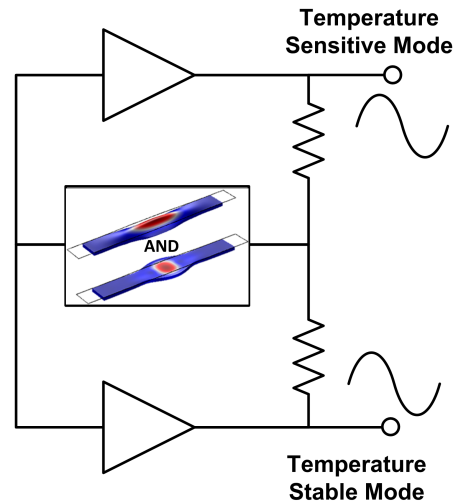


Chip Scale Ultra-Stable Clocks

Miniaturized Phonon Trap Timing Units for PNT of Cubesats

The Chip Scale Ultra-Stable Clocks (CSUSC) project aims to provide a superior alternative to current solutions for low size, weight, and power timing devices. Currently available quartz-based clocks have problems adjusting to the high temperature and extreme acceleration found in space applications, especially when scaled down to match small spacecraft size, weight, and power requirements. The CSUSC project aims to utilize dual-mode resonators on an ovenized platform to achieve the exceptional temperature stability required for these systems. The dual-mode architecture utilizes a temperature sensitive and temperature stable mode simultaneously driven on the same device volume to eliminate ovenization error while maintaining extremely high performance. Using this technology it is possible to achieve parts-per-billion (ppb) levels of temperature stability with multiple orders of magnitude smaller size, weight, and power.

Current state of the art ovenized timing references go to great lengths to compensate for temperature error between the mechanical resonator and the temperature sensor for feedback control. The additional hardware required to control this error adds cost, size, and power consumption to these devices, making integration with small spacecraft difficult. This project takes a novel approach by utilizing technology consisting of computers combined with tiny mechanical devices, called semiconductor microelectromechanical system (MEMS) technology, to create batch-fabricated dual-mode piezoelectric resonators. These resonators are designed to allow two simultaneous resonances in the same device volume, one that shows a large frequency shift with temperature and the other having a stable frequency with temperature. The temperature sensitivity of these two modes is modified using a technique known as acoustic engineering, where evanescent and propagating acoustic modes are combined to confine acoustic energy to specific regions on a resonating device. The acoustic confinement from this method allows for extremely low losses, allowing for high-performance operation while still maintaining multiple resonance modes. The dual-mode resonator will be implemented into a specialized dual-oscillator system that converts



A schematic of the proposed dual mode architecture. One mechanical resonator outputs two timing signals, one that is temperature stable for use as a reference and one temperature sensitive signal for use as a sensor.

the resonance modes into two isolated frequency signals, each with different temperature sensitivity. This ovenized platform, when combined with a properly designed feedback loop, can provide temperature stabilities in the ppb range. The final goal of the project is to demonstrate a clock with small-size (<1mm²), low-weight (<700μg), low-power (<100μW) and, in the long-term, with a low-cost approach.

With the current surge in interest for nano-pico-, and femtosatellites for in-orbit science, the demand for low-cost timing references with extremely high performance is increasing. MEMS dual-mode resonators can provide this high quality, temperature stable performance while maintaining low-cost, radiation and acceleration insensitive performance as compared to quartz. These factors are critical for reliability and functionality in extreme space environments. The small size, weight, and power of these devices in addition to their

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low cost, makes them a viable alternative in many other communication and inertial applications, many of which are used extensively in spacecraft and satellite technology in place today.

The CSUSC project is a collaboration between the University of Michigan in Ann Arbor and the NASA Goddard Space Flight Center in Greenbelt, Maryland. The fabrication facility used for the devices noted in this work is the Lurie Nanofabrication Facility at the University of Michigan.

The project is funded through the SmallSat Technology Partnerships, a program within the Small Spacecraft Technology Program (SSTP). The SSTP is chartered to develop and mature technologies to enhance and expand the capabilities of small spacecraft with a particular focus on communications, propulsion, pointing, power, and autonomous operations. The SSTP is one of nine programs within NASA's Space Technology Mission Directorate.

For more information about the SSTP, please visit:
<http://www.nasa.gov/smallsats>

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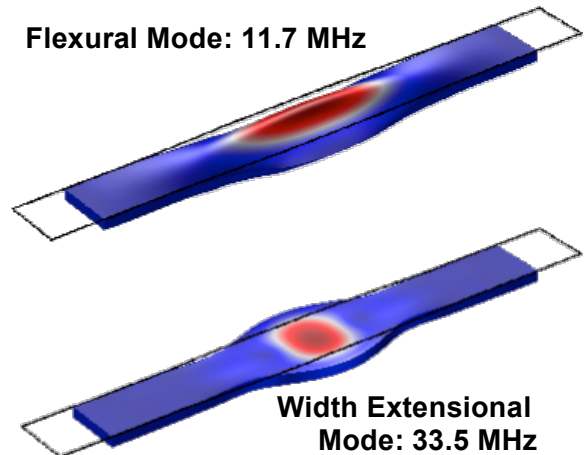
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Simulated mode shapes for the proposed dual-mode architecture. The top mode is a flexural mode, which resonates at 11.7 MHz. The bottom mode is a width extensional mode which resonates at 33.5 MHz.