TKR COLLEGE OF ENGINEERING & TECHNOLOGY
AN AUTONOMOUS INSTITUTION
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ELECTRONICS AND COMMUNICATION ENGINEERING

ELECTRONIC CICUIT ANALYSIS

B.Tech. III Semester **L/T/P/ C**

3/0/0/ 3

Prerequisite: Electronic Devices and Circuits.

COURSE OBJECTIVE:

To give understanding of various types of amplifier such as small signal, Cascaded, Large Signal, tuned or un tuned circuits and to know the concept of feedback in amplifiers and Oscillators.

COURSE OUTCOMES:

Upon completion of the Course, the students will be able to

CO-1:Analyze Small signal Analysis of different transistor amplifier circuits such as single stage or multistage amplifiers using hybrid parameters. L4

CO-2: Analyze the high frequency response of transistor circuits. L4

CO-3: Analyze the gain of JFET and MOSFET amplifier using small signal model. L4

CO-4: Design various Feedback Amplifiers and Oscillator circuits. L5

CO-5: Analyze and Compare the efficiency and distortion of various Power Amplifiers. L4

CO/PO	PO1	PO 2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11
CO-1	3	3	3								
CO-2		3									
CO-3	3	3									
CO-4		3	3								
CO-5		3									

UNIT-I:

Analysis and Design of Small Signal Low Frequency BJT Amplifiers: Classification of Amplifiers, h-parameter analysis, small signal equivalent circuit of a transistor, Analysis of CE, CB, CC amplifiers. Distortion in amplifiers, Miller's theorem, Analysis of CE, CC, and CB Amplifiers, CE Amplifier with emitter resistance, low frequency response of BJT Amplifiers, effect of coupling and bypass capacitors, Design of single stage RC coupled amplifier, Different coupling schemes used in amplifiers, Analysis of Cascaded RC Coupled amplifiers, Cascode Amplifier, Darlington pair.

UNIT-II:

Transistor at High Frequency: Logarithms, Decibels. The Hybrid-pi (π)–Common Emitter transistor model, CE short circuit current gain, current gain with resistive load, Single stage CE transistor amplifier response, Gain-bandwidth product.

UNIT-III:

FET Amplifiers: Analysis of JFET Amplifiers, Analysis of CS, CD, CG JFET Amplifiers, comparison of performance with BJT Amplifiers, Basic Concepts of MOS amplifiers, MOS Small signal model, Common source amplifier with resistive load, Diode connected and Current source loads, Source follower, Common Gate Stage amplifier.

UNIT-IV:

Positive & Negative Feedback in Amplifiers: Concepts of feedback – Classification of feedback amplifiers– General characteristics of negative feedback amplifiers, Effect of Feedback on Amplifier characteristics, Voltage series, Voltage shunt, Current series and Current shunt Feedback configurations, Simple problems.

Oscillators: Condition for Oscillations, RC and LC type Oscillators–Frequency and amplitude stability of oscillators–Generalized analysis of LC oscillators, Quartz, Hartley, and Colpitts Oscillators RC-phase shift and Wien-bridge oscillators.

UNIT-V:

Large Signal Amplifiers: Class A Power Amplifier, Maximum Value of Efficiency of Class–A power Amplifier, Transformer Coupled Class A Power Amplifier, Class B Power Amplifier, Class B Push-Pull and Complimentary Symmetry Power Amplifiers. Distortion in amplifiers, Crossover distortion and harmonic distortion. Transistor Power Dissipation, Heat Sinks.

Tuned Amplifiers: Introduction, Q-Factor, Small Signal Tuned Amplifier, Single Tuned Amplifier (Capacitive coupling & Inductive Coupling).

TEXT BOOKS:

1. David A. Bell, “Electronic Devices and Circuits”, 5th Edition, Oxford Press.
2. Robert L. Boylestead and Louis Nashelsky, “Electronic Devices and Circuit Theory”, 11th Edition, 2009, Pearson Publications.
3. Jacob Millman, Christos C Halkias, “Integrated Electronics”, McGraw Hill Education.

REFERENCE BOOKS:

1. S. Salivahanan, N. Suresh Kumar, AVallvaraj, “Electronic Devices and Circuits”, 5th Edition, McGraw Hill Education.
2. Md. H Rashid, “Electronic Circuits and Applications”, Cengage Learning, 2014

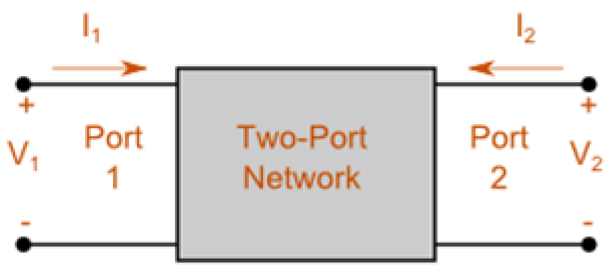
H– Parameter model :-

- The equivalent circuit of a transistor can be dram using simple approximation by retaining its essential features.

- These equivalent circuits will aid in analyzing transistor circuits easily and rapidly.

Two port Network Parameters:-

A transistor can be treated as a two part network. The terminal behaviour of any two part network can be specified by the terminal voltages V1 & V2 at parts 1 & 2 respectively and current i1 and i2, entering parts 1 & 2, respectively, as shown in figure.



Two port network

Of these four variables V1, V2, i1 and i2, two can be selected as independent variables and the remaining two can be expressed in terms of these independent variables. This leads to various two part parameters out of which the following three are more important.

1. Z – Parameters (or) Impedance parameters
2. Y – Parameters (or) Admittance parameters
3. H – Parameters (or) Hybrid parameters.

Hybrid parameters (or) h – parameters:-

If the input current i1 and output Voltage V2 are takes as independent variables, the input voltage V1 and output current i2 can be written as

$$V_1 = h_{11}\, i_1 + h_{12}\, V_2$$

$$i_2 = h_{21}\, i_1 + h_{22}\, V_2$$

The four hybrid parameters h_{11}, h_{12}, h_{21} and h_{22} are defined as follows.

h_{11} = [V_1 / i_1] with V_2 = 0 = Input Impedance with output part short circuited.

h_{22} = [i_2 / V_2] with i_1 = 0 = Output admittance with input part open circuited.

h_{12} = [V_1 / V_2] with i_1 = 0=reverse voltage transfer ratio with input part open Circuited.

h_{21} = [i_2 / i_1] with V_2 = 0=Forward current gain with output part short circuited.

The dimensions of h – parameters are as follows:

h11 - Ω

h22 – mhos

h12, h21 – dimension less.

→ as the dimensions are not alike, (ie) they are hybrid in nature, and these parameters are called as hybrid parameters.

I = 11 = input; 0 = 22 = output;

F = 21 = forward transfer; r = 12 = Reverse transfer.

Notations used in transistor circuits:-

h_{ie} = h_{11e} = Short circuit input impedance

h_{0e} = h_{22e} = Open circuit output admittance

h_{re} = h_{12e} = Open circuit reverse voltage transfer ratio

h_{fe} = h_{21e} = Short circuit forward current Gain.

The Hybrid Model for Two-port Network:-

$V_1 = h_{11}\, i_1 + h_{12}\, V_2$

$I_2 = h_{21}\, i_1 + h_{22}\, V_2$

Transistor Hybrid model: - Use of h – parameters to describe a transistor have the following advantages.

- h – Parameters are real numbers up to radio frequencies .
- They are easy to measure
- They can be determined from the transistor static characteristics curves.
- They are convenient to use in circuit analysis and design.
- Easily convert able from one configuration to other.
- Readily supplied by manufactories.

CE Transistor Circuit

To Derive the Hybrid model for transistor consider the CE circuit shown in figure.The variables are i_b, ic, $V_b(=V_{BE})$ and $V_c(=V_{CE})$. i_b and Vc are considered as independent variables.

Then , $V_b = f1(i_b,, V_c)$

$ic = f2(i_b.V_c)$

Making a Taylor's series expansion around the quiescent point IB, VC and neglecting higher order terms, the following two equations are obtained.

$$V_b=(\partial f_1/\partial i_b)V_c .\ i_b+ (\partial f_1/\partial V_c)i_b \quad V_C$$

$$ic = (\partial f2/\partial i_b)V_c .\ i_b + (\partial f_2/vc)I_B \quad V_C$$

The partial derivatives are taken keeping the collector voltage or base current constant as indicated by the subscript attached to the derivative.Vb , Vc , i_C , i_B represent the small signal(increment) base and collector voltages and currents,they are represented by symbols v_b , vc , i_b and i_c respectively.

$$V_b = h_{ie}\, i_b + h_{re}\, V_c$$

$$i_c = h_{fe}\, i_b + h_{oe}\, V_c$$

Where $h_{ie} = (\partial f_1/\partial i_b)V_c = (\partial v_b/\partial i_b)V_c = (v_b / ib)Vc = (v_b / i_b)V_c$

$h_{re} = (\partial f_1/\partial v_c)Ib = (\partial v_b/\partial v_c) Ib = (v_b / v_c) Ib = (v_b /v_c) Ib$

$h_{fe} = (\partial f_2/\partial i_b)V_c = (\partial i_c /\partial i_b)V_c = (i_c / i_b)Vc = (i_c / i_b)V_c$

$h_{oe} = (\partial f_2/\partial v_c)Ib = (\partial i_c /\partial v_c) I_b = (i_c / v_c) Ib = (i_c /v_c) Ib$

The above equations define the h-parameters of the transistor in CE configuration. The same theory can be extended to transistors in other configurations.

UNIT-1

Single Stage Amplifiers:

Classification of Amplifiers – Distortion in amplifiers, Analysis of CE, CC and CB configurations with simplified hybrid model, Analysis of CE amplifier with emitter resistance and emitter follower, Miller's theorem and its dual, Design of single stage RC coupled Amplifier using BJT.

Multistage Amplifiers:

Analysis of Cascaded RC coupled BJT amplifiers, Cascode Amplifier, Darlington Pair, Different Coupling Schemes used in Amplifiers – RC coupled amplifiers, Transformer Coupled Amplifier, Direct Coupled Amplifier

Classification of Amplifiers

TYPE OF SIGNAL	BASED ON STAGES	TYPE OF CONFIGURATION	CLASSIFICATION BASED ON CONDUCTION ANGLE	FREQUENCY OF OPERATION
Small signal	Single stage	CE,CB,CC		Direct Current
	Multistage			
Large Signal			Class A	AF
			Class B	AF
			Class AB	RF
			Class C	VHF,UHF

Distortion in Amplifiers

Distortion of the output signal waveform may occur because:

- Amplification may not be taking place over the whole signal cycle due to incorrect biasing levels.
- The input signal may be too large, causing the amplifiers transistors to be limited by the supply voltage.
- The amplification may not be a linear signal 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, called gain, multiplied by the input signal for all input frequencies. We saw previously that this multiplication factor is called the Beta, β value of the transistor.

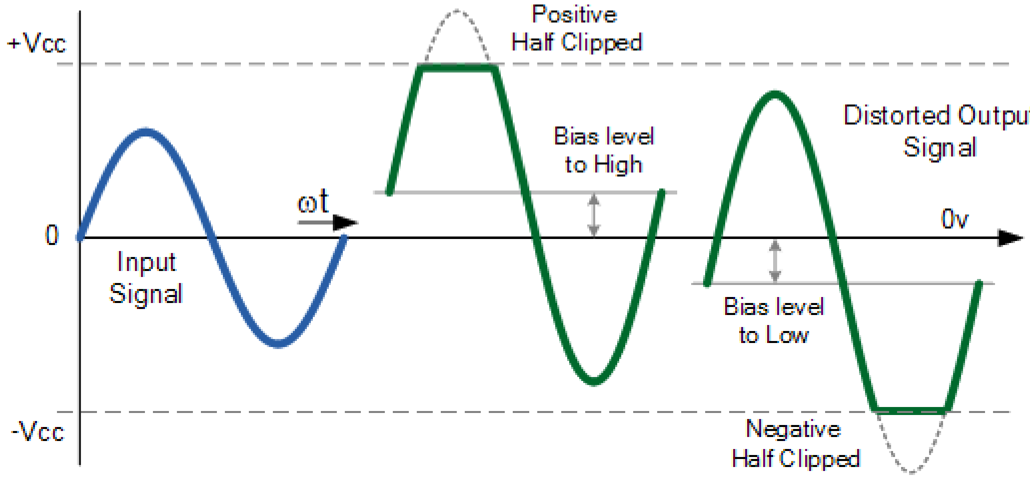
Common emitter or even common source type transistor circuits work fine for small AC input signals but suffer from one major disadvantage, the calculated position of the bias Q-point of a bipolar amplifier depends on the same Beta value for all transistors. However, this Beta value will vary from transistors of the same type; in other words, 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.

Then amplifier distortion occurs because the amplifier is not linear and a type of amplifier distortion called **Amplitude Distortion** will result. Careful choice of the transistor and biasing components can help minimize 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 transistors biasing point is correct, the output waveform should have the same shape as that of the input waveform only bigger, (amplified). If there is insufficient bias and the Q-point lies in the lower half of the load line, then the output waveform will look like the one on the right with the negative half of the output waveform "cut-off" or clipped. Likewise, if there is too much bias and the Q-point lies in the upper half of the load line, then the output waveform will look like the one on the left with the positive half "cut-off" or clipped.

Also, when the bias voltage is set too small, during the negative half of the cycle the transistor does not fully conduct so the output is set by the supply voltage. When the bias is too great the positive half 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.

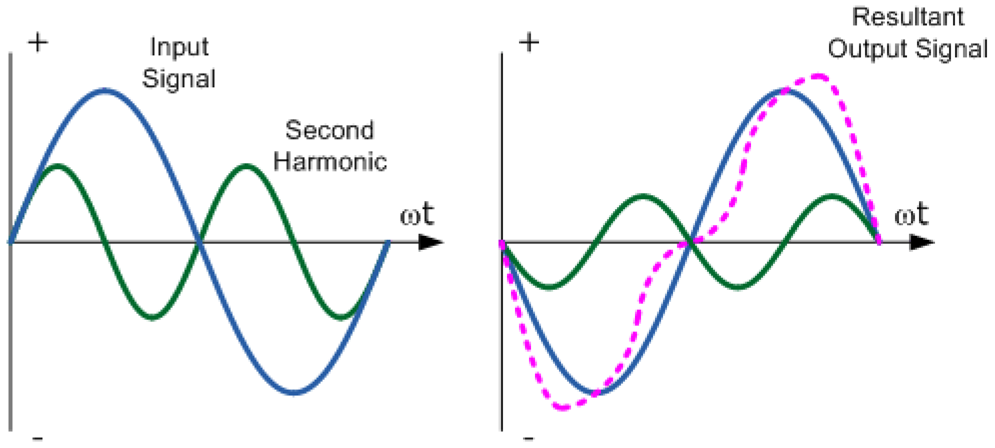
When the input amplitude becomes too large, the clipping becomes substantial and forces the output waveform signal to exceed the power supply voltage rails with the peak (+ve half) and the trough (-ve half) parts of the waveform signal becoming flattened or "Clipped-off". To avoid this maximum value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

Frequency Distortion

Frequency Distortion is another type of amplifier distortion which 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



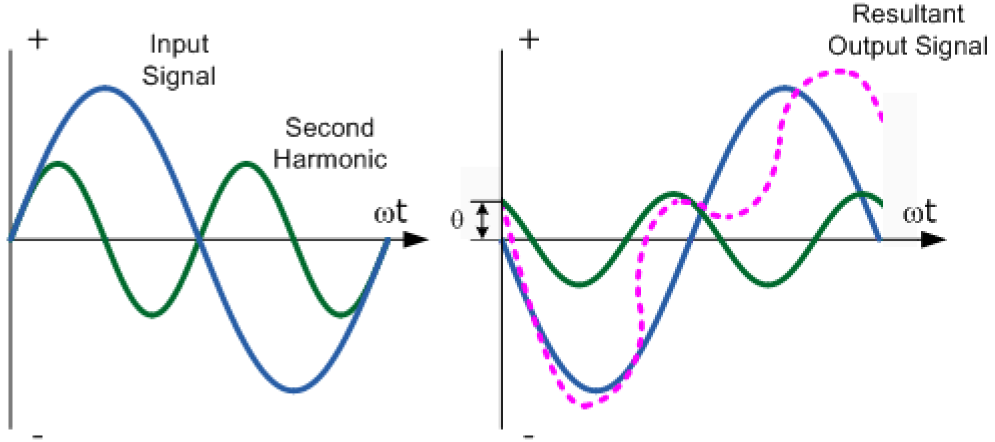
In the example above, the input waveform consists a the fundamental frequency plus a second harmonic signal. The resultant output waveform is shown on the right hand side. The frequency distortion occurs when the fundamental frequency combines with the second harmonic to distort the output signal. Harmonics are therefore multiples of the fundamental frequency and in our simple example a second harmonic was used.

Therefore, the frequency of the harmonic is twice 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** is a type of amplifier distortion which 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 say that the phase change between the input and the output is 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

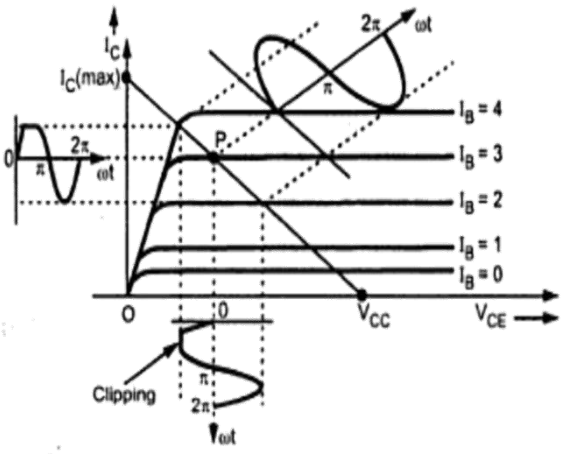


Other than high end audio amplifiers, most practical amplifiers will have some form of **Amplifier Distortion** being a combination of both "Frequency Distortion" and "Phase Distortion", together with amplitude distortion. In most applications such as in audio amplifiers or power amplifiers, unless the amplifiers distortion is excessive or severe it will not generally affect the operation

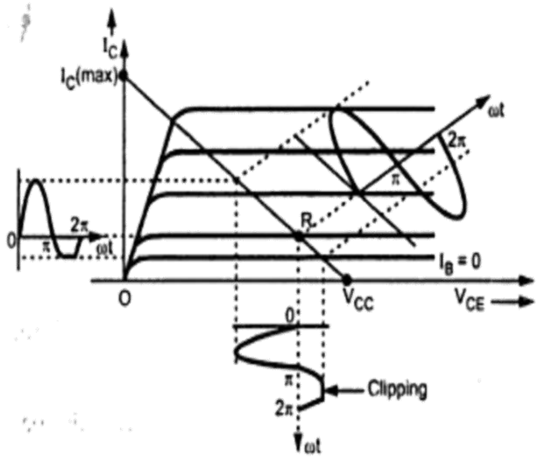
condition for Active & Saturation Regions

For Saturation region $I_B > \frac{Ic}{\beta dc}$

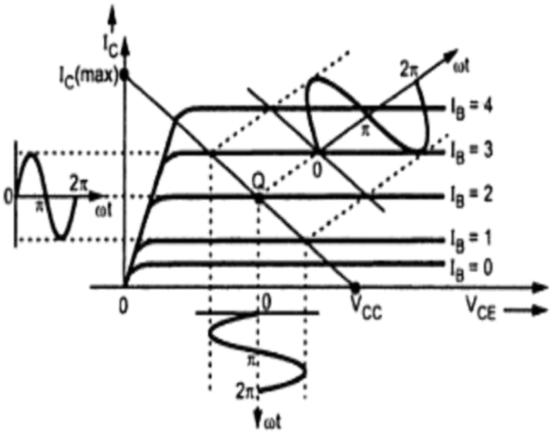
For Active region $V_{CE} > V_{CE\,(sat)}$



Operating point near saturation region gives clipping at the positive peaks

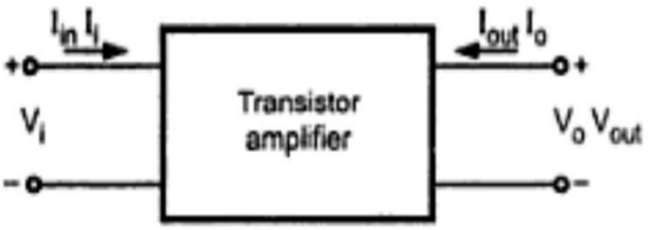


Operating point near cut-off region gives clipping at the negative peaks



Operating point at the centre of active region is most suitable

Analysis of CE, CC, and CB Configurations with simplified Hybrid Model:



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

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

Definitions of h-parameter

The parameters in the above equation are defined as follows :

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

$h_{12} = \left.\frac{V_i}{V_o}\right|_{I_i=0}$ = Fraction of output voltage at input with input open circuited.

This parameter is ratio of similar quantities, hence unitless

$h_{21} = \left.\frac{I_o}{I_i}\right|_{V_o=0}$ = Forward current transfer ratio or current gain with output short circuited.

This parameter is a ratio of similar quantities, hence unitless.

$h_{22} = \left.\frac{I_o}{V_o}\right|_{I_i=0}$ = Output admittance with input open-circuited, in mhos.

a) With output short circuited :

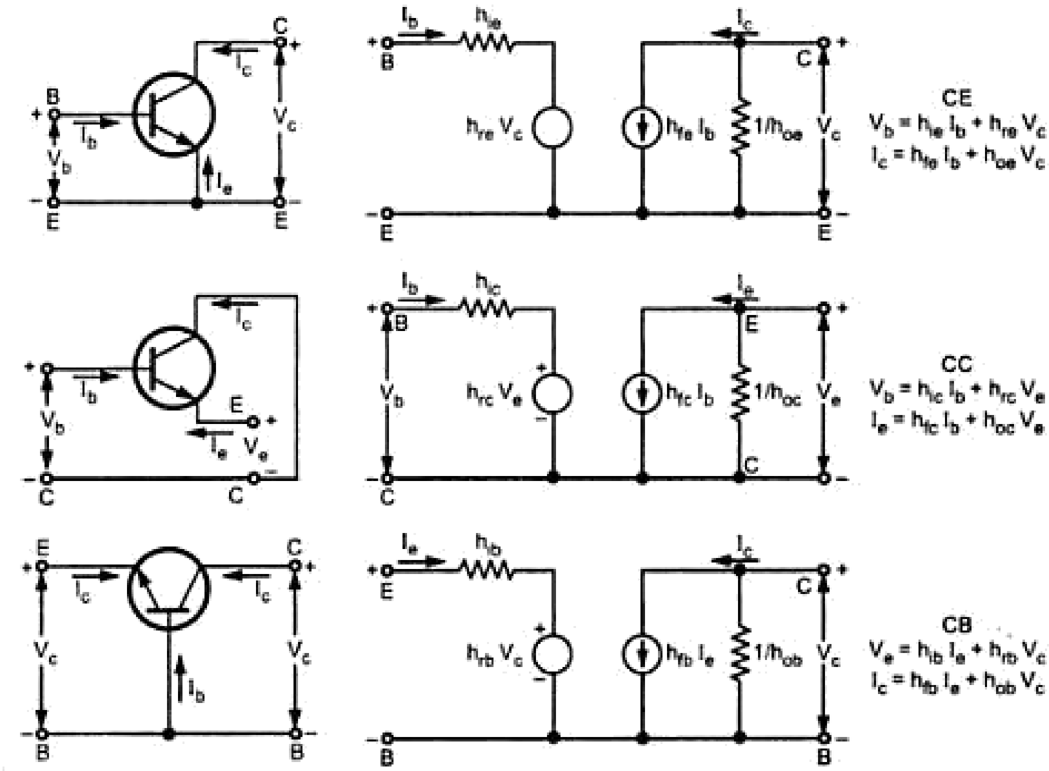
$h_{11} = h_i$: Input resistance

$h_{21} = h_f$: Short circuit current gain

b) With input open circuited :

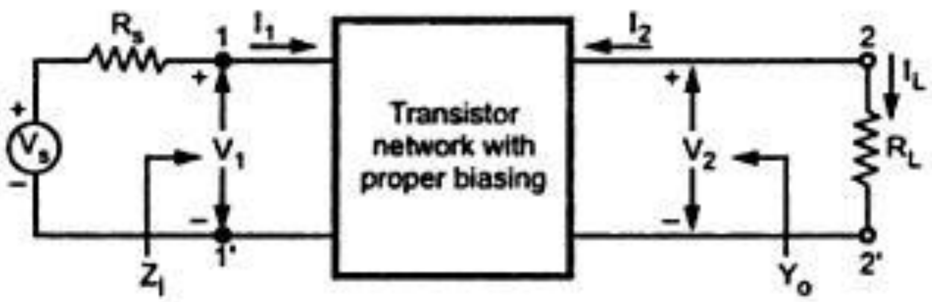
$h_{12} = h_r$: Reverse voltage transfer ratio

$h_{22} = h_o$: Output admittance

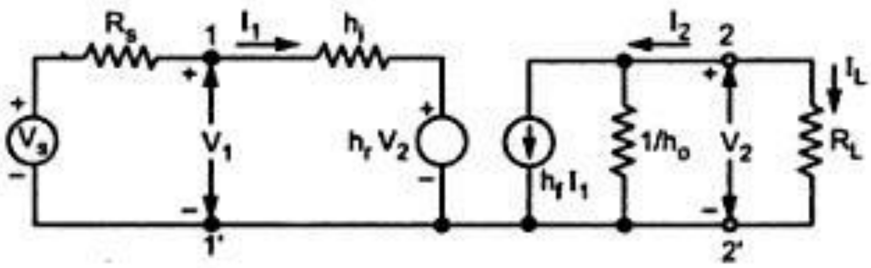


Transistor configurations and their hybrid models

Small Signal Analysis Of A Junction Transistor



Basic transistor amplifier



Transistor amplifier in its h-parameter model

Small signal analysis of a transistor model

$A_i = -\frac{hf}{1+hoRL}$
$A_{is} = \frac{AiRs}{Zi+Rs}$
$Z_i = h_i + h_r A_i R_L = h_i - \frac{hfhr}{ho+YL}$
$A_v = \frac{AiRs}{Zi}$
$A_{vs} = \frac{AvRi}{Zi+Rs} = \frac{AiRL}{Zi+Rs}$
$Y_0 = h_o - \frac{hfhr}{hi+Rs} = \frac{1}{Z0}$

Guidelines for analysis of a transistor circuit

1. Draw the circuit diagram
2. Replace C_c, C_e by short circuit
3. Replace dc source by short circuit
4. Replace the transistor by its h-parameter model

Analysis of CE amplifier with Emitter Resistance

Single stage CE amplifier

Fig shows a single stage CE amplifier. The different circuit elements and their functions are described as follows

.

(i) **Biasing circuit**: The resistances R_1, R_2 and R_E form the biasing and stabilization circuit.

(ii) **Input capacitance C_{in}** : This is used to couple the signal to the base of the transistor. If this is not used, the signal source resistance will come across R_2 and thus change the bias. The capacitor C_{in} allows only a.c. signal to flow.

(iii) **Emitter bypass capacitor C_E** : This is connected in parallel with R_E to provide a low reactance path to the amplified a.c. signal. If it is not used, then amplified a.c. signal flowing through R_E will cause a voltage drop across it, thereby shifting the output voltage.

iv) **Coupling capacitor C** : This is used to couple the amplified signal to the output device. This capacitor C allows only a.c. signal to flow.

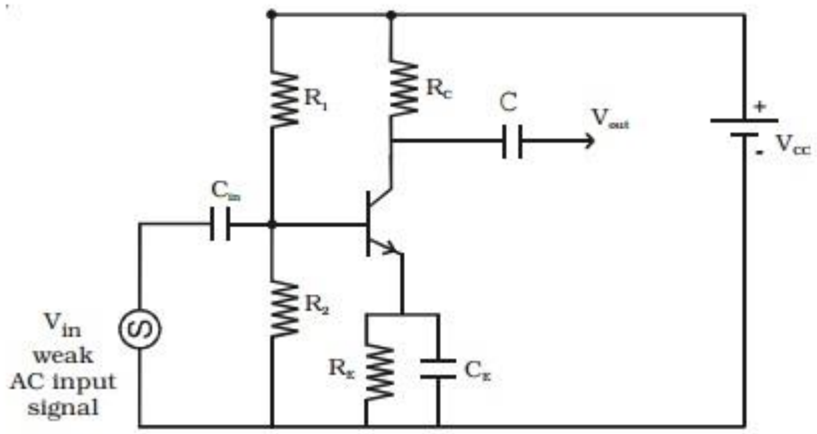


Fig Single stage CE amplifier

Working

When a weak input a.c. signal is applied to the base of the transistor, a small base current flows. Due to transistor action, a much larger a.c. current flows through collector load R_C, a large voltage appears across R_C and hence at the output. Therefore, a weak signal applied to the base appears in amplified form in the collector circuit. Voltage gain (A_v) of the amplifier is the ratio of the amplified output voltage to the input voltage.

Frequency response and bandwidth

The voltage gain (Av) of the amplifier for different input frequencies can be determined. A graph can be drawn by taking frequency (f) along X–axis and voltage gain (A_v) along Y–axis. The frequency response curve obtained will be of the form as shown in Fig. It can be seen that the gain decreases at very low and very high frequencies, but it remains constant over a wide range of mid-frequency region.

Lower cut off frequency (f_L) is defined as the frequency in the low 1

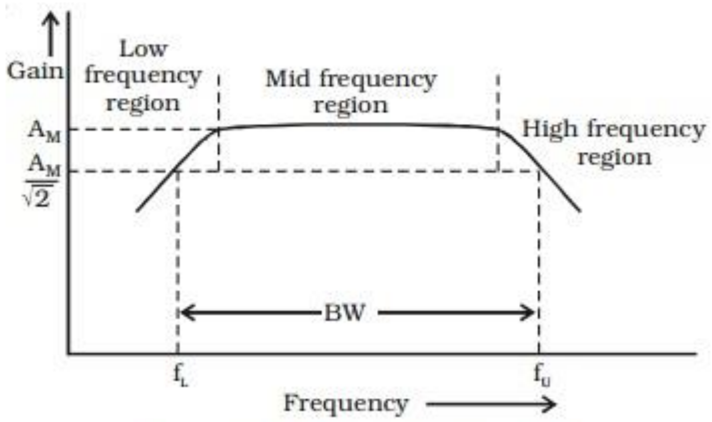


Fig Frequency response curve

frequency range at which the gain of the amplifier is $_2$ times the mid frequency gain (A_M). Upper cut off frequency (f_U) is defined as the frequency in the high frequency range at which the gain of the amplifier is 1/rt(2) times the mid frequency gain (A_M).

Bandwidth is defined as the frequency interval between lower cut off and upper cut off frequencies.

$$BW = f_U – f_L$$

Current Gain: $A_I = \frac{-h_f}{1+hoZ_L}$

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

Input Impedance $zi = \frac{hi-hfhr}{YL+h0}$

Output Admittance: $\therefore Y_0 = h_0 - \frac{h_f h_r}{h_i}$

Power Gain: $A_P = A_I^2 \left(\frac{R_L}{R_i}\right)$

Current Gain with Source Resistance: $A_{IS} = A_{VS} \cdot \frac{R_S}{Z_L}$

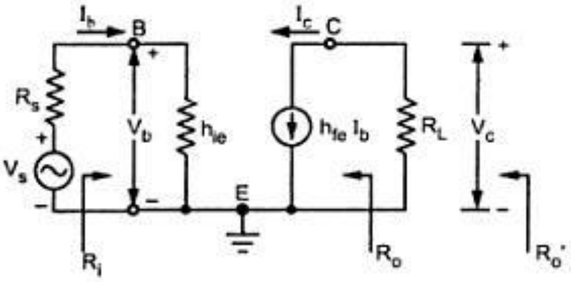
Voltage Gain with Source Resistance: $\therefore A_{VS} = \frac{A_I Z_L}{Z_i + R_S}$

Input Impedance with Source Resistance: $Z_{is} = R_s + Z_i$

Output Admittance with Source Resistance: $\therefore Y_0 = h_0 - \frac{h_f h_r}{R_S + h_i}$

Approximate H-Model For CE Amplifier

h-parameters of transistors are very much sensitive to the temperature therefore the number of h-parameters are minimized $1/h_{oe} >> R_L$ hence the parallel combination of h_{oe} and RL is equal to R_L, so it can be neglected h_{re} value is 0.1 to 0.01 the voltage generated by $h_{re}V_{ce}$<<drop across h_{ie} hence it is neglected the equivalent circuit formed with the other two h-parameters is as follows



Approximate CE model

Current Gain $A_i \approx -h_{fe}$

Input Impedance $R_i \approx h_{ie}$

Voltage Gain : $A_v = \frac{A_i R_L}{R_i} = \frac{A_i R_L}{h_{ie}}$

Output Impedance $Y_o = 0$

$R_o = \frac{1}{Y_o} = \infty$

$R'_o = R_o \parallel R_L = \infty \parallel R_L = R_L$

Characteristics of CE amplifier:

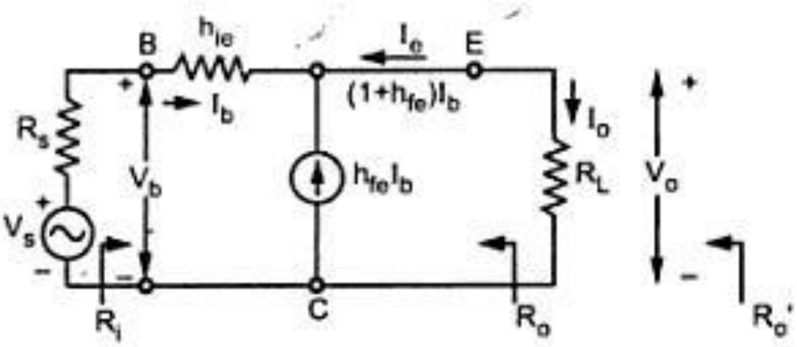
1. Large current gain.
2. Large voltage gain.
3. Large power gain.
4. Voltage phase shift of 180^0.
5. Moderate input impedance.
6. Moderate output impedance.

Applications:

Of the three configurations CE amplifier alone is capable of providing both voltage gain and current gain. The input resistance R_i and the output resistance Ro are moderately high.

Hence the CE amplifier is widely used for amplification purpose.

Approximate H-Model For CC Amplifie



Simplified CC model

Current gain $A_i = \frac{I_o}{I_b} = \frac{-I_e}{I_b} = 1 + h_{fe}$

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

Voltage gain (A_v) $A_v = \frac{(1 + h_{fe}) R_L}{h_{ie} + (1 + h_{fe}) R_L} \cong 1$

Output resistance R_o $R_o = \frac{V_o}{I_e} = \frac{R_s + h_{ie}}{1 + h_{fe}}$

$R'_o = R_o \parallel R_L = \infty \parallel R_L = R_L$

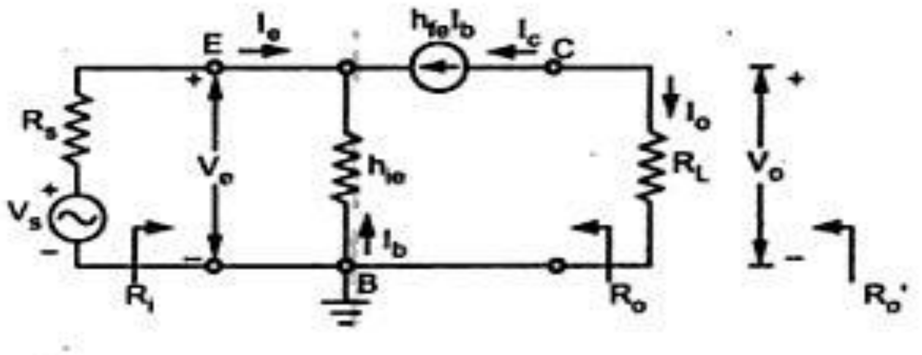
Characteristics of CC Amplifier:

1) High current gain.
2) Voltage gain of approximately unity.
3) Power gain approximately equal to current gain.
4) No current (or) voltage phase shift.
5) Large input impedance.
6) Small output impedance.

Applications:

The CC amplifier is widely used as a buffer stage between a high impedance source and a low impedance load. The CC amplifier is called the emitter follower

Approximate H-Model For CB Amplifier



Simplified CB model

Current gain $A_i = \frac{h_{fe}}{1 + h_{fe}}$

Input resistance (R_i) $R_i = \frac{h_{ie}}{1 + h_{fe}}$

Voltage gain (A_v) $A_v = \frac{\frac{h_{fe}}{1+h_{fe}} \times R_L}{\frac{h_{ie}}{1+h_{fe}}} \doteq \frac{h_{fe} R_L}{h_{ie}}$

Output resistance (R_o) $R_o = \left. \frac{V_o}{I_c} \right|_{V_S = 0}$

$$R'_o = R_o \parallel R_L = \infty \parallel R_L = R_L$$

Characteristics of CB Amplifier:

i) Current gain of less than unity.

ii) High voltage gain.

iii) Power gain approximately equal to voltage gain.

iv) No phase shift for current (or) voltage.

v) Small input impedance.

iv) Large output impedance.

Applications:

1) Matching a very low impedance source.

2) As a non-inverting amplifier with voltage gain exceeding unity.

3) For driving a high impedance load.

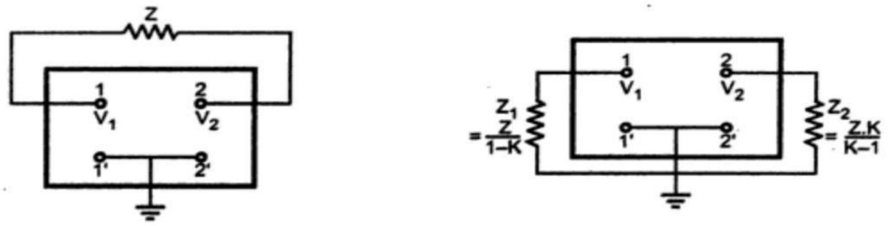
4) As a constant current source.

Miller's Theorem

Miller's theorem is used to simplify the analysis of a circuit whenever there is a feedback connection in the circuit

The Miller theorem establishes that in a linear circuit, if there exists a branch with impedance *Z*, connecting two nodes with nodal voltages V_1 and V_2, we can replace this branch by two branches connecting the corresponding nodes to ground by impedances respectively

$$Z/(1 - K) \text{ and } KZ/(K - 1), \text{ where } K = V_2/V_1.$$



(a) (b)

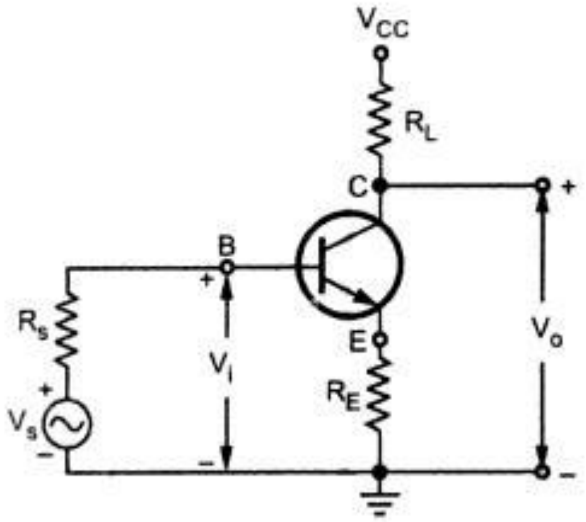
$$Z_1 = \frac{Z}{1-K} \qquad Z_2 = \frac{Z \cdot K}{K-1}$$

Miller theorem implies that an impedance element is supplied by two arbitrary (not necessarily dependent) voltage sources that are connected in series through the common ground. In practice, one of them acts as a main (independent) voltage source with voltage $V_1$and the other – as an additional (linearly dependent) voltage source with voltage . The idea of Miller theorem (modifying circuit impedances seen from the sides of the input and output sources) is revealed below by comparing the two situations – without and with connecting an additional voltage source V_2.

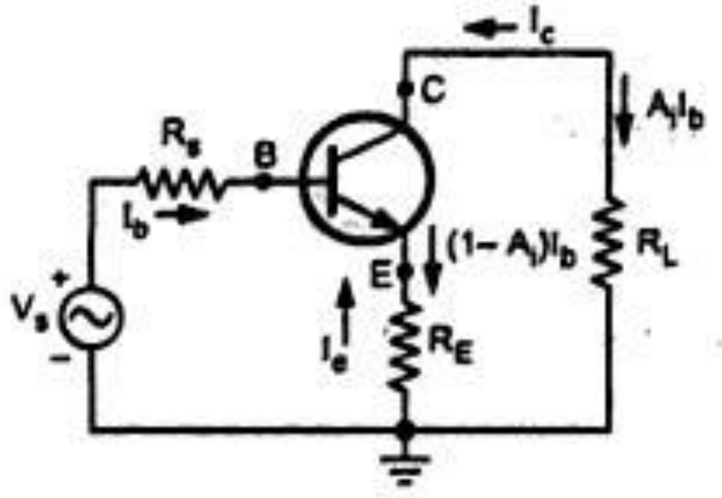
If V_2 was zero (there was not a second voltage source or the right end of the element with impedance *Z* was just grounded), the input current flowing through the element would be determined, according to Ohm's law, only by V_1 and the input impedance of the circuit would be As a second voltage source is included, the input current depends on both the voltages. According to its polarity, V_2 is subtracted from or added to V_1; so, the input current decreases/increases and the input impedance of the circuit seen from the side of the input source accordingly increases/decreases

Miller theorem expresses the fact that connecting a second voltage source with proportional voltage in series with the input voltage source changes the effective voltage, the current and respectively, the circuit impedance seen from the side of the input source. Depending on the polarity, V_2 acts as a supplemental voltage source helping or opposing the main voltage source to pass the current through the impedance.

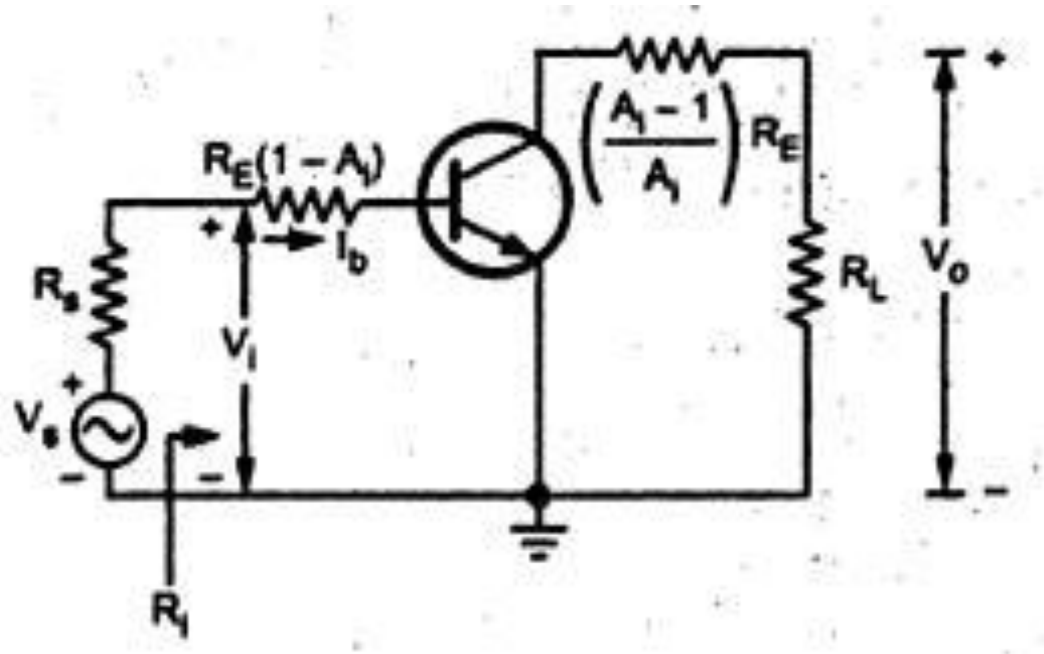
Analysis Of CE Amplifier With Unbypassed RE



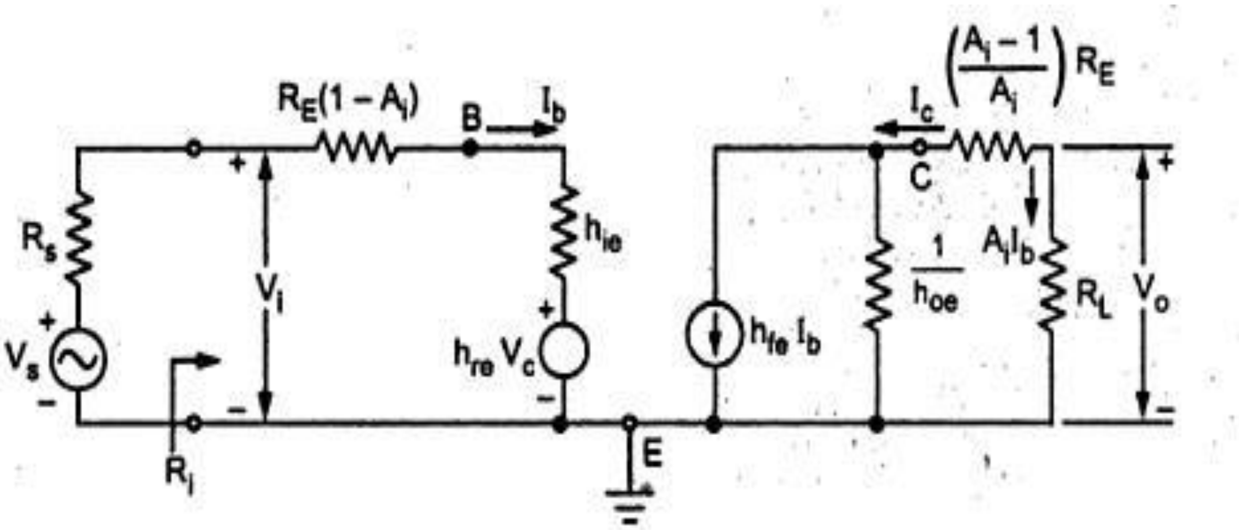
- R_E is added to stabilize the gain of the amplifier
- R_E acts as a feedback resistor
- The overall gain will reduce with unbiased R_E



<u>AC Equivalent Circuit For CE Amplifier with RE Splitted</u>
using dual of Miller's Theorem

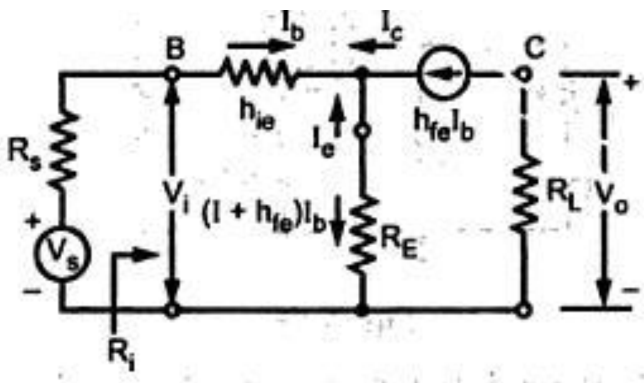


h-Parameter Equivalent Circuit
(Exact Analysis)



$$A_i = \frac{-h_{fe}}{1 + h_{oe} R'_L} = \frac{-h_{fe}}{1 + h_{oe}\left(R_L + \frac{A_i - 1}{A_i} R_E\right)}$$

h-Parameter Equivalent Circuit
(Approximate Analysis)



Approximate model for CE amplifier with R_E

Input resistance $R_i = \frac{V_i}{I_b} = h_{ie} + (1 + h_{fe}) R_E$

Current gain $A_i = \frac{-I_c}{I_b} = \frac{-h_{fe} I_b}{I_b} = -h_{fe}$

Voltage gain $A_v = \frac{A_i R_L}{R_i} = \frac{-h_{fe} R_L}{h_{ie} + (1 + h_{fe}) R_E}$

Output resistance $R_o = \left. \frac{V_o}{I_o} \right|_{V_s = 0}$

$R'_o = R_o \,||\, R_L = \infty \,||\, R_L = R_L$

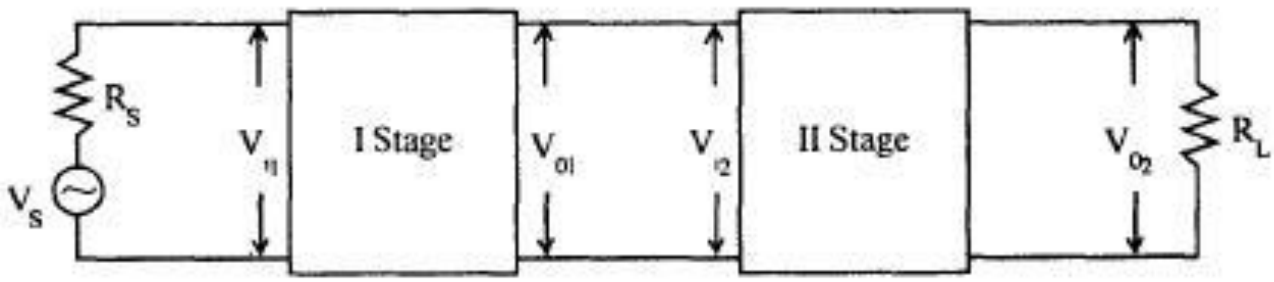
MULTISTAGE AMPLIFIERS

Need For Cascading

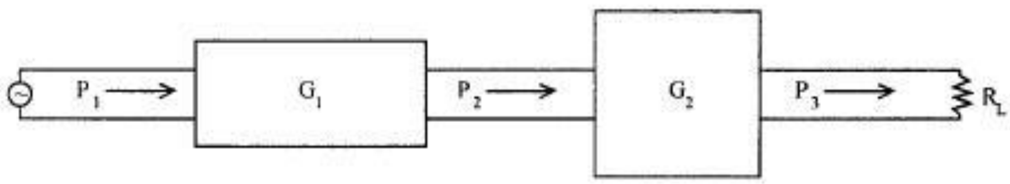
- When the amplification of single stage amplifier is not sufficient, or,
- When the input and output impedance is not of the correct magnitude ,for a particular application

, two or more amplifier stages are connected, in cascade. such amplifiers are called Multistage amplifier.

Block diagram of 2-Stage Cascade Amplifier



Gain of 2-Stage Cascade Amplifier



$$G_1 = \frac{P_2}{P_1}; \quad G_2 = \frac{P_3}{P_2}$$

Overall gain $$G = \frac{P_3}{P_1}$$

$$= \frac{P_2}{P_1} \cdot \frac{P_3}{P_2}$$

$$\mathbf{G = G_1 G_2}$$

Decibel Voltage Gain

Cascaded Stages

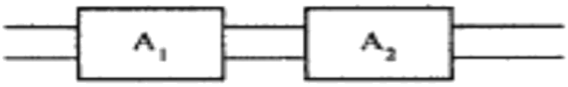


Fig. 2.23 Cascaded stages

$$A = A_1 \times A_2$$

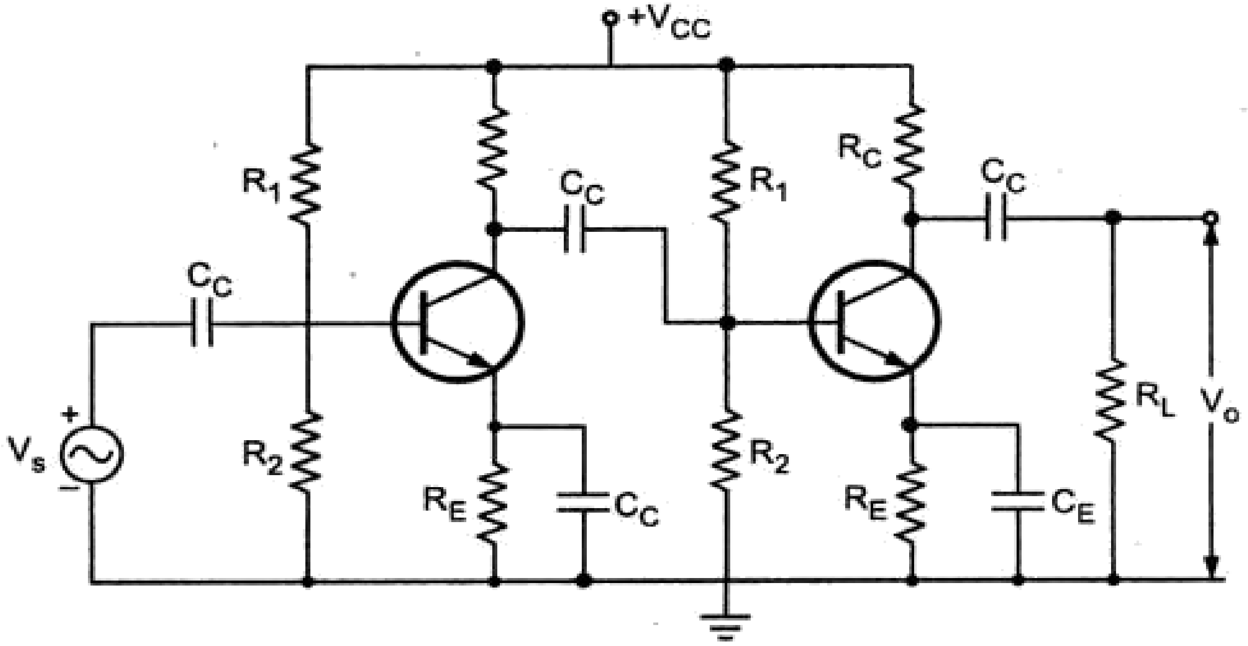
$$A_1 = A_1' + A_2' \text{ (in decibels)}$$

Methods of Coupling

In Multistage amplifiers, the output signal of preceding stage is to be coupled to input circuit of succeeding stage .For this interstate coupling ,different types of coupling devices can be employed. They are

- .RC coupling
- .Transformer Coupling
- Direct Coupling

Analysis of multistage amplifier usingRC coupling



Two stage RC coupled amplifier using transistors

One way to connect various stages of a multistage amplifier is via capacitors, as indicated in the two-stage amplifier where two stages of common emitter amplifiers are coupled to each other by the capacitor C3

In RC-coupled amplifiers:

- The various stages are DC isolated. This feature facilitates the biasing of individual stages.
- The various stages can be similar. Hence the design of the amplifier is simplified.
- The coupling capacitors influence the responses of the amplifier.
- A great number of biasing resistors is necessary.

The most commonly used coupling in amplifiers is RC coupling. An RC-coupling network is shown in the illustration above.

The network of R1, R2, and C1 enclosed in the dashed lines of the figure is the coupling network. You may notice that the circuitry for Q1 and Q2 is incomplete. That is intentional so that you can concentrate on the coupling network. R1 acts as a load resistor for Q1 (the first stage) and develops the output signal of that stage. Do you remember how a capacitor reacts to ac and dc? The capacitor, C1, "blocks" the dc of Q1's collector, but "passes" the ac output signal. R2 develops this passed, or coupled, signal as the input signal to Q2 (the second stage).

The **COMMON-EMITTER CONFIGURATION (CE)** is the most frequently used configuration in practical amplifier circuits, since it provides good voltage, current, and power gain. The input to the CE is applied to the base-emitter circuit and the output is taken from the collector-emitter circuit, making the emitter the element common" to both input and output. The CE is set apart from the other configurations, because it is the only configuration that provides a phase reversal between input and output signals. a coupling capacitor C_C is used to connect the output of first stage to the base i.e. input of the second stage and this continues when more stages are connected.

Since here the coupling from one stage to next is achieved by a coupling capacitor followed by a connection to a shunt resistor, therefore, such amplifiers are known as resistance-capacitance coupled amplifier or simply RC coupled amplifier.

- The resistances R_1, R_2 and R_E form the biasing and stabilization network.
- The emitter bypass capacitor offers a low resistance path to the signal. Without this capacitor the voltage gain of each stage would be lost.
- The coupling capacitor C_C transmits a.c. signal but blocks d.c. This prevents d.c. interference between various stages and the shifting of operating point.
- Working of RC Coupled Amplifier

When a.c. signal is applied to the base of the first transistor, it is amplified and appears across its collector load R_C. Now the amplified signal developed across R_C is given to the base of the next transistor through a coupling capacitor C_C .The second stage again amplifies this signal and the more amplified signal appears across the second stage collector resistance.

In this way the cascaded stages amplify the signal and the overall gain is considerably increased.

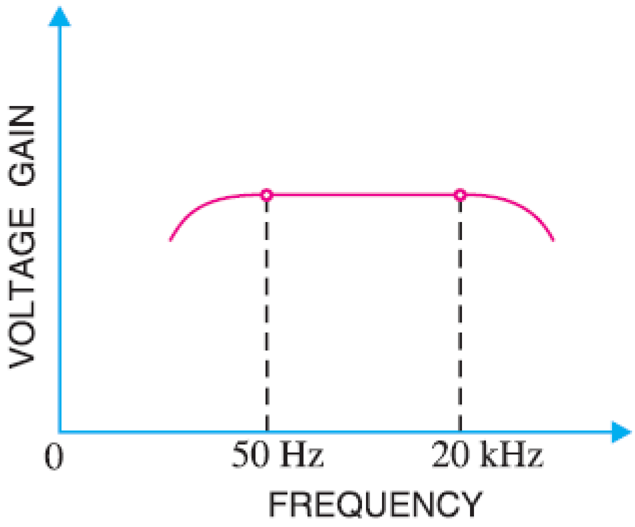
However, the total gain is less than the product of the gains of individual stages. It is because, when a second stage follows the first stage, the effective load resistance of first stage is reduced due to the shunting effect of the input resistance of second stage. This reduces the gain of the stage which is loaded by the next stage.

To explain it better, let us take an example of 3-stage amplifier. The gain of first and second stage will be reduced due to loading effect of the next stage. But the gain of the third stage which has no loading effect due to subsequent stage, remains unchanged.

The overall gain is equal to the product of the gains of three stages.

Frequency Response of RC Coupled Amplifier

The figure below shows the frequency response of a typical RC coupled amplifier.



This behavior of the amplifier can be explained as follows:

(i) At Low Frequencies

At low frequencies i.e. below 50 Hz, the reactance of coupling capacitor C_C is quite high and hence very small part of the signal will pass from one stage to the next stage.

Again C_E cannot shunt the emitter resistance R_E effectively because of its large reactance at low frequencies.

These two factors cause the dropping of voltage gain at low frequencies.

(ii) At High Frequencies

At high frequencies i.e. above 20 KHz, the reactance of coupling capacitor C_C is quite small and hence it behaves as a short circuit. This increases the loading effect of next stage and results in decreased voltage gain.

Again at high frequencies, capacitive reactance of base-emitter junction is low which in result increases the base current. This causes decrease in current amplification factor β.

These two factors cause the dropping of voltage gain at high frequencies.

(iii) At Mid Frequencies

At mid frequencies i.e. between 50 Hz to 20 KHz, the voltage gain of the amplifier is constant. The effect of coupling capacitor in this frequency range is such that the voltage gain remains uniform. As the frequency increases in this range, reactance of C_C decreases which in result increases the gain. However, at the same time lower reactance means higher loading effect of first stage to the next one and hence gains decreases.

Thus, these two factors almost cancel each other, resulting in an uniform gain at this mid frequency.

Advantages of RC Coupled Amplifier

1. It has a great frequency response. The gain is uniform over the audio frequency range which is important for speech, music etc.
2. It employs only resistors and capacitors which are cheap, hence, it has low cost.
3. The circuit is very compact due to the small size and light weight of resistors and capacitors.

Disadvantages of RC Coupled Amplifier

1. The RC coupled amplifiers have low voltage and power gain. Because, the low resistances presented by the input of each stage to the subsequent stage decreases the effective load resistance and hence decreases the gain.
2. These amplifiers become noisy with age, particularly due to moist.
3. Impedance matching is poor because the output impedance of RC coupled amplifier is several hundred ohms whereas the input impedance of a speaker is only few ohms.

Application of RC Coupled Amplifier

Used as voltage amplifiers for example in the initial stages of public address system.

If other type of coupling such as transformer coupling is used in the initial stages, this results in frequency distortion which may be amplified in the next stage.

But, due to its poor impedance matching, it is rarely used in the final stages.

- If the effective load resistance of each stage could be increased, the voltage and power gain could also be increased.
- This can be achieved by transformer coupling. By using the impedance matching properties of transformer, the low resistance of one stage or load can be reflected as a high load resistance to the previous stage.
- Transformer coupling is normally used when the load is small. It is mostly used for poweramplificatio

TRANSFORMER COUPLED AMPLIFIER

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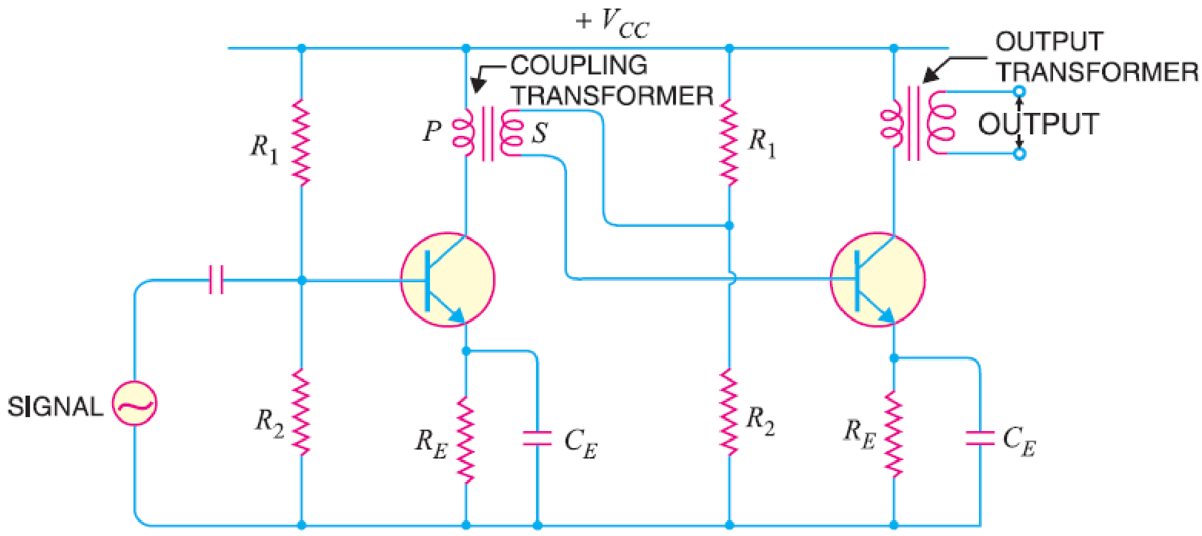
The figure below shows the circuit of a two stage transformer coupled amplifier.

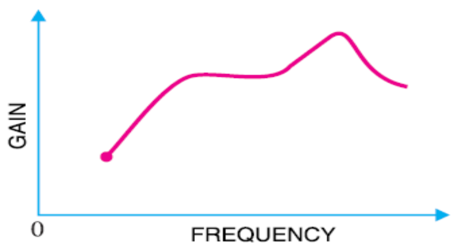


The primary P of this transformer is made the collector load and its secondary S supplies input to the next stage. When an a.c. signal is applied to the base of first transistor, it appears in the amplified form across the primary P of the coupling transformer.

Now the voltage developed across P is transferred to the input of the next stage by the transformer secondary S. The second stage now performs the amplification in an exactly same manner.

Frequency Response of Transformer Coupled Transistor Amplifier

The frequency response of a transformer coupled amplifier is shown in the figure below.



It is clear from the above fig. that its frequency response is poor than the RC coupled amplifier. The gain is constant only over a small range of frequency.

Since, the output voltage is equal to the collector current multiplied by reactance of primary, hence at low frequencies, as the reactance of primary begins to fall , the output voltage also decrease and hence the gain.

At high frequencies, the capacitance between turns of windings acts as a bypass condenser to reduce the output voltage and hence the gain.

Due to these two factors, there will be disproportionate amplification of frequencies in a complete signal such as music, speech etc.

Hence, transformer coupled amplifier introduces frequency distortion.

Advantages of Transformer Coupled Transistor Amplifier

1. There is no loss of signal power in the collector or base resistors.
2. An excellent impedance matching can be achieved in a transformer coupled amplifier.
3. Due to excellent impedance matching, transformer coupling provides higher gain. A properly designed single stage transformer coupling can provide the gain of two stages of RC coupling.

Disadvantages of Transformer Coupled Transistor Amplifier

1. It has a poor frequency response.
2. The coupling transformers are bulky and expensive at audio frequencies.
3. Frequency distortion is higher i.e. low frequency signals are less amplified as compared to the high frequency signals.
4. Transformer coupling introduces hum in the output.

Application of Transformer Coupled Transistor Amplifier

It is mostly used for impedance matching. Normally the last stage of a multi stage amplifier is the power stage. Here it is required to transfer maximum power to the output device for example a loud speaker. Usually the impedance of an output device is few ohms whereas the output impedance of the transistor is several hundred ohms. In order to match the impedance, a step down transformer of proper turn ratio is used. The impedance of secondary of the transformer is made equal to the load impedance and primary impedance equal to the output impedance of the transistor. Thus the load on the primary side is comparable to the output impedance of the transistor and this result in maximum power transfer from the transistor to the primary of transformer.

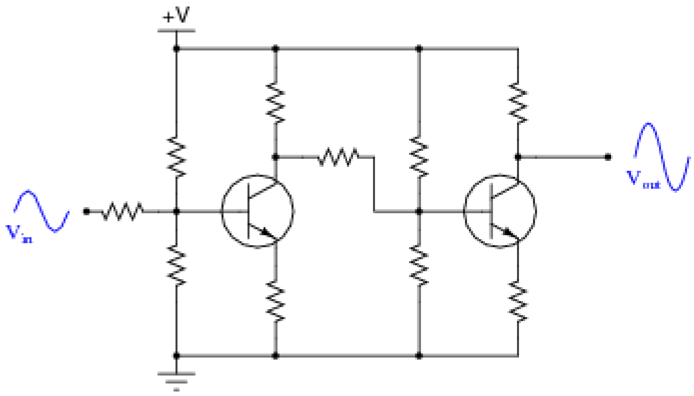
Direct Coupled Transistor Amplifier

There are many applications in which extremely low frequency signals i.e. below 10 Hz are to be amplified, for example, amplifying photo-electric current, thermo-couple current etc. In such applications, use of coupling devices such as capacitors and transformers makes such amplifiers bulky due to the large electrical size of these components at low frequencies.

Hence, in such cases, one stage is directly connected to the next stage without any intervening coupling device. This type of coupling is known as direct coupling.

Working

The figure below shows the circuit of a three-stage direct coupled amplifier.



This circuit uses complementary transistors, which makes the circuit stable with respect to temperature changes. The first stage uses NPN transistor, the second stage uses PNP transistor and so on the output from the collector of first transistor T_1 is fed to the second transistor T_2 and so on.

The weak signal is applied to the input of first transistor T_1 . Due to transistor action, an amplified output is obtained across the collector load R_C of T_1.

Now this voltage drives the base of the second transistor T_2 and produce amplified output at its collector load.

In this way, direct coupled amplifier raises the strength of weak signal.

Advantages of Direct Coupled Transistor Amplifier

1. Circuit is simple because of minimum use of resistors.
2. Cost is low because of the absence of expensive coupling devices

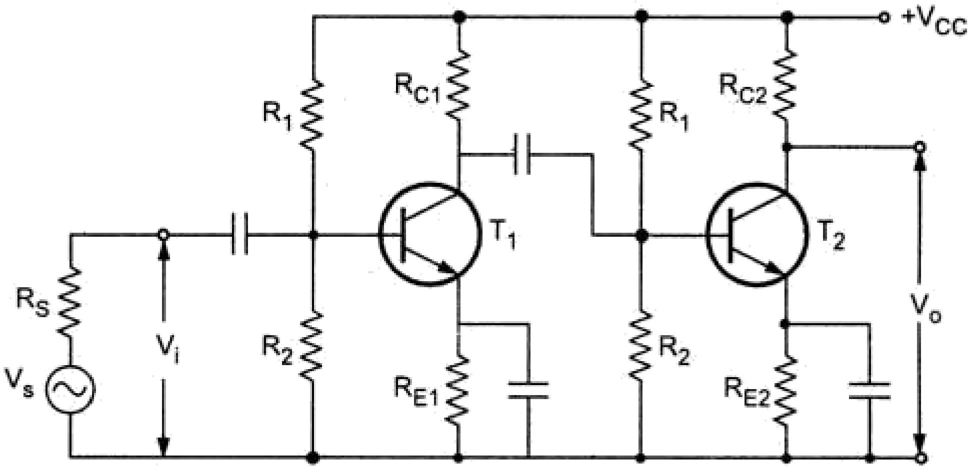
Disadvantages of Direct Coupled Transistor Amplifier

1. This amplifier cannot be used for amplifying high frequency signals.
2. The operating point is shifted due to temperature variations.

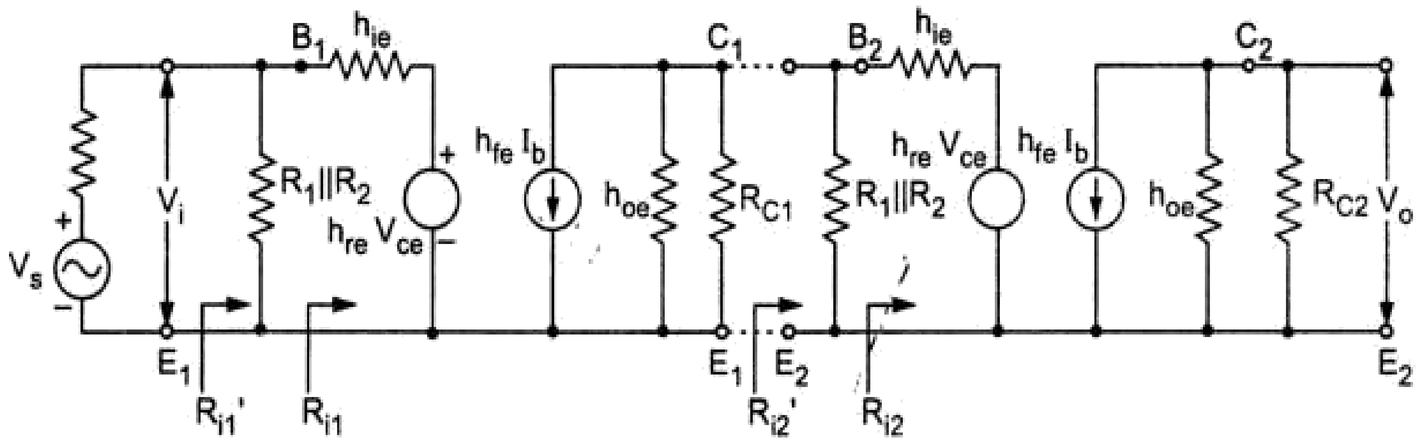
COMPARISION OF COUPLING DEVICES

PARAMETER	RC COUPLED	TRANSFORMER COUPLED	DIRECT COUPLED
Coupling Components	Resistor& Capacitor	Transformers	-
Block DC	yes	yes	No
Frequency Response	Flat at mid frequencies	Not Uniform, high at resonant frequency and low at other frequencies	Flat at mid frequencies and improvement in low frequency response
Impedance Matching	No	Yes	No
DC amplification	No	No	Yes
Weight	Light	Bulky & heavy	Very Light
Drift	Not present	present	Not present
Hum	Not present	present	Not present
Application	Used in record players, tape recorders	Impedance Matching	Used in amplification of slow varying parameters

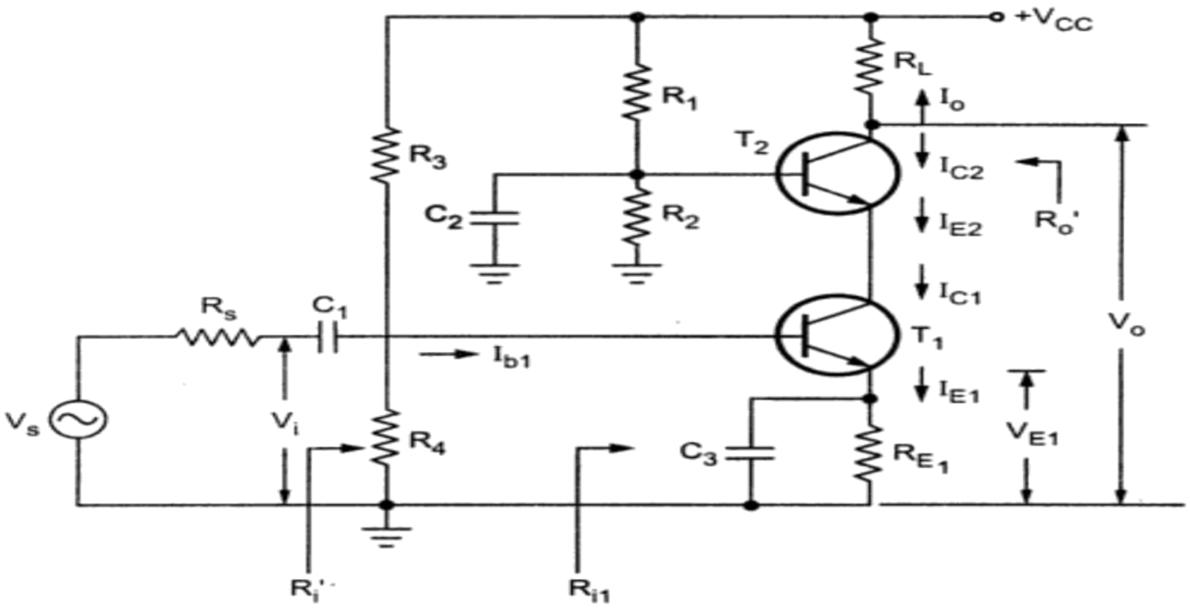
CE –CE CASCADE AMPLIFIER



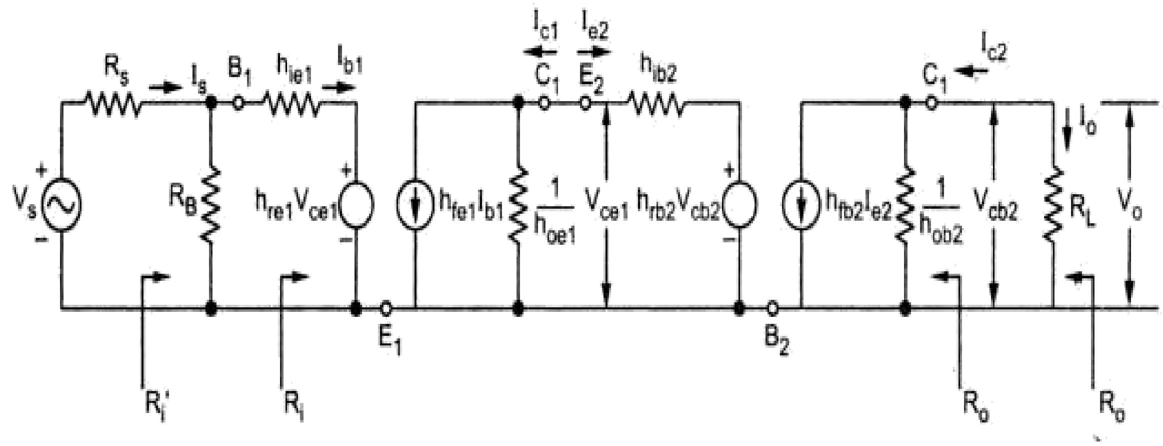
Equivalent circuit of CE –CE CASCADE AMPLIFIER



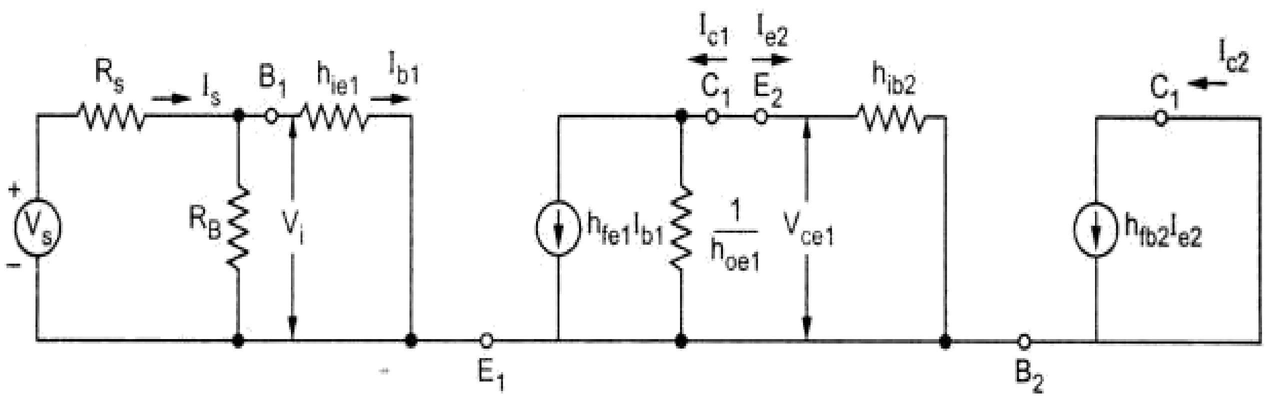
Cascode Amplifier



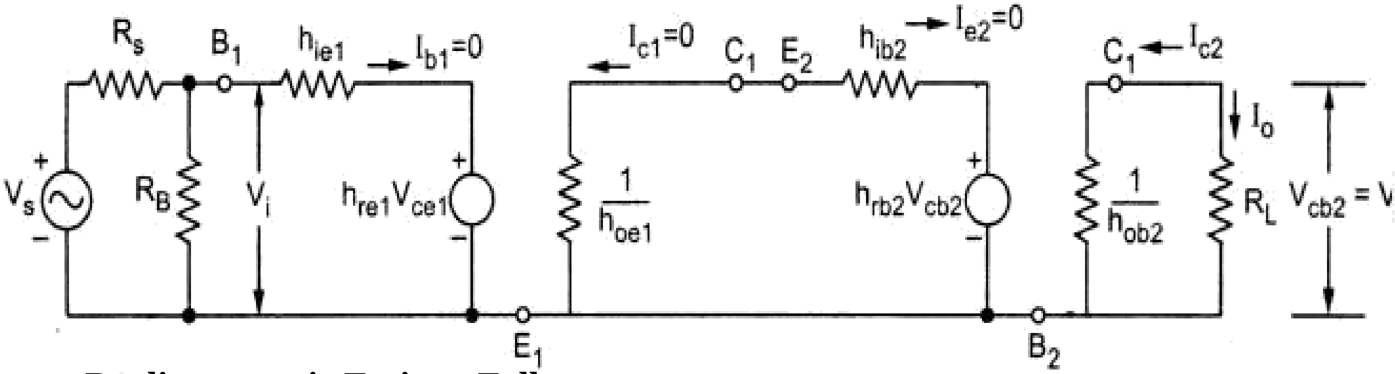
Equivalent circuit



H-parameter equivalent circuit when output short circuited

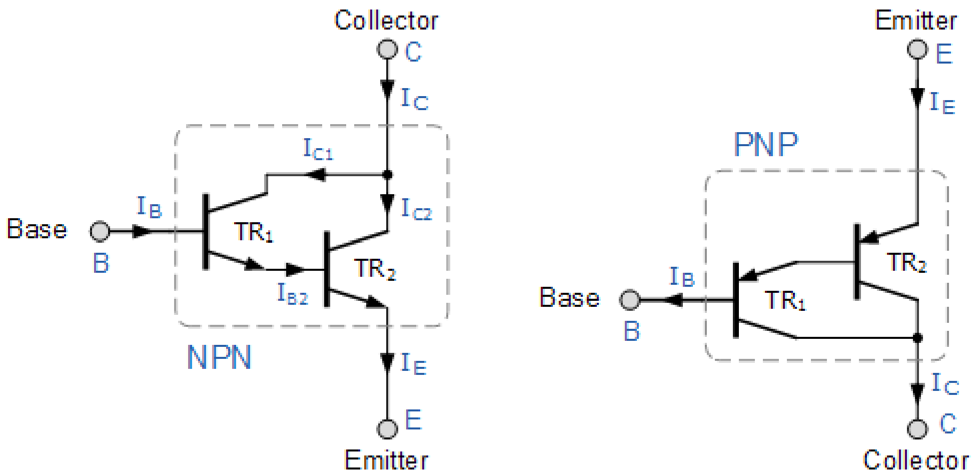


H-parameter equivalent circuit when ib =0



Darlington pair Emitter Follower

A **Darlington Transistor** configuration, also known as a "Darlington pair" or "super-alpha circuit", consist of two NPN or PNP transistors connected together so that the emitter current of the first transistor TR1 becomes the base current of the second transistor TR2. Then transistor TR1 is connected as an emitter follower and TR2 as a common emitter amplifier as shown below.



Also note that in this Darlington pair configuration, the collector current of the slave or control transistor, TR1 is "in-phase" with that of the master switching transistor TR2.

Basic Darlington Transistor Configuration

Using the NPN Darlington pair as the example, the collectors of two transistors are connected together, and the emitter of TR1 drives the base of TR2. This configuration achieves β multiplication because for a base current i_b, the collector current is $\beta.i_b$ where the current gain is greater than one, or unity and this is defined as:

$$I_C = I_{C1} + I_{C2}$$
$$I_C = \beta_1.I_B + \beta_2.I_{B2}$$

But the base current, I_{B2} is equal to transistor TR1 emitter current, I_{E1} as the emitter of TR1 is connected to the base of TR2. Therefore:

$$I_{B2} = I_{E1} = I_{C1} + I_B = \beta_1.I_B + I_B = (\beta_1 + 1).I_B$$

Then substituting in the first equation:

$$I_C = \beta_1.I_B + \beta_2.(\beta_1 + 1).I_B$$

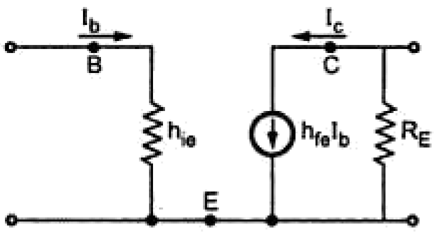
$$I_C = \beta_1.I_B + \beta_2.\beta_1.I_B + \beta_2.I_B$$

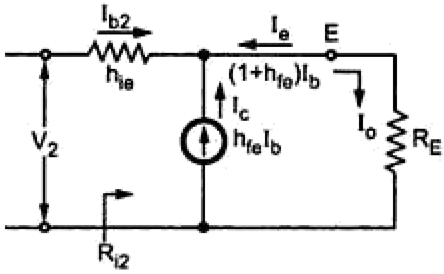
$$I_C = \left(\beta_1 + (\beta_2.\beta_1) + \beta_2\right).I_B$$

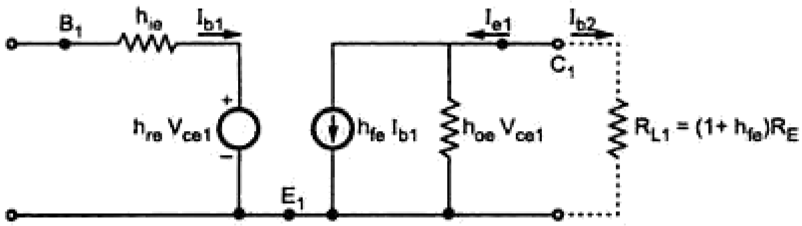
Where β_1 and β_2 are the gains of the individual transistors.

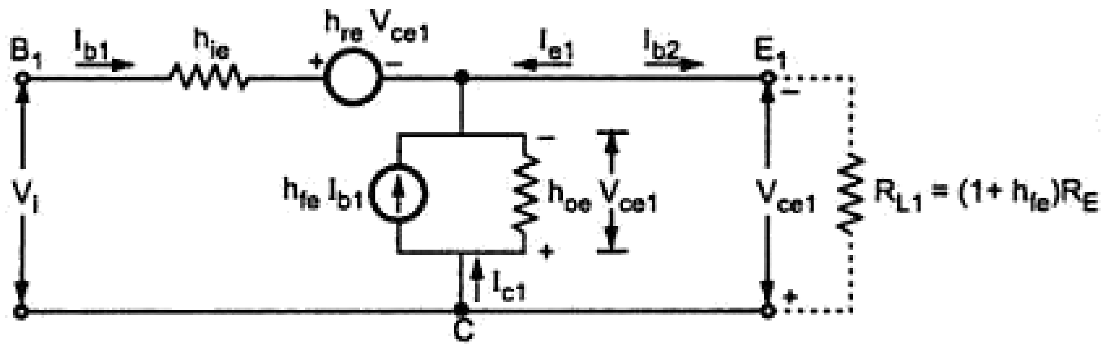
This means that the overall current gain, β is given by the gain of the first transistor multiplied by the gain of the second transistor as the current gains of the two transistors multiply. In other words, a pair of bipolar transistors combined together to make a single Darlington transistor pair can be regarded as a single transistor with a very high value of β and consequently a high input resistance.

Equivalent circuits of both stages separately









Parameter	Single stage	Darlington
Input Resistance	$R_i = (1 + h_{fe})\, R_E = 168.3\ k\Omega$	$R_i = \frac{(1+h_{fe})^2 R_E}{1+h_{oe}(1+h_{fe}) R_E} \approx 1.65\ M\Omega$
Current Gain	$A_i = 1 + h_{fe} = 51$	$A_i = \frac{(1+h_{fe})^2}{1+h_{oe}(1+h_{fe}) R_E} \approx 500$

UNIT – II

BJT Amplifiers-Frequency Response: Logarithms, Decibels, General frequency considerations, Frequency response of BJT Amplifier, Analysis at low and high frequencies, Effect of coupling and bypass capacitors. The Hybrid pi model –Common Emitter Transistor Model, CE Short Circuit current gain, current gain with resistive load, Single stage CE transistor Amplifier Response, Gain –Bandwidth Product, Emitter follower at high frequencies.

LOGARITAHMS:

In this field there is no escaping the need to become comfortable with the logarithmic function. The plotting of a variable between wide limits comparing levels with out having to deal with un widely numbers and identifying levels of a particular importance in the design, review &analysis procedures are all positive features of using the logarithmic function.

As first step in classifying the relationship between the variables of a logarithmic function, consider the following mathematical equations

$$a=b^x \text{ , } X=\log b^a$$

The variables a, b &x are the same in each equation .if we are taking b=10, x=2

$a=b^x= (10)^2=100$

$x= \log_b a=\log_{10} a=\log_{10}(100)=2$

Logarithmic s taken to the base 10 are related to as a common logarithms, where as logarithms to the base e are related to as natural logarithms.

Common logarithm: $x=\log_{10} a$

Natural logarithm: $x=\log_e a$

GAIN:

Gain is defined as the ratio of output voltage to the input voltage . the gain of multi stage is defined as the product of the individual gains of all the stages.

$$G=G_{1*} G_{2*} G_{3*} G_{4*}\ldots\ldots\ldots\ldots. G_N$$

it is defined as such that overall gain is less than the product of all the gains of all stages due to loading effect

DECIBEL GAIN:

Gain is expressed in number, sometimes it is expressed in the unit of bel (or decibel). The common logarithm of power gain is known as bel power gain.

$$\text{Bel power gain} =\log_{10} (p_{out}/p_{in})$$

$$\text{Power gain in db}= 10 \log_{10} (p_{out}/p_{in}) \text{ db} \quad (1 \text{ bel}=10 \text{ db})$$

Voltage gain =20 $\log_{10}$ (v_{out}/v_{in}) db

Current gain = 20 $\log_{10}$ (I_{out}/I_{in}) db

GENERAL FREQUENCY CONSIDERATIONS:

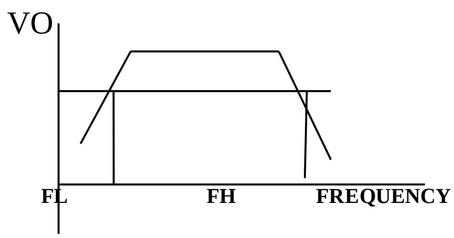
This play very important role in the analysis (or) designing of the amplifier. This is used to study the performance of the amplifiers.

The typical plot of the output voltage gain of an amplifier as a function of frequency.

Normally the output remains constant over arrange of frequencies called middle range. Falls off frequencies called as lower and upper cut-off frequencies

The gain in the middle range is called the mid-frequency gain. the low and high frequencies at which the gain falls to 0.707 of its mid frequency value are denoted by f_l & f_h.

(Fl -$f_{h)}$ is called the bandwidth of the amplifier it is considered to be the useful range of frequencies.

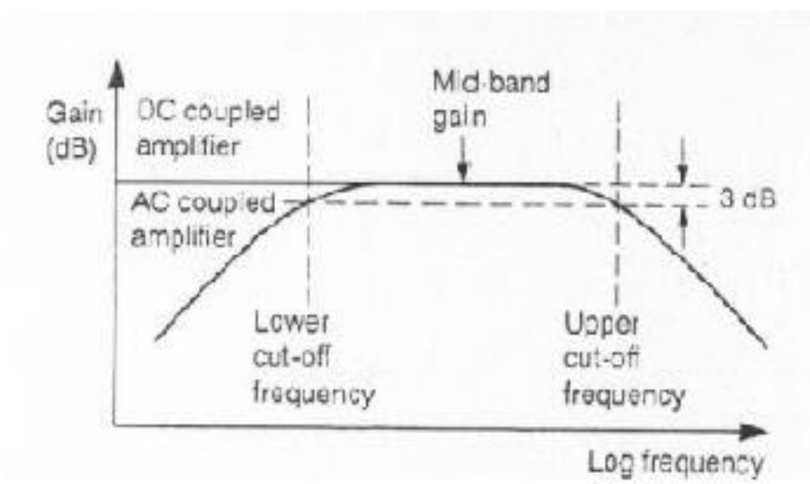


Frequencies f_h & f_l are called half power (or) 3 db from its mid frequency value.

Introduction

All amplifiers typically exhibit a band-pass frequency response as in Figure The cut-off frequency on the low end is usually determined by the coupling and bypass capacitors (if there are no such capacitors the low end extends all of the way to DC). The high frequency limit is typically determined by internal capacitances in the transistor itself.

The generic common-emitter amplifier circuit of Section D2 is reproduced to the left below and the small signal circuit using the high frequency BJT model is given below right. Note that all external capacitors are assumed to be short circuits at high frequencies and are not present in the high frequency equivalent circuit (since the external capacitors are large when compared to the internal capacitances – recall that Zc=1/jωC gets small as the frequency or capacitance gets large).



Low frequency response

If an amplifier does not have coupling or bypass capacitors, then in general the low frequency response goes all of the way down to DC. However, as we discussed in class, it is desirable to have these capacitors in the circuit to isolate the amplifiers DC bias point from the outside world. In the most general case, the input and output coupling capacitors lead to a high-pass filter response determined by the resistances they see:

In general, we can calculate their cutoff frequencies using the following formulas:

$$f_{Low\_C2} = \frac{1}{2\pi\tau_2} = \frac{1}{2\pi C_2 (R_i + R_{in})}$$

$$f_{Low\_C1} = \frac{1}{2\pi\tau_1} = \frac{1}{2\pi C_1 (R_o + R_L)}$$

Where R_i is the source resistance, R_L is the load resistance, R_{in} is the input resistance for your amplifier and R_o is the output resistance for your amplifier. These last two are calculated based on the type of amplifier you are working with once you have calculated the frequencies due to C_1 and C_2, the cutoff is determined by the following rules:

- If the two frequencies are more than a decade apart then flow is simply the higher of the two values.
- If the two frequencies are closer than one decade, then the actual cutoff frequency of the amp is somewhat larger than either of the two calculated frequencies.

- If the amplifier has a bypass capacitor, then it can also influence the cutoff frequency. Typical, emitter bypass capacitors are chosen large enough so that their effects are negligible.

High Frequency Response

As previously stated, the high frequency response of a discrete transistor amp is determined by the internal capacitances of the transistor itself

High frequency model of a BJT

If either C_{be} or C_{ob} short out at high frequencies, then the transistor stops acting as an amplifier and so the response is cut off. The values of C_{be} and C_{ob} can be found or calculated from the transistor spec sheet. Typically, C_{ob} is on the spec sheet and C_{be} is calculated from f_T (the gain-bandwidth product) also found on the spec sheet using:

$$C_{be}= \frac{1}{2\pi f T h i b}$$

$$C_{be}= \frac{ICQ}{52\pi f T x^2-3}$$

Once the capacitance values are known, the high frequency cutoff value can be calculated from the following formulas:

Common Emitter Amplifier

$$F_{high}=\frac{1}{2\pi(\text{Rin}\,ll\,\text{Ri})(\text{Cbe}+\text{Cob}(1-\text{Av}))}$$

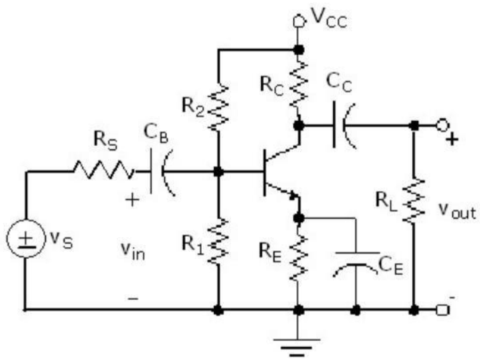
Common Collector Amplifier

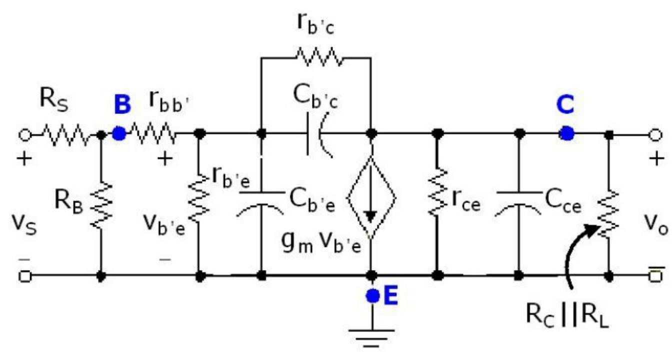
$$F_{high}=\frac{1}{2\pi\text{Cob}[\text{Rb}\beta(\text{RE ll RL}]\text{Ri}}$$

Common Base Amplifier

$$F_{high}=\frac{1}{2\pi\text{Cb}(\text{hib ll RE ll Ri})]}$$

BJT CE Amplifiers at High Frequencies





We can simplify the small signal circuit by making the following observations and approximations:

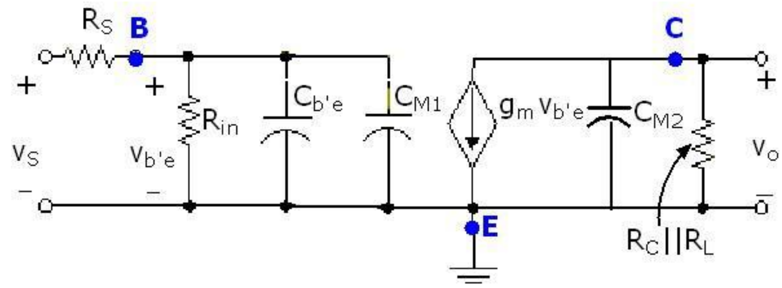
- C_{ce} is very small and may be neglected.
- $r_{ce} >> (R_C||R_L)$, so r_{ce} may be neglected since $r_{ce}||R_C||R_L$ is dominated by $R_C||R_L$
- $r_{b'c}$ is so much larger than all other resistances that it may be considered open and removed from the circuit.
- $r_{bb'} << r_{b'e}$ so it may be neglected; i.e.,

$$r\pi = r_{b'e}.$$

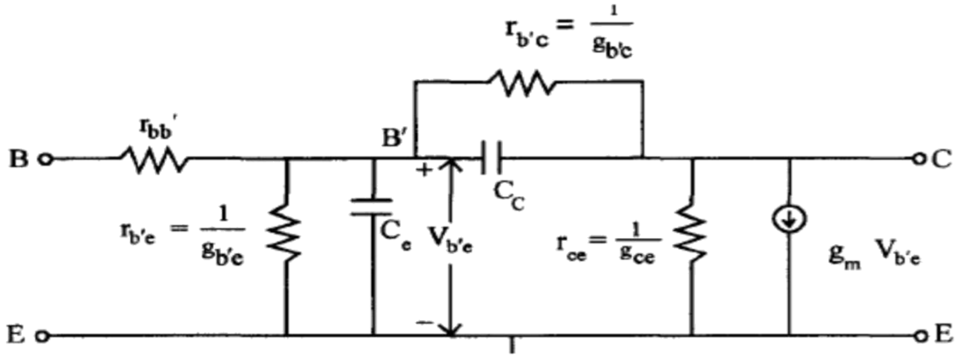
The above simplifications, along with the definition of Rin as

$$R_{in} = R_B || r\pi,$$

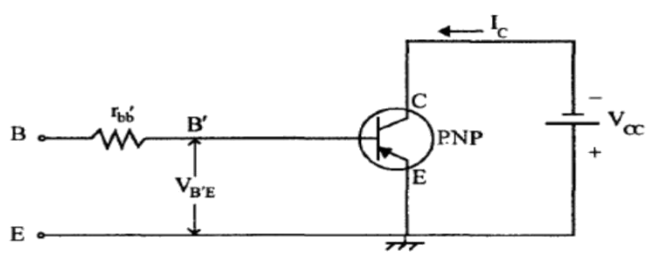
and the reflection of $C_{b'c}$ to the input and output circuits using Miller's theorem



Hybrid - π C.E BJT Model



PNP transistor amplifier



Hybrid - π Parameter Values

Typical values of the hybrid-π parameter at $I_C = 1.3$ mA are as follows :

$g_m = 50$ mA/V $\quad r_{bb'} = 100\ \Omega \quad r_{b'e} = 1\ k\Omega$

$r_{ce} = 80\ k\Omega \quad C_c = 3$ pf $\quad C_e = 100$ pf

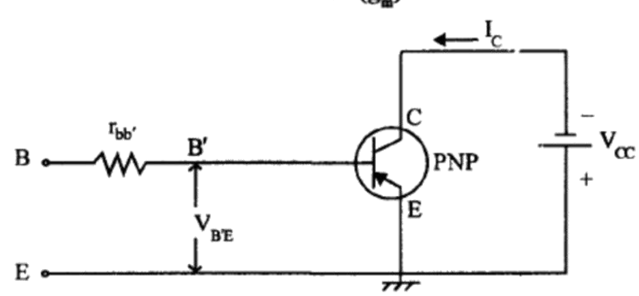
$r_{b'c} = 4\ M\Omega$

These values depend upon :

1. Temperature
2. Value of I_C

Determination of Hybrid-π Conductances

Transconductance or Mutual Conductance (g_m)



$$g_m = \frac{|I_C|}{26}, \ I_C \text{ is in mA.}$$

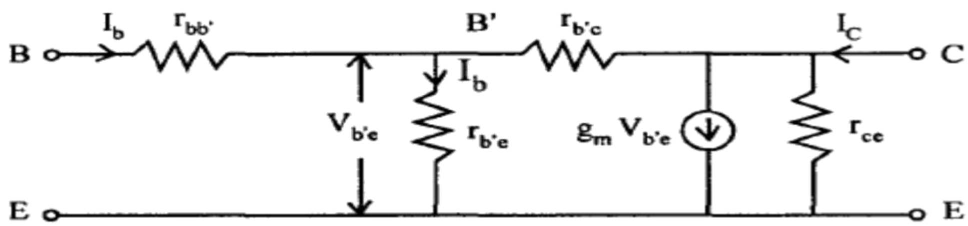
$$\boxed{g_m = \frac{-I_C}{V_T}}$$

If $I_C = 1.3$ mA, $g_m = 0.05$ A/V

If $I_C = 10$ mA, $g_m = 400$ mA/V

INPUT CONDUCTANCE ($g_{b'e}$)

Equivalent circuit at low frequencies



$$g_{b'e} = \boxed{\frac{|I_C|}{h_{fe} V_T}} \text{ or } \boxed{\frac{g_m}{h_{fe}}} \qquad \boxed{r_{b'e} = \frac{h_{fe}}{g_m}}$$

h_{re} = reverse voltage gain, with input open or $I_b = 0$

$$= \frac{V_{b'e}}{V_{ce}} = \frac{\text{Input voltage}}{\text{Output voltage}}$$

FEEDBACK CONDUCTANCE($g_{b'e}$)

$$\boxed{g_{b'c} = h_{re} \; g_{b'e}} \quad \frac{1}{r_{b'c}} = g_{b'c} = \frac{h_{re}}{r_{b'e}}$$

INTER BASE RESISTANCE($r_{bb'}$)

$$\boxed{r_{bb'} = h_{ie} - r_{b'e}}$$

OUTPUTCONDUCTANCE (g_{ce})

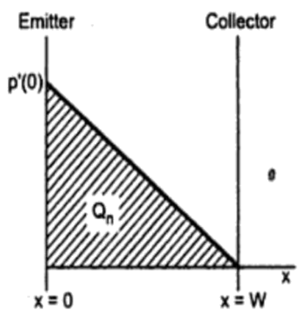
$$\boxed{g_{ce} = h_{oe} - h_{fe} \cdot g_{b'c}} \quad g_{ce} = h_{oe} - g_m \cdot h_{re}$$

Relation between hhbrid π and h-parameters

S.No.	Parameter Relation
1	$g_{m}=I_c/V_T$
2	$r_{b'e}=h_{fe}/g_m$
3	$r_{bb'}=h_{ie}-r_{b'e}$
4	$r_{b'c}=r_{b'e}/h_{re}$
5	$g_{ce}=1/r_{ce}=h_{oe}-g_{b'c}h_{fe}$

The Hybrid-π Capacitances

$$C_e = C_{De} + C_{Te} \approx C_{De}$$



$$Q_B = \frac{1}{2} P'(0)\ A\ W\ q$$

$$I = -Aq\, D_B \frac{dp'}{dx}$$

$$= Aq\, D_B \frac{p'(0)}{W}$$

Combining equations (1) and (2) we get

$$Q_B = \frac{IW^2}{2D_B}$$

$$C_{De} = \frac{dQ_B}{dV} = \frac{W^2}{2D_B}\frac{dI}{dV}$$

$$= \frac{W^2}{2D_B}\frac{I}{r_e}$$

$r_e = dV/dI = V_T/I_E$ is the emitter junction incremental resistance.

$$C_{De} = \frac{W^2 I_E}{2D_B V_T}$$

$$= g_m \frac{W^2}{2D_B}$$

$$C_e \approx \frac{g_m}{2\pi f_T}$$

Gain Band width Product

Note that the high frequency signal equivalent circuit, expressed in phasor notation, is identical in form to the midband signal equivalent circuit, expressed in the time domain. We exploit this identical form, plus the fact that real and complex quantities obey essentially identical rules of algebra, to adapt some of our earlier results for the midband case to the current high frequency case.

First, recall the result for the open-circuit voltage gain at midband:

$$A_{voc}=\frac{vc}{vb}=\frac{-gmRc}{1+\frac{rbb'}{rb'c}+Re(\frac{1}{rb'e}+gm)}$$

The output Thevenin resistance of the amplifier was found to be simply R_c . These two results mean that the midband gain when the amplifier is loaded with a resistor, R_L , across its output is given by:

Or

$$A_R=\frac{-gmRcllRL}{1+\frac{rbb'}{rb'c}+Re(\frac{1}{rb'e}+gm)}$$

To carry this result over to the high frequency case, we make the following substitutions:

$$A_{RL} \rightarrow A_{Rc}$$

It is informative to calculate the product of the magnitude of the mid band gain and the bandwidth to obtain the *gain-bandwidth product*, or *GBW*:

Wher

As we noted above, varying $R_c \| R_L$ permits the designer to trade off gain for bandwidth, and Vice versa. Ideally, *GBW* would remain constant as we trade off gain and bandwidth. For this particular amplifier, unfortunately, such usually is not the case. Note, however,

$$\mathrm{GBW} \approx < \frac{RcllRL}{Re} \frac{1}{(Re + RcllRL)cb'c}$$

or

$$GBW \,\square\, \frac{1}{R\,C}$$

Recall that for our biasing approach,

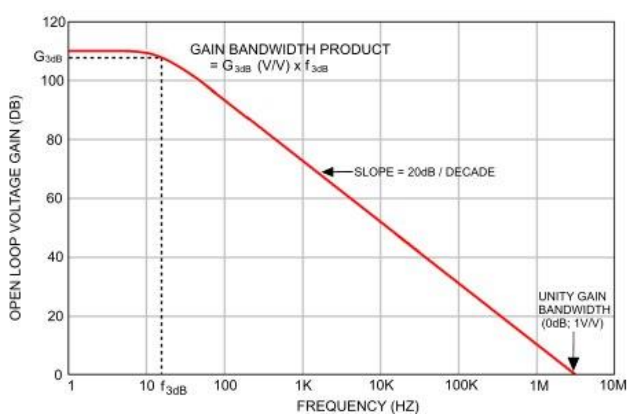
$$g_m R_e \,\square\, 77$$

so that

$$\mathrm{GBW} < \frac{1}{77}\left(1 + \frac{cb'e}{cb'c}\right)\omega T$$

$$\omega T = 2\pi f T = gm/cb'c$$

is termed the *gain-bandwidth product* of the *BJT* and depends only on the *BJT* parameters. (On specification sheets for *BJT*s, the gain-bandwidth product is usually expressed as f_T , in *Hz*, rather than as $\square_T$, in *rad/sec*.) In typical small *BJT*s,



Or,

for the common emitter amplifier,

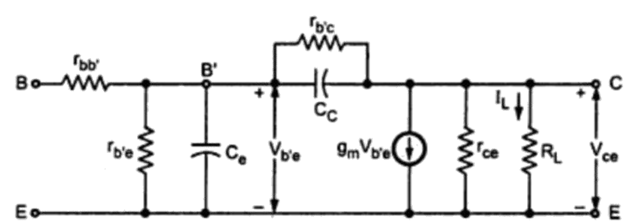
$$GBW \;□□\; □_T$$

Thus, the gain-bandwidth product for the common emitter *BJT* amplifier configuration is substantially less than □$_T$, the gain-bandwidth product for the *BJT*. In contrast, a (*BJT*) emitter follower amplifier (with a voltage gain of nearly one) has a gain-bandwidth product only slightly less than □$_T$. In some sense, then, the common emitter *BJT* amplifier configuration is wasteful of the gain-bandwidth product of the *BJT*. This feature of the configuration may, or may not, be important to a designer for a particular situation.

It turns out that any amplifier built with an amplifying device (*FET*, *BJT*, opamp or vacuum tube) with a gain-bandwidth product,□□$_T$, has a gain-bandwidth product that is no more than □$_T$.

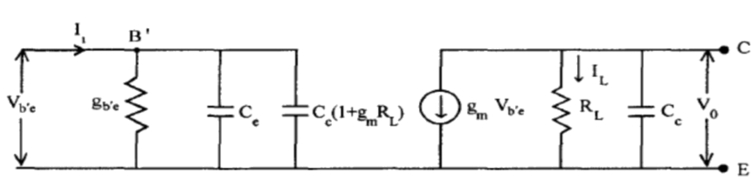
Conveniently for designers, some amplifier configurations, including operational amplifiers, maintain a constant *GBW* as negative feedback is used to trade off gain and bandwidth.

CE Short-Circuit Current Gain using Hybrid π Model



The hybrid-π circuit for a single transistor with a resistive load R_L

Simplified equivalent circuit



The 3db frequency $f_M = \frac{1}{2\pi r_{b'e} C} = \frac{g_{b'e}}{2\pi C}$

where $C = C_e + C_c(1 + g_m R_L)$

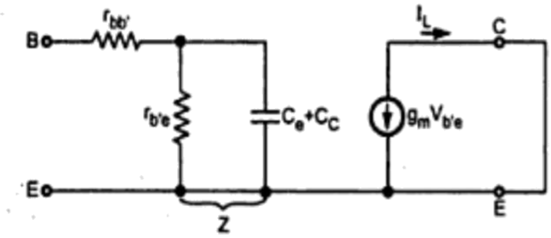
A_i under short-circuit condition is,

$$A_i = \frac{I_L}{I_i} = \frac{-g_m}{g_{b'e} + j\omega(C_e + C_c)}$$

$$A_i = \frac{-1}{\frac{1}{h_{fe}} + j\left(\frac{f}{f_T}\right)}$$

$$= \frac{-h_{fe}}{1 + j\,h_{fe}\left(\frac{f}{f_T}\right)}$$

$$A_i = \frac{-h_{fe}}{1 + j\left(\frac{f}{f_\beta}\right)}$$



Simplified hybrid-π model for short circuit CE transistor

But, $$\frac{f_T}{h_{fe}} = f_\beta$$

∴ $$|A_i| = \frac{h_{fe}}{\sqrt{1 + \left(\frac{f}{f_\beta}\right)^2}}$$

Where $$f_\beta = \frac{g_{b'e}}{2\pi(C_e + C_C)}$$

$$g_{b'e} = \frac{g_m}{h_{fe}}$$

∴ $$f_\beta = \frac{g_m}{h_{fe}\, 2\pi(Ce + C_c)}$$

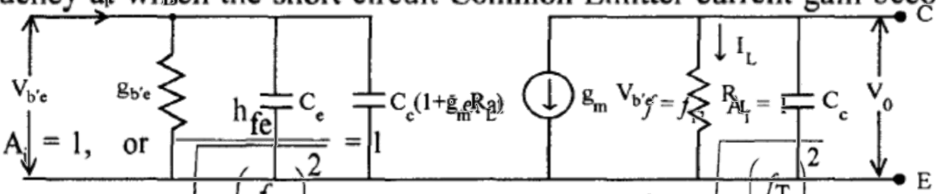
At $f = f_\beta$, $A_i = \frac{1}{\sqrt{2}}$ = 0.707 of h_{fe}.

The frequency range upto f_β *is referred to as the Bandwidth of the circuit.*

Simplified equivalent circuit

The Parameter f_T

f_T is the frequency at which the short circuit Common Emitter current gain becomes unity.



i.e., $A_i = 1$, or $\frac{h_{fe}}{\sqrt{1+\left(\frac{f_T}{f_\beta}\right)^2}} = 1$ or $h_{fe} = \sqrt{1+\left(\frac{f_T}{f_\beta}\right)^2}$

The 3db frequency $f_M = \frac{1}{2\pi r_{b'e} C} = \frac{g_{b'e}}{2\pi C}$

where $C = C_e + C_c(1 + g_m R_L)$

$h_{fe}^2 = 1 + \left(\frac{f_T}{f_\beta}\right)^2 \cong \left(\frac{f_T}{f_\beta}\right)^2$

$\therefore \quad h_{fe} \simeq \frac{f_T}{f_\beta}$ when Ai = 1

$\therefore \quad \boxed{f_T \simeq h_{fe} \cdot f_\beta}$

But $\quad f_\beta = \frac{g_m}{h_{fe}\{C_e + C_c\}}$

$\therefore \quad f_T = f_\beta \cdot h_{fe} = \frac{g_m}{2\pi(C_e + C_c)}$

But $\quad C_e >> C_c$

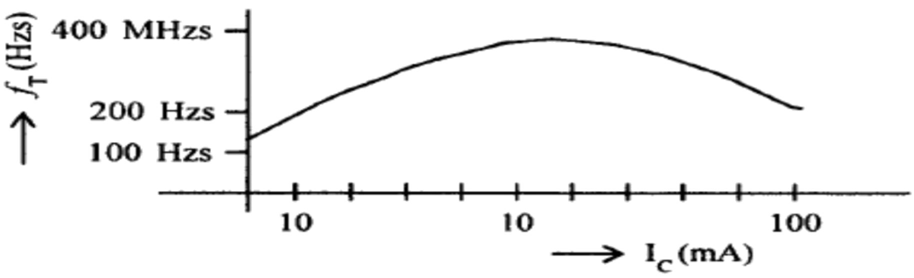
$\therefore \quad \boxed{f_T \simeq \frac{g_m}{2\pi C_e}}$

Current Gain with Resistance Load :

$$f_T = f_\beta \cdot h_{fe} = \frac{g_m}{2\pi(C_e + C_c)}$$

$$f_H = \frac{1}{2\pi C_S (R_C \parallel R_L)}$$

Variation of I_C with frequency

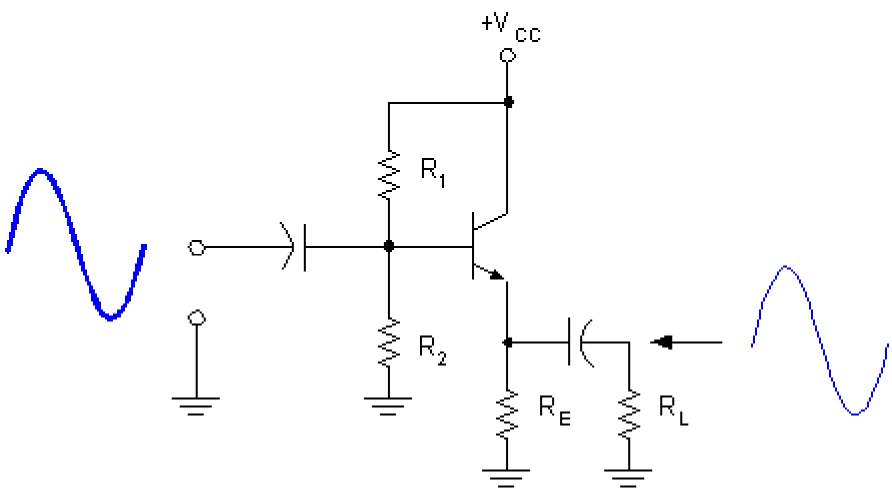


$$f_T = h_{fe} \cdot f_\beta$$

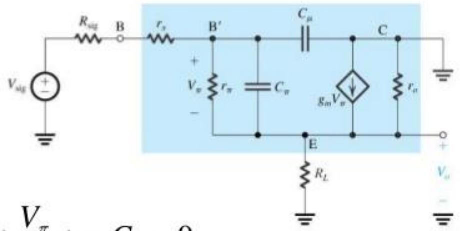
Common-collector amplifier (Emitter Follower) at high-frequency

AC model of a simple BJT common-collector amplifier is shown in Figure

The input portion of the high-frequency equivalent circuit is simplified for analysis as shown in Figure For simplicity, r_o is considered to be very large compared to R_C and R_E.

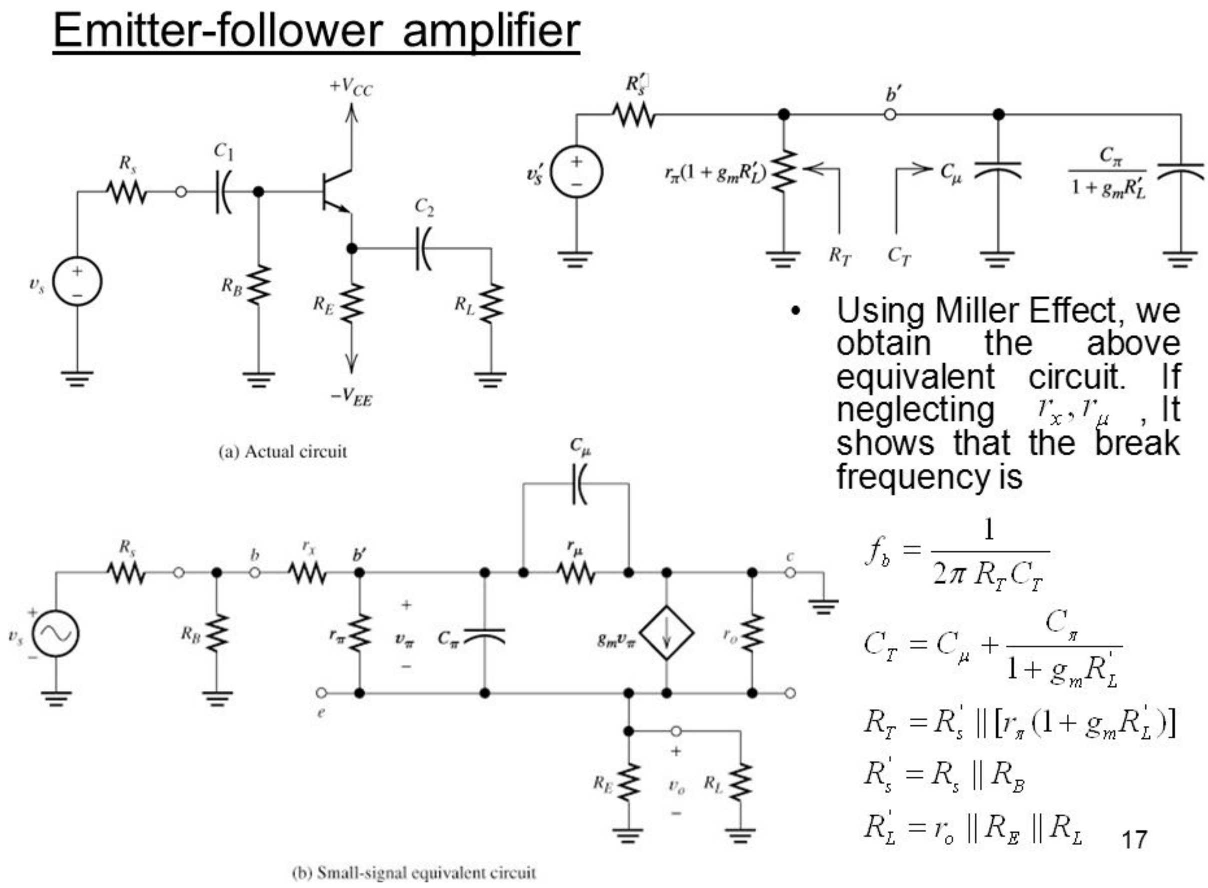


High-Frequency Analysis of Emitter Follower



$$g_m V_\pi + \frac{V_\pi}{r_\pi} + s_Z C_\pi = 0$$

leads to: $$\frac{g_m + (1/r_\pi)}{C_\pi} = -\frac{1}{C_\pi r_e} \rightarrow \omega_Z = \frac{1}{C_\pi r_e}$$



The pole introduced by the C_i is of primary interest since C_o is less than the input capacitance. Therefore, assume that the pole introduced by C_o is sufficiently high so that C_o can be replaced by an open circuit.

The voltage gain of the common-collector amplifier is: A_v=

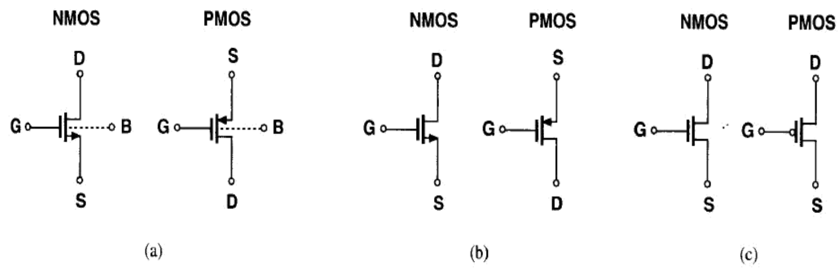
$$\frac{v0}{vs} = \frac{gmr\pi RE}{Rs' + rb(1 + gmRsr\pi) + j\omega Cir\pi(Rs + rb)} Rs'/Rs$$

Common-emitter amplifiers with emitter resistors have the same basic topology as the common-collector amplifier. The resultant pole location remains identical.

UNIT-III

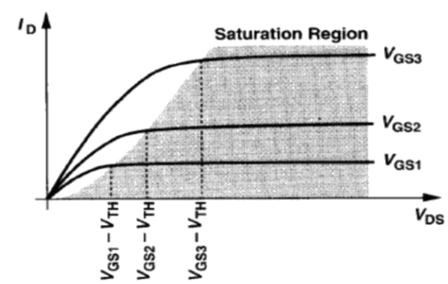
MOS Amplifiers: Basic Concepts, MOS Small signal model, Common source amplifier with resistive load

MOS Symbols

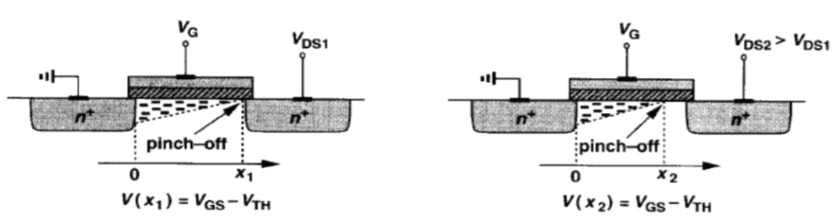


An input signal V_{in} is added to V_{GS} . We shall show later that V_{in} will be amplified. Since the source is signal grounded, we shall call this kind of amplifiers common source amplifiers. It must be noted that the signal is a small signal and is also an alternating current (AC) signal. It will become clear that this kind of amplifiers can hardly amplify large signals. The input signal induces an AC voltage between gate and source. Let us denote this AC voltage by V_{gs} . Throughout this lecture notes, we shall use small letters to denote AC parameters. Obviously, V_{gs} ,V_{in}.

V_{in} □□V_{GS}□□□□V_{in}□□□□V_{GS}□□□□V_{gs}
V_{out} □□V_{DS}□□□□V_{out}
I_{out} □□I□$_{DS}$□□□□i_{out}



Saturation of drain current.



Pinch-off behavior.

Since the amplitude of V_{out} is larger than that of V_{in} , this circuit functions as an amplifier. It is important to note that the DC voltage V_{DS} still exists. In some sense, we may say that V_{out}

(AC) rides on V_{DS} (DC). But, so far as amplification is concerned, we are only interested in the AC output voltage signal V_{out}. Note that the polarity of V_{out} id opposite to that of V_{in}. In other words, the input is inverted.

$$I_D = -\mu_p C_{0x}\frac{W}{L}[(VGS - VTH)VDs - \frac{1}{2}V^2Ds$$

$$I_D = -\frac{1}{2}\mu_n C_{0x}\frac{W}{L'}[(VGS - VTH)]^2$$

$$I_D = -\frac{1}{2}\mu_p C_{0x}\frac{W}{L'}[(VGS - VTH)]^2$$

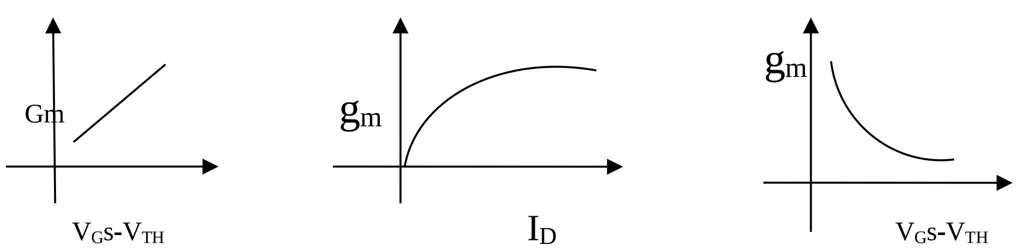
$$g_m = \frac{\partial ID}{\partial VGS}$$

$$= \mu_n C_{0x}\frac{W}{L}(VGS - VTH)$$

$$g_m = \sqrt{2}\ \mu_n C_{0x}\frac{W}{L}$$

$$= \frac{2ID}{(VGS - VTH)}$$

<u>MOS transconductance as a function of overdrive & Drain current</u>

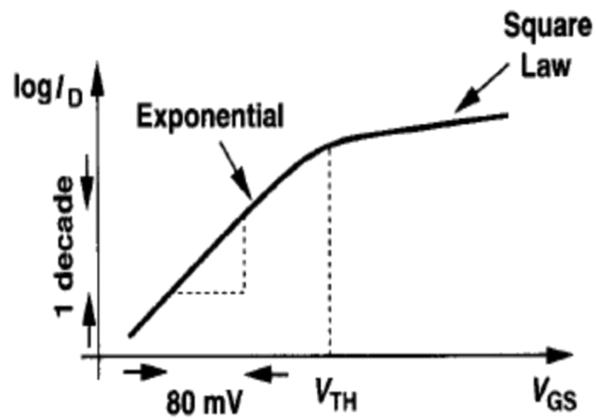


$$g_m = \mu_n C_{0x}\frac{W}{L}\,[(VGS - VTH)(1 + \lambda VDs)$$

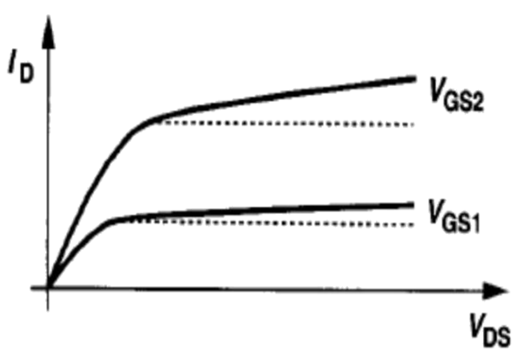
$$= \frac{\sqrt{2}\,\mu nC0x(\frac{W}{L})ID}{(1+\lambda VDs)}$$

Subthreshold Conduction

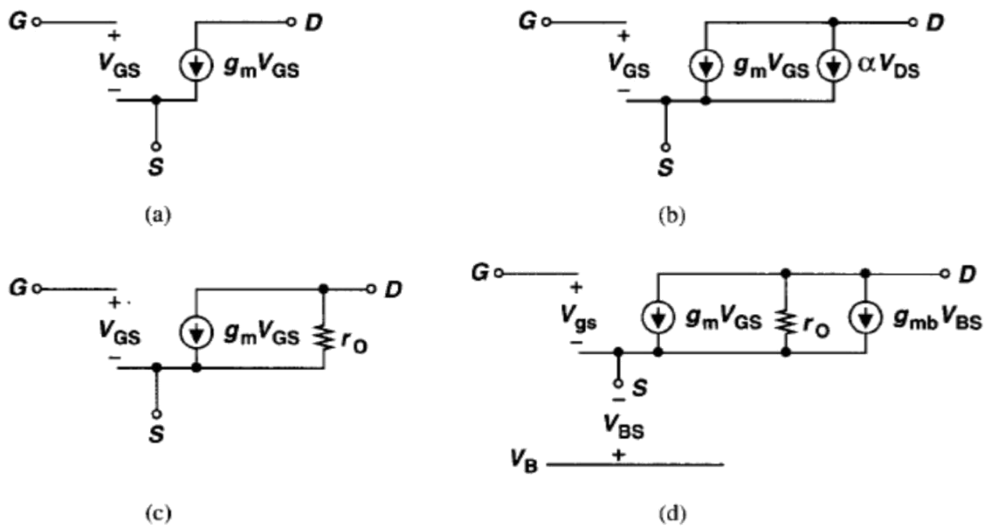
$$I_D = I_0 \exp\frac{V_{GS}}{\zeta V_T},$$



$$I_D \approx \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2(1 + \lambda V_{DS}),$$



Finite saturation region slope resulting from channel-length modulation.



(a) Basic MOS small-signal model, (b) channel-length modulation represented by a dependent current source, (c) channel-length modulation represented by a resistor, (d) body effect represented by a dependent current source.

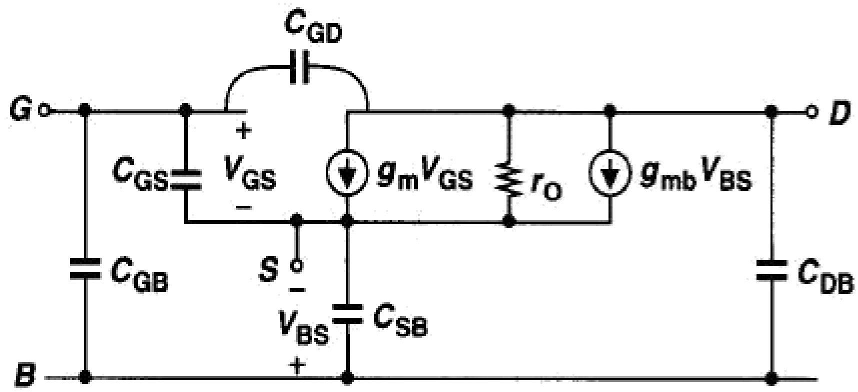
$$r_0 = \frac{\partial VDs}{\partial ID}$$

$$= \frac{1}{\partial ID/\partial VDs}$$

$$= \frac{1}{\frac{1}{2}\mu nC0x\frac{W}{L'}[(VGS - VTH)]\lambda^2}$$

$$= \frac{1}{\lambda ID}$$

Complete MOS Small signal Model



UNIT-IV

Feedback Amplifiers: Concepts of feedback, Classification of feedback amplifiers, General characteristics of negative feedback amplifiers, Effect of feedback on amplifier characteristics, Voltage Series, Voltage Shunt, Current Series and Current Shunt Feedback Configurations, Illustrative examples.

Oscillators: Classification of oscillators, Condition for oscillations, RC Phase shift Oscillators, Generalized analysis of LC Oscillators-Hartley and Colpitts Oscillators, Wien Bridge and crystal Oscillators, Stability of Oscillators

Feedback Amplifiers

INTRODUCTION

A practical amplifier has a gain of nearly one million *i.e.* its output is one million times the input. Consequently, even a casual disturbance at the input will appear in the amplified form in the output. There is a strong tendency in amplifiers to introduce *hum* due to sudden temperature changes or stray electric and magnetic fields. Therefore, every high gain amplifier tends to give noise along with signal in its output. The noise in the output of an amplifier is undesirable and must be kept to as small a level as possible. The noise level in amplifiers can be reduced considerably by the use of *negative feedback i.e*. by injecting a fraction of output in phase opposition to the input signal. The object of this chapter is to consider the effects and methods of providing negative feedback in transistor amplifiers.

Ideally an amplifier should reproduce the input signal, with change in magnitude and with or without change in phase. But some of the short comings of the amplifier circuit are

I. Change in the value of the gain due to variation in supplying voltage, temperature or due to components.

2. Distortion in wave-form due to non linearities in the operating characters of the Amplifying device.

3. The amplifier may introduce noise (undesired signals)

The above drawbacks can be minimizing if we introduce feedback

CLASSIFICATION OF AMPLIFIERS

Amplifiers can be classified broadly as,

I. Voltage amplifiers.

2. Current amplifiers.

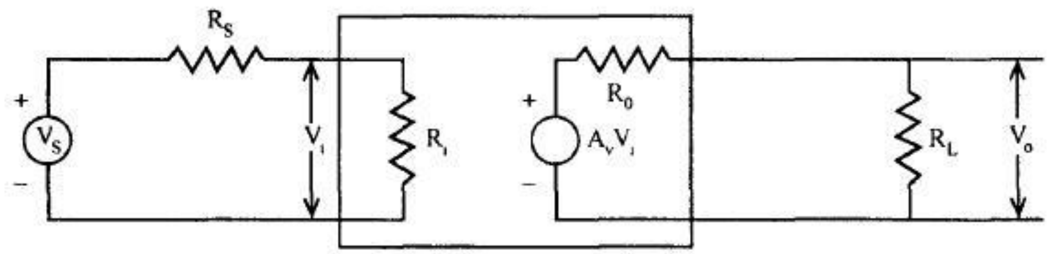
3. Tran conductance amplifiers.

4. Tran résistance amplifiers.

This classification is with respect to the input and output impedances relative to the load and source impedances.

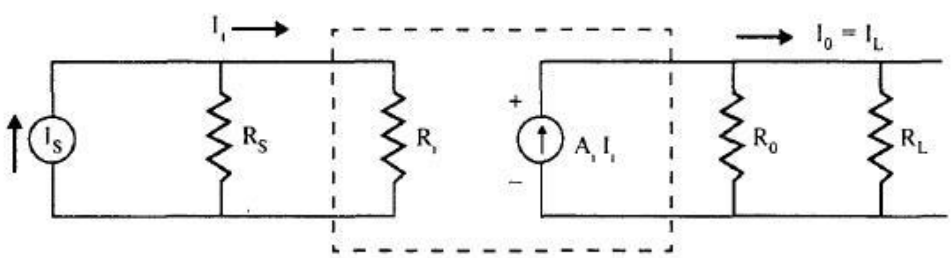
VOLTAGE AMPLIFIER

This circuit is a 2-port network and it represents an amplifier Suppose R,» Rs, drop across Rs is very small.



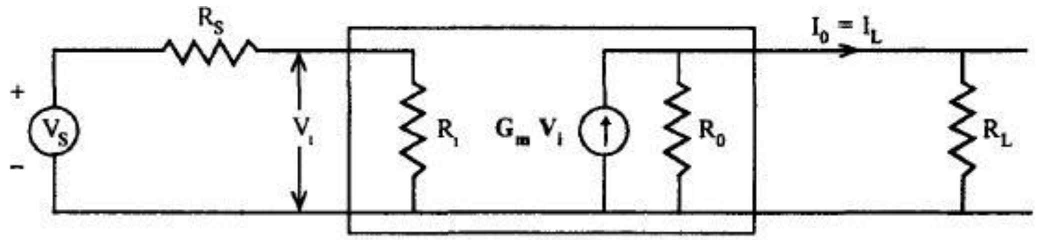
CURRENT AMPLIFIER

An ideal current amplifier is one which gives output current proportional to input current and the proportionality factor is independent ofRs and RL.



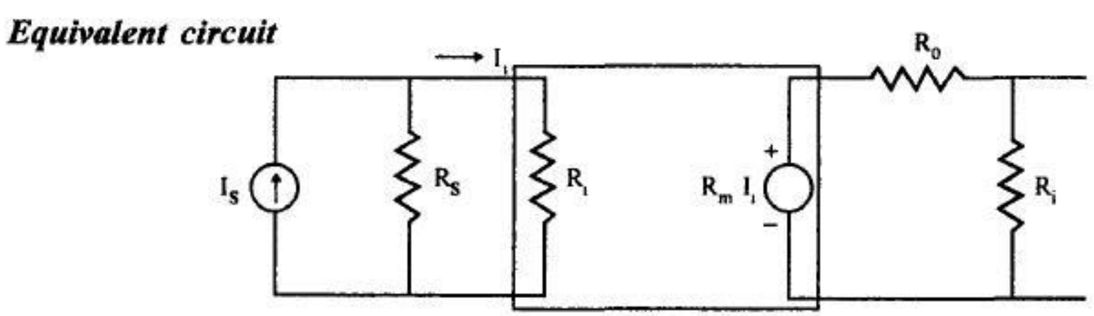
TRANSCONDUCTANCE AMPLIFIER

Ideal Transconductance amplifier supplies output current which is proportional to input voitage independently ofthe magnitude ofRs and RL.



TRANS RESISTANCE AMPLIFIER

It gives output voltage Vo proportional to Is, independent of Rs a. RL. For *ideal amplifiers* Rj =0, Ro=O



Concepts of feedback:

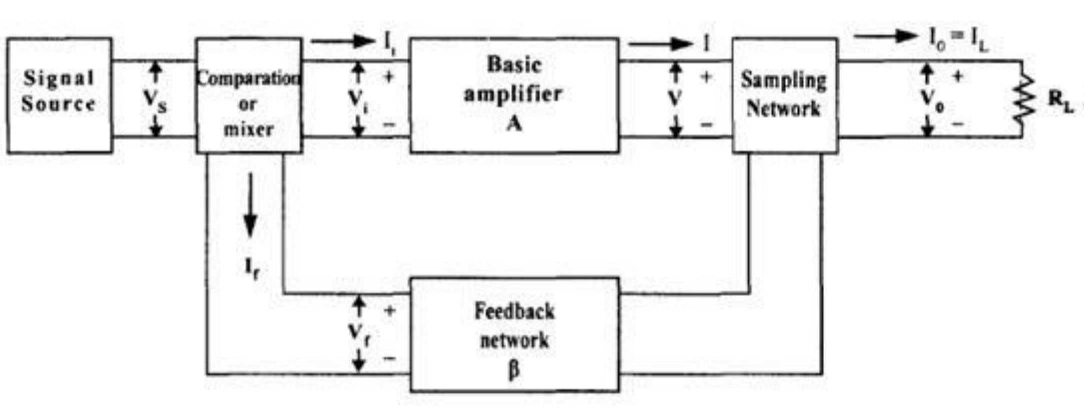
The process of injecting a fraction of output energy of some device back to the input is known as **feedback**. The principle of feedback is probably as old as the invention of first machine but it is only some 50 years ago that feedback has come into use in connection with electronic circuits. It has been found very useful in reducing noise in amplifiers and making amplifier operation stable. Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers viz positive feedback and negative feedback.

Signal Source: It can be a voltage source V s or a current source Is

FEEDBACK NETWORK:

It is a passive two port network. It may contain resistors, capacitors or inductors. But usually a resistance is used as the feedback element. Here the output current is sampled and feedback. The feedback network is connected in series with the output. This is called as *Current Sampling or* Loop Sampling.

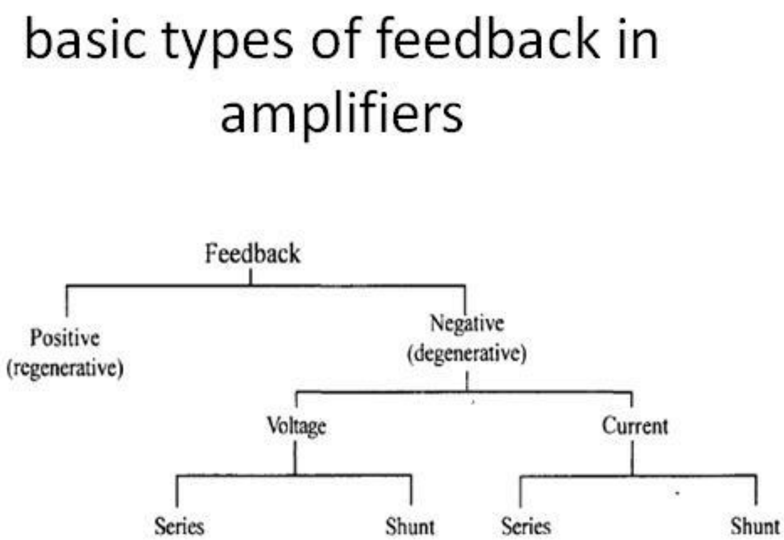
GENERALIZED BLOCK SCHEMATIC



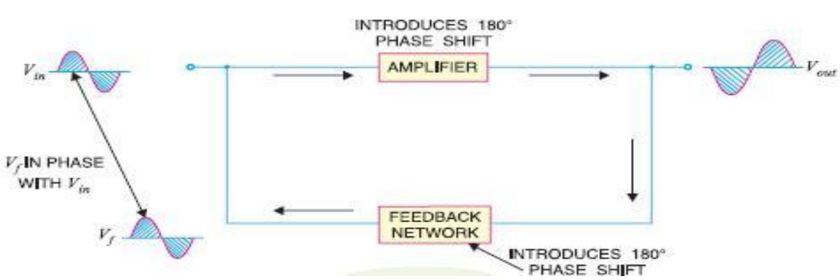
A voltage feedback is distinguished in this way from current feedback. For voltage feedback the feedback element (resistor) will be in parallel with the output. For current feedback the element will be in series.

COMPARATOR OR MIXER NETWORK:

This is usually a differential amplifier. It has two inputs and gives a single output which is the difference of the two inputs.

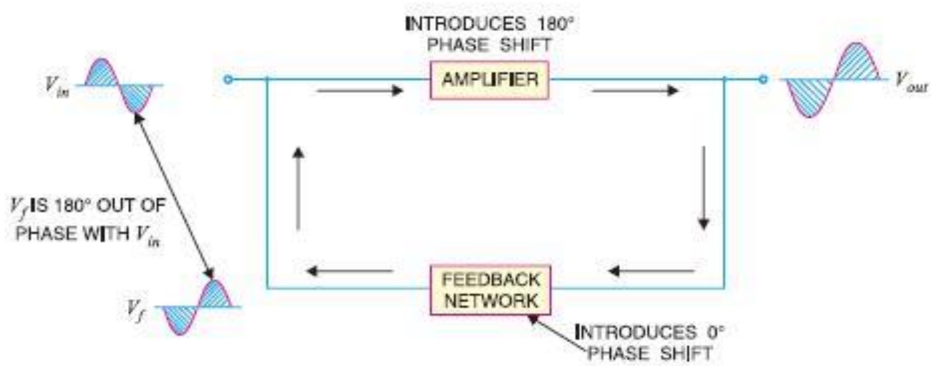


(i) Positive feedback. When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called positive feedback. This is illustrated in Fig.. Both amplifier and feedback network introduce a phase shift of 180°. The result is a 360° phase shift around the loop, causing the feedback voltage Vf to be in phase with the input signal Vin.



The positive feedback increases the gain of the amplifier. However, it has the disadvantages of increased distortion and instability. Therefore, positive feedback is seldom employed in amplifiers. One important use of positive feedback is in oscillators. As we shall see in the next chapter, if positive feedback is sufficiently large, it leads to oscillations. As a matter of fact, an oscillator is a device that converts d.c. power into a.c. power of any desired frequency.

(ii) Negative feedback. When the feedback energy (voltage or current) is out of phase with th input signal and thus opposes it, it is called *negative feedback*. This is illustrated in Fig.. As you can see, the amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift (*i.e.*, 0° phase shift). The result is that the *feedback voltage Vf* is 180° out of phase with the input signal *Vin*.



General characteristics of negative feedback amplifiers

Negative feedback reduces the gain of the amplifier. However, the advantages of negative feedback are: reduction in distortion, stability in gain, increased bandwidth and improved input and output impedances. It is due to these advantages that negative feedback is frequently employed in amplifiers.

Advantages of Negative Voltage Feedback

The following are the advantages of negative voltage feedback in amplifiers :

(*i*) 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.

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

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

$$A_{vf} = \frac{A_v}{A_v\, m_v} = \frac{1}{m_v}$$

It may be seen that the gain now depends only upon feedback fraction *mv 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

***ii*) Reduces non-linear distortion.** A large signal stage has non-linear distortion because its voltage gain changes at various points in the cycle. The negative voltage feedback reduces the nonlinear distortion in large signal amplifiers. It can be proved mathematically that :

$$D_{vf} = \frac{D}{1 + A_v\, m_v}$$

where *D* = distortion in amplifier without feedback

Dvf = distortion in amplifier with negative feedback

It is clear that by applying negative voltage feedback to an amplifier, distortion is reduced by a factor 1 + *Av mv*.

(*iii*) Improves frequency response.

As feedback is usually obtained through a resistive network, therefore, voltage gain of the amplifier is *independent of signal frequency. The result is that voltage gain of the amplifier will be substantially constant over a wide range of signal frequency. The negative voltage feedback, therefore, improves the frequency response of the amplifier.

(*iv*) Increases circuit stability.

The output of an ordinary amplifier is easily changed due to variations in ambient temperature, frequency and signal amplitude. This changes the gain of the amplifier, resulting in distortion. However, by applying negative voltage feedback, voltage gain of the amplifier is stabilized or accurately fixed in value. This can be easily explained. Suppose the output of a negative voltage feedback amplifier has increased because of temperature change or due to some other reason. This means more negative feedback since feedback is being given from the output. This tends to oppose the increase in amplification and maintains it stable. The same is true should the output voltage decrease. Consequently, the circuit stability is considerably increased.

(*v*) Increases input impedance and decreases output impedance.

The negative voltage feedback increases the input impedance and decreases the output impedance of amplifier. Such a change is profitable in practice as the amplifier can then serve the purpose of impedance matching.

(a)Input impedance.

The increase in input impedance with negative voltage feedback can be explained by referring to Fig.. Suppose the input impedance of the amplifier is *Zin* without feedback and *Z 'in* with negative feedback. Let us further assume that input current is *i*1.

$$Z'_{in} = Z_{in}(1 + A_v m_v)$$

(*b*) Output impedance. Following similar line, we can show that output impedance with negative voltage feedback is given by :

$$Z'_{out} = \frac{Z_{out}}{1 + A_v m_v}$$

It is clear that by applying negative feedback, the output impedance of the amplifier is decreased by a factor 1 + *Av mv*. This is an added benefit of using negative voltage feedback. With lower value of output impedance, the amplifier is much better suited to drive low impedance loads.

Effect of feedback on amplifier characteristics

CLASSIFACTIONOF FEEDBACK AMPLIFIERS

There are four types of feedback,

1. Voltage series feedback.

2. Voltage shunt feedback.

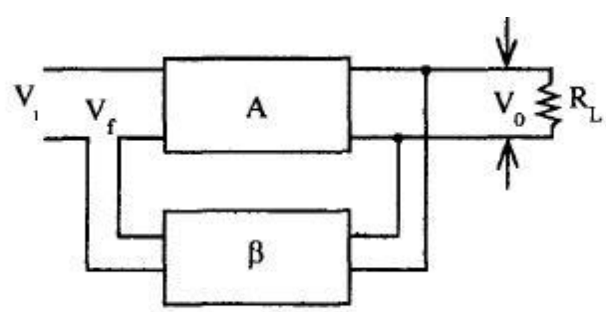
3. Current shunt feedback.

4. Current series feedback.

- If the feedback signal is taken across RL, it is a Vo or so it is *Voltage feedback.*
- If the feedback signal is taken in series with the output terminals, feedback signal is proportional to I0 , So it is *current feedback.*
- If the feedback signal is in series with the input, it is *seriesfeedback.*
- If the feedback signal is in shunt with the input, it is *shuntfeedback*

Voltage Series Configuration

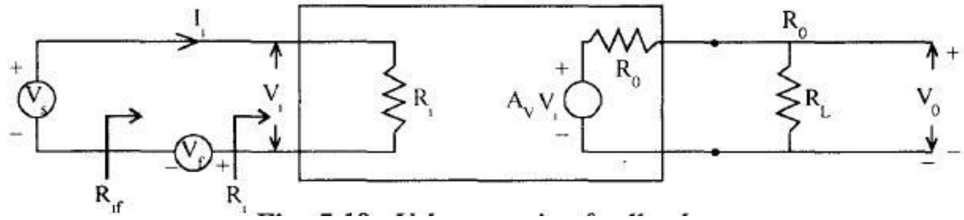
Feedback signal is taken across RL.proportional to Vo. So it is voltage feedback. Vf is coming in series with VI So it is Voltage series feedback.



Voltage series feedback.

EXPRESSION FOR INPUT RESISTANCE RI WITH VOLTAGE SERIES

FEEDBACK In this circuit Av represents the open circuit voltage gain taking Rs into account



$$V_i = V_S - V_f$$
$$V_s = V_i + V_f$$
$$R_0' = R_{if} = V_S / I_i.$$
$$V_f = I_i R_i + V_f = I_i R_i + \beta V_0$$
$$V_0 = \frac{A_v V_i R_L}{R_o + R_L} = (A_V I_i R_i)$$
$$\frac{A_v . R_L}{R_o + R_L} = A_V, V_i = I_i . R_i .$$

$$A_V = \frac{V_o}{V_i} = \frac{A_v R_L}{R_o + R_L}$$
$$V_S = I_i R_i + \beta . V_0$$
$$\boxed{\frac{V_s}{I_i} = R_i + \frac{\beta . V_o}{I_i} = R_i \left(1 + \frac{\beta . V_o}{I_i \times R_i}\right)}$$
$$R_{if} = R_i \left(1 + \beta . \frac{V_o}{V_i}\right) = R_i (1 + \beta . A_V)$$
A_V = voltage gain, without feedback.

EXPRESSION FOR OUTPUT RESISTANCE R_0 WITH VOLTAGE SERIES FEEDBACK

R_O is determined by impressing voltage 'V' at the output terminals or messing 'I', with input R_{of} terminals.-shorted.

Disconnect R_{oL} To find R_{of}' remove external signal (set Vs = 0, or Is = 0)
Let $R_L = \infty$
Impress a voltage V across the output terminals and calculate the current I delivered by V.
Then, R_{Of} = V/I.

$$I = \frac{V_0 - A_V\ V_i}{R_0} = \frac{V_0 + \beta A_v V}{R_o}$$

$\because$ V_0 = output voltage.

$V_i = -\beta_V$

Because with $V_S = 0.\ V_i = -V_f = -\beta_V$

Hence, $R_{of} = \frac{V_0}{I} = \frac{R_o}{1+\beta A_v}$

This expression is excluding R_L. If we consider R_L also R_{of} is in parallel with R_L.

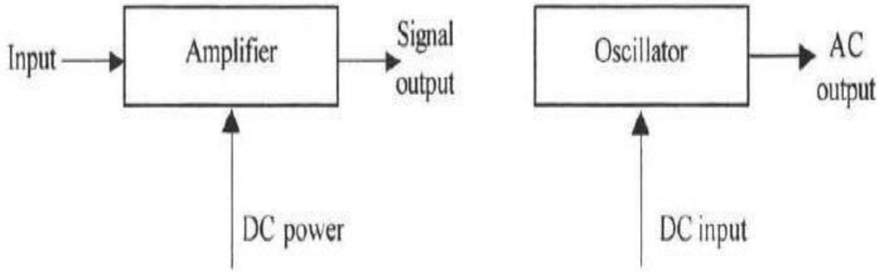
$$R_{of}' = \frac{R_{of} . R_L}{R_{of} + R_L}$$

Substitute the1 value of R_{of}

$$R_{of}' = \frac{\frac{R_o}{1+\beta A_V} \text{ x } R_L}{\frac{R_0}{1+\beta A_V} + R_L} = \frac{R_o R_L}{R_o + R_L + \beta . A_v R_L}$$

OSCILLATORS

Oscillator is a source of AC voltage or current



(a) Amplifier circuit *(b) Oscillator circuit*

Oscillator Circuit

- **Oscillator is an electronic circuit which converts dc signal into ac signal.**
- **Oscillator is basically a positive feedback amplifier with unity loop gain.**
- **For an inverting amplifier- feedback network provides a phase shift of 180° while for non-inverting amplifier- feedback network provides a phase shift of 0° to get positive feedback .**

$$\frac{V_o}{V_s} = \frac{A}{1 - A\beta}$$

If $\beta A=1$ then $V_o = \infty$; Very high output with zero input.

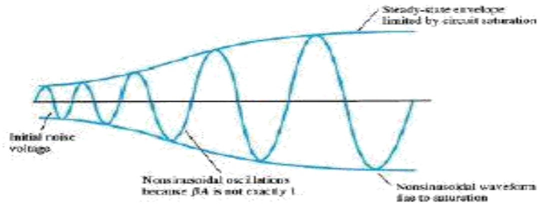
Use positive feedback through frequency-selective feedback network to ensure sustained oscillation at ω_0

Use of Oscillator Circuits

- Clock input for CPU, DSP chips …
- Local oscillator for radio receivers, mobile receivers, etc
- As a signal generators in the lab
- Clock input for analog-digital and digital-analog converters

Oscillators

- If the feedback signal is not positive and gain is less than unity, oscillations dampen out.
- If the gain is higher than unity then oscillation saturates.



Type of Oscillators

Oscillators can be categorized according to the types of feedback network used:

- RC Oscillators: Phase shift and Wien Bridge Oscillators
- LC Oscillators: Colpitt and Hartley Oscillators
- Crystal Oscillators

4

There are two types of oscillator's circuits

I. Harmonic Oscillators 2. Relaxation Oscillators

PERFORMANCE MEASURES OF OSCILLATOR CIRCUITS:

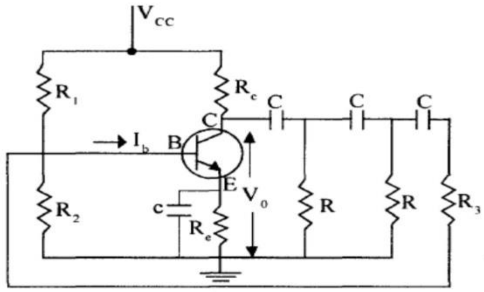
1. Stability:
2. Amplitude stability:
3. Output Power:
4. Harmonics:

BARKHAUSEN CRITERION $|\beta A| = 1$ and phase of $-A\beta = 0$.

Loop gain must be Unity

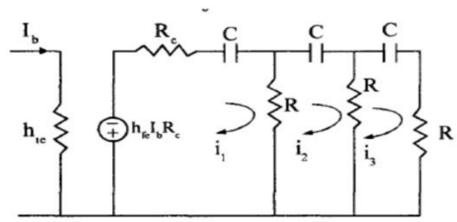
Total phase shift must be 360^0or o^0

R - C PHASE-SHIFT OSCILLATOR



(a)

Transistor phase shift oscillator.

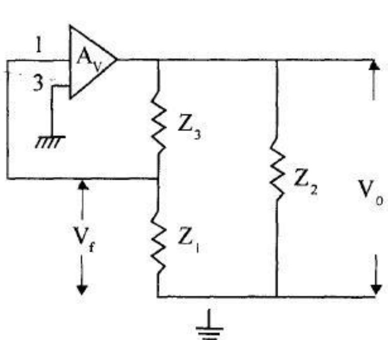


R - C Equivalent circuit.

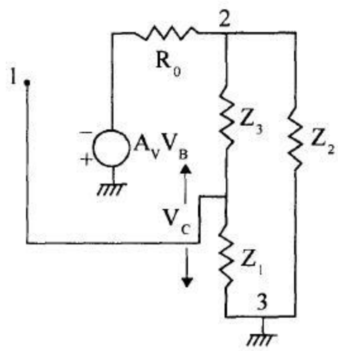
$$h_{fe} K > 4K^2 + 23K + 29 \qquad K < 2.7$$

$$h_{fe} > 4K + 23 + \frac{29}{K} \qquad h_{fe} > 44.5$$

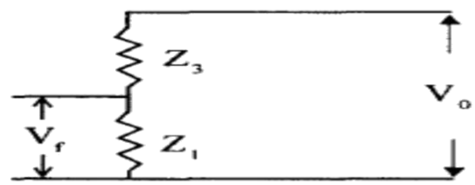
A GENERAL FORM OF LC OSCILLATOR CIRCUIT:



(a)



(b)



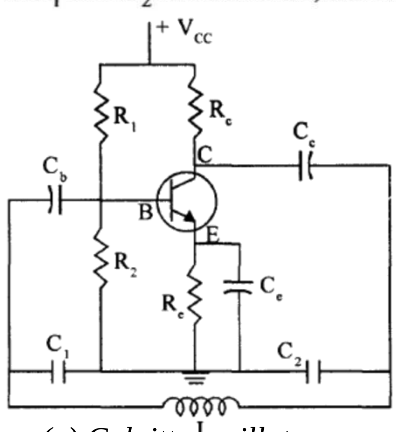
$$-A\beta = \frac{A_V X_1}{X_2}.$$

A**β** must be positive, and at least unity in magnitude. Than XI and X2 must have the same sign.

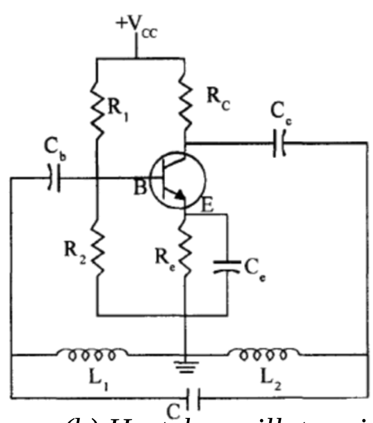
So if X_1 and X_2 are capacitive, X_3 should be inductive and vice versa.

If X_1 and X_2 are capacitors, the circuit is called ***Colpitts Oscillator***

If X_1 and X_2 are inductors, the circuit is called ***Hartely Oscillators***



(a) Colpitts oscillator



(b) Hartely oscillator circuit

For a Collpitt's Oscillator frequency of sustain oscillations is:

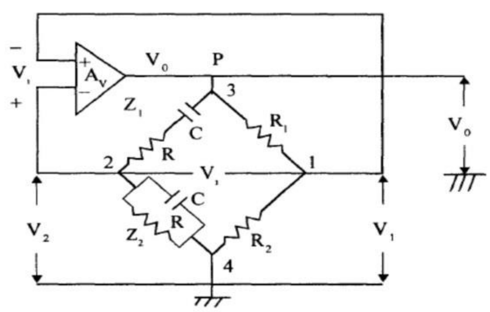
$$f = \frac{1}{2\pi\sqrt{L C_T}}$$

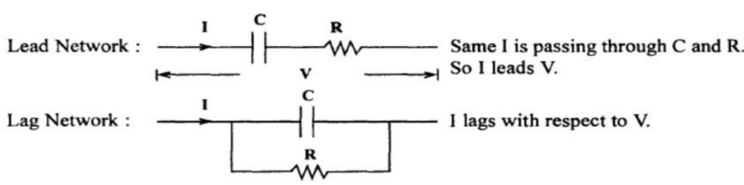
where $C_T = \frac{C_1 C_2}{C_1 + C_2}$

For a Hartly Oscillator frequency of sustain oscillations is:

$$f = \frac{1}{2\pi\sqrt{(L_1 + L_2) C_3}}$$

Wien bridge oscillator circuit.



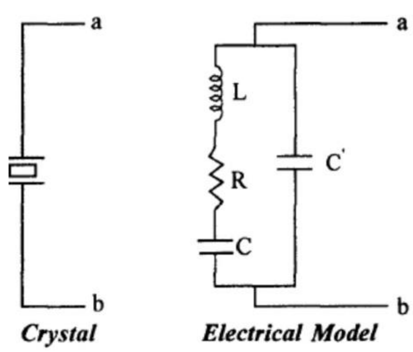


For aBridge Oscillator frequency of sustain oscillations is:

$$F = \frac{1}{2\pi RC}$$

$$h_{fe} = 4K + 23 + 29/K$$

CRYSTAL OSCILLATORS



$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$

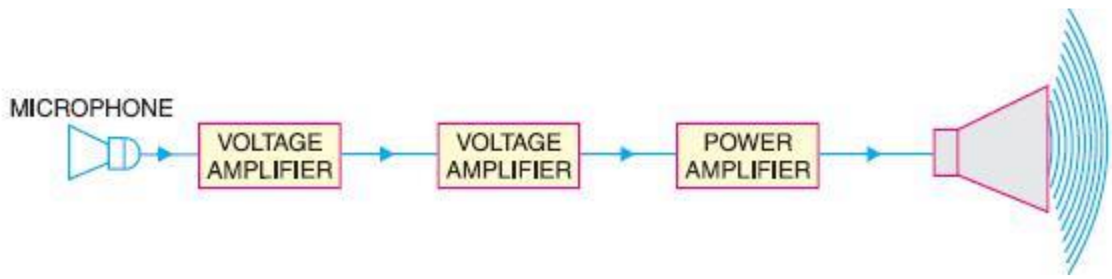
UNIT – IV

LARGE SIGNAL AMPLIFIERS: Classification, Class A Large signal amplifiers, Transformer Coupled Class A Audio Power amplifier, Efficiency of class A amplifier, Class B amplifier, Efficiency of class B Amplifier, class B Push pull Amplifier, Complementary Symmetry Class B Push Pull Amplifier, Distortion of Power Amplifiers, Thermal Stability and Heat sinks.

INTRODUCTION

A practical amplifier always consists of a number of stages that amplify a weak signal until sufficient power is available to operate a loudspeaker or other output device. The first few stages in this multistage amplifier have the function of only voltage amplification. However, the last stage is designed to provide maximum power. This final stage is known as power stage.

The term audio means the range of frequencies which our ears can hear. The range of human hearing extends from 20 Hz to 20 kHz. Therefore, audio amplifiers amplify electrical signals that have a frequency range corresponding to the range of human hearing *i.e.* 20 Hz to 20 kHz. The early stages build up the voltage level of the signal while the last stage builds up power to a level sufficient to operate the loudspeaker. In this chapter, we shall talk about the final stage in a multistage amplifier—the power amplifier.



Transistor Audio Power Amplifier

A transistor amplifier which raises the power level of the signals that have audio frequency range is known as **transistor audio power amplifier.** In general, the last stage of a multistage amplifier is the *power stage*. The power amplifier differs from all the previous stages in that here a concentrated effort is made to obtain maximum output power. A transistor that is suitable

for power amplification is generally called a *power transistor*. It differs from other transistors mostly in size ; it is considerably larger to provide for handling the great amount of power. Audio power amplifiers are used to deliver a large amount of power to a low resistance load. Typical load values range from 300Ω (for transmission antennas) to 8Ω (for loudspeakers). Although these load values do not cover every possibility, they do illustrate the fact that audio power amplifiers usually drive low-resistance loads. The typical power output rating of a power amplifier is 1W or more.

Small-Signal and Large-Signal Amplifiers

The input signal to a multistage amplifier is generally small (a few mV from a cassette or CD or a few μV from an antenna). Therefore, the first few stages of a multistage amplifier handle small signals and have the function of only voltage amplification. However, the last stage handles a large signal and its job is to produce a large amount of power in order to operate the output device (*e.g.* speaker).

(*i*) Small-signal amplifiers.

Those amplifiers which handle small input a.c. signals (a few μV or a few mV) are called *small-signal amplifiers.* Voltage amplifiers generally fall in this class. The small-signal amplifiers are designed to operate over the linear portion of the output characteristics. Therefore, the transistor parameters such as current gain, input impedance, output impedance etc. do not change as the amplitude of the signal changes. Such amplifiers amplify the signal with little or no distortion.

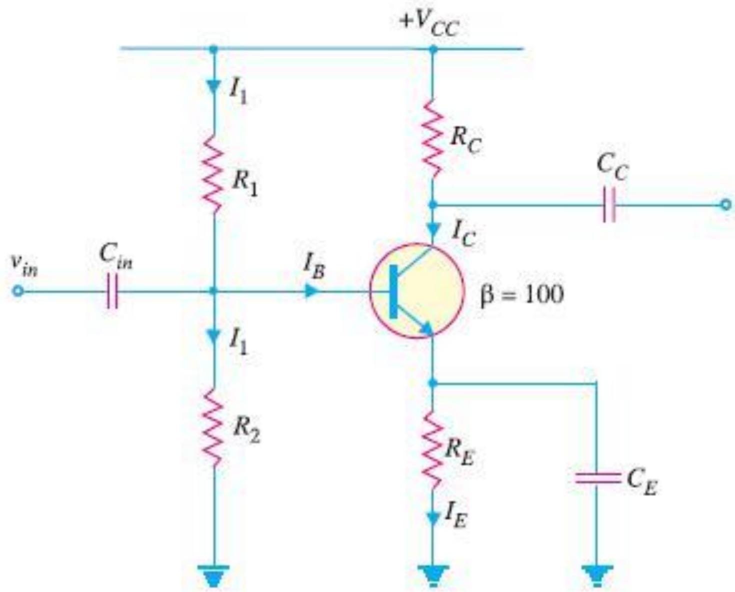
(*ii*) Large-signal amplifiers.

Those amplifiers which handle large input a.c. signals (a few volts) are called *large-signal amplifiers.* Power amplifiers fall in this class. The large-signal amplifiersare designed to provide a large amount of a.c. power output so that they can operate the output device *e.g.* a speaker. The main features of a large-signal amplifier or power amplifier are the circuit's power efficiency, the maximum amount of power that the circuit is capable of handling and the impedance matching to the output device. It may be noted that all large-signal amplifiers are not necessarily power amplifiers but it is safe to say that most are. In general, where amount of power involved is 1W or more, the amplifier is termed as *power amplifier.*

Output Power of Amplifier

An amplifier converts d.c. power drawn from d.c. supply *VCC* into a.c. output power. The output power is always less than the input power because losses occur in the various resistors present in the circuit. The currents are flowing through various resistors causing *I*2*R* loss. Thus power loss in *R*1 is *I*1

2 *R*1, power loss in *RC* is *IC* 2 *RC*, power loss in *RE* is *IE* 2 *RE* and so on. All these losses appear as heat. Therefore, losses occurring in an amplifier not only decrease the efficiency but they also increase the temperature of the circuit.



When load *RL* is connected to the amplifier, A.C. output power,

$$P_O = \frac{V_L^2}{R_L}$$

Difference between Voltage and Power Amplifiers

The distinction between voltage and power amplifiers is somewhat artificial since useful power (*i.e.* product of voltage and current) is always developed in the load resistance through which current flows. The difference between the two types is really one of degree; it is a question of how much voltage and how much power. A voltage amplifier is designed to achievemaximum voltage amplification. It is, however, not important to raise the power level. On the other hand, a power amplifier is designed to obtain maximum output power.

1.Voltage amplifier.

The voltage gain of an amplifier is given by :

$$A_v = \beta \times \frac{R_C}{R_{in}}$$

In order to achieve high voltage amplification, the following features are incorporated in such amplifiers :

(*i*) The transistor with high β (>100) is used in the circuit. In other words, those transistors are employed which have thin base.

(*ii*) The input resistance *Rin* of the transistor is sought to be quite low as compared to the collector load *RC*.

(*iii*) A relatively high load *RC* is used in the collector. To permit this condition, voltage amplifiers are always operated at low collector currents (j 1 mA). If the collector current is small, we can use large *RC* in the collector circuit.

2. Power amplifier.

A power amplifier is required to deliver a large amount of power and as such it has to handle large current. In order to achieve high power amplification, the following features are incorporated in such amplifiers:

(*i*) The size of power transistor is made considerably larger in order to dissipate the heat produced in the transistor during operation.

(*ii*) The base is made thicker to handle large currents. In other words, transistors with comparatively smaller are used.

(*iii*) Transformer coupling is used for impedance matching.

The comparison between voltage and power amplifiers is given below in the tabular form

:

S. No.	Particular	Voltage amplifier	Power amplifier
1.	β	High (> 100)	low (5 to 20)
2.	R_C	High (4 – 10 kΩ)	low (5 to 20 Ω)
3.	*Coupling*	usually *R* – *C* coupling	Invariably transformer coupling
4.	*Input voltage*	low (a few mV)	High (2 – 4 V)
5.	*Collector current*	low (≃ 1 mA)	High (> 100 mA)
6.	*Power output*	low	high
7.	*Output impedance*	High (≃ 12 kΩ)	low (200 Ω)

Performance Quantities of Power Amplifiers

As mentioned previously, the prime objective for a power amplifier is to obtain maximum output power. Since a transistor, like any other electronic device has voltage, current and power dissipation limits, therefore, the criteria for a power amplifier are : ***collector efficiency, distortion*** and ***power dissipation capability*****.**

(*i*) Collector efficiency.

The main criterion for a power amplifier is not the power gain rather it is the maximum a.c. power output. Now, an amplifier converts d.c. power from supply into a.c. power output. Therefore, the ability of a power amplifier to convert d.c. power from supply into a.c. output power is a measure of its effectiveness. This is known as collector efficiency and may be defined as under :

The ratio of a.c. output power to the zero signal power (i.e. d.c. power) supplied by the battery of a power amplifier is known as **collector efficiency.**

Collector efficiency means as to how well an amplifier converts d.c. power from the battery into a.c. output power. For instance, if the d.c. power supplied by the battery is 10W and a.c. output power is 2W, then collector efficiency is 20%. The greater the collector efficiency, the larger is the a.c. power output. It is obvious that for power amplifiers, maximum collector efficiency is the desired goal.

(*ii*) Distortion.

The change of output wave shape from the input wave shape of an amplifier is known as **distortion.** A transistor like other electronic devices, is essentially a non-linear device. Therefore, whenever a signal is applied to the input of the transistor, the output signal is not exactly like the input signal *i.e.* distortion occurs. Distortion is not a problem for small signals (*i.* point. However, a power amplifier handles large signals and, therefore, the problem of distortion immediately arises. For the comparison of two power amplifiers, the one which has the less distortion is the better. We shall discuss the method of reducing distortion in amplifiers in the chapter of negative feedback in amplifiers.

(*iii*) Power dissipation capability.

The ability of a power transistor to dissipate heat is known as **power dissipation capability.** As stated before, a power transistor handles large currents and heats up during operation. As any temperature change influences the operation of transistor, therefore, the transistor must dissipate this heat to its surroundings. To achieve this, generally a *heat sink* (a metal case) is attached to a power transistor case. The increased surface area allows heat to escape easily and keeps the case temperature of the transistor within permissible limits.

Classification of Power Amplifiers

Transistor power amplifiers handle large signals. Many of them are driven so hard by the input large signal that collector current is either cut-off or is in the saturation region during a large portion of the input cycle. Therefore, such amplifiers are generally classified according to their mode of operation *i.e*. the portion of the input cycle during which the collector current is expected to flow. On this basis, they are classified as:

Amplifier circuits may be classified in terms of the portion of the cycle for which the active device conducts.

Class A: It is one, in which the active device conducts for the full 360°.

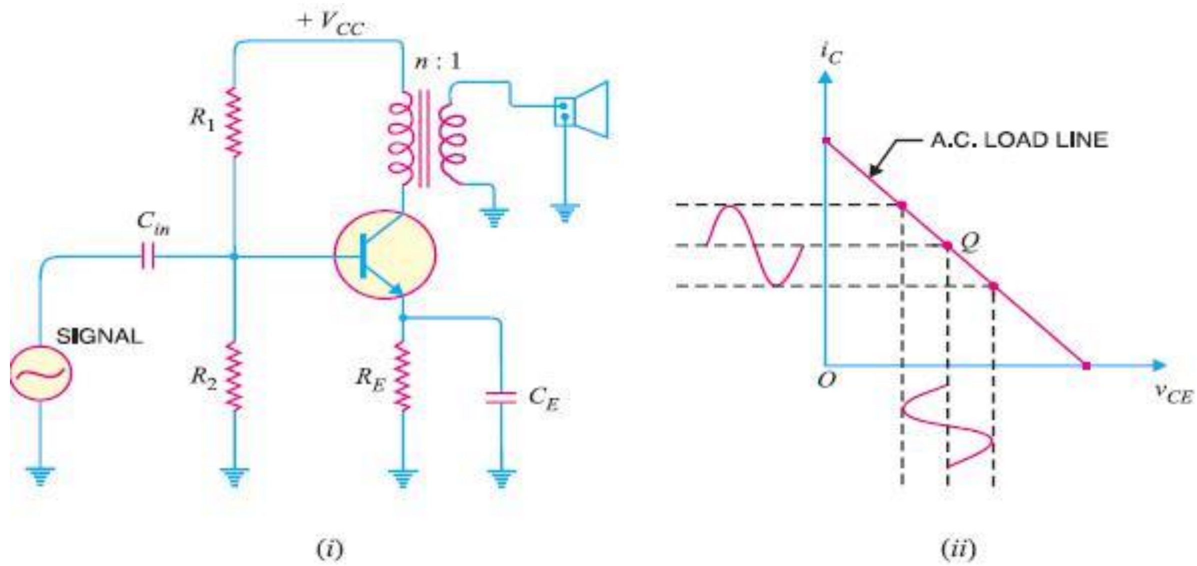
Class B: Conduction for 1800

Class C: Conduction for < 1800

Class AB: Conduction angle is between 1800 and 3600

(*i*) class *A* power amplifier **(*ii*)** class *B* power amplifier **(*iii*)** class *C* power amplifier

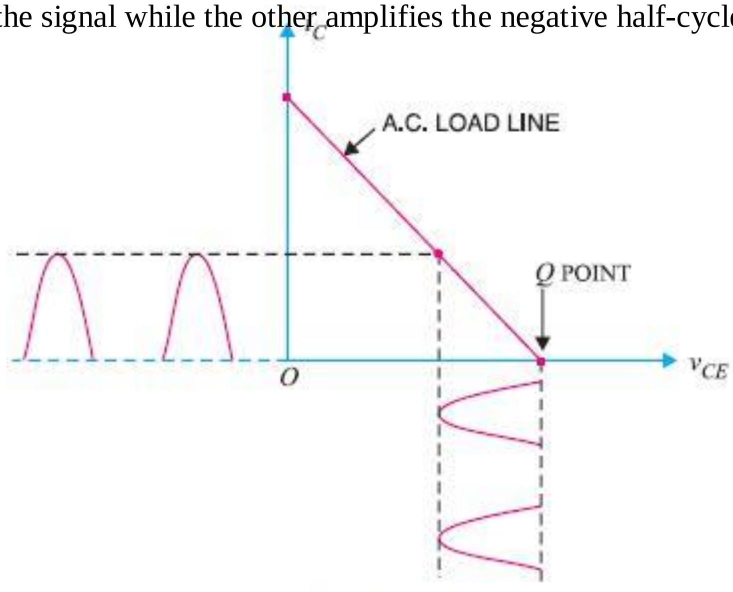
(*i*) Class A power amplifier. *If the collector current flows at all times during the full cycle of the signal, the power amplifier is known as* **class A power amplifier.**



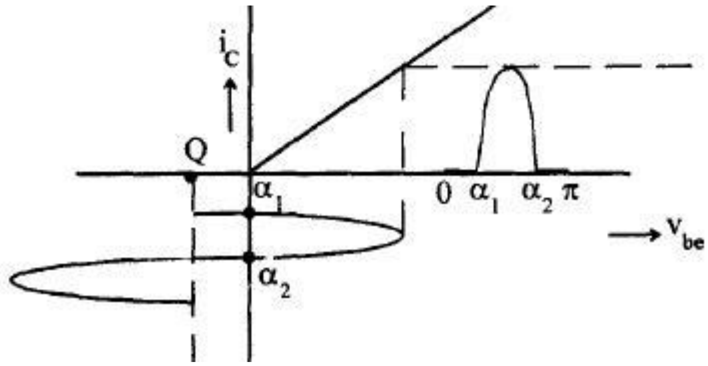
Obviously, for this to happen, the power amplifier must be biased in such a way that no part of the signal is cut off of class *A* power amplifier. Note that collector has a transformer as the load which is most common for all classes of power amplifiers. The use of transformer permits impedance matching, resulting in the transference of maximum power to the load *e.g.* loudspeaker. Fig. 4.4 (*ii*) shows the class *A* operation in terms of *a.c.* load line. The operating point *Q* is so selected that collector current flows at all times throughout the full cycle of the applied signal. As the output wave shape is exactly similar to the input wave shape, therefore, such amplifiers have least distortion. However, they have the disadvantage of low power output and low collector efficiency (about 35%).

(*ii*) Class B power amplifier.

If the collector current flows only during the positive half-cycle
of the input signal, it is called a **class B power amplifier.** In class *B* operation, the transistor bias is so adjusted that zero signal collector current is zero *i.e.* no biasing circuit is needed at all. During the positive half-cycle of the signal, the input circuit is forward biased and hence collector current flows. However, during the negative half-cycle of the signal, the input circuit is reverse biased and no collector current flows. Fig. 12.5 shows the class *B* operation in terms of a.c. load line. Obviously, the operating point *Q* shall be located at collector cut off voltage. It is easy to see that output from a class *B* amplifier is amplified half-wave rectification. In a class *B* amplifier, the negative half-cycle of the signal is cut off and hence a severe distortion occurs. However, class *B* amplifiers provide higher power output and collector efficiency (50 −60%). Such amplifiers are mostly used for power amplification in push-pull arrangement. In such an Arrangement, 2 transistors are used in class *B* operation. One transistor amplifies the positive half cycle of the signal while the other amplifies the negative half-cycle.



(*iii*) Class C power amplifier. *If the collector current flows for less than half-cycle of the in signal, it is called* **class C power amplifier.** In class *C* amplifier, the base is given some negative bias so that collector current does not flow just when the positive half-cycle of the signal starts. Such amplifiers are never used for power amplification. However, they are used as tuned amplifiers *i.e.* to amplify a narrow band of frequencies near the resonant frequency.



Expression for Collector Efficiency

For comparing power amplifiers, collector efficiency is the main criterion. The greater the collector efficiency, the better is the power amplifier. Now, Collector efficiency

$$* P_o = [(0.5 \times 0.707)\, v_{ce(p-p)}]\,[(0.5 \times 0.707)\, i_{c(p-p)}]$$

$$= \frac{v_{ce(p-p)} \times i_{c(p-p)}}{8}$$

$$\text{Collector } \eta = \frac{v_{ce(p-p)} \times i_{c(p-p)}}{8\, V_{CC}\, I_C}$$

where V_{ce} is the *r.m.s.* value of signal output voltage and I_c is the *r.m.s.* value of output signal current. In terms of peak-to-peak values (which are often convenient values in load-line work), the a.c. power output can be expressed as :

$$\text{Collector efficiency, } \eta = \frac{\text{a.c. power output}}{\text{d.c. power input}}$$

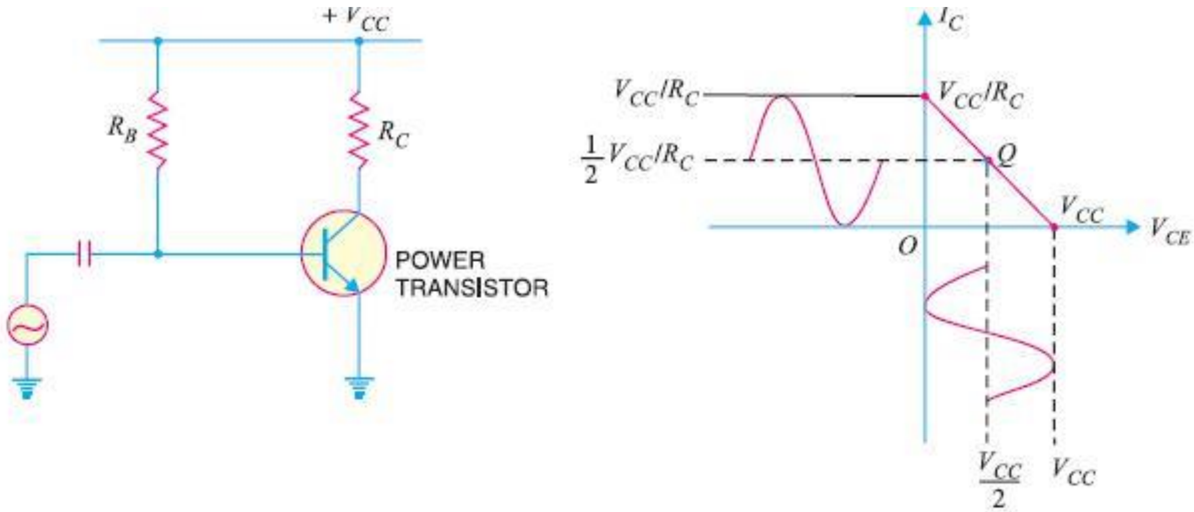
$$= \frac{P_o}{P_{dc}}$$

$$* P_{dc} = V_{CC} I_C$$

$$P_o = V_{ce} I_c$$

Series-Fed Class A Amplifier

An *ac* signal is applied to the amplifier, the output current and voltage will vary about the operating point *Q*. In order to achieve the maximum symmetrical swing of current and voltage (to achieve maximum output power), the *Q* point should be located at the centre of the *dc* load line. In that case, operating point is $IC = VCC/2RC$ and $VCE = VCC/2$.



(i) (ii)

$$\text{Maximum } v_{ce\,(p-p)} = V_{CC}$$

$$\text{Maximum } i_{c\,(p-p)} = V_{CC}/R_C$$

$$\text{Max. } ac \text{ output power,} \quad P_{o\,(max)} = \frac{v_{ce\,(p-p)} \times i_{c\,(p-p)}}{8} = \frac{V_{CC} \times V_{CC}/R_C}{8} = \frac{V_{CC}^2}{8R_C}$$

$$\text{D.C. power supplied, } P_{dc} = V_{CC}\, I_C = V_{CC}\left(\frac{V_{CC}}{2R_C}\right) = \frac{V_{CC}^2}{2R_C}$$

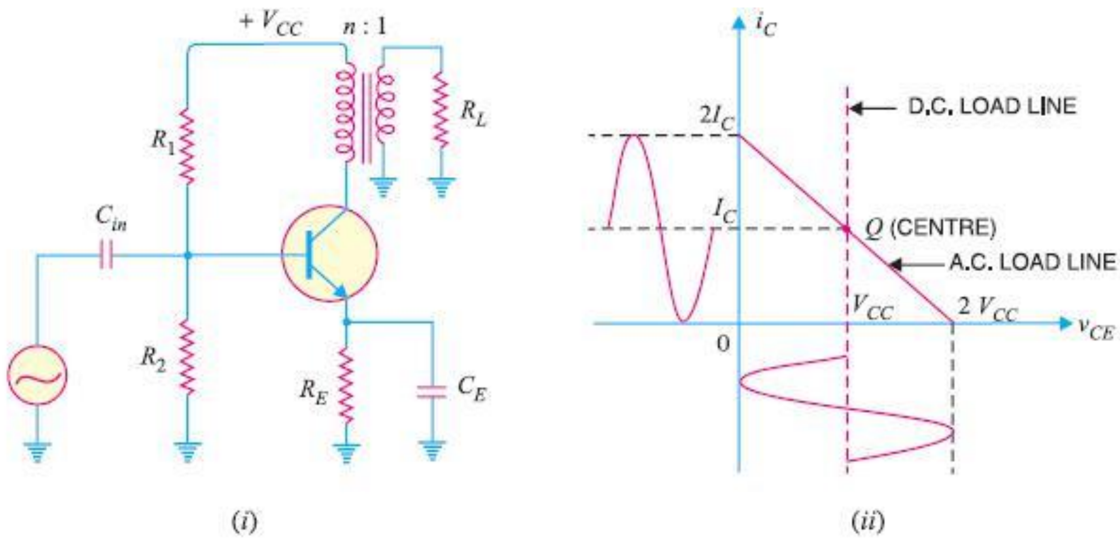
$$\therefore \quad \text{Maximum collector } \eta = \frac{P_{o(max)}}{P_{dc}} \times 100 = \frac{V_{CC}^2/8R_C}{V_{CC}^2/2R_C} \times 100 = 25\%$$

Thus the maximum collector efficiency of a class *A* series-fed amplifier is 25%. In actual practice, the collector efficiency is far less than this value. **Maximum Collector Efficiency of**

Transformer Coupled Class A Power Amplifier

In class *A* power amplifier, the load can be either connected directly in the collector or it can be transformer coupled. The latter method is often preferred for two main reasons. First, transformer coupling permits impedance matching and secondly it keeps the d.c. power loss small because of the small resistance of the transformer primary winding. the transformer coupled class *A* power amplifier. In order to determine maximum collector efficiency, refer to the output characteristics shown in Fig. 4.8 (*ii*). Under zero signal conditions, the effective resistance in the collector circuit is that of the primary winding of the transformer

(*ii*). When signal is applied, the collector current will vary about the operating point In order to get maximum a.c. power output the peak value of collector



During the peak of the positive half-cycle of the signal,

the total collector current is 2 I_C and v_{ce} =0

During the negative peak of the signal, the collector current is zero and $v_{ce} = 2V_{CC}$.

Peak-to-peak collector-emitter voltage is

$v_{ce}(p-p) = 2V_{CC}$

Peak-to-peak collector current, $i_c(p-p) = 2\,I_C$

$$= \frac{v_{ce(p-p)}}{R_L'} = \frac{2V_{CC}}{R_L'}$$

where R_L' is the reflected value of load R_L and appears in the primary of the transformer.

If n (= N_p/N_s) is the turn ratio of the transformer, then, $R_L' = n^2 R_L$.

d.c. power input, $P_{dc} = V_{CC}\,I_C$

***i*)** A *transformer coupled class *A* power amplifier has a maximum collector efficiency of 50% *i.e.*, maximum of 50% d.c. supply power is converted into a.c. power output. In practice, the efficiency of such an amplifier is less than 50% (about 35%) due to power losses in the output transformer, power dissipation in the transistor etc.

(*ii*) The power dissipated by a transistor is given by :

$$P_{dis} = P_{dc} - P_{ac}$$

where P_{dc} = available d.c. power

P_{ac} = available a.c. power

$$= I_C^2 R_L'$$

Clearly, in class *A* operation, the transistor must dissipate less heat when signal is applied and therefore runs cooler.

(*iii*) When no signal is applied to a class *A* power amplifier, $Pac = 0$.

$Pdis = Pdc$

Thus in class *A* operation, maximum power dissipation in the transistor occurs under zero signal conditions. Therefore, the power dissipation capability of a power transistor (for class *A* operation) must be atleast equal to the zero signal rating. For example, if the zero signal power dissipation of a transistor is 1 W, then transistor needs a rating of atleast 1W. If the power rating of the transistor is less than 1 W, it is likely to be damaged.

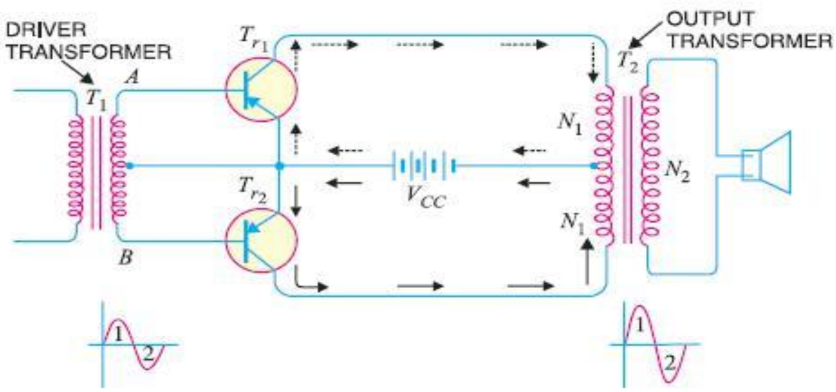
(*iv*) When a class *A* power amplifier is used in the final stage, it is called **single ended class A power amplifier.**

Class B Push-Pull Power Amplifier

The push-pull amplifier is a power amplifier and is frequently employed in the output stages of electronic circuits. It is used whenever high output power at high efficiency is required. Fig. 4.14 shows the circuit of a push-pull amplifier. Two transistors *Tr*1 and *Tr*2 placed back to back are employed. Both transistors are operated in class *B* operation *i.e*. collector current is nearly zero in the absence of the signal. The centre-tapped secondary of driver transformer *T*1 supplies equal and opposite voltages to the base circuits of two transistors. The output transformer *T*2 has the centre-tapped primary winding. The supply voltage *VCC* is connected between the bases and this centre tap. The loudspeaker is connected across the secondary of this transformer.

Circuit operation.

The input signal appears across the secondary *AB* of driver transformer. Suppose during the first half-cycle (marked 1) of the signal, end *A* becomes positive and end *B* negative. This will make the base-emitter junction of *Tr*1 reverse biased and that of *Tr*2 forward biased. The circuit will conduct current due to *Tr*2 only and is shown by solid arrows. Therefore, this half-cycle of the signal is amplified by *Tr*2 and appears in the lower half of the primary of output transformer. In the next halfcycle of the signal, *Tr*1 is forward biased whereas *Tr*2 is reverse biased. Therefore, *Tr*1 conducts and is shown by dotted arrows. Consequently, this half-cycle of the signal is amplified by *Tr*1 and appears in the upper half of the output transformer primary. The centre-tapped primary of the output transformer combines two collector currents to form a sine wave output in the secondary



It may be noted here that push-pull arrangement also permits a maximum transfer of power to the load through impedance matching. If *RL* is the resistance appearing across secondary of output transformer,then resistance *R′L* of primary shall become :

$$R'_L = \left(\frac{2N_1}{N_2}\right)^2 R_L$$

where N_1 = Number of turns between either end of primary winding and centre-tap

N_2 = Number of secondary turns

Advantages

(*i*) The efficiency of the circuit is quite high (i.e 75%) due to class *B* operation.

(*ii*) A high a.c. output power is obtained.

Disadvantages

(*i*) Two transistors have to be used.

(*ii*) It requires two equal and opposite voltages at the input. Therefore, push-pull circuit requires the use of driver stage to furnish these signals.

(*iii*) If the parameters of the two transistors are not the same, there will be unequal amplification

(*iv*) The circuit gives more distortion.

(*v*) Transformers used are bulky and expensive

Maximum efficiency of Class B Power Amplifier:.

we have already seen that a push-pull circuit uses two transistors working in class *B* operation. For class *B* operation, the Q-point is located at cut-off on both d.c. and a.c. load lines. For maximum signal operation, the two transistors in class B amplifier are alternately driven from cut-off to saturation. This is shown in Fig. 4.15 (*i*). It is clear that a.c. output voltage has a peak value of *VCE* and a.c. output current has a peak value of *IC* (*sat*). The same information is also conveyed through the a.c. load line for the circuit [See Fig. 4.15 (*ii*)].

∴ Peak a.c. output voltage $= V_{CE}$

Peak a.c. output current $= I_{C\,(sat)} = {}^{*}\dfrac{V_{CE}}{R_L} = \dfrac{V_{CC}}{2\,R_L} \qquad \left(\because V_{CE} = \dfrac{V_{CC}}{2}\right)$

Maximum average a.c. output power $P_{o\,(max)}$ is

$P_{o\,(max)}$ = Product of r.m.s. values of a.c. output voltage and a.c. output current

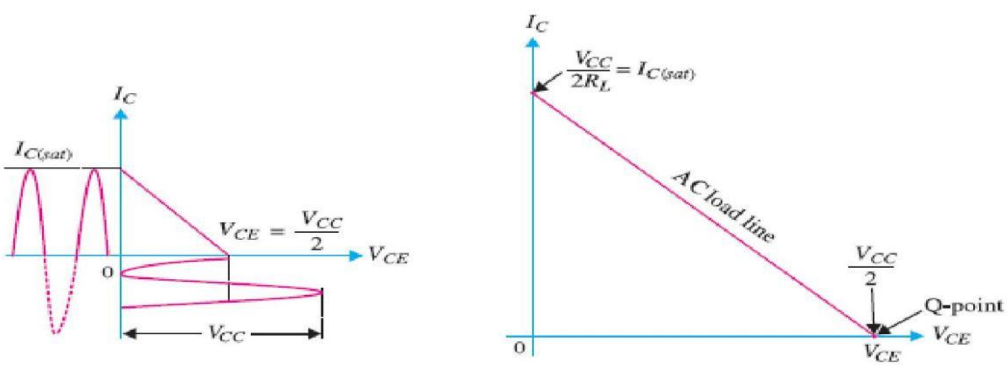
$$= \frac{V_{CE}}{\sqrt{2}} \times \frac{I_{C\,(sat)}}{\sqrt{2}} = \frac{V_{CE}\,I_{C\,(sat)}}{2}$$

$$= \frac{V_{CC}}{2} \times \frac{I_{C\,(sat)}}{2} = \frac{V_{CE}\,I_{C\,(sat)}}{4} \qquad \left(\because V_{CE} = \frac{V_{CC}}{2}\right)$$

$$\therefore \quad P_{o\,(max)} = 0.25\,V_{CC}\,I_{C\,(sat)}$$

The input d.c. power from the supply V_{CC} is

$$P_{dc} = V_{CC}\,I_{dc}$$



(*i*) (*ii*)

where *Idc* is the average current drawn from the supply *VCC*. Since the transistor is on for alternating half-cycles, it effectively acts as a half-wave rectifier.

$$\therefore \quad I_{dc} = \frac{I_{C\,(sat)}}{\pi}$$

$$\therefore \quad P_{dc} = \frac{V_{CC}\,I_{C\,(sat)}}{\pi}$$

$$\therefore \quad \text{Max. collector}\ \eta = \frac{P_{o\,(max)}}{P_{dc}} = \frac{0.25\,V_{CC}\;I_{C\,(sat)}}{\left(V_{CC}\,I_{C\,(sat)}\right)/\pi} \times 100 = 0.25\pi \times 100 = 78.5\%$$

Thus the maximum collector efficiency of class *B* power amplifier is 78.5%. Recall that maximum collector efficiency for class A transformer coupled amplifier is 50%.

Power dissipated by transistors. The power dissipated (as heat) by the transistors in class *B* amplifier is the difference between the input power delivered by *VCC* and the output power delivered to the load *i.e*.

$$P_{2T} = P_{dc} - P_{ac}$$

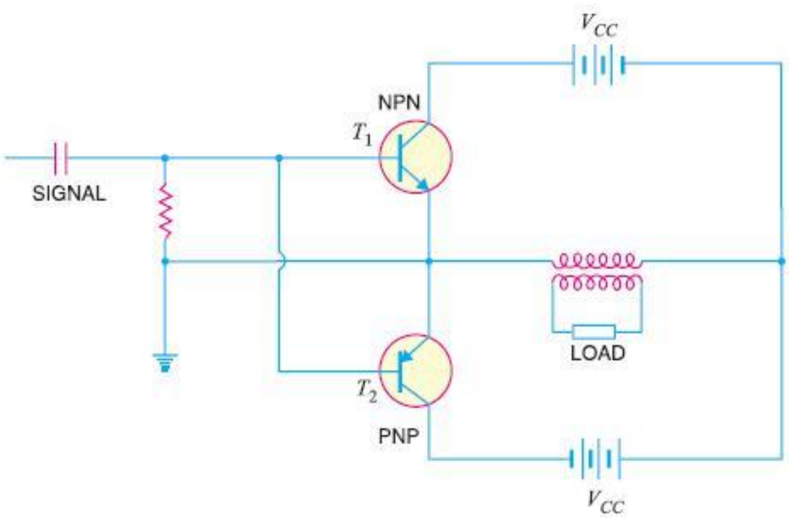
where P_{2T} = power dissipated by the two transistors

∴ Power dissipated by each transistor is

$$P_T = \frac{P_{2T}}{2} = \frac{P_{dc} - P_{ac}}{2}$$

Complementary-Symmetry Amplifier

By complementary symmetry is meant a principle of assembling push-pull class *B* amplifier without requiring centre-tapped transformers at the input and output stages. Fig. 4.16 shows the transistor push-pull amplifier using complementary symmetry. It employs one *npn* and one *pnp* transistor and requires no centre-tapped transformers. The circuit action is as follows. During the positive-half of the input signal, transistor *T*1 (the *npn* transistor) conducts current while *T*2 (the *pnp* transistor) is cut off. During the negative half-cycle of the signal, *T*2 conducts while *T*1 is cut off. In this way, *npn* transistor amplifies the positive half-cycles of the signal while the *pnp* transistor amplifies the negative half-cycles of the signal. Note that we generally use an output transformer (not centre-tapped) for impedance matching.



Advantages

(*i*) This circuit does not require transformer. This saves on weight and cost.

(*ii*) Equal and opposite input signal voltages are not required.

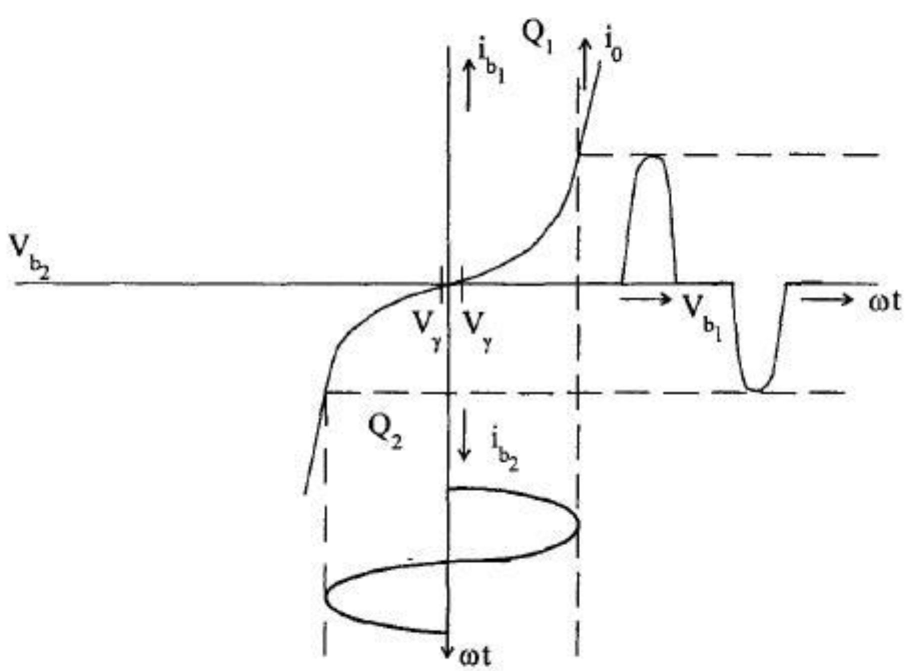
Disadvantages

(*i*) It is difficult to get a pair of transistors (*npn* and *pnp*) that have similar characteristics.

(*ii*) We require both positive and negative supply voltages.

DISTORTION

Let ib1 V c, Vb1 be the input characteristic of the first transistor and ib2, V s, Vb2 is the input characteristic of th6 second transistor. V y is the cut)n voltage. These are t6e two tiansistors of the class B pushpull amplifier. Now the base input voltage being given to the transistor is sinusoidal, i.e., base drive is sinusoidal. So because of the *cut in voltage,* eventhough input voltage is present, output will not be transmitted or there is distortion in the output current of the transistor. This is known as *crossover distortion.* But this will not occur if the base current drive is sinusoidal. Since in the graphical analysis the input current is taken in the I quadrant. No distortion if the operating point is in the active region. Cross-over distortion can also be laminated in class AB operation. A small stand by current flows at zero excitation. The input signal is shifted by constant DC bias so that the input signal is shifted by an amount V γ



Thermal Runaway

All semiconductor devices are very sensitive to temperature variations. If the temperature of a transistor exceeds the permissible limit, the transistor may be *permanently damaged. Silicon transistors can withstand temperatures upto 250ºC while the germanium transistors can withstand temperatures upto 100ºC.

There are two factors which determine the operating temperature of a transistor *viz.*

i) Surrounding temperature and

ii) Power dissipated by the transistor.

When the transistor is in operation, almost the entire heat is produced at the collector-base junction. This power dissipation causes the junction temperature to rise. This in turn increases the collector current since more electron-hole pairs are generated due to the rise in temperature. This produces an increased power dissipation in the transistor and consequently a further rise in temperature. Unless adequate cooling is provided or the transistor has built-in temperature compensation circuits to prevent excessive collector current rise, the junction temperature will continue to increase until the maximum permissible temperature is exceeded. If this situation occurs, the transistor will be permanently damaged.

The unstable condition where, owing to rise in temperature, the collector current rises and continues to increase is known as **thermal runaway.**

Thermal runaway must always be avoided. If it occurs, permanent damage is caused and the transistor must be replaced.

Heat Sink

As power transistors handle large currents, they always heat up during operation. Since transistor is a temperature dependent device, the heat generated must be dissipated to the surroundings in order to keep the temperature within permissible limits. Generally, the transistor is fixed on a metal sheet (usually aluminium) so that additional heat is transferred to the *Al* sheet.

The metal sheet that serves to dissipate the additional heat from the power transistor is known as **heat sink.**Most of the heat within the transistor is produced at the collector junction. The heat sink increases the surface area and allows heat to escape from the collector junction easily. The result is that temperature of the transistor is sufficiently lowered. Thus heat sink is a direct practical means of combating the undesirable thermal effects *e.g.* thermal runaway. material, volume, area, shape, contact between case and sink and movement of air around the sink. Finned aluminium heat sinks yield the best heat transfer per unit cost. It should be realised that the use of heat sink alone may not be sufficient to prevent thermal runaway under all conditions. In designing a transistor circuit, consideration should also be given to the choice of

(i) operating point

(ii) ambient temperatures which are likely to be encountered and

(iii) the type of transistor *e.g.* metal case transistors are more readily cooled by conduction than plastic ones.

Classification of heat Sinks

(i) Low Power Transistor Type.

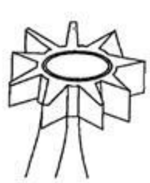
(ii) High Power Transistor Type.

Low Power Transistor Type

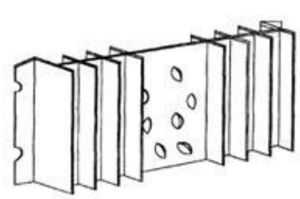
- Low Power Transistors can be mounted directly on the metal chassis to increase the heat dissipation capability. The casing of the transistor must be insulated from the metal chassis to prevent shorting.
- Beryllium oxide insulating washers are used for insulating casing from the chassis. They have good thermal conductivity.
- Zinc oxide film silicon compound between washer and chassis, improves the heat transfer from the semiconductor device to case to the chassis.

High Power Transistor Type.

- re TO-3 and TO-66 types. These are diamond shaped. For power transistors, usually, the ease itself in the collector convention and radiation
- Finned aluminium heat sinks yield the best heat transfer per unit cost.



Fin-type heat sink



Power transistor heat sink

Mathematical Analysis

The permissible power dissipation of the transistor is very important item for power transistors. The permissible power rating of a transistor is calculated from the following relation :

$$P_{total} = \frac{T_{J\,max} - T_{amb}}{\theta}$$

where

P_{total} = total power dissipated within the transistor

$T_{J\,max}$ = maximum junction temperature. It is 90°C for *germanium* transistors and 150°C for *silicon* transistors.

T_{amb} = ambient temperature *i.e.* temperature of surrounding air

θ = *thermal resistance *i.e.* resistance to heat flow from the junction to the surrounding air

The unit of Ə is ºC/ watt and its value is always given in the transistor manual. A low thermal resistance means that it is easy for heat to flow from the junction to the surrounding air. The larger the transistor case, the lower is the thermal resistance and *vice-versa*. It is then clear that by using heat sink, the value of θ can be decreased considerably, resulting in increased power dissipation.ct of Cascading Single tuned Amplifiers on bandwidth, Effect of Cascading Double Tuned Amplifiers on Bandwidth, Stagger Tuned Amplifiers, Stability of tuned amplifiers.

UNIT-V

Transistor Tuned Amplifiers

Introduction, Q Factor, Small signal Tuned Amplifiers, Effect of Cascading Single tuned Amplifiers on bandwidth, Effect of Cascading Double Tuned Amplifiers on Bandwidth, Stagger Tuned Amplifiers, Stability of tuned amplifiers.

INTRODUCTION

An audio amplifier amplifies a wide band of frequencies equally well and does not permit the selection of a particular desired frequency while rejecting all other frequencies. However, sometimes it is desired that an amplifier should be selective *i.e.* it should select a desired frequency or narrow band of frequencies for amplification. For instance, radio and television transmission are carried on a specific radio frequency assigned to the broadcasting station. The radio receiver is required to pick up and amplify the radio frequency desired while discriminating all others. To achieve this, the simple resistive load is replaced by a parallel tuned circuit whose impedance strongly depends upon frequency. Such a tuned circuit becomes very selective and amplifies very strongly signals of resonant frequency and narrow band on either side. Therefore, the use of tuned circuits in conjunction with a transistor makes possible the selection and efficient amplification of a particular desired radio frequency. Such an amplifier is called a *tuned amplifier*. In this chapter, we shall focus our attention on transistor tuned amplifiers and their increasing applications in high frequency electronic circuits.

Advantages of Tuned Amplifiers:

In high frequency applications, it is generally required to amplify a single frequency, rejecting all other frequencies present. For such purposes, tuned amplifiers are used. These amplifiers use tuned parallel circuit as the collector load and offer the following advantages:

(*i*) Small power loss:A tuned parallel circuit employs reactive components *L* and *C*. Consequently, the power loss in such a circuit is quite low. On the other hand, if a resistive load is used in the collector circuit, there will be considerable loss of power. Therefore, tuned amplifiers are highly efficient.

(ii) High selectivity: A tuned circuit has the property of selectivity *i.e.* it can select the desired frequency for amplification out of a large number of frequencies simultaneously impressed upon it.

(*iii*) Smaller collector supply voltage: Because of little resistance in the parallel tuned circuit,it requires small collector supply voltage *VCC*. On the other hand, if a high load resistance is used in the collector for amplifying even one frequency, it would mean large voltage drop across it due to zero signal collector current. Consequently, a higher collector suplly we needed

Why not Tuned Circuits for Low Frequency Amplification?

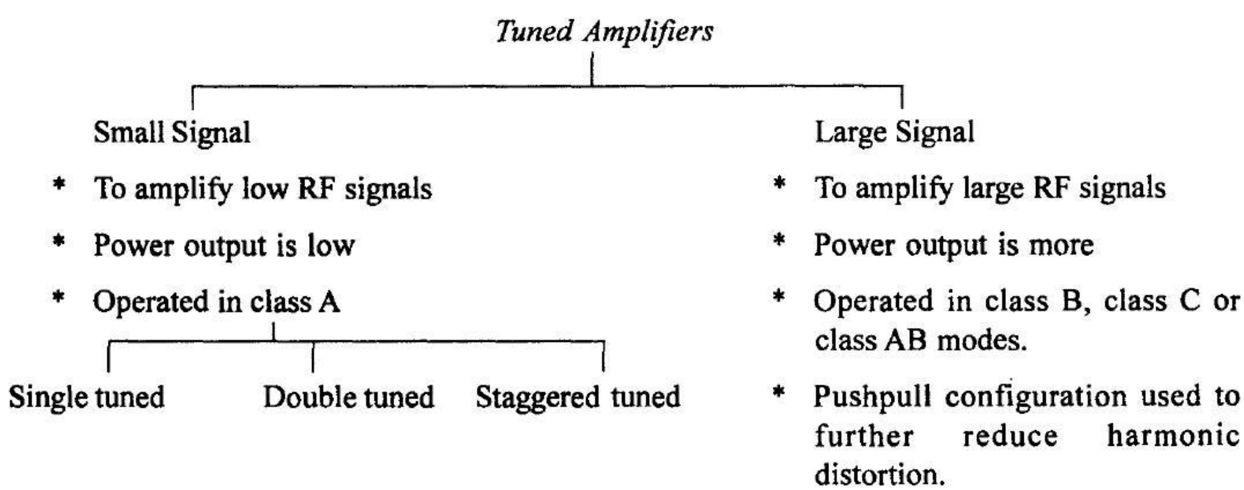
The tuned amplifiers are used to select and amplify a specific high frequency or narrow band of frequencies. The reader may be inclined to think as to why tuned circuits are not used to amplify low frequencies. This is due to the following reasons :

(*i*) *Low frequencies are never single.* A tuned amplifier selects and amplifies a single frequency. However, the low frequencies found in practice are the audio frequencies which are a mixture of frequencies from 20 Hz to 20 kHz and are not single. It is desired that all these frequencies should be equally amplified for proper reproduction of the signal. Consequently, tuned amplifiers cannot be used for the purpose.

(*ii*) *High values of L and C*. The resonant frequency of a parallel tuned circuit is given by; $fr = 1/2\pi LC$

For low frequency amplification, we require large values of *L* and *C*. This will make the tuned Circuit bulky and expensive. It is worthwhile to mention here that *R-C* and transformer coupled Amplifiers, which are comparatively cheap, can be conveniently used for low frequency applications.

Classification

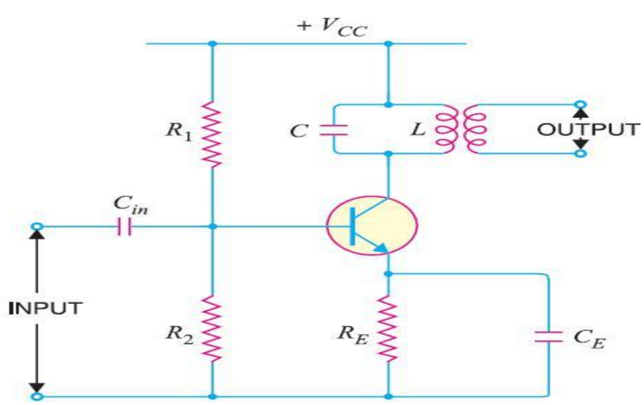


Tuned Amplifiers:

Amplifiers which amplify a specific frequency or narrow band of frequencies are called ***tuned amplifiers.*** Tuned amplifiers are mostly used for the amplification of high or radio frequencies.

It is because radio frequencies are generally single and the tuned circuit permits their selection and efficient amplification. However, such amplifiers are not suitable for the amplification of audio frequencies as they are mixture of frequencies from 20 Hz to 20 kHz and not single. Tuned amplifiers are widely used in radio and television circuits where they are called upon to handle radio frequencies. Fig. 5.1 shows the circuit of a simple transistor tuned amplifier. Here, instead of load resistor, we have a parallel tuned circuit in the collector. The impedance of this tuned circuit strongly depends upon frequency.

It offers a very high impedance at resonant frequency and very small impedance at all other frequencies. If the signal has the same frequency as the resonant frequency of LC circuit, large amplification will result due to high impedance of LC circuit at this frequency. When signals of many frequencies are present at the input of tuned amplifier, it will select and strongly amplify the signals of resonant frequency while *rejecting all others. Therefore, such amplifiers are very useful in radio receivers to select the signal from one particular broadcasting station when signals of many other frequencies are present at the receiving aerial.



Distinction between Tuned Amplifiers and other Amplifiers:

We have seen that amplifiers (*e.g.*, voltage amplifier, power amplifier *etc.*) provide the constant gain over a limited band of frequencies *i.e.*, from lower cut-off frequency *f*1 to upper cut-off frequency *f*2. Now bandwidth of the amplifier, *BW* = *f*2 − *f*1. The reader may wonder, then, what distinguishes atuned amplifier from other amplifiers? The difference is that tuned amplifiers are designed to have specific, usually narrow bandwidth. This point is illustrated in in Fig.5.2. Note that *BWS* is the bandwidth of standard frequency response while *BWT* is the bandwidth of the tuned amplifier. In many applications, the narrower the bandwidth of a tuned amplifier, the better it is.

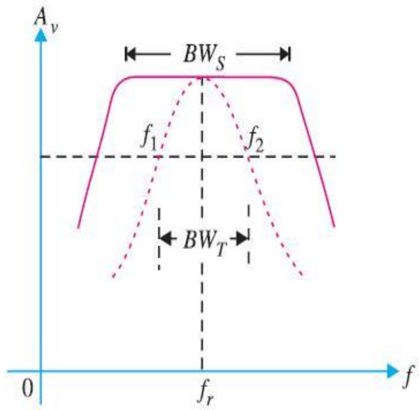


Fig.5.2

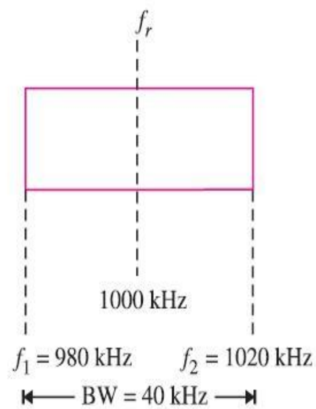


Fig.5.3

Illustration. Consider a tuned amplifier that is designed to amplify only those frequencies that are within ± 20 kHz of the central frequency of 1000 kHz (*i.e.*, *fr* = 1000 kHz). Here [See Fig.
5.3], *f*1 = 980 kHz, *fr* = 1000 kHz, *f*2 = 1020 kHz, *BW* = 40 kHz

This means that so long as the input signal is within the range of 980 – 1020 kHz, it will be amplified. If the frequency of input signal goes out of this range, amplification will be drastically reduced.

Analysis of Parallel Tuned Circuit

A parallel tuned circuit consists of a capacitor *C* and inductor *L* in parallel shown in fig 5.4.(*i*).In practice, some resistance *R* is always present with the coil. If an alternating voltage is applied across this parallel circuit, the frequency of oscillations will be that of the applied voltage. However, if the frequency of applied voltage is equal to the natural or resonant frequency of *LC* circuit, then *electrical resonance* will occur. Under such conditions, the impedance of the tuned circuit becomes maximum and the line current is minimum. The circuit then draws just enough energy from a.c. supply necessary to overcome the losses in the resistance *R*.

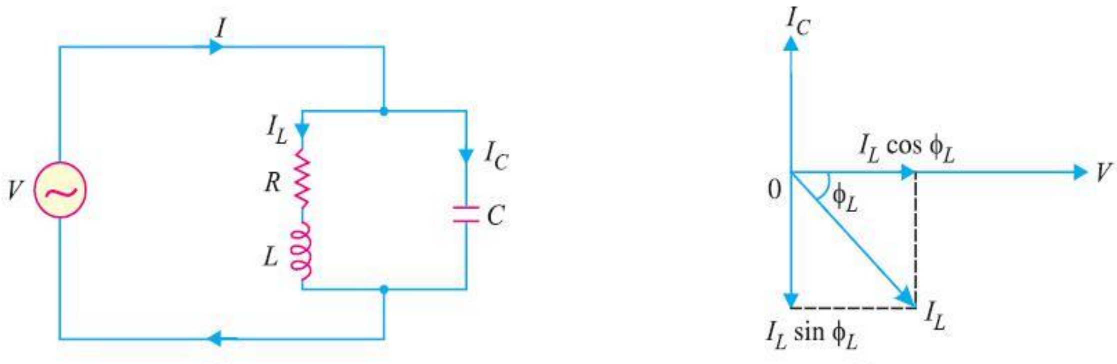
Parallel resonance:

A parallel circuit containing reactive elements (*L* and *C*) is *resonant when the circuit power factor is unity *i.e*. applied voltage and the supply current are in phase. The phasor diagram of the parallel circuit is shown in Fig. 15. 4 (*ii*). The coil current *IL* has two rectangular components *viz* active component *IL* cos □*L* and reactive component *IL* sin w*L*. This parallel circuit will resonate when the circuit power factor is unity. This is possible only when the net reactive component of the circuit current is zero *i.e.*

$$I_C - I_L \sin \phi_L = 0$$

$$I_C = I_L \sin \phi_L$$

Resonant frequency



(i) (ii)

At parallel resonance, we have, $I_C = I_L \sin \phi_L$

Now $I_L = V/Z_L$; $\sin \phi_L = X_L/Z_L$ and $I_C = V/X_C$

$$\therefore \quad \frac{V}{X_C} = \frac{V}{Z_L} \times \frac{X_L}{Z_L}$$

$$\text{or} \quad X_L X_C = Z_L^2$$

$$\text{or} \quad \frac{\omega L}{\omega C} = Z_L^2 = R^2 + X_L^2 \qquad ...(i)$$

$$\text{or} \quad \frac{L}{C} = R^2 + (2\pi f_r L)^2$$

$$\text{or} \quad (2\pi f_r L)^2 = \frac{L}{C} - R^2$$

$$\text{or} \quad 2\pi f_r L = \sqrt{\frac{L}{C} - R^2}$$

$$\text{or} \quad f_r = \frac{1}{2\pi L}\sqrt{\frac{L}{C} - R^2}$$

$$\therefore \quad \text{Resonant frequency, } f_r = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}} \qquad ...(ii)$$

If coil resistance R is small (as is generally the case), then,

$$f_r = \frac{1}{2\pi\sqrt{L\,C}} \qquad ...(iii)$$

The resonant frequency will be in Hz if *R*, *L* and *C* are in ohms, henry and farad respectively.

Note: (i) If in the problem, the value of *R* is given, then eq.
(*ii*) should be used to find *fr*. However, if *R* is not given, then eq.
(*iii*) may be used to find *fr*.

Characteristics of Parallel Resonant Circuit:It is now desirable to discuss some important characteristics of parallel resonant circuit.

(*i*) Impedance of tuned circuit. The impedance offered by the parallel *LC* circuit is given by the supply voltage divided by the line current *i.e.*, *V*/*I*. Since at resonance, line current is minimum, therefore, impedance is maximum at resonant frequency. This fact is shown by the impedance-frequency curve of Fig 5.5. It is clear from impedance-frequency curve that impedance rises to a steep peak at resonant frequency *fr*. However, the impedance of the circuit decreases rapidly when the frequency is changed above or below the resonant frequency. This characteristic of parallel tuned circuit provides it the selective properties *i.e*. to select the resonant frequency and reject all others.

Line current, $I = I_L \cos \phi_L$

or $$\frac{V}{Z_r} = \frac{V}{Z_L} \times \frac{R}{Z_L}$$

or $$\frac{1}{Z_r} = \frac{R}{Z_L^2}$$

or $$\frac{1}{Z_r} = \frac{R}{L/C} = \frac{CR}{L}$$

$$\left[\because Z_L^2 = \frac{L}{C} \text{ from eq. } (i)\right]$$

$\therefore$ Circuit impedance, $$Z_r = \frac{L}{CR}$$

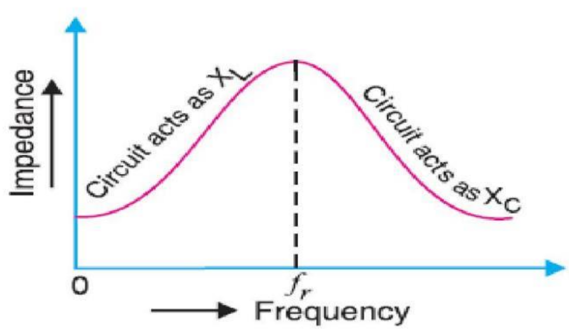


Fig.5.5

Thus at parallel resonance, the circuit impedance is equal to *L/CR. It may be noted that Z_r will be in ohms if R, L and C are measured in ohms, henry and farad respectively.

***ii*) Circuit Current:** At parallel resonance, the circuit or line current I is given by the applied voltage divided by the circuit impedance Z_r *i.e.*,

$$\text{Line current, } I = \frac{V}{Z_r} \qquad \text{where } Z_r = \frac{L}{CR}$$

Because Z_r is very high, the line current I will be very small.

(*iii*) Quality factor Q: It is desired that resonance curve of a parallel tuned circuit should be as sharp as possible in order to provide selectivity. The sharp resonance curve means that impedance falls rapidly as the frequency is varied from the resonant frequency. The smaller the resistance of coil, the more sharp is the resonance curve. This is due to the fact that a small resistance consumes less power and draws a relatively small line current. The ratio of inductive reactance and resistance of the coil at resonance, therefore, becomes a measure of the quality of the tuned circuit. This is called *quality factor* and may be defined as under :

The ratio of inductive reactance of the coil at resonance to its resistance is known as ****quality factor Q** i.e.,

$$Q = \frac{X_L}{R} = \frac{2\pi f_r L}{R}$$

The quality factor Q of a parallel tuned circuit is very important because the sharpness of resonance curve and hence selectivity of the circuit depends upon it. The higher the value of Q, the more selective is the tuned circuit. Fig. 5.6 shows the effect of resistance R of the coil on the sharpness of the resonance curve. It is clear that when the resistance is small, the resonance curve is very sharp. However, if the coil has large resistance, the resonance curve is less sharp. It may be emphasised that where high selectivity is desired, the value of Q should be very large.

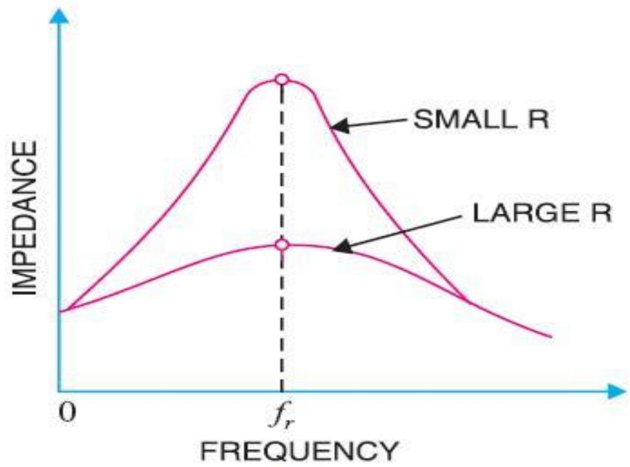


Fig. 5.6

Two things are worth noting. First, *Zr* (= *L*/*CR*) is a pure resistance because there is no frequency term present. Secondly, the value of *Zr* is very high because the ratio *L*/*C* is very large at parallel resonance.

** Strictly speaking, the *Q* of a tank circuit is defined as the ratio of the energy stored in the circuit to the energy lost in the circuit *i.e.*,

$$Q = \frac{\text{Energy stored}}{\text{Energy lost}} = \frac{\text{Reactive Power}}{\text{Resistive Power}} = \frac{I_L^2 X_L}{I_L^2 R} \quad \text{or} \quad Q = \frac{X_L}{R}$$

Frequency Response of Tuned Amplifier

The voltage gain of an amplifier depends upon , input impedance and effective collector load. In a tuned amplifier, tuned circuit is used in the collector. Therefore, voltage gain of such an amplifier is given by :

$$\text{Voltage gain} = \frac{\beta Z_C}{Z_{in}}$$

where ZC = effective collector load

Zin = input impedance of the amplifier

The value of *ZC* and hence gain strongly depends upon frequency in the tuned amplifier. As *ZC* is maximum at resonant frequency, therefore, voltage gain will be maximum at this frequency. The value of *ZC* and gain decrease as the frequency is varied above and below the resonant frequency. Fig. 5.7 shows the frequency response of a tuned amplifier. It is clear that voltage gain is maximum at resonant frequency and falls off as the frequency is varied in either direction from resonance.

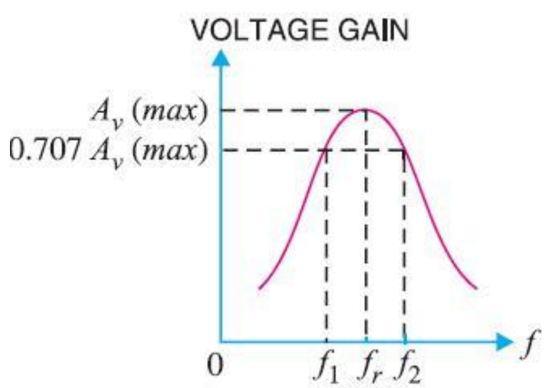


Fig.5.7

Bandwidth:

The range of frequencies at which the voltage gain of the tuned amplifier falls to 70.7 % of the maximum gain is called its *bandwidth*. Referring to Fig.5.7, the bandwidth of tuned amplifier is $f1 - f2$. The amplifier will amplify nicely any signal in this frequency range. The bandwidth of tuned amplifier depends upon the value of *Q* of *LC* circuit *i.e.* upon the sharpness of the frequency response. The greater the value of *Q* of tuned circuit, the lesser is the bandwidth of the amplifier and *vice-versa*. In practice, the value of *Q* of *LC* circuit is made such so as to permit the amplification of desired narrow band of high frequencies. The practical importance of bandwidth of tuned amplifiers is found in communication system. In radio and TV transmission, a very high frequency wave, called *carrier wave* is used to carry the audio or picture signal. In radio transmission, the audio signal has a frequency range of 10 kHz. If the carrier wave frequency is 710 kHz, then the resultant radio wave has a frequency range *between (710 –5) kHz and (710 +5) kHz. Consequently, the tuned amplifier must have a bandwidth of 705 kHz to 715 kHz (*i.e.* 10 kHz). The *Q* of the tuned circuit should be such that bandwidth of the amplifier lies in this range.

Relation between Q and Bandwidth:The quality factor *Q* of a tuned amplifier is equal to the ratio of resonant frequency (*fr*) to bandwidth (*BW*) *i.e.*,

$$Q = \frac{f_r}{BW}$$

The *Q* of an amplifier is determined by the circuit component values. It may be noted here that *Q* of a tuned amplifier is generally greater than 10. When this condition is met, the resonant frequency at parallel resonance is approximately given by:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Single Tuned Amplifier:

A single tuned amplifier consists of a transistor amplifier containing a parallel tuned circuit as the collector load. The values of capacitance and inductance of the tuned circuit are so selected that its resonant frequency is equal to the frequency to be amplified. The output from a single tuned amplifier can be obtained either (*a*) by a coupling capacitor *CC* or (*b*) by a secondary coil

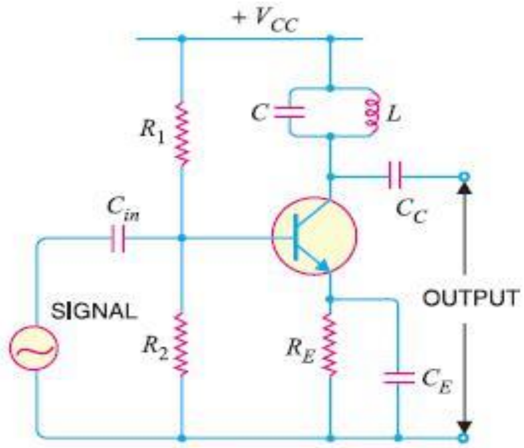


Fig.5.9 Capacitive coupled single tuned amplifier

Operation:

The high frequency signal to be amplified is given to the input of the amplifier. The resonant frequency of parallel tuned circuit is made equal to the frequency of the signal by changing the value of *C*. Under such conditions, the tuned circuit will offer very high impedance to the signal frequency. Hence a large output appears across the tuned circuit. In case the input signal is complex containing many frequencies, only that frequency which corresponds to the resonant frequency of the tuned circuit will be amplified. All other frequencies will be rejected by the tuned circuit. In this way, a tuned amplifier selects and amplifies the desired frequency.The fundamental difference between *AF* and tuned (*RF*) amplifiers is the bandwidth they are expected to amplify. The *AF* amplifiers amplify a major portion of *AF* specturm (20 Hz to 20 kHz) equally well throughout. The tuned amplifiers amplify a relatively narrow portion of *RF* spectrum, rejecting all other frequencies L, C tuned circuit is not connected between collector and ground because, the transistor will be short circuited at some frequency other than resonant frequency. The output of the tuned circuit is coupled to the next stage or output device, through capacitor Cb.

So this circuit is called single tuned capacitbe coupled amplifier. RI, R2, RE, CE are biasing resistors and capacitors. The tuned circuit formed by Inductance (L) and capacitor(C) resonates at the frequency of operation. Transistor hybrid equivalent circuit must be used since the transistor is operated at high frequencies. Tuned circuits are high frequency circuits. Rj = input resistance of the next stage.

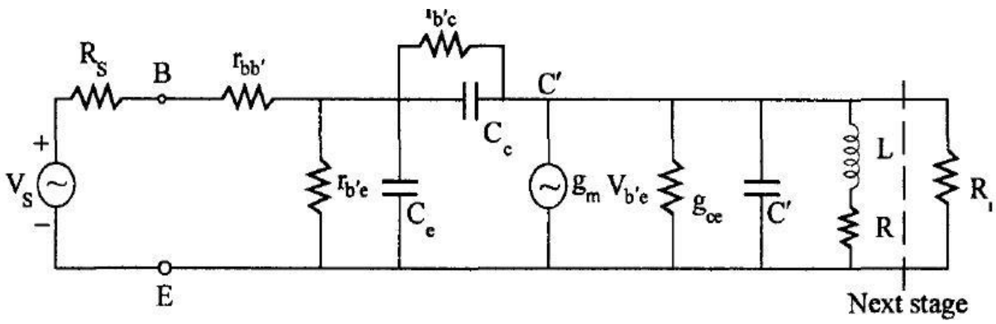


Fig. 5.10 Equivalent circuit

Modified equivalent circuit using Miller's Theorem.According to Miller's theorem, the feedback capacitance Cc is Cc (1 - A) on the input side and

$C_c\left(\frac{A-1}{A}\right)$ $\frac{r_{b'c}}{(1-A)}$ $\frac{r_{b'c}}{\left(\frac{A-1}{A}\right)}$

on the output side. But where as resistance is

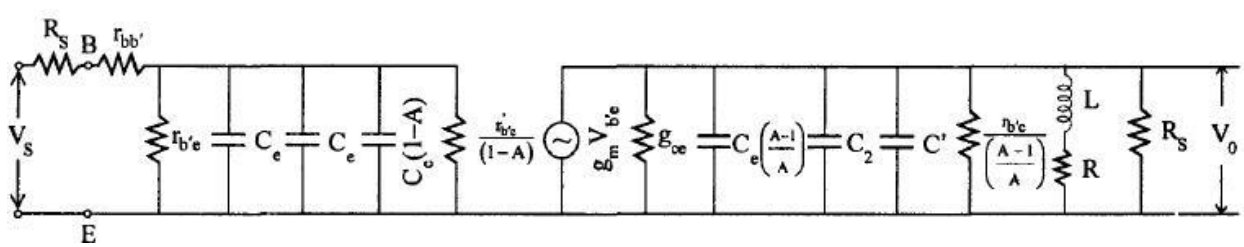


Fig. 5.11 Equivalent circuit (applying Miller's Theorem)

The equivalent circuit after simplification, neglecting $\frac{r_{b'c}}{\left(\frac{A-1}{A}\right)}$ is shown in Fig. 5.12.

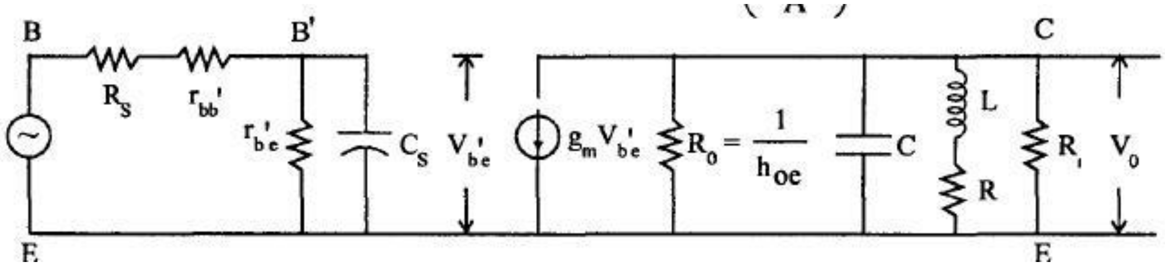


Fig. 5.12 Simplified equivalent circuit

$$Y_i = \frac{1}{R + j\omega L} = \frac{R - j\omega L}{R^2 + \omega^2 L^2} = \frac{R}{R^2 + \omega^2 L^2} - j\frac{\omega L}{R^2 + \omega^2 L^2}$$

Input admittance as seen by II stage.Instead of L and R being in series, they are being represented as equivalent shunt element~ Rp and Lp for parallel $= \frac{1}{R_P} + \frac{1}{j\omega L_P}$

$$R_P = \frac{R^2 + \omega^2 L^2}{R}$$

$$L_P = \frac{R^2 + \omega^2 L^2}{\omega^2 L}$$

Inductor is represented by Rp in series with inductance L

Q at resonance,

$$Q_0 = \frac{\omega_0 L}{R}$$

$$\omega L >> R$$

$$R_P = \frac{\omega^2 L^2}{R}$$

$$L_P = L$$

.: Resistance of the inductor R is small,Therefore output circuit is simplified to,

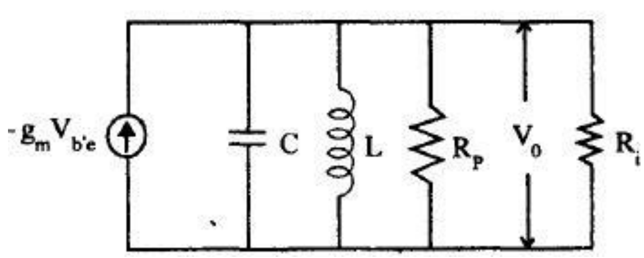


Fig. 5.13 Simplified circuit

$$\frac{1}{R_t} = \frac{1}{R} + \frac{1}{R_P} + \frac{1}{R_i}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

R_i is the input Fesistance of the next stage

$$Q_e = \frac{\text{Suspectance of L or capacitance of C}}{\text{Conductance of shunt resistance } R_t}$$

R_t = resistance of tuned circuit

$$Q_e = \omega_0 CR_t$$

$$= \frac{R_t}{\omega_0 L} \frac{(1/\omega_0 L)}{1/R_t} = \left(\frac{\omega_0 C}{1/R_t}\right)$$

The resonant angular frequency in rad/sec.

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

Output voltage Vo = -gm Vb'e·Z (-gm Vb'e is the current source).

where Z is the impedance of C, Land Rt in parallel.

Admittance

$$Y = \frac{1}{Z} = \frac{1}{R_t} + \frac{1}{j\omega L} + j\omega C$$

$$Y = \frac{1}{R_t}\left[1 + \frac{R_t}{j\omega L} + j\omega C R_t\right]$$

$$= \frac{1}{R_t}\left[1 + j\frac{\omega_0 \omega C R_t}{\omega_0} + \frac{R_t \omega_0}{j\omega_0 \omega L}\right] \text{(Multiplying and dividing by } \omega_0\text{)}$$

$$Y = \frac{1 + jQ_e\left[\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right]}{R_t} \qquad \left(\because \quad Q_e = \frac{R_t}{w_0 L} = \omega_0 CR_t\right)$$

$$Q_e = \omega_0 C R_t$$

$$= \frac{R_t}{\omega_0 L} \qquad \because \quad \omega_0 L = \frac{1}{\omega_0 C}$$

$$Z = \frac{R_t}{1 + jQ_e\left[\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right]}$$

Qe is defined as = $\frac{\text{Susceptance of L or C}}{\text{Conductance of shunt resistance } R_t}$

$$\delta = \frac{\omega - \omega_0}{\omega_0} = \frac{\omega}{\omega_0} - 1$$

$$\frac{\omega}{\omega_0} = 1 + \delta$$

Rewriting the expression for Z, as

$$Z = \frac{R_t}{1 + jQ_e\left[(1+\delta) - \frac{1}{(1+\delta)}\right]}$$

$$= \frac{X + \delta^2 + 2\delta - X}{1+\delta} = \frac{2\delta\left(1 + \frac{\delta}{2}\right)}{1+\delta}$$

$$Z = \frac{R_t}{1 + j2Q_e\delta\left[\frac{1+\delta/2}{1+\delta}\right]}$$

If the frequency □ is close to resonant frequency *Wo« 1*.

Therefore Simplified expression for Z is

$$Z = \frac{R_t}{1 + j2Q_e\delta}$$

$$R_p = Q_0^2 R = Q_0 = \sqrt{\frac{L}{C}} = \omega_0 L Q_0$$

$$V_{b'e} = V_i \cdot \frac{r_{b'e}}{r_{bb'} + r_{b'e}}$$

$$V_0 = -g_m V_{be} \cdot Z$$

$$V_0 = -g_m V_i \cdot \frac{r_{b'e}}{r_{b'e} + r_{b'e}} Z$$

$$A = \frac{V_0}{V_i} = -g_m \cdot \frac{r_{b'e}}{r_{b'e} + r_{bb'}} \cdot Z$$

$$A = -g_m \cdot \frac{r_{b'e}}{r_{b'e} + r_{bb'}} \cdot \frac{R_t}{1 + j2\delta Q_e}$$

voltage gain at resonance. Since at resonance w0 = 0

$$A_{reso} = \frac{-g_m \cdot r_{b'e}}{r_{b'e} + r_{bb'}} \cdot R_t$$

$$\frac{A}{A_{reso}} = \frac{1}{1 + j2\delta Q_e}$$

Magnitude:

$$\left|\frac{A}{A_{reso}}\right| = \frac{1}{\sqrt{1 + (2\delta Q_e)^2}}$$

Phase angle:

$$\left|\frac{A}{A_{reso}}\right| = -\tan^{-1}(2\,\delta\,Q_e)$$

At a frequency w_1 below the resonant frequency □ has the value,

$$= -\frac{1}{2Q_e};$$

$$\frac{A}{A_{reso}} = \frac{1}{\sqrt{2}} = 0.707$$

$w1$ *is* the lower 3db frequency. Similarly

w_2, the upper 3db frequency is

$$\delta = +\frac{1}{2Q_e}; \quad \frac{A}{A_{reso}} = \frac{1}{\sqrt{2}} = 0.707$$

The 3 db band width $w = (w_2 - w_1)$

$$= \frac{[(\omega_2 - \omega_0) + (\omega_0 - \omega_1)] . \omega_0}{\omega_0}$$

$$= [\delta + \delta]\,\omega_0 \quad = 2\,\delta\,\omega_0$$

$$\delta = \frac{1}{2Q_e}$$

$$\Delta\omega = \frac{\omega_0}{Q_e} = \frac{\omega_0}{R_t\,\omega_0\,C} = \frac{1}{R_t C} \quad \text{rad/sec.}$$

Tapped Single Tuned Capacitance Coupled Amplifier:

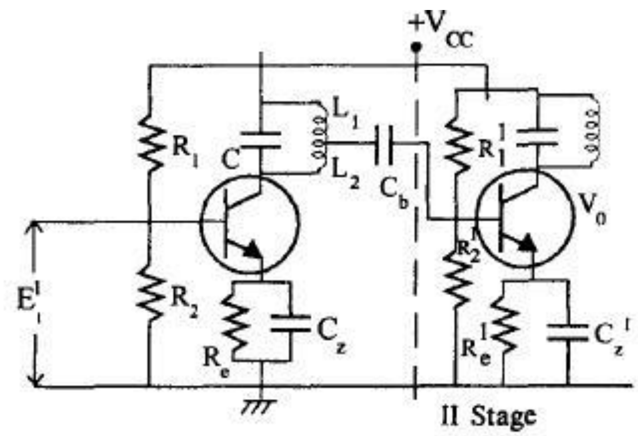
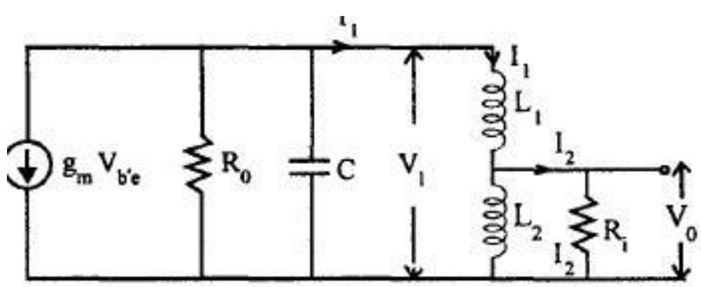


Fig. 5.7 Tapped single tuned capacitive coupled amplifier circuit

5.3.1 Equivalent Circuit on the Output Side of the I Stage RI is the input resistance of the II stage.

Ro is the output resistance of the I stage amplifier.



The input IZI of the common emitter amplifier circuits will be less. So the output impedance of the circuit being coupled to one common emitter amplifier, should also have low IZI for impedance matching and to get maximum power transfer. So in order to reduce the impedance of the LC resonant circuit, to match the low IZI of the common emitter circuit, tapping is made in the LC tuned circuit. Tapped single tuned circuits are used in such applications. 5.3.2 Expression for 'Inductance' for Maximum Power Transfer Let the tapping point divide the impedance into two parts LI and L2.

Let LI = nL so that L2 = (1 - n)

Writing Kirchoff's Voltage Law (KVL)

$$V_1 = j\omega L \cdot I_1 - j\omega (L_2 + M) I_2 \quad .....(1)$$

$$0 = -j\omega (L_1 + M) I_1 + (R_i + j\omega L_2) I_2 \quad .....(2)$$

Where M is the mutual inductance between LI and L2. Solving equations 1 and 2,

$$I_1 = \frac{V_1 (R_i + j\omega L_2)}{j\omega L (R_i + j\omega L_2) + \omega^2 (L_2 + M)^2}$$

Hence the IZI offered by the coil along with input resistance ~i of the next stage is

$$Z_1 = \frac{V_1}{I_1} = \frac{j\omega L (R_i + j\omega L_2) + \omega^2 (L_2 + M)^2}{(R_i + j\omega L_2)}$$

$$= j\omega L + \frac{\omega^2 (L_2 + M)^2}{R_i + j\omega L_2}$$

But wL2 much less than Ri.

As Ri, the input resistance of transistor circuit II stage is KQ and much greater than roL2

$$Z_1 = j\omega L + \frac{\omega^2 (L_2 + M)^2}{R_i}$$

$$M = K\sqrt{L_1 L_2} \qquad M = \text{Mutual Inductance}$$

Where K is the coefficient of coupling. Since Ll = nL, L2 = (l-n)L

$$= K\sqrt{nL(1-n)L} = KL\sqrt{(n-n^2)}$$

Putting K = I, we get

$$M \simeq L\sqrt{n-n^2}$$

$$Z_1 \simeq j\omega L \pm \frac{\omega^2 \left[(1-n)L + L\sqrt{n-n^2}\right]^2}{R_i}$$

$$\simeq j\omega L + \frac{\omega^2 L^2 \left[(1-n) + \sqrt{n-n^2}\right]^2}{R_i}$$

$$(j\omega L + R)$$

The resistance effectively reflected in series with the coil due to the resistance R, is given by,

$$R_{is} \simeq \frac{\omega^2 L^2 \left[(1-n) + \sqrt{n-n^2}\right]^2}{R_i}$$

This is the resistance component; $: series, i : input

This resistance R is in series with the coil L may be equated to a resistance Rip in shunt with the coil where Rip is given by, ~

$$R_{ip} = (\omega L)^2 / R_{is}$$

So the equivalent circuit is

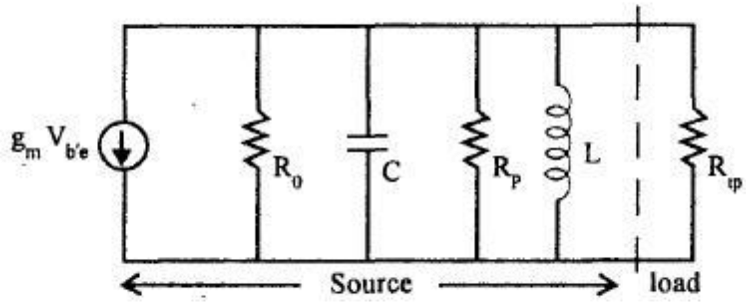


Fig. 5.9 Equivalent circuit

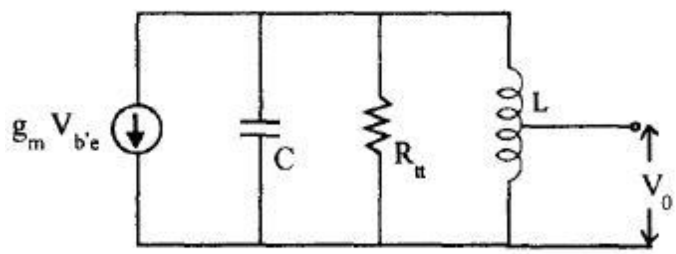


Fig. 5.10 Equivalent circuit after simplification

$$\frac{1}{R_{tt}} = \frac{1}{R_0} + \frac{1}{R_p} + \frac{1}{R_{ip}}$$

$$Q_e = \frac{R_{tt}}{\omega_0 L}$$

Rtt : tuned tapped circuit.

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

Under the conditions of maximum power transfer theorem, the total resistance appearing in shunt with the coil is = Rop

Since it is a resonant circuit, at resonance, the IZI in purely resistive. For maximum power transfer IZI = R/2.

$$Q_e = \frac{R_{op}/2}{\omega_0 L}; \quad R_{tt} = R_{op}/2$$

$$R_{op} = 2\, Q_e \cdot \omega_0\, L$$

$$R_{op} = \frac{R_0 R_p}{R_0 + R_p}$$

$$2\, Q_e\, \omega_0\, L = \frac{R_0\, \omega_0\, Q_0\, L}{R_0 + \omega_0\, Q_0\, L}$$

$$L = \frac{R_0 (Q_0 - 2Q_e)}{2\omega_0\, Q_0\, Q_e}$$

$$L = \frac{R_0}{\omega_0}\left[\frac{1}{2Q_e} - \frac{1}{Q_0}\right]$$

This is the value of L for maximum power transfer.

Expression for voltage gain and Bandwidth are determined in the same way as done for a single tuned circuit. In this circuit we have,

1. R_{tt} instead of ~ (as in single tuned) tapped tuned circuit.

2. Output voltage equals (l - n) times the voltage developed across the complete coil.

IZI at any frequency close to Wo is given by,

$$Z = \frac{R_{tt}}{1 + j\, 2\delta\, Q_e}$$

$$V_0 = \frac{-g_m V_i\, r_{b'e}}{r_{b'e} + r_{bb'}} \cdot Z\,(1 - n)$$

$$A = \frac{V_0}{V_i} = -g_m (1 - n)\, \frac{r_{b'e}}{r_{b'e} + r_{bb'}} \cdot Z$$

$$= -g_m\,(1 - n) \cdot \frac{r_{b'e}}{r_{b'e} + r_{bb'}} \cdot \frac{R_{tt}}{1 + j\, 2\delta Q_e}$$

At resonance, voltage gain is

$$A_{reso} = -\, g_m\,(1 - n) \cdot \frac{r_{b'e}}{r_{b'e} + r_{bb'}} \cdot R_{tt}$$

$$\frac{A}{A_{reso}} = \frac{1}{1 - j\, 2\delta Q_e}$$

Inductive coupled single tuned amplifier:-

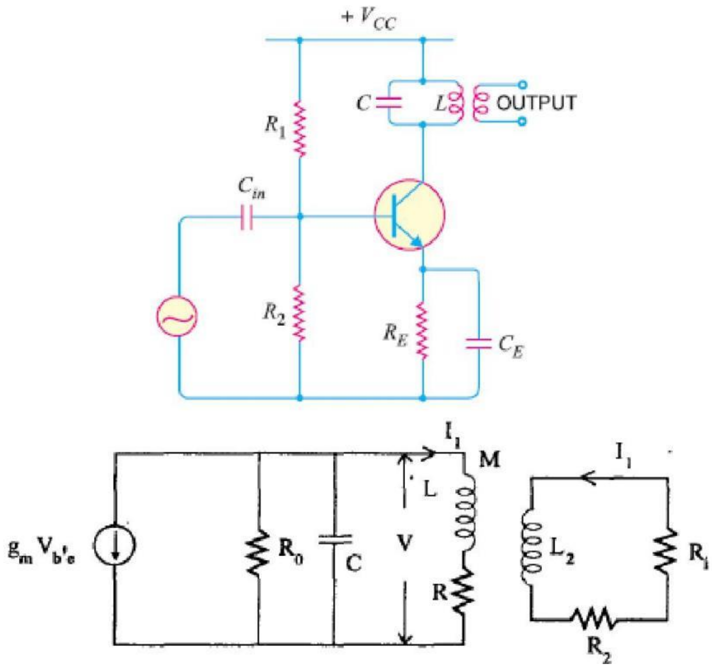


Fig. 5.11 Inductive coupled amplifier circuit (a) and its equivalent (b)

In this circuit, the voltage developed across the tuned circuit is inductively coupled to the next stage. Coil L, of the tuned circuit, and the inductor coupling the voltage to the II stage, L2 form' a transformer with mutual coupling M. This type of circuit is also used, where the input IZI of the II stage is smaller or different from the tuned circuit. SO IZI matching is done by the transformer depending on its tum ratio. In such requirements, this type of circuit is used. The resistors RI, R2 and R; and R2 are the biasing resistors. The parallel tuned circuit,

Land C resonates at the frequency of operation. Fig. (b) shows output equivalent circuit. Input equivalent circuit will be the same as that of the capacitive coupled circuit. In the output equivalent circuit, C is the total capacitance, including the stray capacitance, Miller equivalent capacitance C (A-1)/A. L2 and R2 are the inductance and resistance of the secondary winding. 5.4.1 Expression for Ll for Maximum Power Transformer Writing KVL to the primary and secondary windings,

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

$$V=I_1Z_{21}+I_2Z_{22}$$

where

$Z_{11} = R + jwL$

$Z_{12} = Z_{21} = jwM$

$Z_{22} = R2 + Rj + jwL2$

$$I_1 = \frac{V.Z_{22}}{Z_{11}Z_{22} - Z_{12}^2}$$

The impedance seen looking into the primary is,

$$Z_{in} = \frac{V}{I_1} \frac{Z_{11}Z_{22} - Z_{12}^2}{Z_{22}}$$

$$= Z_{11} - \frac{Z_{12}^2}{Z_{22}}$$

Substituting the values of Zll' Z22 and ZI2 in equation (7) we get,

$$Z_{in} = (R + j\omega L) + \frac{\omega^2 M^2}{R_2 + R_i + j\omega L_2}$$

Rj generally much greater than R2 and wL2.

$$Z_{in} \simeq (R + j\omega L) + \frac{\omega^2 M^2}{R_i}$$

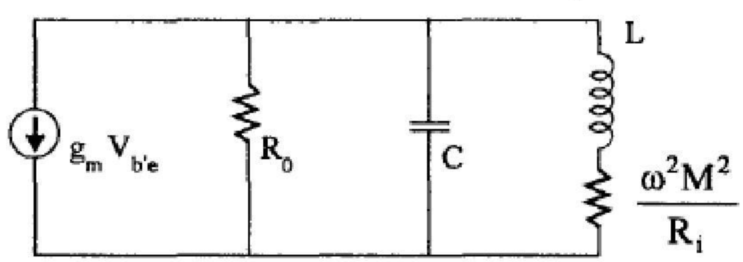


Fig. 5.12 Equivalent circuit

$$\frac{\omega^2 M^2}{R_i}$$

is the impedance of the secondary side reflected to the primary.

If M is reasonably large, then $R << \frac{\omega^2 M^2}{R_i}$

$$Z_{in} \simeq j\omega L + \frac{\omega^2 M^2}{R_i}$$

The equivalent circuit may be written as,

Inductance L with series resistance may be represented as L in shunt with Rio as R. shown below, where

$$R_{ip} = \frac{(\omega L)^2}{\left(\frac{\omega^2 M^2}{R_i}\right)} = \left(\frac{L}{M}\right)^2 . R_i$$

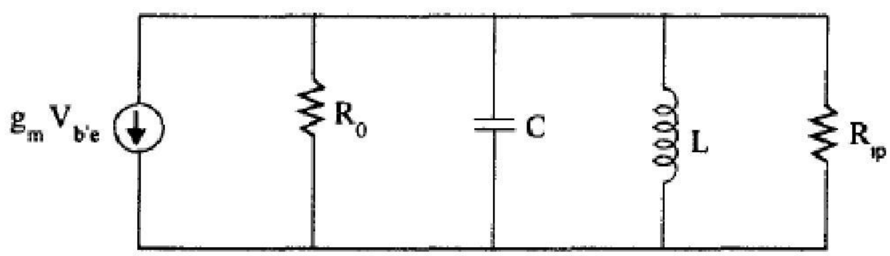


Fig. 5.13 Simplified circuit

$$R_{ip} = R_0$$

$$R_0 = \left(\frac{L}{M}\right)^2 . R_i$$

Gives the value of M for maximum power transfer.

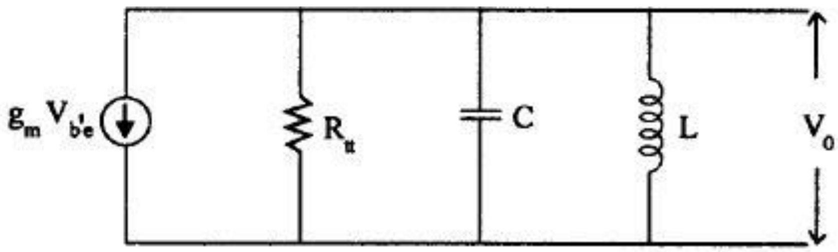


Fig. 5.14 Equivalent circuit

L and L2 are the primary and secondary windings of inductances.

$$M = K\sqrt{LL_2}$$

$$R_0 = \left(\frac{L}{K^2 L_2}\right) R_i$$

Therefore from equation 14, for a given value of Ro and coefficient of coupling K and ~, we can determine L2 for maximum transformer of power.

Shunt resistance Ro and Rip may be combined to yield the total shunt resistance Ru.

$$\frac{1}{R_{tt}} = \frac{1}{R_0} + \frac{1}{R_{ip}}$$

Rtt = Resistance of tapped tuned circuit

Effective Q of the entire circuit is,

$$Q_e = \frac{R_{tt}}{\omega_0 L}$$

where Wo is the resonaqt frequency of Land C.

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

Under conditions of maximum transfer of power, total resistance appearing in shunt with the coil equals *Ro/2*. Since it is respnant circuit, at resonance, IZI = resistance only. maximum power, R = Rl2.

$$Q_e = \frac{R_0/2}{\omega_0 L}$$

$$R_0 = 2\, Q_e\, \omega_0\, L$$

IZI of the output circuit at any frequency 'w' close to ‘w0' is given by,

Impedance of output circuit is

$$Z = \frac{R_{tt}}{1 + j2\delta Q_e}$$

$$V_0 = -g_m . \frac{V_0 \, r_{b'e}}{r_{b'e} + r_{bb'}} . Z . \frac{R_i Z_{21}}{Z_{11} Z_{22} - Z_{12}^2}$$

$$= -g_m V_i . \frac{r_{b'e}}{r_{b'e} + r_{bb'}} . \frac{R_i . Z_{21}}{Z_{11} Z_{22} - Z_{12}^2} . \frac{R_{tt}}{1 + j2\delta Q_e}$$

Voltage gain A at any frequency wo is,

$$A = \frac{V_0}{V_i} = -g_m \frac{r_{b'e}}{r_{b'e} + r_{bb'}} . \frac{R_i Z_{21}}{Z_{11} Z_{22} - Z_{12}^2} . \frac{R_{tt}}{1 + j2\delta Q_e}$$

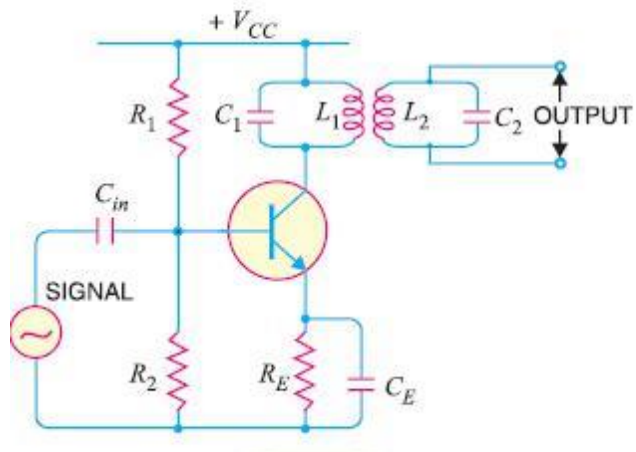
Voltage at resonance,

$$A_{reso} = -g_m . \frac{r_{b'e}}{r_{b'e} + r_{bb'}} . \frac{R_i Z_{22}}{Z_{11} Z_{22} - Z_{12}^2}$$

$$\boxed{\frac{A}{A_{reso}} = \frac{1}{1 + j2\delta Q_e}}$$

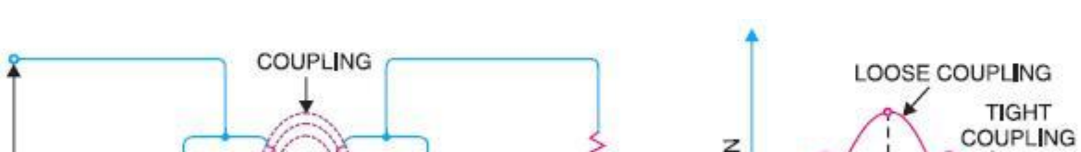
Double Tuned Amplifier

It consists of a transistor amplifier containing two tuned circuits ; one ($L1C1$) in the collector and the other ($L2C2$) in the output as shown. The high frequency signal to be amplified is applied to the input terminals of the amplifier. The resonant frequency of tuned circuit $L1C1$ is made equal to the signal frequency. Under such conditions, the the signal frequency. Consequently, large output appears across the tuned circuit $L1C1$. The output from this tuned circuit is transferred to the second tuned circuit $L2C2$ through mutual induction. Double tuned circuits are extensively used for coupling the various circuits of radio and television receivers.



Frequency response.

The frequency response of a double tuned circuit depends upon the degree of coupling *i.e.* upon the amount of mutual inductance between the two tuned circuits. When coil $L2$ is coupled to coil $L1$ [See Fig. 15.14 (*i*)], a portion of load resistance is coupled into the primary tank circuit $L1C1$ and affects the primary circuit in exactly the same manner as though a resistor had been added in series with the primary coil $L1$. When the coils are spaced apart, all the primary coil $L1$ flux will not link the secondary coil $L2$. The coils are said to have *loose coupling*. Under such conditions, the resistance reflected from the load (*i.e.* secondary circuit) is small. The resonance curve will be sharp and the circuit Q is high as shown in Fig. 15.14 (*ii*). When the primary and secondary coils are very close together, they are said to have *tight coupling*. Under such conditions, the reflected resistance will be large and the circuit Q is lower. Two positions of gain maxima, one above and the other below the resonant frequency, are obtained.



Bandwidth of Double–Tuned Circuit

The bandwidth increases with the degree of coupling. Obviously, the determining factor in a doubletuned circuit is not *Q* but the coupling. For a given frequency, the tighter the coupling, the greater is the bandwidth.

$$BWdt = k\,fr$$

The subscript *dt* is used to indicate double-tuned circuit. Here *k* is coefficient of coupling.

Stagger Tuning

Tuned amplifiers have large gain, since at resonance, Z is maximum. So Av is maximum. To get this large Av over a wide range of frequencies, stagger tuned amplifiers are employed. This is done by taking two single tuned circuits of a certain Bandwidth, and displacing or staggering their resonance peaks by an amount equal to their Bandwidth. The resultant staggered pair will have a Bandwidth, $\sqrt{2}$ times as great as that of each of individual pairs.