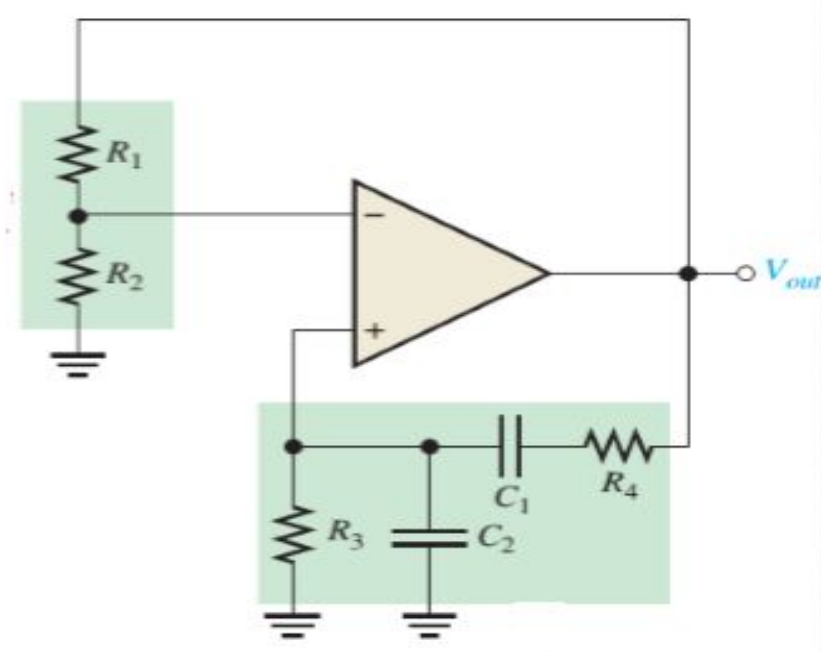
Analog and Digital Systems (UEE505)

Lecture # 13
Wein Bridge & Crystal Oscillator

THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

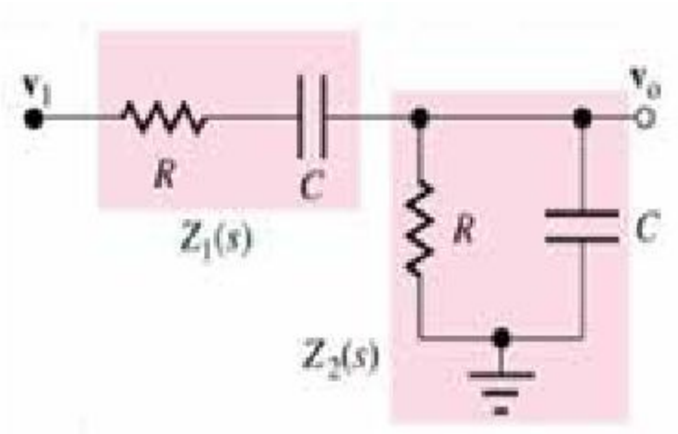
Deptt. Of Electrical & Instrumentation Engineering
Thapar Institute of Engineering & Technology Patiala, India

Wein Bridge Oscillator



- Most widely used RC feedback oscillator .
- The feedback resistors are R_1 and R_2.
- The phase-shift components are R_3, C_1 and R_4, C_2.

Frequency of Oscillation



$$V_o(s) = V_1(s)\frac{Z_2(s)}{Z_1(s)+Z_2(s)}$$

$$T(s) = \frac{V_o(s)}{V_1(s)} = \frac{sRC}{s^2R^2C^2+3sRC+1}$$

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

For zero degree phase shift,

$$\left(1-\omega_o^2R^2C^2\right)=0$$

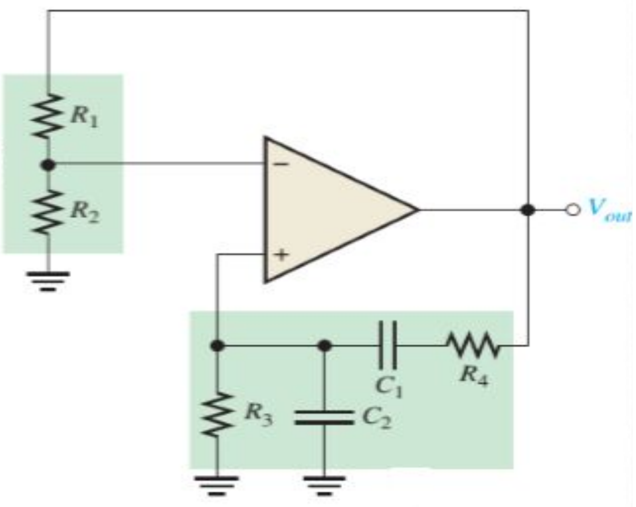
$$\omega_o = \frac{1}{RC}$$

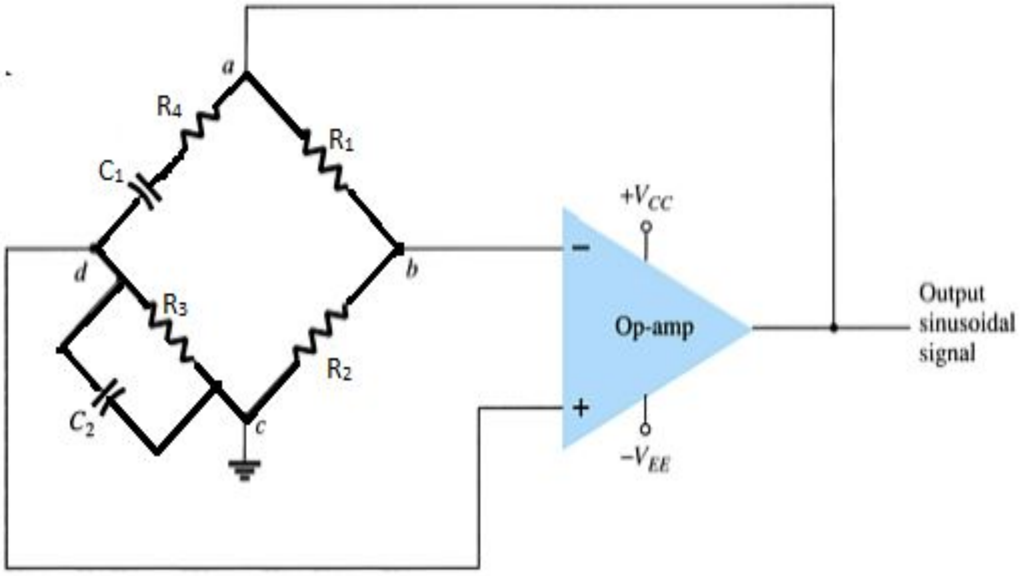
$$T(j\omega_o) = \frac{1}{3}$$

- It means to start up the oscillations, closed-loop gain of the amplifier should be more than 3.
- The gain of the amplifier must then decrease to 3 so that the total gain around the loop becomes unity to sustain the oscillations.

Wein Bridge Oscillator

$$f_r = 1/\ 2\pi\sqrt{R_3 R_4 C_1 C_2}$$



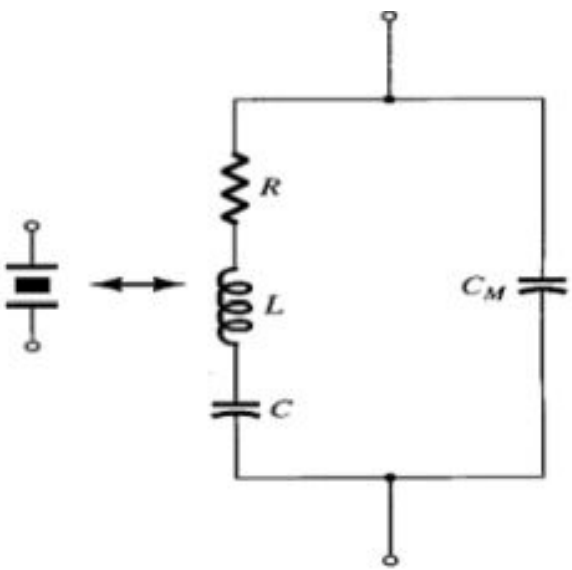


Crystal Oscillator

- The most stable and accurate type of feedback oscillator uses a piezoelectric crystal in the feedback loop to control the frequency.
- Quartz is one type of crystalline substance found in nature that exhibits a property called the piezoelectric effect.
- When a changing mechanical stress is applied across the crystal to cause it to vibrate, a voltage develops at the frequency of mechanical vibration.
- Conversely, when an AC voltage is applied across the crystal, it vibrates at the frequency of the applied voltage.
- The greatest vibration occurs at the crystal’s natural resonant frequency, which is determined by the physical dimensions and by the way the crystal is cut.

Crystal Oscillator

The crystal's equivalent circuit is a series-parallel RLC circuit and can operate in either series resonance or parallel resonance. Symbol & Equivalent circuit is shown as:



- At the series resonant frequency, the inductive reactance is cancelled by the reactance of C.
- When the crystal is not vibrating, it is equivalent to a capacitance C.
- This is due to the fact that two metal plates are separated by a dielectric.
- The vibrating crystal can be represented by a series LCR circuit shunted by C_M .
- The inductance L is electrical equivalent of mass of vibrating crystal, C is electrical equivalent of mechanical compliance and resistance R represents the electrical equivalence of mechanical friction.

Crystal Oscillator

- Parallel resonance occurs when reactance of the series leg equals the reactance of C_M
- At this frequency, crystal offers a very high impedance to the external circuit.
- The parallel resonant frequency is usually at least 1 kHz higher than the series resonant frequency.

Series resonance frequency fs & Parallel resonant frequency fp

At $X_L = X_C$, f = fs

$$\omega_s L = \frac{1}{\omega_s C} \quad \text{or} \quad \omega_s^2 = 1/LC$$

$$\omega_s L = \frac{1}{\omega_s C} \quad \text{or} \quad \omega_s^2 = 1/LC$$

$$f_s = \omega/2\pi = 1/\,2\pi\sqrt{LC}$$

When reactance of series leg equals the reactance of C_m, f = fp

$$\omega_p L - 1/\omega_p C = 1/\omega_p C_m$$

$$\omega_p L = 1/\omega_p C + 1/\omega_p C_m$$

$$\omega_p^2 L = 1/C_m + 1/C$$

$$= C + C_m / CC_m$$

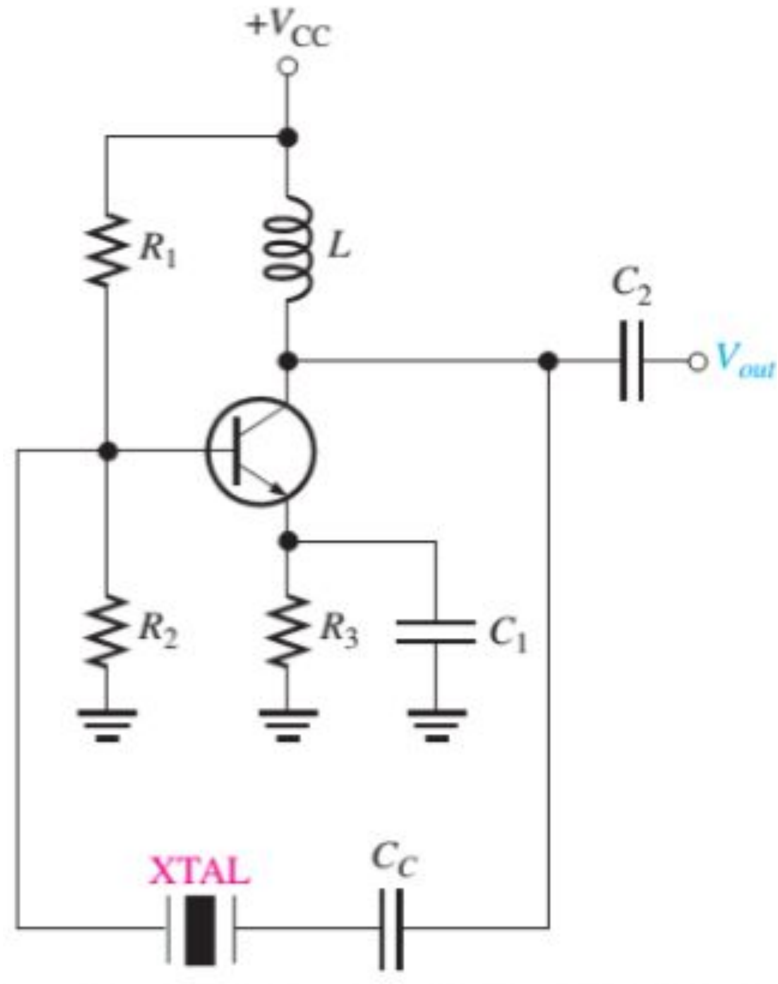
$$\omega_p = \sqrt{\left(\frac{C + C_m}{LCC_m}\right)}$$

Crystal Oscillator

- Crystals are available at frequencies of 15 KHz and above.
- Commercially available crystals can generally be used in the frequency range about 15 KHz to 10MHz.
- The values of L, C, R, Cm are such that the two frequencies fs and fp differ by very small amount.
- This fact gives rise to great frequency stability of crystal oscillator.

Crystal Oscillator Circuit

- A great advantage of the crystal is that it exhibits a very high Q .
- An oscillator that uses a crystal as a series resonant tank circuit is shown here.
- The impedance of the crystal is minimum at the series resonant frequency, thus providing maximum feedback.
- The crystal tuning capacitor, C is used to “fine tune” the oscillator frequency.



Negative Resistance Oscillator

- The term **negative resistance** refers to a condition where an increase in voltage across two points causes a decrease in current.
- Negative resistors are theoretical and do not exist as a discrete component.
- An oscillator that uses negative resistance elements such as tetrodes, tunnel diodes, Gunn diodes etc to provide oscillations.
- These diodes exhibit a negative resistance region in some part of their I-V (current – voltage) curve. They have two terminals like a resistor; but are not linear devices.
- In these, a resonator such as an LC circuit or quartz crystal is connected across the negative resistance device, and a DC bias voltage applied.
- These oscillators are frequently used for oscillations at microwave frequencies (1 -300GHz).

References

- For more details, refer to:

  - *Boylestad R. L., Electronic Devices and Circuit Theory, Pearson Education*
  - *Neamen, Donald A., Electronic Circuit Analysis and Design, McGraw Hill*
  - Thomas L. Floyd, Electronic Devices, *Pearson Education*