The Current State of Innovation in Frequency Generation Electronics

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With all the technical revolution that has taken place in the electronics industry, there are still components that have remained untouched by the far-reaching effects of functional integration: crystal and ceramic frequency references. These components are crucial to almost every electronic system – from garage door openers to satellite receivers. They form the primary building block of data transmission systems by synchronizing data transfers between hosts and receiver ICs.

While often overlooked, frequency generation is an important aspect of any electronic system, assuring that every component is, literally, "on the same wavelength." And though there has been limited advancement in this area until recently, the last five years have seen huge levels of innovation and investment in this multi-billion dollar market to form new companies using new technologies to bring to market new classes of frequency references and to challenge incumbent suppliers.

Included among these new enterprises are those developing micro-electromechanical systems (MEMS) oscillators, precision piezoelectric resonators and monolithic-standard CMOS devices. This article analyzes current market conditions in frequency generation electronics, compares recently proposed alternatives and defines features that an ideal crystal replacement should fulfill.

Despite some concerns, a quartz-based crystal oscillator is still the most widely used technology today, even as alternate solutions close in from behind.

Quartz Crystal

Billions of crystals and oscillators are produced worldwide each year, and remain the dominant frequency source, primarily due to refinements in their manufacturing processes[1].

In spite of certain limitations, quartz crystal resonators exhibit remarkable frequency stability. When subject to a surface charge, piezoelectric materials expand and stretch their lattice structure. Quartz oscillators then take advantage of this material property by applying an electrical field to generate a periodic movement in pre-defined axes.

The reasons for the longevity of quartz include: good frequency stability, low phase noise and jitter, an established technology infrastructure and a long list of suppliers. But in spite of its remarkable properties, in today's highly integrated electronic systems, quartz-based frequency sources present three primary challenges:

- Size and frequency limitations of the lowest-cost, fundamental-mode quartz crystal resonators.
- A broad set of considerations for optimal oscillator circuit design in an application-specific IC (ASIC). When used as an external component, the quartz crystal resonator must be connected to an oscillator circuit in an ASIC to generate a frequency.
- Longer manufacturing cycles when compared to programmable semiconductor devices.

These fundamental issues could have an impact on development schedules and increase the complexity of product design. But other shortcomings exist as well such as sensitivity to shock and vibration, expenses associated with building thin packages and the inability to integrate a quartz crystal resonator element into other silicon devices.

While low-frequency crystals can be manufactured and sold at aggressive price points, high-frequency operation often requires overtone crystals which are more expensive. The frequency limit after which overtone operation[2] is required varies depending on the supplier and the manufacturing process it employs, but it is safe to say that this frequency limit can extend to at least 40MHz to 50MHz. The growing need for higher throughput and lower bit error rate (BER) in interface links requires designers to consider not only the cost, but also the frequency of the reference crystals they choose. A typical preference is to utilize the highest frequency reference available given cost, lead-time and product availability considerations.

A higher reference frequency requires a lower ratio of frequency multiplication by the internal phase-locked loop (PLL) circuit of a physical layer (PHY) device. When allowed, a lower ratio of multiplication is preferred because frequency multiplication with a simple-to-design, ring oscillator-type PLL circuit could, unfortunately, exact a penalty in terms of phase noise and jitter[3] – two critical specifications of interface links. Good phase noise and jitter performance have become more important as new generations of interface standards push the frequency of data transmission higher. And the projected increase in bandwidth requirements of consumer, storage and communication systems demands that more data payload be sent over a communications link within each transmission window.

While improving in efficiency, the overall manufacturing process for crystal oscillators takes longer than that required to configure, test and deliver a programmable semiconductor device. Aggressive lead-time requirements and inconsistent cycles of product demand acceleration and softening, which are common in consumer electronic devices, put pressure on electronics manufacturers as they strive to meet their lead-time objectives more effectively. This problem can become more acute when the design has a unique requirement which can only be fulfilled by a short list of suppliers.

Given the challenges posed by the traditional approach, in recent years innovators and investors in the industry have begun looking for alternate solutions. This has resulted in a plethora of new product propositions, each with unique advantages. It's reasonable to assume that a successful replacement of the ubiquitous quartz crystal frequency reference will need to achieve three major objectives:

- Match the phase noise and jitter performance of quartz crystals.
- Maintain average frequency accuracy within the specified limits of common interface standards, such as Universal Serial Bus (USB) and Serial Advanced Technology Attachment (S-ATA), over all environmental conditions.
- Improve on the cost, reliability and lead time of quartz.

MEMS

Today, there are both established and start-up companies in the market aiming to replace quartz crystals with oscillators utilizing some form of MEMS technology. While differing in methods of implementation, the principal idea common to all market players is that certain issues associated with quartz crystals can be overcome by utilizing silicon microelectronics manufacturing processes of fine geometry lithography and standard batch processing.

According to recent product announcements, improvements have been made in package size (particularly package height) and mechanical reliability with the use of MEMS oscillators. Some of the recently announced MEMS oscillators feature multi-die packaging, where a MEMS resonator die is complemented with a separate CMOS die[4]. In such a topology, the MEMS die could feature a fundamental frequency generation element, and the CMOS die could be used to compensate for the inherent variation of the resonator over temperature and other environmental factors.

CMOS Harmonic Oscillators

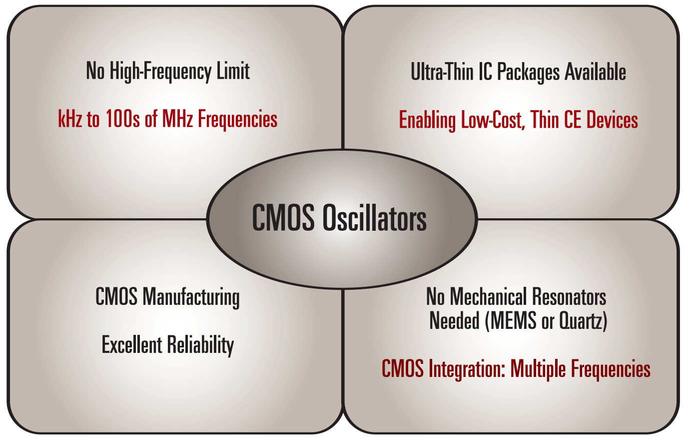
Over the last 25 years, standard CMOS processes have been continually refined to outperform alternative technologies in scalability of cost, breadth of integration and rate of performance improvement over time. Therefore, it is no surprise that CMOS is being proposed as the process platform for next-generation accurate frequency references.

The fundamental difference between quartz/MEMS oscillators and a CMOS alternative is the lack of moving parts in the latter. In essence, the only moving elements in a CMOS harmonic oscillator are electrons, resulting in best-in-class shock and vibration immunity. A standard CMOS oscillator benefits immensely from the vast and vibrant semiconductor ecosystem as it aims to displace a ubiquitous component. It draws upon the infrastructure of reliable and repeatable processes, precision analog design techniques and the availability of integratable memory elements for rapid device configuration.

Therefore, CMOS technology has the promise to be the ideal platform on which to build the most viable, cost-effective, high-performance replacement for quartz crystals for the following reasons:

- **High Frequencies:** For all practical purposes, a CMOS oscillator does not impose any high-frequency limitations in the communication interfaces that are in use today. A CMOS oscillator can easily operate anywhere from kHz frequencies to hundreds of MHz frequencies.
- **Shock and Vibration:** Due to its monolithic, all-electronic make up, CMOS offers complete shock and vibration immunity.
- **Small and Thin Packaging:** A single-die CMOS frequency reference can be assembled in very small, thin IC packages. The demand for improvement in form factor is particularly pronounced for next-generation consumer electronic devices.
- **Integration:** A pure, all-CMOS semiconductor oscillator that meets the performance requirements of a system can not only replace, but in fact completely eliminate, legacy non-semiconductor frequency references from the printed circuit boards (PCBs) of today's electronic devices. It certainly allows for broader functional integration of today's electronics, and leads to bill-of-material (BOM) and cost savings (Figure 1).

Figure 1. CMOS Harmonic Oscillators



The core of such a CMOS-only oscillator could be a harmonic inductor-capacitor (LC) resonator running at gigahertz frequencies. The output of this resonator could then be put through a series of signal conditioning blocks and be calibrated with on-chip automatic frequency-centering circuitry to ensure the device operates at the desired center frequency. The accuracy of this frequency can then be adjusted in real time using control loops on environmental variables such as temperature and voltage.

The proposition of all-CMOS oscillators is not new. In fact, the industry has been able to produce many generations of the technology in the past, albeit at lower performance points than quartz oscillators. It was only recently that the renewed commercial interest in alternative frequency references prompted research that aimed to push the boundaries of what's achievable by an all-CMOS approach. Today, these efforts have begun to result in precision analog ICs that are built on standard CMOS processes and that generate frequencies electronically – on-chip – without the need for quartz, ceramic or any other type of mechanical resonator at equivalent performance levels in far-from carrier phase noise and period jitter, and at frequency accuracies that remain within the requirements of common interface standards.

With such a variety of propositions on the table, the critical, but often overlooked, segment of frequency generation is certainly garnering a lot of attention, and stands to benefit immensely from the infusion of fresh ideas and innovation. ■

About the Author

Tunc Cenger is responsible for all marketing and business development activities at Mobius Microsystems. Mobius Microsystems brings to market the next generation of high-performance frequency references. The company's CHO products are the world's first and most accurate all-CMOS oscillators. Prior to Mobius, he served as business manager for mobile audio products at Maxim, where he was responsible for new product introductions, revenue growth and product line management. Prior to Maxim, he held marketing and design engineering positions at Cypress Semiconductor. Mr. Cenger brings to Mobius a strong engineering background and over 10 years experience in commercialization of new products and technologies. He has authored numerous technical articles and has one patent pending. He holds a B.S.E.E. with top honors in microelectronics from Istanbul Technical University. You can reach Tunc Cenger at cenger@mobiusmicro.com or 408-329-5008.

Resources

[1] *J.R.Vig, "Introduction to Quartz Frequency Standards", IEEE UFFC tutorial.*
[2] *"Introduction to Fundamental Crystal Oscillators", tutorial, http://hem.passagen. se/communication/txo.html.*
[3] *Michael McCorquodale, "A monolithic and self-referenced RF LC clock generator compliant with USB 2.0" IEEE, Journal of Solid State Circuits, 2005.*
[4] *SiTime white paper: Leveraging standard IC packaging for MEMS oscillators.*