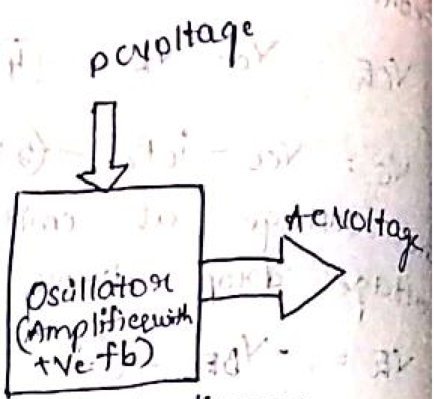
4- Oscillators

Oscillator :-

An oscillator is an electronic ckt which produces Ac o/p voltage without any Ac input, to produce an Ac voltage it is energized with DC power supply.



Simple block diagram representation of oscillator.

It is an electronic ckt which converts D.C voltage to A.C voltage. Then it is also called DC to Ac converter. An amplifier with +Ve feed back is called an oscillator.

Principle of Oscillations:-

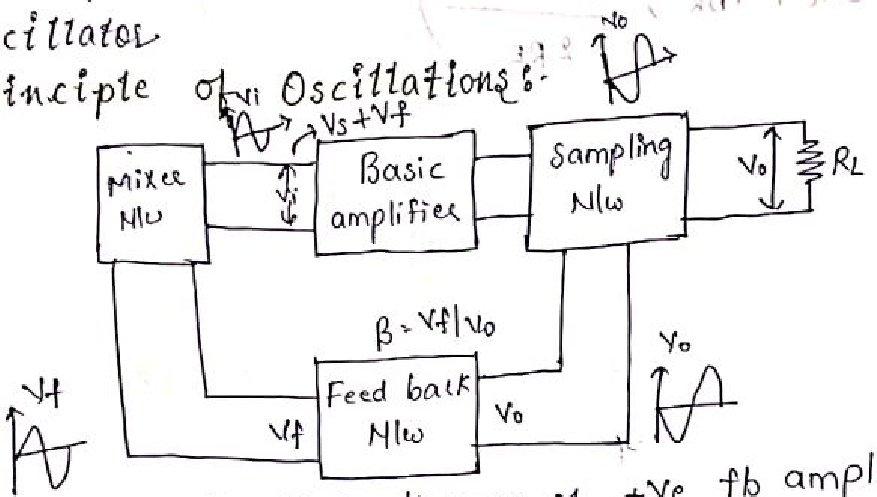


fig: Block diagram of +Ve fb amplifier

The above figure shows an amplifier with +Ve feed back. When dc power supply is switched on, noisy current is developed in the amplifier circuit and it is considered as the input of amplifier. Now the amplifier amplifies that noise input with 180° phase shift. The sampling N/w is used to take the part of the output voltage and it is back to the input of amplifier through a feed back N/w.

The feed back N/w is so designed to provide another 180° phase shift. So that the total phase shift around the closed loop is 360°.

Now the feed back signal is inphase with the input signal and it is added to the i/p of amplifier i.e., $V_i = V_s + V_f$. It is further amplified by the basic amplifies. This process will be continues untill sustained oscillations are generated.

Expression for gain with +Ve fb:
The gain of an amplifier without fb is given by

$$A = \frac{V_o}{V_i} = \frac{V_o}{V_s} \quad \text{--- (1)}$$

By providing +Ve fb, $V_i \rightarrow V_s + V_f$

$$A = \frac{V_o}{V_s + V_f}$$

$$AV_s + AV_f = V_o$$

$$AV_s + A\beta V_o = V_o$$

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

$$A_f = \frac{V_o}{V_s} = \frac{A}{1 - A\beta} \quad \text{--- (2)}$$

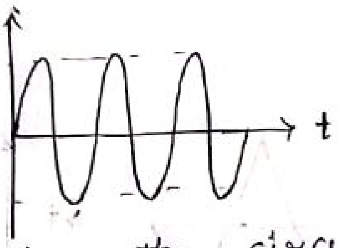
If the product of $A\beta = 1$

$$A_f = \frac{A}{1-1} = \infty.$$

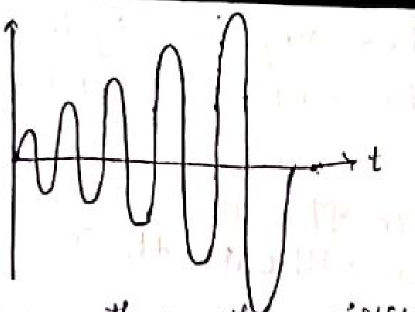
This indicates that the circuit produces an output without external input just by feeding its own input

Barkhausen Criterion:
The barkhausen criterion states that an amplifier with +Ve feed back by satisfying the total phase shift around the closed loop is 360° and the product of A & $\beta = 1$, then the circuit works as an oscillator. In general, an amplifier with +Ve feedback, the total phase shift around the closed loop is 360°.

1. If $A\beta = 1$, then the circuit generates sustained oscillations (or) undamped oscillations. and it is shown in fig(a).

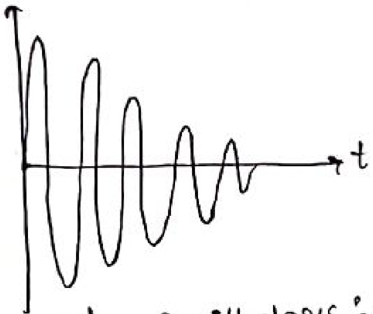


2) If $A\beta > 1$, then the circuit generates continuously increasing types of oscillations and it is shown in fig.



Over damped Oscillations

3) If $A\beta < 1$, then the circuit generates continuously decreasing type of oscillations (or) undamped oscillations. It is as shown in fig.



Under damped oscillations

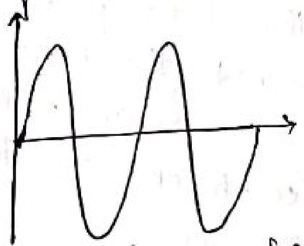
· Classification of Oscillators :-

Oscillators are classified based on four criterias.

I According to waveforms generated :-

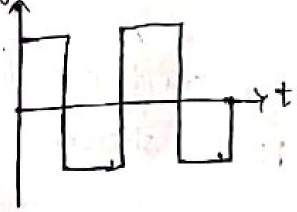
1. Sinusoidal Oscillators
2. Non Sinusoidal Oscillators.

→ The Sinusoidal Oscillators generates sinusoidal voltages (or) currents as shown in fig (a).

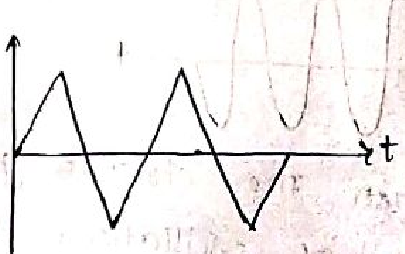


Sinusoidal waveform

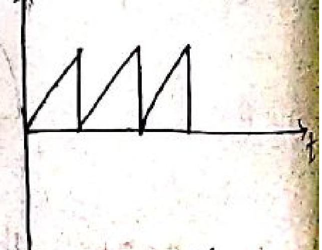
→ Non sinusoidal Oscillators generates nonsinusoidal waveforms which are vary one or more times in a given cycle of time as shown in figures



Square waveform



triangular wave form



Sawtooth waveform

II. According to Fundamental Mechanisms used :-

1. Negative Resistance Oscillators
2. Positive feedback Oscillators

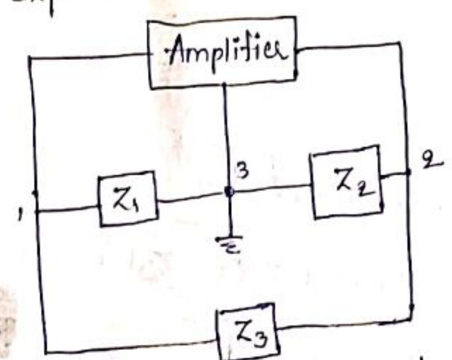
III. According to Frequency Range :-

1. Audio frequency Oscillators - upto 20kHz
2. Radio frequency Oscillators - 20kHz - 30MHz
3. Very high frequency Oscillators : 30MHz - 300MHz
4. Ultra high frequency Oscillators : 300MHz - 3GHz
5. Micro wave Oscillators : > 3GHz

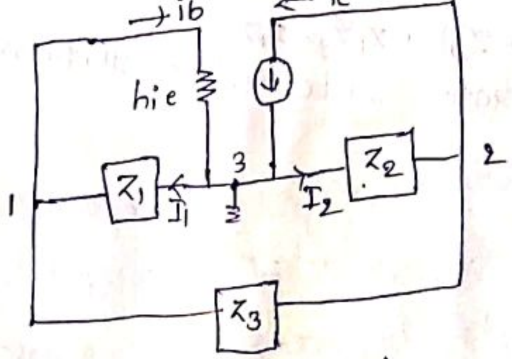
IV. According to Circuit Components: Sinusoidal oscillators are further classified into 2 types.

1. LC Oscillators
   a) Hartley Oscillator
   b) colpitts Oscillator
2. RC Oscillators
   a) RC Phase shift Oscillator
   b) Weinbridge Oscillator

General Expression for LC Oscillator :-



a) General form of LC Oscillator



b) Equivalent ckt

fig(a) shows general form of LC oscillator. It consists of an amplifier with feedback N/w. As shown in fig(a), the feed back N/w is formed by 3 reactive elements Z_1, Z_2 & Z_3. The reactive elements Z_1 & Z_2 acts as voltage divider N/w i.e., the voltage across Z_1 is feedback voltage & the voltage across Z_2 is o/p voltage. To determine condition to generate sustained oscillations fig(a) is replaced by fig(b).

As shown in fig(b) hie & Z_1 are in parallel & their equivalent resistance is given by $Z' = \frac{Z_1 hie}{Z_1 + hie}$ — (1)

The load impedance in b/w terminals 2 & 3 is the equivalent impedance of Z_2 in parallel with the series combination of Z' & Z_3.

$$Z_L = Z_2 \| (Z' + Z_3)$$

$$Z_L = \frac{Z_2(Z' + Z_3)}{Z_2 + Z' + Z_3} = \frac{Z_2 Z' + Z_2 Z_3}{Z_2 + \frac{Z_1 hie}{Z_1 + hie} + Z_3}$$

$$Z_L = \frac{Z_2\left(\frac{Z_1 hie}{Z_1 + hie}\right) + Z_2 Z_3}{Z_2 + \left(\frac{Z_1 hie}{Z_1 + hie}\right) + Z_3}$$

$$= \frac{Z_1 Z_2 hie + Z_2 Z_3 Z_1 + Z_2 Z_3 hie}{Z_1 Z_2 + Z_2 hie + Z_1 hie + Z_1 Z_3 + Z_3 hie}$$

$$Z_L = \frac{Z_2\left[Z_1 hie + Z_3 Z_1 + Z_3 hie\right]}{hie(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3} \quad \text{— (2)}$$

The condition to generate sustained oscillations is

$A\beta = 1$ — (3)

wkt $A = \frac{V_o}{V_i}$ — (4)

where $V_o = I_L Z_L$

$= -i_c Z_L$

$V_o = -h_{fe} i_B Z_L$ — (5)

$V_i = h_{ie} i_B$ — (6)

$$A = \frac{-h_{fe} \cancel{i_B} Z_L}{h_{ie} \cancel{i_B}}$$

$$\boxed{A = \frac{-h_{fe} Z_L}{h_{ie}}} \quad \text{— (7)}$$

$\beta = V_f / V_o$ — (8)

$V_f = -I_1 Z'$ — (9)

The o/p voltage V_o in b/w terminals 2 & 3 in terms of current I_1 is given by

$V_o = -I_1 (Z' + Z_3)$ — (10)

$$\beta = \frac{-\cancel{I_1} Z'}{-\cancel{I_1}(Z' + Z_3)}$$

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

$$\beta = \frac{Z_1 h_{ie}}{Z_1 Z_3 + h_{ie}(Z_1 + Z_3)} \quad \text{— (11)}$$

Now A & β are sub. in eq (3)

$$\frac{-h_{fe} Z_L}{\cancel{h_{ie}}} \cdot \frac{Z_1 \cancel{h_{ie}}}{Z_1 Z_3 + h_{ie}(Z_1 + Z_3)} = 1$$

$$\frac{-h_{fe} Z_L Z_1}{Z_1 Z_3 + h_{ie}(Z_1 + Z_3)} = 1$$

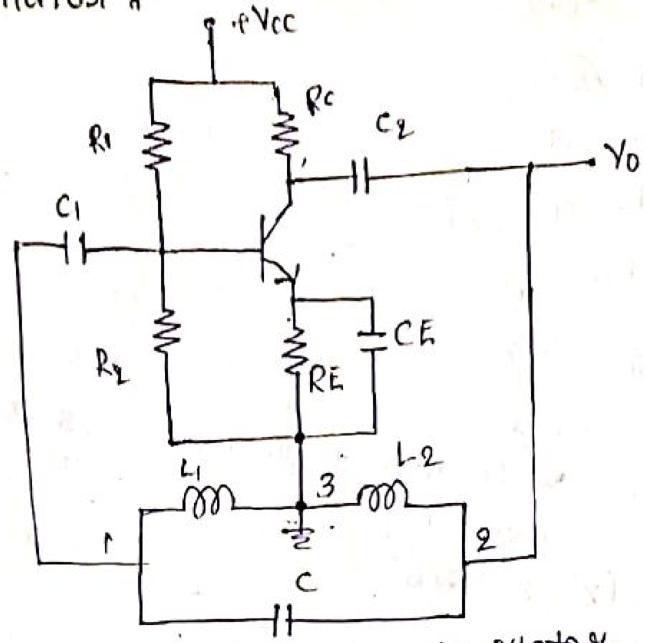
$$\frac{-h_{fe} Z_1 \frac{Z_2 [Z_1 h_{ie} + \cancel{Z_1 Z_3 + Z_3 h_{ie}}]}{h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3}}{Z_1 Z_3 + \cancel{h_{ie}}(Z_1 + Z_3)} = 1$$

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

$\Rightarrow h_{ie}(Z_1 + Z_2 + Z_3) + Z_1(Z_2 + Z_3) + h_{fe} Z_1 Z_2 = 0$ — (12)

The above eq. is general expression of LC oscillator. By using this we can determined the frequency of LC oscillator

Hartley Oscillator :-



ckt diagram of Hartley Oscillator

The above fig shows the circuit diagram of
Hartley oscillator. It consists of an amplifier with
feedback network. Here feedback network is formed
by two inductors and one capacitor i.e., The reactive
elements Z_1 and Z_2 are inductors and Z_3 is capacitor.

Operation :-

when power supply +Vcc is switched on, noisy currents
developed within the amplifier circuit and it will
be considered as input for same amplifier. Then
amplifier amplifies noise inputs and this amplified
noise output back to the feedback network.
Due to this, oscillatory currents developed across
L_1 & L_2. The terminal 3 is grounded and it is at
Zero potential. If terminal 1 is at +Ve potential
with respect to terminal 3 at any instant and
terminal 2 is at -Ve potential with respect to
terminal 3 at the same instant. Thus the phaseshift
b/w terminal 1 and terminal 2 is 180° and another
180° phase shift is provided by amplifier. The
total phase shift around the closed loop is
360° i.e., one of the condition is satisfied and
other condition $A\beta = 1$ is also satisfied by
designing the Feedback N/w. Then the ckt
works as an Oscillator

Frequency of Oscillation :

WKT, the general expression of LC Oscillator is given by $h_{ie}(Z_1+Z_2+Z_3) + Z_1 Z_2(1+h_{fe}) + Z_1 Z_3 = 0$ — (1)

The reactance of inductor L_1

$Z_1 = j\omega L_1 + j\omega M = j\omega(L_1+M)$ — (2)

The reactance of L_2

$Z_2 = j\omega L_2 + j\omega M = j\omega(L_2+M)$ — (3)

The reactance of C

$Z_3 = \frac{1}{j\omega C}$ — (4)

Substitute eq (2),(3),(4) in (1)

~~hie (jωL₁~~

$$h_{ie}\left[j\omega(L_1+M) + j\omega(L_2+M) + \frac{1}{j\omega C}\right] + j\omega(L_1+M)(j\omega(L_2+M)(1+h_{fe}) + \frac{\cancel{j\omega}(L_1+M)}{\cancel{j\omega} C} = 0$$

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

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

To determine the frequency of oscillation, the imaginary part of above eq. equate to zero.

$$h_{ie}j\omega\left[L_1+L_2+2M - \frac{1}{\omega^2 C}\right] = 0$$

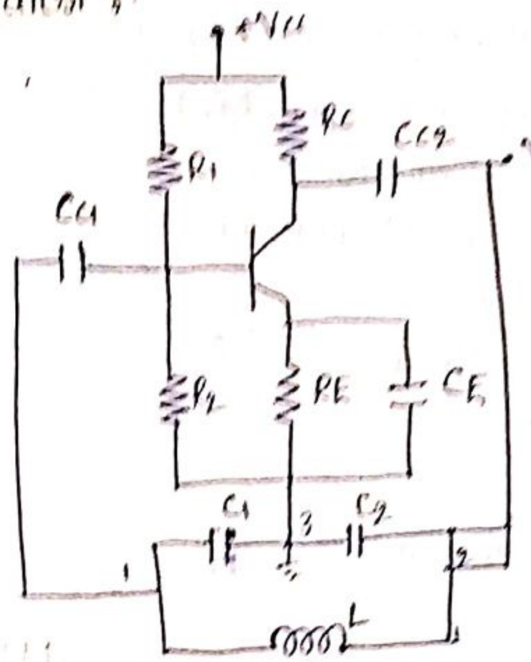
$$\Rightarrow L_1+L_2+2M = \frac{1}{\omega^2 C}.$$

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

$$\omega = \frac{1}{\sqrt{(L_1+L_2+2M)C}}$$

$$\boxed{f = \frac{1}{2\pi\sqrt{(L_1+L_2+2M)C}}} \quad — (5)$$

Colpitts Oscillator :



CKt diagram of colpitts Oscillator

→ Same theory as per Hartley Oscillator.

Frequency of oscillation :

The General expression of LC oscillator is given by $h_{ie}(Z_1+Z_2+Z_3) + Z_1Z_2(1+h_{fe}) + Z_1Z_3 = 0$ —①

From the ckt diagram,

The reactance of capacitor C_1, C_2 is given by

$$Z_1 = \frac{1}{j\omega C_1} \quad —②$$

$$Z_2 = \frac{1}{j\omega C_2} \quad —③$$

$$Z_3 = j\omega L \quad —④$$

Substitute eq 2,3,4 in eq ①

$$h_{ie}\left[\frac{1}{j\omega C_1} + \frac{1}{j\omega C_2} + j\omega L\right] + \frac{1}{j\omega C_1}\cdot\frac{1}{j\omega C_2}(1+h_{fe}) + \frac{1}{j\omega C_1} j\omega L = 0$$

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

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

To determine the frequency of oscillation, the imaginary part of above eq. is equating to zero.

$$\Rightarrow \frac{-h_{ie}j}{\omega}\left[\frac{1}{C_1}+\frac{1}{C_2}-\omega^2 L\right]=0$$

$$\frac{1}{C_1}+\frac{1}{C_2}=\omega^2 L.$$

$$\omega^2=\frac{1}{L}\left[\frac{1}{C_1}+\frac{1}{C_2}\right]$$

$$\omega=\sqrt{\frac{1}{L}\left[\frac{1}{C_1}+\frac{1}{C_2}\right]}$$

$$f=\frac{1}{2\pi}\sqrt{\frac{1}{L}\left(\frac{C_1+C_2}{C_1C_2}\right)}$$

$$C_{eq}=\frac{C_1C_2}{C_1+C_2}$$

$$f=\frac{1}{2\pi}\sqrt{\frac{C_1+C_2}{LC_1C_2}}=\frac{1}{2\pi\sqrt{LC_{eq}}} \quad \text{—(5)}$$

1. In a Hartley Oscillator, if $L_1 = 0.2mH$, $L_2 = 0.3mH$ and $C = 0.003\mu F$, calculate the freq. of its oscillation.

Given, $L_1 = 0.2mH$, $L_2 = 0.3mH$, $C = 0.003\mu F$

$(\because M=0)$

WKT $$f=\frac{1}{2\pi\sqrt{(L_1+L_2)C}}$$

$$f=\frac{1}{2\pi\sqrt{(0.2+0.3)\times10^{-3}\times0.003\times10^{-6}}}$$

$$=\frac{1}{2\pi(1.224\times10^{-6})}$$

$f = 0.130 MHz$. (or) $130 KHz$.

2. In the hartley Oscillator, $L_2 = 0.4mH$ & $C = 0.004\mu F$. If the freq of oscillation is $120 KHz$. Find the value of L_1. (Neglect M)

WKT $$f=\frac{1}{2\pi\sqrt{(L_1+L_2)C}}$$

$$120\times10^3=\frac{1}{2\pi\sqrt{(L_1+0.4\times10^{-3})(0.004\times10^{-6})}}$$

$$240\pi\times10^3=\frac{1}{\sqrt{(L_1+0.4\times10^{-3})(0.004\times10^{-6})}}$$

$$\Rightarrow 5.68\times10^{11}=\frac{1}{(L_1+0.4\times10^{-3})(0.004\times10^{-6})}$$

$\Rightarrow \quad 2212 = \dfrac{1}{(L_1 + 0.41\times10^{-3})}$

$\Rightarrow \quad 2212L_1 + 0.9088 = 1$

$2212L_1 = 0.0912$

$L_1 = 4.01\times10^{-5}\ H$

$L_1 = 0.04mH$

3) In a transistorized hartley oscillator, the 2 inductors are 2mH, 20μH. while the freq. is to be changed from 950 KHz to 2050 KHz. Calculate the range over which the capacitor is to be varied.

Given, $L_1 = 2mH$, $L_2 = 20\mu H$

$f_1 = 950KHz$, $C_1 = ?$

$f_2 = 2050\ KHz$; $C_2 = ?$

WKT $\quad f = \dfrac{1}{2\pi\sqrt{(L_1+L_2)C}}$

$\Rightarrow \sqrt{(L_1+L_2)C_1} = \dfrac{1}{2\pi f_1}$

$\sqrt{(2\times10^{-3} + 20\times10^{-6})} \cdot \sqrt{C_1} = \dfrac{1}{2\pi(950\times10^3)}$

$0.0449\sqrt{C_1} = 1.67\times10^{-7}$

$\sqrt{C_1} = 3.719\times10^{-6}$

$C_1 = 13.83PF$

$\Rightarrow \sqrt{(L_1+L_2)C_2} = \dfrac{1}{2\pi f_2} = \dfrac{1}{2\pi\times2050\times10^3}$

$0.0449\sqrt{C_2} = 7.76\times10^{-8}$

$\sqrt{C_2} = 1.728\times10^{-6}$

$C_2 = 2.98\ PF$

The range of capacitance is from 2.98PF to 13.83PF

4) $L_1 = 38\mu H$, $L_2 = 12\mu H$, $C = 500PF$. Find the freq of oscillation and feed back factor 'β'.

wkt
$$f = \frac{1}{2\pi\sqrt{(L_1+L_2)C}}$$

$$= \frac{1}{2\pi\sqrt{(38+12)\times10^{-6}\times500\times10^{-12}}}$$

$$= \frac{1}{2\pi\sqrt{2.5\times10^{-14}}} = \frac{1}{2\pi\times1.58\times10^{-7}} = 0.10\times10^{7} = 1\times10^{6}$$

$$f = 1MHz.$$

$$\beta = \frac{L_1}{L_2} = \frac{38}{12} = 3.16$$

5) A colpitts Oscillator is designed with $C_1 = 100PF$, $C_2 = 7500PF$. The inductance is variable, determine the range of inductance values, if the freq. of oscillator is to vary b/w 950 KHz, and 2050 KHz.

wkT
$$f = \frac{1}{2\pi\sqrt{LC_{eq}}}$$

$$C_{eq} = \frac{C_1C_2}{C_1+C_2} = \frac{(100\times7500)\times10^{-24}}{(100+7500)10^{-12}}$$

$$C_{eq} = 98.6\ PF$$

$$f_1 = \frac{1}{2\pi\sqrt{L_1 eq}}$$

$$950\times10^{3} = \frac{1}{2\pi\sqrt{L_1}(9.92\times10^{-6})}$$

$$\Rightarrow\ 59.21 = \frac{1}{\sqrt{L_1}}$$

$$\sqrt{L_1} = 0.016$$

$$L_1 = \cancel{28.5}\ 2.85\times10^{-4}$$

$$L_1 = 0.285mH$$

$$\Rightarrow\ 2050\times10^{3} = \frac{1}{\sqrt{L_2}\cdot6.23\times10^{-5}}$$

$$127.90 = \frac{1}{\sqrt{L_2}}$$

$$\sqrt{L_2} = 7.81\times10^{-3}$$

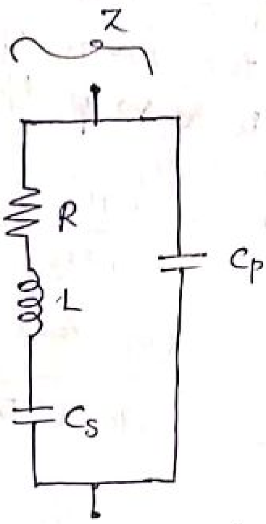
$$\Rightarrow\ \sqrt{L_2} = 7.82\times10^{-3}$$

$$L_2 = 61.3\mu H$$

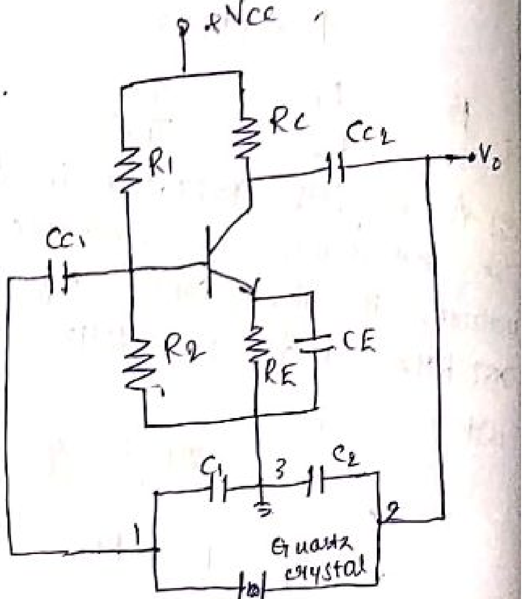
The inductance value changes from 0.28mH to 0.061mH

Why LC oscillators are not used at low frequencies.
For LC oscillators the frequency of oscillation is given by $f = \frac{1}{2\pi\sqrt{LC}}$. It clearly shows that the frequency of oscillation is inversely proportional to inductance and capacitance i.e., $f \propto \frac{1}{LC}$. If we design LC oscillators at low frequencies, it requires large values of inductors and capacitors which having large space size and high cost.
This is the reason the LC oscillators are not used at low frequencies.

Crystal Oscillator:



B) Equivalent ckt of crystal



a) ckt diagram of crystal oscillator

Fig (a) shows the circuit diagram of crystal oscillator. It is similar to the colpitts oscillator except inductor is replaced by Quartz crystal in feedback network. This oscillator works on the principle of piezo electric effect which states that when mechanical force is applied at one phase of crystal and it develops ac voltage at opposite phase of the crystal and in reverse when ac voltage is applied at one phase of the crystal and it develops mechanical vibrations at opposite phase of the crystal.
To determine the frequency of oscillation, Quartz crystal is replaced by its equivalent circuit as shown in fig(b).

When crystal is not vibrating just it is represented by capacitor symbol (C_p) and when it is vibrating it is represented by series RLC circuit i.e., The internal losses are represented by resistor symbol, the magnetic field around the crystal is represented by inductor and the ac voltage which is developed by crystal is represented with the capacitor (C_s).

Frequency of oscillation :-

As shown in fig (6), the equivalent impedance 'Z' is given by (neglecting internal losses)

$$Z = \left(j\omega L + \frac{1}{j\omega C_s}\right) \parallel \frac{1}{j\omega C_p}$$

$$= \frac{\left(j\omega L + \frac{1}{j\omega C_s}\right)\frac{1}{j\omega C_p}}{j\omega L + \frac{1}{j\omega C_s} + \frac{1}{j\omega C_p}}$$

$$= \frac{\cancel{j}\left(\omega L - \frac{1}{\omega C_s}\right)\frac{1}{j\omega C_p}}{\cancel{j}\left(\omega L - \frac{1}{\omega C_s} - \frac{1}{\omega C_p}\right)}$$

$$Z = \frac{\frac{\omega}{L}\left(\omega L - \frac{1}{\omega C_s}\right)\frac{1}{j\omega C_p}}{\frac{\omega}{L}\left(\omega L - \frac{1}{\omega C_s} - \frac{1}{\omega C_p}\right)}$$

$$= \frac{\left(\omega^2 - \frac{1}{LC_s}\right)\frac{1}{j\omega C_p}}{\left[\omega^2 - \left(\frac{1}{LC_s} + \frac{1}{LC_p}\right)\frac{1}{L}\right]}$$

$$Z = \frac{\left(\omega^2 - \omega_s^2\right)\frac{1}{j\omega C_p}}{\omega^2 - \omega_p^2}$$

From the above equation, $\omega_s^2 = \frac{1}{LC_s}$

$$\Rightarrow \omega_s = \frac{1}{\sqrt{LC_s}}$$

$$\boxed{f_s = \frac{1}{2\pi\sqrt{LC_s}}}$$

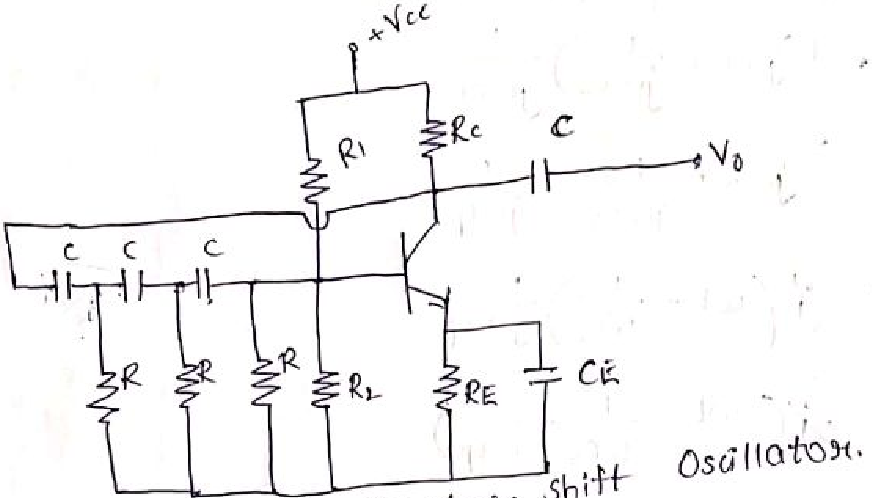
where $\omega_p^2 = \left(\frac{1}{C_s} + \frac{1}{C_p}\right) \cdot \frac{1}{L} = 1/LC_{eq}$.

$$\omega_p = \sqrt{\left(\frac{1}{C_s} + \frac{1}{C_p}\right)\frac{1}{L}}$$

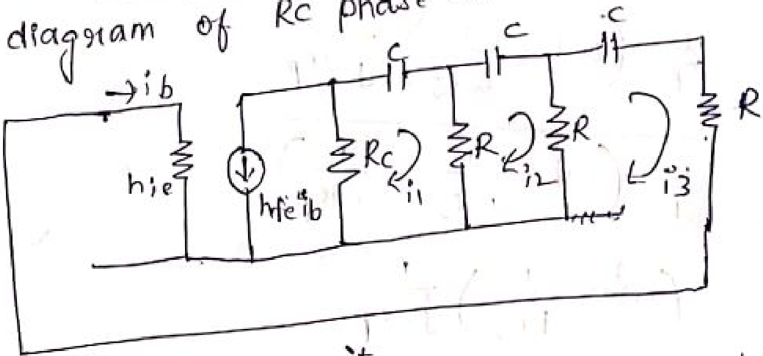
$$\omega_p = \sqrt{\frac{C_p + C_s}{C_s C_p L}} = \frac{1}{\sqrt{LC_{eq}}}$$

$$f_p = \frac{1}{2\pi\sqrt{LC_{eq}}}$$

RC - Phase shift Oscillator :-



a) ckt diagram of RC phase shift Oscillator.



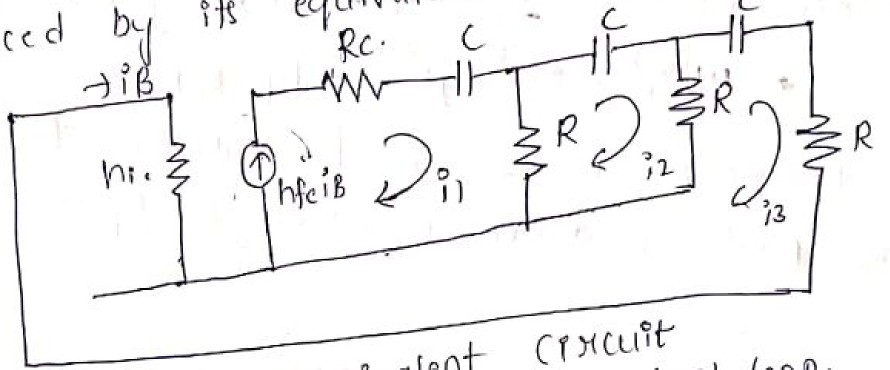
b) Equivalent Circuit

Fig(a) shows the circuit diagram of RC phase shift oscillator. It consists of a CE amplifier and feed back network which is formed by 3 RC networks. when a power supply +Vcc is switched ON, noisy current is developed within the amplifier circuit and it will be considered as input for the amplifier circuit. Thus, an amplifier amplifies it with 180° phase shift and this amplified noise output back to the input of the amplifier through a feedback network.

In a feedback network, Each RC network provides 60° phase shift i.e., the phase shift provided by RC ladder network is 180°. Thus, the total phase shift around the closed loop is 360° and by designing feedback network if $A\beta = 1$ then above circuit works as an oscillator.

Frequency of Oscillation :-

To determine the frequency of oscillation, fig (a) is replaced by its equivalent circuit as shown in fig(b).



c) Simplified Equivalent Circuit

From fig(c), apply KVL to the first loop. $(i_B = i_3)$

$\Rightarrow h_{fe} i_B R_C + i_1 R_C - i_1 j X_C + R(i_1 - i_2) = 0$

$\Rightarrow i_1(R_C - jX_C + R) + i_2(-R) + i_3 h_{fe} R_C = 0$ — (1)

Apply KVL to the second loop.

$\Rightarrow R(i_2 - i_1) - i_2 j X_C + R(i_2 - i_3) = 0$

$\Rightarrow -Ri_1 + i_2(R - jX_C + R) - Ri_3 = 0$ — (2)

Apply KVL to the third loop.

$R(i_3 - i_2) - i_3 j X_C + i_3 R = 0$

$\Rightarrow -Ri_2 + i_3(R + R - jX_C) = 0$ — (3).

From 1, 2, 3.

$$\Delta = \begin{bmatrix} (R_C + R) - jX_C & -R & h_{fe} R_C \\ -R & 2R - jX_C & -R \\ 0 & -R & 2R - jX_C \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = 0$$

$$\begin{vmatrix} R_C + R - jX_C & -R & h_{fe} R_C \\ -R & 2R - jX_C & -R \\ 0 & -R & 2R - jX_C \end{vmatrix} = 0$$

$$\Rightarrow (R_c + R - jX_c)\left[(2R - jX_c)^2 - R^2\right] + R\left[-R(2R - jX_c)\right] + h_{fe}R_c(R^2) = 0$$

$$\Rightarrow (R_c + R - jX_c)\left[4R^2 - j4RX_c - X_c^2 - R^2\right] - 2R^3 + jR^2X_c + h_{fe}R_cR^2 = 0$$

$$\Rightarrow (R_c + R - jX_c)(3R^2 - X_c^2 - j4RX_c) - 2R^3 + jR^2X_c + h_{fe}R_cR^2 = 0$$

$$\Rightarrow 3R^2R_c - R_cX_c^2 - j4RX_cR_c + 3R^3 - RX_c^2 - j4R^2X_c - j3R^2X_c + jX_c^3$$

$$- 4RX_c^2 - 2R^3 + jR^2X_c + h_{fe}R_cR^2 = 0$$

$\Rightarrow$ To determine frequency of oscillation, the imaginary part of above equation is equal to zero.

$$\Rightarrow -4RX_cR_c - 4R^2X_c - 3R^2X_c + X_c^3 + R^2X_c = 0$$

$$\Rightarrow -6R^2X_c + X_c^3 - 4RX_cR_c = 0$$

$$\Rightarrow X_c(X_c^2 - 6R^2 - 4RR_c) = 0$$

$$\Rightarrow X_c^2 = 6R^2 + 4RR_c$$

$$X_c^2 = R(R6 + 4R_c)$$

$$X_c = \sqrt{R^2\left(6 + 4\frac{R_c}{R}\right)}$$

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

$$\omega = \frac{1}{RC\sqrt{6 + \frac{4R_c}{R}}}$$

$$\boxed{f = \frac{1}{2\pi RC\sqrt{6 + 4\frac{R_c}{R}}}} \qquad \frac{R_c}{R} = K$$

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

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

Wein bridge Oscillator :-

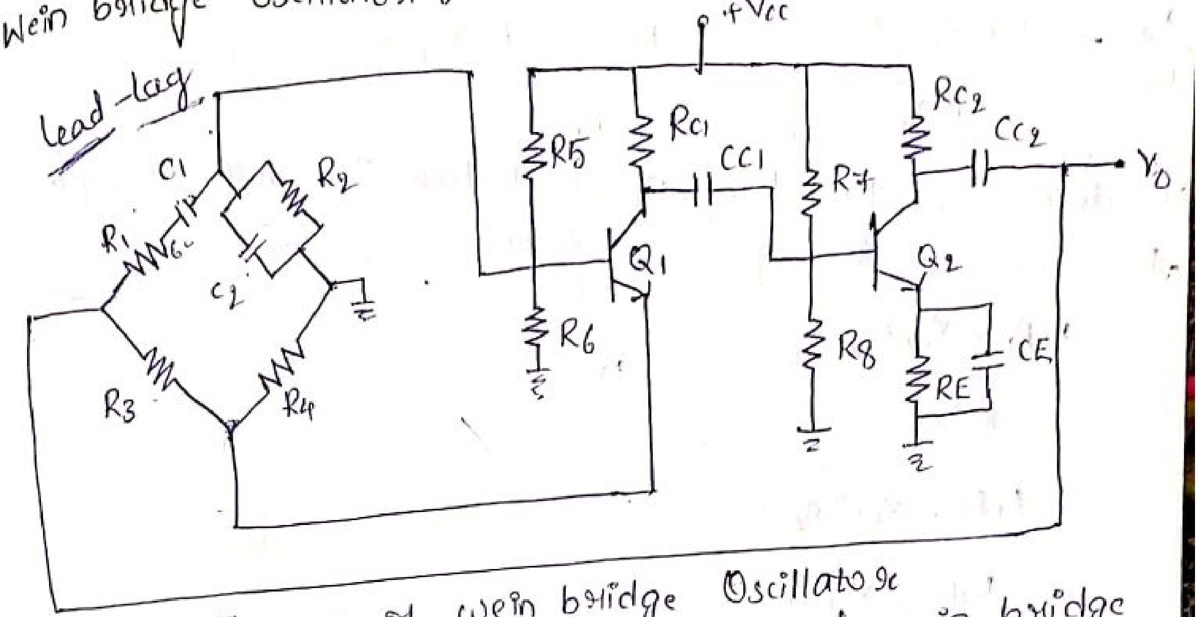


fig: ckt diagram of wein bridge Oscillator

The above fig. shows the ckt diagram of wein bridge oscillator, it consists of two amplifier sections in CE mode and balanced bridge network each CE - amplifier stage provides 180° phase shift and the total phase shift by the two amplifier sections is 360° and hence no need to introduce any additional phase shift by the balanced bridge N/w. The lead - lag N/w which is formed by $R_1 - C_1$ & $R_2 - C_2$ provides the +ve feedback to the i/p of I stage of amplifier and the voltage divider N/w which is formed by R_3 & R_4 provides -ve fb to the emitter of I stage of transistor. This balanced bridge N/w provides stability of oscillations in both amplitude & frequency.

→ To determine freq. of oscillation we consider the condition for balancing the bridge.

i.e., $$\frac{R_3}{R_4} = \frac{R_1 + \frac{1}{j\omega C_1}}{R_2 \,||\, \left(\frac{1}{j\omega C_2}\right)} \quad \text{or} \quad \frac{R_3}{R_4} = \frac{R_1 - jX_{C_1}}{R_2 \,||\, (-jX_{C_2})}$$

$$= \frac{R_1 - jX_{C_1}}{\frac{R_2(-jX_{C_2})}{R_2 - jX_{C_2}}} = \frac{(R_1 - jX_{C_1})(R_2 - jX_{C_2})}{-jR_2X_{C_2}}$$

$$= \frac{R_1R_2 - jR_1X_{C_2} - jR_2X_{C_1} - X_{C_1}X_{C_2}}{-jR_2X_{C_2}}$$

$$= \frac{R_1R_2 - X_{C_1}X_{C_2}}{-jR_2X_{C_2}} + \frac{-\cancel{j}(R_1X_{C_2} + R_2X_{C_1})}{-\cancel{j}R_2X_{C_2}}$$

$$\frac{R_3}{R_4} \Rightarrow \frac{j(R_1R_2 - X_{C_1}X_{C_2})}{R_2X_{C_2}} + \frac{R_1X_{C_2} + R_2X_{C_1}}{R_2X_{C_2}}$$

To determine the freq. of oscillation, the imaginary part of above eq. is equal to zero.

$$\frac{R_1R_2 - X_{C_1}X_{C_2}}{R_2X_{C_2}} = 0$$

$$\Rightarrow R_1R_2 - X_{C_1}X_{C_2} = 0$$

$$R_1R_2 = X_{C_1}X_{C_2}$$

$$R_1R_2 = \frac{1}{\omega C_1} \cdot \frac{1}{\omega C_2}$$

$$\omega^2 = \frac{1}{R_1R_2C_1C_2}$$

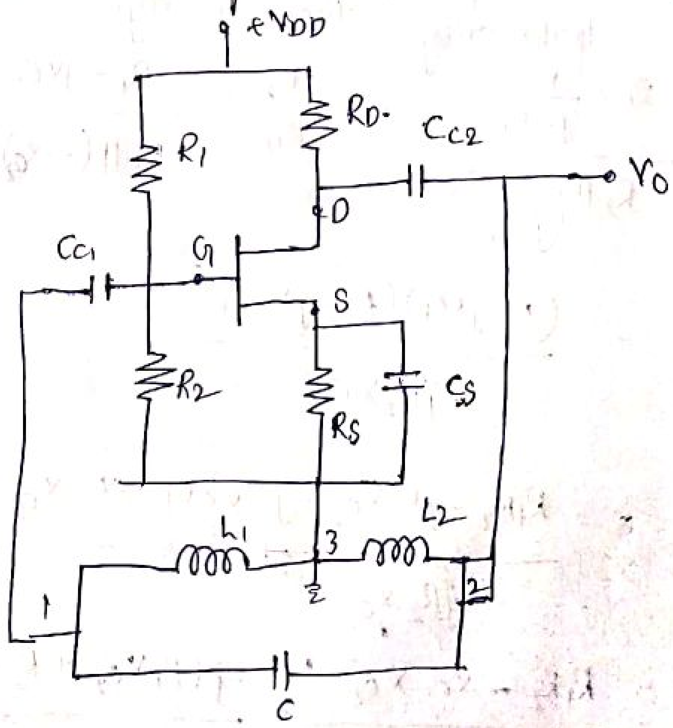
$$\omega = \frac{1}{\sqrt{R_1R_2C_1C_2}}$$

$$\boxed{f = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}}$$

if $R_1 = R_2 = R$ & $C_1 = C_2 = C$

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

Hartley Oscillator using JFET :-



G.E
$h_{ie}(Z_1+Z_2+Z_3)+(1+h_{fe})Z_1Z_2+Z_1Z_3=0$

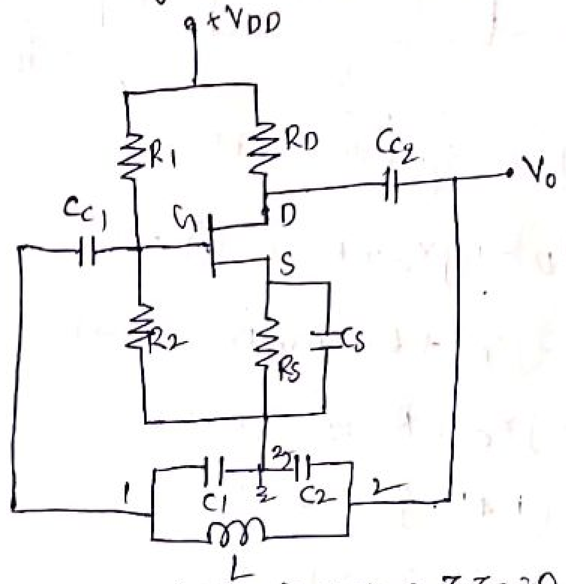
$\Rightarrow Z_1 = j\omega L_1 + j\omega M = j\omega(L_1+M)$

$Z_2 = j\omega L_2 + j\omega M = j\omega(L_2+M)$

$Z_3 = \frac{1}{j\omega C}$

$$f = \frac{1}{2\pi\sqrt{(L_1+L_2+2M)C}}$$

Colpitts Oscillator using JFET :-



G.E $- h_{ie}(Z_1+Z_2+Z_3)+(1+h_{fe})Z_1Z_2+Z_1Z_3=0$

$Z_1 = \frac{1}{j\omega C_1}$ — (4)

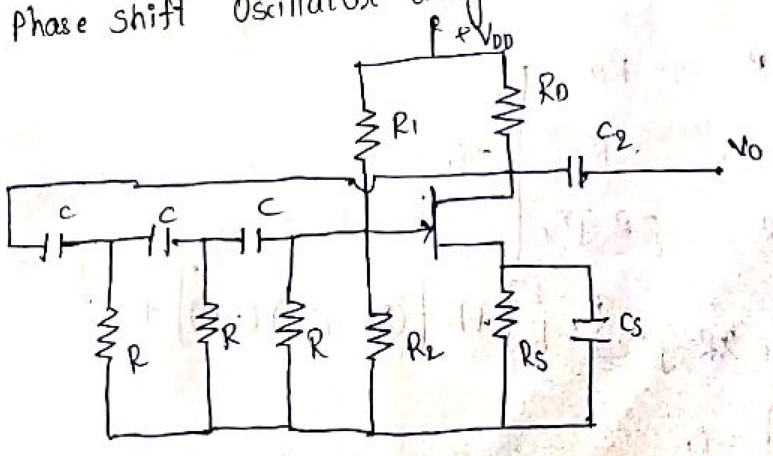
$Z_2 = \frac{1}{j\omega C_2}$

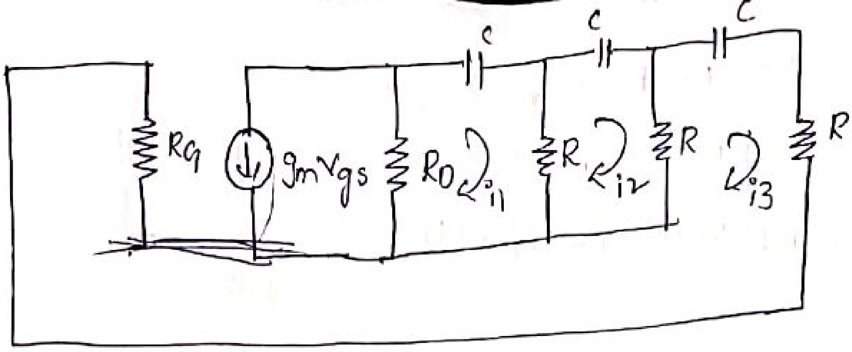
$Z_3 = j\omega L$.

$C_{eq} = \frac{C_1C_2}{C_1+C_2}$

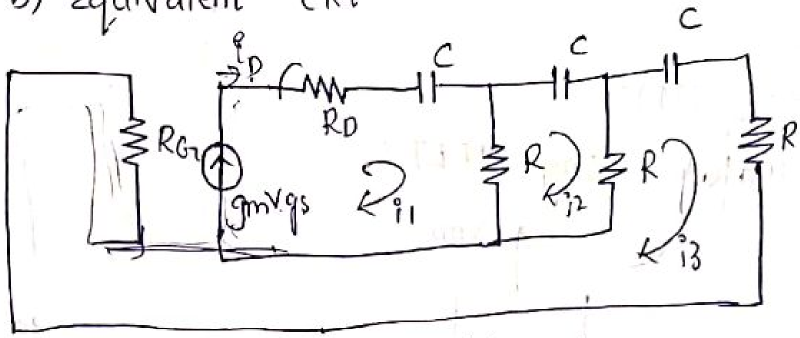
$$f = \frac{1}{2\pi\sqrt{LC_{eq}}}$$

RC Phase shift Oscillator using JFET :-





b) Equivalent Ckt



c) Simplified Equivalent ckt

$g_m = \frac{i_D}{V_{gs}}$

$\rightarrow$ $g_m V_{gs} R_D + i_1 R_D - i_1 j X_C + R(i_1 - i_2) = 0$

$\Rightarrow$ $i_1(R_D + R - jX_C) + Ri_2 + i_3 R_D = 0$ — (1)

$\rightarrow$ $R(i_2 - i_1) - i_2 j X_C + R(i_2 - i_3) = 0$

$\Rightarrow$ $-i_1 R + i_2(R + R - jX_C) - Ri_3 = 0$

$-Ri_1 + i_2(2R - jX_C) - i_3 R = 0$ — (2)

$\rightarrow$ $R(i_3 - i_2) - j i_3 X_C + i_3 R = 0$

$\Rightarrow$ $-Ri_2 + i_3(2R - jX_C) = 0$ — (3)

$$\begin{bmatrix} R_D + R - jX_C & -R & R_D \\ -R & 2R - jX_C & -R \\ 0 & -R & 2R - jX_C \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{vmatrix} R_D + R - jX_C & -R & R_D \\ -R & 2R - jX_C & -R \\ 0 & -R & 2R - jX_C \end{vmatrix} = 0$$

$\Rightarrow (R_D + R - jX_C)\left[(2R - jX_C)^2 - R^2\right] + R\left[(2R - jX_C)(-R)\right] +$

$R_D \left[R^2\right] = 0$

$$\Rightarrow (R_D+R-jX_C)\left[4R^2-4RjX_C-X_C^2\right]R^2]+R\left[-2R^2+jX_CR\right]+R_DR^2=0$$

$$\Rightarrow (R_D+R-jX_C)\left(3R^2-4RjX_C-X_C^2\right)+2R^3+jX_CR^2+R_DR^2=0$$

$$\Rightarrow 3R^2R_D-4R_DRjX_C-R_DX_C^2+3R^3-4R^2jX_C+RX_C^2-3R^2jX_C+4RX_C^2+jX_C^3+2R^3+jX_CR^2+R_DR^2=0$$

To determine the frequency of oscillation, the imaginary part of above eq is zero.

$$jX_C^3+jX_CR^2-3R^2jX_C-4R^2jX_C-4R_DRjX_C=0$$

$$X_C^2+R^2-3R^2-4R^2-4R_DR=0$$

$$X_C^2-6R^2-4R_DR=0.$$

$$X_C^2=6R^2+4R_DR$$

$$X_C^2=R(6R+4R_D)$$

$$X_C=\sqrt{R^2\left(6+\frac{4R_D}{R}\right)}$$

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

$$\omega=\frac{1}{RC\sqrt{\left(6+\frac{4R_D}{R}\right)}}$$

$$f=\frac{1}{2\pi RC\sqrt{\left(6+\frac{4R_D}{R}\right)}} \qquad \boxed{K=\frac{R_D}{R}}$$

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

Frequency and amplitude stability of oscillator :-

In the weinbridge oscillator, if the Rc N/ws consists of resistors of $200K\Omega$ and the capacitors of 300PF, Find its frequency of oscillation.

$$f=\frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

$R_1=R_2=200K\Omega$, $C_1=C_2=300PF$

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 200 \times 10^{3} \times 300 \times 10^{-12}}$$

$$= \frac{10^{5}}{12\pi}$$

$$f = 2.652 \text{ kHz}$$

Frequency and amplitude stability of Oscillator :-

Frequency stability of an oscillator :-

The frequency stability of an oscillator is a measure of its ability to maintain the required frequency over a long time interval. The main drawback in transistor oscillators is that the frequency of ~~oscillation~~ operation is not stable during a long time operation. The following are the factors which contribute to the change in the value of the frequency.

i) Due to change in temperature the values of the frequency determining components such as resistor, inductor and capacitor changes.

ii) Due to variations in the power supply, change in climatic conditions and due to aging of components the transistor parameter changes.

iii) The effective resistance of the tank ckt is changed when the load is connected.

iv) Due to variations in biasing conditions and loading conditions.

In the absence of automatic temp. control, the effect of temp. on the LC ckt can be reduced by selecting the inductance 'L' with +Ve temperature coefficient and capacitance 'C' with -Ve temperature coefficient.

As ~~Piez~~ Piezo-electric crystals have high 'Q' values of the order of 10^5, they can be used as parallel resonant circuits in oscillators to get very high frequency stability.

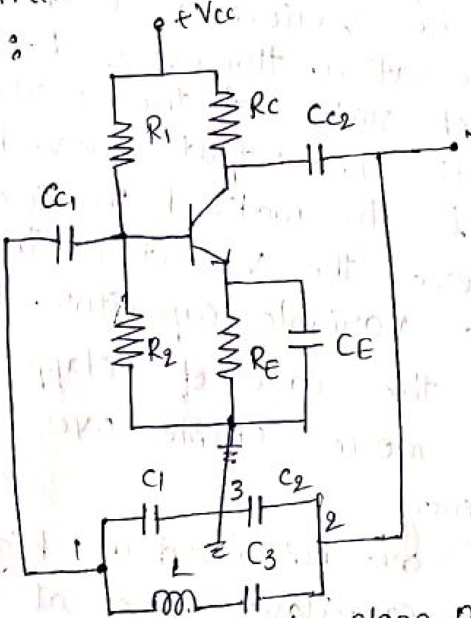
Amplitude stability of an Oscillator:

All oscillators not require +ve feed back for their operation. If the +ve resistance of the LC tank ckt is cancelled by introducing the right amount of -ve resistance across the tank ckt, then the steady oscillation can be maintained.

There are several devices such as Thermister, UJT and tunnel diode exhibits a region of -ve resistance in V-I characteristics. such devices operated in negative resistance region are placed across LC ckt as the frequency determining section.

In the case of RC oscillators, the amplitude against the variations due to aging of the transistors and other components can be stabilized by replacing the resistor in bridge by sensistors, which are temperature dependent resistors. Thus, the stability in amplitude of the RC oscillators can be easily maintained.

Clapp Oscillator:



a) ckt diagram of clapp oscillator

- Clapp oscillator is a advanced version of colpitts oscillator in which an additional capacitor C_3 is added into the tank circuit to be in series with the inductor as shown in figure.

Apart from the presence of extra capacitor, all other components and their connections remains similar to that in the case of colpitts oscillator.

Hence, the working of this circuit is almost similar to that of the colpitts oscillator. However, the frequency of oscillation in the case of clapp oscillator is given by $\boxed{f = \frac{1}{2\pi\sqrt{L\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)}}}$

Usually, the value of C_3 is choosen that to be much smaller than the other two capacitors. This is because at higher frequencies, smaller the C_3, larger will be the inductor, which simplifies the implementation as well as reduces the effect of leakage inductance.

However, is to be noted that when C_3 is choosen to be smaller with comparision in C_1 & C_2, the net capacitance will be more dependent on it. Thus, $\boxed{f = \frac{1}{2\pi\sqrt{LC_3}}}$

In the case of colpitts oscillator, the capacitor C_1 (or) C_2 need to be varied in order to vary its frequency of operation. However, during this process, even the feedback ratio of the oscillator changes which inturn effects its output waveform. One solution to this problem is to make both C_1 & C_2 to be fixed, while achieve the variation in frequency using a seperate variable capacitor. This is what the C_3 does in the case of clapp oscillator, which inturn makes it more stable over colpitts in terms of frequency

Why RC oscillators are not used at high frequency?

The 'c' in RC is capacitance and at high frequencies the capacitor reactance will decreases. than at low frequencies. As capacitor performance goes down, the circuit performance also goes down. Thus, RC oscillators performance is poor at high frequencies and not provides stable oscillations. This is the reason RC oscillators are not used at high frequencies