Comparative Analysis: MEMS vs. Traditional Quartz Oscillators

April 2009

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ABSTRACT

Over the years there has been a natural evolution of frequency control devices. This has come about due to various requirements, some being cost driven, others performance/reliability issues, and others by the ever reducing design cycle times. Quartz based devices have long been the standard by which most of the new invention devices are compared, at least from a commercial standpoint. This is due to the long history of quartz as a very stable, high quality material. Frequency versus temperature response as well as aging, jitter and phase noise characteristics are well chronicled in the industry, however, a concise technical correlation of such characteristics with the 'replacement' technology is elusive. This exercise seeks to apply standard measurement techniques under the same test conditions for all devices for direct comparison of performance and capability.

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1 Introduction

From simple RC oscillators, accurate to about 30,000 PPM, to atomic clocks with accuracies of greater than 0.001 PPB, there are clocking options to meet the needs of every application. For years, Bulk Acoustic Wave (BAW) crystal oscillators satisfied the majority of requirements, providing accuracies up to 10 PPM range. Less accurate options, such as SAW oscillators, ceramic resonators, and IC oscillators each have advantages to meet specific needs.

Quartz-based devices have long been a standard by which most other timing devices have been compared. The history of quartz as a stable, controllable, high quality material for frequency selection and clocking devices is universally recognized, and frequency vs. temperature response, aging, and jitter and phase noise characteristics are well chronicled in the industry.

The relatively recent introduction of MEMS based oscillators has been accompanied by claims that this technology would finally replace quartz by providing lower costs, shorter design and production cycle times, excellent shock and vibration performance, and superior signal quality. Despite these claims, there have been few studies available to help understand the performance characteristics of MEMS oscillators. This investigation seeks to provide a direct comparison of MEMS oscillators with traditional quartz resonator based oscillators.

2 Study Methodology

The results presented here are based on application of established typical frequency control industry measurement techniques and represent technology that was commercially available at the time of this study in 2008. A number of electrical characteristics are reviewed, including:

1. Frequency vs. temperature
2. Phase Noise/Jitter
3. Short term Stability
4. Start Time
5. Current
6. Long term Stability (Aging)

The products chosen for the comparison study were MEMS1 and MEMS2 oscillators manufactured by two different companies and purchased from national distributors. Pletronics' own BAW quartz crystal oscillators (XO's) tested were fundamental mode for the 25 MHZ parts and 3rd overtone at 50MHz. All oscillators studied had CMOS level output, 3.0 or 3.3V operation, and the output frequencies of 25MHz, 50MHz and others. The results presented here are either that of a typical device or the average of several devices of that part number.

3 Frequency – Temperature Test Conditions

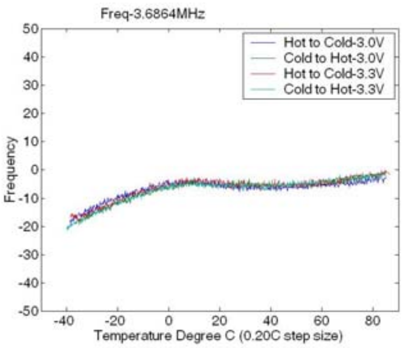
The oscillators were all continuously powered during the testing. All devices were tested at 0.2° C step size in the same test system at the same time.

The data was taken in the cold to hot and hot to cold direction to indicate and evaluate any device hysteresis exists and minimal amounts were found.

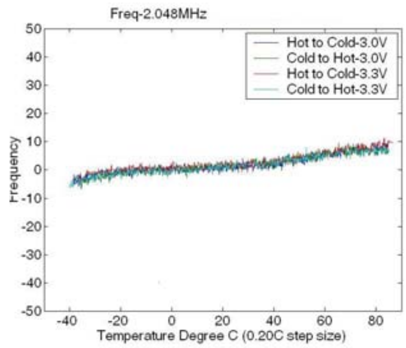
The MEMS1 device was rated at 3.0V and the MEMS2 and BAW device were rated at 3.3V, both conditions were tested for each device.

2.048MHz and 3.6864MHz

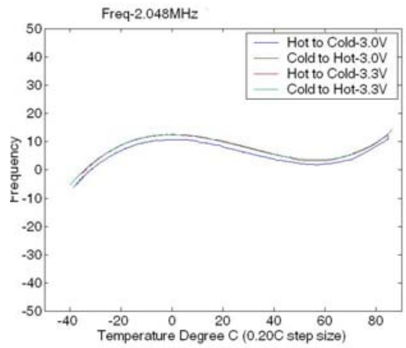
MEMS1



MEMS2

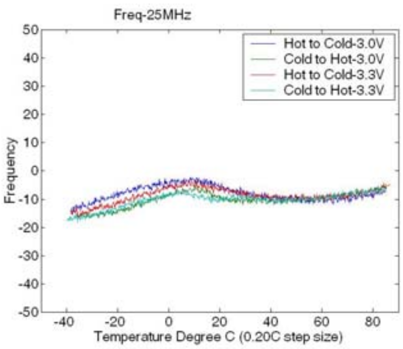


BAW

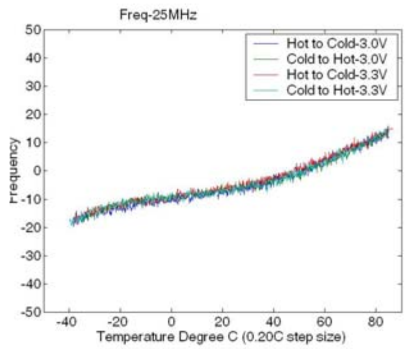


25.0MHz

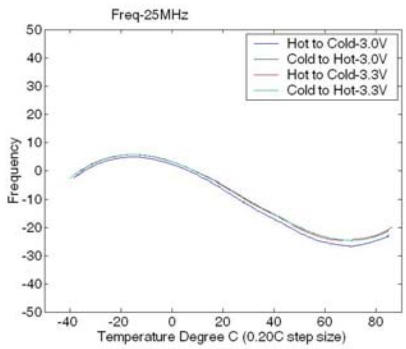
MEMS1



MEMS2



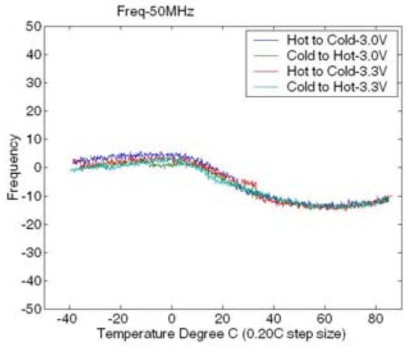
BAW



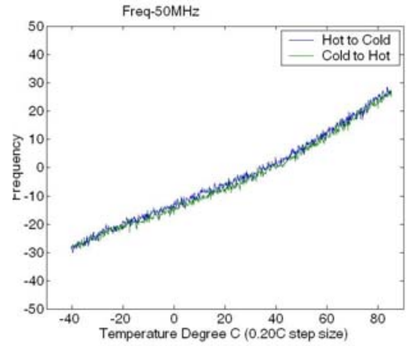
Excursions in the MEMS1 and MEMS2 data are a function of the devices short term stability. This was typical of all devices tested from these manufacturers.

50.0MHz

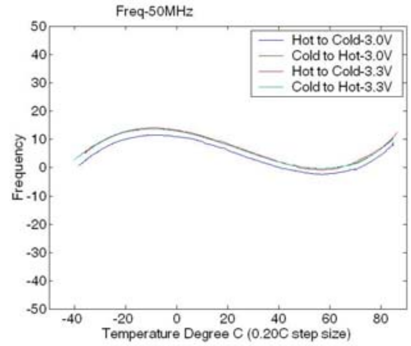
MEMS1



MEMS2



BAW



4 Supply Current Summary

The devices were operated in the same fixture with the same load. The supply voltage was set to nominal and as shown in the table.

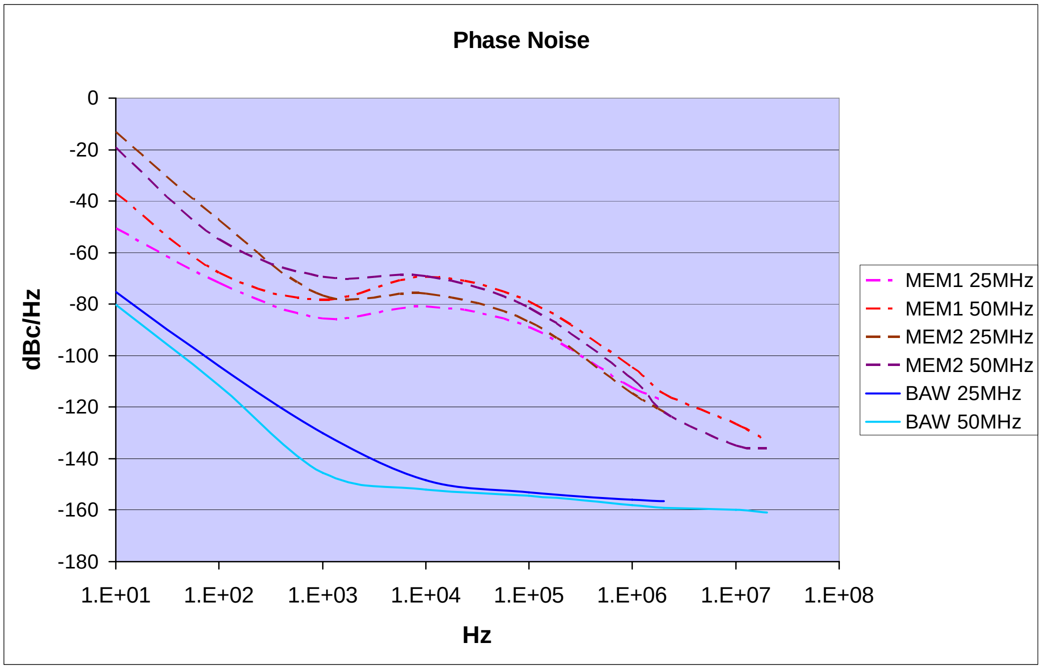
	Power Supply Current (mA)		
Device	2.048 3.6864	25.0	50.0
MEMS1 (3.0V)	2.7	3.4	3.8
MEMS2 (3.3V)	14.3	12.9	18.6
BAW (3.3V)	1.1	2.5	7.2

5 Phase Noise/Jitter

The Agilent 5052 Signal Source Analyzer test system was used to perform the measurements. This system measures the level of the output signal that is other than the desired output and is referenced to the level of the actual main output. The oscillators were operated in the same well capacitor bypassed fixture with a 15pF load powered by a low noise Agilent linear power supply.

The higher levels of phase noise demonstrate that MEMS oscillators are not an equivalent technology. Current communications and data transmission applications will very likely have problems with jitter at the levels indicated in the Agilent test system.

The phase noise plots reveal much about the design and characteristics of these different technology devices. The in-close phase noise level (<1 KHz) is determined primarily by the Q or selectivity of the resonator, the selectivity of the quartz BAW resonator being much higher than either of the MEMS devices.



The 1 KHz to 100 KHz reveals information about the design.

- The MEMS oscillators utilize a Phase Locked Loop (PLL) design with a MEMS resonator being phase locked to a VCO in an M/N synthesizer loop. The phase noise level of the MEMS oscillators is the result of the combined effects of the PLL loop bandwidth, selectivity of the VCO, and Q of the primary resonator.

- The quartz resonator device is operating at the output frequency and does not have the added noise signals of the PLL in the output.

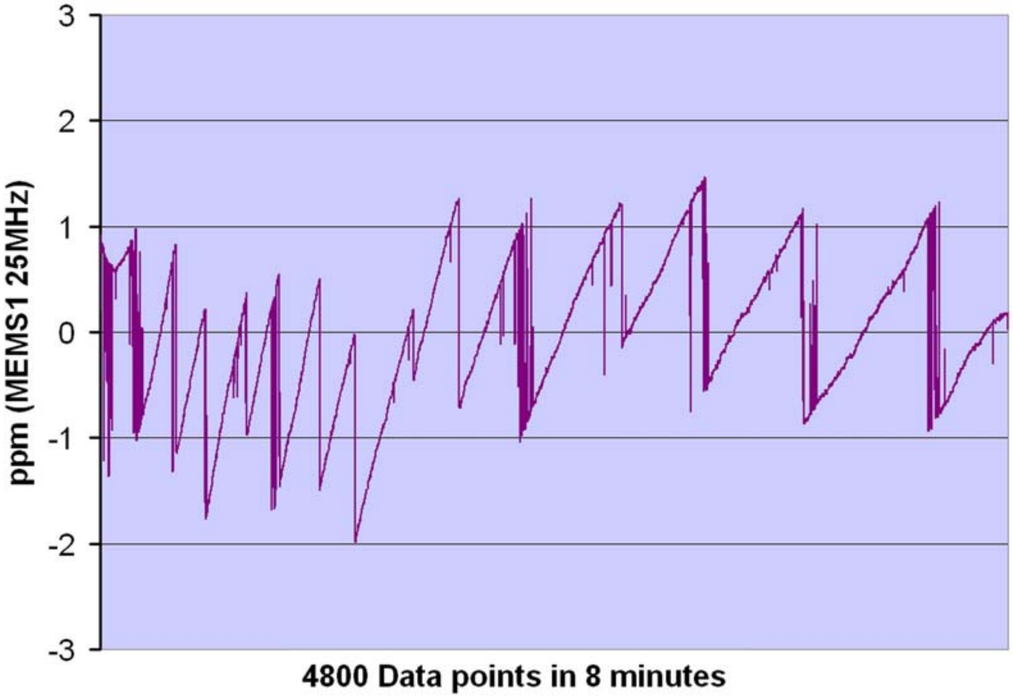
Phase noise can be integrated over a defined frequency region and converted from the frequency to the time domain in order to provide an RMS Jitter value. This is a common practice for the computation of jitter for quartz crystal based resonators, which normally have jitter performance that is equal or exceeds the best oscilloscopes.

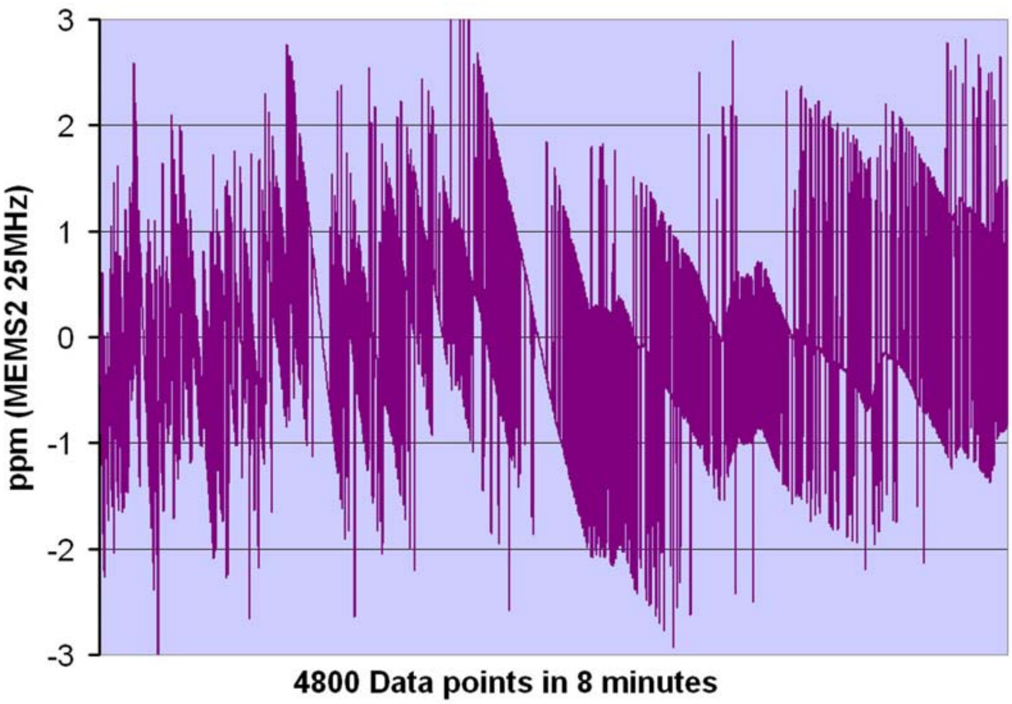
Total RMS Jitter (pS)

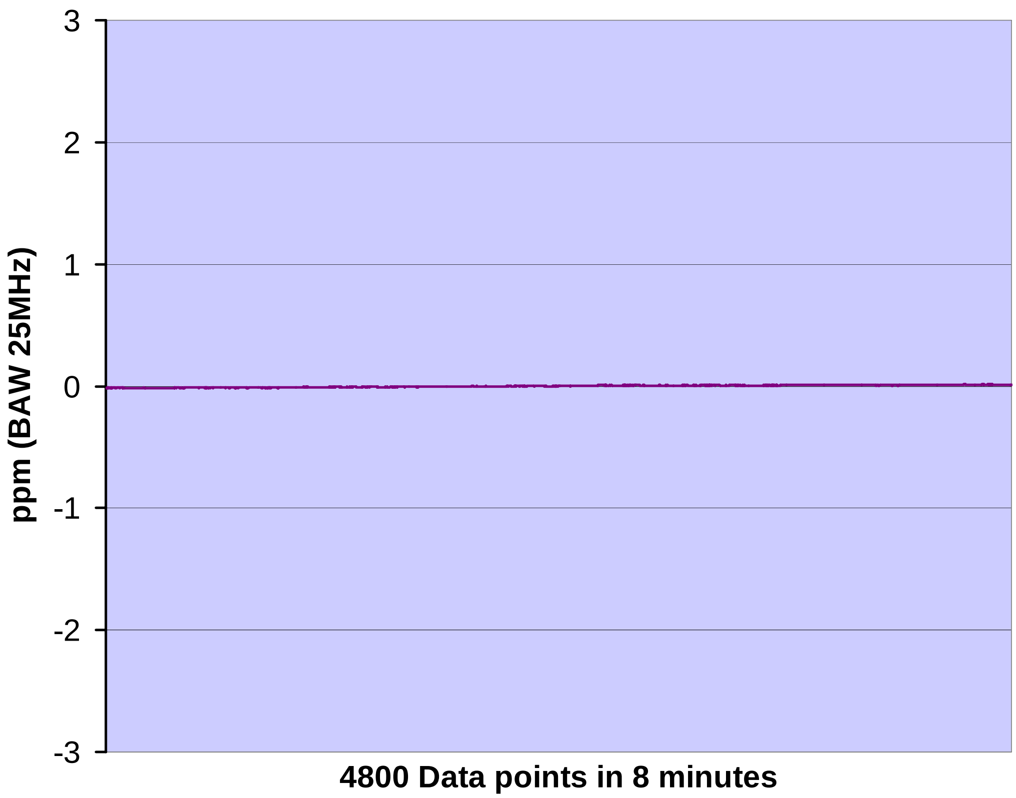
Device	25MHz Oscillator		50MHz Oscillator	
	10Hz to 20MHz	12KHz to 20MHz	10Hz to 20MHz	12KHz to 20MHz
MEMS1	193	162	322	266
MEMS2	4052	228	1031	227
BAW	6.16	0.33	0.98	0.22

6 Short-term Stability

The short-term stability data shown here were determined as frequency measurements taken every 0.1 seconds for 8 minutes with the oscillator stabilized at 25°C within a few tenths of a degree. The parts were all tested with an Agilent 53152 frequency counter operating with a rubidium atomic frequency standard reference. The frequency change is shown in ppm referenced to the first reading.







The charts for BAW oscillators, as shown above, are familiar to most, with typical <+/-0.02ppm (20ppb) variation for the same test.

The data demonstrate that the two technologies are not equivalent and also reveal much about the design and characteristics of the different devices.

- The lower Q in the MEMS devices result in more frequency variations.
- The MEMS devices show step changes of a few ppm. This is characteristic of a temperature compensation circuit correcting for the resonator's temperature changes. This would be a form of digital changing in the PLL circuit to correct the frequency.
- The MEMS1 and MEMS2 designs (two different manufacturers) are quite different in how often the digital compensation switches or corrects the resonator frequency.
- The BAW crystal resonator is much quieter, the result of much higher resonator Q and has no digital correcting signals.

7 Start-up Time Summary

Start-up time is defined as the time period between the time the power supply is turned on and the time the unit reaches the full amplitude and frequency. The power supply was turned on with the equivalent of a debounced moment switch.

Start-up Time (mS)

	Output Frequency (MHZ)		
Device	2.048 3.6864	25.0	50.0
MEMS1	2.2	2.2	2.2
MEMS2	15.0	13.4	14.4
BAW	0.2	0.1	2.0

8 Long Term Stability (Aging)

The aging of the devices was measured for a 122 day (2928 hour) period.

MEMS1 / MEMS2: Both device types showed >1ppm frequency jumping (Short Term Stability) during the measurement period and no trend could be established.

BAW: All data points had a worst case change of 0.26ppm

9 Conclusions

The study discussed here in part and summarized in the table compared a number of different electrical characteristics of commercially available BAW and MEMS oscillators using established measurement techniques. The results indicate that the two technologies are not interchangeable. Frequency variations, from both lower Q and digital temperature compensation in the MEMS oscillators resulted in frequency fluctuations that are unacceptable in many applications.

Past attempts at digitally temperature compensated BAW oscillators failed in the marketplace due to the compensation steps, despite the fact that the steps were significantly smaller than those used in MEMS oscillators. For example, today's cell phone temperature compensated crystal oscillators (TCXOs) are all analog compensated.

SUMMARY

	MEMS	BAW
Short Term Stability	Poor	Excellent
Long Term Aging	Not as good	Very Good
Phase Noise/Jitter	Poor	Very Good

	MEMS	BAW
Temperature Stability	Depends on compensation scheme and has digital frequency jumps in the compensation	Devices can meet +/-20ppm from -40C to 85C without any compensation. No frequency Jumps.
Shock and Vibration	Good shock and vibration capabilities	The crystal resonator is suspended from one end in free space and can be damaged by high shock
Package	Can be thinner	Needs hermetically sealed space for the quartz resonator

MEMS oscillators appear well suited to high vibration environments, to non-critically timed applications, and to applications where the signal-to-noise ratios are not critical. Applications that have complex modulation schemes, very high speed communication, or that require excellent signal-to-noise performance (i.e., A to D Converters) will continue to be clocked by BAW crystal oscillators, taking advantage of the exceptionally high Q and excellent time and temperature stability of quartz.

The devices tested were:

Descriptor	Company	Part Number
MEMS1	Discera	ASFLM1-3.6864M
		ASFLM1-25.0M
		ASFLM1-50.0M
MEMS2	SiTime	EMK23H2H-2.048M
		EMK23H2H-25.0M
		EMK23H2H-50.0M
BAW	Pletronics	SM5544TV-2.048M
		SM5544TEV-25.0M
		SM5544TEV-50.0M

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