"Signal Generators"

"Oscillators"

Introduction:

Three basic waveform extensively used are the Sinusoidal, Square and triangle signal.

* There are two different approaches for generating sinusoidals

1- linear oscillator:

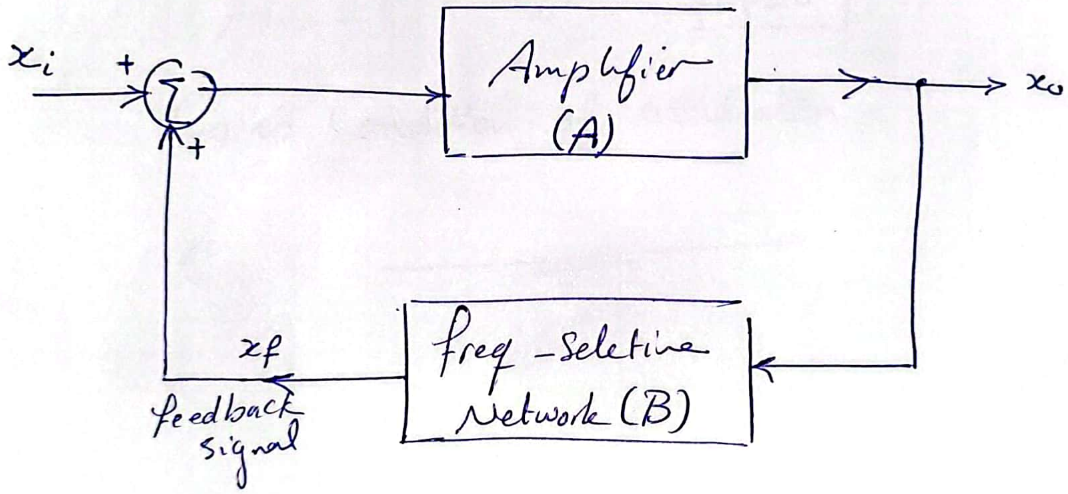
- employ positive feedback loop consisting of an amplifier and a RC or LC frequency-selective network.

2- non linear oscillators (function generator)

- employ circuit building blocks known as multivibrators.
- There are 3 types of multivibrator
  1- The biastable.
  2- The astable.
  3- The monostable.

* The Oscillator feedback loop:

- The basic Structure of a Sinusoidal oscillator Consists of an Amplifier and a frequency-selective Network in a positive feedback loop.



$$x_f = \beta x_o$$

$$x_o = (x_i + x_f) A$$

$$x_o = (x_i + \beta x_o) A$$

$$x_o (1 - \beta A) = x_i A$$

$$\boxed{\frac{x_o}{x_i} = \frac{A}{1 - \beta A}}$$

loop Gain $= A \cdot B$

The characteristic equation

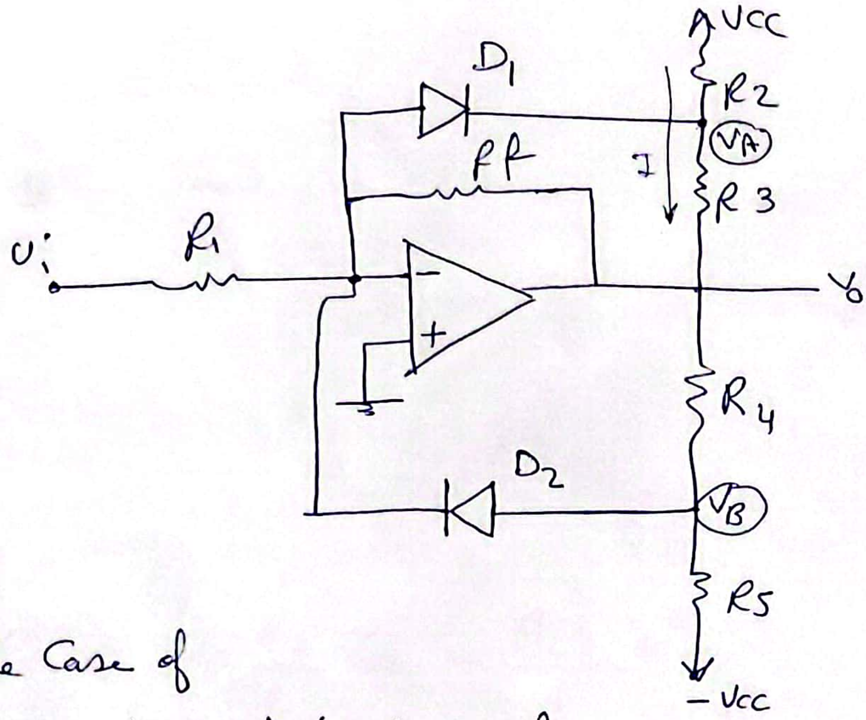
$= 1 - AB = 0$

$\therefore \quad AB = 1$ when $\boxed{V_i = 0}$

This is Condition of oscillation

$\therefore$

⊛ Limiter Circuit for Amplitude Control:



Consider the case of
a small (close to zero) input signal
and small output voltage V_o

∴ V_A is positive
and V_B is negative

∴ D_1, D_2 off

$$\boxed{V_o = -\frac{R_f}{R_1} V_{in}}$$

① lower limit:

V_o is −ve value

D_1 is ON and $V_{D_1} = 0.7\ v$

$$V_A = -0.7$$

$$I = \frac{V_{cc} - V_o}{R_2 + R_3} = \frac{V_{cc} - V_A}{R_2}$$

$$V_{cc} - V_o = \frac{R_2 + R_3}{R_2} V_{cc} - \frac{R_2 + R_3}{R_2} V_A$$

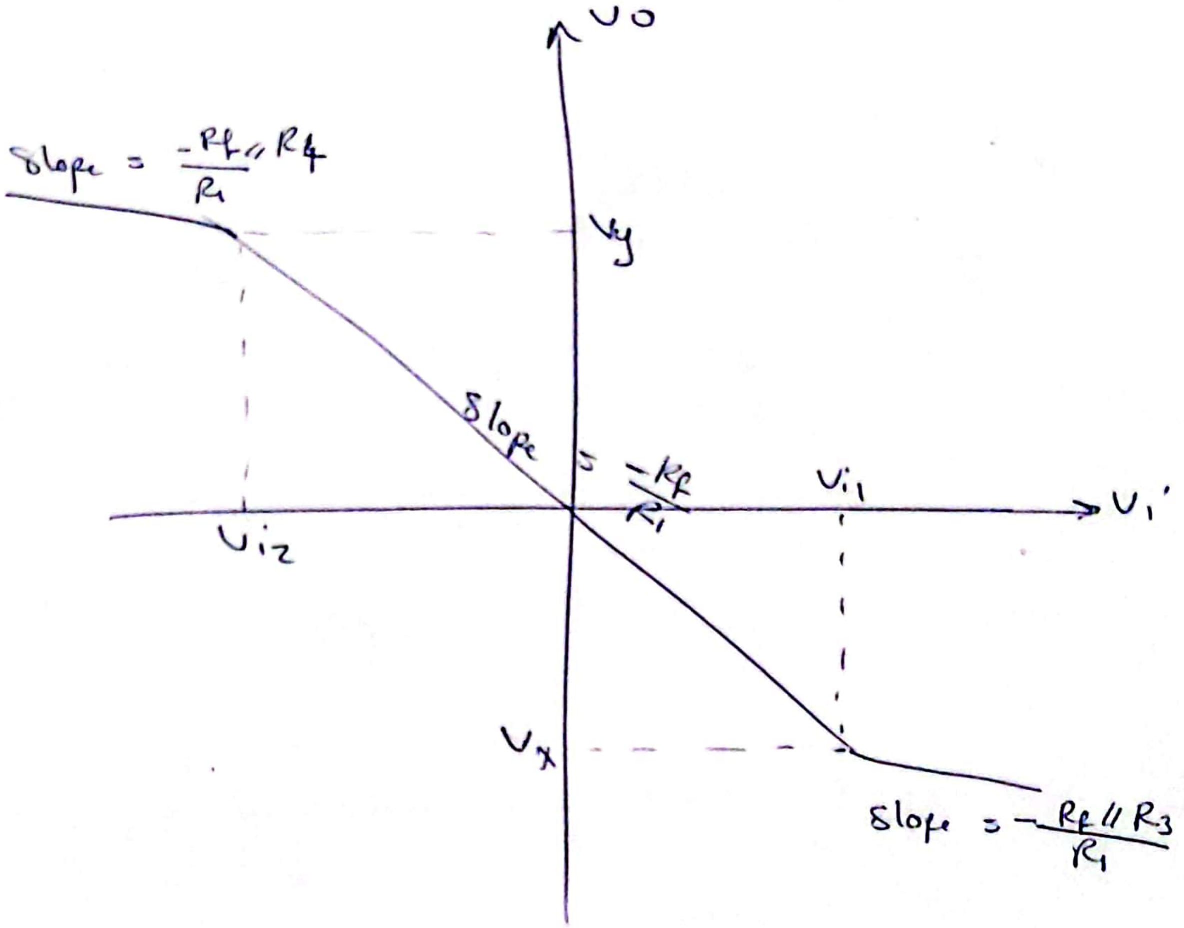
$$\therefore \boxed{V_o = \frac{R_2 + R_3}{R_2} V_A - \frac{R_3}{R_2} V_{cc}} = V_x$$ lower limit

② upper limit:

V_o is +ve value

D_2 is ON $V_B = V_D = 0.7$

Similarly $$\boxed{V_o = \frac{R_4 + R_5}{R_5} V_B + \frac{R_4}{R_5} V_{cc}} = V_y$$



if v_i goes more positive
Vo more negative
for short circuit for D_1

$$\therefore \boxed{V_o = -\frac{R_f \parallel R_3}{R_1} v_i}$$

at The Same way

for V_i more negative

V_o goes more positive

for short circuit for D_2

$$\therefore \boxed{V_o = \frac{-R_f \parallel R_4}{R_1} V_i}$$

* If R_f increased, the result in higher gain in linear region while keeping V_x, V_y unchanged.

* For removing R_f result in this transfer characteristics

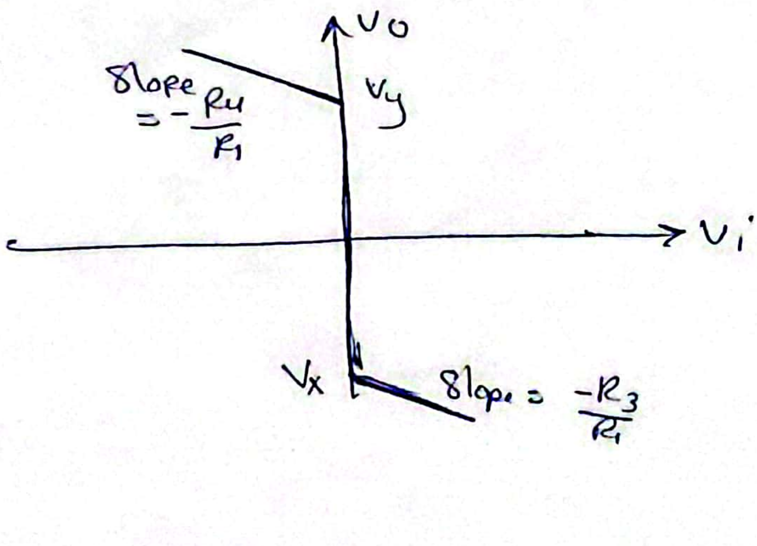
this is a Comparator

$V_i > 0$

$\therefore \boxed{V_o = V_x}$

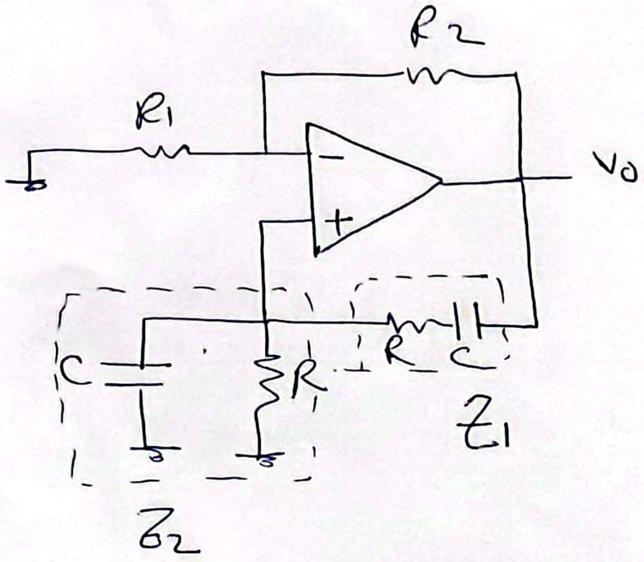
$V_i < 0$

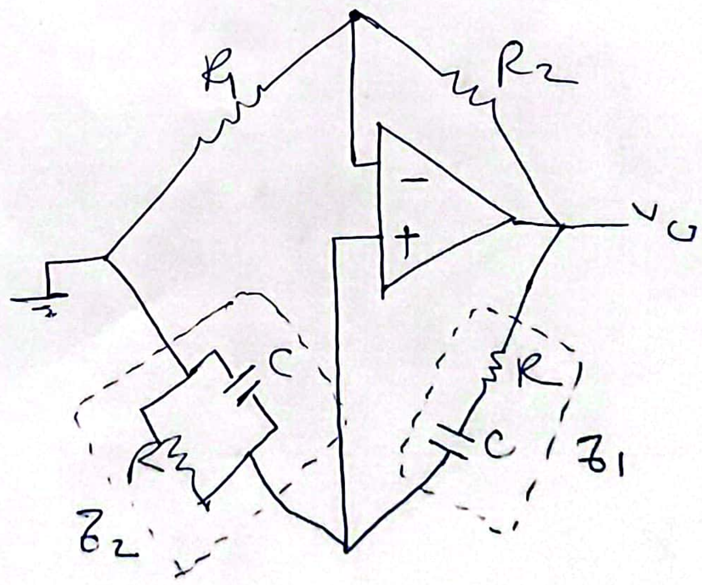
$\therefore \boxed{V_o = V_y}$



* Op Amp RC oscillator Circuits:

① Wien bridge oscillator:





for balance bridge

$$\frac{R_2}{Z_1} = \frac{R_1}{Z_2}$$

or $$\frac{R_2}{R_1} = \frac{Z_1}{Z_2}$$

$$Z_1 = R + \frac{1}{SC} = \frac{RSC+1}{SC}$$ (series C, R)

$$Z_2 = \frac{R \cdot \frac{1}{SC}}{R + \frac{1}{SC}} = \frac{R}{RSC+1}$$ (parallel C, R)

$$\because \quad \frac{R_1}{R_2} = \frac{Z_2}{Z_1}$$

$$\therefore \quad \frac{R_1}{R_2} = \frac{R/RSC+1}{\frac{RSC+1}{SC}} = \frac{RSC}{(1+RSC)^2}$$

$$\therefore \quad \frac{R_1}{R_2} = \frac{RSC}{R^2S^2C^2 + 2RSC + 1}$$

$$\frac{R_2}{R_1} = RSC + 2 + \frac{1}{RSC}$$

$$\boxed{\therefore S = j\omega}$$

↳ for equal Real part obtain value of R

↳ for equal imaginary part obtain oscillator freq ω_0

$$\frac{R_2}{R_1} = j\omega_o CR + 2 - j\frac{1}{\omega_o RC}$$

imaginary part

$$j\omega_o CR = j\frac{1}{\omega_o RC}$$

$$\therefore \omega_o^2 = \frac{1}{R^2C^2}$$

$$\therefore \omega_o = \frac{1}{RC}$$

$$\boxed{f_o = \frac{1}{2\pi RC}}$$

Real part

$$\frac{R_2}{R_1} = 2$$

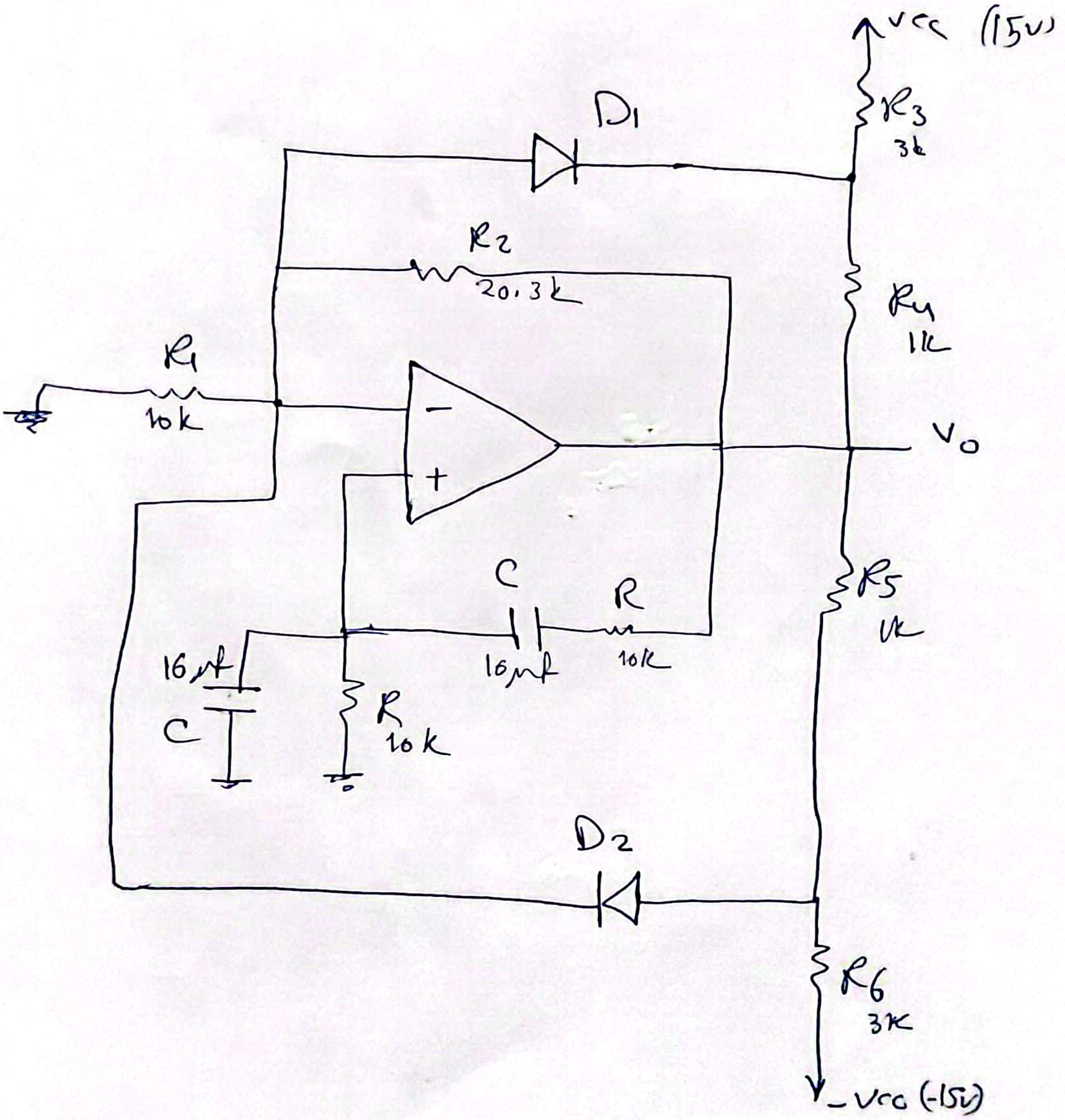
$$\therefore \boxed{R_2 = 2R_1}$$

Condition for oscillator which satisfy $AB = 1$

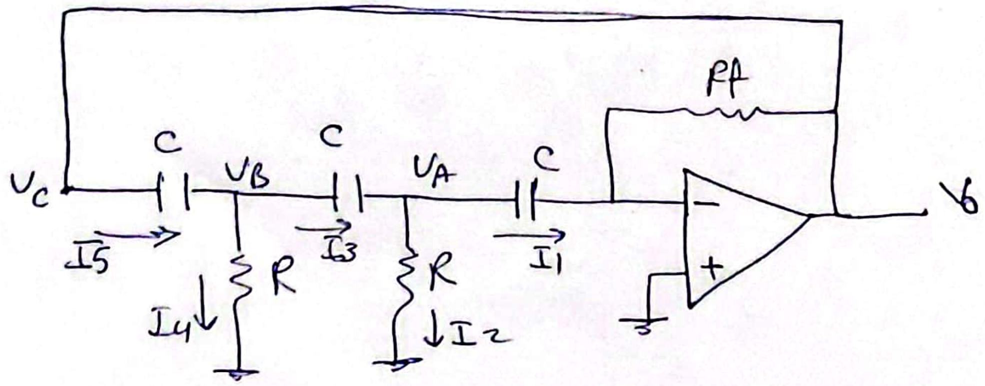
$\therefore$ The output is sinewave with frequency

$$\boxed{f_o = \frac{1}{2\pi RC}}$$

* Wein bridge oscillator with limiter Amplitude Control:



* The phase shift oscillator :



$$V_0 = \frac{-R_f}{1/sC} V_A$$

$$\boxed{V_0 = -R_f sC V_A} \rightarrow (1)$$

$$I_1 = \frac{V_A}{1/sC}$$

$$I_2 = \frac{V_A}{R}$$

$$I_3 = I_2 + I_1 = \frac{V_A}{R} + V_A sC$$

$$= V_A \left(\frac{1}{R} + sC\right)$$

$$\therefore V_B = I_3 \frac{1}{sC} + R I_2$$

$$= I_3 \frac{1}{sC} + V_A$$

$$V_B = V_A\left(\frac{1}{R}+sC\right)\frac{1}{sC} + V_A$$

$$= V_A\left(\frac{1}{sRC}+1+1\right)$$

$$V_B = V_A\left(2+\frac{1}{sRC}\right)$$

$$I_4 = \frac{V_B}{R} = V_A\left(\frac{2}{R}+\frac{1}{sCR^2}\right)$$

$$I_5 = I_4 + I_3$$

$$= V_A\left(\frac{2}{R}+\frac{1}{sCR^2}\right) + V_A\left(\frac{1}{R}+sC\right)$$

$$= V_A\left(\frac{3}{R}+\frac{1}{sCR^2}+sC\right)$$

$$V_C = I_5\frac{1}{sC} + V_B$$

$$= V_A\left(\frac{3}{R}+\frac{1}{sCR^2}+sC\right)\times\frac{1}{sC} + V_A\left(2+\frac{1}{sCR}\right)$$

$$= V_A\left(\frac{3}{RsC}+\frac{1}{s^2C^2R^2}+1\right) + V_A\left(2+\frac{1}{sCR}\right)$$

$$= V_A\left(3+\frac{4}{RsC}+\frac{1}{s^2C^2R^2}\right) = V_0 \longrightarrow (2)$$

from (1), (2)

$$-R_f SC \cancel{V_A} = \cancel{V_A}\left[3 + \frac{4}{SCR} + \frac{1}{S^2C^2R^2}\right]$$

Put $S = j\omega_0$

$$-R_f j\omega_0 C = 3 + \frac{4}{j\omega_0 CR} + \frac{-1}{\omega_0^2 C^2 R^2}$$

$$= 3 - j\frac{4}{\omega_0 CR} - \frac{1}{\omega_0^2 C^2 R^2}$$

imaginary part

$$R_f \omega_0 C = \frac{4}{\omega_0 CR}$$

$$R_f = \frac{4}{\omega_0^2 C^2 R}$$

but $\omega_0 = \frac{1}{\sqrt{3}\, RC}$

$$\therefore R_f = \frac{4}{\frac{1}{3R^2C^2} \cdot C^2 R}$$

$$\therefore \boxed{R_f = 12R}$$

Real part

$$3 = \frac{1}{\omega_0^2 C^2 R^2}$$

$$\therefore \omega_0 = \frac{1}{\sqrt{3}\, CR}$$

$$\therefore \boxed{f_0 = \frac{1}{2\pi\sqrt{3}\, CR}}$$

Oscillation frequency.

We Can change Capacitor C
to Change frequency of Sine wave

* phase shift of each R.C

$$\text{Phase shift} = \tan^{-1} \frac{\frac{1}{wC}}{R}$$

$$= \tan^{-1} \frac{1}{w_o CR} \Big|_{w_o = \frac{1}{\sqrt{3} RC}}$$

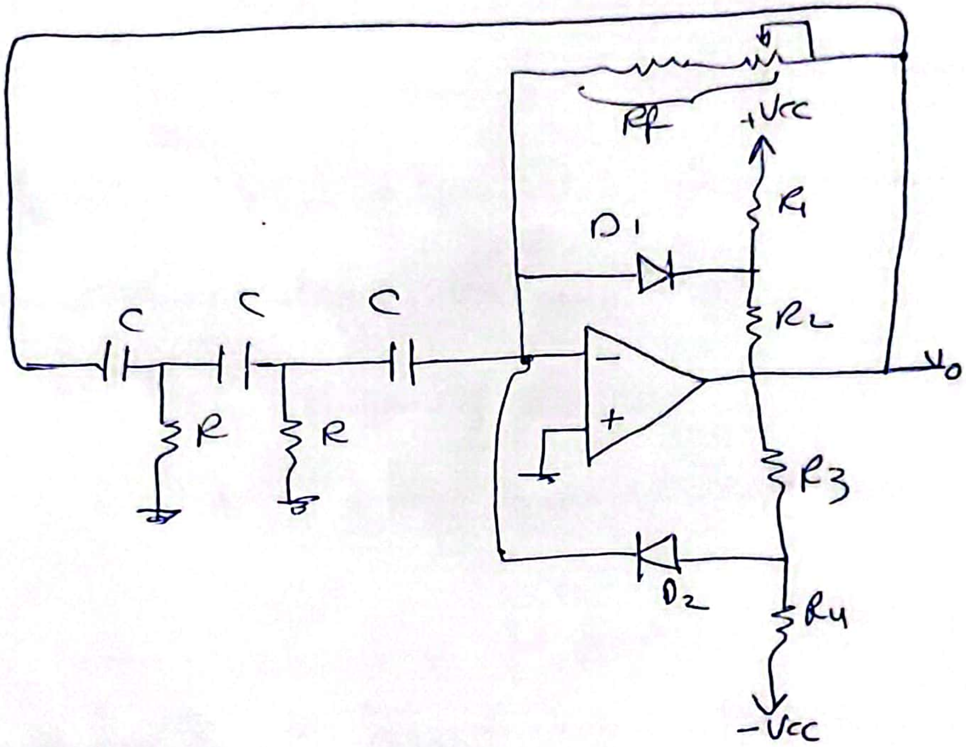
$$= \tan^{-1} \sqrt{3} = 60^\circ$$

∴ Each RC make a phase shift $= 60^\circ$
So That overal shift $= 3 \times 60 = 180^\circ$

<u>Hint:</u>
RC circuit Consider as filter to filtering the required signal of freq($\underline{f_o}$)

* phase shift oscillator with limiter:

Amplitude Control:



* advantages of RC oscillators:

1- high frequency Range (20kHz → 60kHz)

2- large B.W

disadvantages:

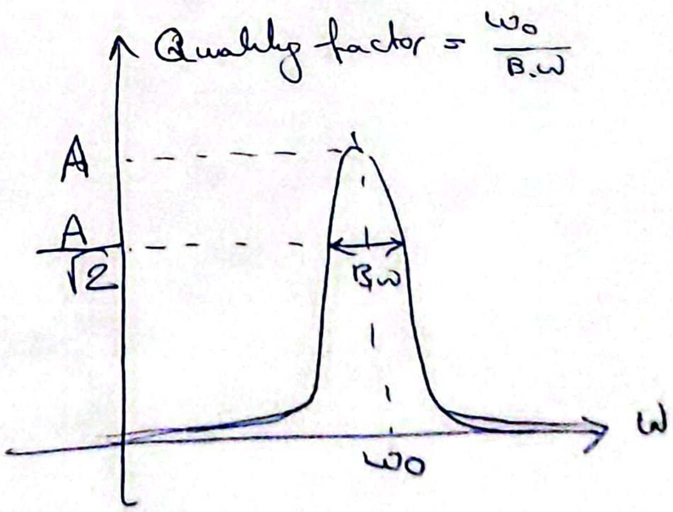
- small quality factor $Q \propto \frac{1}{B.W}$

* LC oscillator Circuit:

- The oscillators described previous are RC Tunable Circuits. That is, The frequency of oscillation is determined by the resistance and Capacitance values used.
- often, The frequency obtained in such Circuits is limited to a few hundred kilo hertz.

where higher freq of oscillation are required, So That LC Circuit are used to obtain a signal of frequency range from 100kHz to 100 MHz:

$BW \propto \frac{1}{Q}$



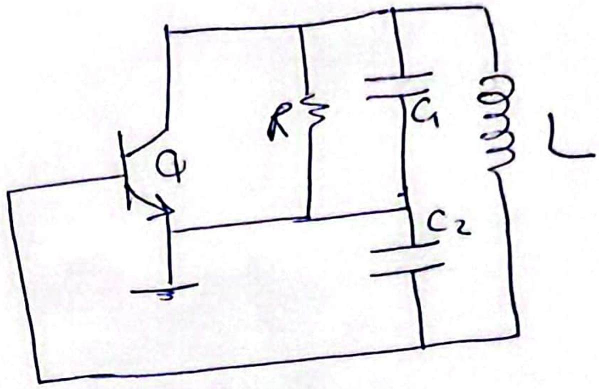
advantages of LC oscillator

1 - high freq range (100k → 100MHz)

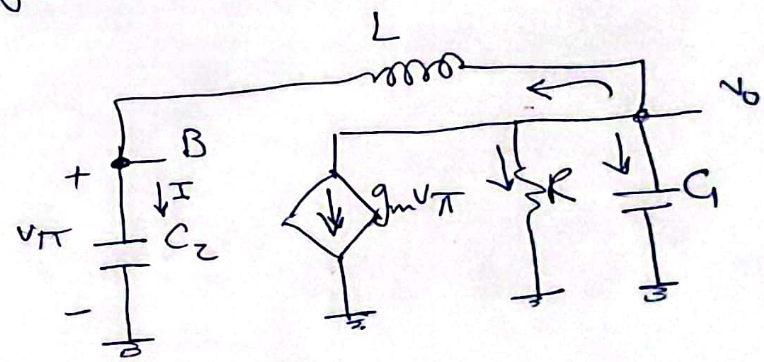
2 - high quality factor

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

① Colpits oscillator :



Small signal Analysis applied for obtaining the resonance frequency.



I → current through C_2 and L

$$I = \frac{V_\pi}{1/SC_2} = SC_2 V_\pi$$

$$I = \frac{V_o - V_\pi}{SL}$$

$$\therefore \; V_o = V_\pi + SL(I)$$

$$\therefore \quad \boxed{V_o = v_\pi + S^2 L C_2 v_\pi} \rightarrow ①$$

Node at V_o: (KCL) all current out from o/p node equal zero

$$-I = \frac{V_o}{1/SC_1} + \frac{V_o}{R} + g_m v_\pi$$

$$-SC_2 v_\pi = V_o S C_1 + \frac{V_o}{R} + g_m v_\pi$$

أعوض عن V_o بدلالة v_π .

$$-SC_2 \cancel{v_\pi} = \cancel{v_\pi} SC_1 + (S^2 L C_2 \cancel{v_\pi})(SC_1) + \frac{\cancel{v_\pi}}{R} + \frac{S^2 L C_2 \cancel{v_\pi}}{R} + g_m \cancel{v_\pi}$$

$$-SC_2 = SC_1 + S^3 L C_2 C_1 + \frac{1}{R} + \frac{S^2 L C_2}{R} + g_m$$

for $S = j\omega_0$

$$-j\omega_0 C_2 = j\omega_0 C_1 - j\omega_0^3 L C_2 C_1 + \frac{1}{R} - \frac{\omega_0^2 L C_2}{R} + g_m$$

imaginary

Real

imaginary

$$\omega_0^3 L C_2 C_1 = \omega_0 C_1 + \omega_0 C_2$$

$$\omega_0^2 L C_1 C_2 = C_1 + C_2$$

$$\therefore \omega_0^2 = \frac{C_1 + C_2}{L C_1 C_2}$$

$$\boxed{\omega_0 = \sqrt{\frac{C_1 + C_2}{L C_1 C_2}}}$$

oscillation frequancy

Real

$$\frac{\omega_0^2 L C_2}{R} = g_m + \frac{1}{R}$$

$$\frac{C_1 + C_2}{\cancel{L} C_1 \cancel{C_2}} \cdot \frac{\cancel{L C_2}}{R} = g_m + \frac{1}{R}$$

$$\frac{C_1 + C_2}{C_1 R} = g_m + \frac{1}{R}$$

نضرب الطرفين ع R

$$\frac{C_1 + C_2}{C_1} = g_m R + 1$$

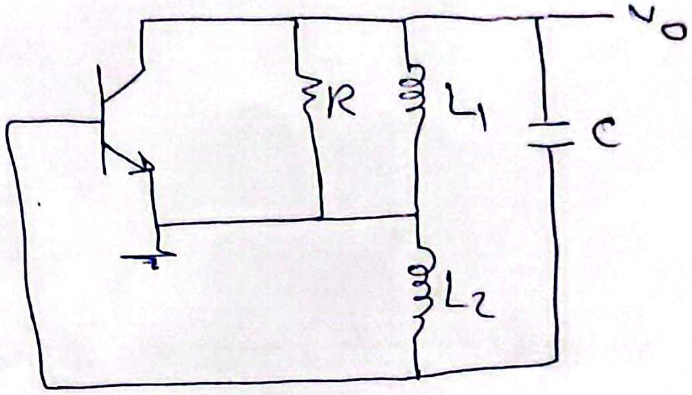
$$\therefore \boxed{g_m R = \frac{C_2}{C_1}}$$

Condition for osc

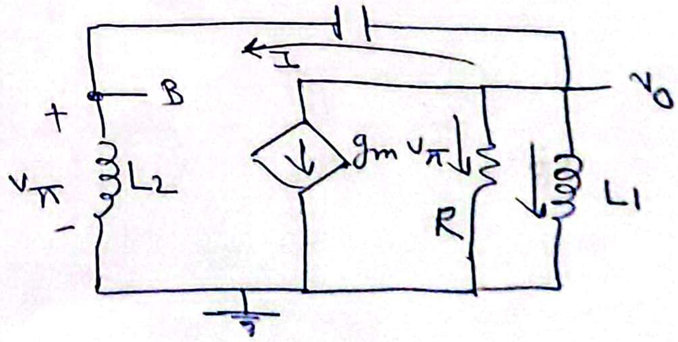
Where: R : represent a resistance Model for losses of inductor, The load of oscillator, and output resistance of BJT.

$$R = R_L \parallel r_o \parallel R_{coil}$$

(21) Hartly oscillator :



- It's Consist of two inductor (L_1, L_2) and Capacitor C.
- Its Small Signal Model Can be obtained



$$I = \frac{v_\pi}{S L_2}$$

$$I = \frac{V_o - v_\pi}{1/SC} = SC(v_o - v_\pi)$$

$$\therefore \quad \frac{v_\pi}{S L_2} = SC(v_o - v_\pi)$$

$$\boxed{v_o = \left(\frac{1}{s^2 L_2 C} + 1\right) v_\pi} \rightarrow (1)$$

Node at v_o:

$$-I_b = g_m v_\pi + \frac{v_o}{sL_1} + \frac{v_o}{R}$$

$$\frac{-\cancel{v_\pi}}{sL_2} = g_m \cancel{v_\pi} + \frac{1}{sL_1}\left(\frac{1}{s^2 L_2 C} + 1\right)\cancel{v_\pi} + \frac{1}{R}\left(\frac{1}{s^2 L_2 C} + 1\right)\cancel{v_\pi}$$

$$\frac{-1}{sL_2} = g_m + \frac{1}{s^3 L_1 L_2 C} + \frac{1}{sL_1} + \frac{1}{R s^2 L_2 C} + \frac{1}{R}$$

Put $s = j\omega_o$

$$j\frac{1}{\omega_o L_2} = g_m + \frac{j}{\omega_o^3 L_1 L_2 C} - \frac{j}{\omega_o L_1} - \frac{1}{R\omega_o^2 L_2 C} + \frac{1}{R}$$

Real

imaginary part:

$$\frac{1}{\omega_0 L_2} + \frac{1}{\omega_0 L_1} = \frac{1}{\omega_0^3 L_1 L_2 C}$$

$$\therefore \quad \frac{1}{L_2} + \frac{1}{L_1} = \frac{1}{\omega_0^2 L_1 L_2 C} \qquad * \, L_1 L_2$$

الطرفين

$$L_1 + L_2 = \frac{1}{\omega_0^2 C}$$

$$\omega_0^2 = 1/(L_1 + L_2)C$$

$$\therefore \boxed{\omega_0 = \frac{1}{\sqrt{C(L_1+L_2)}}}$$

Real part:

$$g_m + \frac{1}{R} = \frac{1}{R\omega_0^2 L_2 C}$$

$$g_m + \frac{1}{R} = \frac{1}{R \cdot \frac{1}{(L_1+L_2)\cancel{C}} L_2 \cancel{C}}$$

$$g_m + \frac{1}{R} = \frac{L_1 + L_2}{R L_2}$$

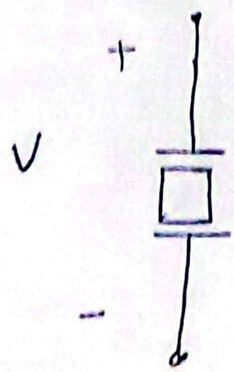
$$g_m R = \frac{L_1 + L_2}{L_2} - 1 = \frac{L_1}{L_2}$$

$$\therefore \boxed{g_m R = L_1/L_2} \quad //$$

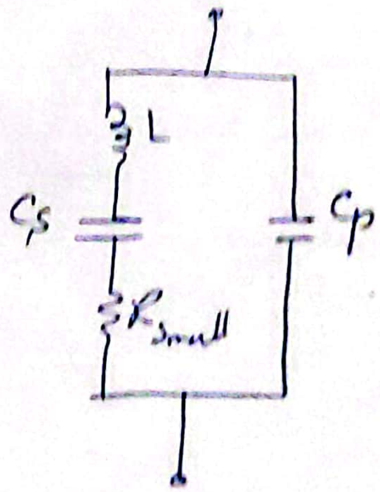
* Crystal oscillator :

- It's called piezoelectric crystal or Quartz oscillator.
- This circuit characterized by large inductor (L), very small series capacitor (C_s) and resistance R which gives $Q = \frac{\omega_0 L}{R}$ and parallel capacitor (C_p).

- This circuit exhibits resonance characteristics that are very stable and having high Quality factor (Q).



Symbol



equivalent circuit

$C_s \ll C_p$ $\quad L \gg$ $\quad R \ll$

$C_s \simeq 0.0005 pf$

$Q_{crystal} \gg Q_{L.C} \gg Q_{R.C}$

- There are two Resonance Freq.:

Series resonance

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

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

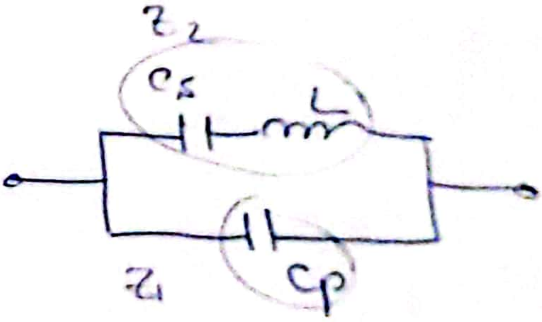
parallel resonance

$$\omega_p = \sqrt{\frac{C_s + C_p}{LC_sC_p}}$$

for $C_p \gg C_s$

$$\omega_p \simeq \frac{1}{\sqrt{LC_2}}$$

* With neglect small R:



$$Z_1 = \frac{1}{SC_p}$$

$$Z_2 = \frac{1}{SC_s} + SL$$

$$Z_T = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

$$= \frac{\frac{1}{SC_p}\left(\frac{1}{SC_s} + SL\right)}{\frac{1}{SC_p} + \frac{1}{SC_s} + SL}$$

$$Z_T = \frac{sL + \frac{1}{sC_s}}{s^2 LC_p + \frac{C_p}{C_s} + 1} = \frac{sL + \frac{1}{sC_s}}{s^2 L C_p + \frac{C_p + C_s}{C_s}}$$

$$= \frac{sL\left(1 + \frac{1}{s^2 L C_s}\right)}{s^2 L C_p \left(1 + \frac{C_p + C_s}{s^2 L C_p C_s}\right)}$$

$s = j\omega$

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

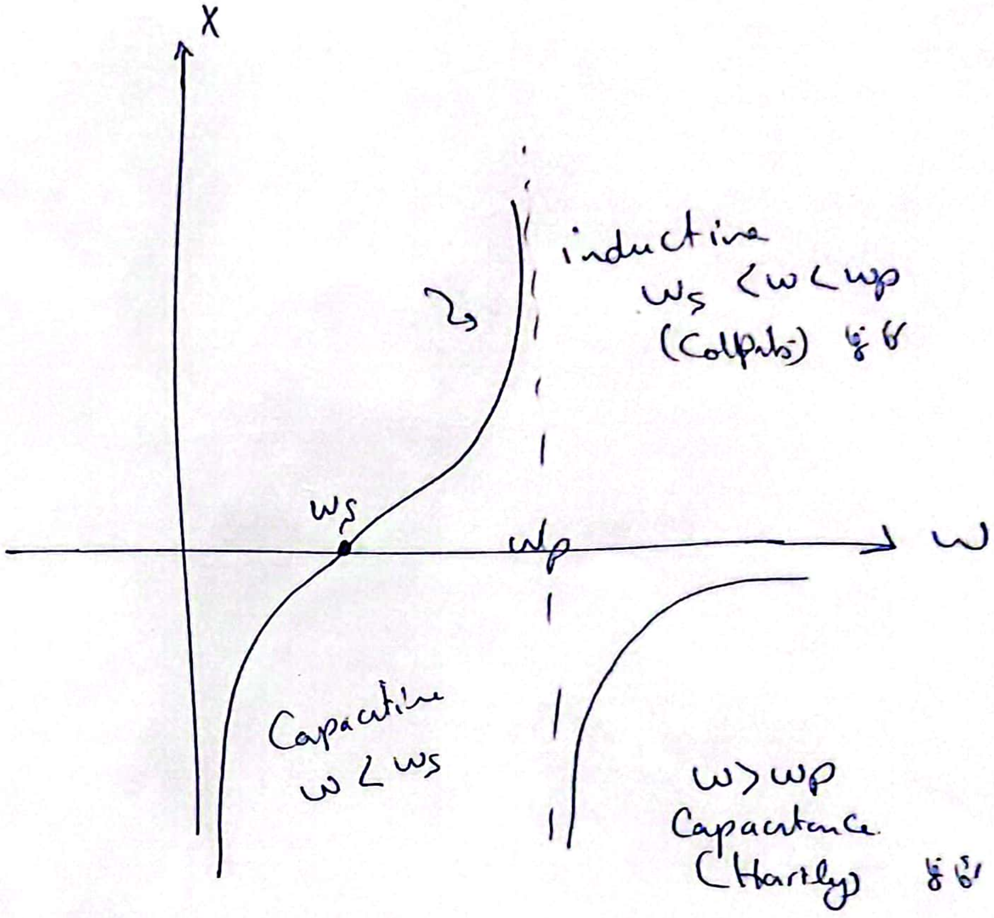
$$\boxed{\omega_p = \sqrt{\frac{C_s + C_p}{LC_s C_p}}}$$

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

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

$$\therefore \boxed{x = -\frac{1}{\omega C_p} \cdot \frac{\omega^2 - \omega_s^2}{\omega^2 - \omega_p^2}}$$

- Crystal reactance versus frequency:



- when $\omega = \omega_s$

  $\therefore \quad Z = 0$

- when $\omega = \omega_p$

  $\therefore \quad Z \rightarrow \infty$

- when $\omega = 0$

  $\therefore \quad Z = -\infty$

- when $\omega_s < \omega < \omega_p$

  $Z \rightarrow +ve$ (inductive effect)

- when $\omega > \omega_p$, $\omega > \omega_s$ $\quad Z \rightarrow -ve$ (Capacitive effect)