UNIT I

SINGLE STAGE AMPLIFIERS

1.1 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.

1.2Two –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**.

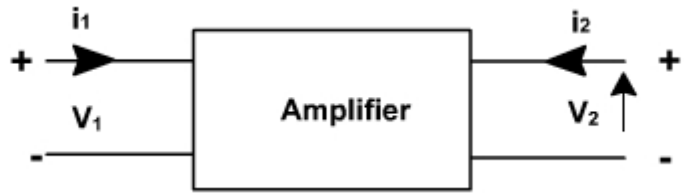


Fig. 1

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)
4.

1.1.1 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

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

1.2.1 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.

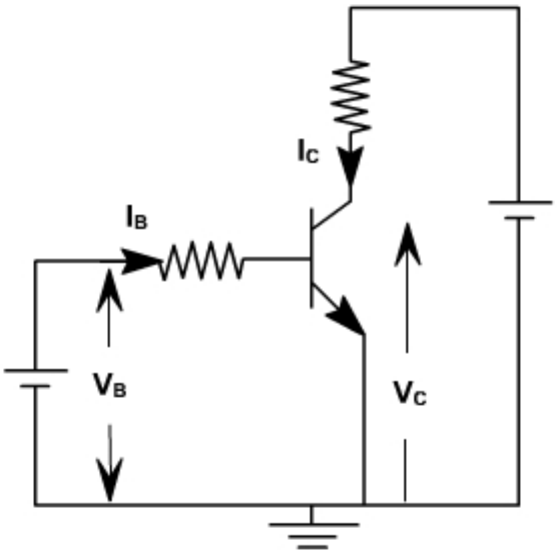


Fig. 3

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

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

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

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.

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

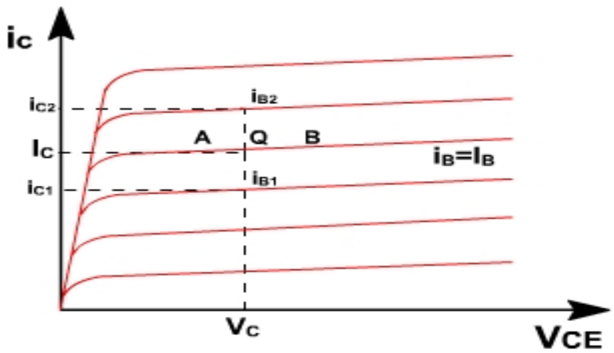


Fig. 5

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).

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

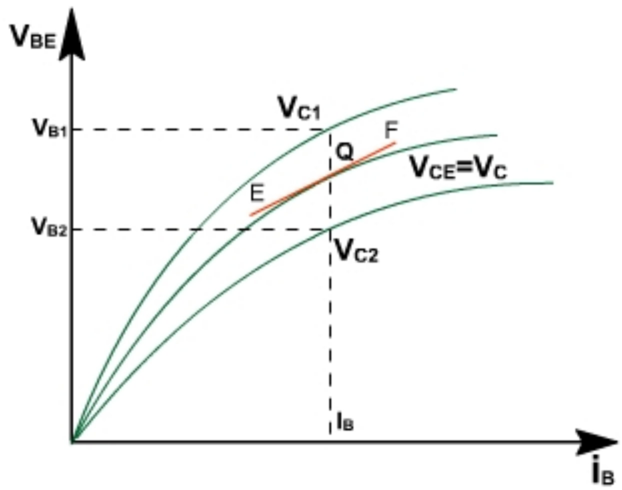


Fig. 6

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 m A / V

1.3 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.

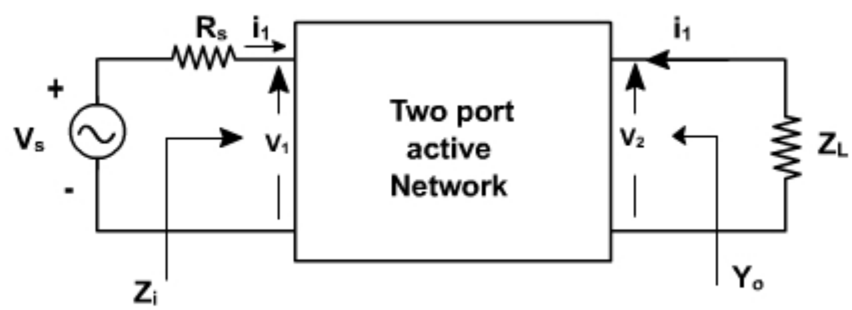


Fig. 1

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.

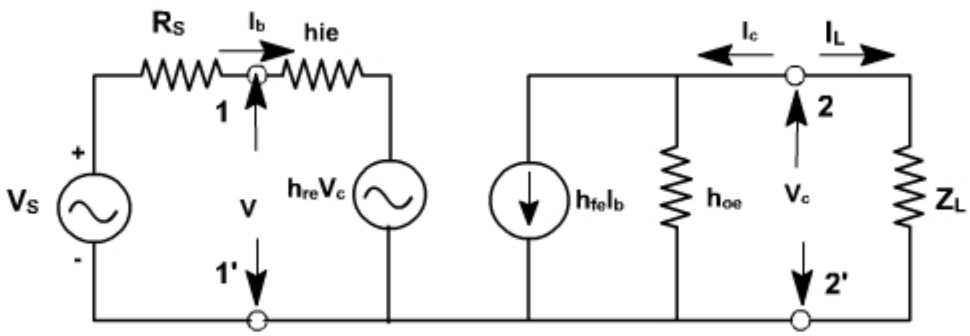


Fig. 2

1.3.1 Current gain:

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

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

1.3.2 Input impedence:

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

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

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

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

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

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

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

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

1.3.3 Voltage gain:

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

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

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

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.

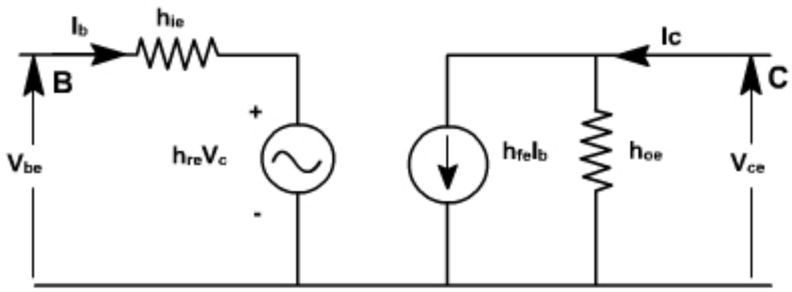


Fig. 4

For CE transistor configuaration

Vbe = hie Ib + hre Vce

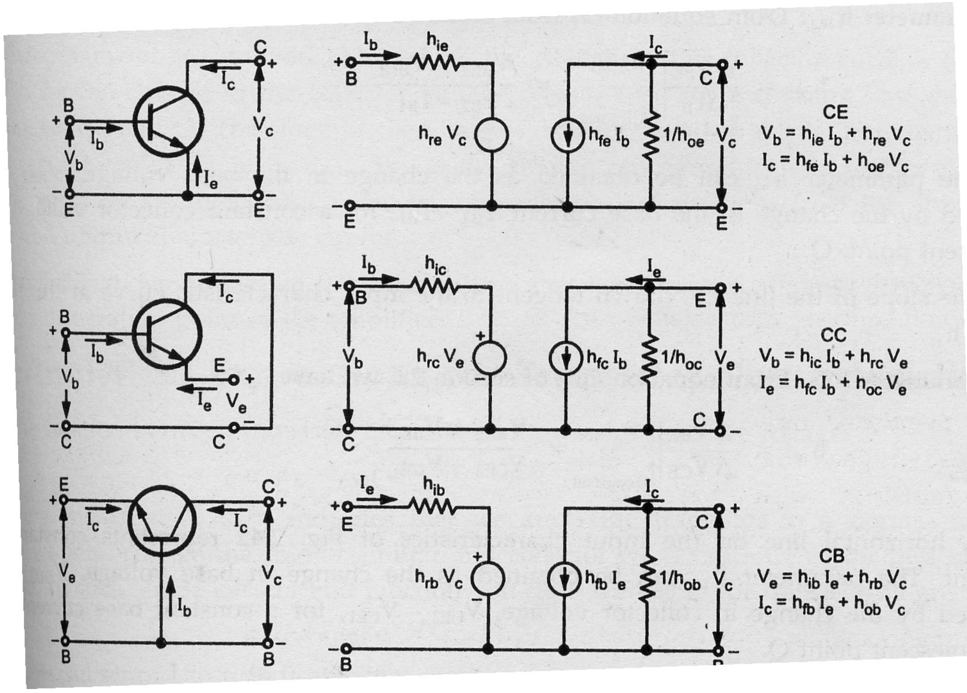
Ic = h fe Ib + hoe Vce

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.

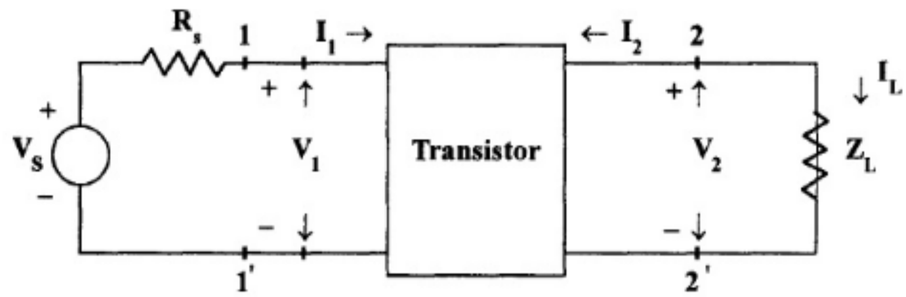


Fig.1.4 Basic Amplifier Circuit

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

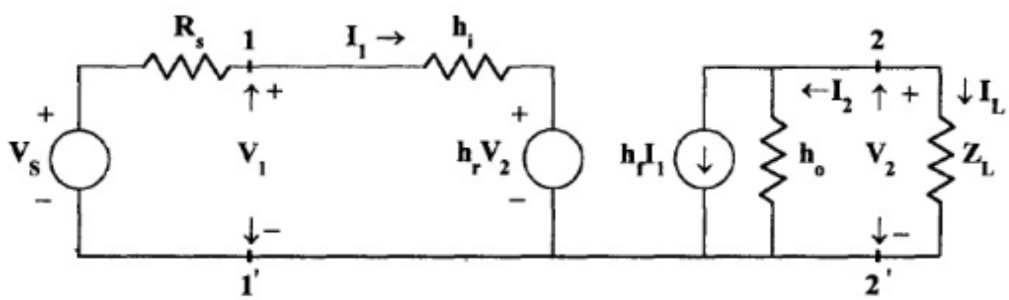


Fig. 1.5 Transistor replaced by its Hybrid Model

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

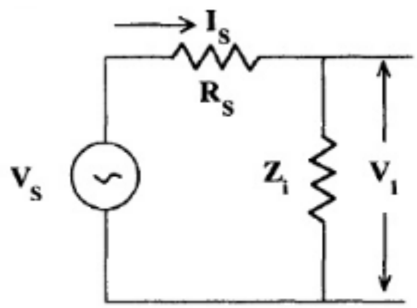


Fig. 5.6 Thevenin's Equivalent Input Circuit

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)

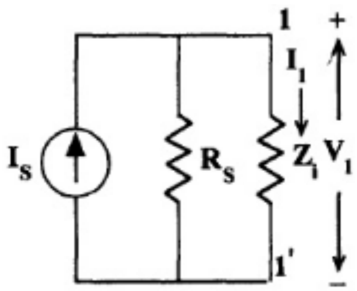


Fig. 1.7 Norton's Equivalent Input Circuit

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 $\qquad I_1 = I_S \, R_S / (R_S + Z_i)$

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

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

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.

$I_c = h_{fe} I_B$.

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

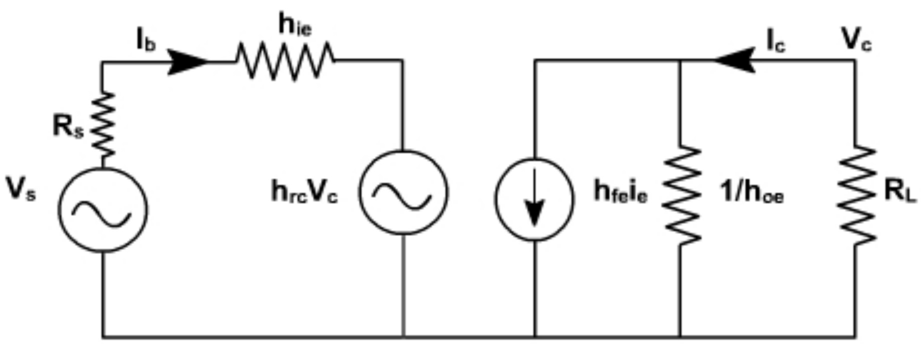


Fig. 4

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.

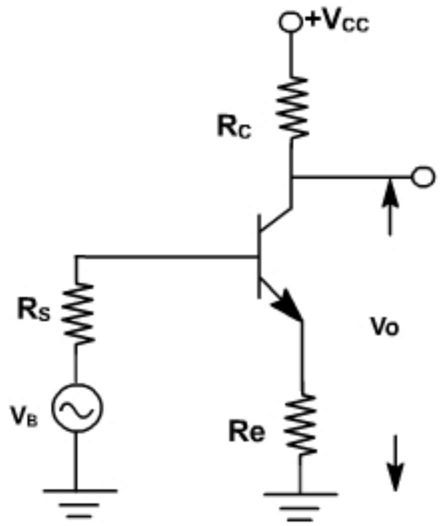


Fig. 5

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:

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$I_c = h_{fe} I_B$.

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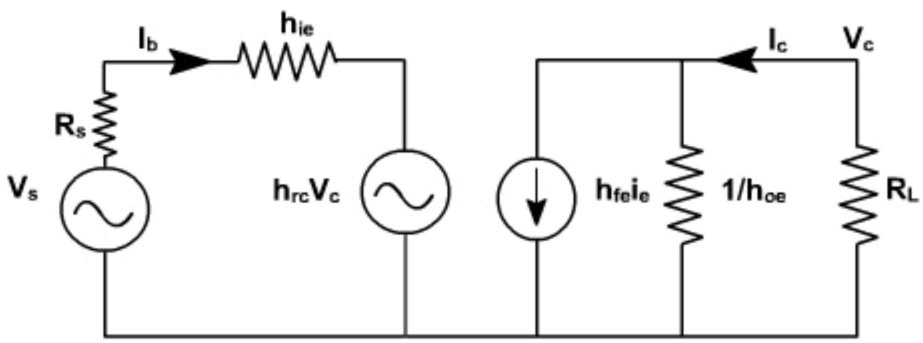

Fig 1.8

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.

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$$R_i = h_{ie}$$

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

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.

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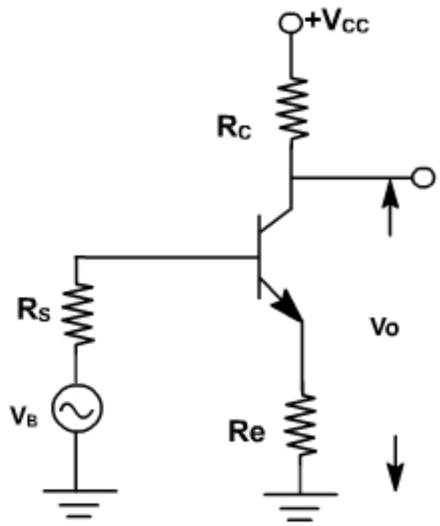


Fig.1.9

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

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**.

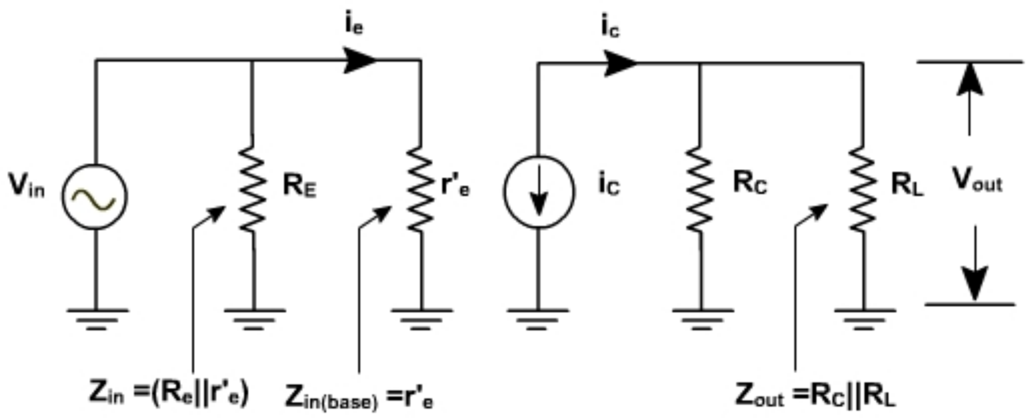


Fig. 2

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).

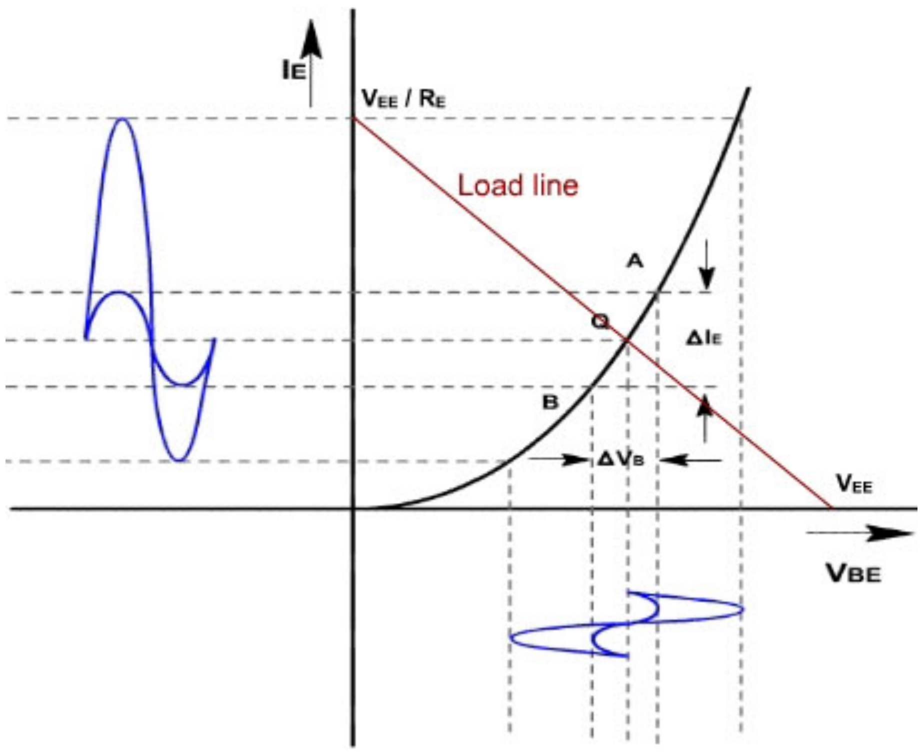


Fig .3

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

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

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

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

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

$$= \frac{r_C}{r}$$

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

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

Example-1

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

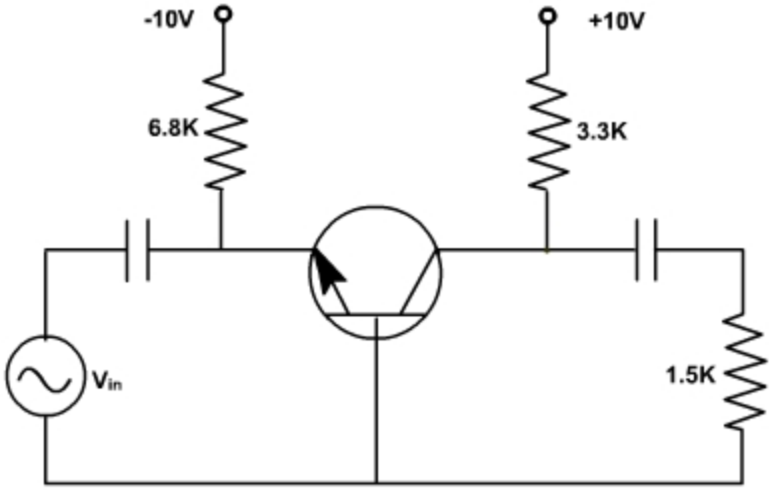


Fig. 4

Solution:

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

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

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 R s = 100 W .

Solution:

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

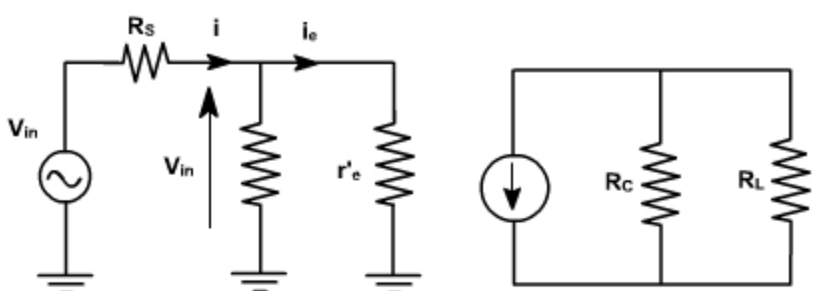


Fig. 5

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 x 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**.

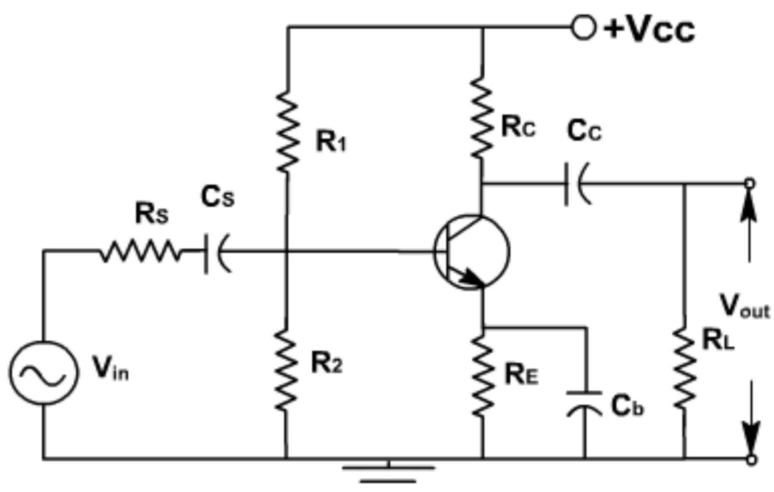


Fig. 1

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.

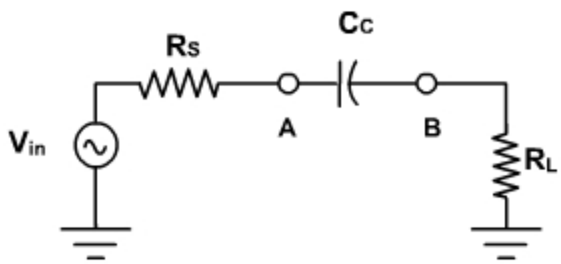


Fig. 2

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 £ 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 .

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.

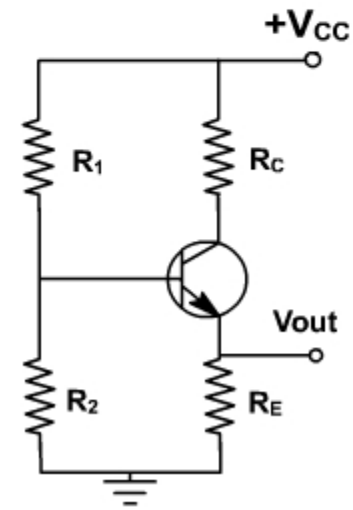


Fig. 3

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**.

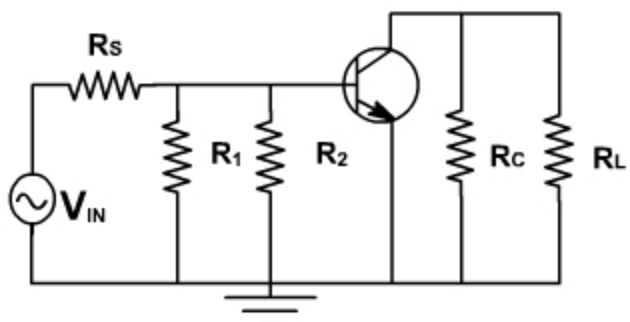


Fig. 4

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^{o} 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**.

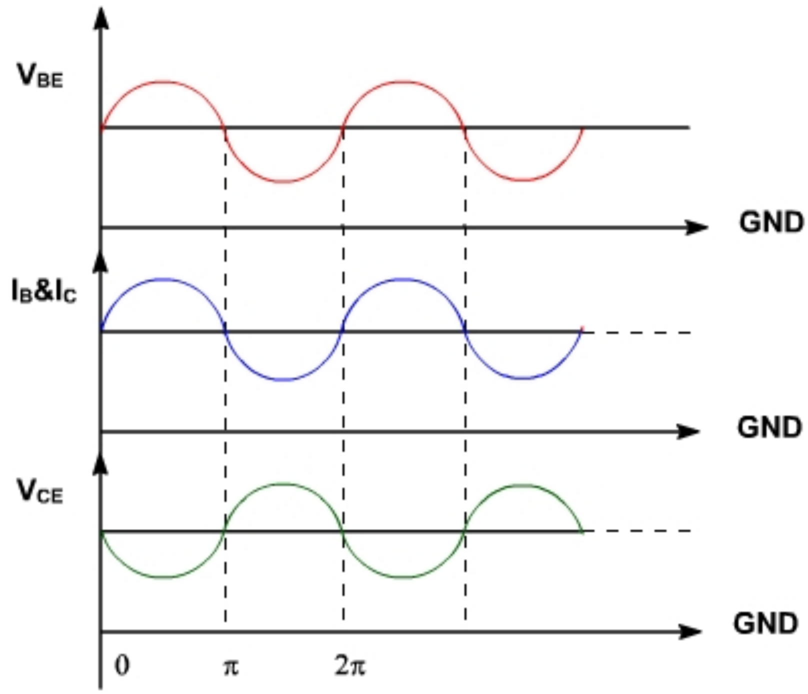


Fig. 5

lowest frequency.

AC Load line:

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

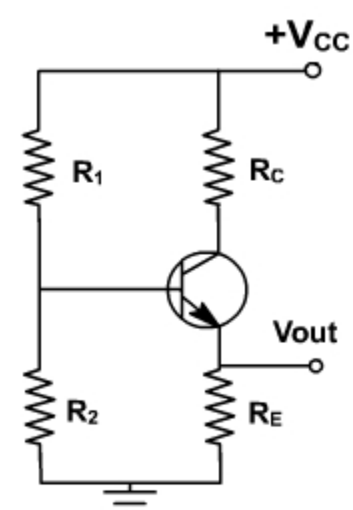


Fig. 1

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.

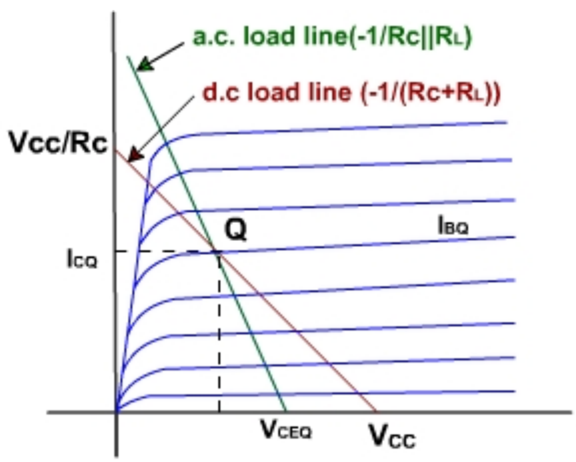


Fig. 2

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.

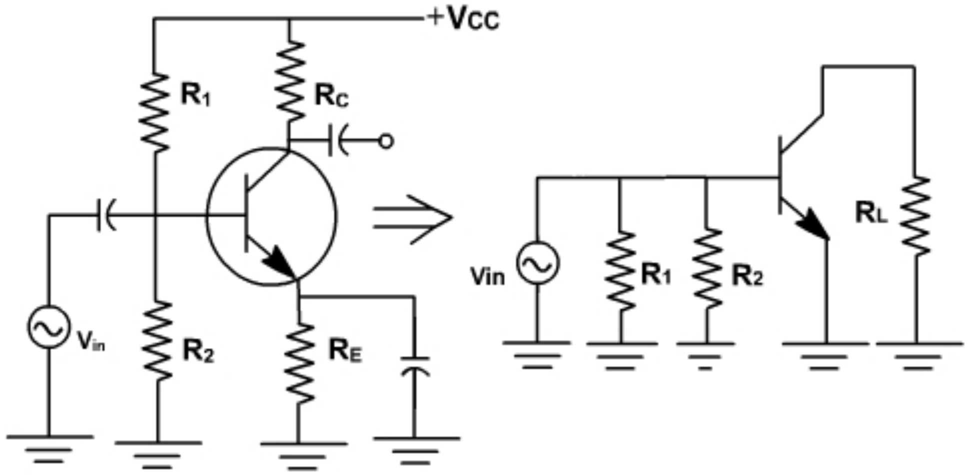


Fig. 3

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.

Analysis of CE amplifier

Example-1:

Select R1 and R2 for maximum output voltage swing in the circuit shown in fig. 5.

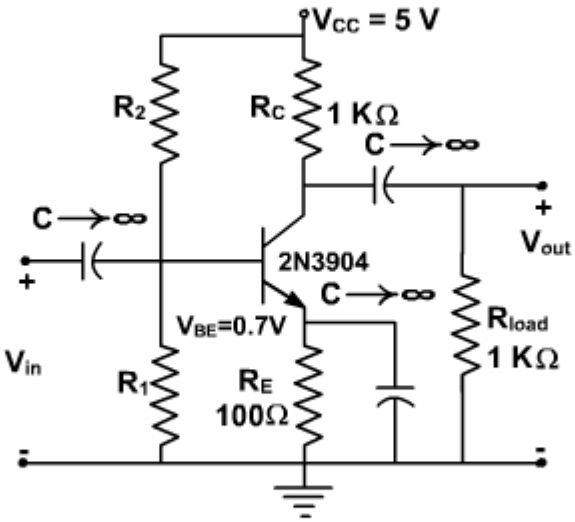


Fig. 5

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,

$$R_1 = \frac{R_B}{1 - V_{BB} / V_{CC}} = \frac{1800}{1 - 1.044/5} = 2.28 \text{ K}\Omega$$
$$R_2 = \frac{R_B V_{CC}}{V_{BB}} = \frac{1800 \times 5}{1.044} = 8.62 \text{ K}\Omega$$

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

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.

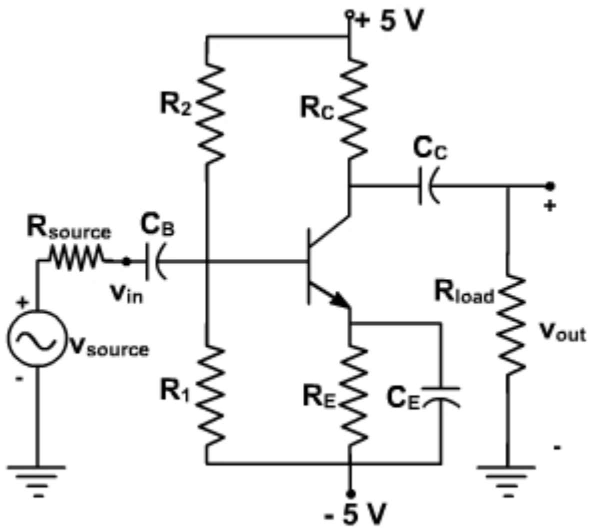


Fig. 1

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

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

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

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.

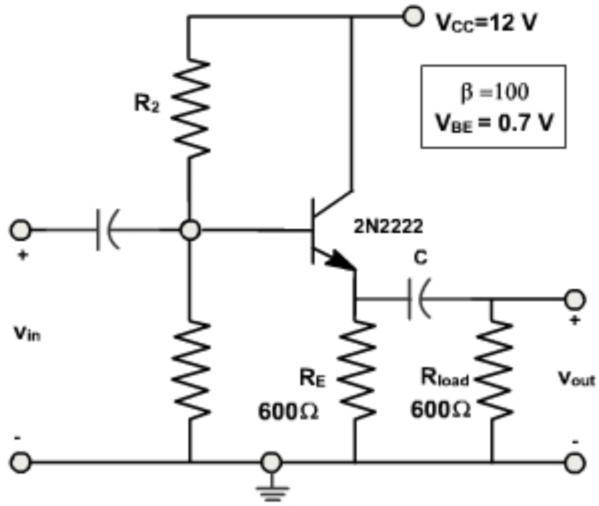


Fig. 7

Solution:

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

$R_B = R_1 \,||\, R_2 = 6.67 \text{ K}\Omega$

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

From the bias equation we have

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

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 **.** $(R_E \,||\, R_{Load})$ = 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

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

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

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)

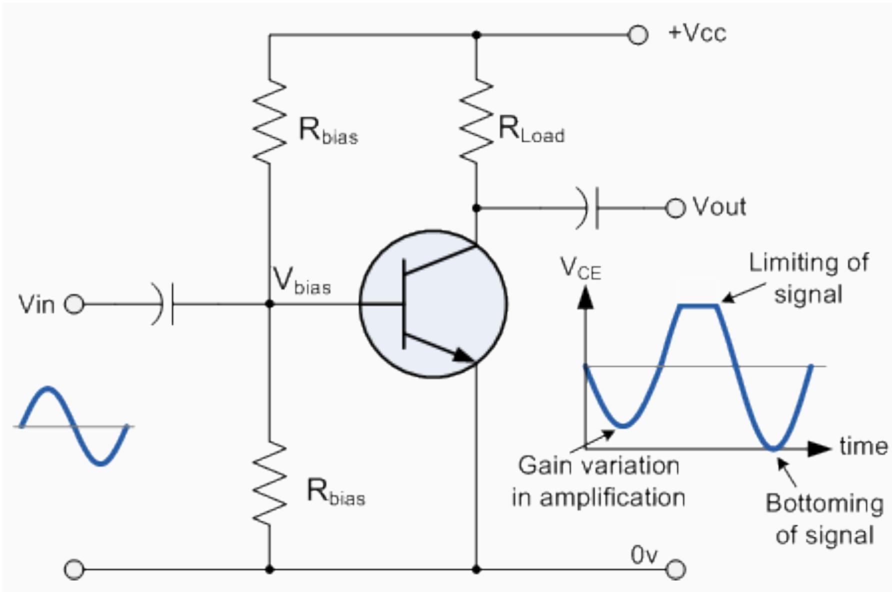
(b)Wide band amplifier(normally video amplifier)

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.

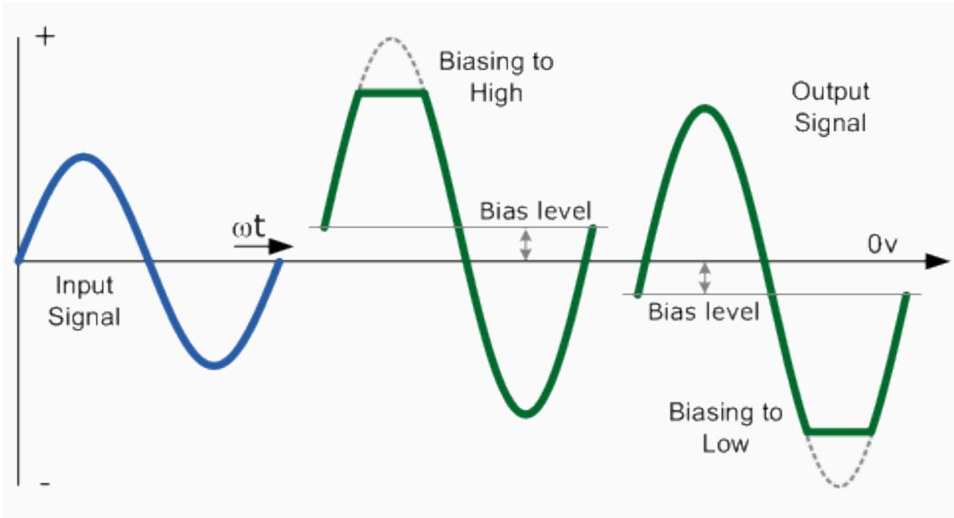
This means then that during the amplification process of the signal waveform, some form of Amplifier Distortion has occurred.

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

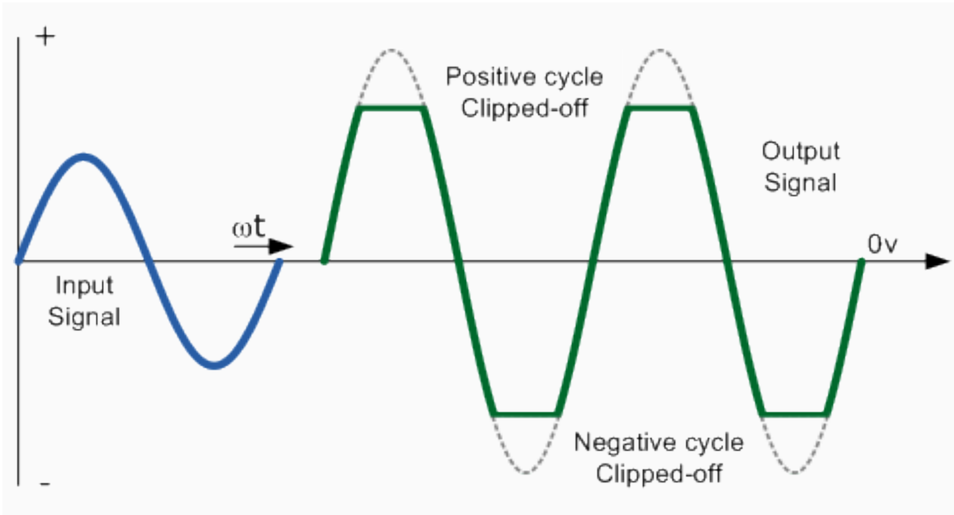


If the bias is correct the output waveform should look like that of the input waveform only bigger, (amplified). If there is insufficient bias the output waveform will look like the one on the right with the negative part of the output waveform "cut-off". If there is too much bias the output waveform 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.