Chip Scale Atomic Clocks (CSACs) for Breakthrough LEO Space Applications

Summary

The number and variety of Low Earth Orbit (LEO) space applications for small satellites (smallsats) is growing quickly with many commercial, scientific and defense payloads requiring low Size, Weight and Power (SWaP) precision timing solutions. The space CSAC is the industry's first commercially available radiation-tolerant CSAC ideally suited to providing the accuracy and stability of atomic clock technology while achieving significant breakthroughs in reduced SWaP consumption.

User Benefits

The space CSAC is radiation tolerant (20 krad TID, 64 MeV) for LEO missions and it consumes less power than a traditional Oven Controlled Crystal Oscillator (OCXO), which saves on batteries and payload weight.

It measures atomic accuracy and contains built-in 1 PPS disciplining for synchronized applications such as earth observation that require precision timestamping.

The space CSAC's better aging means the payload can operate independent of an external reference such as GNSS for longer and still be accurate.

In LEO applications, shadowing during each orbit causes large temperature swings multiple times per day. The space CSAC's much smaller temperature coefficient means it performs better despite wide ambient temperature swings.

Why Atomic Timing Matters

GNSS satellites commonly use cesium and rubidium atomic clocks to provide the ubiquitous commercial time and navigation signals from which we all benefit. However, these clocks are too large and power hungry for use in small LEO payloads. Applications that take advantage of accurate time and frequency reference include time stamping of Radio Frequency (RF) geolocation/earth observation data for post processing, clock holdover capability when GNSS signal is unavailable, synchronization of multiple smallsats for interferometry and satellite ranging. These and many other LEO payloads benefit from use cases that require low SWaP while maintaining the precision timekeeping capabilities that atomic clocks deliver. Satisfying both requirements, the space CSAC is a cesium-based atomic clock miniaturized to a low SWaP design suitable for LEO smallsats.

Performance Advantages

The CSAC can greatly improve the accuracy and reduce the cost of sensor systems while maintaining a much more constant frequency over time and over wide shifts in temperature. With a volume of only 16 cm^3, it is smaller than most OCXOs. In addition, the space CSAC's power consumption of <120 mW is a reduction of approximately 10 to 20 times that of most OCXOs, which typically consume 1.5W to 2W steady state. As a true atomic clock, the CSAC has an aging rate of 3.0E-10/month.

Careful COTS Approach

The space CSAC is a Commercial Off-the-Shelf (COTS) part manufactured to IPC-610 Class 2 standards utilizing commercial electronic components that are radiation tolerant to 20 krad and 64 MeV. We use the term "careful COTS" because we implement ongoing lot date code screening. Before each new batch of space CSACs is manufactured, we use samples from specific lots of components to build space CSAC test units that are radiation tested to exceed 20 krad and only if confirmed to be radiation tolerant are those lots then allocated for space CSAC manufacture. Space CSACs then proceed through the normal rigorous CSAC test procedure before release. Careful COTS bridges the gap between pure COTS and full rad-hard space grade.

LEO Space Applications That Use Atomic Accuracy

- Satellite timing and frequency control
- Optical time transfer (between satellites and between ground and satellite)
- Inter-satellite communications (cross-linking)
- Earth observation
- Ionosphere weather monitoring
- Radio Frequency (RF) geolocation
- Interferometry
- Commercial communications constellations
- Tactical MILSATs
- Alternative PNT Defense Constellations

Typical CSAC Applications

These performance advantages translate into key benefits for breakthrough LEO space applications:

Alternative Position Navigation and Time

Payloads on small LEO satellites can provide GPS-quality alternative X-band navigation and timing information signal to military end users in regions of interest that are GNSS denied. This requires a low SWaP precision oscillator such as the CSAC on the satellite to hold time while driving payload timing systems.

Radio Frequency (RF) Geolocation/Earth Observation

RF detection and location from LEO space is a Geospatial Intelligence (GEOINT) application that has multiple commercial, scientific and defense intelligence applications using a cluster of satellites flying in formation that are precisely time synchronized and can have co-visibility of the signal of interest to compare frequency and time of arrival. Since GNSS and clock stability time and frequency error contribute to signal position and velocity accuracy, this application can leverage the space CSAC with its low SWaP and precise atomic clock performance.

Laser Cross Linking

LEO satellite constellations for commercial and defense applications are developing laser-based inter-satellite communications, navigation and time transfer techniques instead of RF due to the reduced SWaP due in part to more power efficiency and increased security of laser-based systems. The space CSAC is frequently envisioned as a low SWaP on-board reference oscillator on each smallsat to enable this application.

Space Weather (Ionosphere Plasma Monitoring)

Variability in the Earth's ionosphere affects radio frequency and GNSS communication systems. Measuring the phenomenon to understand and predict ionospheric variability can enhance the reliability and accuracy of these systems. LEO systems provide high-resolution, near-real-time ionosphere plasma monitoring using a constellation of cubesats at different LEO altitudes that are precisely time-synchronized between each satellite and with multiple ground stations. This application requires a CSAC with low SWaP and precise atomic clock performance.

Figure 1: Breakthrough applications such as alternative PNT, Earth observation, RF geolocation and space weather monitoring take advantage of CSAC atomic clock accuracy.

Figure 2. CSAC Developer's Kit includes a powered PCBA with full I/O capability and quick start software. Learn more at http://www.microchip.com/CSAC

Why Microchip

Microchip is the world's leading source of highly precise time keeping technologies, instruments and solutions. We provide timekeeping in GPS satellites, national time references and national power grids as well as in critical military and civilian networks. Our products include atomic clocks, hydrogen masers, timescale systems, GPS instrumentation, synchronous supply units, standards- based clients and servers, performance measurement and management tools and embedded subsystems that generate, distribute and apply precise frequency and time.

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