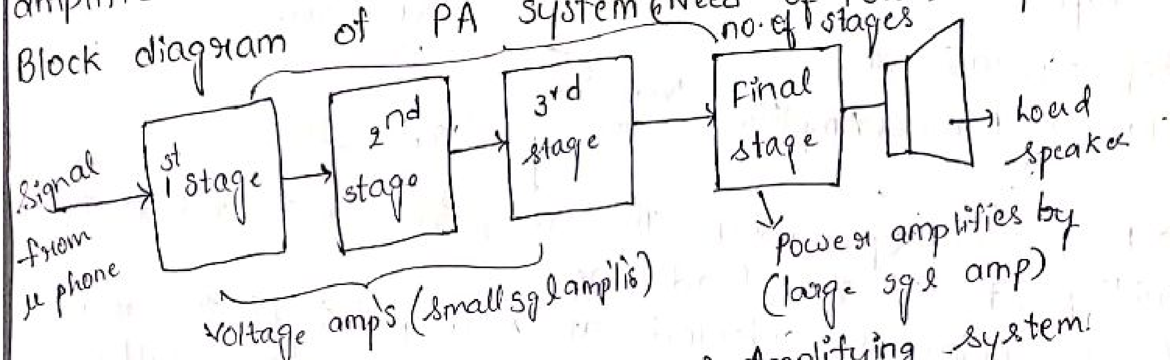
5- Power Amplifiers

Power Amplifier is an amplifier which delievers large amount of AC power by handling large voltage and current swings. as input. Since it handles large voltage and current swings as input, the power amplifier is called as large signal amplifier.

Block diagram of PA system (Need of Power Amplifier)



Block diagram of PA system (or) Amplifying system.

The above figure shows the block diagram of public Addressing system (PA) or amplifying system which consists of several stages of amplifiers, basically it is a multistage amplifier. The input and intermediate stages are voltage amplifiers, the main objective of voltage amplifiers to raise the voltage gain and the final stage by handling large voltage (or) current swings delievers large amount of AC power and it is enough to drive the loud speaker.

Classifications of Power Amplifiers:-

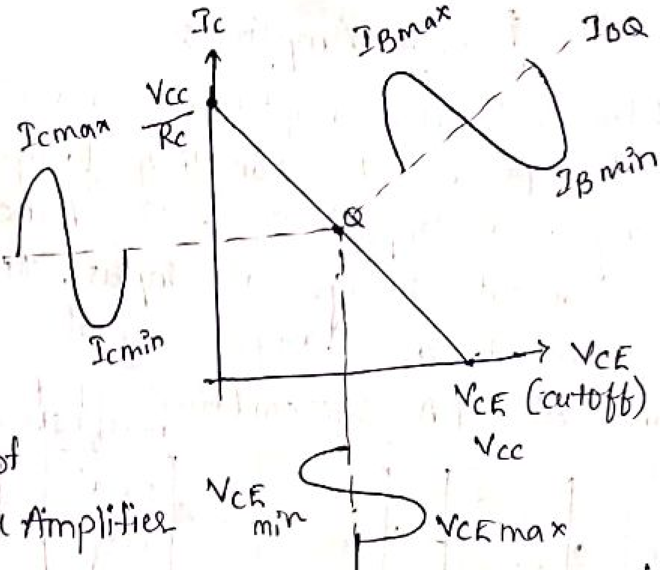
Based on selection of Q- point and amplitude of input signal, there are 4 types of power amplifiers.

1. class -A Power amplifier
2. class - B PA
3. class- AB PA
4. class- C PA

Class-A Power Amplifier:-

Concept of class - A Power Amplifier:- graphical representation

The above figure shows the graphical representation of class-A power amplifier. The power amplifier is said to be class-A, the Q-point and amplitude of the i/p sgl are so selected, such that the O/p is obtained for the full cycle of the input waveform.



Graphical Representation of Class-A Power Amplifier

→ For such operation the Q-point is selected at the mid-point of the load line.

As Q-point is selected at mid-point of the load line the input base current varies sinusoidally above and below the Q-point and it never goes into either saturation region (or) cutoff region.

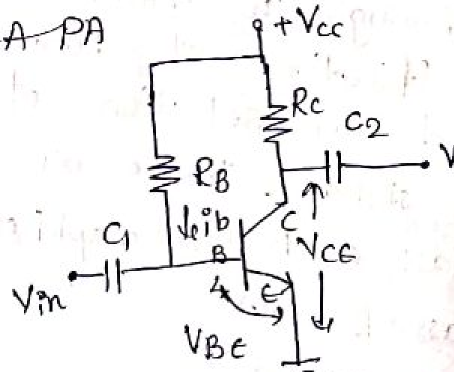
Simultaneously, the collector current and collector voltage also varies sinusoidally above and below the Q-point.

→ Thus the conduction angle for collector current flow is 360°

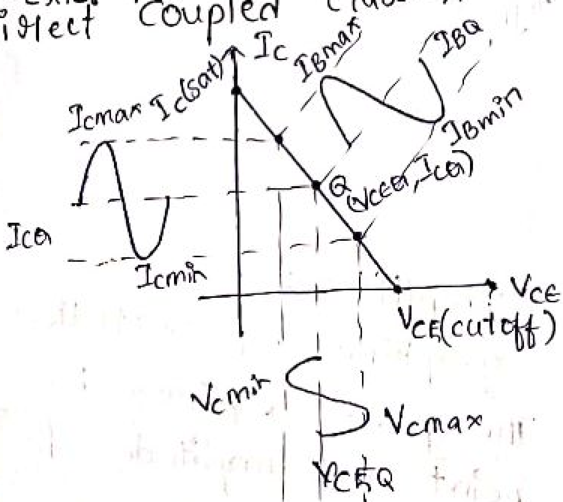
Types of class-A PA :-

1. Direct coupled class-A PA
2. Transformer coupled class-A PA

Series fed
Direct coupled class-A PA :-



a) Ckt diagram of direct coupled class-A power amplifier



b) Graphical Representation of class-A amplifier

Fig (a) shows the ckt diagram of series fed direct coupled class-A power amplifier. As shown in fig(a), the load resistor R_c is directly connected in series with the collector of the transistor. The power supply $+V_{cc}$ and the resistors R_B & R_c are so selected such that the Q-point is located at the midpoint of the load line.

DC Operation :-

Applying KVL to the input loop,

$$V_{cc} = i_b R_b + V_{BE}$$

$$I_{BQ} = i_B = \frac{V_{cc} - V_{BE}}{R_b} \quad \text{—(1)}$$

wkT $i_{CQ} = \beta \cdot i_{BQ}$ —(2)

By applying KVL to the o/p loop.

$$V_{cc} = i_c R_c + V_{CE}$$

$$V_{CEQ} = V_{CE} = V_{cc} - i_c R_c \quad \text{—(3)}$$

From eq 2,3, the Q-point coordinates are

$$Q(V_{CEQ}, i_{CQ}) \quad \text{—(4)}$$

DC Power input (P_{dc}) :-

With the absence of AC input signal, the average collector current drawn from the power supply is given by i_{CQ}.

$$P_{dc} = V_{cc} \cdot i_{CQ} \quad \text{—(5)}$$

AC Operation :-

By applying sinusoidal AC input signal, the input base current varies sinusoidally above (or) below Q-point and consequently, the collector current and collector voltage also varies sinusoidally above and below the Q-point

AC Power Output (P_{ac}) :-

From fig(b), we can write V_{max} = max. value of the o/p volt of the o/p voltage

V_{min} = min. value of the o/p voltage

$V_{(p-p)}$ = peak to peak value of the o/p voltage

$= V_{max} - V_{min}$

V_m = peak amplitude of the o/p voltage

$V_m = V_{max} - V_{min} / 2$

Similarly, for the o/p current,

I_{max} = max. value of the o/p current

I_{min} = min. value of the o/p current

$I_{(p-p)}$ = peak to peak value $= I_{max} - I_{min}$

I_m = peak amplitude of the o/p current.

$I_m = I_{max} - I_{min} / 2$

I_{rms} = rms value of the o/p current $= I_m/\sqrt{2}$

V_{rms} = rms value of the o/p voltage $= V_m/\sqrt{2}$

Interms of rms values ($P_{ac\,rms}$) :-

$$P_{ac(rms)} = V_{rms} \cdot I_{rms}$$

$$= \frac{V_{rms}^2}{R_L} \quad \text{--- (6)}$$

$$= I_{rms}^2 R_L \quad \text{--- (7)}$$

Interms of peak values :-

$$P_{ac(peak)} = V_{rms} \cdot I_{rms}$$

$$= \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} = \frac{V_m I_m}{2} = \frac{V_m^2}{2R_L} \quad \text{--- (8)}$$

$$= \frac{I_m^2 R_L}{2} \quad \text{--- (9)}$$

Interms of peak to peak values :-

$$P_{ac(p-p)} = V_{rms} \cdot I_{rms} = \frac{V_m I_m}{2}$$

$$= \left(\frac{V_{max} - V_{min}}{2}\right)\left(\frac{I_{max} - I_{min}}{2}\right) \Big/ 2$$

$$\boxed{P_{ac(p-p)} = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8}} \quad \text{--- (10)}$$

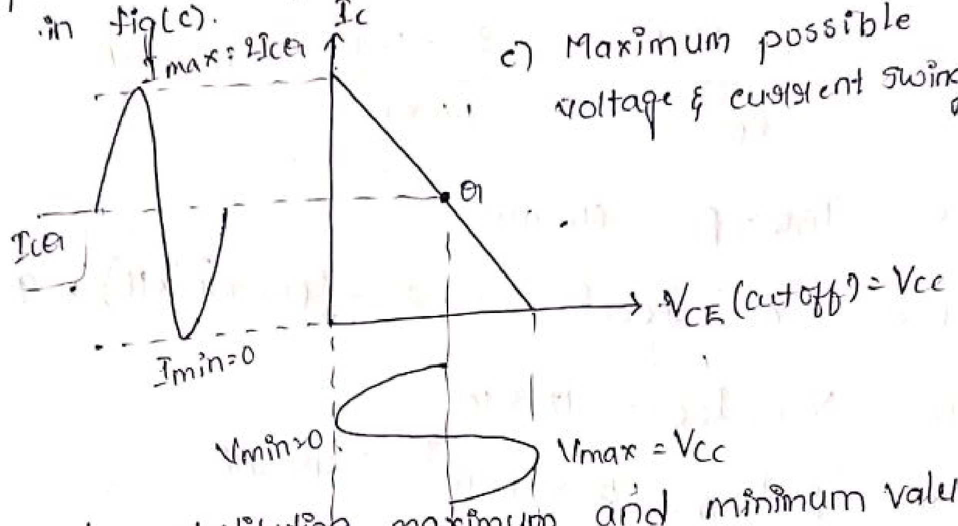
The eq (10) is the general expression to measure the ac output power

Efficiency :-

$$\eta = \frac{P_{ac}}{P_{dc}} \times 100 = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8\, V_{cc} \cdot I_{CQ}} \times 100 \quad \text{--- (11)}$$

Maximum Efficiency :-

To measure the maximum efficiency, we will consider maximum possible voltage and current swings and they are shown in fig(c).



c) Maximum possible voltage & current swings

From fig(c), by substituting maximum and minimum values in eq (11)

$$\eta = \frac{(V_{CC}-0)(2I_{CQ}-0)}{8V_{CC} \cdot I_{CQ}} \times 100 = \frac{2V_{CC}I_{CQ}}{8V_{CC}I_{CQ}} \times 100$$

$$\boxed{\eta = 25\%}$$

For an ideal case, the maximum possible efficiency of an direct couple class-A power amplifier is 25%. But in practical cases, it is about 10-15%.

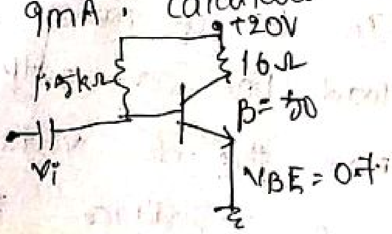
Advantages :-

1. It is easy to design and implementation.
2. As the load resistance R_L is directly connected to the collector of the transistor, no need of transformer.

Disadvantages :-

1. As the load resistance R_L is directly connected to the collector of the transistor, the more power is dissipated across the load.
2. As more power is dissipated, it requires the arrangement of heat sinks.
3. Efficiency is low

1. A series fed class A amplifier shown in figure operates from dc source and applied sinusoidal input signal generates peak base current of 9mA. Calculate I_{CQ}, V_{CEQ}, P_{dc}, P_{ac} & efficiency.



Given, $V_{CC} = +20V$, $R_B = 1.5K\Omega$, $R_C = 16\Omega$, $\beta = 50$,

$V_{BE} = 0.7$, $I_{Bm} = 9mA$

$$I_{BQ} = \frac{V_{CC} - V_{BE}}{R_B} = \frac{20 - 0.7}{1.5 \times 10^3} = 12.8mA$$

$$I_{CQ} = I_{BQ} \times \beta = 640mA$$

$$V_{CEQ} = V_{CC} - I_{CQ} R_L = 20 - (640 \times 10^{-3} \times 16) = 9.76V$$

$$P_{dc} = V_{CC} \cdot I_{CQ} = 12.8 W$$

$$I_{cm} = \beta \cdot I_{Bm} = 50 \times 9 \times 10^{-3} = 450mA$$

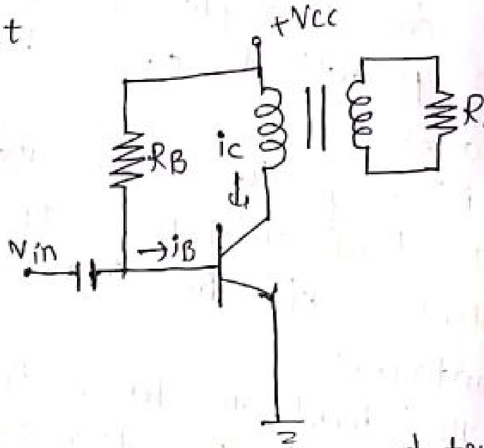
$$P_{ac} = \frac{I_m^2 R_L}{2} = \frac{(450 \times 10^{-3})^2 \times \overset{8}{\cancel{16}}}{\cancel{2}} = 1.62W$$

$$\eta = \frac{P_{ac}}{P_{dc}} \times 100 = \frac{1.62}{12.8} \times 100 = 12.65\%$$

$$P_D = P_{DC} - P_{ac} = 12.8 - 1.62 = 11.18$$

Transformer Coupled class-A power amplifier:

The figure (a) shows the ckt diagram of transformer coupled class-A power amplifier.



a) ckt diagram of transformer coupled class-A amp

As shown in figure, the load R_L is connected to the collector of the transistor through a transformer. The values of V_{CC} and R_B are so selected such that the Q-point is selected at midpoint of the load line.

DC Operation:-

In DC operation, first we need to draw the dc load line on output characteristics of a transistor. For the dc voltages/purposes as both the windings of the transformer have zero resistance, the slope of the dc load line is reciprocal of the collector resistance which is zero in this case.

slope of the dc load line $= \frac{1}{0} = \infty$

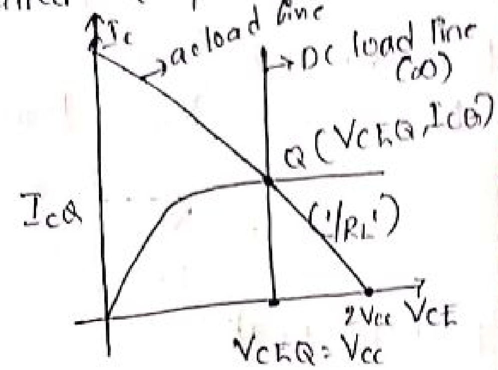
slope of the dc load line is ∞, which tells that the slope of the dc load line is a vertically straight line. By applying KVL to the o/p loop

$V_{cc} = I_C R_C + V_{CE}$ $(R_C = 0)$

$V_{CC} = V_{CEQ}$

The dc load line is a straight line which is passing through a voltage point i.e., $V_{CC} = V_{CEQ}$.

The intersection of collector current which is set by the ckt and dc load line is called Q-point which is shown in fig (b).



b) DC operation & ac operation.

DC Power input :-

with the absence of ac input signal the average collector current drawn from the power supply is I_{CQ}.

$P_{dc} = V_{CC} \cdot I_{CQ}$

Ac Operation :-

For the ac operation, we need to draw the ac load line. For ac purposes. The resistance across the secondary winding of the transformer is R_L and the resistance across the primary winding of the transformer is R_L'. which is equal to R_L / n^2. where $n = \frac{n_1}{n_2}$.

Now, the slope of ac load line is $1/R_L'$ and it is passing through Q-point.

By applying sinusoidal ac input signal the input base current varies sinusoidally above and below the Q-point and consequently the collector current and the collector voltage also varies sinusoidally above and below the Q-point

AC Power Output :-

$V_{(p-p)} = V_{max} - V_{min}$

$V_m = V_{max}/2 - V_{min}/2$

$V_{rms} = V_m/\sqrt{2}$

In terms of rms values :-

$$P_{ac(rms)} = V_{rms} \times I_{rms} = \frac{V_m}{\sqrt{2}} \cdot I_m$$

$$= I_{rms}^2 R_L$$

$$= \frac{V_{rms}^2}{R_L}$$

Peak Values :-

$$P_{ac}(rms) = V_{rms} \cdot I_{rms} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} = \frac{V_m I_m}{2}$$

$$= \frac{V_m^2}{2R_L} = \frac{I_m^2 R_L}{2}$$

Peak to peak :-

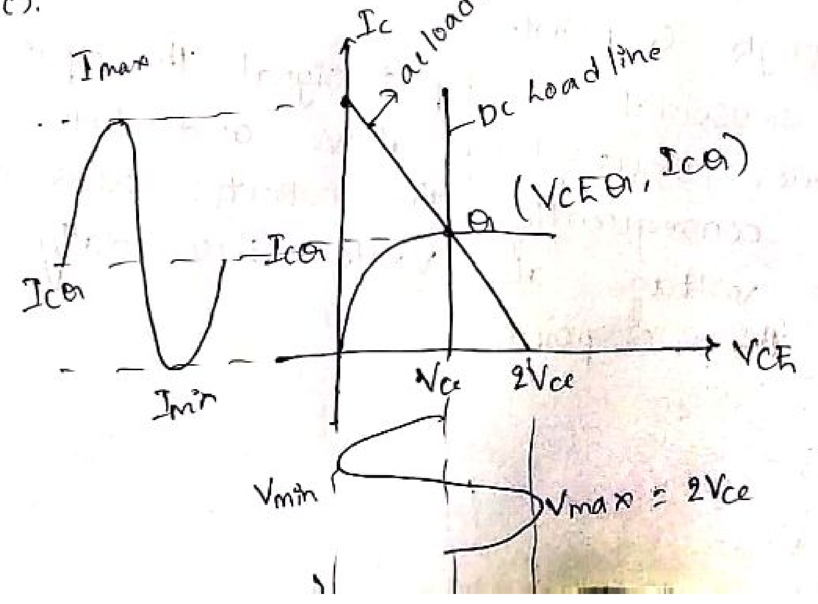
$$P_{ac}(p-p) = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8}$$

Efficiency (η) :-

$$\eta = \frac{P_{ac}}{P_{dc}} \times 100 = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8 V_{cc} I_{CQ}} \times 100$$

Maximum Efficiency :-

The maximum possible voltage and current swings for transformer coupled class-A PA are shown in fig (c).



c) Maximum possible V & I swings

$$\eta_{max} = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8 V_{CC} I_{CQ}} \times 100$$

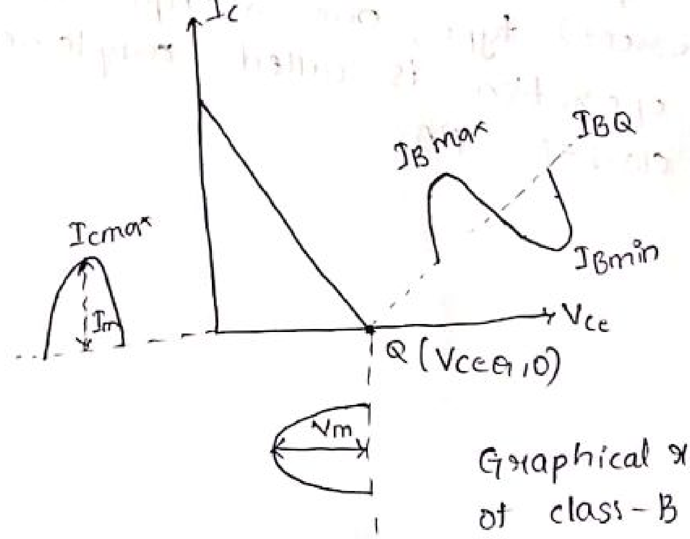
$$= \frac{(2V_{CC} - 0)(2I_{CQ} - 0)}{8 V_{CC} I_{CQ}} \times 100$$

$$= \frac{1}{2} \times 100 = 50\%$$

$$\boxed{\eta = 50\%}$$

For transformer coupled class-A PA, the maximum efficiency for an ideal case is 50%.

Concept of class-B PA :



Graphical representation of class-B PA

If the power amplifier is set to be class-B PA - the location of the Q-point and amplitude of the input signal are so selected such that the output is obtained only for half cycle of the input wave form.

For such operation, the Q-point is located along the horizontal axis. As the Q-point is along the horizontal axis. For the +ve half cycle of input the Q-point enters into active region and it is reproduced at the o/p of the amplifier and for -ve half cycle of the i/p the Q-point enters into deeper of cut off regions and it is not reproduced at the o/p of the amplifier. i.e., the o/p is obtained only for +ve half cycle of the i/p. Thus the conduction angle of collector current

Now is 180.

As we observe the graphical representation, the o/p wave form is not same as the i/p waveform. and o/p is distorted. To avoid this distortion, use 2 transistors and each transistor conducts for alternate half cycles of the i/p wave form. Thus, the full cycle of the o/p is obtained across the load for full cycle of the i/p waveform. Based on using of these transistors there are 2-types of class-B PA. If we use same type of transistors both npn or pnp, the operation is called push pull class-B PA. and if we use complementary (different) type, one is npn and other is pnp, the operation is called complementary and symmetry class-B PA.

UNIT-VI

Tuned Amplifiers : Introduction, Q-Factor, small signal tuned amplifier, capacitance single tuned amplifier, double tuned amplifiers, effect of cascading single tuned amplifiers on band width, effect of cascading double tuned amplifiers on band width, staggered tuned amplifiers, stability of tuned amplifiers, wideband amplifiers.

Introduction:

Most of the audio amplifiers we have discussed in the earlier chapters will also work at radio frequencies *i.e.* above 50 kHz. However, they suffer from two major drawbacks. First, they become less efficient at radio frequency. Secondly, such amplifiers have mostly resistive loads and consequently their gain is independent of signal frequency over a large bandwidth.

In other words, 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.

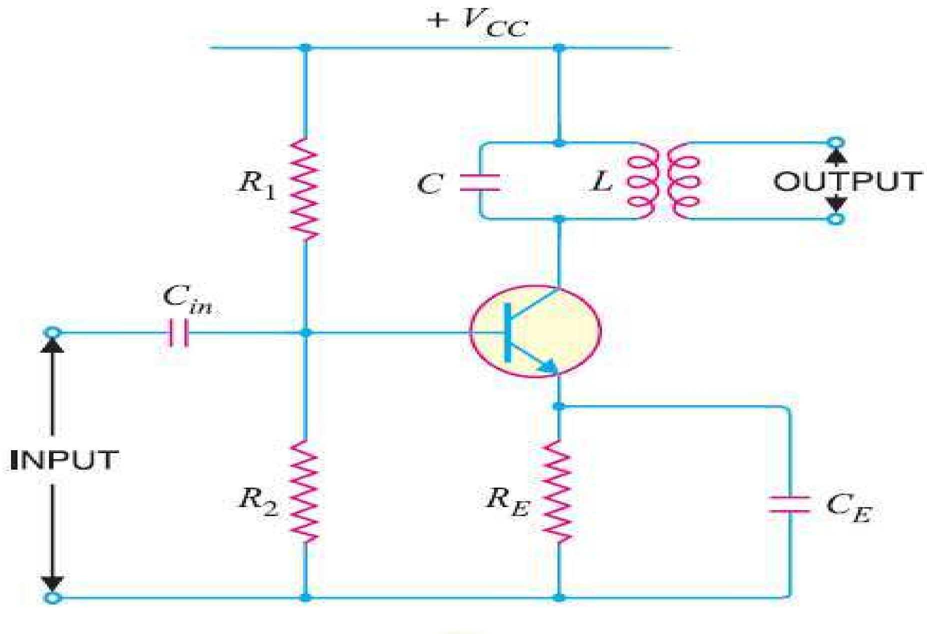
Amplifiers which amplify a specific frequency or narrow band of frequencies are called **tuned amplifiers.**

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. Figure shows the circuit of a simple transistor tuned amplifier. Here, instead of load resistor, we have a parallel tuned circuit in the collector.

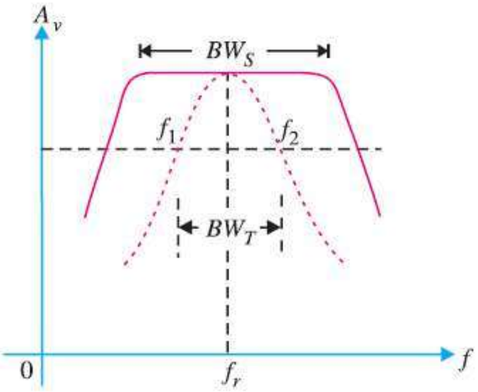
The impedance of this tuned circuit strongly depends upon frequency. It offers a very high impedance at *resonant frequency* and very small impedance at all other frequencies.

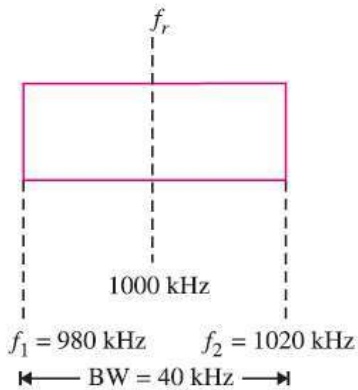
If the signal has the same frequency as the resonant frequency of *LC* circuit, large amplification will result due to high impedance of *LC* circuit at this frequency. When signals of many frequencies are present at the input of tuned amplifier, it will select and strongly amplify the signals of resonant 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 $f1$ to upper cut-off frequency $f2$. Now bandwidth of the amplifier, $BW = f2 - f1$. The reader may wonder, then, what distinguishes a tuned amplifier from other mplifiers? The difference is that tuned amplifiers are designed to have specific, usually narrow bandwidth. This point is illustrated in in Fig. 15.2. 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.





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 *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.

A parallel tuned circuit consists of a capacitor *C* and inductor *L* in parallel as shown in Fig 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. The coil current *IL* has two rectangular components *viz* active component *IL* cosφ $_L$ and reactive component *IL* sin φ $_L$. 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.*

IC □*IL* sin φ $_L$ = 0

or *IC* = *IL* sin φ $_L$

Resonance in parallel circuit can be obtained by changing the supply frequency. At some frequency *fr* (called resonant frequency), *IC* = *IL* sin φ $_L$ and resonance occurs.

Resonant frequency. The frequency at which parallel resonance occurs (*i.e.* reactive component of circuit current becomes zero) is called the *resonant frequency fr*.

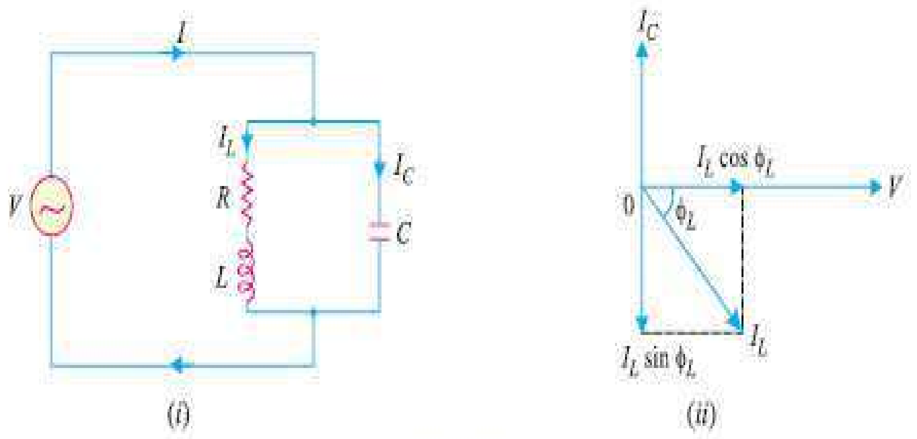


Fig. 15.4

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 $I_C = V/X_C$

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

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

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

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

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

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

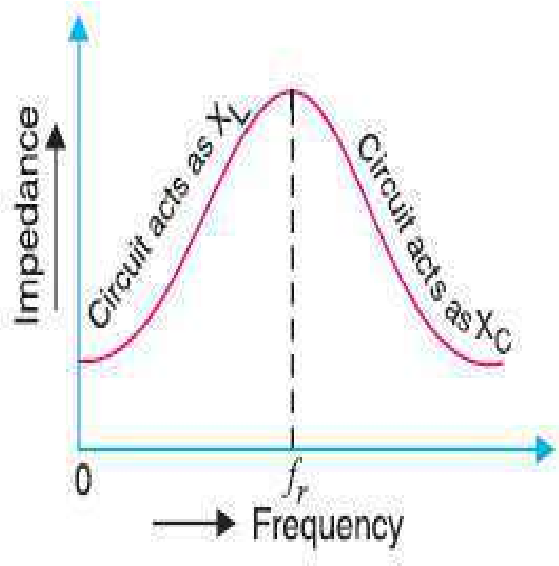
$$\text{or} \quad f_r = \frac{1}{2\pi L}\sqrt{\frac{L}{C} - R^2}$$

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

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

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

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



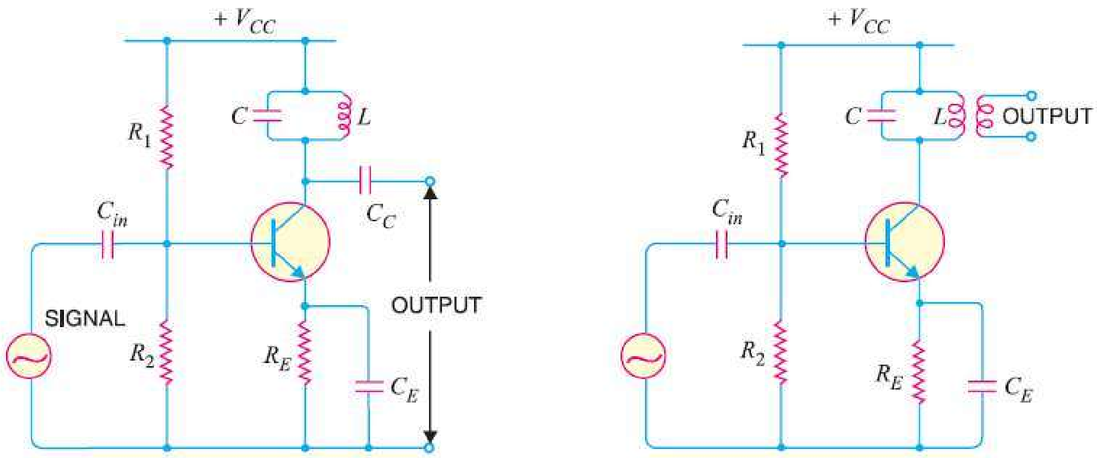
Quality factor Q: It is desired that resonance curve of a parallel tuned circuit should be as sharp as possible in order to provide selectivity. The sharp resonance curve means that impedance falls rapidly as the frequency is varied from the resonant frequency. The smaller the resistance of coil, the 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.*,

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

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. Figure shows the effect of resistance *R* of the coil.

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* as shown in Fig. (*i*) or (*b*) by a secondary coil as shown in Fig. (*ii*).



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.

Analysis of Tuned Amplifier

Fig. (*i*) Shows a single tuned amplifier. Note the presence of the parallel *LC* circuit in the collector circuit of the transistor. When the circuit has a high *Q*, the parallel resonance occurs at a frequency *fr* given by.

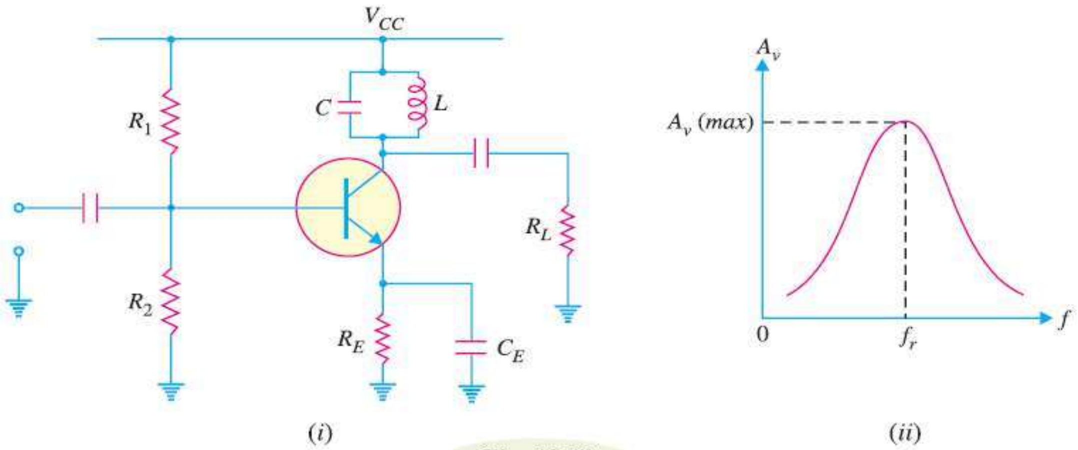


Fig. 15.10

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

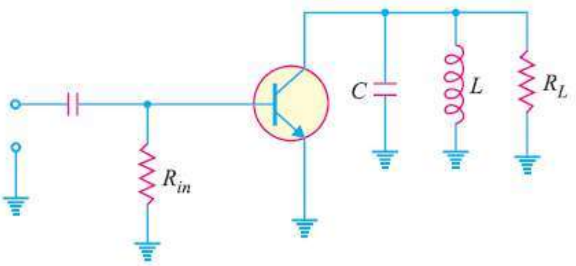
At the resonant frequency, the impedance of the parallel resonant circuit is very high and is purely resistive. Therefore, when the circuit is tuned to resonant frequency, the voltage across *RL* is maximum. In other words, the voltage gain is maximum at *fr*. However, above and below the resonant frequency, the voltage gain decreases rapidly. The higher the *Q* of the circuit, the faster the gain drops off on either side of resonance.

A.C. Equivalent Circuit of Tuned Amplifier

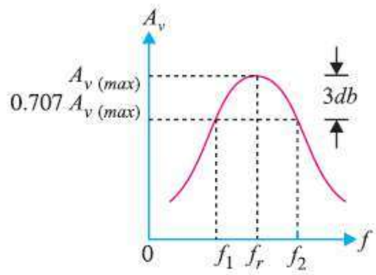
Fig. (*i*) shows the *ac* equivalent circuit of the tuned amplifier. Note the tank circuit components are not shorted. In order to completely understand the operation of this circuit, we shall see its behaviour at three frequency conditions *viz*.,

(*i*) *fin* = *fr* **(*ii*)** *fin* < *fr* **(*iii*)** *fin* > *fr*

(*i*) When input frequency equals *fr* (*i.e*., *fin* = *fr*). When the frequency of the input signal is equal to *fr*, the parallel *LC* circuit offers a very high impedance *i.e*., it acts as an open. Since *RL* represents the only path to ground in the collector circuit, all the ac collector current flows through *RL*. Therefore, voltage across *RL* is maximum *i.e*., the voltage gain is maximum as shown in Fig.ii



(*i*)



(*ii*)

***(ii)* When input frequency is less than** *fr* (*i.e*., *fin* < *fr*). When the input signal frequency is less than *fr*, the circuit is effectively* inductive. As the frequency decreases from *fr*, a point is reached when *XC* −□*XL* = *RL*. When this happens, the voltage gain of the amplifier falls by 3 *db*. In other words, the lower cut-off frequency *f*1 for the circuit occurs when *XC* □*XL* = *RL*.

(*iii*) When input frequency is greater than *fr* (*i.e*., *fin* > *fr*). When the input signal frequency is greater than *fr*, the circuit is effectively capacitive. As *fin* is increased beyond *fr*, a point is reached when *XL* −□*XC* = *RL*. When this happens, the voltage gain of the amplifier will again fall by 3*db*. In other words, the upper cut-off frequency for the circuit will occur when *XL* □*XC* = *RL*.

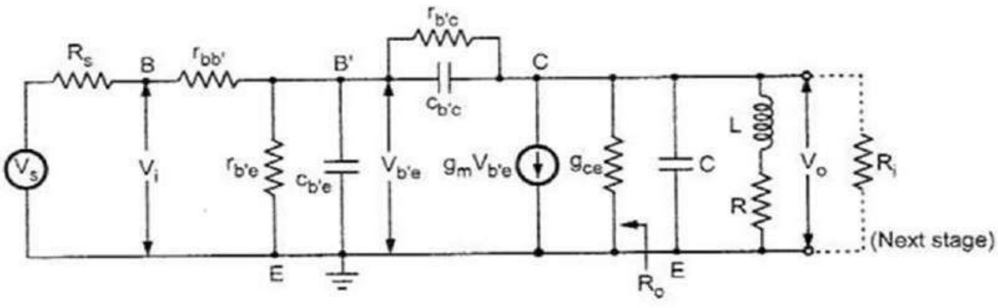


Fig. 3.14 Equivalent circuit of single tuned amplifier

The Fig. 3.14 shows the equivalent circuit for single tuned amplifier using hybrid π parameters.

As shown in the Fig. 3.14, R_i is the input resistance of the next stage and R_o is the output resistance of the current generator $g_m V_{b'c}$. The reactances of the bypass capacitor C_E and the coupling capacitors C_C are negligibly small at the operating frequency and hence these elements are neglected in the equivalent circuit shown in the Fig. 3.14.

The equivalent circuit shown in Fig. 3.14 can be simplified by applying Miller's theorem. Fig. 3.15 shows the simplified equivalent circuit for single tuned amplifier.

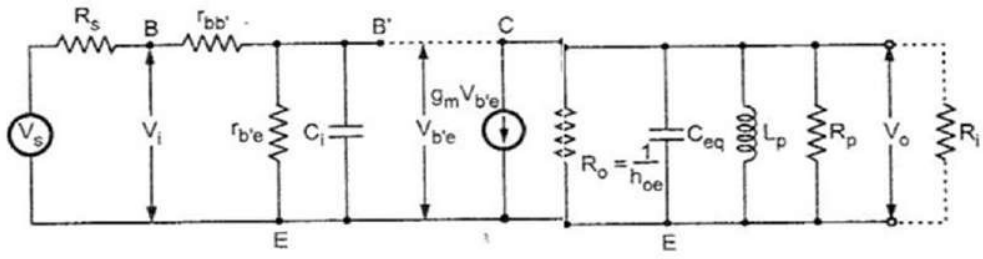


Fig. 3.15 Simplified equivalent circuit for single tuned amplifier

Here C_i and C_{eq} represent input and output circuit capacitances, respectively. They can be given as,

$$C_i = C_{b'e} + C_{b'c}(1 - A) \quad \text{where A is the voltage gain of the amplifier.} \quad ...(1)$$

$$C_{eq} = C_{b'c}\left(\frac{A-1}{A}\right) + C \quad \text{where C is the tuned circuit capacitance.} \quad ...(2)$$

The g_{ce} is represented as the output resistance of current generator $g_m V_{b'e}$.

$$g_{ce} = \frac{1}{r_{ce}} = h_{oe} - g_m h_{re} \approx h_{oe} = \frac{1}{R_o} \quad ...(3)$$

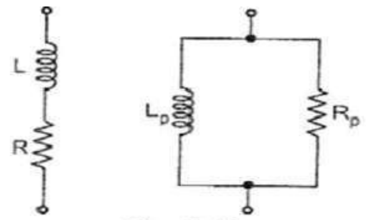


Fig. 3.16

The series RL circuit is represented by its equivalent parallel circuit. The conditions for equivalence are most easily established by equating the admittances of the two circuits shown in Fig. 3.16.

Admittance of the series combination of RL is given as,

$$Y = \frac{1}{R + j\omega L}$$

Multiplying numerator and denominator by $R - j\omega L$ we get,

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

$$= \frac{R}{R^2 + \omega^2 L^2} - \frac{j\omega^2 L}{\omega(R^2 + \omega^2 L^2)}$$

$$= \frac{1}{R_p} + \frac{1}{j\omega L_p}$$

where $$R_p = \frac{R^2 + \omega^2 L^2}{R} \quad \text{... (4)}$$

and $$L_p = \frac{R^2 + \omega^2 L^2}{\omega^2 L} \quad \text{... (5)}$$

Centre frequency

The centre frequency or resonant frequency is given as,

$$f_r = \frac{1}{2\pi\sqrt{L_p C_{eq}}} \quad \text{...(6)}$$

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

and $$C_{eq} = C_{b'c}\left(\frac{A-1}{A}\right) + C \quad \text{...(7)}$$

$$= C_o + C$$

Therefore, C_{eq} is the summation of transistor output capacitance and the tuned circuit capacitance.

Quality factor Q

The quality factor Q of the coil at resonance is given by,

$$Q_r = \frac{\omega_r L}{R} \quad \text{...(8)}$$

This quality factor is also called unloaded Q. but in practice, transistor output resistance and input resistance of next stage act as a load for the tuned circuit. The quality factor including load is called as loaded Q and it can be given as follows:

The Q of the coil is usually large so that ωL >> R in the frequency range of operation.

From equation (4) we have,

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

As $\frac{\omega^2L^2}{R} >> 1$, $R_p \approx \frac{\omega^2L^2}{R}$ ...(9)

From equation (5) we have,

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

$$\approx L \qquad \because \omega L >> R$$ ... (10)

From equation (9), we can express R_p at resonance as,

$$R_p = \frac{\omega_r^2L^2}{R}$$

$$= \omega_r Q_r L \quad \because Q_r = \frac{\omega_r L}{R}$$ ... (11)

Therefore, Q_r can be expressed interms of R_p as,

$$Q_r = \frac{R_p}{\omega_r L}$$ ...(12)

The effective quality factor including load can be calculated looking at the simplified equivalent output circuit for single tuned amplifier.

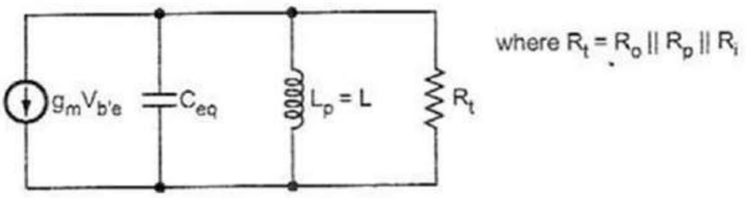


Fig. 3.17 Simplified output circuit for single tuned amplifier

$$\text{Effective quality factor } Q_{eff} = \frac{\text{Susceptance of inductance L or capacitance C}}{\text{Conductance of shunt resistance } R_t}$$

$$= \frac{R_t}{\omega_r L} \text{ or } \omega_r C_{eq} R_t$$ ... (13)

Voltage gain (A_v)

The voltage gain for single tuned amplifier is given by,

$$A_v = -g_m \frac{r_{b'e}}{r_{bb'} + r_{b'e}} \times \frac{R_t}{1 + 2jQ_{eff}\delta}$$

where $R_t = R_o || R_p || R_i$

δ = Fraction variation in the resonant frequency

$$A_v \text{ (at resonance)} = -g_m \frac{r_{b'e}}{r_{bb'} + r_{b'e}} \times R_t$$

$$\therefore \left| \frac{A_v}{A_v(\text{at resonance})} \right| = \frac{1}{\sqrt{1 + (2\delta Q_{eff})^2}} \quad \text{... (14)}$$

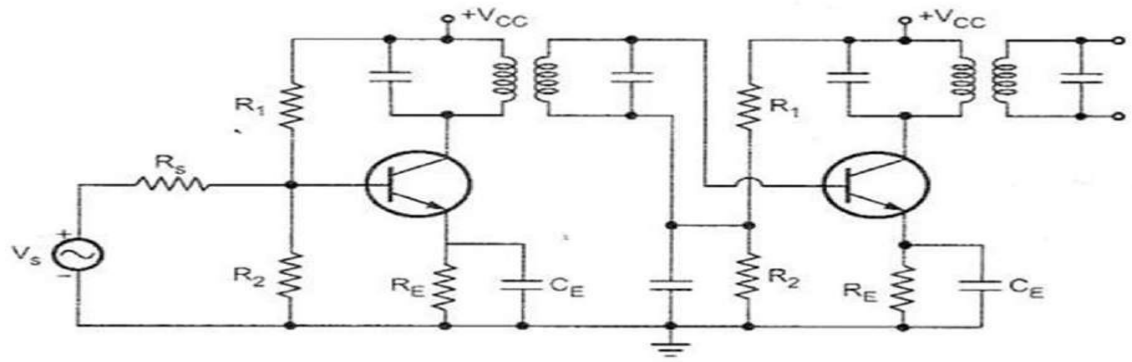
3 dB bandwidth

The 3 dB bandwidth of a single tuned amplifier is given by,

$$\Delta f = \frac{1}{2\pi R_t C_{eq}}$$

$$= \frac{\omega_r}{2\pi Q_{eff}} \quad \because Q_{eff} = \omega_r R_t C_{eq} \quad \text{... (15)}$$

Below figure shows the double tuned RF amplifier in CE configuration. Here, voltage developed across tuned circuit is coupled inductively to another tuned circuit. Both tuned circuits are tuned to the same frequency.



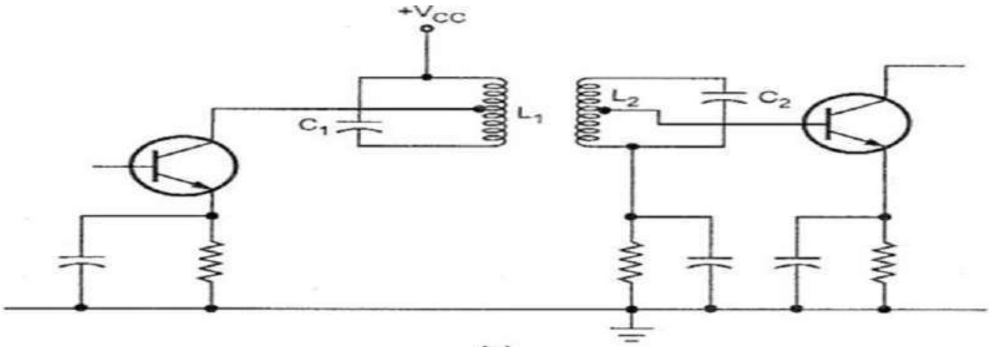
The double tuned circuit can provide a bandwidth of several percent of the resonant frequency and gives steep sides to the response curve.

The Fig. 3.19 (a) shows the coupling section of a transformer coupled double tuned amplifier. The Fig. 3.19 (b) shows the equivalent circuit for it. In which transistor is replaced by the current source with its output resistance (R_o). The C_1 and L_1 are the tank circuit components of the primary side. The resistance R_1 is the series resistance of the inductance L_1. Similarly on the secondary side L_2 and C_2 represents tank circuit components of the secondary side and R_2 represents resistance of the inductance L_2. The resistance R_i represents the input resistance of the next stage.

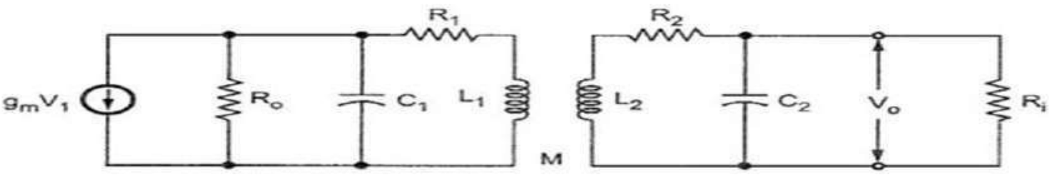
The Fig. 3.19 (c) shows the simplified equivalent circuit for the Fig. 3.19 (b). In simplified equivalent circuit the series and parallel resistances are combined into series elements. Referring equation (9) we have,

$$R_p = \frac{\omega^2 L^2}{R} \text{ i.e. } R = \frac{\omega^2 L^2}{R_p}$$

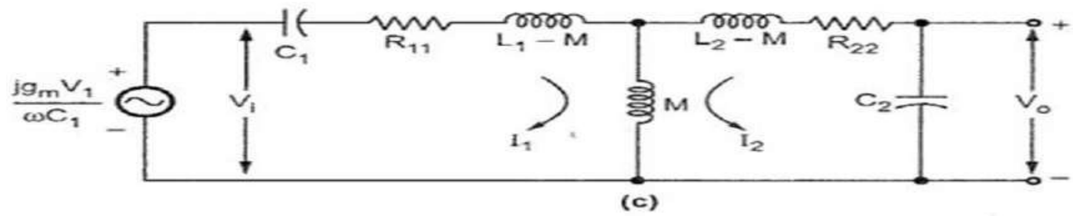
where R represents series resistance and R_p represents parallel resistance.



(a)



(b)



(c)

Fig. 3.19 Equivalent circuits for double tuned amplifier

Therefore we can write,

$$R_{11} = \frac{\omega_o^2 L_1^2}{R_o} + R_1$$

$$R_{12} = \frac{\omega_o^2 L_2^2}{R_i} + R_2$$

In the simplified circuit the current source is replaced by voltage source, which is now in series with C_1. It also shows the effect of mutual inductance on primary and secondary sides.

We know that, $Q = \frac{\omega_r L}{R}$

Therefore, the Q factors of the individual tank circuits are

$$Q_1 = \frac{\omega_r L_1}{R_{11}} \text{ and } Q_2 = \frac{\omega_r L_2}{R_{22}} \quad ...(1)$$

Usually, the Q factors for both circuits are kept same. Therefore, $Q_1 = Q_2 = Q$ and the resonant frequency $\omega_r^2 = 1/L_1 C_1 = 1/L_2 C_2$.

Looking at Fig. 3.19 (c), the output voltage can be given as,

$$V_o = -\frac{j}{\omega_r C_2} I_2 \quad ... (2)$$

To calculate V_o/V_1 it is necessary to represent I_2 interms of V_1. For this we have to find the transfer admittance Y_T. Let us consider the circuit shown in Fig. 3.20. For this circuit, the transfer admittance can be given as,

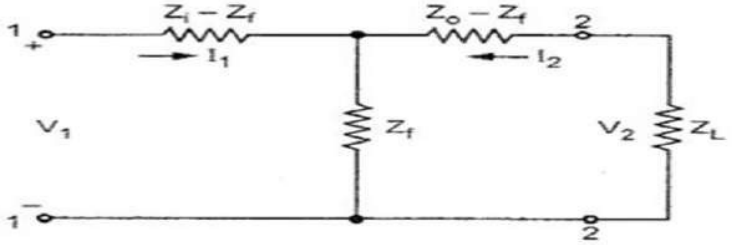


Fig. 3.20

$$Y_T = \frac{I_2}{V_1} = \frac{I_2}{I_1 Z_{11}} = \frac{A_i}{Z_{11}}$$

$$= \frac{Z_f}{Z_f^2 - Z_i\ (Z_o + Z_L)}$$

where $$Z_{11} = \frac{V_1}{I_1} = Z_i - \frac{Z_f^2}{Z_o + Z_L} \text{ and}$$

$$A_i = \frac{I_2}{I_1} = \frac{-Z_f}{Z_o + Z_L}$$

The simplified equivalent circuit for double tuned amplifier is similar to the circuit shown in Fig. 3.20 with

$$Z_f = j\,\omega_r M$$

$$Z_i = R_{11} + j\left(\omega L_1 - \frac{1}{\omega C_1}\right)$$

$$Z_o + Z_L = R_{22} + j\left(\omega L_2 - \frac{1}{\omega C_2}\right)$$

The equations for Z_f, Z_i and $Z_o + Z_L$ can be further simplified as shown below.

$$Z_f = j\omega_r M = j\omega_r k\sqrt{L_1\ L_2}$$

where, k is the coefficient of coupling.

Multiplying numerator and denominator by $\omega_r L_1$ for Z_i we get,

$$Z_i = \frac{R_{11}\,\omega_r\,L_1}{\omega_r\,L_1} + j\omega_r\,L_1\left(\frac{\omega L_1}{\omega_r\,L_1} - \frac{1}{\omega C_1\,\omega_r L_1}\right)$$

$$= \frac{\omega_r\,L_1}{Q} + j\,\omega_r\,L_1\left(\frac{\omega}{\omega_r} - \frac{\omega_r}{\omega}\right) \qquad \because Q = \frac{\omega_r\,L}{R_{11}} \text{ and } \frac{1}{\omega_r\,L} = \omega_r\,C$$

$$= \frac{\omega_r\,L_1}{Q} + j\,\omega_r\,L_1\,(2\,\delta) \qquad \because \frac{\omega}{\omega_r} - \frac{\omega_r}{\omega} = 1 + \delta - (1 - \delta) = 2\,\delta$$

$$= \frac{\omega_r\,L_1}{Q} + (1 + j2\,Q\,\delta)$$

$$Z_o + Z_L = R_{22} + j\left(\omega L_2 - \frac{1}{\omega C_2}\right)$$

By doing similar analysis as for Z_i we can write,

$$Z_o + Z_L = \frac{\omega_r\,L_2}{Q} + (1 + j2\,Q\,\delta)$$

Then

$$Y_T = \frac{Z_f}{Z_f^2 - Z_i\,(Z_o + Z_L)} = \frac{1}{Z_f - Z_i\,(Z_o + Z_L)\,/\,Z_f}$$

$$Y_T = \frac{1}{j\omega_r\,k\sqrt{L_1\,L_2} - \dfrac{\left[\dfrac{\omega_r\,L_1}{Q}\,(1 + j\,2\,Q\delta)\left\{\dfrac{\omega_r\,L_2}{Q}\,(1 + j\,2\,Q\delta)\right\}\right]}{j\omega_r\,k\sqrt{L_1\,L_2}}}$$

$$Y_T = \frac{kQ^2}{\omega_r \sqrt{L_1 L_2}\left[4Q\delta - j(1+k^2Q^2 - 4Q^2\delta^2)\right]} \quad \ldots (3)$$

Substituting value of I_2, i.e. $V_i \times Y_T$ we get,

$$V_o = \frac{-j}{\omega_r C_2} \frac{j g_m V_i}{\omega_r C_1}\left[\frac{kQ^2}{\omega_r \sqrt{L_1 L_2}\left[4Q\delta - j(1+k^2Q^2 - 4Q^2\delta^2)\right]}\right]$$

$$\because V_i = \frac{j g_m V_1}{\omega C_1}$$

$$\therefore \quad A_v = \frac{V_o}{V_i} = g_m \omega_r^2 L_1 L_2 \left[\frac{kQ^2}{\omega_r \sqrt{L_1 L_2}\left[4Q\delta - j(1+k^2Q^2 - 4Q^2\delta^2)\right]}\right]$$

$$\because \frac{1}{\omega_r C} = \omega_r L$$

$$= \left[\frac{g_m \omega_r \sqrt{L_1 L_2}\, kQ^2}{4Q\delta - j(1+k^2Q^2 - 4Q^2\delta^2)}\right] \quad \ldots (4)$$

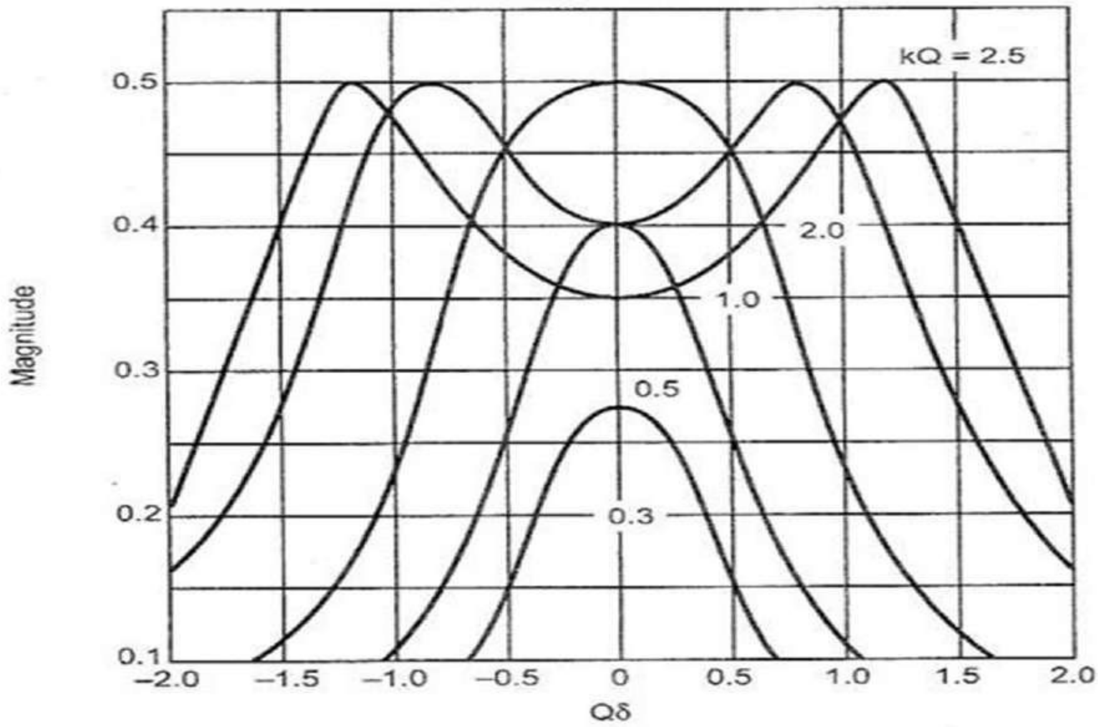
Taking the magnitude of equation (4) we have,

$$|A_v| = g_m \omega_r \sqrt{L_1 L_2}\, Q \frac{kQ}{\sqrt{1+k^2Q^2 - 4Q^2\delta^2 + 16Q^2\delta^2}} \quad \ldots (5)$$

The Fig. 3.21 shows the universal response curve for double tuned amplifier plotted with kQ as a parameter.

The frequency deviation δ at which the gain peaks occur can be found by maximizing equation (4), i.e.

$$4Q\delta - j(1+k^2Q^2 - 4Q^2\delta^2) = 0 \quad \ldots (6)$$



kQ = 2.5
2.0
1.0
0.5
0.3
Magnitude
0.5
0.4
0.3
0.2
0.1
−2.0
−1.5
−1.0
−0.5
0
0.5
1.0
1.5
2.0
Qδ

At $k^2Q^2 = 1$, i.e. $k = \frac{1}{Q}$, $f_1 = f_2 = f_r$. This condition is known as **critical coupling**. For values of $k < 1/Q$, the peak gain is less than maximum gain and the coupling is poor.

At $k > 1/Q$, the circuit is overcoupled and the response shows the double peak. Such double peak response is useful when more bandwidth is required.

The gain magnitude at peak is given as,

$$|A_p| = \frac{g_m \omega_o \sqrt{L_1 L_2}\, kQ}{2} \qquad \text{... (8)}$$

And gain at the dip at $\delta = 0$ is given as,

$$|A_d| = |A_p| \frac{2kQ}{1+k^2Q^2} \qquad \text{... (9)}$$

The ratio of peak gain and dip gain is denoted as γ and it represents the magnitude of the ripple in the gain curve.

$$\gamma = \left|\frac{A_p}{A_d}\right| = \frac{1+k^2Q^2}{2kQ} \qquad \text{... (10)}$$

$$\gamma = \left|\frac{A_p}{A_d}\right| = \frac{1+k^2Q^2}{2kQ} \qquad \text{... (10)}$$

Using quadratic simplification and choosing positive sign we get,

$$kQ = \gamma + \sqrt{\gamma^2 - 1} \qquad \text{... (11)}$$

The bandwidth between the frequencies at which the gain is $|A_d|$ is the useful bandwidth of the double tuned amplifier. It is given as,

$$BW = 2\,\delta' = \sqrt{2}\,(f_2 - f_1) \qquad \text{... (12)}$$

At 3 dB bandwidth,

$$\gamma = \sqrt{2}$$

$$\therefore \quad kQ = \gamma + \sqrt{\gamma^2 + 1} = \sqrt{2} + \sqrt{\sqrt{2}^2 + 1} = 2.414$$

$$\therefore \quad 3\text{ dB BW} = 2\,\delta' = \sqrt{2}\,(f_2 - f_1)$$

$$= \sqrt{2}\left[f_r\left(1 + \frac{1}{2Q}\sqrt{k^2Q^2 - 1}\right) - f_r\left(1 - \frac{1}{2Q}\sqrt{k^2Q^2 - 1}\right)\right]$$

$$= \sqrt{2}\left[\left(\frac{f_r}{Q}\sqrt{k^2Q^2 - 1}\right)\right]$$

$$= \sqrt{2}\left[\frac{f_r}{Q}\sqrt{(2.414)^2 - 1}\right] = \frac{3.1\,f_r}{Q}$$

We know that, the 3 dB bandwidth for single tuned amplifier is $2\,f_r/Q$. Therefore, the 3 dB bandwidth provided by double tuned amplifier ($3.1f_r/Q$) is substantially greater than the 3 dB bandwidth of single tuned amplifier.

Compared with a single tuned amplifier, the double tuned amplifier

1. Possesses a flatter response having steeper sides.
2. Provides larger 3 dB bandwidth.
3. Provides large gain-bandwidth product.

Effect of cascading single tuned amplifier on bandwidth:

In order to obtain a high overall gain, several identical stages of tuned amplifiers can be used in cascade. The overall gain is the product of the voltage gains of the individual stages. Let us see the effect of cascading of stages on bandwidth.

Consider n stages of single tuned direct coupled amplifiers connected in cascade. We know that the relative gain of a single tuned amplifier with respect to the gain at resonant frequency f_r is given from equation (14) of section 3.4.

$$\left|\frac{A_v}{A_v\text{(at resonance)}}\right| = \frac{1}{\sqrt{1+(2\delta Q_{eff})^2}}$$

Therefore, the relative gain of n stage cascaded amplifier becomes

$$\left|\frac{A_v}{A_v\text{(at resonance)}}\right|^n = \left[\frac{1}{\sqrt{1+(2\delta Q_{eff})^2}}\right]^n = \frac{1}{\left[1+(2\delta Q_{eff})^2\right]^{\frac{n}{2}}}$$

The 3 dB frequencies for the n stage cascaded amplifier can be found by equating

$$\left|\frac{A_v}{A_v\text{(at resonance)}}\right|^n = \frac{1}{\sqrt{2}}$$

$$\therefore \quad \left|\frac{A_v}{A_v\text{(at resonance)}}\right|^n = \frac{1}{\left[1+(2\delta Q_{eff})^2\right]^{\frac{n}{2}}} = \frac{1}{\sqrt{2}}$$

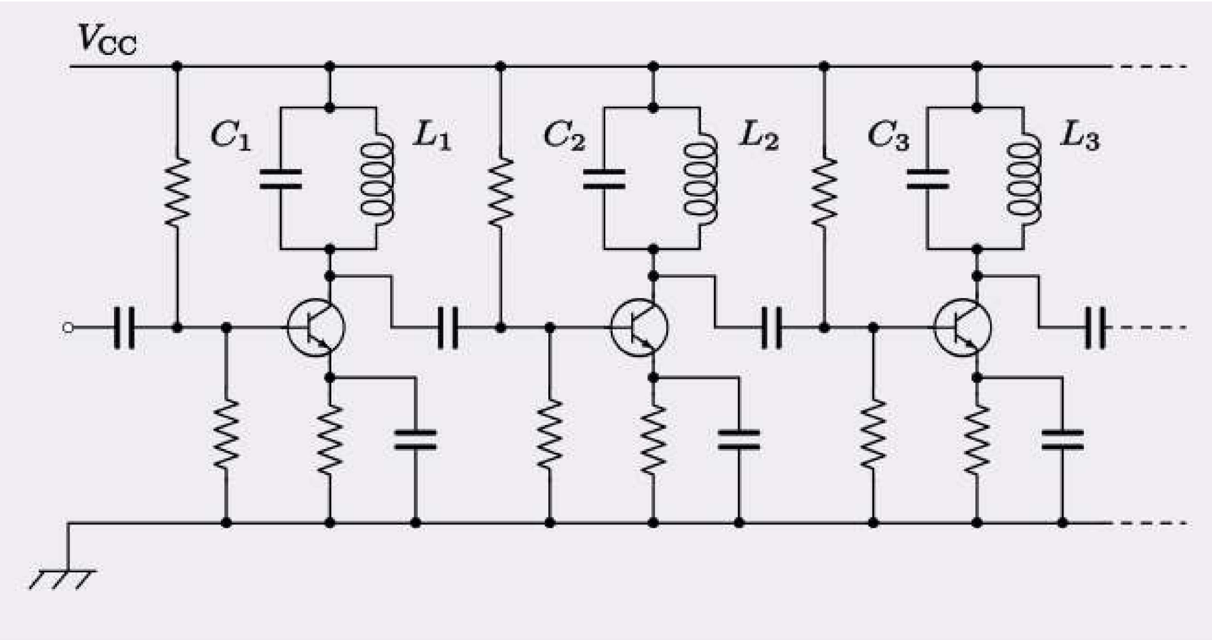


Fig. n-stage single tuned amplifier

$$\left[1+(2\delta Q_{eff})^2\right]^{\frac{n}{2}} = 2^{\frac{1}{2}}$$

$$\left[1+(2\delta Q_{eff})^2\right]^{n} = 2$$

$$1+(2\delta Q_{eff})^2 = 2^{\frac{1}{n}}$$

$$2\delta Q_{eff} = \pm\sqrt{2^{\frac{1}{n}}-1}$$

Substituting for δ, the fractional frequency variation, i.e.

$$\delta = \frac{\omega - \omega_r}{\omega_r} = \frac{f - f_r}{f_r}$$

$$\therefore \quad 2\left(\frac{f - f_r}{f_r}\right) Q_{eff} = \pm\sqrt{2^{\frac{1}{n}} - 1}$$

$$\therefore \quad 2\,(f - f_r)\, Q_{eff} = \pm\, f_r\sqrt{2^{\frac{1}{n}} - 1}$$

$$\therefore \quad f - f_r = \pm\frac{f_r}{2Q_{eff}}\sqrt{2^{\frac{1}{n}} - 1}$$

Let us assume f_1 and f_2 are the lower 3 dB and upper 3 dB frequencies, respectively. Then we have

$$f_2 - f_r = +\frac{f_r}{2Q_{eff}}\sqrt{2^{\frac{1}{n}} - 1} \text{ and similarly,}$$

$$f_r - f_1 = +\frac{f_r}{2Q_{eff}}\sqrt{2^{\frac{1}{n}} - 1}$$

$$f_2 - f_r = +\frac{f_r}{2Q_{eff}}\sqrt{2^{\frac{1}{n}} - 1} \text{ and similarly,}$$

$$f_r - f_1 = +\frac{f_r}{2Q_{eff}}\sqrt{2^{\frac{1}{n}} - 1}$$

The bandwidth of n stage identical amplifier is given as,

$$\begin{aligned} BW_n &= f_2 - f_1 = (f_2 - f_r) + (f_r - f_1) \\ &= \frac{f_r}{2Q_{eff}}\sqrt{2^{\frac{1}{n}} - 1} + \frac{f_r}{2Q_{eff}}\sqrt{2^{1/n} - 1} \\ &= \frac{f_r}{Q_{eff}}\sqrt{2^{\frac{1}{n}} - 1} \\ &= BW_1\sqrt{2^{\frac{1}{n}} - 1} \qquad \text{... (1)} \end{aligned}$$

where BW_1 is the bandwidth of single stage and BW_n is the bandwidth of n stages.

Effect of cascading double tuned amplifier on bandwidth:

When a number of identical double tuned amplifier stages are cascaded in cascade, the overall bandwidth of the system is thereby narrowed and the steepness of the sides of the response is increased, just as when single tuned stages are cascaded. The quantitative relation between the 3 dB bandwidth of n identical double tuned critically coupled stages compared with the bandwidth Δ_2 of such a system can be shown to be 3 dB bandwidth for

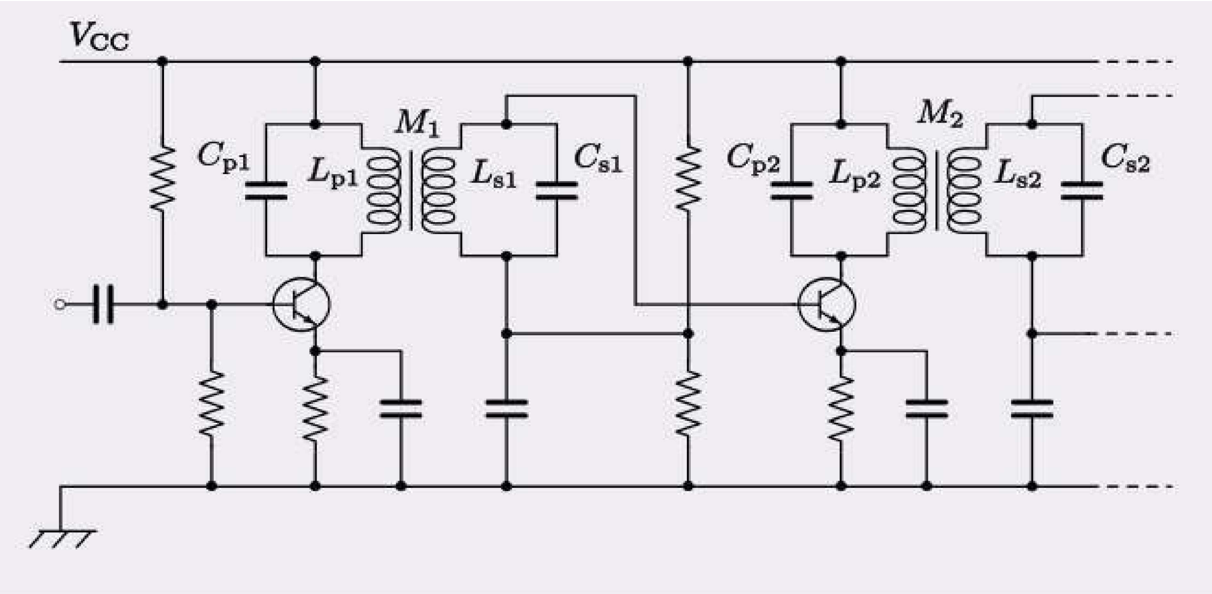


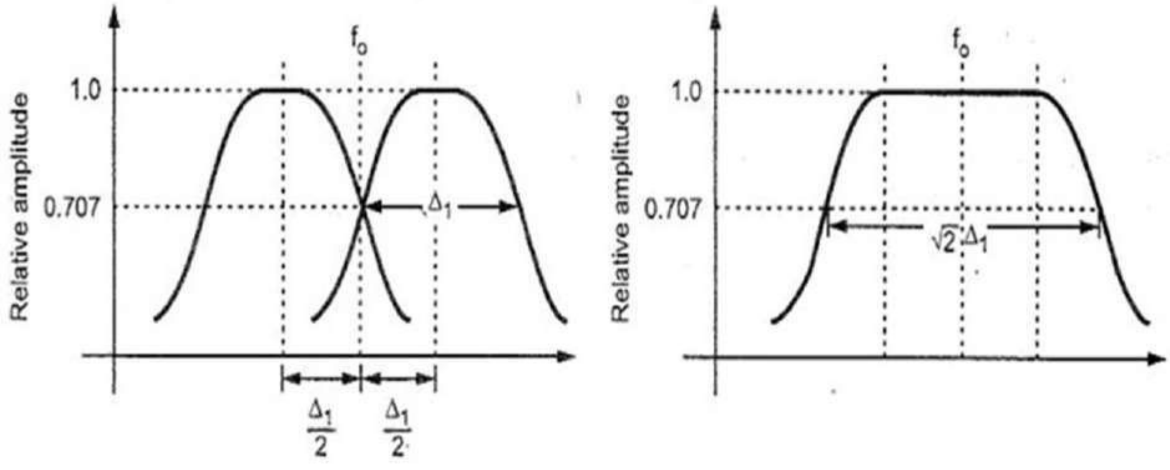
Fig. 2 stage double tuned amplifier

$$\text{n identical stages double tuned amplifiers} = \Delta_2 \times \left(2^{\frac{1}{n}} - 1\right)^{\frac{1}{4}}$$

where Δ_2 = 3 dB bandwidth of single stage double tuned amplifier

STAGGER TUNED AMPLIFIER:

The double tuned amplifier gives greater 3dB bandwidth having steeper sides and flat top. But alignment of double tuned amplifier is difficult. To overcome this problem two single tuned cascaded amplifiers having certain bandwidth are taken and their resonant frequencies are so adjusted that they are separated by an amount equal to the bandwidth of each stage. Since resonant frequencies are displaced or staggered, they are known as stagger tuned amplifiers. The advantage of stagger tuned amplifier is to have better flat, wideband characteristics in contrast with very sharp, rejective, narrow band characteristics of synchronously tuned circuits (tuned to same resonant frequencies). Fig. 3.23 shows the relationship of amplification characteristics of individual stages in a staggered pair to the overall amplification of the two stages.



(a) Response of individual stages

(b) Overall response of staggered pair

Fig. 3.23

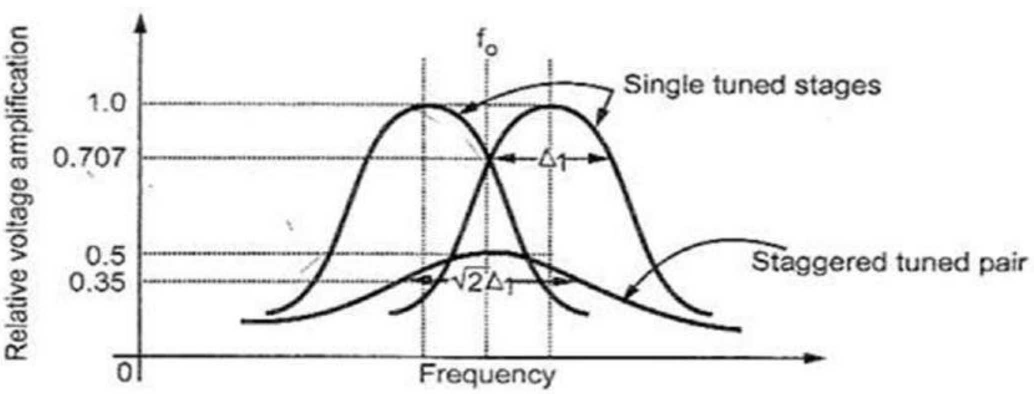


Fig. 3.24 Response of individually tuned and staggered tuned pair

The overall response of the two stage stagger tuned pair is compared in Fig. 3.24 with the corresponding individual single tuned stages having same resonant circuits. Looking at Fig. 3.24, it can be seen that staggering reduces the total amplification of the centre frequency to 0.5 of the peak amplification of the individual stage and at the centre frequency each stage has an amplification that is 0.707 of the peak amplification of the individual stage. Thus the equivalent voltage amplification per stage of the staggered pair is 0.707 times as great as when the same two stages are used without staggering. However, the half power (3 dB) bandwidth of the staggered pair is $\sqrt{2}$ times as great as the half power (3 dB) bandwidth of an individual single tuned stage. Hence the equivalent gain bandwidth product per stage of a stagger tuned pair is $0.707 \times \sqrt{2} = 1.00$ times that of the individual single tuned stages.

The stagger tuned idea can easily be extended to more stages. In case of three stage staggering, the first tuning circuit is tuned to a frequency lower than centre frequency while the third circuit is tuned to higher frequency than centre frequency. The middle tuned circuit is tuned at exact centre frequency.

Analysis of stagger tuned amplifier:

Analysis

From equation (14) of section 3.4 we can write the gain of the single tuned amplifier as,

$$\frac{A_v}{A_v \text{ (at resonance)}} = \frac{1}{1+2jQ_{eff}\,\delta}$$

$$= \frac{1}{1+jX}, \text{ where } X = 2\,Q_{eff}\,\delta$$

Since in stagger tuned amplifiers the two single tuned cascaded amplifiers with separate resonant frequencies are used, we can assume that the one stage is tuned to the frequency $f_r + \delta$ and other stage is tuned to the frequency $f_r - \delta$. Therefore we have,

$$f_{r1} = f_r + \delta$$

and $$f_{r2} = f_r - \delta$$

According to these tuned frequencies the selectivity functions can be given as,

$$\frac{A_v}{A_v \text{ (at resonance)}_1} = \frac{1}{1+j(X+1)} \text{ and}$$

$$\frac{A_v}{A_v \text{ (at resonance)}_2} = \frac{1}{1+j(X-1)}$$

The overall gain of these two stages is the product of individual gains of the two stages.

$$\therefore \quad \frac{A_v}{A_v \text{ (at resonance)}_{\text{cascaded}}} = \frac{A_v}{A_v \text{ (at resonance)}_1} \times \frac{A_v}{A_v \text{ (at resonance)}_2}$$

$$= \frac{1}{1+j(X+1)} \times \frac{1}{1+j(X-1)}$$

$$= \frac{1}{2+2jX-X^2} = \frac{1}{(2-X^2)+(2jX)}$$

$$\therefore \quad \left|\frac{A_v}{A_v \text{ (at resonance)}}\right|_{\text{cascaded}} = \frac{1}{\sqrt{(2-X^2)^2+(2X)^2}}$$

$$= \frac{1}{\sqrt{4-4X^2+X^4+4X^2}} = \frac{1}{\sqrt{4+X^4}}$$

Substituting the value of X we get,

$$\left|\frac{A_v}{A_v \text{ (at resonance)}}\right|_{\text{cascaded}} = \frac{1}{\sqrt{4+(2Q_{eff}\,\delta)^4}} = \frac{1}{\sqrt{4+16Q_{eff}^4\,\delta^4}}$$

$$= \frac{1}{2\sqrt{1+4Q_{eff}^4\,\delta^4}}$$

Wide Band amplifiers/Large signal tuned amplifiers:

The output efficiency of an amplifier increases as the operation shifts from class A to class C through class AB and class B. as the output power of a radio transmitter is high and efficiency is prime concern, class B and class C amplifiers are used at the output stages in transmitter. The operation of class B and class C amplifiers are non-linear since the amplifying elements remain cut-off during a part of the input signal cycle. The non-linearity generates harmonics of the single frequency at the output of the amplifier. In the push-pull arrangement where the bandwidth requirement is no limited, these harmonics can be eliminated or reduced. When an narrow bandwidth is desired, a resonant circuit is employed in class B and class C tuned RF power amplifiers to eliminate the harmonics.

Class B tuned amplifier

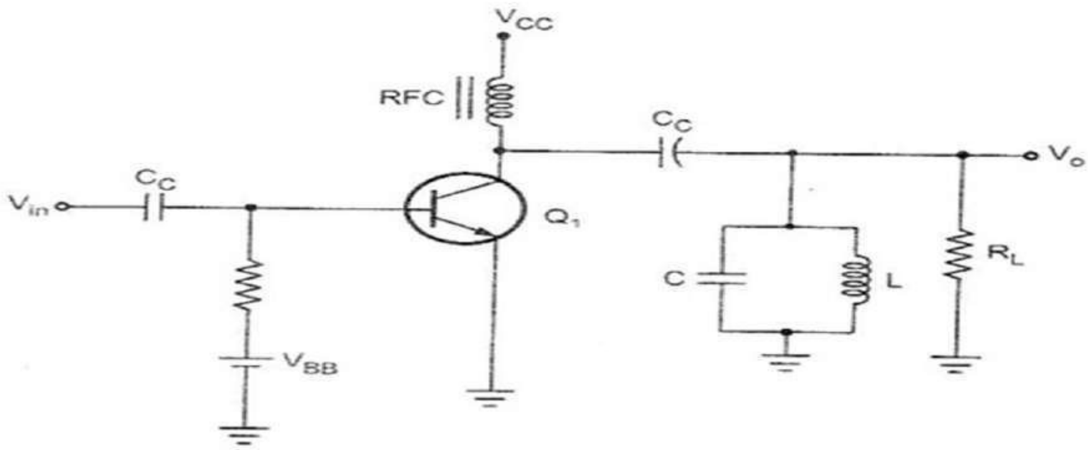


Fig. 3.25 Class B tuned amplifier

It works with a single transistor by sending half sinusoidal current pulses to the load. The transistor is biased at the edge of the conduction. Even though the input is half sinusoidal, the load voltage is sinusoidal because a high Q RLC tank shunts harmonics to ground. The negative half is delivered by the RLC tank. The Q factor of the tank needs to be large enough to do this. This is analogous to pushing someone on a swing. We only need to push in one direction, and the reactive energy stored will swing the person back in the reverse direction.

Class C tuned amplifier:

The amplifier is said to be class C amplifier, if the Q point and the input signal are selected such that the output signal is obtained for less than a half cycle, for a full input cycle. Due to such a selection of the Q point, transistor remains active, for less than a half cycle. Only that much part is reproduced at the output. For remaining cycle of the input cycle, the transistor remains cut-off and no signal is produced at the output.

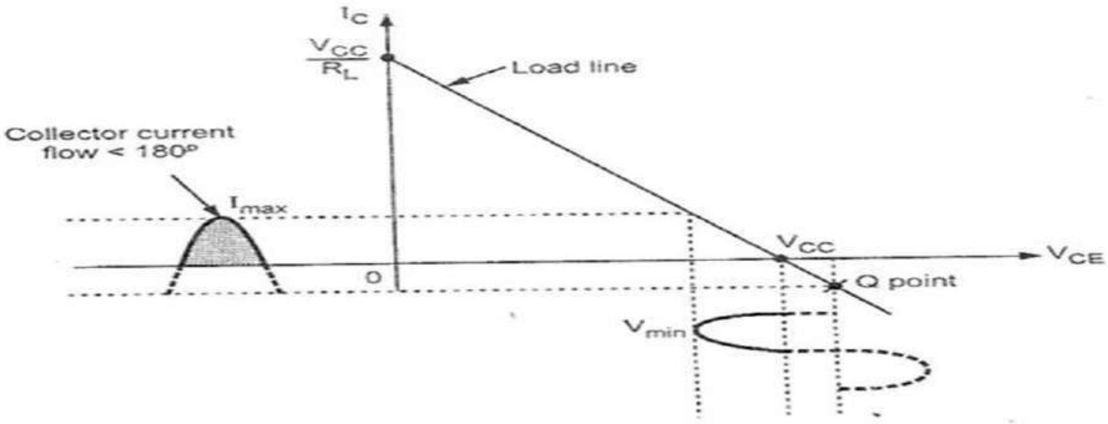
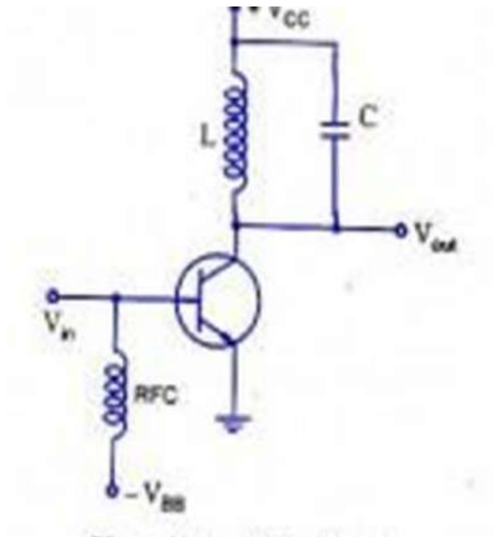


Fig. 3.26 Waveform representing class C operation

From the figure, it is apparent that the total angle during which current flows is less than 180°. this angle is called the conduction angle, θ_c.



The above shows the class C tuned amplifier. Here a parallel resonant circuit acts as load impedance. As collector current flows for less than half a cycle, the collector current consists of a series of pulses with the harmonics of the input signal. A parallel tuned circuit acting as load impedance is tuned to the input frequency. Therefore, it filters the harmonic frequencies a produce a sine wave output voltage consisting of fundamental component of the input signal.

Fast track material for QUICK REFERENCE:

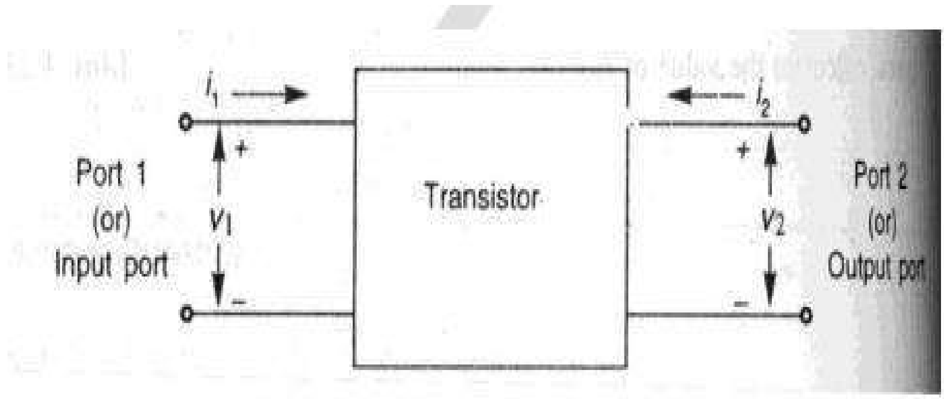
Small signal high frequency transistor amplifier

Introduction:

Electronic circuit analysis subject teaches about the basic knowledge required to design an amplifier circuit, oscillators etc .It provides a clear and easily understandable discussion of designing of different types of amplifier circuits and their analysis using hybrid model, to find out their parameters. Fundamental concepts are illustrated by using small examples which are easy to understand. It also covers the concepts of MOS amplifiers, oscillators and large signal amplifiers.

Two port devices & Network Parameters: -

A transistor can be treated as a two-part network. The terminal behavior of any two-part network can be specified by the terminal voltages V1& V2at parts 1 & 2 respectively and current i1and i2, entering parts 1 & 2, respectively, as shown in figure.

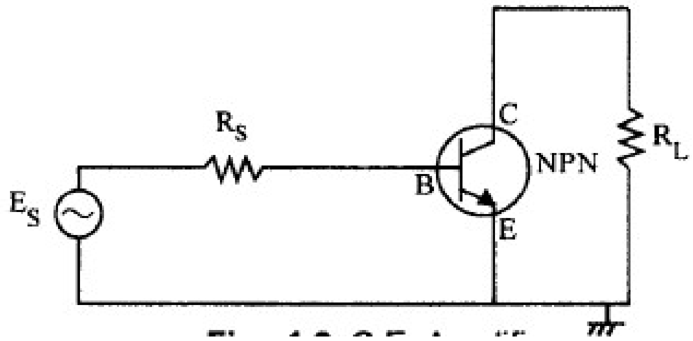


Of these four variables V1, V2, i1and i2, two can be selected as independent variables and the remaining two can be expressed in terms of these independent variables. This leads to various two part parameters out of which the following three are more important.

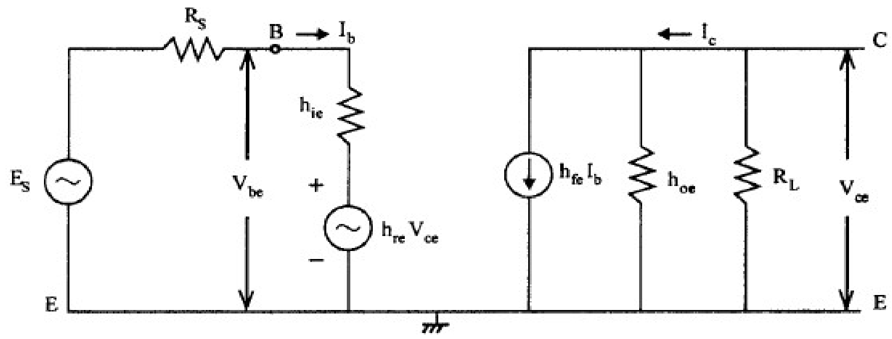
1. Z –Parameters (or) Impedance parameters
2. Y –Parameters (or) Admittance parameters
3. H –Parameters (or) Hybrid parameters

Common Emitter Amplifier:

Common Emitter Circuit is as shown in the Fig. The DC supply, biasing resistors and coupling capacitors are not shown since we are performing an AC analysis.



$E_s$is the input signal source and R_s is its resistance. The h-parameter equivalent for the above circuit is as shown in Fig.



$$h_{ie} = \left.\frac{V_{be}}{I_b}\right|_{V_{ce}=0} \qquad h_{re} = \left.\frac{V_{be}}{V_{ce}}\right|_{I_b=0}$$

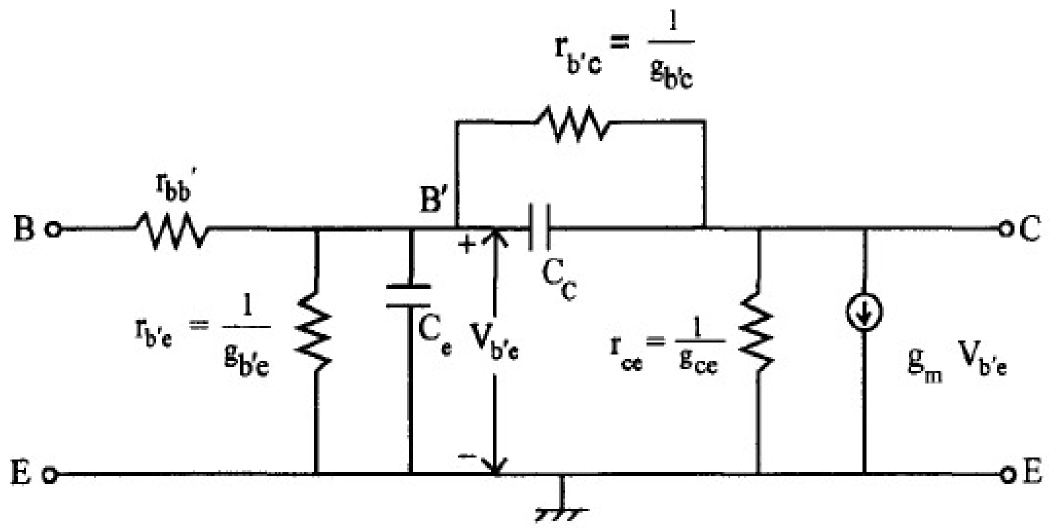
$$h_{oe} = \left.\frac{I_c}{V_{ce}}\right|_{I_b=0} \qquad h_{fe} = \left.\frac{I_c}{I_b}\right|_{V_{ce}=0}$$

The typical values of the h-parameter for a transistor in Common Emitter configuration are,

$$h_{ie} = \frac{V_{be}}{I_b}$$

Hybrid - π Common Emitter Tran conductance Model:

For Tran conductance amplifier circuits Common Emitter configuration is preferred. Why? Because for Common Collector (hrc< 1). For Common Collector Configuration, voltage gain Av < 1. So even by cascading you can't increase voltage gain. For Common Base, current gain is hib< 1. Overall voltage gain is less than 1. For Common Emitter, hre>>1. Therefore Voltage gain can be increased by cascading Common Emitter stage. So Common Emitter configuration is widely used. The Hybrid-x or Giacoletto Model for the Common Emitter amplifier circuit (single stage) is as shown below



Analysis of this circuit gives satisfactory results at all frequencies not only at high frequencies but also at low frequencies. All the parameters are assumed to be independent of frequency.

Where

B' = internal node in base

$r_{bb'}$ = Base spreading resistance

$r_{b'e}$ = Internal base node to emitter resistance

r_{ce} = collector to emitter resistance

C_e = Diffusion capacitance of emitter base junction
$r_{b'c}$ = Feedback resistance from internal base node to collector node
g_m = Transconductance
C_C= transition or space charge capacitance of base collector junction

Hybrid - π Capacitances:

In the hybrid - **π** equivalent circuit, there are two capacitances, the capacitance between the Collector Base junction is the C_c or $C_{b'e}$'. This is measured with input open i.e., I_E = 0, and is specified by the manufacturers as C_{Ob}. 0 indicates that input is open. Collector junction is reverse biased.

$$C_C \; \alpha \; \frac{1}{(V_{CE})^n}$$

$$n = \frac{1}{2} \quad \text{for abrupt junction}$$

$$= 1/3 \quad \text{for graded junction.}$$

C_e = Emitter diffusion capacitance C_{De} + Emitter junction capacitance C_{Te}
C_T = Transition capacitance.
C_D = Diffusion capacitance.
$C_{De} >> C_{Te}$
$C_e \simeq C_{De}$
$C_{De} \; \alpha \; I_E$ and is independent of Temperature T.

Validity of hybrid-π model:

The high frequency hybrid Pi or Giacoletto model of BJT is valid for frequencies less than the unit gain frequency.

Current Gain with Resistance Load:

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

The Parameters f$_T$

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

The Parameters f$_\beta$

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

$$f = f_T, \quad A_i = 1$$

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

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

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

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

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

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

$$C_e >> C_c$$

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

This is a measure to denote the performance of an amplifier circuit. Gain - B. W product is also referred as Figure of Merit of an amplifier. Any amplifier circuit must have large gain and large bandwidth. For certain amplifier circuits, the midband gain Am maybe large, but not Band width or Vice - Versa. Different amplifier circuits can be compared with thus parameter.

Multistage Amplifiers:

Classification of amplifiers

Depending upon the type of coupling, the multistage amplifiers are classified as:

1. Resistance and Capacitance Coupled Amplifiers (RC Coupled)
2. Transformer Coupled Amplifiers
3. Direct Coupled DC Amplifiers
4. Tuned Circuit Amplifiers.

Based upon the B. W. of the amplifiers, they can be classified as:

1. Narrow hand amplifiers
2. Untuned amplifiers

Narrow hand amplifiers: Amplification is restricted to a narrow band offrequencies arounda centre frequency. There are essentially tuned amplifiers.

Untuned amplifiers: These will have large bandwidth. Amplification is desired over a Considerable range of frequency spectrum.

Untuned amplifiers are further classified w.r.t bandwidth.

I. DC amplifiers (Direct Coupled) DC to few KHz	
2. Audio frequency amplifiers (AF)	20 Hz to 20 KHz
3. Broad band amplifier	DC to few MHz
4. Video amplifier	100 Hz to few MHz

The gain provided by an amplifier circuit is not the same for all frequencies because the reactance of the elements connected in the circuit and the device reactance value depend upon the frequency. Bandwidth of an amplifier is the frequency range over which the amplifier stage gain is reasonably constant within ± 3 db, or O. 707 of A_V Max Value.

Resistance and Capacitance Coupled Amplifiers (RC Coupled)

This type of amplifier is very widely used. It is least expensive and has good frequency response.In the multistage resistive capacitor coupled amplifiers, the output of the first stage is coupled to the next through coupling capacitor and R_L. In two stages Resistor Capacitor coupled amplifiers, there is no separate R_L between collector and ground, but Reo the resistance between collector and V cc (R_C) itself acts as R_L in the AC equivalent circuit.

Transformer Coupled Amplifiers

` Here the output of the amplifier is coupled to the next stage or to the load through a transformer. With this overall circuit gain will be increased and also impedance matching can be achieved. But such transformer coupled amplifiers will not have broad frequency response i.e., (f_2-f_1)is small since inductance of the transformer windings will be large. So Transformer coupling is done for power amplifier circuits, where impedance matching is critical criterion for maximum power to be delivered to the load.

Direct Coupled (DC) Amplifiers

Here DC stands for direct coupled and not (direct current). In this type, there is no reactive element. L or C used to couple the output of one stage to the other. The AC output from the collector of one stage is directly given to the base of the second stage transistor directly. So type of amplifiers is used for large amplification of DC and using low frequency signals. Resistor Capacitor coupled amplifiers cannot be used for amplifications of DC or low frequency signals since Xc the capacitive reactance of the coupling capacitor will be very large or open circuit for DC

Tuned Circuit Amplifiers

In this type there will be one RC or LC tuned circuit between collector and V_{CC} in the place of Re. These amplifiers will amplify signals of only fixed frequency.fo which is equal to the resonance frequency of the tuned circuit LC. These are also used to amplify signals of a narrow band of frequencies centered on the tuned frequency f_0.

Distortion in Amplifiers

If the input signal is a sine wave the output should also be a true sine wave. But in all the cases it may not be so, which we characterize as distortion. Distortion can be due to the nonlinear characteristic of the device, due to operating point not being chosen properly, due to large signal swing of the input from the operating point or due to the reactive elements Land C in the circuit. Distortion is classified as:

(a)**Amplitude distortion**: This is also called non linear distortion or harmonic distortion. This type of distortion occurs in large signal amplifiers or power amplifiers. It is due to then on linearity of the characteristic of the device. This is due to the presence of new frequency signals which are not present in the input. If the input signal is of 10 KHz the output signal should also be 10 KHz signal. But some harmonic terms will also be present. Hence the amplitude of the signal (rms value) will be different Vo = Ay Vi.

(b) **Frequency distortion**: The amplification will not be the same for all frequencies. This is due to reactive component in the circuit.

(c) **Phase - shift delay distortion**: There will be phase shift between the input and the output and this phase shift will not be the same for all frequency signals. It also varies with the frequency of the input signal. In the output signal, all these distortions may be present or anyone may be present because of which the amplifier response will not be good.

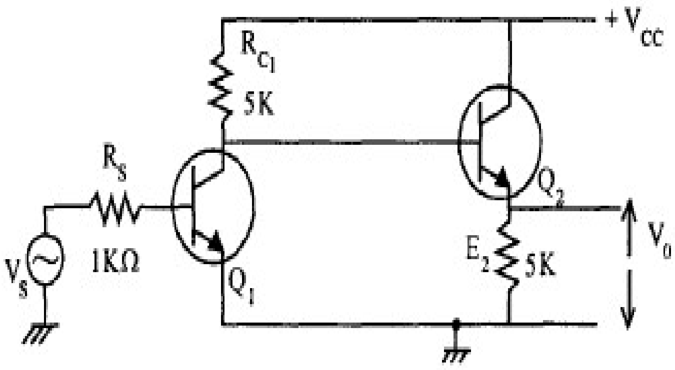
The overall gain of a multistage amplifier is the product of the gains of the individual stage (ignoring potential loading effects):

Gain (A) = A1 * A2 * A3 * A4 * …… *An.

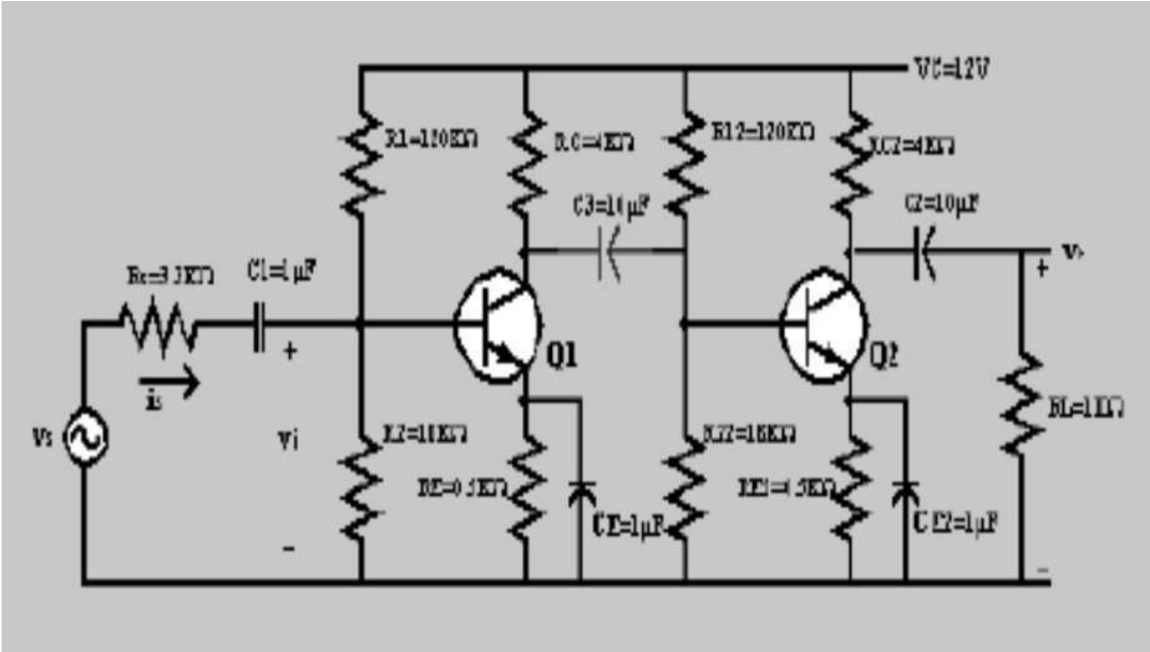
Alternately, if the gain of each amplifier stage is expressed in decibels (dB), the total gain is the sum of the gains of the individual stages

Gain in dB (A) = A1 + A2 + A3 + A4 + …… + An.

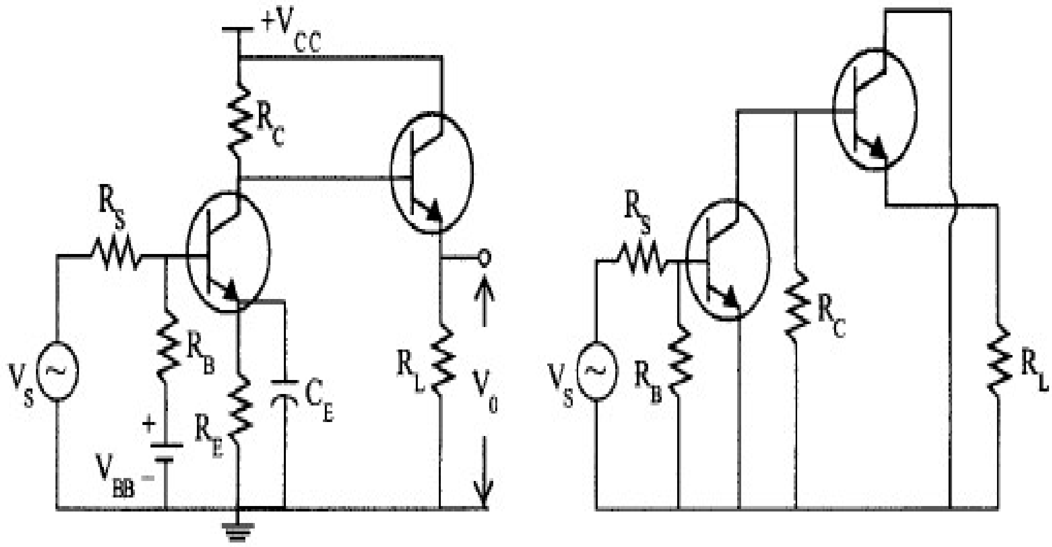
The Two Stage Cascaded Amplifier Circuit:



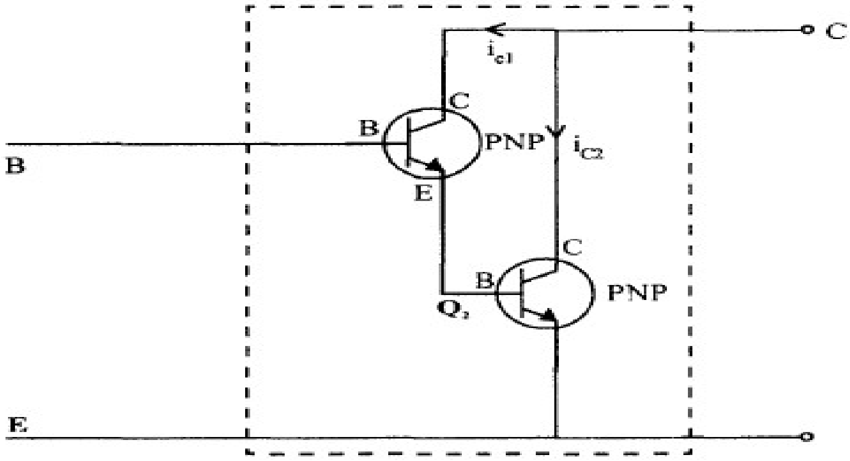
Two stage RC coupled amplifier:



CE - CC Amplifiers:



The Darlington Pair:



Current gain

$$A_I = \frac{I_c}{I_{b_1}} \cong (h_{fe})^2$$

Input resistance

$$R_i \simeq \frac{(1+h_{fe})^2 R_e}{1 + h_{oe} h_{fe} R_e}$$

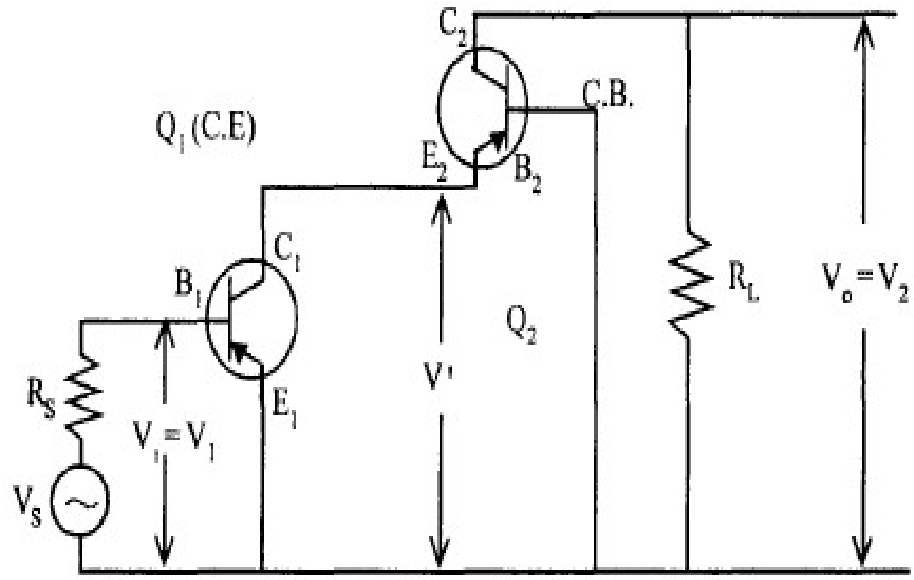
Voltage gain

$$A_v \cong \left(1 - \frac{h_{ie}}{Ri_2}\right)$$

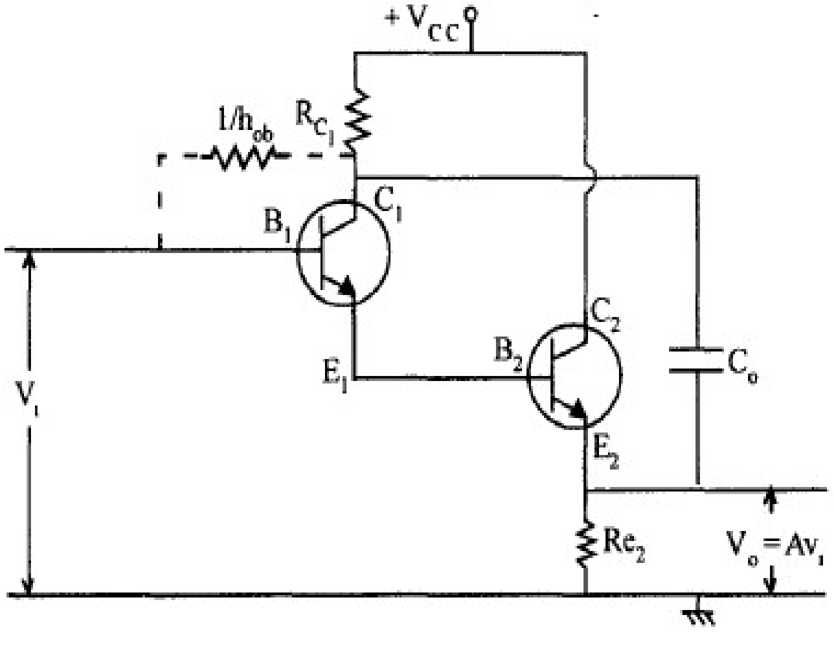
Output resistance

$$R_{o2} = \frac{R_s + h_{ie}}{(1+h_{fe})^2} + \frac{h_{ie}}{1+h_{fe}}$$

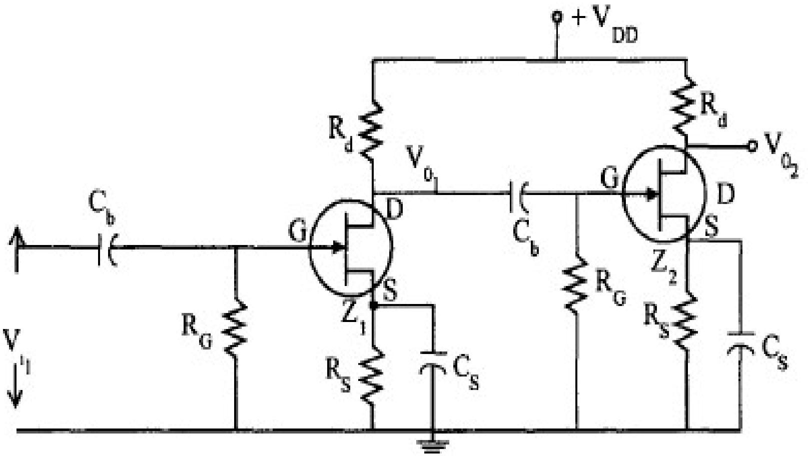
The CASCODE Transistor Configuration:



Boot-strap emitter follower:

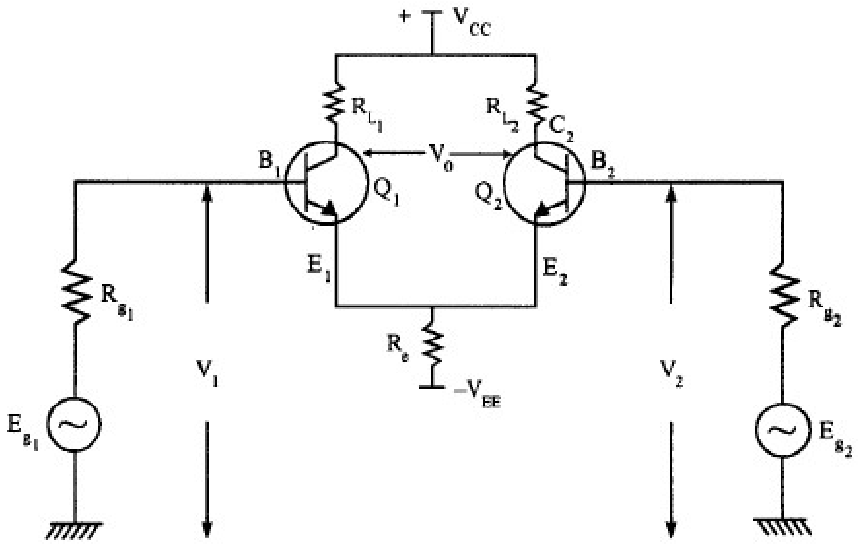


Two Stage RC Coupled JFET amplifier (in Common Source (CS) configuration):

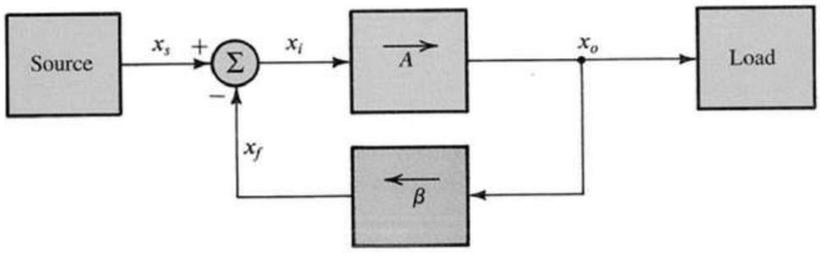


Circuit for Differential Amplifier

In the previous D.C amplifier viz., C.B, C.C and C.E, the output is measured with respect to ground. But in difference amplifier, the output is proportional to the difference of the inputs. So Vo is not measured w.r.t ground but w.r.t to the output of one transistor Q_1 or output of the other transistor Q_2'.



FEEDBACK AMPLIFIER:



- Signal-flow diagram of a feedback amplifier
- Open-loop gain: A
- Feedback factor:
- Loop gain: A
- Amount of feedback: 1 + A
- Gain of the feedback amplifier (closed-loop gain):

Negative feedback:

- The feedback signal xf is subtracted from the source signal xs
- Negative feedback reduces the signal that appears at the input of the basic amplifier
- The gain of the feedback amplifier Af is smaller than open-loop gain A by a factor of (1+A)
- The loop gain A is typically large (A >>1):
- The gain of the feedback amplifier (closed-loop gain)
- The closed-loop gain is almost entirely determined by the feedback network better accuracy of Af.
- xf = xs(A)/(1+A) xs error signal xi = xs – xf

For Example, The feedback amplifier is based on an opamp with infinite input resistance and zero output resistance

- Find an expression for the feedback factor.
- Find the condition under which the closed-loop gain Af is almost entirely determined by the feedback network.
- If the open-loop gain A = 10000 V/V, find R2/R1 to obtain a closed-loop gain Af of 10 V/V.
- What is the amount of feedback in decibel?
- If Vs = 1 V, find Vo, Vf and Vi.

➢ If A decreases by 20%, what is the corresponding decrease in Af ?

Some Properties of Negative Feedback

Gain desensitivity:

➢ The negative reduces the change in the closed-loop gain due to open-loop gain variation

$$dA_f = \frac{dA}{(1+A\beta)^2} \rightarrow \frac{dA_f}{A_f} = \frac{1}{1+A\beta}\frac{dA}{A}$$

➢ Desensitivity factor: $1+A\beta$

The Four Basic Feedback Topologies:

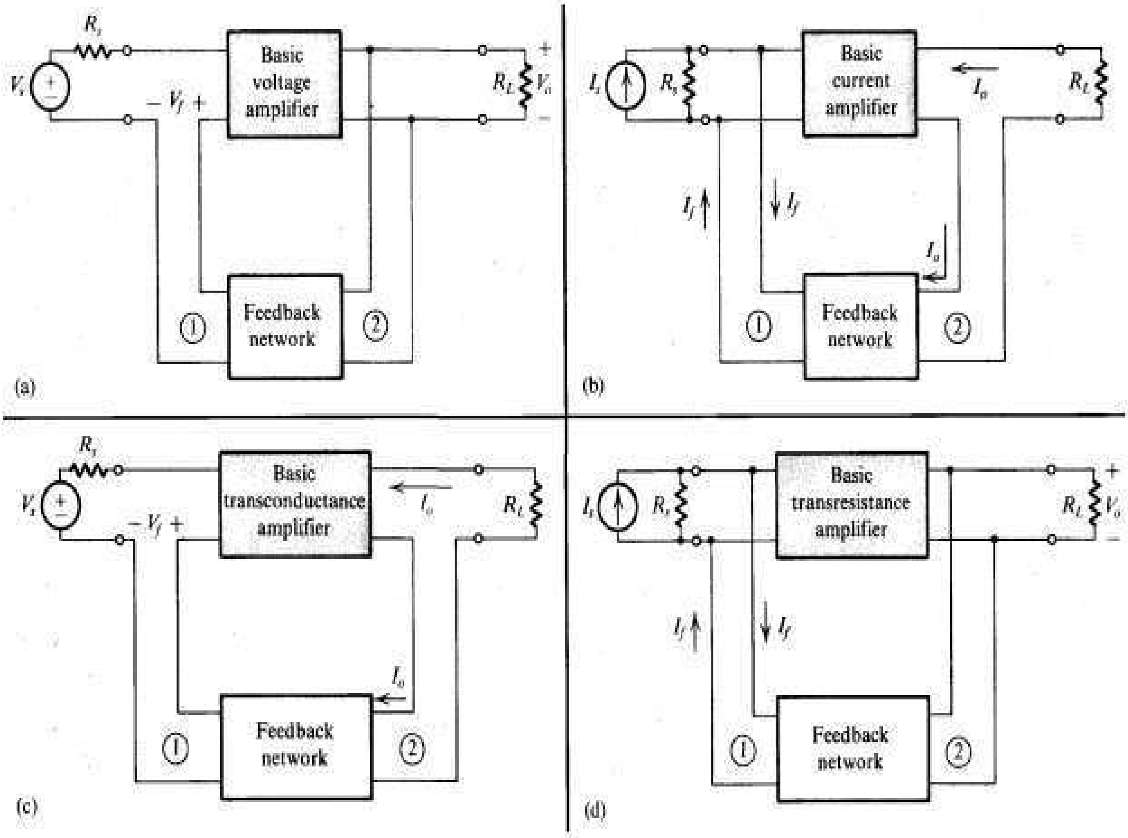
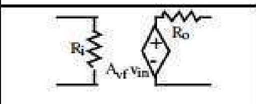
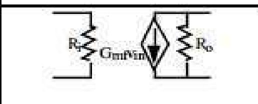
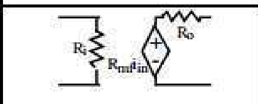
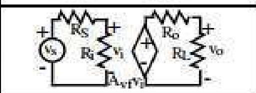
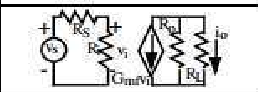
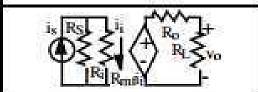
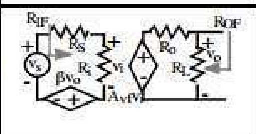
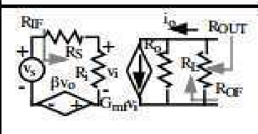
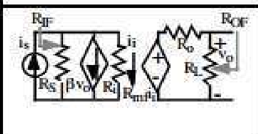
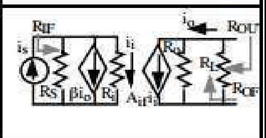


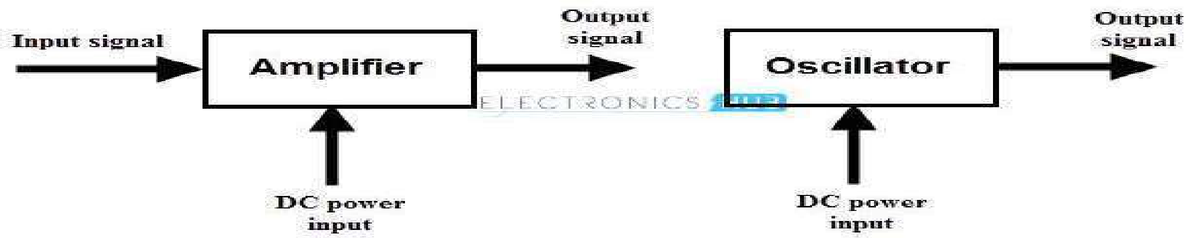
Fig. The four basic feedback topologies: (a) voltage-sampling series-mixing (series-shunt) topology; (b) current-sampling shunt-mixing (shunt-series) topology; (c) current-sampling series-mixing (series-series) topology; (d) voltage-sampling shunt-mixing (shunt-shunt) topology.

Summary of the Important Relationships of Open-loop and Closed-loop Feedback Amplifiers.

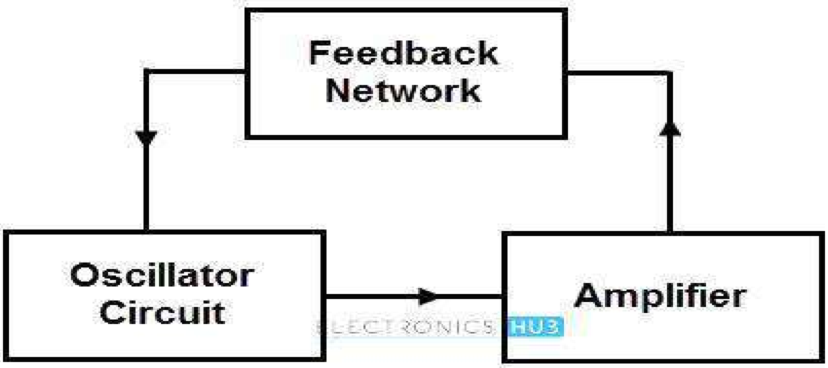
Quantity	Voltage Amplifier	Transconductance Amplifier	Transresistance Amplifier	Current Amplifier
Input-output variable	Voltage-voltage	Voltage-current	Current-voltage	Current-current
Small Signal Model				
Small Signal Amplifier with Source & Load				
Ideal R_S	$R_S = 0$ or $R_S << R_i$	$R_S = 0$ or $R_S << R_i$	$R_S = \infty$ or $R_S >> R_i$	$R_S = \infty$ or $R_S >> R_i$
Ideal R_L	$R_L = \infty$ or $R_L >> R_o$	$R_L = 0$ or $R_L << R_o$	$R_L = \infty$ or $R_L >> R_o$	$R_L = 0$ or $R_L << R_o$
Overall Forward Gain	$A_V = \frac{R_iR_LA_{vf}}{(R_S+R_i)(R_L+R_o)}$	$G_M = \frac{R_iR_oG_{mf}}{(R_S+Ri)(R_L+R_o)}$	$R_M = \frac{R_SR_LR_{mf}}{(R_S+Ri)(R_L+R_o)}$	$A_I = \frac{R_SR_oA_{if}}{(R_S+Ri)(R_L+R_o)}$
Feedback Topology	Series-shunt	Series-series	Shunt-shunt	Shunt-series
Ideal β, finite R_S and R_L Feedback Small Signal Models				
Closed-Loop Gain (Ideal R_S and R_L)	$A_{vF} = \frac{A_{vf}}{(1+A_{vf}\beta_v)}$	$G_{mF} = \frac{G_{mf}}{(1+G_{mf}\beta_g)}$	$R_{mF} = \frac{R_{mf}}{(1+R_{mf}\beta_r)}$	$A_{iF} = \frac{A_{if}}{(1+A_{if}\beta_i)}$
Closed-Loop Input Resistance (Ideal R_S and R_L)	$R_{iF} = R_i(1 + A_{vf}\beta_v)$	$R_{iF} = R_i(1 + G_{mf}\beta_g)$	$R_{iF} = \frac{R_i}{1 + R_{mf}\beta_r}$	$R_{iF} = \frac{R_i}{1 + A_{if}\beta_i}$
Closed-Loop Output Resistance (Ideal R_S and R_L)	$R_{oF} = \frac{R_o}{1 + A_{vf}\beta_v}$	$R_{oF} = R_o(1 + R_{mf}\beta_g)$	$R_{oF} = \frac{R_o}{1 + R_{mf}\beta_r}$	$R_{oF} = R_o(1 + A_{if}\beta_i)$
Closed-Loop Gain	$A_{VF} = \frac{A_V}{(1+A_V\beta_v)}$	$G_{MF} = \frac{G_M}{(1+G_M\beta_g)}$	$R_{MF} = \frac{R_M}{(1+R_M\beta_r)}$	$A_{IF} = \frac{A_I}{(1+A_I\beta_i)}$
Closed-Loop Input Resistance	$R_{IF} = (R_i+R_S)(1+A_V\beta_v)$	$R_{IF} = (R_i+R_S)(1 + G_M\beta_g)$	$R_{IF} = \frac{\frac{R_iR_S}{R_i+R_S}}{1 + R_M\beta_r}$	$R_{IF} = \frac{\frac{R_iR_S}{R_i+R_S}}{1 + A_I\beta_i}$
Closed-Loop Output Resistance	$R_{OF} = \frac{\frac{R_oR_L}{R_o+R_L}}{1 + A_V\beta_v}$	$R_{OF} = (R_o+R_L)(1+G_M\beta_g)$	$R_{OF} = \frac{\frac{R_oR_L}{R_o+R_L}}{1 + R_M\beta_r}$	$R_{OF} = (R_o+R_L)(1+A_I\beta_i)$
Output Resistance of Series Output Fb. Ckt	$R_{OUT} = R_{OF}$	$R_{OUT} = \frac{R_L}{R_{OF}}(R_{OF}-R_L)$	$R_{OUT} = R_{OF}$	$R_{OUT} = \frac{R_L}{R_{OF}}(R_{OF}-R_L)$

Oscillators

An electronic circuit used to generate the output signal with constant amplitude and constant desired frequency is called as an oscillator. It is also called as a waveform generator which incorporates both active and passive elements. The primary function of an oscillator is to convert DC power into a periodic signal or AC signal at a very high frequency. An oscillator does not require any external input signal to produce sinusoidal or other repetitive waveforms of desired magnitude and frequency at the output and even without use of any mechanical moving parts.



In case of amplifiers, the energy conversion starts as long as the input signal is present at the input, i.e., amplifier produces an output signal whose frequency or waveform is similar to the input signal but magnitude or power level is generally high. The output signal will be absent if there is no input signal at the input. In contrast, to start or maintain the conversion process an oscillator does not require any input signal as shown figure. As long as the DC power is connected to the oscillator circuit, it keeps on producing an output signal with frequency decided by components in it.

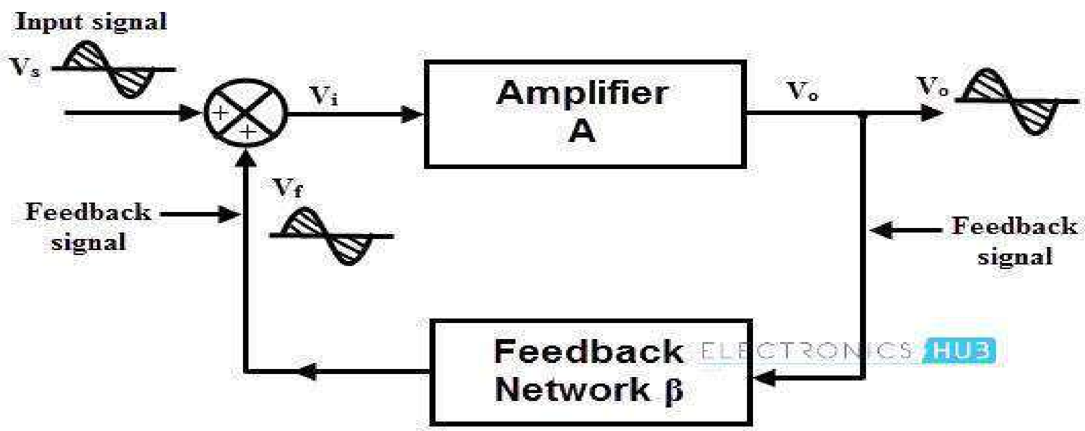


The above figure shows the block diagram of an oscillator. An oscillator circuit uses a vacuum tube or a transistor to generate an AC output. The output oscillations are produced by the tank circuit components either as R and C or L and C. For continuously generating output without the requirement of any input from preceding stage, a feedback circuit is used.

From the above block diagram, oscillator circuit produces oscillations that are further amplified by the amplifier. A feedback network gets a portion of the amplifier output and feeds it the oscillator circuit in correct phase and magnitude. Therefore, un damped electrical oscillations are produced , by continuously supplying losses that occur in the tank circuit.

Oscillators Theory

The main statement of the oscillator is that the oscillation is achieved through positive feedback which generates the output signal without input signal. Also, the voltage gain of the amplifier increases with the increase in the amount of positive feedback. In order to understand this concept, let us consider a non-inverting amplifier with a voltage gain 'A' and a positive feedback network with feedback gain of β as shown in figure.



Let us assume that a sinusoidal input signal Vs is applied at the input. Since the amplifier is non-inverting, the output signal Vo is in phase with Vs. A feedback network feeds the part of Vo to the input and the amount Vo fed back depends on the feedback network gain β. No phase shift is introduced by this feedback network and hence the feedback voltage or signal Vf is in phase with Vs. A feedback is said to be positive when the phase of the feedback signal is same as that of the input signal. The open loop gain 'A' of the amplifier is the ratio of output voltage to the input voltage, i.e.,

$$A = Vo/Vi$$

By considering the effect of feedback, the ratio of net output voltage Vo and input supply Vs called as a closed loop gain Af (gain with feedback).

$$Af = Vo/Vs$$

Since the feedback is positive, the input to the amplifier is generated by adding Vf to the Vs,

$$Vi = Vs + Vf$$

Depends on the feedback gain β, the value of the feedback voltage is varied, i.e.,

$$Vf = \beta\ Vo$$

Substituting in the above equation,

$$Vi = Vs + \beta\ Vo$$

$$Vs = Vi - \beta\ Vo$$

Then the gain becomes

$$Af = Vo/\ (Vi - \beta\ Vo)$$

By dividing both numerator and denominator by Vi, we get

$$Af = (Vo\ /\ Vi)/\ (1 - \beta)\ (Vo\ /\ Vi)$$

$$Af = A/\ (1\text{-}\ A\ \beta)\ \text{since}\ A = Vo/Vi$$

Where Aβ is the loop gain and if Aβ = 1, then Af becomes infinity. From the above expression, it is clear that even without external input (Vs = 0), the circuit can generate the output just by feeding a part of the output as its own input. And also closed loop gain increases with increase in amount of positive feedback gain. The oscillation rate or frequency depends on amplifier or feedback network or both.

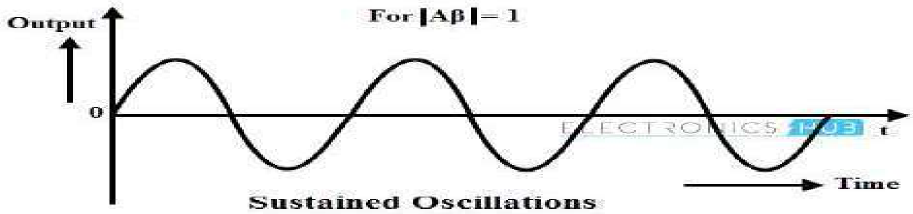
Barkhausen Criterion or Conditions for Oscillation:

The circuit will oscillate when two conditions, called as Barkhausen's criteria are met. These two conditions are

1. The loop gain must be unity or greater
2. The feedback signal feeding back at the input must be phase shifted by 360 degrees (which is same as zero degrees).

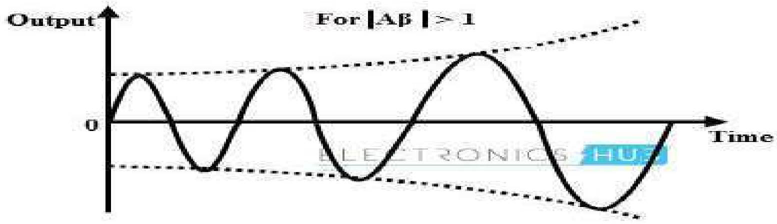
Nature of Oscillations

Sustained Oscillations: Sustained oscillations are nothing but oscillations which oscillate with constant amplitude and frequency. Based on the Barkhausen criterion sustained oscillations are produced when the magnitude of loop gain or modulus of A β is equal to one and total phase shift around the loop is 0 degrees or 360 ensuring positive feedback.



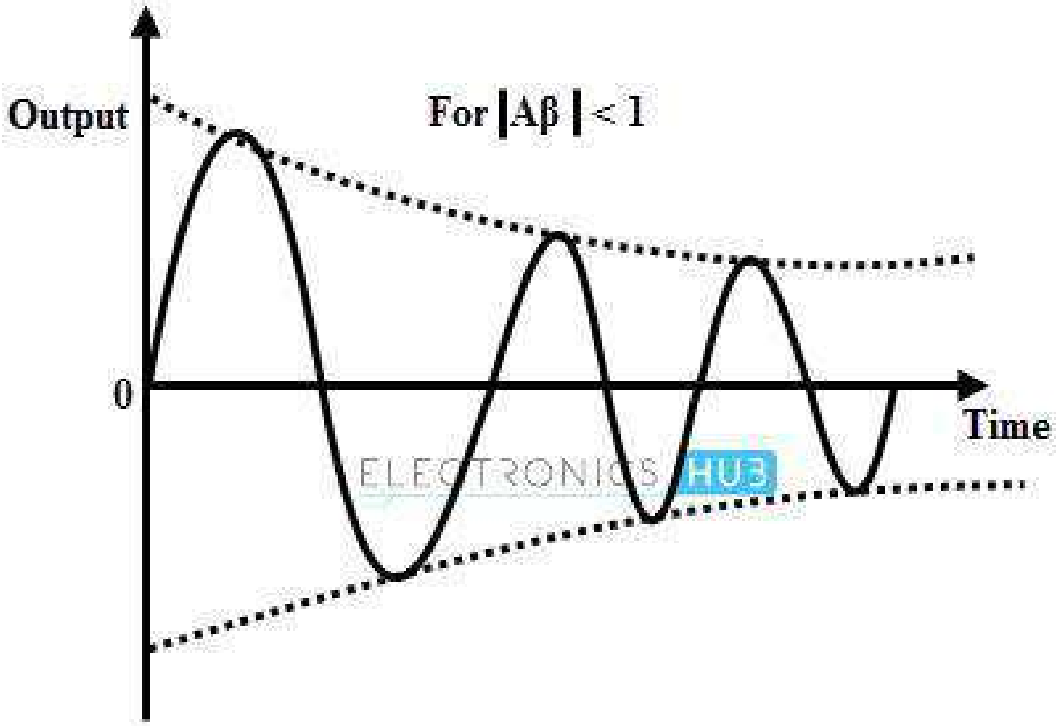
Growing Type of Oscillations:

If modulus of A β or the magnitude of loop gain is greater than unity and total phase shift around the loop is 0 or 360 degrees, then the oscillations produced by the oscillator are of growing type. The below figure shows the oscillator output with increasing amplitude of oscillations.



Exponentially Decaying Oscillations:

If modulus of A β or the magnitude of loop gain is less than unity and total phase shift around the loop is 0 or 360 degrees, then the amplitude of the oscillations decreases exponentially and finally these oscillations will cease.



Classification of oscillators

The oscillators are classified into several types based on various factors like nature of waveform, range of frequency, the parameters used, etc. The following is a broad classification of oscillators.

According to the Waveform Generated

Based on the output waveform, oscillators are classified as sinusoidal oscillators and non-sinusoidal oscillators.

Sinusoidal Oscillators: This type of oscillator generates sinusoidal current or voltages.

Non-sinusoidal Oscillators: This type of oscillators generates output, which has triangular, square, rectangle, saw tooth waveform or is of pulse shape.

According to the Circuit Components: Depends on the usage of components in the circuit, oscillators are classified into LC, RC and crystal oscillators. The oscillator using inductor and capacitor components is called as LC oscillator while the oscillator using resistance and capacitor components is called as RC oscillators. Also, crystal is used in some oscillators which are called as crystal oscillators.

According to the Frequency Generated: Oscillators can be used to produce the waveforms at frequencies ranging from low to very high levels. Low frequency or audio frequency oscillators are used to generate the oscillations at a range of 20 Hz to 100-200 KHz which is an audio frequency range.

High frequency or radio frequency oscillators are used at the frequencies more than 200-300 KHz up to gigahertz. LC oscillators are used at high frequency range, whereas RC oscillators are used at low frequency range.

Based on the Usage of Feedback

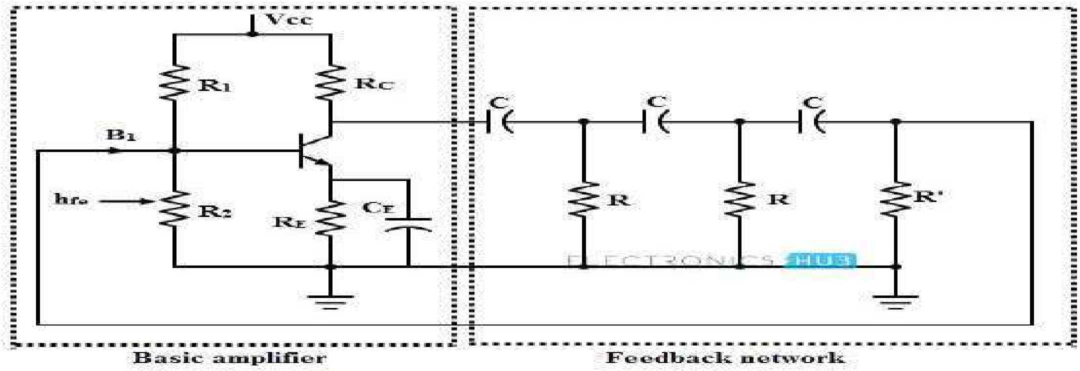
The oscillators consisting of feedback network to satisfy the required conditions of the oscillations are called as feedback oscillators. Whereas the oscillators with absence of feedback network are called as non-feedback type of oscillators.

The UJT relaxation oscillator is the example of non-feedback oscillator which uses a negative resistance region of the characteristics of the device.

Some of the sinusoidal oscillators under above categories are

- Tuned-circuits or LC feedback oscillators such as Hartley, Colpitts and Clapp etc.
- RC phase-shift oscillators such as Wein-bridge oscillator.
- Negative-resistance oscillators such as tunnel diode oscillator.
- Crystal oscillators such as Pierce oscillator.
- Heterodyne or beat-frequency oscillator (BFO).

RC Phase-shift Oscillator:



$$f = 1/ (2 \pi R C \sqrt{((4Rc / R) + 6)})$$

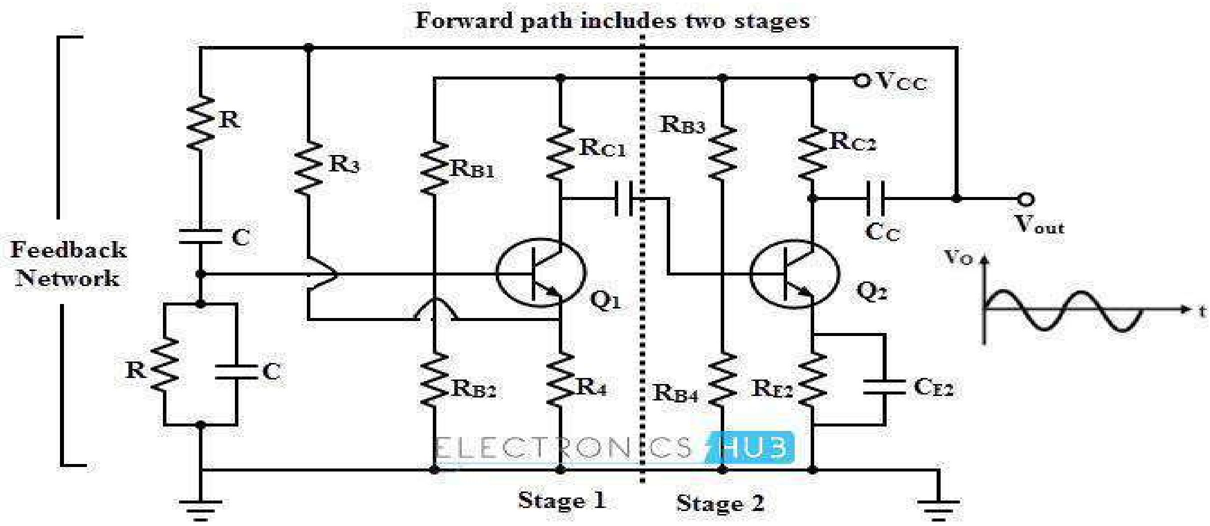
If Rc/R << 1, then

$$f= 1/ (2 \pi R C \sqrt{6})$$

The condition of sustained oscillations,

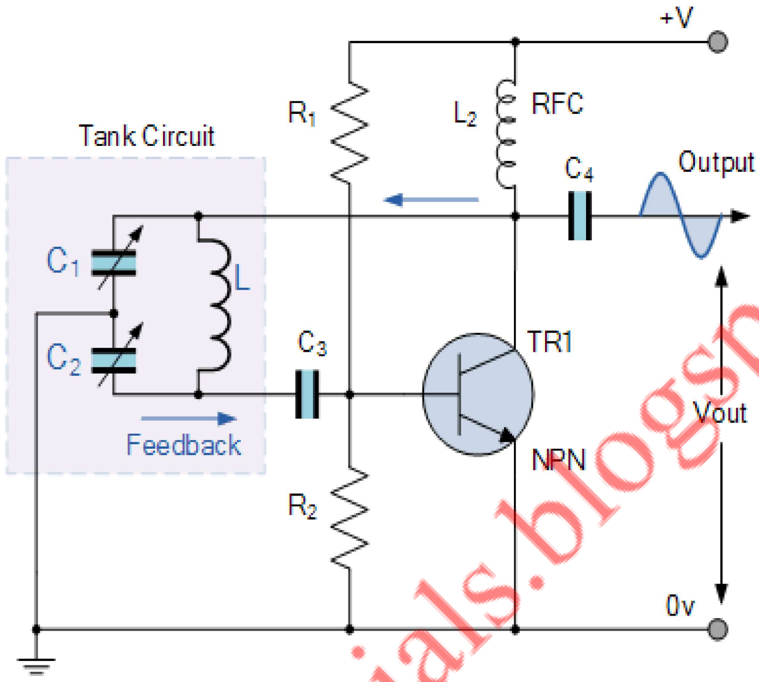
$$hfe\ (min) = (4\ Rc/ R) + 23 + (29\ R/Rc)$$

Wien Bridge Oscillator:



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

Colpitts Oscillator:



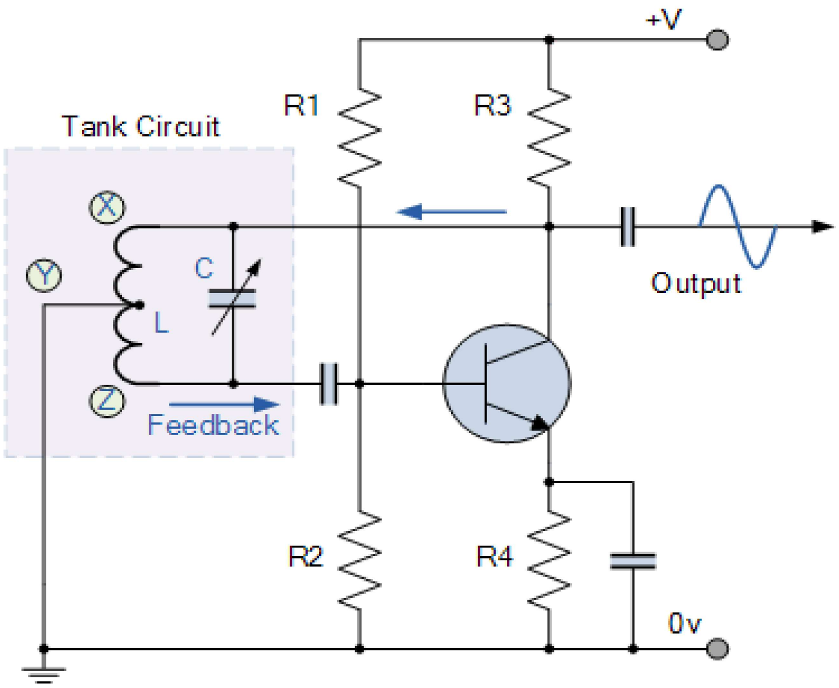
The frequency of oscillations for a Colpitts oscillator is determined by the resonant frequency of the LC tank circuit and is given as:

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

where C_T is the capacitance of C1 and C2 connected in series and is given as:

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} \quad \text{or} \quad C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

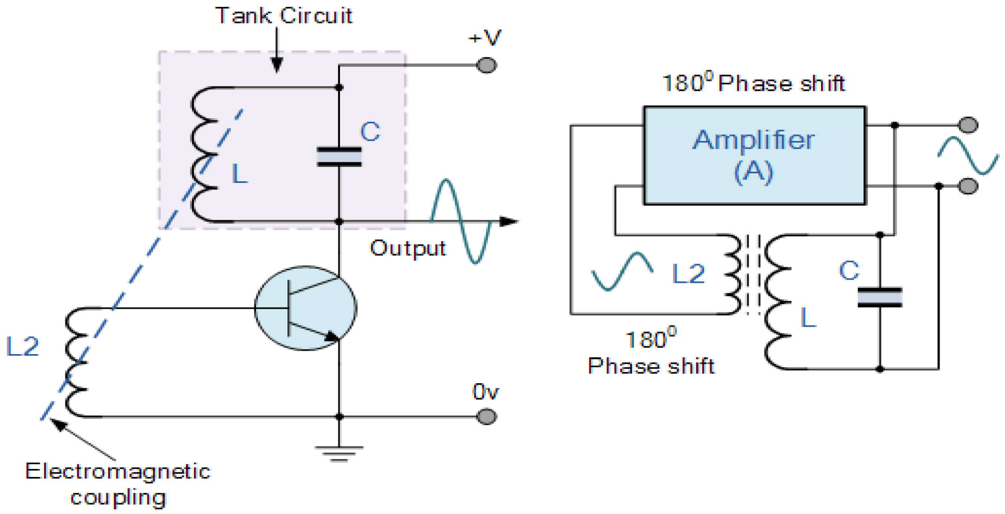
Hartley Oscillator:



$$f = \frac{1}{2\pi\sqrt{L_T C}}$$

where: $L_T = L_1 + L_2 + 2M$

Basic Transistor LC Oscillator Circuit:



An inductance of 200mH and a capacitor of 10pF are connected together in parallel to create an LC oscillator tank circuit. Calculate the frequency of oscillation.

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{200mH \times 10pF}} = 112.5\text{ kHz}$$

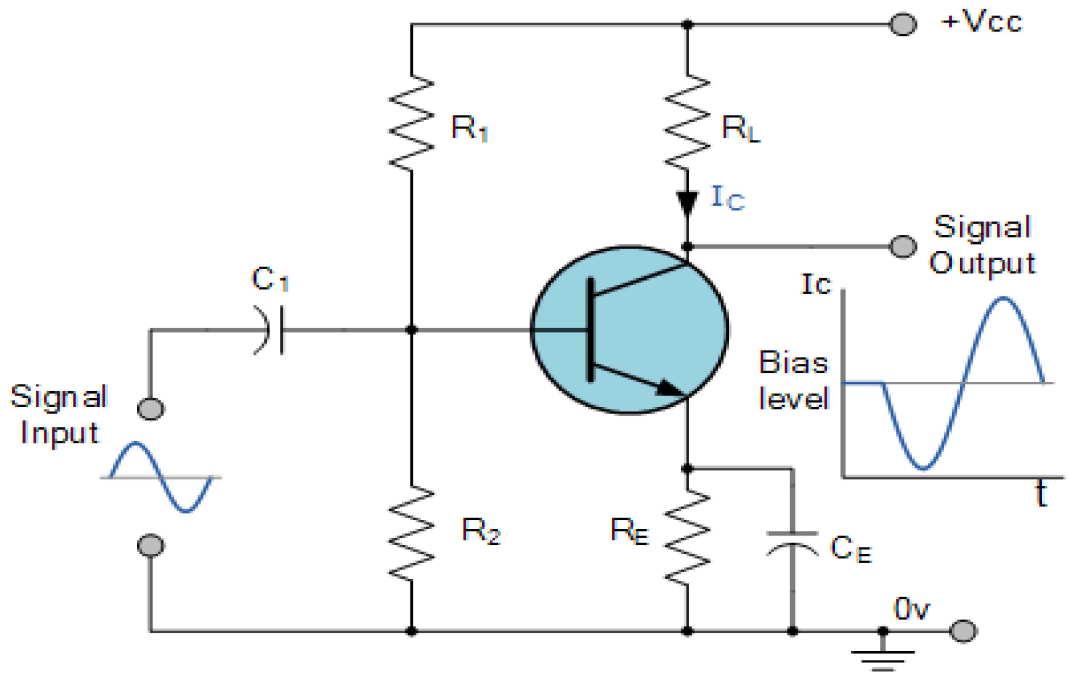
Power Amplifier:

Large input signals are used to obtain appreciable power output from amplifiers. But if the input signal is large in magnitude, the operating point is driven over a considerable portion of the output characteristic of the transistor (BJT). The transfer characteristic of a transistor which is a plot between the output current Ie and input voltage V BE is not linear. The transfer characteristic indicates the change in ic when Vb or IB is changed. For equal increments of VBE, increase in I_e will not be uniform since output characteristics are not linear (for equal increments of VBE, I_e will not increase by the same current). So the transfer characteristic is not linear. Hence because of this, when the magnitude of the input signal is very large, distortion is introduced in the output in large signal power amplifiers. To eliminate distortion in the output, push pull connection and negative feedback are employed.

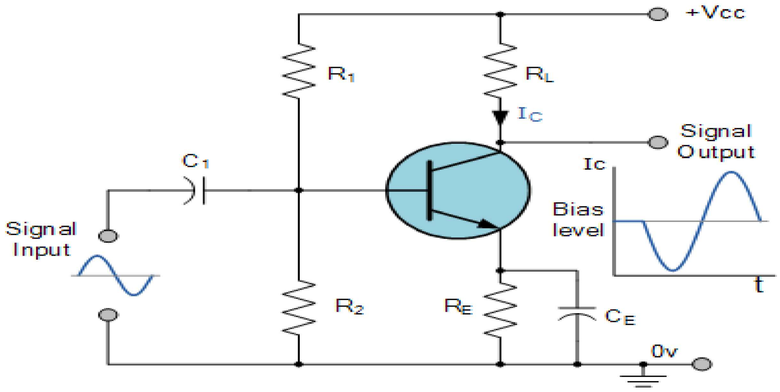
Class A Operation:

If the *Q point is placed near the centre a/the linear region a/the* dynamic curve, class A operation results. Because the transistor will conduct for the complete 360°, distortion is low for small signals and conversion efficiency is low.

Single Stage Amplifier Circuit



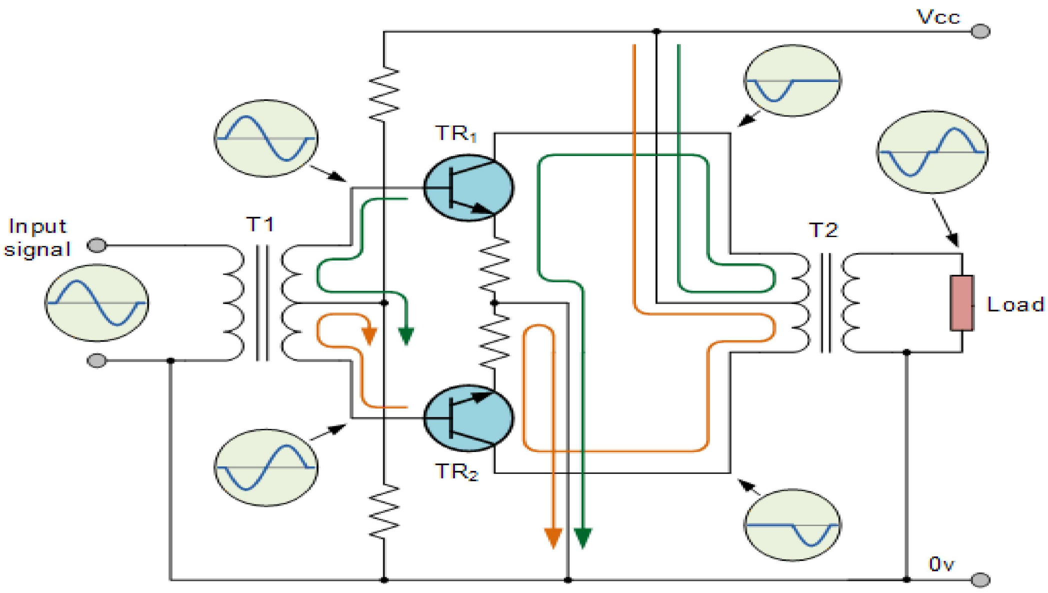
Single Stage Amplifier Circuit



Class B Operation:

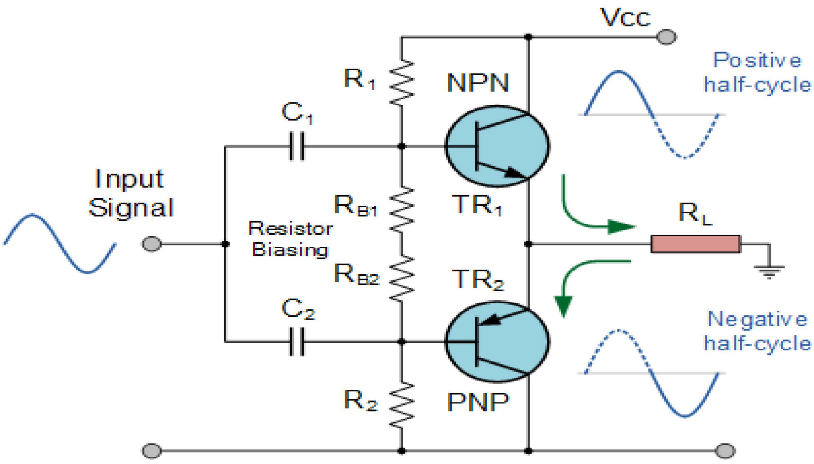
class B operation the Q point is set near cutoff. So output power will be more and conversion efficiency (ll) is more. Conduction is only for 180°, from 1t - 21t. Since the transistor Q point is beyond cutoff, the output is zero or the transistor will not conduct. Output power is more because the complete linear region is available for an operating signal excursion, resulting from one half of the input wave. The other half of input wave gives no output, because it drives the transistor below cutoff.

Class B Push-pull Transformer Amplifier Circuit

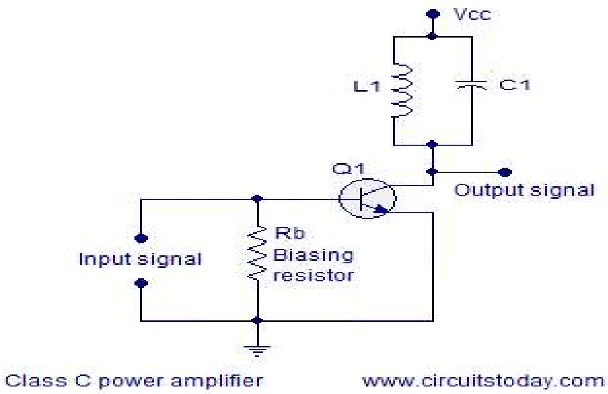


The circuit above shows a standard **Class B Amplifier** circuit

Complementary symmetry push pull amplifier



Class C Operation:



Here Q point is set well beyond cutoff and the device conducts for less than *1800.* The conversion efficiency (ll) can theoretically reach 100%. Distortion is very high. These are used in radio frequency circuits where resonant circuit may be used to filter the output waveform.

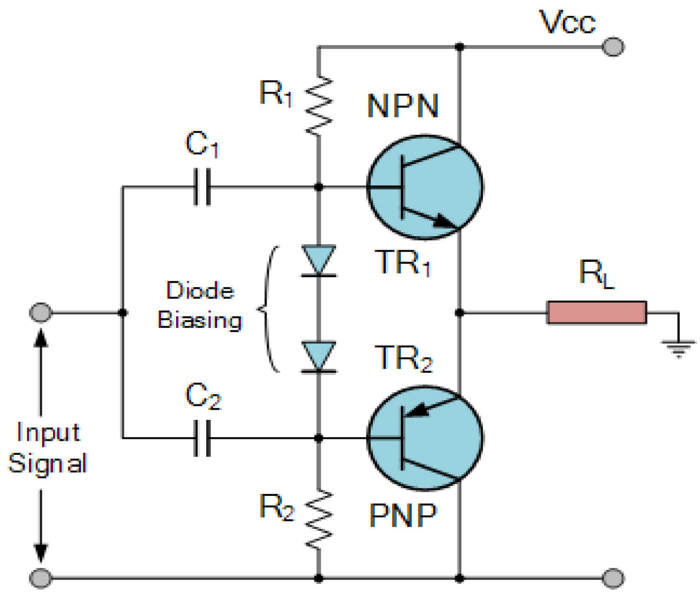
Class A and class B amplifiers are used in the audio frequency range. Class B and class C are used in Radio Frequency range where conversion efficiency is important.

Large Signal Amplifiers:

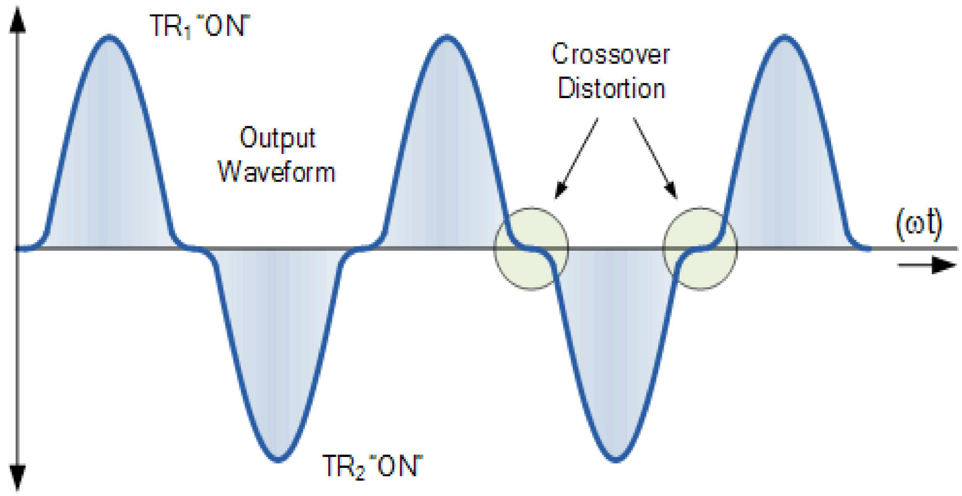
With respect to the input signal, the amplifier circuits are classified as

(i) Small signal amplifiers (ii) Large signal amplifiers

The Class AB Amplifier



Crossover Distortion Waveform



In order that there should be no distortion of the output waveform we must assume that each transistor starts conducting when its base to emitter voltage rises just above zero, but we know that this is not true because for silicon bipolar transistors the base voltage must reach at least 0.7v before the transistor starts to conduct thereby producing this flat spot. This crossover distortion effect also reduces the overall peak to peak value of the output waveform causing the maximum power output.

Tuned Amplifiers

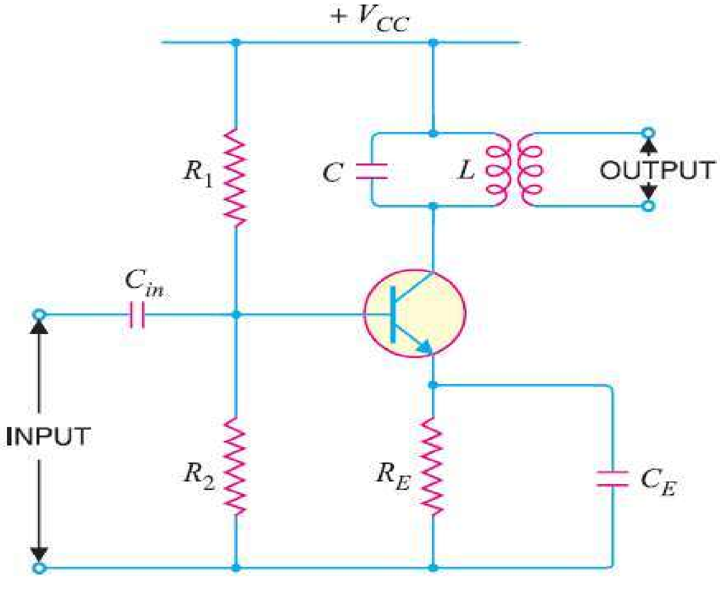
Most of the audio amplifiers we have discussed in the earlier chapters will also work at radio frequencies *i.e.* above 50 kHz. However, they suffer from two major drawbacks. First, they become less efficient at radio frequency. Secondly, such amplifiers have mostly resistive loads and consequently their gain is independent of signal frequency over a large bandwidth. In other words, 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.

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.

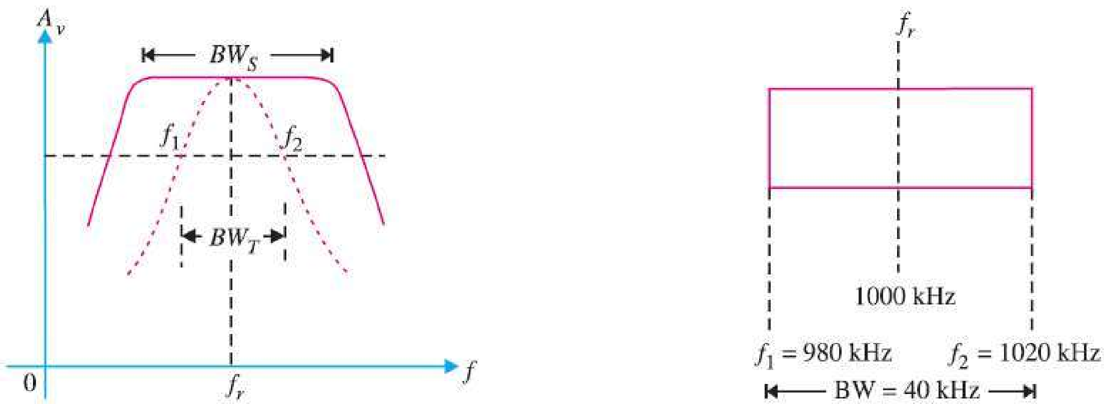
However, such amplifiers are not suitable for the amplification of audio frequencies as they are mixture of frequencies from 20 Hz to 20 kHz and not single. Tuned amplifiers are widely used in radio and television circuits where they are called upon to handle radio frequencies. Figure shows the circuit 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:

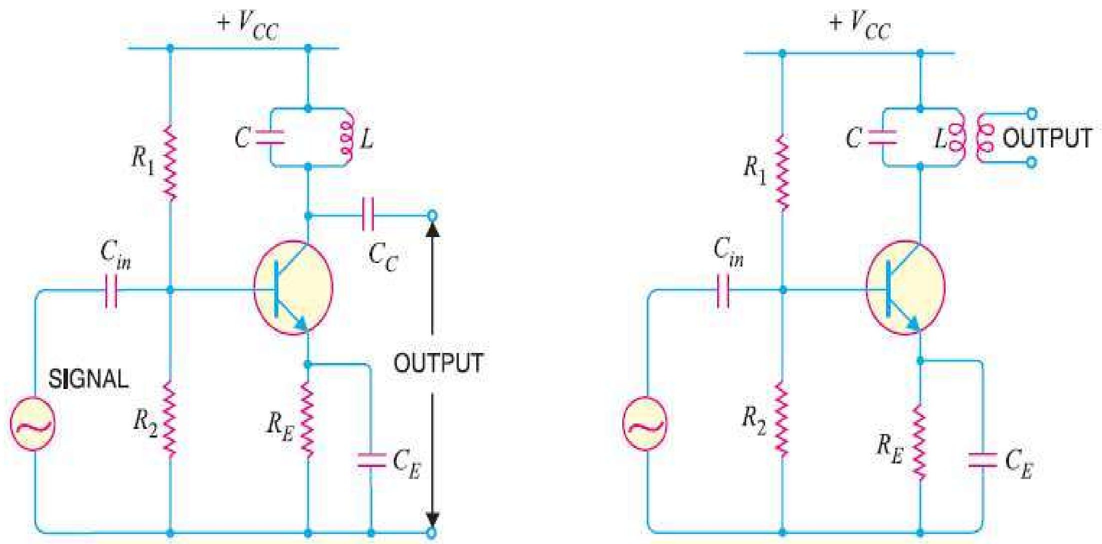
We have seen that amplifiers (*e.g.*, voltage amplifier, power amplifier *etc.*) provide the constant gain over a limited band of frequencies *i.e.*, from lower cut-off frequency *f*1 to upper cut-off frequency *f*2. Now bandwidth of the amplifier, $BW = f2 - f1$. The reader may wonder, then, what distinguishes a tuned amplifier from other mplifiers? The difference is that tuned amplifiers are designed to have specific, usually narrow bandwidth. This point is illustrated in in Fig. 15.2. 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.



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 *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.

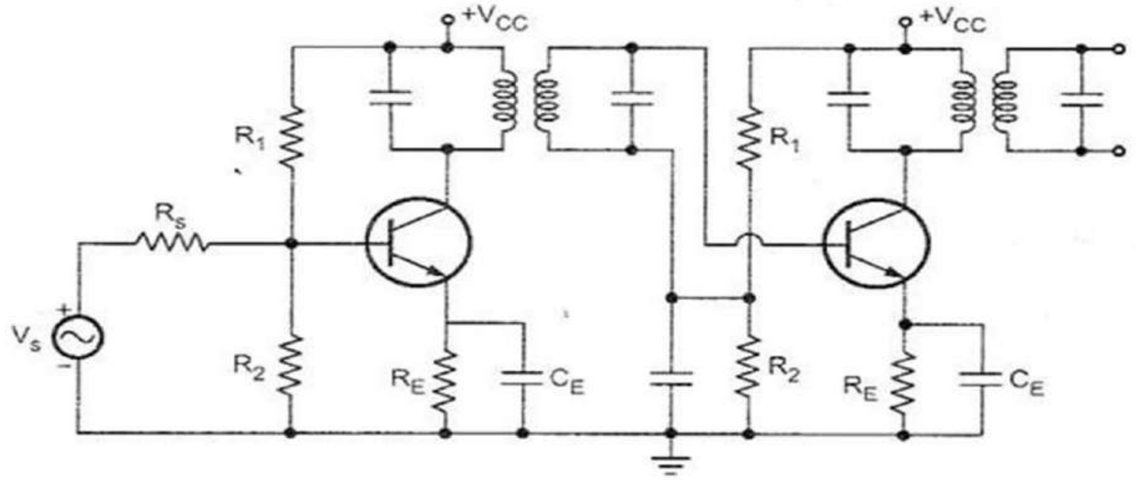
Single Tuned Amplifier

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* as shown in Fig. (*i*) or (*b*) by a secondary coil as shown in Fig. (*ii*).



DOUBLE TUNED AMPLIFIER:

Below figure shows the double tuned RF amplifier in CE configuration. Here, voltage developed across tuned circuit is coupled inductively to another tuned circuit. Both tuned circuits are tuned to the same frequency.



The double tuned circuit can provide a bandwidth of several percent of the resonant frequency and gives steep sides to the response curve.

STAGGER TUNED AMPLIFIER:

The double tuned amplifier gives greater 3dB bandwidth having steeper sides and flat top. But alignment of double tuned amplifier is difficult. To overcome this problem two single tuned cascaded amplifiers having certain bandwidth are taken and their resonant frequencies are so adjusted that they are separated by an amount equal to the bandwidth of each stage. Since resonant frequencies are displaced or staggered, they are known as stagger tuned amplifiers. The advantage of stagger tuned amplifier is to have better flat, wideband characteristics in contrast with very sharp, projective, narrow band characteristics of synchronously tuned circuits (tuned to same resonant frequencies). Fig. 3.23 shows the relationship of amplification characteristics of individual stages in a staggered pair to the overall amplification of the two stages.

Wide Band amplifiers/Large signal tuned amplifiers:

The output efficiency of an amplifier increases as the operation shifts from class A to class C through class AB and class B. as the output power of a radio transmitter is high and efficiency is prime concern, class B and class C amplifiers are used at the output stages in transmitter. The operation of class B and class C amplifiers are non-linear since the amplifying elements remain cut-off during a part of the input signal cycle. The non-linearity generates harmonics of the single frequency at the output of the amplifier. In the push-pull arrangement where the bandwidth requirement is no limited, these harmonics can be eliminated or reduced. When an narrow bandwidth is desired, a resonant circuit is employed in class B and class C tuned RF power amplifiers to eliminate the harmonics.

Class B tuned amplifier

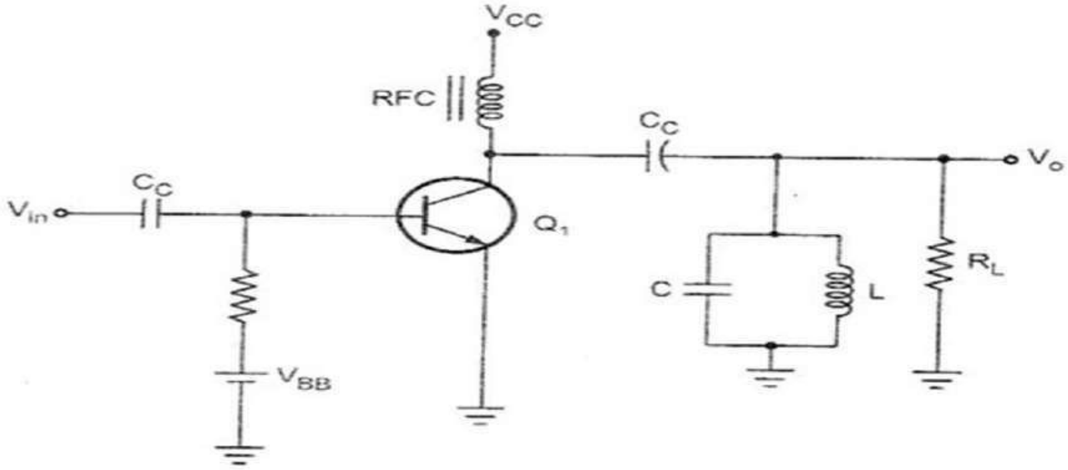


Fig. 3.25 Class B tuned amplifier