Epoch Platform | MEMS-based OCXO

Frequently Asked Questions

1. Oscillators and 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 a resonator?

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

1.3. What is an oscillator?

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

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 ±0.05 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 ±0.5 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 <±0.5 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. Quartz based OCXOs suffer from poor consistency in performance and are prone to failure.

Typical power consumption for the Epoch Platform™ MEMS based OCXO is 420 mW at 60°C ambient temperature and has much higher reliability that its quartz counterparts.

1.6. 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.

1.7. What is frequency stability?

Frequency stability is a fundamental performance specification for oscillators. This specification represents the deviation of output frequency from the ideal frequency due to external conditions. Lower frequency stability values mean lower deviation from the nominal frequency. Frequency stability is typically expressed in parts per million (ppm) or parts per billion (ppb) which is referenced to the nominal output frequency.

OCXO stability is typically comprised of the following components:

- Initial tolerance: the initial frequency at 25°C inclusive of solder-down shift at 48 hours after 2 reflows
- Frequency stability over temperature: the variation of output frequency as a function of the ambient temperature
- Load sensitivity: the variation of output frequency as a function of the load that the oscillator drives
- Supply voltage sensitivity: the variation of output frequency as a function of the supply voltage
- Frequency stability over temperature is the most important frequency stability component for OCXOs
- Aging: the frequency shift over time. Low daily aging is important for good holdover performance

1.8. What are the different technologies used for oscillators?

Prior to the advent of MEMS, quartz was the primary technology used in the implementation of oscillators. SAW (surface acoustic wave) was also utilized mostly for high frequency, low jitter oscillators.

SiTime was the first to successfully commercialize MEMS based oscillators. Since 2007, SiTime has shipped over 3 billion units of MEMS oscillators. MEMS technology now is used for a wide variety of timing solutions including ultra-low noise clock generators, ultra-low power kHz XOs, ultra-low different differential XOs, in-system programmable XOs and ultra-stable TCXOs and OCXOs.

1.9. What is Stratum?

Five Stratum levels are defined by Telecordia (now part of Ericsson) GR-1244 *Clocks for The Synchronized Network: Common Generic Criteria* 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, 3E
- 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. Both OCXOs and low grade OCXOs can meet Stratum 3 requirements.

1.10. What is Stratum 3E?

Stratum 3E is a more accurate version of Stratum 3, with the same ±4.6 ppm free run stability, but with ±12 parts-per-billion (ppb) over 24 hours hold-over spec, almost 31 times tighter than Stratum 3 discussed in 1.6. OCXOs are required for Stratum 3E compliance, and the biggest applications are Telephone Central Offices and Mobile Infrastructure networks.

1.11. What are the critical parameters for Stratum 3E oscillators?

- Frequency stability
- Frequency slope
- Daily aging rate
- Allan Deviation (ADEV)
- No Activity Dips and micro jumps
- Aging
- Holdover
- Power consumption

See detailed explanation of these parameters below. A more thorough Oscillator/Timing Glossary can also be found on SiTime website.

1.12. Why does SiTime use "X" within its product category names (i.e., OCXO)?

While all SiTime's devices use MEMS technology (and not quartz crystal technology), we have chosen to not replace the "X" in the above acronyms with a "M" because these product category names 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 acronyms.

1.13. What is Allan deviation (ADEV)?

Also known as short-term frequency stability, Allan deviation (ADEV) is the measure of oscillator stability in the time-domain. It represents a frequency change over an interval of time called averaging time. Allan deviation is calculated as the root mean square (RMS) change in successive frequency measurements. The averaging time typically ranges from milliseconds to thousands of seconds depending on the target application. The formula for Allan deviation is shown below, where the y values represent the values of fractional frequency deviation between adjacent clock cycles and M is the sample size.

$$\sigma_y(\tau) = \sqrt{\frac{1}{2(M-1)} \sum_{i=1}^{M-1} (y_{i+1} - y_i)^2}$$

Allan deviation is used for clock oscillators because it converges for more types of oscillator noise compared to standard deviation. Allan deviation converges for several types of random noise including white phase modulation, flicker phase modulation, white frequency modulation, flicker frequency modulation, and random walk frequency.

In addition to these types of random noise, Allan deviation also takes the systematic daily aging of the oscillator into account. The daily aging can be removed, therefore leaving just the random sources of oscillator noise, with a similar metric called Hadamard deviation (HDEV).

1.14. What is holdover?

From GR-1244, the holdover mode is the operating condition of a clock that has lost its references and is using data previously acquired (when it was operating in the normal mode) to control its output signal. In general, the stored data or "holdover value" used by a clock in the holdover mode is an average value obtained over some period (to reduce the effects of any short-term variations that might occur in the reference frequency during normal operations). Reliable holdover in real world conditions is critical to maintaining service continuity in the face of regular time reference disruptions.

In practice, holdover is generally defined as the accumulated time error over a specified period. For 5G base station infrastructure, the specified period is ±1.5 µsec, as this is the required time alignment for normal operation. Base stations and usually aim for 8 hours or more hours of holdover over the ±1.5 µsec period. 3GPP terminology for this metric is Time Alignment Error (TAE). This ±1.5 µsec is a system budget and network nodes between the mobile switching center and the remote radio heads will often have an even tighter requirement so that the overall system budget of ±1.5 µsec among RRHs is met.

The holdover performance of an oscillator is determined by three components: the frequency over temperature slope (ΔF/ΔT), the daily aging rate, and the random oscillator noise. The daily aging rate and the random oscillator noise are both included in the ADEV of the oscillator.

1.15. What is frequency vs. temperature slope?

Frequency vs temperature slope, also shown as ΔF/ΔT, is the magnitude of frequency change due to a 1°C change in temperature. It quantifies sensitivity of the oscillator output frequency to small temperature variations near the operating temperature point. It is one of the major performance metrics of precision TCXOs and OCXOs that determines if the oscillator is stable enough to support the needs of the target application. Smaller frequency vs temperature slope values mean lower frequency variation due to the temperature change in a confined temperature window.

In systems that require time and frequency transfer using IEEE 1588, better (lower) frequency vs temperature slope helps improve time error and accuracy of the recovered IEEE 1588 clock. The unit of measure is in ppm/°C or ppb/°C.

1.16. What is the daily aging rate?

The daily aging rate is the magnitude of the systematic frequency change in 24 hours, with the unit of measure being ppb/day. The aging of an OCXO is one of the three main metrics that determines the holdover performance.

Most of an oscillator's aging is largely derived from two sources: changes in the stress properties of both the resonator and the packaging. While quartz crystals will age over time, SiTime's unique MEMS EpiSeal® process leads to completely smooth and uniform resonators, without the stress defects that lead to resonator aging. In addition, SiTime has made several innovations in package engineering to minimize changes in the stress properties of the key oscillator components including the CMOS and attach materials.

Unlike the random sources of noise accounted for in ADEV, the aging of an oscillator is predictable and can be compensated for extended holdover performance.

SiTime

2. Product, Market and Technology Overview

2.1. What is the Epoch Platform?

The Epoch Platform is a group of advanced MEMS based oven-controlled oscillators. They comprise the SiT58XX family for communications, enterprise, and industrial applications and the ruggedized SiT71XX family designed and manufactured for aerospace and defense applications. Epoch Platform devices are the industry's smallest (9 mm x 7 mm) Stratum 3E Grade OCXOs with down to ±1 ppb over-temperature stability and ±0.02 ppb/°C frequency slope (ΔF/ΔT), providing best in class holdover in real world conditions for 2x better service continuity. This device is engineered for best dynamic performance. Leveraging SiTime's unique DualMEMS® and TurboCompensation® temperature sensing technology, it delivers the most stable timing in the presence of environmental stressors – airflow, temperature perturbation, vibration, shock, and electromagnetic interference (EMI).

2.2. How does Epoch Platform work?

The Epoch Platform combines a MEMS resonator system with the world's most accurate temperature sensor, along with a proprietary temperature compensation scheme and a low-noise frequency synthesizer, and a heater control system to deliver exceptional dynamic stability, ultra-low jitter, and wide frequency range.

Four key elements of the Epoch 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 µK temperature resolution (10x better than quartz)
- Heater control circuit that maintains approximately constant temperature inside the package.

2.3. What markets benefit from Epoch Platform products?

Epoch Platform products are ideal for networking, datacenter, and telecom equipment. Epoch Platform products are well suited for other high reliability applications such as Base Station Infrastructure Networks, Small Cells, Wired Network Infrastructure, Edge Data centers, IEEE 1588 and Synchronous Ethernet Synchronization, and Test & Measurement.

2.4. What are the key differentiators of Epoch-based products?

- Up to 12 hours of holdover (±1.5 µs), 8 hours in dynamic conditions (8°C temperature change & 1 m/s airflow) – 2x better than Quartz OCXOs
- ±1, ±3, ±5 ppb frequency stability over temperature
- Highest operating temperature range: -40 to 95°C
- 3X lower power: 420 mW
- 3X better ADEV under airflow: 4e-12 at 10 seconds averaging time
- 3X lower aging: ±0.1 ppb/day
- 2X faster time to stability – 60 seconds
- 9X smaller, 3X lower: 9 mm x 7 mm x 3.73 mm
- Any frequency between 10 and 220 MHz, programmable up to 6 decimal places of accuracy.
- Digital control with 5E-14 resolution: I2C and SPI interfaces
- 2.5, 2.8, and 3.3 operating supply voltage

2.5. How do Epoch Platform products fit within SiTime's existing product portfolio?

The previous release of Elite and Elite X TCXOs supported Stratum 3 and 4 network infrastructure applications and also have OCXO grade frequency vs. temperature slope ($\Delta f/\Delta T$) for IEEE 1588 clock recovery. The Epoch Platform ±1, 3, and 5 ppb OCXOs support more stringent networks used for mobile and wired networking infrastructure and enable extended holdover performance for service continuity. The Epoch Platform family also inherits the dynamic performance and resilience to environmental stress offered in the Elite TCXO and will be ideal for remote deployments to support 5G, data center, and network infrastructure.

2.6. What is the availability of Epoch Platform products?

General samples of Epoch Platform OCXOs are available in October 2023. These devices support ±1, 3, and 5 ppb stability grades and will be released to production in early 2024.

2.7. What applications benefit from Epoch Platform products?

Exceptional dynamic performance and overall environmental robustness make Epoch Platform OCXOs ideal for high reliability applications in networking, datacenters, and telecom. 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
- 5G Mobile Networks
- Small form factor systems
- Position, Navigation and Timing (PNT)

3. Epoch Platform OCXO Overview

3.1. What devices make up Epoch Platform OCXO families?

The Epoch Platform OCXOs include the following devices with different frequency stability grades and frequency coverage.

Part #	Frequency Stability	Frequency	Max Temperature Range	Digital Control	Holdover
SiT5801	±3, 5 ppb	10 to 60 MHz	-40°C to 95°C	Yes	8 hours
SiT5802	±3, 5 ppb	60 to 220 MHz	-40°C to 95°C	Yes	8 hours
SiT5811	±1 ppb	10 to 60 MHz	-40°C to 95°C	Yes	12 hours
SiT5812	±1 ppb	60 to 220 MHz	-40°C to 95°C	Yes	12 hours

All Epoch Platform OCXOs offer superior dynamic performance, delivering the most stable timing in the presence of common environmental stressors.

The ruggedized Endura Epoch OCXOs are listed below.

Part #	Frequency Stability	Frequency	Max Temperature Range	Digital Control	g-sensitivity
SiT7101	±3, 5 ppb	10 to 60 MHz	-40°C to 95°C	Yes	0.01 ppb/g
SiT7102	±3, 5 ppb	60 to 220 MHz	-40°C to 95°C	Yes	0.01 ppb/g
SiT7111	±1 ppb	10 to 60 MHz	-40°C to 95°C	Yes	0.01 ppb/g
SiT7112	±1 ppb	60 to 220 MHz	-40°C to 95°C	Yes	0.01 ppb/g

3.2. What are the major customer benefits to using Epoch Platform OCXOs?

- Enables compact design and reduces design iterations due to poor spacing rules
- Longer holdover and therefore service continuity in real world conditions
- Fewer equipment calibrations needed for test and measurement applications
- Ease of design due to insensitivity to board level noise

- Higher service quality, enabling operator to easily meet SLA (service level agreement)
- Reliable delivery eliminates the quartz OCXO as a production bottleneck
- Shorter lead times and fast scalability in production
- Flexibility to choose the best frequency for your application
- Enables power supply flexibility for lower BOM cost
- Lower operating expenses due to fewer truck rolls
- Better user experience leading to higher subscriber retention and therefore higher operator revenue

3.3. What applications do Epoch Platform OCXOs target?

- 5G base stations, cell site routers, fronthaul switches
- 5G small cells and femtocells
- 5G O-RAN DU and CU
- Microwave backhaul
- Datacenter servers, switches, and smart NICs
- Core network routers
- Edge network switches and routers
- Access routers and switches
- Passive Optical Network (PON) and optical transport
- Test instrumentation
- Grandmaster timing references
- IEEE 1588 routers and switches
- ITU-T G.8273.2 Class D
- SONET/SDH Stratum 3E
- Synchronous Ethernet (G.8262, Options 1 and 2)
- Positioning, Navigation and Timing (PNT)

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