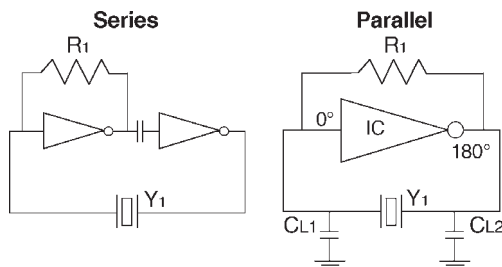


# QUARTZ CRYSTAL DESIGN NOTES

## Series vs. Parallel

"Series" resonant crystals are intended for use in circuits which contain no reactive components in the oscillator feedback loop. "Parallel" resonant crystals are intended for use in circuits which contain reactive components (usually capacitors) in the oscillator feedback loop. Such circuits depend on the combination of the reactive components and the crystal to accomplish the phase shift necessary to start and maintain oscillation at the specified frequency. Basic depictions of two such circuits are shown below.

Figure 5



## Load Capacitance

This refers to capacitance external to the crystal, contained within the feedback loop of the oscillator circuit. If the application requires a "parallel" resonant crystal, the value of load capacitance must be specified. If the application requires a "series" resonant crystal, load capacitance is not a factor and need not be specified. Load capacitance is the amount of capacitance measured or computed across the crystal terminals on the PCB.

## Frequency Tolerance

Frequency tolerance refers to the allowable deviation from nominal, in parts per million (PPM), at a specific temperature, usually  $+25^\circ\text{C}$ .

## Frequency Stability

Frequency stability refers to the allowable deviation, in parts per million (PPM), over a specified temperature range. Deviation is referenced to the measured frequency at  $+25^\circ\text{C}$ .

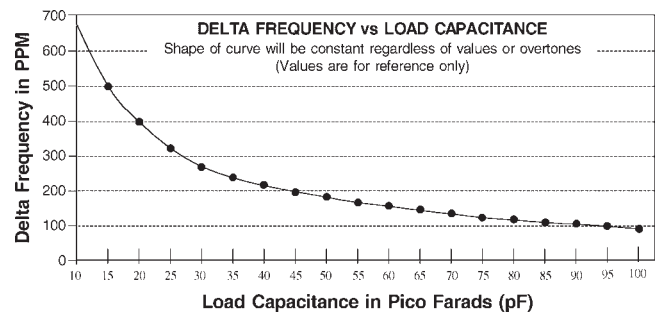
## Aging

Aging refers to the cumulative change in frequency experienced by a crystal unit over time. Factors affecting aging are excessive drive level, various thermal effects, wire fatigue and frictional wear. Circuit design incorporating low operating ambients and minimum drive level will reduce the aging rate.

## Pullability

Pullability refers to the change in frequency of a crystal unit, either from the natural resonant frequency ( $F_r$ ) to a load resonant frequency ( $F_L$ ), or from one load resonant frequency to another. See Figure 6. The amount of pullability exhibited by a given crystal unit at a given value of load capacitance is a function of the shunt capacitance ( $C_0$ ) and the motional capacitance ( $C_1$ ) of the crystal unit.

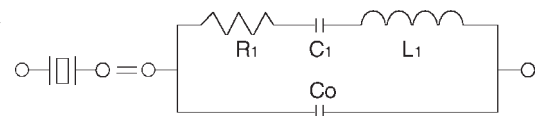
Figure 6



## Equivalent Circuit

The equivalent circuit, shown in Figure 7, is an electrical depiction of the quartz crystal unit when operating at a frequency of natural resonance. The  $C_0$ , or shunt capacitance, represents the capacitance of the crystal electrodes plus the capacitance of the holder and leads.  $R_1$ ,  $C_1$ , and  $L_1$  compose the "motional arm" of the crystal and are referred to as the motional parameters. The motional inductance ( $L_1$ ), represents the vibrating mass of the crystal unit. The motional capacitance ( $C_1$ ), represents the elasticity of the quartz and the resistance ( $R_1$ ), represents bulk losses occurring within the quartz.

Figure 7

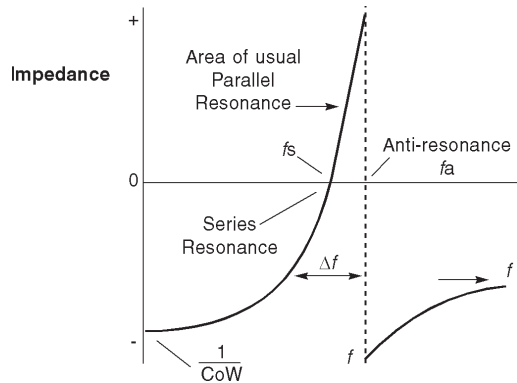


## Impedance/Reactance Curve

A crystal has two frequencies of zero phase, as illustrated in Figure 8. The first, or lower of the two, is the Series Resonant Frequency, denoted as ( $f_s$ ). At this point, the crystal appears resistive in the circuit, impedance is at a minimum and current flow is maximum. As the frequency is increased beyond the point of series resonance, the crystal appears inductive in the circuit. When the reactances of the motional inductance and shunt capacitance cancel, the crystal is at the Frequency of Anti-resonance, denoted as ( $f_a$ ). At this point, impedance is maximized and current flow is minimized.

# QUARTZ CRYSTAL DESIGN NOTES

Figure 8



## Quality Factor (Q)

The "Q" value of a crystal unit is a measure of the units relative quality, or efficiency of oscillation. The maximum attainable stability of a crystal unit is dependent on the "Q" value. In Figure 8 above, the separation between the series and parallel frequencies is called the bandwidth. The smaller the bandwidth, the higher the "Q" value, and the steeper the slope of the reactance. Changes in the reactance of external circuit components have less effect (less "pullability") on a high "Q" crystal, therefore such a part is more stable.

## Calculation of Load Capacitance

If the circuit configuration is as shown in Figure 5 for the parallel version, the load capacitance may be calculated by means of the following equation:

$$CL = \frac{CL1 * CL2}{CL1 + CL2} + Cstray$$

Cstray includes the pin to pin input and output capacitance of the microprocessor chip at the *Crystal 1* and *Crystal 2* pins, plus any parasitic capacitances. As a rule of thumb, Cstray may be assumed to equal 5.0 pF. Therefore, if CL1 = CL2 = 50pF, CL = 30pF.

## Trim Sensitivity

Trim sensitivity is a measure of the incremental fractional frequency change for an incremental change in the value of the load capacitance. Trim sensitivity (S) is expressed in terms of PPM/pF and is calculated by the following equation:

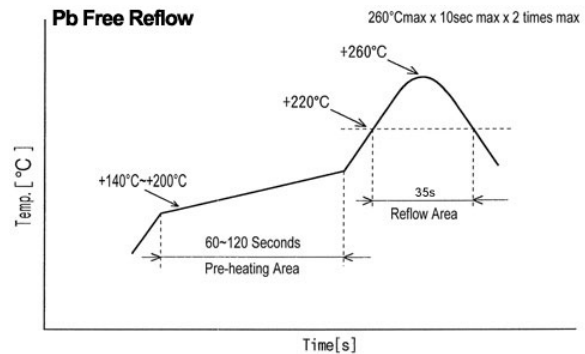
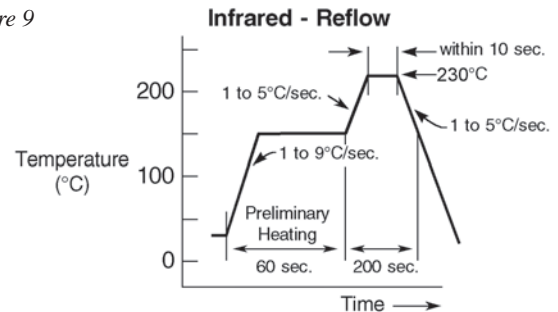
$$S = \frac{C1 * 1000000}{2 * Ct^2}$$

Where (Ct) is the sum of Co and CL.

## Solder Reflow of Surface Mount Devices

Mounting of SMD units is typically accomplished by means of solder reflow, in Figure 9 either by infrared heat or by vapor phase. The following graphs depict the recommended times and temperatures for each of the two methods:

Figure 9



$$Ct = Co + Cl$$

$$fs = \text{Series Resonant Frequency} = \frac{1}{2\pi \sqrt{C1 * L1}}$$

$$fa = \text{Anti Resonant Frequency} = \frac{1}{2\pi \sqrt{\frac{C0 * C1}{C0 + C1} * L1}}$$

$$fL = \text{Load Resonant Frequency} = \frac{1}{2\pi \sqrt{\frac{Ct * C1}{Ct + C1} * L1}}$$

$$C1 = \text{Motional Capacitance} = \frac{2 * Ct * \Delta F}{fs}$$

$$L1 = \text{Motional Inductance} = \frac{1}{4\pi^2 * fs^2 * C1}$$

$$\frac{\Delta F}{F} = \text{Change in Frequency} = \frac{fs * C1}{2 * Ct}$$

$$R1 = \text{Series Resonant Resistance} = \frac{2\pi fs L1}{Q}$$

$$Ra = \text{Anti Resonant Resistance} = R1 \left(1 + \frac{Co}{C1}\right)^2$$

$$Q = \text{Quality Factor} = \frac{2\pi fs L1}{R1}$$