# High Reliablity vs. COTS Oscillators

APPLICATION NOTE QTAN-112

## I. Introduction

When selecting a crystal oscillator for modern electronics applications, engineers are often keen to select an inexpensive COTS ("commercial off-the-shelf") parts due to relatively low unit cost and lead times. On the surface, this option appears adequate for many applications and recently many programs have attempted to use these products in lieu of a high-reliability option, such as Q-Tech's products, resulting in poor performance. High-reliability oscillators are the safest and, ultimately, most cost effective option for flight applications.

## II. Performance Differences

With a myriad of stark differences between Q-Tech and commercial oscillators, it is easiest to begin with performance. For time-keeping and precision applications the electrical performance, as well as phase noise and jitter characteristics, can significantly alter a circuit's output.

The phase noise and jitter of oscillators often leads to erroneous detection of phase transitions, (i.e. bit errors) when phase shift keyed (PSK) digital modulation is used. In digital communications, for example, where 8-phase PSK is used, the maximum phase tolerance is ±22.5°, of which ±7.5° is the typical allowable carrier noise contribution. For example, due to the statistical nature of phase deviations, if there is a 1.5° phase deviation the probability of exceeding the ±7.5° phase deviation is $6 \times 10^{-7}$, which can result in a bit error rate that is significant in many applications. As such, minimizing phase noise and jitter are increasingly important in modern circuit applications. With respects to oscillators, the phase noise and jitter is largely dependent on the crystal and its design and assembly within the oscillator. The expertise in crystal handling and design isn't something readily available to the average commercial oscillator house and requires dedicated engineering and manufacturing that is found in high-reliability companies like Q-Tech. This is especially important in designs using open-blank crystals, as opposed to the packaged variety. Q-Tech's process for crystal manufacturing has over 40 years of heritage with outputs being used for the most demanding applications, from high-temperature downhole to deep space flight. The same manufacturing and crystal design teams oversee all of Q-Tech's crystal operations, regardless of end-use.

Even still, design engineering plays an important role as shock and vibration can produce large phase deviations even in "low noise" oscillators. Moreover, when the frequency of an oscillator is multiplied by N, the phase deviations are also multiplied by N. For example, a phase deviation of $10^{-3}$ radian at 10 MHz becomes 1 radian at 10 GHz. Such large phase excursions can be catastrophic to the performance of systems, e.g., of those which rely on phase locked loops (PLL) or phase shift keying (PSK). Low noise, acceleration insensitive oscillators are essential in such applications. Q-Tech uses a variety of crystal mounting options dependent on the package and application of each oscillator:

- TO Package w/ 3 Nickel Clips welded
- DIP Package with 3-point mount on posts (used on QT1-QT3 series)
- Flat Pack and DIP Package with 3 or 4-point Tulip Clip mount (30+ Years of Space Heritage)
- SMD Package with 4-point Bridge Mount
- LCC with 4-point "Picture Frame" Mount
- 5x7mm Ceramic Package with 2 or 4-point Ledge Mount on ceramic shelf
- Packaged Crystal 4-point Mount option

It is important to note that for high-shock applications Q-Tech's 4-pt mount options have proven vastly superior to any other mounting offered by a commercial oscillator, particularly in the small 5x7mm package where most COTS products use the simple 2-pt mounting.

Q-Tech crystal oscillators are a safe choice for demanding environments because they are designed, constructed and tested for those environments, and with the purpose of making a 100% reliable product for situations in which failure is expensive or life threatening. The oscillators are designed for operation from -55°C to +125°C, beginning with the quartz crystal element and including the circuitry. The angle at which the crystal is cut from the quartz bar is optimized for the exact temperature range. While COTS clocks may operate at -55°C if they are turned on at room temperature and subsequently cooled down to -55°C, they are known to have a problem starting when turned on at -55°C or other cold temperatures (the cold-start problem). With over 40 years of design experience, Q-Tech's oscillators are not susceptible to cold-start issues.

The drive level dependency of a commercial oscillator can also prove an issue for high-reliability applications. Q-Tech mitigates this potential issue by custom pairing the crystal parameters of each design with the IC being designed, also preventing the cold-start issue previously mentioned.

An activity dip is a relatively sudden increase in the crystals resistance, (a perturbation) in the quartz crystals series resistance over temperature. Generally activity dips are caused by an interfering mode of vibration (coupled mode) in the quartz crystal. These modes bleed energy from the main mode. Therefore, a coupled mode sharply increases the resistance of the main mode as soon as the frequency of the coupled mode coincides with the frequency of the main mode. These interfering modes are actually high overtones (up to the 50th overtone) of low frequency flexure modes. Due to a very steep temperature coefficient of about -20 ppm/°C, they only coincide with the main mode frequency for a fairly narrow temperature range. An interfering mode can be designed out, however, if not designed out, the coupled mode will cause an activity dip. These are usually fairly narrow in temperature (roughly 5 to 30°C wide), and for a given design, activity dips will tend to be about the same temperature range. Because a coupled mode is quartz based, it causes any activity dip is very repeatable over time and temperature. See the example below.

The magnitude of the effect of a coupled mode can range from minor to catastrophic to intermittent, depending on the strength of the interfering mode and how sensitive the application is to changes in oscillator output level (frequency shifts of about 2 to 20 ppm). An activity dip can cause a myriad of system issue, possibly even the loss of phase lock. Another cause of activity dip is a particle stuck on or near to the active area of the crystal. This type of activity dip can change with time and temperature and time. These would be affected by the particle becoming either detached from the crystals surface or moving to another position. This position change could therefore cause the dip to get better, worse or disappear temporarily, with the possibility to resurface later. At Q-Tech, we have the capabilities to design around potential activity dips and screen them out in our temperature test procedures as part of a high-reliability approach to design and construction.

## III. Manufacturing and Screening

Q-Tech's approach to oscillator aging results in a precision manufacturing approach and substantial testing and performance monitoring unmatched in the commercial space. To achieve the accuracy and precision required of our designs, Q-Tech leans on design heritage and expertise in electrical engineering coupled with in-house manufacturing. All of Q-Tech's oscillators are manufactured on-site in the United States under strict clean room contamination controls. After oscillator assembly is completed, Q-Tech is able to perform almost all testing in-house per MIL-PRF-38534 and MIL-PRF-55310 for Class B/H and Class S/K. Testing becomes extremely important for applications where the aging characteristics of the oscillator are crucial. Q-Tech tests all devices over the entire operating temperature range using a sweep method with single degree increments. A sample list of testing can be found below:

**Tests performed on 100% of all Q-Tech Class B oscillators:**

**GROUP A**

- **ELECTRICAL TEST:** Supply Voltage, Input Current, Output Waveform, Output Voltage Power, Rise and Fall Times, Duty Cycle, and Start-Up Time (as required)
- **FREQUENCY-TEMPERATURE STABILITY:** Initial Accuracy at Reference Temperature, Initial Frequency-Temperature Accuracy and Frequency-Temperature Tolerance
- **FREQUENCY-VOLTAGE TOLERANCE:** Output Frequency is measured when oscillator supply voltage is adjusted to its specified nominal value up to its maximum / minimum values
- **OVERVOLTAGE SURVIVABILITY:** Overvoltage of 20% above the maximum specified
- **VISUAL AND MECHANICAL:** Verify Material, Design, Construction, Workmanship, Physical Dimensions, and Marking per MIL-PRF-55310
- **SOLDERABILITY TEST** per MIL-STD-202, Method 208
- **GROUP B**
- **AGING TEST:** Oscillator is energized in oven for a continuous period of 30 days at 70ºC ±3ºC. The Output frequency is measured within an interval of 72 hours maximum per MIL-PRF-55310

**Tests performed on a sample basis on all Q-Tech Class B oscillator types:**
**GROUP C**

- **VIBRATION** (Sinusoidal) non-operating per MIL-STD-202, Method 204, per MIL-PRF-55310
- **SHOCK** (Specified Pulse) per MIL-STD-202, Method 213 (non-operating)
- **THERMAL SHOCK** per MIL-STD-202, Method 107
- **AMBIENT PRESSURE** (operating and non-operating) per MIL-STD-202, Method 105, and MIL-PRF-55310
- **STORAGE TEMPERATURE** per MIL-PRF-55310
- **RESISTANCE TO SOLDERING HEAT** per MIL-STD-202, Method 210
- **MOISTURE RESISTANCE** per MIL-STD-202, Method 106
- **SALT SPRAY** per MIL-STD-883, Method 1009
- **TERMINAL STRENGTH** per MIL-STD-202, Method 211
- **RESISTANCE TO SOLVENTS** per MIL-STD-202, Method 215

## IV. Quality Differences & Heritage

In addition to a strong high-reliability approach to design and manufacturing of each oscillator, a strong Quality Management System is an important mitigation of many potential risks that occur with commercial parts. Q-Tech has certifications to both AS9100C and ISO 9001:2008, and complies with the tenants of a process driven and configuration controlled approach to quality. Q-Tech maintains complete traceability of all components and materials used in each individual oscillator with a dedicated incoming inspection team providing surveillance over all parts. Operators, inspectors and assemblers are trained to controlled procedures with full revision and record control, and Q-Tech regularly performs surveillance audits in accordance with AS9100 requirements. In addition, Q-Tech employees a strong counterfeit prevention plan by exclusively purchasing components directly from the manufacturer or from authorized distributors. This, coupled with the incoming inspection of all lots, provides customers the assurance that each part produced by Q-Tech meets the same stringent requirements for reliability as parts purchased in the past or future, allowing Q-Tech to proudly offer an anti-obsolesce plan second to none in the oscillator industry. In contrast, COTS oscillators are almost always built in Asia, usually China, and may come from a different factory each time they are procured, and even with a different internal electrical design. This is often true even when purchasing COTS parts from a USA company with a USA brand name.

## V. Conclusion

The nature of precision time-keeping for circuits and communications in the modern environment have helped shape the high-reliably crystal oscillator market over the last four decades of Q-Tech's business. As program requirements for reliability and performance become more and more stringent, the importance of crystal oscillator quality is more important today than it ever was in the past. Choosing a COTS part exposes an assembly to a variety of problems that are preventable with a high-reliability part offered by Q-Tech which provides engineers with the flexibility, performance, and dependability to achieve maximum results.