UNIT VI

SMALL SINGLE LOW FREQUENCY TRANSISTOR AMPLIFIERS

6.1 Introduction

V-I characteristics of an active device such as BJT are non-linear. The analysis of a non- linear device is complex. Thus to simplify the analysis of the BJT, its operation is restricted to the linear V-I characteristics around the Q-point i.e. in the active region. This approximation is possible only with small input signals. With small input signals transistor can be replaced with small signal linear model. This model is also called small signal equivalent circuit.

6.1.1 Hybrid parameters (h-parameters)

If the input current I1 and output voltage V2 are taken as independent variables, the dependent variables V1 and I2 can be written as

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

Where h_{11}, h_{12}, h_{21}, h_{22} are called as hybrid parameters.

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

Input impedence with o/p port short circuited

$$h_{12} = \left.\frac{V_1}{V_2}\right|_{I_1=0}$$

Reverse voltage transfer ratio with i/p port open circuited

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

Forward voltage transfer ratio with o/p port short circuited

$$h_{22} = \left.\frac{I_2}{V_2}\right|_{I_1=0}$$

output impedence with i/p port open circuited

6.2 THE HYBRID MODEL FOR TWO PORT NETWORK:

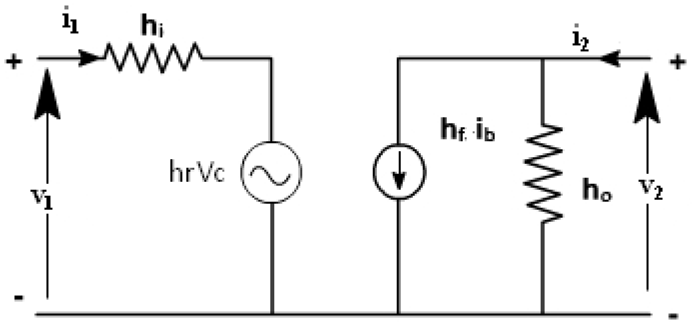
Based on the definition of hybrid parameters the mathematical model for two pert networks known as h-parameter model can be developed. The hybrid equations can be written as: $V_1 = h_i I_1 + h_r V_2$

$I_2 = h_f I_1 + h_o V_2$

(The following convenient alternative subscript notation is recommended
by the **IEEE Standards**:
***i*=11= input** ***o* = 22 = output**

***f* =21 = forward transfer *r* = 12 = reverse transfer)**

We may now use the four h parameters to construct a mathematical model of the device of Fig.(1). The hybrid circuit for any device indicated in Fig.(2). We can verify that the model of Fig.(2) satisfies above equations by writing Kirchhoff's voltage and current laws for input and output ports.



If these parameters are specified for a particular configuration, then suffixes e,b or c are also included, e.g. h_{fe} ,h_{ib} are h parameters of common emitter and common collector amplifiers

Using two equations the generalized model of the amplifier can be drawn as shown in **fig. 2**.

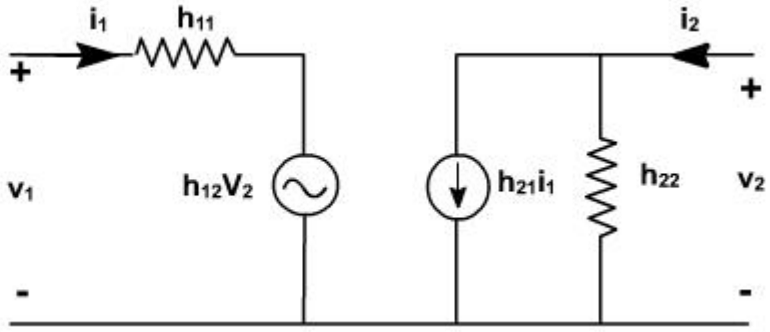


Fig. 2

6.2.1 TRANSISTOR HYBRID MODEL:

The hybrid model for a transistor amplifier can be derived as follow:

Let us consider CE configuration as show in fig. 3. The variables, i_B, i_C ,v_C, and v_B represent total instantaneous currents and voltages i_B and v_C can be taken as independent variables and v_B, I_C as dependent variables.

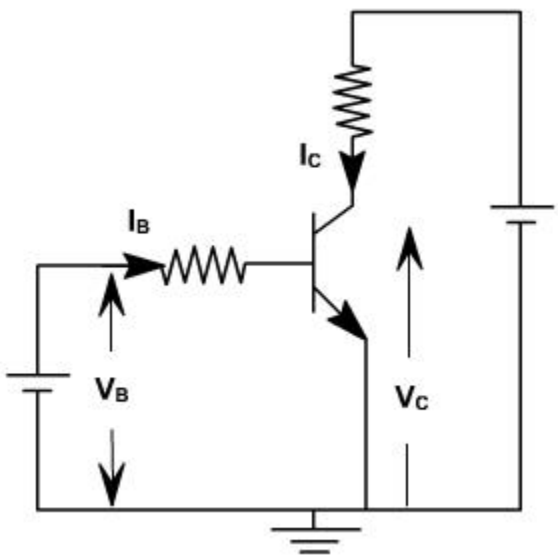


Fig. 3

$V_B = f1\ (i_B\ ,v_C\ )$

$I_C = f2\ (i_B\ ,v_C)$.

Using Taylor 's series expression, and neglecting higher order terms we obtain.

$$\Delta v_B = \left.\frac{\partial f_1}{\partial i_B}\right|_{v_C} \Delta i_B + \left.\frac{\partial f_1}{\partial v_C}\right|_{i_B} \Delta v_C$$

$$\Delta i_C = \left.\frac{\partial f_2}{\partial i_B}\right|_{v_C} \Delta i_B + \left.\frac{\partial f_2}{\partial v_C}\right|_{i_B} \Delta v_C$$

The partial derivatives are taken keeping the collector voltage or base current constant. The Δv_B, Δv_C, Δi_B, Δi_C represent the small signal (incremental) base and collector current and voltage and can be represented as v_B, i_C, i_B, v_C

$$\therefore v_b = h_{ie}\, i_B + h_{re}\, v_C$$

$$i_C = h_{fe}\, i_B + h_{oe}\, v_b$$

where

$$h_{ie} = \left.\frac{\partial f_1}{\partial i_B}\right|_{v_C} = \left.\frac{\partial v_B}{\partial i_B}\right|_{v_C}; \qquad h_{re} = \left.\frac{\partial f_1}{\partial v_C}\right|_{i_B} = \left.\frac{\partial v_B}{\partial v_C}\right|_{i_B}$$

$$h_{fe} = \left.\frac{\partial f_2}{\partial i_B}\right|_{v_C} = \left.\frac{\partial i_C}{\partial i_B}\right|_{v_C}; \qquad h_{oe} = \left.\frac{\partial f_2}{\partial v_C}\right|_{i_B} = \left.\frac{\partial v_B}{\partial v_C}\right|_{i_B}$$

The model for CE configuration is shown in fig. 4.

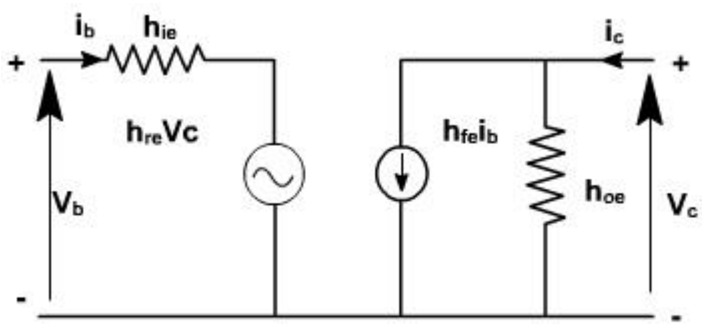


Fig. 4

To determine the four h-parameters of transistor amplifier, input and output characteristic are used. Input characteristic depicts the relationship between input voltage and input current with output voltage as parameter. The output characteristic depicts the relationship between output voltage and output current with input current as parameter. **Fig. 5**, shows the output characteristics of CE amplifier.

$$h_{fe} = \left.\frac{\partial i_C}{\partial i_B}\right|_{V_C} = \frac{i_{C2} - i_{C1}}{i_{b2} - i_{b1}}$$

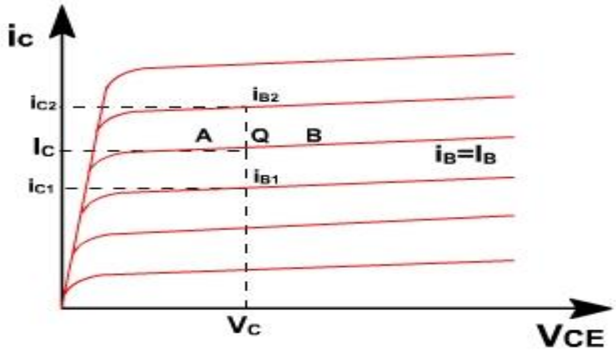


Fig. 5

The current increments are taken around the quiescent point Q which corresponds to $i_B = I_B$ and to the collector voltage $V_{CE} = V_C$

$$h_{oe} = \left.\frac{\partial i_C}{\partial V_C}\right|_{i_B}$$

The value of h_{oe} at the quiescent operating point is given by the slope of the output characteristic at the operating point (i.e. slope of tangent AB).

$$h_{ie} = \frac{\partial V_B}{\partial i_B} \approx \left.\frac{\Delta V_B}{\Delta i_B}\right|_{V_C}$$

h_{ie} is the slope of the appropriate input on **fig. 6**, at the operating point (slope of tangent EF at Q).

$$h_{re} = \frac{\partial V_B}{\partial V_C} = \left.\frac{\Delta V_B}{\Delta V_C}\right|_{I_B} = \frac{V_{B2} - V_{B1}}{V_{C2} - V_{C1}}$$

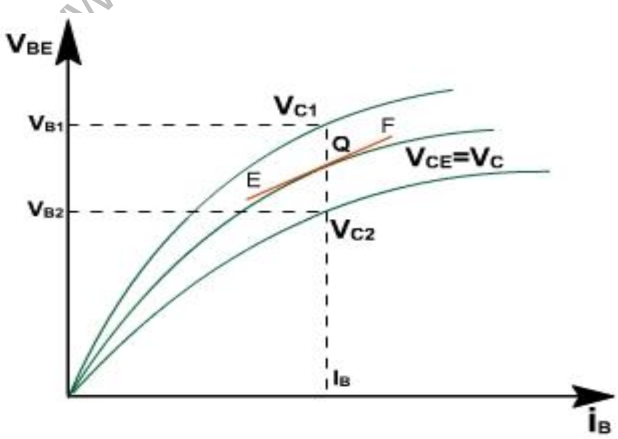


Fig. 6

A vertical line on the input characteristic represents constant base current. The parameter hre can be obtained from the ratio (V_{B2}– V_{B1}) and (V_{C2}– V_{C1}) for at Q.

6.3 ANALYSIS OF A TRANSISTOR AMPLIFIER USING H-PARAMETERS:

To form a transistor amplifier it is only necessary to connect an external load and signal source as indicated in **fig. 1** and to bias the transistor properly.

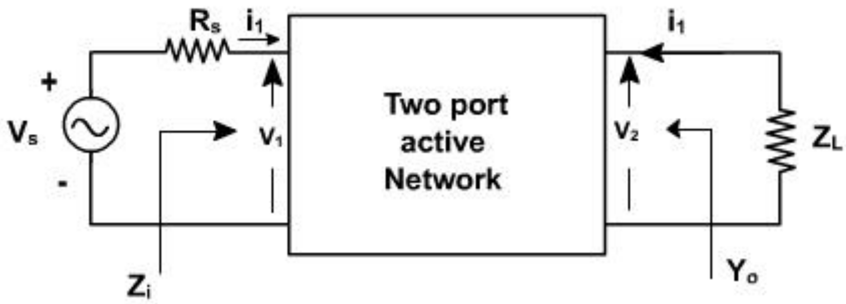


Fig. 1

Consider the two-port network of CE amplifier. R_S is the source resistance and Z_L is the load impedence h-parameters are assumed to be constant over the operating range. The ac equivalent circuit is shown in **fig. 2**. (Phasor notations are used assuming sinusoidal voltage input). The quantities of interest are the current gain, input impedence, voltage gain, and output impedence.

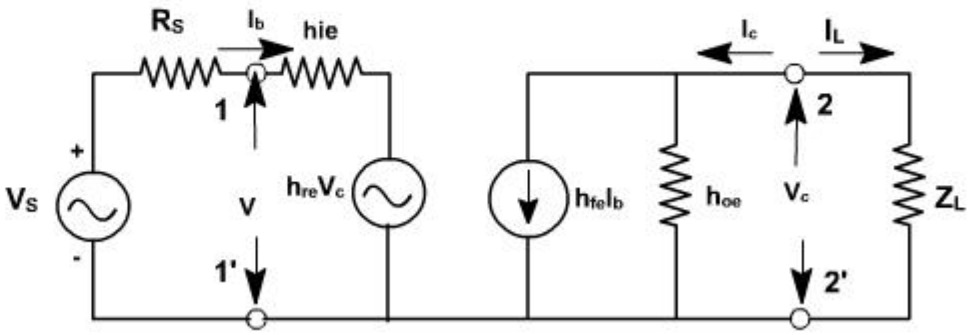


Fig. 2

6.3.1 Current gain:

For the transistor amplifier stage, A_i is defined as the ratio of output to input currents.

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

6.3.2 Input impedence:

The impedence looking into the amplifier input terminals (1,1') is the input impedence Z_i

$$Z_i = \frac{V_b}{I_b}$$

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

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

$$= h_{ie} - \frac{h_{re} I_c Z_L}{I_b}$$

$$\therefore Z_i = h_{ie} + h_{re} A_I Z_L$$

$$= h_{ie} - \frac{h_{re} h_{fe} Z_L}{1 + h_{oe} Z_L}$$

$$\therefore Z_i = h_{ie} - \frac{h_{re} h_{fe}}{Y_L + h_{oe}} \qquad (\text{since } Y_L = \frac{1}{Z_L})$$

6.3.3 Voltage gain:

The ratio of output voltage to input voltage gives the gain of the transistors.

$$A_v = \frac{V_C}{V_b} = -\frac{I_C Z_L}{V_b}$$

$$\therefore A_v = \frac{I_B A_i Z_L}{V_b} = \frac{A_i Z_L}{Z_i}$$

6.3.4 Output Admittance:

It is defined as

$$Y_0 = \left.\frac{I_c}{V_c}\right|_{V_s} = 0$$

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

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

when $V_s = 0$, $\quad R_s . I_b + h_{ie} . I_b + h_{re} V_c = 0.$

$$\frac{I_b}{V_c} = -\frac{h_{re}}{R_s + h_{ie}}$$

$$\therefore Y_0 = h_{oe} - \frac{h_{re}\, h_{fe}}{R_s + h_{ie}}$$

Voltage amplification taking into account source impedance (R_S) is given by

$$A_{VS} = \frac{V_c}{V_s} = \frac{V_c}{V_b} * \frac{V_b}{V_s} \qquad \left(V_b = \frac{V_s}{R_s + Z_i} * Z_i\right)$$

$$= A_V . \frac{Z_i}{Z_i + R_s}$$

$$= \frac{A_i\, Z_L}{Z_i + R_s}$$

A_v is the voltage gain for an ideal voltage source ($R_v = 0$).

Consider input source to be a current source I_S in parallel with a resistance R_S as shown in **fig. 3**.

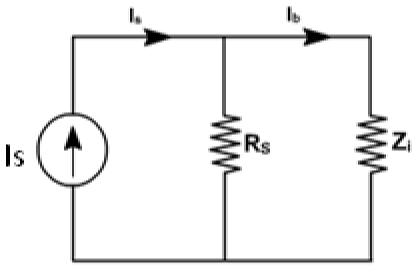


Fig. 3

In this case, overall current gain A_{IS} is defined as

$$A_{I_s} = \frac{I_L}{I_s}$$
$$= -\frac{I_c}{I_s}$$
$$= -\frac{I_c}{I_b} * \frac{I_b}{I_s} \qquad \left(I_b = \frac{I_s * R_s}{R_s + Z_i} \right)$$
$$= A_I * \frac{R_s}{R_s + Z_i}$$
$$\text{If } R_s \to \infty, \quad A_{I_s} \to A_I$$

h-parameters

To analyze multistage amplifier the h-parameters of the transistor used are obtained from manufacture data sheet. The manufacture data sheet usually provides h-parameter in CE configuration. These parameters may be converted into CC and CB values. For example fig. 4 hrc in terms of CE parameter can be obtained as follows.

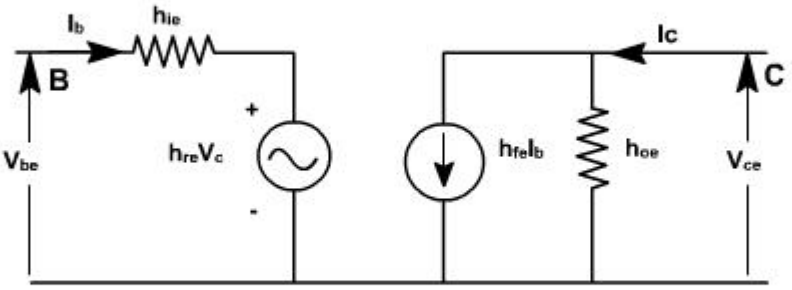


Fig. 4

For CE transistor configuaration

Vbe = hie Ib + hre Vce

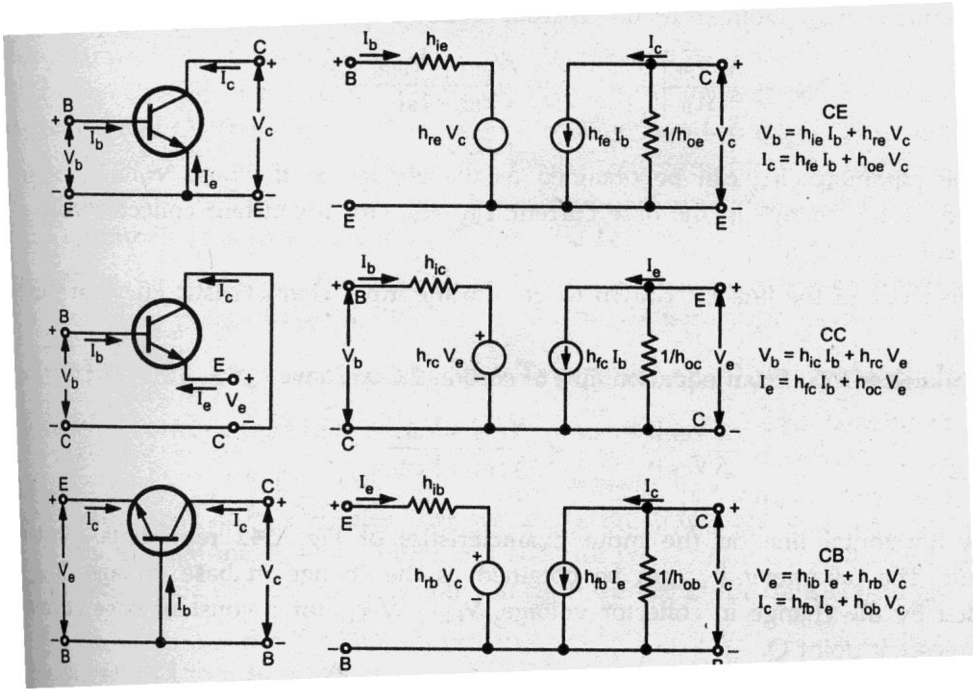
Ic = h fe Ib + hoe Vce

The circuit can be redrawn like CC transistor configuration as shown in fig. 5.

Vbc = hie Ib + hrc Vec

Ic = hfe Ib + hoe Vec

hybrid model for transistor in three different configurations



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-parameters

A transistor amplifier can be constructed by connecting an external load and signal source and biasing the transistor properly.

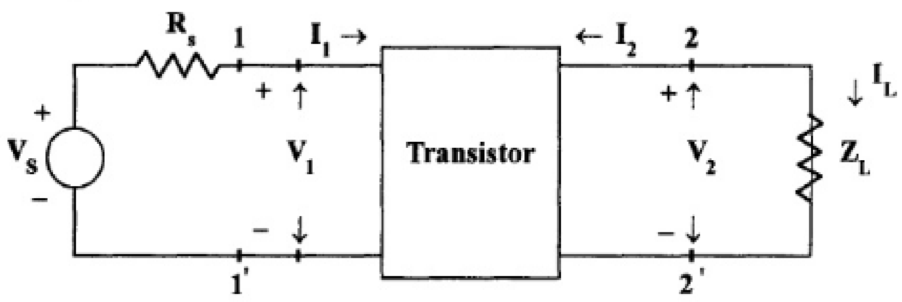


Fig.1.4 Basic Amplifier Circuit

The two port network of Fig. 1.4 represents a transistor in any one of its configuration. It is assumed that h-parameters remain constant over the operating range.The input is sinusoidal and I_1,V_1,I_2 and V_2 are phase quantities

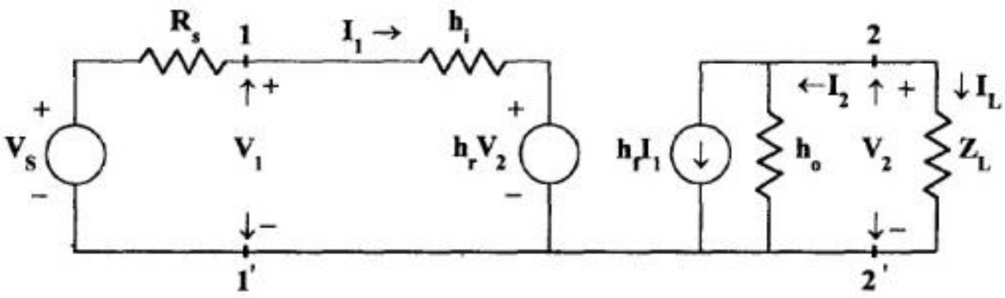


Fig. 1.5 Transistor replaced by its Hybrid Model

Current Gain or Current Amplification (A_i)

For transistor amplifier the current gain A_i is defined as the ratio of output current to input current,i.e,

$$A_i = I_L / I_1 = -I_2 / I_1$$

From the circuit of Fig

$$I_2 = h_f I_1 + h_o V_2$$

Substituting $V_2 = I_L Z_L = -I_2 Z_L$

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

$I_2 + I_2 Z_L h_o = h_f I_1$

$I_2(1 + Z_L h_o) = h_f I_1$

$A_i = -I_2 / I_1 = - h_f / (1 + Z_L h_o)$

Therefore,

$A_i = - h_f / (1 + Z_L h_o)$

Input Impedence (Z_i)

In the circuit of Fig , R_S is the signal source resistance .The impedence seen when looking into the amplifier terminals (1,1') is the amplifier input impedence Z_i,

$Z_i = V_1 / I_1$

From the input circuit of Fig $V_1 = h_i I_1 + h_r V_2$

$Z_i = (h_i I_1 + h_r V_2) / I_1$

$= h_i + h_r V_2 / I_1$

Substituting

$V_2 = -I_2 Z_L = A_1 I_1 Z_L$

$Z_i = h_i + h_r A_1 I_1 Z_L / I_1$

$= h_i + h_r A_1 Z_L$

Substituting for A_i

$Z_i = h_i - h_f h_r Z_L / (1 + h_o Z_L)$

$= h_i - h_f h_r Z_L / Z_L(1/Z_L + h_o)$

Taking the Load admittance as $Y_L = 1/ Z_L$

$Z_i = h_i - h_f h_r / (Y_L + h_o)$

Voltage Gain or Voltage Gain Amplification Factor(A_v)

The ratio of output voltage V_2 to input voltage V_1 give the voltage gain of the transistor i.e,

$$A_v = V_2 / V_1$$

Substituting

$$V_2 = -I_2 Z_L = A_1 I_1 Z_L$$

$$A_v = A_1 I_1 Z_L / V_1 = A_i Z_L / Z_i$$

Output Admittance (Y_o)

Y_o is obtained by setting V_S to zero, Z_L to infinity and by driving the output terminals from a generator V_2. If the current V_2 is I_2 then $Y_o = I_2/V_2$ with $V_S=0$ and $R_L=\infty$.

From the circuit of fig

$$I_2 = h_f I_1 + h_o V_2$$

Dividing by V_2,

$$I_2 / V_2 = h_f I_1/V_2 + h_o$$

With $V_2 = 0$, by KVL in input circuit,

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

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

Hence, $$I_2 / V_2 = -h_r / (R_S + h_i)$$

$$= h_f (-h_r/(R_S + h_i)+h_o$$

$$Y_o = h_o - h_f h_r/(R_S + h_i)$$

The output admittance is a function of source resistance. If the source impedence is resistive then Y_o is real.

Voltage Amplification Factor(A_{vs}) taking into account the resistance (R_s) of the source

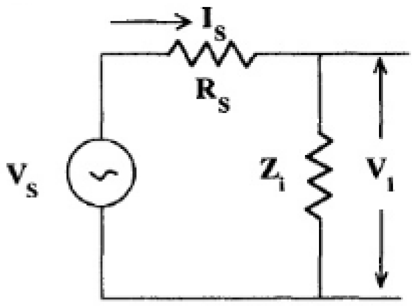


Fig. 5.6 Thevenin's Equivalent Input Circuit

This overall voltage gain A_{vs} is given by

$$A_{vs} = V_2 / V_S = V_2V_1 / V_1V_S = A_v V_1 / V_S$$

From the equivalent input circuit using Thevenin's equivalent for the source shown in Fig. 5.6

$V_1 = V_S Z_i / (Z_i + R_S)$

$V_1 / V_S = Z_i / (Z_i + R_S)$

Then, $A_{vs} = A_v Z_i / (Z_i + R_S)$

Substituting $A_v = A_iZ_L / Z_i$

$A_{vs} = A_iZ_L / (Z_i + R_S)$

$A_{vs} = A_iZ_L R_S / (Z_i + R_S) R_S$

$A_{vs} = A_{is}Z_L / R_S$

Current Amplification (A_{is}) taking into account the sourse Resistance(R_S)

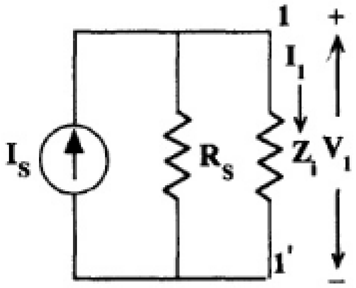


Fig. 1.7 Norton's Equivalent Input Circuit

The modified input circuit using Norton's equivalent circuit for the calculation of A_{is} is shown in Fig. 1.7

Overall Current Gain, $A_{is} = -I_2 / I_S = - I_2 I_1 / I_1 I_S = A_i I_1/I_S$

From Fig. 1.7 $I_1 = I_S R_S / (R_S + Z_i)$

$I_1 / I_S = R_S / (R_S + Z_i)$

and hence, $A_{is} = A_i R_S / (R_S + Z_i)$

Operating Power Gain (A_P)

The operating power gain A_P of the transistor is defined as

$$A_P = P_2 / P_1 = -V_2 I_2 / V_1 I_1 = A_v A_i = A_i A_i Z_L / Z_i$$

$$A_P = A_i^2 (Z_L / Z_i)$$

Small Signal analysis of a transistor amplifier

$A_i = - h_f / (1+ Z_L h_o)$	$A_v = A_i Z_L / Z_i$
$Z_i = h_i + h_r A_1 Z_L = h_i - h_f h_r / (Y_L + h_o)$	$A_{vs} = A_v Z_i / (Z_i + R_S) = A_i Z_L / (Z_i + R_S) = A_{is} Z_L / R_S$
$Y_o = h_o - h_f h_r / (R_S + h_i) = 1/ Z_o$	$A_{is} = A_i R_S / (R_S + Z_i) = A_{vs} = A_{is} R_S / Z_L$

Simplified common emitter hybrid model:

In most practical cases it is appropriate to obtain approximate values of A_V , A_i etc rather than calculating exact values. How the circuit can be modified without greatly reducing the accuracy. **Fig. 4** shows the CE amplifier equivalent circuit in terms of h-parameters Since 1 / h_{oe} in parallel with R_L is approximately equal to R_L if 1 / h_{oe} >> R_L then h_{oe} may be neglected. Under these conditions.

$I_c = h_{fe} I_B$.

$h_{re} v_c = h_{re} I_c R_L = h_{re} h_{fe} I_b R_L$.

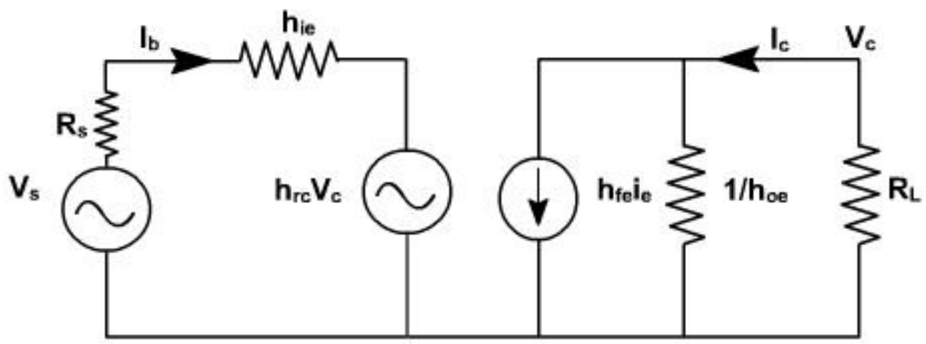


Fig. 4

Since $h_{fe}.h_{re}$ = 0.01(approximately), this voltage may be neglected in comparison with $h_{ic} I_b$ drop across h_{ie} provided R_L is not very large. If load resistance R_L is small than hoe and h_{re} can be neglected.

$$A_I = -\frac{h_{fe}}{1+h_{oe} R_L} \approx -h_{fe}$$
$$R_i = h_{ie}$$
$$A_V = \frac{A_I R_L}{R_i} = -\frac{h_{fe} R_L}{h_{ie}}$$

Output impedence seems to be infinite. When V_s = 0, and an external voltage is applied at the output we fined I_b = 0, I_C = 0. True value depends upon R_S and lies between 40 K and 80K.

On the same lines, the calculations for CC and CB can be done.

CE amplifier with an emitter resistor:

The voltage gain of a CE stage depends upon h_{fe}. This transistor parameter depends upon temperature, aging and the operating point. Moreover, h_{fe} may vary widely from device to device, even for same type of transistor. To stabilize voltage gain A_V of each stage, it should be independent of h_{fe}. A simple and effective way is to connect an emitter resistor R_e as shown in **fig. 5**. The resistor provides negative feedback and provide stabilization.

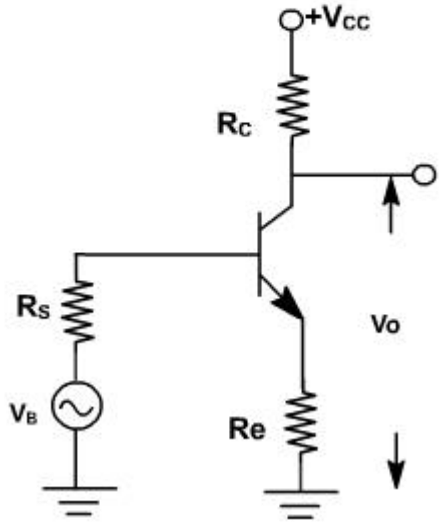


Fig. 5

An approximate analysis of the circuit can be made using the simplified model.

$$\text{Current gain } A_i = \frac{I_L}{I_b} = -\frac{I_C}{I_b} = -\frac{h_{fe}\, I_b}{I_b}$$
$$= -h_{fe}$$

It is unaffected by the addition of R_C.

Input resistance is given by

$$R_i = \frac{V_i}{I_b}$$
$$= \frac{h_{ie}\, I_b + (1+h_{fe})\, I_b\, R_e}{I_b}$$
$$= h_{ie} = (1+h_{fe})\, R_e$$

The input resistance increases by $(1+h_{fe})\, R_e$

$$A_v = \frac{A_i R_L}{R_i} = \frac{-h_{fe}\, R_L}{h_{ie} + (1+h_{fe})R_e}$$

Clearly, the addition of R_e reduces the voltage gain.
If $(1+h_{fe})R_e >> h_{ie}$ and $h_{fe} >> 1$
then

$$A_v = \frac{-h_{fe}\, R_L}{(1+h_{fe})R_e} \approx -\frac{R_L}{R_e}$$

Subject to above approximation A_V is completely stable. The output resistance is infinite for the approximate model.

Comparison of Transistor Amplifier Configuration

The characteristics of three configurations are summarized in Table .Here the quantities A_i,A_v,R_i,R_o and A_P are calculated for a typical transistor whose h-parameters are given in table .The values of R_L and R_s are taken as 3KΩ.

Table: Performance schedule of three transistor configurations

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

The values of current gain, voltage gain, input impedance and output impedance calculated as a function of load and source impedances

Characteristics of Common Base Amplifier

(i) Current gain is less than unity and its magnitude decreases with the increase of load resistance R_L,

(ii) Voltage gain A_V is high for normal values of R_L,

(iii) The input resistance R_i is the lowest of all the three configurations, and

(iv) The output resistance R_o is the highest of all the three configurations.

Applications The CB amplifier is not commonly used for amplification purpose. It is used for

(i) Matching a very low impedance source

(ii) As a non inverting amplifier to voltage gain exceeding unity.

(iii) For driving a high impedance load.

(iv) As a constant current source.

Characteristics of Common Collector Amplifier

(i) For low R_L (< 10 kΩ), the current gain A_i is high and almost equal to that of a CE amplifier.

(ii) The voltage gain A_V is less than unity.

(iii) The input resistance is the highest of all the three configurations.

(iv) The output resistance is the lowest of all the three configurations.

Applications The CC amplifier is widely used as a buffer stage between a high impedance source and a low impedance load.

Characteristics of Common Emitter Amplifier

(i) The current gain A_i is high for R_L < 10 kΩ.

(ii) The voltage gain is high for normal values of load resistance R_L.

(iii) The input resistance R_i is medium.

(iv) The output resistance R_o is moderately high.

Applications: CE amplifier is widely used for amplification.

Simplified common emitter hybrid model:

In most practical cases it is appropriate to obtain approximate values of A_V, A_i etc rather than calculating exact values. How the circuit can be modified without greatly reducing the accuracy. **Fig 1. 8** shows the CE amplifier equivalent circuit in terms of h-parameters Since $1 / h_{oe}$ in parallel with R_L is approximately equal to R_L if $1 / h_{oe} >> R_L$ then h_{oe} may be neglected. Under these conditions.

$I_c = h_{fe} I_B$.

$h_{re} v_c = h_{re} I_c R_L = h_{re} h_{fe} I_b R_L$.

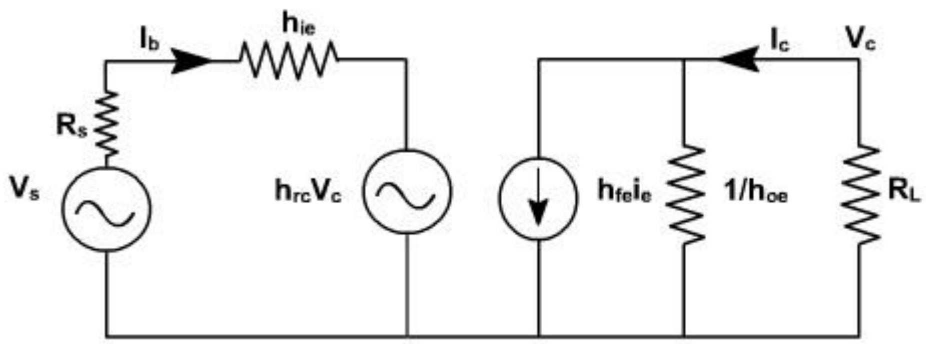


Fig 1.8

Since $h_{fe}.h_{re}$ » 0.01, this voltage may be neglected in comparison with h_{ic} I_b drop across h_{ie} provided R_L is not very large. If load resistance R_L is small than hoe and h_{re} can be neglected.

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

$$R_i = h_{ie}$$

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

Output impedence seems to be infinite. When V_s = 0, and an external voltage is applied at the output we fined I_b = 0, I_C = 0. True value depends upon R_S and lies between 40 K and 80K.

On the same lines, the calculations for CC and CB can be done.

CE amplifier with an emitter resistor:

The voltage gain of a CE stage depends upon h_{fe}. This transistor parameter depends upon temperature, aging and the operating point. Moreover, h_{fe} may vary widely from device to device, even for same type of transistor. To stabilize voltage gain A_V of each stage, it should be independent of h_{fe}. A simple and effective way is to connect an emitter resistor R_e as shown in **fig.1.9**. The resistor provides negative feedback and provide stabilization.

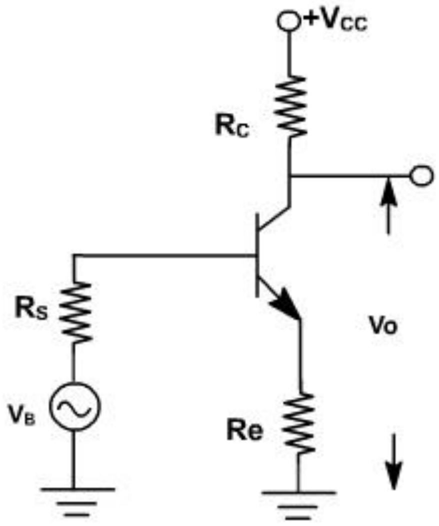


Fig.1.9

An approximate analysis of the circuit can be made using the simplified model.

Current gain $A_i = \frac{I_L}{I_b} = -\frac{I_C}{I_b} = -\frac{h_{fe}\, I_b}{I_b}$

$= -h_{fe}$

It is unaffected by the addition of R_C.

Input resistance is given by

$$R_i = \frac{V_i}{I_b}$$

$$= \frac{h_{ie}\, I_b + (1+h_{fe})\, I_b\, R_e}{I_b}$$

$$= h_{ie} = (1+h_{fe})\, R_e$$

The input resistance increases by $(1+h_{fe})R_e$

$$A_v = \frac{A_i R_L}{R_i} = \frac{-h_{fe}\, R_L}{h_{ie} + (1+h_{fe})R_e}$$

Clearly, the addition of R_e reduces the voltage gain.

If $(1+h_{fe})R_e >> h_{ie}$ and $h_{fe} >> 1$

then

$$A_v = \frac{-h_{fe}\, R_L}{(1+h_{fe})R_e} \approx -\frac{R_L}{R_e}$$

Subject to above approximation A_V is completely stable. The output resistance is infinite for the approximate model.

Common Base Amplifier:

The common base amplifier circuit is shown in **Fig. 1**. The V_{EE} source forward biases the emitter diode and V_{CC} source reverse biased collector diode. The ac source v_{in} is connected to emitter through a coupling capacitor so that it blocks dc. This ac voltage produces small fluctuation in currents and voltages. The load resistance R_L is also connected to collector through coupling capacitor so the fluctuation in collector base voltage will be observed across R_L.

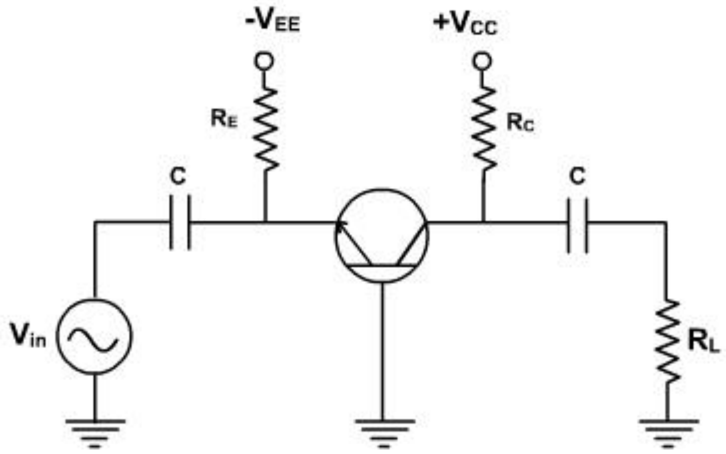


Fig. 1

The dc equivalent circuit is obtained by reducing all ac sources to zero and opening all capacitors. The dc collector current is same as I_E and V_{CB} is given by

$V_{CB} = V_{CC} - I_C R_C$.

These current and voltage fix the Q point. The ac equivalent circuit is obtained by reducing all dc sources to zero and shorting all coupling capacitors. r'_e represents the ac resistance of the diode as shown in **Fig. 2**.

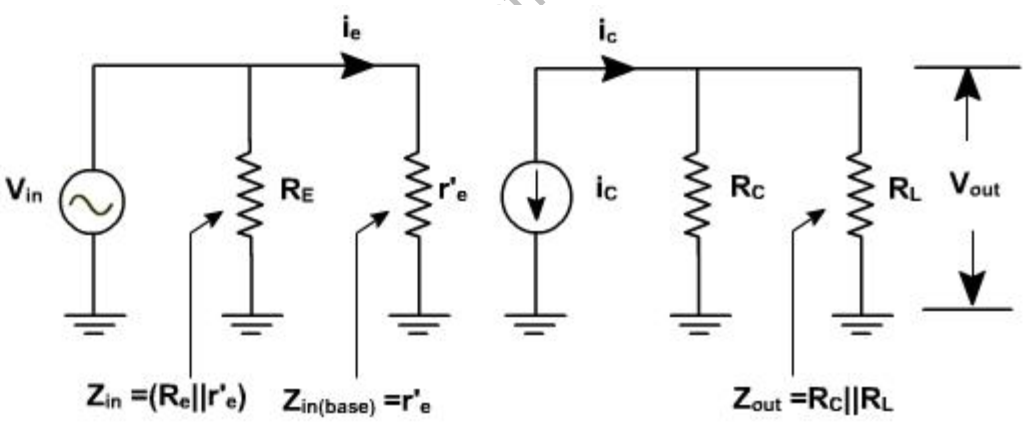


Fig. 2

Fig. 3, shows the diode curve relating I_E and V_{BE}. In the absence of ac signal, the transistor operates at Q point (point of intersection of load line and input characteristic). When the ac signal is applied, the emitter current and voltage also change. If the signal is small, the operating point swings sinusoidally about Q point (A to B).

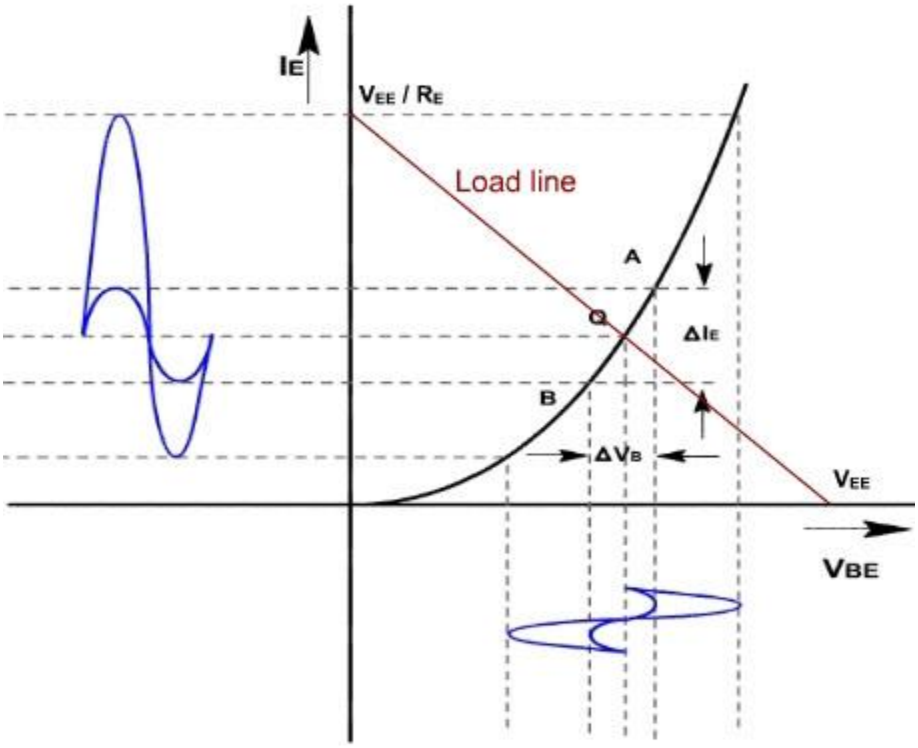


Fig .3

If the ac signal is small, the points A and B are close to Q, and arc A B can be approximated by a straight line and diode appears to be a resistance given by

$$r'_e = \left.\frac{\Delta V_{BE}}{\Delta I_E}\right|_{\text{small change}}$$

$$= \frac{V_{be}}{i_e} = \frac{\text{ac voltage across base and emitter}}{\text{ac current through emitter}}$$

If the input signal is small, input voltage and current will be sinusoidal but if the input voltage is large then current will no longer be sinusoidal because of the non linearity of diode curve. The emitter current is elongated on the positive half cycle and compressed on negative half cycle. Therefore the output will also be distorted.

r'_e is the ratio of ΔV_{BE} and Δ I_E and its value depends upon the location of Q. Higher up the Q point small will be the value of r' e because the same change in V_{BE} produces large change in I_E. The slope of the curve at Q determines the value of r'_e. From calculation it can be proved that.

r'_e = 25mV / I_E

Common Base Amplifier

Proof:

In general, the current through a diode is given by

$$I = I_{co}(e^{\frac{qV}{KT}} - 1)$$

Where q is he charge on electron, V is the drop across diode, T is the temperature and K is a constant.

On differentiating w.r.t V, we get,

$$\frac{dI}{dV} = I_{co} * e^{\frac{qV}{KT}} * \frac{q}{KT}$$

The value of (q / KT) at 25°C is approximately 40.

Therefore,
$$\frac{dI}{dV} = 40 * I_{co} * e^{\frac{qV}{KT}}$$
$$= 40 * (I + I_{co})$$

or,
$$\frac{dV}{dI} = \frac{1}{40 * (I + I_{co})} \approx \frac{1}{40 * I}$$

$$\text{Therefore, ac resistance of the emitter diode} = \frac{dV}{dI} = \frac{25mV}{I}\text{ Ohms}$$

To a close approximation the small changes in collector current equal the small changes in emitter current. In the ac equivalent circuit, the current ‘i_C' is shown upward because if ‘i_e' increases, then ‘i_C' also increases in the same direction.

Voltage gain:

Since the ac input voltage source is connected across r'_e. Therefore, the ac emitter current is given by

$i_e = V_{in} / r'_e$

or, $V_{in} = ie\, r'_e$

The output voltage is given by $V_{out} = i_c (R_C \| R_L)$

$$\text{Therefore, voltage gain } A_V = \frac{v_{out}}{v_{in}} = \frac{(R_C \parallel R_L)}{r'_e}$$

$$= \frac{rc}{r}$$

Under open circuit condition $v_{out} = i_c R_c$

$$\text{Therefore, voltage gain in open circuit condition} = A_V = \frac{R_C}{r'_e}$$

Small Signal CE Amplifiers:

CE amplifiers are very popular to amplify the small signal ac. After a transistor has been biased with a Q point near the middle of a dc load line, ac source can be coupled to the base. This produces fluctuations in the base current and hence in the collector current of the same shape and frequency. The output will be enlarged sine wave of same frequency.

The amplifier is called linear if it does not change the wave shape of the signal. As long as the input signal is small, the transistor will use only a small part of the load line and the operation will be linear.

On the other hand, if the input signal is too large. The fluctuations along the load line will drive the transistor into either saturation or cut off. This clips the peaks of the input and the amplifier is no longer linear.

The CE amplifier configuration is shown in **fig. 1**.

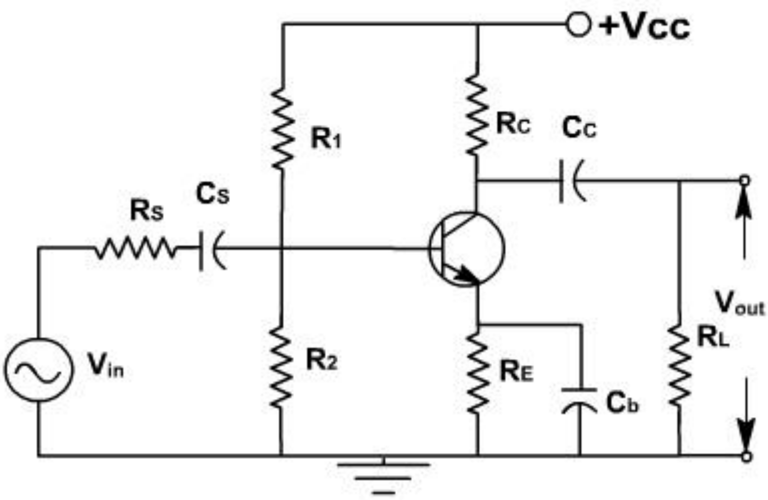


Fig. 1

The coupling capacitor (C_C) passes an ac signal from one point to another. At the same time it does not allow the dc to pass through it. Hence it is also called blocking capacitor.

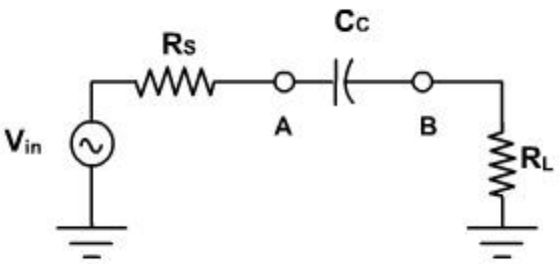


Fig. 2

For example in **fig. 2**, the ac voltage at point A is transmitted to point B. For this series reactance X_C should be very small compared to series resistance R_S. The circuit to the left of A may be a source and a series resistor or may be the Thevenin equivalent of a complex circuit. Similarly R_L may be the load resistance or equivalent resistance of a complex network. The current in the loop is given by

$$i = \frac{v_{in}}{\sqrt{(R_S + R_L)^2 + X_C^2}}$$

$$= \frac{v_{in}}{\sqrt{R^2 + X^2}}$$

As frequency increases, $X_C\left(= \frac{1}{2\pi fc}\right)$ decreases, and current increases until it reaches to its maximum value v_{in} / R. Therefore the capacitor couples the signal properly from A to B when $X_C << R$. The size of the coupling capacitor depends upon the lowest frequency to be coupled. Normally, for lowest frequency X_C □□0.1R is taken as design rule.

The coupling capacitor acts like a switch, which is open to dc and shorted for ac.

The bypass capacitor C_b is similar to a coupling capacitor, except that it couples an ungrounded point to a grounded point. The C_b capacitor looks like a short to an ac signal and therefore emitter is said ac grounded. A bypass capacitor does not disturb the dc voltage at emitter because it looks open to dc current. As a design rule X_{Cb} □ $0.1R_E$ at Analysis of CE amplifier:

In a transistor amplifier, the dc source sets up quiescent current and voltages. The ac source then produces fluctuations in these current and voltages. The simplest way to analyze this circuit is to split the analysis in two parts: dc analysis and ac analysis. One can use superposition theorem for analysis .

Analysis of CE amplifier

Voltage gain:

To find the voltage gain, consider an unloaded CE amplifier. The ac equivalent circuit is shown in

fig. 3. The transistor can be replaced by its collector equivalent model i.e. a current source and emitter diode which offers ac resistance r'_e.

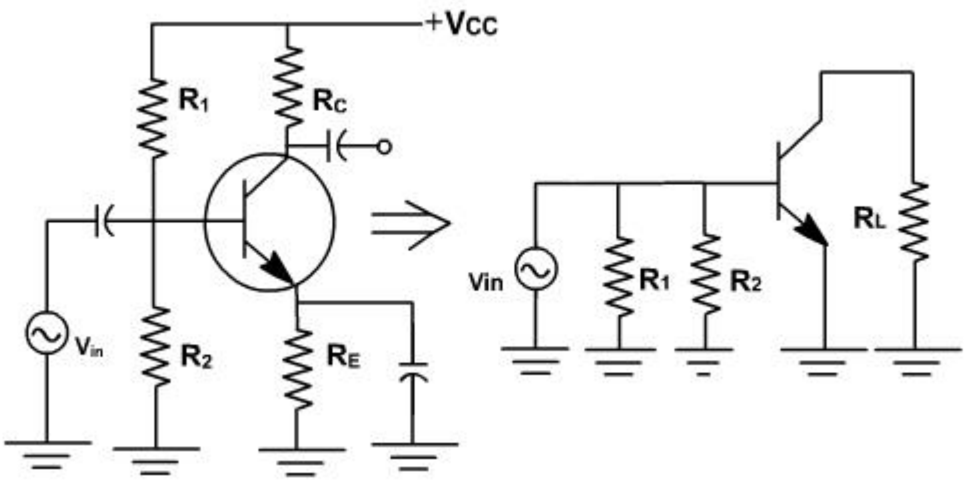


Fig. 3

The input voltage appears directly across the emitter diode.

Therefore emitter current $i_e = V_{in} / r'_e$.

Since, collector current approximately equals emitter current and $i_C = i_e$ and $v_{out} = - i_e R_C$ (The minus sign is used here to indicate phase inversion)

Further $v_{out} = - (V_{in} R_C) / r'_e$

Therefore voltage gain $A = v_{out} / v_{in} = -R_C / r'_e$

The ac source driving an amplifier has to supply alternating current to the amplifier. The input impedance of an amplifier determines how much current the amplifier takes from the ac source.

In a normal frequency range of an amplifier, where all capacitors look like ac shorts and other reactance are negligible, the ac input impedance is defined as

$z_{in} = v_{in} / i_{in}$

Where v_{in}, i_{in} are peak to peak values or rms values

The impedance looking directly into the base is symbolized $z_{in\,(base)}$ and is given by

$Z_{in(base)} = v_{in} / i_b$,

Since, $v_{in} = i_e r'_e$

$z_{in\ (base)} = r'_e.$

From the ac equivalent circuit, the input impedance z_{in} is the parallel combination of R_1 , R_2 and r'_e.

$Z_{in} = R_1 \parallel R_2 \parallel \square\ r'_e$

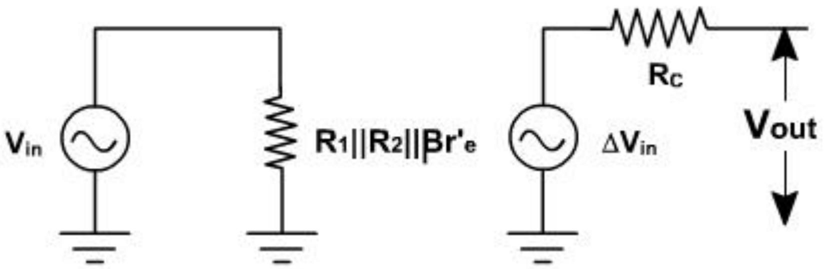
The Thevenin voltage appearing at the output is

$v_{out} = A\ v_{in}$

The Thevenin impedance is the parallel combination of R_C and the internal impedance of the current source. The collector current source is an ideal source, therefore it has an infinite internal impedance.

$z_{out} = R_C.$

The simplified ac equivalent circuit is shown in **fig. 4**.



Analysis of CE amplifier

FET AMPLIFIERS

INTRODUCTION

Field Effect Transistor (FET) amplifiers provide an excellent voltage gain and high input impedence. Because of high input impedence and other characteristics of JFETs they are preferred over BJTs for certain types of applications.

There are 3 basic FET circuit configurations:

i)Common Source

ii)Common Drain

iii)Common Gain

Similar to BJT CE,CC and CB circuits, only difference is in BJT large output collector current is controlled by small input base current whereas FET controls output current by means of small input voltage. In both the cases output current is controlled variable.

FET amplifier circuits use voltage controlled nature of the JFET. In Pinch off region, I_D depends only on V_{GS}.

THE FET SMALL SIGNAL MODEL:-

The linear small signal equivalent circuit for the FET can be obtained in a manner similar to that used to derive the corresponding model for a transistor.

We can express the drain current i_D as a function f of the gate voltage and drain voltage V_{ds}.

$I_d = f(V_{gs}, V_{ds})$------------------(1)

The transconductance g_m and drain resistance r_d:-

If both gate voltage and drain voltage are varied, the change in the drain current is approximated by using taylors series considering only the first two terms in the expansion

$$\Delta i_d = \frac{\partial id}{\partial Vgs}|_{V_{ds}=\text{constant}} .\Delta v_{gs} + \frac{\partial id}{\partial Vds}|_{vgs=\text{constant}} \Delta v_{ds}$$

we can write $\Delta i_d = i_d$

$\Delta v_{gs} = v_{gs}$

$\Delta v_{ds} = v_{ds}$

$$I_d = g_m\, vgs + \frac{1}{rd}\ Vds \rightarrow (1)$$

Where $g_m = \frac{\partial id}{\partial Vgs}|Vds \cong \frac{\Delta id}{\Delta Vgs}|Vds$

$$g_m = \frac{id}{Vgs}|Vds$$

Is the mutual conductance or transconductance .It is also called as gfs or yfs common source forward conductance .

The second parameter r_d is the drain resistance or output resistance is defined as

$$r_d = \frac{\partial Vds}{\partial id}|Vgs \cong \frac{\Delta vds}{\Delta ids}|Vgs = \frac{Vds}{id}|Vgs$$

$$r_d = \frac{Vds}{id}\Big|_{Vgs}$$

The reciprocal of the rd is the drain conductance gd .It is also designated by Yos and Gos and called the common source output conductance . So the small signal equivalent circuit for FET can be drawn in two different ways.

1.small signal current –source model

2.small signal voltage-source model.

A small signal current –source model for FET in common source configuration can be drawn satisfying Eq→(1) as shown in the figure(a)

This low frequency model for FET has a Norton's output circuit with a dependent current generator whose magnitude is proportional to the gate-to –source voltage. The proportionality factor is the transconductance 'g_m'. The output resistance is 'r_d'. The input resistance between the gate and source is infinite, since it is assumed that the reverse biased gate draws no current. For the same reason the resistance between gate and drain is assumed to be infinite.

The small signal voltage-source model is shown in the figure(b).

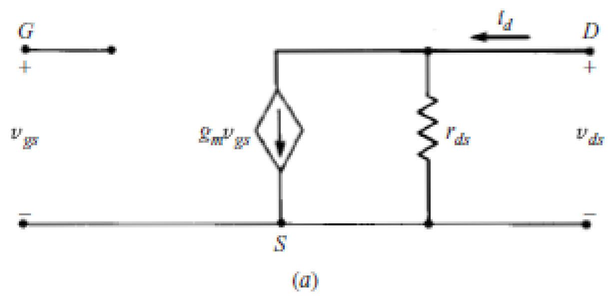
This can be derived by finding the Thevenin's equivalent for the output part of fig(a) .

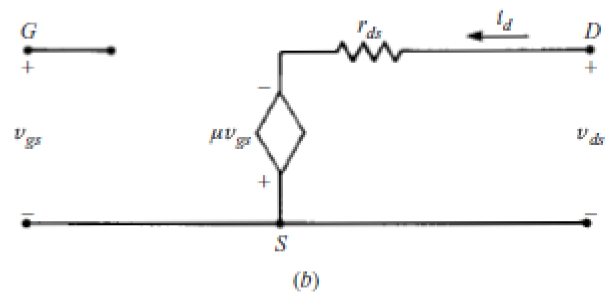
These small signal models for FET can be used for analyzing the three basic FET amplifier configurations:

1.common source (CS) 2.common drain (CD) or source follower

3. common gate(CG).

(a)Small Signal Current source model for FET (b)Small Signal voltage source model for FET





Here the input circuit is kept open because of having high input impedance and the output circuit satisfies the equation for ID

Common Source (CS) Amplifier

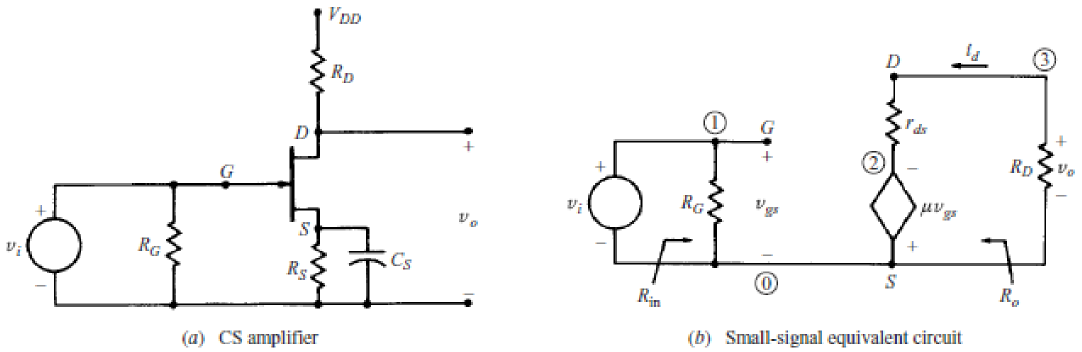


Fig. 7.1 (a) CS Amplifier (b) Small-signal equivalent circuit

A simple Common Source amplifier is shown in Fig. 7.1(a) and associated small signal equivalent circuit using voltage-source model of FET is shown in Fig. 7.1(b)

Voltage Gain

Source resistance (R_S) is used to set the Q-Point but is bypassed by C_S for mid-frequency operation. From the small signal equivalent circuit ,the output voltage

$$V_O = -R_D\mu V_{gs}(R_D + r_d)$$

Where $V_{gs} = V_i$, the input voltage,

Hence, the voltage gain,

$$A_V = V_O / V_i = -R_D\mu(R_D + r_d)$$

Input Impedence

From Fig. 7.1(b) Input Impedence is

$$Z_i = R_G$$

For voltage divider bias as in CE Amplifiers of BJT

$$R_G = R_1 \parallel R_2$$

Output Impedance

Output impedance is the impedance measured at the output terminals with the input voltage V_I = 0

From the Fig. 7.1(b) when the input voltage $V_i = 0$, $V_{gs} = 0$ and hence

$$\mu V_{gs} = 0$$

The equivalent circuit for calculating output impedence is given in Fig. 7.2.

Output impedence $Z_o = r_d \parallel R_D$

Normally r_d will be far greater than R_D . Hence $Z_o \approx R_D$

Common Drain Amplifier

A simple common drain amplifier is shown in Fig. 7.2(a) and associated small signal equivalent circuit using the voltage source model of FET is shown in Fig. 7.2(b).Since voltage V_{gd} is more easily determined than $V_{gs,}$ the voltage source in the output circuit is expressed in terms of V_{gs} and Thevenin's theorem.

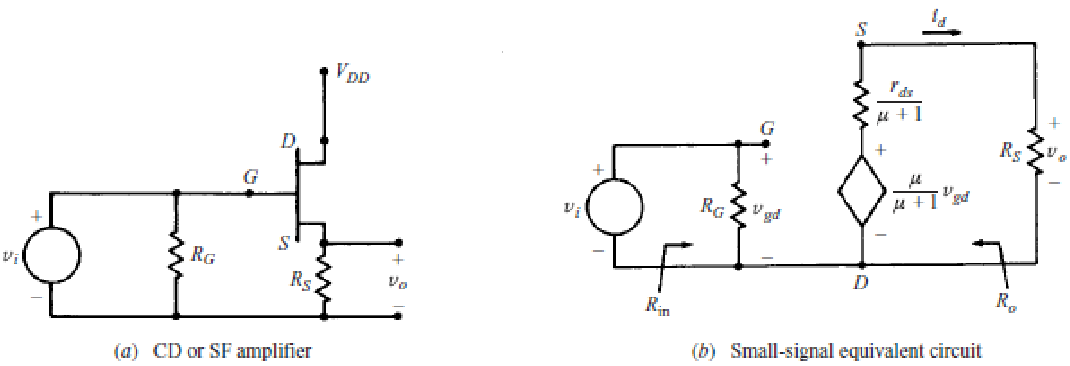


Fig. 7.2 (a)CD Amplifier (b)Small-signal equivalent circuit

Voltage Gain

The output voltage,

$$V_O = R_S \mu V_{gd} / (\mu + 1) R_S + r_d$$

Where $V_{gd} = V_i$ the input voltage.

Hence, the voltage gain,

$$A_v = V_O / V_i = R_S \mu / (\mu + 1) R_S + r_d$$

Input Impedence

From Fig. 7.2(b), Input Impedence $Z_i = R_G$

Output Impedence

From Fig. 7.2(b), Output impedence measured at the output terminals with input voltage $V_i = 0$ can be calculated from the following equivalent circuit.

As $V_i = 0$: $V_{gd} = 0$: $\mu v_{gd} / (\mu + 1) = 0$

Output Impedence

$$Z_O = r_d / (\mu + 1) \parallel R_S$$

When $\mu » 1$

$$Z_O = (r_d / \mu) \parallel R_S = (1/g_m) \parallel R_S$$