CRYSTAL OSCILLATOR:

The principle of crystal oscillators depends upon the Piezo electric effect.

- The natural5shape of a crystal is hexagonal. When a crystal wafer is cut perpendicular to X-axis, it is called as X-cut and when it is cut along Y-axis, it is called as Y-cut.
- The crystal used in crystal oscillator exhibits a property called as Piezo electric property. So, let us have an idea on piezo electric effect.

Piezo Electric Effect

- The crystal exhibits the property that when a mechanical stress is applied across one of the faces of the crystal, a potential difference is developed across the opposite faces of the crystal. Conversely, when a potential difference is applied across one of the faces, a mechanical stress is produced along the other faces. This is known as Piezo electric effect.
- Certain crystalline materials like Rochelle salt, quartz and tourmaline exhibit piezo electric effect and such materials are called as Piezo electric crystals. Quartz is the most commonly used piezo electric crystal because it is inexpensive and readily available in nature.
- When a piezo electric crystal is subjected to a proper alternating potential, it vibrates mechanically. The amplitude of mechanical vibrations becomes maximum when the frequency of alternating voltage is equal to the natural frequency of the crystal

Working of a Quartz Crystal

- In order to make a crystal work in an electronic circuit, the crystal is placed between two metal plates in the form of a capacitor. Quartz is the mostly used type of crystal because of its availability and strong nature while being inexpensive. The ac voltage is applied in parallel to the crystal.

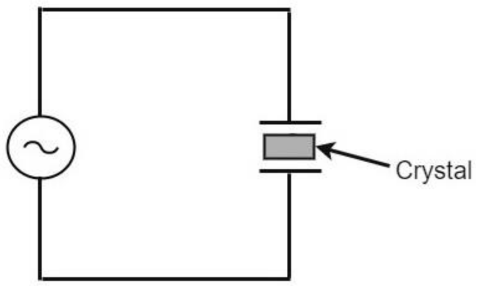


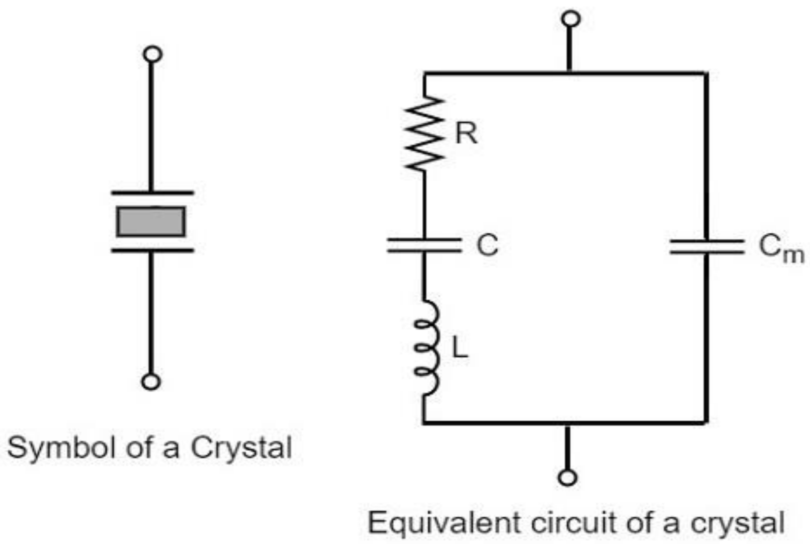
Figure 2.7.2 Quartz Crystal

[Source: Microelectronics byJ. Millman and A. Grabel, Page-423]

- If an AC voltage is applied, the crystal starts vibrating at the frequency of the applied voltage. However, if the frequency of the applied voltage is made equal to the natural frequency of the crystal, resonance takes place and crystal vibrations reach a maximum value. This natural frequency is almost constant.

Equivalent circuit of a Crystal

- If we try to represent the crystal with an equivalent electric circuit, we have to consider two cases, i.e., when it vibrates and when it doesn't. The figures below represent the symbol and electrical equivalent circuit of a crystal respectively.



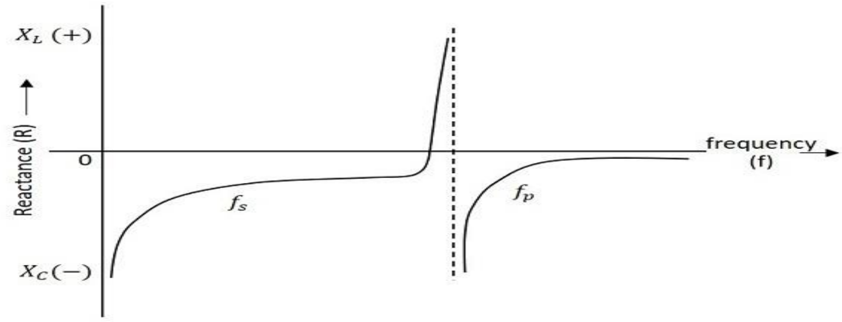
2.7.3.Symbol and Equivalent circuit of crystal

[Source: Microelectronics by J. Millman and A. Grabel, Page-423]

- The above equivalent circuit consists of a series R-L-C circuit in parallel with a capacitance C_m. When the crystal mounted across the AC source is not vibrating, it is equivalent to the capacitance C_m. When the crystal vibrates, it acts like a tuned R-L-C circuit.

Frequency response

- The frequency response of a crystal is as shown below. The graph shows the reactance (X_L or X_C) versus frequency (f). It is evident that the crystal has two closely spaced resonant frequencies.



2.7.4. Frequency Response

[Source: Microelectronics by J. Millman and A. Grabel, Page-486]

- The first one is the series resonant frequency (f_s), which occurs when reactance of the inductance (L) is equal to the reactance of the capacitance C. In that case, the impedance of the equivalent circuit is equal to the resistance R and the frequency of oscillation is given by the relation,

$$_{s} = \frac{1}{2\pi\sqrt{LC}}$$

- The second one is the parallel resonant frequency (f_p), which occurs when the reactance of R-L-C branch is equal to the reactance of capacitor C_m. At this frequency, the crystal offers very high impedance to the external circuit and the frequency of oscillation is given by the relation.

$$_{p} = \frac{1}{2\pi\sqrt{LCeq}}$$

Where,

$$C_{eq} = \frac{C_M C}{C_M + C}$$

- The value of C_m is usually very large as compared to C. Therefore, the value of C_T is approximately equal to C and hence the series resonant frequency is approximately equal to the parallel resonant frequency (i.e., $f_s = f_p$).
- The expression for resonating frequency,

$$r = \frac{1}{2\pi\sqrt{LC}}\sqrt{\frac{Q^2}{1+Q^2}}$$

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

- Q factor of the crystal is very high.(10^6)

$\sqrt{\frac{Q^2}{1+Q^2}}$ factor is unity hence $r = \frac{1}{2\pi\sqrt{LC}}$

- $Q \propto \frac{1}{t}$; t- thickness of crystal

Crystal Oscillator Circuit

- A crystal oscillator circuit can be constructed in a number of ways like a Crystal controlled tuned collector oscillator, a Colpitts crystal oscillator, a Clap crystal oscillator etc. But the transistor pierce crystal oscillator is the most commonly used one. This is the circuit which is normally referred as a crystal oscillator circuit.
- The following circuit diagram shows fig 2.7.5 the arrangement of a transistor pierce crystal oscillator.

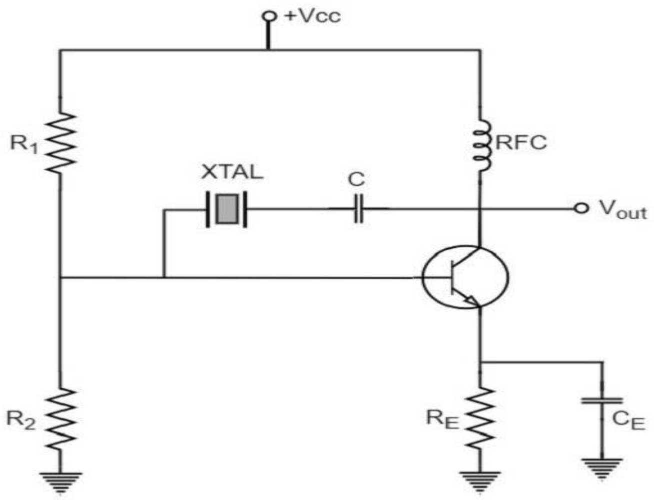


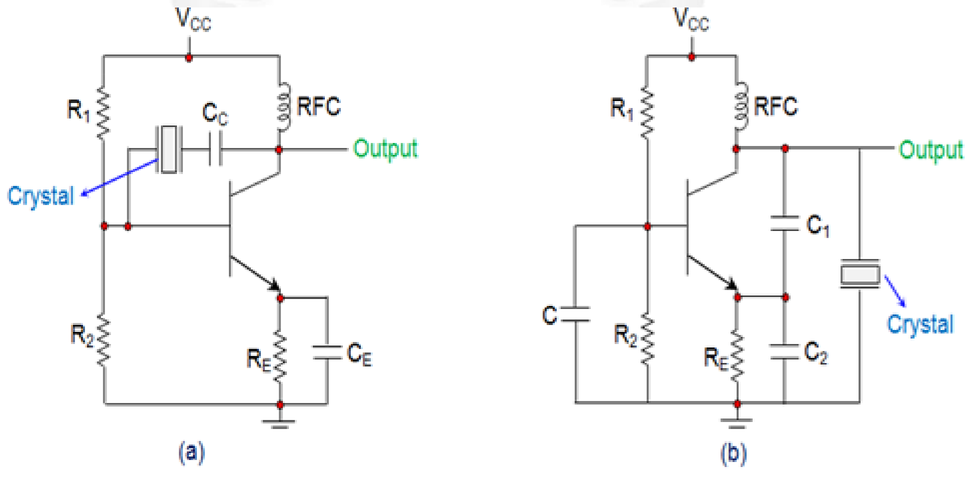
Figure 2.7.5 Transistor pierce crystal oscillator

‘[Source: Microelectronics by J. Millman and A. Grabel, Page-418]

- In this circuit, the crystal is connected as a series element in the feedback path from collector to the base. The resistors R_1, R_2 and R_E provide a voltage-divider stabilized d.c. bias circuit.
- The capacitor C_E provides a.c. bypass of the emitter resistor and RFC (radio frequency choke) coil provides for d.c. bias while decoupling any a.c. signal on the power lines from affecting the output signal. The coupling capacitor C has negligible impedance at the circuit operating frequency. But it blocks any d.c. between collector and base.
- The circuit frequency of oscillation is set by the series resonant frequency of the crystal and its value is given by the relation,

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

- It may be noted that the changes in supply voltage, transistor device parameters etc. have no effect on the circuit operating frequency, which is held stabilized by the crystal.
- Crystal Oscillators can be designed by connecting the crystal into the circuit such that it offers low impedance when operated in series-resonant mode (Fig. 2.7.6 a) and high impedance when operated in anti-resonant or parallel resonant mode (Figure 2.7.6 b).



Crystal Oscillator Operating in (a) Series Resonance (b) Parallel Resonance

2.7.6 Series resonance and Parallel resonance in crystal oscillator circuit

[Source: Microelectronics byJ. Millman and A. Grabel, Page-419]

- In this circuit R_1 and R_2 form the voltage divider network while the emitter resistor R_E stabilizes the circuit. Further, C_E (Figure 2.7.6 a) acts as an AC bypass capacitor while the coupling capacitor C_C (Figure2.7.6 a) is used to block DC signal propagation between the collector and the base terminals.
- The capacitors C_1 and C_2 form the capacitive voltage divider network in the case of Figure 2.7.6 b.
- There is also a Radio Frequency Coil (RFC) in the circuits which offers dual advantage as it provides even the DC bias as well as frees the circuit-output from being affected by the AC signal on the power lines.

Advantages

1. They have a high order of frequency stability.
2. The quality factor (Q) of the crystal is very high.