YIC

Design note for YIC Quartz Crystal Unit

CRYSTAL EQUIVALENT CIRCUIT

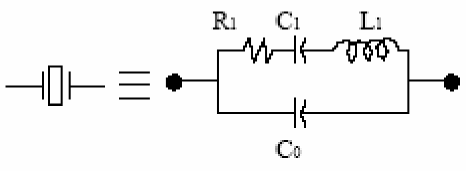


Figure 1

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 Cl, inductance Ll, series resistance Rl, and a
shunted capacitance C0. The first three parameters are known as the "motional parameters" of the quartz crystal

SERIES RESONANCE

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

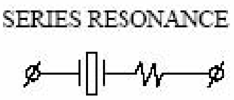


Figure 2

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/Clratio of the crystal unit, and the inductance Ll. In parallel circuit

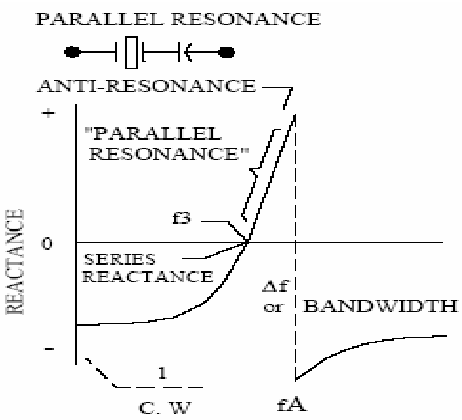
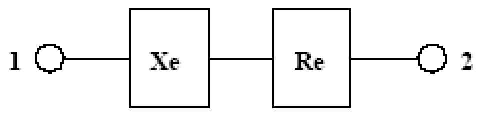


Figure 3

The crystal equivalent circuit can be simplified as a series resistance Re with a reactance Xe. (Fig. 4)



Ze=Re+jXe Figure 4

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

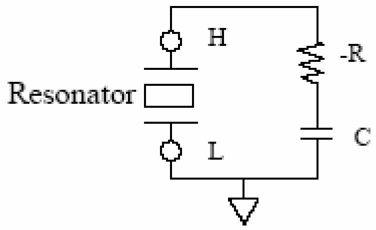


Fig. 5. Negative Resistance in an oscillator circuit

CHANGE OF LOAD CAPACITANCE AND PULLABILITY

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/Cl ratio of the crystal unit. The frequency changes by A F,

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

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

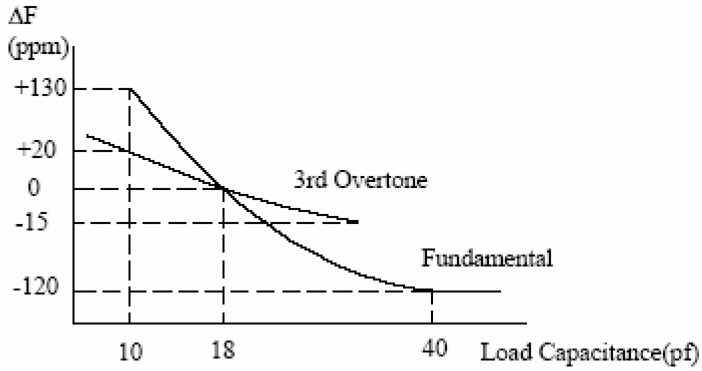


Fig. 6 Change of load capacitance and pullability

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

C_1 (pF)=0.22xA(m2)xF(Hz)/1 670
Where A=area of the electrode
F=resonant Frequency

OVERTONE CRYSTAL

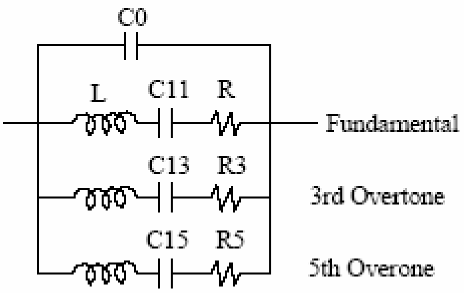

Figure 7

The Cl 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)/1 670+0.8(pF)
L_1(H)=4.22x10^4x(1670)F^3/*(Hz)/A(m^3)

FORMULAS

$$R_1 = \text{Series Resistance} = \frac{2\pi fr L_1}{Q}$$

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

$$L_1 = \text{Motional Inductance} = \frac{1}{4\pi^3 fr^3 C_1}$$

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

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

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

$$\Delta f = \text{Change in Frequency} = \frac{fr C_1}{2(C_0 + C_1)}$$

(Series to Parallel)

$$C_L = \text{Load Capacitance} = \frac{fr C_1}{2\Delta f} - C_0$$

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.

3.0 Circuit description:
Most chips includes an inverter design with a positive feedback resistor (typical 1 M) with an optional series resistor with value varied from 10 to 1k (see figure 8).

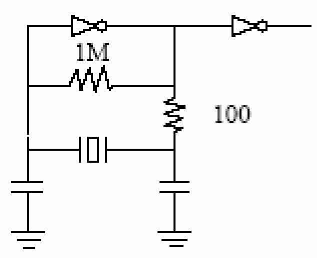

Figure 8

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 requires 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 Cland C2 are required for a necessary phase shift in oscillation. Cl and C2 are needed whether the crystal is in fundamental mode or overtone mode. Values of Cl and C2 are specified by the chip manufacturer and vary from 6pF to 47pF. Cland C2 may not be balanced, i.e., equal in value, but sometimes are offset in a particular ratio (Cl/C2) for best performance, depending on crystal and amplifier characteristics and board lay-out. Figure 9 shows a typical configuration for a fundamental mode

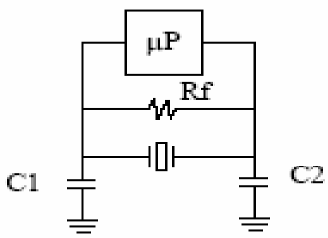

Figure 9

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

■ The LlCc 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

■ The LlCc and C2 components form a parallel resonant circuit atafrequency 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 10.

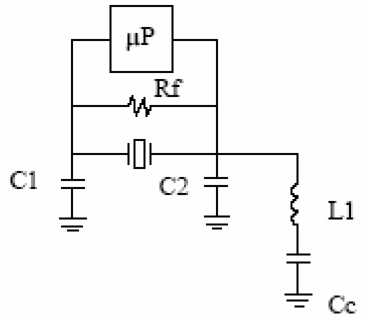

Figure 10

■ In a standard overtone mode, C2 value varies from 10pF to 30pF. Cc value should be chosen at least 10 times the value of C2, so its equivalent Cequiv. will be approximately the value of C2.

■ Typical values of Ll for different crystal frequencies:

25 MHz	4.7uH, 6.8uH, 8.2uH, 10uH
32 MHz	2.7uH, 3.9uH, 4.7uH, 5.6uH
40 MHz	1.5uH, 1.8uH, 2.2uH, 2.7uH, 3.3uH

Figure 11 shows a typical circuit configuration for a 40.3200MHz, third-overtone mode operation.

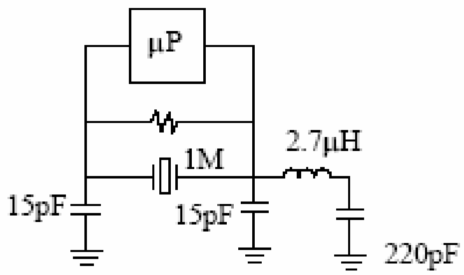

Figure 11

DIFFERENCE BETWEENAT CUT AND BT CUT CRYSTALS

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

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

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

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

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

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.

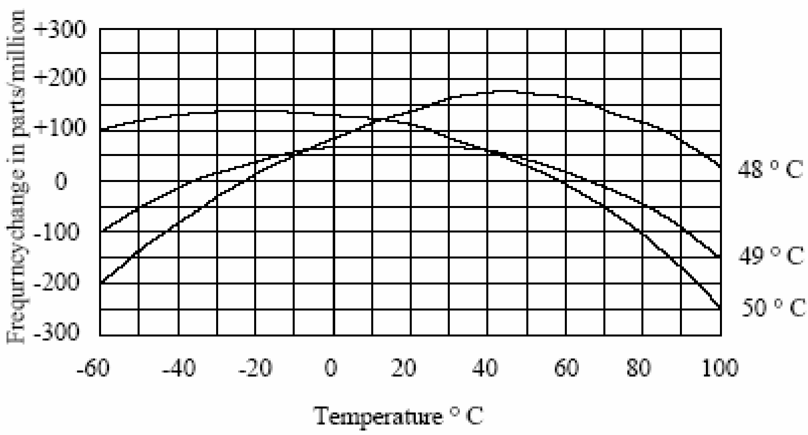

Fig. 12 Frequency-temperature curves for the BT-cut at different angles of the angle

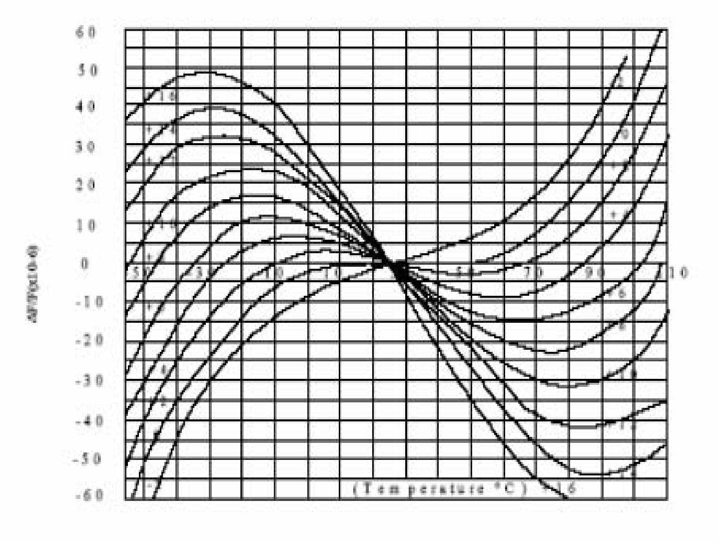

Fig.13Frequencytemperaturecurves for the AT-cut