White Paper

Thermally-Improved Microsemi Chip Scale Atomic Clock (CSAC)

Power Matters.™

Introduction

Figure 1 • Microsemi Chip Scale Atomic Clock (CSAC)

The Microsemi SA.45s Chip Scale Atomic Clock (CSAC) was developed for applications requiring low power, low profile height, and atomic clock stability. In 2016, the product was re-launched with a wider operating temperature (–10 °C to 70 °C) to meet a broader range of applications. Since the re-launch, as part of the continuous improvement and monitoring of CSAC quality, a sample of production units were periodically sequestered to observe their long-term reliability and performance. This white paper will discuss the performance and how the temperature range was extended.

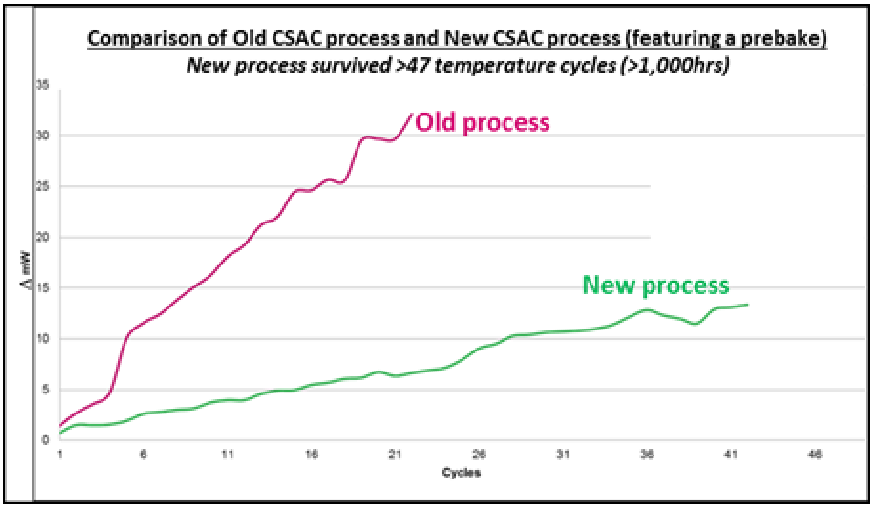
Prior to 2016, the CSAC was limited to an operating temperature of –10 °C to 35 °C . Operation outside this range was found to degrade the vacuum integrity within the physics package. When the vacuum fails, excess heater power will burden the electronics and the performance is severely degraded.

A joint investigation by a cross-functional team to improve the manufacturing process of CSAC was assembled with an end goal of producing a product that would reliably operate over a wider temperature range, while still meeting the key specifications. The investigation concluded the following:

- Additional manufacturing controls to ensure purity of the physics package are necessary
- Due to the small size and complex construction of the physics package, any contamination will affect the reliability of the product

These conclusions necessitated several proprietary modifications to our manufacturing process. To verify that each CSAC is free of contamination, additional screening measures have been put in place to ensure every CSAC is compliant with the recommendations of the R&D team.

Figure 2 • CSAC High-Temperature Test



Note: A CSAC should never be exposed to temperatures outside of the specified operating and storage temperatures. Failure to do so will void the warranty. The above test was performed on the physics package only. CSAC electronics are not rated to withstand the above temperature profile and thus were not included in the test.

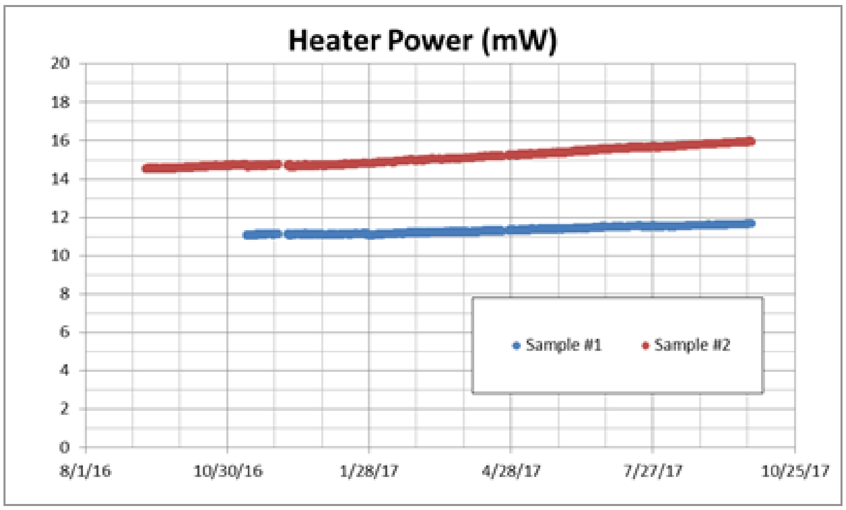
To compare the changes to the manufacturing process, an extreme high temperature test was performed on CSAC physics packages: high temperature-soak while the power consumption was monitored. The old process (pink sample curve) typically failed after 20 cycles of this extreme test, as evidenced by the rapid rise in power consumption. However, the new process (green sample curve) was able to maintain normal power consumption beyond 40 test cycles—a dramatic improvement. The next section will further discuss power consumption as it relates to vacuum integrity.

Heater Power

Heater power is a good indication of CSAC health. It directly relates to the vacuum integrity of each clock. If compromised, the heater power may suddenly jump in value or rapidly increase >1 mW over a one month period. A loss of vacuum will ultimately result in a catastrophic failure: inability to achieve atomic lock. If this failure should occur, the output drift rate will behave similar to an inexpensive TCXO and be much more sensitive to environmental perturbations.

Microsemi has spent many years improving the manufacturing process and below we show the payoff of this investment as evidenced by the heater power trends for two CSACs over many months. Both show an acceptable rise of ~1 mW over a 10-month period. These are stable units and are not in danger of losing vacuum.

Figure 3 • CSAC Heater Power over 10+ Months

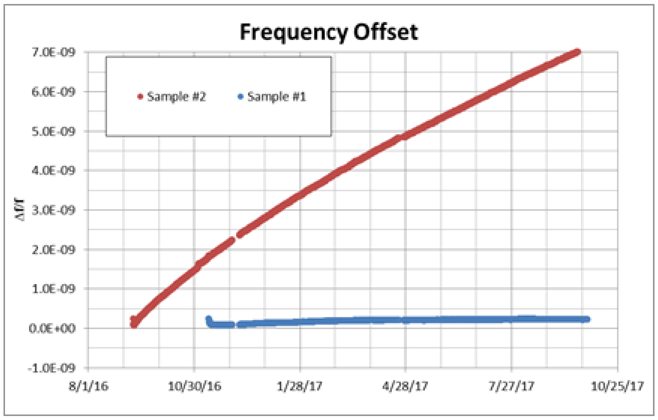


The slight rise in heater power is considered normal behavior and not a cause for alarm. However, as additional precaution we advise users to monitor the heater power drift and flag units that rapidly rise >1 mW/month. Upon delivery, absolute heater power should reside <20 mW at room temperature conditions.

Aging Rate

Unlike a high performance Cesium Standard such as the Microsemi 5071A, secondary clocks such as CSAC have inherent frequency drift when observed over a long duration. This drift is termed “aging rate” and quantified as the change in frequency per month. In the following graph, we show two units toward the extremes of the CSAC performance spectrum. Most units typically lie between the red and blue curves.

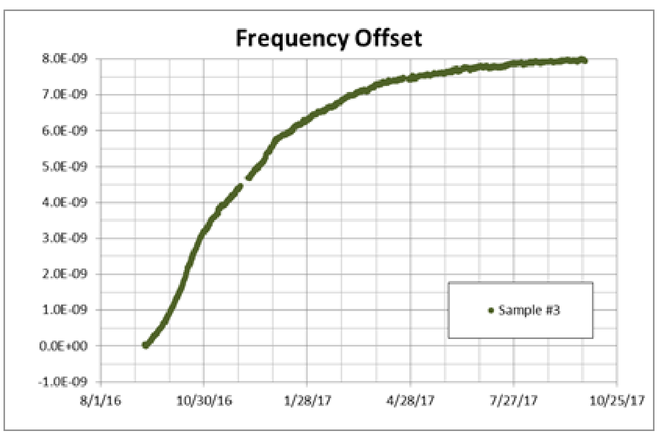
Figure 4 • CSAC Aging Rates Monitored over 10+ Months



The red curve demonstrated drift of 6×10^{-10}/month, within the current specifications but unexceptional. However, with an aging rate of 2×10^{-11}/month, the blue curve is remarkable. Its drift performance approaches our highest performance Rubidium oscillator, the XPRO, but with 120x less power (120 mW)!

Occasionally, CSACs with relatively poor drift (such as the following one) will improve over the course of their lifetime. In the case of Sample #3, it had an unacceptable aging rate and was screened out of our production test accordingly. However, in the most recent 5 months, it improved to ~1×10^{-10}/month aging rate.

Figure 5 • CSAC Aging that Improved over Time



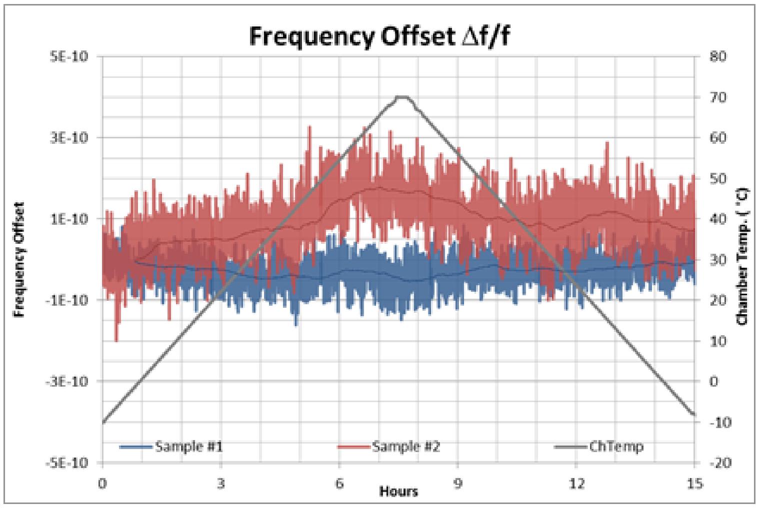
Most units in our long-term test program have aging rates well below our published specifications. For a complete list of the CSACs in our long-term aging test, please see the Table of Samples (see page 7).

Temperature Performance

The improvements in vacuum reliability have enabled the CSAC to operate over a wider temperature range: –10 °C to 70 °C. Performance over temperature is important for mobile applications and can give an indication of time error (or "holdover") in a temperature-exposed environment. As shown in the following graph, performance below 40 °C is quite good on these sample units. The main difference between these CSACs occurs at warmer temperatures, indicated by the bump in the red curve where the temperature is raised in the middle of the plot.

Note that temperature (gray trace) is plotted versus the right-hand y-axis.

Figure 6 • Frequency Offset Due to Temperature Ramp (–10 °C to 70 °C)



The following graph shows that corresponding time error over this temperature profile is 5.1 µs and –1.3 µs, respectively.

Figure 7 • Time Error Due to Temperature Ramp (–10 °C to 70 °C)

Applications

Several products have leveraged the CSAC's key attributes (low power and atomic-clock performance) to launch products targeted at mobile applications. Microsemi distributes a line of GNSS disciplined oscillators that includes a CSAC-based version (the GPS-2700). It boasts an impressive ±2 µs of 24-hour holdover while consuming <1.4 W. Other key attributes include its wide input voltage range and its multiple signal outputs.

Figure 8 • CSAC-based GPSDO (GPS-2700)

Other well-established applications include the underwater seismic exploration industry. Arrays of hundreds of CSACs are used to image the ocean-bottom. The CSAC's low power enables extended battery life/mission time and therefore reduces the overall cost of deployment. Its frequency accuracy versus power consumption is unrivaled: Aging rates are typically $<9 \times 10^{-10}$/month while the power consumption is <120 mW.

Conclusion

Predictable long-term performance is important for all products. For CSAC-based products, vacuum within the physics package is key to maintaining reliability. Due to a number of improvements within the manufacturing process, CSACs have shown an ability to maintain vacuum integrity over long duration of operation.

The thermally-improved CSAC released in 2016 has thus far been a success. The temperature range has been extended to 70 °C without any compromise to reliability or performance. CSACs will continue to be monitored over the long-term in a continuing effort to improve the product.

Table of Samples

	Monthly Aging	HtrPwr slope (mW/month)		Monthly Aging	HtrPwr slope (mW/month)
CSAC 01	13.00×10^{-10}	0.030	**CSAC 24**	2.00×10^{-10}	0.009
CSAC 02	8.70×10^{-10}	0.049	**CSAC 25**	1.80×10^{-10}	0.013
CSAC 03	6.90×10^{-10}	0.033	**CSAC 26**	-1.70×10^{-10}	0.022
CSAC 04	6.20×10^{-10}	0.107	**CSAC 27**	1.70×10^{-10}	0.012
CSAC 05	5.90×10^{-10}	0.063	**CSAC 28**	1.70×10^{-10}	0.090
CSAC 06	5.40×10^{-10}	0.115	**CSAC 29**	1.60×10^{-10}	0.013
CSAC 07	5.10×10^{-10}	0.091	**CSAC 30**	1.60×10^{-10}	0.030
CSAC 08	-4.50×10^{-10}	0.245	**CSAC 31**	1.50×10^{-10}	0.066
CSAC 09	-4.00×10^{-10}	-0.046	**CSAC 32**	-1.40×10^{-10}	0.039
CSAC 10	3.20×10^{-10}	0.188	**CSAC 33**	1.40×10^{-10}	0.024
CSAC 11	3.00×10^{-10}	0.024	**CSAC 34**	1.30×10^{-10}	0.018
CSAC 12	2.90×10^{-10}	0.012	**CSAC 35**	-1.10×10^{-10}	0.076
CSAC 13	2.70×10^{-10}	0.026	**CSAC 36**	1.10×10^{-10}	0.016
CSAC 14	2.70×10^{-10}	0.036	**CSAC 37**	-0.81×10^{-10}	0.133
CSAC 15	2.50×10^{-10}	0.084	**CSAC 38**	0.60×10^{-10}	0.039
CSAC 16	2.50×10^{-10}	0.072	**CSAC 39**	0.43×10^{-10}	0.024
CSAC 17	2.40×10^{-10}	-0.008	**CSAC 40**	-0.33×10^{-10}	0.051
CSAC 18	2.40×10^{-10}	0.071	**CSAC 41**	-0.26×10^{-10}	0.157
CSAC 19	2.30×10^{-10}	0.024	**CSAC 42**	0.24×10^{-10}	0.064
CSAC 20	2.20×10^{-10}	0.044	**CSAC 43**	0.21×10^{-10}	0.056
CSAC 21	2.20×10^{-10}	0.049	**CSAC 44**	-0.20×10^{-10}	0.055
CSAC 22	2.10×10^{-10}	0.026	**CSAC 45**	-0.039×10^{-10}	0.012
CSAC 23	2.10×10^{-10}	0.043			

Aging (Δf/mo): Mean= 2.62×10^{-10}, median= 2.1×10^{-10}, standard deviation= 2.48×10^{-10}, min= 0.039×10^{-10}, max= 13×10^{-10}.

HtrPwr rate (mW/mo): Mean= 0.053, median= 0.039, standard deviation= 0.052, min= –0.046, max= 0.245.

Note: These statistics are based upon a sample of 45 units. Product performance will vary by lot and Microsemi will ship per the latest product specifications. For the latest datasheet, please see SA.45s CSAC.

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