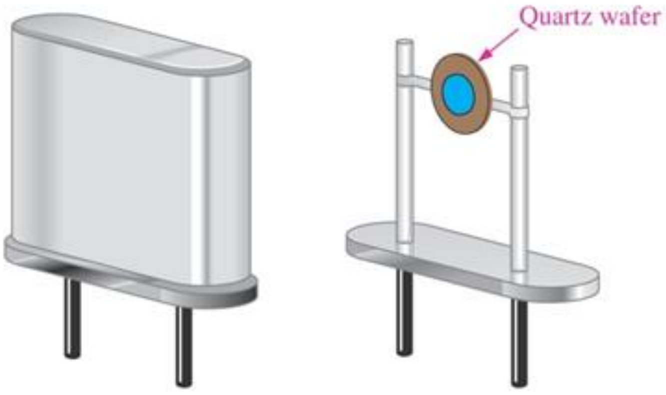
Crystal Oscillator

- Most communications and digital applications require the use of oscillators with extremely stable output. Crystal oscillators are invented to overcome the output fluctuation experienced by conventional oscillators.
- Crystals used in electronic applications consist of a quartz wafer held between two metal plates and housed in a package as shown in Fig. (a) and (b).



(a) Typical packaged crystal
(b) Basic construction (without case)

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Piezoelectric Effect

- The quartz crystal is made of silicon oxide (SiO_2) and exhibits a property called the *piezoelectric*
- When a changing an alternating voltage is applied across the crystal, it vibrates at the frequency of the applied ac voltage. In the other word, the frequency of the applied ac voltage is equal to the natural resonant frequency of the crystal.
- The thinner the crystal, higher its frequency of vibration. This phenomenon is called piezoelectric effect.
- The main substances those produce piezoelectric effect are quartz, Rochelle salts and tourmaline.
- Rochelle salts show the highest piezoelectric effect but its mechanical strength is very poor. Used in microphone, headsets and loudspeakers.
- On the other hand tourmaline shows weak piezo effect has highest mechanical strength among the three. This is very expensive.
- Quartz is a compromise between the above two and because of readily availability and being inexpensive quartz is widely used at RF frequency.

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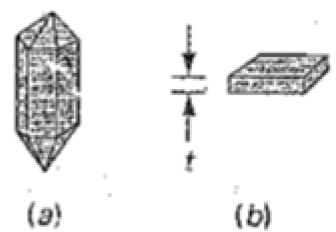
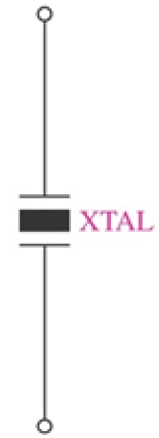
- Crystal slab

The natural shape of a quartz crystal is hexagonal prism with pyramids at the ends. To get usable crystal slab out of this, a manufacturer slices a rectangular slab out of natural crystal.



(a) natural quarz (b) slab with thickness, t



(c) Symbol

For use in electronic circuits, the slab must be mounted between two metal plates . In this circuit the amount of crystal vibration depends on the frequency of the applied voltage. By changing the frequency, we can find resonant frequencies at which the crystal vibrations reach a maximum.

Since the energy for the vibrations must be supplied by the ac source, the ac current is maximum at each resonant frequency.

Fundamental Frequency and Overtones

Most of the time, the crystal is cut and mounted to vibrate best at one of its resonant frequencies, usually the **fundamental frequency,** or lowest frequency. Higher resonant frequencies, called *overtones,* are almost exact multiples of the fundamental frequency. As an example, a crystal with a fundamental frequency of 1 MHz has a first overtone of approximately 2 MHz, a second overtone of approximately 3 MHz, and so on.

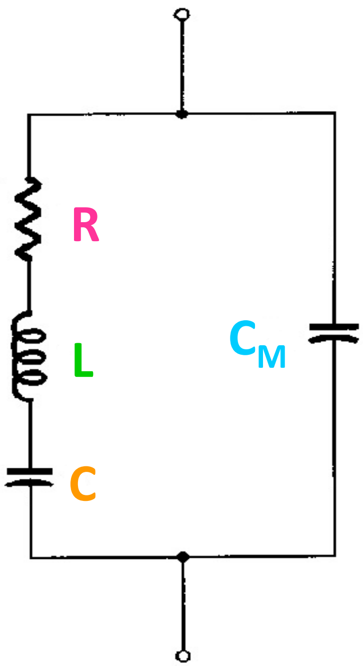
The formula for the fundamental frequency of a crystal is:

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

where K is a constant and t is the thickness of the crystal. Since the fundamental frequency is inversely proportional to the thickness, there is a limit to the highest fundamental frequency. The thinner the crystal, the more fragile it becomes and the more likely it is to break when vibrating.

Quartz crystals work well up to 10 MHz on the fundamental frequency. To reach higher frequencies, we can use a crystal that vibrates on overtones. In this way, we can reach frequencies up to 100 MHz. Occasionally, the more expensive but stronger tourmaline is used at higher frequencies.

- When no signal is applied the crystal is equivalent to a capacitance C_M since two metal plates are separated by quartz dielectric. C_M is said to be mounting capacitance.
- When the crystal is vibrating
- it acts like a tuned circuit



Crystal Stability

The frequency of any oscillator tends to change slightly with time. This *drift* is produced by temperature, aging, and other causes. In a crystal oscillator, the frequency drift is very small, typically less than 1 part in 10^6 per day. Stability like this is important in electronic wristwatches because they use quartz-crystal oscillators as the basic timing device.

By putting a crystal oscillator in a temperature-controlled oven, we can get a frequency drift of less than 1 part in 10^{10} per day. A clock with this drift will take 300 years to gain or lose 1 s. Stability like this is needed in frequency and time standards.

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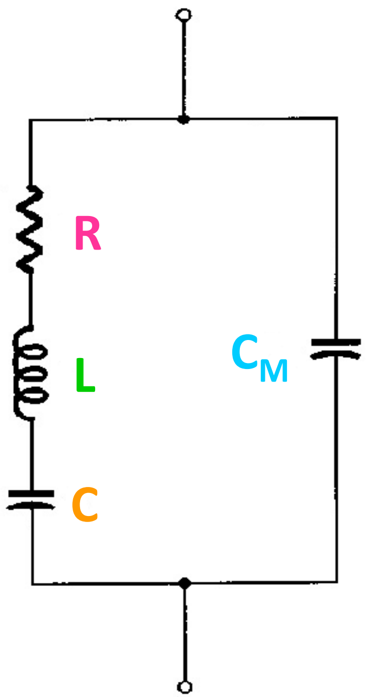
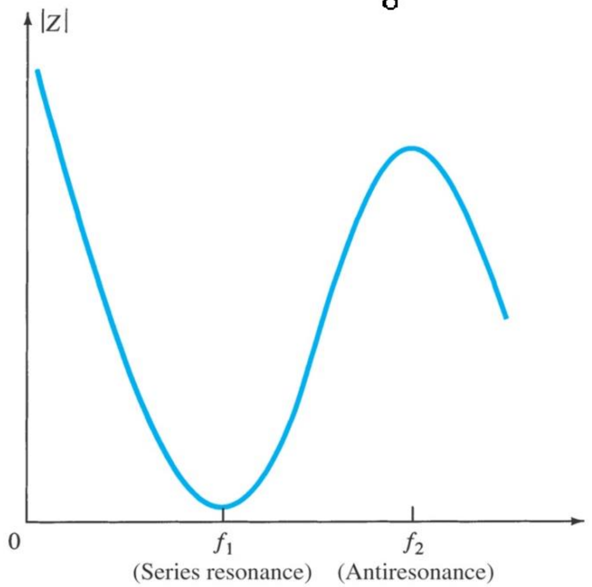


- Characteristic of Quartz Crystal
  - The crystal can have two resonant frequencies;
  - One is the series resonance frequency f_1 which occurs when $X_L = X_C$. At this frequency, crystal offers a very low impedance to the external circuit where Z = R.
  - The other is the parallel resonance (or anti resonance) frequency f_2 which 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



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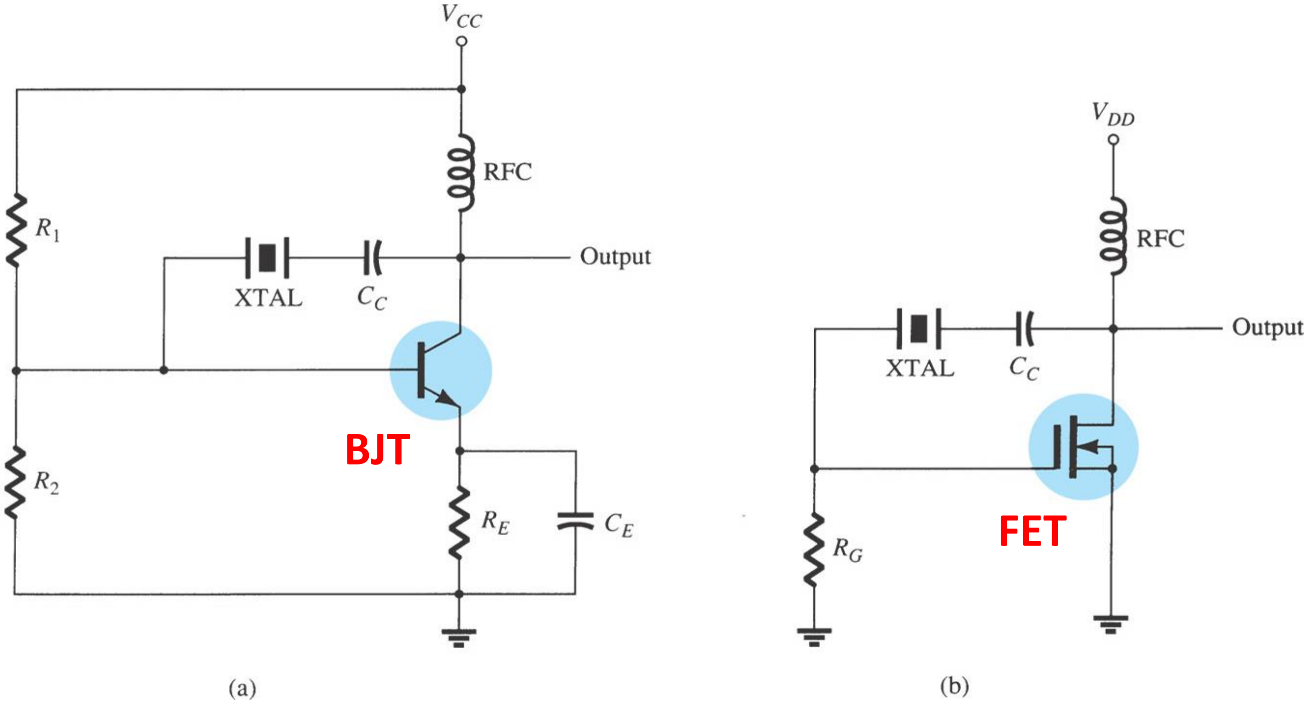
- The crystal is connected as a series element in the feedback path from collector to the base so that it is excited in the series-resonance mode



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- Since, in series resonance, crystal impedance is the smallest that causes the crystal provides the largest positive feedback.
- Resistors R_1, R_2, and R_E provide a voltage-divider stabilized dc bias circuit. Capacitor C_E provides ac bypass of the emitter resistor, R_E to avoid degeneration.
- The RFC coil provides dc collector load and also prevents any ac signal from entering the dc supply.
- The coupling capacitor C_C has negligible reactance at circuit operating frequency but blocks any dc flow between collector and base.
- Series and parallel-resonance frequencies of the crystal and are given by:

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

$$f_p = \frac{1}{2\pi\sqrt{LC_p}}, \quad C_p = \frac{CC_m}{C + C_m}$$

Example

A crystal has these values: $L = 3$ H, $C_s = 0.05$ pF, $R = 2$ kΩ, and $C_m = 10$ pF. What are the series and parallel resonant frequencies of the crystal?

SOLUTION Equation (23-20) gives the series resonant frequency:

$$f_s = \frac{1}{2\pi\sqrt{(3\text{H})(0.05\text{pF})}} = 411 \text{ kHz}$$

Equation (23-21) gives the equivalent parallel capacitance:

$$C_p = \frac{(10 \text{ pF})(0.05 \text{ pF})}{10 \text{ pF} + 0.05 \text{ pF}} = 0.0498 \text{ pF}$$

Equation (23-22) gives the parallel resonant frequency:

$$f_p = \frac{1}{2\pi\sqrt{(3\text{H})(0.0498 \text{ pF})}} = 412 \text{ kHz}$$

As we can see, the series and parallel resonant frequencies of the crystal are very close in value. If this crystal is used in an oscillator, the frequency of oscillation will be between 411 and 412 kHz.

PRACTICE PROBLEM Repeat Example with $C_s = 0.1$ pF and $C_m = 15$ pF.