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Assessment of Operation of EMK21 MEMS Silicon Oscillator Over Wide Temperature Range

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Background

Electronic control systems, data-acquisition instrumentation, and microprocessors require accurate timing signals for proper operation. Traditionally, ceramic resonators and crystal oscillators provided this clock function for the majority of these systems. Over the last few years, MEMS (Micro-Electro-Mechanical Systems) resonator-based oscillators began to surface as commercial-off-the-shelf (COTS) parts by a few companies. These quartz-free, miniature silicon devices could easily replace the traditional crystal oscillators in providing the timing/clock function for many digital and analog circuits. They are reported to provide stable output frequency, offer great tolerance to shock and vibration, and are immune to electro-static discharge [1-2]. In addition, they are encapsulated in compact lead-free packages and cover a wide frequency range (1 MHz to 125 MHz). The small size of the MEMS oscillators along with their thermal stability make them ideal candidates for use in space exploration missions. Limited data, however, exist on the performance and reliability of these devices under operation in applications where extreme temperatures or thermal cycling swings, which are typical of space missions, are encountered. This report presents the results of the work obtained on the evaluation of an Ecliptek Corporation MEMS silicon oscillator chip under extreme temperatures.

Test Procedure

The device selected for evaluation comprised of an EMK21-Series MEMS silicon oscillator chip that had a fixed frequency output of 1.0 MHz. This 4-pin low cost device is factory-programmed to a specified frequency, and is designed for applications such as computer peripherals, video cameras, and portable media players. Table I shows some of the manufacturer's specifications for this device [3]. Operation stability of this MEMS silicon oscillator was investigated under exposure to extreme temperatures. Performance characterization was obtained in terms of the oscillator's output frequency, duty cycle, rise and fall times, and supply current at specific test temperatures. Restart capability at extreme temperatures, i.e. power switched on while the device was soaking at extreme (hot or cold) temperature, was also examined. The effects of thermal cycling under a wide temperature range on the operation of the silicon oscillator were also investigated. The oscillator was subjected to a total of 12 cycles in the temperature range of -112 °C to +110 °C at a temperature rate of 10 °C/minute and a soak time of 20 minutes at the temperature extremes.

Table I. Manufacturer's specifications of EMK21-Series MEMS silicon oscillator [3].

Parameter	EMK21
Operating voltage (V)	1.8
Frequency (MHz)	1
Input current (mA), max	15
Operating temperature (°C)	-40 to +85
Duty cycle (%)	50 ±5
Frequency tolerance (ppm)	±50
Output rise/fall time (ns)	2
Package (RoHS compliant lead-free)	SMD Plastic 4-lead QFN
Part #	EMK21H2H-1.000M
Lot number	0020

Test Results

Temperature Effects

The EMK21 MEMS oscillator exhibited excellent stability in its output frequency with variation in temperature between -112 °C and +110 °C. Throughout this range, the frequency exhibited only a small change with temperature, as shown in Figure 1. A typical waveform of the output obtained in this temperature range is shown in Figure 2. As the test temperature was reduced below -112 °C, however, the oscillator began to behave erratically as the output waveform became unstable and the frequency value was continuously fluctuating. This instability in the oscillator's output was transitory in nature as the circuit completely recovered when the test temperature was increased to about -112 °C and above. As far as high temperature is concerned, the test was limited to only +110 °C because the chip is rated for operation between -40 °C and +85 °C. Nonetheless, the chip produced very stable output in a temperature range that exceeded both ends of the manufacturer's specified limits. Similar to frequency, the duty cycle of the output signal did not display any significant change over the test temperature range between -112 °C and +110 °C, as depicted in Figure 3.

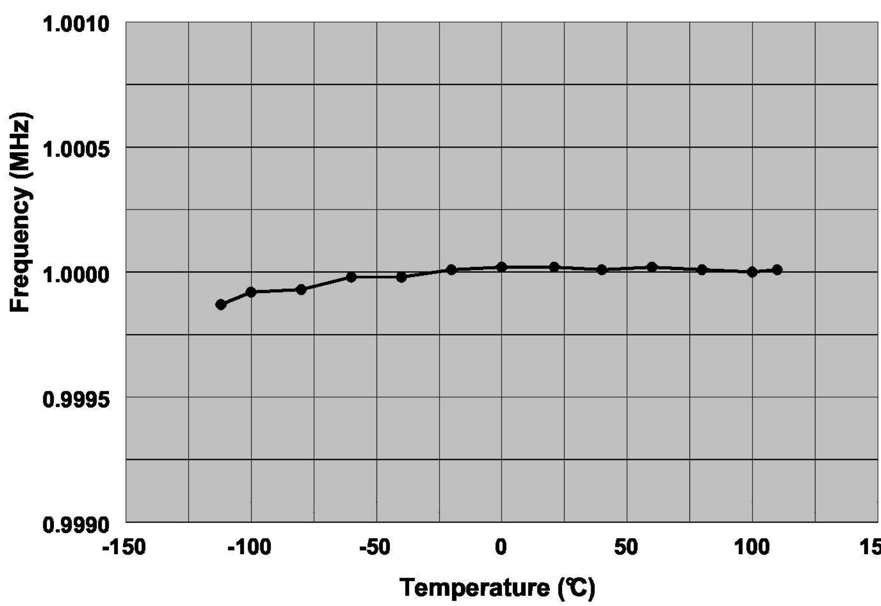

Figure 1. Variation in oscillator output frequency with temperature.

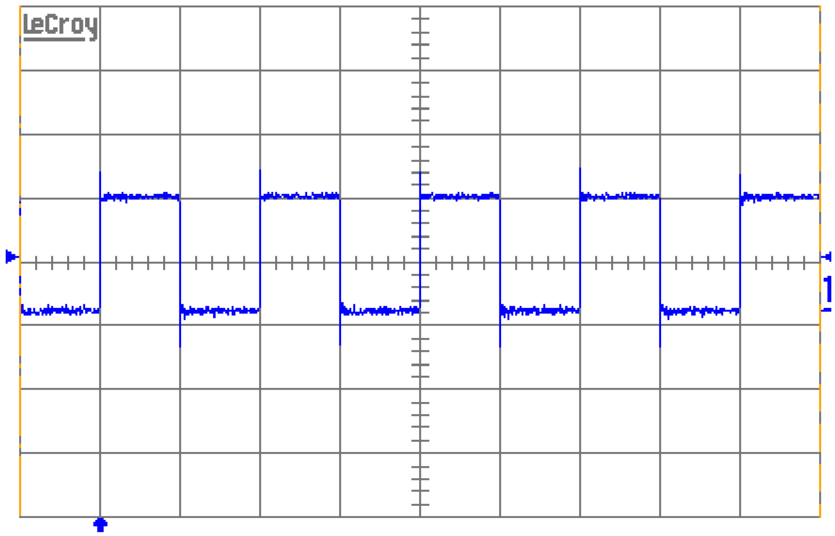

Figure 2. Output waveform of the EMK21 silicon oscillator.
(Scale: Horizontal 0.5 μs/div, Vertical 1 V/div)

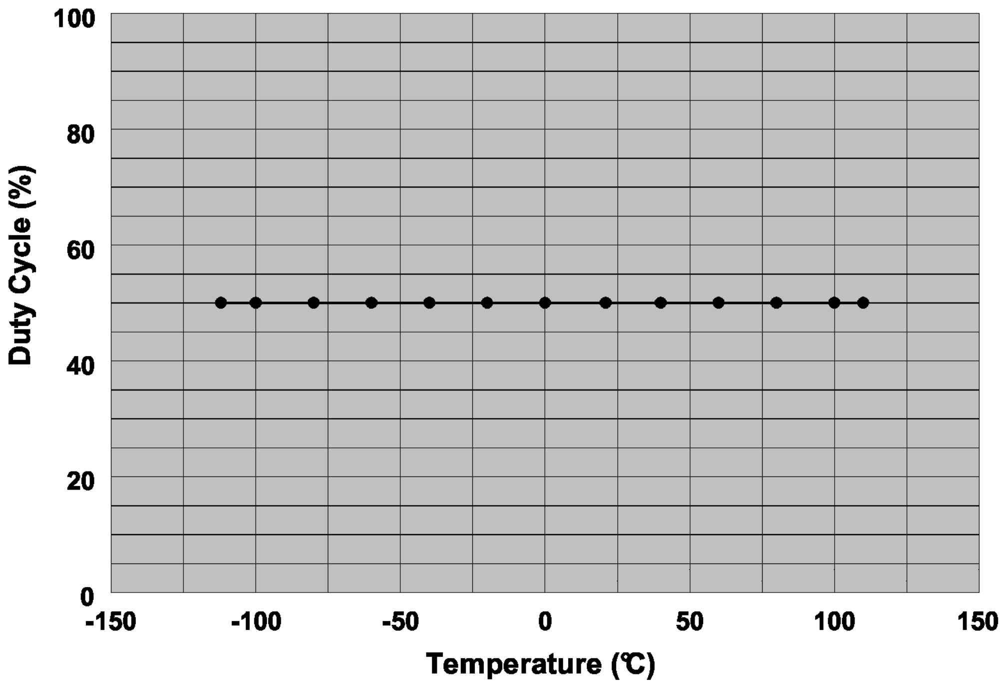

Figure 3. Duty cycle of oscillator output versus temperature.

The rise time as well as the fall time of the output signal displayed similar but weak dependence on temperature. Both of these characteristics were found to exhibit gradual but very small reduction in their values as temperature was decreased below room temperature; and the reverse was true when the circuit was exposed to high temperatures. These changes in the rise and fall time of the silicon MEMS oscillator are shown in Figures 4.

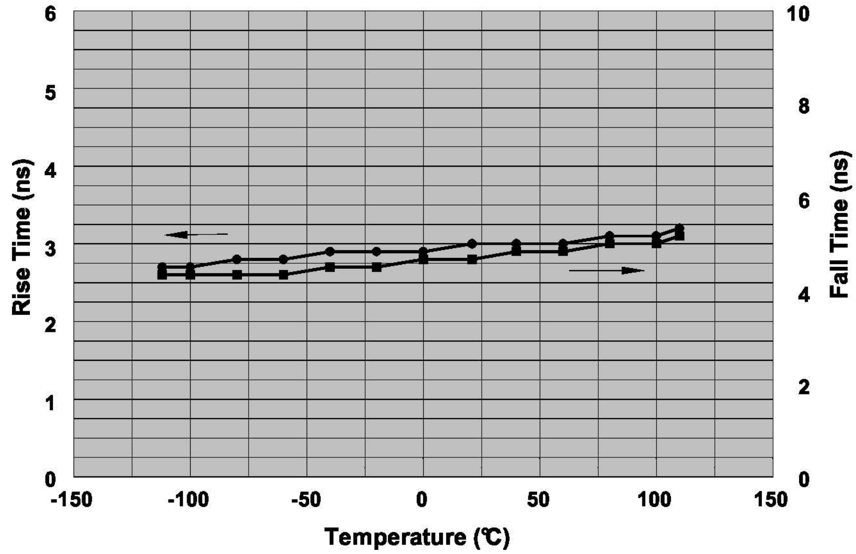

Figure 4. Rise and fall times of output signal versus temperature.

The supply current of the oscillator as a function of temperature is shown in Figure 5. While the current seemed to exhibit a gradual but very slight increase as the test temperature was increased from ambient to higher temperatures, it underwent a decrease in its value with temperature as the silicon oscillator was subjected to test temperatures lower than room temperature. The supply current ranged from 11.65 mA at +110 °C to 10.63 mA at -112 °C. This favorable reduction in the supply current at cryogenic temperatures would translate into lower power consumption of the oscillator circuit.

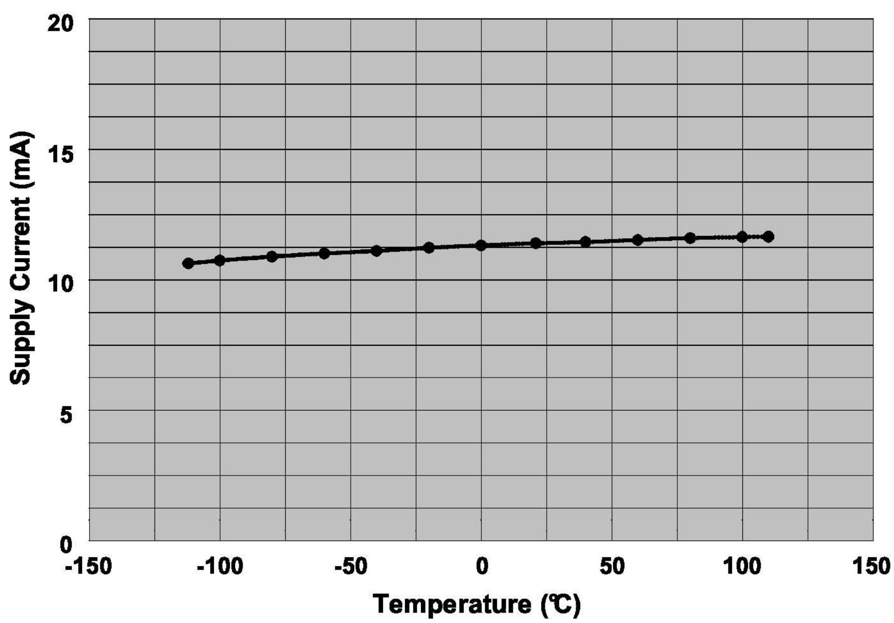

Figure 5. Supply current of oscillator as a function of temperature.

Re-Start at Extreme Temperatures

Re-start capability of this EMK21 silicon oscillator was investigated at the extreme test temperatures at which stable operation was maintained, i.e. -112 °C and +110 °C. The oscillator chip was allowed to soak separately at those two temperatures, with electrical power off for at least 20 minutes. Power was then applied to the circuit, and measurements of the oscillator's output waveform characteristics and frequency were recorded. The oscillator circuit successfully operated under cold start at -112 °C as well as at the hot temperature of +110 °C, and the data obtained was similar to those obtained earlier at these respective temperatures.

Effects of Thermal Cycling

The effects of thermal cycling were investigated by subjecting the EMK21 silicon oscillator chip to a total of 12 cycles between -112 °C and +110 °C at a temperature rate of 10 °C/minute. Although the 12-cycle activity is by no means considered as representative of accelerated or life testing to determine reliability of the device under test, it provides, nonetheless, some preliminary insight on the effect of thermal cycling on its behavior. During cycling, a dwell time of 20 minutes was applied at the extreme temperatures. Post-cycling measurements on the characteristics of the oscillator circuit were then performed at selected test temperatures. Table II lists post-cycling data along with the data obtained prior to cycling. A comparison between pre- and post-cycling data reveals that this silicon oscillator did not undergo any significant changes in its operational characteristics due to this limited cycling. The thermal cycling also appeared to have no effect on the structural integrity of the device as no packaging damage was noted upon inspection.

Table II. Pre- and post-cycling characteristics of the EMK21 silicon oscillator.

T(°C)	Cycling	f (MHz)	Duty cycle (%)	T_{rise} (ns)	T_{fall} (ns)	I_S (mA)
22	pre	1.00002	50.04	3.0	2.8	11.40
	post	1.00000	50.04	2.9	2.8	11.29
-112	pre	0.99987	50.02	2.7	2.6	10.63
	post	0.99987	50.02	2.6	2.5	10.56
+110	pre	1.00001	50.05	3.2	3.1	11.65
	post	1.00001	50.05	3.1	3.0	11.63

Conclusions

The emergence of silicon MEMS oscillators as small integrated circuit chips with excellent frequency stability, superior resistance to vibration and shock, and good immunity to EMI might constitute an alternative to using crystal oscillators and ceramic resonators as timing control elements in various electronic systems. The performance of a silicon MEMS oscillator chip, which was introduced recently by Ecliptek Corporation, was evaluated under exposure to extreme, both low and high, temperatures. The oscillator was characterized in terms of its output frequency stability, output signal rise and fall times, duty cycle, and supply current. The effects of thermal cycling and re-restart capability at extreme cold and hot temperatures were also investigated. The EMK21 oscillator was found to exhibit good operation with excellent frequency stability within the temperature range of -112 °C to +110 °C. This temperature operating range exceeded its recommended specified boundaries of -40 °C to +85 °C. At temperatures below -112 °C, the oscillator kept on functioning but exhibited frequency instability. The high temperature testing was limited to +110 °C due to the plastic packaging of the chip. This silicon MEMS oscillator was also able to re-start separately at -112 °C and at +110 °C, and it exhibited no change in performance due to the thermal cycling. In addition, no physical damage was observed in the packaging material due to extreme temperature exposure and thermal cycling. More comprehensive testing under long term cycling, however, is required to fully establish the reliability of these devices and to determine their suitability for use in space exploration missions under extreme temperature conditions.

References

[1]. ABRACON Corporation, "Ultra Miniature Pure Silicon Clock Oscillator, ASFLM1" Data Sheet, Revised: 10.04.07.

[2]. SiTime Corporation, "SiT1 SiRes Fixed Frequency Oscillator, SiT1101 to SiT1273" Data Sheet, SiT1_Rev D.

[3]. Ecliptek Corporation, "EMK21 Series Oscillator" Data Document, Rev 11/07.

Acknowledgments

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