Increase automotive reliability and performance with ultra-robust MEMS oscillators

As the automotive industry continues to add electronic-based features and systems, the need for reliable and robust automotive-grade timing solutions increases. Soon cars will need upwards of 70 timing devices. 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 becoming the technology of choice because they offer the highest performance and reliability. Additionally, these MEMS timing solutions have unique features that solve longstanding timing problems—features that are required for emerging automotive applications as the industry moves toward autonomous driving with complete connectivity and security.

Today, the most reliable timing devices are based on MEMS technology. Key features of automotive-grade MEMS timing components:

- AEC-Q100 compliant (Grade 1 to 4) with extended operating temperature range from -55 to +125°C
- Widest frequency range from 1 MHz to 725 MHz
- Best oscillator frequency stability at ±20 ppm, TCXO stability at ±0.1 ppm
- Most robust with 10,000*g* shock and 70*g* vibration, up to 30 times better than quartz oscillators
- Best reliability at over 1 billion hours MTBF (<1 FIT), 30 times better than quartz oscillators
- Best quality at <2 DDPM, 50 times better than quartz oscillators
- Smallest package in 2016 QFN, best board-level reliability with SOT23-5 and wettable flank packages
- Unique EMI reduction through programmable drive strength and spread spectrum
- Guaranteed cold startup at -55°C
- No activity dips or micro-jumps

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 and enable the stability control system to autocorrect, invisibly improving handling and safety. Automotive MEMS sensors can't fail, and after billions of miles in 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. This yields semiconductor-level quality which is much higher than quartz as shown in Figure 1. SiTime has instituted a 6-sigma design and development philosophy, and after shipping over one billion units, has had no MEMS field failure returns and maintains less than 2 DPPM. As shown in Figure 2, mean time between failure (MTBF) for SiTime parts is over 1 billion hours (translating to FIT<1), which is 30 times better than typical quartz devices [1], [2].

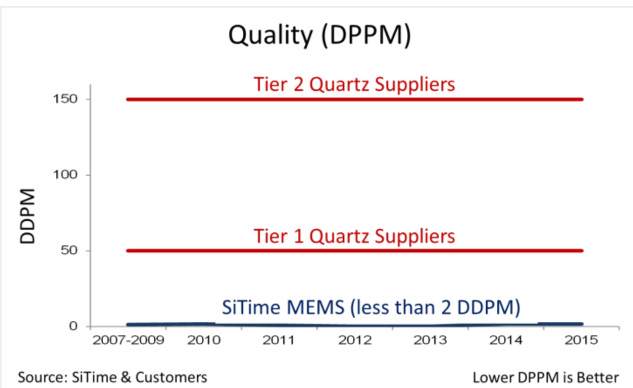


Figure 1: Oscillator quality comparison of defective parts per million (DPPM)

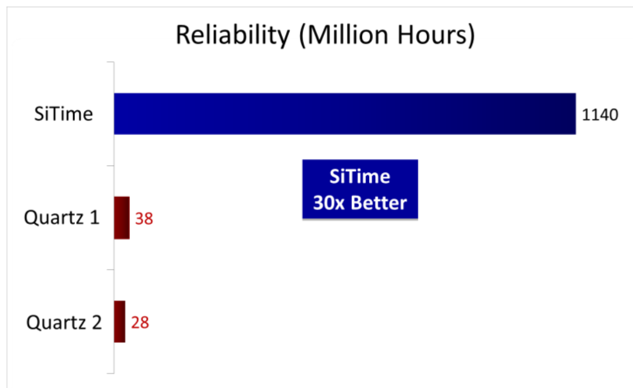


Figure 2: Oscillator reliability comparison of mean time between failure (MTBF in million hours) [2]

Silicon MEMS manufacturing process

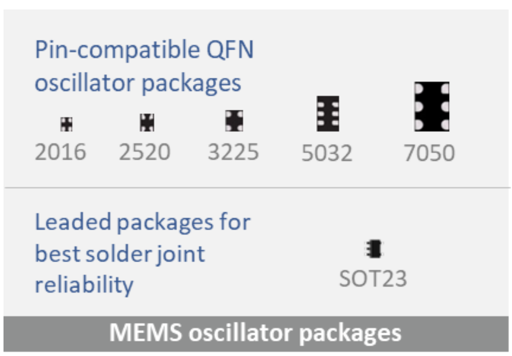
SiTime MEMS resonators are built from single-crystal silicon, a defect-free material that is 15 times stronger than titanium [3]. SiTime's resonators are produced using the patented MEMS First™ and EpiSeal™ manufacturing processes that anneal the resonator at 1100°C. Therefore, the extreme temperatures present in automotive environments have no meaningful impact on the MEMS resonator [4]. This high-temperature process produces a high-quality resonator which is hermetically sealed without contaminants. The resonator is fully encapsulated within a silicon die, 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. By using the MEMS First process, an ISO/TS 16949-certified semiconductor supply chain, and standard packaging processes, MEMS oscillators have higher quality and reliability, as well as virtually unlimited capacity.

In contrast, quartz oscillator manufacturers use a specialized 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 50 ppm to 150 ppm, an order of magnitude higher than what is acceptable for ICs. In addition, the specialized packaging process and materials (i.e., metals and epoxies) used with quartz components introduce added reliability issues.

MEMS packaging features for automoitve manufacturing

MEMS oscillators are assembled using 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 housed together in MSL-1 rated packages. MEMS oscillators are available in quad flat no-lead (QFN) packages as small as 2.0 x 1.6 mm. Compared to quartz packages, MEMS QFN 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.

For lower cost and increased board-level reliability, SiTime offers SOT23-5 packages. Because this package has leads, it has the highest solder joint reliability and allows for easier re-work if needed, which has proven to be especially beneficial in engine control units (ECU) and powertrain applications. Additionally, SOT23-5 packages allow for automatic visual inspection (AVI), an optical-only solder-joint inspection method that is lower-cost compared to X-ray or electrical testing. SiTime also offers wettable flank-plated QFN packages. This package has an area of the lead which is cut-out to accommodate additional solder and allow for easy AVI. These wettable flank terminations overcome the challenge of inspecting the solder joint integrity of QFN packages, offer the smallest footprint, and are a drop-in replacement for quartz oscillators.



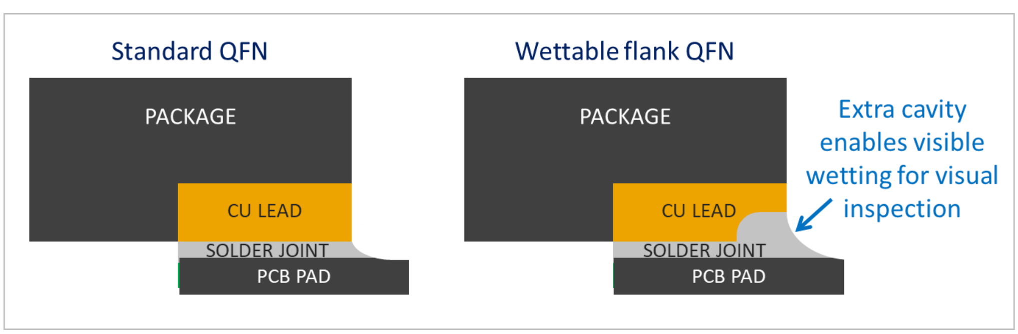
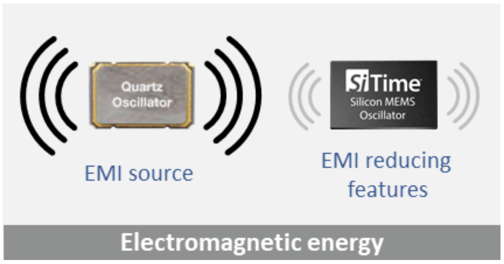


Figure 3: SiTime offer wettable flank-pated QFN packages for automated visual inspection

MEMS oscillators reduce unwanted noise



The increasing number of high-performance infotainment and wireless systems deployed in today's connected automobiles requires designers to pay special attention to electromagnetic energy present at frequencies to which these systems are sensitive. Electromagnetic interference (EMI) can be problematic in AI server/ECUs or ADAS camera modules that depend on the transfer of high-volumes of data at high speeds. The clock can be the largest contributor of noise and often, this EMI is not observed until the final stages of qualification. This can cause rework late in the design cycle, incurring unplanned delays and costs.

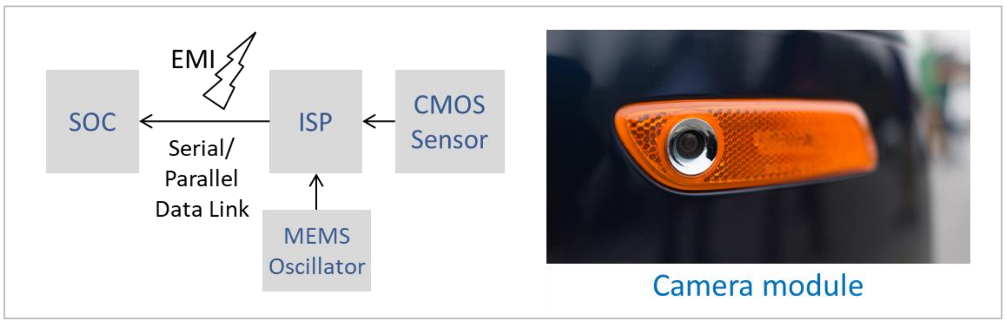


Figure 4: MEMS oscillators offer EMI reduction features for applications such as camera modules

To address this problem, SiTime offers the SiT9025, the first AEC-Q100-compliant spread spectrum oscillator (SSXO). This device has a wide spectrum range up to 4% with 0.25% resolution and is available in a tiny 2016 package. The SiT9025 reduces EMI with two techniques: spread spectrum clocking and FlexEdge™ programmable drive strength that allows the rise/fall time to be adjusted to reduce the slew rate. By using these EMI reduction features, the SiT9025 can lower noise by up to 30 dB.

The SiT9025 SSXO, along with the SiT8924/25 and SiT2024/25 oscillators, have programmable FlexEdge™ and are supported by SiTime's Time Machine II Programmer [5]. Designers can use this tool in their own lab to program EMI reduction oscillators and experiment with different techniques at different levels to achieve the optimal balance of noise reduction and system performance. Because SiTime QFN devices are a drop-in replacement for quartz oscillators, they can be used to pass compliance tests without any board changes or the use of expensive components or shielding.

Silicon MEMS are more robust

Vehicles are subject to harsh environments such as high levels of mechanical shock and vibration forces that can degrade quartz oscillator performance and cause them to fail. While operating in these conditions, 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 to mechanical force, resulting in frequency spikes, increased phase noise and jitter, and even damage to the resonator.

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. This makes MEMS oscillators have a lower *g*-sensitivity rating, which is expressed in ppb/*g* and represents the change in frequency caused by an acceleration force. SiTime's automotive grade oscillators deliver 0.1 ppb/*g* performance in a tiny 2016 plastic package. Quartz devices must use large, specialized packaging to achieve low *g*-sensitivity performance.

MEMS oscillators are also resilient against power supply noise which is amplified when the power supply and other devices on the board turn on and off. This can increase the jitter on the output clock and negatively impact system timing margins. For example in ADAS systems, when jitter worsens, it can affect how quickly data is sent from sensors to the decision engine. On the road where vehicle surroundings are constantly changing, a lag in data transmission can be devastating.

SiTime's SiT9386/87 differential oscillators have RMS phase jitter (random) that is less than 300 fs typical and power supply noise rejection (PSNR) at 0.02 ps/mV. These devices are ideal for high-performance AI processing in autonomous driving and automotive 10G/40G/100G automotive Ethernet applications that need to handle massive amounts of critical data captured from cameras, radar, lidar, and other sensors.

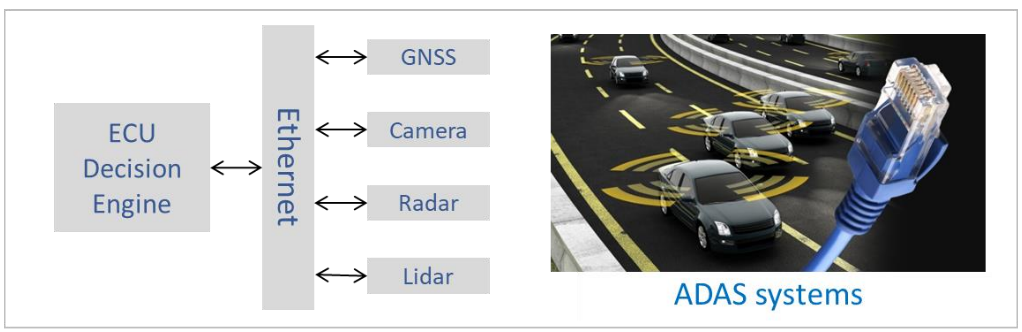


Figure 5: Low-jitter MEMS oscillators are resistant to shock, vibration, power supply noise, and thermal gradients, making them ideal for timing in automotive Ethernet for ADAS systems

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 and random vibration using standardized testing methodologies. As shown in Figures 6 and 7, SiTime's MEMS-based oscillators demonstrate superior resistance to vibration and board noise. To read more about testing methodology and measurement results, refer to SiTime technology papers Shock and Vibration Performance Comparison of MEMS and Quartz-based Oscillators [6] and Resilience and Reliability of Silicon MEMS Oscillators [2].

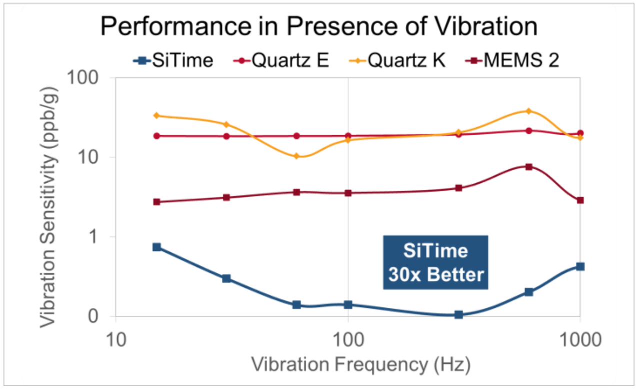


Figure 6: Oscillator sensitivity to sinusoidal vibration

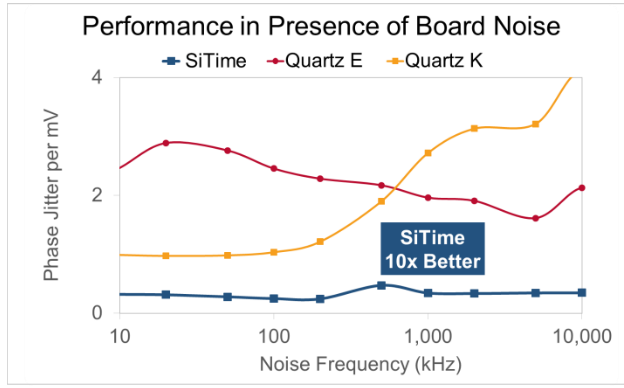


Figure 7: Oscillator sensitivity to board noise

Precision built for dynamic performance

In addition to shock, vibration, and power supply noise, automotive systems are subject to other environmental conditions such as rapid temperature changes and airflow that can also disturb timing signals. While cars today use timing devices for everything from infotainment to backup cameras, autonomous driving systems require even more stringent timing specifications. Precision GNSS receivers and V2X communication systems are a few application examples that demand extremely accurate and stable timing that can't be disrupted by environmental stressors.

The latest generation of MEMS timing solutions are built on the Elite Platform™ and are designed to maintain very tight stability under a wide range of dynamic conditions. This platform uses a DualMEMS™ architecture and TurboCompensation™ temperature sensing technology [7] to provide exceptional frequency stability under environmental stressors. SiTime's SiT5186/87 and SiT5386/87 TCXOs (temperature compensated oscillators) provide stability as precise as ±0.1 ppm, and maintain this stability under rapid temperature changes, airflow, shock, vibration, and power supply noise.

Figure 8: Elite Platform TCXOs are engineered to maintain the best performance under a wide range of harsh automotive conditions, making them ideal for precision timing applications

SiTime

MEMS Oscillators

The following table lists automotive MEMS oscillator families from SiTime [8].

<table>
<tr><th>Device Type</th><th>Device</th><th>Frequency</th><th>Temp. Range (°C)</th><th>Stability (ppm)</th><th>Output Type</th><th>EMI Reduction Feature</th><th>Package Size (mm)</th></tr>
<tr><td rowspan="2">QFN Oscillators</td><td>SiT8924[1]</td><td>1 to 110</td><td rowspan="4">-40 to 85,
-40 to 105,
-40 to 125,
-55 to 125</td><td rowspan="4">±20, ±25,
±30, ±50</td><td rowspan="4">LVCMOS</td><td rowspan="4">8 output drive strength options</td><td rowspan="2">QFN[3]:
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</td></tr>
<tr><td>SiT8925[1]</td><td>115.2 to 137</td></tr>
<tr><td rowspan="2">SOT23 Oscillators</td><td>SiT2024[1]</td><td>1 to 110</td><td rowspan="2">SOT23-5:
2.9 x 2.8</td></tr>
<tr><td>SiT2025[1]</td><td>115.2 to 137</td></tr>
<tr><td rowspan="2">Differential Oscillators</td><td>SiT9386[1,Error! Reference source not found.]</td><td>1 to 220</td><td rowspan="2">-20 to 70,
-40 to 85,
-40 to 95</td><td rowspan="2">±25, ±50</td><td rowspan="2">LVPECL,
LVDS,
HCSL</td><td rowspan="2">–</td><td rowspan="2">QFN:
3.2 x 2.5,
7.0 x 5.0</td></tr>
<tr><td>SiT9387[1,Error! Reference source not found.]</td><td>220 to 725</td></tr>
<tr><td>EMI Reduction Oscillators</td><td>SiT9025</td><td>1 to 150</td><td>-40 to 85,
-40 to 105,
-40 to 125,
-55 to 125</td><td>±20, ±25,
±50</td><td>LVCMOS</td><td>48 spread options up to ±2.0%, down to -4.0%</td><td>QFN:
2.0 x 1.6,
2.5 x 2.0,
3.2 x 2.5</td></tr>
<tr><td rowspan="4">TCXO/ VCTCXOs</td><td>SiT5186</td><td>1 to 60</td><td rowspan="2">-40 to 85,
-40 to 105</td><td rowspan="2">±0.5, ±1,
±2.5</td><td rowspan="4">LVCMOS,
Clipped Sinewave</td><td rowspan="4">–</td><td rowspan="4">Ceramic QFN:
5.0 x 3.2</td></tr>
<tr><td>SiT5187</td><td>60 to 220</td></tr>
<tr><td>SiT5386</td><td>1 to 60</td><td rowspan="2">-40 to 85,
-40 to 105</td><td rowspan="2">±0.1, ±0.2,
±.25</td></tr>
<tr><td>SiT5387</td><td>60 to 220</td></tr>
</table>

1. Contact SiTime for ≤±10 ppm stability options. 2. Contact SiTime for 95°C & 105°C products. 3. Available in wettable flank package

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. Production quantities (in any configuration) are available within 3 to 5 weeks. Samples can be ordered and received within one week. Alternately, designers can instantly program instant samples in their own lab by using the Time Machine II™ Programmer.

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

Summary

The growing use of in-vehicle electronic systems has increased the need for reliable automotive-grade reference timing components. Today's highest quality automotive 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 technologies result in ultra-high quality products. And because these timing devices are based on silicon, they are AEC-Q100 compliant that has higher qualification requirements compared to AEC-Q200.

	SiTime MEMS XO/TCXO	Quartz XO
Automotive qualification	AEC-Q100	AEC-Q200
Product coverage	Any frequency, voltage and stability in small package	Limited options for small packages & tight stabilities from -55°C to 125°C
Frequency stability over-temp	±0.1 PPM (-40 to 105°C) ±20 PPM (-55 to 125°C)	±50 PPM -40 to 125°C
Configurable rise/fall time for EMI control	0.25 to 40 ns	Not available
Vibration sensitivity	0.1 ppb/*g*	0.5 ppb/*g*
Quality level	<2 DPPM	50 to 150 DPPM
Long term reliability (MTBF)	>1 billion hours	<50 million hours

MEMS-based timing solutions provide any frequency, wider temperature ranges, tighter frequency stability, better packaging options, programmable EMI reduction features, high quality and reliability, and short lead-time. Most important, SiTime's MEMS oscillators have the capability to withstand vibration, electrical noise, rapid airflow, and temperature transients present in harsh automotive environments while continuing to perform reliably and within specifications. This reliability, along with the flexibility of SiTime products, makes them the ideal choice for tomorrow's feature-rich vehicles.

References

[1] SiTime Reliability Calculations Application Note:
https://www.sitime.com/sites/default/files/gated/AN10025-SiTime-Reliability-Calculations.pdf

[2] Data Source: Reliability documents of named companies. SiTime Resilience and Reliability Application Note:
https://www.sitime.com/sites/default/files/gated/AN10045-SiTime-Resilience-Reliability-MEMS-Oscillators_0.pdf

[3] The ultimate strength (or tensile strength) of silicon is 5,000 to 9,000 MPa (megapascal, a measurement of pressure) compared to titanium at 246 to 620 MPa.

[4] SiTime MEMS First™ and EpSeal™ Processes Application Note:
https://www.sitime.com/sites/default/files/gated/AN20001-MEMS-First-and-EpiSeal-Processes.pdf

[5] Time Machine II™ Programmer: https://www.sitime.com/time-machine-oscillator-programmer

[6] SiTime Shock and Vibration Comparison Technology Paper:
https://www.sitime.com/sites/default/files/gated/AN10032-Shock-Vibration-Comparison-MEMS-and-Quartz-Oscillators.pdf

[7] SiTime DualMEMS and TurboCompensation Temperature Sensing Technology Paper:
https://www.sitime.com/sites/default/files/gated/TechPaper-DualMEMS-Temp-Sensing-2018.pdf

[8] SiTime Automotive Solutions: https://www.sitime.com/solutions/automotive

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