Application Note AN-103

Crystals for the T73227 Type of VCXO

Introduction

This application note is intended to familiarize the reader with the various types of crystals that can be used with TLSI's T73227 27 MHz VCXO clock generator IC. Included in this discussion is a description of the key parameters of the crystals and their overall affect on the performance of the VCXO. TLSI's VCXOs can be found in many diverse applications. A common application for the T73227 series is in Set-Top Boxes (STB). This note will review the essential requirements in selecting a crystal to be used with the T73227 and other VCXOs.

Background

Generally designers need to specify the resonant center frequency of the crystal, type of operational mode (fundamental), holder or package type, frequency tolerance, frequency stability, load capacitance, operating temperature range, equivalent series resistance (ESR), drive power and aging. One can also request other specs or requirements from the crystal manufacturer specific to the given application. The following terminology explanations will help the reader to better understand crystal selection.

Crystal Package Types

Crystal packages can be classified into several types such as thru-hole or surface mount (SMD).

Thru-hole crystals are leaded packages that are, typically, manually installed. Common applications for thru-hole crystals include applications where size is not a critical factor and that require a range of frequencies. Thru-hole crystals have more desirable temperature and electrical characteristics.

Surface mount crystals are leadless components designed for pick and place or automatic installation. Surface mount crystals are typically used for single frequency applications where size is a critical factor.

Crystal Performance Parameters

Frequency tolerance vs. frequency stability – There is a major difference between frequency tolerance and frequency stability. The frequency stability is the maximum allowable frequency deviation in ppm, over a specified operating temperature range, from the "*reference*" frequency. The "*reference*" frequency is usually referred to as the initial resonant frequency of a crystal at room temperature. The frequency tolerance of a crystal is defined as the maximum allowable frequency deviation, in ppm, from the nominal (spec) frequency at a specified temperature, usually +25^{o}C.

Rated temperature range – What happens when the crystal is not operating within the temperature range stated in the specification? The crystal performance will be adversely affected. It can cause the frequency of the crystal to drift. In the worst-case scenario it may cause a malfunction of the designer's circuit or, at best, unpredictable performance. We strongly recommend against operating the crystal outside of its specified temperature range.

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Crystal aging is the change in frequency of a crystal over time. Aging can be in the positive or negative direction. Aging effects contribute to the overall frequency drift of the oscillator in which the crystal is used. Aging will be mainly affected by two important factors, namely, contamination and mechanical stress. Experiments prove that contamination on the crystal wafer usually causes a negative frequency shift, whereas excessive mechanical stress, possibly due to improper assembly techniques, often results in a positive frequency shift. Over-driving the crystal can also induce mechanical stress.

Load capacitance, C_L, of a crystal is that capacitance which the crystal needs to see across its terminals in order to generate the desired oscillation frequency. Remember that this is the equivalent capacitance of the oscillator circuit as seen by the crystal. The designer must select a crystal that will oscillate at the desired frequency under this load capacitance. Alternately the designer could also design the oscillator to provide the load capacitance as specified for a particular crystal. Such a load capacitance is the equivalent capacitive effect of the entire oscillation circuitry that appears at or presents itself to the crystal.

The nominal spec frequency of a crystal is often defined as f_L , which stands for "load resonant frequency" at a given capacitance value. This capacitance value is to reflect the actual "load capacitance" presented to the crystal when it is placed and working in a real oscillation circuit. This capacitance value is generally expressed in pF.

In addition, a crystal with zero (0 pF) load capacitance has its resonant frequency designated as f_R, series resonant frequency.

Pull-ability of a crystal is a measure of frequency change as a function of load capacitance and the so-called Gamma value (C_0/C_1) of the crystal. The circuit designer can move the operating frequency over a limited range by changing or varying the load capacitance presented to the crystal. This is the fundamental mechanism used in VCXO circuits to move the frequency of the oscillator circuit.

The crystal used by the T73227 series of VCXOs may be represented by the equivalent LCR circuit, shown below in Figure 1. C_0 is the **shunt capacitance** formed by the crystal electrodes plus any holder capacitance. The L_1, C_1, R_1 branch is called the **motional arm**, where C_1 is called the **motional capacitance**. The ratio of the shunt capacitance C_0 over the motional capacitance, C_1, together with C_1 itself, controls the "pull-ability" of the crystal.

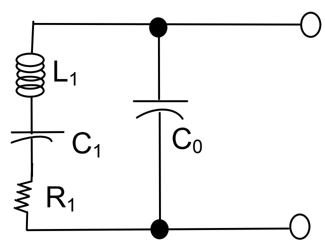

Figure 1: The equivalent LCR crystal circuit

The pulling range, stated in ppm, of a crystal can be calculated by the following formula:

$$pullingrange = \frac{\Delta f}{fs}(ppm) = \frac{1}{2(C_{gamma} + C_L / C_1)}$$

Where f_s is the series resonant frequency of the crystal without load, C_{gamma} is the ratio C_0/C_1 (typical value should be < 250 for a pulling range required above +/-100 ppm), and C_L is the load capacitance.

Typical values of R_1 are 10 to 35 ohms for a fundamental mode crystal and higher for overtone crystals. Typical motional capacitance values are between 15fF and 25fF for a fundamental crystal. Shunt capacitance (C_0) is typically about 210 times C_1 for fundamental mode. L_1 can be calculated knowing the series frequency of the crystal by the following formula:

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

EXAMPLE: Given a 20fF C_1 and a C_0 of 4.3pf the pulling range for a crystal specified for a 20pf load is ±412ppm and the pulling range of a 27pf load crystal is ±319ppm. This gives us a difference in tuning range of 93 ppm between 20 pf and 27pf loads and clearly demonstrates how crystals with varying load capacitance ratings affect the pulling range of the crystal.

Pullability as a function of package style – Crystals in an HC-49S (low profile) package generally don't have as much pulling range as would a crystal in an HC-49U (high profile) package. Pullability is usually a function of the size of the termination electrode connected to the crystal blank. A bigger crystal blank, of course, can accommodate a larger electrode. Due to its low profile, an HC-49S crystal has a smaller electrode than an HC-49U, thus a reduced pullability.
The larger electrode of the HC-49U would typically provide a wider frequency pulling range when the crystal is placed in series with a given load capacitance in the oscillation circuit.

Drive level – This is the maximum current supplied by the oscillator circuit to the crystal as specified by the crystal manufacturer. When a crystal is driven over its maximum drive level spec it may cause its frequency and resistance to change, in many cases to a higher value. This clearly implies changes in the crystal's electrical characteristics. This could cause the oscillator to stop functioning intermittently. It could also result in a broken crystal wafer caused by too much power over drive for too long a period of time. Over-driving the crystal can also affect long term aging.

Conclusions and Recommendations

- Be sure to select a crystal with the proper parameters for C_0/C_1, ESR and C_L as recommended by the VCXO IC manufacturer.
- The VCXO IC manufacturer will generally specify the appropriate crystal C_L to ensure maximum pullability.
- The VCXO IC manufacturer can generally provide recommendations if the particular application requires that the pull range be specifically limited to less than the maximum.
- Make sure to use the crystal within its specified performance range, particularly as it relates to operating temperature and drive current.

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