ONYX OSCILLATORS IN LOW EARTH ORBIT

Commercial Oven-Controlled Crystal Oscillators for Space Applications

Mike Sawicki & Patrick Mullin
Wenzel Associates, Inc. dba Quantic Wenzel
2215 Kramer Lane
Austin, TX 78758
https://quanticwenzel.com/

***ABSTRACT* – As access to and utilization of the low Earth orbit (LEO) region has expanded, so too has demand increased for affordable, mass producible space-worthy timing devices. Wenzel outlines the approach, process, and results of adapting and qualifying an established family of Onyx oscillators to production for commercial LEO space applications.**

INTRODUCTION

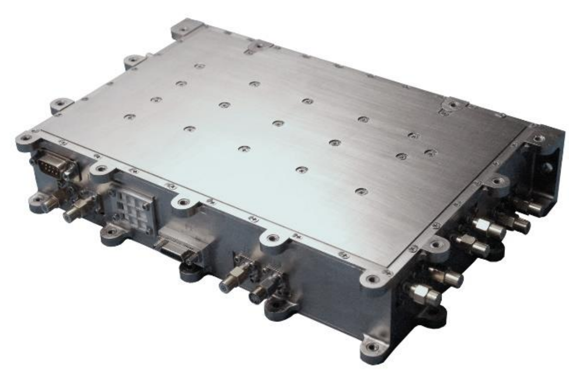
LEO Requirements

At altitudes less than approximately 2000 km, LEO satellites present an increasingly attractive option across a range of industries due to their relatively low energy threshold for placement, ease of accessibility, and superior bandwidth and latency characteristics. The LEO region also allows for greater flexibility in orbital path and speed than other orbital regions, prompting the deployment of multiple satellites in constellations for increased coverage. However, even at these low altitudes, the satellites are subject to the rigors of the space environment such as vacuum pressure, radiation exposure, and thermal extremes. The intersection of these criteria has compounded in growing demand for lower cost and higher volume manufacturability coupled with reasonable reliability assurance and risk mitigation.

Wenzel Space Heritage

Wenzel has a decades-long history of designing and developing precision, low noise devices for use in a variety of space applications, and has supplied traditional, space-qualified flight equipment for orbital and deep space missions such as:

- NOAA Joint Polar Satellite System (JPSS) – Advanced Technology Microwave Sounder (ATMS) Instrument
- NASA ICESat-2 – ATLAS instrument
- NASA SAC-D – Aquarius Instrument
- JPL Mars Curiosity Lander – Synthesizer for Terminal Descent System
- JPL Europa Clipper – REASON Instrument
- JPL Mars Perseverance Lander – Synthesizer for Terminal Descent System



Wenzel Frequency Synthesizer for JPL Mars Terminal Descent System.

JPL Mars Curiosity Sky Crane and Rover with location of Wenzel Frequency Synthesizer circled in red.

Wenzel's experience with these and other missions has provided thorough familiarity with the critical requirements and exacting demands of developing high performance space hardware, which in turn has established a solid foundation for outlining and fulfilling key criteria of a COTS-based space oscillator: functionality, availability, reliability, repeatability, economy, and clear documentation.

DESIGN: APPROACH and CRITICAL REQUIREMENTS

Development of a COTS-based product for space can be described as shift from traditional lot-based, component level qualification to design qualification at the final assembly level. By subjecting a proven design such as the COTS Onyx to an iterative cycle of careful component and materials review followed by selected qualification testing activities, the design is optimized and validated for reliable performance in space while retaining its basic COTS characteristics.

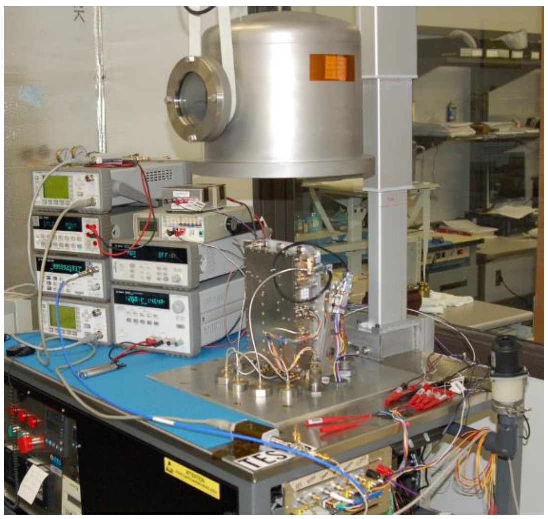
Parts and Materials

The premise of the development approach was to use the well-established Wenzel Onyx low noise, low G, oven-controlled crystal oscillator as the foundation for a robust, producible space oscillator. The Onyx has been fielded for numerous rugged applications such as airborne tactical radar surveillance and ground-based infantry satellite communications, as well as precision laboratory use such as Holzworth phase noise test systems. A thorough review of components and materials was performed with respect to criteria such as manufacturer ratings, recommended derating per EEE-INST-002, package construction, and potential outgassing, with substitutes being identified as needed. Layout of the PCB and internal controlling oven were modified and optimized for the unique performance requirements of operation in a vacuum environment. Lack of atmosphere alters the thermal conduction paths of the system and must be accounted for when designing the ovenized portion of the oscillator. A companion multiplier board option was also developed for production, allowing the base oscillator frequency to be tailored to specific customer output requirements. Finally, the entire assembly was packaged into a solder-sealed steel can.

Wenzel Onyx IV – Package Exterior View

Testing

The Onyx oscillators chosen for this effort were already proven to perform well in their intended terrestrial applications; one of the primary challenges of the project was how the established performance of the design would translate to the space environment. The testing regimen performed included but was not limited to validating static phase noise performance in ambient atmosphere, frequency stability and output power under vacuum across an operating temperature range of -40°C to +85°C, and radiation sensitivity. All tests were performed in-house at the Wenzel facility except for radiation testing, described below.



Wenzel Space Simulation Thermal Vacuum Chamber (SSTC or TVAC)

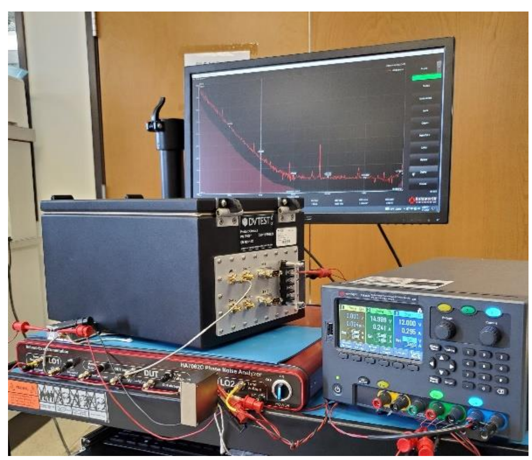
RADIATION TESTING: Methods and Data

Total Irradiating Dose (TID) testing was performed on three different models of Onyx oscillators: 100 MHz Onyx, 10 MHz Onyx, and 10 MHz Onyx-ST. Six sample units of each model were solder sealed, leak tested, and shipped to VPTRad in Chelmsford, MA for TID testing per a Wenzel specified test procedure based on MIL-STD-202. Five units from each sample lot were powered on and irradiated with Co-60 gamma rays up to 50 kRad per the specified Wenzel procedure, with 1 unit from each lot serving as a control. Baseline measurements of warm-up current and RF output power were performed prior to exposure and performed again at post 30 kRad and post 50 kRad intervals. All units tested within specified parameters at all intervals and showed no significant parametric degradation post-irradiation. Upon completion of testing the units were packed in dry ice and returned to Wenzel for further evaluation.

Heavy ion and high energy proton testing were also performed to evaluate Onyx response to Single Event Effects (SEE) up to 200 MeV magnitude. This testing revealed non-damaging current excursions in the original design that were traced back to the CMOS op amp. This component was replaced with a more robust alternative that successfully mitigated SEE risk while preserving expected functionality and performance.

Radiation and Phase Noise

Static phase noise testing was performed at the Wenzel facility on all irradiated and control sample units and compared to baseline phase noise performance measured prior to radiation testing. While some degradation in phase noise performance was noted between the control unit and the irradiated units, the phase noise measurements still fall into the acceptable range of values considered to be “premium” phase noise levels.



Wenzel Phase Noise Test Station with Holzworth Analyzer.

Figure 1: Post-Irradiation Static Phase Noise, 100 MHz Onyx, Control Unit vs. Irradiated Units

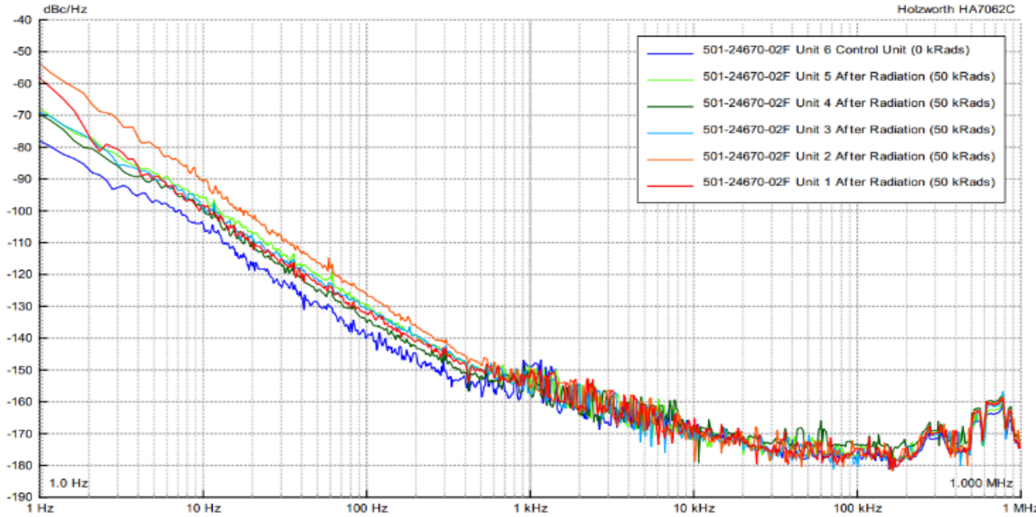


Figure 2: Post-Irradiation Static Phase Noise, 10 MHz Onyx, Control Unit vs Irradiated Units

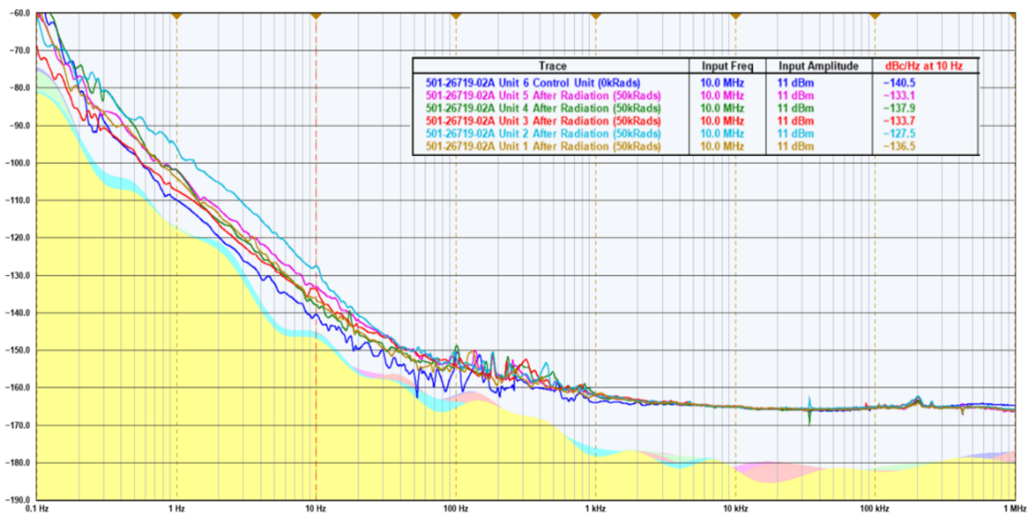
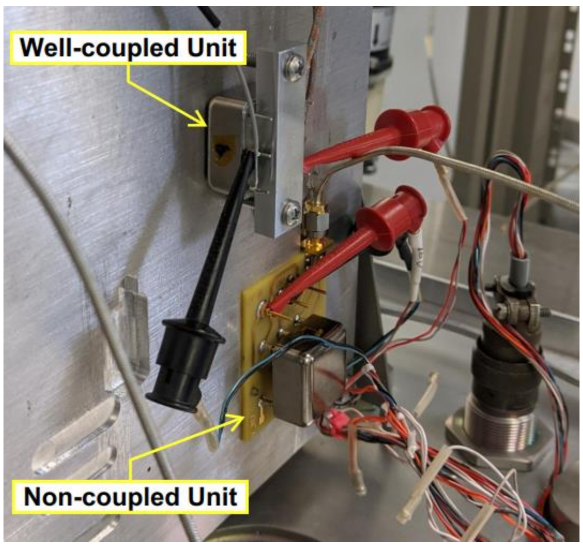


Figure 3: Post-Irradiation Static Phase Noise, 10 MHz Onyx-ST, Control Unit vs. Irradiated Units

THERMAL VACUUM TESTING: Methods and Data

Two 100 MHz Onyx oscillators were solder sealed, leak tested, then mounted to a fixture on the thermal control platform of the vacuum chamber (TVAC). Two different test fixtures were employed: one fixture to maximize thermal dissipation between the oscillator housing and the TVAC platform, the other to limit thermal dissipation to only the carrier PCB and external pins. These two fixtures are referred to as well-coupled and non-coupled, respectively.



Onyx Units in TVAC Test Fixtures

The TVAC profile performed cold start at -41°C, then gradually ramped to +85°C, pausing to soak at -41°C, -11°C, +25°C, +55°C, and +85°C. Test data was collected at 60 second intervals for case temperature, frequency, RF output power, input voltage, and current.

Analysis of the test data indicated that both oscillator configurations performed well when mounted to the thermally controlled surface, whether through the housing (well-coupled) or the pins only (non-coupled). Both units stayed well within their lock range (<15% of tuning range) and steady state output power shifted by less than ±1 dBm across the full test temperature range.

Power consumption for the well-coupled unit was similar to that at room ambient pressure, using 2.3 Watts at -41°C and 1.3 W at +25°C, with a modest frequency shift of <0.5 ppm (500 ppb) from -41°C to +85°C. The non-coupled unit had extremely low power consumption, using just 0.62 W at -41°C and 0.45 W at +25°C, with an overall frequency shift of <2 ppm (2000 ppb) from -41°C to +85°C, and a frequency shift of <100 ppb from -41°C to +50°C.

Figure 4: TVAC Results, RF Power Over Temperature, Well-Coupled vs. Non-Coupled

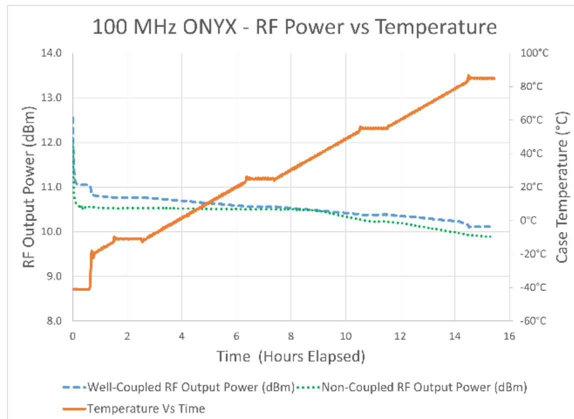


Figure 5: TVAC Results, DC Power Over Temperature, Well-Coupled vs. Non-Coupled

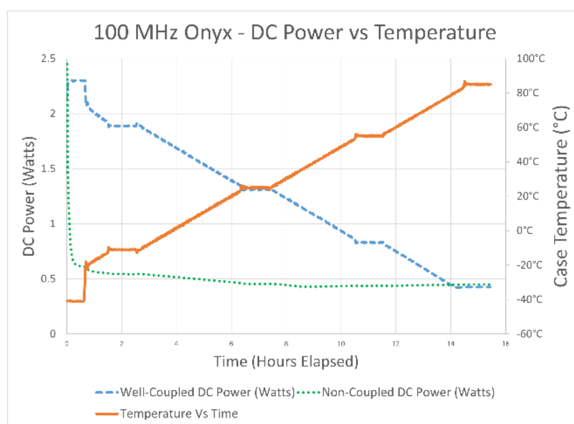
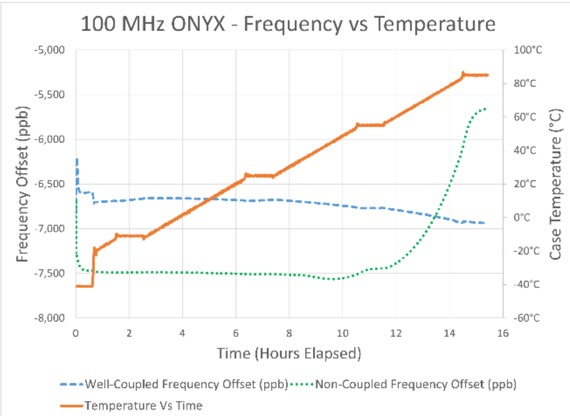


Figure 6: TVAC Results, Frequency Over Temperature, Well-Coupled vs. Non-Coupled



At the mounting extremes, both the well-coupled and non-coupled units provided different but acceptable performance. RF output power and phase-locking capability remain consistent between the two configurations, while the different levels of power consumption and frequency shift observed indicate that thermal coupling and desired frequency stability can be optimized for the specific application and location within the LEO satellite.

LEO ONYX PRODUCT OFFERING

- Onyx for Space (currently 10 MHz and 100 MHz output frequencies)[1]
- Onyx Multiplier option (currently limited to odd-order multiplication)
- 1 PPS for Space (future)

CONCLUSION

Initial testing and production of Wenzel's Onyx oscillators provide strong support to the premise that COTS-based devices are viable, reliable, and cost-effective solutions for LEO space applications. Future goals for this design effort include expanding the capabilities of the multiplier board option, supplementary environmental and radiation testing to better establish typical performance, and synchronization with the 1 PPS for space design effort. As improvement of the baseline product continues, manufacturing flows and processes will also fall under renewed scrutiny for enhanced production quality and manufacturing efficiency. Finally, as satellites using LEO-qualified Onyx oscillators continue to be deployed into service, field data reports will bring the process full circle and provide valuable documentation of the long-term success of these devices, earning them their rightful place in the catalog of Wenzel heritage space products.

For more information, visit our Onyx web pages:

- https://wenzel.com/model/hf-onyx/
- https://wenzel.com/model/vhfonyx-iv/

WENZEL HERITAGE SPACE PRODUCTS

[1] Other HF and VHF frequencies available; contact Wenzel directly for more information.