Comparison of Crystal Oscillator and Si-MEMS Oscillators

A Comparison of Oscillator Performance as Required by Electronic Devices and Communications System Equipment

[Preface]

The selection of the oscillator for electronic devices and communications system equipment is a major factor affecting system performance . "Signal Quality and Reference Signal Sources Required for Communications Systems," a set of two earlier White Papers explained how the oscillator affects overall system performance. In this application note, we have measured and compare two types of oscillators: 1) a fundamental Quartz crystal oscillator and 2) a Si-MEMS oscillator.

[Structure and Characteristics of Oscillators]

A crystal oscillator uses a Quartz crystal in fundamental mode and a simple oscillator circuit. A Si-MEMS oscillator uses a silicon resonator as the oscillating source and requires a PLL circuit to correct the frequency for manufacturing tolerances and temperature coefficient. The basic structure of these oscillators is given in Figure 1 below.

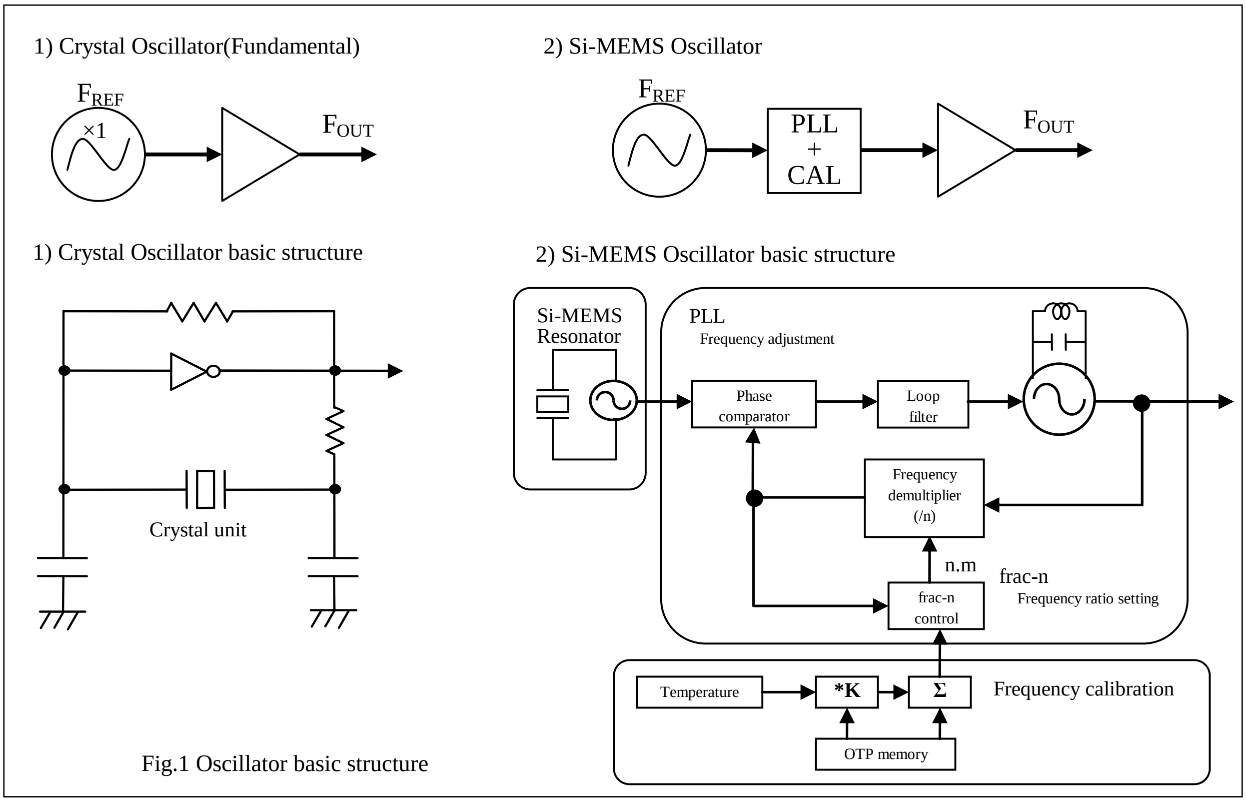

Fig.1 Oscillator basic structure

As these basic structures indicate, crystal oscillators are simply built. In contrast, Si-MEMS oscillators have a complex structure consisting of a resonator, a fractional-n PLL, and temperature compensation and manufacturing calibration. The complex structure results in several differences in oscillator performance. Most importantly, jitter and power are higher, as shown in Figure 2 below.

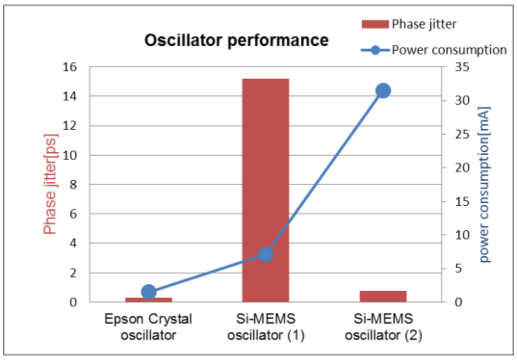

Fig.2 Oscillator performance (comparing of Epson and Si-MEMS)

[Comparison of Properties of Crystal Oscillators and Si-MEMS Oscillators]

We measured crystal oscillators and Si-MEMS oscillators and compared them for five parameters which are critical for the design of communications, industrial, and consumer electronic devices:

1) Phase noise, phase jitter: How is the noise performance (a critical factor in communications equipment)?
2) Power consumption: How much current is consumed?
3) Oscillator start up: How quickly does the oscillator start after power is turned on, and how stable is it?
4) Frequency temperature characteristics: How stable is the frequency with respect to temperature changes?
5) Frequency stability: How stable is the frequency?

For the comparison, we measured an Epson SG-210S*B crystal oscillator and two types of Si-MEMS oscillators.

1) Phase noise and phase jitter

Laboratory measurements demonstrate that the Epson SG-210S*B has much better phase noise than the two Si-MEMS oscillators. Measured phase noise for the crystal oscillator and Si-MEMS oscillators is shown below in Figure 3.

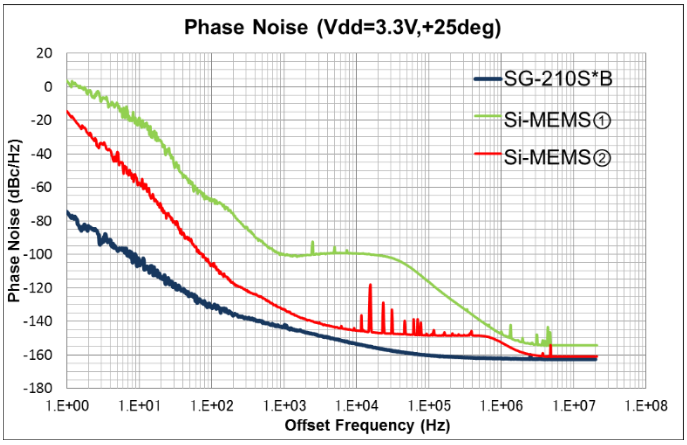

Fig. 3: Measured phase noise of Epson SG-210S*B vs. two Si-MEMS oscillators

Si-MEMS1 is a “standard” Si-MEMS oscillator and achieves 15.2 ps rms jitter from 12 kHz to 20 MHz.
Si-MEMS2 is a “low-jitter” Si-MEMS oscillator and achieves 0.76 ps rms jitter from 12 kHz to 20 MHz.
The Epson SG-210S*B crystal oscillator achieves 0.32 ps rms jitter from 12 kHz to 20 MHz, which is 2.5 better than the “low-jitter” Si-MEMS oscillator and 50x better than the “standard” Si-MEMS oscillator. Crystal and SAW oscillators are also available with much lower jitter, as low as 11 fs. The SG-210S*B was selected for the comparison because it is a “standard” oscillator used in many applications and manufactured in very large volume.

Table 1 below summarizes measured phase jitter for the three oscillators compared.

Product	Frequency	Phase jitter (offset frequency: 12 kHz - 20 MHz)
Crystal oscillator (SG-210S*B)	25 MHz	0.32 ps
Si-MEMS oscillator (1)	24 MHz	15.2 ps
Si-MEMS oscillator (2)	19.2 MHz	0.76 ps

Table 1: Phase jitter measurements for each product

Si-MEMS oscillators have higher phase noise for low offsets because the Silicon resonator has a poor Q compared to Quartz. At 1 Hz, the Quartz oscillator has 60 dB better phase noise than the "low-jitter" Si-MEMS oscillator and 80 dB better phase noise than the "standard" Si-MEMS oscillator. Phase noise at low offsets is critical for wireless communications and can cause bit errors in optical communications.

Si-MEMS oscillators have higher phase noise for high offsets (10 kHz - 1 MHz) because they use a low-Q LC oscillator for the PLL circuit.

The above phase jitter measurements do not include spurs. Si-MEMS oscillators, especially the "low-jitter" variety, have spurs caused by the fractional-n divider, as shown in Figure 4. These spurs occur in-band and cause deterministic jitter (DJ), which degrades system bit error performance. Spur-induced DJ must be considered as part of the jitter budget for all types of circuits: wired, optical, and wireless. Quartz oscillators using fundamental crystals do not have such spurs.

2) Power consumption

Power consumption of each oscillator is shown below in Table 2. This data is taken at 3.3 V and 25°C with an output load of 10 pF.

Table 2: Power consumption measurements for each product

Product	Frequency	Power consumption
Crystal oscillator (SG-210S*B)	25 MHz	1.5 mA
Si-MEMS oscillator (1)	25 MHz	7.1 mA
Si-MEMS oscillator (2)	19.2 MHz	31.5 mA

The Epson SG-210S*B has the lowest power consumption, 1.5 mA, 5x lower than the "standard" Si-MEMS oscillator and 20x lower than the "low-jitter" Si-MEMS oscillator.

Crystal oscillators have the lowest power consumption because they have the advantage of the fundamental harmonic oscillation of the oscillating source and a simple circuit structure.

By contrast, Si-MEMS oscillators consume more power because they have more circuitry. The PLL and LC VCO raise the total power consumption. As a result, the "standard" Si-MEMS oscillator (Si-MEMS1) draws 7.1 mA, about 5x larger than the Epson SG-210S*B. In order to reduce jitter, the "low-jitter" Si-MEMS oscillator (SiMEMS2) uses more current in its Silicon oscillator, PLL, and LC VCO, with the result that its total operating current is 31.5 mA, which is 20x the Epson SG-210S*B at 2.5x the jitter.

3) Oscillator start up characteristics

Oscillator start up characteristics are shown below in Figure 4. These results are measured at 3.3 V, 25°C, and from 0 to 0.5 s in 1 ms steps.

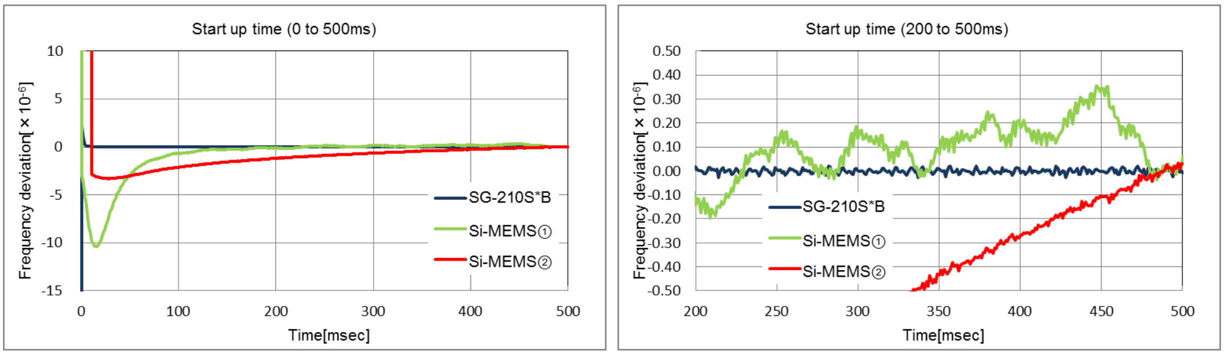

Fig. 4: Oscillation start up characteristics of each product

Comparing time it takes for the frequency to stabilize within $\pm 1.0\times10^{-6}$, the Epson SG-210S*B achieves 1 ppm accuracy within 1.5 ms, while Si-MEMS (1) took about 90 ms and Si-MEMS (2) took about 250 ms. After startup, the Epson SG-210S*B is stable but both of the Si-MEMS oscillators exhibit frequency tremors.

Fast startup is important for consumer and home automation applications where the system must be turned on and off quickly to save battery power. Using an oscillator with fast startup, such as the Epson SG-210S*B, allows shorter wakeup cycles and longer battery life.

4) Frequency temperature characteristics

Frequency temperature characteristics were measured by first achieving a stable low temperature of -40°C, then ramping the temperature up to 85°C at a slope of +2.0°C/minute. The results are given in Figures 5 and 6.

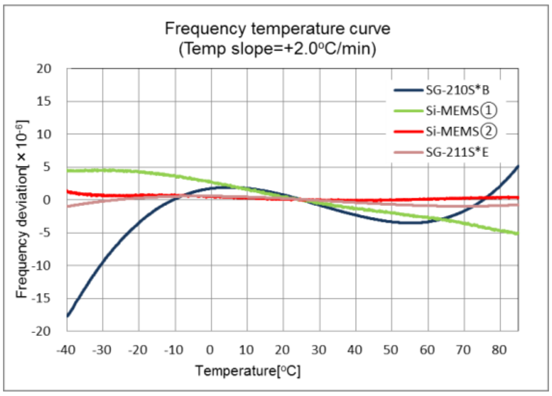

Fig. 5: Frequency temperature characteristic measurements for each product

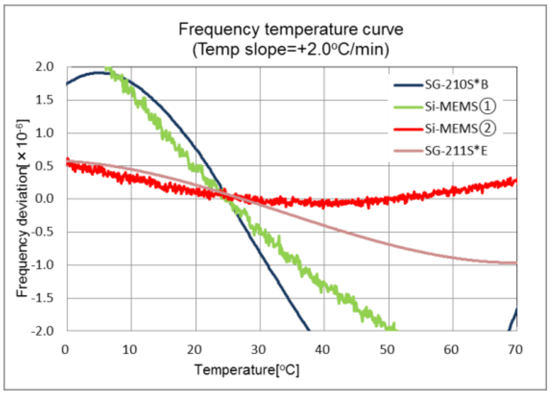

Fig. 6: Magnified view of temperature characteristics

Frequency vs. temperature of the Epson SG-210S*B follows the continuous cubic curve of an AT crystal and achieves ±25 ppm from -40 to +85°C, which is sufficient for most applications.

On first inspection, the Si-MEMS oscillators seem to have better frequency vs. temperature characteristics, but the magnified view in Figure 3 shows that the Si-MEMS oscillators have frequency jumps (as revealed by the jagged temperature curves) when the division ratio switches to compensate for temperature changes. This is because the fractional-N PLL circuit adjusts frequency in discrete steps to correct for the very high (30 ppm/°C or 3750 ppm from -40 to +85 °C) temperature coefficient of the Silicon resonator.

The Epson SG-210S*B does not employ temperature compensation, but temperature-compensated Quartz crystal oscillators are widely available at low cost.　For example, the Epson SG-211S*E, uses a simple temperature compensation circuit and achieves ±3 ppm from -40 to +85°C without frequency jumps.
Temperature-compensated crystal oscillators are available with temperature stability as low as ±0.1 ppm.
Because Quartz-based TCXOs use analog temperature compensation, they do not suffer from frequency jumps]

5) Frequency stability
Measurements of the frequency stability of each oscillator are shown below in Figure 7.　These results are measured at 3.3V and 25 °C for a time of 50 seconds.

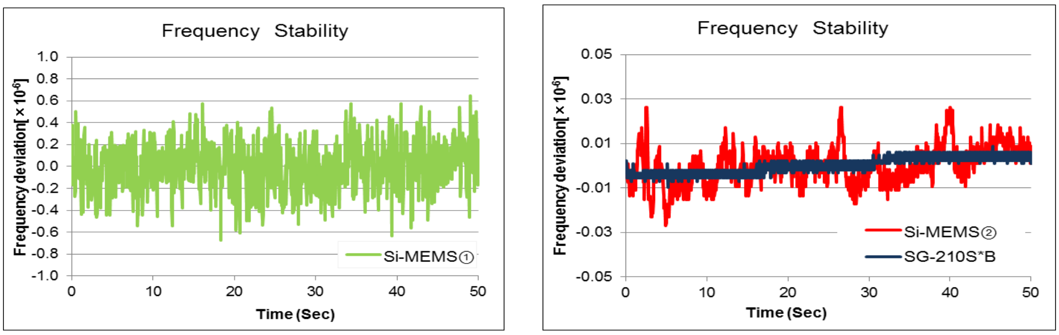

Fig. 7: Frequency stability measurements for each product

The “standard” Si-MEMS oscillator, SiMEMS1, has frequency jumps on the order of ±600 ppb, well in excess of most wireless standards.　The “low-jitter” Si-MEMS oscillator, SiMEMS2, has better performance
but the Quartz oscillator is by far more stable.

[Conclusion]

A summary of evaluation results for indicators 1) to 5) is given in Table 3.

Table 3: Evaluation summary for each product

Indicator evaluated	**Crystal oscillator (SG-210S*B)**	Si-MEMS oscillator (1)	Si-MEMS oscillator (2)
1) Phase jitter	◎ **0.32 ps**	× 15.2 ps	○ 0.76 ps
2) Power consumption	◎ **1.5 mA**	△ 7.1 mA	× 31.5 mA
3) Oscillator start up time	◎ **< 1.5 ms**	× ~ 90 ms	× ~ 250 ms
4) Frequency temperature characteristics	○ **Cubic curve (SG-211S*E has a simple temperature compensation function)**	△ Compensates for 30 ppm/°C resonator temperature coefficient by dithering frac-n PLL synthesizer, but dithering causes frequency jumps.	
5) Frequency stability	◎ **$\pm 0.01\times10^{-6}$** **no frequency jumps**	× $\pm 0.6\times10^{-6}$ frequency jumps	○ $\pm 0.03\times10^{-6}$ frequency jumps
General evaluation	◎	×	△

This comparison and its supporting measured data demonstrates that a crystal oscillator is superior to Si-MEMS oscillators for the critical parameters of power, jitter, frequency vs. temperature, startup, and frequency stability.

Quartz crystal oscillators minimize design risk for a variety of electronic equipment from consumer to industrial and networking. Their low power and fast startup improves battery life for handheld consumer applications. Their lower jitter enables wireless, wired, and high-speed optical communications. Good frequency stability and the lack of frequency jumps qualifies Quartz crystal oscillators for a wide variety of communications standards.

Epson is committed to meeting customer needs by releasing a succession of oscillator products that take advantage of the high precision and stability of crystals and offer the performance that customer applications require in high-performance and cost-competitive markets.