Analog Electronics

Course No: AE-2

Lec: LC & Crystal Oscillators

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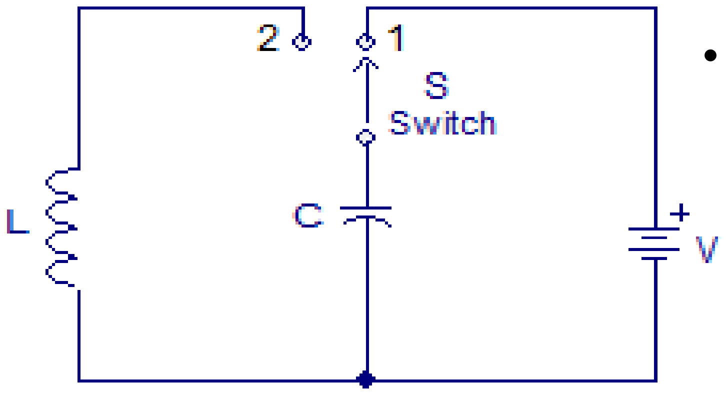
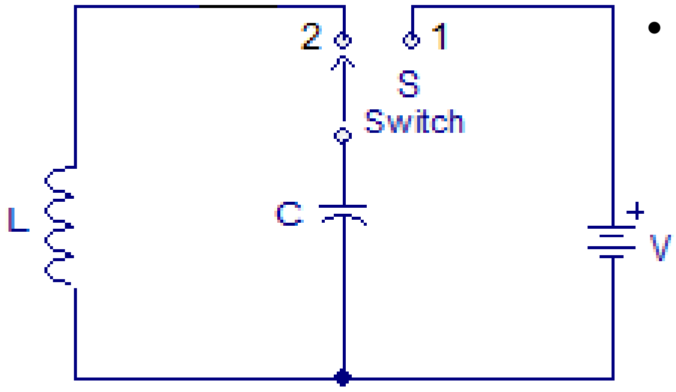
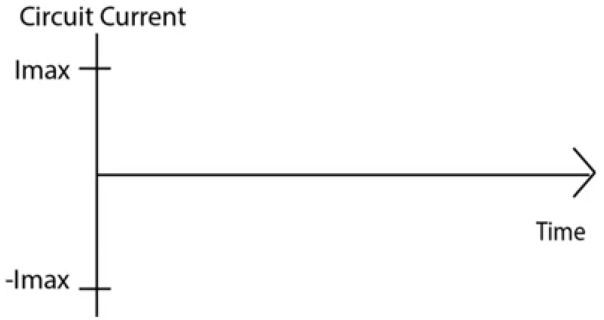
LC Tank Circuit:

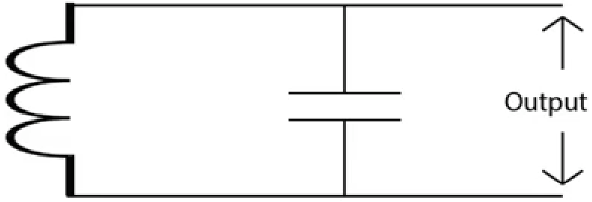


- Initially capacitor is not charged: $V_c(0^-) = 0$



- Continuous charging and discharging of capacitor and inductor

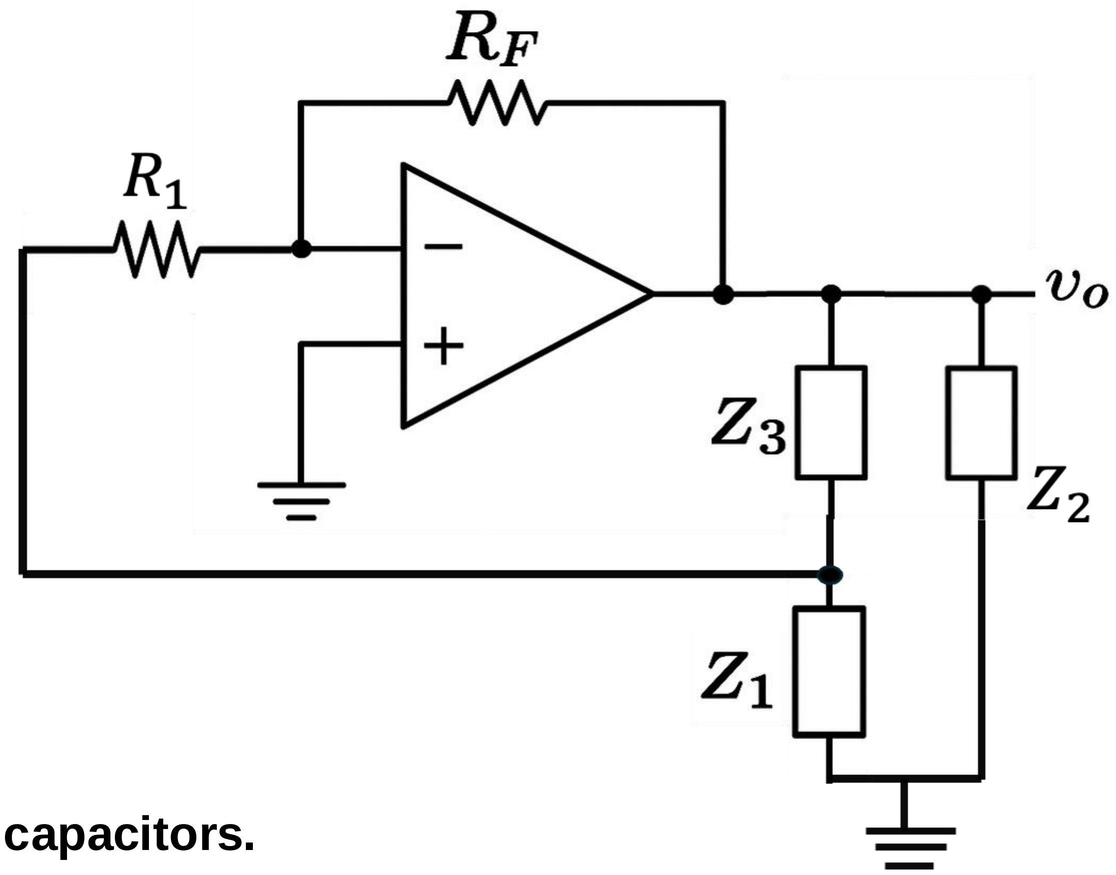




Tuned Oscillators Circuits: LC Oscillators

Tuned oscillators use a parallel LC resonant circuit (LC tank) to provide the oscillations.

- **The frequency selection network (Z_1, Z_2 and Z_3) provides a phase shift of 180º**
- **Output voltage is developed across Z_2 and feedback voltage is developed across Z_1.**
- **The amplifier provides additional shift of 180º**

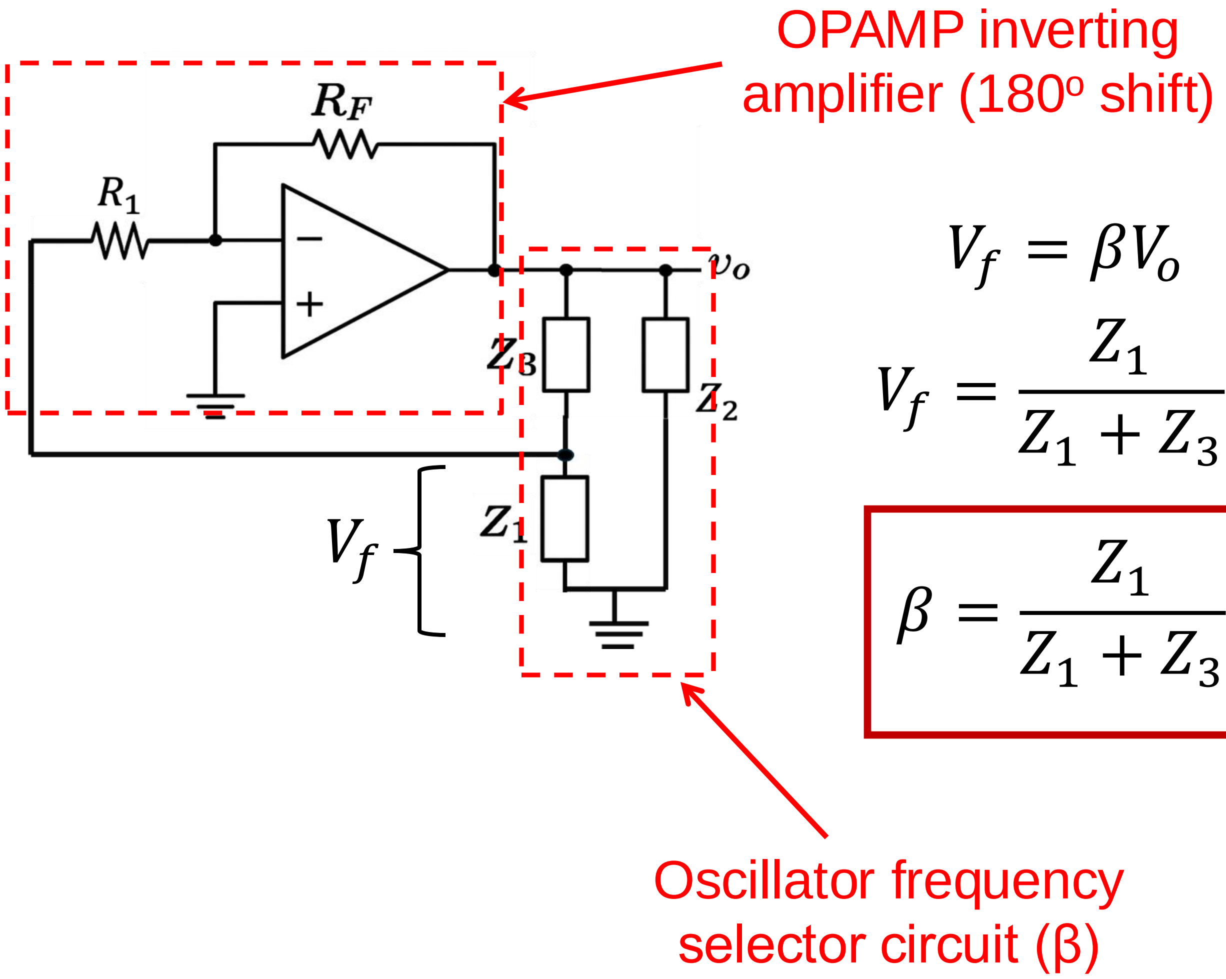


There are two common types:

Colpitts—The resonant circuit is an inductor and two capacitors.

Hartley—The resonant circuit is a tapped inductor or two inductors and one capacitor.

Generalized LC Oscillator:

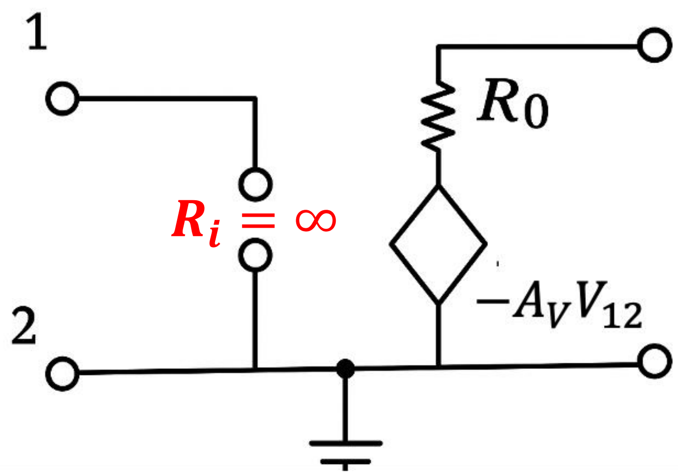


$$V_f = \beta V_o$$

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

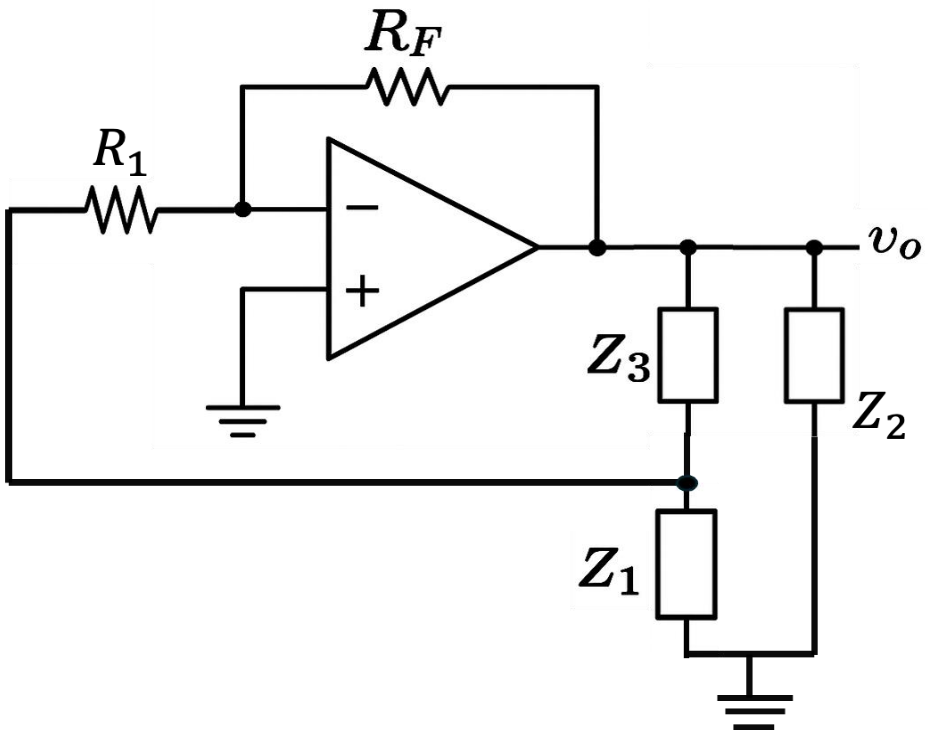
$$\boxed{\beta = \frac{Z_1}{Z_1 + Z_3}}$$

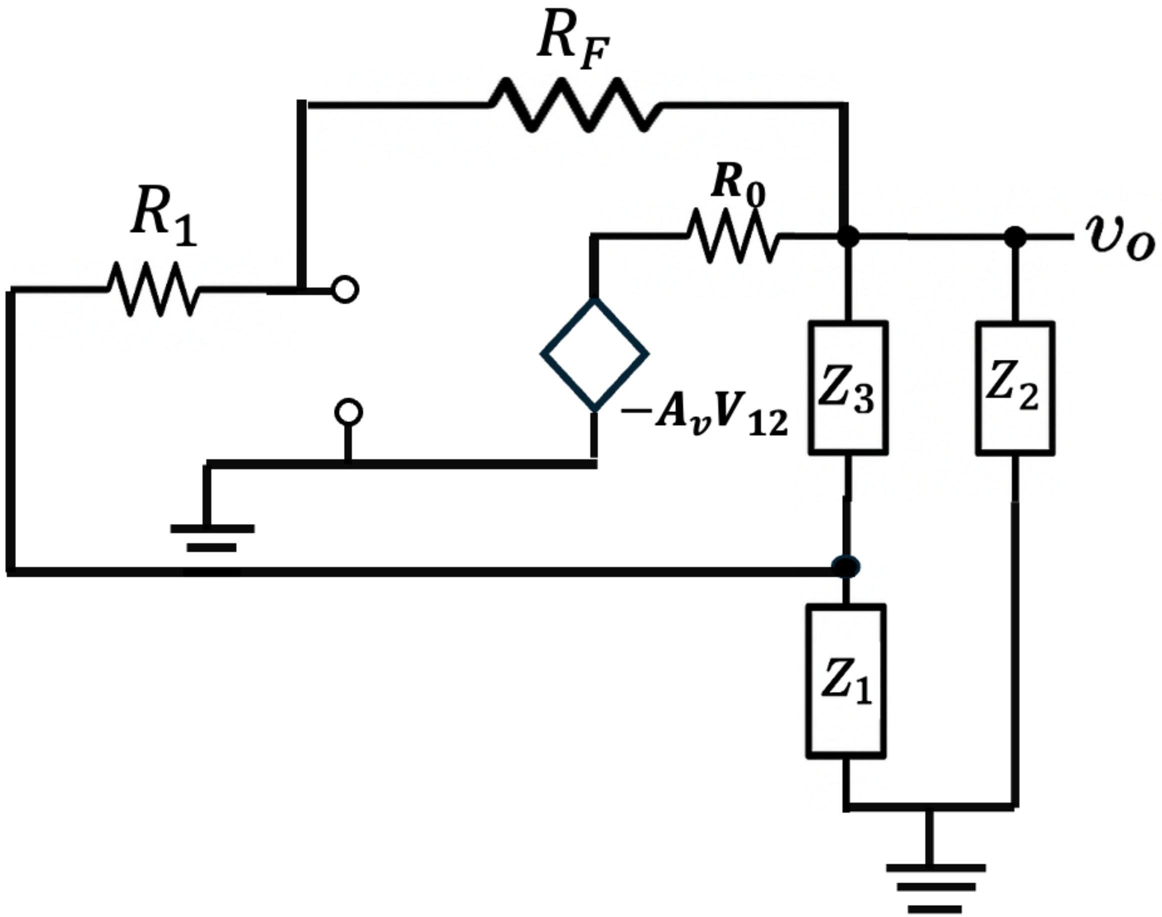
OPAMP's internal ckt:



- $\boldsymbol{R_i} = \infty$ (very high so we can reject)
- But $\boldsymbol{R_o}$ is finite but low

Generalized LC Oscillator:





$$V_0 = -A_v V_{12} \times \frac{Z_l}{Z_l + R_0}$$

$$Z_l = Z_2 || (Z_1 + Z_3)$$

$$= \frac{Z_2 \times (Z_1 + Z_3)}{Z_1 + Z_3 + Z_2}$$

$$A = \frac{V_0}{V_{12}} = -A_v \times \frac{Z_l}{Z_l + R_0}$$

$$A = \frac{-A_v \times \; Z_2 \times (Z_1 + Z_3)}{R_0 \times (Z_1 + Z_3 + Z_2) + Z_2 \times (Z_1 + Z_3)}$$

$$\boxed{A = \frac{-A_v \times Z_2 \times (Z_1 + Z_3)}{R_0 \times (Z_1 + Z_3 + Z_2) + Z_2 \times (Z_1 + Z_3)}}$$

$$\boxed{\beta = \frac{Z_1}{Z_1 + Z_2}}$$

$$\boxed{A\beta = \frac{-A_v \times Z_2 \times Z_1}{R_0 \times (Z_1 + Z_3 + Z_2) + Z_2 \times (Z_1 + Z_3)}}$$

Let $Z_1, Z_2, Z_3 = j\,X_1, j\,X_2, j\,X_3$;

$$where\ X = \omega L, or(-\frac{1}{\omega C})$$

$$A\beta = \frac{A_v \times X_2 \times X_1}{jR_0 \times (X_1 + X_3 + X_2) - X_2 \times (X_1 + X_3)}$$

Aβ should be equal for sustained oscillation:

$$jR_0 \times (X_1 + X_3 + X_2) = 0$$

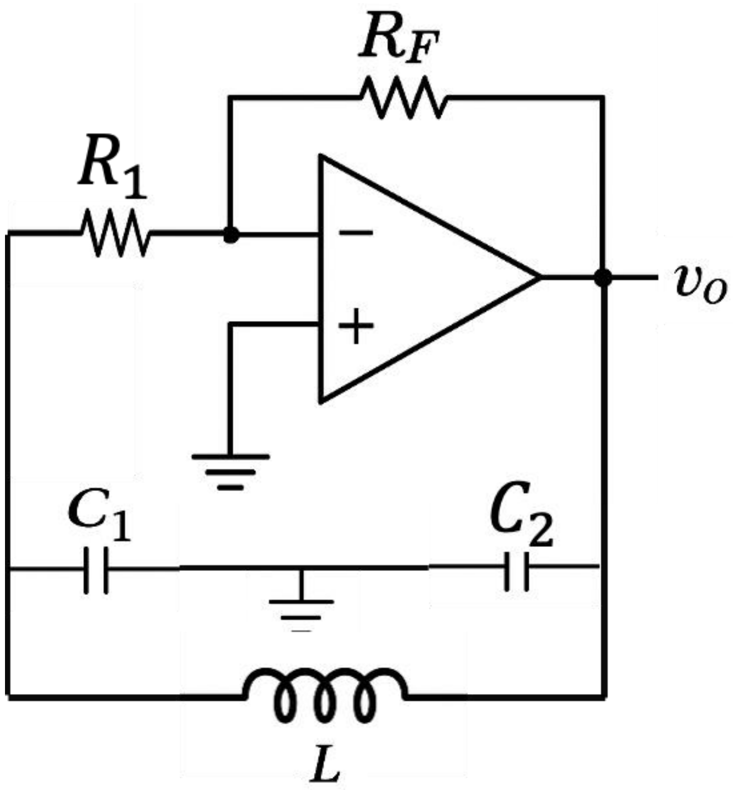
$$\Rightarrow \boxed{(X_1 + X_3 + X_2) = 0}$$

$$A\beta = \frac{A_v \times X_2 \times X_1}{-X_2 \times (X_1 + X_3)}$$

$$A\beta = \frac{A_v \times X_2 \times X_1}{-X_2 \times -X_2} = \frac{A_v \times X_1}{X_2}$$

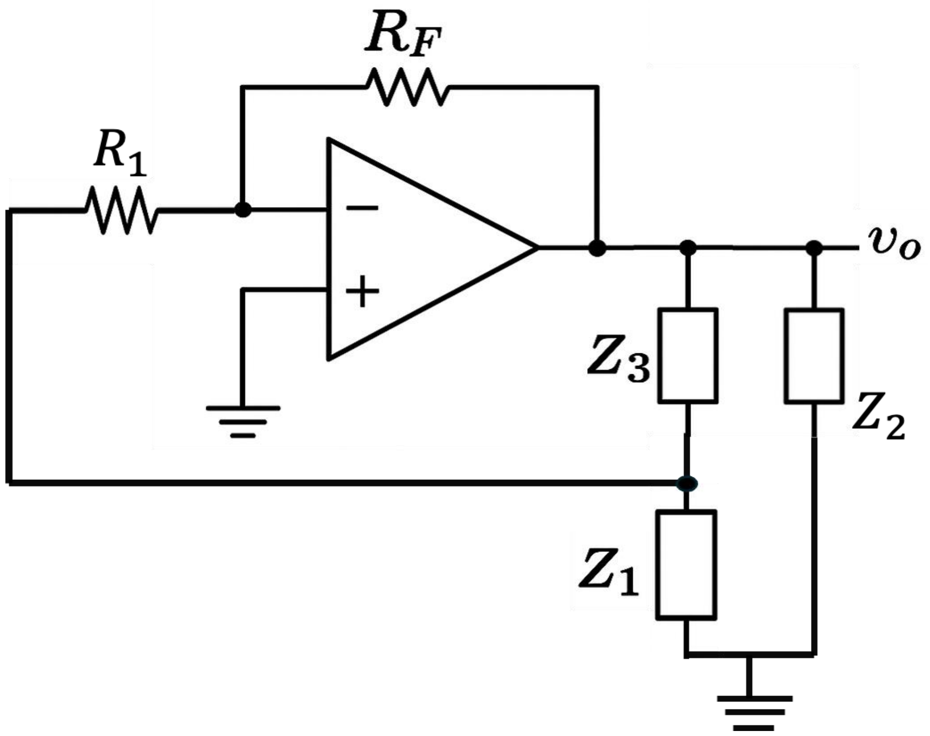
$$\boxed{A_v = \frac{X_2}{X_1}}$$

Colpitt's Oscillator:



$Z_1, Z_2 \rightarrow$ **Capacitors**

$Z_3 \rightarrow$ **Inductor**



Derive relation of f_0 !!

$$\Rightarrow (X_1 + X_3 + X_2) = 0$$

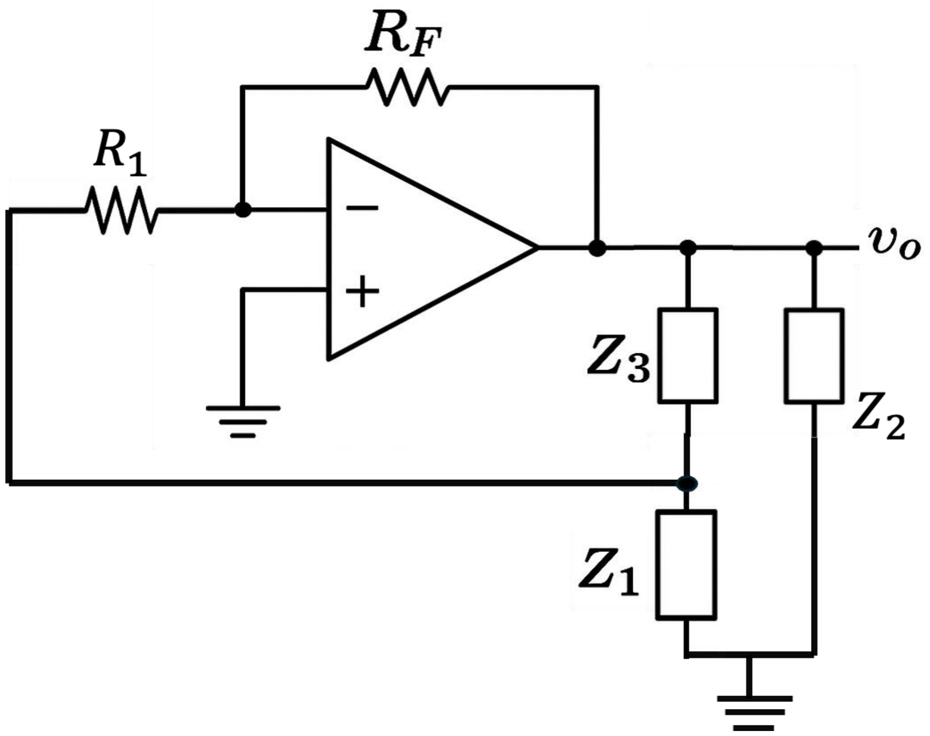
$$-\frac{1}{\omega C_1} + \omega L + -\frac{1}{\omega C_2} = 0$$

$$\boxed{f_0 = \frac{1}{2\pi}\sqrt{\frac{(C_1 + C_2)}{L C_1 C_2}}}$$

Hartley's Oscillator:

$Z_{1,}$ Z_2→ Inductor

Z_3→ Capacitors



Derive relation of f_0 !!

$$\Rightarrow (X_1 + X_2 + X_3) = 0$$

$$\omega L_1 + \omega L_2 + -\frac{1}{\omega C} = 0$$

$$\boxed{f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC + L_2)}}}$$

Crystal Oscillators

- Piezoelectric crystals are those materials which start vibrating under the application of ac voltage and vibration frequency is equal to the applied voltage. This effect is known as piezoelectric effect. Some examples are quartz, tourmaline, Rochelle Salt...etc.

- In Crystal Oscillator, piezoelectric crystal is used in feedback network in place of RC or LC circuit.

- Each crystal has a natural frequency which is given by

$$\boldsymbol{f = \frac{K}{t}}$$

Where K is a constant depends on the cut;

t : thickness of the crystal

- Extremely thin crystal may break due to vibrations which puts the limit to the frequency obtainable. Crystal oscillator can be used in the frequency range of 25kHz to few hundred MHz.

The frequency of CO changes by less than 0.1% due to temperature or other changes.

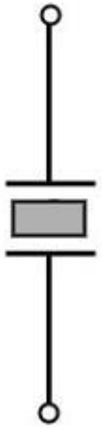
Crystal Oscillator

- In order to use the crystal in an electronic circuit, it is placed between two metal plates.

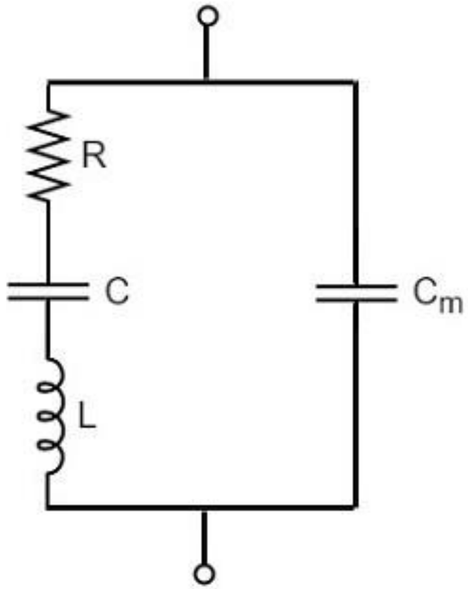
- A piezoelectric crystal exhibit electromechanical resonance characteristics.

- The resonance properties are characterized by large inductance L, a very small series capacitance C, and small series resistance R to make Q factor very high.

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



Symbol of a Crystal



Equivalent circuit of a crystal

Crystal Oscillator (series resonating frequency)

The crystal has two resonant frequencies:

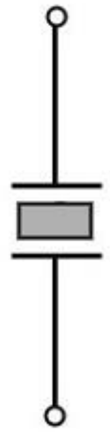
- **Series resonant frequencies at ω_s**
- **Parallel resonant frequencies at ω_P**

In series path impedance

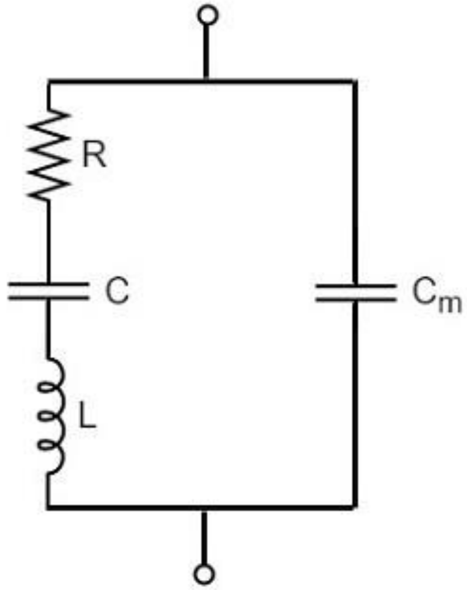
$$Z = R + j(\omega L - \frac{1}{\omega C})$$

Imaginary part has to be zero: $\omega_s L - \frac{1}{\omega_s C} = 0$

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



Symbol of a Crystal



Equivalent circuit of a crystal

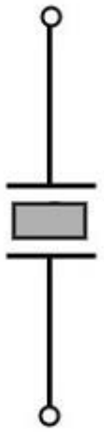
Crystal Oscillator (paralle resonating frequency)

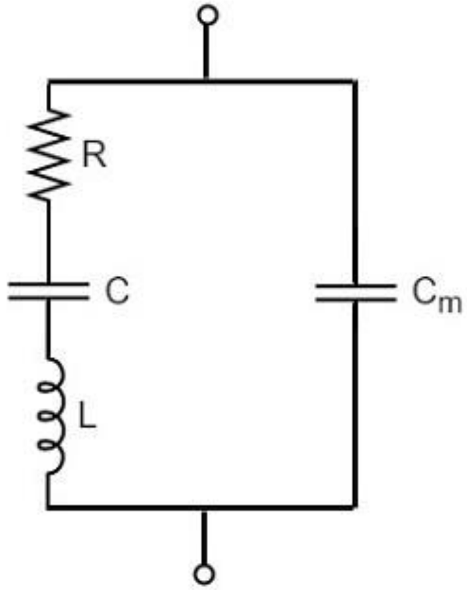
$$\frac{1}{Z_T} = \frac{1}{Z_{sp}} + \frac{1}{Z_{pl}}$$
$$= \frac{1}{j(\omega L - \frac{1}{\omega C})} + j\omega C_m$$

Imaginary part has to be zero:

$$-\frac{j}{\left(\omega L - \frac{1}{\omega C}\right)} + j\omega C_m = 0$$

$$\boxed{\boldsymbol{f_p = \frac{1}{2\pi} \times \frac{1}{\sqrt{\frac{LCC_m}{(C + C_m)}}}}}$$





Equivalent circuit of a crystal

THE END.