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Quartz Crystal Basics: From Raw Materials to Oscillators

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Here is an overview of the history, manufacture and current technology of quartz crystals, one of the most common components in high frequency, high speed electronics

How did the use of quartz crystals come about? The Curie brothers discovered the piezoelectric effect of quartz in the early 1880s. In 1917, Prof. P. Langevin used X-cut plates of quartz to generate and detect sound waves in water. His objective was to provide a means for detecting submarines, and his work led to the development of SONAR. Today this technology is still being used in ultrasonic imaging.

In 1923, Prof. G. W. Pierce of Harvard University proved that a quartz plate with only one set of electrodes could be made to control the frequency of an oscillator circuit and a single vacuum tube. Since then the Pierce oscillator circuit has been used in more oscillators than any other. During the 1920s and '30s, the main application was in amateur ("ham") radio.

Mr. Dan Noble of the Galvin Mfg. Co. (Motorola) worked extensively to prove that crystal control was essential to effective two-way radio communication. The first applications were police radios. Then, in 1939, it was decided to make large-scale use of crystal controls in military communication systems. To support WWII efforts, by 1943, about 130 manufacturers were engaged in the production of crystal units using natural quartz.

After the war, the demand for quartz crystals dropped dramatically, reducing the number of manufacturers to less than 50 in a few months. The Korean War spurred new growth, but it once again declined after the war ended.

Working with natural quartz for electronics was difficult due to the amount of impurities. It was discovered that synthetic quartz could be manufactured in an autoclave by dissolving raw quartz and reforming it into bars of pure quartz. This finding has helped quartz become a key factor in frequency control in today's exploding wireless market.

Figure 1 · Raw quartz crystal fragments.

Some Of The Advantages of Quartz

It's Piezoelectic Effect: Applying mechanical stress to quartz material (piezein means "to press" in Greek) results in a corresponding electric potential. The converse is also true—applying a potential difference across quartz results in vibration. By controlling the geometrics of the material, the rate of vibration or frequency can be controlled.

Low Temperature Coefficient: Quartz crystals are very stable in varying temperatures. The temperature coefficient is specified in units of parts per million (example: ±50 ppm) over the operating temperature change.

Low Loss (High Q): Quartz crystals exhibit excellent aging hysteresis. In other words, the products' stable performance is

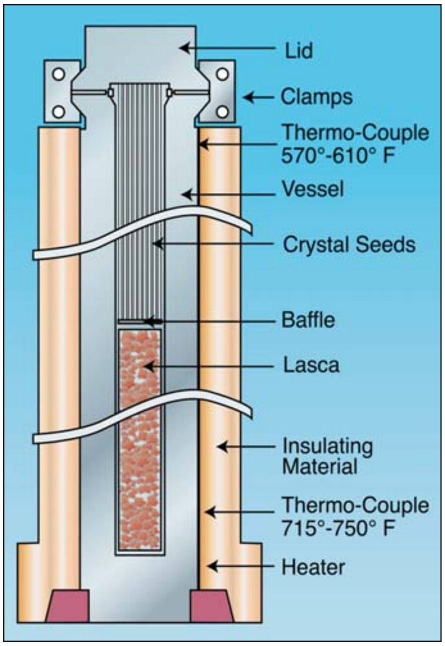

Figure 2 · Quartz crystal-growing autoclave construction.

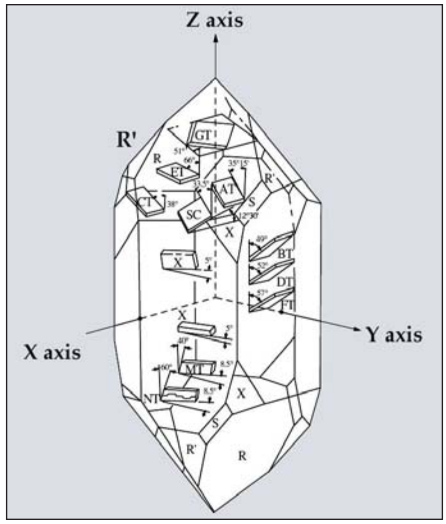

Figure 3 · Diagram of the various cut angles for crystals.

repeatable over time, often specified as: 10 MHz ±50 ppm over 5 years.

Pullability: Quartz crystals have a pullability range. The oscillation frequency can be varied by simply changing the capacitance load of the oscillator circuit.

Abundant in Nature: Quartz crystal is the second most common mineral in the Earth's continental crust, feldspar being the most common. It can be found very near the surface, and the mined material is called lasca (Figure 1).

Can Be Reproduced: Quartz crystal can be synthetically reproduced. The raw lasca is processed in an autoclave (Figure 2) and grown into a quartz crystal bar exhibiting high purity and perfection.

Repeatable Processing Techniques: Advanced manufacturing techniques with tight tolerance controls ensure lot-to-lot accuracy.

Hard But Not Brittle: The uniqueness of the material is that it is hard so it can be processed, yet it is not brittle. This gives quartz crystal excellent shock and vibration resistance.

From Rocks To Clocks

Growing Rocks: The growing of synthetic quartz starts with placing the lasca in an autoclave. Quartz seeds are then attached to the growing rack, which is then loaded into the autoclave. An alkaline solution is added, the vessel is sealed, and the power is turned on. Through constant temperature monitoring the lasca is dissolved and adheres to the seeds. In a matter of 100 to 150 days (depending on what type of crystal is being grown), the vessel is opened and the synthetic quartz bars are removed.

Cutting Angle: The bars are cut at specific angles determined by the required characteristic of the crystal (Figure 3). Accuracy in this process is ensured by using high precision x-ray inspection equipment. The wafers are batched and ground to a predetermined shape.

Precision Wafer Finishing: To ensure specified thickness, surface finish, flatness, and parallelism the wafers must be processed. They are first lapped, then polished, etched, and cleaned. Electrodes are then attached through a vapor evaporation process.

Final Packaging: The crystal wafer is mounted to a base and electrically connected. The frequency is adjusted to specification, and the cover is attached and sealed. The completed units are inspected to ensure 100% quality. The finished crystals are now ready to be applied in a clock oscillator circuit.

Designing Your Own Oscillator

The XO, TCXO, OCXO, and VCXO are excellent solutions for many circuits. However in some high volume applications, these devices are not the most cost effective method for frequency control. An excellent solution here is to specify a crystal (see Figure 4) and design your own crystal oscillator. An uncompensated oscillator circuit (greater than ±20 ppm accuracy) is often designed with a Pierce oscillator circuit by utilizing a crystal, amplifier, a resistor or two and two capacitors. Some ASICs incorporate the full oscillator circuit on-chip so you just provide an external crystal.

While the design-in of a simple crystal can be more cost effective, versus a packaged oscillator module, the design engineer must be wary of some pitfalls such as:

- Insufficient negative resistance (the oscillator circuit resistance must exceed the crystal resistance over all conditions. See Figure 5)
- Incorrectly specifying the crystal parameters (particularly matching the capacitive load of the crystal to the capacitive load of the oscillator circuit)
- Over-driving the crystal, which could cause activity dips (sudden frequency jumps to a spurious response on the crystal).

Many top crystal manufacturers will evaluate a customer's board to ensure that the oscillation margins are correct. It is essential that the user work closely with the crystal supplier early in the development cycle. This upfront time will help to perfect the design with minimal delays and deliver the most cost effective frequency control for the

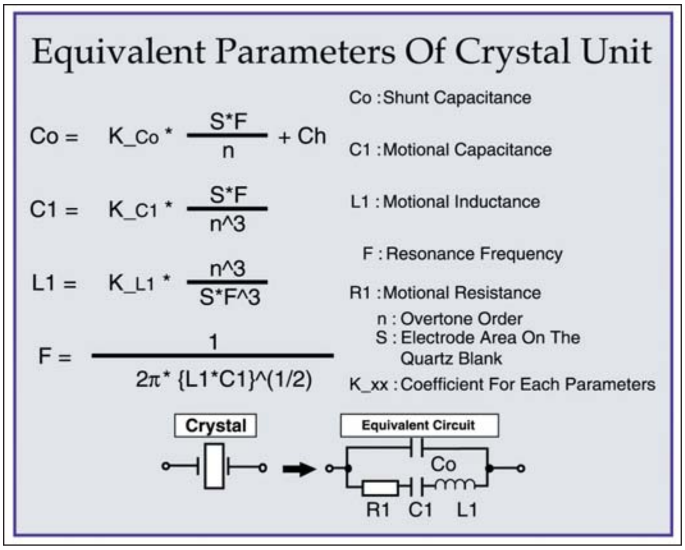

Figure 4 · Equivalent parameters of a crystal unit.

project. Please see the oscillation margin requirements section for additional information.

Specifying Crystals

Mode of Operation: Crystals can be specified to operate at their fundamental frequency or at a harmonic mode (a multiplication of the fundamental mode). The most common crystal is an "AT" cut which has overtone modes at the odd frequency harmonics. You can apply a 10 MHz fundamental mode crystal as a third overtone (approximately 30 MHz), fifth overtone (50 MHz), and seventh overtone (70 MHz). Other crystal cuts (Figure 3) provide a variety of operational characteristics.

Package Selection: Aside from size restrictions, proper package selection is key to ensure the components you choose are mainstream. The largest user of frequency control devices is the mobile phone industry. They drive the volume and package size. Today's phones keep getting thinner and thinner while delivering more features than ever. This trend will continue to force smaller and smaller components to be developed. What might be a popular size today will not necessarily be mainstream in a few years. The manufacturers of frequency control components continue to make investments in the production tooling of these smaller packages. As the volume demand for the smaller packages increases the price point drops. As the volume demand decreases for the larger packages pricing will go up and lead to an end-of life product.

Figure 5 · Oscillator failure rate data.

Frequency Accuracy: The first step is to establish the required frequency accuracy. These specifications include:

- Initial tolerance
- Temperature tolerance
- Aging (loss of accuracy over time)

This is referred to as the "overall accuracy" of the oscillator. Bear in mind though that in the actual application there are slight frequency changes due to load change, supply voltage tolerance, shock, vibration, etc.

Drive Level Dependency (DLD): Since the crystal may see various drive levels it should be tested while the crystal is swept from low to high drive levels to ensure that the frequency and resistance stay within specifications.

Oscillation Margin Requirements: Working closely with your frequency component supplier will allow you to tap into their many years of oscillation experience. Some suppliers even offer to analyze your current circuit performance. They will measure the negative resistance for optimal oscillation. They will adjust the frequency to the nominal operating frequency. The analysis report may include before and after performance graphs along with recommended circuit improvements and recommended crystal load.

Start-up Time & System Synchronization: System start-up time must be synchronized with the stabilization of the reference clock signal. Starting the system before the oscillator is stable will cause a frequency error. However, note that excessively long waiting time may cause high power consumption.

In Conclusion

The quartz crystal is a vital part of the clock oscillator circuit in your application. You cannot overlook the importance of specifying the proper frequency control device. Working closely and early on with your frequency device manufacturer will help deliver your designs on time, on budget, and with higher reliability. We hope that this brief overview gives you a good start toward understanding and properly specifying quartz crystals.

Author Information

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