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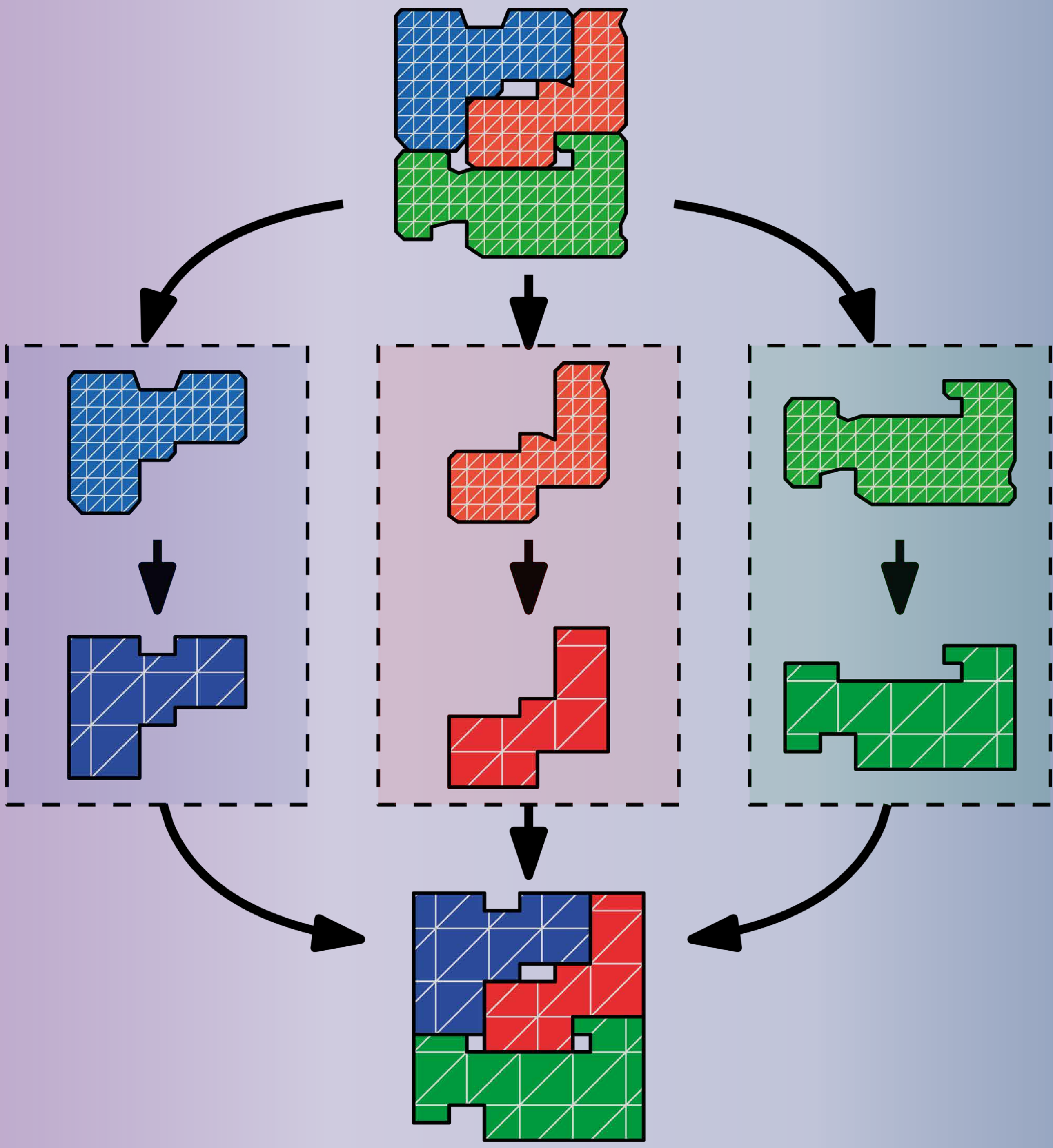

- THEME: DEFENCE TECHNOLOGY
- SHOCKING MECHANICS IN RADAR SYSTEM DEVELOPMENT
- RADIATION HARDNESS TESTING
- STRUCTURE-PRESERVING MODEL REDUCTION OF MODULAR, HIGH-PRECISION SYSTEMS
- ULTRA-SHORT LASER ABLATION FOR HIGH-VALUE INDUSTRIAL APPLICATIONS

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The cover illustration (featuring a schematic representation of structure-preserving model reduction) is courtesy of Luuk Poort. Read the article on page 18 ff.

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IT'S TIME TO STEP OUT OF THE SHADOWS

For decades, the Dutch innovative high-tech industry built its reputation on chip machines, medical scanners and satellite optics: precision work admired for its ingenuity. Yet for many people working in the sector, defence was something you didn't mention at a birthday party. A reticence made sense in a world that felt stable. But times are different.

Europe is rearming, NATO commitments are rising and the security architecture we took for granted is being renegotiated in real time. Defence is essential, not only to our national prosperity, but to our security and to Europe's strategic autonomy. The precision mechatronics, systems engineering and advanced manufacturing that make our supply chain world-class in semiconductors and medtech are exactly what modern security systems need. We are not being asked to build something new, but to point capabilities we already have at a market we often preferred to avoid.

But we see a shift. Signify's TruLiFi is a clear illustration: a light-based wireless connection that cannot be intercepted, jammed or tracked from outside its beam, already in use by the Dutch Ministry of Defence in secure rooms, ammunition bunkers and in the field, precisely because radio and Wi-Fi are often not an option there. A lighting company built on photonics, pointing that same technology at one of defence's hardest problems: getting secure data where radio is not allowed. Proof that diversifying into defence is not a niche exercise for a handful of specialists, but a viable path for serious high-tech players.

We are backing that shift with our policy, not just words. Last November, the province of North-Brabant reserved €8 million aimed at companies that can strengthen digital and physical security. In Brabant, we believe innovative technology can make the difference. For our security, our economy and our strategic autonomy. We are not chasing large-scale defence production itself, but five different dual-use technology fields, serving both civilian and defence purposes: for sensors, intelligent/autonomous systems, smart materials, cybersecurity and integrated photonics. Together with companies, knowledge institutions and governments, we are building towards a stronger Europe. We are forging coalitions like Brabant House of Cyber and campuses such as Brainport and Aviolanda, built together with the ministries of Economic Affairs and Defence, and TNO.

I still meet entrepreneurs who build excellent components for defence primes who ask us, explicitly, not to mention their expertise. Part of the answer sits in our policy itself: our focus is dual-use innovation with a primarily defensive character. For example, detection, protection and digital resilience. I understand the remaining caution over brand image or workforce sentiment. But it deserves a second look. There is a difference between responsible caution about what you build and for whom, which is legitimate, and reflexive silence about contributing to Europe's ability to defend itself, which is not. Deterrence is not the opposite of the defensive industry's values; increasingly, it is the precondition for pursuing them at all.

There is also a straightforward economic argument: defence budgets are among the few in Europe on an upward trajectory. A well-supported security order book is diversification done well, not a compromise. Our role as the province is to make the step to diversification and innovation in the defence industry much easier: matching suppliers to both primes and requirement owners, (co)-funding the technology itself and helping companies to connect to and combine different technologies that understandably give them pause or hesitation. I would encourage companies to be a little less shy about their work. They should, in this new era, be able to talk about with pride: innovating to keep Europe safe.

Martijn van Gruijthuijsen
Regional Minister for Economy, Talent development, Knowledge and Finance, Province of North-Brabant
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SHOCKING MECHANICS

Defence radar development is challenging because radar functionality under extreme operating conditions needs to be guaranteed using delicate and complex electronic hardware. Contemporary radars use digital beam-steering phased-array technology to create an almost instantaneous spatial awareness in a 3D sector without rotation. Their development requires quick multidisciplinary design analysis cycles where dynamic shock loads tend to dominate the design. Testing and validation ensure that the final product meets the requirements within the given time and financial constraints.

ERIC KAPPEL

Introduction

This article describes how current radars work and addresses a few typical considerations in the multidisciplinary development of defence radars from a mechanical perspective. It discusses the loads that are typical for defence radar structures and their impact on the design via the shock-response-spectrum method. It also discusses pitfalls in current finite-element analysis method modelling codes that should be geared towards quick response cycles rather than including everything applicable in one model. Finally, it lists a few design considerations when integrating such a system on a naval vessel and the need for testing in the design process.

Defence hardware

Accuracy is a relative term. At Thales Netherlands, our defence radar systems do not operate on the nanoscale, but neither do the systems of aircraft and ship manufacturers. We are generally satisfied with part accuracies of several tens of microns for the function-critical elements. Creating family-car-size radar systems containing delicate electronics that survive bone-breaking shocks and keep operating within accuracy specifications under extremely uncomfortable vibrations and temperature ranges, whilst handling high power electronics and cooling; that is our challenge.

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GM200-MM/C mobile multi-mission radar.

From a historical perspective, Thales was leading in the mechanical systems that performed on-the-spot calculations for gunfire control in the 1950s; mechanical precision engineering at its best. Those systems are long gone, and we would have to re-iterate the knowledge that left the company as people retire. But then again, the technology has moved on and still offering mechanical calculators for contemporary radar operations would definitely not guarantee a successful business.

Keeping up in the race

Developing a radar system generally takes many years from the conception of a system-level principle to the first prototype and eventual product. It generally starts with a new operational concept, a novel mathematical technique or improvement of computing power to enable object detection and classification in an ever-changing environment. Developments can be driven by the type, number and agility of threats, new electronic threats, and changing target-stealth characteristics to even the availability of energy and rare-earth materials. On top of that, there are also continuous research efforts made to improve the energy efficiency and electronics cooling capacity.

The research findings, not all having the same level of maturity, need to come together in a next-generation radar system. This requires a clear strategy that involves planning many years in advance and collaboration with governments, research institutes and industry partners. It is continuously keeping steps ahead of the competition, achieving a functionality that others do not have or others can only achieve with unsustainable resources, that keeps one relevant in today's radar-systems market.

AUTHOR'S NOTE

Eric Kappel, a mechanical analyst at Thales Netherlands for over 30 years, finished his studies in the Faculty of Aerospace Engineering at Delft University of Technology (NL) in the Aerospace Structures & Materials department. At Thales in Hengelo (Ov, NL), he is a member of the Mechanical & Electrical Engineering department performing radar-related structural analyses and vibration-based condition monitoring. Stiffness & strength design considerations for dynamically loaded lightweight structures are recurring themes and an important part of his activities.

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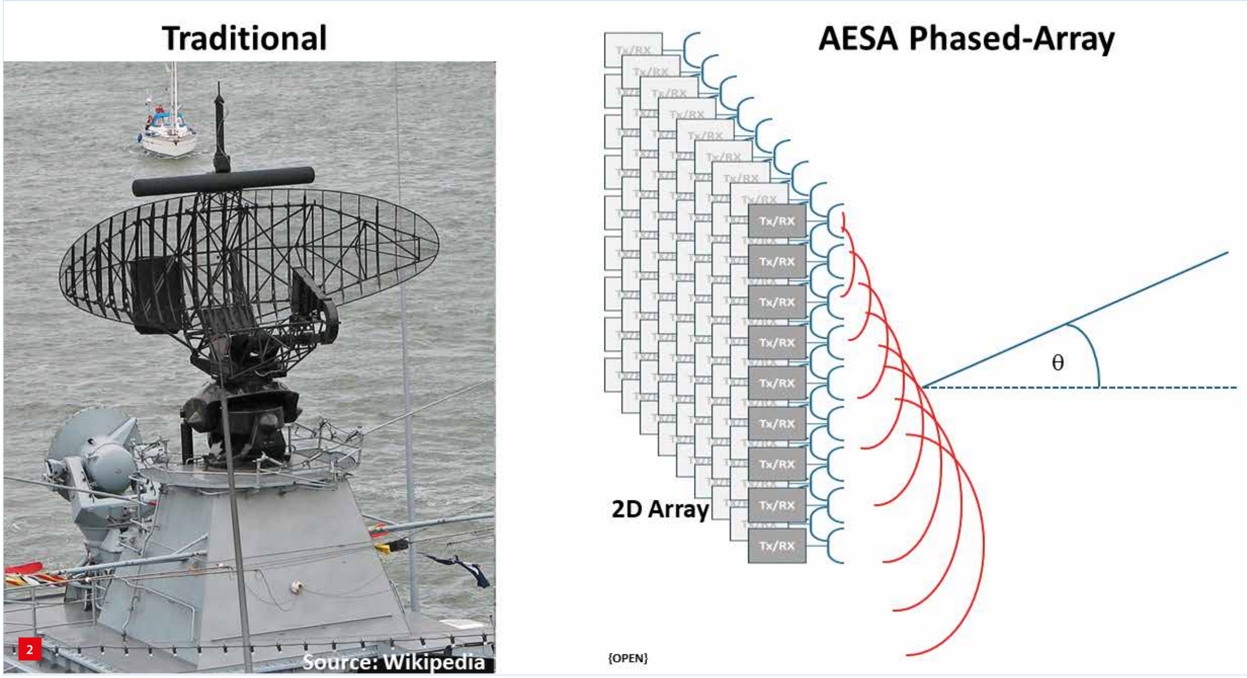

Traditional versus an active electronic scanned array (AESA) phased-array radar.

Time, budget and human resources are always limited but still, using these scarce resources wisely, Thales NL managed to develop 2D-multibeam phased-array radars that can scan electronically in two directions to detect and identify aircraft, rockets, drones and mortar-fire simultaneously. A highly successful, highly mobile radar system using this technique is shown in Figure 1.

A traditional radar (radio detection and ranging) consists of a single transmit-and-receive (TX-RX) chain and a mechanically directed antenna, this only being capable of tracking targets in a single vertical plane. A phased-array radar (see Figure 2) is composed of multiple TX-RX channels arranged in a 2D array. It does not require a radar antenna face to physically point towards the target. It allows for an almost instantaneous view of targets in a volume sector spanning – without rotation – an azimuth, elevation and radial range, up to 2,000 km, depending on the radar type. This significantly improves the reaction time and therefore the time to take countermeasures. Also, digital beamforming and processing techniques deliver flexibility to prevent hostile interference susceptibility.

But what does this all have to do with precision engineering? The answer is: "Everything, if one views accuracy from a scarcity perspective." Every type of industry aims to use their required accuracy and tolerance capability to obtain a product that just meets the requirements. A too precise product is wasteful on the limited available resources; not reaching the minimum requirements yields defective products, which is even more wasteful since all the preceding actions to create the product are wasted. Precision and tolerance, combined with material use, are among the most important features affecting the resource claim.

Radar structures engineering and fat-bikes

Diving into the radar structures, locational precision of the TX-RX elements in a 2D array literally creates more focus and reduces the radar's susceptibility to hostile interference. TX-RX element surfaces that are in close contact to cooling manifolds release their heat better compared to ones that do not mate well. From a purely mechanical perspective, rotating radar systems require drive-part tolerances that are comparable to machinery with gears, pumps, motors and ball-bearings. The accuracy of radar structures is comparable to that of aircraft structures.

What distinguishes naval defence radar systems from general mechanical systems is the severe overload capacity needed to survive shock loads (see later in this article). It is safe to state that the vast majority of radar systems will never encounter the shock loads for which they have generally been designed. It is this insurance policy that sets military radar systems apart from most other radar products. The latter might provide some radar functionality at a fraction of the cost but fail at the moment it matters most. Note that the threat is also evolving as commercially available electronic hardware (drones for instance) can be weaponised, also at a fraction of the costs. Being able to handle changes requires agility and diligence in every step of the engineering process, which is aimed at reducing the effort in creating and operating the product whilst maximising its performance.

RADIATION HARDNESS OF SENSORS FOR FINE STEERING MIRRORS

Fine steering mirrors are high-precision optical devices used in laser-based satellite communications. They rapidly tilt, often on dual axes, to lock ultra-narrow laser beams for communication links from both satellite-to-satellite and ground-to-satellite. Due to the low divergence of laser beams, exact pointing solutions are required. Ultra-precision eddy-current sensors offer a solution. However, radiation hardness is key to their performance.

THERESA SPAAN-BURKE, WOUTER JUTTE AND TEUNIS VAN DAM

AUTHORS' NOTE
Theresa Spaan-Burke (innovation director), Wouter Jutte (engineer) and Teunis van Dam (mechanical lead engineer) all work at IBS Precision Engineering, located in Eindhoven (NL).
The authors would like to thank Jasper Dijks, NLR (Netherlands Aerospace Centre), for calculations of the expected lifetime dose, and valuable discussions.

Introduction

The desire for low-latency, high-capacity, secure and uninterrupted internet connectivity everywhere on earth has driven explosive growth in the laser-based satellite communications (satcom) market more recently. In defence applications in particular, laser-based communications offer more security than broad-beam radio-frequency systems as they use tightly focused, narrow light beams that are extremely difficult to intercept or jam.

For over 30 years, IBS Precision Engineering has been developing sensor solutions for demanding precision industrial environments and space offers the next such challenge. For the laser satcom market, sensors are required to measure highly repeatable tilting mirror motions for so-called fine steering mirrors (FSMs).

FSMs are used for secure high-data-rate connections over long distances between two terminals. They enable ground, airborne and satellite optical communications. To achieve successful communications over those long distances, high accuracies are required to achieve the required pointing performance. The sensors are therefore required to be high precision with high bandwidth, low noise, small form factor, low weight and low power consumption. In addition to these technical requirements, the FSM should be commercially attractive by having low recurring costs in volume production.

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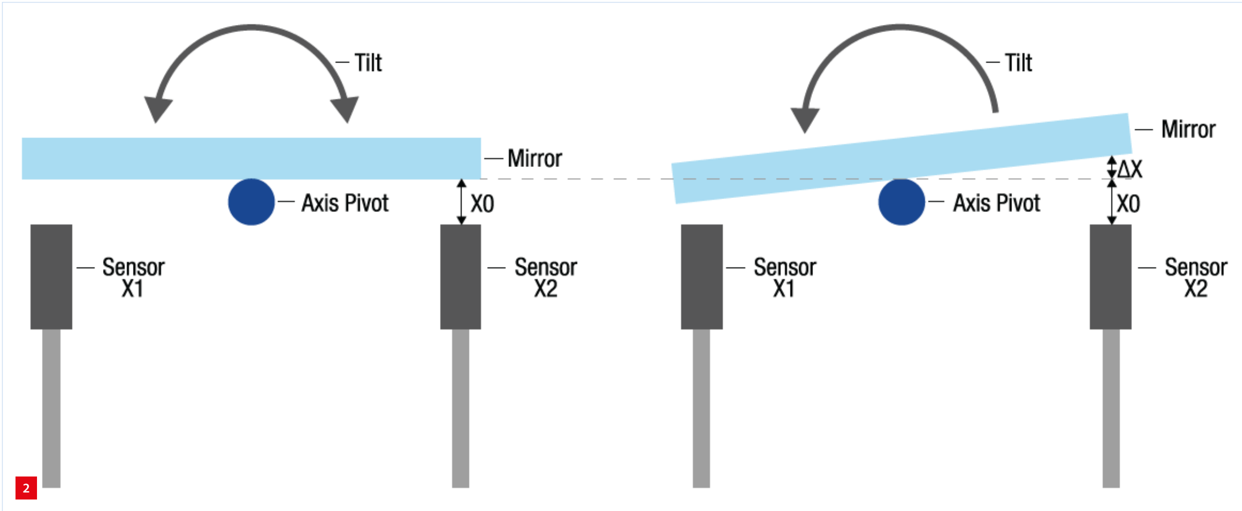
Differential sensor system with X+,X– (horizontal) and Y+,Y– (vertical) pair shown in a flexure mount configured for mirror-tilt measurement.

Sensor systems

FSMs used in laser communications / free-space optical communications are high-precision tip/tilt mechanisms used to keep laser beams stabilised and precisely on target. The FSM maintains the pointing in the presence of various sources of misalignment, such as atmospheric aberrations and disturbances on the vehicle or satellite platform stemming from active elements, which could have a relatively high-frequency signature. In the communication terminal, these beam misalignments can be measured with a tracking sensor and closed-loop compensated by an FSM.

A differential sensor system has been developed that measures the FSM mirror positioning; here, the mirror aperture is of the order of Ø 20 mm and a functional rotation of ±1° is required at bandwidths of 28 kHz. Requirements for the FSM differential sensor system are given for the four environments: ground, airborne, low earth Orbit (LEO), and medium earth orbit (MEO).



Working principle of differential sensor measurement.

For LEO and MEO satellite applications, requirements such as size, weight and power are critical. Reliability, including the ability to stand launch conditions and the space environment, is also necessary. For airborne and ground, some of these requirements become less stringent. However, in the terrestrial and air environment, there are challenges to control the laser beam during PAT (point, acquire, track) operations, which can be affected by conditions such as dust, heat, turbulence, rain, spray and clouds. The sensors must be suitable for such conditions, while also adhering to materials regulations such as RoHS (EU rules restricting the use of hazardous substances in electrical and electronic equipment).

To meet the sensor need a state-of-the-art differential eddy-current sensor system was developed. The system comes with two matched pairs of high-resolution non-contact eddy-current sensors for simultaneous measurement in X and Y (see Figure 1). The working principle is shown in Figure 2. Resolutions down to < 7.0 nm are achieved with this system, equating to < 0.62 μrad tilt.

The benefits of a differential system include an improved insensitivity to temperature variations in addition to a reduced number of electronic components. The latter can be very beneficial when sensors are exposed to challenging environments such as high radiation levels. The challenge of a differential system is that the sensor pairs must be precisely positioned relative to each other and the target to avoid gain offsets. Industrial sensor-integration strategies are also necessary. Extensive modelling, simulation and testing has been carried out on these sensors leading to a new sensor type that allows for electronic integration excluding mechanical references. This patented technique, which is more practical and yields better performance, may be applied for various mirror-measurement applications. In this article, the sensor system developed is tested for its radiation hardness as required for space applications.

Radiation testing

In space applications, the impact of radiation on sensors can be critical. Radiation effects on electronics can be divided in three categories:

- Total Ionising Dose (TID).
- Displacement Damage or Total Non-Ionising Dose (TNID).
- Single Event Effects (SEE).

The experiment on the sensors described here was limited to TID hardness testing. TID testing demonstrates tolerance against what is expected to be a major long-term radiation degradation mechanism for the considered MEO environment. The sensor system developed has been specifically designed using analogue electronics only, reducing SEE susceptibility. TID effects were therefore expected to dominate radiation impacts on performance.

TID effects occur when an electron is removed from an atom in response to radiation exposure, leaving a 'hole'. On a high level, the effects of TID on electronics can be ascribed to the trapping of such holes in the insulation material in semiconductor devices, which can lead to functional failure or loss of performance. When exposing a device to a continuous radiation flux, the damage builds up over time. In experiments with artificially high dose rate, part of the induced damage can recover after the exposure is stopped, due to the (limited) mobility of the holes and electrons in the material. This effect is called 'annealing'. A more detailed description of the impact of radiation on electronics devices can be found in [1],[2].

For TID, the amount of absorbed radiation (dose) is expressed in rad or gray (1 gray = 100 rad). The unit gray (symbol: Gy) is the official SI unit and represents one Joule of energy per kg of material. For space applications, rad is the more commonly used unit. The amount of absorbed energy with a certain radiation intensity depends on the material; therefore, the material is usually specified: 1 rad(Si) means 1 rad (0.01 J/kg) of absorbed energy *in silicon*. In this article, the unit rad is always defined as rad(Si).