

Three advantages of MEMS timing technology in industrial automation applications



Micro-electro-mechanical systems (MEMS) technology has provided the foundation for transformational change in the electronics industry. In timing components, MEMS technology enables superior performance compared to traditional quartz oscillators in key areas such as greater stability, far higher shock and vibration resistance, higher reliability, and smaller size.

And the technology is proven: SiTime, which pioneered the application of MEMS technology to timing components, has shipped more than 3 billion MEMS-based oscillators.

The characteristics of MEMS timing components are particularly valuable for equipment installed in industrial environments such as:

- [Robotics and factory automation](#)
- [Servo drives](#)
- [Computer numerical control](#)
- [Automated ground vehicles \(AGVs\)](#)

This white paper describes in detail:

- The characteristics of industrial environments that affect the operation of traditional quartz timing components
- The role of timing in industrial automation equipment
- The three advantages of SiTime MEMS timing components in industrial applications: reliability, easier EMC compliance, and programmability

The characteristics of applications in the industrial sector

Precision timing components play an important role in industrial equipment, providing a stable timing signal – the heartbeat of an electronic circuit. Yet for many generations, electronics system designers had no choice but to live with the compromises and implementation problems caused by traditional quartz oscillators (XOs). These XOs are highly susceptible to environmental phenomena that disturb their operation or cause premature failure. But in the absence of a different option, the quartz XO was the *de facto* standard technology for timing.

Manufacturers of industrial equipment, however, have a particularly strong motivation to consider alternative timing technologies that can eliminate the workarounds and compromises associated with the use of quartz XOs. This is because factors that disturb the operation of a quartz XO – exposure to high temperatures, shock and vibration, and high levels of electrical noise – are particularly prevalent in industrial and manufacturing environments.

The operating conditions relevant to timing components include:

Shock and vibration – powerful motors can produce vibration, a continuous high-frequency motion. Engineers are increasingly choosing to control motors locally for a faster response to position measurements, and therefore higher torque and smoother operation. Clocks mounted adjacent to the motor driver and the encoder (position sensor) are in close proximity to the motor shaft and its load, and cannot be isolated from the vibration that they create. Shock is a single, powerful motion event that can be caused by equipment such as die stamping machines or materials handling equipment.

Shock and vibration are readily transmitted mechanically to the crystal of an XO. This increases its phase noise or jitter, and can cause frequency shifts, perturbing the timing signal. In extreme cases, a shock can destroy the crystal.

MEMS-based XOs are virtually immune to shock and vibration.

Extreme temperatures – powerful machinery generates waste heat as a by-product, locally increasing the ambient temperature to which electronics systems in industrial equipment are exposed. In process plants such as petrochemical refineries, steel mills or food manufacturing facilities, high temperature is a necessary feature of the industrial operation.

Power supply noise and EMI – the power distribution busses supplying manufacturing equipment typically operate at very high voltages. In addition, high-frequency and high-voltage switching operations are prevalent in equipment such as DC-DC power converters and motors. This factory equipment generates large amounts of electrical noise, and both conducted and radiated emissions of electromagnetic interference (EMI).

Quartz timing components display large variances in frequency output (low stability) when subject to even mild shock or vibration, to temperature swings, and to electrical noise. This frequency instability temporarily disturbs the operation of electronics systems. The symptoms can include:

- Bit errors and data loss or corruption in networking systems

- Slow or failed operation of key components such as microprocessors, microcontrollers, FPGAs, or memory devices

Use of MEMS timing technology provides equipment designers with unique advantages:

- Up to 50x better reliability than quartz oscillators: mean time before failure (MTBF) is 2.2 billion hours
- Up to 20x better shock survivability
- 4x better vibration resistance – 0.1 ppb/g typical – due to the smaller size (0.4mm x 0.4mm) and lower mass of a MEMS resonator compared to a crystal (see Figure 1)
- High resistance to airflow and thermal shock – 1 ppb/°C
- Spread-spectrum capability to mitigate the effects of EMI
- No activity dips or cold start issues

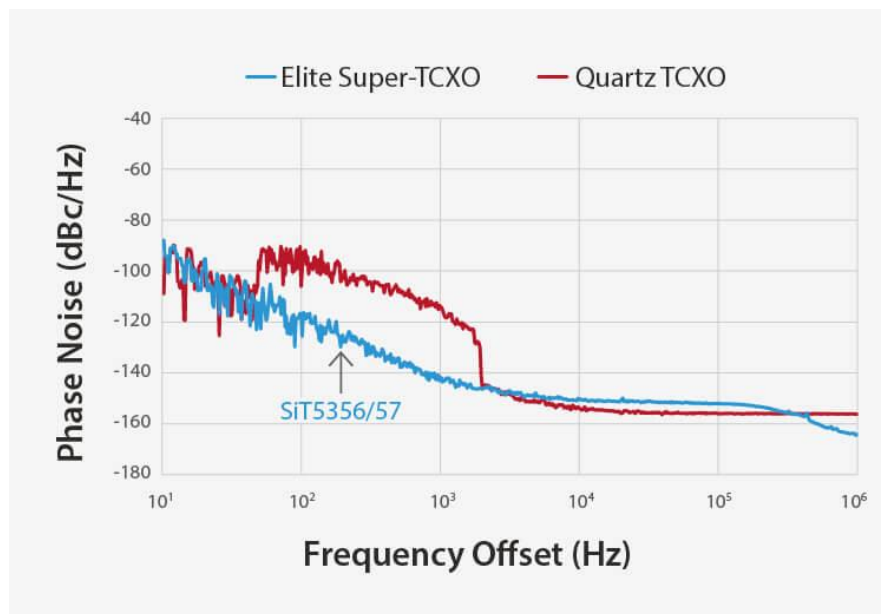


Figure 1: Vibration markedly impairs the phase noise performance of a quartz TCXO while the SiTime Elite product's output remains unaffected

The role of timing in common types of industrial equipment

Industrial equipment manufacturers and their customers are increasingly adopting an approach to system-wide control that is summed up by the term 'Industry 4.0'. This implies:

- High levels of connectivity both within the factory and to the cloud
- Advanced edge intelligence and the use of smart industrial devices
- Sophisticated human-machine interfaces that make operators' interactions more reliable, reduce human error and enhance safety
- The increased use of robots to replace human operators, and cobots to enhance operators' capabilities

Equipment manufacturers are gearing up the technology embedded in Industry 4.0 systems to support this new mode of operation. Embedded processors and microcontrollers are operating at higher speeds with faster data transfers both within and between boards. The change is reflected in the use of high-speed interfaces, including industrial Ethernet and TSN for factory networking and MIPI for display systems (see Figure 2).

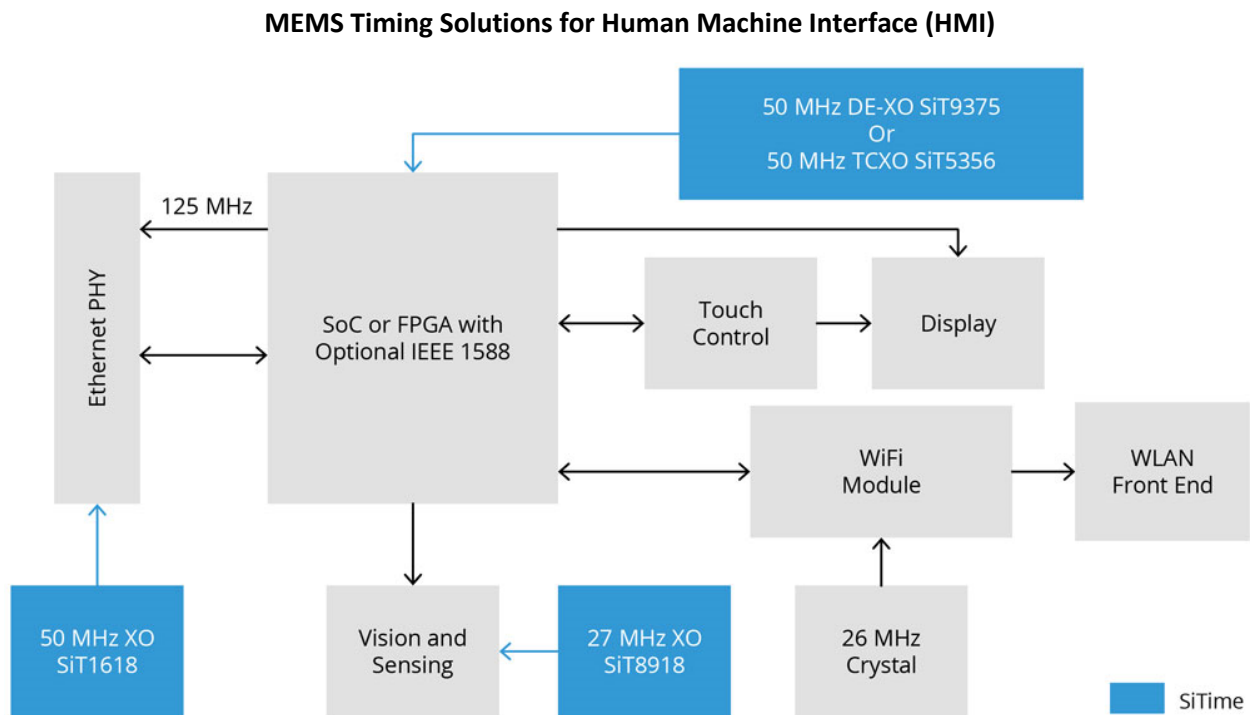


Figure 2: A typical application circuit for an industrial HMI shows the proliferation of high-frequency interfaces supported by robust timing devices

Similarly, the specifications of precision motor control systems are tightening to support the need for millimeter-accurate guidance in robots, cobots, and autonomous ground vehicles (AGVs), to protect the safety of human operators nearby. This calls for more advanced, high-speed processors and increased data traffic flows between position sensors and LiDAR scanners, and the digital devices that control them (see [Figure 3](#)).

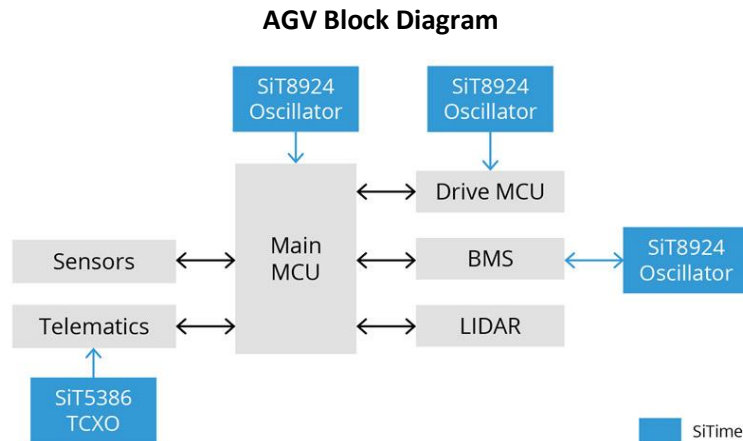


Figure 3: The typical application circuit of an AGV shows that high-speed devices such as MCUs are supported by robust oscillators

In these industrial applications that require high-speed data transfers, the margin for error in the timing system is sharply reduced. With every doubling of clock frequency, the allowable jitter – fluctuation in the temporal position of timing pulses – halves. When a clock’s jitter exceeds its specified threshold, it causes random bit errors that render an industrial control application slow and laggy. Industrial equipment designers therefore need to generate a timing signal that has low jitter, and that remains stable across all operating conditions.

The frequency instability of quartz XOs when exposed to temperature swings, shock and vibration, and noise militates against the designer’s efforts to achieve low jitter, clean timing signals, and reliable system operation (see [Figure 4](#)).

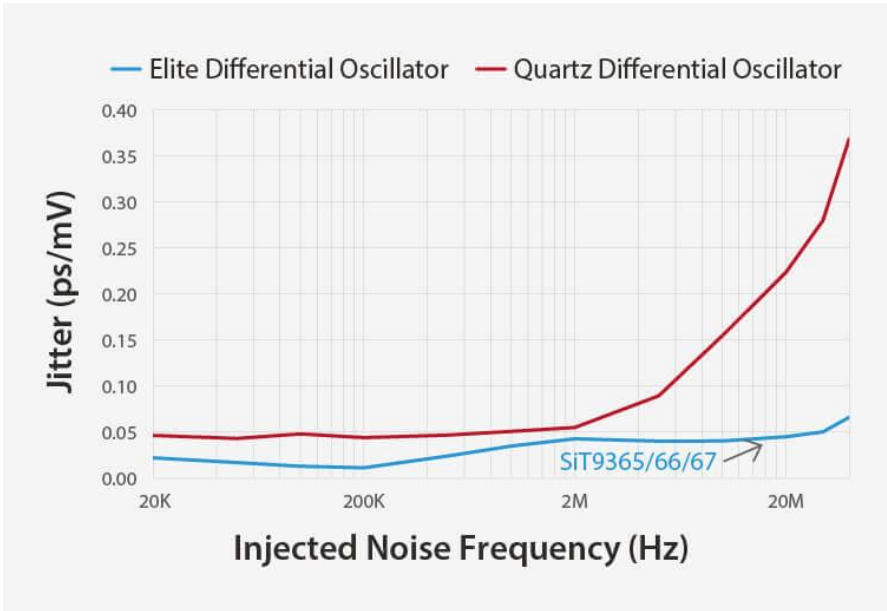


Figure 4: A SiTime XO is much more stable when exposed to noise than a typical quartz XO

The three advantages of MEMS timing in industrial applications

The instability of quartz oscillators when operating in industrial environments is an inherent consequence of the physical attributes of the quartz material, and the quartz XO's construction and packaging.

The physical construction of SiTime MEMS timing products is fundamentally different, and produces three advantages for industrial applications: reliability, programmability, and easier EMC compliance.

High reliability and long operating lifetime

SiTime timing solutions are completely fabricated in silicon, using standard semiconductor manufacturing processes. This produces semiconductor-level quality which is much higher than quartz. SiTime operates according to a six-sigma design and development philosophy and has a defect rate of less than 0.1 DPPM (see [Figure 5](#)).

SiTime MEMS resonators are built from single-crystal silicon, a defect-free material that is 15 times stronger than titanium. SiTime resonators are produced using the patented MEMS First[®] and EpiSeal[®] manufacturing processes that anneal the resonator at 1100°C. These processes produce a high-quality resonator that is fully encapsulated within a silicon die, making it free from contaminants, and extremely resistant to damage from external sources. MEMS resonators can be handled like standard CMOS chips and are packaged using standard IC packaging processes. The MEMS First process, an IATF 16949-certified semiconductor supply chain, and standard packaging processes ensure that MEMS oscillators have higher quality and reliability than quartz.

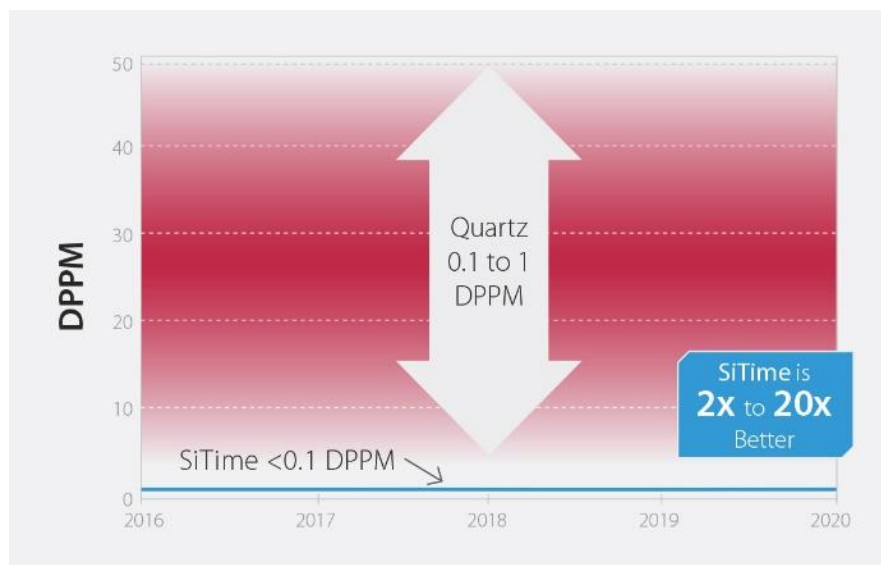


Figure 5: Comparison of the defect rate of production units of SiTime oscillators with that of widely used quartz XOs

These features are the reason why SiTime MEMS oscillators offer so much higher reliability in industrial applications than quartz timing products (see [Figure 6](#)).

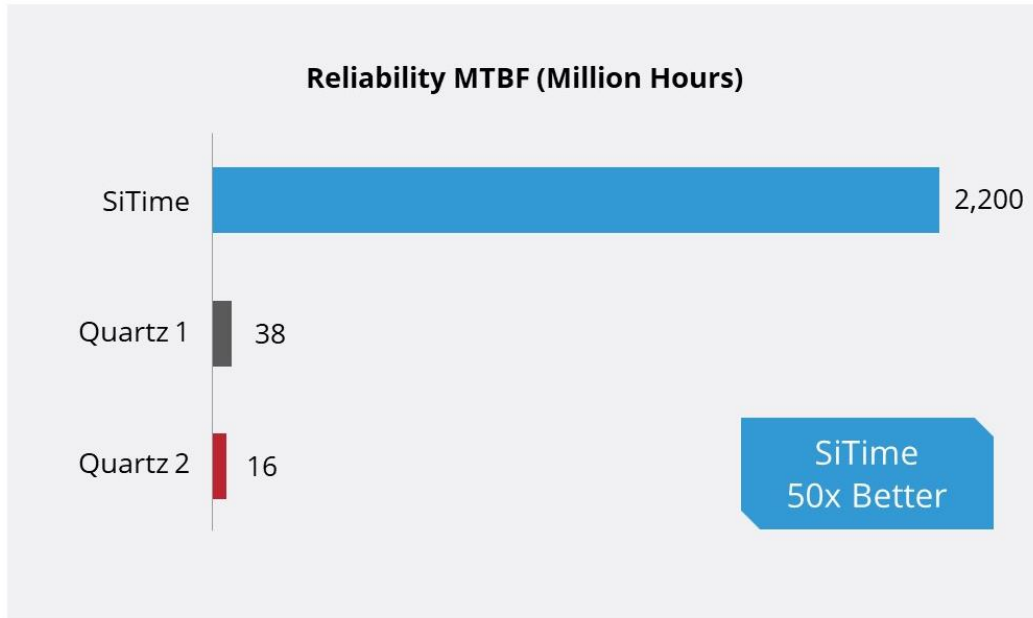


Figure 6: Comparison of the reliability in MTBF of SiTime oscillators against that of widely used quartz XOs

But other characteristics of the MEMS technology as implemented by SiTime provide additional benefits to manufacturers of industrial automation equipment.

Multiple programmable functions

The output frequency of SiTime MEMS oscillators is factory programmable. Most SiTime products can be programmed to provide any frequency, up to six decimal places, within a wide range. While frequencies in some market sectors are largely governed by regulation or standards, in the industrial sector, proprietary system designs give rise to a requirement for unique frequencies. The programmability of SiTime products readily satisfies this need.



Figure 7: Unlike quartz XO, SiTime MEMS XOs offer a wide range of configuration options, to enable designers to meet exact application requirements

The programmability of SiTime MEMS timing products has another benefit: multiple timing requirements can be satisfied by a single product, with each unit programmed to produce the required frequency. This streamlines inventory management.

It also reduces the cost and time associated with component qualification and can help accelerate time-to-market.

Component qualification is the process of testing electronic parts to ensure they meet specific requirements before they are integrated into a larger system or product. It's an important step in the development of electronic products, since parts that fail to meet the necessary standards can compromise the safety, reliability, and functionality of the entire system.

Because of the programmability of MEMS timing products, qualifying one SiTime part has the same effect as qualifying thousands or millions of SiTime parts. As [Figure 7](#) shows, SiTime oscillators can be configured to numerous combinations of specifications, so each product can generate thousands or even millions of part numbers.

The cost saving through eliminating the need for multiple qualification processes can amount to many tens of thousands of dollars. Development speed and production flexibility are enhanced by the availability of SiTime products programmed to order and ready to ship as fast as 48 hours.

Easier EMC compliance

Another feature available with many SiTime products is programmable rise and fall time of the clock signal. Additionally spread-spectrum capability is available in MEMS oscillators such as the [SiT9025](#). These EMI-reduction techniques make compliance with noise emissions standards substantially easier to achieve (see [Figure 8](#)).

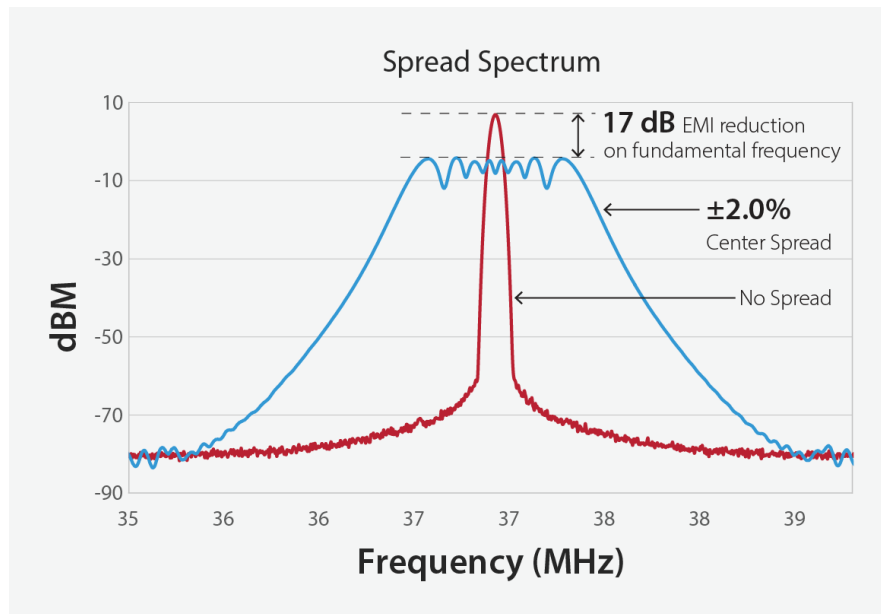


Figure 8: The SiT9025 spread-spectrum oscillator reduces a clock system’s EMI by 17dB

The SiT9025 is supported by SiTime’s Time Machine II programmer, which enables designers to instantly program spread modulation and/or drive strength. The SiT9025 is supplied in three industry-standard packages, so that customers can replace quartz products without any change to their board design.

This combination accelerates time to revenue by ensuring emissions compliance with minimum engineering effort.

MEMS Oscillators

The following table lists MEMS oscillator families for Industrial from SiTime [1].

Device	Frequency	Temp. Range (°C)	Stability (ppm)	Supply Current (Typ)	Output Logic	Features	Packages (mm)
SINGLE-ENDED OSCILLATORS Better reliability Pin-compatible footprints							
SiT1602 SiT8008/09	1 MHz to 137 MHz	-20 to 70, -40 to 85	±20, ±25, ±50	3.1 to 5.5 mA (0.6 - 1.0 µA stby)	LVCMOS	1.3 ps RMS phase jitter, Small 2016 QFN package	QFN: 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
SiT1618 SiT8918/19	1 MHz to 137 MHz	-40 to 105, -40 to 125	±20, ±25, ±30, ±50	3.6 to 5.4 mA (1.0 µA stby)			SOT23: 2.9 x 2.8
SiT2018/19		-40 to 105, -40 to 125					
SiT1630	32.768, 16.384 kHz	-10 to 70, -40 to 85, -40 to 105	75, 100, 150	1.0 µA		Small 2012 QFN package	QFN: 2.0 x 1.2
DIFFERENTIAL OSCILLATORS Better reliability 0.2 ps/mV power supply noise rejection (PSNR)							
SiT9501	14 standard frequencies	-20 to 70, -40 to 85, -40 to 95, -40 to 105	±20, ±25, ±30, ±50	-	LVPECL, LVDS, HCSSL, Low-power HCSSL, FlexSwing	Ultra-low jitter, small size	2.0 x 1.6, 2.5 x 2.0, 3.2 x 2.5
SiT9375/76/77	31 standard frequencies	-20 to 70, -40 to 85, -40 to 95, -40 to 105		-			
SiT9365/66/67*	1 MHz to 725 MHz	-20 to 70, -40 to 85, -40 to 105	±10, ±20, ±25, ±50	76 to 84 mA	Low-swing LVPECL, LVPECL, LVDS, HCSSL	0.21 ps RMS phase jitter	QFN: 3.2 x 2.5, 5.0 x 3.2, 7.0 x 5.0
SiT9120/21/22	1 MHz to 625 MHz	-20 to 70, -40 to 85		54 to 69 mA	LVPECL, LVDS	0.6 ps RMS phase jitter	
VCXOs ±25 to ±3200 ppm pull range, <1% linearity Better reliability 0.1 ppb/g accelerator sensitivity							
SiT3372/73*	1 MHz to 700 MHz	-20 to 70, -40 to 85, -40 to 105	±15, ±25, ±30, ±50	76 to 84 mA	LVPECL, LVDS, HCSSL	0.21 ps RMS phase jitter	QFN: 3.2 x 2.5, 5.0 x 3.2, 7.0 x 5.0

*Elite Platform products, **Emerald Platform products

Device	Frequency	Temp. Range (°C)	Stability (ppm)	Supply Current (Typ)	Output Logic	Features	Packages (mm)
EMI REDUCTION OSCILLATORS Most flexible EMI reduction options Low cycle-cycle jitter							
SiT9025	1 MHz to 150 MHz	up to -40 to 125	±20, ±25, ±50	5.0 to 5.6 mA (0.4 - 2.1 µA stby)	LVCMOS	40 spread options, up to ±2.0%, down to -4.0%	QFN: 2.0 x 1.6, 2.5 x 2.0, 3.2 x 2.5
SiT9005	1 MHz to 141 MHz	up to -40 to 85					
DCXOs In-system programmable Digital pull for low noise Up to ±1600 ppm pull, 5 ppt pull resolution, <1% linearity							
SiT3521/22*	1 MHz to 725 MHz	-20 to 70, -40 to 85, -40 to 105	±20, ±25, ±50	70 to 82 mA	LVPECL, LVDS, HCSL	I2C programmable, 0.23 ps RMS phase jitter	SMD: 5.0 x 3.2
Super-TCXOs ±1 ppb/°C ΔF/ΔT slope 5 ppt resolution frequency control 0.001 ppb/g acceleration sensitivity							
SiT5501	1 to 60 MHz	-40 to 85, -40 to 105	±0.01, ±0.02	-	LVCMOS, Clipped sinewave	±0.5 ppb/°C freq. slope, 0.5 ppb/day aging, 110 mW typical (2.5 V)	7.0 x 5.0 10-pin ceramic
SiT5356/57*	1 MHz to 220 MHz	-20 to 70, -40 to 85, -40 to 105	±0.1, ±0.2, ±0.25	40 to 45 mA	LVCMOS, Clipped Sinewave	I2C programmable, ±1 ppb/°C (ΔF/ΔT) slope, -40 to 105°C	5.0 x 3.2 ceramic
SiT5155/56/57*	1 MHz to 625 MHz	-20 to 70, -40 to 85, -40 to 105	±0.5, ±1, ±2.5				
STRATUM 3E OCXOs Airflow and thermal shock resistant Better holdover in dynamic conditions Smallest OCXO							
SiT5711**	1 MHz to 60 MHz	-20 to 70, -40 to 85	±0.005, ±0.008	180 mA (at 50°C in steady state)	LVCMOS, Clipped Sinewave	±50 ppt/°C ΔF/ΔT	9.0 x 7.0, 14.0 x 9.0, 25.0 x 22.0
SiT5712**	60 MHz to 220 MHz						
ClkSoCs Integrated MEMS resonator eliminates the need for quartz, along with quartz related issues							
Device	Phase Jitter (rms)	# of Inputs	# of Outputs	# of Clock Domains	Max Output Frequency	Features	Packages (mm)
SiT95141 Clock Generator	120 fs	4	10	4 PLL 1 time domain	2.1 GHz	Hitless switching, zero-delay buffer mode, DCO with 50-ppt resolution, programmable output delay control	9.0 x 9.0, 64-pin
SiT95145 Jitter Cleaner			10				
SiT95147 Network Synchronizer			8	4 PLLs 4 time domains			
SiT95148 Network Synchronizer			11				

The benefits of MEMS timing in industrial equipment

The latest generation of industrial equipment demands greater accuracy and operates at higher speed, with faster data transfers. This imposes more stringent requirements on timing operation, exposing the weaknesses of traditional quartz crystal oscillator technology.

Avoiding the compromises and workarounds associated with the use of traditional quartz XOs, manufacturers of industrial equipment that adopt MEMS timing solutions can create more reliable and higher-performance products. In the industrial automation market, users of SiTime products benefit from peace of mind, knowing the timing solution will operate reliably in hot, noisy, harsh conditions, without the risk that unpredictable or anomalous timing signals will perturb system operation.

Compared to conventional quartz XO timing products, SiTime MEMS oscillators offer:

- Higher resistance to shock and vibration
- Better frequency stability over temperature
- Better power supply and EMI noise rejection

In addition, SiTime programmable products support a streamlined supply chain and the quick availability of custom of frequencies.

For more information, go to www.sitime.com/solutions/industrial.

References

[1] SiTime Industrial Solutions: <https://www.sitime.com/solutions/industrial>

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