Increase Automotive Reliability and Performance with High-temperature, Ultra Robust MEMS Oscillators

Reference timing components such as resonators, oscillators and clock generators are used in automotive systems from safety critical applications such as collision avoidance systems, to powertrain control, central body control and infotainment systems. As the automotive industry continues to add electronic-based features as standard equipment, the need for reliable automotive-grade timing solutions increases. For several decades, timing components were based on quartz crystal technology—previously the only viable option that offered high stability and performance. However MEMS (micro-electro mechanical systems) timing solutions are rapidly replacing quartz-based components by offering a more reliable high-quality cost-effective alternative.

Today, the highest quality AEC-Q100 compliant timing devices are based on MEMS technology which provides a combination of wider frequency and temperature ranges, improved frequency stability, higher shock and vibration resistance, and smaller size.

Key features of automotive grade MEMS timing components:

- AEC-Q100 compliant with extended temperature range -55 to +125°C
- Widest frequency range from 1 MHz to 137 MHz
- Tightest frequency stability at ±20 ppm
- Low vibration sensitivity (g-sensitivity) of 0.1 ppb/g
- Most robust with 50k*g* shock and 70*g* vibration resistance
- Best reliability at over 1000 million hours MTBF (<1 FIT)
- Smallest package in 2.0x1.6 mm DFN; highest reliability with SOT23-5

MEMS proven in automotive applications

MEMS sensors such as accelerometers and gyroscopes have been used in automotive applications as active safety devices for many years. Accelerometers detect abrupt changes in velocity causing airbags to inflate and save lives. Gyroscopes continuously monitor the direction the car is traveling. When a loss of steering control is detected, the stability control system autocorrects to invisibly improve handling and enhance driver and passenger safety. Automotive MEMS sensors can't fail, and after billions of miles on millions of cars, these devices have proven to function as designed.

Similarly, MEMS resonators are extremely reliable. MEMS timing solutions are completely fabricated in silicon, using standard semiconductor manufacturing practices. SiTime has instituted a 6-sigma design and development philosophy, resulting in products with unmatched quality and reliability. After shipping over 250 million units (as of January 2015), SiTime has had no MEMS field failure returns and less than 2 DPPM. As shown in Figure 1, mean time between failure (MTBF) for SiTime parts is over 1000 million hours (translating to FIT<1) which is 30 times better than typical quartz devices [1], [2].

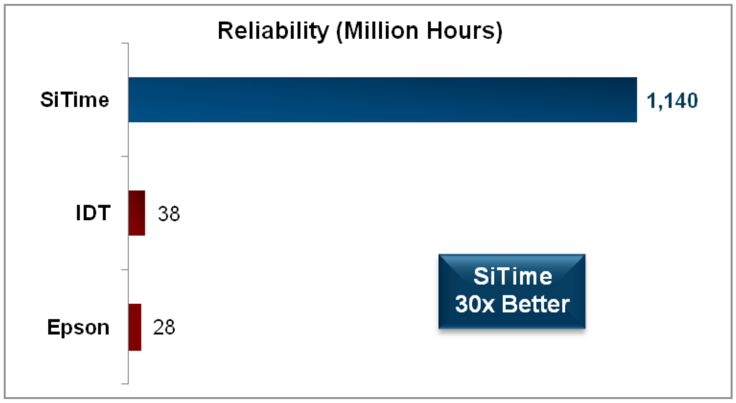
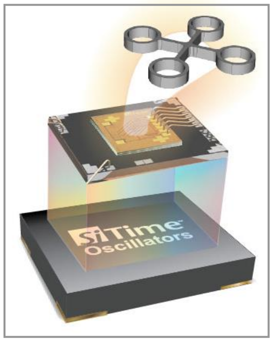


Figure 1: Oscillator reliability comparison of mean time between failure (million hours) [2]

Silicon MEMS manufacturing process

SiTime MEMS oscillators and clock generators are built completely within the IC supply chain using established CMOS foundries to fabricate resonators from silicon, a defect-free material. SiTime's MEMS First™ and EpiSeal™ manufacturing technologies anneal the resonator at 1100°C, thus the extreme temperatures present in automotive environments have no meaningful impact on the MEMS resonator [3]. This high-temperature process yields a resonator which is hermetically sealed without contaminants that could lead to mass-loading of the resonator and cause frequency drift. The resonator is fully encapsulated within a silicon chip, making it extremely resistant to damage from external sources. MEMS resonators can be handled like standard CMOS chips, and are packaged using standard IC packaging processes. Fabless manufacturing and standard packaging processes used for silicon MEMS resonators result in higher quality and reliability, as well as virtually unlimited capacity.

In contrast, quartz oscillator manufacturers don't leverage the IC industry supply chain. Quartz crystals are grown in single-purpose reactors delivering a material that, unlike silicon, has significant defects. The crystals have to be carefully cut to avoid regions of microscopic defects, and this process isn't perfect. Quartz oscillators have failure rates of 20 to 50 ppm, an order of magnitude higher than what is acceptable for ICs. In addition, the specialized packaging process and materials used with quartz components introduces added reliability issues.

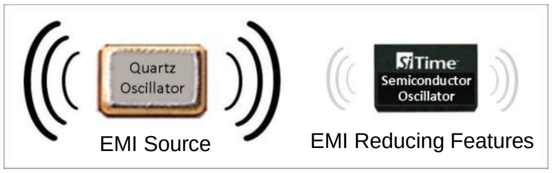


Packaging, features and performance

MEMS devices use a stacked die configuration. The MEMS resonator is mounted on an oscillator IC which drives and calibrates the resonator. Using plastic injection molding, the dies are packaged together in MSL-1 rated packages. MEMS oscillators are available in dual flat no-lead (DFN) packages as small as 2.0 x 1.6 mm. Compared to quartz packages, MEMS DFN packages have a lower profile, yet they fit common quartz oscillator PCB pad layout and are pin compatible to quartz devices for easy drop-in replacement without requiring any PCB design changes. For the lowest cost and increased board-level reliability, SiTime offers clock generators in an SOT23-5 package. This package style offers higher solder joint reliability and allows for low cost optical-only (no X-ray) solder joint inspection.

Unlike quartz oscillator companies, SiTime designs the analog oscillator IC for its silicon MEMS devices. This core competency allows SiTime to offer higher performance and more features with greater reliability compared to automotive quartz devices. SiTime's high-temperature automotive grade timing components operate over the widest temperature range (-55 to +155°C) while consuming half the power of quartz oscillators. SiTime's oscillators are two times tighter in frequency stability, 30 times more reliable, up to 25 times more robust against shock and up to 30 times more robust against vibration compared to quartz oscillators.

SiTime timing products have a programmable architecture that enables ultra-short lead times and allows designers to select from a range of specifications including any frequency within the operating range with six decimal places of accuracy. SiTime's devices operate at 1.8V and any voltage between 2.5 and 3.3V, irrespective of package size or frequency. Production quantities (in any configuration) are available within 3 to 5 weeks. Samples can be ordered, shipped and received within one week. Alternately, designers can program instant samples in their own lab by using the Time Machine II Programmer [4].



SiTime's programmable features can also be used to resolve unwanted noise that originates at the clock source and can be problematic in some systems. The increasing number of high-performance multi-media and wireless systems deployed in today's connected automobiles requires designers to pay special attention to electromagnetic energy present at frequencies to which these subsystems are sensitive. However, EMI is often observed at the final stages of qualification and this can cause rework late in the design cycle. To address this problem, SiTime components have programmable drive strength with SoftEdge™ rise/fall time control [5]. This feature allows the drive strength to be adjusted to reduce interference with other subsystems. Because SiTime DFN devices are a drop-in replacement for quartz oscillators, they can be used to pass EMI tests without any board changes or the use of expensive components or shielding.

The following tables list automotive AEC-Q100 MEMS families available from SiTime [6].

AEC-Q100 single-output clock generators in SOT23-5 package (higher board-level reliability, lower cost)

Product Family	Frequency Range (kHz)	AEC-Q100 Grade and Temp. Range (ºC)	Package Options (mm x mm)	Freq. Stability (ppm)	Voltage (V)
SiT2024	1 to 110	Grade 1(ext.): -55 to +125 Grade 1: -40 to +125 Grade 2: -40 to +105	2.9 x 2.8 (SOT23-5)	±25, ±30, ±50	1.8, 2.5 to 3.3
SiT2025	115.20 to 137				

AEC-Q100 oscillators in DFN packages (drop in replacement for quartz components, smallest size)

Product Family	Frequency Range (kHz)	AEC-Q100 Grade and Temp. Range (ºC)	Package Options (mm x mm)	Freq. Stability (ppm)	Voltage (V)
SiT8924	1 to 110	Grade 1(ext.): -55 to +125 Grade 1: -40 to +125 Grade 2: -40 to +105	2.0 x 1.6, 2.5 x 2.0, 3.2 x 2.5, 5.0 x 3.2, 7.0 x 5.0 (DFN)	±25, ±30, ±50	1.8, 2.5 to 3.3
SiT8925	115.20 to 137				

All SiTime components are lead-free, RoHS and REACH compliant. SiTime offers a lifetime warranty on all production oscillators and clock generators that guarantees products conform to specifications and are defect free [7].

Silicon MEMS are more robust

Vehicles are subject to high levels of mechanical shock and vibration forces that can degrade quartz oscillator performance and cause them to fail. While operating in these harsh environments, an oscillator must conform to its specifications. If the oscillator is not reliable, it has the potential to cause catastrophic failure. Crystal resonators are cantilevered structures that can be very sensitive, resulting in damage to the resonator, increased phase noise and jitter from vibration, and frequency spikes from shock.

In contrast, MEMS resonators experience less vibration because they have a mass that is 1000 to 3000 times less than quartz resonators. This reduces the force applied to the resonator from vibration-induced acceleration. SiTime's 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.

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

G-sensitivity, expressed in ppb/*g*, represents the change in frequency caused by an acceleration force. SiTime's automotive grade oscillators deliver 0.1ppb/*g* performance in a tiny 2016 plastic package. Quartz devices must use large, specialized packaging to achieve low G-sensitivity performance as shown in Figure 2.

To simulate the performance of devices in real-world conditions, SiTime has tested various oscillators with similar specifications under a variety of conditions including sinusoidal vibration, random vibration and shock impact using standardized testing methodologies. As shown in Figures 3 and 4, SiTime's MEMS-based oscillators demonstrate superior resistance to shock and vibration. To read more about testing methodology and measurement results, refer to SiTime application note *Shock and Vibration Performance Comparison of MEMS and Quartz-based Oscillators* [8].

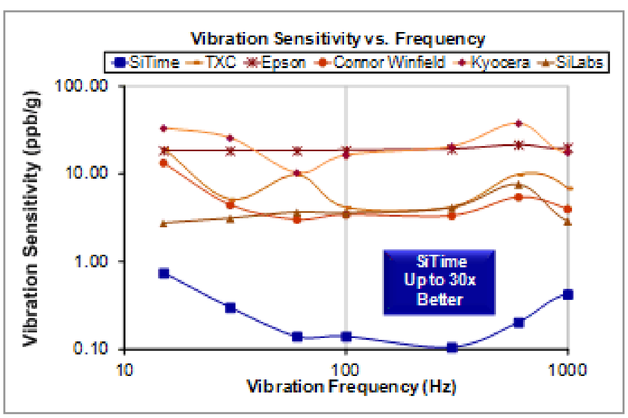


Figure 3: Oscillator sensitivity to sinusoidal vibration

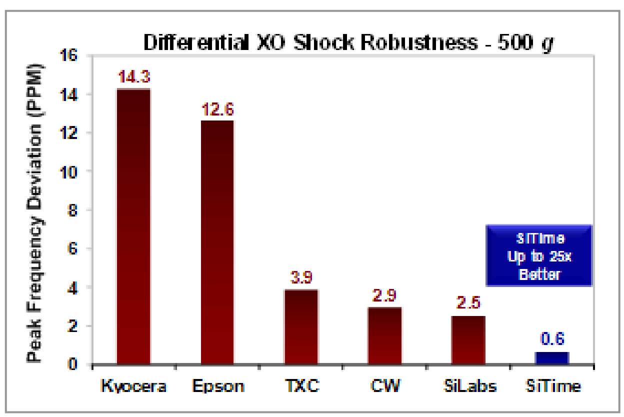


Figure 4: Oscillator sensitivity to shock

Conclusion

The growing use of in-vehicle electronic systems has increased the need for reliable automotive-grade reference timing components. Today's highest quality AEC-Q100 compliant timing solutions are based on MEMS timing technology, a technology that is inherently more robust than quartz technology. Silicon MEMS timing components are manufactured using exacting controls and standards developed by the IC industry. These processes and standards, combined with SiTime's proprietary MEMS and analog IC design result in ultra-high quality products at a reasonable cost.

MEMS-based timing solutions provide wider frequency and temperature ranges, tighter frequency stability, better packaging options, programmable features, short lead-time and low cost. Most important, SiTime's MEMS oscillators and clock generators have the capability to withstand high amounts of vibration and shock present in harsh environments while continuing to perform reliably and within specifications. This reliability along with the features and flexibility of SiTime products make them the ideal choice for tomorrow's feature-rich vehicles.

References

[1] SiTime Reliability Calculations Application Note:
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