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Stability of a Crystal Oscillator, Type Si530, Inside and Beyond Its Specified Operating Temperature Range

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Background

Data acquisition and control systems depend on timing signals for proper operation and required accuracy. These clocked signals are typically provided by some form of an oscillator set to produce a repetitive, defined signal at a given frequency. Crystal oscillators are commonly used because they are less expensive, smaller, and more reliable than other types of oscillators. Because of the inherent characteristics of the crystal, the oscillators exhibit excellent frequency stability within the specified range of operational temperature. In some cases, however, some compensation techniques are adopted to further improve the thermal stability of a crystal oscillator. Very limited data exist on the performance and reliability of commercial-off-the-shelf (COTS) crystal oscillators at temperatures beyond the manufacturer's specified operating temperature range. This information is very crucial if any of these parts were to be used in circuits designed for use in space exploration missions where extreme temperature swings and thermal cycling are encountered. This report presents the results of the work obtained on the operation of Silicon Laboratories' crystal oscillator, type Si530, under specified and extreme ambient temperatures.

Test Procedure

The device selected for evaluation comprised of a Si530-series crystal oscillator. This line of oscillators utilizes Silicon Laboratories' advanced circuitry and patented technology to provide a low jitter clock at high frequencies [1]. Unlike traditional crystal oscillators, the Si530 device uses one fixed crystal to provide a wide range of output frequencies. The operating frequency is selected near the end of the manufacturing process. The internal fixed crystal frequency setting allows exceptional frequency stability, high reliability, and low aging. The 6-pin device had a fixed frequency output of 10 MHz and was designed for use as a clock, for FPGA/ASIC clock generation, and in networking. Table I shows some of the manufacturer's specifications for this device [1]. Operation stability of this CMOS-output crystal 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. Re-start 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 crystal oscillator were also investigated. The oscillator was subjected to a total of 12 cycles in the temperature range of -120 °C to +130 °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 Si530 crystal oscillator [1].

Parameter	
Operating voltage (V)	1.8
Frequency (MHz)	10
Input current (mA)	81
Operating temperature (°C)	-40 to +85
Duty cycle (%)	45 to 55
Frequency tolerance (ppm)	±50
Output rise/fall time (ns)	1
Package (RoHS compliant lead-free)	6-pin 5x7 mm
Part #	530JA10M0000G
Lot number	1045

Test Results

Temperature Effects

The Si530 crystal oscillator exhibited excellent stability in its output frequency with variation in temperature between -60 °C and +110 °C as the frequency held a steady value close to 10 MHz, as shown in Figure 1. As test temperature was lowered below -60 °C, the frequency exhibited very slight decrease with decreasing temperature; reaching a value of 9.9978 MHz at the extreme low temperature of -120 °C. This reduction amounts to about 0.022% of the nominal value of 10 MHz. At high temperatures, the output frequency underwent a very small increase with increase in temperature beyond +110 °C. The changes were very miniscule as the output frequency measured at the extreme high temperature of +130 °C was 10.0003 MHz; a mere 0.003% change. A typical waveform of the output is shown in Figure 2. Higher test temperatures were avoided to prevent catastrophic failure of the device. At test temperatures below -120 °C the device output completely collapsed but recovered readily when temperatures was brought back to the vicinity of -120 °C, a step that was done repetitively. It should be pointed out that the crystal oscillator was allowed to soak for at least one hour at the extreme high and low test temperature in the environmental chamber prior to recording the data. At other temperatures, the soak time was 30 minutes. This was done in order to ensure thermal stabilization of the device under test and to account for any thermally-induced stresses emanating for expansion/contraction of contacts, solder joints, and interfaces. Given the fact that this crystal oscillator is only rated for operation between -40 °C to +85 °C, this preliminary evaluation of its performance suggests that this range could be extended at either end provided more comprehensive and long term testing are done to corroborate its usefulness outside the specified limits.

Similar to the frequency, the duty cycle of the output signal did not display any significant change over the test temperature range between -120 °C and +130 °C, as depicted in Figure 3.

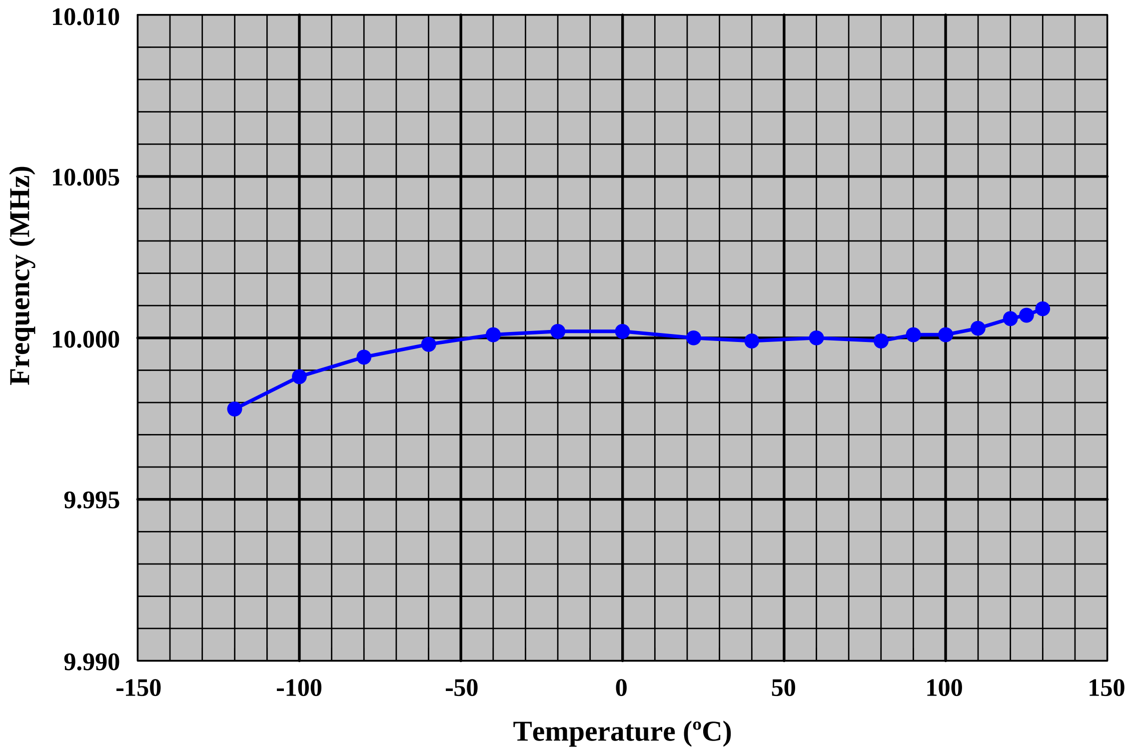

Figure 1. Variation in oscillator output frequency with temperature.

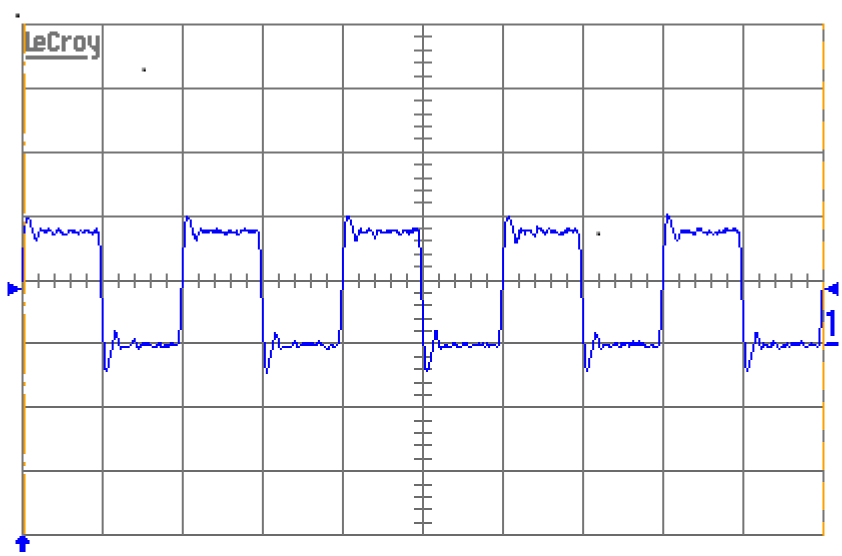

Figure 2. Typical output waveform of the Si530 crystal oscillator.
(Scale: Horizontal 50 ns/div, Vertical 1 V/div)

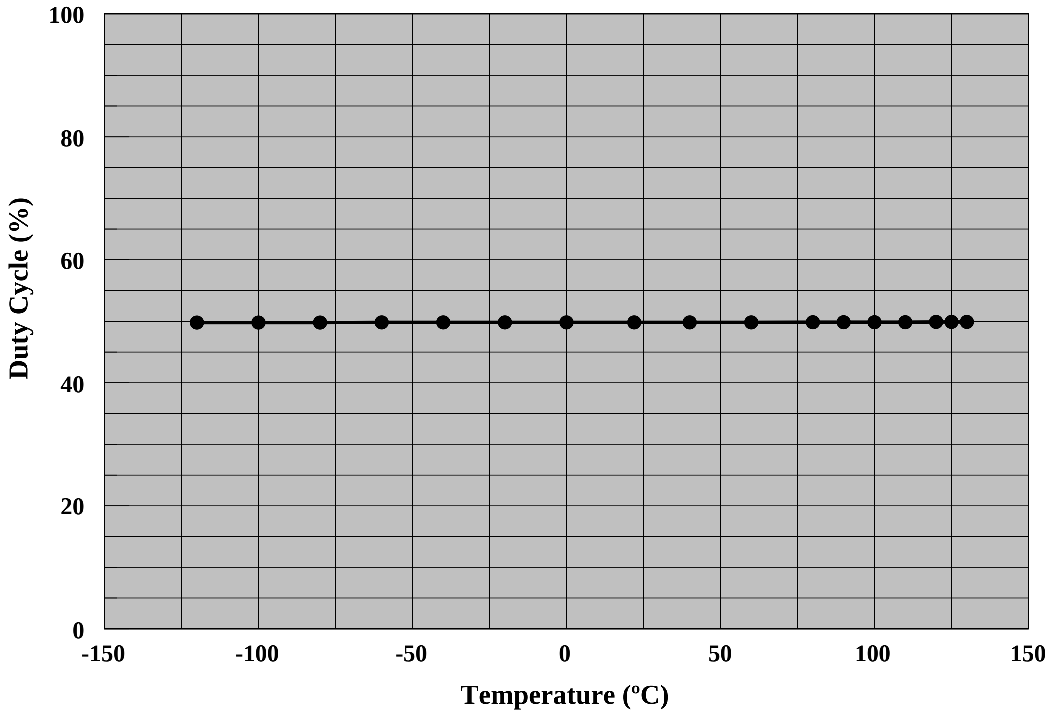

Figure 3. Duty cycle of oscillator output versus temperature.

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 oscillator's output are shown in Figures 4.

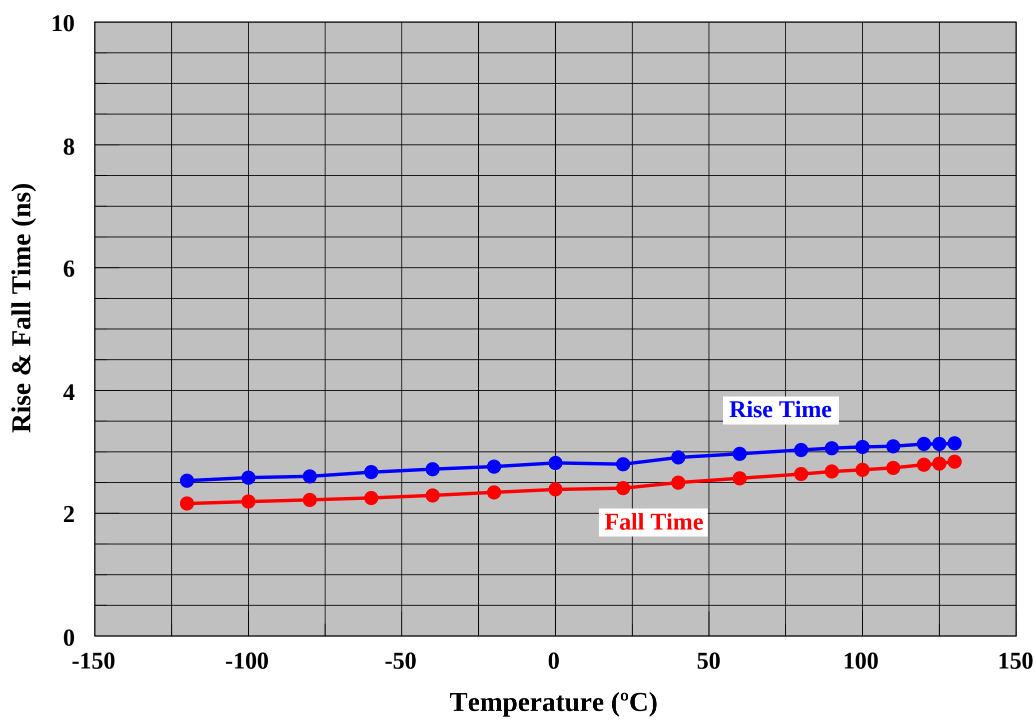

Figure 4. Rise and fall times of output signal versus temperature.

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 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. Compared to the room temperature value of 62.37 mA, the supply current reached 71.11 mA at +130 °C while it dropped to 57.63 mA at -120 °C. This favorable reduction in the supply current at cryogenic temperatures translates into lower power consumption of the oscillator circuit.

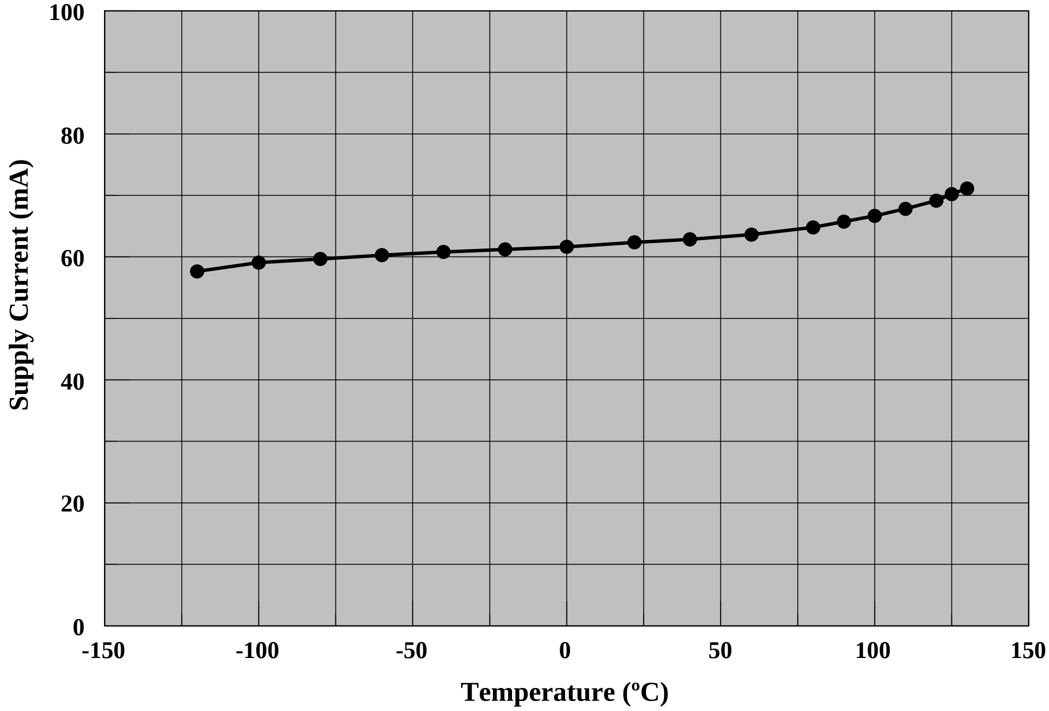

Figure 5. Supply current of oscillator as a function of temperature.

Re-Start at Extreme Temperatures

Re-start capability of this Si530 crystal oscillator was investigated at the extreme test temperatures at which stable operation was maintained, i.e. -120 °C and +130 °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 -120 °C as well as at the hot temperature of +130 °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 Si530 crystal oscillator chip to a total of 12 cycles between -120 °C and +130 °C at a temperature rate of 10 °C/minute. Although this short-term activity does not replace highly accelerated or life testing for reliability determination, it provides, nonetheless, some preliminary insight on the effect of thermal cycling on the device's 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 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 Si530 crystal oscillator.

T(°C)	Cycling	f (MHz)	Duty cycle (%)	T_{rise} (ns)	T_{fall} (ns)	I_S (mA)
+130	pre	1.00009	49.88	3.14	2.84	71.11
	post	10.0008	49.87	3.14	2.84	70.71
22	pre	10.0000	49.84	2.80	2.41	62.37
	post	10.0000	49.81	2.83	2.42	62.45
-120	pre	9.9978	49.79	2.53	2.16	57.63
	post	9.9978	49.79	2.48	2.11	57.53

Conclusions

Silicon oscillators are considered an integral part of almost all electronic systems whether for clock generation in data acquisition and processing or for synchronization in signal control. The typical output of this kind of oscillator is a representative of the resonant frequency of the used crystal. Stability of the resonant frequency, which is usually determined by the crystal's cut and geometry, will vary with temperature. In applications where accurate timing is required, it is important, therefore, to employ highly stable oscillators. In this work, the performance of Si530 crystal oscillator was evaluated under wide temperature range 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 oscillator was found to exhibit good operation with excellent frequency stability within the temperature range of -120 °C to +130 °C. This temperature operating range exceeded its recommended specified boundaries of -40 °C to +85 °C. This crystal oscillator was also able to re-start at -120 °C and at +130 °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. Additional testing 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]. Silicon Labs, "Si530/531 Crystal Oscillator, 10 MHz to 1.4 GHz" Data Sheet, Revision D, Rev. 1.1 6/07. http://www.silabs.com

Acknowledgments

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