Application Note

Crystal Basics

Author:
Min Ko
Applications Engineer
Aye.Minko@ctscorp.com
T: +65 65517515
CTS Corporation - singapore

Co-Author:
John Metzler
Applications Engineer
John.Metzler@ctscorp.com
T: 630-577-8816
CTS Corporation - North America

Your Partner in Smart Solutions

Application Note

Crystal Basics

Background

History

The piezoelectric properties of quartz were discovered by Jacques and Pierre Curie in 1880. The first quartz crystal oscillator was built by Walter G. Cady in 1921. In 1923, D. W. Dye at the National Physical Laboratory in the UK and Warren Marrison at Bell Telephone Laboratories produced sequences of precision time signals with quartz oscillators.

Piezo Effect

Quartz plates show a mechanical movement or strain when subjected to an electrical charge and conversely, they show a difference of potential between faces when subjected to a mechanical stress. This relationship between electrical stress and mechanical movement is known as **piezoelectric** effect.

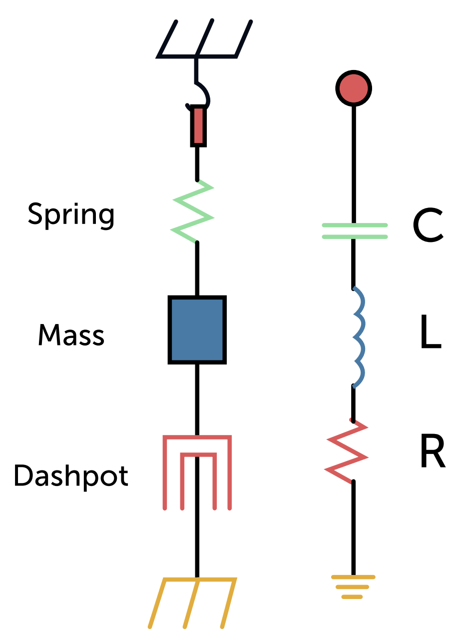
There are four basic modes of mechanical vibration used in piezo electric resonators.

1. Flexure Mode
2. Shear Mode
3. Longitudinal Mode
4. Torsional Mode

Mechanical vs Electrical Equivalancies

AT Cut Crystal

One of the most common crystal designs is the AT Cut crystal and will be the referenced crystal type throughout this application note. For frequencies above 1MHz, only the thickness shear mode of vibration is commonly used. The frequency of AT Cut crystals is determined by the thickness of the crystal, i.e. the thinner the crystal, the higher the frequency. The vibrating mass of the crystal is equivalent to a series motional inductance, L_1. The mechanical losses of the crystal appear as an equivalent series resistance, R_1, while the mechanical elasticity of the crystal is equivalent to a series capacitor, C_1. C_0 is the parallel capacitance associated with the holder and the electrode capacitance. AT Cut crystals have good Stability vs. Temperature characteristics, which is one reason for their popularity. ***Reference Page 20.***



Application Note

Crystal Basics

Formulas - Electrical Equivalents

Unless it is stated otherwise, AT Cut crystals will operate on the fundamental mode. However, it is possible for any AT crystal to operate in an overtone or odd multiples of the fundamental mode. This means a 10MHz fundamental crystal will operate at 10MHz, at 30MHz [3rd overtone], at 50MHz [5th overtone], etc. Use of the overtone [odd harmonic] allows for high frequency operation while maintaining a thicker quartz wafer.

$$C_1 = \frac{2\pi f_S[C_0+C_L]}{F_S}$$

$$R_1 = \frac{2\pi f_S L_1}{Q}$$

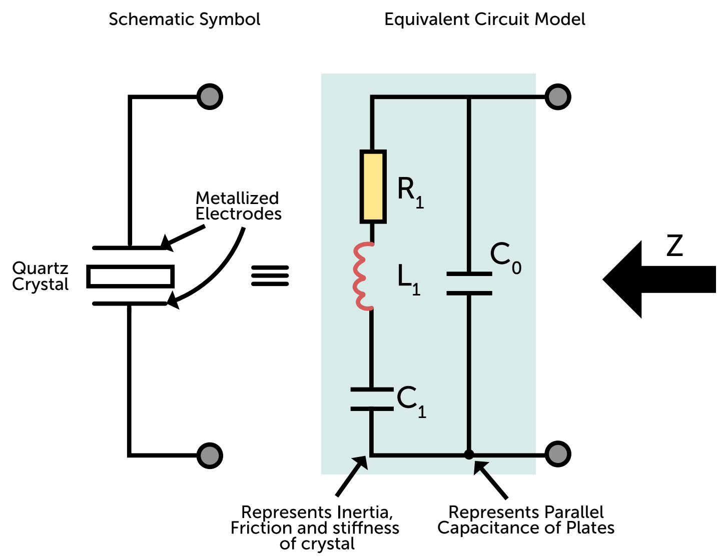
$$L_1 = \frac{1}{[2\pi f_S]^2 C_1}$$

$$F_S = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

C_0 = Shunt Capacitance
C_L = Load Capacitance
R_1 = Series Resistance
Q = Quality Factor
f_s = Series Resonance
f_a = Anti-Resonance
F_S = Frequency of Oscillation

Equivalent Circuit

The equivalent circuit for a quartz crystal is shown below. Each component can be specified to help characterize the unique properties of the device. When defining a specification for a quartz crystal, the individual parameters of the equivalent circuit should be examined. For all designs, there are limits for each type of crystal design.



The equivalent circuit consists of the following parameters. All the parameters can be customized through design, but are tied together, so that a change to one parameter changes other parameters.

L_1: The motional inductance of the crystal is determined by the mechanical mass of quartz in motion. The lower frequencies [thicker and larger quartz wafers] tend to run at a few henries where higher frequencies [thinner and smaller quartz wafers] tend to run at a few milli-henries. The relationship between L_1 and C_1 is defined by the formula below. It is preferable to have the customer specify C_1 [if necessary], then L_1 can be calculated.

$$L_1 = \frac{1}{4\pi^2 f_S{}^2 C_1}$$

C_1: The motional capacitance is determined by the stiffness of the quartz [which is constant], the area of metallization [electrode size] on the face of crystal and the thickness and the shape of the wafer. At lower frequencies, the wafer must be shaped [contoured or bevelled] to improve the performance. This will lower the C_1 of the device. The C_1 for fundamental mode crystals can range from approximately 0.005pF to 0.030pF. As a general rule, if a fundamental design is used on an overtone, C_1 will divide be the square of the overtone. [3rd overtone will be 1/9 of the fundamental]

$$C_1 = 2[C_0+C_L]\Delta f$$

R_1: Motional resistance is the resistive element of the quartz crystal equivalent circuit. This resistance represents the equivalent impedance of the crystal at natural resonant frequency [series resonance]. For a given crystal Q and series resonant frequency, motional resistance is inversely proportional to the active area of the crystal. The active area is about the same as the electrode area. Therefore smaller crystals have a higher R_1. In practice, the Q for smaller crystals is not as high as the larger ones. The reduced Q also contributes to a higher R_1. If the circuit is not adjusted to accommodate the higher R_1, this could result in an oscillator with start-up problems.

$$R_1 = \frac{2\pi f_S L_1}{Q}$$

C_0: The shunt capacitance of a crystal is due in part to the thickness of the wafer. This is the measured capacitance while not vibrating. Shunt capacitance ranges from 1-7pF. It is not typical to exceed 7pF due to compatibility with oscillator circuit.

$$C_0 = \frac{C_1}{2\Delta f} - C_L$$

Quality Factor [Q]: The factor that represents the sharpness of the resonant curve. Quartz has a very high Q compared to other resonator types, typical values range from 10,000 to 100,000s.

$$Q = \frac{2\pi f_S L_1}{R_1}$$

Application Note

Crystal Basics

Frequency, Tolerance, and Stability

Frequency

Frequency values are normally specified in kilohertz [kHz] up to 999.999 and in megahertz [MHz] from 1.0 and above.

Tolerance and Stability

Frequency values are normally specified in kilohertz [kHz] up to 999.999 and in megahertz [MHz] Crystal tolerances can be broken down into separate components.

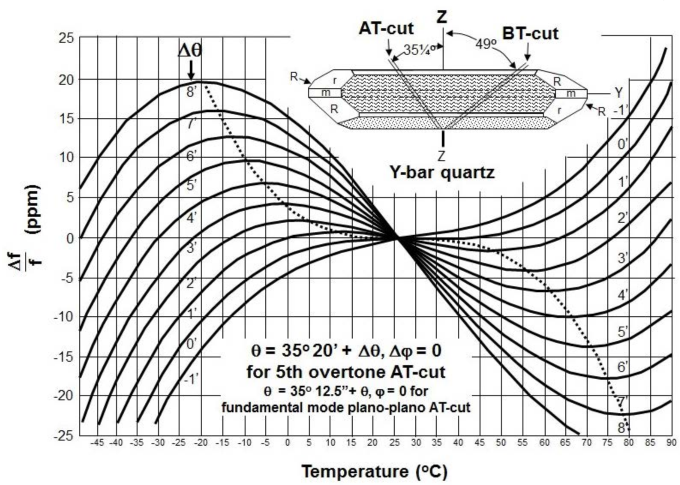
1. Calibration at room temperature, or sometimes referred to as Tolerance
2. Stability over the temperature range
3. Aging

Calibration at Room Temperature is the accuracy of the frequency in the circuit at +25°C. Typical tolerances range from ±10ppm to ±100ppm. Crystals are tuned to the required frequency within the stated tolerance by changing the mass of the electrodes. Higher frequencies are more sensitive to mass change and therefore more difficult to hold tighter tolerances. Capability exists of meeting ±5ppm accuracies on certain designs, but in some cases measurement repeatability becomes a problem. For most designs, a premium cost is not incurred until tighter than ±10ppm is specified and a significant cost adder is applied for ±5ppm requests.

Stability Over Temperature is determined by the angle at which the quartz bar is cut to produce the wafer. This is independent of calibration. The selection of this angle controls the frequency drift across a given temperature range. The most popular frequency family of cut is "AT" cut. The AT Cut is used for a noncontrolled environment centred around +25°C.

Three different angles can be selected to optimize performance over different ranges. Lower angles can be used for -20°C to +70°C temperature ranges and higher angles should be selected for wider temperature ranges. The performance in tighter tolerances [smaller ppm shift] over a given temperature range are limited by the curves themselves and the accuracy at which the angle can be cut. Good cutting accuracy can be as small as 1 to 2 minutes and measurement accuracy as tight as 0.1 minute. There is spread associated with the process and increased costs for the tolerance tighter than 3 minutes. The curves allow theoretical limits to the tolerance applied to a temperature range. Care should be taken not to specify an impossible situation.

The temperature curves of a typical AT-Cut crystal are shown to the right. This is often referred to as the Bechmann curves.



Aging of a crystal is its frequency change with respect to time. More details on this topic can be found on Page 9.

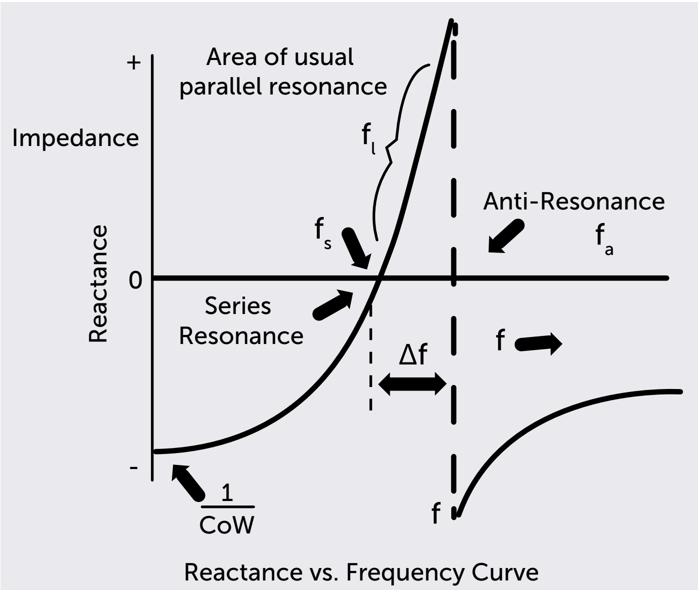
Series vs Parallel Resonance

Series or Parallel

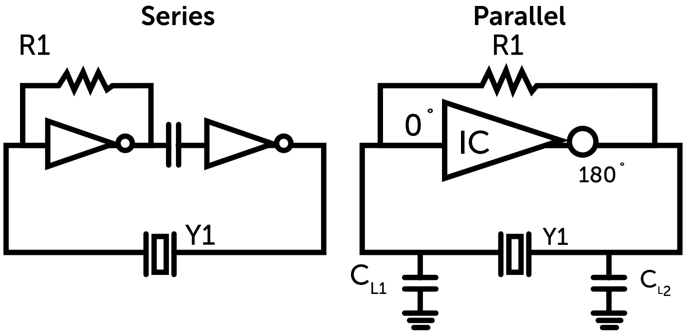
A common question is what correlation should be specified for a crystal: series or parallel? If parallel, what load capacitance should be specified? These questions can be answered by analyzing what type of oscillator circuit will be used with the crystal. The crystal manufacturer must know this information to properly tune the crystal to the desired frequency for a particular application. The frequency at which oscillation occurs is defined by this formula.

$$F_s = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

The reactance curve of a crystal reveals where mechanical resonance occurs. Series resonance occurs at the point the curve crosses zero. This is the point at which the crystal appears to be a simple resistor shunted by a capacitance. Parallel resonance can occur by adding capacitance [load] to the crystal in series or parallel, resulting in a positive frequency shift.



Reactance vs. Frequency Curve



Series and Parallel Resonant Circuits

$$f_L - f_s = \Delta f = \frac{C_1}{2[C_0 + C_L]}$$

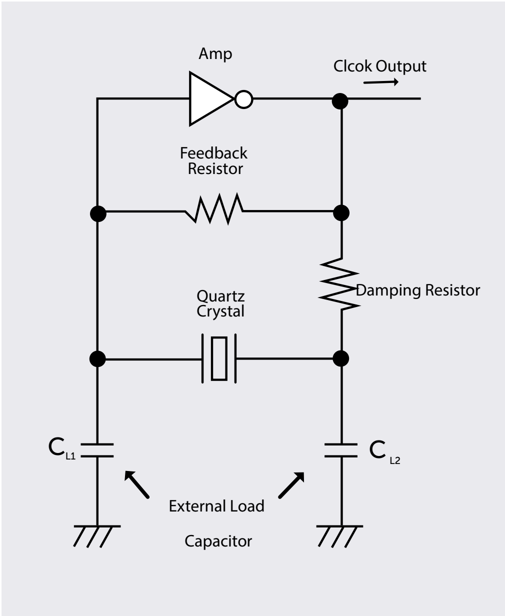
If a crystal is specified wrong for correlation, the crystal will still operate, but will operate offset from desired frequency. For most applications, this frequency shift will be approximately $\pm$300ppm between series and parallel.

Load Capacitance, Pullability and Spurious Modes

Load Capacitance

If a parallel resonance is specified but the wrong load capacitance is called out, there will be an error in frequency. For tighter tolerance applications, specifying this correctly is critical. For most microprocessor applications, two load capacitors are connected to each leg of the crystal to ground. To calculate the proper load capacitance C_L, you must account for the total capacitance C_T which the crystal will see when inserted in the application. It will see the load capacitors plus any additional stray capacitances C_S, due to the application board. The formula for calculating the overall load is defined as:

$$C_L = \left[\frac{C_{L1} \times C_{L2}}{C_{L1} + C_{L2}} \right] + C_s$$



Example 1

$C_{L1} = C_{L2} = 22pF$

$C_s = 8pF$

$$C_L = \left[\frac{22 \times 22}{22 + 22} \right] + 8 = 19pF$$

Example 2

$C_{L1} = C_{L2} = 27pF$

$C_s = 8pF$

$$C_L = \left[\frac{27 \times 27}{27 + 27} \right] + 8 = 21.5pF$$

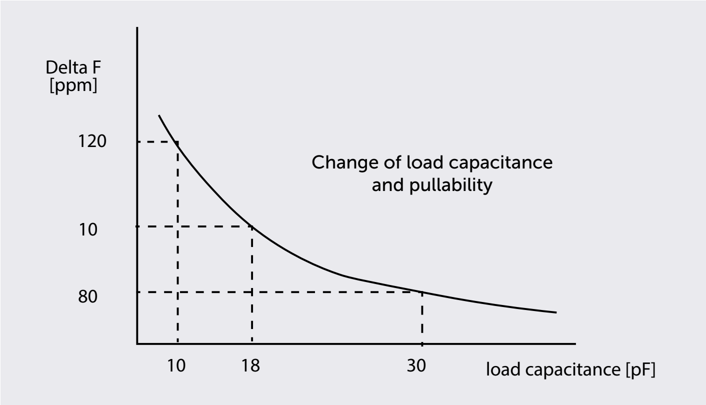
In the above examples, the calculated load capacitance is 19pF or 21.5pF, depending on which value for C_{L1} and C_{L2} is chosen. A standard load capacitance for most crystal companies is either 18pF or 20pF, which would be acceptable for these examples. A variable capacitor can be substituted for one of the fixed capacitors and the frequency can be “trimmed” or adjusted a small amount to a desired frequency. The amount of the trim range is sometimes called “pullability” or “trim sensitivity”. If this is important to your circuit, the motional capacitance of the crystal should be specified to ensure consistency of trim range from lot to lot.

Pullability

When a crystal is operating at parallel resonance, it looks inductive in the circuit. As the reactance changes, the frequency changes correspondingly, thus changing the Pullability of the crystal. The difference between the fs and fa depends on the C_0/C_1 ratio of the crystal.

The following crystal parameters specify the Pullability:

a. Motional capacitance C_1 in fF
b. Motional inductance L_1 in mH
c. Ratio of shunt capacitance to motional capacitance C_0/C_1.
The smaller ratio the better the pulling.
d. The difference of the parallel resonant frequency $\Delta F = F_{L2} - F_{L1}$



The Pullability of the crystal can be designes to meet customer's requirements. However, the pulling function varies with package size, electrode size, frequency, load capacitance range, and operating mode. Please contact CTS whenever you have a need for a pulling crystal.

The following formula determines the Pullability of crystal in ppm.

$$\text{Pull [ppm]} = \frac{C_1 \times 10^6}{2} \times \frac{C_{L2} - C_{L1}}{[C_0+C_{L2}][C_0+C_{L1}]}$$

The following formula determines the trim sensitivity [T.S.] in ppm/pF.

$$\text{T.S. [ppm/pF]} = \frac{C_1 \times 10^6}{2\,[C_0+C_L]^2}$$

Note: Trim Sensitivity [T.S.] changes as C_1 changes. Therefore, a trim sensitivity specification should be stated at a given load capacitance: i.e. 15ppm/pF @ 20pF.

Spurious Modes

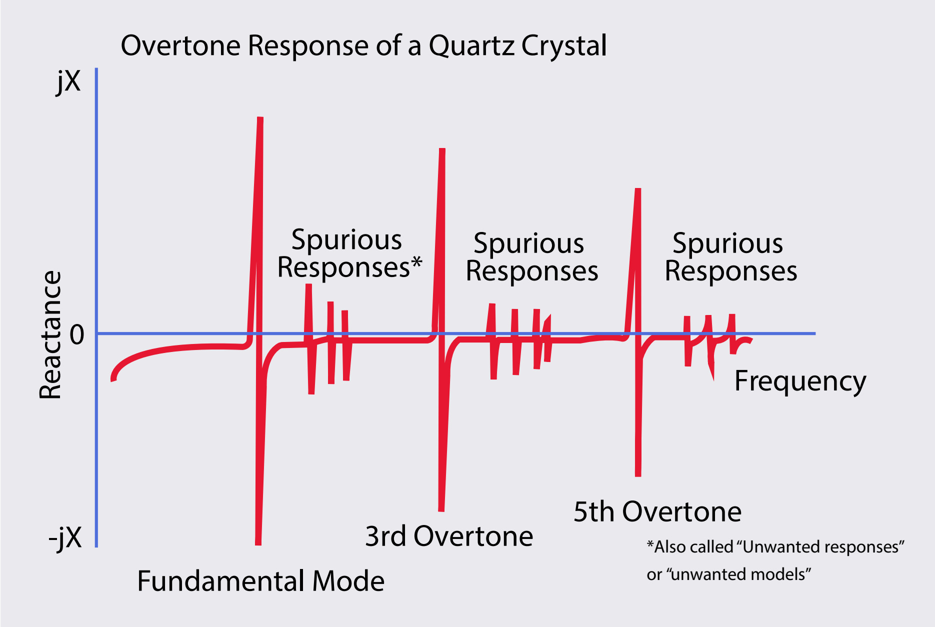
A quartz crystal has many vibration modes that can be excited with the right frequency input from the oscillator. The design of the wafer, electrode pattern and amount of metallization can be adjusted to suppress these unwanted modes. These unwanted modes are referred to as spurious modes.

A spurious mode can be a problem if the response is as strong as main mode. When this happens, the oscillator may run on the spur instead of main mode. This is called mode hopping. Spurious modes should be specified as either a resistance ratio to the main mode or dB suppression. A resistance ratio of 1.5 or 2 to 1, is sufficient to avoid mode hopping for most oscillators. A -3dB to -6dB is approximate equivalent for a specification in terms of dB.

Fundamental modes of the crystal can achieve the best spurious suppression, while overtone responses are more difficult to control. Designs that require higher C_1 values for pullability reasons also can sacrifice spurious mode suppression. For crystal filter designs, spurious mode suppression as low as -40dB, can be met with fundamental mode/low C_1 designs.

The spurious modes occur below the main mode within a few hundred kilo hertz. The responses may look like this plot below.

It is sometimes necessary to specify the suppression of the overtone responses for some oscillator designs. Since all the overtone responses can be excited into vibration, a mode hop from the fundamental to the 3rd overtone can occur. Proper oscillator design may also be needed or desired to reduce circuit modification costs. These modifications can sometimes affect other parameters, so it is wise to contact the factory to discuss design options.



Other Common Terms and Concepts

Aging of a crystal is the change in frequency with respect to time. This performance is affected by two main factors: **contamination and stress.** Aging values range from less than ±1ppm first year to as high as ±5ppm first year and are dependent on frequency, design and package style.

Contamination that attaches itself to the face of the wafer causes a negative frequency shift due to mass loading. Cleanliness of the manufacturing process and cleanliness of the crystal can improve aging performance. The Hermeticity of the package will help keep out contamination during the life of the crystal. The package type and sealing method can also improve aging performance.

Stress effects on the quartz wafer cause positive frequency shifts during the relaxation of the stress with time. This stress is a result of the mounting structure twisting, pushing or pulling on the wafer. This can occur within various components of the crystal from the processing of the quartz blank, the curing of the epoxy mounting adhesive, the crystal mounting structure and the type of metal electrode material used in the device. Heating and cooling also causes stress due to different expansion coefficients. Stress in the system usually changes over time as the system relaxes and this can cause a change in frequency. To help accelerate the relaxation of the stress, thermal cycling is sometimes used to "exercise" the mount structure and relax the stress.

Accelerated Aging Aging performance can be predicted by accelerating the shift through heating. Placing crystals in a high temperature oven will accelerate the aging effect, so that one year of aging can be seen over just a few weeks. The aging curve for a crystal is logarithmic so that the worst aging is seen in its first year. A common mistake when specifying an aging specification is to assume $\pm$1ppm first year aging means $\pm$10ppm for 10 years. This is not true. A $\pm$1ppm first year aging will result in approximately $\pm$3ppm over 10 years.

Measurement Accuracy When specifying a tolerance for a crystal, the accuracy of the measurement can be an issue of manufacturability. With “zero phase” or passive measurement techniques, accuracies of a few tenth of a part per million are possible. For a series resonance crystal, tolerances of $\pm$5ppm are not considered a problem due to measurement repeatability. The trouble begins when parallel resonance or load measurement is specified. The ultimate accuracy of the measurement is dependent on the accuracy of the load capacitance. The accuracy of the load capacitor used in a parallel resonance measurement is shown by the trim sensitivity formula below. If the load capacitance gets small, the Delta F/pF will get large. Also, if the motional capacitance gets large, the delta F/pF gets large.

$$\text{Delta F/pf} = \frac{C_1 \times 10^6}{2\,[C_0+C_L]^2}$$

For example:

100 MHz fundamental
C_1 of 0.020pF
C_0 of 4.5pF
For a load capacitance of 10pF, trim sensitivity would be 48ppm/pF.

If the accuracy of the load capacitance is 0.5pF, then accuracy of the measurement is 24ppm. If on the other hand, the load was 20pF, then the trim sensitivity would be 16ppm/pF and with the same load accuracy, the measurement would be 8ppm accurate. These are only examples to show the effects of the specifying low load capacitance.

Drive Level is the amount of RMS power dissipated in a crystal, typically expressed in millwatts [mW] or microwatts [µW]. Maximum drive level is the most power a crystal can safely dissipate and still maintain function within defined electrical parameters. Excessive drive levels will create unexpected changes in frequency [accelerated aging], causing increases in equivalent series resistance. These changes can be permanent if damage to the crystal mount structure occurs and catastrophic if the resonator breaks.

Measurement of crystals also requires drive level to be specified. For better accuracy, lower drive levels are preferred. Drive levels are typically between 10uW to 2mW. Lower frequency devices with larger quartz wafers can handle higher drive levels without damage. Smaller, higher frequency devices may be damaged by high drive levels, above 5mW. Today’s applications rarely drive a crystal higher than 2mW with typical levels at 100uW maximum.

CTS will specify a standard maximum drive level at 100uW, if not defined by a customer. Since drive level indicates power consumption by the crystal unit while the oscillation circuit works, it is important to keep the crystal within drive level specifications.

Crystal Basics

Drive Level Dependency [DLD] or Drive Level Sensitivity [DLS] describes the phenomenon that all resonators are dependent on a certain drive level, due to small material nonlinearities inherent in the quartz. DLD is one reason that can prevent a crystal to start oscillating. At low drive levels, some quartz resonators may exhibit a large increase in their series resistance, which prevents them to start oscillation. Some engineers describe these as “sleeping crystals”. The circuit will start-up sometimes and not start at other times, but can be excited with a touch of a scope probe, a finger or more drive. Implementation of a DLD test can guarantee that the changes in ESR and frequency are within maximum limits, thus assuring initial power start-up.

Enviromental In crystal specifications, the electrical performance specification will determine if it will operate correctly, but the environmental specifications ensure the reliability of the crystal. It is important to recognize the application environment and specify the requirements appropriately. MIL-STD-202 defines the environmental tests that are applicable to crystals. To the right are the major areas of evnviromental testing

- **Mechanical Shock**
- **Vibration**
- **Corrosion Resistance**
  - Humidity
  - Salt Spray
  - Moisture
- **Thermal Shock**
- **Hermeticity**
- **Solderability**

Mechanical shock testing determines the strength of the design when dropped. A standard base line specification that the military uses is 100g’s. If the application environment is benign, and proper handling during assembly is used, this specification is adequate. But as in many cases, parts accidentally get dropped during assembly and we expect the crystal to still function. Dropping a crystal from table top height can result in excess of 1,000g’s. CTS designs range from 500g’s to over 10,000g’s. A duration [time] usually accompanies the g level to characterize the pulse. Durations at low shock levels can be long [20ms]. Higher shock levels [5,000g’s] will have shorter durations [1/4ms]. Some designs are specialized and sometimes compromise electrical performance. Please contact CTS for information on a particular crystal design performance. Also, CTS can advise proper handling procedure to avoid damaging crystals.

Vibration tests the ability of a crystal to function under a vibration condition. If a cooling fan is running in a rack, it may vibrate causing the crystal to vibrate. If an engine is near the crystal, it will feel the vibration. Vibration can damage a crystal by cracking or breaking the quartz wafer. Proper design of the internal mounting structure is required to pass tougher vibration requirements. The military base line specification for vibration is 10g’s applied over 10 to 500Hz. Tougher specifications for crystals are at higher frequencies [up to 200Hz] and/or higher g levels. It is also important to mount the crystal on the printed circuit board in a way to reduce Q-ing of the crystal and the board. Q-ing is when the vibration amplifies due to natural resonance with the board or crystal. When this occurs, g levels rise significantly usually damaging the crystal. If these types of problems are suspected, consult the factory for additional information.

Corrosion resistance is the crystal ability to resist rust. Salt spray testing demonstrates that metal or ceramic packages will not support rust and the package will not break down with time. Aqueous wash systems used in manufacturing, may foster rust in packages if metal portions are not plated properly. For resistance weld applications, CTS uses Nickel Alloy covers or nickel plated KOVAR lids to ensure that CTS parts will not rust.

Humidity and moisture tests not only test resistance to rust but also test for permeability of the hermetic package. If moisture were to get inside the package, poor performance or no output will result. A good dry atmosphere is necessary for excellent long-term performance in a crystal.

Thermal shock is a method to test compatibility of the package and quartz wafer under rapid temperature changes. If not compatible, the performance of the crystal will change drastically or the package may leak. Typically, a leak test is performed after a thermal shock. For crystals, the standard test is performed in an air to air environment, using temperatures as low as -65°C to as high as +125°C. Liquid to Liquid tests are usually not used for crystals.

Hermeticity tests determine if any leaks exist in the package. Two tests are commonly specified: **gross leak and fine leak**. Most crystal packages should pass both. The gross leak test involves some type of bubble check by immersing the crystal in a chamber of liquid. Fine leak test systems use helium as a tracer gas and a helium detector. Levels down to 1x10-9cc/sec can be detected. Most crystal specifications are 1x10-8cc/sec. Good hermeticity will ensure good aging over the life of the crystal.

Solderability tests determine the wettability of solder to the lead or attach pad of the crystal. Good solderability is necessary in high-volume manufacturing that uses weaker fluxes or no clean processes to reduce the need for board washing. Steam Aging is a test method used to verify that good solderability performance is achieved with time. This preconditioning of the leads with steam before the solderability test can help stimulate up to 6 months of shelf life. This may be important to your application. If you are using crystals quickly after receiving them, the steam test may not be required. By specifying MIL-STD-202, Method 208, steam preconditioning will be required. Requiring this test on your crystal may affect the price slightly, so it may be to your advantage to consider your application before specifying steam preconditioning.

Glossary

Activity Dip
An unwanted crystal characteristic that exhibits a sudden change in the crystal resistance and resonant frequency, followed by an equally sudden return to the prior values. Activity dips are strongly influenced by crystal drive level and load capacitance.

Aging
The systematic change in frequency with time due to internal changes in the quartz crystal resonator. Aging is often expressed as a maximum value in parts per million per year [ppm/year]. The rate of aging is logarithmic in nature. The following factors effect crystal aging: adsorption and desorption of contamination on the surfaces of the resonator, stress relief of the mounting and bonding structures, material outgassing, and hermetic seal integrity.

Angle
The angle [specified in degrees, minutes, and seconds] at which the resonator blank is cut from the quartz material in relation to the main crystallographic axis. The cut angle is a primary factor controlling the frequency versus temperature performance of the quartz crystal unit.

AT Cut Crystal Unit
A classification for a specific type of quartz crystal cut. The AT Cut is the most popular cut type manufactured today for crystal units in the MHz range. The AT Cut is classified as a thickness-shear bulk acoustic wave [BAW] crystal unit and has a cubic frequency versus temperature curve with inflection point near room temperature. It is widely popular due to its excellent temperature versus frequency characteristics.

Base
Often called a holder or header, a base is a subcomponent of a quartz crystal unit package.

Blank
A semi-processed quartz resonator typically without electrode plating and its holder or base.

BT Cut Crystal Unit
A classification for a specific type of quartz crystal cut. The BT Cut is processed at an angle approximately opposite that of the AT Cut and is classified as a thickness-shear crystal unit with a parabolic frequency versus temperature curve with its inflection point near room temperature. Thus, over a given operating temperature range, the BT Cut crystal will exhibit a greater frequency shift than the AT Cut crystal.

Capacitive Ratio
The crystal shunt capacitance [C_0] divided by the crystal motional capacitance [C_1]. An indicator of the change in a parallel load resonant frequency as a direct result of a given change in crystal load capacitance. In VCXO applications where variations in the crystal parallel resonant frequency are desired for frequency modulation, the capacitive ratio, symbol ‘r’, may be specified. The value of this ratio has limitations when it is realized in a physical quartz crystal design.

Ceramic Package
Often called a header or leadless chip carrier [LCC], this is a type of surface mount crystal package fabricated using ceramic as its primary packaging material. Integrated with a metal lid or cover, this package provides a hermetically seam-sealed enclosure for the quartz crystal.

Crystal Cut
The crystal blank plate is cut with respect to the crystallographic axis of a quartz bar. The type of crystal cut influences the crystal’s aging frequency stability and other parameters.

Crystal Equivalent Circuit
A crystal device consists of a quartz resonator blank with metal plating [electrode]. This plating is located on both sides of the crystal and is connected to insulated leads on the crystal package. The device exhibits a piezoelectric response between the two crystal electrodes as expressed in the crystal equivalent circuit consisting of the following components: motional capacitance [C_1], motional inductance [L_1], motional resistance [R_1], and shunt capacitance [C_0].

Crystal Oscillator
A timing device that consists of a quartz crystal resonator and an oscillator sustaining circuit, typically a clock IC, incorporated into a single package, providing an output waveform at a specified reference frequency. This term is often abbreviated as XO or SPXO [Simple Packaged Crystal Oscillator].

Crystal Unit
A timing device that consists of a quartz crystal resonator and its associated package.

Drive Level
A function of the driving or excitation current flowing through the crystal. Drive level is the amount of power dissipation in the crystal, expressed in microwatts or milliwatts. The maximum drive power is the most power the device can dissipate while still maintaining operation with all electrical parameters guaranteed. Drive level should be maintained at the minimum levels necessary to initiate proper start-up and assure steady state oscillation. Excessive drive level will cause poor aging characteristics and may cause permanent damage to the crystal.

Equivalent Series Resistance [ESR]

The resistive element [R_1], measured in ohms, of a crystal device. At the series resonant frequency of a crystal, the motional inductance [L_1] and motional capacitance [C_1] are of equal ohmic value but are exactly opposite in phase. The net result is that they cancel one another and only a resistance remains in the series leg of the equivalent circuit. The ESR measurement is made only at the series resonant frequency [f_S], not at some predetermined parallel resonant frequency [f_L].

Flexure Vibration

A vibration mode of a tuning fork crystal resonator, in which a flexure motion of the vibrating plate is used as the oscillation source. This type of vibration is suited for low-frequency [kHz] crystal devices.

Frequency

Measured in Hertz [Hz], it is a periodic repetition of an event within a unit of time. In an electrical circuit, it is the number of times a resonator plate oscillates or vibrates in one second.

Frequency Stability

The amount of frequency deviation from the ambient temperature frequency over the operating temperature range. This term is expressed as a minimum and maximum percent [%] or parts per million [ppm] and is determined by the following primary factors: type of quartz cut and angle of the quartz cut. Some of the secondary factors include: mode of operation, load capacitance, and drive level.

Frequency Tolerance

Often called Calibration Accuracy, it is the amount of frequency deviation from the specified nominal frequency at room temperature [+25°C]. This term is expressed as a minimum and maximum percent [%] or parts per million [ppm].

Fundamental Mode

The first and lowest frequency vibration order a resonator plate will oscillate, determined by the physical dimensions of the plate.

Hertz [Hz]

The basic unit of measurement of frequency. It is a measurement used to denote one complete occurrence of an event in one second. The frequency of a crystal is measured in megahertz [MHz] or kilohertz [kHz].

Insulation Resistance

The resistance, expressed as a minimum value, between the leads of the crystal and between the crystal leads and the base.

Load Capacitance
A capacitance, specified in Pico Farads [pF], presented to the crystal. The parallel load resonant frequency [f_L] is a function of the load capacitance.

Mode of Operation
A quartz crystal is designed to vibrate either on its fundamental mode or one of its overtones. For AT Cut quartz crystals, overtone modes are at odd frequency harmonics. The mode of operation of a quartz device is one of the factors that will determine the frequency of oscillation.

Motional Capacitance
The equivalent electrostatic capacitance component in a crystal unit. The motional capacitance [C_1] and the motional inductance [L_1] of a crystal resonate at a series resonance frequency [f_S]. The actual value of C_1 has physical limitations when it is realized in a quartz crystal design. These constraints include mode of operation, crystal cut, mechanical design, and nominal frequency.

Motional Inductance
The equivalent inductive component in a crystal unit. The motional inductance [L_1] and motional capacitance [C_1] of a crystal resonate at a series resonance frequency [f_S]. The actual value of L_1 has physical limitations when it is realized in a quartz crystal design. These constraints include mode of operation, crystal cut, mechanical design, and nominal frequency.

Nominal Frequency
The specified reference or center frequency of the crystal typically expressed in megahertz [MHz] or kilohertz [kHz]. The desired frequency for which the crystal is designed and manufactured.

Operating Temperature Range
The minimum and maximum temperatures that a device can be exposed to during oscillation. Over this temperature range, all of the device specified operating parameters are guaranteed.

Overtone Mode
An odd-numbered multiple of the fundamental vibration order.

Package
Holder or header used to contain the quartz crystal blank. The package facilitates the blank mounting and maintains an inert atmosphere in order to sustain the internal crystal's oscillation performance. Packaging includes materials such as metal or ceramic, and are classified as through-hole or surface mount [SMD].

Parabolic Temperature Curve
A frequency versus temperature curve showing a decrease in frequency as the temperature goes above or below the turnover temperature.

Parallel Load Resonance
A crystal employed in a typical oscillator application operates in either of two resonant modes: Series Resonance or Parallel Load Resonance. The crystals used in these two types of modes are physically the same crystal but are calibrated to slightly different frequencies. When a crystal is placed into an oscillator circuit, the crystal and oscillator circuit components resonate together at a tuned frequency. This frequency is dependent upon the crystal design and the amount of load capacitance, if any, the oscillator circuit presents to the crystal. Specified in Pico Farads [pF], load capacitance is comprised of a combination of the circuits discrete load capacitance, stray board capacitance, and capacitance from semiconductor Miller effects. When an oscillator circuit presents some amount of load capacitance to a crystal, the crystal is termed ‘Parallel Load Resonant’, and a value of load capacitance must be specified. If the circuit does not exhibit any capacitive loading, the crystal is termed ‘Series Resonant’ and no value of load capacitance is specified.

Parallel Resonant Frequency
The resonant frequency of a crystal unit operating with a specified value of load capacitance.

Piezoelectric Effect
The electric charge generated in a particular axial direction when pressure is applied to a defined axial direction on a quartz crystal. By contrast, the mechanical stress that results when a charge is applied in the same axial direction is called a converse piezoelectric effect.

PPM
The abbreviation for Parts Per Million, a method of calculation used to specify the frequency tolerance or stability of a crystal unit.

Pullability
A specification for the change in the parallel load resonant frequency, expressed in ppm, as a function of change in crystal load capacitance. The frequency can be pulled in a parallel resonant circuit by changing the value of load capacitance.

Quartz Crystal Unit
An electronic component, consisting of a resonator plate with electrodes and a hermetically sealed package with suitable mounting structures, used in frequency control applications. Synthetic quartz crystals are hexagonal mono-crystals composed of Silicon and Oxygen [SiO_2] and are cultured in autoclaves under high pressure and temperature. Quartz crystals exhibit piezoelectric properties and can be used to stabilize the frequency of an oscillator circuit.

Reflow Profile
The reflow profile specifies the temperatures and time periods to be used when mounting electronic components onto printed circuit boards.

Resistance Weld
A crystal package sealing process involving pressure sealing with electricity to reflow the metal joint interface of a cover and base.

Resonant Frequency
The natural frequency at which a crystal device vibrates.

Resonance
The creation of vibrations in a system by applying a periodic force. Resonance occurs when the frequency of the applied force is equal to the natural frequency of the system.

Resonator
A device, operating at some resonant frequency, capable of being set into resonance by the application of a periodic electrical force.

SAW Resonator
A crystal device that employs a SAW [surface acoustic wave] blank. A SAW device consists of a structure that has alternating positive and negative electrodes on the surface of a quartz element creating a wave-like vibration emitting from the surface.

Series Resonant Frequency
The resonant frequency of a crystal unit operating without the presence of load capacitance resulting in a crystal frequency lower than the parallel resonant frequency. The motional capacitance [C_1] and the motional inductance [L_1] of a crystal resonate at a series resonance frequency [F_S].

Shunt Capacitance
The static capacitance measured between the crystal terminals, in picofarads [pF]. The shunt capacitance [C_0] is present whether the device is oscillating or not [unrelated to the piezoelectric effect of the quartz]. Shunt capacitance is derived from the dielectric of the quartz, the area of the crystal electrodes, and the capacitance presented by the crystal holder.

SMD Package
An acronym for surface mount device, it is a package with pads that mount to the surface of a printed circuit board.

Spurious Response
An unwanted non-harmonic signal found in the frequency response of a quartz crystal, occurring at some point higher than the desired mode but lower than the next overtone.

Storage Temperature Range
The minimum and maximum temperatures that the device can be stored or exposed to when in a non-oscillation state. After exposing or storing the device at any temperature over this range, all of the specifications are guaranteed over the operating temperature range. Exceeding the storage temperature range may result in device failure or internal component damage.

Strip Crystal or Resonator
A crystal unit processed and manufactured in the shape of a rectangular. It typically has a higher crystal resistance as compared with a round crystal and is smaller in size, thus allowing it to be placed into a smaller package.

Synthetic Quartz Crystal
The product result of a high quality artificial manufacturing process called hydrothermal synthesis. This process 'grows' quartz over a period of time in an autoclave.

Thickness Shear Vibration
A classification of the type of vibration motion of a bulk acoustic mode [BAW] crystal unit. For this vibration mode, the top and bottom surfaces along the crystal plate's thickness direction move opposite to each other. This mode is prevalent in AT Cut crystal units.

Through-hole Package
A package that is mounted by insertion of pins into holes of a printed circuit board.

Trim Sensitivity
Amount by which the parallel resonant frequency of a crystal oscillating with a specific value of load capacitance will vary if that load capacitance is varied one Pico Farad about its nominal value.

Tuning Fork
A type of low frequency [kHz] crystal device that uses a tuning fork-shaped crystal blank.

Turnover Temperature
The temperature at which the frequency is at the vertex of the parabolic curve.

Bechmann Curve

The curves represent Frequency vs. Temperature characteristics of AT Cut crystals. Each numbered curve is accomplished by controlling the angle of the crystal cut and one minute of change. See the figure below.