Sodern's Auriga™ Star Tracker upgrades

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ABSTRACT

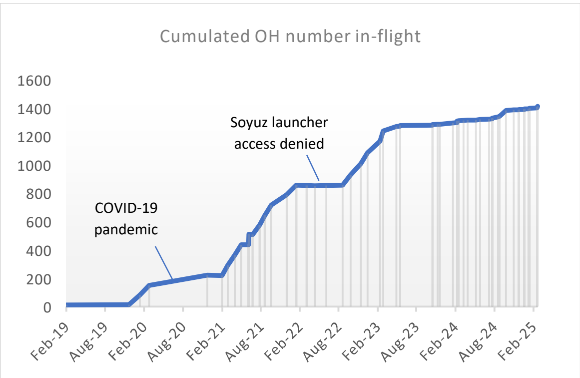
In February 2019, Sodern's Auriga^{TM} star tracker (STR) reached TRL9 during the launch of the first six satellites of the Eutelsat OneWeb constellation. This CMOS multi-head star tracker has become the reference in the New Space market, with over 1,400 Optical Heads (OH) having accumulated more than 38 million operational hours without failure. Sodern is now enhancing and expanding its Auriga™ product line. The OH originally designed for the LEO OneWeb constellation has been upgraded with rad-hard glasses and a thicker structure to support 15-year GEO orbits, resulting in the Auriga V2. A new baffle with a 26-degree Sun Exclusion Angle is also available. The Auriga™ software library now supports the integration of angular rates from any onboard gyrometer, enhancing robustness and performance through a "double coupling" approach. This results in a fully autonomous coupled Gyro-STR system that can be used independently or in conjunction with the STR for improved robustness. Tests with two different gyrometers—a high-precision inertial grade one and a tactical grade one—have demonstrated significant improvements in robustness, with MEMS technology being sufficient for robust acquisition and tracking. However, accuracy depends on gyrometer performance, with inertial-grade devices achieving better precision. The system's robustness and autonomy are highlighted through various scenarios, including automatic switching to single star tracker mode in case of gyrometer unavailability or after occultation and slew maneuvers. Additionally, the system features self-calibration capabilities for fine-tuning performance in agile missions.

1. INTRODUCTION

In 2019, SODERN was the first manufacturer to launch the production and commercialization of a compact, reliable, standardized, and ready-to-use star tracker. Initially aimed at the Eutelsat OneWeb constellation, it revolutionized the NewSpace market. The need for high-performance, accessible, and quickly deliverable small trackers quickly expanded to all satellite manufacturers ranging from 6U to 500 kg.

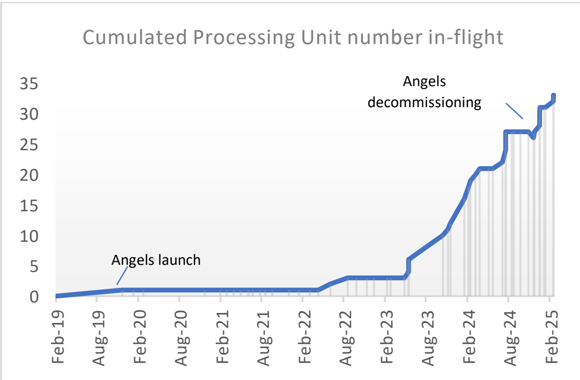
Auriga™ was designed with four fundamental criteria in mind: compactness, robustness across the entire celestial dome, commoditization (industrial capability of several thousand units per year), and radiation tolerance to ensure mission durations. Auriga™ is available without a Processing Unit (PU), meaning a Software library has to be hosted on the Client's On Board Computer (OBC), or with a dedicated Processing Unit where the Software is factory embedded.

As of today, Auriga™ cumulates 38 million hours of faultless in-flight operations and 10% of them already achieved the expected in-flight life time, which confirms its lifetime duration and reliability.



Concerning the reliability of the product, a strategy based on the use of large-scale industrial electronic components combined with statistical methods an additional screening has yielded a proven by 38 million cumulative operating hours without failures. This approach is safer and more effective than seeking to optimize the costs of traditional space-qualified components by removing screening and lot acceptance tests, which reduces the detectability of failures and the final reliability of the parts.

The AURIGA processing unit also cumulates important heritage with 340000 hours of in-flight operation and the proven life time duration thanks to Angels.



Based on this undisputed legacy, the strong commercial success of AURIGA™ and the trust of our customers, Sodern is pleased to bring three new features to the AURIGA™ product line:

- Radiation Hardening improvement
- New 26° SEA baffle,
- New software library (AURIGA-GYRO)

2. RADIATION HARDENING IMPROVEMENT

Industrial and Reliable Production to Guarantee the Best Offer

From the beginning of the Auriga™ star tracker design, SODERN placed the ability to deliver 2,000 trackers per year at the center of its strategy. To achieve this, the company had to think about industrialization from the product design phase, choosing the most robust and agile supply chain possible. Instead of using components from Hi-Rel sources, SODERN mainly chose automotive-grade components and carefully targeted upscreenings or complementary tests with no compromise on reliability. This choice ensures that customers have access to a competitive product based on a supply chain accustomed to high volumes and short lead times. How? For over 60 years, SODERN, a world-class supplier of neutron sources, has developed unique skills in the study and analysis of radiation phenomena with a recognized team of experts, including physicists specializing in fundamental interactions and elementary particles. This core competence has enabled, among other things, participation in the design of emblematic space missions in extremely radiative environments and working with demanding clients. Missions to Jupiter Juice (specialized navigation cameras and Hydra star trackers) and Europa Clipper (modified Hydra star trackers for better radiation resistance) are good examples. This expertise led to the identification that an electronics that tolerates 35 krad is the exact requirement for clients whose LEO, MEO, and GEO missions generally do not exceed 15 years.

All electronic components and image sensors are upscreened.

The image sensor and all electronic components used in the Auriga™ star tracker are upscreened. They undergo rigorous screening, including systematic accelerated ageing tests and electrical characterizations across the entire operating temperature range of the equipment. Components that do not meet the selection criteria are rejected and not used for production. This screening ensures the reliability of all produced equipment. Similarly, all batches of components are subjected to radiation and environmental tests to ensure their quality of manufacture and their tolerance up to an ionizing dose of 35 krad. Looking more closely, over a 15-year mission lifespan, the first radiation phenomena that reduce performance, and thus potentially the mission's lifespan, are proton displacement damages. They decrease the detector's performance by degrading its signal-to-noise ratio, independently of the detector's tolerance to ionizing dose.

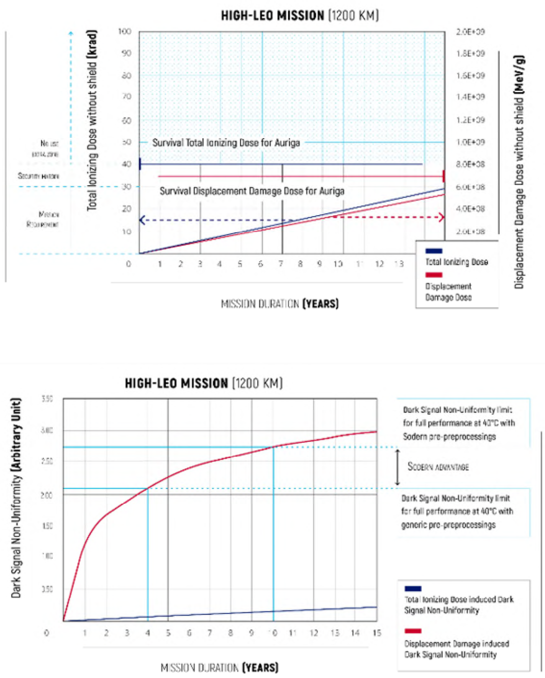


Figure 1 : TID and DDD induced Dark Signal Non Uniformity

Our answer to that was to develop proprietary image preprocessing algorithms associated with proximity electronics to compensate for these degradations. Another technique, but with a much higher electrical consumption cost, is to cool the image sensor, which SODERN decided not to prioritize. Then, the choice of an image sensor with small pixels and reduced volume photodiodes, unlike most competitors' star trackers, was crucial, as the lower the volume of the photodiodes, the less sensitive the detector is to proton displacement damage.

What criteria to consider for assessing radiation tolerance?

In summary, the level of tolerance to the ionizing dose, often expressed in krad in datasheets, or the use of a space-grade foundry does not guarantee, by itself, the overall resistance to radiation effects. For the majority of missions with a duration of less than 15 years, the most impactful and limiting factors will be proton displacement damages. A reliable detector that can tolerate 35 krad will therefore be better in most cases than a detector that supports 100 krad but suffers from its weakness to proton damages without powerful image preprocessing algorithms.

With these compromises, since 2019, more than 700 satellites have been equipped with SODERN's star trackers, accumulating over 38 million hours of flight with 100% mission success. With its supply chain and technological advancements, SODERN delivers an average of 400 Auriga™ star trackers per year worldwide, outside of constellations, with a lead time of less than 1 month.

From Auriga V1 to Auriga V2

The second version of the Auriga™ star tracker (V2) reached TRL9 and now replacesthe orginal version (V1). V2 features new optics with Rad-Hard glasses and a new mechanical housing with thicker shielding, but without electronic/detector change thus preserving TRLs. The V1 and V2 are fully compatible in terms of Electrical, mechanical, thermal and software interface.

AURIGA™	V1	V2
Mass (g)	<205	<225
Dimension (mm^3)	56 × 66 × H94	59 × 66 × H94
LEO (years)	10 (400 - 850km) 6 (850 - 1200km)	10 (400 – 1200km)
GEO (years)	6	15
Power (W)	0.8	0.8

Table 1 : AURIGA™ V2 specsheet compared to V1

3. NEW 26° BAFFLE

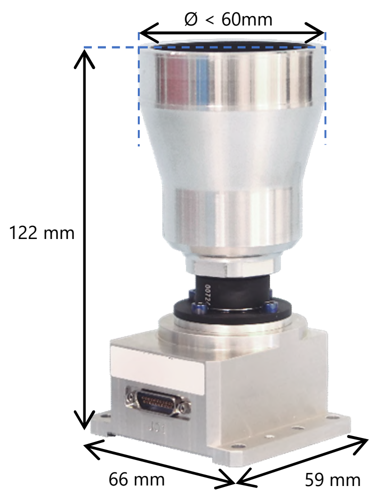


Figure 2 : AURIGA™ 26° Baffle picture

A 26° baffle has been developed for an easier accommodation on the satellite. This baffle is an option available for the AURIGA™ V2 design, which slightly impacts mass and dimension as given in the following table and previous picture. Only the baffle is changed from 35° to 26° and the OH with 26° has the same electronic, detector and optic as the OH with 35° baffle. This option is now available to order.

AURIGA™ V2	35° Baffle	26° Baffle
Mass (g)	<225	<250
Dimension (mm^3)	59 × 66 × H94	59 × 66 × H122
LEO (years)	10 (400 – 1200km)	10 (400 – 1200km)
GEO (years)	15	15
Power (W)	0.8	0.8

Table 2 : AURIGA™ 26° baffle specsheet compared to the 35°

4. GYRO OPTION

The Auriga-Gyro software option transforms the Auriga™ Star-Tracker in a “Gyro - Star-Tracker” (GSTR) equipment, which merges STR quaternion with gyro rate through combined:

- ‘Tight coupling’ which uses the gyro angular rate measurement inside STR algorithms, instead of using the STR’s rate estimation, which is less accurate, especially in case of satellite maneuvers. This tight coupling brings a significant kinematic robustness to the STR, available directly from tactical grade gyros.
- ‘High level coupling’ (or Kalman coupling) between STR attitude and gyro angular rate using an Extended Kalman filter (EKF). This hybridization takes benefit of both equipments and provides a continuous merged attitude, even in case of OH blinding by the sun or occultation by the earth, and helps the STR going back to tracking mode after such unavailability.

Furthermore, both couplings are mutually feeding each other in a virtuous loop: the Kalman filter removes the bias of the gyro angular rate for a more robust tight coupling, which increases the STR availability and in turn provides more STR measurements to feed the Kalman coupling.

The Auriga-Gyro option functionality is described on Figure 3.

Auriga-Gyro provides 2 types of Telemetries:

- The STR raw attitude, based on the stars, but with increased robustness due to tight coupling. STR information are therefore still available for primes who want to perform their own hybridization.
- A GSTR attitude which hybridizes STR data with gyro angular rate, and which is continuously available. In case the STR is unavailable (due to sun blinding, earth occultation, take a photo with the OH…), the GSTR propagates the attitude based on gyro information and provides a quality index which increases in absence of STR attitude, reflecting the gyro propagation error. During the STR unavailability, the GSTR feeds the STR with the propagated attitude, in order to go back to tracking mode as soon as the STR measures stars again.

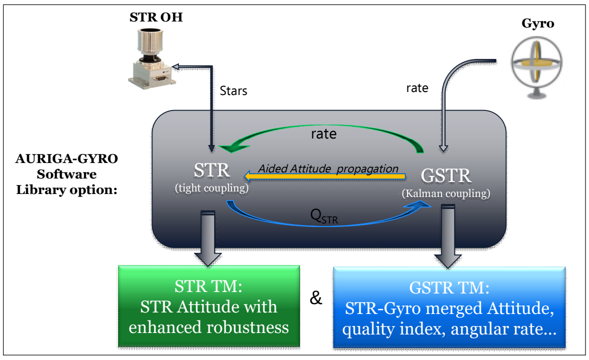


Figure 3 : Auriga-Gyro functional schematic

This new software has been tested on ground through night-sky testing with 2 different gyro classes: a Fiber Optic Gyro (ARW=0.006 deg/√h) and a MEMS gyro (ARW= 0.1 deg/√h). The set-up includes a one-axis turn-table and an Optical Head oriented at 30°from vertical.

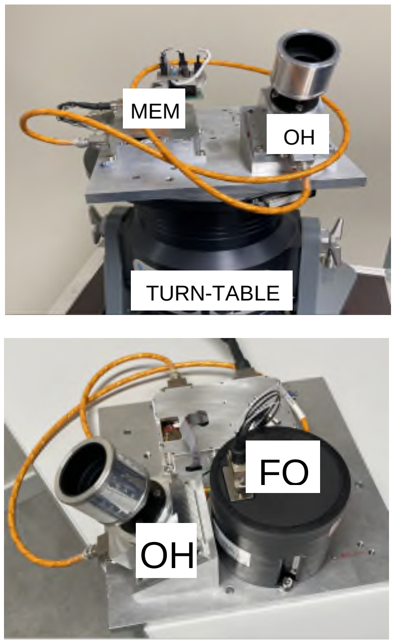


Figure 4 : Night sky test setup

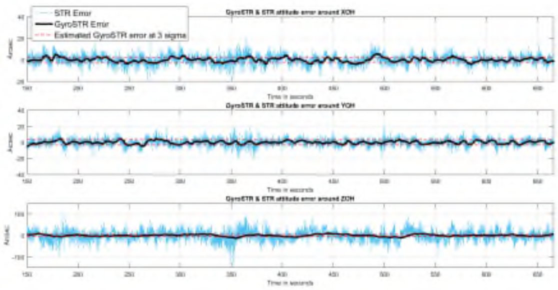


Figure 5 : Test in quasi-static (FOG)

The accuracy of a FOG-class gyro allows a highly efficient filtering of the star tracker high frequency error, only the low frequency error cannot be filtered.

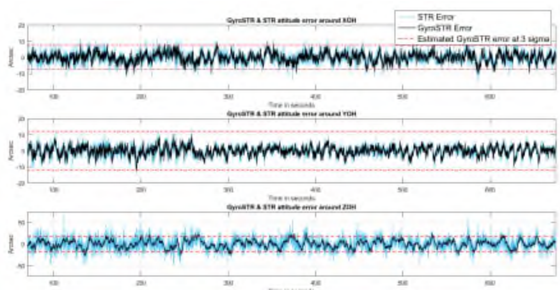


Figure 6 : Test in quasi-static (MEMS)

As shown in Figure 4, the filter efficiency is important around the Z axis (the boresight axis of the star tracker which is 7 times less accurate than the XY cross-boresight axes) whereas the limited accuracy of the MEMS gyro provided a moderate improvement of the accuracy around the cross-boresight axes. Some star tracker measurement error peaks are removed thanks to the Kalman filter which is important for the overall robustness of the gyro-stellar solution.

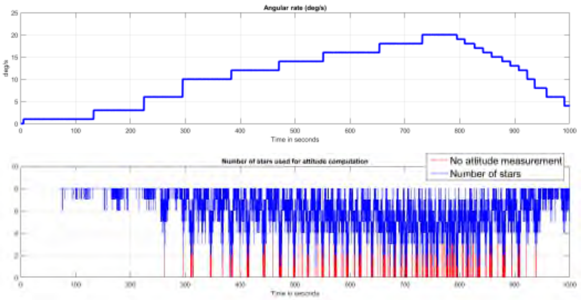


Figure 7 : Test with angular rate

In Figure 7, an angular rate is applied up to 20 deg/s to test the robustness of the overall gyro-stellar system. As the optical head is oriented at 30° from the turn table axis, half (sin(30°)) of the angular rate is projected on sensitive cross-boresight axes of the star tracker.

From 12°/s to 16°/s, the number of coherent stars is mainly between 5 and 8 stars and only a few measurements are not valid. For higher angular rate, it is much more difficult for the star tracker to perform measurement (as expected). Nevertheless, the gyro maintains the attitude propagation and the star tracker keeps tracking mode and provides to the Kalman filter its attitude when available as soon as the star tracker faces a position in the sky with some bright stars. Without gyro, Auriga would have lost the tracking.

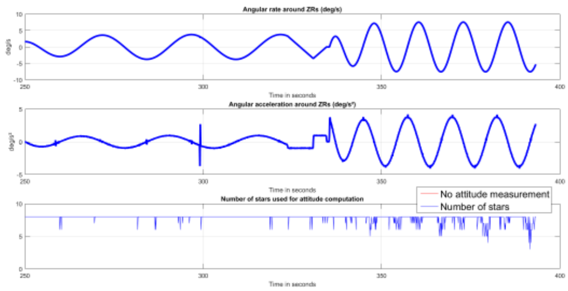


Figure 8 : Test with acceleration

Now, a sine slew rate is applied with different amplitudes and frequencies around ZRs up to 7.5°/s and 4°/s²:

As shown in Figure 8, the tracking is maintained without any difficulty. Only at a maximum angular rate >7°/s do we lose a few stars for the attitude computation, as was expected. Without this gyro-stellar solution, the robustness of the star tracker alone at 10Hz is limited to 2deg/s².

For filtering process reasons, Auriga alone without gyro data is limited by default to 0.3 deg/s which is far from its true capability of 3-4 deg/s in terms of signal to noise ratio. Auriga-Gyro leverages the gyro data to remove this limit and provides excellent lost-in-space acquisition even for high angular rates.

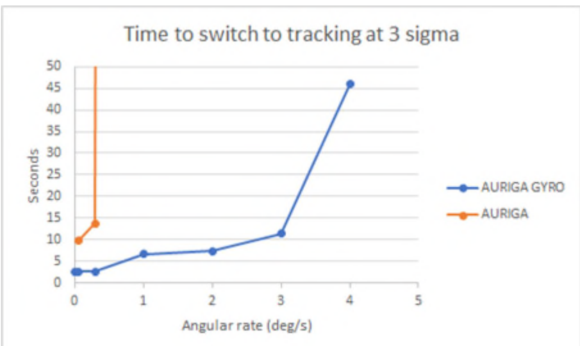


Figure 9 : Lost-in-space acquisition time

5. Conclusion

Auriga™ is the reference star tracker for mega-constellations and small spacecraft with already extensive in-flight lifetime without anomaly and a high number of customers.

With these new features, options and improvements, Auriga™ product line offers enhanced capabilities and very high robustness

6. ACKNOWLEDGEMENTS

Sodern thanks ESA and CNES for their financial support to AURIGA V2 development.

Sodern thanks CNES, French government and the European Union for their financial support AURIGA-GYRO development.

Sodern is particularly thankful to Johan MONTEL (CNES) for his expertise on EKF and merging algorithms, as well as Guillaume DELAVOIPIERE (CNES) for his technical support on gyrometers.

Financé par GOUVERNEMENT Liberté Égalité Fraternité

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