MEMS Timing Technology:
Shattering the Constraints of Quartz Timing to Improve Smartphones and Mobile Devices

The trends toward smaller size and increased functionality continue to dominate in the mobile electronics market. As OEMs and ODMs develop small feature-rich devices, they must design products within a tight power budget. In addition, mobile products are developed in a cost-competitive environment where time-to-market is critical.

Improving form and functionality are dependent on components that can deliver smaller size with more features and higher performance, at the right price point. There is no indication these trends will slow, yet traditional quartz-based timing components are reaching their limits of size reduction, performance improvement and cost reduction. As consumer products become more feature rich, they require new timing solutions.

Table 1: Example of timing component usage in Smartphones and tablets

Component	Application	Usage
32 kHz	Timekeeping, Sleep clock	All phones and tablets, 1 to 2 per phone
MHz resonators	Reference clock	2 to 4 per Smartphone or tablet Apps processor, WiFi, NFC, USB…
TCXO	GPS and RF	Smartphone and tablet with GPS

5 Timing ICs

All-Silicon MEMS Timing

Mobile device makers no longer need to depend on inflexible quartz devices to provide timekeeping or reference clocks in their products. The latest timing innovations are based on micro-electro mechanical systems (MEMS) technology which brings significant advantages to mobile consumer electronics. These silicon MEMS timing solutions provide several benefits for mobile applications compared to legacy 32 kHz quartz crystals (XTALs).

- Smaller size – up to 85% size reduction
- Lower power for long battery life – up to 50% less power
- Improved shock and vibration resistance for long life – up to 30x better
- Superior stability – 2x better stability over industrial temperature
- Reduced component count – 1-chip compared to 3 components required with quartz XTALs

MEMS Oscillators Improve Mobile Systems

A typical Smartphone or tablet design, depending on the applications processor, partitioning and other functions it supports, can contain several timing devices including one or more 32 kHz XTALs.

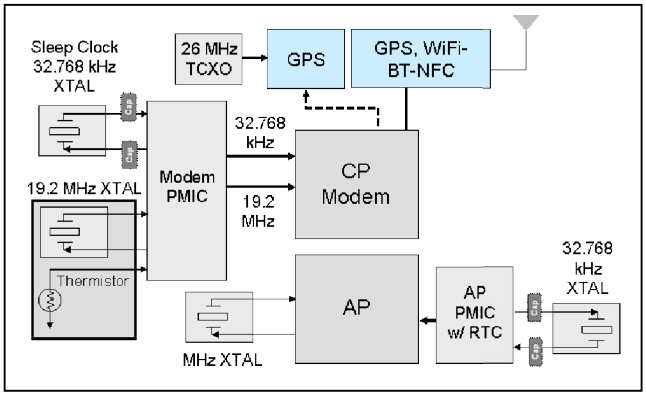

Figure 1: Smartphone block diagram

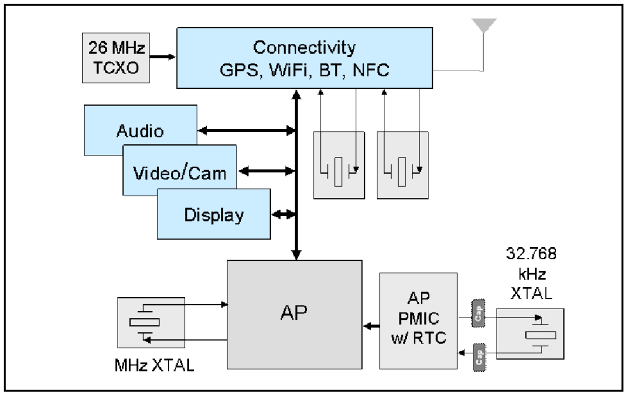

Figure 2: Tablet block diagram

In smart mobile systems, the 32 kHz XTALs can be replaced with SiT15xx 32 kHz MEMS oscillators (see Table 2) to reduce size and power consumption. MEMS oscillators such as the low-power SiT1602 or SiT8008 (see Table 3) can provide MHz reference clocks for improved performance. These MEMS oscillators have low power consumption with additional power saving features, and they are extremely robust, lead-free, RoHS and REACH compliant.

Table 2: Ultra-low-power 1 Hz to 32 kHz MEMS oscillators (SiT15xx)

Device	Frequency	Temp. Range (°C)	Stability (PPM)	Package Size (mm x mm)	Supply Voltage (V)	Supply Current
The SiT153x family is optimized for **regulated** supply applications such as coin-cell or super-cap battery backup						
SiT1532	32.768 kHz	-10 to 70 or -40 to 85	±20 at 25°C, ±75 at -10 to 70°C, ±100 at -40°C to 85°C	1.5 x 0.8 CSP	1.2 to 3.63	750nA (typical)
SiT1533	32.768 kHz			2.0 x 1.2 SMD		
SiT1534	Programmable 1 Hz to 32.768 kHz			1.5 x 0.8 CSP or 2.0 x 1.2 SMD		
The SiT154x family is optimized for **unregulated** Li+ battery-powered applications						
SiT1542	32.768 kHz	-10 to 70 or -40 to 85	±20 at 25°C, ±75 at -10 to 70°C, ±100 at -40°C to 85°C	1.5 x 0.8 CSP	2.7 to 4.5	750 nA (typical)
SiT1543	32.768 kHz			2.0 x 1.2 SMD		
SiT1544	Programmable 1 Hz to 32.768 kHz			1.5 x 0.8 CSP or 2.0 x 1.2 SMD		

Table 3: Low-power MHz MEMS oscillators (SiT1602/SiT8008)

Device	Frequency	Temp. Range (°C)	Stability (PPM)	Package Size (mm x mm)	Supply Voltage (V)	Supply Current
SiT1602	50 frequencies	-20 to 70 or -40 to 85	±20, ±25 or ±50 over temp.	As small as 2.0 x 1.6	1.8, 2.5 to 3.3	1.2uA (typ standby); 3.6mA (typ active)
SiT8008	Programmable 1 to 110 MHz					

Reduce Size with 32 kHz MEMS Oscillators

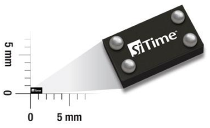

Figure 3:
Smallest 32 kHz device
(1.5 x 0.8 x 0.55H mm CSP)

A typical MEMS oscillator is an all-silicon device, comprising a MEMS resonator die stacked on top of a high-performance analog oscillator IC. MEMS oscillators are molded into standard low-cost SMD plastic packages with footprints as small as 2.0 x 1.2 mm, making them ideal for applications that require XTAL footprint compatibility. To support the demand for even smaller mobile devices, the SiT15xx MEMS oscillators are also available in 1.5 x 0.8 x 0.55H mm CSPs (chip scale packages). Quartz suppliers cannot offer chip-scale packaging.

The SiT15xx 32 kHz family is ideal for replacing traditional quartz crystals in mobile applications where space is critical. The SiT15xx CSP solution reduces footprint by as much as 85% compared to common 2.0 x 1.2 mm SMD XTAL packages. Unlike XTALs, the SiT15xx family has a unique output that drives directly into the chipset's XTAL-IN pin. The external components that are required with traditional quartz XTALs are no longer needed (See Figures 4 and 5). In addition to eliminating external output load capacitors, the SiT15xx devices have special power supply filtering and thus, eliminate the need for an external Vdd bypass-decoupling capacitor. This feature further simplifies the design and keeps the footprint as small as possible. Internal power supply filtering is designed to reject noise up to ±50 mVpp through 5 MHz.

The low-profile (0.55 mm height) MEMS oscillator output gives designers additional flexibility in component placement. Because the oscillator can drive clock signals over traces, it does not need to be placed adjacent to the chipset, allowing the board designer to further optimize board layout and space.

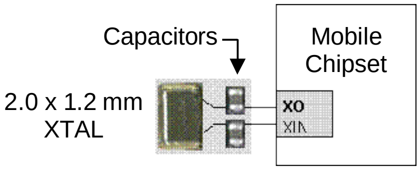

Figure 4: Three devices are required for quartz XTAL timing consuming a total footprint of 7.98 mm^2 (2012 DFN + 2 ea 0201 caps)

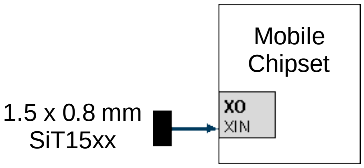

Figure 5: MEMS single chip footprint is 1.2 mm^2 (1508 CSP), an 85% reduction in board area

Reduce Power with 32 kHz MEMS Oscillators

The SiT15xx 32 kHz family has an ultra-low power output that consumes only nanoamps of current and has unique power savings features to extend battery life.

- Lowest power 32 kHz oscillator at 750nA core supply current (typical)
- Operation down to 1.2V to support coin-cell or supercap battery backup
- Programmable frequency down to 1 Hz to save power
- NanoDrive™ output reduces swing to consume up to 40% less power than full swing LVCMOS

The frequency of SiT15xx devices is programmable from1 Hz to 32.768 kHz in powers of two. Reducing the frequency significantly reduces the output load current (C*V*F). For example, reducing the frequency from 32.768 kHz to 10 kHz improves load current by 70%. Similarly, reducing the output frequency from 32.768 kHz down to 1Hz reduces the load current by more than 99%. (See examples on pages 4-5.) Quartz XTALs, due to the physical size limitations of the resonator at low frequencies, cannot offer frequencies lower than 32.768 kHz.

With lower frequency options, the SiT15xx family enables new battery-powered architecture possibilities and is ideal for devices where the low-frequency reference clock is always running. Target applications include pulse-per-second (PPS) timekeeping and power management monitoring and timekeeping.

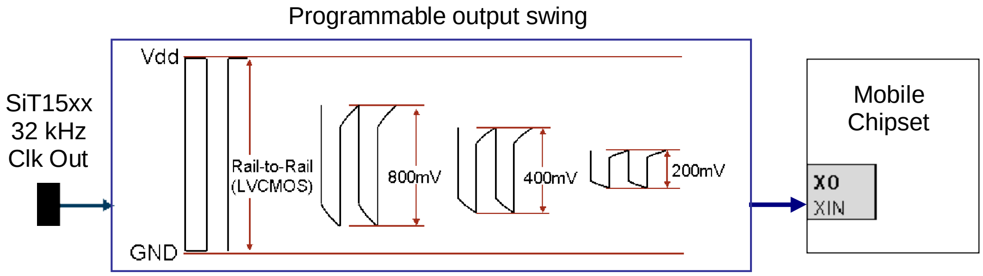

Figure 6: Unique NanoDrive™ output swing is programmable down to 200 mV to minimize power

The SiT15xx devices also have NanoDrive, a unique programmable output swing shown in Figure 6. This programmable output stage is optimized for low voltage swing to minimize power and maintain compatibility with the downstream oscillator input. The output swing is programmable from full swing down to 200 mV, to match the chipset and significantly reduce power.

Reduce Current Consumption using Programmable Features of 32 kHz MEMS Oscillators

The following examples illustrate how reducing the output swing and frequency impact current consumption. The lowest possible current consumption is achieved by using programmable NanoDrive to reduce output swing and by reducing output frequency to 1 Hz. This combination can virtually eliminate the current consumption from the output stage and load current.

No Load Supply Current – When calculating no-load power for SiT15xx devices, the core and output driver components need to be added. Since the output voltage swing can be programmed for reduced swing between 250 mV and 800 mV, the output driver current is variable. Therefore, no-load operating supply current is broken into two sections, core and output driver. The examples below illustrate the low-power benefits of the NanoDrive reduced swing output. For example, no load current is improved by over 20% when compared to an LVCMOS (2.1V) swing.

The equation is as follows:

> Total Supply Current (no load) = Idd Core + Idd Output Stage
> Where,
> - Idd Core = 750nA
> - Idd Output Stage = (165nA/V)(Voutpp)
> - For NanoDrive reduced swing, select the output voltage swing, or VOH/VOL

Example 1: Full-swing LVCMOS

- Vdd = 3.3V (Avg)
- Voutpp = 2.1V (max output of device)
- Idd Core = 750nA
- Idd Output Stage = (165nA/V)(2.1V) = 347nA

No Load Supply Current = 750nA + 397nA = **1097nA**

Example 2: NanoDrive™ Reduced Swing

- Vdd = 3.3V (Avg)
- NanoDrive Output Selection:
- Voutpp = VOH – VOL = 0.6V
- Where, VOH = 1.1V, VOL = 0.5V
- Idd Core = 750nA
- Idd Output Stage = (165nA/V)(0.6V) = 100nA

No Load Supply Current with NanoDrive = 750nA + 100nA = **850nA**

Total Supply Current with Load – To calculate the total supply current, including the load, follow the equation listed below. The additional load current comes from a combination of the load capacitance, output voltage, and frequency (C*V*F). Since the SiT15xx includes NanoDrive reduced swing output and a selectable output frequency down to 1 Hz, these two variables will significantly improve load current.

The benefits of NanoDrive really become significant when the load current is considered. Power is reduced by greater than 40% with NanoDrive as shown in Example 4. Reducing the output clock frequency reduces the load current significantly as shown in Example 5.

Total Current = Idd Core + Idd Output Driver + Load Current
Where,
- Idd Core = 750nA
- Idd Output Stage = (165nA/V)(Voutpp)
- Idd Load = CLoad * Vout * Frequency
- Assume load capacitance is 10pF

Example 3: Full-swing LVCMOS
- Vdd = 3.0V (Avg)
- Voutpp = 2.1V (max output swing for this device)
- Idd Core = 750nA
- Idd Output Driver: (165nA/V)(2.1V) = 347nA
- Load Current: (10pF)(2.1V)(32.768kHz) = 688nA

Total Current with Load = 750nA + 347nA + 688nA = **1785nA**

Example 4: NanoDrive™ Reduced Swing
- Vdd = 3.0V (Avg)
- NanoDrive Output Selection:
- Voutpp = VOH – VOL = 0.5V
- Where, VOH = 1.1V, VOL = 0.6V
- Idd Core = 750nA
- Idd Output Stage = (165nA/V)(0.5V) = 83nA
- Load Current: (10pF)(0.5V)(32.768kHz) = 164nA

Total Current with Load = 750nA + 83nA + 164nA = **997nA**

Example 5: NanoDrive™ Reduced Swing and 1Hz Output Frequency
- Same conditions as above example 2, but with output frequency = 1Hz. This will significantly reduce the current consumption from the output stage and the load.
- Idd Core = 750nA
- Idd Output Stage = (5.04pA/V)(0.5V)(1Hz) = 2.52pA
- 1Hz Output Frequency impacts the load current as shown below:

Load Current = CVF = (10pF)(0.5V)(1Hz) = 5pA
Total Supply Current with Load = Core Current + Output Stage Current + Load Current = 750nA + 0.00252nA + 0.005nA = **750nA**

Improve Accuracy with 32 kHz MEMS Oscillators

Aging and variation in frequency stability are error sources that contribute to clock inaccuracy. Frequency stability is the clock's stability over voltage and temperature. The SiT15xx family is factory calibrated (trimmed) to guarantee frequency stability to be less than 20 PPM at room temperature and less than 100 PPM over the full -40°C to +85°C temperature range. Unlike quartz crystals that have a classic tuning fork parabola temperature curve with a 25°C turnover point, the temperature coefficient of SiT15xx devices is extremely flat across temperature. This family maintains less than 100 PPM frequency stability over the full operating temperature range when the operating voltage is between 3.0V and 4.3V, and 150 PPM frequency stability for low-voltage operation down to 2.7V.

Aging defines the clock's frequency stability over time, typically measured in 1-year intervals. Aging of the SiT15xx devices is ± 3 PPM at 25°C compared to ± 5 PPM in quartz XTALs.

Improve Reliability with 32 kHz MEMS Oscillators

Mobile products can be subjected to harsh environments. MEMS oscillators outperform quartz devices under various conditions such as mechanical shock and vibration, EMI and extreme temperatures. With 50,000 *g* shock, 70 *g* vibration and 2 FIT reliability, the inherent durability and small mass of silicon MEMS resonators make them much more robust compared to quartz. For more details on the resiliency and reliability of MEMS oscillators, see applications notes at www.sitime.com/support/application-notes.

In addition to mechanical robustness and FIT reliability, MEMS oscillators have reliable startup over temperature. MEMS oscillator combine a correctly matched resonator and sustaining circuit within the same package, eliminating the start-up issues common with quartz XTALs.

Summary

Mobile product designers and manufacturers require new solutions that enable rapid innovation. Technology advances in MEMS timing has quickly excelled and surpassed quartz timing. MEMS-based oscillators now deliver the size, performance and features required by leading mobile devices.

- Smaller and thinner design enabled by ultra-small timing solutions
- Longer battery life with low power oscillators and unique power saving features
- Higher reliability and resistance to shock and vibration
- Higher performance with better stability and accuracy

Table 4: Summary comparison of quartz XTALs to SiT15xx MEMS oscillators

Spec	Quartz Resonator	SiTime MEMS XO (SiT15xx)
Size	3 devices – more components, larger footprint	1 chip – 85% smaller
Power	1.5 mA	0.75 mA – 50% lower power
Stability	20 ppm at room temp, 160 ppm over industrial temp.	20 ppm at room temp., 100 ppm over industrial temp.
Frequency	32 kHz – no flexibility	1 Hz to 32 kHz – lower frequency, lower power
Aging	± 5 ppm	± 3 ppm – more accurate time
Robustness	Brittle in small sizes	Very robust – 50,000 *g* shock, 70 *g* vibration

MEMS oscillators are designed with a programmable platform that make them highly flexible. In addition to size and performance benefits, MEMS timing offers significant supply chain advantages. As part of the fabless semiconductor ecosystem, SiTime leverages the massive semiconductor manufacturing, packaging and test infrastructure to offer cost-effective solutions with very short lead times.

As mobile devices become more sophisticated and timing requirements increase, SiTime's ultra small MEMS-based solutions are the ideal solution for smart mobile applications.

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