Programmable MEMS-Based Silicon Timing Solutions Change the Game

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ABSTRACT

For the past few decades, the electronics industry has relied on quartz based timing solutions, which involve machining of crystals and then combining them to analog circuits inside expensive, ceramic packages. Since few years now, programmable MEMS products have provided a compelling alternative to quartz timing solutions. This paper discusses the advances of the MEMS based silicon timing solution and its advantages in performance, manufacturing flow, programmability, and short lead time.

Keywords: programmable oscillator, timing chips, MEMS oscillators, silicon timing solution

1 INTRODUCTION

Micro electro mechanical system (MEMS) devices have been widely used in applications such as accelerometer, gyroscopes, and microphones due to their size, reliability, performance, manufacturability, and cost advantages. In the 90's the automotive market [1] led the MEMS revolution producing pressure sensors for engine management, acceleration sensors for airbags, gyroscopes for vehicle dynamics control and navigation systems. During the last view years MEMS products have expanded their growth in the consumer market: microphones [2] for cell phones, acceleration sensors for gaming and cell phones [3] and lately also gyros [4] further improving the user interface experience and many more applications.

Researchers have worked on using the resonance properties of MEMS structures to build resonators since 1967 [5] [6]. However, stability, reliability, and manufacturability issues related to sealing and packaging the resonator elements prevented cost efficient manufacturing. In the last 10 years, new silicon processing techniques were developed that can seal silicon resonating structures within a silicon cavity [7][8]. This breakthrough makes it possible to manufacture reliable MEMS resonator devices in high volume cost-effectively, using the large available silicon manufacturing infrastructure

MEMS resonators are manufactured in Silicon, as are the programmable analog circuits that accompany them. Unlike quartz, MEMS-based timing solutions don't need exotic packaging – they use the same plastic packages that are used by billions of semiconductor devices every year. In addition, these MEMS-based timing solutions are manufactured with the fabless semiconductor model, making product available in standard semiconductor lead times.

Programmability gives the system designer what they want; they need not compromise their specifications to match commonly available quartz products. Programmability is revolutionizing the timing industry. Designers can easily tune and optimize their systems for performance, power, EMI, reliability, without waiting 20 weeks or paying high prices. MEMS-based silicon timing solutions are delivering these benefits today and dramatically changing the market.

2 SILICON MEMS RESONATOR

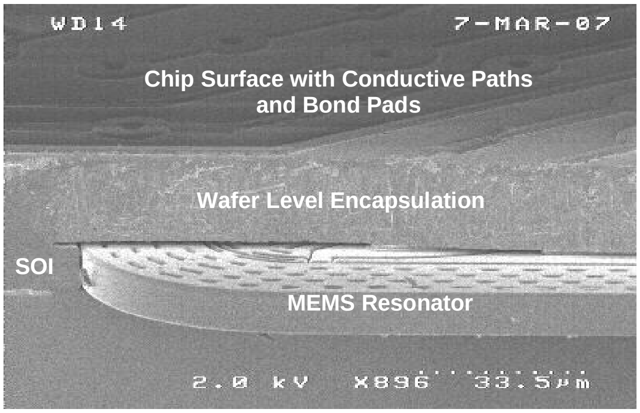

Figure 1: MEMS resonator cross section

The MEMS resonator cross section is shown in Figure 1. The resonator structure is etched in a silicon on insulator (SOI) layer. The single crystalline silicon mechanical material properties are very stable, reproducible enabling high quality [9] factors and virtually zero frequency drift. The vacuum packaging of the resonator is built into the MEMS process - the resonator is covered by a thick poly silicon layer deposited at high temperatures leading to an ultra clean vacuum required for the stability of micrometer scale resonating structures.

The electronic IC is designed in a standard 180nm mixed signal CMOS process. Both silicon dies are co-packaged in standard plastic packaging flow. The thin film wafer encapsulation as described above leads to a MEMS die which can be handled in the backend packaging process the same way as any CMOS die. State of the art ultra thin plastic packages are available [10] as thin as 250um thick.

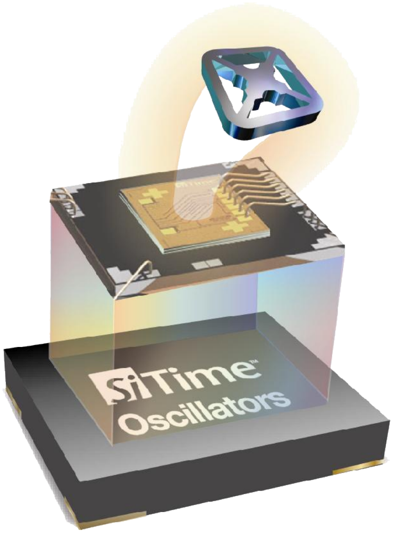

Figure 2: Package concept

Figure 2 shows a schematic view of the die stack in the plastic packed product. The die and package leads are electrically connected using bond wires.

2.1 Architecture and Electrical Performance

A highly flexible fractional-N PLL based architecture is used to calibrate the offset frequency, compensate the temperature drift of the silicon material property, enable frequency modulation for EMI reduction, and allow the programming of any output frequency between kHz and several 100MHz as shown in figure 3.

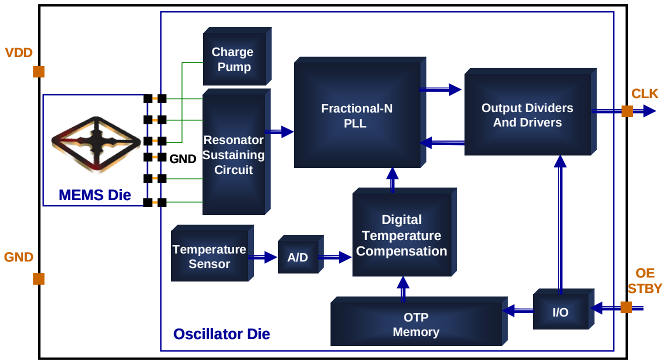

Figure 3: Block diagram

The core of the architecture is a high resolution fractional-N PLL, a temperature to digital converter (TDC) and a digital compensation engine. The TDC senses the temperature and digitizes it. It then drives the fractional-N PLL to compensate the temperature related frequency variation of the MEMS oscillator. The temperature compensation circuit uses a polynomial-based approach. The coefficients for the polynomial are stored in a non-volatile memory (NVM).

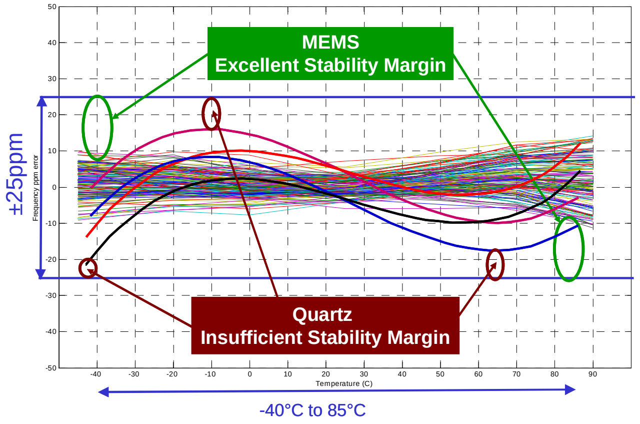

Figure 4: Frequency stability of 100 production units compared to typical quartz 3rd order temperature drift.

Figure 4 shows the MEMS-based oscillator frequency versus temperature behavior after temperature compensation. It clearly shows the effectiveness of the PLL-based compensation to achieve great frequency stability, exceeding those of typical crystal oscillators. A stability of ±25ppm can be achieved using a room temperature calibration only. The temperature coefficients of the single crystal MEMS resonator are very reproducible and therefore a standard set of compensation coefficients can be programmed.

The programmable architecture allows individual temperature compensation and the temperature stability can be further improved to meet TCXO frequency stability of better than ±5ppm as shown in figure 5.

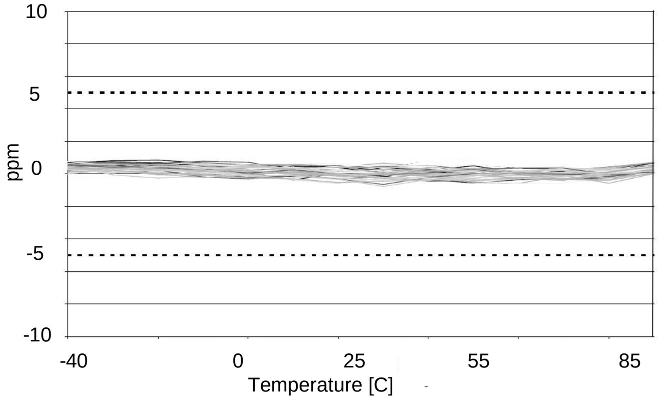

Figure 5: Temperature compensated MEMS Oscillator

State of the art PLL design is overcoming some of the short comings of older PLL architectures such as high phase noise and jitter. Figure 5 shows the phase noise performance of a fully PLL compensated 20MHz MEMS oscillator.

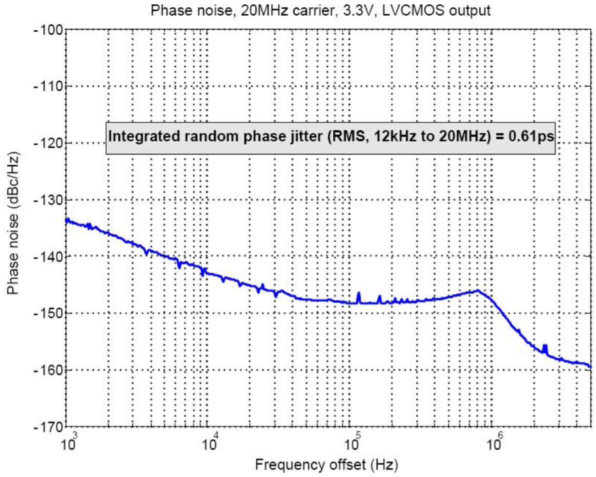

Figure 5: Phase noise and phase jitter performance

The phase noise is comparable with quartz oscillators; sub Pico second phase jitter (integrated from 12kHz to 20MHz) meets the requirements for high speed serial applications such as 10 gigabit Ethernet and SONET.

2.2 Product Benefits

There are several key benefits from this configurability. First, the customer can optimize their system by tuning the frequency to a value that offers maximum performance. Because the device can be configured to operate at 1.8V, 2.5V, or 3.V, the customer will not need external components such as level translators or additional regulators, thus saving on board space and cost. In addition, because the semiconductor die is highly programmable, one base product can be used in a variety of different applications, configured for different frequencies, voltages, stability and other features. As the semiconductor die has been characterized over the operating range for all these different configurations, and the results are predictable and specified in the datasheet, the component qualification process is massively simplified. As a result, the customer can consolidate the supply chain, eliminating the need for multiple suppliers and parts, while replacing them with one base device that will provide predictable, reliable operation across different voltages, frequencies and packages.

MEMS oscillators are programmable and can offer any frequency and features within the operating range. Due to the inherent limitations of quartz oscillators, they are only available in “spots,” i.e. quartz has limited product offerings which cannot be customized to the customer’s requirements. Every quartz frequency requires new mechanical dimensions causing different behaviors such as Q variations, activity dips. Programmable MEMS oscillators use one mechanical design; the frequency programming is a simple mathematical function in the fractional-N PLL architecture. The mechanical design of quartz also limits the frequency range and accuracy of quartz oscillators. For frequencies above 70MHz more complex constructions [11][12] and operating modes are required such as the operation of the quartz blank in the third over tone or SAW (surface acoustic wave) devices. ±25 PPM devices are becoming increasingly important to customers because they provide better timing margin in the system, and as a result improve its performance and long-term reliability The frequency stability performance degrades for higher frequency quartz based solutions because of the complexity of the construction, a MEMS programmable oscillator retains all frequency stability related performance parameters at any frequency.

Another benefit of the proposed programmable architecture is EMI (Electro Magnetic Interference) reduction. Electronic devices may radiate electromagnetic energy, which can interfere with the operation of the rest of the devices. To avoid such harmful interference, governments and industry bodies limit the amount of energy that any device can radiate. Environmental compliance standards such as FCC Class A and B [13][13] specify these limits for different categories of equipment, based on the location of end use. Known methods for reducing EMI are 1. Shielding, 2. Using solid ground or signal return path for high-speed signals, 3. Signal filtering. 4. Reducing rise/fall time, and 5. Using spread-spectrum clocking (SSC) modulation. Options 1-3 require costly changes in the construction and circuit design. Options 4 and 5 can be addressed by the described programmable architecture without any costly changes in a very timely manner: Adjusting the rise/fall times will reduce the harmonic EMI as shown in figure 6.

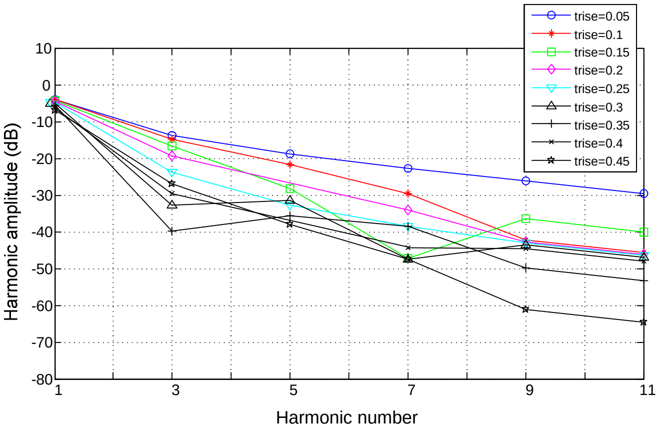

Figure 6: Clock signal harmonic amplitude decreases as the rise/fall time increases. Rice/fall time is expressed as fraction of one cycle

SSC is implemented by modulating the clock signal with a low rate frequency modulation. The modulation can be easily implemented in the programmable PLL architecture by modulating the fractional divider of the PLL. The amount of the frequency modulation can be adjusted from 0.25% to 2% to optimize the system performance. Figure 7 shows an example reducing the EMI by -10db using a 2% down spread frequency modulation.

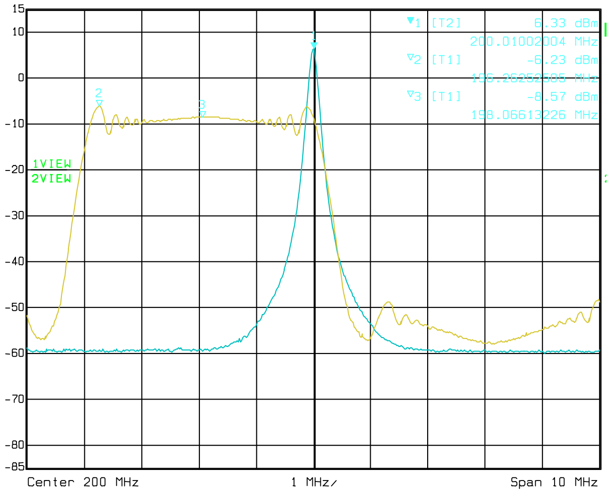

Figure 7: Main harmonic spectrum for a 12 MHz clock with and without 2% -spread spectrum modulation

2.3 Supply Chain advantages

Almost as important as the performance however, is availability. There are many line items of oscillators available from distributors. In generally, less than five percent of those products are held in stock, because each quartz oscillator configuration is a different product. The quartz manufacturing flow is complex. Manufacturing is specialized and needs to be done in custom facilities that often require long lead times to build. Since quartz material has to be cut to the right frequency, blanks cannot be created and inventoried for quick turnaround. Instead, quartz is held as a raw material until it is manufactured to the customer's specifications. Typically, after a customer places an order, these manufacturing sites will begin the build, which will take anywhere from 6-16 weeks to determine whether the component was manufactured correctly. For custom products, this lead-time is even longer, and can be anywhere from 10-16 weeks.

In contrast, MEMS Silicon Timing solutions are delivered on demand. The wafers are produced using batch manufacturing and standard semiconductor industry back end flow. In addition, non programmed but packaged and calibrated oscillators can be hold in inventory, or high volumes before packaging in die bank form. As a result, samples can be easily turned around in a matter of minutes, and custom products in any volumes will be delivered in 2-4 weeks.

2.4 Conclusions

For the past 60 years, the electronics industry has relied on inflexible quartz based timing solutions. MEMS based configurable oscillators enable customers to differentiate their products with higher performance, reduced size and better reliability. The rich feature set and flexibility of our solutions allows customers to consolidate their supply-chain, reducing cost of ownership and time to market. By using standard semiconductor processes and high volume plastic packaging, SiTime offers the best availability and shortest lead times in the industry.

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