Electronic PRODUCTS

## Let’s talk oscillators

Quartz crystals and crystal oscillators are shrinking without sacrificing performance or cost

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Due to their high Q and stable temperature properties, quartz crystal oscillators have been important clock sources in consumer, commercial, industrial, and military products for many years. The demand for quartz crystals and crystal oscillators has been increasing steadily between 4% and 10% annually since the “dotcom” market collapse in 2000 to 2001.

The total market in 2008 exceeded $4.1B. The year 2008 marked the 90th anniversary of the birth of the first quartz oscillator. These old horses the quartz crystals and crystal oscillators can be found in almost all portable and stationary electronic equipment around us. One good portable example is the cellular handset.

In the earlier days, a typical GSM handset had four different sets of piezoelectric frequency control and generation components: RF SAW filter (900 MHz to 2 GHz using piezoelectric lithium tantalate or lithium niobate) for transmission and receiving filtering between the antenna and the transceiver chipset; IF SAW filter (50 to 400 MHz using mainly quartz) if superheterodyne down conversion was used; TCXO (13/26 MHz using quartz crystal) as clock reference in the transceiver synthesizer for channelization; and tuning fork (32.768 kHz using quartz crystal) for standby clocking in the baseband section.

Later on, the successful development of direct conversion technology obsoleted the IF SAW filter in many GSM handsets. A few years ago GSM transceiver chipsets with on-chip digitally compensated crystal oscillator (DCXO) circuits eliminated the need of TCXO. However, an off-chip quartz crystal is still needed.


### Consumer demand

Nowadays handsets don’t seem to get smaller, as they are quite small already. In fact, some handsets are

becoming bigger to accommodate more functions desired by consumers multiband, multimode, DSC, DVC, MP3, GPS, internet access, Bluetooth, DTV, etc.

Opposite to the earlier thought that fewer and fewer off-chip quartz crystal, crystal oscillator and SAW components would be needed as time progressed, handsets nowadays have many more of them quartz tuning fork, quartz crystal, crystal oscillator, voltage-controlled crystal oscillator (VCXO), TCXO, and RF SAW/FBAR (film bulk acoustic resonator) filter/duplexer. Though the unique fabrication and encapsulation requirements of these components render them close to impossible to be integrated onto the mature silicon-based IC platforms, they have become very small, and they provide excellent frequency control and generation functions to support the demanding requirements from the handset designers.

Powered by the fierce growth in the wireline and wireless markets, quartz crystal and its high frequency version SAW devices are being used widely and range from a simple passive quartz crystal for an electronic toy to a complex synchronous timing module (STM) for the backbone clocking of the most sophisticated telecom networks, as shown in *Table 1*.

**Table 1. Crystal- and SAW-based products**

| Crystal-based (<MHz to 200 MHz) | SAW-based (<50 MHz to 2.5 GHz) |
|---|---|
| Passives | |
| Tuning Fork and AT-Cut Crystal | SAWR |
| MCF | SAWF |
| Oscillators | |
| CXO (=XO=SPXO) | CSO |
| PCXO (Programmable) | PCSO |
| VCXO (Voltage-Controlled) | VCSO |
| TCXO (Temperature-Compensated) | TCSO |
| OCXO (Oven-Controlled) | OCSO |
| Timing Modules | |
| CDR (Clock Data Recovery) | CDR (Clock Data Recovery) |
| CS (Clock Smoother) | CS (Clock Smoother) |
| FX (Frequency Translator) | FX (Frequency Translator) |
| STM (Synchronous Timing Module) | STM (Synchronous Timing Module) |

The tremendous growth of electronic equipment for the entertainment, gaming and portable markets in the past few years propels the demand of smaller and smaller quartz crystals and crystal oscillators to an unprecedented level. Though unthinkable a few years ago, MHz quartz crystal as small as 2.0 x 1.6 $mm^2$ is now being shipped in volume. Plastic-molded with metal tubular encapsulated 32.768-kHz quartz tuning forks have been available for many years.

Recently quartz tuning forks using the traditional megahertz-quartz-crystal-packaging methods became available in real small sizes 4.1 x 1.5, 3.2 x 1.5 and 2.0 x 1.2 $mm^2$. The thrust now is to push the thickness of such quartz tuning forks to 0.4 mm or lower for low-profile applications. Applications that need even smaller quartz crystals (1.6 x 1.0 and 1.0 x 0.8 $mm^2$) are expected to appear in the next couple of years and quartz crystal suppliers are getting ready for them.

Smaller-than-5 x 3.2-$mm^2$, quartz crystals in general need to be sealed in vacuum to sustain impedance integrity. Low-megahertz small-size quartz crystal blanks also need to be beveled (thinning of the quartz crystal edges) to achieve efficient energy trapping.

The photolithographic method used in processing quartz tuning forks is being implemented for the ultra small size quartz crystals and low-megahertz quartz crystals by the most competent suppliers. The method will become a major technical barrier in further miniaturizing quartz crystals for those suppliers who rely only on using the conventional lapping method to process quartz crystals.

As for the crystal oscillators, shipping of 2.5 x 2-$mm^2$ CMOS fixed-frequency crystal oscillators is in full swing and the yet smaller 2 x 1.6- and 1.6 x 1.0-$mm^2$ versions are at the sampling or development stage. A supply voltage of 2.5 V is typical nowadays with the 1.8-V-or-lower supply voltage market starting to emerge.

The frequency stability over temperature of the above megahertz quartz crystals and crystal oscillators is usually specified at less than ±25, 50, and 100 ppm depending on the temperature range of operation. Hence, quartz crystal is the only known resonant element which can provide such stability without any compensations.

To provide even better frequency stability, TCXOs are available. An AT-cut quartz crystal’s frequency-temperature relationship is cubic. The TCXO oscillator circuit has a voltage-frequency pulling function to analogously or digitally compensate the cubic frequency-temperature change to the sub-10-ppm level over temperature with a remarkably low frequency change gradient.

For today’s handset applications, a frequency stability of better than ±2.5 ppm TCXO is needed to provide the accurate reference clock for frequency synthesizing. For GPS equipment, TCXO of less than ±1.0 or ±0.5 ppm is needed. For example Epson Toyocom offers tiny TCXOs (2 x1.6 $mm^2$) for the above applications.

Unknown to many, quite a few quartz products (quartz crystal, quartz tuning fork, quartz gyro-sensor, etc.) are being manufactured with some MEMS (micro-electromechanical system) processing steps such as photolithography, metallization, etching, sacrificial layer deposition and removal, and gold etch protection. In fact, the complicated processing steps nonplanar metallization schemes (for quartz tuning fork), resistant to etching due to the hardness of quartz crystal, different etch rates of the highly anisotropic quartz crystal, etc. make the processing of miniaturized quartz crystal products more technically challenging when compared with many silicon-based MEMS processes. Epson Toyocom coined the term “QMEMS” a couple of years ago to recognize the importance of linking the quartz and MEMS technologies for the next generations of quartz crystal devices.

Overall, in the past decade, quartz crystal and crystal oscillator suppliers have done what once was thought impossible shrinking the sizes of quartz crystal, crystal oscillator, VCXO, and TCXO to where we are, and most important of all, without sacrificing performance or cost. More and more quartz crystal devices are shipped each year. The average selling price of the mature products continues to decline.

The industry is continuing its successful efforts of the last decade, which include innovation, miniaturization, cost reduction, development of new applications, and improvement of performance, ease of use, and reliability all to maintain its position as “the clock solution” for the electronics industry. The thrust is to provide the best-performing and most-cost-effective quartz solutions so customers have no reason to explore other technologies. ■