Frequency Range of RC and LC oscillators:

(i) Wien bridge RC oscillator is used in the range of 5Hz - 1MHz. (ie) Low freq application → Suitable. Not suitable for high freq application above 1MHz.

(ii) LC oscillator can be used for freq's from 1MHz to 500MHz, they are called Radio frequency oscillators.

(iii) Crystal oscillator Freq → 0.5 MHz to 30MHz

Unit - 3

Tuned Amplifier.

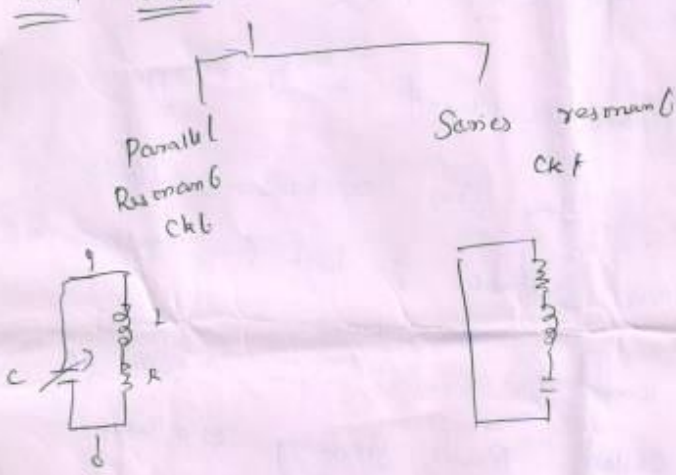
→ Tuned amplifier is used in communication Equipment, especially in broad cast receiver.

→ In a radio receivers (or) TV receivers, it is necessary to select a particular channel among the all the other channels available, thus some sort of frequency selective circuit is needed that will allow us to amplify the freq band required and reject all other unwanted signals such a circuit is known as Tuned amplifier.

→ The tuned amplifier is designed to reject all frequencies below a lower cutoff freq. f_L and above a upper cut off freq f_H.

→ So, it is also known as band pass amplifiers (or) narrow band amplifiers.

Tuned Circuit :



(i) Smaller power loss

(ii) High Selectivity

(iii) Smaller collector Supply Vcc

(iv) High gain

Resonant frequency

The admittance of the inductive branch

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

The admittance of Capacitive branch

$$Y_c = \frac{1}{1/j\omega C} = j\omega C$$

Total admittance $Y_t = Y_L + Y_c$

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

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

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

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

Imag part = 0

$$\omega C - \frac{\omega L}{R^2 + \omega^2 L^2} = 0$$

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

$$C[R^2 + \omega^2 L^2] = L$$

$$R^2 + \omega^2 L^2 = L/C$$

$$\omega^2 L^2 = L/C - R^2$$

$$\omega^2 = \frac{1}{LC} - (R/L)^2$$

$$\omega = \frac{1}{\sqrt{LC}} - R/L$$

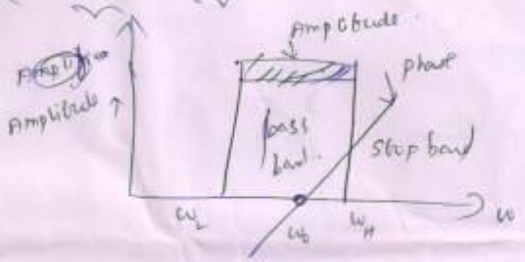
$$f = 1/2\pi \sqrt{\frac{1}{LC} - (R/L)^2}$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

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

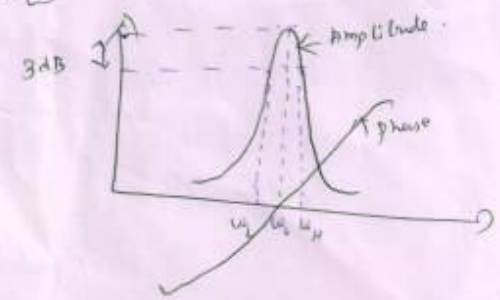
Response of Tuned amplifiers:

(i) Ideal Response



} maximum at resonant freq, and frequencies above and below the resonant frequency.

(ii) Actual Response:



→ At resonance, the tuned circuit can be used as a resistive load for amplifiers, because the reactance part = 0 (ie) Capacitive & Inductive effects cancel out. The ckt acts as a pure resistive one. with both V and I in phase.

→ For freq above f_0, the ckt acts as capacitive. and Currents leads V.

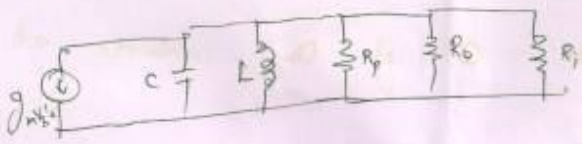
→ For Freq below f_0, the ckt acts as Inductive, and Currents lag V.

→ The gain of a transistor amplifier is directly proportional to the value of its load impedance.

→ A parallel tuned ~~circuit~~ circuit has high impedance at its resonant frequency.

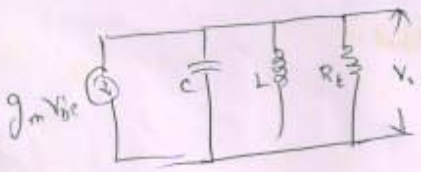
So gain Vs Freq = Impedance Vs Freq.

o/p of the ckt modified as:



R_t = Parallel combination of R_o, R_p and R_i

$$\frac{1}{R_t} = \frac{1}{R_o} + \frac{1}{R_p} + \frac{1}{R_i} \quad \text{---------- (6)}$$



effective quality factor:

Q_e = Susceptance of inductor L (or) capacitance C / Conductance of shunt resistance R_t.

$$Q_e = \omega_0 C R_t \quad \left(= \frac{R_t}{\omega_0 L}\right) \quad \text{---------- (7)}$$

Z is the impedance of C, L and R_t in parallel.

The admittance $Y = \frac{1}{Z}$

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

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

Multiplying num & den by ω_0.

$$Y = \frac{1}{R_t}\left[1 + \frac{R_t \omega_0}{j\omega L \omega_0} + \frac{j\omega C \omega_0 R_t}{\omega_0}\right]$$

So, inductor branch may be represented by a resistor R_p and inductor L_p in shunt.

Quality factor Q of the inductor at resonance is given by

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

$\omega_0 = \frac{1}{\sqrt{LC}}$ → free of resonance of the CKT.

Q_0 → usually large. So, that

$$\omega L \gg R$$

From eqn (1)

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

$$= \frac{R\left(R + \omega^2 L^2/R\right)}{R}$$

$\omega L \gg R$

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

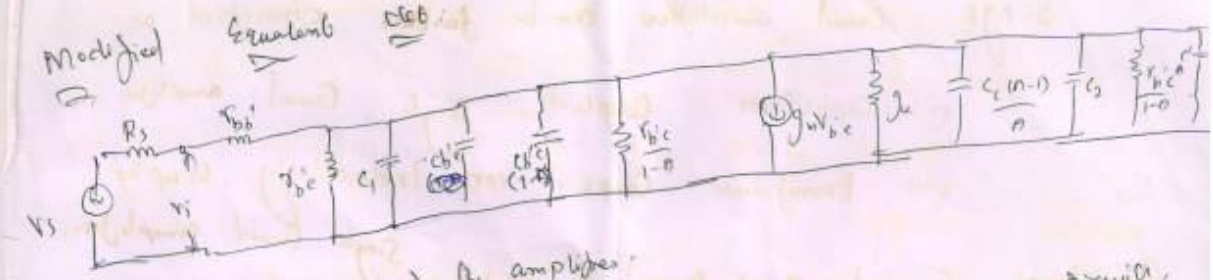
$$L_p = \frac{R^2 + \omega^2 L^2}{\omega^2 L}$$

$$L_p = \frac{\frac{R^2}{\omega^2 L} + L}{1} \quad \text{(5)}$$

Eqs (4) & (5)

,

Modified Equivalent CKT:



A → Voltage gain of the amplifier.

C_1 & C_2 are the Stray wiring capacitances in the i/p & o/p circuits respectively.

Simplified:

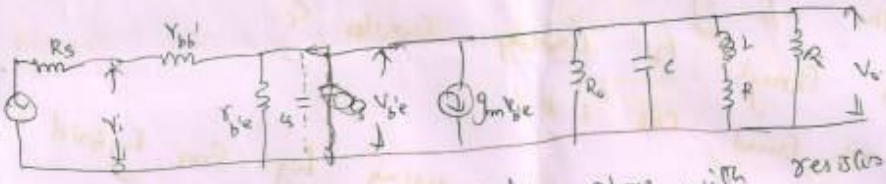
All capacitance in the i/p ckt

$C_S = C_{b'e} + C_1 + C_{b'c}(1-A)$

All capacitance at the o/p ckt.

$C = C_{b'e}\left(\frac{A-1}{A}\right) + C_2 + C'$

R_o → output resistance



The admittance of the inductor along with resistor R is given by

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

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

$$= \frac{1}{R_p} + \frac{1}{j\omega L_p} \quad \text{---------- (1)}$$

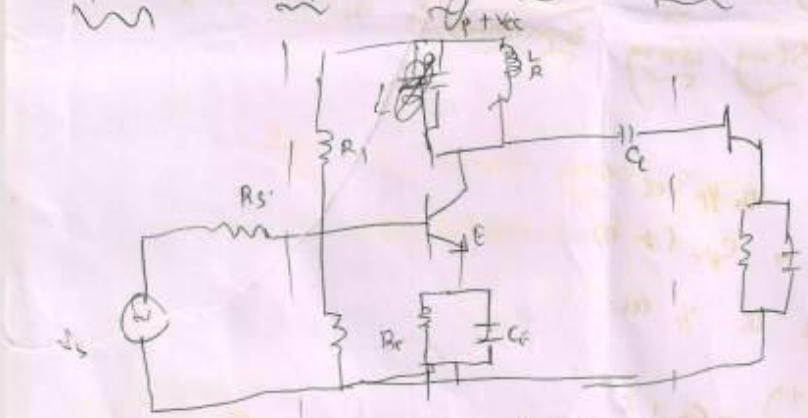
$$R_p = \frac{R^2+\omega^2L^2}{R} \quad \text{(2)}, \qquad L_p = \frac{R^2+\omega^2L^2}{\omega^2 L} \quad \text{(3)}$$

Single tuned amplifiers can be further classified as

(i) Capacitance Coupled Single tuned amplifier

(ii) Transformer Coupled (or) Inductively Coupled Single tuned amplifier.

Capacitance Coupled Single tuned amplifier:

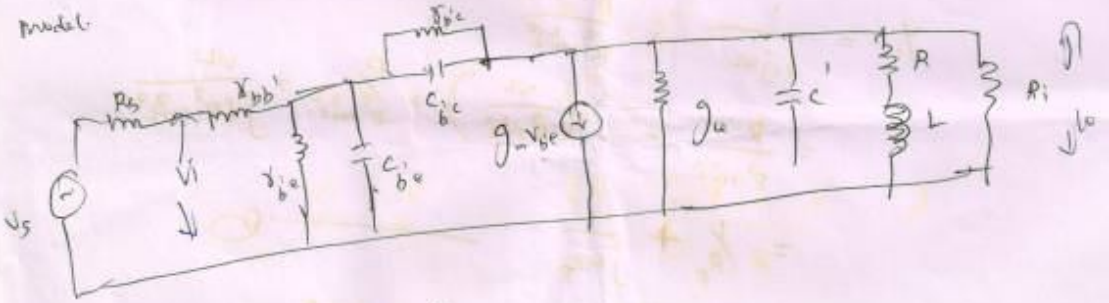


← one stage →

The o/p of the tuned ckt is connected to the next stage through the coupling capacitor C_c.

The tuned ckts I & II

Equivalent ckt for the amplifier using high freq hybrid π model



Miller Theorem:

Capacitance $C(1-A)$

Resistance $R/(1-A)$

$C_M(1-A)$

$R_M/(A-1)$

Q factor:

The inductor possesses a small resistance in addition to its inductance. The lower the value of this resistance, the better the Q factor of the inductor.

Q factor of an inductor at operating freq 'ω' is defined as the ratio of impedance of the coil to its resistance.

$$Q = 2\pi \times \frac{\text{max energy stored per cycle}}{\text{Energy dissipated per cycle}}$$

max. energy stored per cycle $= \frac{1}{2} \cdot L I_m^2$

Average pwr dissipated per cycle.

$$= R\left(\frac{I_m}{\sqrt{2}}\right)^2 R$$

Energy = Power × Time

$$= \left(\frac{I_m}{\sqrt{2}}\right)^2 R \times T$$

$$= \frac{I_m^2 R}{2} \frac{1}{f}$$

$$Q = \frac{2\pi \times \frac{1}{2} L I_m^2 \times f}{I_m^2 \times R} = 2\pi f \frac{L}{R}$$

$$\boxed{Q = \omega L / R}$$

Q factor of a Capacitor :-

max. energy stored $= \frac{1}{2} C V_{max}^2$

$V_{max} = I_m / \omega C$

$= \frac{1}{2} \frac{I_m^2}{\omega^2 C}$

$Q = 2\pi \left(\frac{\frac{1}{2} I_m^2 \times \frac{1}{2} f}{\frac{1}{2} I_m^2 \omega^2 C \times \frac{1}{2} R} \right)$

$= \frac{\omega}{\omega^2 CR}$

$\boxed{Q = \frac{1}{\omega CR}}$

Classification :- i) Tuned amplifier.

Tuned amplifier → are used to amplify small signals at radio frequency

(i) Small signal
- → Power involved is small.
- → operated under class A condition
- → Distortion is small.

(ii) Large
- ↓
- Amplify large signals at radio freq
- → Power involved is large.
- → operated under class B, AB or C condition.
- → distortion gets increased.

Single tuned amplifier :

→ ↓ s use one parallel resonant circuit as the load impedance in each stage and all the tuned circuits are tuned to the same freq.

$\delta \rightarrow$ Fractional Frequency Variation.

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

$$\boxed{\omega/\omega_0 = 1+\delta}$$

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

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

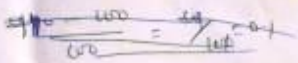
$$= \frac{1+jQ_e\left[\frac{1+\delta^2+\delta+\delta-1}{1+\delta}\right]}{R_t}$$

$$= \frac{1+jQ_e\left[\frac{\delta^2+2\delta}{1+\delta}\right]}{R_t}$$

$$Z = \frac{1}{Y} = \frac{R_t}{1+j2\delta Q_e\left[\frac{\delta/2+1}{1+\delta}\right]}$$

At any freq ω, close to the frequency of resonance ω_0,

$$\boxed{\delta << 1}$$



So, $\omega - \omega_0 << 1$

$$\boxed{Z = \frac{R_t}{1+j2\delta Q_e}}$$

At resonance R_p can be expressed as

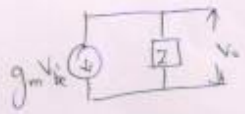
$$R_p = \frac{\omega_0^2 L^2}{R}$$

$$Q_0 = \omega_0 L/R$$

$$Q_0^2 = \omega_0^2 L^2/R^2$$

$$Q_0^2 R = \omega_0^2 L^2/R$$

$$\boxed{R_p = Q_0^2 R} \Rightarrow \frac{\omega_0 L/R \cdot R}{\omega_0 L}$$



$$V_o = -g_m V_{b'e} Z$$

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

$$V_o = -\frac{g_m V_i \, r_{b'e}}{r_{bb'} + r_{b'e}} \times Z$$

Find Voltage gain:

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

Substituting Values

$$A = \frac{-g_m r_{b'e}}{r_{bb'} + r_{b'e}} \cdot \frac{R_L}{1 + j Q_e S}$$

Voltage gain Resonance:

$\omega = \omega_0$

$S = 0$

$$A_{res} = \frac{-g_m \, r_{b'e}}{r_{bb'} + r_{b'e}} \cdot R_L$$

$$A/A_{res} = \frac{1}{1 + j 2 S Q_e} \qquad |A/A_{res}| = \frac{1}{\sqrt{1 + (2 S Q_e)^2}}$$

Phase angle of A/A_{res} is given by

$$\phi = -\tan^{-1}(2 S Q_e)$$

δ → Fractional Frequency Variation.

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

$$\boxed{\omega/\omega_0 = 1+\delta}$$

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

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

$$= \frac{1 + jQ_e\left[\frac{1+\delta^2+\delta+\delta-1}{1+\delta}\right]}{R_t}$$

$$= \frac{1 + jQ_e\left[\frac{\delta^2+2\delta}{1+\delta}\right]}{R_t}$$

$$= \frac{R_t}{1 + j2\delta Q_e\left[\frac{\delta/2+1}{1+\delta}\right]}$$

$$Z = \frac{1}{Y}$$

At any freq ω, close to the frequency of resonance ω_0,

$$\boxed{\delta << 1}$$

$\omega/\omega_0 = 1+\delta$

So, $\omega - \omega_0 << 1$

$$\boxed{Z = \frac{R_t}{1 + j2\delta Q_e}}$$

At resonance R_p can be expressed as

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

$$Q_0 = \omega_0 L/R$$

$$Q_0^2 = \omega_0^2 L^2/R^2$$

$$Q_0^2 R = \omega_0^2 L^2/R$$

$$\boxed{R_p = Q_0^2 R} \Rightarrow \frac{\omega_0 L}{R} \cdot \omega_0 L$$

$$= \omega_0 L Q_0$$

At a freq below the resonant freq.

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

$$\left|A/A_{res}\right| = \frac{1}{\sqrt{2}} = 0.707$$

At a freq above the resonant freq

let $\delta = \frac{1}{2Q_e}$ $\left|A/A_{res}\right| = 0.707$

Find 3dB Bandwidth:

$$\Delta\omega \text{ (or } B) = \omega_2 - \omega_1$$

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

$$= \left(\frac{\omega_2 - \omega_0}{\omega_0} + \left(\frac{\omega_0 - \omega_1}{\omega_0}\right)\right)\omega_0$$

$$= (\delta + \delta)\omega_0$$

$$\Delta\omega = 2\delta\omega_0$$

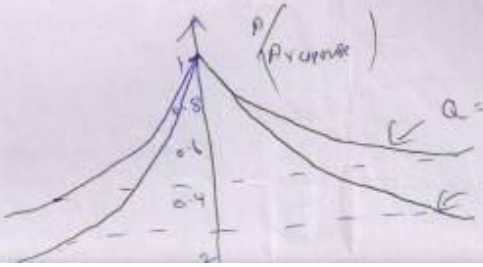
$\delta = \frac{1}{2Q_e}$ $\Delta\omega = \frac{2\omega_0}{2Q_e}$

$$\boxed{\Delta\omega = \frac{\omega_0}{Q_e}}$$

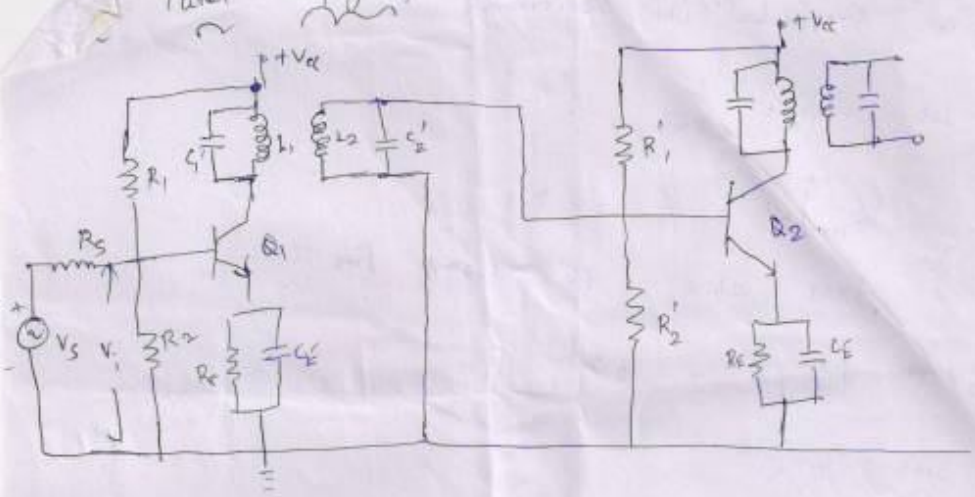
$Q_e = \omega_0 C R_t = R_t/\omega_0 L$

$$\Delta\omega = \frac{1}{R_t C} = \frac{1}{R_t L} \text{ rad/sec}$$

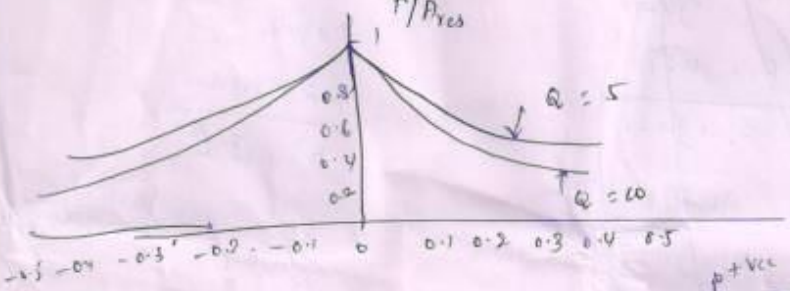
The magnitude of relative gain A/A_{res}



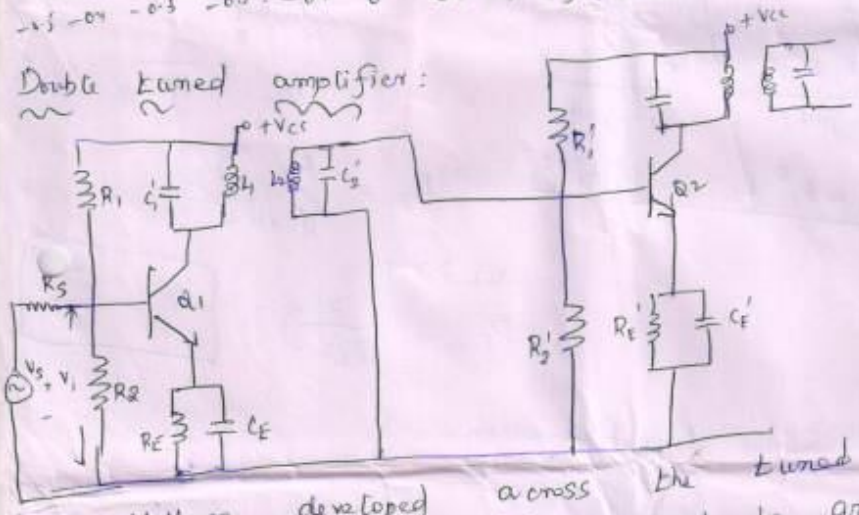
Tuned amplifier :



Response of a Single Tuned amplifier: Unit - III

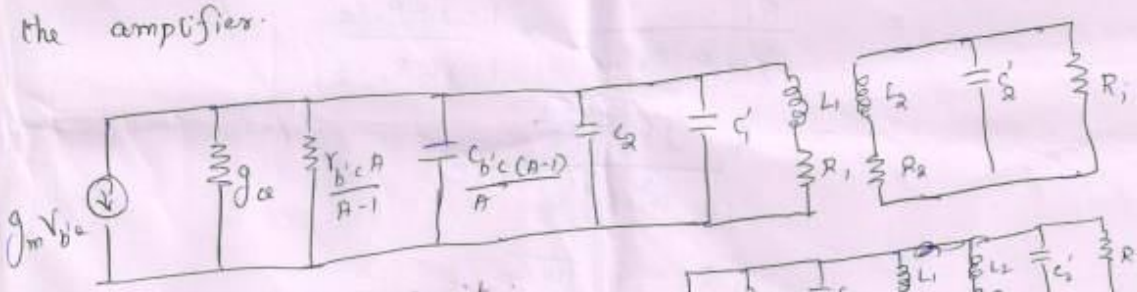


Double tuned amplifier:

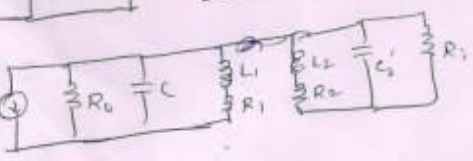


The voltage developed across the tuned Circuit in the Collector Circuit is inductively coupled to another tuned Circuit, both the tuned circuits being tuned to the same frequency.

Equivalent Circuit: For the output Circuit of the amplifier.



Simplified equivalent Circuit:



Step 2: Series to parallel transformation.

Consider L_1 and R_1 : Connected in Series.

$$Y = \frac{1}{R_1} + \frac{1}{j\omega L_1}$$

$$= \frac{R_1 + j\omega L_1}{R_1 \cdot j\omega L_1}$$

$$Z = \frac{1}{Y} = \frac{j\omega R_1 L_1}{R_1 + j\omega L_1}$$

$$Z = \frac{j\omega R_1 L_1}{R_1 + j\omega L_1} \times \frac{R_1 - j\omega L_1}{R_1 - j\omega L_1}$$

$$= \frac{j\omega R_1^2 L_1 + \omega^2 L_1^2 R_1}{}$$

$$Y_1 = \frac{1}{R + j\omega L}$$

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

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

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

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

$\omega L \gg R$

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

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

Step 3 :

Parallel to Series Transformation.

R_i and C_2' are in Parallel.

$R_i \| \frac{1}{C_2'} \left(\frac{1}{j\omega C_2'}\right)$

$$Z = \frac{R_i \left/ j\omega C_2'\right.}{R_i + \frac{1}{j\omega C_2'}} = \frac{R_i \left/ j\omega C_2'\right.}{j\omega R_i C_2' + 1 \left/ j\omega C_2'\right.}$$

$$= \frac{R_i}{j\omega R_i C_2' + 1} \times \frac{1 - j\omega R_i C_2'}{1 - j\omega R_i C_2'}$$

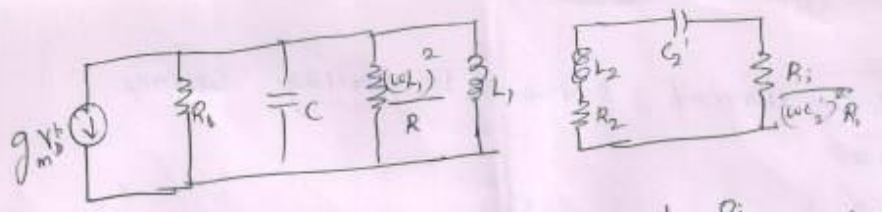
$$= R_i \frac{-j\omega R_i^2 C_2'}{1 + \omega^2 R_i^2 C_2'^2}$$

$$= R_p' + \frac{1}{j\omega C_p}$$

$$R_p' = \frac{R_i}{1 + (\omega R_i C_2')^2}$$

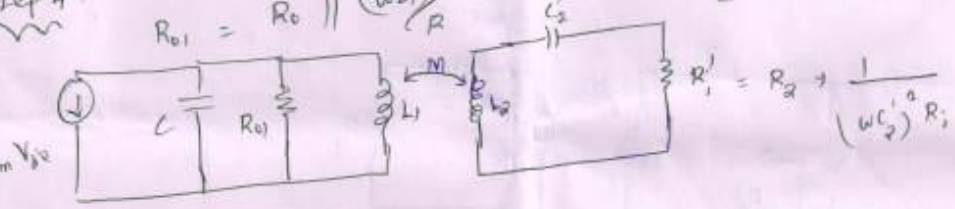
$\omega R_i C_2' \gg 1$

$$R_p' = \frac{R_i}{\omega R_i C_2'} = \frac{1}{\omega^2 C_2'^2 R}$$



Step 4:

$R_{o1} = R_o \parallel \frac{(\omega L_1)^2}{R}$; R_B and $\frac{R_i}{(\omega C_2')^2 R_i}$ are in series

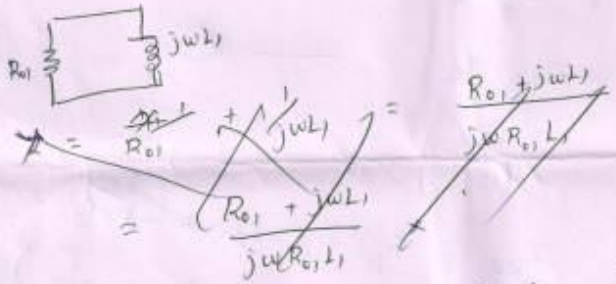


$R_i' = R_2 + \frac{1}{(\omega C_2')^2 R_i}$

Step 5:

Parallel to series transformation:

$R_{o1} \parallel L_1$



$$Z = \frac{R_{o1} + j\omega L_1}{j\omega R_{o1} L_1}$$

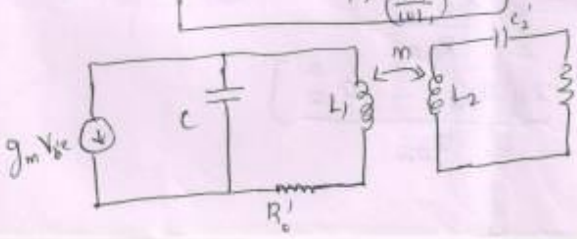
$$Z = \frac{R_{o1} + j\omega L_1}{R_{o1} + j\omega L_1} = \frac{j\omega R_{o1} L_1}{R_{o1} + j\omega L_1} \times \frac{R_{o1} - j\omega L_1}{R_{o1} - j\omega L_1}$$

$$= \frac{j\omega R_{o1}^2 L_1 + \omega^2 L_1^2 R_{o1}}{R_{o1}^2 + \omega^2 L_1^2}$$

$$= R \frac{\omega^2 L_1^2 R_{o1}}{R_{o1}^2 + \omega^2 L_1^2} + \frac{j\omega R_{o1}^2 L_1}{R_{o1}^2 + \omega^2 L_1^2} = R_B + j\omega L_B$$

$$R = \frac{\omega^2 L_1^2 R_{o1}}{R_{o1}^2 + \omega^2 L_1^2} = \frac{R_{o1}}{1 + \frac{R_{o1}^2}{\omega^2 L_1^2}}$$

$$\boxed{R_o' = \frac{R_{o1}}{1 + \left(\frac{R_{o1}}{\omega L_1}\right)^2}}$$

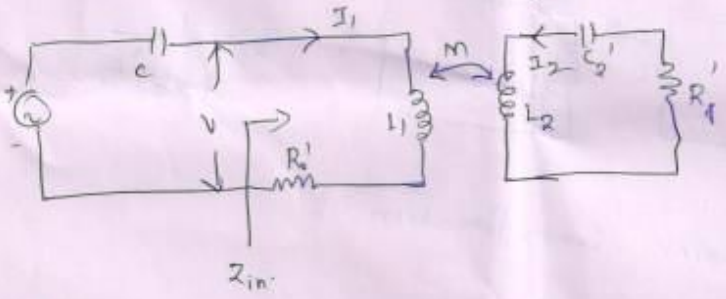


Step 6 :

Convert current source to Voltage Source

$V = IR$

$V_i = \frac{g_m V_{b'e}}{j\omega C} \times C = \frac{g_m V_{b'e}}{j\omega C}$



Find Z_{in} :

$$V = Z_{11} I_1 + Z_{12} I_2 \quad \text{---} \quad (1)$$

$$0 = Z_{21} I_1 + Z_{22} I_2 \quad \text{---} \quad (2)$$

$Z_{11} = R_b' + j\omega L$, $Z_{12} = j\omega M$

$Z_{21} = j\omega M$, $Z_{22} = R_1' + j\omega L_2 + \frac{1}{j\omega C_2'}$

$= R_1' + j\left(\omega L_2 - \frac{1}{\omega C_2'}\right)$

From eqn (2)

$$Z_{22} I_2 = -Z_{21} I_1$$

$$\boxed{I_2 = -\frac{Z_{21} I_1}{Z_{22}}} \quad \text{---} \quad (3)$$

Sub (3) in (1).

$$V = Z_{11} I_1 - \frac{Z_{12} Z_{21} I_1}{Z_{22}} \qquad \boxed{Z_{21} = Z_{12}}$$

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

$$= I_1 \left[\frac{Z_{11} Z_{22} - Z_{12}^2}{Z_{22}} \right]$$

$\boxed{Z_{in} = V/I_1}$

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

$$= R_1' + j\omega L_1 + \frac{\omega^2 M^2}{R_2' + j(\omega L_2' - 1/\omega C_2')}$$

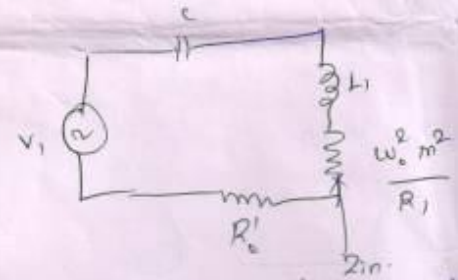
At resonance, $\omega = \omega_0$,

$$\omega_0 L_2' = \frac{1}{\omega_0 C_2'}$$

$$Z_{in} = R_1' + j\omega L_1 + \frac{\omega_0^2 M^2}{R_2'}$$

Condition for maximum transfer of power

$$\frac{\omega_0^2 M^2}{R_2'} = R_1' \qquad (4)$$



When M is adjusted to critical value of M_c. $M = M_c$

$$R_1' = \frac{\omega_0^2 M_c^2}{R_2'}$$

$$R_1' R_2' = \omega_0 M_c$$

$$M_c = \frac{\omega_0}{\sqrt{R_1' R_2'}} \qquad (5)$$

In General

$$V_1 = Z_{11} I_1 + Z_{12} I_2 \qquad (6)$$

$$0 = Z_{21} I_1 + Z_{22} I_2 \qquad (7)$$

$$Z_{11} = R_0' + j\omega L_1 + \frac{1}{j\omega C} = R_0' + j\left(\omega L_1 - \frac{1}{\omega C}\right).$$

$$Z_{22} = R_i' + j\left(\omega L_2 - \frac{1}{\omega C_2'}\right)$$

$$Z_{12} = Z_{21} = j\omega M.$$

At resonance, $\omega_0 L_1 = \frac{1}{\omega_0 C}$ and $\omega_0 L_2 = \frac{1}{\omega_0 C_2'}$

From (7).

$$Z_{21} I_1 = -Z_{22} I_2$$

$$I_1 = \frac{-Z_{22} I_2}{Z_{21}} \quad \text{---(8)}$$

Sub (8) in (6).

$$V_1 = -Z_{11} Z_{22} I_2 + Z_{12} I_2.$$

$$V_1 Z_{21} = \left(-Z_{11} Z_{22} + Z_{12} Z_{21}\right) I_2$$

$$I_2 = \frac{V_1 Z_{21}}{-Z_{11} Z_{22} + Z_{12}^2} \quad \text{---(9)}.$$

$$I_{2\,max} = \frac{V_1 (j\omega_0 M_c)}{-R_0' R_i' + \omega_0^2 M_c^2} = -\frac{j V_1 \omega_0 M_c}{R_0' R_i' + \omega_0^2 M_c^2}$$

Sub eq (5) $M_c = \frac{\sqrt{R_0' R_i'}}{\omega_0}$

$$I_{2\,max} = \frac{-j V_1 \sqrt{R_0' R_i'}}{R_0' R_i' + R_0' R_i'} = \frac{-j V_1}{2\sqrt{R_0' R_i'}} \quad \text{---(10)}$$

$$\left| I_{2\,max} \right| = \frac{V_1}{2\sqrt{R_0' R_i'}}$$

For coupling greater than the critical coupling, power transfer is maximum at two other frequencies.

These two frequencies can be obtained by equating $|I_{2max}|$ to $|I_2|$.

$$|I_{2\,max}| = |I_2|$$

$$\left| \frac{-jV_1}{2\sqrt{R_0' R_1'}} \right| = \left| \frac{-V_1 Z_{21}}{Z_{11} Z_{22} - Z_{12}^2} \right|$$

Substitute $Z_{11}, Z_{12}, Z_{21}, Z_{22}$

$$\left| \frac{-jV_1}{2\sqrt{R_0' R_1'}} \right| = \left| \frac{-V_1 (j\omega m)}{\left(R_0' + j\omega L_1 + \frac{1}{j\omega C}\right)\left(R_1' + j\omega L_2 + \frac{1}{j\omega C_2'}\right) - (j\omega m)^2} \right|$$

The condition for maximum power transfer is

$$\boxed{R_0' = \frac{\omega_0^2 m_c^2}{R_1'}}$$

At a frequency other than resonant frequency $m \neq m_c$,

$$m = b\, m_c$$

$$\boxed{m_c = m/b}$$

So, $$R_0' = \frac{\omega_0^2 m^2}{b^2 R_1'}$$

$$\omega m = b\sqrt{R_0' R_1'}$$

$$\left| \frac{-jV_1}{2\sqrt{R_0' R_1'}} \right| = \left| \frac{-jV_1 b \sqrt{R_0' R_1'}}{\left(R_0' + j\omega L_1 + \frac{1}{j\omega C}\right)\left(R_1' + j\omega L_2 + \frac{1}{j\omega C_2'}\right) + b^2 R_0' R_1'} \right|$$

$L_2 = L_1 = L$, $C_2' = C$, $R_0' = R_1' = R$

$j(\omega L - \frac{1}{\omega C}) = jX$

$$\left| \frac{-jV_1}{2R} \right| = \left| \frac{-jV_1 bR}{(R + jX)^2 + b^2 R^2} \right|$$

Cross multiply

$$|2bR^2| = |R^2 + 2jRX - X^2 + b^2 R^2|$$

$$2bR^2 = \sqrt{[R^2(1+b^2) - X^2]^2 + (2RX)^2}$$

squaring both sides

$$4b^2R^4 = [R^2(1+b^2) - X^2]^2 + 4R^2X^2$$

Solving for X,

$$X = \pm\sqrt{b^2 - 1}$$

b) Co-efficient of Coupling is less than critical value.

$$|I_2| = \frac{1}{\sqrt{2}} |I_{2max}|$$

$$X = \pm\sqrt{b^2 - 1 \pm 2b}$$

$X = \omega L - \frac{1}{\omega C}$

$$\omega L - \frac{1}{\omega C} = \pm\sqrt{b^2 - 1 \pm 2b}$$

multiplying by C

$$\omega LC - \frac{1}{\omega} = \pm\sqrt{b^2 - 1 \pm 2b}\, C$$

multiplying by ω_0

$$\omega LC\omega_0 - \frac{\omega_0}{\omega} = \pm\sqrt{b^2 - 1 \pm 2b}\, C\omega_0$$

Subswibe $Q = \frac{1}{\omega_0 CR}$

$$\omega_0 CR = \frac{1}{Q}$$

$\omega_0 L = \frac{1}{\omega_0 C}$

$\omega_0^2 = \frac{1}{LC}$

$$LC = \frac{1}{\omega_0^2}$$

$$\frac{\omega_2}{\omega_0} - \frac{\omega_0}{\omega_2} = \pm \frac{\sqrt{b^2 - 1 \pm 2b}}{Q}$$

$\omega_0 = \sqrt{\omega_1 \omega_2}$

3dB Bandwidth:

$\Delta\omega = \omega_2 - \omega_1$

From eqn

$$\frac{\omega_2}{\omega_0} - \frac{\omega_0}{\omega_2} = \frac{\omega_2^2 - \omega_0^2}{\omega_0 \omega_2} = \frac{\pm \sqrt{b^2 - 1 \pm 2b}}{Q}$$

$$\Delta\omega = \frac{\omega_2^2 - \omega_1 \omega_2}{\omega_0 \omega_2} = \frac{\omega_2 - \omega_1}{\omega_0} = \frac{1}{Q}\sqrt{b^2 - 1 \pm 2b}$$

$$\Delta\omega = \omega_2 - \omega_1 = \frac{\omega_0}{Q}\sqrt{b^2 - 1 \pm 2b}$$

$\omega_2 - \omega_1$ is proportional to $\frac{\omega_0}{Q}$.

In Single tuned amplifier, 3 dB Bw is $\Delta\omega = \omega_0/Q$. In 3dB Bw is a double tuned amplifier exceeds that in the single tuned amplifier by a factor $\sqrt{b^2 - 1 \pm 2b}$.

Advantages:

→ Larger 3dB Bw than the Single tuned amplifiers and provides Larger gain - bandwidth product.

→ It provides gain Vs freq curve having steeper sides & flatter top

Large Signal Tuned Amplifiers:

The large signal tuned amplifiers amplify high power signals of the radio frequency range using class C operation.

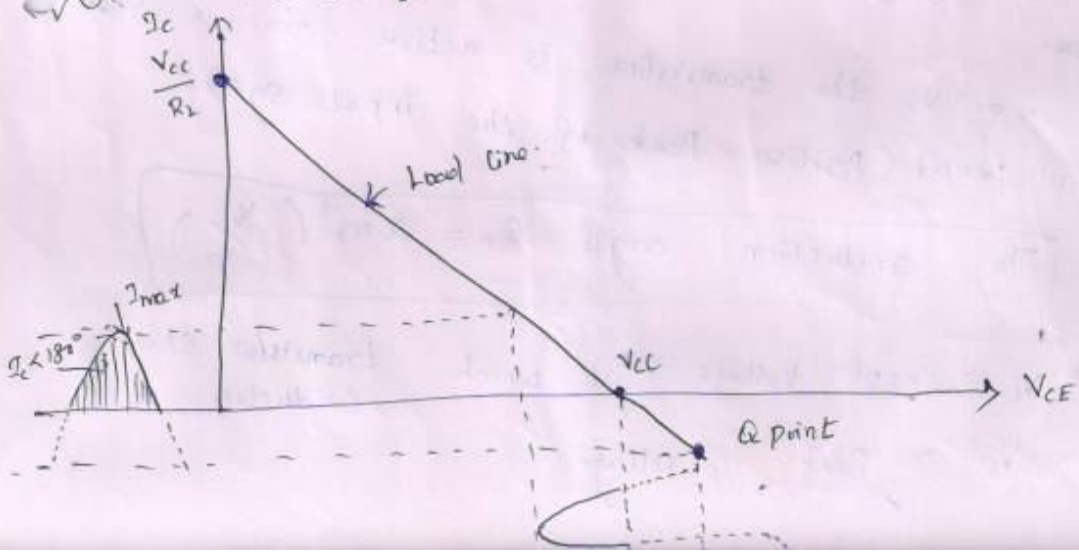
Class C tuned amplifiers:

The amplifier is said to be a class C amplifier if the output signal is obtained for less than half a cycle for a full input cycle.

The Q point and the input signal are selected so as to achieve the conditions for a class C amplifier.

→ Transistor active for less than a half cycle.
→ For remaining cycle of input, the transistor remains cut off region and no signal is produced at the output.

Waveform representing class C operation:

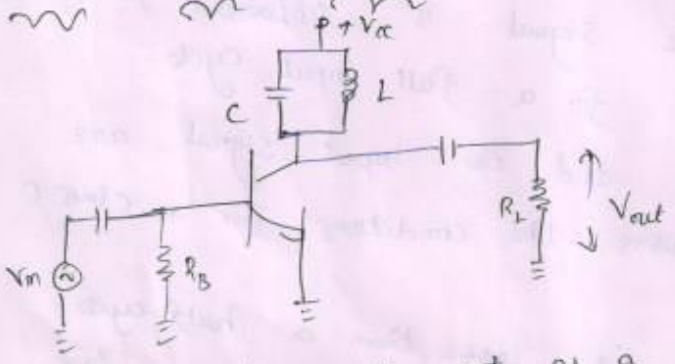


Conduction angle θ_c:

It is defined as the total angle during which the collector current exists at the output.

θ_c is always less than 180°.

Class C Tuned amplifier:



→ Parallel tuned circuit act as a load impedance and it is tuned to the input frequency.

→ So, it filters the harmonic frequencies and produce a sine wave output voltage.

→ $V_{BE} = 0$ (no bias condition), collector current will not flow.

→ $V_{BE} = 0.7$ V, the transistor is active for a small period (positive peak of the input sgl).

$\theta = 2\sin^{-1}\left(\frac{V_c}{V_p}\right)$

V_c → input voltage at which transistor start conducting

V_p → Peak i/p voltage.

→ The output pulse is applied to tuned circuits and it is tuned to resonant frequency, and produced Sinusoidal output.

→ The purpose of tank circuit is to produce the fundamental Component of the class C waveform, which has the same freq at input.

→ When the resonant frequency of the tank circuit is equal to the input freq, the impedance of the tank circuit is maximum, [So, gain is maximum].

→ The amplitude of class C amplifier is depends on the conduction angle θ_c.

→ Greater the conduction angle

Let γ_1 be the ratio of the peak value of the fundamental component to the peak value of the class C waveform

$$\gamma_1 = \left(-3.54 + 4.1\,\theta_c - 0.0072\,\theta_c^2\right) \times 10^{-3}$$

$$0^\circ \le \theta_c \le 180^\circ$$

The values of γ_1 varies from 0

γ_0 be the ratio of the peak value of the class C waveform to peak value

$$\gamma_0 = \frac{\text{d.c value}}{\text{Peak Value}} = 1$$

$$\boxed{\gamma_0 = \frac{\theta_c}{180}}$$

The Values of r_0 Varies from

0 to $1/11$ as θ_c Varies 0° to 180°.

The output power

$$P_0 = (r_1 I_p) \frac{V_{cc}}{\sqrt{2}} \left(\frac{r_1 I_p}{\sqrt{2}} \right) = \frac{V_{cc}\, r_1 I_p}{2}$$

$I_p \rightarrow$ peak output current.

The average power supplied by the d.c Source is V_{cc} times the average current drawn from the Source.

Since current flows only when the transistor is conducting. this current waveform is the same as the class C collector currents waveform having peak value I_p.

Average Supplied pwr

$$P_s = (r_0 I_p) V_{cc}$$

$$\eta = \frac{P_0}{P_s} = \frac{V_{cc}\, r_1 I_p}{2\, r_0 I_p V_{cc}}$$

$$\boxed{\eta = \frac{r_1}{2 r_0}}$$

efficiency is related to r_1 & r_0 ↓ in terms of conduction angle.

Application:

(i) It is used as tuned circuit in radio/TV Communication System

(ii) It is used as modulator in AM / FM transmitter circuits because of its high efficiency.

B_1 → BW of single stage.

Bandwidth of n stages B_n is equal to B_1 multiplied by a factor of $\sqrt{2^{1/n}-1}$

$n = 2$, $\sqrt{2^{1/n}-1} = 0.643$

$n = 3$, $\sqrt{2^{1/n}-1} = 0.510$

The BW is reduced to 64.3% for two stages, and 51% for 3 stages of cascade amplifiers.

To maintain a 3dB bandwidth, Q of the tuned circuit should be reduced.

Result:

1. High overall gain.
2. Reduced BW (narrow BW).

Effect of cascading double tuned amplifiers on BW:

1. Overall BW of the system is reduced.
2. Side steepness of the response is increased.

The 3 dB BW of the cascaded double tuned amplifier is given by

$$B_{2n} = B_2 \left[2^{1/n} - 1\right]^{1/4}.$$

B_{2n} → BW of single stage double tuned amplifier.

n → number of stages.

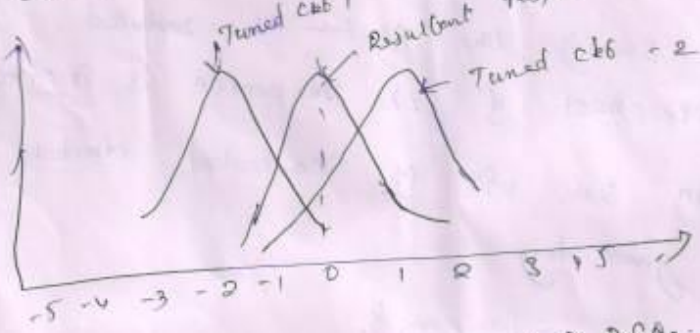
Stagger Tuned amplifiers:

→ To increase Bw, double tuned amplifiers are preferred, but alignment of double tuned amplifiers is difficult.

→ In Stagger tuned, two single tuned Cascaded amplifiers having a certain Bw are taken.

→ The resonant freq of the two tuned circuits are adjusted that they are separated by an amount equal to the Bw of each stance.

→ Since the resonant frequencies are transferred (or) staggered, they are known as Stagger tuned circuits.



$$\frac{A}{A_M} = \frac{1}{\sqrt{2}} \frac{1}{\sqrt{1+4S^4 Q^4}}$$

$$\left| \left(\frac{A}{A_{res}}\right)_1 \left(\frac{A}{A_{res}}\right)_2 \right| = \frac{1}{\sqrt{(2-x^2)^2 + (2x)^2}}$$

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

$$= \frac{1}{\sqrt{4 + x^4}}$$

$$= \frac{1}{\sqrt{4 + (2 S_0 Q_e)^4}}$$

$$\boxed{\left| \left(\frac{A}{A_{sca}}\right)_1 \left(\frac{A}{A_{res}}\right)_2 \right| = \frac{1}{2} \sqrt{1 + A S_0^A Q_e^4}}$$

The relative gain of a single tuned amplifier is

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

$$x = 2\delta Q_e$$

$$\frac{A}{A_{res}} = \frac{1}{1+jx}$$

BW $B = \frac{f_0}{Q_e}$ and under 3dB condition $\delta = \frac{1}{2Q_e}$

$$B = 2\delta f_0$$

One stage is tuned above f_0 and another stage is tuned below f_0.

$$\left(\frac{A}{A_{res}}\right)_1 = \frac{1}{1+j(x-1)}$$

$$\left(\frac{A}{A_{res}}\right)_2 = \frac{1}{1+j(x+1)}$$

The overall gain

$$\left(\frac{A}{A_{res}}\right)_{pair} = \left(\frac{A}{A_{res}}\right)_1 \left(\frac{A}{A_{res}}\right)_2$$

$$= \frac{1}{1+j(x-1)} * \frac{1}{1+j(x+1)}$$

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

$$= \frac{1}{2-x^2+2jx}$$

magnitude of the resulting function.

Stability of Tuned amplifiers:

→ At high frequency, the inter junction capacitance between base and collector, C_{bc} of the transistor becomes dominant (The reactance becomes low).

→ As reactance of C_{bc} at low, it provides the FB path from collector to base.

⇒ Some feedback signal reach the input from output, with phase shift, then there is a possibility of circuit converted to an unstable [It generating own oscillation, and can stop working as an amplifier].

→ Avoid this problem, to lowering the Q of tune circuits.

It creates following Problems:

1. Reduced gain.
2. Affect Selectivity.

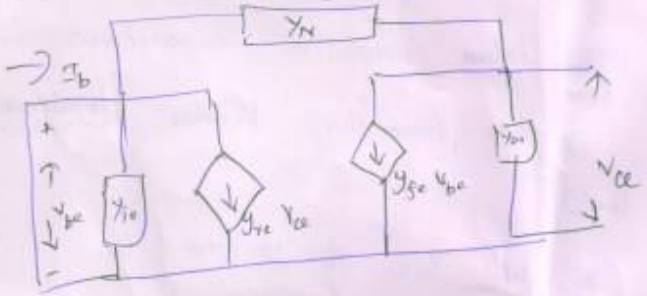
Neutralization:

The technique used for the elimination of potential oscillation is called neutralization.

BJT and FET are potentially unstable over some frequency range due to the feedback parasitic.

If the feedback can be cancelled by an additional feedback signal that is equal in amplitude and opposite phase, the transistor becomes unilateral from input to output & the oscillation completely stop.

Equivalent Circuit of Neutralized transistor:



$$y'_{re} = \left.\frac{I_b}{V_{ce}}\right|_{V_{be}=0} \quad \text{---(1)}$$

$$I_b = y_{re} V_{ce} - Y_N V_{ce}$$

$$= V_{ce}\left[y_{re} - Y_N\right]$$

$$\left.I_b\right|_{V_{ce}} = y_{re} - Y_N \quad \text{---(2)}$$

$$y'_{re} = y_{re} - Y_N$$

For perfect neutralization

$$y'_{re} = 0,$$

So, $y_{re} = Y_N$ → oscillation does not exist, if the designed Circuit external matches y_{re} for all values of frequency and operating Conditions.

$$y_{re} = -j\omega C_{re}$$

Stability of Tuned amplifiers

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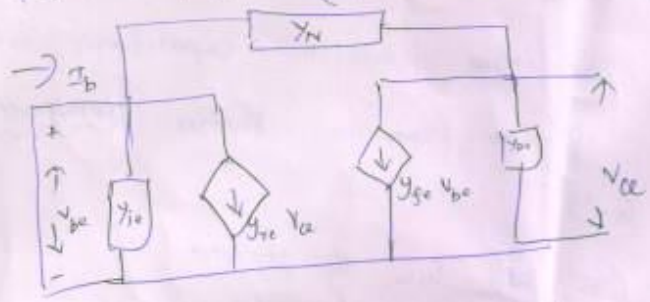
Equivalent Circuit of Neutralized transistor:



$$y'_{re} = \left.\frac{I_b}{V_{ce}}\right|_{V_{be}=0} \quad \text{---} (1)$$

$$I_b = y_{re} V_{ce} - Y_N V_{ce}$$

$$= V_{ce}\left[y_{re} - Y_N \right].$$

$$\frac{I_b}{V_{ce}} = y_{re} - Y_N \quad \text{---} (2).$$

$$y'_{re} = y_{re} - Y_N$$

For perfect neutralization

$$y'_{re} = 0,$$

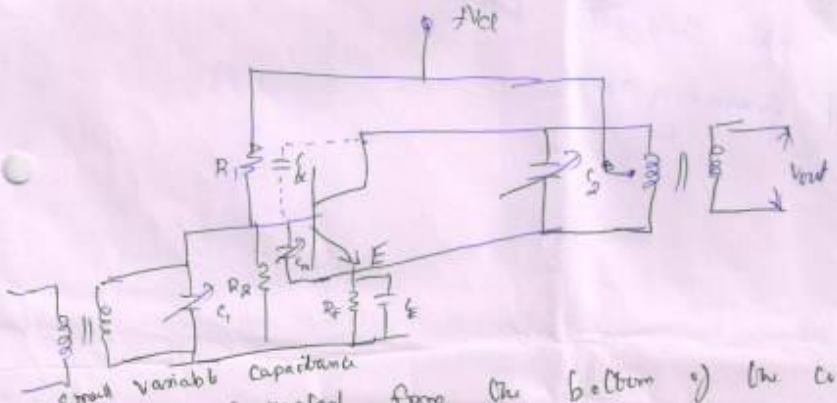
So, $y_{re} = Y_N$. → Oscillation doesn't exist, if the designed Circuit element matches y_{re} for all values of frequency and operating conditions.

$$y_{re} = -j\omega C_{re}$$

Hazeltine neutralization method:

→ This is a neutralization technique employed in tuned RF amplifiers to maintain stability.

→ The undesired effect of the collector to base capacitance of the transistor is neutralized by introducing a signal which cancels the signal coupled through the collector to base capacitance.



→ C_N is connected from the bottom of the coil to the base of the transistor.

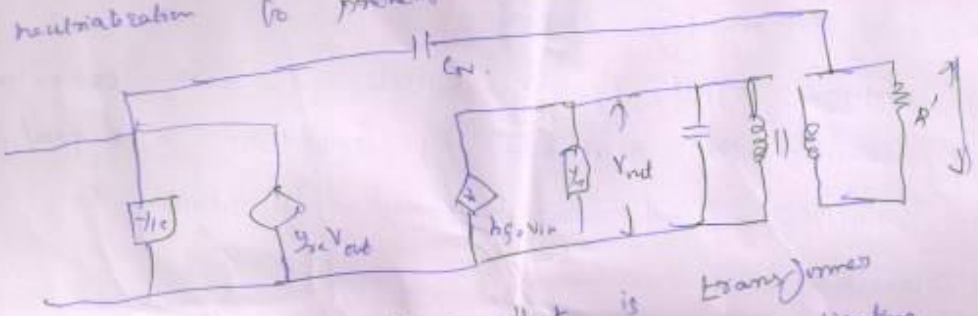
→ The neutralization process is achieved by C_N.

→ It introduces a signal to the base of the signal, it cancels out the signal feed to the base by C_{bc}.

→ Generally a variable capacitor is used for neutralization as the value of cbc changes with time.

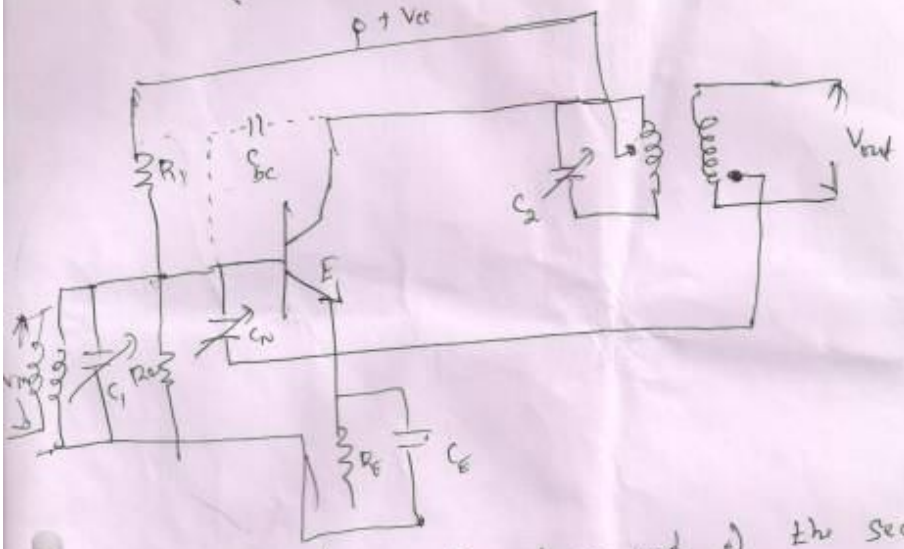
→ By proper adjusting C_N, exact neutrialization is achieved.

A tuned ~~Circuit~~ amplifier with narrow band neutralization to prevent oscillation.



⇒ To use fixed Capacitance that is transformer Coupled for 180° phase shift to produce neutralization over a ~~g~~ limited frequency range.

Modified Hazeltine - Neutrodyne Neutralization



→ C_N is connected to the lower end of the secondary coil of the next stage.

→ So, it is insensitive to any variation in the supply voltage V_{cc}, and provide high stability for the tuned amplifier.

Problem :

→ A single tuned RF amplifier uses a transistor with an output resistance of 50kΩ, output capacitance of 15pF and i/p resistance of next stage is 20kΩ. The tuned circuit for has 47pF capacitance in parallel with series combination of 1μH inductance and 2Ω resistance. Calculate

(i) Resonant frequency

(ii) Effective quality factor.

(iii) BW of the circuit

$$f_r = \frac{1}{2\pi\sqrt{L C_{eq}}} = 20.2\text{MHz}$$

$$Q_{eff} = \omega_0 C_{eq} R_t \qquad R_t = R_0 \parallel R_p \parallel R_i$$

$$R_p = \omega_0 L Q = 830\Omega \qquad Q_{eff} = 40.52$$

$$BW = \frac{f_0}{Q_{eff}} = 498.5\text{kHz}$$

Effect of cascading Single Tuned amplifiers on Bandwidth:

(i) To obtain a high overall gain, several tuned amplifiers can be used in cascade.

(ii) The overall voltage gain is the product of the voltage gain's of the each stages.

(iii) Consider n stages of single tuned amplifiers connected in series.

The aim is to determine overall gain and bandwidth of an amplifier.

The relative gain of a single tuned amplifier w.r.t the gain at resonant frequency f_o is gn by

$$\left|\frac{A}{A_{res}}\right| = \frac{1}{\sqrt{1+(2SQ_e)^2}}$$

The gain of n stage cascaded amplifiers

$$\left|\frac{A}{A_{res}}\right|^n = \left[\frac{1}{\sqrt{1+(2SQ_e)^2}}\right]^n$$

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

$\left|\frac{A}{A_{res}}\right|^n$ to $1/\sqrt{2}$.

$$\left(\frac{A}{A_{mid}}\right)^n = \frac{1}{\left[\sqrt{1+(2\delta Q_e)^2}\right]^n} = 1/\sqrt{2}$$

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

$$\sqrt{1+(2\delta Q_e)^2} = 2^{\frac{1}{2n}}$$

square root

$$1+(2\delta Q_e)^2 = 2^{1/n}$$

$$(2\delta Q_e)^2 = 2^{1/n} - 1$$

$$2\delta Q_e = \sqrt{2^{1/n}-1}$$

$\delta \Rightarrow$ Fractional variation

$$\delta = \frac{\omega - \omega_0}{\omega} = \frac{f - f_0}{f_0}$$

$$2\left(\frac{f-f_0}{f_0}\right)Q_e = \pm\sqrt{2^{1/n}-1}$$

$$\boxed{f - f_0 = \pm \frac{f_0}{2Q_e}\sqrt{2^{1/n}-1}}$$

$$f_2 - f_0 = \frac{f_0}{2Q_e}\sqrt{2^{1/n}-1}$$

$$f_0 - f_1 = \frac{f_0}{2Q_e}\sqrt{2^{1/n}-1}$$

The Bandwidth of n stage identical amplifiers is

$$B_{1n} = f_2 - f_1 = f_2 - f_0 + f_0 - f_1$$

$$= \frac{f_0}{2Q_e}\sqrt{2^{1/n}-1} + \frac{f_0}{2Q_e}\sqrt{2^{1/n}-1}$$

$$= \frac{f_0}{2Q_e}\sqrt{2^{1/n}-1}$$

$$\boxed{B_{1n} = B_1\sqrt{2^{1/n}-1}}$$