Analog & Digital Electronics

Course No: PH-218

Lec-17: LC and Crystal Oscillator

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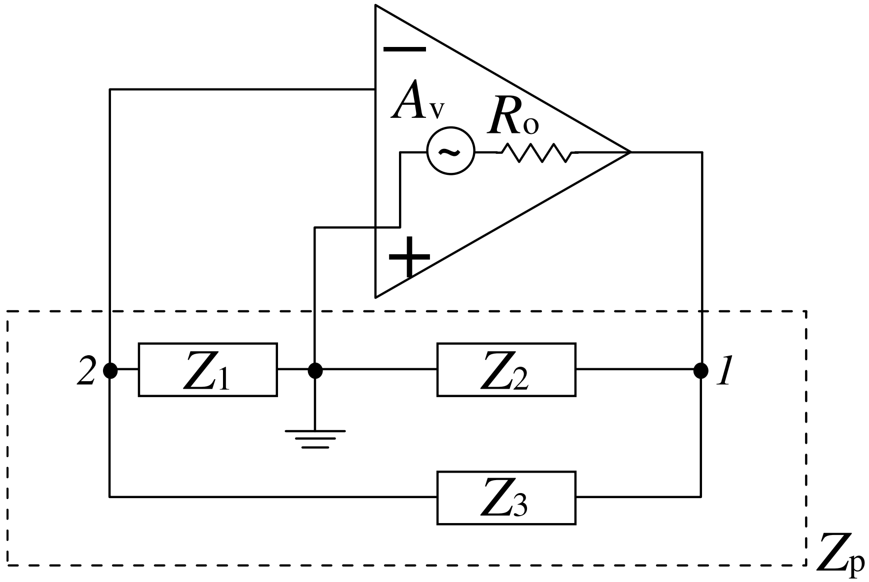
Tuned Oscillators Circuits: LC Oscillators

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**



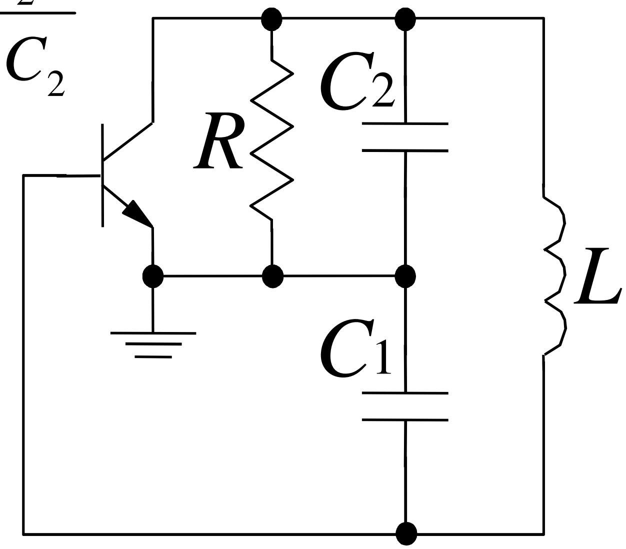
There are two common types:

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

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

Colpitt Oscillator

$$\omega_o = \frac{1}{\sqrt{LC_T}} \quad C_T = \frac{C_1 C_2}{C_1 + C_2}$$



BJT output is developed across C_1 and feedback voltage is developed across C_2 .

Each capacitor causes 90° phase shift hence total 180° phase shift.

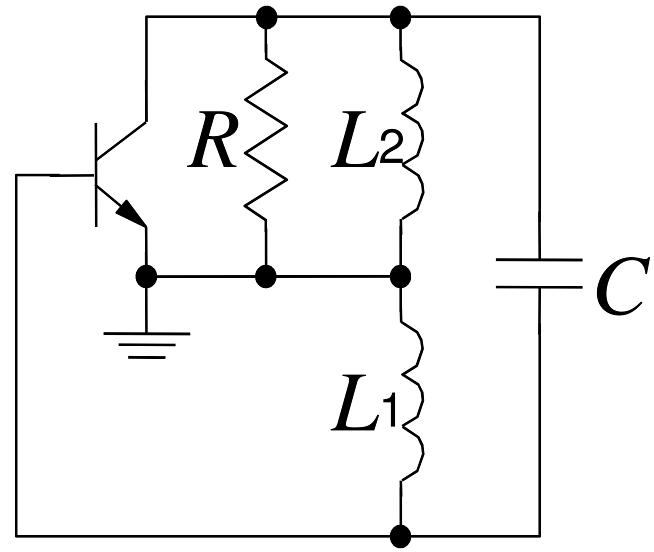
Feedback fraction β

$$\beta = \frac{C_2}{C_1}$$

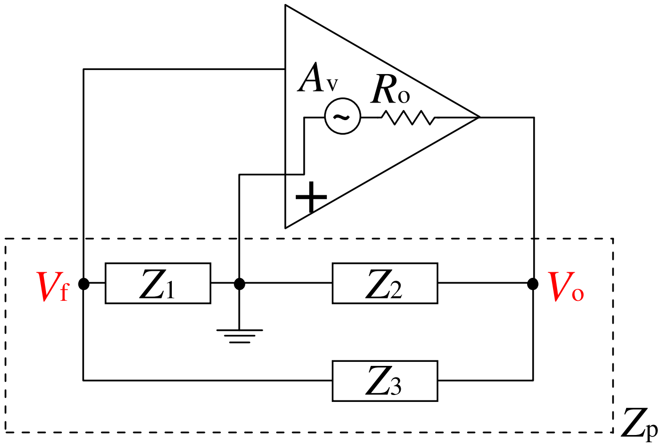
Hartley Oscillator

$$\omega_o = \frac{1}{\sqrt{(L_1 + L_2)C}}$$

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



Tuned Oscillators Circuits: LC Oscillators

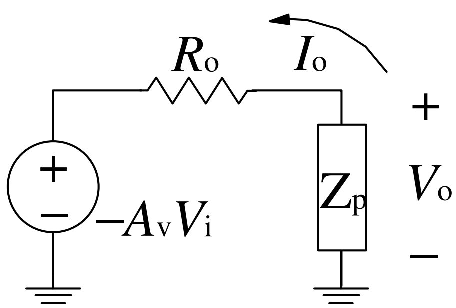


$$V_f = \beta V_o = \frac{Z_1}{Z_1 + Z_3} V_o$$

$$Z_p = Z_2 // (Z_1 + Z_3)$$

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

For the equivalent circuit from the output



$$\frac{-A_v V_i}{R_o + Z_p} = \frac{V_o}{Z_p} \quad \text{or} \quad \frac{V_o}{V_i} = \frac{-A_v Z_p}{R_o + Z_p}$$

Therefore, the amplifier gain is obtained,

$$A = \frac{V_o}{V_i} = \frac{-A_v Z_2 (Z_1 + Z_3)}{R_o (Z_1 + Z_2 + Z_3) + Z_2 (Z_1 + Z_3)}$$

Tuned Oscillators Circuits: LC Oscillators

The loop gain,

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

If the impedance are all pure reactances, i.e.,

$$Z_1 = jX_1, \quad Z_2 = jX_2 \text{ and } \quad Z_3 = jX_3$$

The loop gain becomes,

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

The imaginary part = 0 only when $X_1 + X_2 + X_3 = 0$

- It indicates that at least one reactance must be –ve (capacitor)
- X_1 and X_2 must be of same type and X_3 must be of opposite type

With imaginary part = 0,

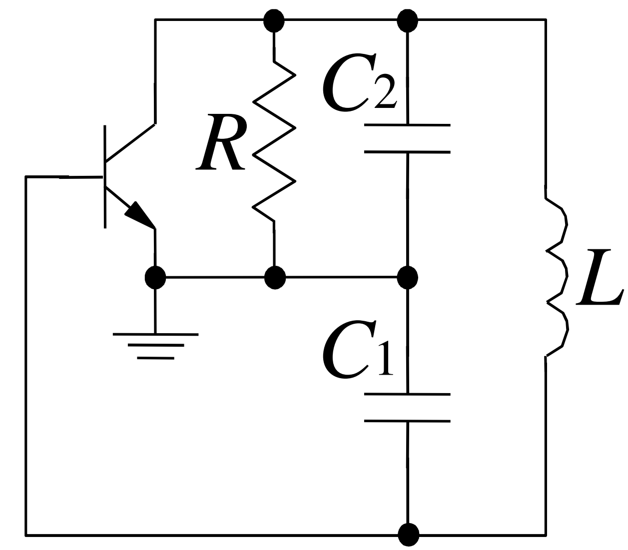
$$A\beta = \frac{-A_v X_1}{X_1 + X_3} = \frac{A_v X_1}{X_2}$$

For Unit Gain & 180° Phase-shift,

$$A\beta = 1 \quad \Rightarrow \quad A_v = \frac{X_2}{X_1}$$

LC Oscillators

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



Colpitt Oscillator

$Z_1 = 1 / j\omega C_1$; $Z_2 = 1 / j\omega C_2$; $Z_3 = j\omega L$

$$A\beta = \frac{-A_v}{j(\omega^2 LC_1C_2 - C_2 - C_1)R_o - (\omega^2 LC_2 - 1)}$$

For ***Barkhausen Criterion*** $A\beta$=1, imaginary part = 0, $\omega^2 LC_1C_2 - C_2 - C_1 = 0$

$$\omega^2 = \frac{C_2+C_1}{LC_1C_2} = \frac{1}{LC_T}$$

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

$$where \Rightarrow C_T = \frac{C_2+C_1}{C_1C_2}$$

At this frequency βA=1,

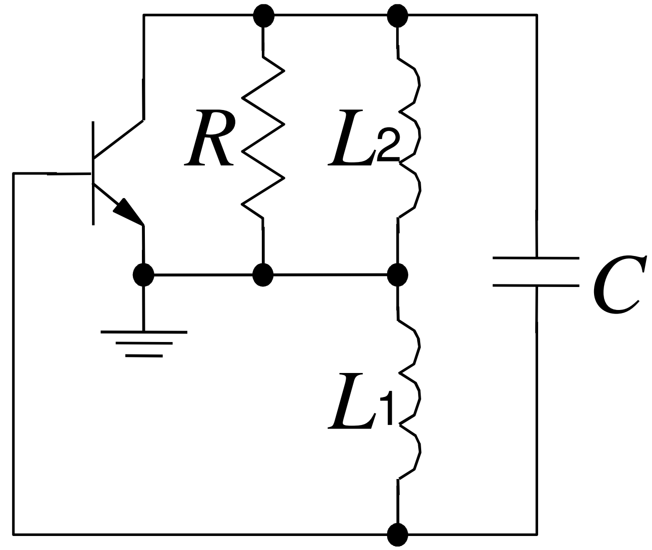
$$1 = \frac{-A_v}{-(\omega^2 LC_2 - 1)}$$

$$A_v = (\omega^2 LC_2 - 1) = \frac{C_1}{C_2}$$

$$\beta = \frac{C_2}{C_1}$$

LC Oscillators

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



Hartley Oscillator

Z_1=jωL$_1$; Z_2= jωL$_2$; Z_3=1/jωC

$$A\beta = \frac{-A_v(\omega^2 L_1 L_2)}{j(\omega L_1 + \omega L_2 - 1/\omega C)R_o - (\omega L_1 + 1/\omega C)}$$

For ***Barkhausen Criterion*** $A\beta$=1, imaginary part = 0,

$$\omega L_1 + \omega L_2 = 1/\omega C \qquad \omega = \frac{1}{\sqrt{(L_1+L_2)C}}$$

At this frequency βA=1,

$$A_v == \frac{L_2}{L_1} \qquad \beta = \frac{L_1}{L_2}$$

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**

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

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 Oscillators

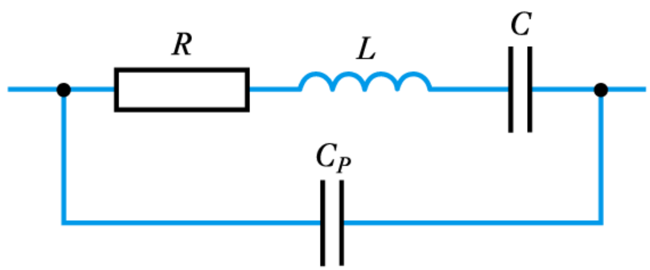
➢ **In order to use the crystal in an electronic circuit, it is placed between two metal plates. The arrangement then forms the capacitor with crystal as a dielectric (electrostatic capacitor).**

➢ **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 ($Q = \omega_o L / R$) very high.**

➢ **Generally $C_p >> C$**

(a) Circuit symbol



(b) Equivalent circuit

Piezoelectric crystals act like resonant circuits.

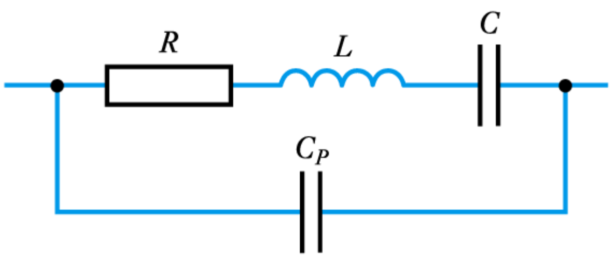
Crystal Oscillators

- Since the Q factor is very high, we may neglect R.

$$Z(j\omega) = Z_3 // (Z_1 + Z_2) = \frac{Z_3(Z_1 + Z_2)}{Z_1 + Z_2 + Z_3}$$

$Z_1 = j\omega L$; $Z_2 = 1/j\omega C$; $Z_3 = 1/j\omega C_p$;

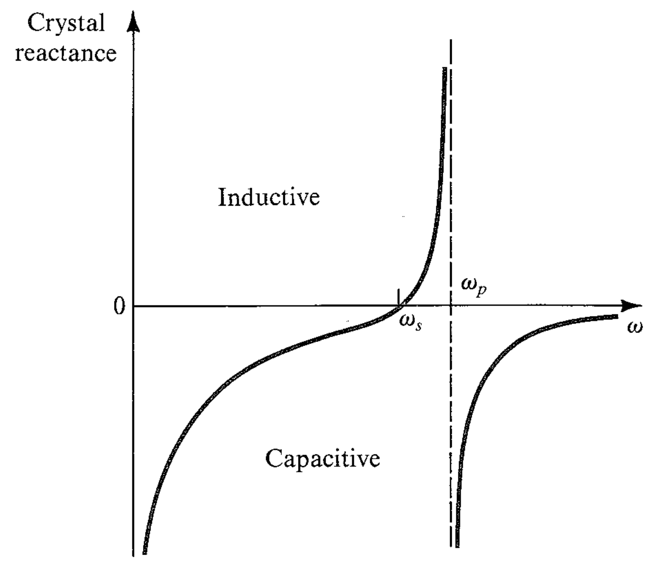
(a) Circuit symbol



(b) Equivalent circuit

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

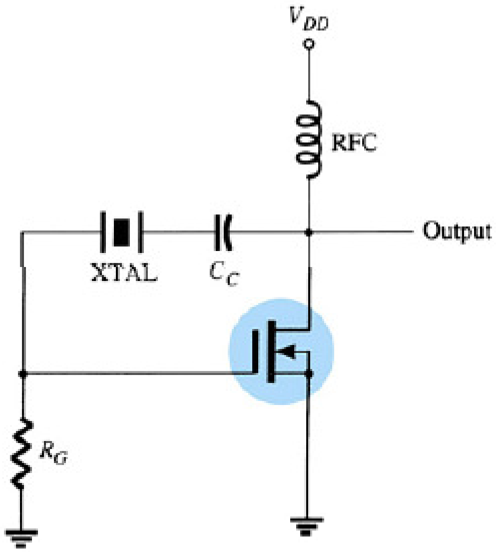
Where $\omega_s = \frac{1}{\sqrt{LC}}$ $\omega_P = \frac{1}{\sqrt{\frac{LCC_P}{(C + C_P)}}}$



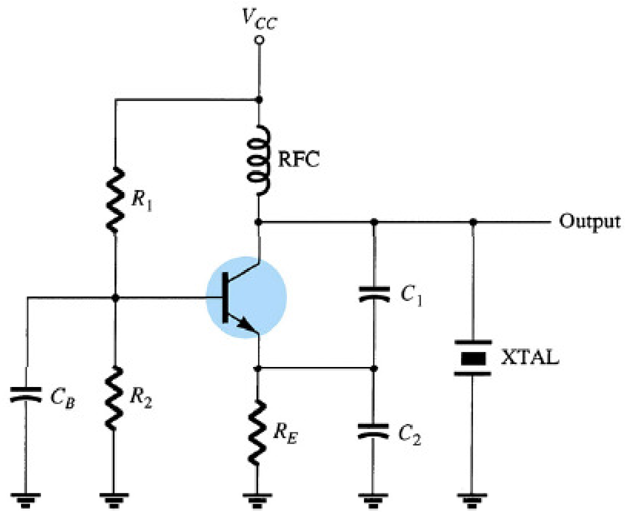
The crystal has two resonant frequencies:
(1) Series resonant frequencies at ω_s
(2) Parallel resonant frequencies at ω_P

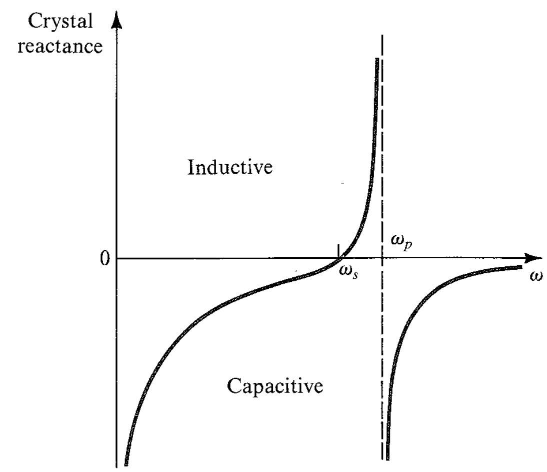
Crystal Oscillators

Series resonant condition



Parallel resonant condition





- If we use the crystal in place of series LC circuit, the oscillator will operate at frequency ω_s and If the crystal is used in place of parallel LC circuit, the oscillator will operate at frequency ω_P
- The series and parallel resonant frequencies are very close, within 1% of each other.

Frequency Stability

- **The frequency stability of an oscillator is defined as**

$$\frac{1}{\omega_o} \cdot \left(\frac{d\omega}{d\mathbf{T}} \right)_{\omega = \omega_o} \qquad \textbf{ppm/}^{\circ}\textbf{C}$$

- **Use high stability capacitors, e.g. silver mica, polystyrene, or teflon capacitors and low temperature coefficient inductors for high stable oscillators.**

Amplitude Stability

- **In order to start the oscillation, the loop gain is usually slightly greater than unity.**
- **LC oscillators in general do not require amplitude stabilization circuits because of the selectivity of the LC circuits.**
- **In RC oscillators, some non-linear devices, e.g. zener diodes or Ar bulb can be used to stabilized the amplitude.**