MEMS Timing for Aerospace and Defense Applications

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1 Introduction

SiTime was founded to provide the next generation of timing solutions based on micro-electro mechanical systems (MEMS) and advanced analog technology. These solutions are designed to solve the most difficult timing problems and overcome the inherent weaknesses of quartz-based devices. SiTime's MEMS-based products excel in rugged, real-world environmental conditions and provide a highly-reliable, high-quality solution with predictable and easily scalable production capacity. SiTime MEMS technology is a pure silicon implementation, and combined with advanced packaging, it provides a robust timing solution and a supply chain that cannot be matched by quartz-based devices.

Coming from the automotive industry, SiTime's founders instilled a culture focused on quality. These values result in quality and reliability levels that are orders of magnitude better than what is available from any other timing solution available today. SiTime oscillators have the lowest defective parts per million (0.61 DPPM) and the highest mean time between failures (1.96B hours MTBF).

SiTime has shipped over 1.5 billion units as of 2020 and has been an established timing solutions supplier to many of our nation's top defense contractors for the last eight years. Over 10 different product families, across multiple generations, have been successfully designed and launched into production by dozens of aerospace-defense customers worldwide.

SiTime's Endura™ products, a line of ultra-robust oscillators, are uniquely qualified to suit the specific needs of aerospace-defense applications, offering system vendors a competitive advantage in the market. SiTime also has the ability to develop custom solutions to provide higher system performance and lower power consumption than other products available in the market. SiTime has a history of customizing solutions which has always met or exceeded customer expectations for performance and time to market.

2 Aerospace-Defense systems and the importance of timing

Modern military systems encompass multiple domains and leverage space and high altitude, aerial, terrestrial and ocean layer sensors to provide targetable data to fires networks. These systems provide multi-discipline intelligence support to targeting and situational awareness to mission command, and true real-time processing and communications are central to these operations. The timing function provided by oscillators within the network is essential for rapidly distributing vital data. Timing devices must reliably operate with high accuracy to enable the low latency and fast processing needed to support the advanced capabilities within military defense networks.

SiTime MEMS-based Endura products are the most rugged and reliable timing solution in the industry. These devices deliver excellent frequency stability while operating under harsh environmental conditions such as airflow, temperature perturbation, mechanical shock, vibration, power supply noise, and electromagnetic interference (EMI). Endura oscillators conform to MIL-PRF-55310 specifications and are engineered to perform in extreme conditions. The Endura line is built on a programmable platform that offers maximum choice to customers and yields over five million possible part numbers that can be created from 17 programmable base products. This enables oscillators to be configured to meet the specification combination required for each application and optimize system performance.

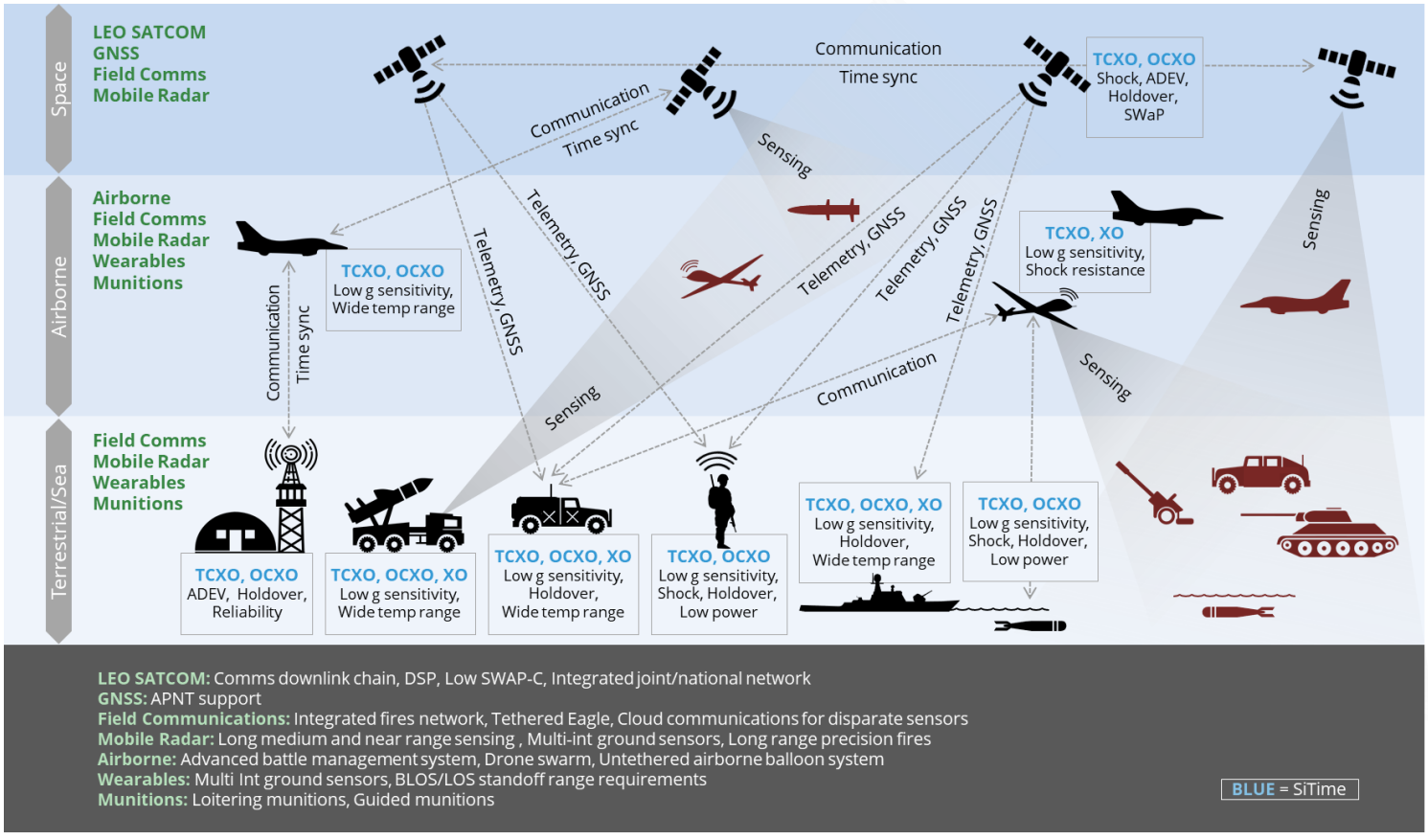


Figure 1: SiTime MEMS timing solutions are designed for the requirements of dynamic military systems across all domains

3 Technology

SiTime's silicon MEMS resonators are manufactured on standard semiconductor production equipment that can maintain part-per-billion levels of purity. Semiconductor manufacturing processes ensure repeatable, stable, and scalable production of highly predictable resonators which are encapsulated in EpiSeal™ wafers[1]. The MEMS resonator is mated to a SiTime-designed mixed-signal CMOS IC, which includes oscillator circuitry, noise regulators, phase lock loops, and temperature compensation, to provide a programmable oscillator capable of parts-per-billion levels of timing stability over extreme temperature, shock, and vibration profiles. Figure 2 shows a cross section of a MEMS EpiSeal resonator captured by scanning electronic microscopy.

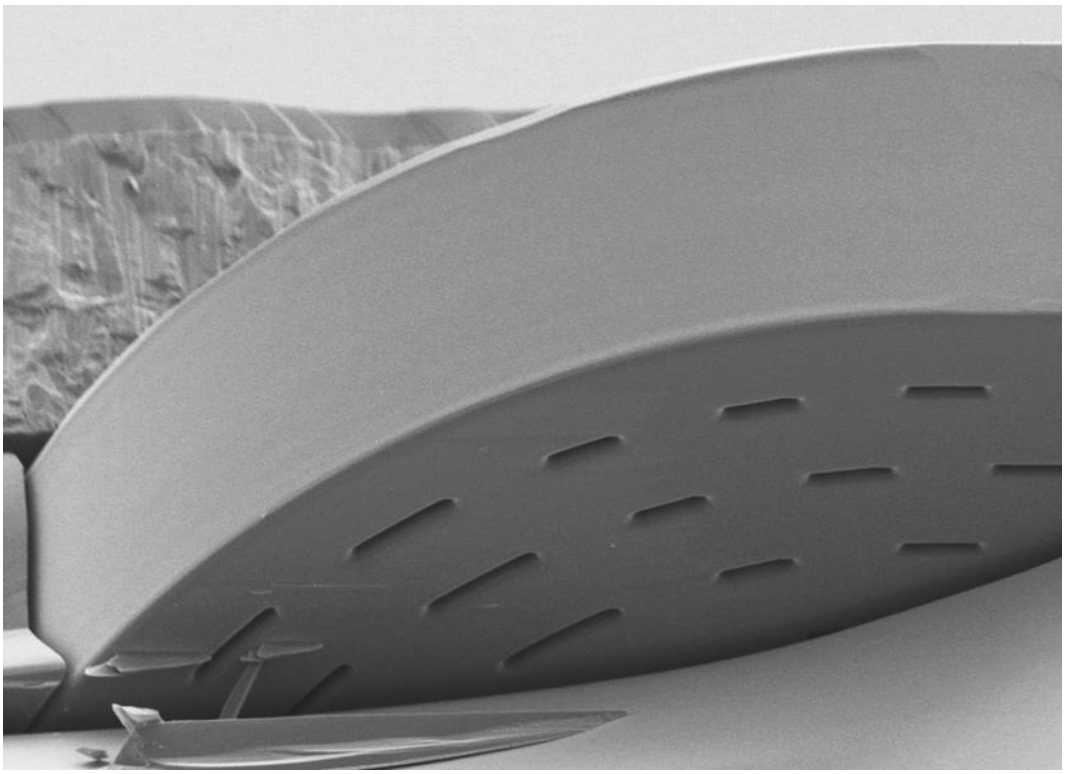
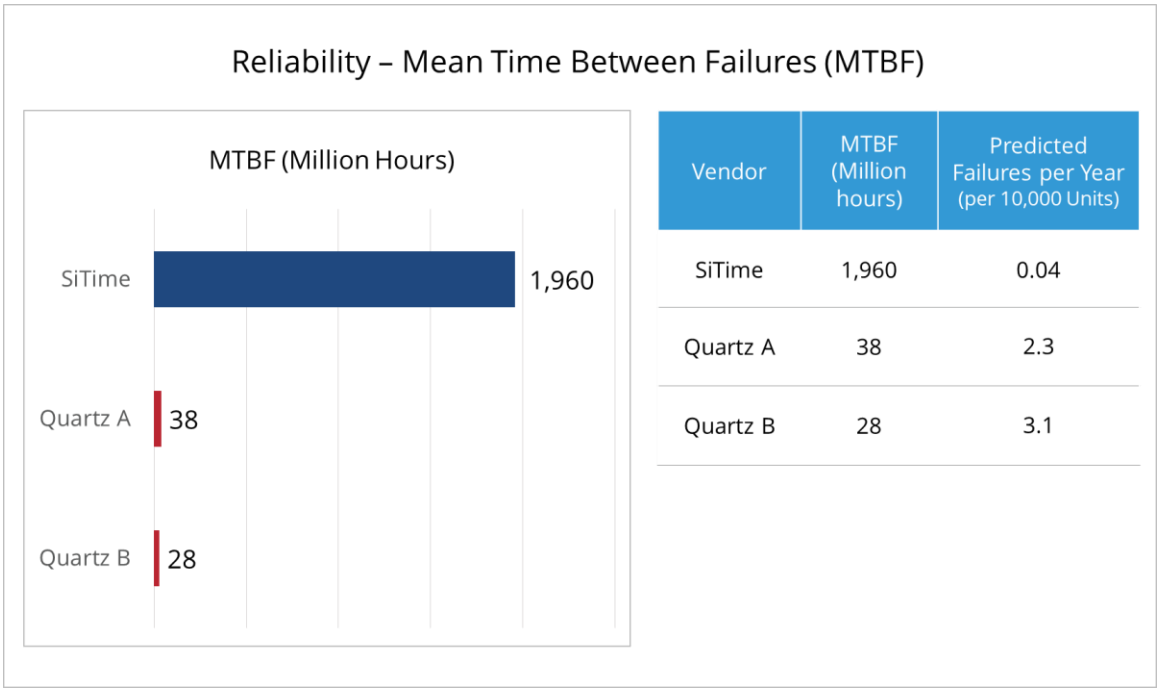


Figure 2: Single crystal silicon MEMS resonator with reformed surface, encapsulated in EpiSeal wafer

As a result of the silicon construction and the tiny mass of the MEMS resonator, these devices are extremely reliable yielding quality and reliability that is tens of orders better than what is available from quartz-based devices as shown in Figures 3 and 4.



Vendor	MTBF (Million hours)	Predicted Failures per Year (per 10,000 Units)
SiTime	1,960	0.04
Quartz A	38	2.3
Quartz B	28	3.1

Figure 3: Reliability of SiTime MEMS-based oscillators is about 50 times better than quartz oscillators

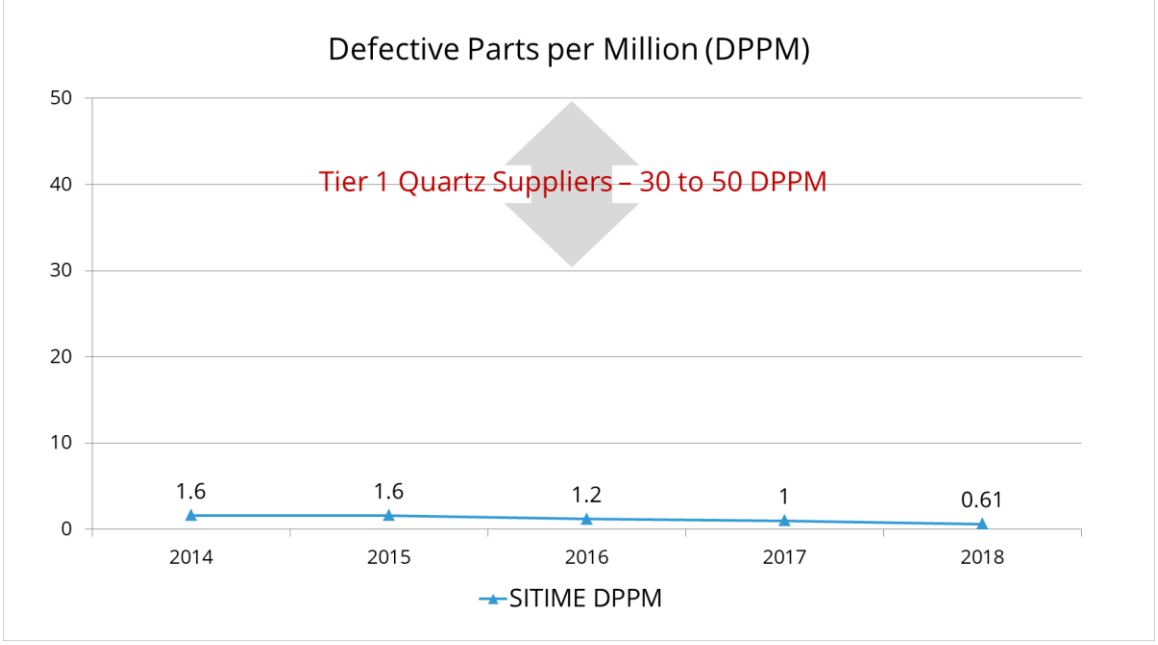


Figure 4: Quality of SiTime MEMS-based oscillators is orders of magnitude better than quartz oscillators

In addition to ultra-high quality and reliability, SiTime oscillators are able to maintain high performance under dynamic operating conditions such as rapid temperature variances, shock, and vibration. The architecture and temperature compensation circuitry of SiTime devices provide high immunity to temperature transients. The mechanical design of SiTime's MEMS resonators make them extremely robust against shock and vibration.

Esterline Research and Design, a firm that specializes in the testing of precision oscillators for military applications, has tested SiTime devices and found their acceleration sensitivity performance to be 4 ppt/g typical, 9 ppt/g max operation with no degradation in phase noise up to 15g RMS vibration. One customer has demonstrated continuous operation of a SiTime MEMS oscillator while experiencing 70Kg of acceleration. Under 50Kg of steady state acceleration profile (single pulse, half-sine wave, duration 2 ms), the maximum deflection of a SiTime MEMS resonator is 53 nm, which results in less than 25 MPa of stress in the resonator structure. The resonator would have to experience a stress greater than 250 times this level to reach the critical stress point of single silicon MEMS resonators of 7 GPa.

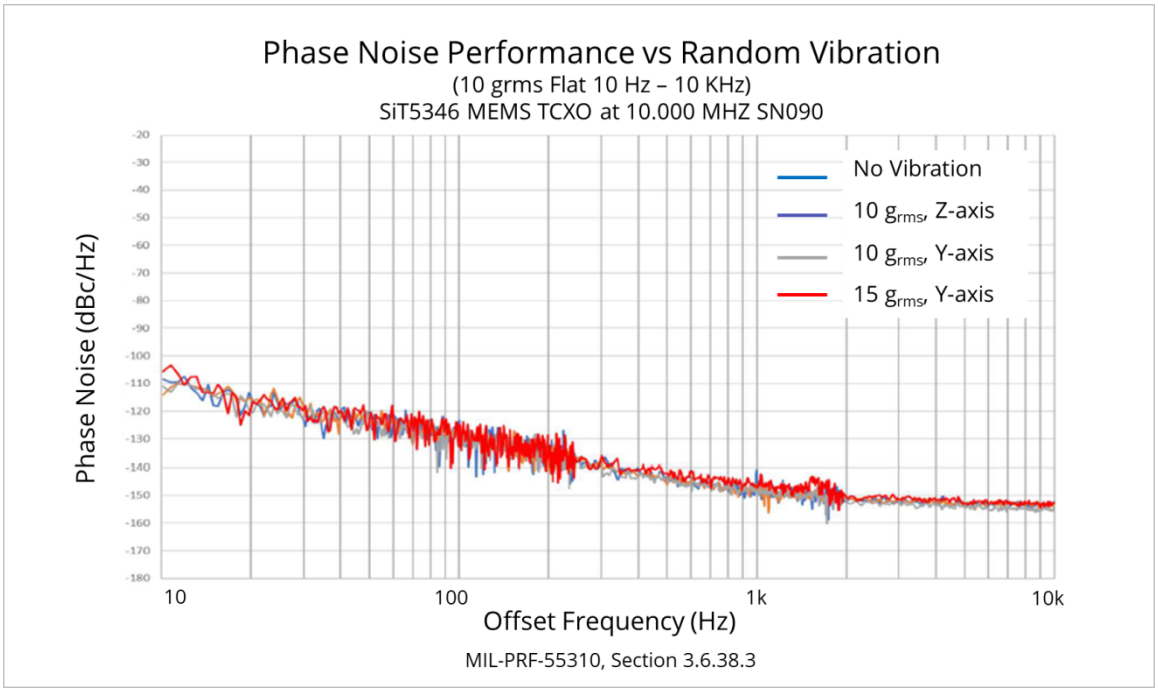


Figure 5: SiTime Endura MEMS-based TCXO phase noise performance under vibration

Beyond Esterline, SiTime products have been reviewed by Martin Bloch at FEI for Dr. John Burke (Program Manager in the Microsystems Technology Office) at DARPA and were deemed to have *lower* acceleration sensitivity than can be measured. Further, SiTime's defense customers have reported that SiTime's products perform well past the performance of quartz, and that when testing SiTime devices, they have found the test fixture failed before the SiTime devices failed.

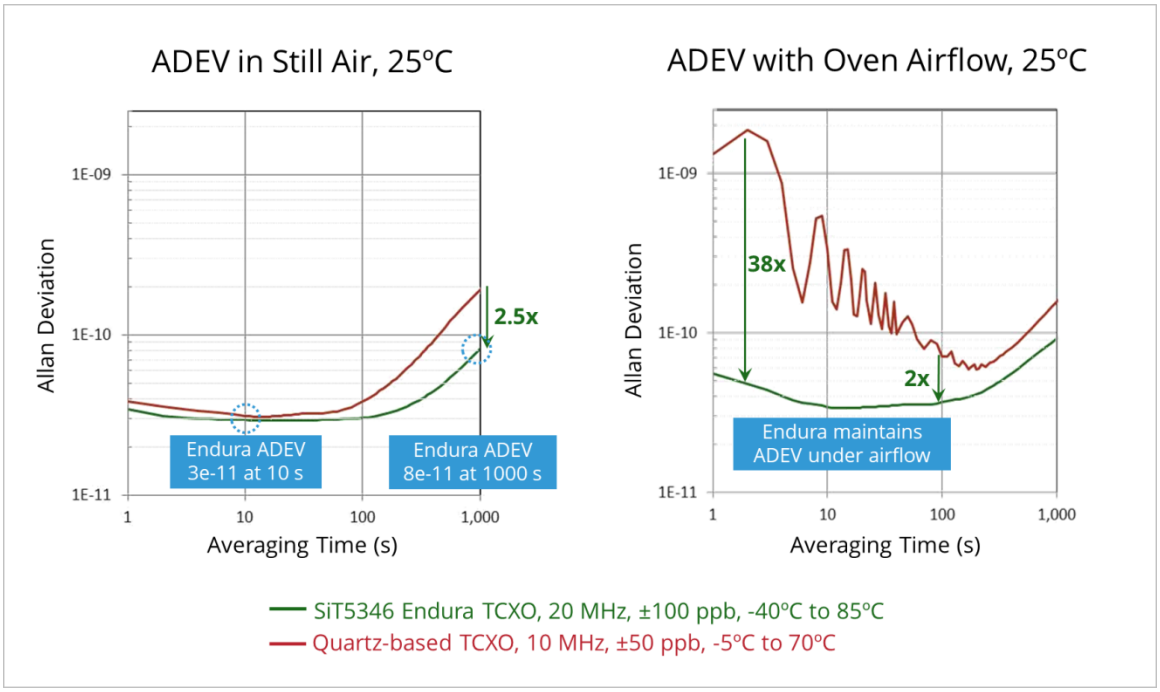


Figure 6: SiTime MEMS-based Endura TCXO ADEV performance comparted to quartz TCXO in still air and airflow conditions

SiTime TCXOs have the lowest Allan deviation (ADEV) under dynamic conditions which is important for GNSS and time synchronization filters heavily used across military domains. Figure 6 shows the ADEV of SiTime's Endura TCXO compared with quartz-based TCXO under still air and breezy conditions with a system cooling fan blowing. The performance of the quartz TCXO is significantly impacted by the airflow and does not meet the system requirements. The Endura TCXO performance remains in specification of better than 2E-11 at 10 to 100 Hz gate time.

In applications that endure shock and higher than normal g-loads, as well as high temperatures or rapid temperature changes, the SiTime products provide superior performance, allowing system level operation without degradation or failure. With the environmental performance provided by SiTime MEMS timing products, equipment operating under the severe and extreme conditions of combat will not only survive, but will continue to perform without compromise.

As for power consumption, SiTime's devices are competitive, but the real improvement may come from the fast turn on/off times and accurate time keeping of Endura oscillators. Because the start-up time of SiTime TCXOs and OCXOs measures in milliseconds instead of minutes or days, duty cycle management techniques can be utilized bringing system level power down to levels not previously achieved.

4 Conclusion

SiTime's highly accurate, robust timing solutions will enable the low latency and advanced analytic capabilities required by intelligence personnel to provide timely and accurate support to commanders and decision-makers. Furthermore, SiTime's solutions will enable military systems to autonomously and rapidly process, correlate, model, monitor, and generate timely and accurate results, perform predictive analytics, and provide visualized updates to the common operating picture (COP).

5 References

[1] SiTime Corp, Technology Paper: SiTime's MEMS First and EpiSeal Processes, March 2018

Table 1: Revision History

Version	Release Date	Change Summary
1.0	10/04/2020	Initial release

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