TECHNICAL NOTES

CRYSTAL INFORMATION

TERMINOLOGY -

Frequency Calibration Tolerance: The allowable frequency deviation from the specified nominal frequency at a specific temperature (typically 25 °C). The unit is typically (ppm). This tolerance is controlled by the final tuning process of the crystal manufacturer.

Frequency Deviation Tolerance: The allowable frequency deviation over a specified temperature range. The deviation is referenced a specific temperature (typically 25 °C). The unit is typically (ppm). This tolerance is controlled by the angle of cut of the quartz wafer.

Absolute (Inclusive) Tolerance: The allowable frequency deviation from the specified nominal frequency over a range of temperature. The unit is typically (ppm). This tolerance is essentially a combination of the Frequency Calibration and the Frequency Deviation Tolerance and is controlled accordingly.

Motional Capacitance (C1): The capacitive component of the motional arm of the crystal equivalent circuit. The unit is typically picofarads (pF) or femtofarads (fF) and value typically ranges from 0.1 ~ 30 fF. C1 is controlled by electrode diameter and/or the geometry of the quartz wafer.

Motional Inductance (L1): The inductance component of the motional arm of the crystal equivalent circuit. The unit is typically millihenries (mH) and the value typically ranges from 1 ~ 500 mH. L1 is controlled in the same manner as C1.

Motional Resistance (R1): The resistance component of the motional arm of the crystal equivalent circuit. The unit is ohms (Ω) and the value typically ranges from 5 ~ 500 Ω.

Equivalent Series Resistance (Rs): The resistance of a crystal when measured at series resonance. The unit is ohms (Ω) and the value typically ranges from 5 ~ 500 Ω. Rs is typically specified by the crystal user as a maximum allowable value. The crystal manufacturer controls Rs by the geometry and/or the surface finish of the quartz wafer.

Series Resonant Frequency (Fs): A crystal operating at series resonance appears resistive in the circuit. Impedance at Fs is near zero. Series resonant crystals are intended for use in circuits that contain no reactive components such as capacitors in the oscillator feedback loop. Load capacitance does not have to be defined in a well-designed series resonant circuit because correlation is not a problem.

Load Resonant Frequency (Fl): A crystal operating at load resonance (also known as parallel) appears inductive in the circuit. Load resonant crystals are intended for use in circuits that contain reactive components such as capacitors in the oscillator feedback loop. The load capacitance is the dynamic capacity of the circuit measured across the crystal terminals and should always be specified when the crystal is to be used in load resonance.

Load versus Series: There is no difference between a load resonant and a series resonant crystal other than the final tuning method used in manufacturing.

Shunt Capacitance (C0): The capacitance of the crystal electrodes plus the capacitance of the holder and leads. The unit is picofarads (pF) and the value typically ranges from 1 ~ 7 pF.

Load Capacitance (Cl): The dynamic capacity of the circuit measured across the crystal terminals in an oscillator. If the application requires a load resonant crystal, Cl must be specified. However, the load capacitance is not to be specified if the application requires a series resonant crystal. The value is typically 10 ~ 50 pF.

Determination of Load Capacitance: The load capacitance can be determined as follows:

$$Cl = \frac{C1 \times C2}{C1 + C2} + Cstray$$ (Figure 2)

Example: $$Cl = \frac{22 \times 22}{22 + 22} + 5 = 16\,pF$$

The Cstray value includes the pin-to-pin input and output capacitances of the microprocessor chip at the crystal pins 1 & 2 in addition to any parasitic capacitances. The value is typically 3 ~ 7 pF.

Equivalent Circuit: The equivalent circuit (Figure 1) is an electrical depiction of the quartz crystal when operating at a frequency of natural resonance. The C0 is the capacitance of the electrodes plus the capacitance of the holder and leads. The “motional arm” is composed of the L1, C1 & R1 values of the crystal and are referred to as motional parameters. The motional inductance (L1) is the vibrating mass of the crystal, the motional capacitance(C1) is the elasticity of the crystal and the motional resistance (R1) is the bulk losses occurring within the resonating quartz.

Quality Factor: The “Q” value of a crystal is a measure of the device’s relative quality, or efficiency of oscillation. The crystal stability is directly related to the Q factor. The greater the Q, the smaller the bandwidth and the steeper the slope of the reactance will be. Also, greater Q results in lower pullability and trim sensitivity.

Trim Sensitivity: The measure of the incremental fractional frequency change for an incremental change in the value of the load capacitance. The typical unit is (ppm/pF) and the value ranges from <1 ~ >30.

Pullability: The change in frequency from that at one load capacitance $(Fl1)$ to that at a second load capacitance $(Fl2)$ or to the series resonant frequency (Fs). The typical unit is parts-per-million (ppm) and the value range depends on the motional parameters and the load capacitance. (Fig. 7)

Spurious Modes: The inharmonic mode of vibration of the crystal. Spurious modes are usually unwanted. The equivalent resistance of a spurious frequency should be at least twice the series resonant resistance of the crystal for oscillator applications. Attenuation of spurious modes to very low levels is often required for crystal filter applications. The typical unit is (dB) and ranges from 2 ~ 50.

Aging: The cumulative change in the frequency of a crystal over time. The typical unit is parts-per-million (ppm) or parts-per-billion (ppb).

Drive Level: The amount of power dissipated thru the crystal during oscillation. The unit is typically micro-watts (µW) and ranges from 1 ~ 5,000.

CRYSTAL CUTS -

X-Cut: The X-Cut is used for frequencies below 1 Megahertz (MHz). The most common device is the 32.768 Kilohertz (KHz) watch crystal that is used in all kinds of timing applications. The temperature characteristic (TC) curve of the X-Cut is shown in Figure 4. The inflection temperature of the X-Cut is designed to be near room temperature.

AT-Cut: The AT-Cut is the workhorse of the field. It is the most common cut used above 1 MHz. The AT-Cut TC curve is shown in Figure 5. The AT-Cut is economical combined with having good performance characteristics across a wide variety of environmental conditions. The inflection temperature of the AT-Cut is near room temperature. The upper and lower turnover points are typically separated by 50 ~ 150 °C.

SC-Cut: The SC-Cut is frequently used in higher stability applications such as ovenized oscillators. The SC-Cut is less sensitive to drive level changes, starts easily and is very frequency stable over narrow ranges of temperature. The inflection temperature of the SC-Cut is typically 92 ~ 100 °C. The upper and lower turnover points are typically separated by 2 ~ 50 °C.

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... Quality crystals and oscillators

CRYSTAL EQUATIONS -

Total Circuit Capacitance = $Ct = C0 + Cl$

Series Resonant Frequency = $Fs = \frac{1}{2\pi \times \sqrt{C1 \times L1}}$

Anti Resonant Frequency = $Fa = \frac{1}{2\pi \times L1 \times \sqrt{\frac{C0 \times C1}{C0 + C1}}}$

Load Resonant Frequency = $Fl = \frac{1}{2\pi \times L1 \times \sqrt{\frac{Ct \times C1}{Ct + C1}}}$

Motional Capacitance = $C1 = \frac{2 \times Ct \times \Delta F}{Fs}$

Motional Inductance = $L1 = \frac{1}{4\pi^2 \times Fs^2 \times C1}$

Change in Frequency = $\frac{\Delta F}{F} = \frac{Fs \times C1}{2 \times Ct}$

Series Resonant Resistance = $R1 = \frac{2\pi \times Fs \times L1}{Q}$

Load Resonant Resistance = $Rl = R1 \times \left(1 + \frac{C0}{Cl}\right)^2$

Quality Factor = $Q = \frac{2\pi \times Fs \times L1}{R1}$

Trim Sensitivity = $TS = \frac{C1 \times 1{,}000{,}000}{2 \times Ct^2}$

Load Capacitance = $Cl = \frac{C1 \times C2}{C1 + C2} + Cstray$

All specification subject to change. Please contact factory for current specifications (Rev.12/04)

OSCILLATOR INFORMATION

CLASSIFICATIONS -

Crystal Oscillator (XO): An oscillator with only a crystal to control the stability of the output frequency.

Voltage Controlled Crystal Oscillator (VCXO): An oscillator with a crystal and associated components to deviate or modulate the output frequency using an external control voltage.

Temperature Compensated Crystal Oscillator (TCXO): An oscillator with a crystal and associated components to provide temperature compensation of the output frequency.

Oven Controlled Crystal Oscillator (OCXO): An oscillator that uses an internal oven to control the temperature of the crystal and temperature sensitive circuitry, providing an excellent frequency vs. temperature response

Voltage Controlled, Temperature Compensated Crystal Oscillator (VC/TCXO): An oscillator that combines the features of the TCXO with external voltage control of the output frequency.

Voltage Controlled, Oven Controlled Crystal Oscillator (VC/OCXO): An oscillator that combines the features of the OCXO with external voltage control of the output frequency.

TERMINOLOGY -

Duty Cycle: The measure of output waveform symmetry. This term is expressed as a percentage. The voltage at which the measurement is made varies by waveform type.

Enable/Disable (E/D): A control function that allows the output of the oscillator to be toggled on or off as desired by applying or removing an external logic control voltage to an oscillator pin.

Tristate: A control function that allows the output to be placed into a high impedance state. This feature is activated by the application of a external logic control voltage to an oscillator pin.

Rise Time: The time measured for the output signal voltage to transition from the “0” level to the “1” level.

Fall Time: The time measured for the output signal voltage to transition from the “1” level to the “0” level.

Frequency Adjustment: The range of frequency that the oscillator can be tuned from the nominal frequency.

Inclusive Tolerance: The amount of frequency change allowable from the nominal frequency given a set of operating conditions. This includes the deviation at reference temperature, deviation over the operating temperature range, changes in input voltage, changes in load, shock, vibration and aging.

Calibration Tolerance: The amount of frequency deviation allowable from the nominal frequency at the reference temperature.

Temperature Stability: The amount of frequency deviation allowable from the nominal frequency over the operating temperature range.

Input Current: The amount of current drawn by the oscillator.

Load Drive Capability: The maximum load the oscillator can drive specified in terms of the number of gates or the type of load circuit.

Operating Temperature Range: The range of ambient temperature over which the oscillator shall operate while satisfying the specified values for its performance.

Reference Temperature: The ambient temperature of a crystal controlled oscillator at the measurement of characteristics other than temperature and aging characteristics.
(Typically 25 ± 2 °C)

Storage Temperature Range: The temperature range over, which the oscillator can be stored while not operating.

Operable Temperature Range: The temperature range over, which the oscillator can be operated but not necessarily meet the requirements of the operating temperature range.

Supply Voltage: The input voltage required for the oscillator to operate within specification.

Symmetry: A measure of the uniformity of the output waveform.

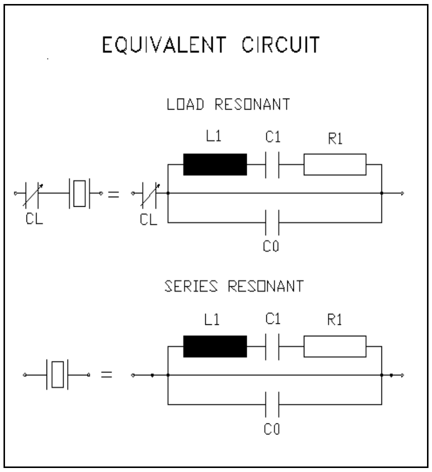

Figure 1

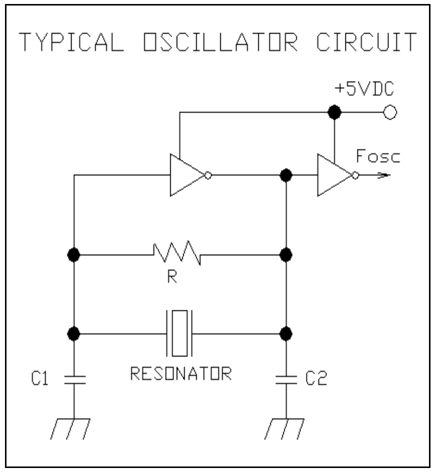

Figure 2

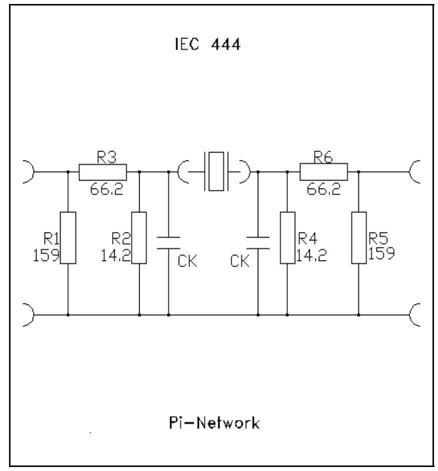

Figure 3

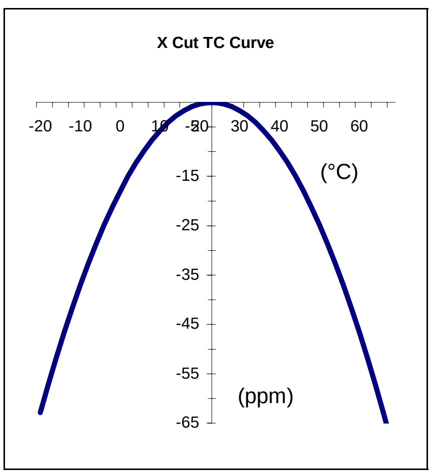

Figure 4

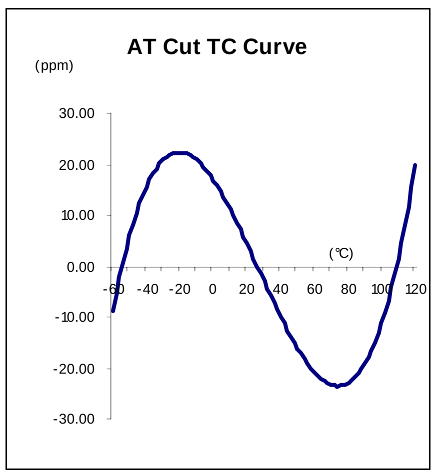

Figure 5

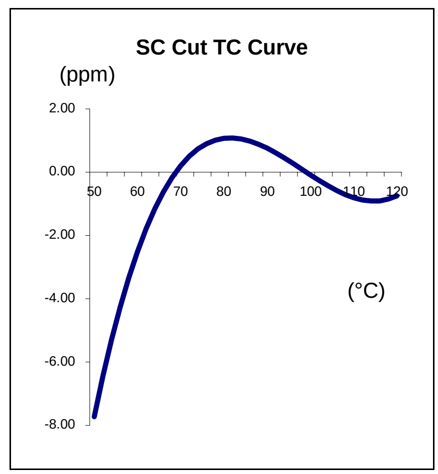

Figure 6

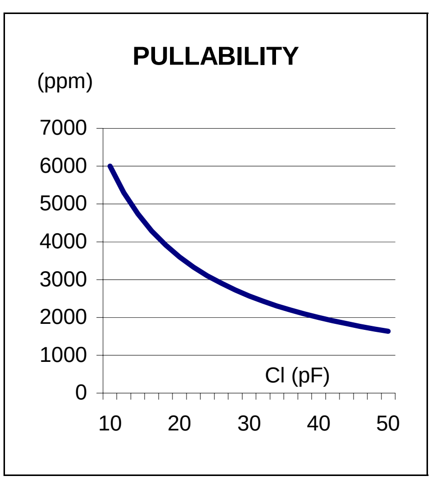

Figure 7

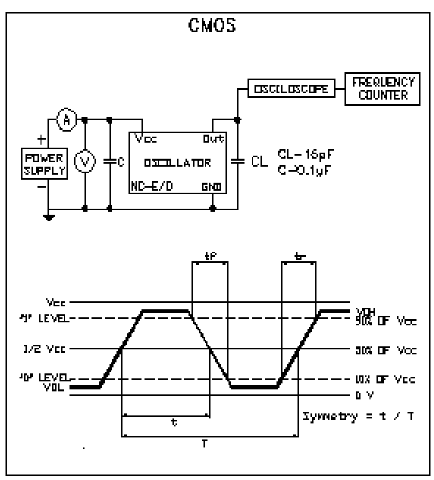

Figure 8

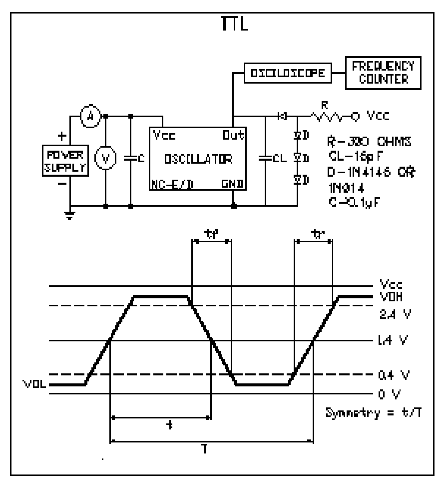

Figure 9

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