Unit - II

Oscillators

Classification, Barkhausen Criterion - Mechanism for start of oscillation and stabilization of amplitude, General form of an oscillator, Analysis of LC oscillators - Hartley, Colpitts, Clapp, Franklin, Armstrong, Tuned Collector oscillators, RC oscillators - Phase shift - Weinbridge - Twin T oscillators, Frequency range of RC and LC oscillators, Quartz crystal construction, Electrical equivalent circuit of Crystal Miller and pierce crystal oscillators, frequency stability of oscillators

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Introduction:-

* electroic devices like TV, Radio, Computer, etc.. ~~having~~ require different types of waveform such as sinusoidal, square wave pulse (or) triangular wave of specified freq and amplitude.

* They are generated by electroic ckt known as oscillator (or) waveform generator.

* It's basically known as positive F.B

* Oscillator :- can be defined as a circuit which self generating some waveform such as sine, triangular, square, etc., It is also known as a converter, it converts power from dc power supply in to ac power.

* Types (1) Sinusoidal (or) Harmonic oscillator
(2) Relaxation oscillator (or) non sinusoidal oscillator.

* Classification of sinusoidal oscillators,

(uses -ve resistance of the amplifying devices to neutralize the +ve resistance of the oscillator.)

(1) Two terminal oscillators (or) Negative resistance oscillators.
   - It consists of primarily two terminal devices (that has (-ve) resistance in a portion of its operating char.) and a freq. selective N/w. Ex: Tunnel diode oscillator.

(2) Four Terminal oscillators (or) FB oscillator
   - It consists of an amplifier & a freq. selective N/w
   Ex:- RC oscillator, LC oscillator, crystal oscillator etc,

* Relaxation oscillation - classified as
   (1) Multivibrator
   (2) UJT relaxation oscillator
   (3) Bootstrap Sweep Circuit.

* Oscillator must contain three basic components,
   (1) An amplifier
   (2) A freq. determining N/w
   (3) +ve (or) regenerative F.B

Method For Start of oscillation:-

* oscillator is a ckt which self generating some waveform like sine, triangular, and square wave etc.,

* It is basically amplifier ckt with +ve F.B, F.B N/w consist by RC, LC or crystal ckts.

* Oscillator also defined as, without application of any I/P's, the ckt is able to self generate some oscillation with defined freq.

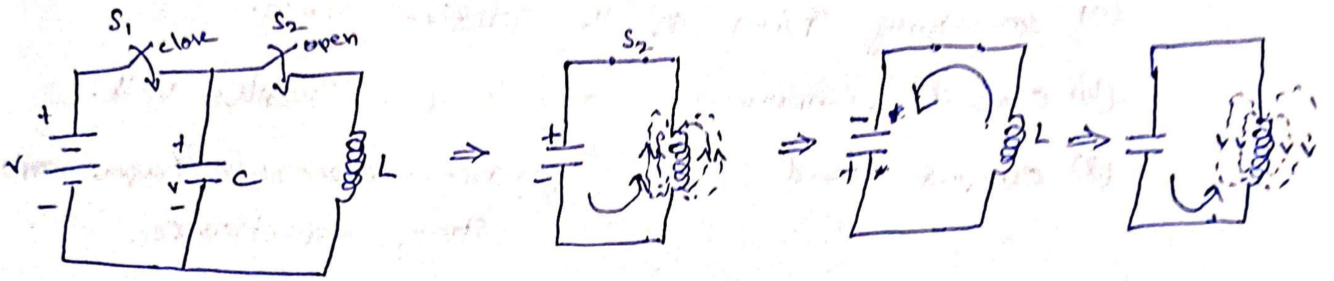
74 * Oscillator ckt consist of passive element L & C, This LC ckt is known as tank circuit.

- both elements are capable of storing electrical energy.

L (Inductor) = store energy in the form of magnetic field whenever ct flow through it

C (Capacitor) = store energy in its electric field whenever a volt. is applied across the plates.

Ckt operation:-



Stability of An Oscillator:-

* Let us consider an amplifier with +ve F.B as shown in fig.

we know,

$i;\ V_i = V_s + V_f = V_s + \beta V_o$

$\therefore V_s = V_i - \beta V_o$

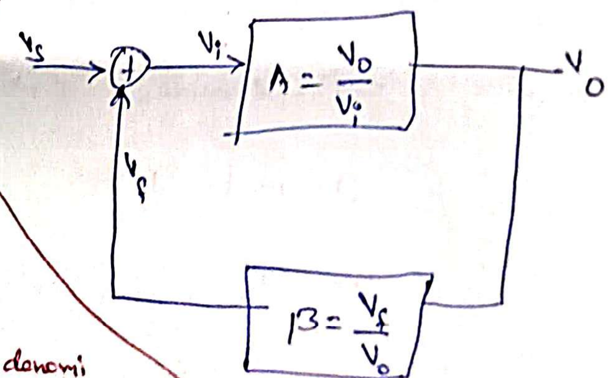
$V_o = (V_s + V_f)A$ (but $V_f = \beta V_o$)

$= (V_s + \beta V_o)A = AV_s + A\beta V_o$

$V_o(1 - A\beta) = AV_s$

(or)

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



$A_f = \frac{V_o}{V_s}$

$= \frac{V_o}{V_i - \beta V_o}$

÷ V_i in numer. & denomi

$= \frac{V_o/V_i}{\frac{V_i}{V_i} - \beta\frac{V_o}{V_i}} = \frac{A}{1 - \beta A}$

$V_s = V_i - V_f = V_i - \beta V_o$

$\therefore |A_f = \frac{A}{1 - A\beta}| \Rightarrow |A_f| > |A|$

* From F.B Amplifier,

If $|HA\beta| > 1$ is negative (or) degenerative F.B

If $|1+A\beta| < 1$ is +ve (or) regenerative F.B

* +ve F.B amplifier the stability is affect by supply volt., ageing of transistor, noise, etc.;

* <u>Frequency stability</u> :- i.e; maintain constant freq over a longtime interval.

⇒ change in freq. of oscillation is due to the following factor

(a) operating point of the active device.

(b) circuit components

(c) supply volt.

(d) output load

(e) Inter electrode capacitance and stray capacitance.

* <u>Barkhausen Criterion</u> :-

- To generate oscillation $|\beta A| > 1$. To maintain oscillation the condition $|\beta A_v| = 1$. If $|\beta A_v| \geq 1$ exists non-linearity which gives rise to damping

- Barkhausen criterion, defines two basic requirements for oscillation

(1) Total phase shift in the closed loop is 0° (or) 360°

(2) The magnitude of loop gain i.e; $|A\beta| = 1$.

If the two conditions are satisfied, the F.B amplifier will produce an oscillation without applying any external I/P

General Form of LC oscillator

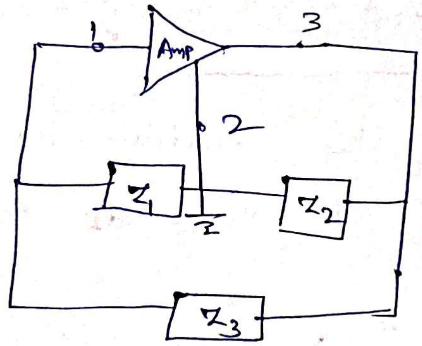
* It is a combination of amplifier & F.B components.

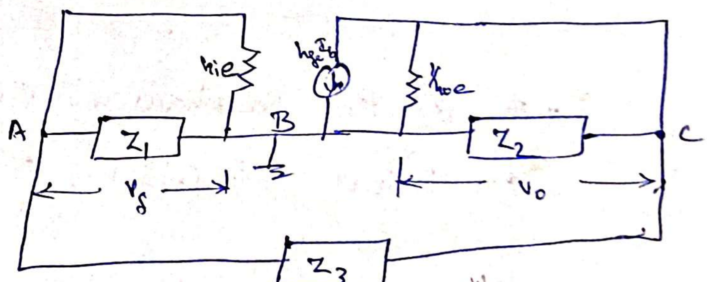
* amplifier produce 180° phase shift and F.B N/w produce 180°, thus the total phase shift is 360°. It is the required condition for the oscillation.

(1) BJT LC oscillator provides finite I/P impe.

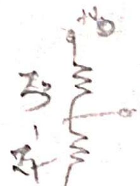
(2) FET (or) op-amp provides Infinite I/P Impe.

* General form of LC oscillator shown in figure.





* The impe. across BC (or) 2 & 3 = Z_L



$$V_f = \frac{Z_1'}{Z_1' + Z_3}$$

$$Z_L = ((h_{ie} \| Z_1) + Z_3) \| Z_2$$

$$= Z_2 \| \left(Z_3 + \frac{Z_1 h_{ie}}{Z_1 + h_{ie}} \right) = \frac{Z_2\left(Z_3 + \frac{Z_1 h_{ie}}{Z_1 + h_{ie}}\right)}{Z_2 + Z_3 + \frac{Z_1 h_{ie}}{Z_1 + h_{ie}}}$$

$$= \frac{Z_2\left[Z_3(Z_1 + h_{ie}) + Z_1 h_{ie}\right]}{(Z_2 + Z_3)(Z_1 + h_{ie}) + Z_1 h_{ie}}$$

$$Z_L = \frac{Z_2\left[Z_3 Z_1 + (Z_3 + Z_1) h_{ie}\right]}{Z_2 Z_1 + Z_3 Z_1 + (Z_1 + Z_2 + Z_3) h_{ie}}$$

* The volt. F.B to I/p terminal 1 & 2 is determined by potential division rule such as,

$$V_f = \frac{V_o (Z_1 \| h_{ie})}{(Z_1 \| h_{ie}) + Z_3}$$

The F.B factor, $\beta = \frac{V_f}{V_o}$ hence $\frac{V_f}{V_o} = \frac{\frac{Z_1 h_{ie}}{Z_1 + h_{ie}}}{\frac{Z_1 h_{ie}}{Z_1 + h_{ie}} + Z_3}$

(or) $\beta = \frac{Z_1 h_{ie}}{Z_1 h_{ie} + (Z_1 + h_{ie}) Z_3} = \frac{Z_1 h_{ie}}{Z_3 Z_1 + h_{ie}(Z_1 + Z_3)}$

* Volt. gain of CE amplifier is,

$$A_v = \frac{-h_{fe} Z_L}{h_{ie}} = \frac{-h_{fe}}{h_{ie}} \left(\frac{Z_2 [(Z_3 + Z_1) h_{ie} + Z_3 Z_1]}{Z_3 Z_1 + Z_2 Z_1 + h_{ie}(Z_1 + Z_2 + Z_3)} \right)$$

where h_{ie}

* As per the Barkhausen criterion the condition for sustained oscillations $|A\beta| \geq 1$, substitute the value of A_v and β.

thus, $\frac{-h_{fe}}{h_{ie}} \left(\frac{Z_2 [(Z_3 + Z_1) h_{ie} + Z_3 Z_1]}{Z_3 Z_1 + Z_2 Z_1 + h_{ie}(Z_1 + Z_2 + Z_3)} \right) \frac{Z_1 h_{ie}}{[Z_3 Z_1 + h_{ie}(Z_1 + Z_3)]} \geq 1$

(or)

$$\left(\frac{-h_{fe} Z_1 Z_2}{Z_3 Z_1 + Z_2 Z_1 + h_{ie}(Z_1 + Z_2 + Z_3)} \right) \geq 1$$

(or)

$$-h_{fe} Z_1 Z_2 = Z_3 Z_1 + Z_2 Z_1 + h_{ie}(Z_1 + Z_2 + Z_3)$$

$$h_{fe} Z_1 Z_2 + Z_3 Z_1 + Z_1 Z_2 + h_{ie}(Z_1 + Z_2 + Z_3) = 0$$

← general form of an LC oscillator eq.

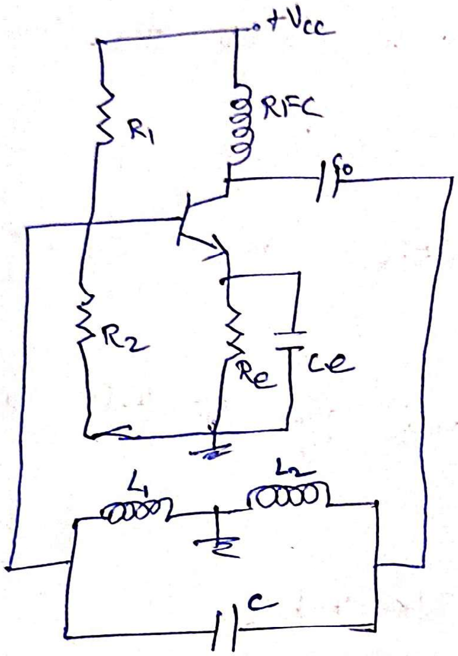
At resonant condition,

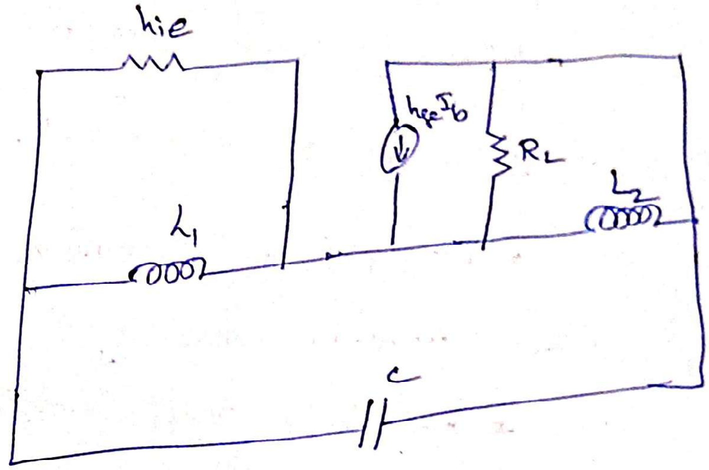
* LC oscillations produce oscillations at resonant condition,
- At resonance, imaginary part is zero i.e; $h_{ie}(Z_1 + Z_2 + Z_3) = 0$

To determine

* freq. of oscillation is determined and real part is equated to zero. to determine condition for the oscillations.

Hartley Oscillator:-





Construction:-

* Construct by amplifier and F.B N/W
  - amplifier is CE configuration & Volt. divider biasing.
  - F.B N/W consist by two Inductance and one capacitor.

* In general form, LC ckt Z_1, Z_2 and Z_3 are here

  Z_1 & Z_2 - Inductors and Z_3 is a capacitor.

* R_1, R_2, R_e - provide biasing and stabilisation.

* RFC & C_o - provide high reactance for DC signal.

Operation :- (L_1 - I/p ckt, L_2 - O/p ckt, L_3 - F.B element)

* when V_{cc} is applied, o/p volt. of transistor is flow into tanker ckt LC. and capacitor start to charge maxi. volt.

* It is initial excitation for the tank ckt causing a ct flow in the LC ckt.

* It's producing damping oscillation across L_1, which drives transistor base.

* then base signal amplifier and given o/p itself again given I/p to C and L_2.

* F.B signal is inphase of I/p volt.

* L_1 & L_2 connecting opposit polarity they are produces 180° phase shift of CE O/p. & sustained oscillation.

Analysis

* The general equ. for LC oscillator,

$$h_{fe} Z_1 Z_2 + Z_3 Z_1 + Z_1 Z_2 + h_{ie}(Z_1 + Z_2 + Z_3) = 0$$

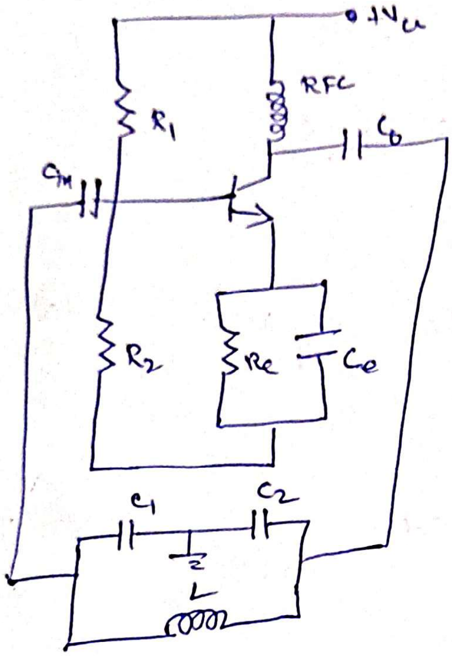
substitute $Z_1 = j\omega L_1$, $Z_2 = j\omega L_2$, $Z_3 = \frac{-j}{\omega C}$

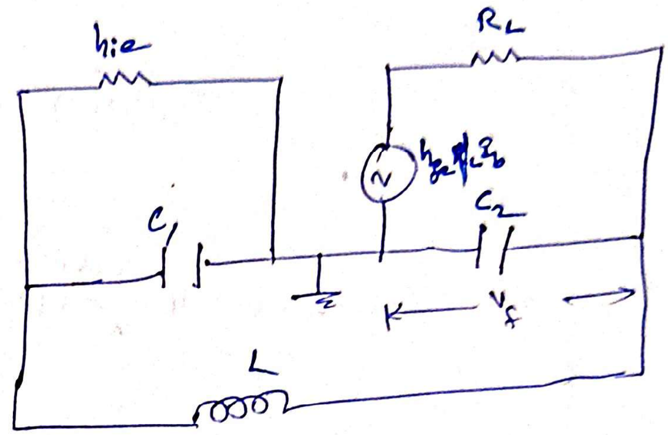
$$-h_{fe}\omega^2 L_1 L_2 + \frac{L_1}{C} - \omega^2 L_1 L_2 + h_{ie} j\omega \left(L_1 + L_2 - \frac{1}{\omega^2 C}\right) = 0$$

* To determine the freq. of oscillation, the imaginary part is equaled to zero.

ie; $\omega h_{ie} \left(L_1 + L_2 - \frac{1}{\omega^2 C}\right) = 0$

27 Colpits Oscillator:-





Construction:- Z_1 & Z_2 are Capacitor (C_1 & C_2)

Z_3 is Inductance.

Operation:- C_1 - I/p capacitor, C_2 - O/p capacitor

* When V_{cc} is applied, ct flow is increased in L and C_1, C_2 charge maxi. volt. They are produce oscillation in tank ci

* This damping. signal applied to I/p of base ckt.

* C_1 & C_2 ~~produces~~ convert F.B signal Inphase of I/p signal i.e; produces 180° phase shift of V_0.

(or) $L_1+L_2 = \frac{1}{\omega^2 C}$ (or) $\omega^2 = \frac{1}{(L_1+L_2)C}$

(or)

$$f = \frac{1}{2\pi\sqrt{(L_1+L_2)C}} \quad \text{(or)} \quad \frac{1}{2\pi\sqrt{L_{eq}C}}$$

* To determine the condition for oscillation, the real part is equated to zero,

$$-h_{fe}\omega^2 L_1 L_2 + \frac{L_1}{C} - \omega^2 L_1 L_2 = 0$$

$$-\omega^2 L_1 L_2 (1+h_{fe}) + \frac{L_1}{C} = 0$$

$$\frac{L_1}{C} = \omega^2 L_1 L_2 (1+h_{fe})$$

Substitute the value of ω^2 we get, ie; $\omega^2 = \frac{1}{(L_1+L_2)C}$

$$\frac{L_1}{C} = \frac{L_1 L_2 (1+h_{fe})}{(L_1+L_2)C}$$

$$L_1 = \frac{L_1 L_2 (1+h_{fe})}{(L_1+L_2)}$$

$$\frac{L_1+L_2}{L_2} = (1+h_{fe})$$

$$1+\frac{L_1}{L_2} = 1+h_{fe}$$

$$h_{fe} = \frac{L_1}{L_2} = \beta$$

ie; the condition for sustained oscillation.

Analysis:

The general equ. for LC oscillator is,

$$h_{fe}Z_1Z_2 + Z_3Z_1 + Z_1Z_2 + h_{ie}(Z_1+Z_2+Z_3) = 0$$

In this case, $Z_1 = \frac{-j}{\omega C_1}$; $Z_2 = \frac{-j}{\omega C_2}$ & $Z_3 = j\omega L$

$$-h_{fe}\frac{1}{\omega^2 C_1 C_2} + \frac{L}{C_1} - \frac{1}{\omega^2 C_1 C_2} + h_{ie}\left(-\frac{j}{\omega C_1} - \frac{j}{\omega C_2} + j\omega L\right) = 0$$

$$\frac{-h_{fe}}{\omega^2 C_1 C_2} + \frac{L}{C_1} - \frac{1}{\omega^2 C_1 C_2} + j h_{ie}\left(\frac{-1}{\omega C_1} - \frac{1}{\omega C_2} + \omega L\right) = 0$$

* At resonant freq, the reactance cancel one another, thus to determine the freq of oscillation equate the imaginary part to zero.

$$h_{ie}\left(-\frac{1}{\omega C_1} - \frac{1}{\omega C_2} + \omega L\right) = 0$$

$$-\frac{1}{\omega C_1} - \frac{1}{\omega C_2} + \omega L = 0 \quad \text{(or)} \quad \omega L = \frac{1}{\omega C_1} + \frac{1}{\omega C_2}$$

$$\omega^2 L = \frac{1}{C_1} + \frac{1}{C_2} \quad \text{(or)} \quad \omega^2 = \frac{1}{C_{eq} \cdot L}$$

$$\omega = \frac{1}{\sqrt{C_{eq} \cdot L}}$$

$$\boxed{f = \frac{1}{2\pi\sqrt{C_{eq} \cdot L}}}$$

* This freq. is slightly less than the resonant freq of tank ckt; f_0

* To determine the condition for oscillation, real part is equated to zero.

Thus, $-h_{fe}\frac{1}{\omega^2 C_1 C_2} + \frac{L}{C_1} - \frac{1}{\omega^2 C_1 C_2} = 0$

$$-\frac{(h_{fe}+1)}{\omega^2 C_1 C_2} + \frac{L}{C_1} = 0$$

$\because \frac{h_{fe}+1}{\omega^2 C_1 C_2} = \frac{L}{C_1}$

$\frac{1}{\omega^2 C_2}(h_{fe}+1) = L$, we know $\omega^2 L = \frac{1}{C_1} + \frac{1}{C_2}$

hence $h_{fe}+1 = \omega^2 L C_2 = \left(\frac{C_1+C_2}{C_1 C_2}\right) C_2 = \left(1+\frac{C_2}{C_1}\right)$

$$h_{fe}+1 = \frac{C_2}{C_1}+1$$

(or)

$$\boxed{h_{fe} = \frac{C_2}{C_1}}$$

This is the condition for the sustained oscillation.

Clapp oscillator:-

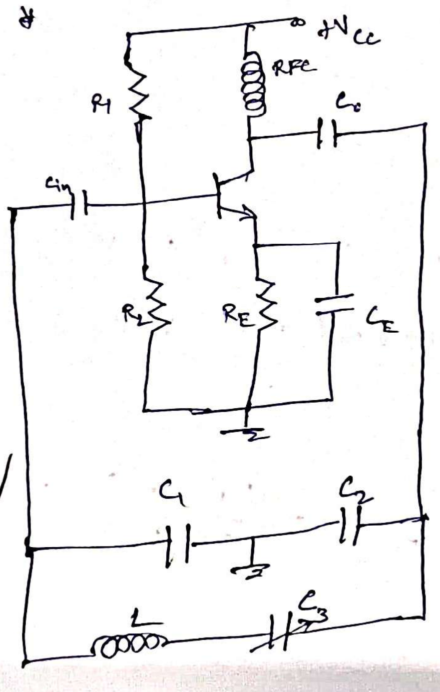
* Modified form of Colpits oscillator (or) Variable Colpits oscillator.

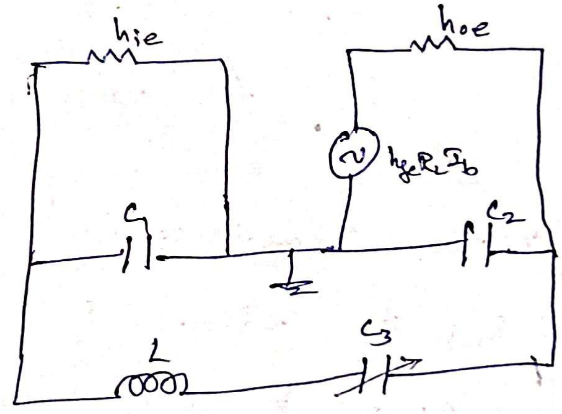
* F.B N/w consist of C_1, C_2, C_3 and L.

* C_1 - made large so as to reduce the effect of collector capacitor variations due to the collector voltage change.

* biasing Resistor R_2 may be in the form of a thermistor so that emitter current gets reduced at high Temperatures.

*





* The freq. of oscillation can be determined from the resonance condition. we know, at resonance the imaginary part of general LC oscillator ~~refer section~~ is equated to zero

i.e; $h_{fe}Z_1Z_2 + Z_3Z_1 + Z_1Z_2 + h_{ie}(Z_1+Z_2+Z_3) = 0$

$$h_{ie}(Z_1 + Z_2 + Z_3) = 0$$

(or)

$$Z_1 + Z_2 + Z_3 = 0$$

Let, $Z_1 = \frac{-j}{\omega C_1}$; $Z_2 = \frac{-j}{\omega C_2}$; $Z_3 = j\omega L + \frac{1}{j\omega C_3}$

hence, $\frac{-j}{\omega C_1} - \frac{j}{\omega C_2} - \frac{j}{\omega C_3} + j\omega L = 0$

(or)

$$j\omega L = j\left(\frac{1}{\omega C_1} + \frac{1}{\omega C_2} + \frac{1}{\omega C_3}\right)$$

(or)

$$\omega^2 L = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right), \quad \omega^2 = \frac{1}{LC_T} \quad \text{where } \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

(or)

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

* The capacitance C_3 is used for tuning purpose only hence to find the condition for the oscillation real part of general equ. is equated to zero.

i.e., $h_{fe} Z_1 Z_2 + Z_1 Z_3 + Z_1 Z_2 = 0$

(or)

$$(h_{fe}+1)\left(-\frac{1}{\omega^2 C_1 C_2}\right) + \frac{-j}{\omega C_1}(j\omega L) = 0$$

(or)

$$\frac{-(h_{fe}+1)}{\omega^2 C_1 C_2} + \frac{L}{C_1} = 0$$

$$\frac{L}{C_1} = \frac{(h_{fe}+1)}{\omega^2 C_1 C_2}$$

(or)

$\omega^2 L C_2 = (h_{fe}+1)$ we know $\omega^2 L = \frac{1}{C_1} + \frac{1}{C_2}$

$$C_2\left(\frac{1}{C_1} + \frac{1}{C_2}\right) = h_{fe}+1$$

$$\frac{C_2}{C_1} + 1 = h_{fe}+1$$

(or)

$$\boxed{h_{fe} \geq \frac{C_2}{C_1}}$$

Principle of RC Oscillators:-

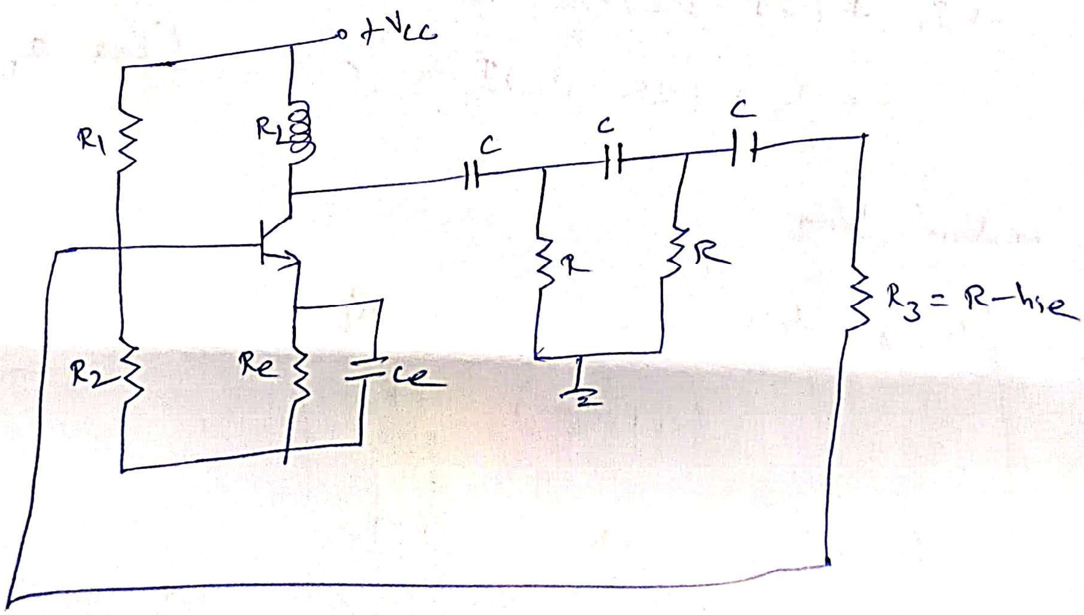
* LC oscillators are operating in high freq. (20KHz to 3MHz).

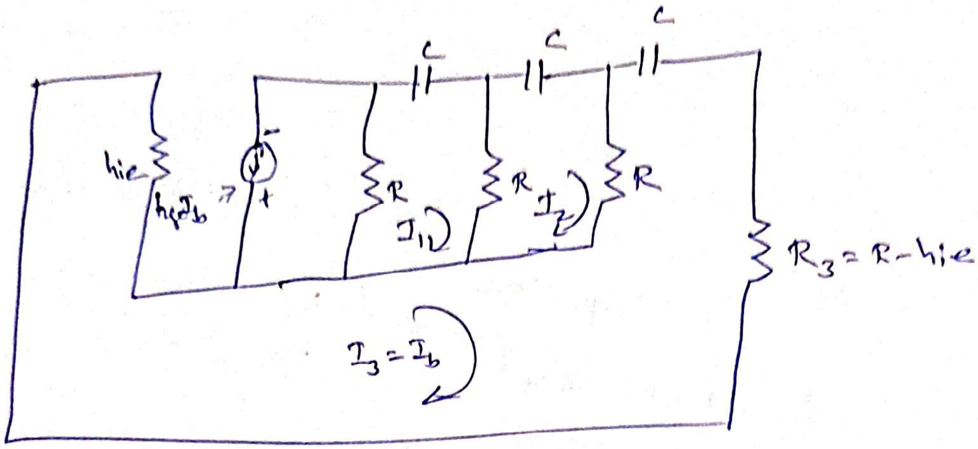
* But At low freq, they are not suitable. so we are go to RC ~~phase shift~~ oscillator.

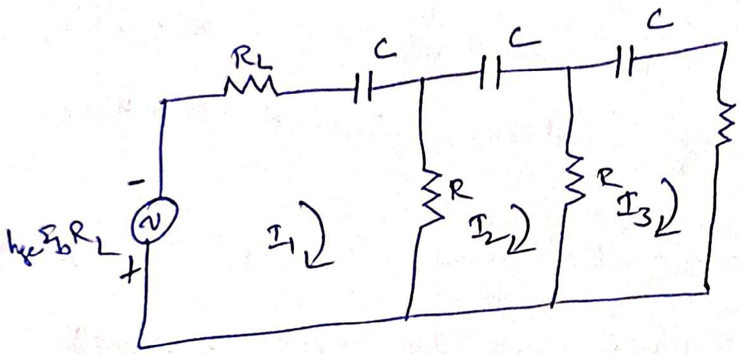
* RC oscillator two types
  (1) RC phase shift oscillator (20 to 20 KHz)
  (2) Wein bridge oscillator. (upto to 100 KHz)

* RC N/w, produces 180° Phase shift of CE o/p signal. i.e; using to match with I/p signal (in-phase)

RC phase Shift oscillator:-







[∵ $R - h_{ie} + h_{ie} = R$

i.e., R_3 connecting series with h_{ie}

Applying KVL for the fig,

$\rightarrow -h_{fe}I_bR_L$

$$(R_L + R - jX_c) I_1 - R I_2 + h_{fe} I_b R_L = 0$$

$$-R I_1 + (2R - jX_c) I_2 - R I_3 = 0$$

$$-R I_2 + (2R - jX_c) I_3 = 0$$

[Let $I_b = I_3$

In matrix form,

$$\begin{vmatrix} (R_L + R + \frac{1}{j\omega C}) & -R & h_{fe}R_L \\ -R & (2R + \frac{1}{j\omega C}) & -R \\ 0 & -R & 2R + \frac{1}{j\omega C} \end{vmatrix} = 0$$

$(a+b)^2 = a^2 + b^2 + 2ab$

$$\left(R+R_L+\frac{1}{j\omega C}\right)\left[\left(2R+\frac{1}{j\omega C}\right)^2 - R^2\right] + R\left[-R\left(2R+\frac{1}{j\omega C}\right)\right] + h_{fe}R_LR^2 = 0$$

$$\left(R+R_L+\frac{1}{j\omega C}\right)\left[4R^2 - \frac{1}{\omega^2C^2} + \frac{4R}{j\omega C} - R^2\right] - R^2\left(2R+\frac{1}{j\omega C}\right) + h_{fe}R_LR^2 = 0$$

$$(R+R_L)\left[3R^2 - \frac{1}{\omega^2C^2} + \frac{4R}{j\omega C}\right] + \frac{1}{j\omega C}\left[3R^2 - \frac{1}{\omega^2C^2} + \frac{4R}{j\omega C}\right]$$

$$-R^2\left(2R+\frac{1}{j\omega C}\right) + h_{fe}R_LR^2 = 0$$

(or)

$$(R+R_L)\left(3R^2 - \frac{1}{\omega^2C^2}\right) - (R+R_L)\left(\frac{j4R}{\omega C}\right) - j\left(\frac{3R^2}{\omega C} + \frac{1}{\omega^3C^3}\right)$$

$$-\frac{4R}{\omega^2C^2} \quad \left[-j\left(\frac{3R^2}{\omega C} + \frac{1}{\omega^3C^3}\right) - \frac{4R}{\omega^3C^3}\right]$$

$$-2R^3 + j\left(\frac{R^2}{\omega C}\right) + h_{fe}R_LR^2 = 0$$

Equating the Imaginary part to zero, to find the freq. of oscillation.

$$-(R+R_L)\left(\frac{4R}{\omega C}\right) - \left(\frac{3R^2}{\omega C} + \frac{1}{\omega^3C^3}\right) + \frac{R^2}{\omega C} = 0$$

Taking $1/\omega C$ commonly outside,

$$\left[-(R+R_L)4R - 3R^2 + \frac{1}{\omega^2C^2} + R^2\right]\frac{1}{\omega C} = 0$$

$$-4R^2 - 4R_LR - 3R^2 + R^2 + \frac{1}{\omega^2C^2} = 0$$

(or) $\frac{1}{\omega^2 C^2} = 6R^2 + 4R_L R$

$$\omega^2 = \frac{1}{C^2(6R^2+4R_L R)} = \frac{1}{C^2R^2\left(6+\frac{4R_L}{R}\right)}$$

$$\omega = \frac{1}{RC\sqrt{6+4K}} \quad \text{where } K = \frac{R_L}{R}$$

$$\boxed{f_o = \frac{1}{2\pi RC\sqrt{6+4K}}}$$

This is freq. of oscillation of RC oscillator.

* To obtain the condition for oscillation real part is equated to zero

$$(R+R_L)\left(3R^2 - \frac{1}{\omega^2 C^2}\right) - \frac{4R}{\omega^2 C^2} - 2R^3 + h_{fe} R_L R^2 = 0$$

$$3R^3 - \frac{R}{\omega^2 C^2} + 3R^2 R_L - \frac{R_L}{\omega^2 C^2} - \frac{4R}{\omega^2 C^2} - 2R^3 + h_{fe} R_L R^2 = 0$$

we know $\frac{1}{\omega^2 C^2} = 6R^2 + 4R_L R$ Sub. this value in the above eqn. and it becomes,

$$3R^3 - R(6R^2+4R_L R) + 3R^2 R_L - R_L(6R^2+4R_L R) - 4R(6R^2+4R_L R) - 2R^3 + h_{fe} R R^2 = 0$$

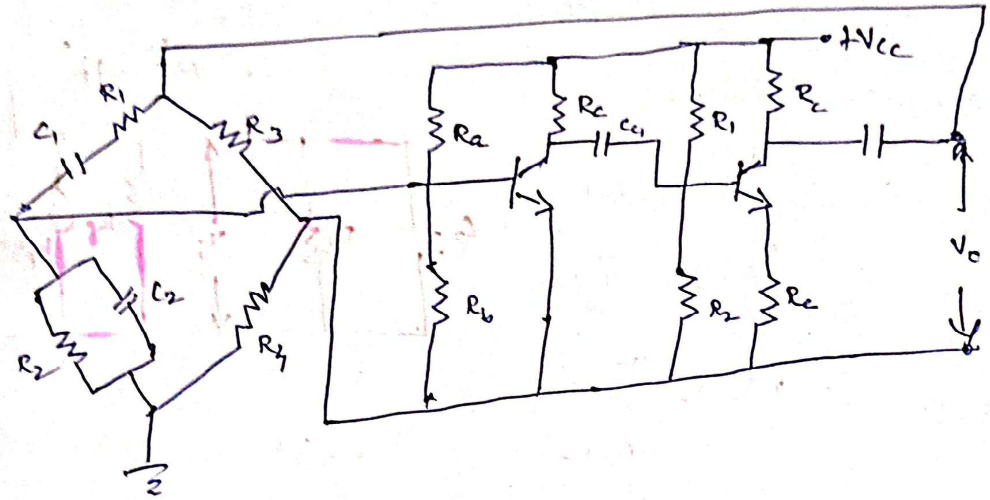
$$3R^3 - 6R^3 - 4R_L R^2 + 3R^2 R_L - 6R^2 R_L - 4R_L^2 R - 24R^3 - 16R_L R^2 - 2R^3 + h_{fe} R_L R^2 = 0$$

$$-29R^3 - 23R_L R^2 - 4R_L^2 R + h_{fe} R_L R^2 = 0$$

(or) $h_{fe} R_L R^2 = 29R^3 + 23R_L R^2 + 4R_L^2 R$

$$\boxed{h_{fe} = 29\frac{R}{R_L} + 23 + \frac{4R_L}{R} = 29k + 23 + 4K}$$

Wein Bridge oscillator:-



* It consist of a non-inverting amplifier and freq. determing n/w.

* freq. determing ckt consist of R_1C_1 in series R_2C_2 in shunt.

* R_1C_1 and R_2C_2 act as F.B N/w. The volt. across the parallel combination of R_2C_2 is fed to the I/p of the amplifier

* freq. of oscillation is determined by R_1C_1 and R_2C_2.

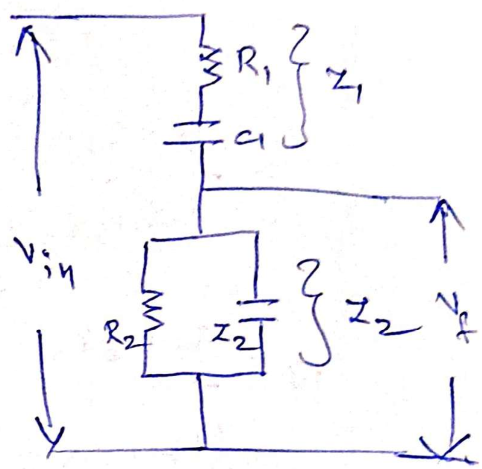
* R_3 and R_4 provides -ve F.B hence this oscillator has better amplitude stability.

* R_4 - is often a temp. sensitive resister with a +ve temp. co. effi.

* oscillation increase due to +ve F.B → R_2 also ↑ and provide -ve F.B to the ckt and reduce gain and kept oscillator in stable state.

Feedback N/w of Wein-Bridge oscillator

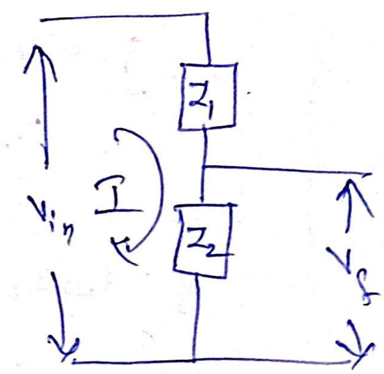
$$Z_1 = R_1 + \frac{1}{j\omega C_1} = \frac{1 + j\omega R_1 C_1}{j\omega C_1}$$



$$Z_2 = R_2 \parallel \frac{1}{j\omega C_2} = \frac{R_2 \frac{1}{j\omega C_2}}{R_2 + \frac{1}{j\omega C_2}}$$

$$= \frac{\frac{R_2}{j\omega C_2}}{\frac{j\omega C_2 R_2 + 1}{j\omega C_2}} = \frac{R_2}{1 + j\omega R_2 C_2}$$

$$I = \frac{V_{in}}{Z_1 + Z_2}$$



$$V_f = I \cdot Z_2 = \frac{V_{in} Z_2}{Z_1 + Z_2}$$

$$\frac{V_f}{V_{in}} = \frac{Z_2}{Z_1 + Z_2}$$

Defining, $\beta = \frac{V_f}{V_0} = \frac{Z_2}{Z_1 + Z_2}$ ——— (1)

Sub. Z_1 & Z_2 in eqn. (1),

$$\beta = \frac{\frac{R_2}{1 + j\omega R_2 C_2}}{\frac{1 + j\omega R_1 C_1}{j\omega C_1} + \frac{R_2}{1 + j\omega R_2 C_2}} = \frac{\frac{R_2}{1 + j\omega R_2 C_2}}{\frac{(1 + j\omega R_1 C_1)(1 + j\omega R_2 C_2) + j\omega R_2 C_1}{(j\omega C_1)(1 + j\omega R_2 C_2)}}$$

$$= \frac{R_2}{\frac{(1+j\omega C_1 R_1)(1+j\omega R_2 C_2)+j\omega R_2 C_1}{j\omega C_1}} = \frac{R_2 j\omega C_1}{(1+j\omega C_1 R_1)(1+j\omega R_2 C_2)+j\omega R_2 C_1}$$

$$= \frac{j\omega R_2 C_1}{1+j\omega R_2 C_2 + j\omega C_1 R_1 + j^2\omega^2 R_1 C_1 R_2 C_2 + j\omega R_2 C_1}$$

$$\beta = \frac{j\omega R_2 C_1}{(1-\omega^2 R_1 C_1 R_2 C_2) + j\omega(R_1 C_1 + R_2 C_2 + R_2 C_1)}$$

Multiplying by its conjugate,

$$\beta = \frac{j\omega R_2 C_1 \left[(1-\omega^2 R_1 C_1 R_2 C_2) - j\omega(R_1 C_1 + R_2 C_2 + R_2 C_1)\right]}{(1-\omega^2 R_1 C_1 R_2 C_2)^2 + \omega^2 (R_1 C_1 + R_2 C_2 + R_2 C_1)^2}$$

$$\beta = \frac{j\omega R_2 C_1 (1-\omega^2 R_1 C_1 R_2 C_2) + \omega^2 R_2 C_1 (R_1 C_1 + R_2 C_2 + R_2 C_1)}{(1-\omega^2 R_1 C_1 R_2 C_2)^2 + \omega^2 (R_1 C_1 + R_2 C_2 + R_2 C_1)^2} \longrightarrow (2)$$

Eqn. imag. parts to be zero, we get.

$$\omega R_2 C_1 (1-\omega^2 R_1 C_1 R_2 C_2) = 0$$

$$1-\omega^2 R_1 C_1 R_2 C_2 = 0$$

$$\omega^2 = \frac{1}{R_1 C_1 R_2 C_2}$$

$$\omega = \frac{1}{\sqrt{R_1 C_1 + R_2 C_2}}$$

$$\therefore f = \frac{1}{2\pi\sqrt{R_1 C_1 + R_2 C_2}} = \frac{1}{2\pi RC}$$ [where, $R_1 = R_2 = R$, $C_1 = C_2 = C$

If $R_1 = R_2 = R$ & $C_1 = C_2 = C$, then eqn ② is
~~The real part values are,~~

$$\beta = \frac{\omega^2 RC[3RC] + j\omega RC[1-\omega^2R^2C^2]}{(1-\omega^2R^2C^2)^2 + \omega^2(3RC)^2}$$

Sub $\omega = \frac{1}{RC}$

$$\beta = \frac{\frac{3R^2C^2}{R^2C^2} + \frac{jRC}{RC}\left[1-\frac{R^2C^2}{R^2C^2}\right]}{\left(1-\frac{R^2C^2}{R^2C^2}\right)^2 + \frac{1}{R^2C^2}(3RC)^2} = \frac{3}{9} = \frac{1}{3}$$

$\therefore |A\beta| \geq 1$ ie; $|A(\frac{1}{3})| \geq 1$.

$\therefore A \geq 3$, It is the condition for sustained oscillation.

Adv

① Good stability.

② By replacing R_2 with a thermistor, the amplitude stability of oscillator output volt. can be increased

③ overall gain is high because of two transistors employed in the circuit.

(4) freq. of oscillation can be changed varying R and C.

(5) Good sine wave output.

(6) It does not require inductors.

Disadv:-

(1) Circuit requires two transistors and large number of components.

(2) It can't generate very high freq.

Introduction to Tuned Amplifiers

Why Tuned Amplifiers?
In low-frequency amplifiers (RC coupled amplifiers), the gain remains almost constant over a wide frequency range.
However, in communication systems (radio, TV, wireless), we do not want amplification of all frequencies.
We require:
- Amplification of only one specific frequency
- Rejection of all other frequencies

This is achieved using a Tuned Amplifier, which uses a resonant circuit (LC circuit) as load.

Tuned Amplifier
A tuned amplifier is an amplifier in which the load is a resonant circuit (L and C) tuned to a particular frequency.
At resonance:
- The circuit offers maximum response
- Gain is maximum
- Selectivity is highest

Applications:
- RF amplifiers
- IF amplifiers
- Communication receivers

Resonance
Resonance occurs when inductive reactance equals capacitive reactance.

$$X_L = X_C$$
$$\omega L = \frac{1}{\omega C}$$
$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Where:
- f_0= Resonant frequency

At this frequency, the circuit behaves purely resistive.

a) Series Resonance
Condition:
L and C connected in **series**.
At Resonance:
- Impedance is minimum
- Current is maximum
- Circuit behaves like a short circuit (ideally)

$$Z = R$$

Characteristics:
- High current
- Low impedance
- Used in current-selective circuits

Bandwidth:

$$BW = \frac{R}{2\pi L}$$

b) Parallel Resonance

Condition:

L and C connected in parallel.

At Resonance:

- Impedance is maximum
- Current is minimum
- Circuit behaves like open circuit (ideally)

$$Z_{max} = \frac{L}{CR}$$

Characteristics:

- High voltage across tank
- Used in tuned amplifiers
- Provides high gain

Bandwidth:

$$BW = \frac{f_0}{Q}$$

Quality Factor (Q-Factor)

Quality factor indicates **selectivity** of the resonant circuit.

$$Q = \frac{\text{Energy stored}}{\text{Energy dissipated per cycle}}$$

For series circuit:

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

For parallel circuit:

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

Interpretation:

- High Q → Narrow bandwidth → High selectivity
- Low Q → Wide bandwidth → Poor selectivity

$$BW = \frac{f_0}{Q}$$

Tuned Amplifier

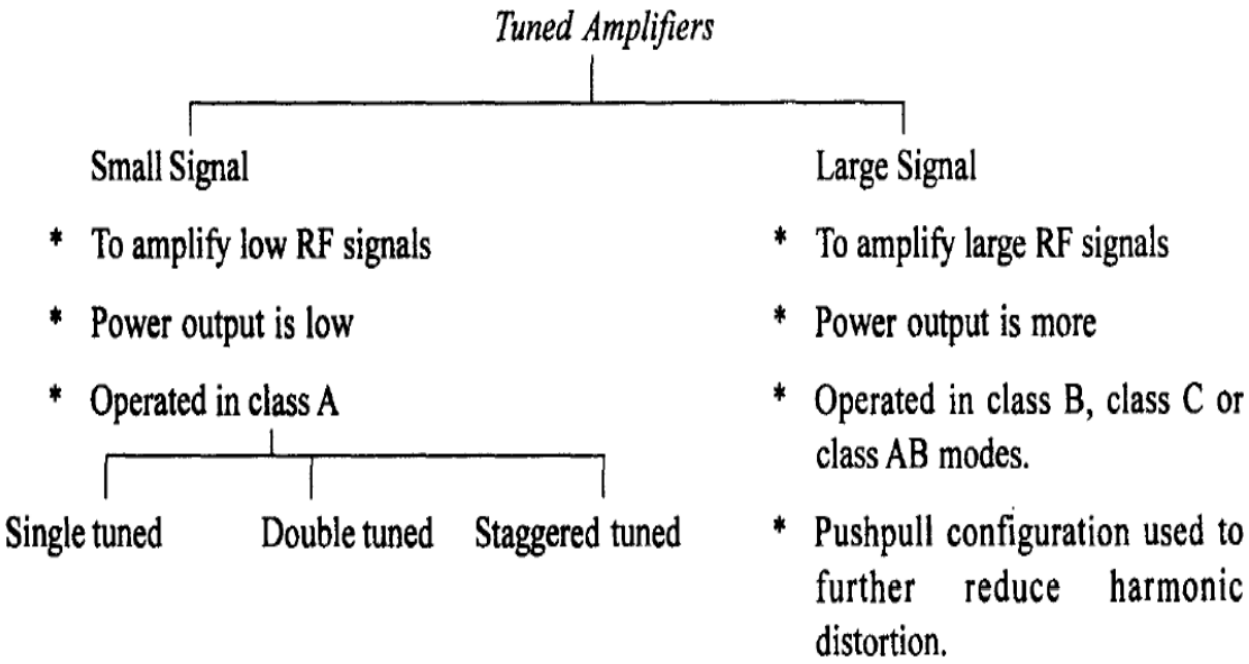
In tuned amplifiers:

- We use parallel resonant circuit (tank circuit) as load.
- At resonance:

  - Impedance is maximum
  - Voltage gain is maximum
- Away from resonance:
  - Gain decreases

Thus, tuned amplifier acts as a band-pass amplifier.

Classification of Tuned Amplifiers



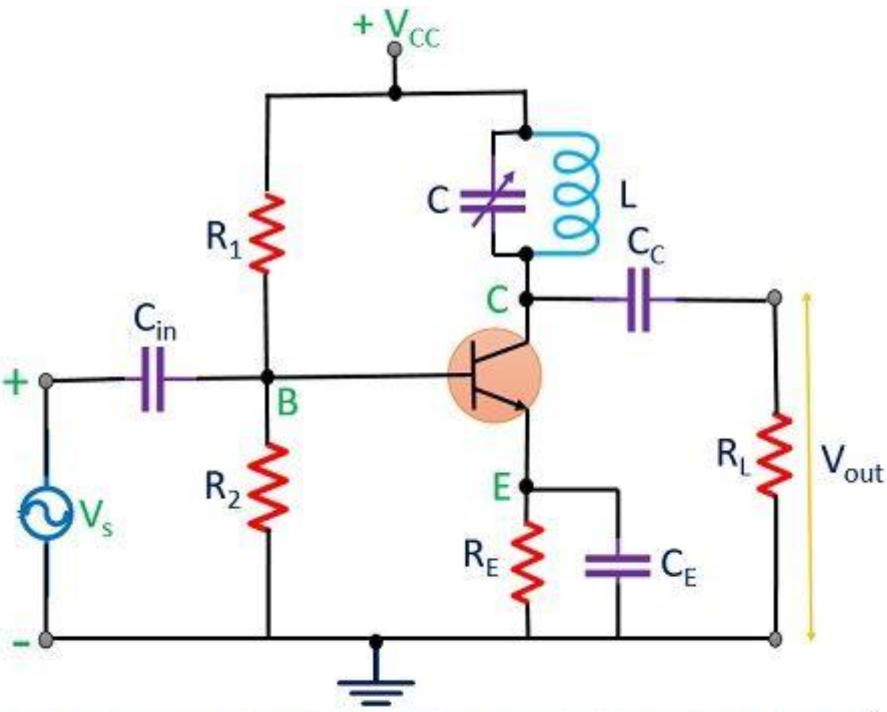
Single Tuned Amplifiers

Single Tuned Amplifiers are multistage amplifier circuit that employs a parallel tuned circuit as a load. However, the tuned circuit in each stage is required to be tuned to similar frequencies. A common emitter configuration amplifier can be used as a single tuned amplifier which includes the parallel tuned circuit.

During wireless communication, the radio frequency stage requires a tuned voltage amplifier in order to select the desired carrier frequency and amplify the allowed passband signal.

Construction of a Single Tuned Amplifier

The figure below shows the circuit arrangement of a single tuned amplifier with capacitive coupling.



Circuit of Single tuned amplifier with capacitive coupling

It is noteworthy here that for a tuned circuit, capacitance and inductance value must be so selected that the frequency of resonance must be equivalent to the frequency of the applied signal.

We can get the output of the circuit either by capacitive or inductive coupling. However, here we have used **capacitive coupling**.

The capacitor C_E employed in the circuit is a bypass capacitor whereas biasing and stabilization circuits are followed by R_1, R_2 and R_E.

Tuned LC circuit employed in the collector region acts as the load. In order to have a variable resonant frequency, the capacitor is variable. Large signal amplification can be obtained if the frequency of input signal is similar to the frequency of resonance of the LC circuit.

Operation of Single Tuned Amplifier

The circuit operation of single tuned amplifiers begins with the application of the high-frequency signal that is to be amplified at the base-emitter terminal of the transistor. By varying the capacitor employed in the tuned circuit, the resonant frequency of the circuit can be made equivalent to the frequency of the applied input signal.

Here, the high impedance is offered to the signal frequency by the tuned circuit. Thus, a large output is achieved. For an input signal with multiple frequencies, only the frequency that corresponds to resonant frequency will get amplified. While all other frequencies are rejected the LC circuit.

Hence, only the desired frequency signal gets selected and thus amplified by the circuit.

Voltage gain and frequency response

For a tuned amplifier, voltage gain is given by

$$A_v = \frac{\beta R_{ac}}{r_{in}} = \frac{\beta L/CR}{r_{in}}$$

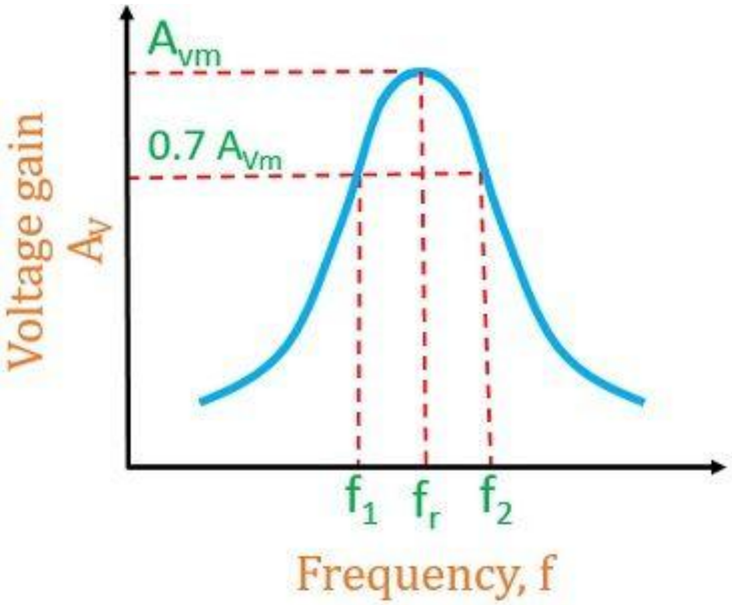
$$= \frac{\beta L}{CRr_{in}}$$

: R_{ac}= impedance of tuned circuit

z = L/CR

r_{in}= input impedance

Let us now move further and have a look at the frequency response curve shown below:



Frequency response curve of tuned amplifier

As we know that the impedance of the circuit is very high and is entirely resistive in nature at the frequency of resonance.

Thus, the maximum voltage is obtained across RL for a circuit tuned at the resonant frequency.

The bandwidth for a tuned amplifier is given as

$$BW = f_2 - f_1 = \frac{f_r}{Q}$$

Any frequency within this range will be amplified by the amplifier.

Cascading effect on bandwidth

Cascading of multiple stages of a tuned amplifier is basically done, to improve the overall gain of the system. As the total gain of the system is the result of the product of gain of each stage of the amplifier.

Double Tuned Amplifier

The double-tuned amplifier is one of the types of tuned amplifiers. The designing of this circuit can be done using two tuned circuits which are coupled inductively. The primary tuned circuit includes L1, C1 whereas the secondary circuit includes L2 C2. Here L1C1 and L2C2 are inductors and capacitors. In the collector terminals of the circuit, the coupling change in the tuned circuit will result in the change in the curve shape of frequency response. The adjustment of proper coupling among the two coils kin the double-tuned circuits, the necessary outcomes may be attained.

What is a Double Tuned Amplifier?

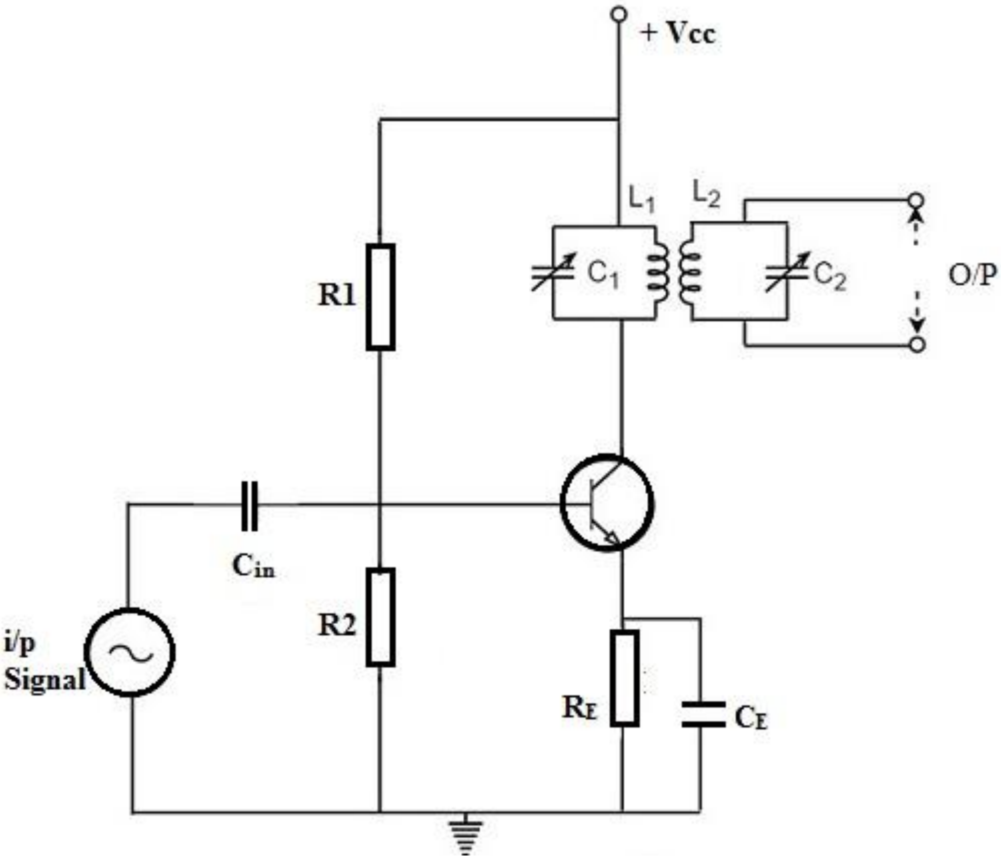
This is one kind of tuned amplifier that uses the coupling of transformer among the two stages like inductances of both the windings. The tuning of these windings can be done separately across a capacitor.

For the transformer, there is a critical value of coefficient where the amplifier's frequency response can be even maximally within the passband & the gain of this can be highest at the resonant frequency. The coupling can be used by the design which is greater than over coupling to get a level wider BW at the expenditure of a minute loss of gain within the middle of the passband.

The multiple stages of cascading in the amplifier can result in the bandwidth reduction in the entire amplifier. The BW of these stages includes 80% of the BW of the single stage. A substitute to these tuning neglects the bandwidth loss is called as staggered tuning. These amplifiers can be planned to a prearranged bandwidth that is superior to the BW of any single stage. But, this tuning needs several stages & includes less gain compare with double tuning.

Construction and Operation of Double Tuned Amplifier

The construction of this amplifier can be understood by the following circuit. This circuit can be built with two tuned circuits namely L1C1 & L2C2 within the collector segment of the amplifier.

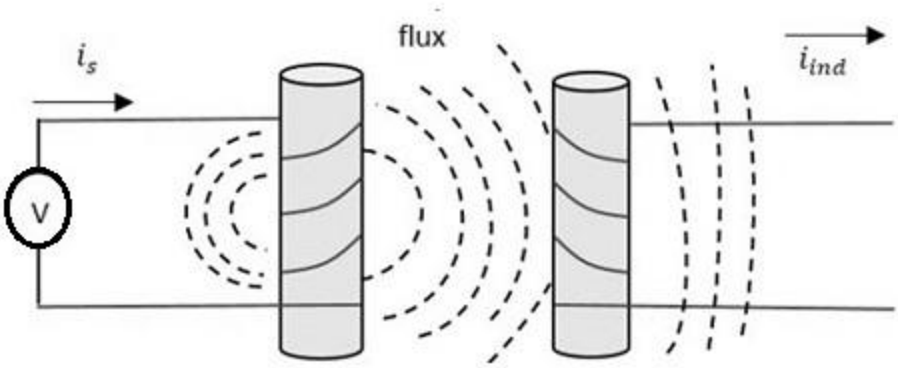


The sign at the o/p of the primary tuned circuit like L1C1 can be coupled with the secondary tuned circuit like L2C2 throughout the common coupling technique. The other details of this circuit are similar to the single tuned amplifier.

Operation

The signal which has to amplify is a high-frequency signal and it is given to the i/p of the amplifier. The primary tuning circuit like L1C1 can be tuned toward the i/p signal frequency.

In this state, the tuned circuit gives high reactance toward the signal frequency. As a result, huge o/p becomes visible at the o/p of the primary tuned circuit then it is coupled with the secondary tuned circuit like L2C2 using mutual induction. These circuits are widely used to connect different circuits of TV and radio receivers.

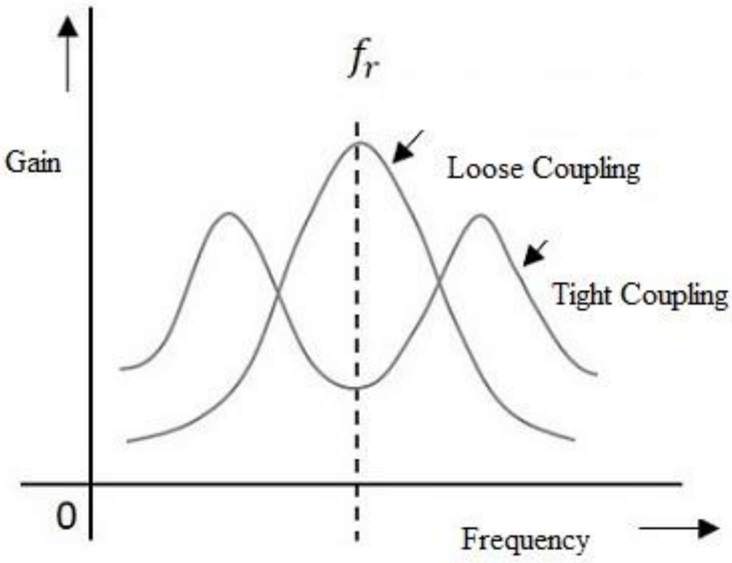


Based on the concept of mutual inductance, the coupling is shown in the following figure. As the two coils are spaced separately, the primary coil's flux linkages will not link to the secondary coil. Here the two coils are represented with L1 & L2. At this state, these coils have loose coupling. The reflected resistance from the L2 coil on this state is minute & the resonance curve is sharp.

When the two coils are arranged together, then they have tight coupling. Below these forms, the reflected resistance will be huge & the circuit is lesser. The gain maxima two positions are obtained one above & the other under the resonant frequency.

Bandwidth

The bandwidth of this amplifier is shown in the above figure which states that the BW rises by the amount of coupling. In a double-tuned circuit, the determining factor is not Q other than the coupling. From this, we can conclude that for a known frequency when the coupling is tighter then the bandwidth will be greater.



bandwidth-of-double-tuned-amplifier

The bandwidth equation is given as

$\mathbf{BW_{dt} = kf_r}$

In the above equation

'BW_{dt}' is BW of a double-tuned circuit

'K' is a coupling coefficient

'fr' is a resonant frequency.

Advantages

The advantages of the Double Tuned Amplifier include the following.

- The main advantage of a double-tuned amplifier is an amplifier including a tuned circuit on the input & the output.
- It has a narrow bandwidth.
- One more advantage of this circuit is impedance matching using the previous phase, etc.
- 3 dB BW is large
- It gives a frequency response including flatter sides.

- When the overall gain is increased then sensitivity will be increased. Here sensitivity is the capacity of receiving weak signals.
- Selectivity is improved.

Disadvantages

The disadvantages of a Double Tuned Amplifier include the following.

- These are not suitable for amplifying audio frequencies
- If the frequency band increases, then this design becomes complex
- The design uses tuning elements like capacitors & inductors, then the circuit is costly & bulky.

Applications of Double-tuned Amplifier

The applications of Double Tuned Amplifier include the following

- It is used in a superheterodyne receiver like an IF (intermediate frequency) amplifier.
- It is used in a satellite transponder like an intermediate frequency amplifier.
- These amplifiers are used within UHF radio relay systems.
- It is used in a spectrum analyzer like extremely narrow-band intermediate frequency amplifier
- These amplifiers are used like wideband tuned amplifiers intended for video amplification.
- These amplifiers are used like RF amplifiers within receivers.

Stagger Tuned Amplifier

Staggered tuned amplifier definition is an amplifier that is used to improve the total frequency response of the tuned amplifier. Usually, these amplifiers are designed to exhibit an overall response for maximal flatness in the region of the center frequency. The total frequency response of this amplifier can be achieved by adding up the separate response as one. When the different tuned circuit's resonant frequencies are staggered otherwise displaced, then it is known as a stagger tuned amplifier.

Stagger Tuned Amplifier Working

The circuit diagram shown below is a two-stage stagger tuned amplifier. In this circuit, the stagger tuning can be achieved by producing the tuned circuits like L1C1 and L2C2 to a little different frequency. The **stagger tuned amplifier circuit** is shown below.

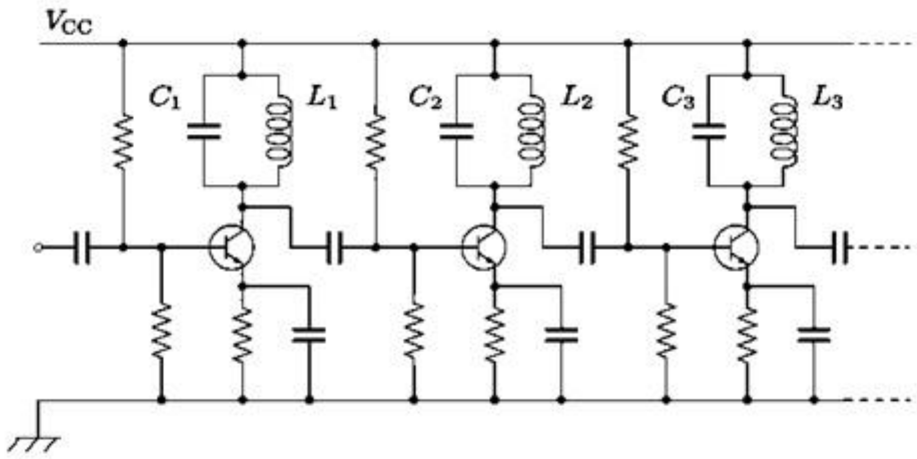


Fig. Stagger-tuned-amplifier

The double-tuned amplifier offers high BW like 3dB. However, the arrangement of this amplifier is not easy. So to conquer this difficulty two single tuned cascaded amplifiers are employed which have certain bandwidth. The resonant frequencies of BWs are adjusted and divided through an amount equivalent to the BW of every stage.

As these frequencies are staggered and called as stagger tuned amplifiers. The characteristics of these amplifiers are shown below. The following image shows the main relationship between individual stages amplification characteristics within a stagger tuned amplifier.

The amplifier using stagger tuning has greater BW, faster passband and number of stages used. The flatter will be the passband. The circuit is called stagger because the tuned circuit's resonance frequencies are displaced.

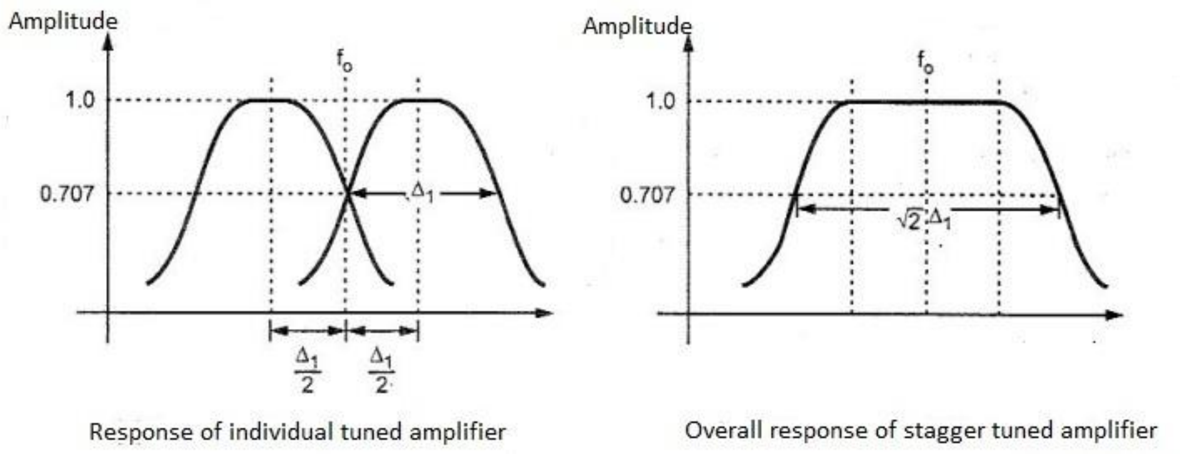


Fig. Stagger-tuned-amplifier-output-response

The stagger tuned amplifier's total frequency response is contrasted with the equivalent and separate single tuned stages. These stages include similar resonant circuits. In the following characteristics, the staggering decrease in the total amplification of the middle frequency to 0.5 of the crest amplification of the separation stage. At middle frequency, every stage includes 0.707 crest amplification of the separation stage. Therefore, the corresponding voltage amplification for each stage of the stagger will be 0.707 times higher when the two similar stages are utilized without staggering.

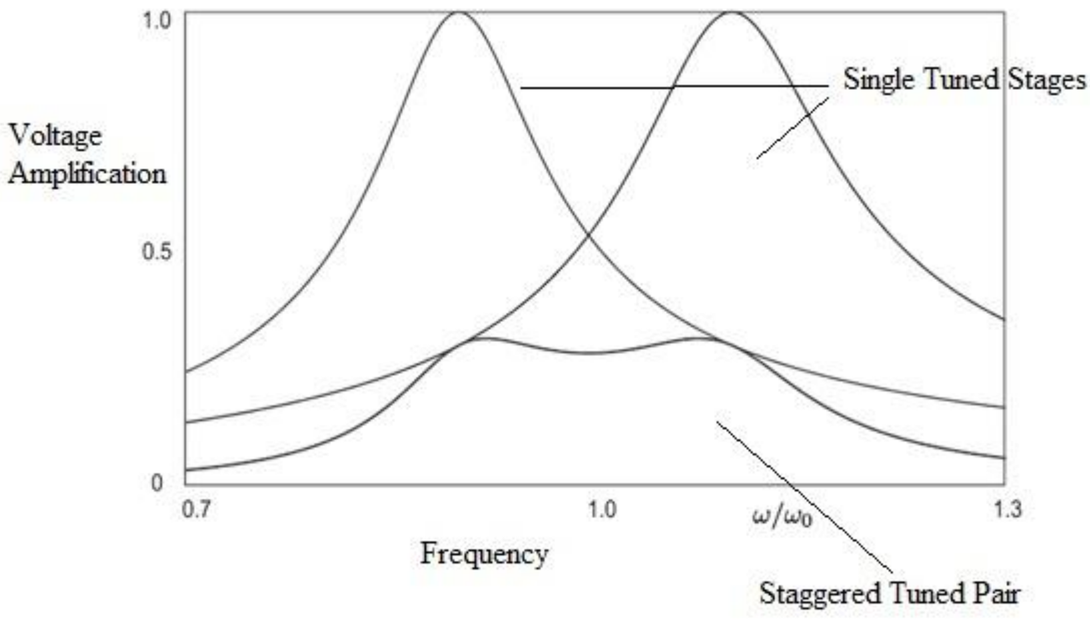


Fig. Stagger-tuned-amplifier-characteristics

But, the 3dB BW of the stagger pair is √2 times higher than the BW of an individual single tuned stage. Therefore the corresponding gain BW product for each stage of stagger tuned pair can be 0.707 x √2 is equal to 1.00 times with the separate single tuned stages.

The thought of stagger tuned can be simply expanded to additional stages. In 3-stage staggering, the tuning of the primary circuit can be adjusted to a lower frequency than the center frequency. The 3rd circuit can be adjusted to high frequency compared with middle frequency. The tuned frequency which is in middle is adjusted at the precise center frequency.

Advantages and Disadvantages

The stagger tuned amplifier advantages & disadvantages include the following.

- Increased BW. Compare with a single tune, the BW is √2 times.
- High value of gain BW.
- In every stage of the amplifier, there is a small difference within the resonance. Therefore, enhanced stability within an operation can be obtained.
- The bandpass of this amplifier is faster compare with a single tuned amplifier. The alignment of this circuit is easy when we compare it with the single tuned amplifier.

Applications

It is used in,

- Superheterodyne receiver as an IF (intermediate frequency) amplifier
- UHF radio relay systems.
- extremely narrow-band intermediate frequency amplifier within a spectrum analyzer
- for video amplification like a wideband tuned amplifier.
- RF amplifiers within receivers

SOLVED PROBLEMS

Problem.1

A parallel resonant circuit has an inductance of 150 μH and a capacitor of 100 pF. Find the resonant frequency.

Given:

L = 150 μH, C = 100 pF

Solution:

We know that, Resonant frequency,

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

$$= \frac{1}{2\pi\sqrt{150 \times 10^{-6} \times 100 \times 10^{-12}}}$$

$$= 1.3 \times 10^6$$

$$\boxed{f_o = 1.3 \text{ MHz}}$$

Problem. 2

Calculate the bandwidth between the half-power points of circuit which resonates at 1 MHz frequency and has Q of 100.

Given:

f_O = 1 MHz, Q_O = 100

Solution:

$$\text{Bandwidth} = \frac{f_o}{Q_o} = \frac{1 \times 10^6}{100} = 10 \text{ KHz}$$

$$\boxed{BW = 10 \text{ KHz}}$$

Problem. 3

A tuned amplifier has its maximum gain at a frequency 2 MHz and bandwidth of 50 KHz. Find the Q-factor.

Given:

f_O = 2 MHz, BW = 50 KHz

Solution:

We know that

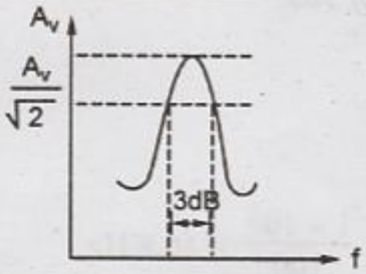
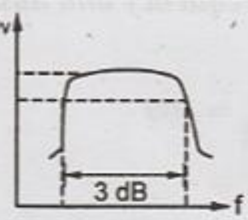
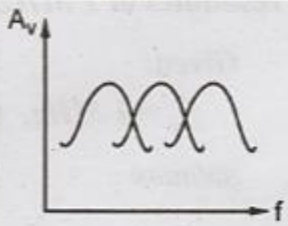
$$BW = \frac{f_o}{Q_o}$$

$$Q_o = \frac{f_o}{BW} = \frac{2 \times 10^6}{50 \times 10^3} = 40$$

$$\boxed{Q_o = 40}$$

Comparison of Tuned Amplifiers

Parameter	Single Tuned	Double Tuned	Stagger Tuned Amplifier
Tuning circuit	Single	Two tuned circuits	More than two tuned amplifiers connected in cascade
Frequency	Cascaded stages are tuned to same frequency	Tuned to same center frequency	Successive circuits are tuned to different frequencies 3 dB bandwidth of staggered

Parameter	Single Tuned	Double Tuned	Stagger Tuned Amplifier
3 dB Bandwidth	Narrow	Larger than single tuned amplifiers	Circuit has $\sqrt{2}$ times 3 dB bandwidth of individual stage.
Frequency response			
Design	Easy	Complex	Similar to single tuned amplifier

Advantages of Tuned Amplifiers

i. They amplify the desired frequencies
ii. Good SNR
iii. Suitable for radio transmitters and receivers
iv. The range of frequencies can be varied.

Disadvantages of Tuned Amplifiers

i. Not suitable for amplifying audio frequencies
ii. If band of frequency is increased, design becomes complex
iii. Circuit is bulky and expensive.