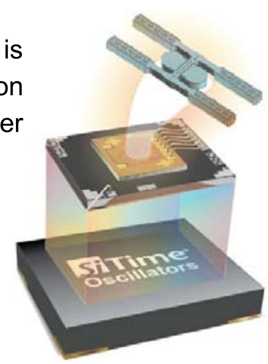
MEMS Oscillators: Enabling Smaller, Lower Power IoT & Wearables

The explosive growth in Internet-connected devices, or the Internet of Things (IoT), is driven by the convergence of people, device and data across the web. Future growth will be strongly influenced by wearable technology as products transition from the laptop to the pocket to the body. Activity trackers are leading this segment in number of units shipped per year, followed by smart watches and medical monitors/devices, as well as wearable cameras and smart glasses. These devices are enabled by advancements in MEMS and sensor technology, wireless connectivity and new power savings capability.

Wearable devices leverage new timing technology

All electronic products require one or more timing devices depending on the processor, partitioning and various functions in the system. Traditionally, 32.768 kHz crystals and low power MHz quartz-based oscillators have been used for implementing clock functions in battery-powered electronic systems. A new class of low current, low frequency 1 Hz to 32.768 kHz MEMS oscillators now offers advantages over the ubiquitous 32 kHz crystal clock.



Small size and low power are critical in IoT applications and wearable devices. Cost is also an important factor as many wearables fall into the consumer category. Innovation in MEMS timing technology is making significant contributions to space and power savings in new wearable applications, as well as improving reliability and costs.

Key benefits of MEMS timing solutions include:

- Smaller footprint
  - Smallest 32 kHz footprint in a 1.5 x 0.8mm CSP; 80% smaller than quartz
  - Oscillator output drives multiple loads and reduces component count
- Higher accuracy compared to quartz XTAL
  - 32 kHz XO is 2 to 3x more accurate over temperature; < 10 ppm at 25°C, 100 ppm over temp
  - 32 kHz TCXO is 30 to 40x more accurate over temperature; 5 ppm over temp
- Lower power:30 to 50% lower compared to XTAL + SoC oscillator
  - 32 kHz TCXO reduces system sleep-mode power up to 50%; 5 ppm accuracy means less reliance on network timekeeping updates
- Programmable frequency from 1 Hz to 32 kHz for sensor interface
- More resilient; 50x greater resistance to shock and vibration

All silicon MEMS timing solutions

Unlike quartz-based devices, silicon MEMS oscillators employ modern packaging technologies. MEMS oscillators consist of a MEMS resonator die mounted on top of a high-performance, programmable analog oscillator IC which is molded into standard low-cost plastic SMD packages, with footprints compatible with quartz devices. To support the space requirements of ultra-small applications, SiTime MEMS oscillators are available in ultra small CSP (chip-scale packages). MEMS oscillators are based on a programmable architecture that allows customization of features including frequency, supply voltage and other features.

Miniaturization through integration, smaller package size, and board layout flexibility

SiTime oscillators offer higher integration, new packaging options and other features that enable size reduction. The SiT15xx 32 MEMS timing solutions are designed for replacing traditional quartz crystals in mobile, IoT and wearable applications where space and power are critical. These devices are available in a 2.0 x 1.2 mm (2012) SMD package for designs that require crystal (XTAL) resonator compatibility. SiT15xx 2012 oscillators have power supply (Vdd) and ground (GND) pins in the center area between the two large XTAL pads as shown in Figure 1b.

For even smaller size, SiT15xx devices are available in a CSP (Figure 1a), which lessens footprint by up to 80% compared to existing 2012 SMD crystal packages and is 60% smaller than the 1610 (1.6 x 1.0 mm) XTAL package. Another option, as a result of SiTime's manufacturing processes, is the capability to integrate MEMS resonator die with a SOC, ASIC or microprocessor die within a package. This option eliminates external timing components and provides the highest level of integration and size reduction. Due to the limitations of crystal resonators, quartz suppliers cannot offer CSP or integrated solutions.

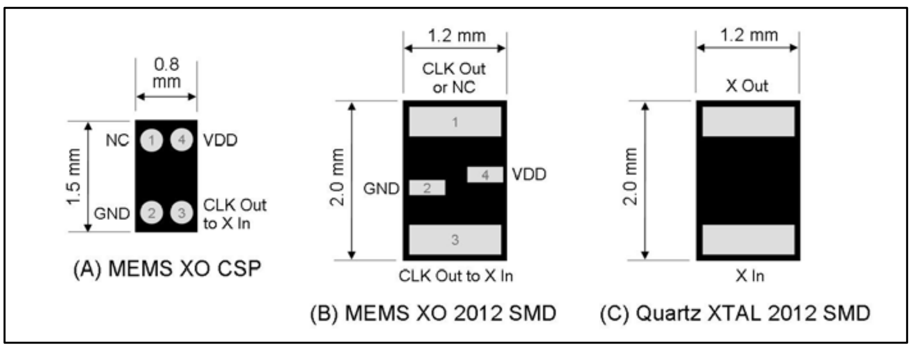
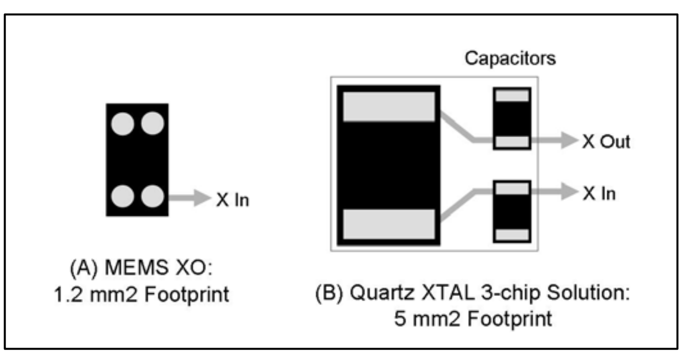


Figure 1: Package size and pin location of 32 kHz MEMS XO and TCXO compared to quartz XTALs

Unlike quartz crystals, the SiT15xx output drives directly into the chipset's XTAL-IN pin eliminating the need for output load capacitors as shown in Figure 2. Because the oscillator can drive clock signals over traces, it does not need to be placed adjacent to the chipset. This feature, combined with the ultra-low profile (0.55 mm height), enables flexibility in board layout and additional space optimization. In addition to eliminating external load capacitors, SiT15xx devices have special power supply filtering that eliminate the need for an external Vdd bypass-decoupling capacitor, further simplifying board design and miniaturization. Internal power supply filtering is designed to reject noise up to ±50 mVpp through 5 MHz.



	SiT15xx MEMS XO	Quartz XTAL
Package Footprint w/ Load Capacitors	1.2 mm^2	5 mm^2
Load Capacitors	No	Yes
Load Dependent Start-up	No	Yes
Bypass Caps	No	n/a

Figure 2: Total footprint of 32 kHz MEMS XO and TCXO compared to quartz XTAL and required capacitors

Extended battery life through low current consumption

Low frequency, low power 32 kHz timekeeping devices are widely used in mobile devices where the device is continuously ON for time keeping or controlling sleep modes. These low frequency oscillators are also used to time events such as monitoring and control functions in a power management IC (PMIC) used in battery-powered devices or to perform short system wakeup for timing reference synchronization.

Traditionally, systems generate the 32 kHz clock signal by connecting a tuning fork type or AT-cut quartz crystal to an on-chip pierce oscillator circuit. These quartz time-keeping oscillators are always ON and continuously drawing a few micro-amps. SiTime's SiT15xx 32 kHz MEMS oscillators draw less than a micro-amp of current and can run off a range of regulated or unregulated supply voltages, from 1.2 to 3.63V. Figure 3 plots a SiT153x oscillator drawing less than 1µA over supply and temperature.

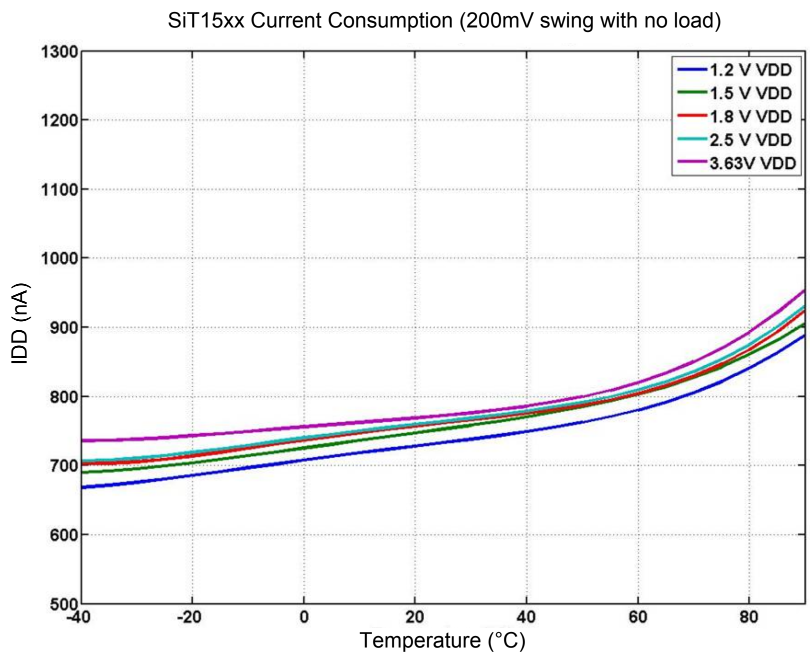


Figure 3: SiT153x draws less than 1µA over supply and temperature

Measured frequency stability

32 kHz MEMS timing devices have a temperature coefficient that is extremely flat across temperature compared to quartz crystals as shown in Figure 4. The SiT15xx oscillators are calibrated (trimmed) to guarantee frequency stability to less than 10 PPM at room temperature and less than 100 PPM over the full -40 to +85°C temperature range. In contrast, quartz crystals have a classic tuning fork parabola temperature curve with a 25°C turnover point as indicated by the red lines in Figure 4.

Figure 5 plots the frequency stability of 32 kHz MEMS TCXOs. In these devices, the temperature coefficient is calibrated and corrected over temperature with an active temperature correction circuit. The result is a 32 kHz TCXO with less than 5 ppm frequency variation over temperature. This low level of frequency variation results in extremely accurate clocks that translate to significant power savings. With higher accuracy, wireless systems are less reliant on network timekeeping updates and can stay in sleep mode for much longer periods of time.

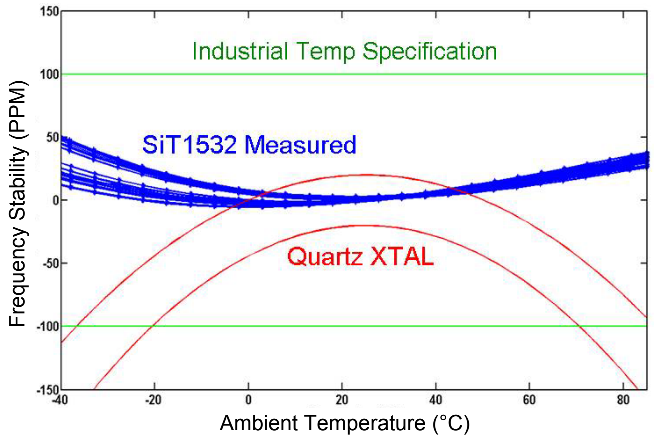


Figure 4: SiT1532 MEMS XO frequency stability trimmed to <10 ppm at 25°C compared to quartz XTAL -160 to -200 ppm over temp at 25°C

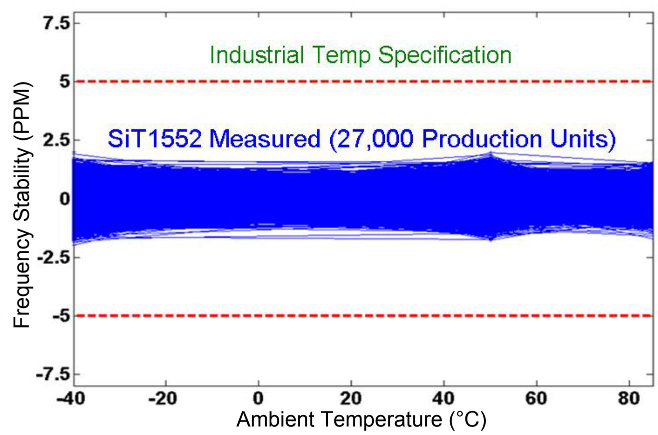


Figure 5: SiT1552 MEMS TCXO frequency stability is 30 to 40 times more accurate than quartz XTAL

Extended battery life through better frequency stability

Frequency stability, the clock's stability over voltage and temperature, translates to power conservation. Many mobile devices reduce power consumption by shutting down the functional blocks with the highest current drain when inactive. However, the system must wakeup and periodically communicate with the network. Higher frequency stability allows the device to stay in its low power state, or sleep state, for longer periods, resulting in significant power savings.

Many wearables continuously collect data, compress and upload it to the cloud via an Internet hub device such as a smart phone. This upload is transferred in short bursts that last a few milliseconds and then the device goes to sleep to conserve power. The cyclic sleep scenario is typical of battery powered devices where the device core is shut down for a pre-set time called "sleep time" typically in the range of 2 to 10 seconds and woken when it needs to transmit data during a short burst. The connection event is the "ON" time during which certain functional blocks of the device wake up and stay active for short periods.

Power consumption is proportional to the ratio of "ON" time to the time devices spend in the "sleep" state. And the sleep clock accuracy (SCA) of the 32 kHz clock that is used to time the sleep state has a direct impact on the battery life. Sleep clock inaccuracies cause the radio receiver (RX) to turn on earlier and stay on longer to avoid missing packets from the master. Clock inaccuracy, measured in PPM, causes early ON time (ΔT) as shown in figure 6. ΔT = (SCA) * (SLEEP TIME).

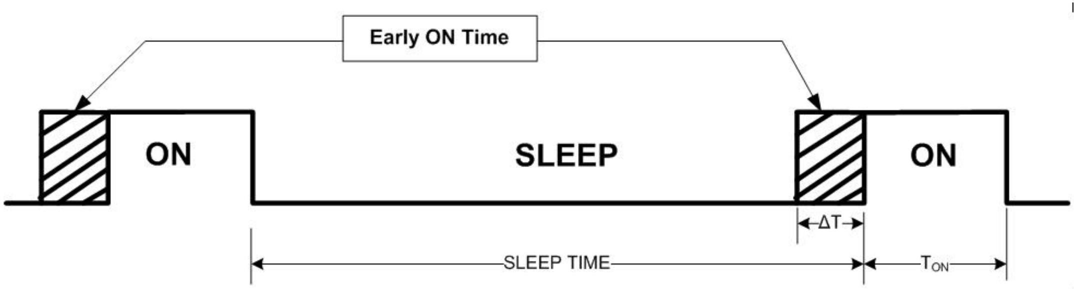


Figure 6: Early ON time (or window widening) is effected by clock accuracy and causes a power penalty

The following table shows that tighter slave clock accuracy reduces early ON time, thereby reducing power consumption.

Sleep Clock Accuracy \ Sleep Interval	2 Seconds	20 Seconds	50 Seconds
	Early ON Time		
5 ppm	0.01 ms	0.1 ms	0.25 ms
50 ppm	0.10 ms	1.0 ms	2.5 ms
70 ppm	0.14 ms	1.4 ms	3.5 ms
200 ppm	0.40 ms	4.0 ms	10.0 ms

The SiT1552 MEMS-based TCXO, with less than 5 ppm frequency variation over temperature, is a much more accurate alternative than quartz crystals. This accuracy reduces ON time and allows the system to stay in sleep mode. Using a SiT1552, system designers can leverage compression and transmit data in short bursts only when required while keeping the device in its lowest power sleep state for extended periods and potentially achieve up to twice the battery life extension. Figure 7 shows the increased battery life gained through using a 5 ppm 32 kHz TCXO compared to a 180 ppm 32 kHz quartz crystal resonator.

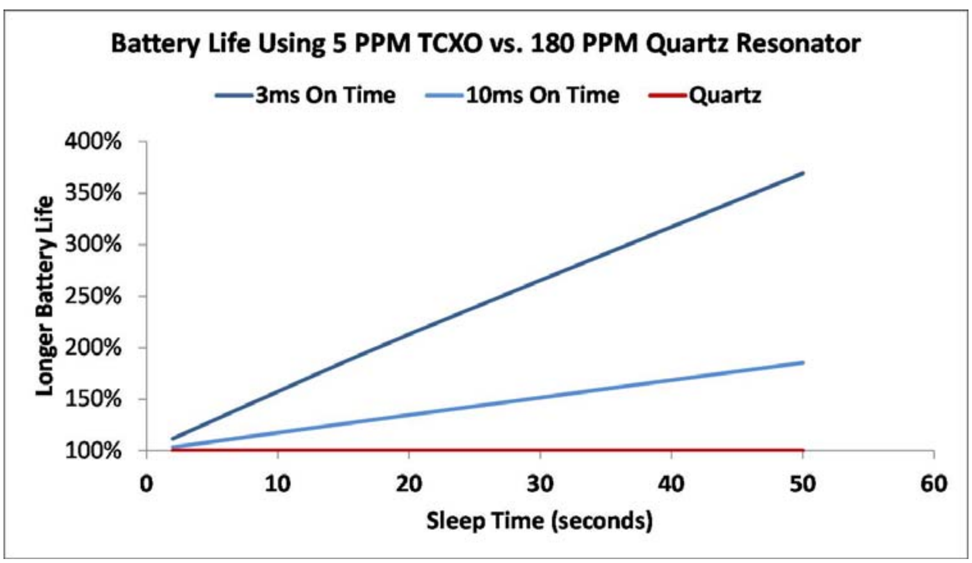


Figure 7: Battery life through use of MEMS TCXO compared to quartz XTAL resonator

Extended battery life with programmable features

The analog oscillator IC in SiT15xx devices supports several functions including a low noise sustaining circuit, an ultra-low power precision PLL and an ultra-low power programmable output driver. The fractional-N PLL with sub-hertz resolution, is used for device calibration and frequency programming from 32.768 kHz down to 1 Hz. The capability to lower output frequency significantly reduces current consumption. Quartz XTALs, due to the physical size limitations of the resonator at low frequencies, do not offer frequencies lower than 32.768 kHz. With lower frequency options, the SiT15xx family enables new architecture possibilities in battery-powered applications where the reference clock is always running.

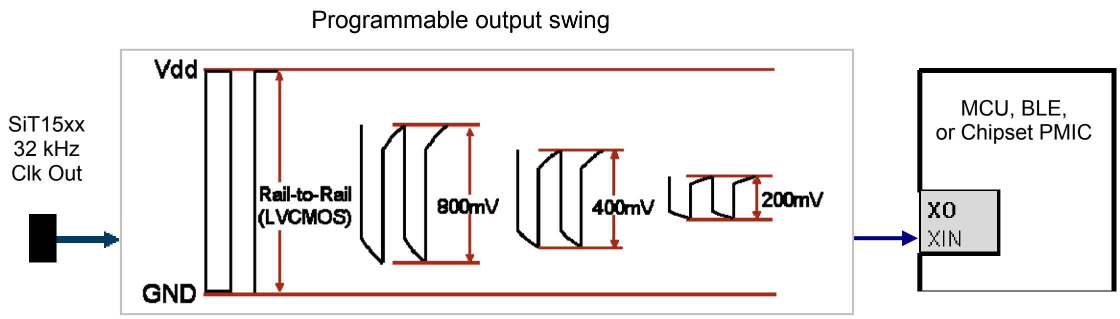


Figure 6: Unique NanoDrive™ output swing is programmable down to 200 mV to minimize power

Unlike standard oscillators, SiT15xx oscillators can function in tandem with the on-chip 32 kHz oscillator circuit via the oscillator's highly programmable output driver. The output driver can generate various common mode voltages and swing levels to match different implementations of the on-chip 32 kHz oscillator circuits as shown in Figure 6. This output swing is factory programmable from full swing down to 200 mVpp for the lowest power. The ability to reduce output frequency and output driver current significantly reduces the output load current (C*V*F). See SiT15xx datasheets for load calculation details and examples at www.sitime.com/products/32-khz-oscillators.

MEMS are 50 times more robust

By nature of their application, IoT and wearables are used in a variety of environments and can be subjected to frequent and extreme mechanical shock and vibration. When operating in harsh environments, quartz oscillators will degrade and not conform to datasheet specifications. Some quartz oscillators are especially sensitive to sinusoidal vibration and shock, and will exhibit significant frequency variation. The SiT15xx device architecture lends itself to higher reliability and resiliency to environmental factors relative to their quartz counterparts. The very small mass (3000 times smaller than quartz resonators) and structural design of SiTime resonators make them extremely immune to external forces such as vibration and shock.

For more details on the resiliency and reliability of MEMS oscillators, see applications notes at: http://www.sitime.com/support/application-notes.

Application and design examples

In the wearable market, products are increasing in functionality, while at the same time they must consume less power and space. 32 kHz MEMS timing solutions can be used for true pulse-per-second (pps) timekeeping, RTC reference clocking and battery management timekeeping to lengthen battery life and shrink footprint.

Figure 7 shows the clocking needs in a typical wearable device. A low power 32-bit MCU runs off a 16 MHz crystal to clock the core and peripherals, and a 32 kHz crystal is used for real-time clocking. The MCU sends data to a connectivity chip that runs off a 32 kHz crystal used for sleep clock timing.

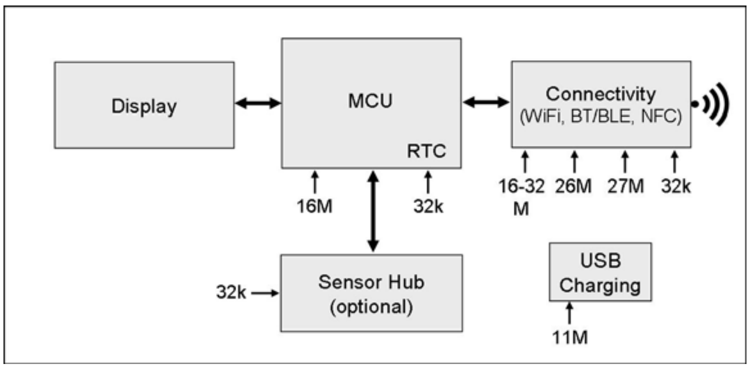


Figure 7: Typical wearable timing architecture

Figure 8 illustrates a design where a programmable 1Hz to 32 kHz SiT1534 MEMS oscillator is used for the sensor application and a 32 kHz MEMS SiT1532 reference clock drives the RTC in an MCU. In this design, the board space is reduced to less than half through use of 1.5 x 0.8 mm CSP oscillators.

Figure 9 shows an architecture where a 32.768 kHz timing solution is required for two chips; one a reference clock for the microcontroller and a second is the sleep clock for the BlueTooth chip. In this design a single MEMS timing device (either a SiT1532 oscillator or a SiT1552 TCXO), in a tiny 1.5 x 0.8 mm CSP, drives two loads. Since the XO/TCXO can drive two loads, one 32 kHz MEMS device will replace two 32 kHz quartz XTALs. The footprint is eight times smaller than a design that uses two quartz XTALs in 2012 SMD packages plus the four required load capacitors. This design also saves significant power with 100 times better stability of a SiT1552 compared to the BLE chip's internal 32 kHz RC over temperature.

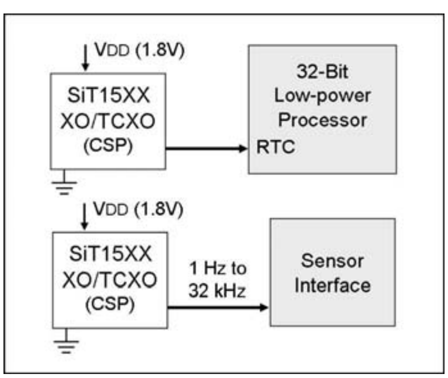


Figure 8: Fitness device timing example 1

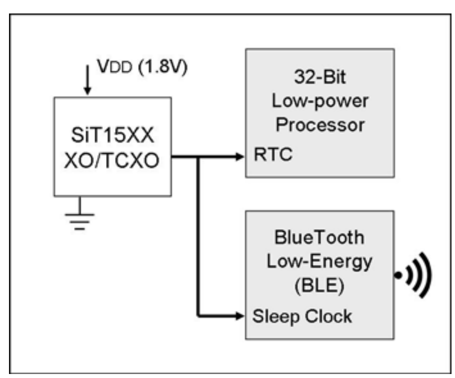


Figure 9: Fitness device timing example 2

Summary

Innovation in the rapidly growing wearable and IoT segments is fueled by advancements in underlying technologies. New MEMS timing technology is one of the key supporting technologies enabling the trends toward smaller size, lower power and increased robustness.

A small form factor MEMS-based 32 kHz XO/TCXO offers an alternative to the 180 to 200 ppm quartz crystal-based clock sources used in past designs.

MEMS timing reduces footprint through:

- Smaller, unique packages
- Higher integration that reduces component count
- Board layout flexibility

MEMS timing reduces power consumption through:

- Lower core current draw
- Higher frequency stability that enables longer sleep states
- Programmable frequency
- Programmable output swing voltage

MEMS timing increases robustness through:

- Greater resistance to shock and vibration error

As the IoT continues to expand with increasingly smaller, battery-powered devices, SiTime's ultra-small, low power, low frequency MEMS-based oscillators provide the optimal timing solution and enable new products that were not previously possible with bulky, less accurate quartz products.

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