

Quartz Crystal Parameters

The key parameters a quartz crystal manufacturer requires when producing crystals are resonance frequency, resonance mode, load capacitance and temperature calibration. In addition series resistance, holder capacitance, motional inductance and capacitance as well as drive level can also be important for some applications. If these parameters are understood it will be possible to successfully specify crystals for your application. A quartz crystal can be modelled as a series $L_m C_m R_m$ circuit in parallel with a shunt capacitor C_o (see Figure 1).

Simplified equivalent circuit of a Quartz Crystal

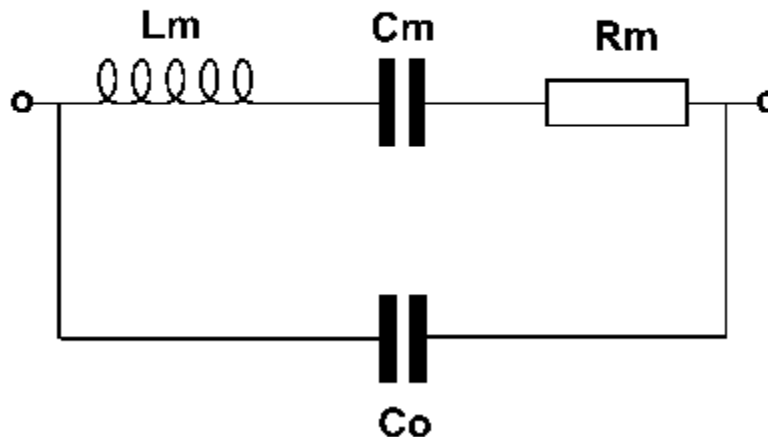


Figure 1. Generic crystal model (fundamental mode).

Resonance Frequency

Crystals below about 26 MHz are often specified at the fundamental frequency, whereas above 26 MHz they are typically specified as 3rd, 5th, 7th or 9th overtone. (overtones occur only at odd multiples). It is therefore important to know whether the oscillator is operating in fundamental or overtone mode.

An overtone is similar in concept to a harmonic; however crystal overtones are not exact multiples of the fundamental frequency. Overtone selection is based on using the lowest possible overtone that will result in a crystal's fundamental frequency being below 26 MHz. A crystal supplier will calibrate a 3rd overtone crystal at the 3rd overtone frequency, not the fundamental oscillating frequency of the crystal. QuartSLab would for example provide a 3rd overtone 66 MHz crystal, if the fundamental mode or overtone mode was not specified. If a 66 MHz, 3rd overtone crystal is placed in an oscillator designed for a fundamental-mode crystal, it is likely that it will oscillate at 66 MHz /3 or

22 MHz! If you do not know the frequency mode of your crystal, contact the designer or the manufacturer of the oscillator circuit.

Crystal suppliers provide overtone crystals because as the frequency increases the quartz blank becomes thinner, more difficult to work and hence the crystal becomes more expensive to produce. Crystals between 22 MHz and 26 MHz can be specified as operating either in a fundamental or 3rd overtone mode. Given the extra manufacturing effort involved with thin quartz, choosing a crystal specified at an overtone mode instead of the fundamental mode can be significantly less expensive.

Resonance Mode

Crystals have two modes of resonance, parallel and series, and all crystals exhibit both resonance modes. The oscillator circuit is calibrated for one mode or the other, but not both. For applications requiring no tighter than 100 ppm frequency accuracy, resonance mode is usually not an issue. If it is needed to control frequency (or time) to within 100 ppm, the resonance-mode specification becomes important. The crystal supplier's principal concern is in which mode the crystal is calibrated during manufacturing. The crystal supplier then calibrates the crystal with an oscillator circuit in a customer-specified series resonance or parallel resonance condition. Figure 2 shows crystal impedance behaviour versus frequency, and the relative location of each resonance mode.

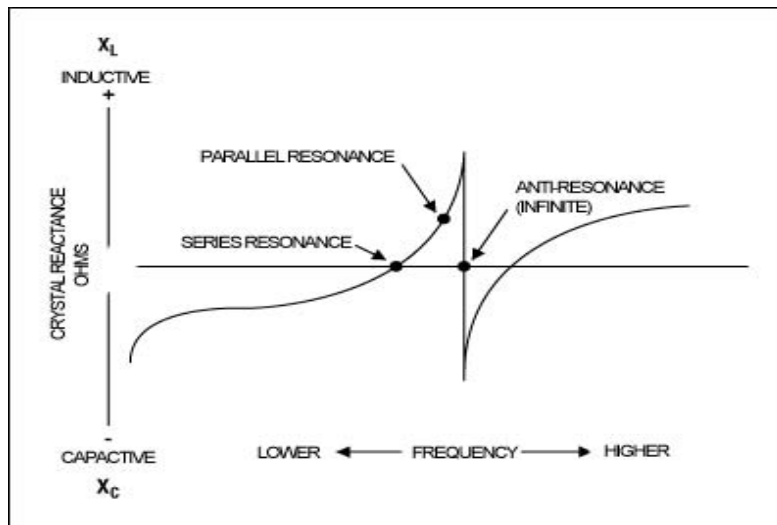


Figure 2. Crystal impedance versus frequency.

Load Capacitance

Load capacitance is an important parameter when using the parallel-resonant oscillation mode. Figure 2 shows that crystal parallel-resonance mode is always above the series resonance frequency. It is characterised by inductive reactance. In the parallel-resonant oscillation mode, the crystal's inductance (motional inductance) is in parallel with the oscillator's load capacitance, thereby forming an LC tank circuit. This LC determines the

oscillator frequency. If your oscillator uses parallel resonance, the crystal supplier must know the load capacitance employed by the oscillator circuit. The load capacitance is simply the amount of external circuit capacitance in parallel with the crystal itself when it is placed in the oscillator circuit. The crystal supplier will then ensure that your crystal is calibrated at the factory using this same load capacitance. QuartSLab is flexible regarding load capacitance; load capacities can be provided in the range 6pF to 150pF. If parallel resonance is specified without a load capacity QuartSLab will provide a crystal calibrated for 30pF load capacity.

With a series-resonant crystal, load capacitance can be ignored. This is because the crystal's motional inductance and motional capacitance are the only LC components that determine oscillation frequency. In Figure 2, the anti-resonance occurs when the net inductive component of the crystal model resonates with the crystal's internal holder capacitance. Anti-resonance is not used for oscillator designs.

Series Resistance

Series resistance is the effective resistive component in series with the LC model of the crystal itself (see Figure 1). Oscillator circuits can tolerate some degree of series resistance, but not too much. A typical range is 25 ohms to 100 ohms for most crystals. The supplier usually specifies typical or maximum values for series resistance. Excessive crystal series resistance can lead to oscillator startup failure, so sufficient margin must be built into the oscillator design.

Holder Capacitance

All crystals have small electrodes that connect the crystal to the package pins. The electrodes form a shunt capacitance C_0 in parallel with the crystal's LC model, as shown in Figure 1. Depending on the crystal's size and package, the holder capacitance can vary. Typical values range from 2pF to 6pF. Some oscillators will not tolerate excessive holder capacitance. This is particularly true at higher frequencies as the reactance of the holder capacitance decreases. Make sure the holder capacitance is within the allowable range for your oscillator. As a general rule, minimize the holder capacitance (the smaller, the better).

Motional Inductance and Capacitance

Motional inductance and capacitance are specifications provided by the crystal vendor. They describe the L and C values that comprise the crystal's electrical LC model. The extreme ratio of L_m to C_m results from very large inductive and capacitive reactance values at the operating frequency. These large values are instrumental in providing a crystal with its extraordinarily high 'quality (Q) factor. Q is the ratio of energy stored to energy dissipated or the ratio of reactance to series resistance at the resonant frequency. For an LRC circuit, $Q = 1/R * \sqrt{L/C}$. A high Q is desirable, because higher Q values mean less frequency shift for a change in oscillator load capacitance and less frequency shift, due to other external factors such as oscillator supply voltage. Depending on the application, an oscillator circuit may or may not require the specification of motional inductance and capacitance.

Temperature Calibration

The frequency of the quartz crystal varies with temperature. The amount of frequency variation depends on the angle at which the quartz is cut from the original crystal. As the tolerance of the frequency becomes tighter, the temperature range reduces. An AT cut crystal is most commonly used for its highest stability over a wide temperature range.

Drive Level

The power dissipated in the crystal must be limited or the quartz crystal can actually fail due to excessive mechanical vibration. Crystal characteristics also change with drive level due to nonlinear behaviour. The power dissipated in the crystal is the product of the crystal current squared multiplied by the crystal's series resistance. For a parallel-resonant oscillator, the crystal current equals the RMS voltage across the load capacitor divided by the load capacitor's reactance at the frequency of oscillation. For a series-resonant crystal, the crystal current is the RMS voltage across the crystal divided by the crystal's internal series resistance. The crystal supplier can specify maximum drive levels for a particular product line.

Summary

The following check-table will facilitate the specification and ordering of quartz crystals.

	Parameter	Action
1	Frequency Above 30MHz	Specify overtone number
2	Resonance mode	Specify parallel or series
3	Load capacitance	Check with oscillator designer/supplier
4	Series resistance	Specify maximum value, obtained from oscillator designer
5	Holder capacitance	Crystal supplier will provide
6	Motional inductance and capacitance	Varies between suppliers
7	Drive level	A maximum value obtained from the crystal supplier

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