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,

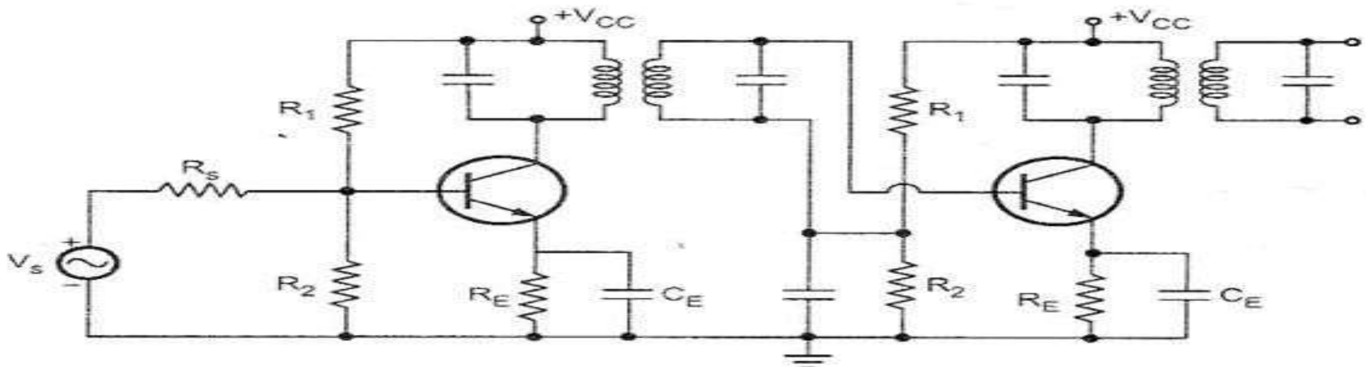
$$\Delta f = \frac{1}{2\pi R_t C_{eq}}$$

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

$$= \frac{f_r}{Q_{eff}} \quad \because \omega_r = 2\pi f_r \quad \text{... (16)}$$

DOUBLE TUNED AMPLIFIER:

The below figure shows 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.

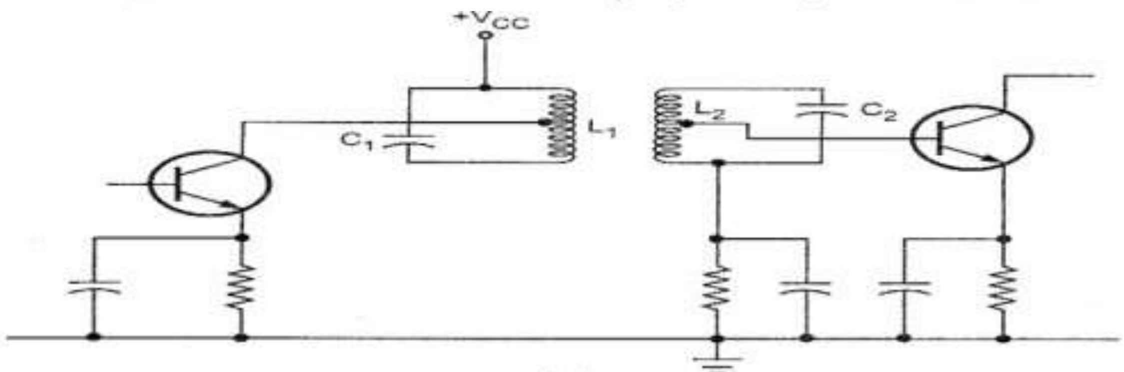
Analysis of double tuned circuits:

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.

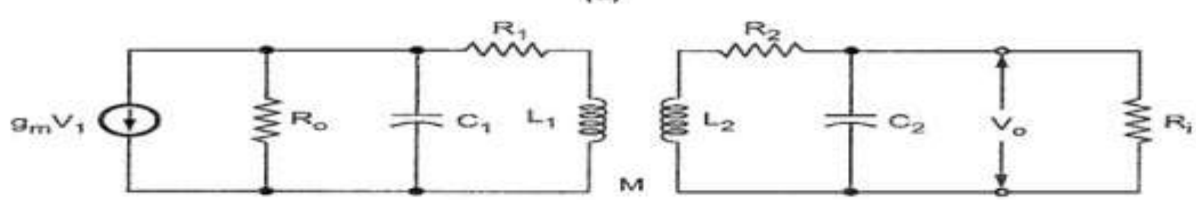
The Fig. 3.19 (c) shows the simplified equivalent circuit for the Fig. 3.19 (b). In simplified equivalent circuit the series and parallel resistances are combined into series elements. Referring equation (9) we have,

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

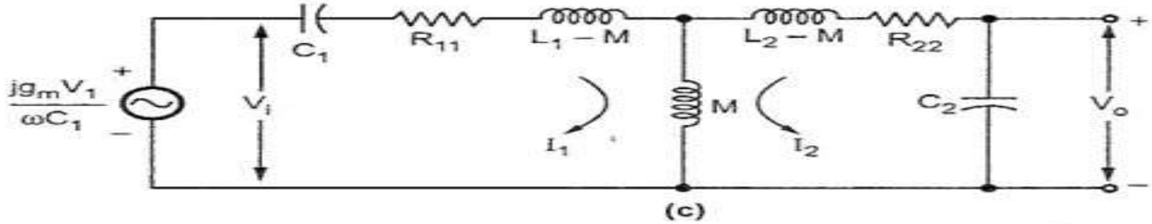
where R represents series resistance and R_p represents parallel resistance.



(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

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

Usually, the Q factors for both circuits are kept same. Therefore, $Q_1 = Q_2 = Q$ and the resonant frequency $\omega_r^2 = 1/L_1 C_1 = 1/L_2C_2$.

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

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

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,

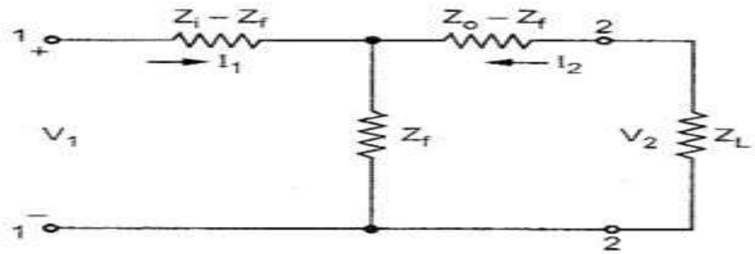


Fig. 3.20

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

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

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,

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

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

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

$$= \frac{\omega_r\,L_1}{Q} + (1 + j2Q\delta)$$

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

By doing similar analysis as for Z_i we can write,

$$Z_o + Z_L = \frac{\omega_r\,L_2}{Q} + (1 + j2Q\delta)$$

Then

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

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

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

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

$$V_o = \frac{-j}{\omega_r\,C_2}\,\frac{j\,g_m\,V_1}{\omega_r\,C_1}\left[\frac{kQ^2}{\omega_r\,\sqrt{L_1\,L_2}\,[4Q\delta - j\,(1 + k^2Q^2 - 4Q^2\delta^2)]}\right]$$

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

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

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

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

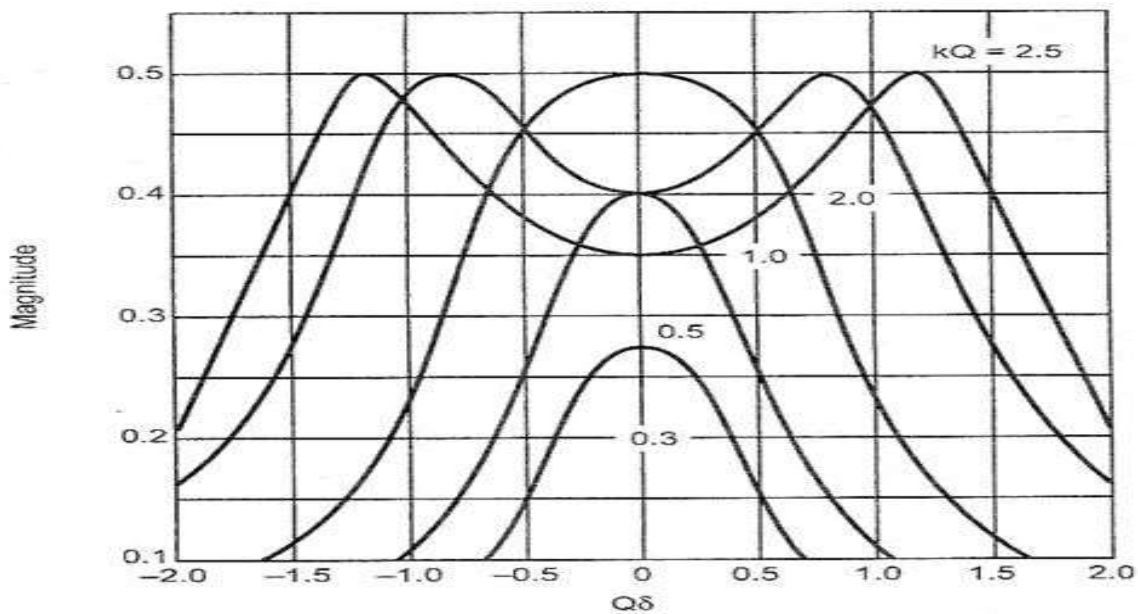
Taking the magnitude of equation (4) we have,

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

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.

$$4Q\delta - j\,(1 + k^2Q^2 - 4Q^2\delta^2) = 0 \quad \text{... (6)}$$



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,

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

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

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

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

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

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

Using quadratic simplification and choosing positive sign we get,

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

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,

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

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 ($3.1 f_r/Q$) 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.

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 a better flat, wideband characteristics in contrast with a very sharp, rejective, narrow band characteristics of synchroı
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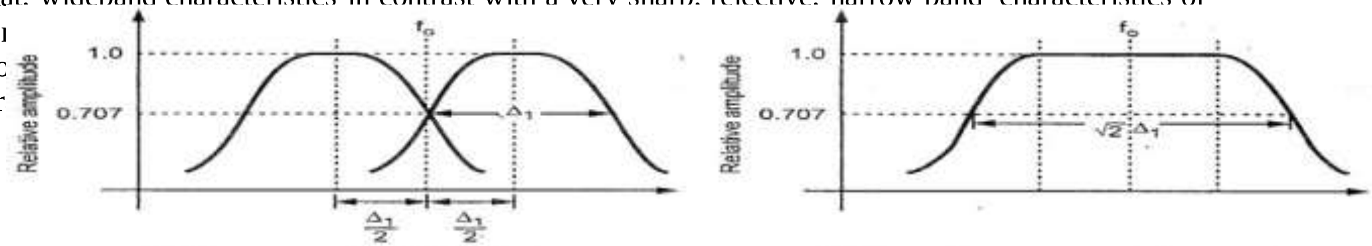

(a) Response of individual stages

(b) Overall response of staggered pair

Fig. 3.23

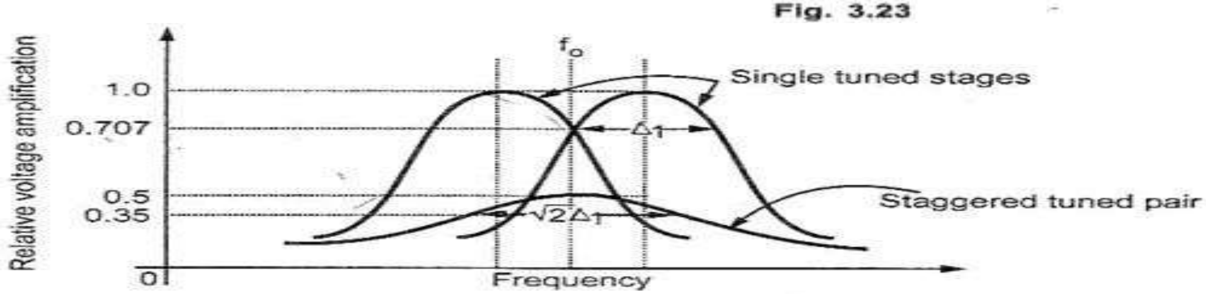

Fig. 3.24 Response of individually tuned and staggered tuned pair

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,

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

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

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,

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

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

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,

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

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

3. 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.