Ultra-robust MEMS timing solutions improve performance and reliability in meter applications

New technologies that support the collection and transfer of information have become more critical as the monitoring of resources (typically energy, gas, or oil) has rapidly expanded. Data must be reliably and securely captured and transferred, and this can be challenging considering the varied locations and environmental conditions surrounding installed metering hardware. For example, smart meters that measure, collect, and analyze energy usage, or meters that measure seismic information provide critical data—and these meters must provide reliable information over long periods of time.

Silicon MEMS (micro-electro mechanical systems) timing is one of the innovative technologies improving the reliability and performance of metering equipment. This equipment requires robust timing components with stable frequencies to provide accurate timekeeping and synchronization with the clock source. Because of the intrinsic robustness and resiliency of MEMS-based components, this technology is rapidly replacing legacy quartz components. In addition to greater reliability, MEMS timing provides flexible and specialized features that improve system performance, along with very short lead-times.

MEMS oscillators offer higher reliability, resiliency, and more features

Meters are used in a variety of applications and environments, and often operate under harsh conditions with high temperatures and/or high-levels of noise, vibration, or shock. For reliable operation over many years, the timing components must be extremely resilient. Compared to quartz resonators, MEMS are inherently more robust due to their design, smaller mass, and ultra-clean manufacturing process. Unlike quartz suppliers, SiTime has in-house expertise to develop advanced MEMS resonators and oscillator ICs that employ techniques to increase resiliency and performance. These capabilities result in oscillators with extremely high reliability. SiTime is the only timing company to offer a lifetime warranty on all production products.

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
- Custom frequencies – from 1 Hz to 725 MHz with 6 decimals of accuracy
- Higher reliability at < 1 FIT rate (1 billion hours MTBF) – 30 times better than quartz oscillators
- 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
- Low power features – ideal for battery operated meters/controllers

MEMS oscillators are more resistant to shock and vibration

Meters are often deployed in harsh and/or remote locations. They can be exposed to hazards such as shock and vibration forces which can degrade quartz oscillator performance and cause them to fail. Quartz 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.

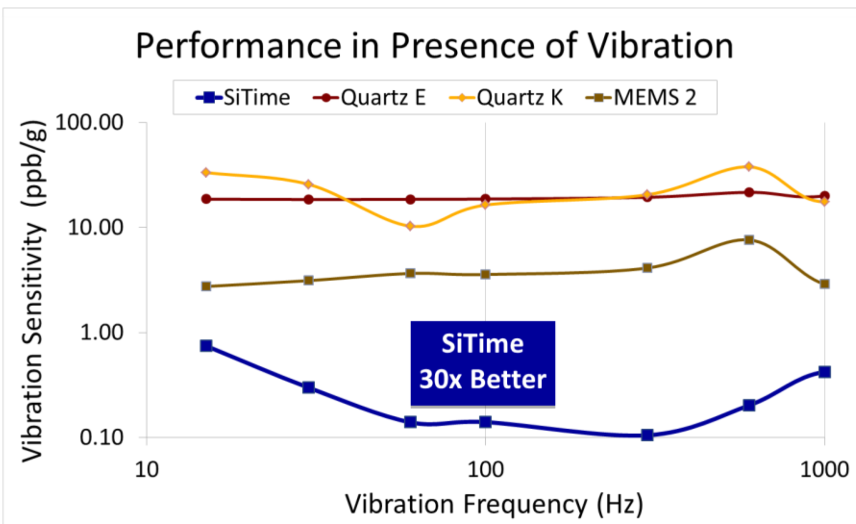

Figure 1: Oscillator sensitivity to sinusoidal vibration

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.

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

Electromagnetic susceptibility (EMS) is an important consideration in meting applications because electromagnetic (EM) energy can significantly impact oscillator performance. 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 2.

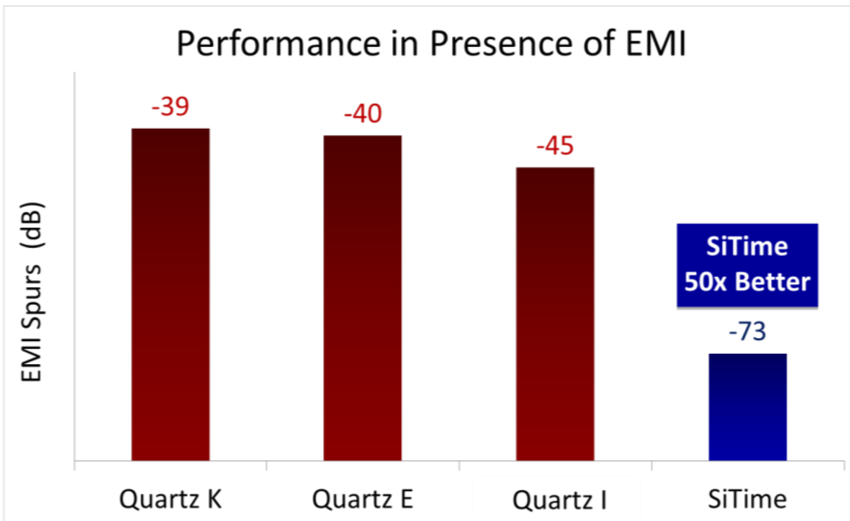

Figure 2: Average EM-induced phase noise spurs on various oscillators

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 3 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.

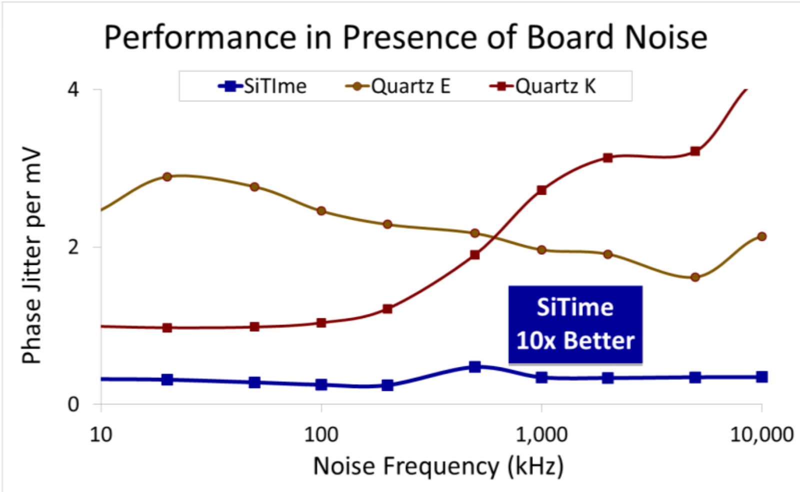

Figure 3: Phase jitter in the presence of 50 mV peak-to-peak power supply noise for SiTime MEMS oscillator (lower line) and quartz oscillators as a function of power supply switching noise frequency

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 demonstrate better frequency stability over temperature

Metering equipment operates in varied environments and often within wide temperature ranges. MEMS oscillators are ideal for high temp environments since they provide a highly stable clock signal over temperature. For example, SiTime MEMS-based 32 kHz timekeeping devices which are used in low-power meter applications employ TempFlat MEMS™ technology that enables excellent frequency over the full temperature range.

Figure 4a: SiT1532 32 kHz Oscillator stability

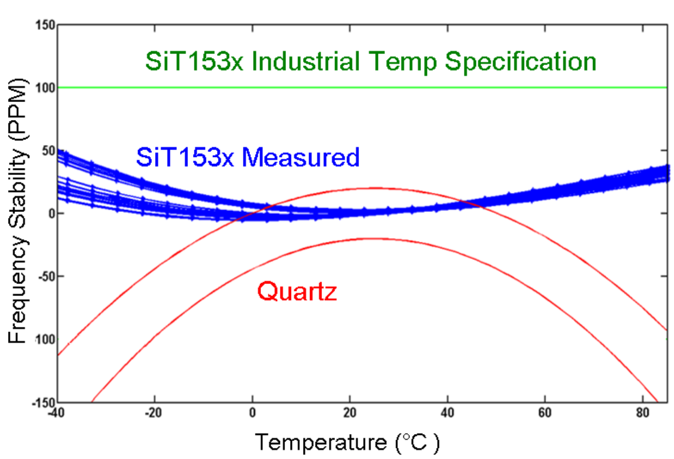

Figure 4b: SiT1552 32 kHz TCXO ±5 ppm stability

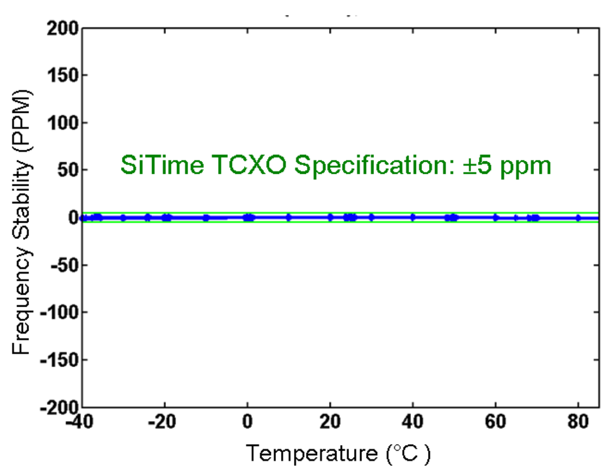

Figure 4a shows the frequency stability vs. temperature characteristic curves of SiT1532 MEMS-based 32.768-kHz oscillators. SiT1532 spec limits for industrial temperature (< 100 PPM p-p) are shown in blue dash lines. Typical spec limits of 32.768 kHz oscillators using quartz-based, tuning fork type XTAL are shown in red curves. Figure 4b shows the frequency stability of a SiT1552 MEMS-based TCXO (temperature compensated oscillator) which is factory calibrated (trimmed) over multiple frequency points to guarantee extremely tight stability over temperature.

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 can be specified 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.

MEMS oscillators for low -power, battery-operated meters

Gas and water meters are typically battery powered and often employ a wireless communications sub-system. In these applications low power consumption is essential. Underground water meters, for example, are designed to operate for 20 years or more without service and therefore require ultra-long battery life. The timing component can have a significant impact on system power and battery life.

SiTime's low-frequency, low-power oscillators are ideal for optimizing power. These devices have power consumption as low as <1 µA and unique features that enable further power savings. For example, SiTime kHz oscillators have NanoDrive™, a reduced swing output voltage. This feature allows the system designers to select an output voltage to match the downstream PMIC or MCU input and minimize load current. Additionally, the availability of customized low-frequencies enables meter designers to select the optimal frequency for best performance and power. Meter designers are no longer restricted to a limited number of output frequencies and can use a made-to-order frequency to draw less power.

The stability of MEMS kHz oscillators, as good as ±3 ppm, also lengthens battery live. Improved stability reduces system power with fewer network timekeeping updates required. Subsystems within the meter can stay in sleep mode for longer periods of time and still stay in synch with the central hub.

Lastly, in contract to quartz crystals, SiTime MEMS kHz oscillators can drive multiple loads. This not only lowers BOM (bill of materials), it can lower total system power.

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MEMS oscillators for metering applications

MEMS-based kHz Low Power Oscillators and TCXOs

Product Family	Frequency	Package Options (mm x mm)	Stability (ppm)	Temp. Range (°C)	Voltage (V)
SiT1532/33/34 Oscillators for XTAL replacement*	1 Hz to 32.768 kHz	1.5 x 0.8 CSP, 2.0 x 1.2 QFN	10 (room), 75 to 100 (over temp.)	-40 to +85, -10 to +70	1.2 to 3.63
SiT1630 High temp oscillators	32.768 kHz	2.0 x 1.2 QFN, SOT23-5	10 (room), 75 to 100 (over temp.)	-40 to +105, -40 to +85, -10 to +70	1.5 to 3.63
SiT1552 TCXOs*	32.768 kHz	1.5 x 0.8 CSP	±5, ±10, ±20 (over temp.)	-40 to +85, -0 to +70	1.5 to 3.63
SiT1566 TCXOs	32.768 kHz	1.5 x 0.8 CSP	±3, ±5 over temp.)	-40 to +85, -20 to +70	1.62 to 3.63
SiT1576 TCXOs	1 Hz to 2.5 MHz (programmable)	1.5 x 0.8 CSP	±5, ±10, ±20 (over temp.)	-40 to +85, -20 to +70	1.62 to 3.63

MEMS Low Power LVCMOS Oscillators

<table>
<tr><th>Product Family</th><th>Frequency</th><th>Package Options (mm x mm)</th><th>Stability (ppm)</th><th>Temp. Range (°C)</th><th>Voltage (V)</th></tr>
<tr><td>SiT1602 Oscillators**</td><td>52 standard freq.</td><td rowspan="3">2.0x1.6, 2.5x2.0, 3.2x2.5, 5.0x3.2, 7.0x5.0 in QFN
(See SiT2001/2 and SiT2018/19 for SOT23-5 package)</td><td rowspan="3">±20, ±25, ±50</td><td rowspan="2">-40 to +85, -20 to +70</td><td rowspan="4">1.8, 2.5 to 3.3</td></tr>
<tr><td>SiT8008/9 Oscillators**</td><td>1 to 137 MHz (programmable)</td></tr>
<tr><td>SiT8918/19 High-temperature oscillators**</td><td>1 to 137 MHz (programmable)</td><td>-40 to +105, -40 to +125</td></tr>
<tr><td>SiT8208/9 Low phase jitter oscillators**</td><td>1 to 220 MHz (programmable)</td><td>2.5x2.0, 3.2x2.5, 5.0x3.2, 7.0x5.0 in QFN</td><td>±10, ±20, ±25, ±50</td><td>-40 to +85, -20 to +70</td></tr>
</table>

*NanoDrive reduced swing output available; **Field programmable with the SiTime Time Machine II oscillator programmer

MEMS oscillator package styles and sizes

As shown in the tables on the previous page, SiTime timing products are available with a range of options including various package options 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

Meters are often subjected to a variety of operating environments from extreme temperatures to high levels of vibration and power supply induced noise. Reference timing devices must conform to their specifications in the presence of harsh conditions and over very long periods of time. Silicon MEMS oscillators are much more robust than quartz oscillators. Test data demonstrate that SiTime MEMS oscillators outperform quartz-based oscillators when subjected to vibration, mechanical shock, and EMI.

In addition, SiTime oscillators offer more features and supply chain advantages. Low power MEMS oscillators have a number of power saving features, from low supply current to programmable output voltage and output frequency. The programmability of SiTime timing products provides system performance optimization, design flexibility, and fast lead times – a combination that quartz manufacturers can't provide. SiTime oscillators are an excellent choice for applications such as smart meters and battery-powered controllers.

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