Ultra Robust MEMS Timing Solutions Improve Performance and Reliability of Smart Meters

As the power grid and digital meters become smarter, new technologies that support the collection and transfer of accurate information has become more critical. 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. Smart meters that measure, collect and analyze energy usage, provide a critical communication path, and these meters must provide reliable data over long periods of time.

Silicon MEMS (micro-electro mechanical systems) timing is one of the new 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 enhanced reliability, MEMS timing provides flexible and specialized features that improve system performance, along with very short lead-times and low cost.

MEMS oscillators are more resilient and reliable

Smart meters are used in a variety of environments and often operate under harsh conditions with very high temperatures and/or high-levels of noise, vibration or shock. For reliable operation over many years, the timing components in meters must be extremely resilient. MEMS resonators have an advantage over quartz since they are inherently more robust due to their design and smaller size (mass). Unlike quartz suppliers, SiTime has in-house analog design experience to develop oscillator ICs that employ several techniques that increase resiliency and performance. With the combination of ultra robust MEMS resonators and advanced analog expertise, SiTime has developed extremely high quality products and had zero MEMS field failures over more than six years of shipments. 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
- Higher reliability at < 1 FIT rate (1140 million 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) – 54 times better than quartz oscillators
- Low sensitivity to power supply noise (PSNS) – 3 times better than quartz SAW oscillators

MEMS oscillators are resistant to shock and vibration

Shock and vibration forces can degrade quartz oscillator performance and cause them to fail. Quartz crystal resonators are cantilevered structures that can be very sensitive and are prone to damage, resulting in increased phase noise and jitter from vibration, and frequency spikes from shock.

In contrast, MEMS resonators experience less vibration because they have lower mass which 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. Additionally, SiTime's resonator structures are self-compensating. When mechanical forces cause the resonator to move in a given direction, a mechanism within the device causes a frequency shift in the opposite direction to cause a cancelling effect and minimize frequency deviation.

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 below), random vibration and shock impact using standardized testing methodologies. To read more about testing methodologies and measurement results, refer to SiTime application note *Shock and Vibration Performance Comparison of MEMS and Quartz-based Oscillators.*

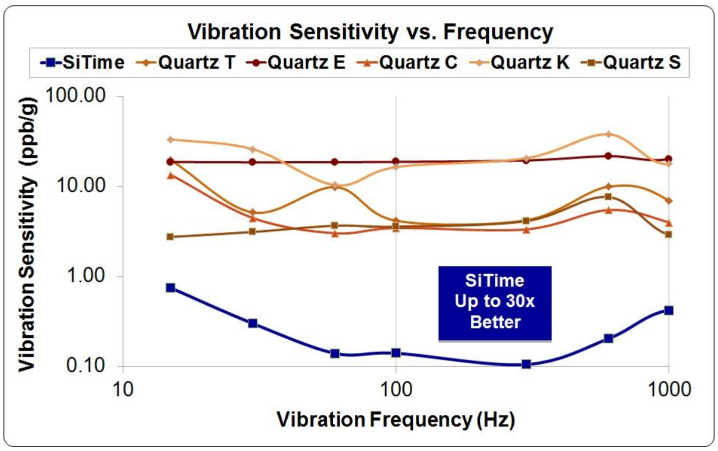

Figure 1: Oscillator sensitivity to sinusoidal vibration

Vibrations 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 (lower plots/line) at different frequencies compared to quartz-based 3rd overtone and SAW oscillators (top and middle plots/lines).

Quartz 0.4 ppb/*g* Device
9 x 14 x 6.2 mm

SiTime 0.1 ppb/*g* Device
2.0 x 1.6 x 0.75 mm

Figure 2: Quartz vs. SiTime low-G sensitivity parts

SiTime's high-temperature MEMS devices deliver 0.1ppb/g performance in a small plastic 2016 SMD or SOT23 package. Quartz devices must use large specialized packaging to achieve low *g*-sensitive as shown in Figure 2.

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

Electromagnetic susceptibility (EMS) is an important consideration in industrial applications because 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 more immune to EM noise. The metal covers on quartz oscillator packages do not always provide adequate protection from EM forces or guarantee good EMS performance. 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.

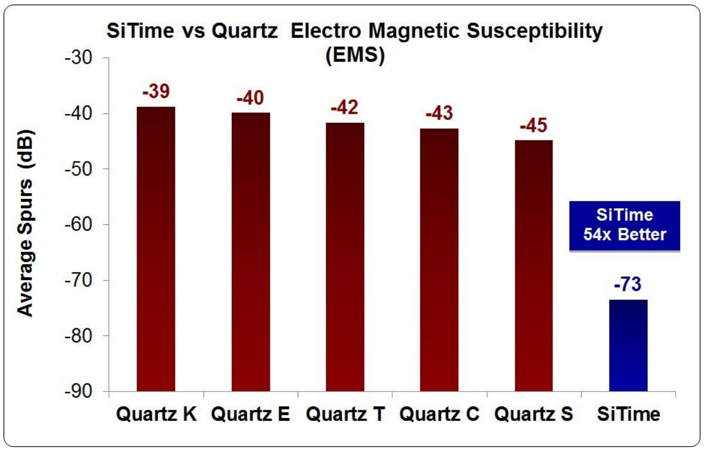

Figure 3: Average EM-induced phase noise spurs on various oscillators

In addition to external EMI, power supplies in the system can be a major source of noise that is detrimental to system performance. Power supply noise is amplified when the power supply is 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 SiTime's PSNS 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 a SAW oscillator with a SiTime MEMS oscillator. As the plot indicates, SiTime's MEMS oscillator jitter is lower at nearly all noise frequencies. Unlike typical quartz oscillator companies, SiTime designs the analog circuits for its MEMS oscillators. SiTime devices use advanced analog design techniques including PSNS circuitry to protect the oscillator from power supply-induced jitter.

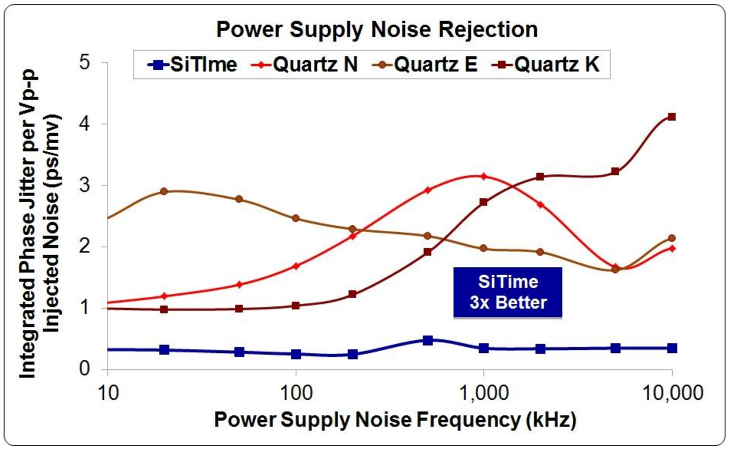

Figure 4: Phase jitter in the presence of 50 mV peak-to-peak power supply noise for SiTime MEMS (lower line) and SAW oscillator (top line) as a function of power supply switching noise frequency

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

MEMS oscillators demonstrate better frequency stability over temperature

Industrial equipment operates in varied environments and often within wide temperature ranges. MEMS oscillators provide a highly stable clock signal over temperature. For example, SiTime's MEMS-based 32 kHz timekeeping devices, which employ TempFlat™ technology, demonstrate excellent frequency stability at room temperature and over the full temperature range.

Figure 5a: SiT1532 32 kHz Oscillator (100 ppm)

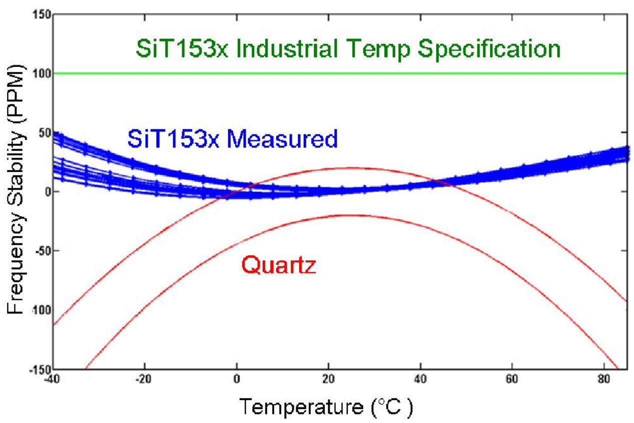

Figure 5b: SiT1552 32 kHz TCXO (±5 ppm)

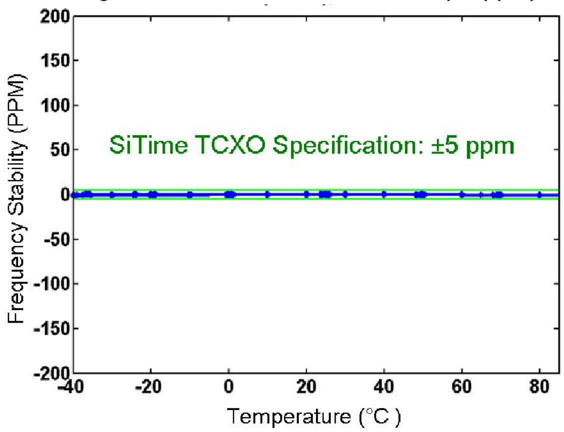

Figure 5a shows the frequency stability vs. temperature characteristic curves of SiT1532 MEMS-based 32.768 kHz oscillators. SiT1532 spec limits for industrial temperature (< 100 PPM p-p) are shown in blue dash lines. Typical spec limits of 32.768 kHz oscillators using quartz-based, tuning fork type XTAL are also shown in red curves. Figure 5b shows the frequency stability of SiT1552 MEMS-based temperature compensated oscillator which is factory calibrated (trimmed) over multiple frequency points to guarantee extremely tight stability over temperature.

MEMS-based 32 kHz Oscillators and 32 kHz TCXOs

Product Family	Frequency Range (kHz)	Package Options (mm x mm)	Freq. Stability (ppm)	Temp. Range (ºC)	Voltage (V)
SiT1532/3/4 Low power oscillators for XTAL replacement	1 to 32.768 (programmable)	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 Low power, high temp oscillators	32.768	2.0 x 1.2 QFN	10 (room), 75 to 100 (over temp.)	-40 to +105, -40 to +85, -10 to +70	1.2 to 3.63
SiT1552 Low power TCXO	32.768	1.5 x 0.8 CSP, 2.0 x 1.2 QFN	±5, ±10, ±20 (over temp.)	-40 to +85, -0 to +70	1.5 to 3.63

MEMS-based Low Power, High Performance, Low-Vibration Sensitivity (0.1 ppb/g) Oscillators

Product Family	Frequency Range (MHz)	Package Options (mm x mm)	Freq. Stability (ppm)	Temp. Range (ºC)	Voltage (V)
SiT1602 Low power LVCMOS oscillators*	50 standard freq. from 3.57 to 77.76	2.0x1.6, 2.5x2.0, 3.2x2.5, 5.0x3.2, 7.0x5.0 in QFN	±20, ±25, ±50	-40 to +85, -20 to +70	1.8, 2.5 to 3.3
SiT8008/9 Low power LVCMOS oscillators*	1 to 137 (programmable)				
SiT8208/9 Low phase jitter LVCMOS oscillators*	1 to 220 (programmable)	2.5x2.0, 3.2x2.5, 5.0x3.2, 7.0x5.0 in QFN			

MEMS-based High Temperature, Low-Vibration Sensitivity (0.1 ppb/g) Oscillators

Product Family	Frequency Range (MHz)	Package Options (mm x mm)	Freq. Stability (PPM)	Temp. Range (ºC)	Voltage (V)
SiT1618 High performance, high temperature LVCMOS oscillators*	33 standard freq. from 7.3728 to 48	2.0x1.6, 2.5x2.0, 3.2x2.5, 5.0x3.2, 7.0x5.0 in QFN	±20, ±25, ±30, ±50	-40 to +105, -40 to +125	1.8, 2.5 to 3.3
SiT8918/19 High performance, high temperature LVCMOS oscillators*	1 to 137 (programmable)				

MEMS-based Clock Generators with Integrated MEMS Resonator

Product Family	Frequency Range (MHz)	Package Size (mm x mm)	Freq. Stability (ppm)	Temp. Range (ºC)	Voltage (V)
SiT9201 1x LVCMOS	1 to 110 (programmable)	2.9 x 2.8 in SOT23-5	±20, ±25, ±50	-40 to +85, -20 to +70	1.8, 2.5 to 3.3
SiT2002 1x LVCMOS	115 to 137 (programmable)				
SiT2018 1x LVCMOS, low-vibration sensitivity (0.1ppb/g)	1 to 110 (programmable)			-40 to +105, -40 to +125	
SiT2019 1x LVCMOS, low-vibration sensitivity (0.1ppb/g)	115 to 137 (programmable)				

*Field programmable samples are available with the SiTime Time Machine II oscillator programmer

MEMS timing package styles and sizes

As shown in the tables on page 5, SiTime timing products are available with a range of options including package styles and sizes to suite application requirements.

- **Drop-in replacement for quartz:** SiTime's 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 layout, board design changes are not required if MEMS oscillators are used as a replacement for quartz devices.
- **Highest board-level reliability:** SiTime's MHz products are available in SOT23-5 packages for applications that require higher solder joint reliability. These leaded packages also offer the benefits of lower cost optical-only (no X-ray) solder joint inspection.
- **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).

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 oscillator features can be programmed by system designers in their own lab using field programmable oscillators and the Time Machine II™, a low-cost MEMS oscillator programmer. This programmer can quickly configure oscillators and create instant samples. Since SiTime oscillators are footprint compatible with quartz packages, they can replace quartz devices as designers are developing prototypes.

Summary

Smart 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's 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. The programmability of SiTime timing products provides design flexibility and fast lead times – a combination that quartz manufacturers cannot provide. SiTime oscillators are an excellent choice for applications such as smart meters.

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