Radiation Mitigation in ASIC-Based Oscillators

Comparative Analysis of Design for Resilience and COTS Foundation Approaches

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rakon
A Bourns Company



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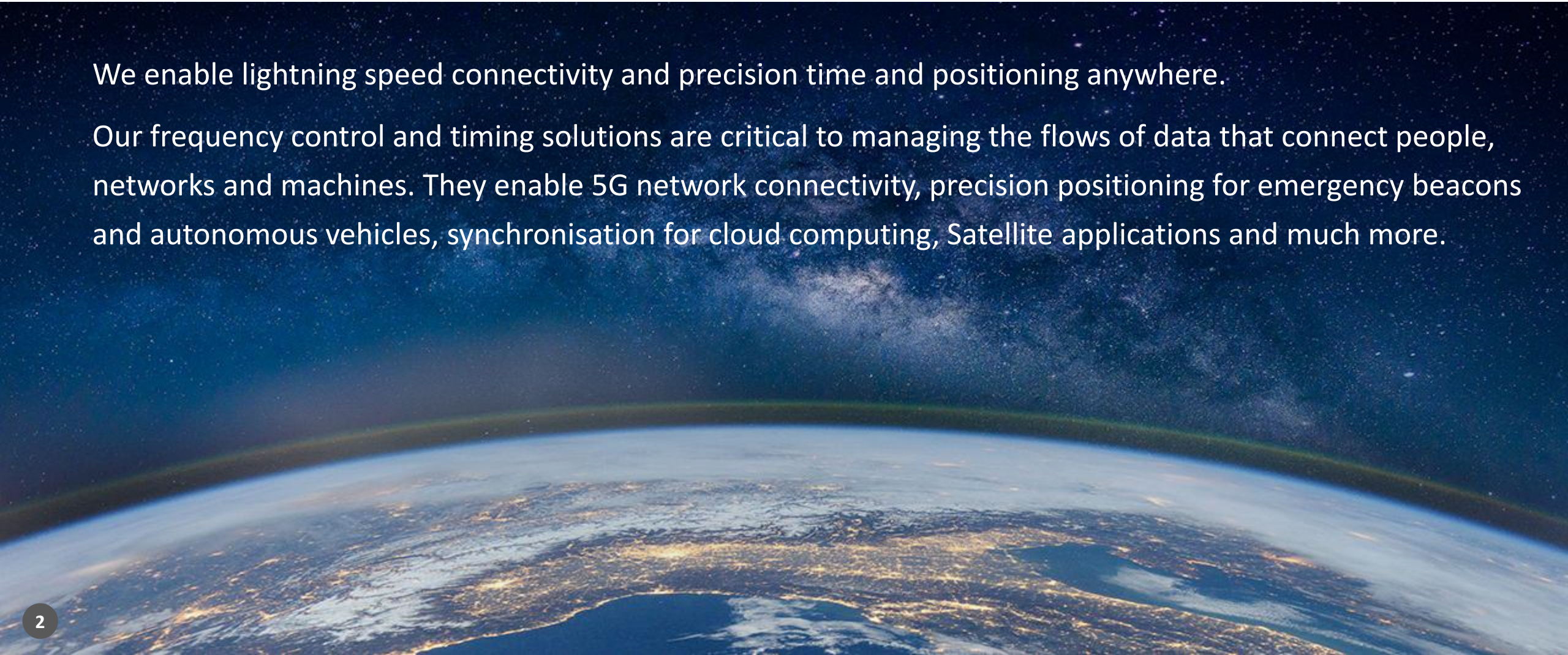
The increasing deployment of NewSpace constellations and radiation-constrained missions has intensified the need for robust and scalable timing solutions. ASIC-based oscillators are emerging as a key technology to address stringent requirements in terms of size, power consumption, and integration. However, ensuring radiation tolerance in such architectures remains a critical challenge.

We presents comparison of two radiation mitigation strategies for ASIC-based oscillators: Intrinsic design resilience and COTS **foundation** approaches.

- The first strategy focuses on **radiation-hardening-by-design techniques**, including architecture-level redundancy, layout optimization, and mitigation of single-event effects (SEE) and total ionizing dose (TID) degradation mechanisms combined with optimized qualification, **manufacturing process management.**
- The second approach leverages commercial-off-the-shelf (COTS) foundation component **selected for base ASIC process resilience potential** combined with optimized qualification, **manufacturing process management** and screening to ensure acceptable performance under radiation exposure.

We highlight the respective advantages and limitations of each approach based on two ASIC case-studies. The results provide practical guidelines for understanding and selecting radiation-resilient oscillator solutions, enabling optimized balance between performance, cost, and risk in next-generation space systems.

What We Do



We enable lightning speed connectivity and precision time and positioning anywhere.

Our frequency control and timing solutions are critical to managing the flows of data that connect people, networks and machines. They enable 5G network connectivity, precision positioning for emergency beacons and autonomous vehicles, synchronisation for cloud computing, Satellite applications and much more.

Our Markets and Applications Today



Telecommunications

- Radio heads and small cells
- Base Stations, CUs and DUs
- Data Centres
- Switching and routing
- Access Networks



Space

- Traditional Space
- NewSpace
- Ground Stations



Defence

- RADAR
- Aerospace
- Communications
- Positioning & Navigation



Positioning

- Agriculture, Exploration & Mining
- Precision Positioning
- Emergency Beacons
- Tracking
- Consumer PND
- Aircraft / Drones
- Modules



IoT, Automation and Controls

- IoT
- Consumer/Home
- Wireless Networks



Instrumentation

- Laboratory
- Maser / Atomic Fountains

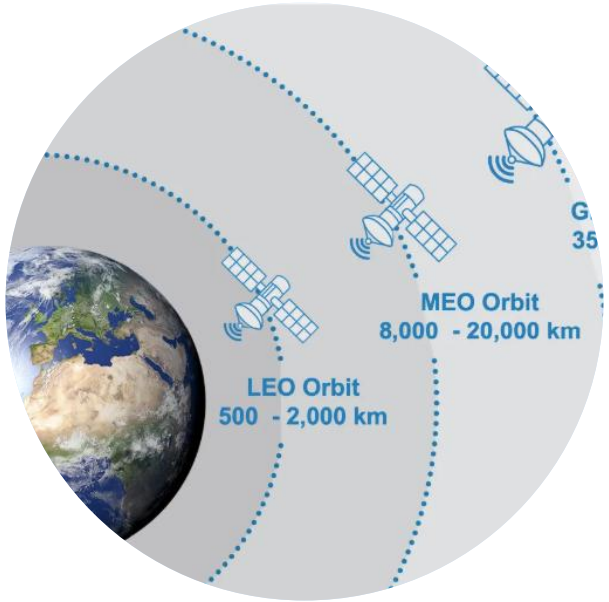
The Space Radiation Environment: A Constant Threat



- LEO and deep-space environments subject components to high-energy particles that cause SEEs, TID drift, and long-term device degradation.
- Oscillators are among the most critical subsystems, and instability can compromise payload and platform performance.
- Rakon’s radiation-qualified solutions leverage decades of proven reliability in critical space missions.

Why Radiation Resilient Oscillators Matter

Space requirements for oscillators



Reliability in Orbit

Rad-resilient oscillators maintain operation, frequency stability and low phase noise even under prolonged radiation exposure



Mission Longevity

Satellites are expected to operate for years without maintenance



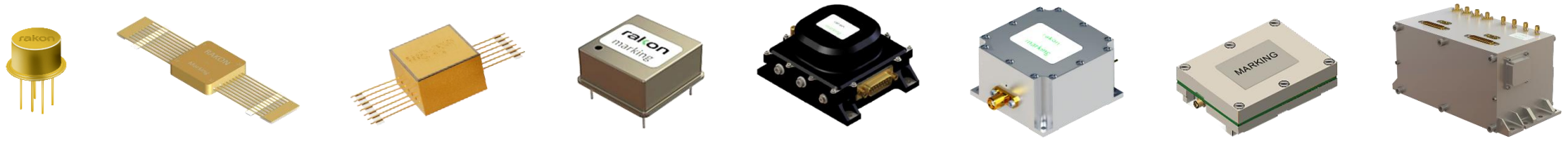
Cost of Failure

While COTS oscillators may be cheaper upfront, the cost of a failed mission can far outweigh the savings

Why Radiation Resilient Oscillators Matter

Radiation Resilient oscillators in space

- **Mission Assurance Importance**
  Radiation resilient oscillators protect costly satellite investments by ensuring reliable timing and preventing hardware failure.
- **Operational Reliability**
  Stable oscillators prevent communication dropouts, data corruption, navigation errors, and payload shutdowns on critical missions.
- **Cost Efficiency Over Time**
  Though initial costs are higher, radiation resilient components reduce total mission costs by avoiding failures and reducing redundancy.
- **Customer Confidence and Compliance**
  Using resilient oscillators enhances customer trust, simplifies regulatory approvals, and improves insurance underwriting outcomes.



Bridging the Radiation Tolerance Gap

Rakon's RT-COTS and Design Hardened products bridging and filling the customer needs

Tested COTS

Commercial parts selected primarily for availability and performance

- **Standard components** with no inherent radiation design objective
- **Radiation testing** provides observed behaviour for tested samples
- **Application limits** depend mainly on available test evidence

TEST EVIDENCE, LIMITED DESIGN INTENT

BRIDGE

RT-COTS

Commercial foundation solution engineered to improve Radiation Tolerance

- **Purpose-selected commercial ASIC Foundation** for inherent radiation robustness
- **Radiation-aware design** combined with Qualification campaign to verify performance
- **Manufacturing process management, traceability** and quality control

BRIDGES DESIGN INTENT + TEST EVIDENCE + MANUFACTURING

BRIDGE

Design-Hardened Product

Radiation resilience built into the component and system architecture

- **Swept Quartz Crystal** selected for radiation-resilient frequency behaviour
- **Hardened ASIC design** with dedicated circuit and layout rules
- **Qualification campaign** verifies performance against requirements
- **Manufacturing process management, traceability** and quality control

MAXIMUM DESIGN ASSURANCE

Comparative Analysis

Comparison

Design Hardened Approach

Radiation resilient design strategy

Swept XTAL resonator

Radiation-screened frequency reference

- **Swept quartz** reduces radiation-sensitive impurities and defect centres
- **Screening & lot control** establish stable resonator behaviour
- **Radiation characterisation** verifies frequency stability and ageing

SYSTEM-LEVEL RESILIENCE

COMBINED

Radiation-tolerant ASIC

Architecture, circuit and layout hardening

- **TID-aware design** with robust biasing, references and margins
- **SEE mitigation** using protection, filtering, redundancy and recovery
- **Radiation layout rules** including guard rings, spacing and isolation

Manufacturing process management, traceability and quality control

The crystal and ASIC must be qualified together: a resilient resonator alone cannot compensate for vulnerable electronics, and a hardened ASIC cannot recover an unstable frequency reference

Radiation Hardened ASIC Oscillator

SAPHIR PLL XO (10MHz to 3GHz) – Development partnership between RAKON and SAPHYRION with ESA support

ESA Project 1-10755 : Development of Flexible and Miniaturized rad-hard Oscillators up to L-band. ESA Contract No. 4000133505/21/NL/FE

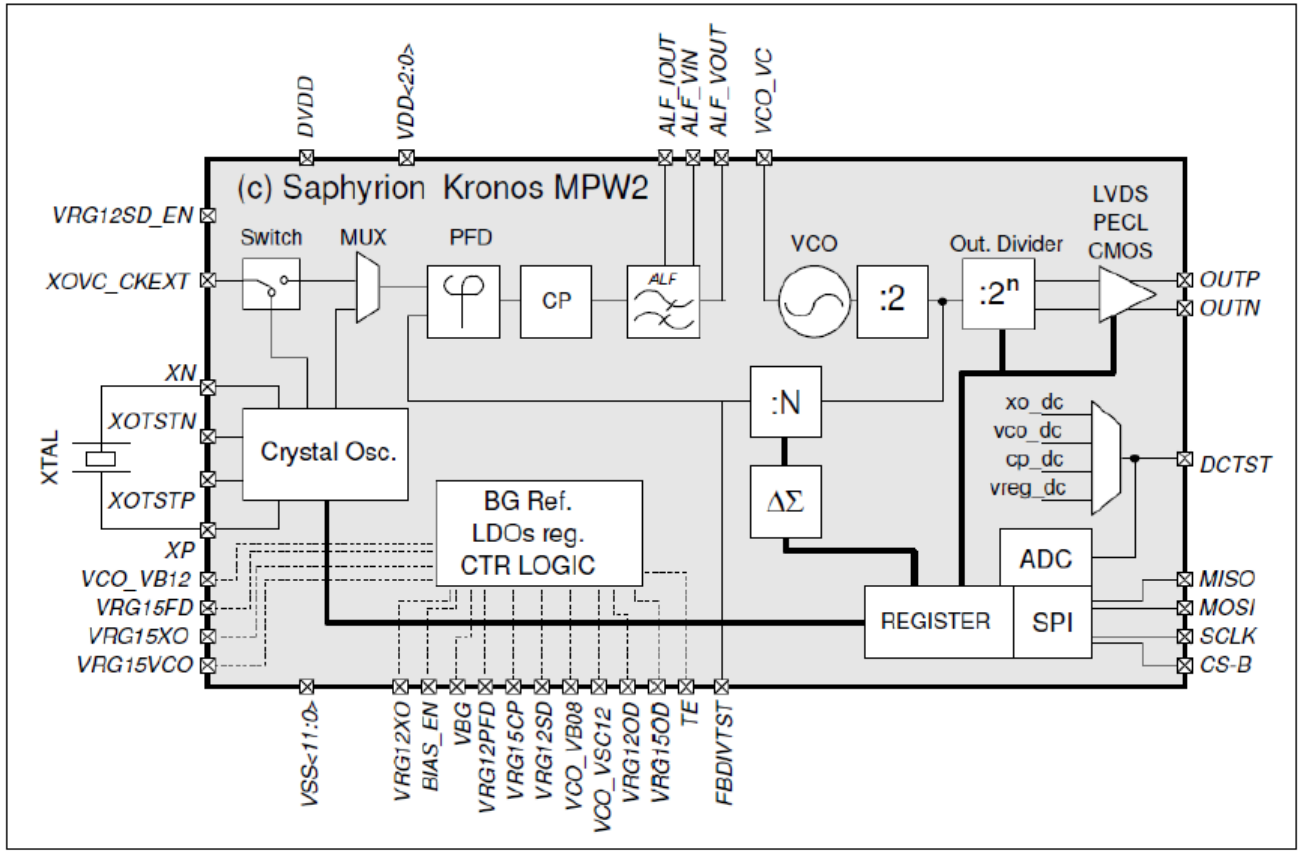


Figure 1 : Block diagram of KRONOS MPW-2 ASIC.

- Process Selection: IHP SiGe SG13SCu process
- For SEU (Single Event Upsets), the mitigation strategy combines Triple Modular Redundancy (TMR) where required with Hamming code error correction for register memories.
- For SEL (Single Event Latch-up), mitigation primarily relies on layout techniques, such as implementing proper guard rings, maintaining adequate spacing between sensitive structures, and following latch-up prevention design rules.
- For TID (Total Ionizing Dose), we evaluate the fabrication process and all radiation-related information provided by the foundry regarding parameter degradation under ionizing radiation, such as transistor threshold voltage shifts, current gain (β) degradation, and other device characteristics. Based on this analysis, we design circuits that remain robust despite these degradations, while also accounting for the standard PVT (Process, Voltage, and Temperature) variations.
- Traceability and manufacturing controls apply from the wafer level.

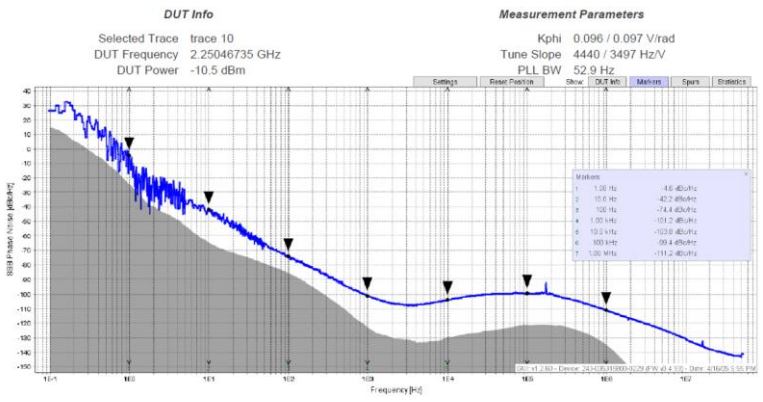
Saphir XO platform

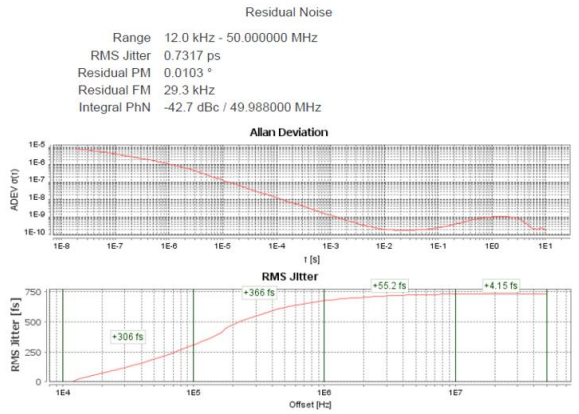
Frequency Flexible Oscillator for Space

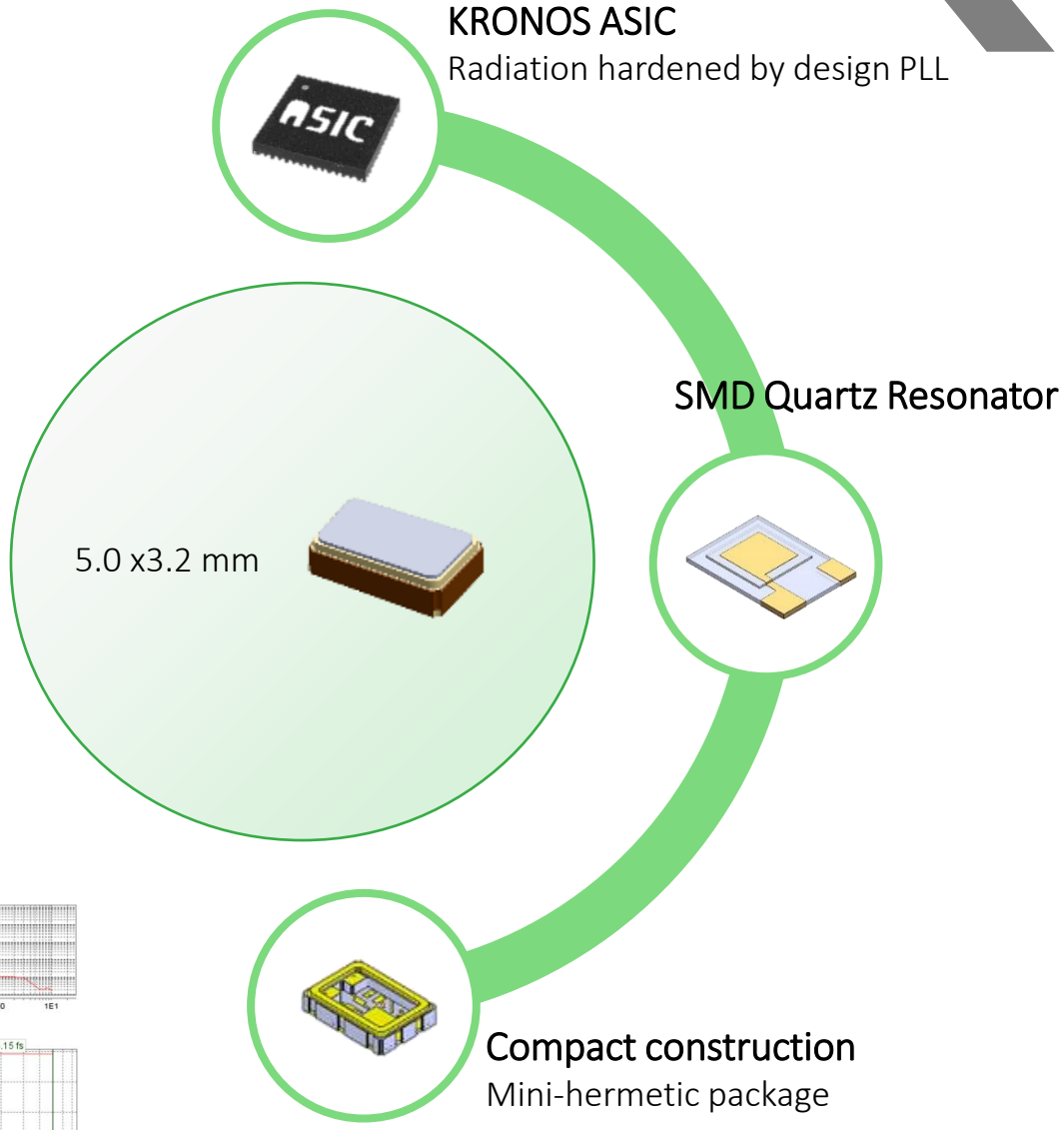
Space Grade Fractional-N PLL XO enables reduced lead-time flexible output frequency clock oscillators

Specifications:

- **Extended Frequency range:** 10 MHz to 3 GHz
- **Stability:** ±50 ppm (-40 to 105°C)
- **Jitter:** RMS phase jitter < 1 ps
- **Supply Voltage:** 1.8V, 2.5V, 3.3V
- **Output:** CMOS, LVDS, PECL
- **Fully Hermetic Construction** – 5.0mm x 3.2mm XO







Radiation Tolerant COTS

Radiation tolerant COTS design strategy

Commercial XTAL

Conditioned commercial frequency reference

- **Standard quartz,** rather than swept radiation-grade crystal
- **Pre-irradiation option,** stabilises the response before deployment
- **Screening & selection,** identify suitable commercial resonators

A pragmatic route between standard COTS and fully radiation-hardened solutions

COMBINED

Purpose-selected SOI ASIC

Commercial process chosen for inherent robustness

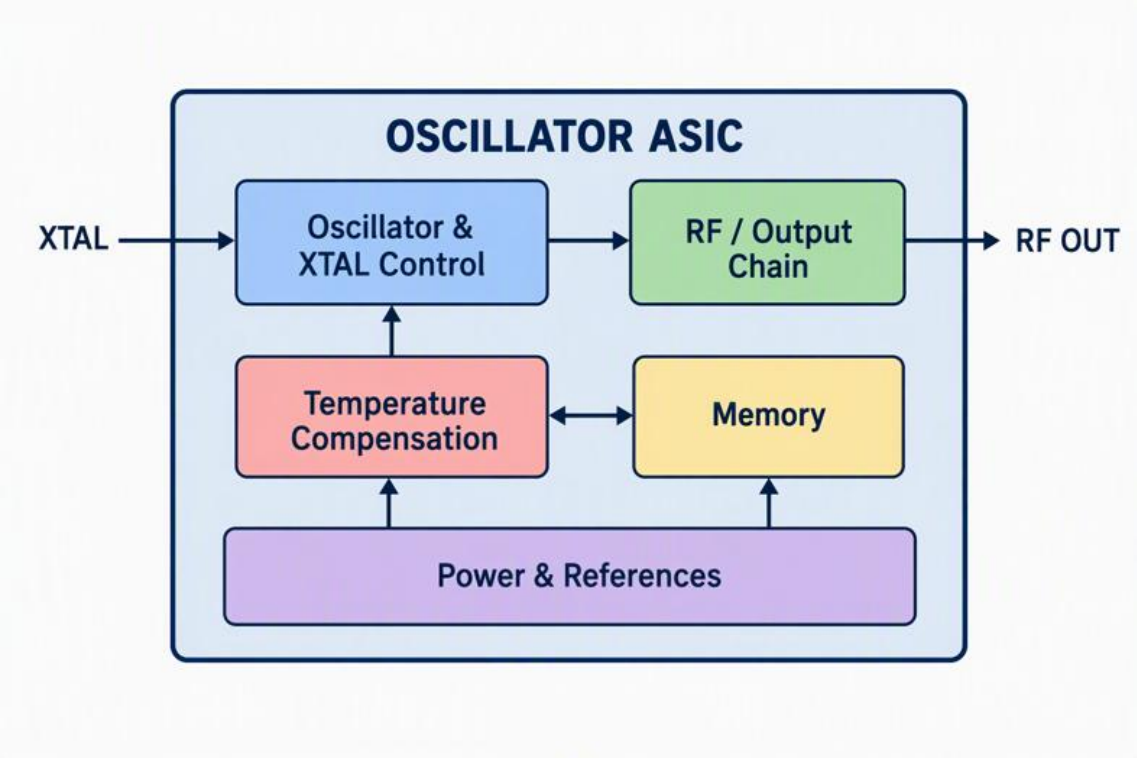
- **SOI (Silicon-On-Insulator) technology,** reduces charge collection and parasitic paths
- **Process choice,** intentionally improves radiation tolerance
- **Design measure options,** OTP Memory, added margin, protection and recovery capability

Manufacturing process management, traceability and quality control

Radiation testing is essential to generate measured data on frequency shift, current consumption and functional behaviour, enabling evidence-based qualification and application limits.

RT-COTS ASIC Oscillator

Niku TCXO (10 MHz – 160 MHz)



- Process Selection: BICMOS 180nm SOI process
- The selected process supports the requirements of the target space application as well as the foundation commercial use.
- For TID (Total Ionizing Dose) the utilisation of a SOI (Silicon On Insulator) process and OTP fuse blow memory provide a foundation for mitigation of TID effects
- For SEU (Single Event) and SEL (Single Event Latch-up) the utilisation of a SOI (Silicon On Insulator) process and OTP fuse blow memory provide a foundation for mitigation of these effects
- Traceability and manufacturing controls apply from the wafer level.
- Niku TCXO combines intentional process selection, radiation test evidence and controlled manufacturing.

Niku USTCXO platform

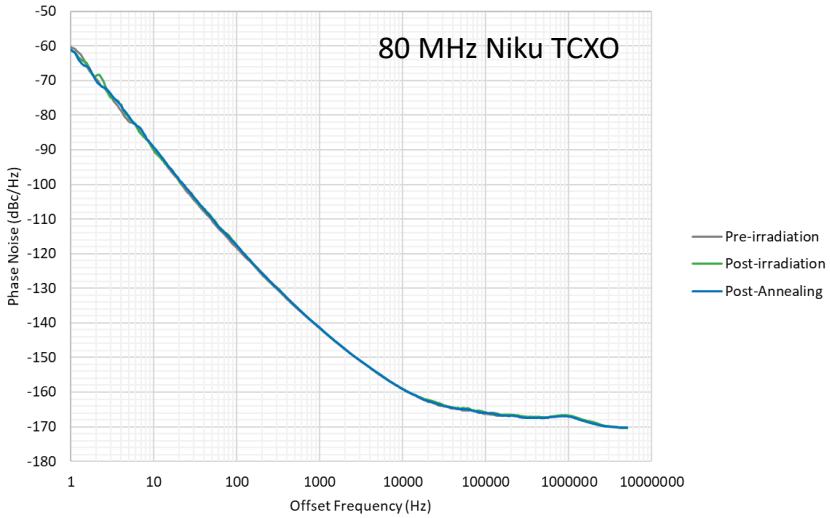
Advanced TCXO technology integration for low phase noise and stability

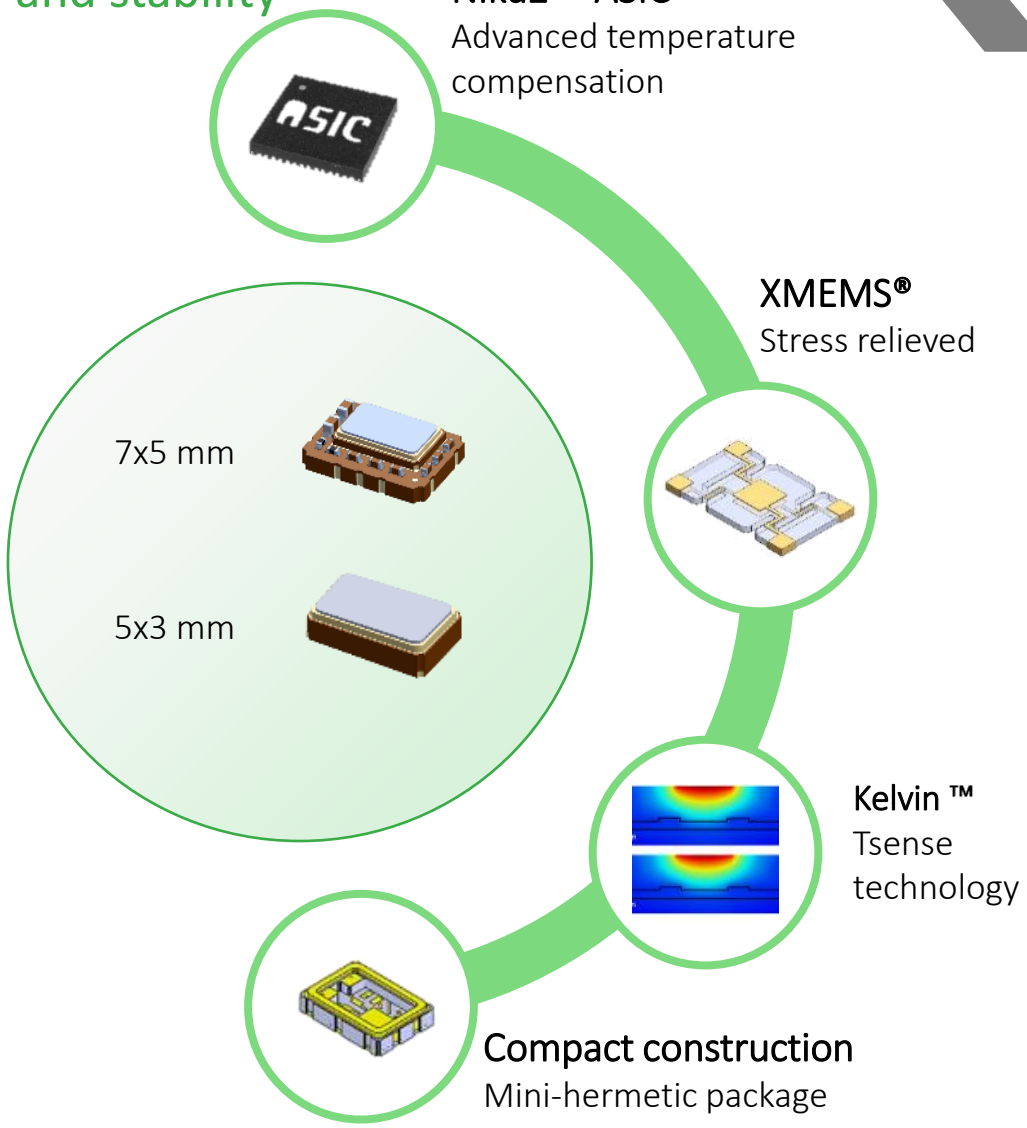
The next generation US-TCXO ASIC platform - Niku

enables best-in-class Ultra Stable TCXO performance.

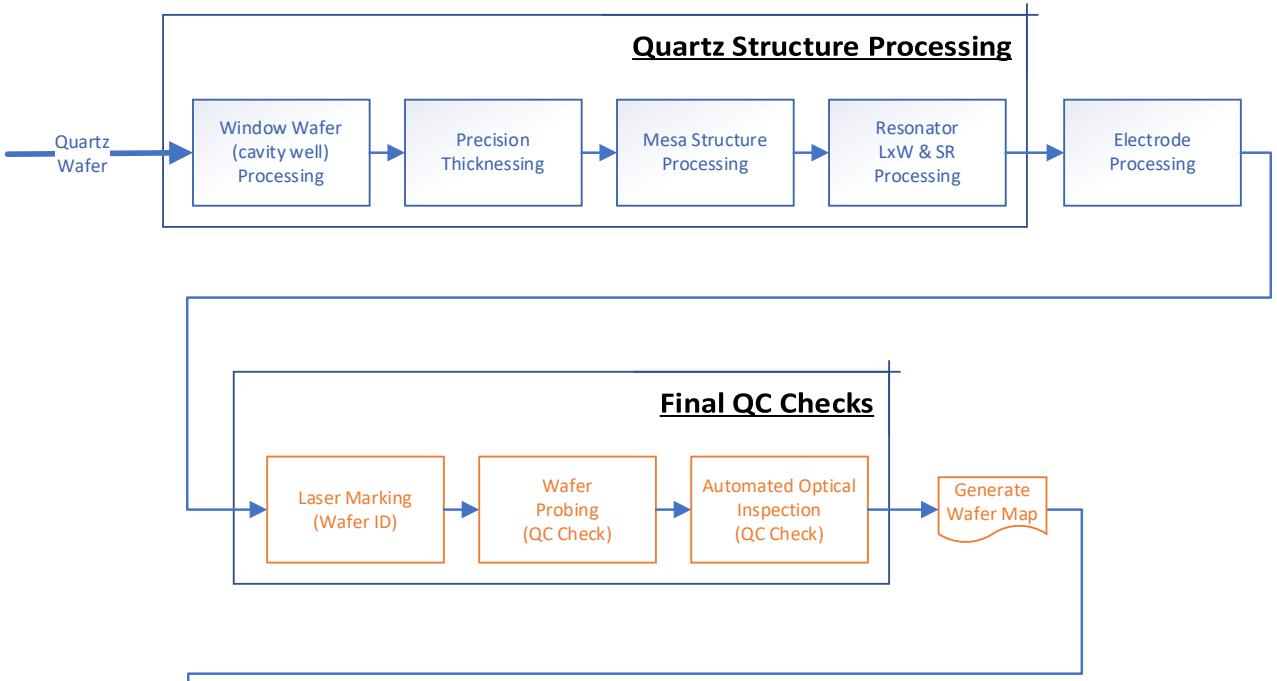
Specifications:

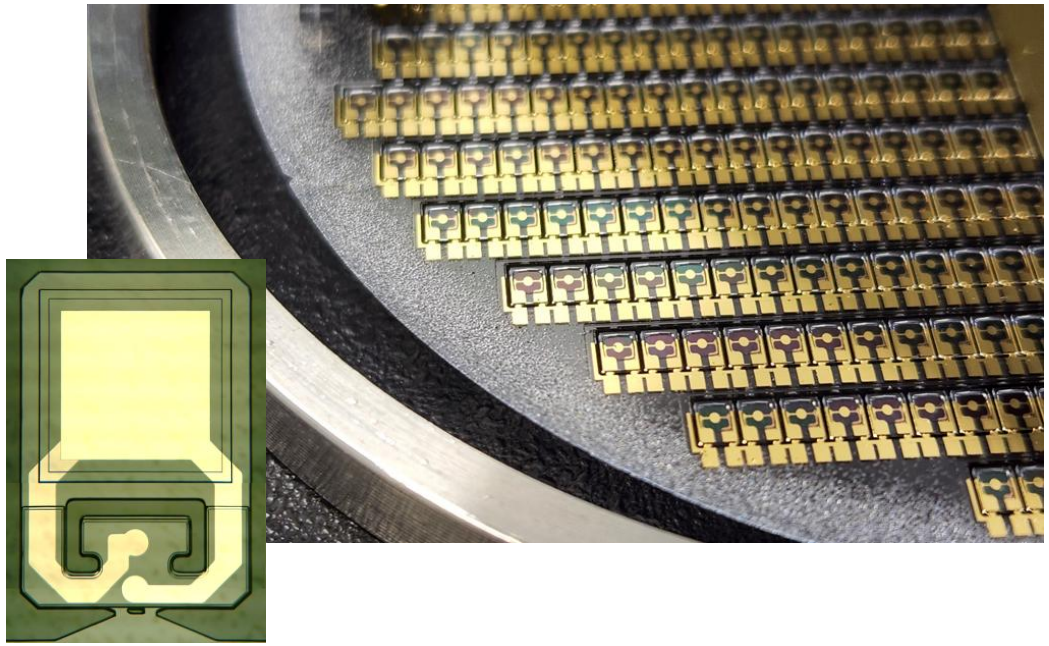
- **Extended Frequency range:** 10 to 160 MHz
- **Stability:** ±100 ppb (-40 to 95°C)
- **Best-in-class floor noise:** -170 dBc/Hz. RMS phase jitter 50 fs
- **Supply Voltage:** 2.5V, 3.3V
- **Output:** LV-CMOS (1.2v, 1.8v, 2.5v, 3.3v)
- **Fully Hermetic Construction** – 5.0mm x 3.2mm TCXO





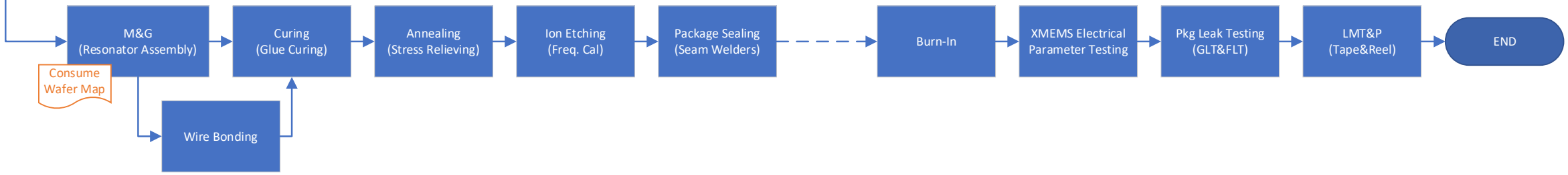
XMEMS Fabrication Process – Major Steps





ATMP Assembly (Back-End Processes) – Inside CR

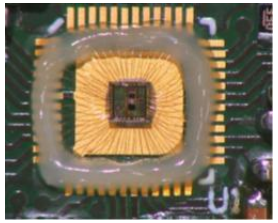
ATMP Test, Marking & Pack (Back-End Processes) - Outside CR



Radiation Exposure Test Results

Comparison

Radiation Exposure	RT-COTS (Niku TCXO)		Hardened by Design (SAPHIR PLL XO)	
	Condition	Result	Condition	Result
TID(Total Ionizing Dose)	50 krad @ 235 rad/hr	PASSED Operational and in specification	114 krad @ 310 rad/hr	PASSED Operational and in specification
SEU(Single Event Upsets)	-	Underway	86.7 (tilted) and 61.3 MeV.cm²/mg Xenon heavy ion	PASSED No Single Event observed
SET(Single Event Transients)	-	Underway	86.7 (tilted) and 61.3 MeV.cm²/mg Xenon heavy ion	PASSED No Single Event observed
SEL(Single Event Latch-up)	-	Underway	86.7 (tilted) and 61.3 MeV.cm²/mg Xenon heavy ion	PASSED No Single Event observed
SEFI(Single Event Functional Interrupt)	-	Underway	86.7 (tilted) and 61.3 MeV.cm²/mg Xenon heavy ion	PASSED No Single Event observed



RT-COTS Radiation Testing Project

Background and objectives

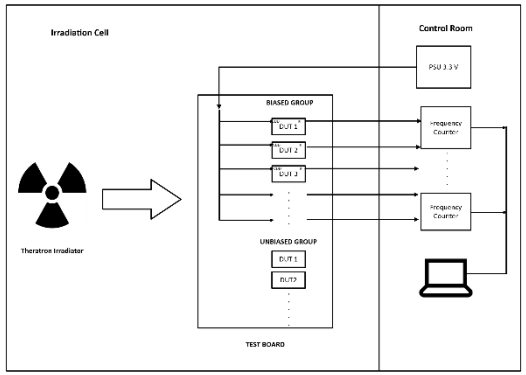
Background

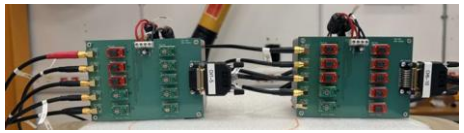
- Selection of Niku TCXO designed and built for commercial Telecom and PNT applications leverages the COTS foundation for equivalent application needs in Space.
- However, space remains one of the harshest environments for electronics, where natural radiation exposure can lead to everything from minor dysfunctions to catastrophic mission failures where the RT-COTS approach provides mitigation and management to meet the customer needs and expectations

Objectives

The primary objective of this test is to validate that the target product oscillators can withstand a TID of 50 krad(Si).

- **Continuous frequency monitoring during radiation exposure is implemented to detect any frequency jumps for validation of behaviour for PNT and particularly GNNS applications which is beyond the standard qualification testing procedures.**
- This level validates for Low-Earth Orbit (LEO) or Near-Earth Orbit (NEO) applications.
- To be fully qualified for those applications, Heavy Ion testing for Single Event Effects will also be required and is planned and underway.



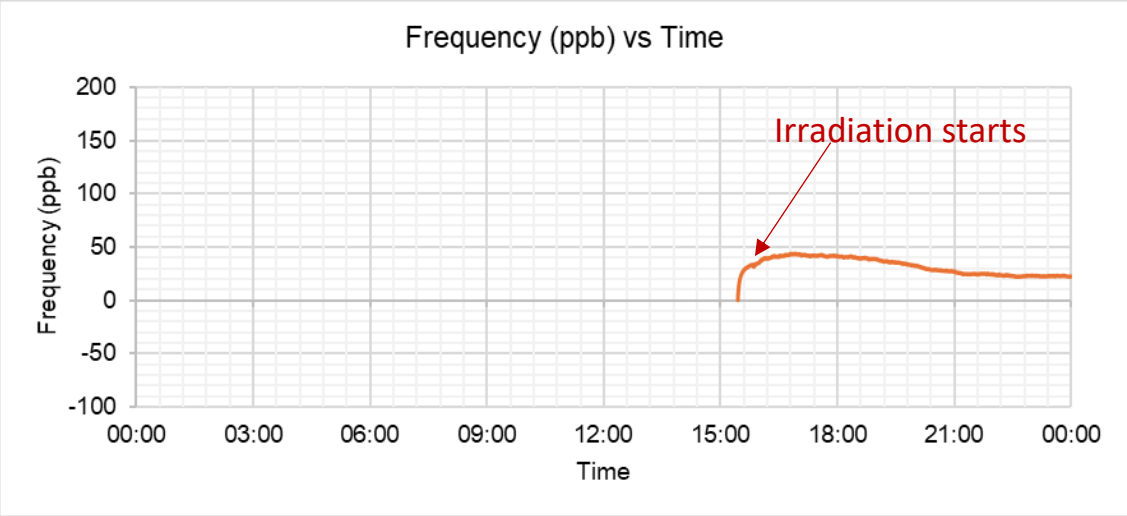


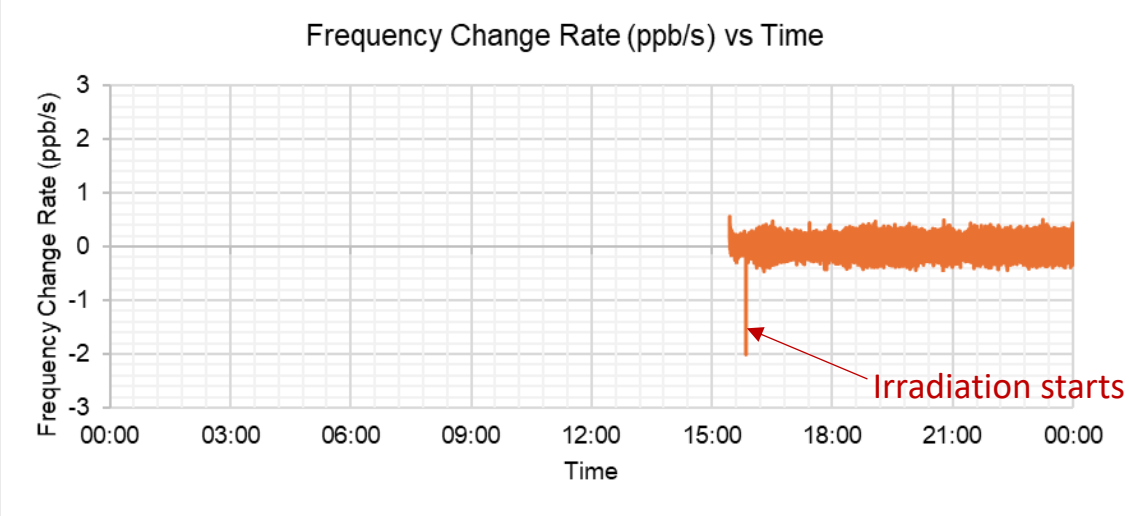


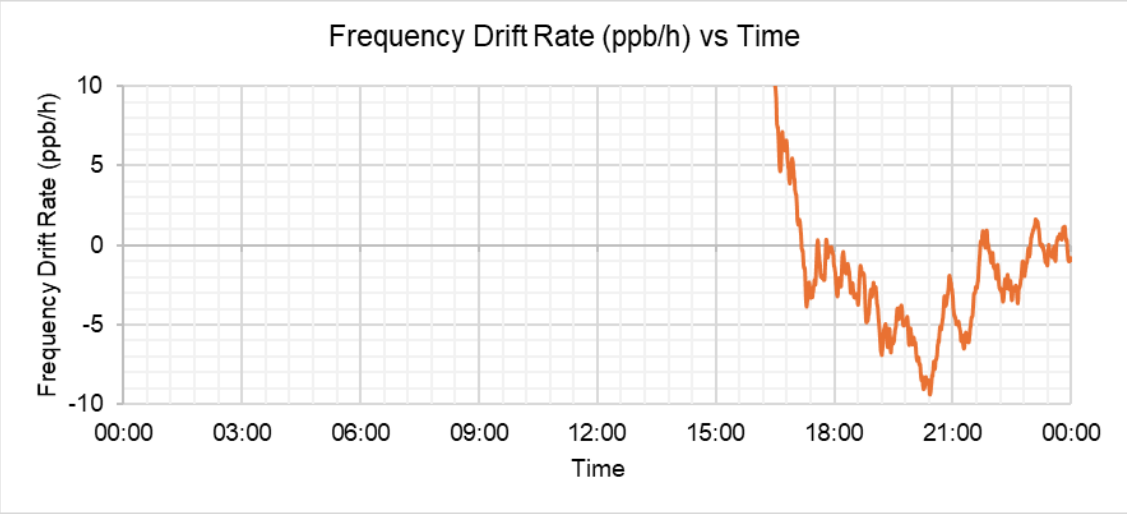


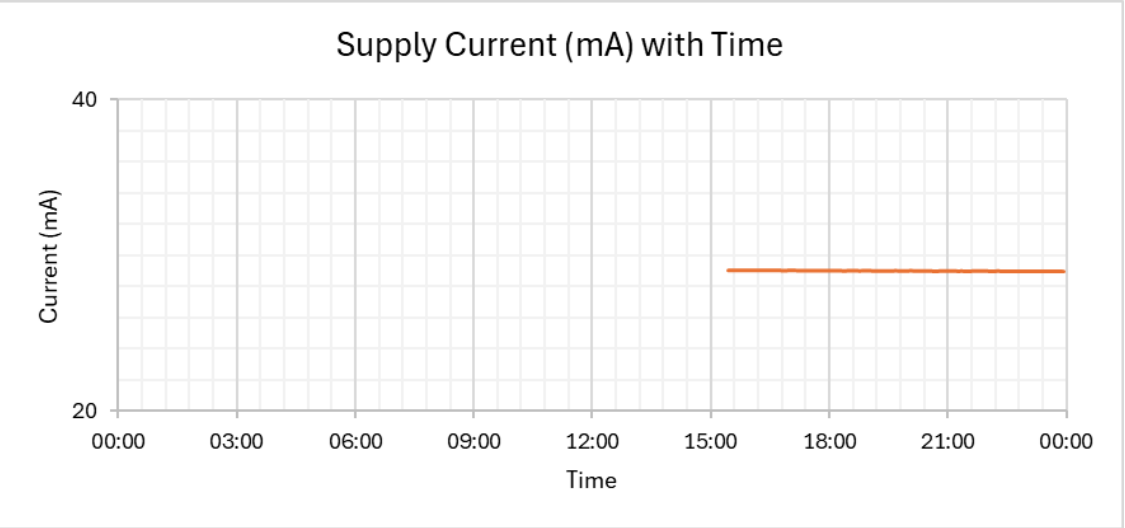
Detailed Frequency Monitoring Result

Niku2 DUT#B2 – Day 1



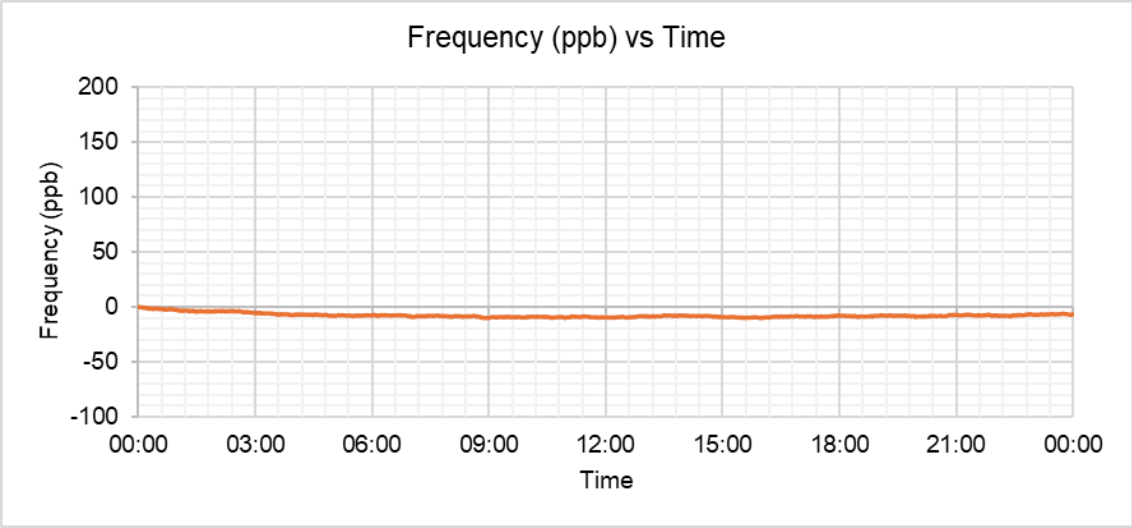


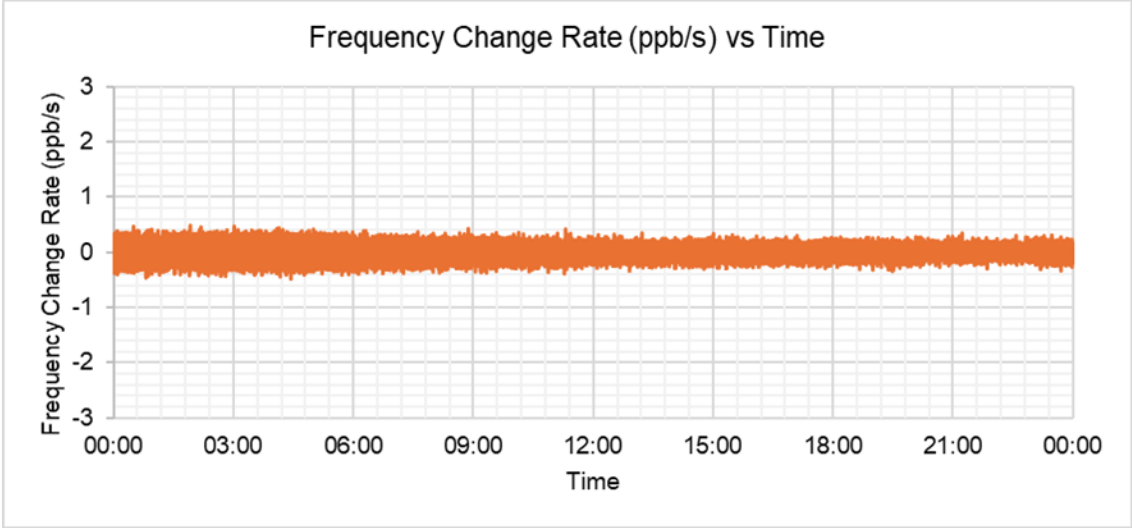


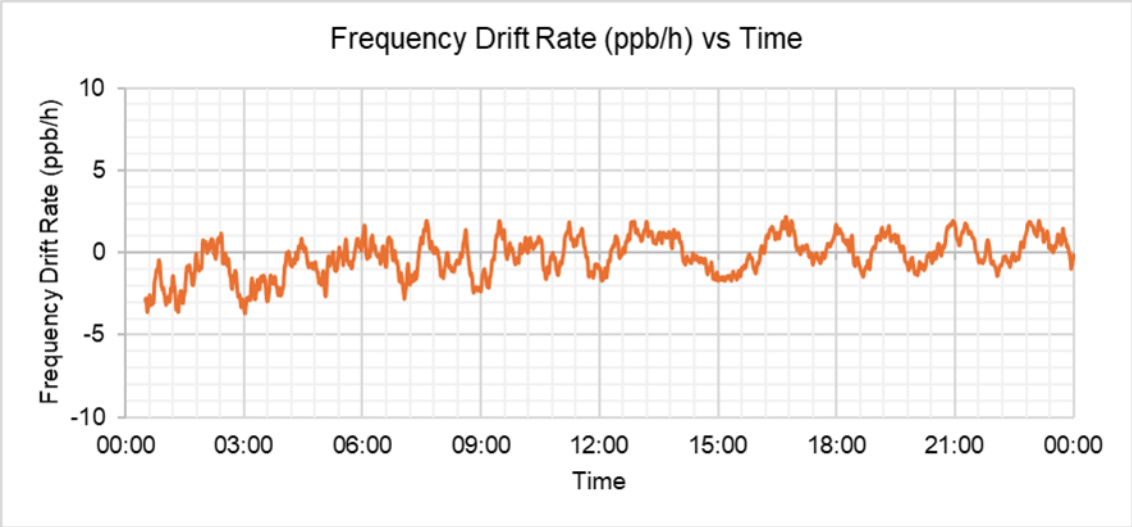


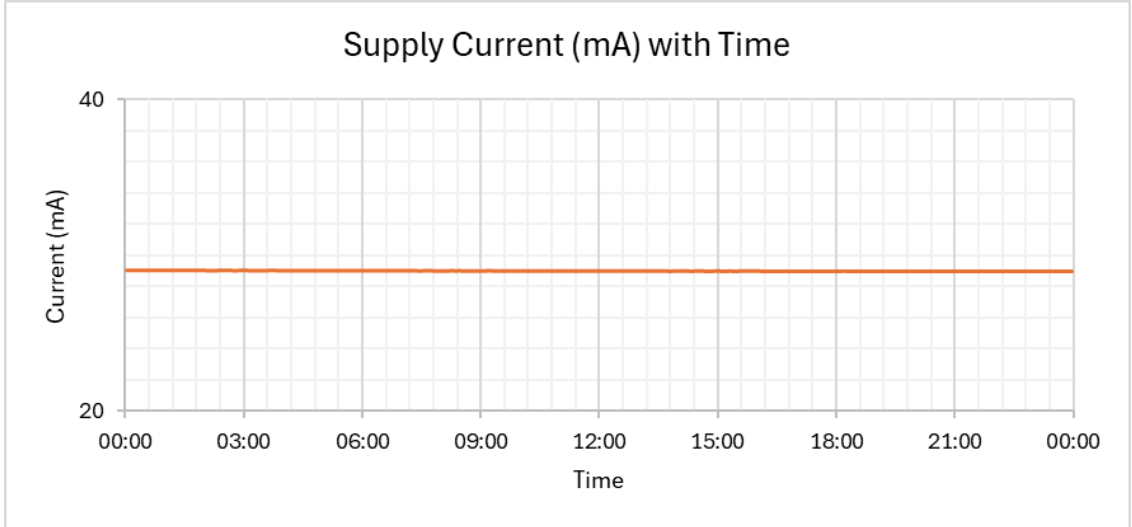
Detailed Frequency Monitoring Result

Niku2 DUT#B2 – Day 2



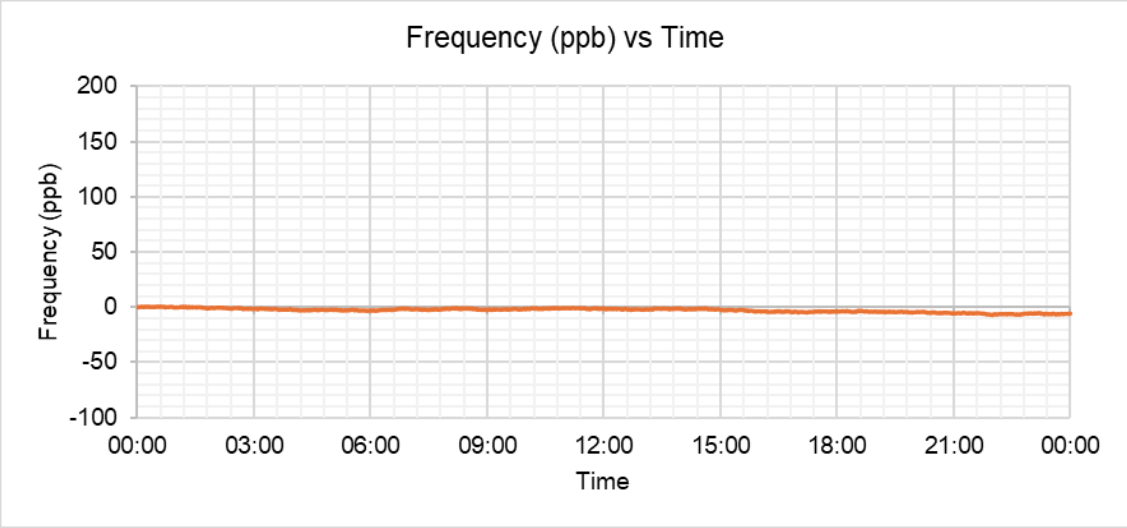


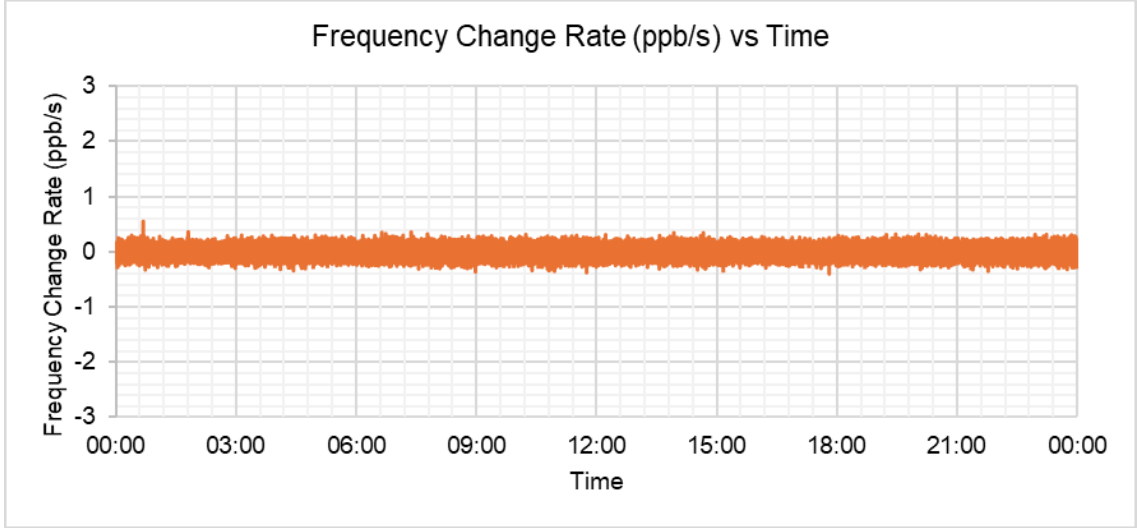


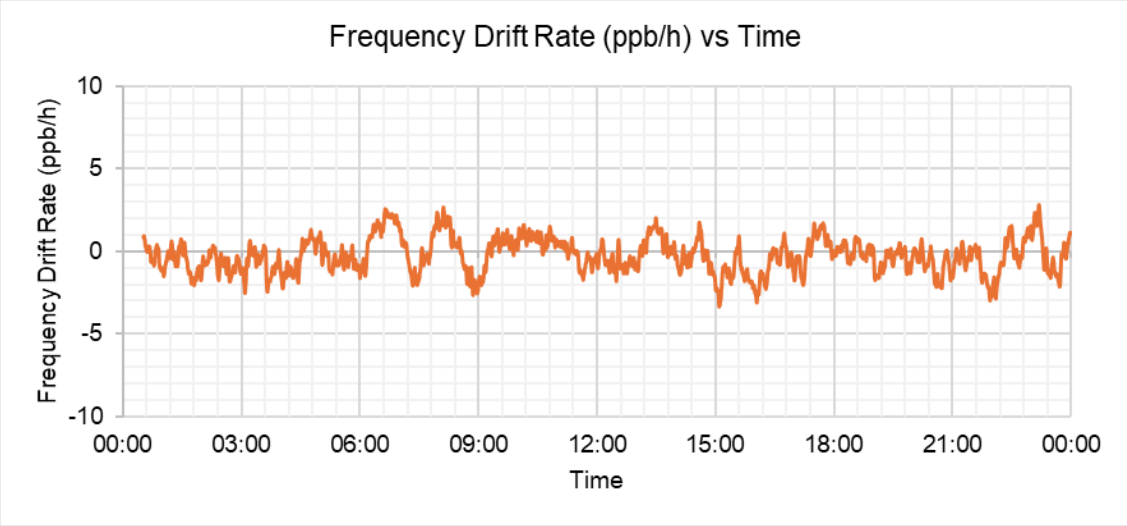


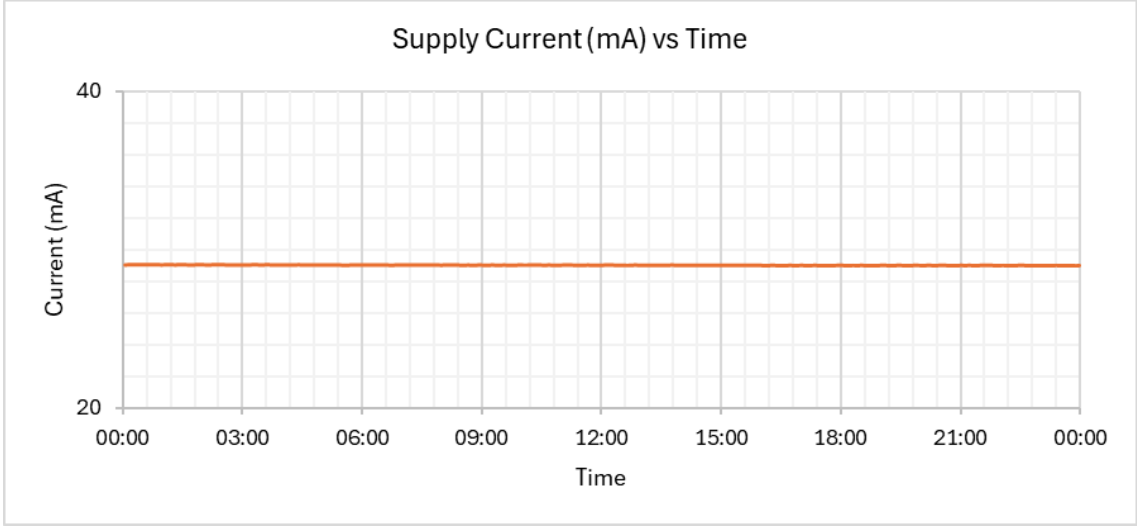
Detailed Frequency Monitoring Result

Niku2 DUT#B2 – Day 3



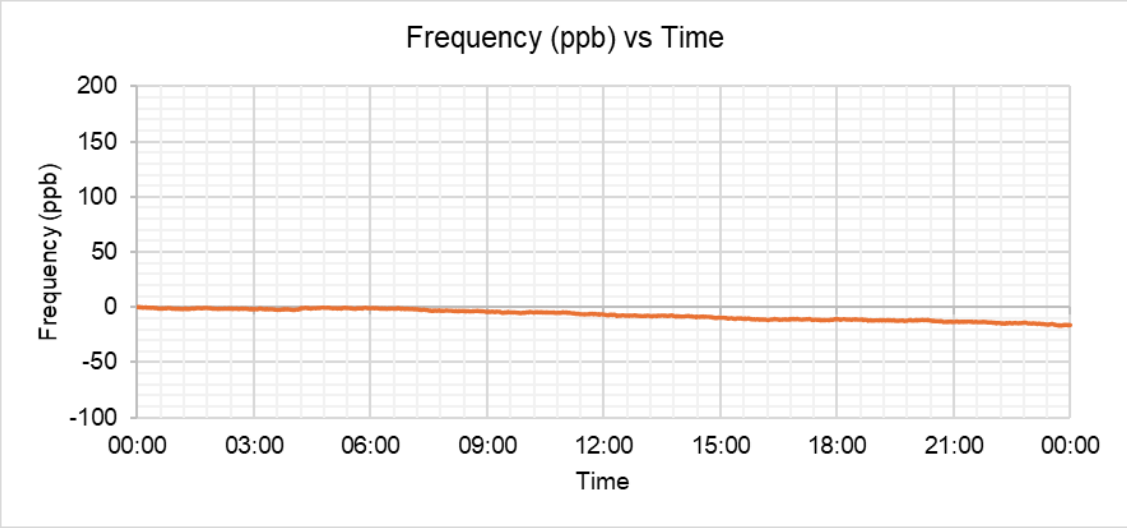


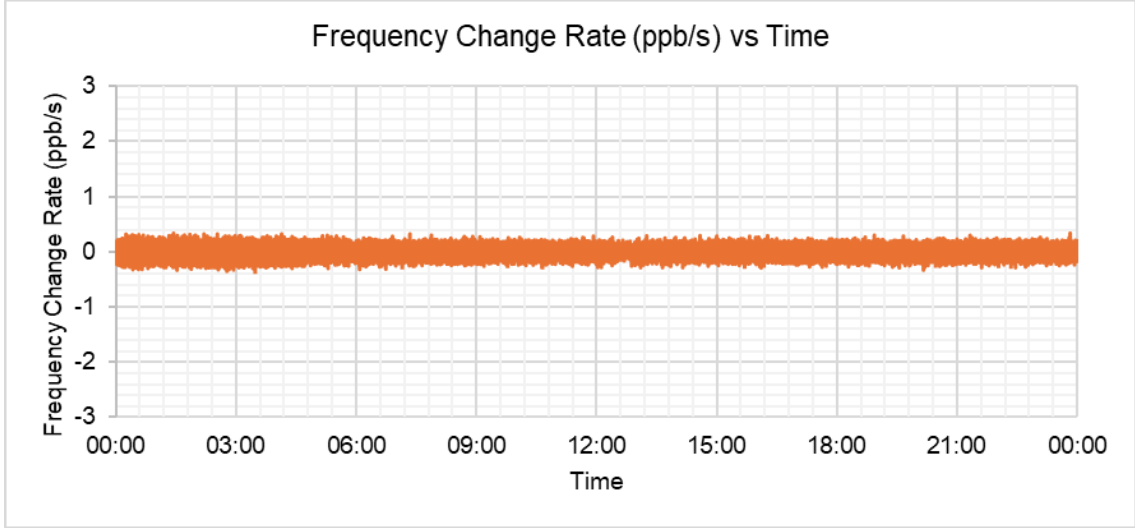


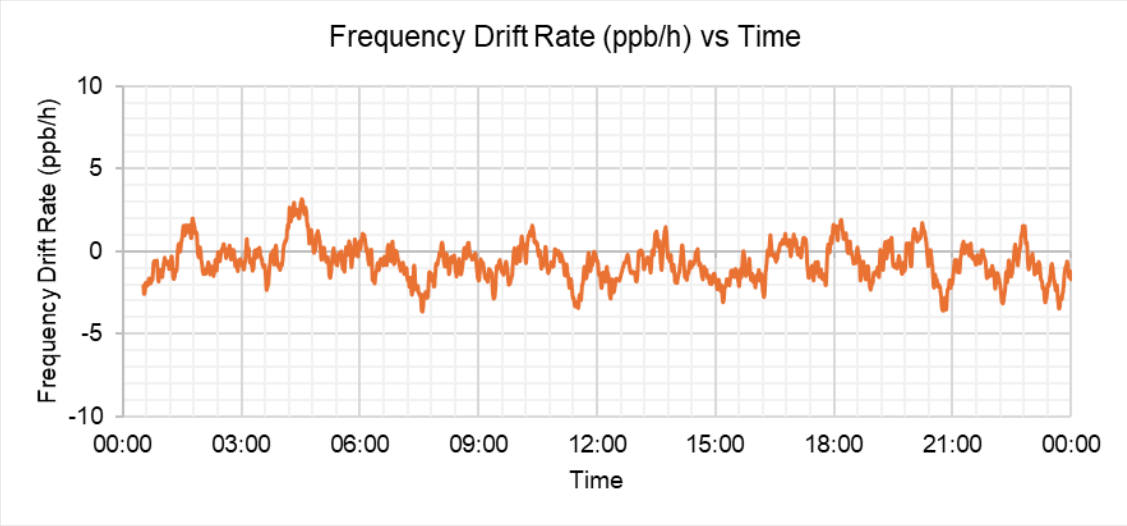


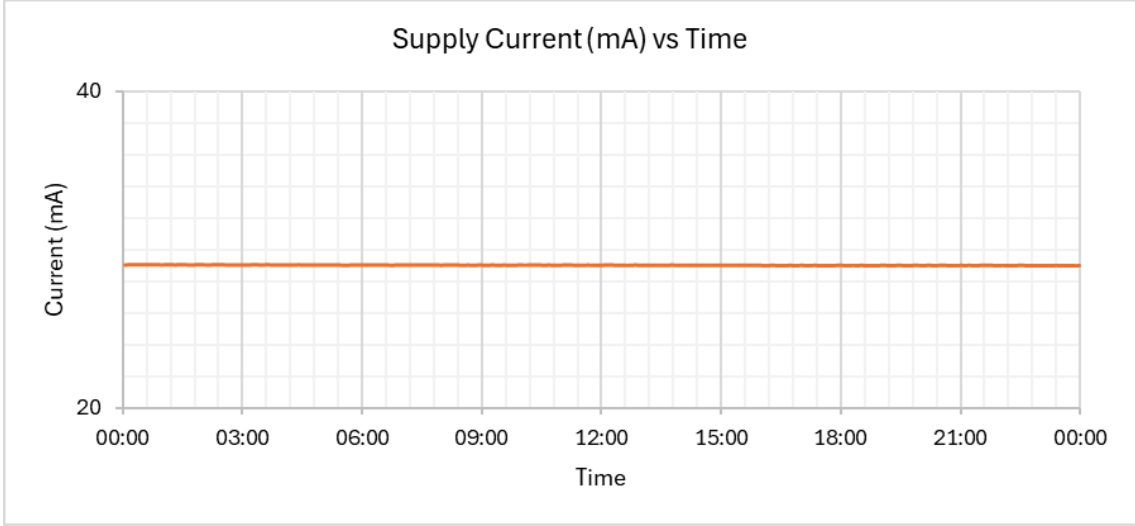
Detailed Frequency Monitoring Result

Niku2 DUT#B2 – Day 4









Summary

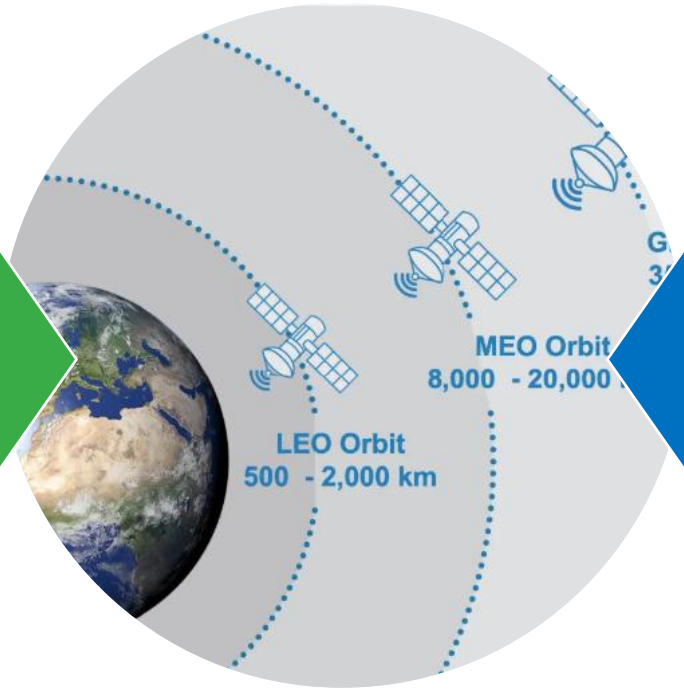
Two Complementary Approaches to Space-Resilient Timing

Rakon's In-House Capability and partnerships enables complementary developments

rakon

<u>The RT-COTS foundation approach</u>

Begins with a commercially mature ASIC platform selected for intrinsic radiation resilience. The design is maintained as close as possible to the commercial implementation, preserving cost, manufacturability and performance advantages. Radiation assurance is achieved through process control, lot management, screening and qualification testing. RAKON's Niku devices are representative examples.



<u>The radiation-hardened-by-design approach</u>

Starts from radiation requirements as primary design objectives. Circuit topology, device selection, guard structures, redundancy, bias management, layout spacing, body ties and SEE mitigation are incorporated during ASIC development. The SAPHYR space ASIC programme follows this philosophy and targets predictable behaviour across a wider mission envelope while enabling flexible and shorter lead-time

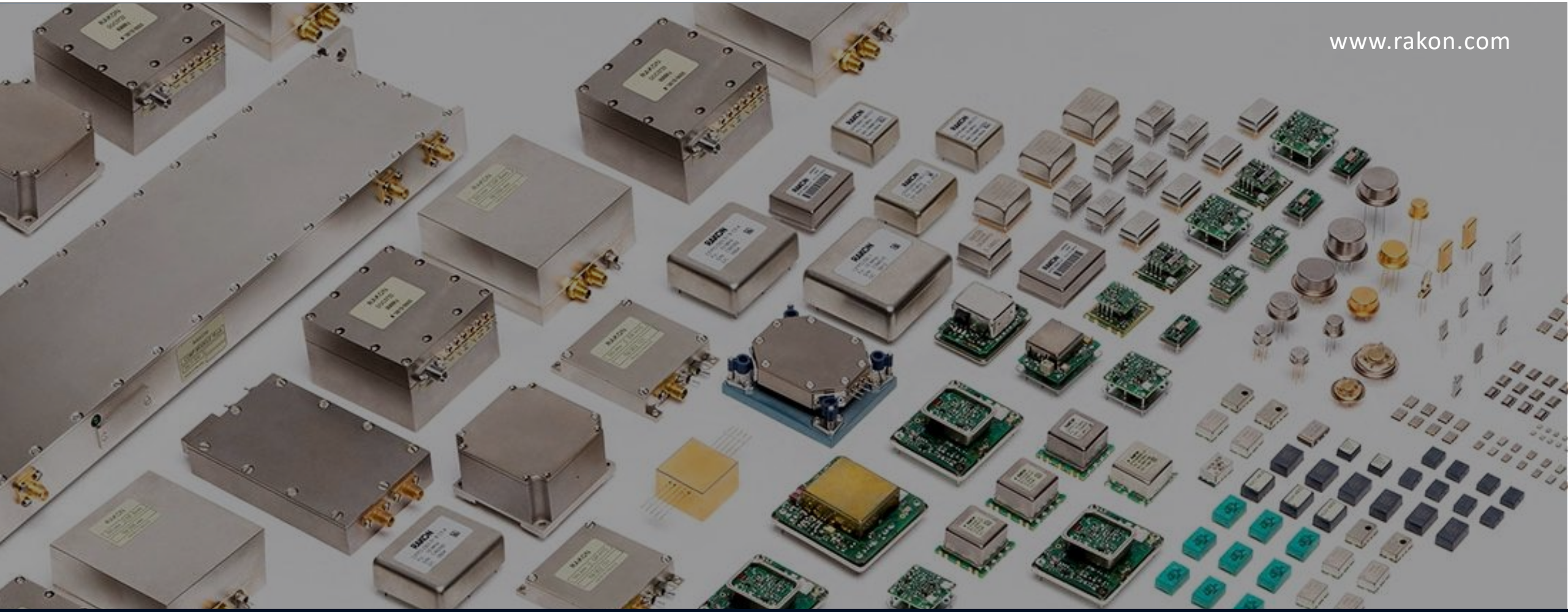
Both approaches seek acceptable mission risk, but they optimise different parameters. RT-COTS prioritises affordability, rapid deployment and commercial scale. Radiation-hardened ASIC development prioritises maximum robustness and design assurance for broadest programme applications.

Key Takeaways

Radiation Tolerant Oscillators

- There is **no single solution for every space mission**.
- The objective is to understand the trade-offs and select the right level of radiation resilience solution for the application, while maintaining the best possible balance between **performance, cost, integration and mission risk**.





Equipment • Subsystems • Oscillators • Filters • Resonators