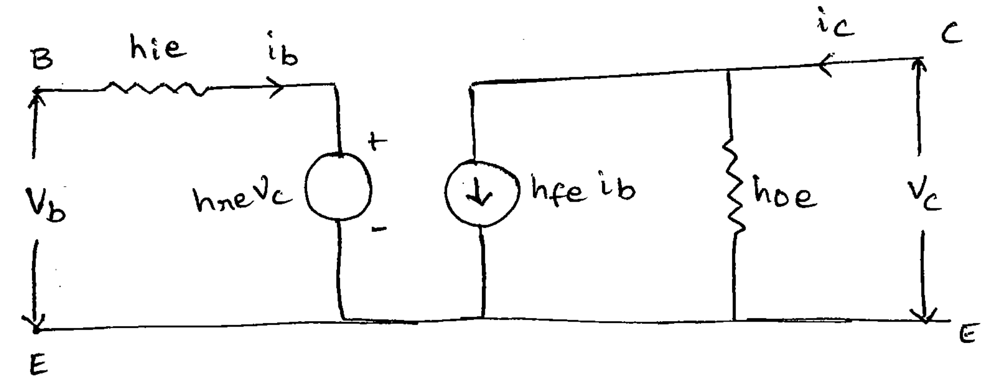
$$h_{fe} = \left.\frac{\Delta I_c}{\Delta I_B}\right|_{V_c = \text{constant}} = \left.\frac{i_c}{i_b}\right|_{V_c = \text{constant}}$$

$$h_{oe} = \left.\frac{\Delta I_c}{\Delta V_c}\right|_{I_B = \text{constant}} = \left.\frac{i_c}{V_c}\right|_{i_b = \text{constant}}$$

Hybrid model for the transistor in three different configurations

CE

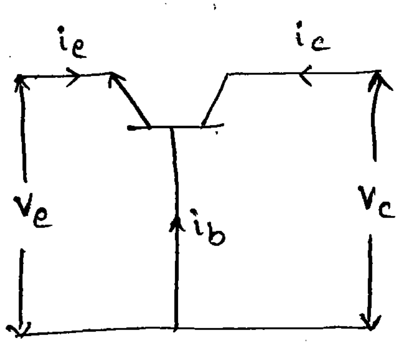


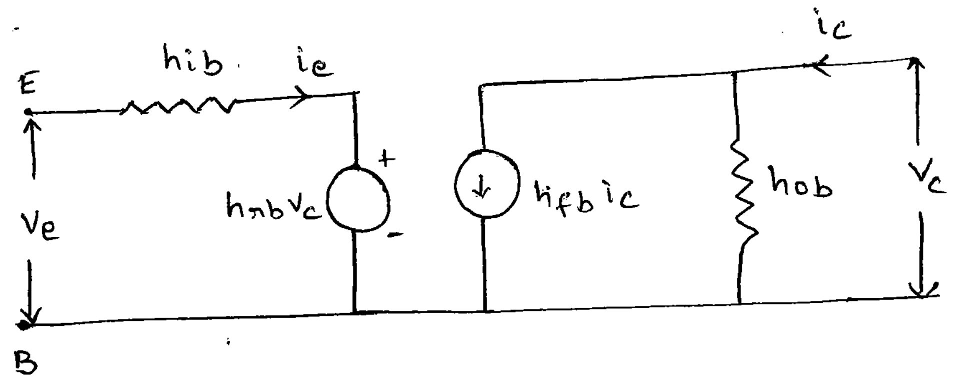


$V_b = h_{ie} i_b + h_{re} v_c$

$i_c = h_{fe} i_b + h_{oe} v_c$

CB

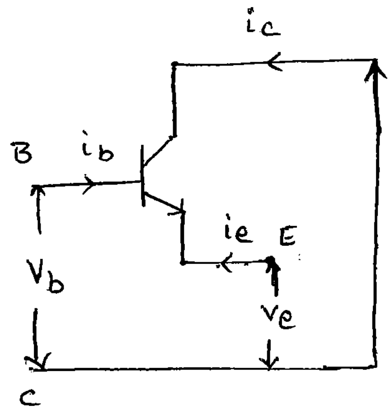


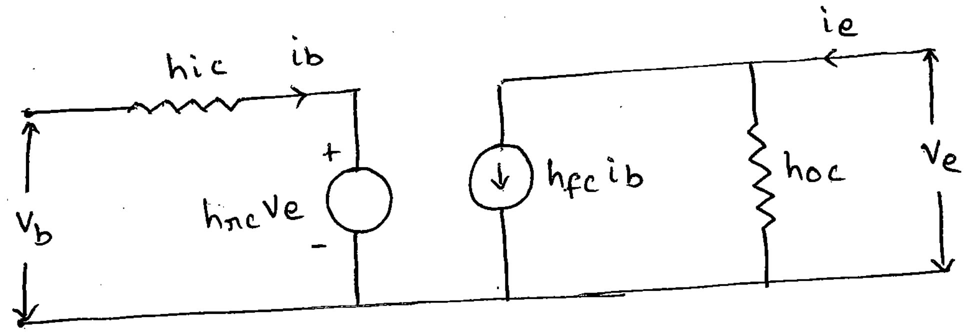


$V_e = h_{ib} i_e + h_{rb} v_c$

$i_c = h_{fb} i_e + h_{ob} v_c$

CC





$V_b = h_{ic} i_b + h_{rc} v_e$

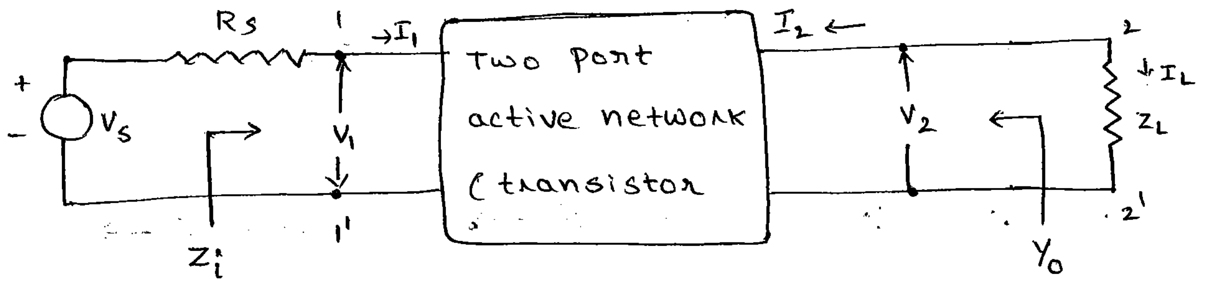
$i_e = h_{fc} i_b + h_{oc} v_e$

Typical h-parameter values for a transistor

Parameter	CE	CC	CB
h_i	1100 Ω	1100 Ω	22 Ω
h_r	2.5×10^{-4}	1	3×10^{-4}
h_f	50	-51	-0.98
h_o	25 μA/V	25 μA/V	0.49 μA/V

Analysis of a transistor amplifier circuit using h-parameter model.

A transistor amplifier can be constructed by connecting an external load and signal source as indicated in figure below. and biasing the transistor properly.



The hybrid parameter model for above network is shown in figure below.

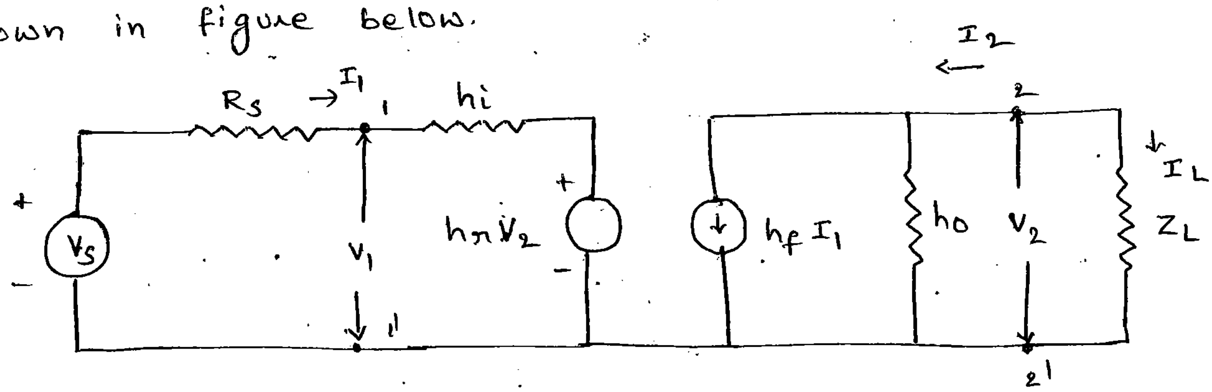


Fig: Transistor hybrid parameter model.

1) Current Gain (or) Current Amplification A_i :

For a transistor amplifier the current gain A_I is defined as the ratio of output current to input current.

$$A_I = \frac{I_L}{I_1} = \frac{-I_2}{I_1}$$

From the circuit $I_2 = h_f I_1 + h_o V_2 \longrightarrow (1)$

$$V_2 = I_L Z_L = -I_2 Z_L \longrightarrow (2)$$

Sub (2) in (1)

$$I_2 = h_f I_1 - I_2 Z_L h_o$$

$$I_2 + I_2 Z_L h_o = h_f I_1$$

$$I_2 (1 + Z_L h_o) = h_f I_1 \Rightarrow \frac{I_2}{I_1} = \frac{h_f}{1 + Z_L h_o}$$

$$\boxed{A_I = \frac{-I_2}{I_1} = \frac{-h_f}{1 + Z_L h_o}}$$

	CE	CB	CC
A_I	$\frac{-h_{fe}}{1 + Z_L h_{oe}}$	$\frac{-h_{fb}}{1 + Z_L h_{ob}}$	$\frac{-h_{fc}}{1 + Z_L h_{oc}}$

2) Input Impedance Z_i

In the circuit R_s is the signal source resistance. The impedance seen when looking in to the amplifier terminals $(1, 1')$ is the amplifier input impedance Z_i

$$Z_i = \frac{V_1}{I_1}$$

From figure $V_1 = h_i I_1 + h_r V_2$

So $$Z_i = \frac{h_i I_1 + h_r V_2}{I_1} = h_i + h_r \frac{V_2}{I_1} \rightarrow (1)$$

$$V_2 = -I_2 Z_L = A_I I_1 Z_L \qquad \left(\because A_I = \frac{-I_2}{I_1}\right)$$

$(1) \Rightarrow$ $$Z_i = h_i + h_r \frac{A_I I_1 Z_L}{I_1}$$

$$Z_i = h_i + h_r A_I Z_L$$

$$Z_i = h_i - h_r Z_L \frac{h_f}{1 + h_o Z_L} \qquad \left[\because A_I = \frac{-h_f}{1 + h_o Z_L}\right]$$

$$Z_i = h_i - \frac{h_f h_r}{\frac{1}{Z_L} + h_o}$$

$$Z_i = h_i - \frac{h_f h_r}{Y_L + h_o} \qquad \left[\because Y_L = \frac{1}{Z_L}\right]$$

	CE	CB	CC
Z_i	$h_{ie} - \frac{h_{fe} h_{re}}{Y_L + h_{oe}}$	$h_{ib} - \frac{h_{fb} h_{rb}}{Y_L + h_{ob}}$	$h_{ic} - \frac{h_{fc} h_{rc}}{Y_L + h_{oc}}$

3) Voltage gain (A_V):

The ratio of output voltage V_2 to input voltage gives the voltage gain of the transistor

$$A_V = \frac{V_2}{V_1}$$

Substituting $V_2 = -I_2 Z_L = A_I I_1 Z_L$

$$\Rightarrow A_V = \frac{A_I I_1 Z_L}{V_1} = \frac{A_I Z_L}{V_1 / I_1} = \frac{A_I Z_L}{Z_i}$$

	CE	CB	CC
A_V	$\frac{A_I Z_L}{Z_i}$	$\frac{A_I Z_L}{Z_i}$	$\frac{A_I Z_L}{Z_i}$

4) **Output Admittance (Y_o) :**

$$Y_o = \frac{I_2}{V_2} \quad \text{with} \quad V_s = 0 \quad \text{and} \quad R_L = \infty$$

From the circuit $I_2 = h_f I_1 + h_o V_2$

Dividing by V_2, $\frac{I_2}{V_2} = h_f \frac{I_1}{V_2} + h_o \longrightarrow ①$

With $V_s = 0$, by KVL in input circuit

$$R_s I_1 + h_i I_1 + h_r V_2 = 0$$

$$I_1 (R_s + h_i) + h_r V_2 = 0$$

Hence $\frac{I_1}{V_2} = \frac{-h_r}{R_s + h_i}$

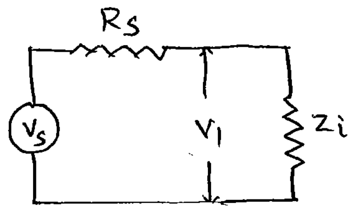
Now Eq ① $\Rightarrow \frac{I_2}{V_2} = \frac{-h_f h_r}{R_s + h_i} + h_o$

$$\Rightarrow Y_o = h_o - \frac{h_f h_r}{R_s + h_i}$$

	CE	CB	CC
Y_o	$h_{oe} - \frac{h_{fe} h_{re}}{R_s + h_{ie}}$	$h_{ob} - \frac{h_{fb} h_{rb}}{R_s + h_{ib}}$	$h_{oc} - \frac{h_{fc} h_{rc}}{R_s + h_{ic}}$

5) **Voltage gain (A_{vs}) (Including source) :**

$$A_{vs} = \frac{V_2}{V_s} = \frac{V_2}{V_1} \frac{V_1}{V_s} \Rightarrow A_{vs} = A_v \frac{V_1}{V_s}$$



$$V_1 = \frac{V_s Z_i}{R_s + Z_i} \Rightarrow \frac{V_1}{V_s} = \frac{Z_i}{R_s + Z_i}$$

Now $A_{vs} = \frac{A_v Z_i}{R_s + Z_i}$

$$A_{VS} = \frac{A_I R_L}{Z_i} \times \frac{Z_i}{R_S + Z_i} = \frac{A_I R_L}{R_S + Z_i}$$

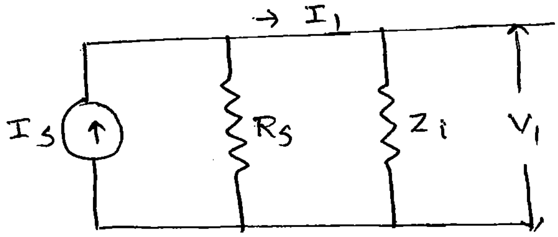
If $R_S = 0$ then $A_{VS} = \frac{A_I R_L}{Z_i} = A_V$.

6) Current Amplification (A_{IS})

$$A_{IS} = \frac{-I_2}{I_S} = \frac{-I_2}{I_1} \cdot \frac{I_1}{I_S} = A_I \frac{I_1}{I_S}$$

The modified input circuit using Norton's equivalent circuit for the source for the calculation of A_{IS}

$$A_{IS} = A_I \frac{R_S}{R_S + Z_i}$$



$$A_{VS} = \frac{A_{IS} Z_L}{R_S}$$

⇒ In CE configuration

Current Gain $A_I = \frac{-h_{fe}}{1 + h_{oe} Z_L}$ $[Z_L = R_L]$

Input Impedance $Z_i = h_{ie} - \frac{h_{fe} h_{re}}{Y_L + h_{oe}}$ $[Y_L = \frac{1}{Z_L} = \frac{1}{R_L}$

Voltage Gain $A_V = A_I \frac{Z_L}{Z_i}$

Output Admittance $Y_o = h_{oe} - \frac{h_{fe} h_{re}}{h_{ie} + R_S}$

⇒ In CB configuration

Current gain $A_I = \frac{-h_{fb}}{1 + h_{ob} Z_L}$

Input Impedance $Z_i = h_{ib} - \frac{h_{fb} h_{rb}}{Y_L + h_{ob}}$

Voltage gain $A_V = A_I \frac{Z_L}{Z_i}$

Output Admittance $Y_o = h_{ob} - \frac{h_{fb} h_{rb}}{h_{ib} + R_S}$

⇒ In CC configuration

Current gain $A_I = \dfrac{-h_{fc}}{1 + h_{oc} Z_L}$

Input Impedance $Z_i = h_{ic} - \dfrac{h_{fc} h_{rc}}{Y_L + h_{oc}}$

Voltage gain $A_V = \dfrac{A_I Z_L}{Z_i}$

Output Admittance $Y_o = h_{oc} - \dfrac{h_{fc} h_{rc}}{h_{ic} + R_s}$

Conversion formulae for hybrid parameters

CB	CC
$h_{ib} = \dfrac{h_{ie}}{1 + h_{fe}}$	$h_{ic} = h_{ie}$
$h_{rb} = \dfrac{h_{ie} h_{oe}}{1 + h_{fe}} - h_{re}$	$h_{rc} = 1$
$h_{fb} = \dfrac{-h_{fe}}{1 + h_{fe}}$	$h_{fc} = -(1 + h_{fe})$
$h_{ob} = \dfrac{h_{oe}}{1 + h_{fe}}$	$h_{oc} = h_{oe}$

1) characteristics of common emitter Amplifier

1) Current gain A_I is high for $R_L < 10 K\Omega$

2) The voltage gain is high for normal values of Load resistance R_L

3) The input resistance R_i is medium

4) The output resistance R_o is moderately high

Applications of common emitter amplifier:

1. Of the three configurations CE amplifier alone is capable of providing both voltage gain and current gain.
2. The output resistance R_o and input resistance R_i are moderately high
3. CE amplifier is widely used for Amplification purpose

2) ## Characteristics of Common Base Amplifier:

1. Current gain is less than unity and its magnitude decreases with the increase of load resistance R_L
2. Voltage gain A_V is high for normal values of R_L
3. The input resistance R_i is the lowest of all the three configurations.
4. The output resistance R_o is the highest of all the three configurations.

Applications of common base Amplifier

The CB Amplifier is not commonly used for Amplification purpose. It is used for

1) Matching a very low impedance source.
2) As a non inverting amplifier with voltage gain exceeding unity
3) For driving a high impedance load
4) As a constant current source.

3) ## Characteristics of common collector Amplifier

1. For low value of R_L ($< 10k\Omega$) the current gain A_I is high and almost equal to that of a CE amplifier

2. The voltage gain A_V is less than unity.
3. The input resistance is the highest of all the three configurations.
4. The output resistance is the lowest of all the three configurations.

Applications of common collector Amplifier:

1. The CC Amplifier is widely used as a buffer stage between a high impedance source and low impedance load. (CC Amplifier is called emitter follower)

Comparison of Transistor Amplifier configurations.

The characteristics of three configurations are summarized in table below. Here the quantities A_I, A_V, R_i, R_o and A_p (Power gain) are calculated for $R_L = R_S = 3\,K\Omega$

Quantity	CB	CC	CE
A_I	0.98	47.5	-46.5
A_V	131	0.989	-131
A_p	128.38	46.98	6091.5
R_i	22.6 Ω	144 KΩ	1065 Ω
R_o	1.72 MΩ	80.5 Ω	45.5 KΩ

Simplified CE Hybrid Model (or) Approximate CE Hybrid model (Approximate Analysis):

As the h parameters themselves vary widely for the same type of transistor, it is justified to make approximations and simplify the expressions for A_I, A_V, A_P, R_i and R_o.

The behaviour of the transistor circuit can be obtained by using the simplified hybrid model. The h-parameter equivalent circuit of the transistor in the CE configuration is shown in figure below.

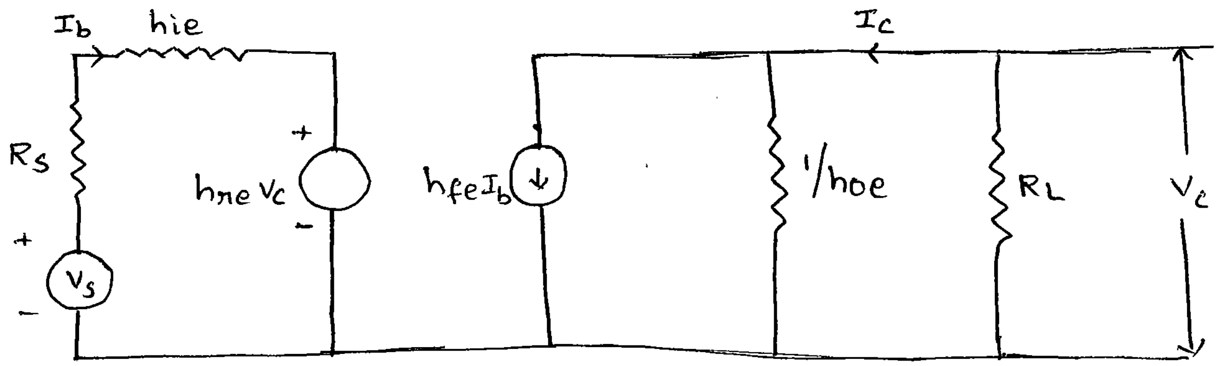


Fig: Exact CE Hybrid model.

Here $\frac{1}{h_{oe}}$ is in parallel with R_L

The parallel combination of two unequal impedances is approximately equal to the lower value ie R_L. Hence if $\frac{1}{h_{oe}} >> R_L$, then the term h_{oe} may be neglected provided that $h_{oe} R_L << 1$

If h_{oe} is omitted, the collector current I_c is given by

$$I_c = h_{fe} I_b .$$

under this condition the magnitude of voltage generated in the emitter circuit is

$$h_{re}\,|V_c| = h_{re}\, I_c\, R_L = h_{re}\, h_{fe}\, I_b\, R_L$$

Since $h_{re} h_{fe} \approx 0.01$, this voltage may be neglected in comparison with the voltage drop across hie. ie $h_{ie} I_b$ provided that R_L is not too large. ie if the load resistance R_L is small it is possible to neglect the parameter h_{re} and h_{oe} and the approximate equivalent circuit is obtained as shown in figure below.

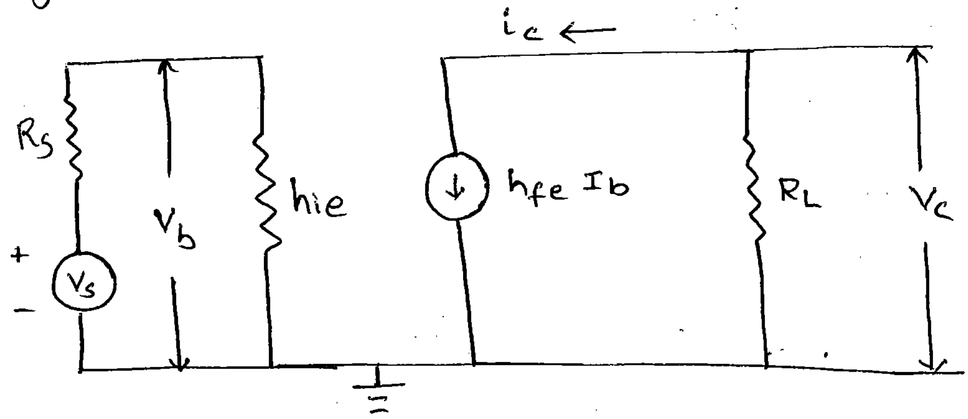


Fig : Approximate CE Hybrid model.

1) <u>Current Gain</u> (A_I) :

The current gain for CE configuration is

$$A_I = \frac{-h_{fe}}{1 + h_{oe} R_L}, \quad \text{If } h_{oe} R_L < 0.1$$

$$\boxed{A_I = -h_{fe}}$$

2) <u>Input Impedance</u> (Z_i) :

By exact analysis $Z_i = R_i = \frac{V_1}{I_1}$

$$V_1 = h_{ie} I_1 + h_{re} V_2$$

$$Z_i = \frac{h_{ie} I_1 + h_{re} V_2}{I_1} = h_{ie} + h_{re} \frac{V_2}{I_1}$$

$$V_2 = -I_2 Z_L = -I_2 R_L = A_I I_1 R_L \qquad \left[\because A_I = \frac{-I_2}{I_1} \right]$$

$$\Rightarrow Z_i = h_{ie} + \frac{h_{re} A_I I_1 R_L}{I_1} \qquad \left[\because V_2 = A_I I_1 R_L \right]$$

$$R_i = \left[h_{ie} + h_{re} A_I R_L \right]$$

$$R_i = h_{ie} \left[1 + \frac{h_{re} A_I R_L}{h_{ie}} \right]$$

$$R_i = h_{ie} \left[1 + \frac{h_{re} A_I R_L}{h_{ie}} \times \frac{h_{fe} h_{oe}}{h_{fe} h_{oe}} \right]$$

using the typical values for the h- parameters

$$\frac{h_{re} h_{fe}}{h_{ie} h_{oe}} \simeq 0.5$$

$$\Rightarrow R_i = h_{ie} \left[1 + \frac{0.5 A_I R_L h_{oe}}{h_{fe}} \right]$$

we know that $A_I = \frac{-h_{fe}}{1 + h_{oe} R_L}$ if $h_{oe} R_L < 0.1$

then $A_I = -h_{fe}$

$$\Rightarrow R_i = h_{ie} \left[1 - \frac{0.5 h_{fe} R_L h_{oe}}{h_{fe}} \right]$$

$$\Rightarrow R_i = h_{ie} \left[1 - 0.5 h_{oe} R_L \right]$$

If $h_{oe} R_L < 0.1$

then $\boxed{R_i \simeq h_{ie}}$ $\qquad [R_i = Z_i]$

Voltage gain: $A_V = A_I \frac{R_L}{R_i} = \frac{-h_{fe} R_L}{h_{ie}}$

Output Impedance:

It is the ratio of V_c to I_c with $V_s = 0$ and R_L excluded. The simplified circuit has infinite output impedance because with $V_s = 0$ and external voltage source applied at output, it is found that $I_b = 0$ and hence $I_c = 0$

$$R_o = \frac{V_c}{I_c} = \infty \quad [\because I_c = 0]$$

Approximate analysis of CE Amplifier
current gain $A_I = -h_{fe}$
Input resistance $R_i = h_{ie}$
Voltage gain $A_V = \frac{-h_{fe} R_L}{h_{ie}}$
Output resistance $R_o = \infty$

Analysis of CC Amplifier using the approximate Model:

Figure shows the equivalent circuit of CC Amplifier using the approximate model with the collector grounded, input signal applied between base and ground and load connected between emitter and ground.

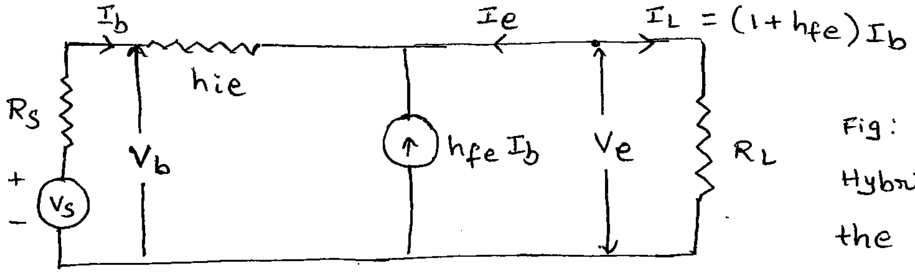


Fig: Simplified Hybrid model for the CC circuit

1) <u>current gain</u> :-

$$A_I = \frac{I_L}{I_b} = \frac{(1+h_{fe}) I_b}{I_b} = (1+h_{fe})$$

2) <u>Input resistance</u>

$$V_b = I_b h_{ie} + (1+h_{fe}) I_b R_L$$

$$R_i = \frac{V_b}{I_b} = h_{ie} + (1+h_{fe}) R_L$$

3) <u>Voltage gain</u>

$$A_V = \frac{V_e}{V_b} = \frac{(1+h_{fe}) I_b R_L}{[h_{ie} I_b + (1+h_{fe}) I_b R_L]}$$

$$A_V = \frac{(1+h_{fe}) R_L}{h_{ie} + (1+h_{fe}) R_L} = \frac{h_{ie} + (1+h_{fe}) R_L - h_{ie}}{h_{ie} + (1+h_{fe}) R_L}$$

$$A_V = 1 - \frac{h_{ie}}{h_{ie} + (1+h_{fe}) R_L}$$

$$A_V = 1 - \frac{h_{ie}}{R_i} \qquad \left[\because R_i = h_{ie} + (1+h_{fe}) R_L\right]$$

4) <u>Output Impedance</u> :-

$$\text{output } \sout{\text{impedance}} \text{ admittance } (Y_o) = \frac{\text{short circuit current in o/p terminals}}{\text{open circuit voltage b/n o/p terminals}}$$

short circuit current in output terminals $= (1+h_{fe}) I_b = (1+h_{fe}) \frac{V_s}{R_s + h_{ie}}$

open circuit voltage b/n output terminals $= V_s$

$$\therefore \quad Y_o = \frac{1+h_{fe}}{R_s + h_{ie}} \Rightarrow R_o = \frac{h_{ie} + R_s}{1 + h_{fe}}$$

output impedance including R_L ie $R_o' = R_o \| R_L$

Analysis of CB Amplifier using the approximate model

Figure shows the equivalent circuit of CB amplifier using the approximate model, with the base grounded, input signal is applied between emitter and base and load connected between Collector and base

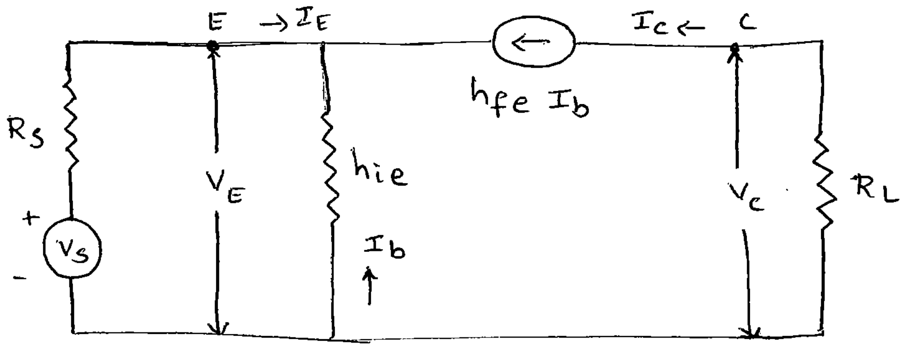


Fig: Simplified Hybrid model for the CB circuit

1) Current gain :

From the figure above $A_I = \frac{-I_c}{I_e} = \frac{-h_{fe} I_b}{I_e}$

$$I_e = -(I_b + I_c)$$

$$I_e = -(I_b + h_{fe} I_b) = -(1+h_{fe}) I_b$$

$$\therefore A_I = \frac{-h_{fe} I_b}{-(1+h_{fe}) I_b} = \frac{h_{fe}}{1+h_{fe}} = -h_{fb}$$

2) Input Resistance :

Input Resistance $R_i = \frac{V_e}{I_e}$

From figure $V_e = -I_b h_{ie}$, $I_e = -(1+h_{fe}) I_b$

$$R_i = \frac{h_{ie}}{1+h_{fe}} = h_{ib}$$

3) Voltage gain :

$$A_V = \frac{V_c}{V_e}$$

$$V_c = -I_c R_L = -h_{fe} I_b R_L$$

$$V_e = -I_b h_{ie}$$

$$A_V = \frac{h_{fe} R_L}{h_{ie}}$$

<u>output Impedance</u>

$$R_o = \frac{V_c}{I_c} \quad \text{with} \quad V_s = 0, \quad R_L = \infty$$

with $V_s = 0$, $I_e = 0$ and $I_b = 0$ hence $I_c = 0$

$$\therefore \quad R_o = \frac{V_c}{0} = \infty$$

Approximate Analysis of CB Amplifier

1) current gain $A_I = \frac{h_{fe}}{1+h_{fe}} = -h_{fb}$

2) Input Resistance $R_i = \frac{h_{ie}}{1+h_{fe}} = h_{ib}$

3) voltage gain $A_V = \frac{h_{fe} R_L}{h_{ie}}$

4) output Resistance $R_o = \infty$

Approximate Analysis of CC Amplifier

1) current gain $A_I = (1 + h_{fe})$

2) Input resistance $R_i = h_{ie} + (1 + h_{fe}) R_L$

3) voltage gain $A_V = 1 - \frac{h_{ie}}{R_i}$

4) output Resistance $R_o = \frac{h_{ie} + R_s}{1 + h_{fe}}$

Problem: A CE Amplifier is drawn by a voltage souce of Internal resistance $r_s = 800\Omega$ and the load impedance is a resistance $R_L = 1000\Omega$. The h parameters are $h_{ie} = 1k\Omega$, $h_{re} = 2 \times 10^{-4}$, $h_{fe} = 50$ and $h_{oe} = 25\,\mu A/V$. compute the current gain A_I, input resistance R_i, voltage gain A_V, and output resistance R_o using exact analysis and approximate analysis.

Solution: Given data

$r_s = 800\Omega$, $R_L = 1000\Omega$, $h_{ie} = 1k\Omega$, $h_{re} = 2 \times 10^{-4}$, $h_{fe} = 50$, and $h_{oe} = 25\,\mu A/V$

Exact Analysis:-

Current Gain $A_I = \dfrac{-h_{fe}}{1 + h_{oe} R_L} = -48.78$

Input Resistance $R_i = h_{ie} - \dfrac{h_{fe} h_{re}}{h_{oe} + \frac{1}{R_L}} = 990.24\Omega$

Voltage gain $A_V = A_I \dfrac{R_L}{R_i} = -49.26$

Output Resistance

$$Y_o = h_{oe} - \frac{h_{fe} h_{re}}{h_{ie} + R_s} = 194 \times 10^{-5} \text{ mho}$$

$$R_o = \frac{1}{Y_o} = 51.42\,k\Omega$$

Approximate Analysis:

$$A_I = -h_{fe} = -50$$

$$R_i = h_{ie} = 1\,k\Omega$$

$$A_V = \frac{-h_{fe} R_L}{h_{ie}} = \frac{-50 \times 1000}{1000} = -50$$

$$R_o = \infty$$

Problem: A voltage source of Internal resistance $R_s = 900\Omega$ drives a CC amplifier using load resistance $R_L = 2000\Omega$. The CE h-parameters are $h_{ie} = 1200\Omega$, $h_{re} = 2\times10^{-4}$, $h_{fe} = 60$ and $h_{oe} = 25\,\mu A/V$. Compute the current gain A_I, input Resistance R_i, voltage gain A_V, and output resistance R_o using exact analysis and approximate analysis.

Sol Conversion formulae:

$$h_{ic} = h_{ie} = 1200\Omega$$

$$h_{fc} = -(1+h_{fe}) = -(1+60) = -61$$

$$h_{rc} = 1$$

$$h_{oc} = h_{oe} = 25\,\mu A/V$$

Exact Analysis:

$$A_I = \frac{-h_{fc}}{1 + h_{oc} R_L} = 58.095$$

$$R_i = h_{ic} - \frac{h_{fc}\, h_{rc}}{Y_L + h_{oe}} = 117.39\,K\Omega$$

$$A_V = \frac{A_I R_L}{R_i} = 0.9897$$

Output Admittance

$$Y_o = h_{oc} - \frac{h_{fc} h_{rc}}{h_{ic} + R_s}$$

$$\Rightarrow R_O = \frac{1}{Y_O} = 34.396\ \Omega$$

Approximate Analysis

$$A_I = 1 + h_{fe} = 1 + 60 = 61$$

$$R_i = h_{ie} + (1 + h_{fe}) R_L = 123.2\ K\Omega$$

$$A_V = 1 - \frac{h_{ie}}{R_i} = 0.99$$

$$R_o = \frac{h_{ie} + R_s}{1 + h_{fe}} = 34.43\ \Omega$$

Problem:

For a CB transistor Amplifier driven by a voltage source of internal resistance $R_s = 1200\Omega$, the load impedance is a resistor $R_L = 1000\Omega$. The h-parameters are $h_{ib} = 22\Omega$, $h_{rb} = 3 \times 10^{-4}$, $h_{fb} = -0.98$, $h_{ob} = 0.5\mu A/V$. Compute the current gain A_I, Input impedance R_i, voltage gain A_V, overall voltage gain A_{VS}, over all current gain A_{IS}, output impedance R_o and power gain A_P using exact and approximate analysis.

Solution:

$$\text{Current gain } A_I = \frac{-h_{fb}}{1 + h_{ob} R_L} = 0.98$$

$$\text{Input Impedance } R_i = h_{ib} - \frac{h_{fb} h_{rb}}{Y_L + h_{ob}} = 22.3\Omega$$

voltage gain $A_V = \frac{A_I R_L}{R_i} = \frac{0.98 \times 1000}{22.3} = 43.94$

overall voltage gain $A_{VS} = \frac{A_V R_i}{R_i + R_S} = 0.802$

overall current gain $A_{IS} = \frac{A_I R_S}{R_i + R_S} = 0.962$

output Admittance $Y_o = h_{ob} - \frac{h_{fb} h_{rb}}{h_{ib} + R_S} = 0.74 \times 10^{-6}$ mho

$$R_o = \frac{1}{Y_o} = 1.35 M\Omega$$

Power gain $A_P = A_V A_I = 43.06$

Approximate Analysis :

1) $A_I = -h_{fb} = 0.98$

2) $R_i = h_{ib} = 22\ \Omega$

3) $A_V = \frac{h_{fe} R_L}{h_{ie}}$

$A_V = \frac{49 \times 1000}{1100}$

$A_V = 44.54$

4) $R_o = \infty$

A_{VS}, A_{IS}, A_P are same as that of Exact analysis.

$\because$ conversion formulae

$h_{fb} = \frac{-h_{fe}}{1 + h_{fe}}$

$\Rightarrow h_{fe} = \frac{-h_{fb}}{1 + h_{fb}} = 49$

$h_{ib} = \frac{h_{ie}}{1 + h_{fe}}$

$\Rightarrow h_{ie} = h_{ib}(1 + h_{fe})$

$h_{ie} = 22(1 + 49) = 1100\ \Omega$