[C] TUNED AMPLIFIERS

13·16 NEED FOR TUNED AMPLIFIER

We have studied audio frequency amplifiers. They suffer from two major drawbacks. Firstly, they become less efficient at radio frequencies. Secondly, the gain is independent of signal frequency over a large bandwidth. Thus, the amplifier does not permit the selection of a particular frequency while rejecting all other frequencies. Sometimes, we require the selection of a desired frequency or a narrow band of frequencies for amplification. For example, when *rf* signals (modulated waves) from different broadcasting stations reach the receiving antenna, a weak signal is induced in it. To extract the original audio signal from the received signal, it is necessary to amplify it. This is achieved in radio-receiver with the help of a tuned amplifier. The tuned amplifier also performs another function of selecting the desired *rf* signal of a particular broadcasting station and rejecting the rest signals. Hence the tuned amplifier serves the following two purposes:

(i) Selection of the desired *rf* signal of a particular broadcasting station and rejecting all other signals

(ii) Amplification of the selected *rf* signal.

The tuned circuit consists of an inductance in parallel with a variable capacitor. The selection of a particular frequency is based on the phenomenon of resonance.

Classification of Tuned Amplifiers

Tuned amplifiers may be classified into two categories: (i) small signal tuned amplifiers and (ii) large signal tuned amplifiers. Small signal tuned amplifiers amplify small signals at radio frequencies. As power involved is small, these amplifiers are operated under class *A* operation. Hence, the distortion is negligibly small. On the other hand, large signal tuned amplifiers, amplify large signals at radio frequencies. As power involved is large, these amplifiers are operated under *B* or under *C* operation. Hence, distortion is large. But the tuned circuit itself eliminates most of the harmonic distortion. Here, we shall consider only small signal tuned amplifiers.

Small signal tuned amplifier may be a single tuned amplifier or a double tuned amplifier. In single tuned amplifier, one parallel tuned circuit is used as load impedance. In double tuned amplifier, two inductively coupled tuned circuits are used per stage and both the tuned circuits being tuned to the same frequency.

13·17 FEW FUNDAMENTALS ABOUT TUNED CIRCUITS

Parallel tuned circuit

A parallel tuned circuit is shown in fig. (13·32). It consists of an inductor and a capacitor connected in parallel with each other with respect to supply source. In practice, some resistance *R* is always present with the inductor. The value of *R* is negligibly small as compared to other impedances. It should be noted that $I_L = V_s/X_L$ and $I_C = V_s/X_C$ where, X_L and X_C are the impedances of inductor and capacitor respectively. Further, $I = I_L + I_C$. We know that the current in inductor lags V_s by 90° while the current in capacitor leads V_s by 90°. Thus, the two currents are out of phase with each other. When alternating voltage is applied across the parallel circuit, the frequency of oscillations will be the same as that of applied voltage.

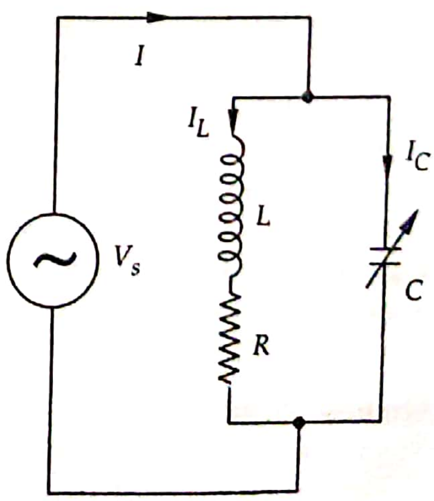

Fig. 13·32

However, at a particular frequency of applied voltage, the inductive reactance X_L equals the capacitive reactance X_C. Now, the circuit behaves as purely resistive circuit. The phenomenon is called as resonance. Thus, a circuit is said to be resonant when the frequency of applied voltage is equal to the natural frequency of the circuit. The resonant frequency is given by

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

So under resonance condition

(i) $f_r = 1/2\pi\sqrt{LC}$

(ii) $X_L = X_C$ and $I_L = I_C$

(iii) As I_L and I_C are in opposite phase, they cancel each other and the line current is zero (neglecting R of coil)

(iv) The impedance Z_r of the circuit is maximum. This is shown below

$$I = \frac{V_s}{Z_r} \quad \text{or} \quad Z_r = \frac{V_s}{I} = \frac{V_s}{0} = \infty$$

Impedance of tuned circuit

The impedance of tuned circuit is given by

$$\frac{1}{Z} = \frac{1}{R + j\omega L} + \frac{1}{(1/j\omega C)} = \frac{1}{R + j\omega L} + j\omega C$$

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

$$= \frac{R}{R^2 + \omega^2 L^2} + j\omega\left[C - \frac{L}{R^2 + \omega^2 L^2}\right] \quad ...(1)$$

At resonance, the reactive component of impedance is zero, *i.e.*,

$$j\omega\left[C - \frac{L}{R^2 + \omega^2 L^2}\right] = 0 \quad \text{where } \omega = \omega_r \quad ...(2)$$

Now $$\frac{1}{Z} = \frac{R}{R^2 + \omega_r^2 L^2} \approx \frac{R}{\omega_r^2 L^2}$$

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

$$\therefore \quad \frac{1}{Z} \approx \frac{L}{CR} \quad ...(3)$$

The variation of impedance with frequency is shown in fig. (13·33). It is clear from the figure that impedance is maximum at resonant frequency f_r. However, the impedance decreases rapidly on both sides of the resonant frequency. This characteristic of the parallel tuned circuit provides its selective properties. In this way a parallel resonant circuit select the resonant frequency and rejects all other frequencies.

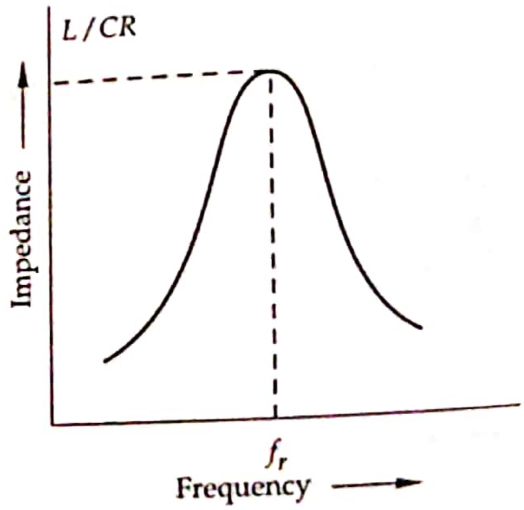

Fig. 13·33

Quality factor *Q*

To provide better selectivity, the curve of fig. (13·33) should be a *sharp resonance curve*. The sharp resonance curve means that impedance should fall very rapidly as the frequency is varied from resonant frequency. Figure (13·34) shows the impedance-frequency curves of a parallel tuned

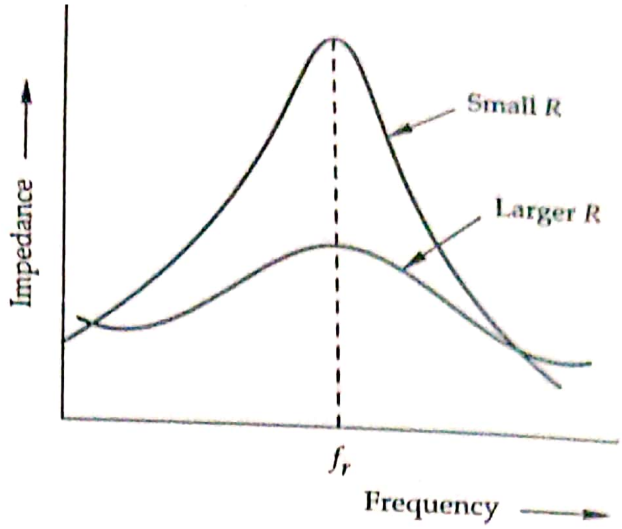

Fig. 13·34

circuit for different values of R. It is observed that smaller is the resistance of the coil, the more sharp is the resonance curve. The reason is that a small resistance consumes less power and draws a relatively small line current. *The ratio of inductive reactance of the coil at resonance to its resistance is known as quality factor*. This is expressed by Q and is given by

$$Q = \frac{X_L}{R} = \frac{\omega_r L}{R} = \frac{2\pi f_r L}{R} \qquad ...(4)$$

Figure (13 · 35) shows the variation of parallel circuit impedance as a function of frequency for different Q values.

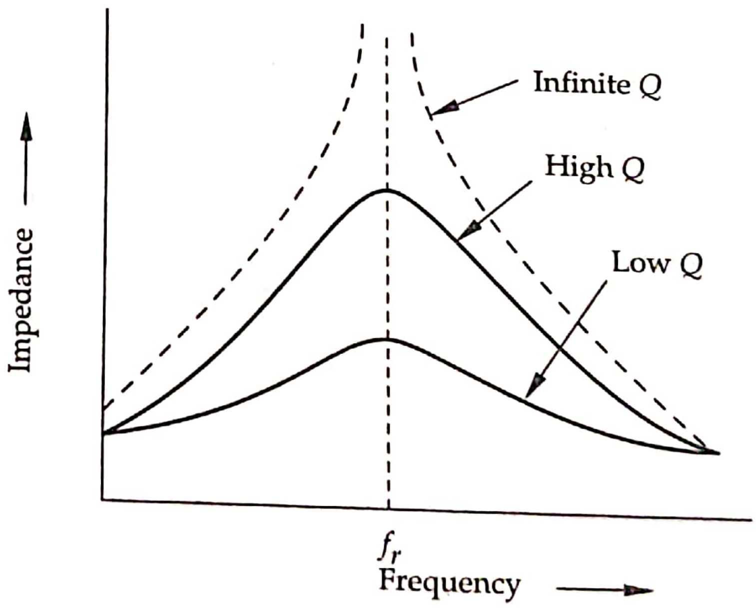

Fig. 13·25

Bandwidth

The range of frequencies at which the impedance of the tuned amplifier falls to 70·7% of the maximum impedance is called its bandwidth. This is shown in fig. (13 · 36). This is given as

$$\text{Bandwidth} = f_2 - f_1 = \frac{f_r}{Q} \qquad ...(5)$$

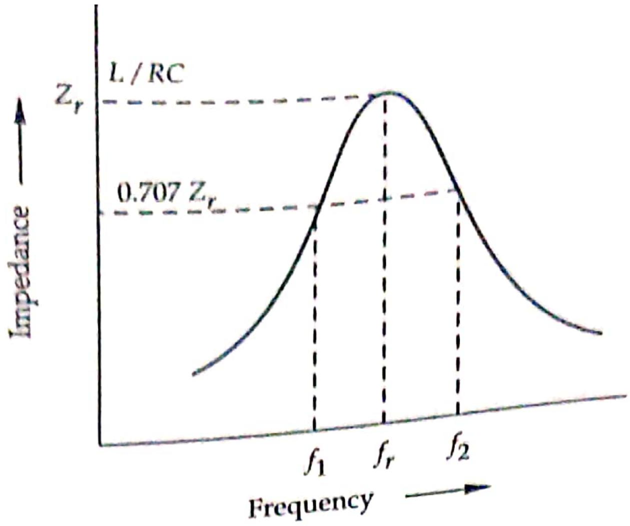

Fig. 13·36

The difference $f_1 - f_2$ is also called as *pass band* of the circuit. The frequencies below f_1 and above f_2 will not pass. So, the bandwidth gives the discriminating property of the resonant circuit. So, higher is the Q value, smaller is the bandwidth.

Advantages of tuned circuit

The tuned amplifier has the following advantages:

(i) ***High selectivity.*** The tuned amplifier has high selectivity *i.e.*, it is capable to select the desired frequency for amplification out of a number of frequencies simultaneously impressed on it.

(ii) ***Smaller collector supply voltage.*** The tuned circuit requires a small collector supply voltage because its resistance is negligibly small.

(iii) ***Small power gain.*** The tuned circuit employs reactive components *i.e.*, inductance L and capacitance C. Hence, the power loss in such a circuit is quite low.

When the tuned amplifier has so many advantages, the question is whether we can use a tuned circuit as load in low frequency amplifiers or not. The answer is that we can not use a tuned amplifier at low frequencies due to the following reasons:

(i) The resonant frequency of a parallel tuned circuit is given by

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

For low frequency amplification, L and C should be large. Using L and C large, the tuned circuit becomes bulky and expensive.

(ii) The low frequencies are not single. The audio frequencies are mixture of frequencies from 20 Hz to 20 KHz. All these frequencies should be equally amplified for proper production of the signal. Hence tuned amplifier cannot be used.

SOLVED EXAMPLES

Example 1. *A tuned circuit has resonant frequency of* 1500 kHz *and a bandwidth of* 15 kHz. *What is the value of its Q factor?*

We know that, Bandwidth $= f_r Q$

$$\therefore \quad Q = \frac{f_r}{\text{Bandwidth}} = \frac{1500\ \text{kHz}}{15\ \text{kHz}} = 100$$

Example 2. *A circuit is resonant at 455 kHz and has a 10 kHz bandwidth. The inductive reactance is 1255 Ω. What is the parallel impedance of the circuit at resonance?*

The quality Q is given by

$$Q = \frac{455 \text{ kHz}}{10 \text{ kHz}} = 45.5$$

We know that, $Q = \dfrac{X_L}{R} = \dfrac{1255}{R}$

$\therefore$ $$45.5 = \frac{1255}{R} \quad \text{or} \quad R = \frac{1255}{45.5} = 27.6\,\Omega$$

Further, $X_L = 2\pi f_r \cdot L$

or $$1255 = 2 \times 3.14 \times (455 \times 10^3) \times L$$

Solving it, we get, $L = 0.439 \times 10^{-3}$ henry

At resonance, $X_L = X_C$

$$\therefore \quad 1255 = \frac{1}{2\pi f_r C} = \frac{1}{2 \times 3.14 \times (455 \times 10^3)\, C}$$

or $$C = \frac{1}{2 \times 3.14 \times (455 \times 10^3) \times 1255} = 278.7 \times 10^{-12} \text{ F}$$

The circuit impedance at resonance is given by

$$Z = \frac{L}{CR} = \frac{0.439 \times 10^{-3}}{(278.7 \times 10^{-12}) \times 27.6} = 57 \times 10^3\,\Omega = 57 \text{ k}\Omega$$

13·18 SINGLE TUNED AMPLIFIER

Circuit arrangement. Figure (13 · 37) shows the circuit of a single tuned amplifier. In fig. (13 · 37), the output is taken with the help of capacitive coupling whereas in fig. (13 · 38), the output is obtained by inductive coupling. The signal to be amplified is applied between base and emitter. R_1, R_2, and R_e fix up and stabilize the operating point. C_e is the bypass capacitor. A tuned circuit consisting of inductance L and capacitance C acts as collector load. C is generally variable so that

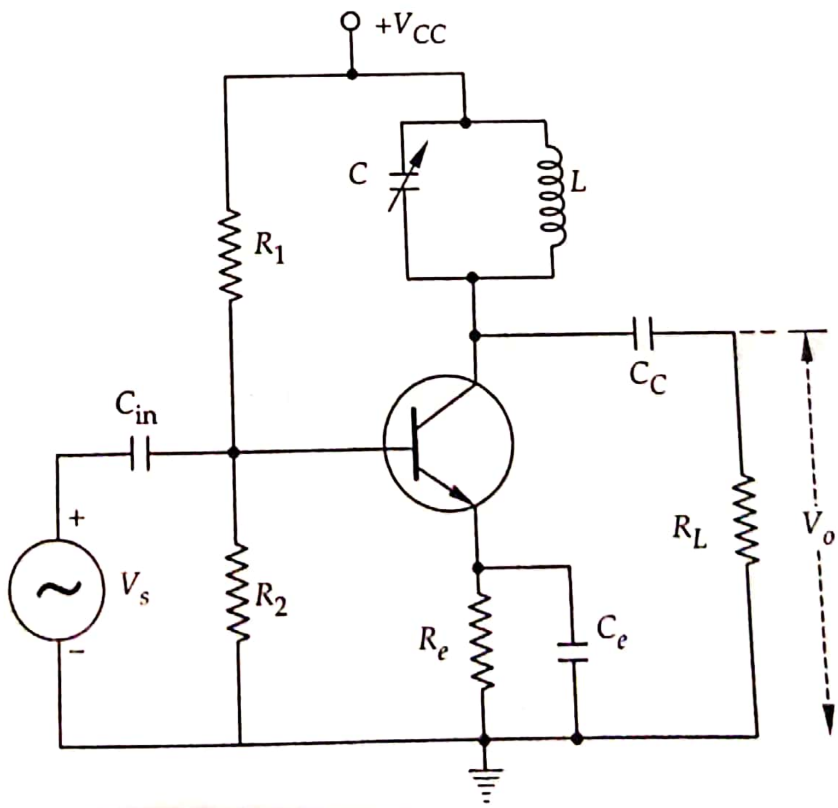

Fig. 13·37 Capacitively coupled amplifier

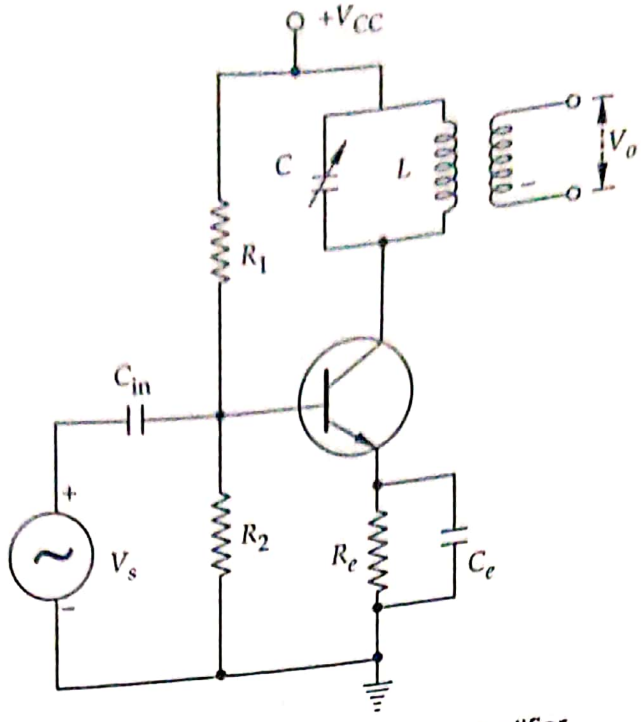

Fig. 13·38 Inductively coupled amplifier

the resonant frequency of the circuit may be adjusted. We can also use a variable inductor. Thus the values of capacitance and inductance of the tuned circuit are adjusted in such a way that its resonant frequency is equal to the frequency of the applied signal to be amplified.

Circuit operation

The high frequency signal to be amplified is applied between base and collector. The value of C of tuned circuit is changed such that the resonant frequency becomes equal to the frequency of the signal. At resonance frequency, the tuned circuit offers very high impedance to the signal frequency and thus large output appears across it. If the signal is complex (consists of many frequencies), then the frequency corresponding to resonant frequency will be amplified. Other frequencies will be rejected by the tuned circuit. So, the tuned amplifier selects and amplifies the desired frequency.

Voltage gain and frequency response curve

The voltage gain of an amplifier is given by

$$A_v = \frac{\beta\ R_{ac}}{r_{in}} \quad ...(1)$$

where, R_{ac} is the impedance of the tuned circuit.

We know that the impedance of a tuned circuit at resonance is resistive and its value is L/CR. Hence, the voltage gain is given by

$$A_v = \frac{\beta\ (L/C\ R)}{r_{in}} = \frac{\beta\ L}{C\ R\ r_{in}} \quad ...(2)$$

where, r_{in} = input resistance.

As (L/CR) is very high and hence voltage gain is very high.

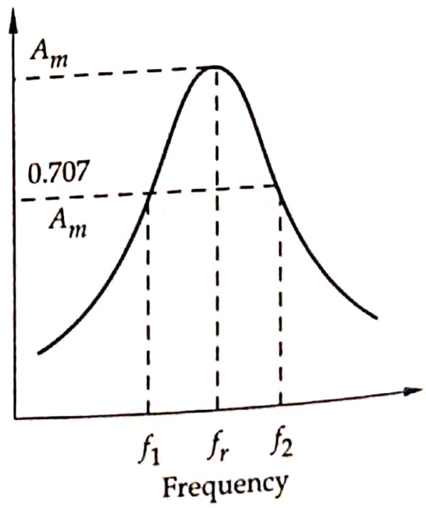

Fig. 13·39

On both sides of resonant frequency, the impedance of tuned circuit decreases. Hence, the voltage gain on either side of resonant frequency decreases. The frequency response curve is shown in fig. (13 · 39). The frequency response curve is similar to impedance-frequency curve.

The range of frequencies at which the voltage gain of the tuned amplifier falls to 70·7% of the maximum gain is called as its bandwidth. The bandwidth BW of a tuned amplifier is given by

$$BW = f_2 - f_1$$

The amplifier will amplify any frequency well within this frequency range.

Limitation of single tuned amplifier

The tuned amplifiers are used in wireless communication systems. The communication transmitters transmit the modulated wave in which the audio signal is raised to some high frequency (radio frequency). The modulated wave has a relatively narrow band of frequencies centred around the carrier frequency.

In communication receivers, the tuned voltage amplifier is used to select the desired carrier frequency. It also amplify the complete band of frequencies around the selected carrier frequency. Therefore, the tuned voltage amplifier should have a high selectivity *i.e.*, high Q factor. We know that bandwidth is reciprocal to Q factor. This shows that a tuned voltage amplifier with reduced bandwidth may not be able to amplify equally the complete band of transmitted signal. Therefore, a narrow bandwidth will result in a poor reproduction of audio signal. This is the major limitation of a single tuned amplifier. The limitation is removed by the use of double tuned circuit.

13·19 EFFECT OF CASCADING SINGLE TUNED AMPLIFIERS ON BANDWIDTH

Let us consider that several identical stages of tuned amplifiers are cascaded. Now, overall voltage gain is the product of the voltage gains of individual stages. Simultaneously, the high voltage gain is accompanied by narrow bandwidth in comparison of single stage. Consider n stages of single tuned direct coupled amplifiers connected in cascade.

The relative gain of a single tuned amplifier with respect to the gain at resonant frequency f_r is given by

$$\left|\frac{A}{A_{\text{resonance}}}\right| = \frac{1}{\sqrt{\left[1+(2\delta Q_e)^2\right]}} \quad \dots (1)$$

where Q_e is effective circuit magnification factor. This is also known as quality factor and δ is the fractional frequency variation.

The gain of n stage cascaded amplifier is given by

$$\left|\frac{A}{A_{\text{resonance}}}\right| = \left[\frac{1}{\sqrt{[1+(2\delta Q_e)^2]}}\right]^n = \frac{1}{\left[1+(2\delta Q_e)^2\right]^{n/2}} \quad \dots (2)$$

The 3-dB frequencies for n stage cascaded amplifier can be determined by the following condition:

$$\left|\frac{A}{A_{\text{resonance}}}\right|^n = \frac{1}{\sqrt{2}}$$

From eqs. (2) and (3), we get

$$\frac{1}{\left[1+(2\delta Q_e)^2\right]^{n/2}} = \frac{1}{\sqrt{2}} \quad \dots (3)$$

or

$$(1+2\delta Q_e)^2 = 2^{1/n} \text{ or } 2\delta Q_e = \pm\sqrt{(2^{1/n}-1)} \quad \dots (4)$$

We know that

$$\delta = \frac{\omega - \omega_r}{\omega_r} = \frac{f - f_r}{f_r} \quad \dots (5)$$

Substituting the value of δ from eq. (5) eq. (4), we get

$$2\left(\frac{f-f_r}{f_r}\right)Q_e = \pm\sqrt{(2^{1/n}-1)}$$

or

$$2(f-f_r)Q_e = \pm f_r\sqrt{(2^{1/n}-1)} \quad \cdots (6)$$

Now, we have

$$(f_2-f_r) = +\frac{f_r}{2Q_e}\sqrt{(2^{1/n}-1)} \quad \cdots (7)$$

and,

$$(f_r-f_1) = +\frac{f_r}{2Q_e}\sqrt{(2^{1/n}-1)} \quad \cdots (8)$$

The bandwidth of n stage identical amplifier (B_{1n}) is

$$B_{1n} = f_2 - f_1 = (f_2 - f_r) + (f_r - 1)$$

Substituting the values from eqs. (7) and (8) and solving, we get

$$B_{1n} = \frac{f_r}{Q_e}\sqrt{(2^{1/n}-1)} = B_1\sqrt{(2^{1/n}-1)} \quad \cdots (9)$$

where B_1 is the bandwidth for single stage (f_r/Q_e)

For $n = 2$, $\sqrt{(2^{1/n}-1)} = 0.643$ and for $n = 3$, $\sqrt{(2^{1/n}-1)} = 0{\cdot}51$

Therefore, it is clear that for two stages, the bandwidth is reduced to 64.3% while in case of three stages, it reduces to 51%. So, in order to maintain the prescribed 3-dB bandwidth, Q of the tuned circuit should be reduced.

13·20 DOUBLE TUNED AMPLIFIER

Figure (13·40) shows the circuit of a double tuned amplifier. There are two tuned circuits. One (L_1, C_1) in the collector circuit and the other (L_2, C_2) in the output circuit. The voltage developed across the tuned circuit in the collector circuit is inductively coupled to the output tuned circuit. The two circuits are tuned to the same frequency *i.e.*, the frequency of the signal.

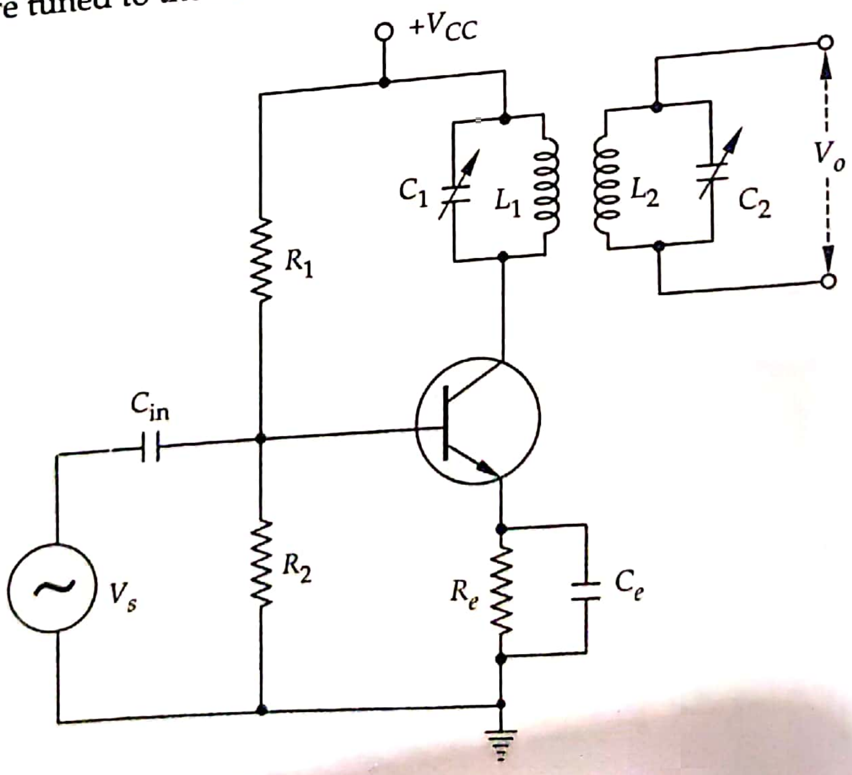

Fig. 13·40 Double tuned amplifier

By changing the value of C_1, the resonant frequency of the tuned circuit is adjusted equal to the frequency of signal. Now, the tuned circuit offers very high impedance to the signal frequency. Hence, large output appears across the tuned circuit $L_1 C_1$. The output of this tuned circuit is transferred to the second tuned circuit $L_2 C_2$ through mutual induction.

The frequency response curve of double tuned amplifier for different coefficients of coupling (mutual inductance of two tuned circuits) is shown in fig. (13·41).

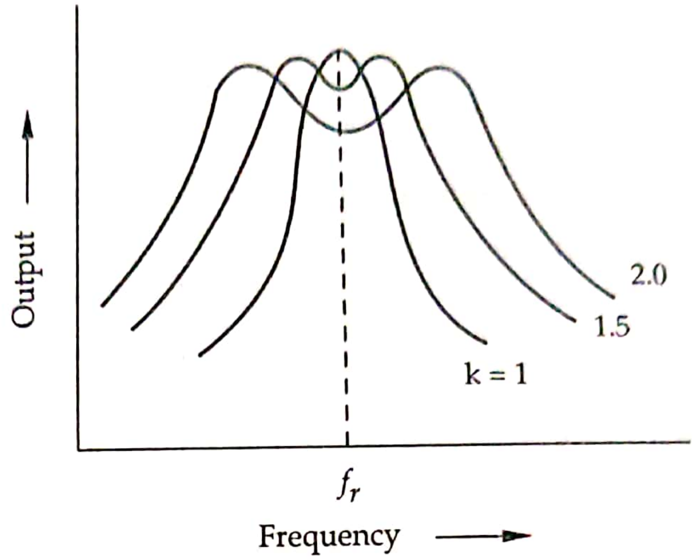

Fig. 13·41 Frequency response curve of double tuned amplifier

It is to be noted that most suitable response curve is one when optimum coefficient of coupling exists between two tuned circuits. The circuit is then highly selective. Now the circuit provides sufficient amount of gain for a particular band of frequencies.