MEMS oscillators improve reliability and system performance in motor control applications

Reference timing devices such as resonators and oscillators are used in electronic motors control circuits to provide stable reference clocks. These timing devices have historically been based on quartz crystal technology – previously the only viable option. However, in recent years, silicon MEMS (micro-electro mechanical systems) timing devices have begun to rapidly replace quartz-based devices because they offer higher reliability and robustness against shock and vibration, better frequency stability over high temperature, programmable features, and very short lead-times.

MEMS oscillators are more resilient in hostile environments

Electronic motors are used in a wide variety of applications and are often subject to environmental stressors including very high temperatures and high levels of noise, vibration, or shock. For reliable operation, the reference timing devices must be extremely resilient. Silicon MEMS resonators are inherently more robust than quartz due to their design, smaller mass, and ultra-clean manufacturing process. Additionally, sophisticated analog design technology in the oscillator IC adds to the resiliency and performance of MEMS oscillators.

To meet motor control needs, SiTime MEMS oscillators offer the following features.

- High operating temperature – up to 125°C in MHz oscillators and 105°C in kHz oscillators
- Excellent frequency stability – over the full temperature range
- Resistant to vibration (70 *g* vibration) – up to 30 times better than quartz oscillators
- Resistant to shock (50,000 *g* shock) – up to 25 times better than quartz oscillators
- Low electromagnetic susceptibility (EMS) – 50 times better than quartz oscillators
- Low sensitivity to power supply noise (PSNS) – 10 times better than quartz oscillators
- Higher reliability at < 1 FIT rate (1 billion hours MTBF) – 30 times better than quartz oscillators

MEMS oscillators are more resistant to shock and vibration

Shock and vibrational forces can degrade performance and cause quartz oscillators to fail. Crystal resonators are cantilevered structures that can be very sensitive to mechanical forces and are prone to increased phase noise and jitter from vibration, and frequency spikes from shock.

In contrast, MEMS resonators experience less vibration because their mass is 1000 to 3000 lower than quartz resonators. This reduces the force applied to the resonator from vibration-induced acceleration. SiTime MEMS resonators are stiff structures that vibrate in-plane in a bulk mode, a geometry that is inherently vibration-resistant.

Vibration sensitivity or *g*-sensitivity, expressed in ppb/g, represents the change in frequency caused by an acceleration force. Figure 1 plots noise spurs induced by sinusoidal vibration in terms of ppb/g to demonstrate the low vibration sensitivity of SiTime MEMS oscillators at different frequencies compared to quartz-based oscillators.

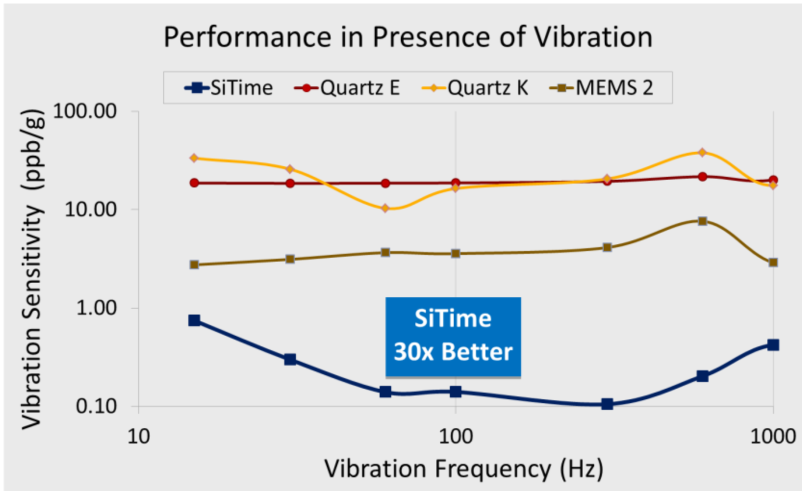

Figure 1: Oscillator sensitivity to sinusoidal vibration

Furthermore, SiTime oscillators deliver 0.1ppb/g performance in a tiny 1.5 x 0.8 mm package (kHz oscillators) and small 2.0 x 1.6 QFN and SOT23-5 packages (MHz oscillators). Quartz devices must use large specialized packaging to achieve low *g*-sensitivity.

To simulate the performance of devices in real-world conditions, SiTime has tested MEMS and quartz oscillators with similar specifications under various conditions including sinusoidal vibration (as shown above), random vibration, and shock impact. To read more about measurement results and testing methodologies, refer to SiTime technology papers Shock and Vibration Performance Comparison of MEMS and Quartz-based Oscillators and Resilience and Reliability of Silicon MEMS Oscillators.

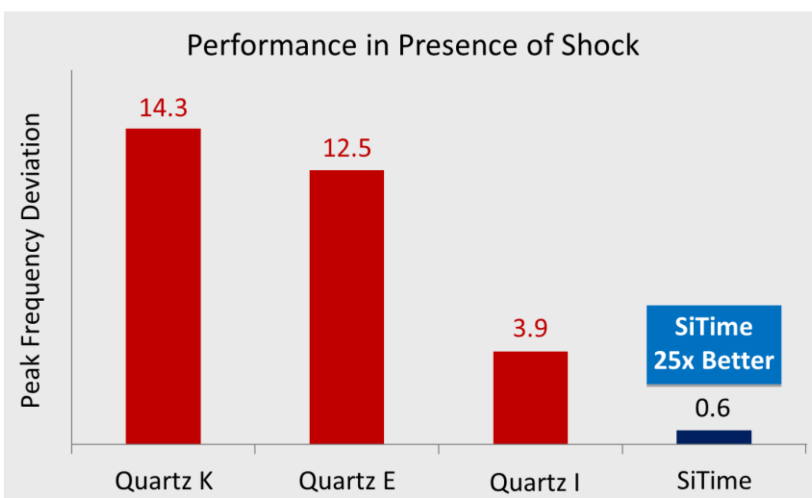

Figure 2: Oscillator sensitivity to 500-g shock

Figure 2 shows the results of mechanical shock testing on different oscillators. Some quartz devices are especially sensitive to shock and exhibit significant frequency deviation.

MEMS oscillators are highly immune to electromagnetic energy and power supply noise

Electromagnetic susceptibility (EMS) is an important consideration in motor control design because electromagnetic (EM) energy can significantly impact oscillator performance. The switching action of electric motors can be a major source of transient disturbance (electromagnetic pulse). Power supplies and other electronic components can also emit EM energy that creates noise spurs and degrades clock signals.

MEMS oscillators, with well-designed analog circuits, are less sensitive to EM noise compared to quartz oscillators. The metal covers on quartz oscillator packages do not guarantee protection from EM forces. EMS performance is more dependent on the intrinsic resonator impedance and coupling mechanism as well as the analog circuit design of the oscillator. Standard-based testing demonstrates that SiTime oscillators outperform other clock devices, as shown in Figure 3.

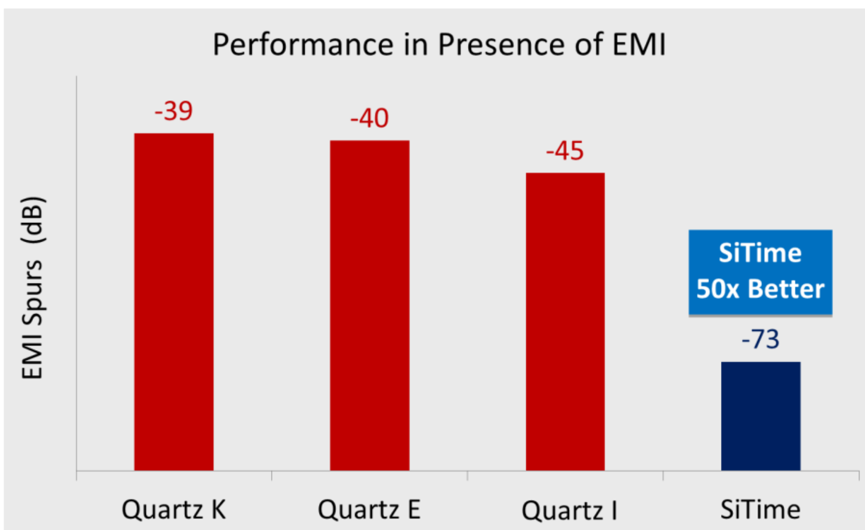

Figure 3: Average EM-induced phase noise spurs on various oscillators

Power supplies in the system can be a major source of noise that is detrimental to system performance and this noise is amplified when the power supplies are switched on and off. Much of this noise can be filtered out by passive filters and decoupling capacitors. However, some noise remains and board issues such as ground bounce, negatively affects clock jitter. Power supply noise sensitivity (PSNS) is a parameter used in the design of analog circuits and it provides an indication of how robust a circuit is to noise from the power supply. Test results show that the PSNS of SiTime oscillators is much better than quartz devices, including quartz surface acoustic wave (SAW) oscillators that are designed to meet high frequency, low jitter requirements.

Figure 4 shows integrated phase jitter as a function of power supply switching noise frequency for 50 mV of peak-peak power supply noise, comparing results for quartz oscillators with a SiTime MEMS oscillator. As the plot indicates, the jitter of the SiTime MEMS oscillator is lower at nearly all noise frequencies. Unlike typical quartz oscillator manufacturers, SiTime designs the analog circuits for its MEMS oscillators, using advanced analog design techniques including PSNS circuitry to protect the oscillator from power supply-induced jitter.

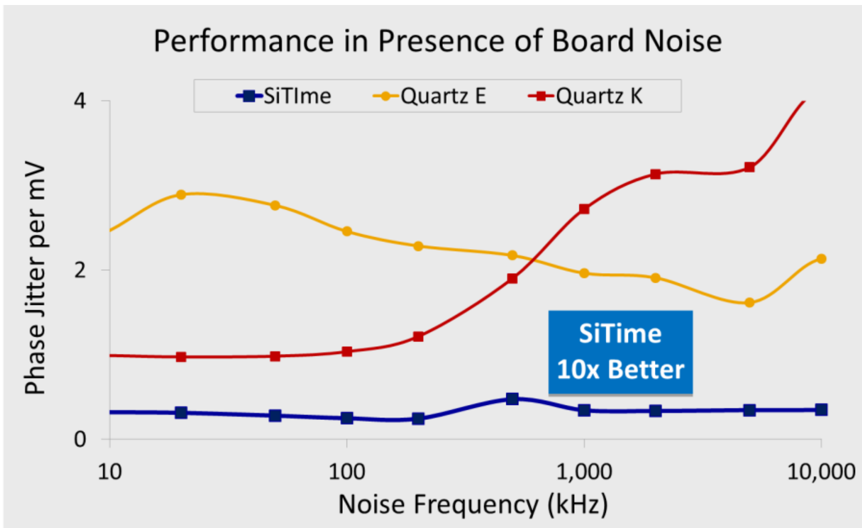

Figure 4: Phase jitter in the presence of 50 mV peak-to-peak power supply noise for SiTime MEMS oscillator (lower line) and quartz oscillators as a function of power supply switching noise frequency

For more details on measurement results and testing methodology of EM-induced phase noise and power supply induced phase jitter, see SiTime technology paper Electromagnetic Susceptibility Comparison of MEMS and Quartz-based Oscillators.

MEMS oscillators are programmable

SiTime timing solutions are designed with a programmable architecture. A wide range of specifications are factory programmed to order and delivered within very short lead-times giving designers an extremely wide range of configurable options. For example, output frequency is programmed within a wide operating range with six decimals of accuracy. SiTime devices have special features such as programmable drive strength to control rise and fall time. This feature allows designers to change the output edge rate which can reduce EMI within the system.

In addition, SiTime MHz oscillators can be instantly programmed by system designers in their own lab using field programmable oscillators and the Time Machine II™ oscillator programmer. Since SiTime oscillators are available in industry-standard footprints, they are drop-in replacements for quartz devices and can easily replace quartz devices as designers develop prototypes.

Table 1: Wide range of configurable features in SiTime oscillators

Feature	Configuration Options with SiTime Oscillators
Customizable Frequency	From 1 Hz to 725 MHz with 6 decimals of accuracy
Frequency Stability	As good as ±3 ppm in kHz oscillators and ±0.5 ppm in MHz TCXOs
Temperature Range	High Temp (-55 to +125°C and -40 to +125°C), Extended Industrial (-40 to +105°C), Industrial (-40 to +85°C) or Ext. Commercial (-20 to +70°C)
Supply Voltage	kHz oscillators: 1.2 to 3.3V; MHz oscillators: 1.8V (CMOS), 2.5V, 2.8V or 3.3V (customizable between 2.5 to 3.3V)
Output Signal	LVCMOS, LVPECL, LVDS, CML, HCSL, NanoDrive™
Special Functions	Spread spectrum, Digital pull, In-system programmability via 1^2C/SPI
Pull Range	Up to ±3200 ppm
Drive Strength	Programmable low for best EMI; High for driving multiple loads

MEMS oscillator package styles and sizes

In addition to the rich feature set shown above, SiTime timing products are available in a range of packages to suite application requirements.

- **Drop-in replacement for quartz:** SiTime industry-standard QFN plastic packages (2012, 2016, 2520, 3225, 5032, and 7050) are pin compatible with quartz devices. Because these packages fit common quartz oscillator PCB pad layouts, MEMS oscillators can easily replace quartz devices with any board changes.
- **Highest board-level reliability:** SiTime oscillators are available in SOT23-5 packages for applications that require the highest solder joint reliability.
- **Ultra-small:** 32 kHz oscillators are available in 2012 QFN package and ultra-small 1508 (1.5 x 0.8 x 0.6H mm) CSP (chip-scale package).

Summary

Industrial motor control applications are often subjected to a variety of operating environments from extreme temperatures to high levels of vibration, shock, and power supply induced noise. In the presence of these harsh conditions, a reference oscillator must conform to its specifications and not fail due to mechanical or electrical damage. If the oscillator is not resilient, it has the potential to cause catastrophic failure. MEMS oscillators overcome the weaknesses of traditional quartz oscillators and offer a much more robust and reliable timing solution for motor controlled equipment.

SiTime Corporation | 5451 Patrick Henry Drive, Santa Clara, CA – USA | Phone: +1-408-328-4400