Recent Trends in High Reliability Timing and Frequency Control Devices for Extreme Environment Applications

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Abstract: Performance requirements for higher reliability extreme environment timing and Frequency control (TF) components have continued to evolve in the recent years. Bulk of this demand has been focused on specific performance attributes governed by system applications. Enhanced performance requirement has become the mainstream of requirements where SWaP (size, weight and power) improvement is interleaved with other critical parameters such as temperature range, frequency tolerance and long-term effects and in some cases the output spectral purity. Trendlines set by customer demand continues to be the main guide for more efficient solutions. Frequency Management International (FMI) has been in the forefront of advancing the performance attributes for Hi-Rel extreme environment components. We continue to proactively respond to the pressing needs and challenges for robust frequency control components that operate under extreme environmental conditions including extreme temperatures ranging from -200ºC to + 500ºC. The material in this writeup covers the more recent performance achievements tied to specific products and form-factors for high temperature applications.

Keywords: extreme environment; high temperature; crystal; clock; oscillator; miniature package; frequency stability; thermal cycle; shock; radiation; vibration; VCXO

Introduction

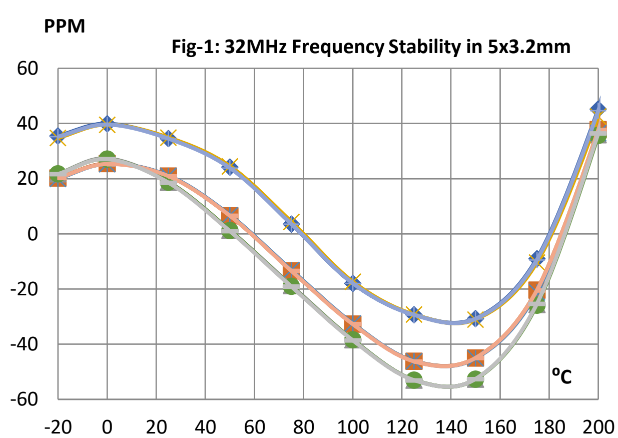
TF components uniquely provide reference timing for wide range of systems, The attributes associated with the said components operating in extreme environment typically target the reliability of the output signal levels and frequency stability under the range of environmental operating conditions. Those include operating temperature, thermal cycle, shock, vibration, radiation and ambient pressure. The performance related parameters would typically include output signal at the operating frequency as a function of the applied voltage, power consumption, frequency stability vs. temperature, package size, and long-term drift. The operating power efficiency is desired in almost every case and is an important performance parameter in growing number of new power efficient designs. Our focus has been to provide engineered solution is to realize the intended performance by utilizing the most reliable and efficient manufacturing processes and the most appropriate material.

Therefore, our goal remains to be offering component based extreme environment TF solutions that deliver reliable performance under a combination of extreme environment temperatures, vibration, acceleration and shock, ambient pressure and radiation. In addition to the energy market, our solutions are optimum for Geothermal renewable energy, jet engine sensor and control, avionics, automotive, submersible systems and space applications.

Operating Temperature & Frequency Stability

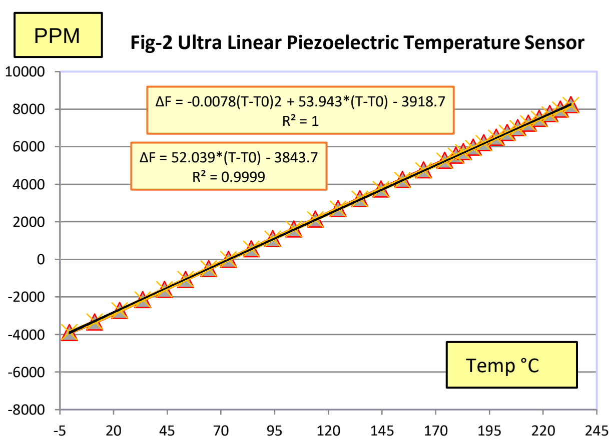
Although wide range of solutions have been available for conventional clock sources, the extreme low and high temperature ranges present their own challenges. Microelectronic packaging solutions need to take into account all the relevant stresses over the operating environment while the electronics (in particular the active devices) need to be optimized for the required performance over the specified temperature range. Our past achievements include CMOS output oscillator designs with proven performance and reliability at +300˚C.

Our continued progress on optimized piezoelectric resonators and crystal cuts have resulted in outstanding frequency vs. temperature performance for packaged crystals, fixed frequency crystal oscillators and voltage-controlled crystal oscillators (VCXO). As for fixed frequency, Fig-1 shows the changes in frequency in parts per million (ppm) as a function of temperature extending to +200˚C and in a 5x3.2mm SMD package. The precision stability is improved 3.5X to 4X compared to that of conventional type resonator/oscillator.



Optimization of the crystalline orientation of Quartz significantly contributes to the much-improved F vs. T performance. The improvement offered in this example plays a critical role in increasing the accuracy of real time measurement systems. Our new designs also address and mitigate frequency shift as a function of operating voltage over the entire temperature range. By doing so, the more accurate clocks can seamlessly be used in battery powered circuits that routinely need to operate independent of the magnitude of the reduced and fluctuating voltage.

Temperature sensing crystals and oscillators represent a more recent product series for FMI. With wide temperature performance, it offers outstanding linearity for a temperature to frequency transducer. Product range includes miniature package size such as SMD 5x7 and 5x3.2mm.
The consistent slope and sensitivity further facilitate sampling of temperature on different units positioned at different locations within a system or to use them to compensate thermal sensitivity of other functional blocks within the system and at very low power budget.
Temperature sensing oscillators with extreme low power consumption are offered at common frequencies such as 32.768KHz or higher. Our 953 series provide very good linearity, low power and wide operating voltage range from 1.5 to 3.8V that mitigates battery operated power restrictions.
Fig-2 shows the performance and linearity of a specific temperature sensor measured up to about +245˚C while the manufacturing process could support +300˚C.

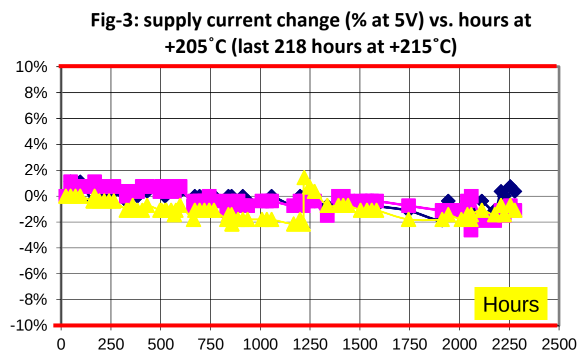


In this case the goodness of fit (R^2) for linear fit and second order fit are remarkably similar reflecting the linearity of the F vs. T.

Operating life

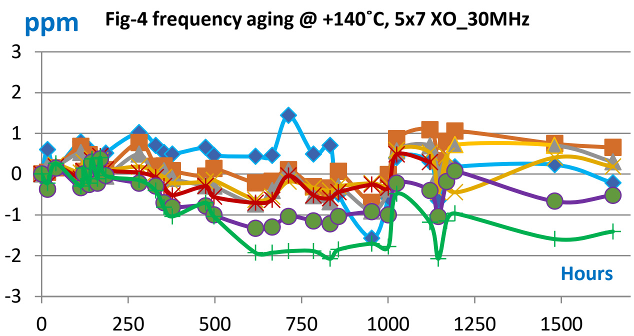
Supply current has often been a leading indicator and a proxy for operating life of active electronic devices. Operating life is often measured long enough until failure is observed. While that is the best method, often there is limited time availability for a given test setup. Accelerated life at higher temperature could be useful to achieve a sufficiently reliable result.
Our ceramic surface mount products similar to our other products in larger metal packages also achieve outstanding operating life. In doing so, the smaller surface mount packages deliver the long-term reliability while meeting the form factors of more modern systems with shrinking PCB sizes or MCM hybrid assemblies. Fig-3 illustrates a 2.8 to 5v oscillator at 15 MHz being monitored for more than 2000 hours, mostly at +205˚C and also a short period at the higher temperature of +215˚C for a close to 2250 hours of test.

Although the life test did not arrive at the "end of life", it showed the robustness level of the design.



Long Term Drift

Hi-Rel systems demand long term stability. When applied to frequency and timing, the precision scale of the frequency performance demands a higher level of process quality. As required in specific cases, FMI performs routine long term aging test that goes way beyond the scope of MIL-PRF-55310 requirement which points to evaluation at much lower temperatures like +70˚C. Real time measurements require long term stability of the clock rate. Various techniques have been used to thermally stabilize the clocks in order to improve the accuracy over the long term. However, the cost, power and size in achieving such stabilization at higher temperature may be prohibitive as compared to conventional temperature ranges. Regardless of the approach, the design techniques and the assembly process quality should inherently help to reduce the long-term frequency shift (aging). In general, the frequency aging accelerates at higher temperatures yet partially in line with Arrhenius equation $K = A\ e^{-Ea/RT}$ while following a diminished and settling pattern. Frequency should stabilize as aging process reach its equilibrium. Sample aging test data for hybrid crystal oscillator aging is shown in Fig-4 that illustrates the aging pattern for a group of 5x7 crystal oscillators when continuously operated for 1600 hours at +140ºC. in this case the special design of the resonator, as well as excellent process control at both pre and post hermetic seal steps contribute to much quicker settling of frequency. Achieving this scale of long-term aging may include some minor tradeoff of power consumption. Note that each data point includes a power cycle which by itself could contribute to some frequency error as the part is powered up at every measurement increment.



Packaging and Assembly

Successful integration of the high-Q factor resonator as the physically larger element in the system is at the heart of the optimum product performance. The right design would address the boundaries between mechanical ruggedness and stress compliance performing under the varying extreme environment exposure. FMI offers highly reliable solutions in a number of surface mount package sizes. Specifically, the examples of surface mount and ceramic packages like 5x7, 5x3.2 and 3.2x2.5 mm represent commonly available platforms with sufficient extreme environment compliance to meet the high temperature performance requirements. With a 2.5D structure, all aspects of sub-component assemblies are mitigated via a carefully implemented, controlled manufacturing process flow which includes specific visual and functional inspections.

The Road Ahead and conclusion

Our quest continues with the objective to provide higher performance, more compact, scalable, and robust fixed and variable clock oscillator solutions for extreme operating environments and for prolonged reliable operation. On the higher temperature side, the next generation jet engine controllers would require commercially available electronic components that deliver operating life of at least 10 years at +200ºC in order to meet and exceed the operational reliability for commercial and defense avionics. The challenge when it comes to stable/robust clocks is typically in the active device technology. Such low power devices should be able to drive high quality factor resonators and provide stable, low jitter output signal in compact and mechanically rugged packages. The outcome of our recent effort so far has resulted in products that address some aspects of operating temperature range, operating voltage range and output frequency range. As for the highest operating temperatures while high temperature SOI has the potential to meet most of the needs at temperatures to ≤300ºC range, they do not scale much above those temperatures with considerable reliability. The present devices are highly limited in the operating voltage and frequency range regardless of the operating temperatures. Other alternatives such as SiC and GaN so far have been available for mostly higher power circuits yet both offer hope if they were to become more commonly available for lower voltage operation and industry standard logic interface compatibility. In parallel initiatives, we will be aiming at making incremental improvement along the stated directions and challenge areas.

Conclusion

Frequency Management International continues to press forward with higher quality and performance frequency control products. We have established wide range of reliable extreme environment device configurations that have been commercially available for high operating temperature ranges. With close to twenty years of direct customer experience and technology development, our path continues to be paved with new innovation.