



Elite Platform™

MEMS-based Super-TCXOs and Oscillators

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1.0 Terminology

1.1 What is a crystal?

A crystal (X, XTAL) is a passive resonator that vibrates at a fixed frequency. It can be quartz crystal or MEMS-based. These devices are used as external timing references for semiconductor ICs with an integrated oscillator circuit (i.e. on-chip clock generation).

1.2 What is an oscillator?

An oscillator (XO) is an active device that uses a resonator and an oscillation circuit to generate a clock signal. XOs are also known as OSC and SPXO in various geographies. Typical frequency stability (variation of frequency over temperature) of XOs is between ± 10 and ± 100 ppm.

1.3 What is a VCXO?

A VCXO is a voltage-controlled oscillator and is an active device. Through voltage control (VC), the oscillator output can be fine-tuned within a specified range called pull range. VCXOs are typically used in clock synchronization in telecom, broadband, video and instrumentation.

The output frequency of quartz-based VCXO can be pulled or fine-tuned by ± 50 ppm to ± 200 ppm typically. The pull range linearity of quartz VCXOs usually varies from 5% to 10%. MEMS VCXOs support a wider pull range up to ± 3600 ppm and have pull range linearity down to 0.1% (50x better than quartz), making it easier to implement a synchronization loop.

1.4 What is a TCXO?

A TCXO is a temperature-compensated oscillator and is an active device. These devices typically have frequency stability of ± 0.1 ppm to ± 5 ppm over the operating temperature range. These devices are used in applications where precision timing references are required such as high performance telecom and networking equipment including small cells, synchronous Ethernet, optical transports, and GNSS modules.

1.5 What is an OCXO?

OCXO stands for oven controlled oscillator. These devices have very high stability, typically better than ± 50 ppb, and more commonly in the range of ± 5 to ± 20 ppb. OCXOs achieve high stability by encasing the crystal along with temperature-sensing and compensation circuits inside a heated metal enclosure to create an oven with a relative constant temperature. A double-oven OCXO (an oven inside another oven) can reach $< \pm 1$ ppb stability.

OCXOs use complex constructions and consume high power, 350 mW for a low-grade OCXO to 2.5W for a double oven OCXO. OCXOs suffer from poor consistency in performance and are prone to failure.

1.6 What is Stratum 3?

Five Stratum levels are defined by Bellcore GR-1288, Clock for Synchronized Network to represent intrinsic accuracy of reference clocks needed for certain levels of network performance. The lower the stratum level, the more accurate the clock is.

- Stratum 1
- Stratum 2
- Stratum 3
- Stratum 4



A Stratum 3 clock has a free run stability of ± 4.6 ppm over 20 years and a hold-over requirement of ± 0.37 ppm over 24 hours, both inclusive of frequency errors under all conditions. Stratum 3E is a more accurate version of Stratum 3, with the same ± 4.6 ppm free run stability, but with ± 0.01 ppm over 24 hold-over spec, 37 times tighter than Stratum 3. TCXO has replaced OCXO as the primary option for a Stratum 3 clock, whereas OCXO is currently used for Stratum 3E level stability.

1.7 What is a differential oscillator?

Differential oscillators are typically used to provide high frequencies (100 MHz or above) in high performance systems such as 10G/40G/100G Ethernet. In contrast to single-ended oscillators, differential oscillators make use of two signals that are exactly opposite in phase to each other, eliminating common mode noise and resulting in higher system performance. Differential oscillators are used in high speed systems to ensure the best possible signal integrity and robustness against power supply noise or other noise sources.

The most commonly used differential output signaling types include LVPECL, LVDS, and HCSL; although CML is also used in some cases. Quartz-based differential oscillators typically have frequency stabilities from ± 20 ppm to ± 100 ppm. MEMS differential oscillators can support stabilities as low as ± 2.5 ppm, a benefit to Ethernet designs where frequency skew is needed to ensure best throughput.

1.8 What are specialty oscillators?

Through semiconductor technology, unique features can be added to oscillator circuits used in the above active oscillators. Examples include:

- SSXO – Spread Spectrum Oscillator, which incorporates spread spectrum techniques to reduce EMI
- ISPXO – In-System Programmable Oscillator with an I2C/SPI interface to dynamically make changes in the system
- DCXO – Digitally Controlled Oscillator, which digitally fine-tunes the oscillator output frequency and reduces analog noise
- FSXO – Frequency Select Oscillator, which allows the user to select from several frequencies that have been pre-programmed into the device, and make these changes dynamically in the system

1.9 Why does SiTime use “X” within its product category names (i.e., TCXO)?

While all of SiTime’s devices use MEMS technology and not quartz crystal technology, we have chosen not to replace the “X” in the above acronyms with “M” (for MEMS) because these industry acronyms have been established in the market for many decades and are associated with certain timing functions. As SiTime devices offer the same or better functionality, it causes less confusion to continue with the same well-known product category names and acronyms.

1.10 What is Allan Deviation (ADEV)?

Allan Deviation is a time domain measure of frequency stability. Its main advantage over standard deviation is that it converges for most noise types, and is therefore widely used for characterizing frequency stability of oscillators. Allan deviation is a two-sample deviation of fractional frequency values measured continuously in time. Essentially it quantifies how much average frequency changes over a certain time interval (τ), called averaging time. Allan deviation can be specified in a table format or as a plot versus averaging time.



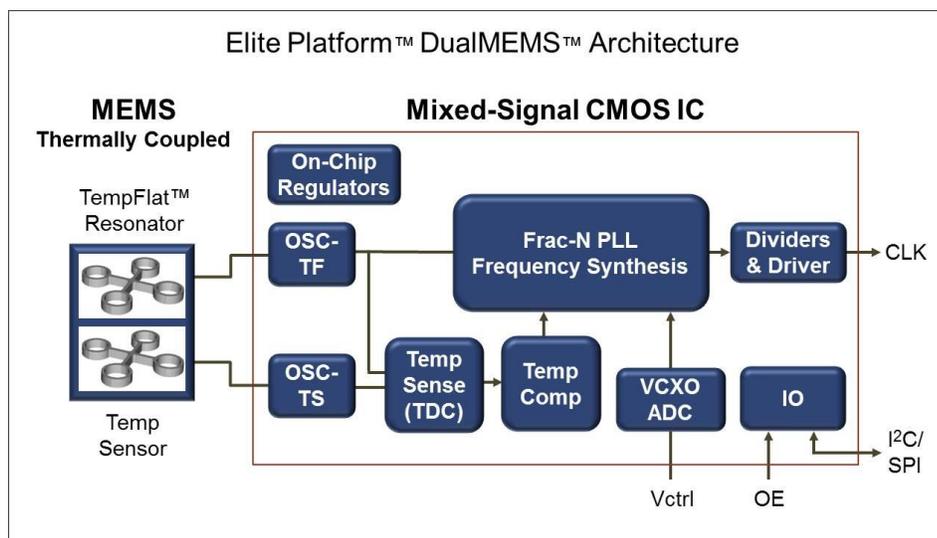
2.0 Product, Market and Technology Overview

2.1 What is Elite?

Elite is an innovative MEMS timing Platform for precision TCXOs, VCXOs, and low jitter oscillators. This platform leverages SiTime's unique DualMEMS™ architecture with TurboCompensation™. Elite-based precision Super-TCXOs and oscillators are engineered to solve deep-rooted timing problems in high-performance applications such as telecom and networking equipment. Elite products deliver the most stable timing even in the presence of environmental stressors. With SiTime's Elite Platform, telecom and networking equipment can deliver the highest performance, best reliability and the highest quality of service under real life operating conditions.

2.2 How does Elite work?

The Elite Platform combines the world's most accurate temperature sensor, with a proprietary temperature compensation scheme and a low-noise frequency synthesizer to deliver exceptional dynamic stability, ultra-low jitter, wide frequency range and programmability.



Three key elements of the Elite Platform include:

- Robust, reliable, and proven TempFlat MEMS™ that eliminate activity dips and enables 30x better vibration immunity than quartz
- DualMEMS temperature sensing with 100% thermal coupling that enables 40x faster temperature tracking, ensuring the best performance under airflow and rapid temperature changes
- Highly integrated mixed-signal circuits with on-chip regulators, a TDC (temperature to digital converter) and a low-noise PLL that delivers 5x better immunity to power-supply noise, 30 uK temperature resolution (10x better than quartz), support for any frequency between 1 and 700 MHz, and 0.23 ps jitter

2.3 What markets benefit from Elite products?

Elite products are ideal for networking, server, storage and telecom (NSST) equipment. Elite products are well suited for other high reliability applications such as test instrumentation, smart power grid, high precision GNSS/GPS positioning for automotive ADAS, avionics, surveying and precision farming.



2.4 How large is the market for Elite?

The Elite Platform targets NSST applications. The total available market (TAM) for all frequency control products, such as resonators (X, XTAL), and oscillators (XO, VCXO, TCXO, OCXO, Specialty Oscillators), that are used in NSST is over \$1.5 billion.

2.5 What products are available with the launch of the Elite Platform?

The Elite Platform launch includes four product families:

- Precision Super-TCXOs for wireless, wireline and time synchronization applications
 - 1 to 220 MHz, ± 0.1 ppm to ± 2.5 ppm stability, +105 °C
- Super-TCXOs for GNSS, industrial and automotive applications
 - 1 to 220 MHz, ± 0.5 ppm to ± 2.5 ppm stability, +105 °C
- Ultra-low jitter differential oscillators for 10G/40G/100G applications
 - 10 to 700 MHz, 0.1 ps jitter for Ethernet, +95 °C
- High temp, high reliability differential VCXOs for RF radios, video broadcast, wireless repeaters, and other industrial applications
 - 10 to 700 MHz, 0.1 ppb/g vibration resistance, +105 °C, wide pull range from ± 25 ppm to ± 3600 ppm

2.6 What are the key differentiators of Elite-based products?

Each Elite family offers unique differentiators for target applications.

Elite Products	Differentiators
Precision Super-TCXOs	<ul style="list-style-type: none"> • -40 to +105°C while maintaining ± 100 ppb frequency stability, the widest operating temperature available with any TCXO • 1 to 5 ppb/°C frequency slope ($\Delta F/\Delta T$) at an extremely fast temperature ramp rate of 10°C/minute • $3e-11$ Allan deviation (ADEV) at 10 second average time, 10x better than quartz TCXOs • No activity dips or micro-jumps • 0.2 ps/mV power supply noise rejection (PSNR), eliminates dedicated system LDO • Any frequency from 1 to 220 MHz • Optional I2C frequency tuning, eliminates external DAC
Super-TCXOs	<ul style="list-style-type: none"> • -40 to +105°C while maintaining ± 0.5 ppm frequency stability • No activity dips or micro-jumps • 0.1 ppb/g vibration immunity • Any frequency from 1 to 220 MHz
Differential Oscillators	<ul style="list-style-type: none"> • 0.23 ps jitter (12 kHz to 20 MHz) and 0.1 ps with Ethernet mask in the smallest 3.0 x 2.5 mm package • 0.02 ps/mV power supply noise rejection (PSNR) • Any frequency from 10 to 700 MHz • ± 10 ppm frequency stability over -40 to +95°C, enabling better system reliability
VCXOs	<ul style="list-style-type: none"> • 0.1 ppb/g vibration resistance • Up to +105°C with excellent phase noise • Wide pull range from ± 25 ppm to ± 3600 ppm • 0.1% frequency tuning linearity under all conditions, 50x better • Any frequency from 10 to 700 MHz



2.7 What are the key features and specifications of Elite products?

Device Type	Part Number	Frequency Range (MHz)	Temp. Range (°C)	Stability (ppm)	Output Type	Package Size (mm)	Special Features
Precision Super-TCXO	SiT5356	1 to 60		±0.1 to ±0.25			
	SiT5357	60 to 220					
Super-TCXO	SiT5155	10 standard GNSS freq.	-20 to 70 -40 to 85 -40 to 105	±0.5 to ±2.5	LVCMOS Clipped Sine Wave	SOIC-8: 6.0 x 4.9	-40 to +105°C 1 to 5 ppb/°C ΔF/ΔT 10 °C/min temp ramp 3e-11 ADEV, 10 sec stride No activity dips No micro jumps I2C programmability (option)
	SiT5156	1 to 60					
	SiT5157	60 to 220					
Differential Oscillator	SiT9365	32 standard frequencies	-20 to 70 -40 to 85 -40 to 95	±10 to ±50	LVPEC LVDS HCSL	QFN: 3.2 x 2.5 7.0 x 5.2	0.1 ps jitter, Ethernet mask 0.02 ps/mV PSNR
	SiT9366	10 to 220					
	SiT9367	220 to 700					
Differential VCXO	SiT3372	10 to 220					±25 to ±3600 ppm pull range 0.1% pull range linearity 0.1 ppb/g vibration resistance
	SiT3373	220 to 700					

2.8 How do Elite products fit within SiTime's existing product portfolio?

The initial release of Elite products expands MEMS timing in NSST (networking, server, storage, telecom), automotive and high-precision GNSS, and test instrumentation applications.

- The ±0.1-ppm precision Super-TCXOs expand MEMS precision oscillators into new applications areas such as small cell, IEEE 1588, Synchronized Ethernet and optical transport where Stratum-3 compliance and dynamic performance are critical to ensure robust system level performance.
- The ±0.5-ppm Super-TCXOs address the reliability and performance requirements for industrial and automotive GNSS systems with dynamic stability. These products enable more accurate positioning and faster satellite acquisition even in the presence of common environmental stressors.
- The Elite ultra-low jitter differential oscillators are complementary to our existing jitter offerings, targeting high-speed data communications that require 0.1 to 0.3 ps jitter.
- High-temperature, high-reliability Elite VCXOs target applications such as wireless repeaters, CMTS (cable modem termination systems) and broadcast systems, whereas SiTime's existing VCXOs focus on audio and industrial applications.

2.9 What is the availability of Elite products?

Engineering samples of Elite ultra-low jitter differential oscillators and high-temp VCXO are available to qualified customers now. Samples of Elite Super-TCXOs are scheduled for sampling in the first half of 2017.



2.10 What applications benefit from Elite products?

Exceptional dynamic performance and overall environmental robustness make Elite Super-TCXOs and oscillators ideal for high reliability applications in networking, server, storage and telecom (NSST). Examples of these applications include:

- Outdoor equipment subject to rapid temperature change
- Systems employing fan cooling that are subject to unpredictable and fluctuating air flow
- Pole-mount or curb-side systems subject to high vibration
- Datacenter and central office (CO) equipment prone to packet loss due to board bending and flexes
- OCXO replacement in IEEE 1588 systems with one-third of the power consumption, one-half of the size and much greater reliability

Elite products are also ideal for mission-critical applications such as GNSS-based ADAS and high accuracy positioning in construction and farming systems.

2.11 Does the Elite Platform and products achieve any industry firsts?

Elite products are the first to offer the following.

- ± 0.1 ppm stability at 105°C operating temperature with 10 °C/min temperature change
- OCXO quality ± 1 to ± 5 ppb frequency over temperature slope ($\Delta F/\Delta T$), enabling Elite Super-TCXOs to replace OCXOs in IEEE 1588 applications
- Maintaining the same ADEV and wander specs (TDEV and MTIE) in the presence of airflow and temperature perturbation
- I2C interface and digital frequency tuning with 0.1 ppb resolution, improving tuning accuracy and reducing external component requirements (eliminating external DAC)
- Eliminate the need for a dedicated LDO (Elite oscillators can share any switching power supply on the board, reducing cost and simplifying design)
- Completely eliminate any activity dips and/or micro jumps that can cause dropped calls or link loss
- Any output frequency between 1 MHz and 220 MHz while maintaining ± 0.1 ppm stability
- SOIC-8 leaded package, providing greater shock and vibration resistance, best solder-joint reliability, and low cost visual and/or optical inspection
- 0.23 ps jitter with LVPECL, LVDS or HCLS output in the smallest 3.2 x 2.5 mm package, enabling a high-frequency, low-jitter timing reference for small form factor applications such as SFP modules

3.0 Elite Super-TCXO Overview

3.1 What devices make up Elite Super-TCXO families?

The Elite Super-TCXO families initially comprise five devices with different frequency stability grades and frequency coverage.

Family	Part #	Frequency Stability	Frequency	Stratum 3 Compliance
Precision Super-TCXOs	SiT5356	± 0.1 to ± 0.25 ppm	1 to 60 MHz	Yes
	SiT5357	± 0.1 to ± 0.25 ppm	60 to 220 MHz	Yes
Super-TCXOs	SiT5155	± 0.5 ppm	10 standard frequencies for GNSS	-
	SiT5156	± 0.5 to ± 2.5 ppm	1 to 60 MHz	-
	SiT5157	± 0.5 to ± 2.5 ppm	60 to 220 MHz	-



All Elite Super-TCXOs offer superior dynamic performance, delivering the most stable timing in the presence of common environmental hazards. In addition, all Elite Super-TCXOs have a VC-TCXO operating mode with programmable pull ranges of ± 6.25 ppm, ± 12.5 ppm, and ± 25 ppm.

3.2 Why do you call these devices Super-TCXOs?

Super-TCXOs have exceptional dynamic performance under real life operating conditions. One of the key issues with quartz TCXOs is the inability to meet performance specs in actual systems under common environmental conditions. Elite Super-TCXOs are engineered to maintain rated performance specifications, such as stability, phase noise, jitter and Allan deviation, in the presence of environmental hazards such as shock, vibration, airflow and noisy power supply. The dynamic stability of Elite Super-TCXOs enables stable system performance under conditions that directly impact user experience, for example by minimizing mobile phone call drops.

3.3 What are the major customer benefits to using Elite Super-TCXOs?

- Reduce dropped calls and link loss under all conditions
- Lower field service expenses by eliminating TCXO failures
- Simplify system design with best features and performance

3.4 What applications do Elite Super-TCXOs target?

- SONET/SDH Stratum 3 and Stratum 4
- Synchronous Ethernet (G.8262, Options 1 and 2)
- Small cells, femtocells
- Synchronized Ethernet
- IEEE 1588
- Optical transport (OTN, OLT, etc.)
- Microwave backhaul
- CMTS (cable headend and video distribution equipment)
- COSPAS / SARSAT
- Broadband satellite
- Test instrumentation
- Industrial GNSS
- GNSS-based autonomous driving

3.5 What customer problems are solved by Elite Super-TCXOs in these applications?

- IEEE 1588 applications typically use an OCXO which are very large in size, have high power consumption and require special considerations in board placement and system location to ensure optimal performance. Compared to quartz-based OCXOs, Elite Super-TCXOs consume half the footprint and one-third of the power. Elite Super-TCXOs can be placed anywhere on the PCB, simplifying system designs.
- In many types of outdoor equipment such as small cell and microwave backhaul, quartz oscillators cannot maintain accuracy and stability when subjected to temperature perturbation or airflow. Elite Super-TCXOs deliver stable timing under all operating conditions, enabling the best system level performance.
- In industrial and automotive GNSS applications, positioning accuracy is difficult to maintain when the GNSS receiver oscillator is subjected to shock, vibration and activity dips caused by temperature variation. Elite products eliminate activity dips and provide superior shock and vibration immunity. Elite Super-TCXOs enable GPS systems to maintain positioning accuracy and improve satellite lock time irrespective of the environmental stressors.



3.6 What customer feedback has SiTime received on Elite Super-TCXOs?

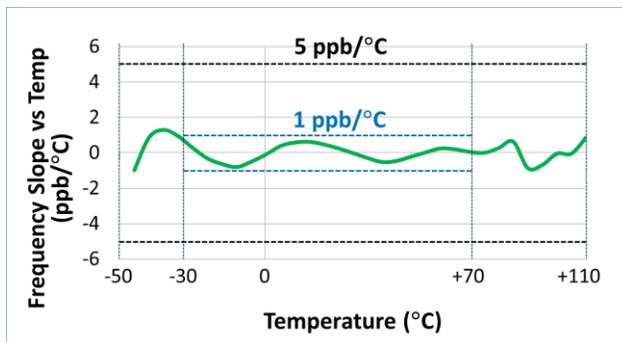
- Great phase noise performance for GPS applications under all conditions
- Unmatched dynamic performance which is critical to ensure system level performance in real life operating conditions, a persistent issue with quartz-based TCXOs
- Elimination of activity dips and micro jumps guarantees system performance at any temperature without the need for expensive incoming TCXO testing
- Digital features such as I2C enable BOM reduction and simplify designs
- Superior power supply noise immunity enables BOM reduction by eliminating a dedicated LDO

3.7 What are the key differentiators between Elite Super-TCXOs and quartz TCXOs?

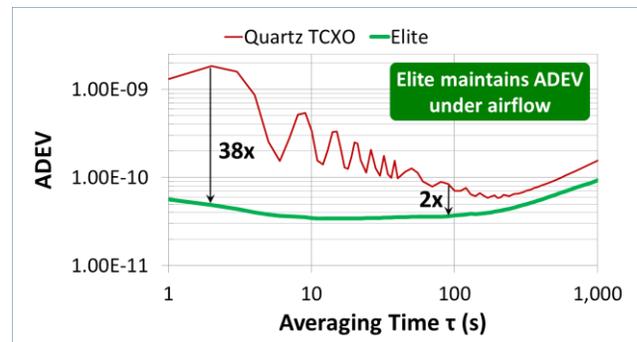
Elite Super-TCXOs provide superior dynamic performance by delivering stable timing in the presence of airflow, rapid temperature changes, mechanical shock, vibration, EMI and power supply noise. Elite products also offer a number of features, such as digital control through I2C that provides multi-protocol support and simplifies system designs.

3.8 What is the dynamic performance of Elite Super-TCXOs with respect to critical telecom specifications such as ADEV, TDEV and MTIE?

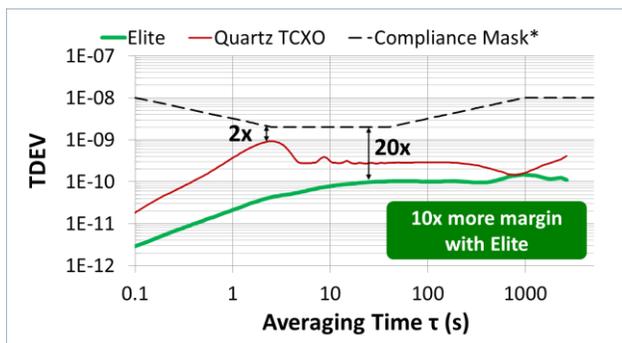
Elite Super-TCXOs are engineered to be resistant to environmental stressors such as air flow, thermal shock and vibration. Below are examples of Elite dynamic performance that illustrates the performance differentiation. The ADEV, TDEV and MTIE plots compare Elite performance with the best-in-class ± 50 ppb quartz TCXO under airflow using a standard cooling fan employed in many CPU-based systems.



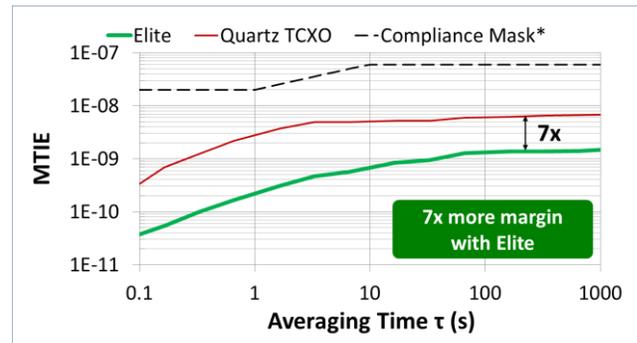
Best Dynamic Frequency Stability;
Up to 10C/Minute Temperature Ramp



Best Allan Deviation (ADEV)
in Still Air and Under Airflow



Best Time Deviation (TDEV)
in Still Air and Under Airflow



Best Maximum Time Interval Error (MTIE)
in Still Air and Under Airflow

*IUTU-T G.8262 option 2.0 1 Hz bandwidth compliance mask

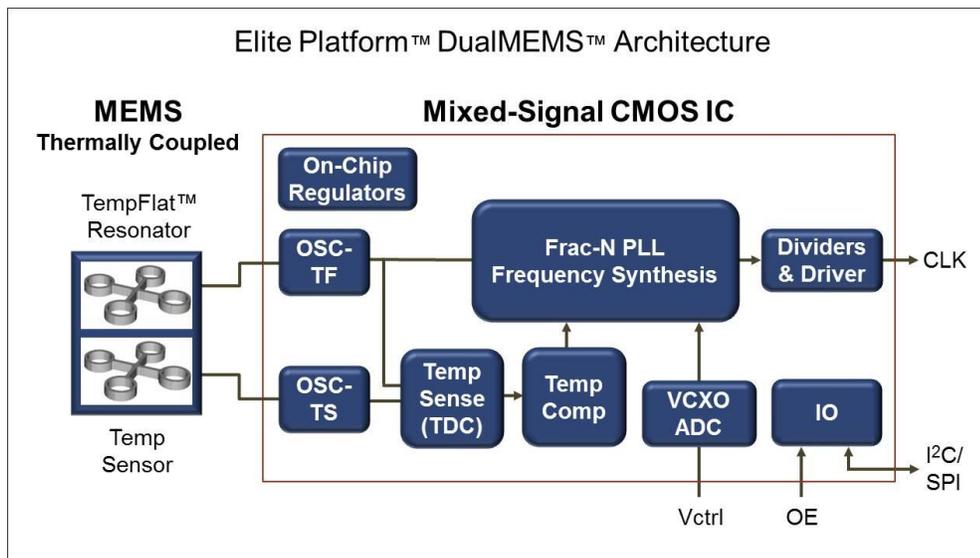


3.9 How does Elite Super-TCXO achieve its dynamic performance? Can quartz TCXO do the same?

Elite Super-TCXOs have an innovative DualMEMS architecture with TurboCompensation that is designed to deliver superior dynamic performance.

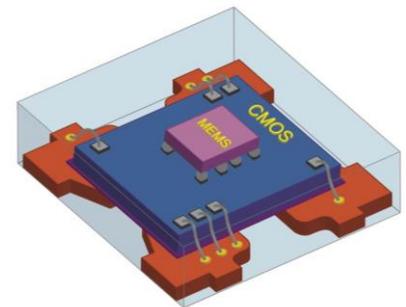
Underlying this architecture is the world's most accurate silicon temperature sensor. This temperature sensing scheme consists of two MEMS resonators fabricated on the same die (a unique construction that is only possible with semiconductors and not with quartz). One is designed with flat frequency characteristic over temperature; the second MEMS resonator is sensitive to temperature changes and acts as a temperature sensor. The ratio of frequencies between these two resonators provides an accurate reading of the resonator temperature with 30 μK resolution.

This DualMEMS design eliminates thermal gradients between the resonator and the temperature sensor. There is no lag between the MEMS resonator and the MEMS temperature sensor as both resonators are physically located on the same die substrate and therefore have 100% thermal coupling.



This accurate DualMEMS temperature sensing structure is combined with a state-of-the-art temperature compensation circuit in the CMOS IC. The MEMS die is mounted on top of the mixed-signal oscillator IC, creating tight coupling between the MEMS and CMOS IC die. The TurboCompensation design, with compensation bandwidth that runs at 100s of Hz, achieves dynamic performance that is far superior to any quartz TCXO.

Because DualMEMS share the same substrate, they are very tightly coupled. Additionally, the DualMEMS die is physically stacked on top of the oscillator/PLL IC thereby creating tight coupling between the MEMS and CMOS IC. With this tightly coupling arrangement, the Super-TCXO can sense and compensate for temperature transients much more quickly than a quartz-based solution.



Quartz TCXO performance is fundamentally hindered by the use of a discrete temperature sensor that is located on the oscillator IC at a distance from the resonator. The quartz crystal is mounted on pads and connected to the oscillator IC through vias. A separation between the resonator and oscillator IC must be maintained so the crystal can freely vibrate.



This physical separation between quartz resonator and temperature sensor results in a thermal lag which leads to frequency compensation error, especially during fast thermal transients. As a result, quartz TCXOs can generate abrupt and large frequency transients when subjected to airflow and/or temperature perturbation.

The Elite DualMEMS architecture offers additional dynamic performance gains not possible with quartz:

- Superior shock and vibration immunity due to the smallness of the MEMS resonator – a MEMS resonator is typically 1/3000th the mass of a quartz resonator
- Elimination of activity dips and micro jumps as the MEMS resonators are engineered without any spurious modes
- Superior aging characteristics because MEMS resonators have no known aging mechanism
- Better immunity to supply voltage fluctuation (VDD sensitivity) and noise due to carefully crafted internal voltage regulation chains

3.10 Why is the VDD sensitivity of Elite products significantly better than quartz TCXOs?

There are two reasons that Elite products have superior VDD sensitivity compared to quartz TCXOs. The first is due to the design of the CMOS IC which has two stages of power regulation circuitry that provide greater power supply noise rejection and much lower sensitivity to VDD variations.

The second reason for superior VDD sensitivity comes from the temperature sensing capability of Elite products, a fundamental advantage of the Elite Platform design.

With quartz TCXOs, the variation in power consumption causes VDD sensitivity. VDD changes induce power consumption transients that affect the thermal self-heating of the die and therefore the die temperature. This causes the temperature sensor to sense a temperature change and the temperature compensation circuitry will try to compensate for it. However, because the crystal resonator inside a quartz TCXO is some distance from the temperature sensor, it doesn't have good thermal coupling with the resonator, and this causes a temperature gradient between the temperature sensor and the resonator. This in turn causes frequency error.

In the case of Elite products with a DualMEMS design, the temperature sensor is located on the same die as the main resonator. This results in very good thermal coupling and temperature sensing that is always accurate and immediately responsive to power changes on the die. In addition to much smaller total frequency changes compared to quartz, Elite products have significantly lower overshoot and undershoot during the transient response.

3.11 What is SiTime's roadmap beyond ±100 ppb Super-TCXOs?

Due to market demand, SiTime's ±100 ppb device is the first to go into production. SiTime has plans to develop products with better than ±100 ppb stability. Please contact your SiTime representative for more information.



4.0 Elite Super-TCXO Technical Details

4.1 How are Elite Super-TCXOs packaged?

Elite Super-TCXOs are packaged in a 6.0 x 4.9 mm SOIC-8, a surface-mounted small outline integrated circuit package.

4.2 What are the advantages of an SOIC-8 package?

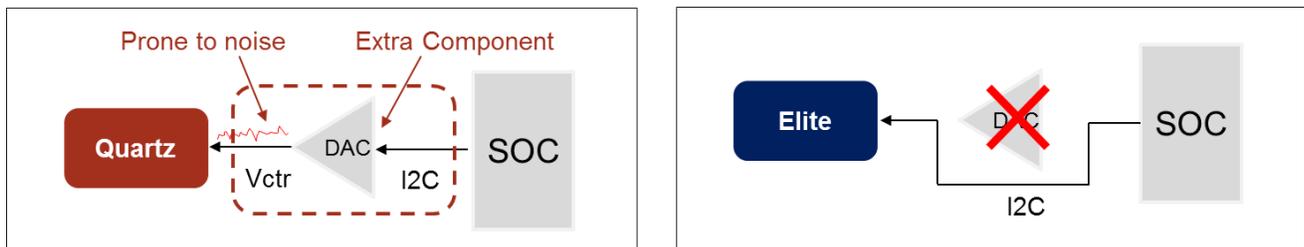
The SOIC-8 package has several advantages over traditional ceramic packages for precision TCXOs.

- Gull-wing style leads act as a stress relief buffer between the device and the board so that board level stresses do not impact the device, for example due to board bending or expansion/compression due to temperature change. Additionally, this style of lead provides the best solder-joint reliability and allows for low-cost visual and/or optical inspection.
- SOIC-8 is one of the most commonly used semiconductor packages with huge installed capacity, ensuring supply continuity and best lead time.

4.3 How quickly can the frequency be changed using I2C? And what is the impact on phase noise?

Digital pulling in a low bandwidth synchronization loop has no impact on phase noise because of the fine 0.1 ppb PLL resolution and fast update rate at 10 kHz updates per second. In comparison with traditional VCTCXOs, digital pulling provides two benefits.

- Elimination of analog VCXO noise on close-in phase noise
- Elimination of the external DAC or PWM that is typically required to convert digital control to analog control voltage



In-system programmability of Elite products improves immunity to noise and lowers BOM. As shown above, quartz-based designs require a DAC while MEMS-based designs do not require a DAC.

4.4 Are there any spurs?

Spurs are estimated to be <100 dBc/Hz for all common TCXO frequencies, meeting all application requirements.

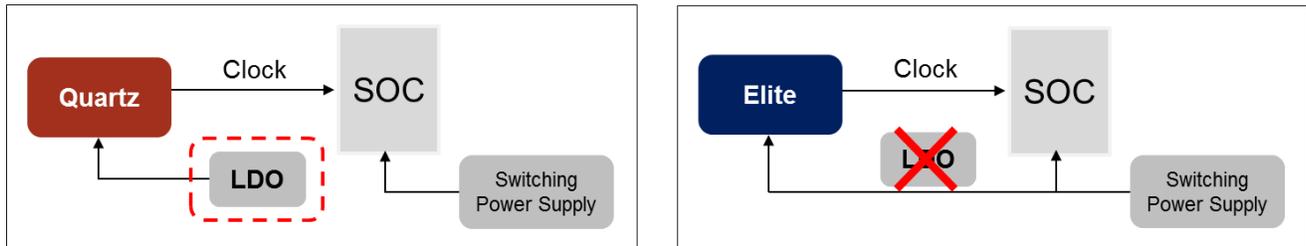
4.5 How does Elite Super-TCXO aging compare with quartz TCXO?

Elite Super-TCXOs have significantly better aging than comparable quartz devices because MEMS resonators have no known aging mechanism. In MEMS-based oscillators, a small amount of aging comes from the CMOS IC and interactions between electronic circuits and the package. This is controlled through optimized CMOS and package design.



4.6 Do I need a dedicated LDO regulator for Elite Super-TCXOs?

Elite Super-TCXOs do not require a dedicated LDO regulator because they have multi-level internal voltage regulation, resulting in excellent immunity to voltage variations and power supply noise. Because Elite products have excellent power supply noise rejection (PSNR) performance, any on-board switching power supply can be used to power the Super-TCXO.



In contrast, quartz oscillators are susceptible to power supply noise and require a dedicated LDO regulator.

4.7 What is the PSNR performance?

Elite Super-TCXO PSNR performance is 0.2 ps peak-to-peak per mV, best-in-class for a single-ended output device. This enables Elite Super-TCXOs to maintain performance even in noisy power supply conditions.

5.0 Application Scenarios

5.1 What applications benefit from Elite precision Super-TCXOs and its dynamic performance and digital frequency control features?

Typical applications for Elite Super-TCXO include:

- SONET/SDH Stratum 3 and Stratum 4
- Synchronous Ethernet (G.8262, Options 1 and 2)
- Small cells and femtocells
- Synchronized Ethernet
- IEEE 1588
- Optical transport (OTN, OLT, etc.)
- Microwave backhaul
- CMTS (cable headend and video distribution equipment)
- COSPAS / SARSAT
- Broadband satellite
- Test instrumentation
- Industrial GNSS
- GNSS-based autonomous driving



5.2 How does SiTime provide such benefits compared to alternative solutions?

The Elite Platform is based on SiTime's unique DualMEMS architecture with TurboCompensation. It is engineered to deliver dynamic performance not possible with quartz technology. The inherent advantages of MEMS include the following.

- ± 0.1 ppm stability at 105°C operating temperature and with 10 °C/min temperature change
- OCXO quality ± 1 to ± 5 ppb frequency over temperature slope ($\Delta F/\Delta T$), enabling it to replace OCXOs in IEEE 1588 applications
- Superior dynamic performance, maintaining the same ADEV and wander spec in the presence of airflow and temperature perturbation
- I2C interface and digital frequency tuning with 0.1 ppb resolution, improving tuning accuracy and reducing external component requirements (eliminating external DAC)
- Elimination of a dedicated LDO; Elite products can share any switching power supply on the board, reducing cost and simplifying design
- No activity dips and/or micro jumps that cause dropped calls or link loss
- Any frequency between 1 MHz and 220 MHz enabling flexible frequency planning for optimal system level performance
- SOIC-8 leaded package, providing greater shock and vibration resistance, best solder-joint reliability, and low-cost visual and/or optical inspection

5.3 Can Elite Super-TCXOs be used in place of OCXOs in IEEE 1588 applications?

Yes, in some cases Elite Super-TCXOs can be used as a replacement for OCXO in IEEE 1588 boundary clocks or SFP grandmasters where holdover is enabled by SyncE, GNSS or another source. In such an implementation, $\Delta F/\Delta T$ (frequency slope over temperature) is the most critical spec for maintaining time error spec in an IEEE 1588 loop. Elite Super-TCXOs with 100 ppb frequency stability have $\Delta F/\Delta T$ within 1 to 2 ppb/°C, similar to that of a Stratum 3E OCXO, and can be used in place of an OCXO. Traditional quartz TCXOs cannot be used in these scenarios due to poor $\Delta F/\Delta T$, typically in the range of 20 to 200 ppb/°C, up to 100x worse than Elite products.

Compared to an OCXO, Elite Super-TCXOs provide several benefits:

- 3x to 10x lower power consumption
- 2x to 5x smaller size
- More than 1000x faster in time-to-first-accurate-pulse (100 ms vs. minutes and hours)
- Superior reliability and consistency

5.4 What functions do Super-TCXOs provide in these applications?

Super-TCXOs provide a stable, accurate reference clock for timing subsystems. They are used to meet the frequency stability and holdover requirements as specified by the particular communication protocols and standards the system supports.

As an example, an Elite Super-TCXO can be used in a SDH or SyncE implementation to provide the necessary frequency synchronization across different network elements and prevent dropped frames and/or packets. In the case of small cell, the Elite Super-TCXO clocks the baseband and transceiver SOC to provide frequency and phase alignment. In both cases, the Super-TCXO provides the necessary holdover capability for the local system to continue its operation for some given time period after losing its primary clock source, such as the GPS clock, SyncE clock or IEEE1588.



5.5 How is an Elite Super-TCXO used in networking and telecom applications?

Elite Super-TCXO is typically used as a highly accurate local reference clock. There are two implementation scenarios:

- Elite Super-TCXO clocks directly into a SOC such as a small cell baseband chip, a wireless transceiver or a SyncE SOC.
- Alternatively, Elite Super-TCXO can be used as a reference clock for a multi-output PLL which generates all necessary frequencies for the entire system.

The Super-TCXO comes with a factory programmable voltage control option (VCTCXO) in which the device will be used in a closed loop to lock to another clock or in an open loop for periodic calibration purposes.

5.6 How does dynamic performance from Elite Super-TCXOs affect system level performance?

Network densification is driving rapid deployment of equipment in uncontrolled environments such as basements, curbsides, rooftops and on poles. The chassis density of the equipment also continues to rise, with hotter SOCs and a larger number of high-power cooling fans in close proximity to each other. Precision timing components must now operate in highly hostile environments, in the presence of high temperature, thermal shock, vibration and unpredictable airflow. Service providers are openly questioning whether legacy quartz technology is up to the challenge. In contrast, MEMS based Elite Super-TCXOs are resistant to environmental stressors such as rapid airflow or temperature change, shock and vibration. The excellent dynamic performance of Elite enables telecom and networking systems to maintain the same quality of service in harsh operating environments.

This dynamic performance enables Elite Super-TCXOs to have little or no degradation of close-in phase noise, ADEV, MTIE and TDEV under any operating conditions. This ensures proper system performance such as:

- Continued GPS lock without any disruption
- No link or packet loss for SyncE
- Reduced dropped calls in small cells

5.7 How does Elite Super-TCXO performance quantifiably compare to best-in-class quartz TCXOs?

For critical telecom specifications, Elite Super-TCXOs have:

- 50x better pull range linearity
- 38x better ADEV
- 10x better TDEV
- 10x better frequency stability vs. supply voltage sensitivity
- 7x better MTIE
- 5x better $\Delta F/\Delta T$
- 4x wider frequency coverage
- 2x better power supply noise rejection



5.8 How is I2C/SPI used and what are the benefits of this unique feature?

I2C/SPI can be used in place of a traditional voltage control function to digitally fine tune the output frequency of the system SOC. This new feature, which is not available with quartz TCXOs, provides a number of benefits.

- BOM is reduced by eliminating the DAC between the SOC and the TCXO. A DAC is typically required to convert digital control into analog control voltage, when using quartz TCXOs.
- Output frequency can be fine-tuned in 0.1 ppb steps or set to any frequency between 1 MHz and 220 MHz. This flexibility and level of accuracy provides new application and architectural possibilities.
- Noise interference on the voltage control signal is eliminated, improving frequency tuning accuracy and system performance.

6.0 Competition and Data

6.1 Who is the competition?

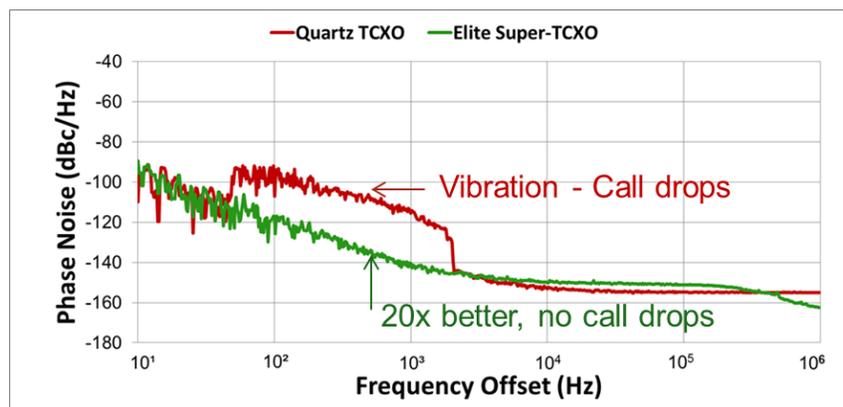
Rakon and Vectron have historically been the top two suppliers of precision TCXOs for telecom and networking applications. Other suppliers include Epson, TXC, NDK, Kyocera and Connor Winfield.

Additionally, the dynamic stability performance of Elite Super-TCXOs make them suitable to replace OCXOs in emerging applications such as IEEE 1588 and 4G/5G small cells.

6.2 How does Elite Super-TCXO phase noise and phase jitter compare with competitive parts?

Elite Super-TCXO phase noise is a key differentiator, particularly for systems operating in the presence of common environmental stresses. The plot below compares phase noise under vibration of Elite Super-TCXO to quartz TCXO. Elite demonstrates 20x better performance, significantly improving mobile quality of service (QoS) by reducing call drops. In the wireline applications such as OLT, DSL/G.fast and SyncE, Elite's vibration resistance can significantly reduce the loss of data links and ensure high data throughput even when these equipment are installed in high vibration environments such as curbside or in close proximity to high density cooling fans.

Vibration testing was based on Mil-STD-883F Method 2026, frequency range of 15 Hz to 2 kHz, and total vibration intensity of 7.5 g rms.



Elite Super-TCXO also offers excellent integrated phase jitter:

- 0.23 ps integrated RMS phase jitter (12 kHz to 20 MHz)
- 0.1 ps integrated RMS phase jitter under Ethernet mask for 10G/40G/100G