Crystal Terms and Application Notes

TECHNICAL TERMS

Holder: A case housing a thin piece of quartz crystal or crystal strip with vacuum-evaporated metal electrode and terminals for connections.

Frequency: The number of cycles of output waveform occurring per second. The unit of frequency is cycles per second, or Hertz, abbreviated Hz.

Fundamental mode: The main mode of the crystal. it is also called first overtone.

Overtone mode: Odd numbers assigned for frequencies in terms of specified oscillation mode. Standard third overtone mode, followed by fifth, seventh, ninth, etc. It is not practical to go beyond ninth overtone. The frequencies are not exactly three, five, seven, or nine times the fundamental frequency.

Frequency tolerance: The allowable deviation from the nominal frequency at room temperature. Frequency tolerance is expressed in percentage, typical ±0.005% or in parts per millions (ppm), ±50ppm.

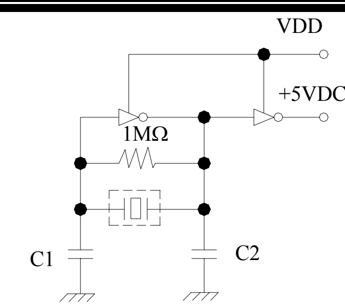
Equivalent Series Resistance: The value of impedance the crystal exhibits in the operating resonant circuit.

Drive level: The amount of power dissipation experienced by the crystal in the circuit. Drive level is expressed in milliwatts or microwatts. Excessive drive level will result in possible long-term frequency drift or crystal fracture.

***Aging**:* The relative frequency change over a certain period of time. This rate of change of frequency is normally exponential in character. Typically, aging is computed within first 30 days and is calculated over a long term (one year or ten years). The highest aging rate occurs within the first week of aging and decreases slowly after that.

Frequency stability: The maximum allowable frequency deviation compared to the measured frequency at 25º C over the temperature window, i.e., 0 to + 70ºC.

***Load capacitance**:* Load capacitance (C_L) is the amount of capacitance that the oscillator exhibits when looking into the circuit through the two crystal terminals. Load capacitance is needed to be specified when the crystal is used in a parallel mode. Load capacitance is calculated as follows:



C_1, C2: See Specifications
IC: 4069 (Hex inverter)
(MOTOROLA)

$$C_L = \frac{(C_1 \times C_2)}{(C_1 + C_2)} + Cstray$$

Cstray may vary from 2pF to 6pF.

Figure 1 Load capacitance in circuit

Shunt capacitance: Shunt capacitance (C_O) is the capacitance between the crystal terminals. It varies with package; usually it is smaller in SMD (4pF typical) and is 6pF in leaded crystals.

Spurious: Unwanted resonances usually above the operating mode, specified in dB max. or number of times of ESR. Frequency range must be specified. For example, spurious response shall be minimum 6dB or 2.5 x R in the frequency window of F_0 ± 200kHz.

Operating temperature range: Temperature range within which crystal units operate under specified conditions.

Mode of *vibration:* It is a piezoelectric effect of quartz crystal. The mode of vibration of quartz crystal varies with crystal cuts such as Thickness-shear for AT cuts and BT cuts, or Length-width-flexure for tuning fork crystals (+2ºX) cut, or Face-shear for CT, DT cuts. The most popular cut is the AT-cut which offers a symmetrical frequency shift over a wide temperature change.

Pullability: Frequency change as a function of load capacitance CL in a parallel resonant crystal. Pullability is a function of shunt capacitance Co motional capacitance C_1, and size of crystal.

Insulation resistance: Resistance between crystal's leads, or between lead and case (metal case). It is tested with a DC voltage at 1 OOV ± 15V and insulation resistance is in the range Of 500 Mil.

Series resonance: Series resonance occurs when its impedance is at minimum at resonance. Its equivalent circuit at series resonance is a resistor.

QVS TECH INC
6965 El Camino Real, Suite 105 Carlsbad, CA 92009
Phone: (760) 929-8677 Fax: (760) 929-8077
email: sales@qvstech.com

Crystal Terms and Application Notes

Quality Factor: is a quality function of motional inductance, resonant frequency, and ESR. It is typical in the range of ten's to hundred's of thousands.

QUARTS CRYSTAL CHARACTERISTICS

CRYSTAL EQUIVALENT CIRCUIT

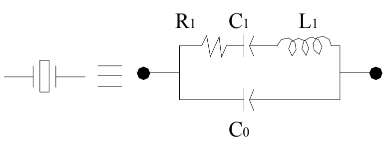


Figure 2

The equivalent circuit of a quartz crystal is shown to explain the basic elements governing the crystal characteristics and performance. It consists of a motional capacitance C_l, inductance L_l, series resistance R_l, and a shunted capacitance C_0. The first three parameters are known as the "motional parameters" of the quartz crystal element. See Fig. 2.

SERIES RESONANCE

When a crystal is operating at series resonance (Fs), it looks resistive in the circuit. Thus, impedance at Fs is near zero. In a well designed series resonant circuit, correlation is not a problem and load capacitance does not have to be specified. See Fig. 3.

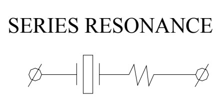


Figure 3

PARALLEL RESONANCE

When a crystal is operating at parallel resonance (Fs<Fr<Fa), it looks inductive in the circuit. Thus, function of a load capacitance is very important in selecting the stable point of oscillation. As well as reactance changes, the frequency changes correspondingly, thus changing the pullability of the crystal. The difference in frequency between the Fs and Fa depends on the Co/C_l ratio of the crystal unit, and the inductance L_l. In parallel circuit design, load capacitance CL shall be specified. (Fig. 4)

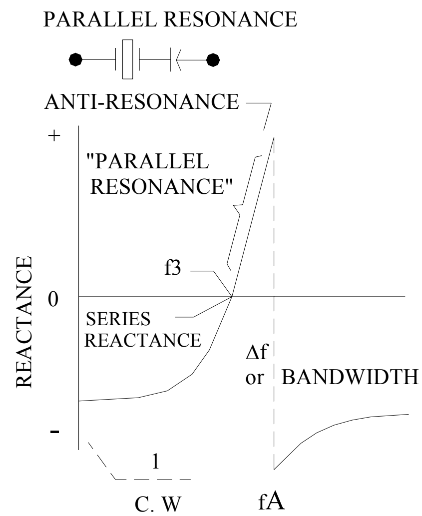
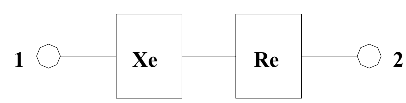


Figure 4

The crystal equivalent circuit can be simplified as a series resistance Re with a reactance Xe. (Fig. 5)



Ze=Re+jXe Figure 5

NEGATIVE RESISTANCE "-R"

Negative resistance is an important parameter to consider when designing an oscillator. Figure 1 shows an equivalent circuit for an oscillator. "-R' represents the negative resistance; to maintain stable oscillation at a constant frequency,
The oscillator must have enough negative resistance I-RI > 10 Re) to compensate for the resistance (loss) of the resonator.

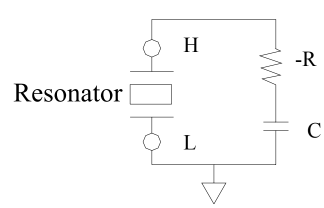


Fig. 6. Negative Resistance in an oscillator circuit

CHANGE OF LOAD CAPACITANCE AND PULLABILITY

QVS TECH INC
6965 El Camino Real, Suite 105 Carlsbad, CA 92009
Phone: (760) 929-8677 Fax: (760) 929-8077
email: sales@qvstech.com

Crystal Terms and Application Notes

When a crystal is operating at parallel resonance (Fs<Fr<Fa), it looks inductive in the circuit. As the reactance changes, the frequency changes correspondingly, thus changing the pullability of the crystal. The difference in frequency between the Fs and Fa depends on the Co/C_l ratio of the crystal unit. The frequency changes by A F, i.e., F_L-F_O

$$\frac{\Delta F}{F_0} = \frac{1}{2\frac{C_0}{C_1}(1 \times \frac{C_L}{C_0})}$$

The same crystal with frequency at third-overtone mode will have much less pulling because it's motional capacitance C_l' is approximately 1/9 of C_l at fundamental.

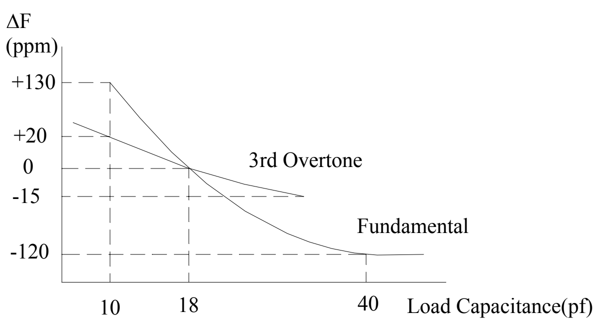


Fig. 7 Change of load capacitance and pullability

Frequency pullability of a fundamental 2OMHz crystal vs. its 3rd overtone crystal.
The oscillating mass of the quartz crystal corresponds to the motional inductance L_l while the elasticity of the oscillating body is represented by the motional capacitance C_l.

C_l (pF) =0.22xA(m2)xF(Hz)/l 670
Where A=area of the electrode
F=resonant Frequency

OVERTONE CRYSTAL

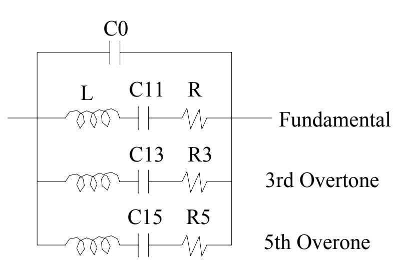


Figure 8

The C_l value can be changed for a particular resonant frequency by varying the electrode area. The range of variation of the electrode area depends on the diameter of the quartz element.

The static parallel capacitance C. is the capacitance between the vacuum-deposited metal electrodes and quartz material as a dielectric and we have:

Co(pF)=40.4xA(ml)xF(Hz)/l 670+0.8(pF)
L_l(H)=4.22xl0^{4}x(1670)F^3/*(Hz)/A(m^3)

FORMULAS

R_l = Series Resistance $= \frac{2\pi fr L_1}{Q}$

C_l = Motional Capacitance $= \frac{2\Delta f}{fr}(C_0 + C_1)$

L_l = Motional Inductance $= \frac{1}{4\pi^3 fr^3 C_1}$

Co= Shunt Capacitance $= \frac{frC_1}{2\Delta f} - C_1$

Fr = (Series) Frequency $= \frac{1}{2\pi\sqrt{L_1 C_1}}$

Q = Quality Factor $= \frac{2\pi fr L_1}{R_1} = \frac{1}{2\pi C_1 fr R_1}$

Δf = Change in Frequency $= \frac{frC_1}{2(C_0 + C_1)}$

(Series to Parallel)

C_L = Load Capacitance $= \frac{frC_1}{2\Delta f} - C_0$

APPLICATION NOTES

Selecting a crystal for a microcontroller

1.0 Purpose:

This application note describes the selection of a crystal used with any type of microcontroller that accepts a parallel mode, AT or BT cut crystal, fundamental or third-overtone mode.

2.0 Functionality and comparability:

Unless otherwise specified in the microcontroller data sheet, this application note can be used as a general guidance in the selection of a crystal which can be used with many leading manufacturers of microcontrollers.

QVS TECH INC
6965 El Camino Real, Suite 105 Carlsbad, CA 92009
Phone: (760) 929-8677 Fax: (760) 929-8077
email: sales@qvstech.com

Crystal Terms and Application Notes

3.0 Circuit description:

Most chips include an inverter design with a positive feedback resistor (typical 1 MΩ) with an optional series resistor with value varied from 10Ω to 1kΩ (see figure 9).

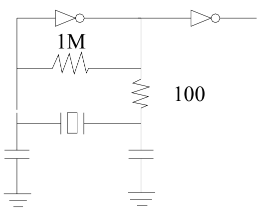


Figure 9

It has an input port (normally called XIN, XTALL) and an output port (XOUT, XTALO) for crystal connections between those two ports. Most chips are designed with an option either driven by an external clock oscillator fed to the crystal input port, or with an external crystal.
Depending on frequency, crystals can be selected as fundamental or an overtone mode. Normally, frequencies above 24 MHz require the third overtone mode for price advantage and delivery. Higher fundamental frequencies, up to 40 MHz can be bought as a BT-cut with a lower price compared to an AT-cut. In parallel mode, where the crystal reactance is inductive, two external capacitors C_l and C_2 are required for a necessary phase shift in oscillation. C_l and C_2 are needed whether the crystal is in fundamental mode or overtone mode. Values of C_l and C_2 are specified by the chip manufacturer and vary from 6pF to 47pF. C_l and C_2 may not be balanced, i.e., equal in value, but sometimes are offset in a particular ratio (C_l/C_2) for best performance, depending on crystal and amplifier characteristics and board lay-out. Figure 10 shows a typical configuration for a fundamental mode operation.

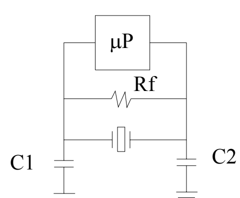


Figure 10

In an overtone mode, an additional inductor L_l and capacitance Cc is required to select the third-overtone mode while suppressing or rejecting the fundamental mode. Choose L_l and Cc component values in the third overtone crystal circuit to satisfy the following conditions:

- The L_lCc components from a series resonant circuit at a frequency below the fundamental frequency, which makes the circuit look inductive at fundamental frequency. This condition does not favor to oscillation at fundamental mode.

- The L_lCc and C_2 components form a *parallel resonant circuit* at a frequency about half-way between the fundamental and third-overtone frequency. This condition makes the circuit capacitive at the third-overtone frequency, which favors the oscillation at the desired overtone mode. See figure 11.

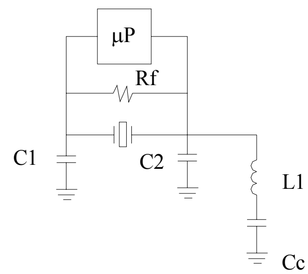


Figure 11

- In a standard overtone mode, C_2 value varies from 10pF to 30pF. Cc value should be chosen at least *10 times the value of* C_2, so it's equivalent Cequiv. will be approximately the value of C_2.

- Typical values of L_l for different crystal frequencies:

25 MHz	4.7uH, 6.8uH, 8.2uH, l0uH
32 MHz	2.7uH, 3.9uH, 4.7uH, 5.6uH
40 MHz	1.5uH, 1.8uH, 2.2uH, 2.7uH, 3.3uH

Figure 12 shows a typical circuit configuration for a 40.3200MHz, third-overtone mode operation.

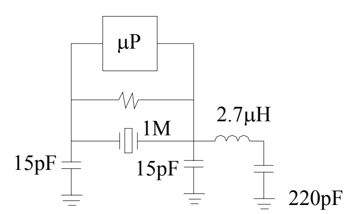


Figure 12

DIFFERENCE BETWEEN AT CUT AND BT CUT CRYSTALS

QVS TECH INC
6965 El Camino Real, Suite 105 Carlsbad, CA 92009
Phone: (760) 929-8677 Fax: (760) 929-8077
email: sales@qvstech.com

Crystal Terms and Application Notes

As described, AT cut crystals and BT cut crystals possess different angle cut (35 degrees on AT fundamental vs. 49 degrees on BT cut). Both types have the same vibration mode (thick-ness-shear). However, the BT cut crystal on the 50MHz fundamental is slightly thicker (2mils) compared to its AT cut (1.3mils), thus offers a better yield and unit cost. AT cut and BT cut have different temperature vs. frequency curves, but they are made to meet all specifications.

AT Fundamental $F=\frac{1670}{t}$

AT Overtone $F=\frac{1670\times n}{t}$ $\begin{cases} \text{F in KHz} \\ \text{t in mm} \\ \text{n =overtone mode} \end{cases}$

BT Fundamental $F=\frac{2560}{t}$

Unless chemical etching is used (which increases the unit cost), standard fundamental crystal 50 MHz was lapped to the frequency. Due to its thin and delicate plate, the control process is so difficult in handling and processing, thus results in a much lower yield. In contrast with a 50 MHz fundamental, the blank thickness of the 3rd overtone crystal is approximately 4 mils (in AT-cut).

Besides mechanical lapping required on fundamental 50 MHz, special material finishing process is added (polishing and sometimes use aluminum or silver material).

Overtone and Fundamental Modes:
The main operating mode of the crystal is the Fundamental mode (or sometimes called first overtone). It has strongest energy as far as contribution to oscillation as well as lowest Equivalent Series Resistance (ESR). Because of handling problem (due to thin plate greater than 24 MHz), overtone modes are recommended. Special processes are made to create best suitable parameters for appropriate overtones, i.e. third-overtone, fifth overtone, seventh overtone, etc. ESR increases as overtone mode increases. However, 9th overtone mode is the highest recommended crystal in any application.

Notes: -The frequencies are not exactly three, five, seven, or nine times the fundamental frequency.
- Fundamental higher frequencies options are available However, it will affect cost.

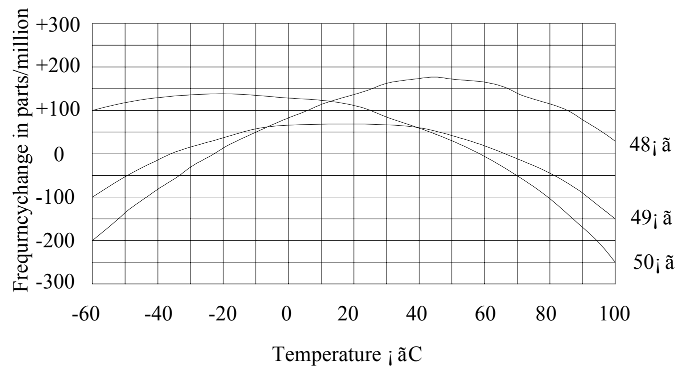


Fig. 13 Frequency-temperature curves for the BT-cut at different angles of the angle ϕ.

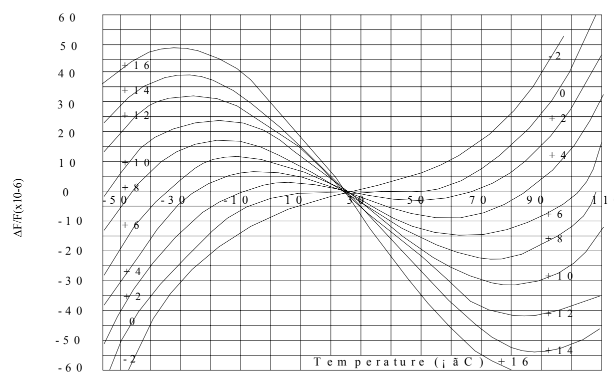
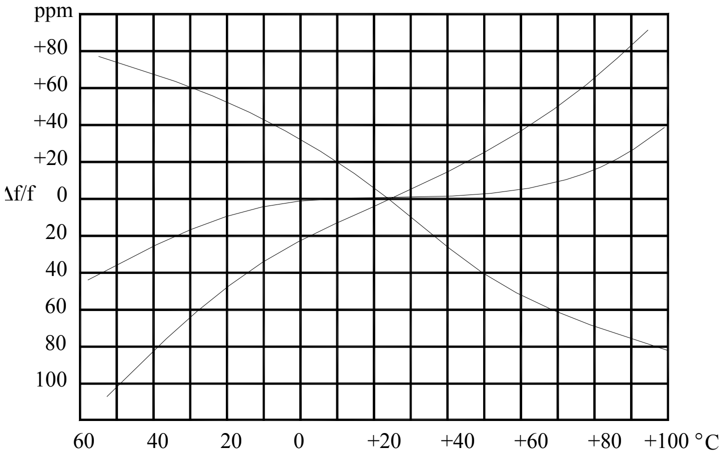


Fig. 14 Frequency temperature curves for the AT-cu

QVS TECH INC
6965 El Camino Real, Suite 105 Carlsbad, CA 92009
Phone: (760) 929-8677 Fax: (760) 929-8077
email: sales@qvstech.com

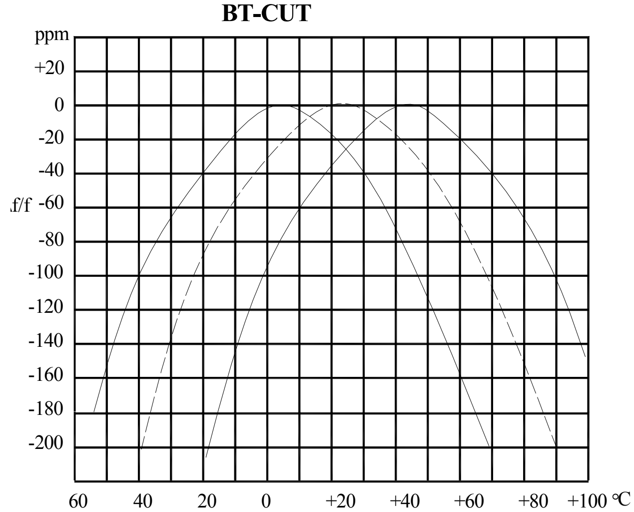
Crystal Terms and Application Notes

AT-CUT



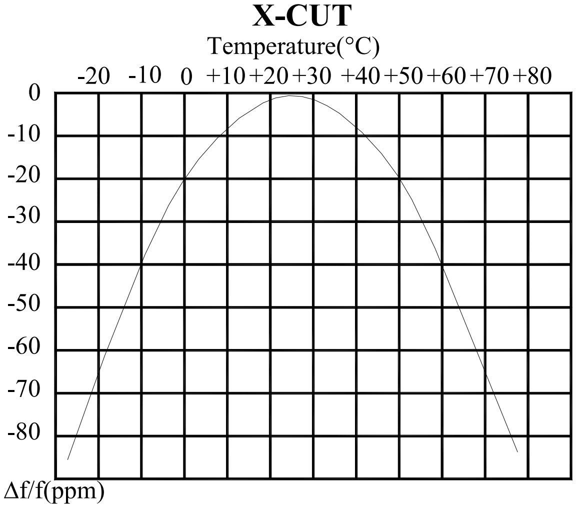
TYPICAL TEMPERATURE CHARACTERISTICS

BT-CUT



TYPICAL TEMPERATURE CHARACTERISTICS

X-CUT



TYPICAL TEMPERATURE CHARACTERISTICS

QVS TECH INC
6965 El Camino Real, Suite 105 Carlsbad, CA 92009
Phone: (760) 929-8677 Fax: (760) 929-8077
email: sales@qvstech.com