Unit III
Transistor Small Signal Analysis & Negative feedback amplifier

h-parameter model, Analysis of Transistor Amplifier circuits using h-parameters, CB,CE and CC Amplifier configurations and performance factors.

Principle of Negative feedback in electronic circuits, Voltage series, Voltage shunt, Current series, Current shunt types of Negative feedback, Typical transistor circuits effects of Negative feedback on Input and Output impedance, Voltage and Current gains, Bandwidth, Noise and Distortion.

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.

Two –Port Devices and Network Parameters

Small signal low frequency transistor Models:

All the transistor amplifiers are two port networks having two voltages and two currents. The positive directions of voltages and currents are shown in **fig. 1**.

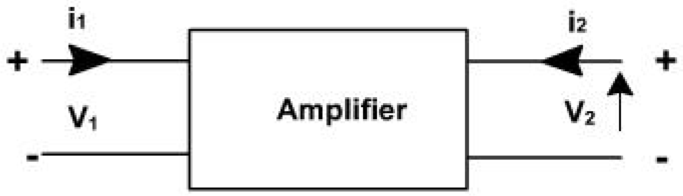


Fig. 1

A two-port network is represented by four external variables: voltage V_1 and current I_1 at the input port, and voltage V_2 and current I_2 at the output port, so that the two-port network can be treated as a black box modeled by the relationships between the four variables, V_1, V_2, I_1, I_2 . Out of four variables two can be selected as are independent variables and two are dependent variables.The dependent variables can be expressed interns of independent variables. This leads to various two port parameters out of which the following three are important:

1. Impedance parameters (z-parameters)
2. Admittance parameters (y-parameters)
3. Hybrid parameters (h-parameters)

z-parameters

A two-port network can be described by z-parameters as

$V_1 = Z_{11}I_1 + Z_{12}I_2$

$V_2 = Z_{21}I_1 + Z_{22}I_2$

In matrix form, the above equation can be rewritten as

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

Where

$$z_{11} = \left. \frac{V_1}{I_1} \right|_{I_2=0}$$

Input impedance with output port open circuited

$$z_{12} = \left. \frac{V_1}{I_2} \right|_{I_1=0}$$

Reverse transfer impedance with input port open circuited

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

Forward transfer impedance with output port open circuited

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

Output impedance with input port open circuite

Y-parameters

A two-port network can be described by Y-parameters as

$I_1 = Y_{11}V_1 + Y_{12}V_2$

$I_2 = Y_{21}V_1 + Y_{22}V_2$

In matrix form, the above equation can be rewritten as

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

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

Input admittance with output port short circuited

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

Reverse transfer admittance with input port short circuited

$$y_{21} = \left.\frac{I_2}{V_1}\right|_{V_2=0}$$

Forward transfer admittance with output port short circuited

$$y_{22} = \left.\frac{I_2}{V_2}\right|_{V_1=0}$$

Output admittance with input port short circuited

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 impedance with i/p port open circuited

THE HYBRID MODEL FOR TWO PORT NETWORK:

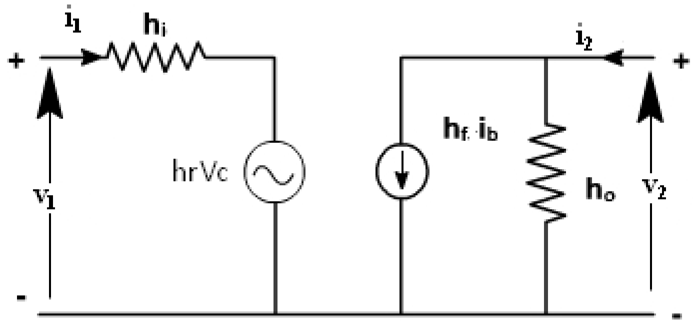
Based on the definition of hybrid parameters the mathematical model for two pert networks known as h-parameter model can be developed. The hybrid equations can be written as:

$$V_1 = h_i I_1 + h_r V_2$$

$$I_2 = h_f I_1 + h_o V_2$$

***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**.

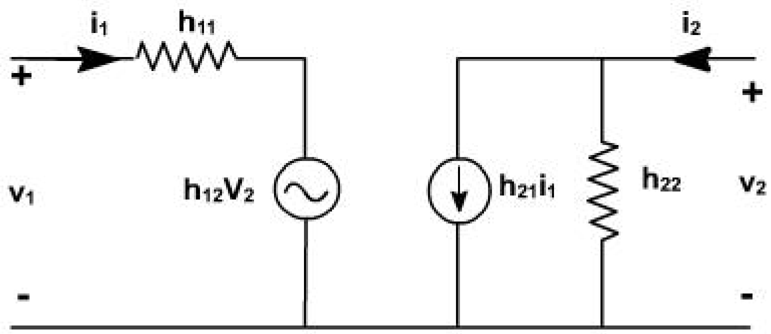


Fig. 2

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.

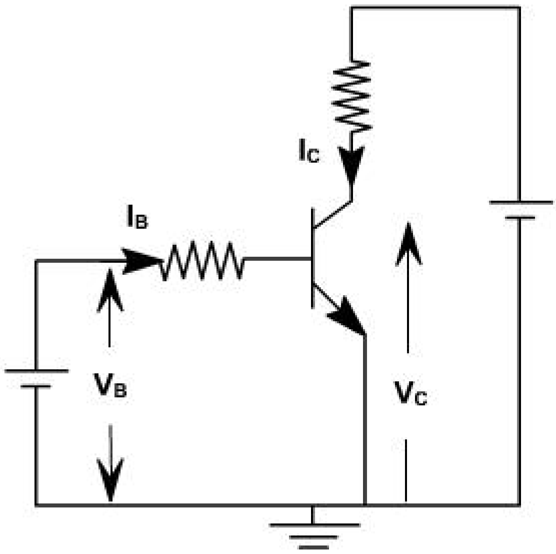


Fig. 3

$V_B = f_1\ (i_B\ ,v_C\ )$ $\qquad$ $I_C = f_2\ (i_B\ ,v_C)$.

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 $\Delta\ v_B$, $\Delta\ v_C$, $\Delta\ i_B$, $\Delta\ i_C$ 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.

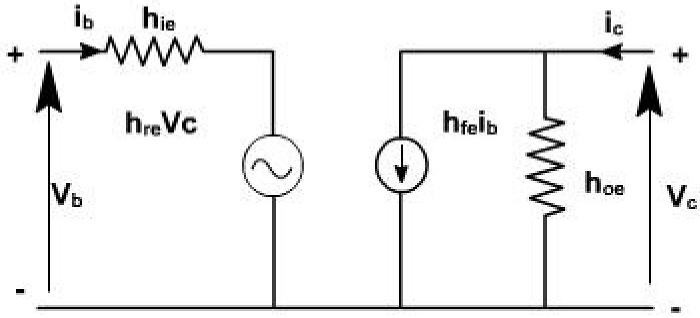


Fig. 4

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.

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

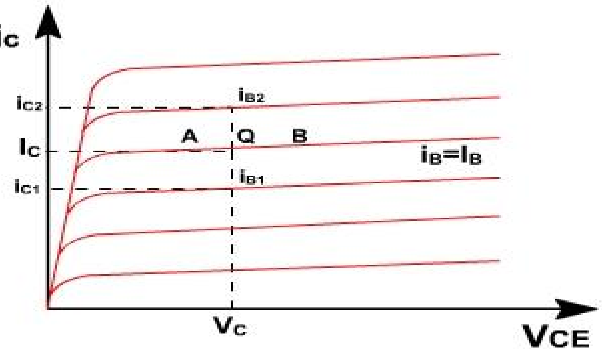


Fig. 5

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).

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

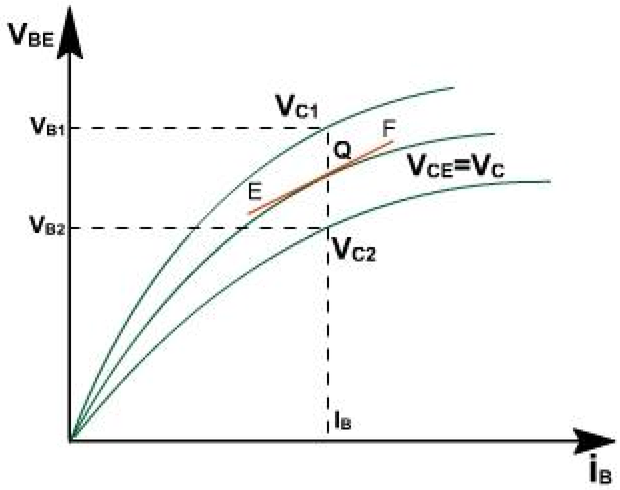


Fig. 6

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.

Typical CE h-parametersof transistor 2N1573 are given below:

h_{ie} = 1000 ohm.

$h_{re} = 2.5 * 10^{-4}$

h_{fe} = 50

h_{oe} = 25 µ A / V

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.

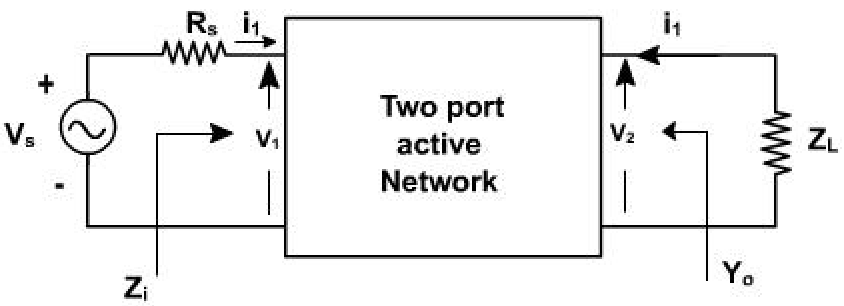


Fig. 1

Consider the two-port network of CE amplifier. R_S is the source resistance and Z_L is the load impedance 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.

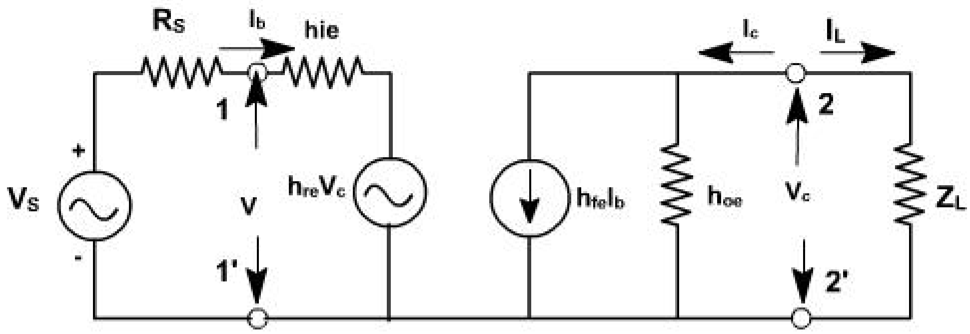


Fig. 2

Current gain:

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

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

Input impedance:

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

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

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

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

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

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

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

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

Voltage gain:

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

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

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

Output Admittance:

It is defined as

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

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

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

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

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

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

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**.

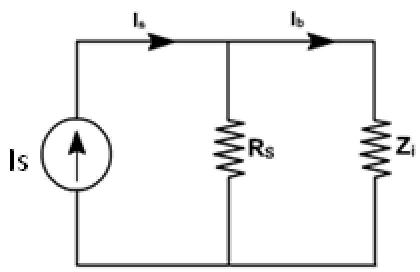


Fig. 3

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.

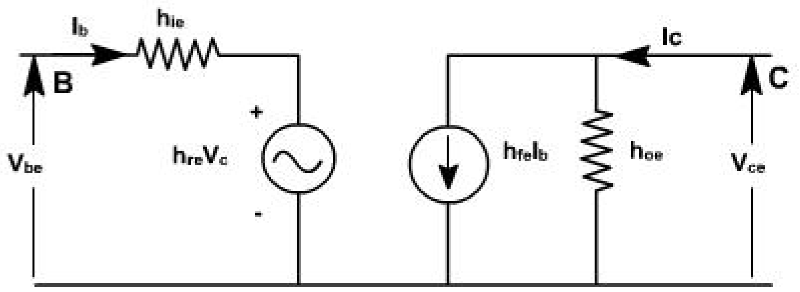


Fig. 4

For CE transistor configuaration

Vbe = hie Ib + hre Vce

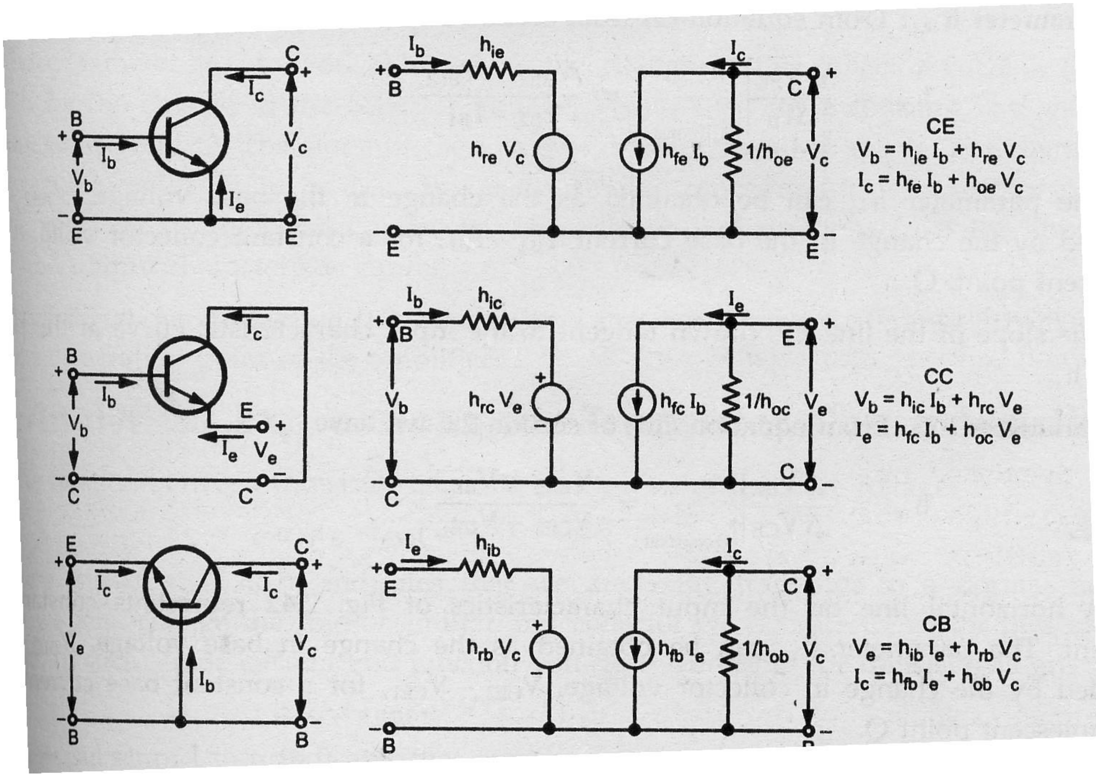
Ic = h fe Ib + hoe Vce

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.

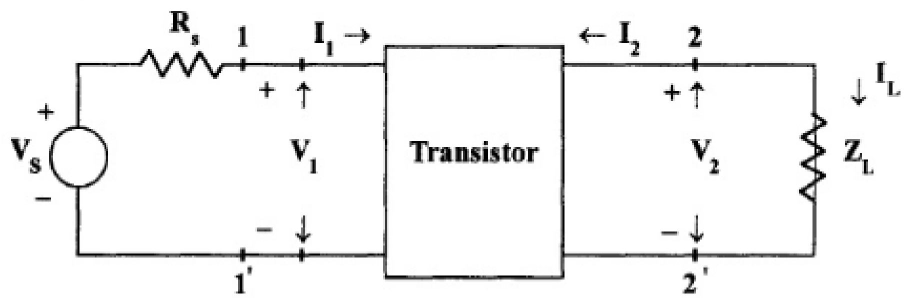


Fig.1.4 Basic Amplifier Circuit

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

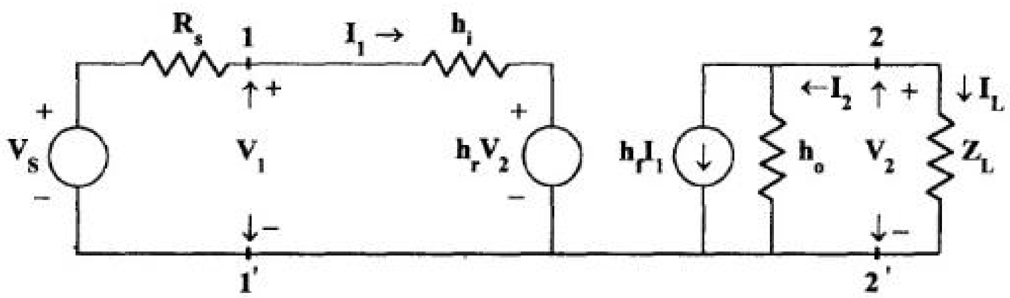


Fig. 1.5 Transistor replaced by its Hybrid Model

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

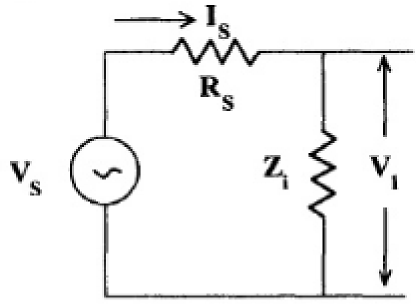


Fig. 5.6 Thevenin's Equivalent Input Circuit

This overall voltage gain A_{vs} is given by

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

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 $A_v = A_i Z_L / Z_i$

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

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

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

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

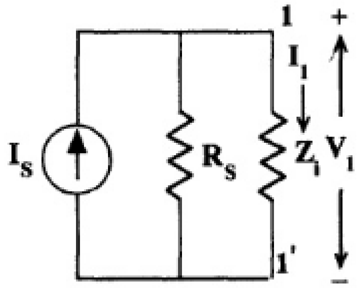


Fig. 1.7 Norton's Equivalent Input Circuit

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.

$I_c = h_{fe} I_B$.

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

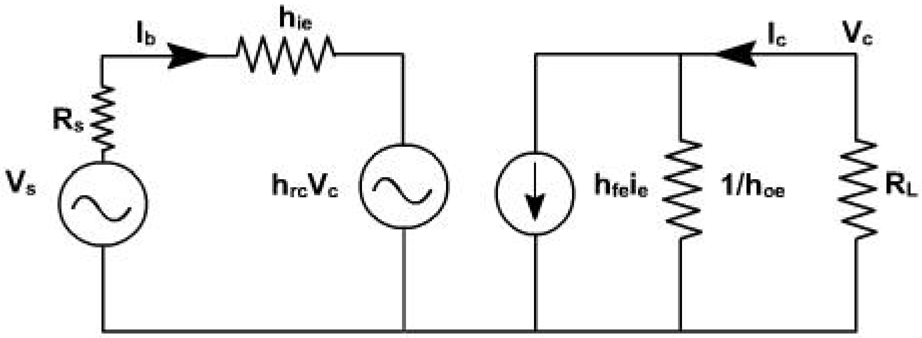


Fig. 4

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.

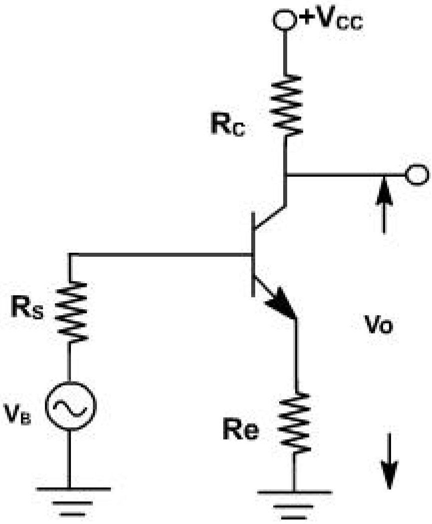


Fig. 5

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 $R_L < 10\ k\Omega$.

(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.

$I_c = h_{fe} I_B$.

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

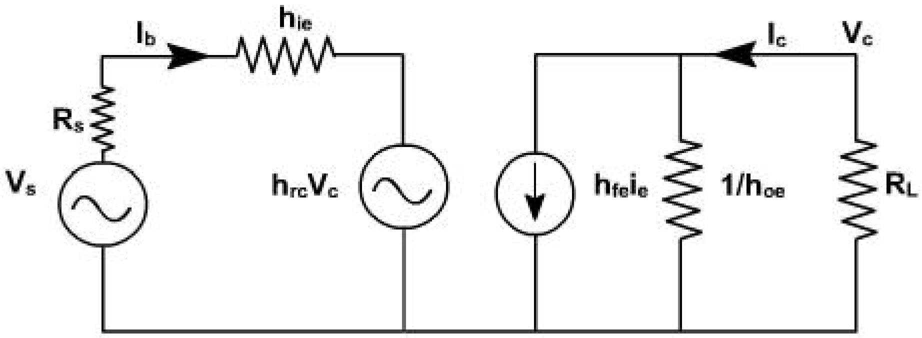


Fig 1.8

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.

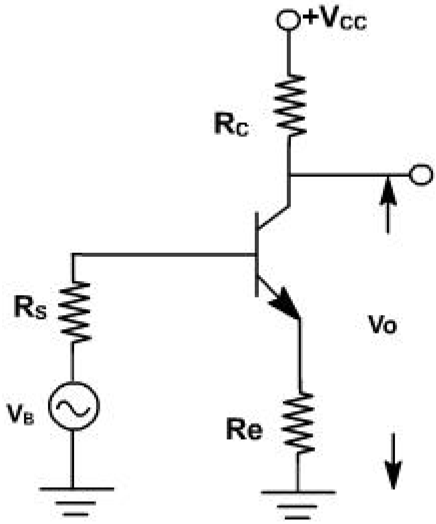


Fig.1.9

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

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

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.

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.

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

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

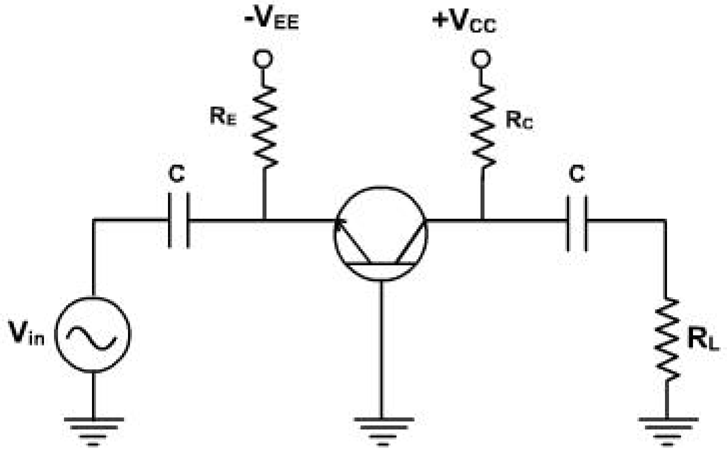


Fig. 1

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.

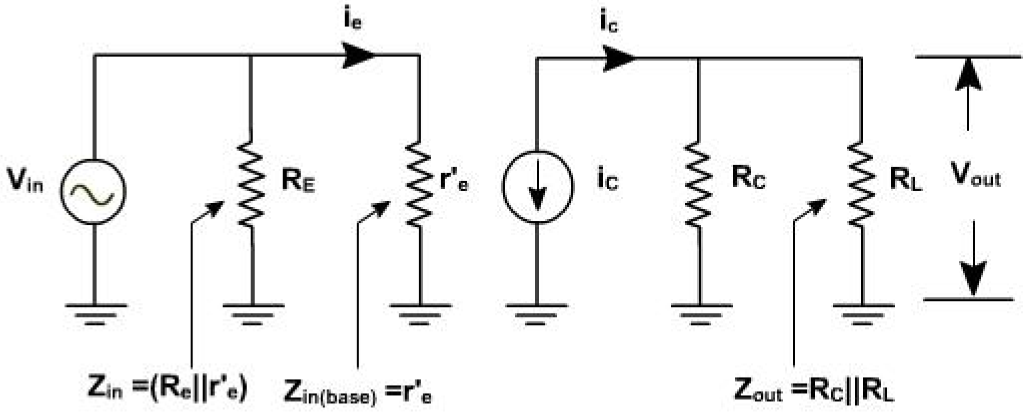


Fig. 2

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).

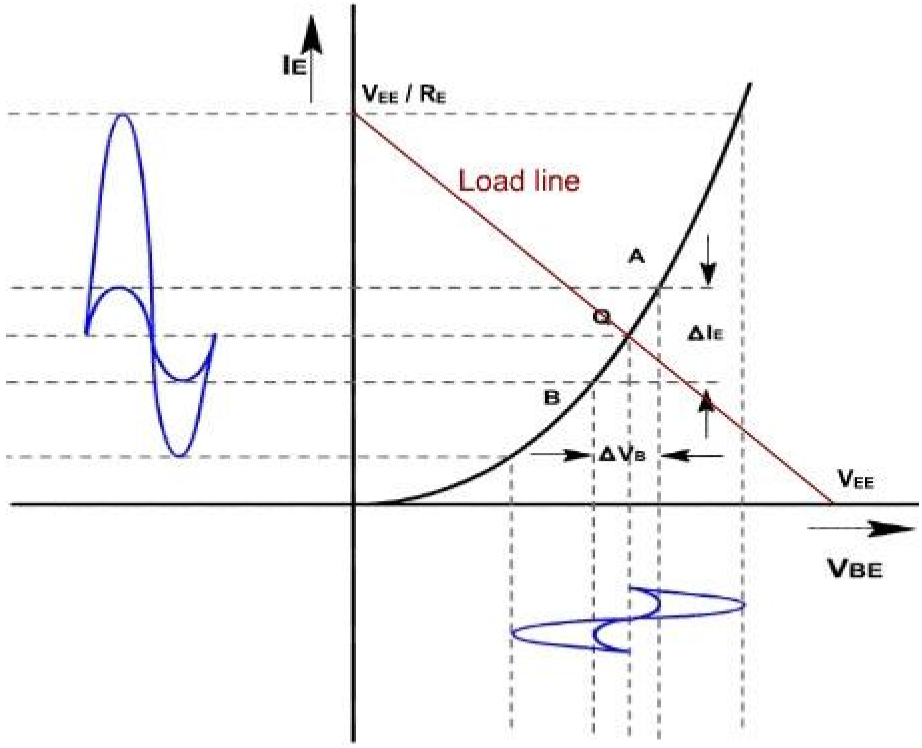


Fig .3

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

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

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

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 ΔI_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.

$$\frac{dI}{dV} = 40 * I_{co} * e^{\frac{qV}{KT}}$$

Therefore, $= 40 * (I + I_{co})$

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 $V_{out} = i_c (R_C \| R_L)$

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

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

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

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

Example-1

Find the voltage gain and output of the amplifier shown in fig. 4, if input voltage is 1.5mV.

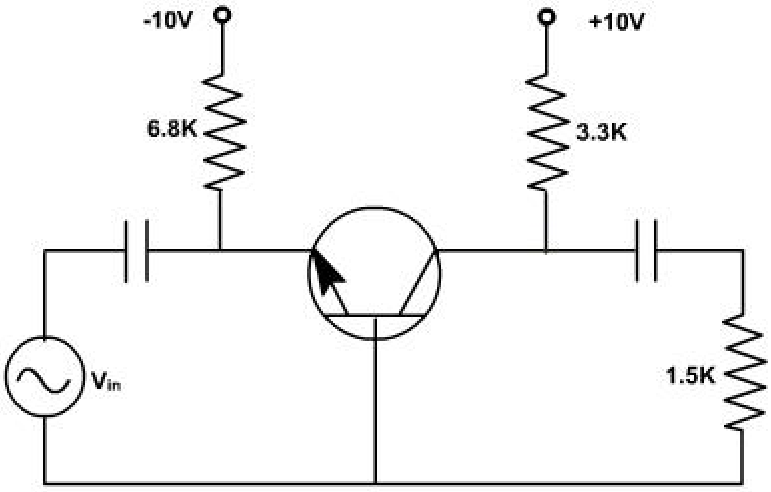


Fig. 4

Solution:

The emitter dc current I_E is given by $I_E = \dfrac{10 - 0.7}{6.8k} = 1.37mA$

Therefore, emitter ac resistance = $A_V = \dfrac{r_c}{r'_e} = \dfrac{3.3k \| 1.5k}{18.2\,\Omega}$

or, $A_V = 56.6$

and, $V_{out} = 1.5 \times 56.6 = 84.9$ mV

Example-2

Repeat example-1 if ac source has resistance Rs = 100 ohm .

Solution:

The ac equivalent circuit with ac source resistance is shown in fig. 5.

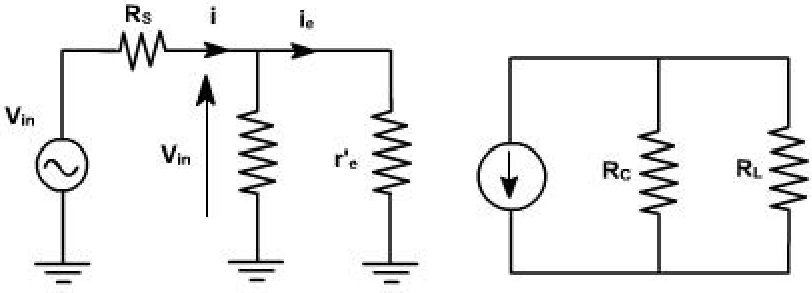


Fig. 5

The emitter ac current is given by $i_e = \frac{v_{in}}{R_s + (R_E \| r_e')} \times \frac{R_E}{R_E + r_e'}$

or, $i_e = \frac{v_{in}}{(R_s + r_e')R_E + R_s r_e'} \times R_E ; \frac{v_{in}}{R_s + r_e'}$

Therefore, voltage gain of the amplifier = $A_V = \frac{v_{out}}{v_{in}} = \frac{i_c\, r_c}{i_e\,(R_s + r'_e)} = \frac{r_c}{R_s + r_e'}$

$$A_V = \frac{3.3k \| 1.5k}{100\Omega + 18.2\,\Omega} = 8.71$$

and, $V_{out} = 1.5 \times 8.71 = 13.1$ mV

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.

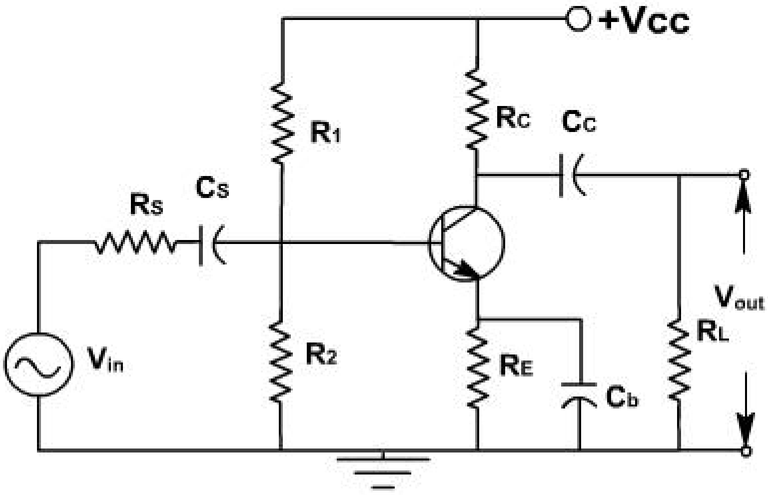


Fig. 1

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.

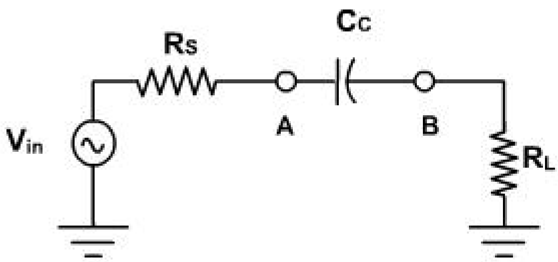


Fig. 2

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 $X_C \leq 0.1R$ 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 $X_{Cb} \leq 0.1R_E$ 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 .

AC & DC Equivalent Circuits:

For dc equivalent circuit, reduce all ac voltage sources to zero and open all ac current sources and open all capacitors. With this reduced circuit shown in **fig. 3** dc current and voltages can be calculated.

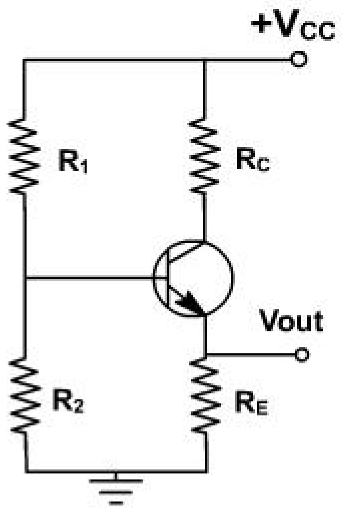


Fig. 3

For ac equivalent circuits reduce dc voltage sources to zero and open current sources and short all capacitors. This circuit is used to calculate ac currents and voltage as shown in **fig. 4**.

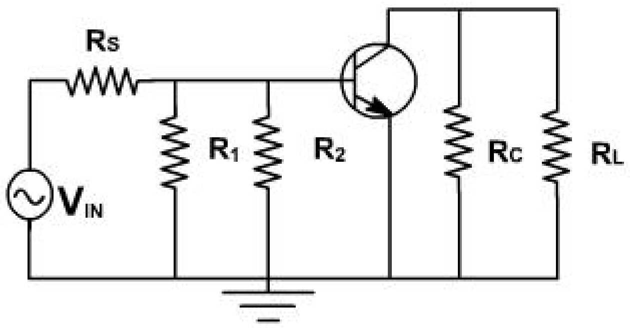


Fig. 4

The total current in any branch is the sum of dc and ac currents through that branch. The total voltage across any branch is the sum of the dc voltage and ac voltage across that branch.

Phase Inversion:

Because of the fluctuation is base current; collector current and collector voltage also swings above and below the quiescent voltage. The ac output voltage is inverted with respect to the ac input voltage, meaning it is 180° out of phase with input.

During the positive half cycle base current increase, causing the collector current to increase. This produces a large voltage drop across the collector resistor; therefore, the voltage output decreases and negative half cycle of output voltage is obtained. Conversely, on the negative half cycle of input voltage less collector current flows and the voltage drop across the collector resistor decreases, and hence collector voltage increases we get the positive half cycle of output voltage as shown in fig. 5.

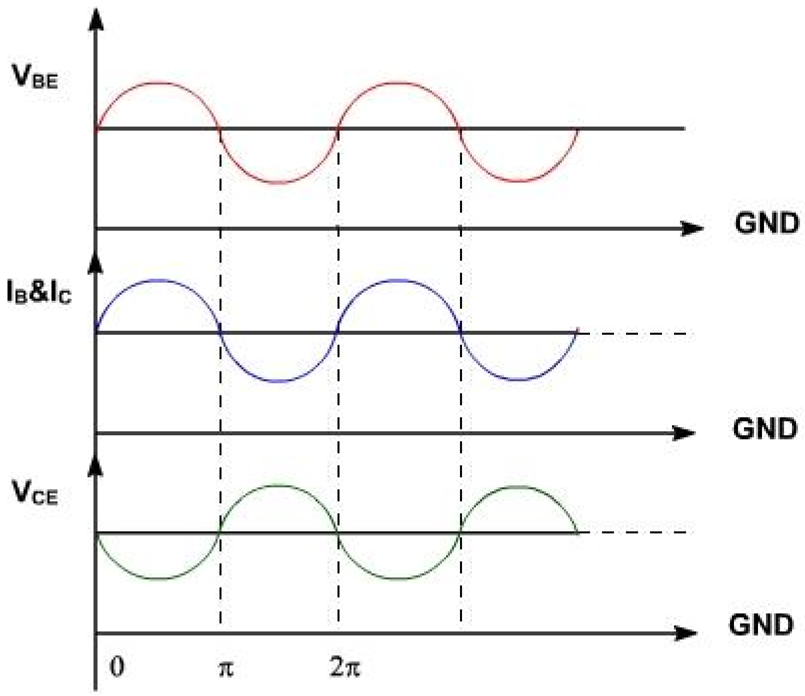


Fig. 5

lowest frequency.

AC Load line:

Consider the dc equivalent circuit [fig. 1](#).

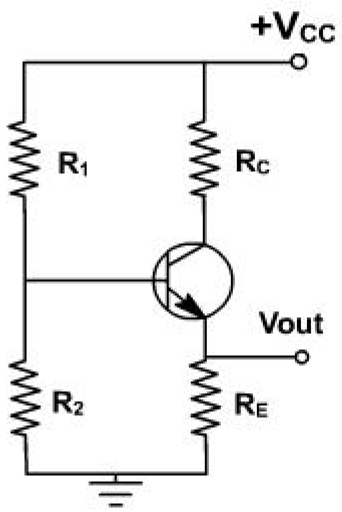


Fig. 1

Assuming $I_C = I_C$(approx), the output circuit voltage equation can be written as

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$

and $$I_C = -\frac{V_{CE}}{R_C + R_E} + \frac{V_{CC}}{R_C + R_E}$$

$$V_{CE} = 0, \quad I_C = \frac{V_{CC}}{R_C + R_E}$$

and $$I_C = 0, \quad V_{CE} = V_{CC}$$

The slop of the d.c load line is $-\frac{1}{R_C + R_E}$.

When considering the ac equivalent circuit, the output impedance becomes $R_C \parallel R_L$ which is less than $(R_C + R_E)$.

In the absence of ac signal, this load line passes through Q point. Therefore ac load line is a line of slope $(-1 / (R_C \parallel R_L))$ passing through Q point. Therefore, the output voltage fluctuations will now be corresponding to ac load line as shown in fig. 2. Under this condition, Q-point is not in the middle of load line, therefore Q-point is selected slightly upward, means slightly shifted to saturation side.

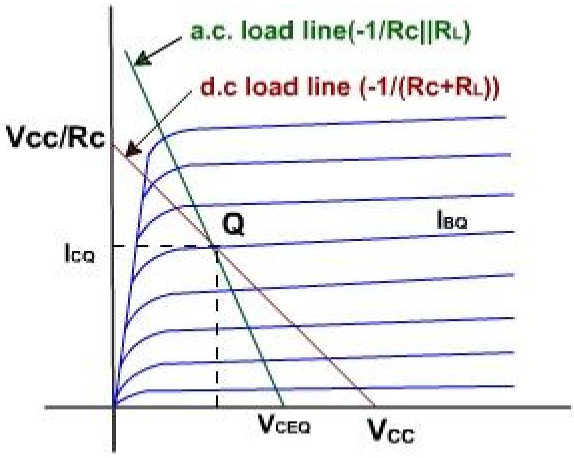


Fig. 2

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.

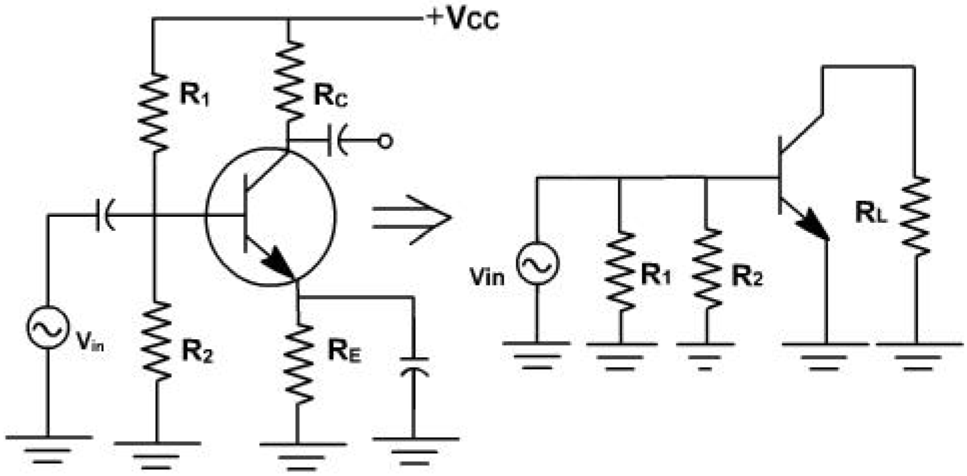


Fig. 3

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.

$Z_{in} = R_1 \,||\, R_2 \,||\, \beta\, r'_e$

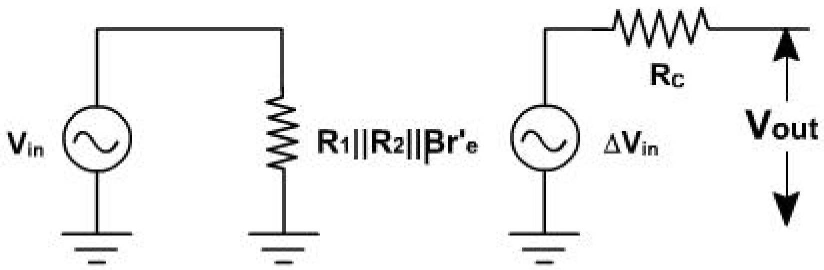
The Thevenin voltage appearing at the output is

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

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

Example-1:

Select R_1 and R_2 for maximum output voltage swing in the circuit shown in fig. 5.

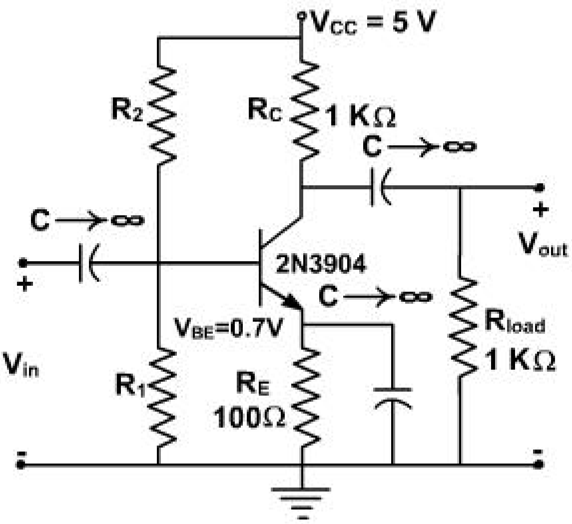


Fig. 5

Solution:

We first determine ICQ for the circuit

$$R_{ac} = R_C \parallel R_{load} = 500$$

$$R_{dc} = R_E + R_C = 1100$$

$$I_{CQ} = \frac{V_{CC}}{R_{ac} + R_{dc}} = \frac{5}{500 + 1100} = 3.13 \text{ mA}$$

For maximum swing,

V'CC = 2 VCEQ

The quiescent value for VCE is the given by

VCEQ= (3.13 mA) (500 W) = 1.56 V

The intersection of the ac load line on the vCE axis is V'CC = 3.13V. From the manufacturer's specification, β for the 2N3904 is 180. RB is set equal to 0.1 βRE. So,

RB = 0.1(180)(100) = 1.8 K W

VBB = (3.13 x 10-3) (1.1 x 100) + 0.7 = 1.044 V

Since we know VBB and RB, we find R1 and R2,

$$R_1 = \frac{R_B}{1 - V_{BB} / V_{CC}} = \frac{1800}{1 - 1.044/5} = 2.28\ K\Omega$$

$$R_2 = \frac{R_B V_{CC}}{V_{BB}} = \frac{1800 \times 5}{1.044} = 8.62\ K\Omega$$

The maximum output voltage swing, ignoring the non-linearity's at saturation and cutoff, would then be

$$\text{Max collector current swing} = 2\, I_{CQ}\, (R_C \,||\, R_{load})$$
$$= 2\,(3.13\ mA)\,(500\ \Omega) = 3.13\ V$$

The load lines are shown on the characteristics of fig. 6.

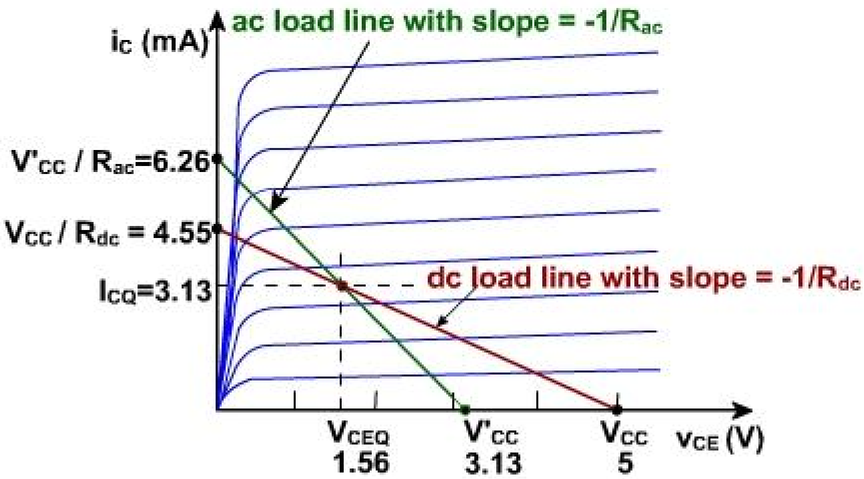


Fig. 6

The maximum power dissipated by the transistor is calculated to assure that it does not exceed the specifications. The maximum average power dissipated in the transistor is

P(transistor)= VCEQ ICQ = (1.56 (V)) (3.13 mA) =4.87 mW

This is well within the 350 mW maximum given on the specification sheet. The maximum conversion efficiency is

$$\eta = \frac{P_{out}(ac)}{P_{VCC}(dc)} = \frac{\left(3.13 \times 10^{-3}/2\right)^2 \times 1000/2 \times 100}{5 \times 3.13 \times 10^{-3} + 5^2/10.9 \times 10^3} = 6.84\%$$

The swamped Amplifier:

The ac resistance of the emitter diode r'e equals 25mV / IE and depends on the temperature. Any change in r'e will change the voltage gain in CE amplifier. In some applications, a change in voltage is acceptable. But in many applications we need a stable voltage gain is required.

To make it stable, a resistance rE is inserted in series with the emitter and therefore emitter is no longer ac grounded. fig .7.

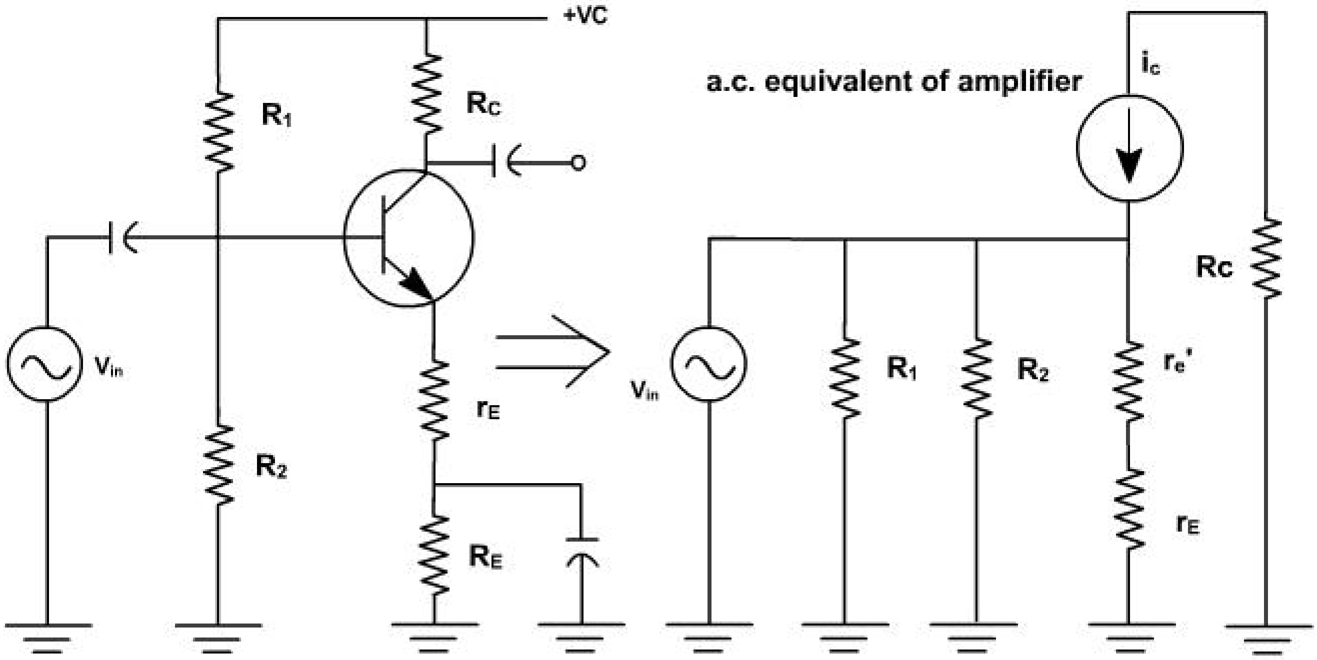


Fig. 7

Because of this the ac emitter current flows through rE and produces an ac voltage at the emitter. If rE is much greater than r'e almost all of the ac input signal appears at the emitter, and the emitter is bootstrapped to the base for ac as well as for dc.

In this case, the collector circuit is given by

$$i_C = \frac{V_{in}}{r'e + r_E}$$

and $V_{out} = -i_C R_C$

Therefore,

$$A = \frac{V_{out}}{V_{in}} = -\frac{i_C R_C}{i_C (r'_e + r_E)}$$

$$= -\frac{R_C}{(r'_e + r_E)}$$

Now r'e has a less effect on voltage gain, swamping means rE >> r'e If swamping is less, voltage gain varies with temperature. If swamping is heavy, then gain reduces very much.

Design of Amplifier :

Example -1 (Common Emitter Amplifier Design)

Design a common-emitter amplifier with a transistor having a β =200 and VBE = 0.7 V. Obtain an overall gain of |A V | ≥ 100 and maximum output voltage swing. Use the CE configuration shown in fig. 1 with two power supplies. Rsource is the resistance associated with the source, vsource. Let Rsource= 100 Ohms. The output load is 2KΩ. Determine the resistor values of the bias circuitry, the maximum undistorted output voltage swing, and the stage voltage gain.

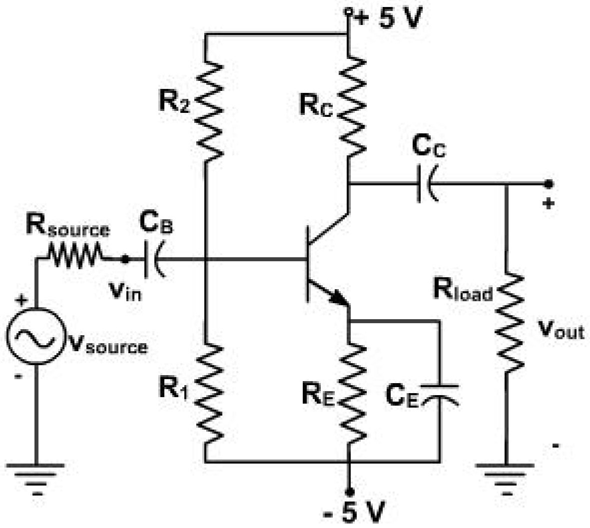


Fig. 1

Solution:

The maximum voltage across the amplifier is 10 V since the power supply can be visualized as a 10V power supply with a ground in the center. In this case, the ground has no significance to the operation of the amplifier since the input and output are isolated from the power supplies by capacitors.

We will have to select the value for RC and we are really not given enough information to do so. Let choose RC = Rload.

We don't have enough information to solve for RB – we can't use the bias stability criterion since we don't have the value of RE either. We will have to (arbitrarily) select a value of RB or RE. If this leads to a contradiction, or “bad” component values (e.g., unobtainable resistor values), we can come back and modify our choice. Let us select a value for RE that is large enough to obtain a reasonable value of VBB, Selecting RE as 400Ω will not appreciably reduce the collector current yet it will help in maintaining a reasonable value of VBB. Thus,

RB = 0.1 β RE = 0.1 (200)(400) = 8 K Ω

To insure that we have the maximum voltage swing at the output, we will use

$$I_{CQ} = \frac{V_{CC}}{R_{ac} + R_{dc}} = \frac{10}{1000 + 2400} = 2.94 \text{ mA}$$

$$V_{BB} = V_{BE} + I_{CQ}\,(R_B/\beta + R_E) = 0.7 + 2.9 \times 10^{-3}\left(\frac{8000}{200} + 400\right) = 1.99 \text{ V}$$

Note that we are carrying out our calculations to four places so that we can get accuracy to three places. The bias resistors are determined by

$$R_1 = \frac{R_B}{1 - V_{BB}/V_{CC}} = \frac{8000}{1 - 1.99/10} = 9.99 \text{ K}\Omega$$

$$R_2 = R_B\frac{V_{CC}}{V_{BB}} = 8000\left(\frac{10}{1.99}\right) = 40.2 \text{ K}\Omega$$

Since we designed the bias circuit to place the quiescent point in the middle of the ac load line, we can use V_{out}(undistorted p-p) 1.8 (2.94 x 10-3) (2 K Ω || 2 K Ω) =5.29 V

Now we can determine the gain of the amplifier itself.

$$|A_v| = g_m\,(R_C \,||\, R_{load}) = \frac{2.94 \times 10^{-3} \times 1000}{26 \times 10^{-3}}$$

Using voltage division, we can determine the gain of the overall circuit.

The value of Rin can be obtained as

$$R_{in} = r_\pi \,||\, R_B = 1.77\text{k}\Omega \,||\, 8\text{k}\Omega = 1.45 \text{ k}\Omega$$

Thus the overall gain of the amplifier is

$$|A_v|\text{ overall} = \left|\frac{v_{out}}{v_{in}} = 113\right| \times \frac{R_{in}}{R_{in} + R_{source}} = 106$$

This shows that the common-emitter amplifier provides high voltage gain. However, it is very noisy, it has a low input impedance, and it does not have the stability of the emitter resistor common emitter a

Design of Amplifier

Example-2 (Emitter-Resistor Amplifier Design)

Design an emitter-resistor amplifier as shown in fig. 2 to drive a 2 KΩ load using a pnp silicon transistor, V_{CC} = -24V, β = 200, A_v = -10, and V_{BE} = -0.7 V. Determine all element values and calculate A_i, R_{in}, I_{CQ} and the maximum undistorted symmetrical output voltage swing for three values of R_C as given below:

1. $R_C = R_{load}$
2. $R_C = 0.1\ R_{load}$
3. $R_C = 10\ R_{load}$

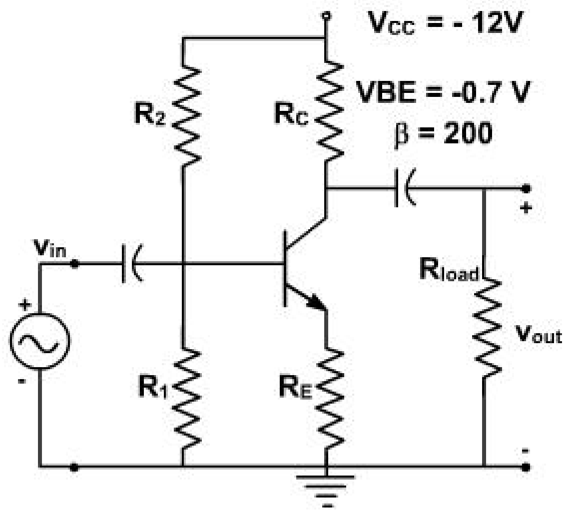


Fig. 2

Solution:

(a) $R_C = R_{load}$

We use the various equations derived in previous lecture in order to derive the parameters of the circuit.

From the voltage gain, we can solve for R'_E.

$$A_v = -10 = -\frac{R_{load} \| R_C}{r_e + R_E} = -\frac{2K\Omega \| 2K\Omega}{r_e + R_E}$$

So $R'_E = r_e + R_E = 100\ \Omega$

We can find the quiescent value of the collector current I_C form the collector-emitter loop using the equation for the condition of maximum output swing.

$$I_{CQ} = \frac{V_{CC}}{R_{dc} + R_{ac}} = -7.5\ mA$$

Therefore, $$r_E' = \frac{25 \times 10^{-3}}{7.5 \times 10^{-3}} = 3.33\Omega$$

This is small enough that we shall ignore it to find that $R_E = 100\ \Omega$. Since we now know β and R_E. We can use the design guideline.

$R_B = 0.1\ \beta\ R_E = 2\ k\ \Omega$

As designed earlier, the biasing circuitry can be designed in the same manner and given by

$V_{BB} = -1.52\ V$

$R_1 = 2.14\ K\ \Omega$

$R_2 = 3.6\ K\ \Omega$

The maximum undistorted symmetrical peak to peak output swing is then

$V_{out}\ (P\text{-}P) = 1.8\ I_{CQ}\ (R_{load} \parallel R_C) = 13.5\ V$

Thus current gain $A_i = -9.1$

and input impedance $R_{in} = 1.82\ K\ \Omega$

(b) $R_C = 0.1\ R_{load}$

we repeat the steps of parts (a) to find

$R_C = 200\ \Omega$	$R_i = 390\ \Omega$
$I_{CQ} = -57.4\ mA$	$R_2 = 4.7K\ \Omega$
$r'_e = 0.45\ \Omega$	$v_{out}(p\text{-}p) = 18.7\ V$
$R_B = 360\ \Omega$	$A_i = -1.64$
$V_{BB} = -1.84\ V$	$R_{in} = 327\ \Omega$

(C) $R_C = 10\ R_{load}$

Once again, we follow the steps of part (a) to find

$R_C = 20\ K\ \Omega$	$R_1 = 3.28K\ \Omega$
$I_{CQ} = -1.07\ mA$	$R_2 = 85.6K\ \Omega$

$r'_e = 24.2\ \Omega$ $v_{out}(p\text{-}p) = 3.9$ V

$R_B = 3.64K\ \Omega$ $A_i = -14.5$

$V_{BB} = -0.886$ V $R_{in} = 2.91K$ W

We now compare the results obtained Table-I for the purpose of making the best choice for R_C.

	I_{CQ}	A_i	R_{in}	$v_{out}(p\text{-}p)$
$R_C = R_{load}$	-7.5 mA	-9.1	1.82K W	13.5 V
$R_C = 0.1\ R_{load}$	-57.4 mA	-1.64	327 W	20.8 V
$R_C = 10\ R_{load}$	-1.07mA	-14.5	2.91W	3.9 V

Table - 1 Comparsion for the three selections of R_C

It indicates that of the three given ratios of R_C to R_{load}, $R_C = R_{load}$ has the most desirable performance in the CE amplifier stage.

It can be used as a guide to develop a reasonable designs. In most cases, this choice will provide performance that meets specifications. In some applications, it may be necessary to do additional analysis to find the optimum ratio of R_C to R_{load}.

Design of Amplifier

Example-2 (Emitter-Resistor Amplifier Design)

Design an emitter-resistor amplifier as shown in fig. 2 to drive a 2 KΩ load using a pnp silicon transistor, $V_{CC} = -24V$, $\beta = 200$, $A_v = -10$, and $V_{BE} = -0.7$ V. Determine all element values and calculate A_i, R_{in}, I_{CQ} and the maximum undistorted symmetrical output voltage swing for three values of R_C as given below:

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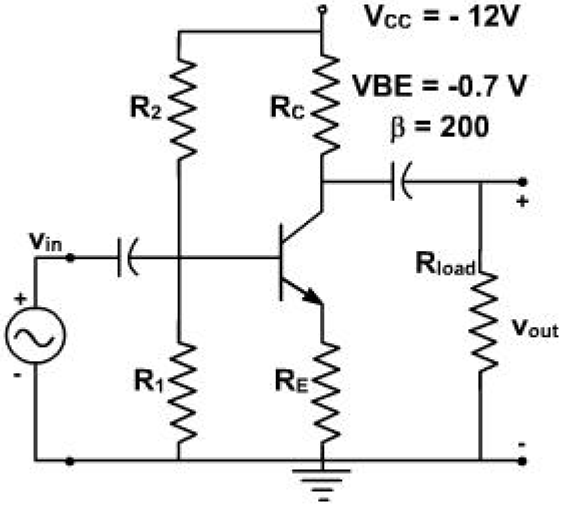

Fig. 2

Solution:

(a) $R_C = R_{load}$

We use the various equations derived in previous lecture in order to derive the parameters of the circuit.

From the voltage gain, we can solve for R'_E.

$$A_v = -10 = -\frac{R_{load} \parallel R_C}{r_e + R_E} = -\frac{2K\Omega \parallel 2K\Omega}{r_e + R_E}$$

So $R'_E = r_e + R_E = 100\ \Omega$

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$V_{BB} = -1.84\ V$	$R_{in} = 327\ \Omega$

(C) $R_C = 10\ R_{load}$

Once again, we follow the steps of part (a) to find

$R_C = 20\ K\ \Omega$	$R_1 = 3.28K\ \Omega$
$I_{CQ} = -1.07\ mA$	$R_2 = 85.6K\ \Omega$
$r'_e = 24.2\ \Omega$	$v_{out}(p\text{-}p) = 3.9\ V$
$R_B = 3.64K\ \Omega$	$A_i = -14.5$
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We now compare the results obtained Table-I for the purpose of making the best choice for R_C.

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$R_C = 0.1\ R_{load}$	-57.4 mA	-1.64	327 W	20.8 V
$R_C = 10\ R_{load}$	-1.07mA	-14.5	2.91W	3.9 V

Table - 1 Comparsion for the three selections of R_C

It indicates that of the three given ratios of R_C to R_{load}, $R_C = R_{load}$ has the most desirable performance in the CE amplifier stage.

It can be used as a guide to develop a reasonable designs. In most cases, this choice will provide performance that meets specifications. In some applications, it may be necessary to do additional analysis to find the optimum ratio of R_C to R_{load}.

Design of Amplifier

Example- 3 (Capacitor-Coupled Emitter-Resistor Amplifier Design)

Design an emitter-resistor amplifier as shown in fig. 3 with A_V =-10, β =200 and R load = 1K Ω. A pnp transistor is used and maximum symmetrical output swing is required.

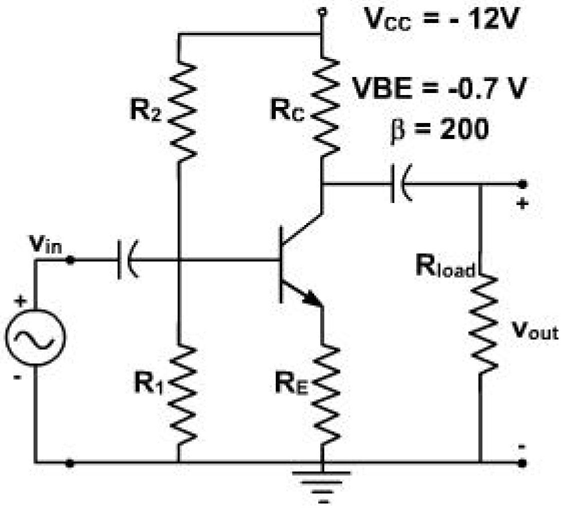


Fig. 3

Solution:

As designed earlier, we shall chose $R_C = R_{load}$ = 10 kΩ.

The voltage gain is given by $A_v = \frac{R_{load} \parallel R_C}{R'_E}$

where $R'_E = R_E + r'_e$.

Substituting A_V, R_{load} and R_C in this equation, we find R'_E= 50 Ω.

We need to know the value of r'_e to fine R_E. We first find R_{ac} and R_{dc}, and then calculate the Q point as follows (we assume r'_e is small, so $R_E = R'_E$)

$R_{ac} = R_E + R_C \parallel R_{load}$ = 550 Ω

$R_{dc} = R_E + R_C$ = 1050 Ω

Now, the first step is to calculate the quiescent collector current needed to place the Q-point into the center of the ac load line (i.e., maximum swing). The equation is

$$I_{CQ} = \frac{V_{CC}}{R_{ac} + R_{dc}} = -7.5 \text{ mA}$$

The quantity, r'_e , is found as follows

$$r_e' = \frac{25(mV)}{|I_{CQ}|} = \frac{25(mV)}{7.5(mA)} = 3.33\Omega$$

Then

$R_E = 50 - r_e = 46.67\ \Omega$

If there were a current gain or input resistance specification for this design, we would use it to solve for the value of R_B. Since is no such specification, we use the expression

$R_B = 0.1\ \beta\ R_E = 0.1\ (200)\ (46.6) = 932\ \Omega$

Then continuing with the design steps,

$$A_i = \frac{-R_B}{R_B/\beta + r_E' + R_B} \cdot \frac{R_C}{R_C + R_{load}} = -8.50$$

$$V_{CEQ} = V_{CC} - (R_C + R'_E)\, I_{CQ} = -4.125 \text{ V}$$

and

$$V_{BB} = I_{CQ} - \left(R_E + \frac{R_E}{\beta}\right) + V_{BE} = -1.08 \text{ V}$$

$$R_1 = \frac{R_B}{1 - V_{BB}/V_{CC}} = 1.02 \text{ K}\Omega$$

$$R_2 = \frac{R_B V_{CC}}{V_{BB}} = 10.3 \text{ K}\Omega$$

$$R_{in} = \frac{R_B(r_e + R_E)}{R_B/\beta + r_e + R_E} = 8.51\Omega$$

$$R_0 = R_C = 1 \text{ K}\Omega$$

The last equality assumes that r_O is large compared to R_C.

The maximum undistorted peak to peak output swing is given by

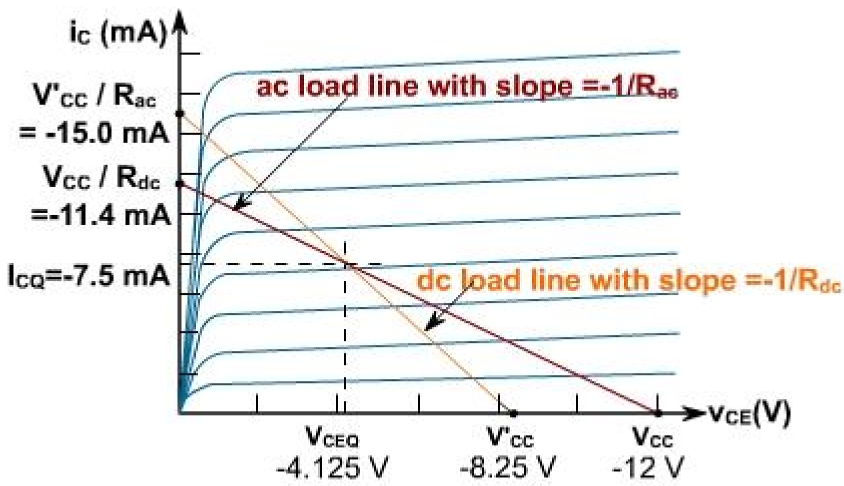
$1.8\ |\ I_{CQ}\ |\ (\ R_C\ ||\ R_{load}\ ) = 1.8\ (\ 0.0075\ )\ (\ 500\ ) = 6.75$ V

The power delivered into the load and the maximum power dissipated by the transistor are found as

$$P_{Load} = \frac{1}{2}\left(I_{CQ}\frac{R_C}{R_C + R_{load}}\right)^2 R_{load} = \frac{I_{CQ}^2 R_{load}}{8} = 7 \text{ mW}$$

$$P_{transistor} = V_{CEQ} I_{CQ} = (-4.125V)(-7.5mA) = 31 \text{ mW}$$

The load lines for this circuit are shown in fig. 4.



Common Collector Amplifier:

If a high impedance source is connected to low impedance amplifier then most of the signal is dropped across the internal impedance of the source. To avoid this problem common collector amplifier is used in between source and CE amplifier. It increases the input impedence of the CE amplifier without significant change in input voltage.

Fig. 1, shows a common collector (CC) amplifier. Since there is no resistance in collector circuit, therefore collector is ac grounded. It is also called grounded collector amplifier. When input source drives the base, output appears across emitter resistor. A CC amplifier is like a heavily swamped CE amplifier with a collector resistor shorted and output taken across emitter resistor.

$V_{out} = V_{in} - V_{BE}$

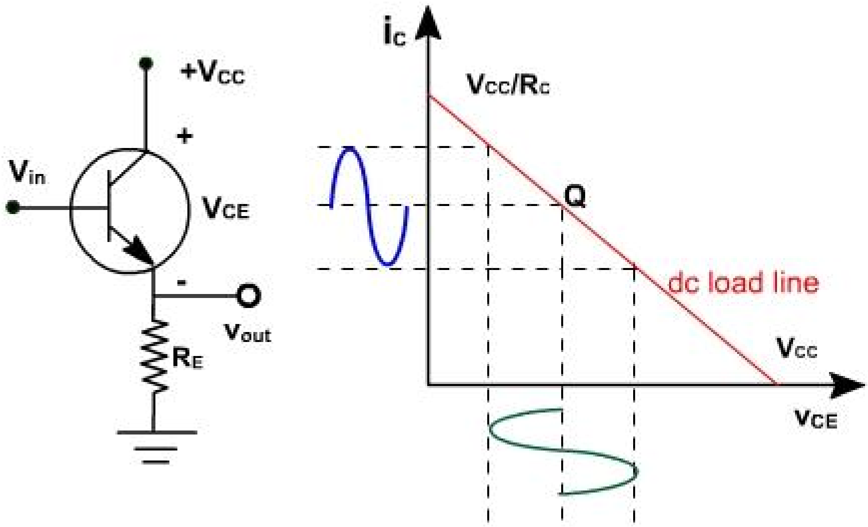


Fig. 1

Therefore, this circuit is also called emitter follower, because V_{BE} is very small. As v_{in} increases, v_{out} increases.

If v_{in} is 2V, v_{out} = 1.3V

If v_{in} is 3V, v_{out} = 2.3V.

Since v_{out} follows exactly the v_{in} therefore, there is no phase inversion between input and output.

The output circuit voltage equation is given by

$V_{CE} = V_{CC} - I_E R_E$

Since I_E =□I_C

$I_C = (V_{CC} - V_{CE}) / R_E$

This is the equation of dc load line. The dc load line is shown in Fig. 1.

Common Collector Amplifier:

Voltage gain:

Fig. 2, shows an emitter follower driven by a small ac voltage. The input is applied at the base of transistor and output is taken across the emitter resistor. Fig. 3, shows the ac equivalent circuit of the amplifier. The emitter is replaced by ac resistance r'_e.

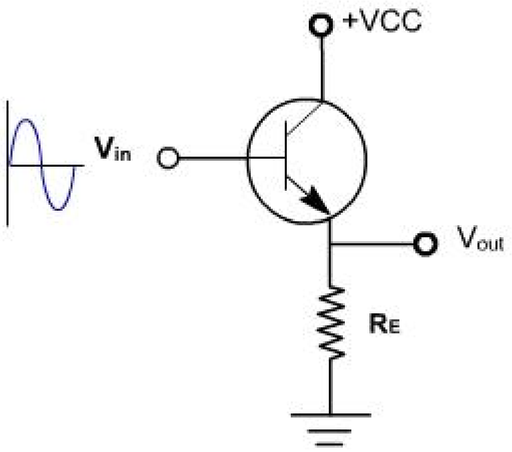


Fig. 2

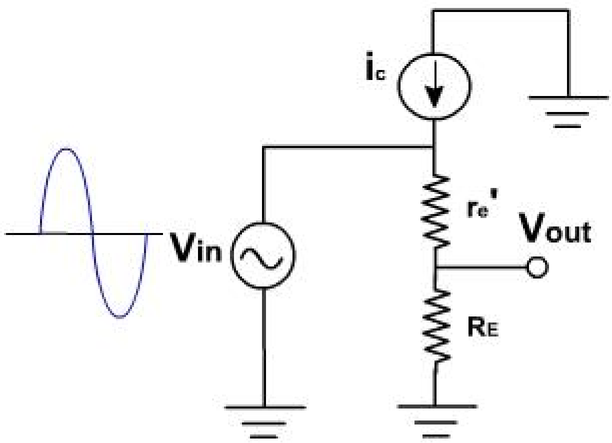


Fig. 3

The ac output voltage is given by

$v_{out} = R_E \, i_e$

and, $v_{in} = i_e (R_E + r'_e)$

Therefore, $A = R_E / (R_E + r'_e)$

Since $r'_e << R_E$

$\therefore A_v \approx 1$. (approx)

Therefore, it is a unity gain amplifier. The practical emitter follower circuit is shown in Fig. 4.

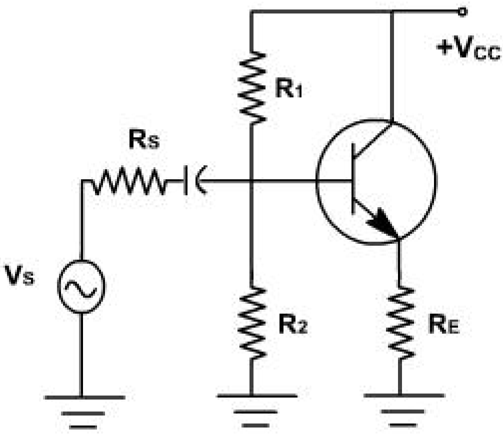


Fig. 4

The ac source (v_S) with a series resistance R_S drives the transistor base. Because of the biasing resistor and input impedance of the base, some of the ac signal is lost across the source resistor. The ac equivalent circuit is shown in Fig. 5.

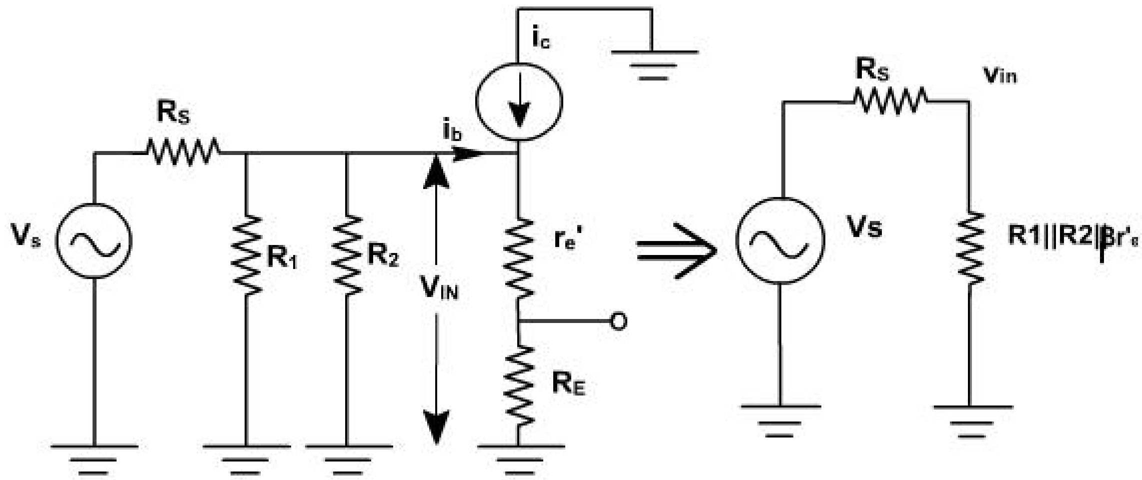


Fig. 5

The input impedance at the base is given by

$$Z_{in(base)} = \frac{v_{in}}{i_B}$$
$$= \frac{i_e(r'_e + R_E)}{i_b}$$
$$= \frac{\beta i_b (r'_e + R_E)}{i_b}$$
$$= \beta(r'_e + R_E)$$

Since r'_e is very small in comparison with R_E

$$\therefore Z_{in(base)} \approx \beta R_E$$

The total input impedance of an emitter follower includes biasing resistors in parallel with input impedance of the base.

$z_{in} = R_1 \parallel R_2 \parallel (r'_e + R_E)$

Since R_E is very large as compared to R_1 and R_2.

Thus, $z_{in} \approx R_1 \parallel R_2$

Therefore input impedance is very high.

Applying Thevenin's theorem to the base circuit of Fig. 5, it becomes a source v_{in} and a series resistance ($R_1 \parallel R_2 \parallel R_S$) as shown in Fig. 6.

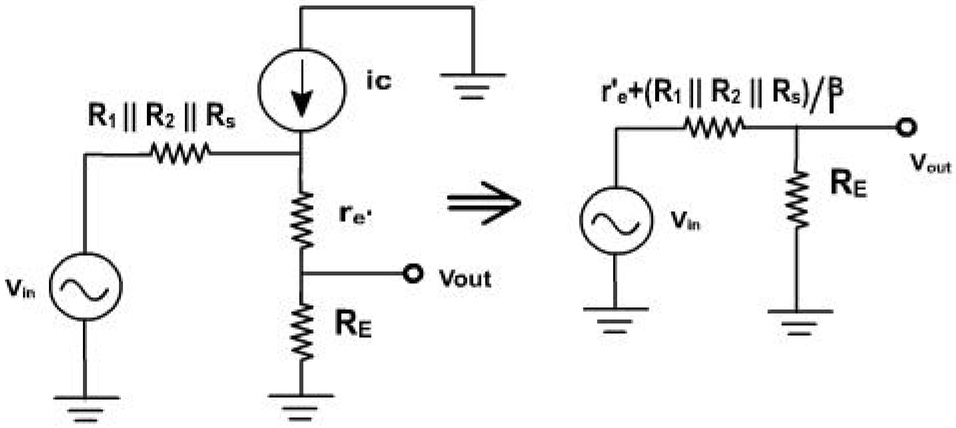


Fig. 6

$$v_{in} = (R_1 \parallel R_2 \parallel R_S) + i_e\ (r'_e + R_E)$$

or,

$$i_e = \frac{V_{in}}{R_E + r'_e + \dfrac{R_1 \parallel R_2 \parallel R_S}{\beta}}$$

The emitter resistor R_E is driven by an ac source with output impedance of

$$Z_{out} = r'_e + \frac{R_1 \parallel R_2 \parallel R_S}{\beta}$$

The impedance of the amplifier seen from the output terminal is given by

$$Z = R_E \parallel r'_e + \frac{R_1 \parallel R_2 \parallel R_S}{\beta}$$

The ouput voltage is given by

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

$$= \frac{R_E}{R_E + r'_e + \dfrac{R_1 \parallel R_2 \parallel R_S}{\beta}} v_{in}$$

$$\approx v_{in} \quad (\text{if } R_E \text{ is very larage})$$

Common Collector Amplifier

Example 1:

Find the Q-point of the emitter follower circuit of **fig. 7** with R_1 = 10 KΩ and R_2 = 20 KΩ. Assume the transistor has a β of 100 and input capacitor C is very-very large.

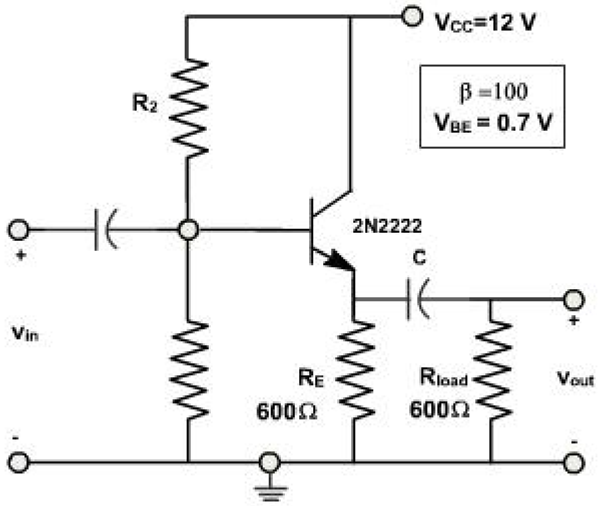


Fig. 7

Solution:

We first find the Thevenin's equivalent of the base bias circuitry.

$R_B = R_1 \parallel R_2 = 6.67$ K Ω

$$V_{BB} = \frac{R_1 V_{CC}}{R_1 + R_2} = \frac{12(10^4)}{30\times10^3} = 4\ V$$

From the bias equation we have

$$I_C = I_{CQ} = \frac{V_{BB} - V_{BE}}{R_B/\beta + R_E} = \frac{4 - 0.7}{6670/100 + 600} = 4.95\ mA$$

Example - 2

Find the output voltage swing of the circuit of **fig. 7**.

Solution:

The Q-Point location has already been calculated in **Example-1**. We found that the quiescent collector current is 4.95 mA.

The Output voltage swing = 2 **.** I_C peak **.** $(R_E \parallel R_{Load})$ = 2(4.95 x 10^{-3}) (300) = 2.97V

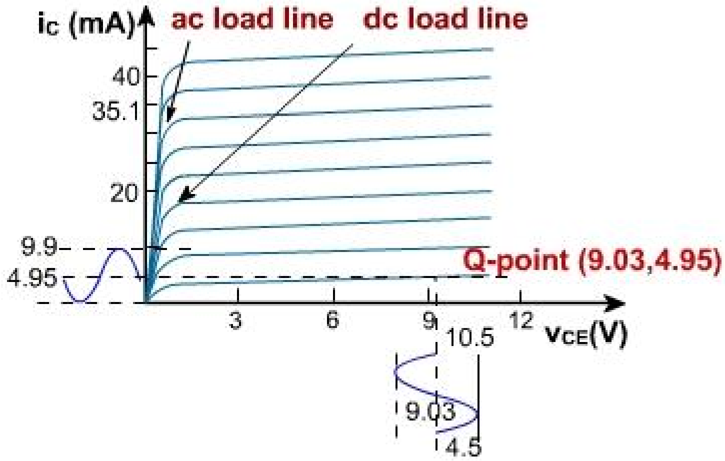
This is less than the maximum possible output swing. Continuing the analysis,

$V_{CEQ} = V_{CC} - I_{CQ} R_E = 9.03$ V

$V'_{CC} = V_{CEQ} + I_{CQ} (R_E \parallel R_{Load}) = 10.5$ V

$$I'_{CC} = \frac{10.5}{300} = 35.1\ mA$$

The load lines for this problem are shown in **Fig. 8**.



CLASSIFICATION OF AMPLIFIERS:

A circuit that increases the amplitude of the given input signal is an amplifier.A small ac signal fed to the amplifier is obtained as a larger ac signal of the same frequency at the output.Amplifiers constitute an essential part of radio,television and other communication circuits.Depending on the nature and level of amplification and the impedance matching requirements different types of amplifiers can be considered and they are discussed in this chapter.

Amplifiers can be classified as follows:

1.Based on the transistor configuration

(a) Common emitter amplifier

(b) Common base amplifier

(c) Common emitter amplifier

2.Based on the active devices

(a) BJT amplifier

(b) FET amplifier

3.Based on the Q-point(operating condition)

(a) Class A amplifier

(b) Class B amplifier

(c) Class C amplifier

(d) Class AB amplifier

4.Based on the number of stages

(a) Single stage amplifiers

(b) Multistage amplifiers

5.Based on the output

(a)Voltage amplifiers

(b)Power amplifiers

6.Based on the frequency response

(a)Audio frequency(AF) amplifier

(b)Intermediate Frequency amplifier(IF)

(c)Radio Frequency amplifier(RF)

7.Based on the bandwidth

(a)Narrow band amplifier(normally RF amplifier)

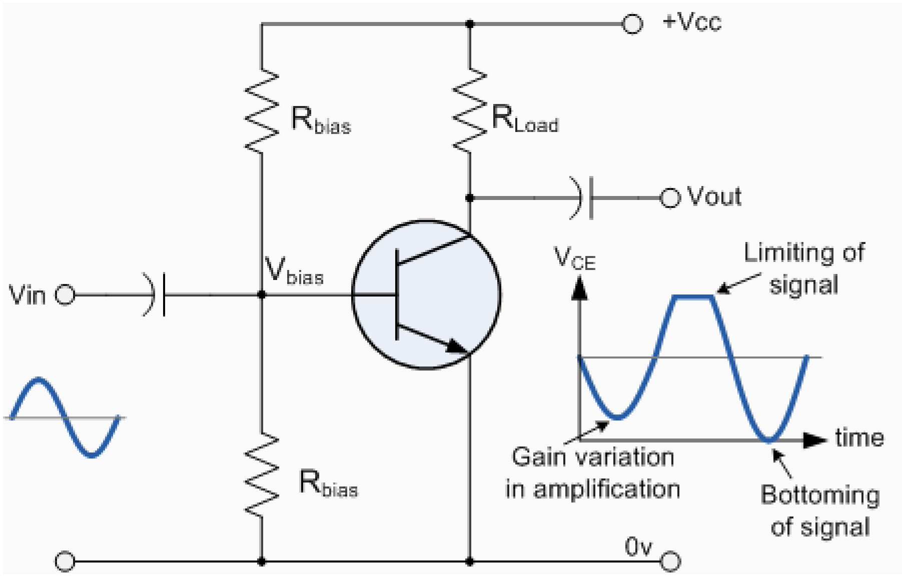
(b)Wide band amplifier(normally video amplifier)

Distortion in amplifiers:

Amplifier Distortion

From the previous tutorials we learnt that for a signal amplifier to work correctly it requires some form of DC Bias on its Base or Gate terminal so that it amplifies the input signal over its entire cycle with the bias "Q-point" set as near to the middle of the load line as possible. This then gave us a "Class-A" type amplification with the most common configuration being Common Emitter for Bipolar transistors and Common Source for unipolar transistors. We also saw that the Power, Voltage or Current Gain, (amplification) provided by the amplifier is the ratio of the peak input value to its peak output value. However, if we incorrectly design our amplifier circuit and set the biasing Q-point at the wrong position on the load line or apply too large an input signal, the resultant output signal may not be an exact reproduction of the original input signal waveform. In other words the amplifier will suffer from distortion. Consider the common emitter amplifier circuit below.

Common Emitter Amplifier



Distortion of the signal waveform may take place because:

1. Amplification may not be taking place over the whole signal cycle due to incorrect biasing.
2. The input signal may be too large, causing the amplifier to limit.
3. The amplification may not be linear over the entire frequency range of inputs.

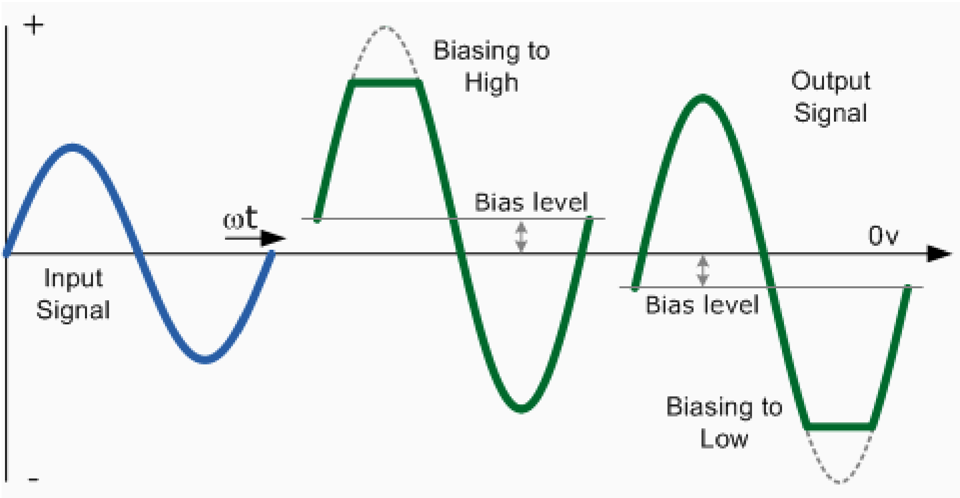
This means then that during the amplification process of the signal waveform, some form of Amplifier Distortion has occurred.

Amplifiers are basically designed to amplify small voltage input signals into much larger output signals and this means that the output signal is constantly changing by some factor or value times the input signal for all input frequencies. We saw previously that this multiplication factor is called the Beta, β value of the transistor. Common emitter or even common source type transistor circuits work fine for small AC input signals but suffer from one major disadvantage, the bias Q-point of a bipolar amplifier depends on the same Beta value which may vary from transistors of the same type, ie. the Q-point for one transistor is not necessarily the same as the Q-point for another transistor of the same type due to the inherent manufacturing tolerances. If this occurs the amplifier may not be linear and Amplitude Distortion will result but careful choice of the transistor and biasing components can minimise the effect of amplifier distortion.

Amplitude Distortion

Amplitude distortion occurs when the peak values of the frequency waveform are attenuated causing distortion due to a shift in the Q-point and amplification may not take place over the whole signal cycle. This non-linearity of the output waveform is shown below.

Amplitude Distortion due to Incorrect Biasing

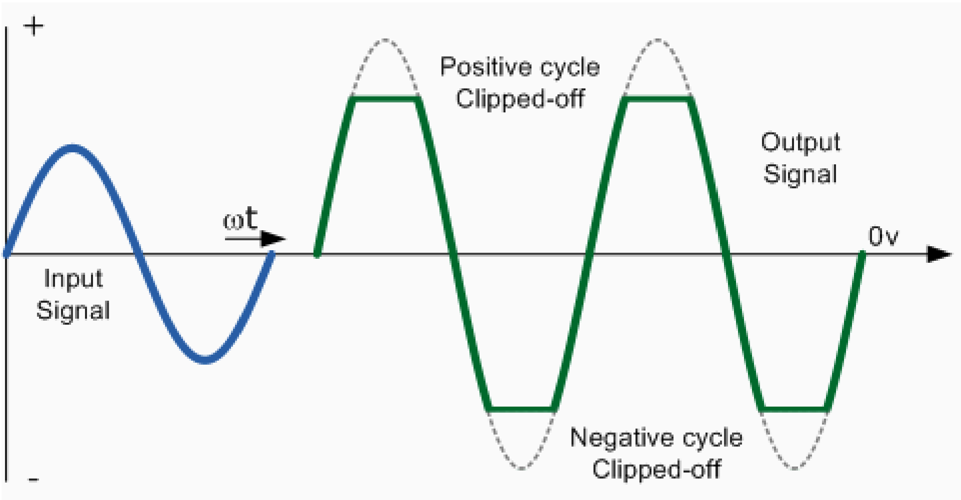


If the bias is correct the output waveform should look like that of the input waveform only bigger, (amplified). If there is insufficient bias the output waveform will look like the one on the right with the negative part of the output waveform "cut-off". If there is too much bias the output waveform will look like the one on the left with the positive part "cut-off". When the bias voltage is too small, during the negative part of the cycle the transistor does not conduct fully so the output is set by the supply voltage. When the bias is too great the positive part of the cycle saturates the transistor and the output drops almost to zero.

Even with the correct biasing voltage level set, it is still possible for the output waveform to become distorted due to a large input signal being amplified by the circuits gain. The output voltage signal becomes clipped in both the positive and negative parts of the waveform an no longer resembles a sine wave, even when the bias is correct. This type of amplitude distortion is called Clipping and is the result of "Over-driving" the input of the amplifier.

When the input amplitude becomes too large, the clipping becomes substantial and forces the output waveform signal to exceed the power supply voltage rails with the peak (+ve half) and the trough (-ve half) parts of the waveform signal becoming flattened or "Clipped-off". To avoid this the maximum value of the input signal must be limited to a level that will prevent this clipping effect as shown above.

Amplitude Distortion due to Clipping



Amplitude Distortion greatly reduces the efficiency of an amplifier circuit. These "flat tops" of the distorted output waveform either due to incorrect biasing or over driving the input do not contribute anything to the strength of the output signal at the desired frequency. Having said all that, some well known guitarist and rock bands actually prefer that their distinctive sound is highly distorted or "overdriven" by heavily clipping the output waveform to both the +ve and -ve power supply rails. Also, excessive amounts of clipping can also produce an output which resembles a "square wave" shape which can then be used in electronic or digital circuits.

We have seen that with a DC signal the level of gain of the amplifier can vary with signal amplitude, but as well as Amplitude Distortion, other types of distortion can occur with AC signals in amplifier circuits, such as Frequency Distortion and Phase Distortion.

Frequency Distortion

Frequency Distortion occurs in a transistor amplifier when the level of amplification varies with frequency. Many of the input signals that a practical amplifier will amplify consist of the required signal waveform called the "Fundamental Frequency" plus a number of different frequencies called "Harmonics" superimposed onto it. Normally, the amplitude of these harmonics are a fraction of the fundamental amplitude and therefore have very little or no effect on the output waveform. However, the output waveform can become distorted if these harmonic frequencies increase in amplitude with regards to the fundamental frequency. For example, consider the waveform below:

Frequency Distortion due to Harmonics

In the example above, the input waveform consists a the fundamental frequency plus a second harmonic signal. The resultant output waveform is shown on the right hand side.

The frequency distortion occurs when the fundamental frequency combines with the second harmonic to distort the output signal. Harmonics are therefore multiples of the fundamental frequency and in our simple example a second harmonic was used. Therefore, the frequency of the harmonic is 2 times the fundamental, 2 x f or 2f. Then a third harmonic would be 3f, a fourth, 4f, and so on. Frequency distortion due to harmonics is always a possibility in amplifier circuits containing reactive elements such as capacitance or inductance.

Phase Distortion

Phase Distortion or Delay Distortion occurs in a non-linear transistor amplifier when there is a time delay between the input signal and its appearance at the output. If we call the phase change between the input and the output zero at the fundamental frequency, the resultant phase angle delay will be the difference between the harmonic and the fundamental. This time delay will depend on the construction of the amplifier and will increase progressively with frequency within the bandwidth of the amplifier. For example, consider the waveform below:

Phase Distortion due to Delay

Any practical amplifier will have a combination of both "Frequency" and "Phase" distortion together with amplitude distortion but in most applications such as in audio amplifiers or power amplifiers, unless the distortion is excessive or severe it will not generally affect the operation of the system.

Feedback Amplifiers

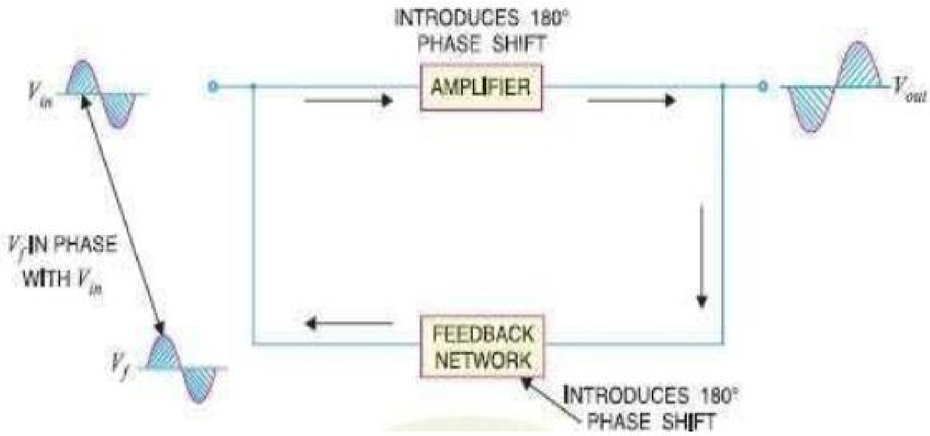
Introduction of Feedback Amplifiers:

The phenomenon of feeding a portion of the output signal back to the input circuit is known as feedback. The effect results in a dependence between the output and the input and an effective control can be obtained in the working of the circuit. Feedback is of two types.

- Positive Feedback
- Negative Feedback

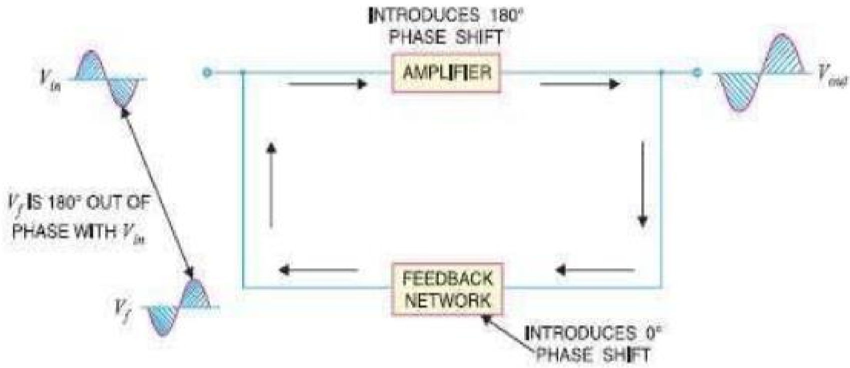
Positive or regenerate feedback:

- In positive feedback, the feedback energy (voltage or currents), is in phase with the input signal and thus aids it. Positive feedback increases gain of the amplifier also increases distortion, noise and instability.
- Because of these disadvantages, positive feedback is seldom employed in amplifiers. But the positive feedback is used in oscillators.



Negative or Degenerate feedback:

- In negative feedback, the feedback energy (voltage or current), is out of phase with the input signal and thus opposes it.
- Negative feedback reduces gain of the amplifier. It also reduce distortion, noise and instability.
- This feedback increases bandwidth and improves input and output impedances.
- Due to these advantages, the negative feedback is frequently used in amplifiers.



Comparison Between Positive and Negative Feed Back:

Sr. No.	Negative Feedback	Positive Feedback
1	Feedback energy is out phase with their input signal.	Feedback energy is in phase with the input signal.
2	Gain of the amplifier decreases.	Gain of the amplifier increases.
3	Gain stability increases.	Gain stability decreases.
4	Noise and distortion decreases.	Noise and distribution increases.
5	Increase the band width.	Decreases bandwidth.
6	Used in amplifiers.	Used in Oscillators.

Principle of Feedback Amplifier:

A feedback amplifier generally consists of two parts. They are the **amplifier** and the **feedback circuit**. The feedback circuit usually consists of resistors. The concept of feedback amplifier can be understood from the following

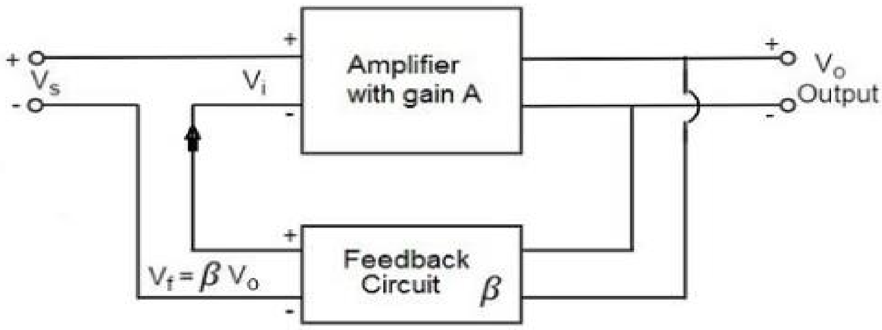
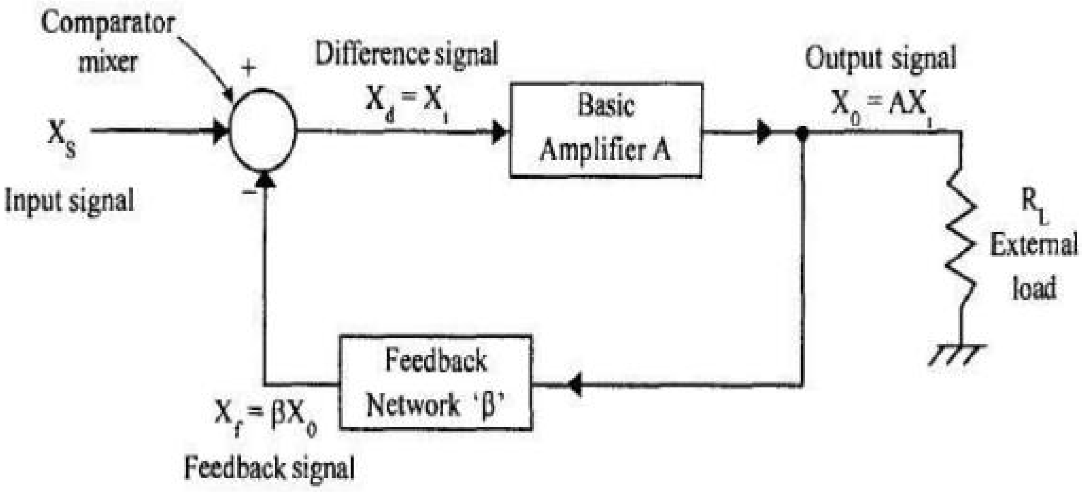


figure.



Generalized feedback amplifier

In the above figure, the gain of the amplifier is represented as A. The gain of the amplifier is the ratio of output voltage Vo to the input voltage Vi. The feedback network extracts a voltage Vf = β Vo from the output Vo of the amplifier. This voltage is subtracted for negative feedback, from the signal voltage Vs. Now,

$$V_i = Vs - V_f = Vs - \beta Vo$$

The quantity β = Vf/Vo is called as feedback ratio or feedback fraction.

The output Vo must be equal to the input voltage (Vs - βVo) multiplied by the gain A of the amplifier.

Hence,

$$(Vs-\beta Vo)A=Vo$$
$$AVs-A\beta Vo=Vo$$
$$AVs=Vo(1+A\beta)$$
$$Vo/Vs=A/(1+A\beta)$$

Therefore, the gain of the amplifier with feedback is given by **Af =A/(1+Aβ)**

Effect of negative feedback on amplifier performance:

The effect of negative feedback on an amplifier is considered in relation to gain, gain stability, distortion, noise, input/output impedance and bandwidth and gain-bandwidth product.

Gain:

The gain of the amplifier with feedback is given by

$$A_f = A/(1+A\beta)$$

Hence, gain decreases with feedback.

Gain Stability:

An important advantage of negative voltage feedback is that the resultant gain of the amplifier can be made independent of transistor parameters or the supply voltage variations,

$$A_f = A/(1+A\beta)$$

For negative voltage feedback in an amplifier to be effective, the designer deliberately makes the product **Aβ** much greater than unity. Therefore, in the above relation, '1' can be neglected as compared to **Aβ** and the expression becomes

$$A_f = A/(1+A\beta) = 1/\beta$$

It may be seen that the gain now depends only upon feedback fraction, **β,** i.e., on the characteristics of feedback circuit. As feedback circuit is usually a voltage divider (a resistive network), therefore, it is unaffected by changes in temperature, variations in transistor parameters and frequency. Hence, the gain of the amplifier is extremely stable.

Distortion:

A power amplifier will have non-linear distortion because of large signal variations. The negative feedback reduces the nonlinear distortion. It can be proved mathematically that:

$$D_f = D/(1+A\beta)$$

Where D = distortion in amplifier without feedback

D_f = distortion in amplifier with negative feedback

It is clear that by applying negative feedback, the distortion is reduced by a factor **(1+Aβ)**

Noise :

There are numbers of sources of noise in an amplifier. The noise *N* can be reduced by the factor of **(1+Aβ),** in a similar manner to non-linear distortion, so that the noise with feedback is given by

$$N_f = N/(1+A\beta)$$

However, if it is necessary to increase the gain to its original level by the addition of another stage, it is quite possible that the overall system will be noisier that it was at the start. If the increase in gain can be accomplished by the adjustment of circuit parameters, a definite reduction in noise will result from the use of negative feedback.

Input / Output Impedance :

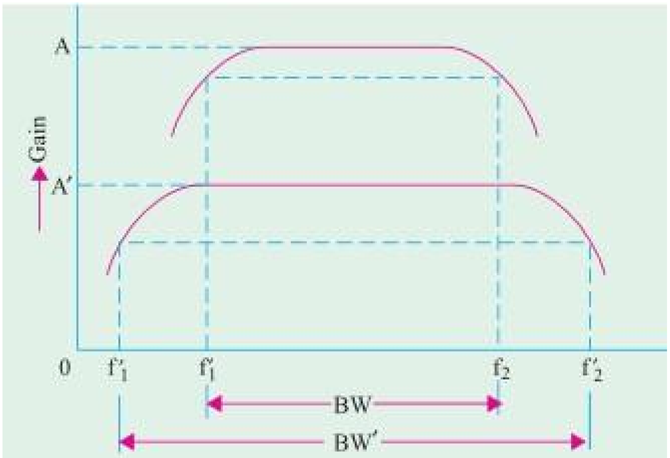
The input and output impedances will also improve by a factor of **(1+Aβ),** based on feedback connection type.

Bandwidth and Gain-bandwidth Product:

Each of higher and lower cut-off frequencies will improve by a factor of **(1+Aβ).** However, gain-bandwidth product remains constant.

$$f_{hf} = f_h (1+A\beta)$$

$$f_{lf} = f_l / (1+A\beta)$$



Bandwidth and Gain-bandwidth Product

An important piece of information that can be obtained from a frequency response curve is the bandwidth of the amplifier. This refers to the ‘band’ of frequencies for which the amplifier has a useful gain.

Outside this useful band, the gain of the amplifier is considered to be insufficient compared with the gain at the centre of the bandwidth. The bandwidth specified for the voltage amplifiers is the range of frequencies for which the amplifiers gain is greater than 0.707 of the maximum gain Alternatively, decibels are used to indicate gain, the ratio of output to input voltage. The useful bandwidth would be described as extending to those frequencies at which the gain is -3db down compared to the gain at the mid-band frequency.

Feedback in Emitter Follower Amplifier:

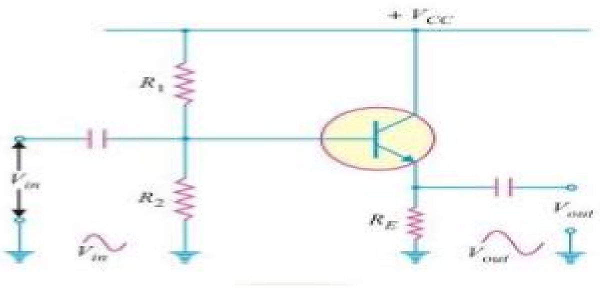


Diagram of an emitter follower

Operation:

For the emitter follower, the input voltage is applied at base and the resulting a.c. emitter current produces an output voltage (IeR_E) across the emitter resistance. This voltage opposes the input voltage, thus providing negative feedback (Voltage series). It is called emitter follower because the output voltage follows the input voltage.

The major characteristics of the emitter follower are:

The voltage gain of an emitter follower is close to 1. Relatively high current gain and power gain. High input impedance and low output impedance. Input and output ac voltages are in phase.

Classification of Basic Amplifiers:

Amplifiers can be classified broadly as,

• Voltage amplifiers.

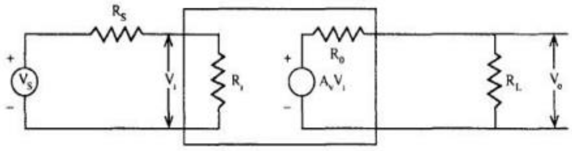
• Current amplifiers.

• Transconductance amplifiers.

• Transresistance amplifiers.

Voltage Amplifier:

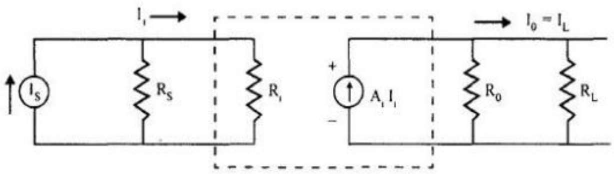
Ri >> Rs and Ro << RL



Equivalent circuit of voltage amplifier.

Current Amplifier:

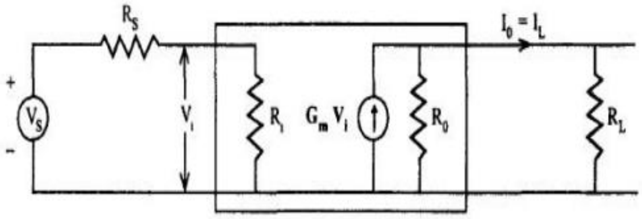
Ri << Rs and Ro >> RL



Equivalent circuit for current amplifier

Transconductance Amplifier:

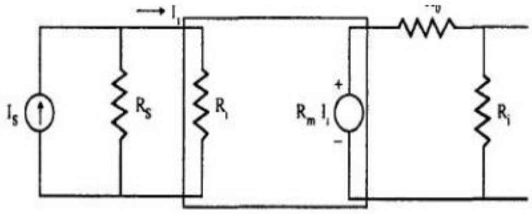
Ri >> Rs and Ro >> RL



Equivalent circuit for transconductance amplifier

Transresistance Amplifier:

Ri << Rs and Ro << RL



Equivalent circuit for transresistance amplifier

Summary:

Sl. No.	Type	Input	Output	Ri	Ro
1	Voltage Amplifier	Voltage	Voltage	High	Low
2	Current Amplifier	Current	Current	Low	High
3	Transconductance Amplifier	Voltage	Current	High	High
4	Transresistance Amplifier	Current	Voltage	Low	Low

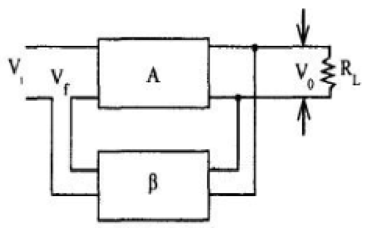
Classification of Feedback Amplifiers:

There are four types of feedback,

- Voltage series feedback.
- Voltage shunt feedback.
- Current shunt feedback.
- Current series feedback

$$R_{if} = R_i\,(1+A\beta)$$

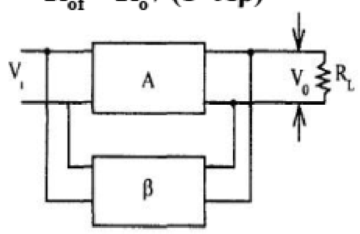
$$R_{of} = R_o / (1+A\beta)$$



Voltage series feedback.

$$R_{if} = R_i / (1+A\beta)$$

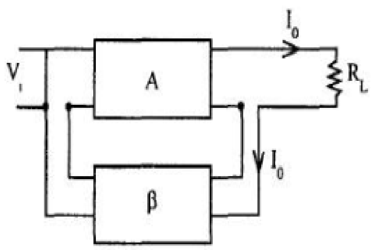
$$R_{of} = R_o / (1+A\beta)$$



Voltage shunt Feedback

$$R_{if} = R_i / (1+A\beta)$$

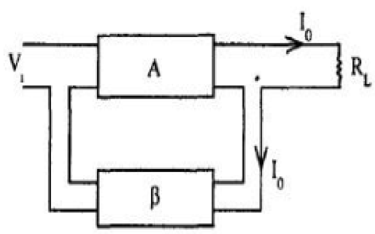
$$R_{of} = R_o\,(1+A\beta)$$



Current Shunt Feedback

$$R_{if} = R_i\,(1+A\beta)$$

$$R_{of} = R_o\,(1+A\beta)$$



Current Series Feedback

Effect of feedback on Input Resistance:

Voltage shunt Feedback	Current Shunt Feedback
Rif = Ri / (1+Aβ)	Rif = Ri / (1+Aβ)
Voltage series feedback.	Current series Feedback
Rif = Ri (1+Aβ)	Rif = Ri (1+Aβ)

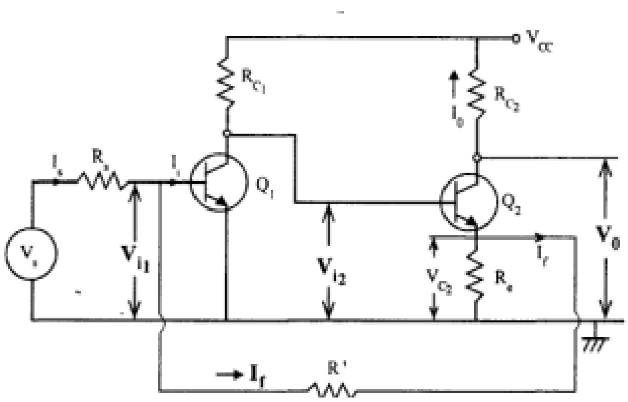
Effect of feedback on Output Resistance:

Voltage shunt Feedback	Current Shunt Feedback
Rof = Ro / (1+Aβ)	Rof = Ro (1+Aβ)
Voltage series feedback.	Current series Feedback
Rof = Ro / (1+Aβ)	Rof = Ro (1+Aβ)

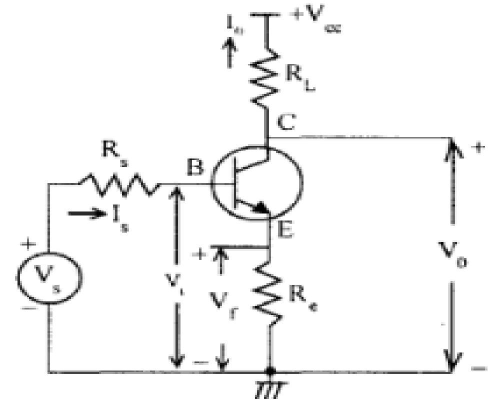
Summary:

Sl. No.	Type	Rif	Rof
1	Voltage Shunt Feedback Amplifier	Rif = Ri / (1+Aβ)	Rof = Ro / (1+Aβ)
2	Current Shunt Feedback Amplifier	Rif = Ri / (1+Aβ)	Rof = Ro (1+Aβ)
3	Voltage Series Feedback Amplifier	Rif = Ri (1+Aβ)	Rof = Ro / (1+Aβ)
4	Current Series Feedback Amplifier	Rif = Ri (1+Aβ)	Rof = Ro (1+Aβ)

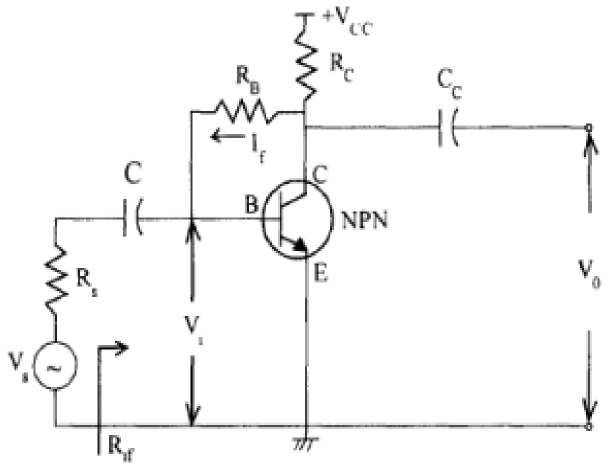
Current shunt feedback.



Current Series Feedback



Voltage Shunt Feedback



Objective Questions and Solutions :

1.

If the input impedance & voltage gain of a open loop voltage series feedback amplifier are 3kΩ & 100, and the feedback factor is $\frac{1}{50}$, then the input impedance of closed loop configuration is ________

(A) 9kΩ (B) 6kΩ

(C) 3kΩ (D) 12kΩ

$A = 100$, $R_{in} = 3k\Omega$

$R_{inf} = R_{in}(1 + A\beta)$

$= 3k\Omega\,(1 + 100\ \frac{1}{50})$

$R_{inf} = 9k\Omega$ Choice (A)

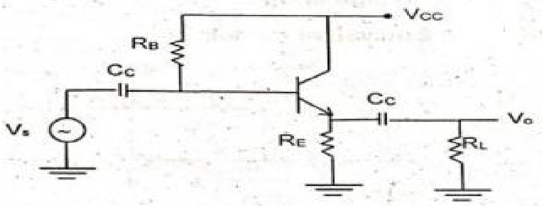
Note: Voltage – series feedback

(i) $R_{inf} = R_{in}(1 + A\beta)$

(ii) $R_{of} = \frac{R_o}{(1 + A\beta)}$

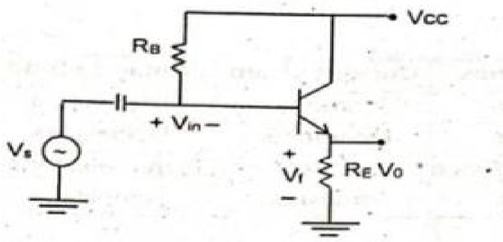
2.

Find the type of the feedback in the given circuit



(A) Current – series
(B) Voltage shunt
(C) Voltage series
(D) Current shunt

a.c equivalent circuit:

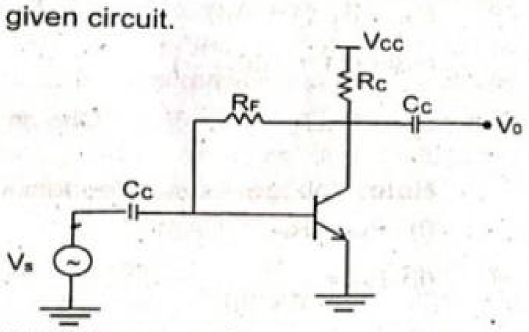


Input – series connection
Output – shunt connection
∴ Voltage series feedback

Choice (C)

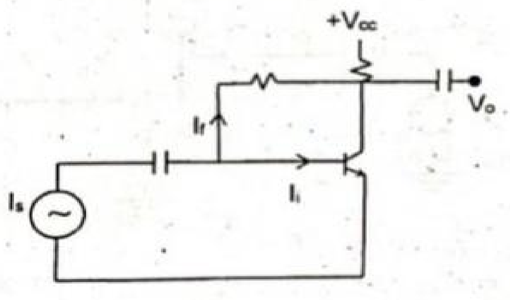
3.

Find the type of the feedback in the given circuit.



(A) Voltage – series
(B) Current – series
(C) Current shunt
(D) Voltage shunt

a.c Equivalent model:



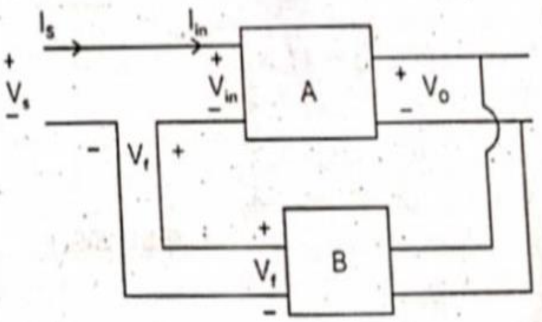
Input:– shunt connection
Output:– shunt connection
∴ Voltage shut feedback.

Choice (D)

4.

What are the effects of negative voltage series feedback on the characteristics of an amplifier? Derive an expression for input resistance of such an amplifier with feedback in terms of input resistance without feedback and feedback factor.

Sol.



Effects of negative voltage series feedback on the characteristics of an Amplifier:

(i) Input impedance increases:

$$R_{inf} = \frac{V_s}{I_s} = \frac{V_{in}[1 + A\beta]}{I_{in}} = R_{in}[1 + A\beta]$$

$\therefore V_{in} = V_s - V_f \Rightarrow V_{in} = V_s - \beta A V_{in}$

$V_s = [1 + A\beta] V_{in}$

$I_s = I_{in}$ since series at the input

(ii) Similarly output impedance decreases

$$R_{of} = \frac{R_o}{1 + A\beta}$$

(iii) Voltage gain decreases

$$A_f = \frac{A}{1 + A\beta}$$

(iv) Lower cut off frequency decreases

$$f_L^1 = \frac{f_L}{1 + A\beta}$$

(v) Upper cut off frequency increases

$$f_H^1 = f_H[1 + A\beta]$$

(vi) Bandwidth increases

$$B_W^1 = B_W[1 + A\beta]$$

(vii) Distortion decreases

$$D_1 = \frac{D}{1 + A\beta}$$

(viii) Stability increases.