SPECIFYING QUARTZ CRYSTALS

With the proliferation of wireless and digital circuits in present day electronic equipment, the use of quartz crystal resonators for precise control of frequency and timing functions has become widespread. As a result, it is important that circuit designers planning to use these devices are familiar with the elements that constitute a crystal specification and know how they should be correctly described to the crystal manufacturer.

The majority of crystals that are used in everyday applications operate in the frequency range of 1MHz up to 200 MHz. The crystals in this category are cut along particular angular orientations with respect to the major axes of the original quartz stone and are identified as AT-Cut resonators.

AT cut crystals possess thermal characteristics that are suitable for both wide temperature and controlled temperature applications depending on the angle of cut selected which is the reason for their wide use.

The important elements of a crystal specification are described below:

NOMINAL FREQUENCY

This is the actual frequency on which the crystal will vibrate when it is operating in the oscillator.

HOLDER STYLE

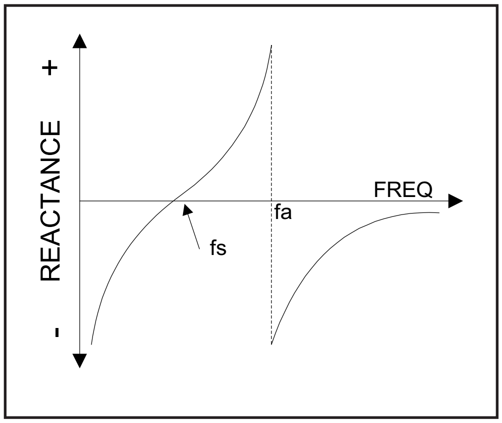
The crystal resonator is encapsulated in a hermetically sealed metal or glass package, which can be filled with inert gas or evacuated. In each case the crystal resonator operates in an environment that will protect it from exterior contamination. The choice of holder will depend on such factors as frequency, available space and long term stability requirements.

MODE OF VIBRATION

The mode of vibration of the AT-Cut crystal is in thickness shear. In the simple fundamental mechanical mode as the thickness of the plate is reduced the frequency of the resonator increases. Eventually a point is reached where the plate thickness can be reduced no further which represents the maximum fundamental frequency that can be attained. By modifying the oscillator design to include a resonant tuned circuit, it is possible to increase the operating frequency of the resonator by causing it to operate on its 3rd, 5th or 7th mechanical overtone rather than its fundamental. The approximate ranges of each of each of the above modes using standard production techniques is as follows:

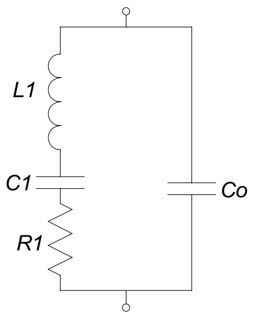
Fundamental: 1MHz to 45 MHz
Third Overtone: 10MHz to 135 MHz
Fifth Overtone: 40 MHz to 200 MHz
Seventh Overtone: 110 MHz to 300 MHz

CIRCUIT CONDITION



Although the crystal vibrates in a mechanical mode, it can be represented by an equivalent electrical circuit, as shown. It is important to remember that the crystal resonator is not an absolute frequency-determining device. Its frequency of operation will in fact depend on the design of the oscillator and the influence of surrounding reactive components.

The equivalent circuit shown has two main points of resonance. The SERIES mode resonance (Fs) occurs when reactance's XL1 and XC1 cancel which is the point of minimum impedance. The PARALLEL or ANTIRESONANT mode (Fa) occurs where Co, the pin to pin capacitance of the crystal, resonates with the L1, C1 combination to produce a point of maximum impedance. These points are shown on the reactance chart. In reality, when operating in the ANTIRESONANT mode the crystal sees an additional load capacity across C0 which is derived from the oscillator. Its value can typically lie between 10pF up to 50 pF and is often used to trim the crystal onto it nominal frequency.



$$fs = \frac{1}{2\pi\sqrt{L1C1}}$$

$$fa = \frac{1}{2\pi\sqrt{L1\frac{C1Co}{C1+Co}}}$$

Since any of the conditions described above will modify the frequency at which the crystal will operate, it is important that the correct circuit condition is stated in the crystal specification, otherwise unacceptable frequency errors will result. For this reason, in cases where the circuit is ANTIRESONANT it is particularly important to specify the correct value of load capacity.

CALIBRATION TOLERANCE

The calibration tolerance or adjustment tolerance as it is sometimes known, is the tolerance in parts per million (PPM) to which the crystal manufacturer will set the resonator frequency during manufacture. This tolerance is always specified at a particular reference temperature. In the case of crystals intended for wide temperature operation e.g. –20 to +70°C, the reference temperature is usually specified at +25°C, which is close to the inflection point for AT-cut resonators and reasonably centered within the operating temperature range.
Example: +/- 10 PPM at +25°C.
For crystals that are designed to operate at an elevated controlled temperature in a crystal oven, the calibration tolerance is referenced to the oven temperature.
Example: +/- 5 PPM at 75°C
In all cases the calibration tolerance is agreed with the circuit designer. In cases where the crystals are to be trimmed onto nominal frequency in the oscillator, it is important that the limits of the calibration tolerance do not exceed the adjustment range of the trimmer network.

FREQUENCY/TEMPERATURE DEVIATION

Frequency temperature characteristics for AT-Cut resonators are shown above. Each of the curves shown on the graph is the product of a precise angle of cut relative to the major axes of the mother crystal. Frequency/ Temperature deviation is expressed in the form +/- 20 PPM over –20 to + 70 °C and is determined by the stability requirements of the system in which the crystal is to operate. It will be seen that there are limitations to the available combinations of maximum deviation and temperature range. For example while it is possible to manufacture a crystal with a stability of +/- 5PPM over -20 +70°C a stability of +/- 5PPM over –40 + 70°C is not possible. This latter stability would require some form of external temperature compensation of the crystal in the lower temperature regime.

MAXIMUM EQUIVALENT SERIES RESISTANCE (ESR)

A crystal operating at its series resonant point will appear as a resistor with no reactive component present. The value of this apparent resistor is a measure of the crystal's activity and the lower the value the better the activity and the higher the "Q" factor of the resonator.

The ESR value in a specification is expressed as a maximum value. For example most 3rd overtone resonators have a maximum ESR value of 40 ohms while 5th overtones are rated at 60 ohms and 7th overtones at 90 ohms maximum. In production units , the typical ESR values are lower than the rated maximum values.

In specifying ESR limits it is important that the oscillator design should function satisfactorily with standard ESR limits. Designs that specify extremely low ESR limits can lower manufacturing yields and therefore incur cost penalties.

AGING

A crystal resonator will gradually change frequency over a period of time. there are several reasons why this occurs but the effect can be minimized by careful processing during manufacture and the type of encapsulation used to enclose the crystal. In general cold weld and all glass encapsulations provide the most suitable enclosures for best aging performance.

DRIVE LEVEL

In the interests of overall stability both short and long term it is recommended that the oscillator drive level be kept as low as possible. Generally as a rule of thumb for most of the crystals in the AT range , drive levels should not exceed 0.2 mW.

SPECIAL APPLICATIONS

Where crystals are used in applications such as filter circuits, temperature compensated oscillators (TCXOs) or voltage controlled oscillators where significant frequency pulling ranges are required, additional parameters will need to be specified. These will include limits on the spurious responses and the values of C1, L1 and C0 (see Fig3). In addition, many high performance oscillators must meet exacting low phase noise requirements, which in turn call for special considerations in the resonator design.

As can be seen the crystal specification can contain many features that are unique to a particular application. To avoid performance problems later it is strongly recommended that the circuit design engineer discuss the parameters that are required with the crystal manufacturer at the start of the project.

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