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A new compact fiber optic gyroscope for a better line of sight management

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ABSTRACT

In this paper, we present user-cases for Astrix NS. Astrix NS is a new commercially available space gyroscope. It is small and precise enough to enhance the telescope line-of-sight (LOS) command and control loop. Moreover, its fully solid-state technology (no moving or vibrating parts) avoids any parasitic vibrations that could damage the performances of the telescopes and prevent its installation close or even inside the optical instrument.

With an absolute angular knowledge error (AKE [1]) of 0.3 µrad at 10 milliseconds inside a 100 x 100 x 100 mm box and 1.4 kg weight, Astrix NS can be placed inside or near the telescope. Then, it can measure the deformation of the satellite or telescope structure in order to compensate them and to enhance imaging performances.

Astrix NS is designed and qualified for LEO and GEO missions. Its performances, such as an ARW of 5 m°/√h and down to 2.5 m°/√h, a scale factor life stability below 200 ppm and a bias stability of 0.02°/h, already allow Astrix NS to be used in a large range of classical AOCS roles: telecommunication, Earth observation and scientific missions.

Astrix NS has been developed with CNES support.

1. ARCHITECTURE AND TECHNICAL DESCRIPTION

Astrix NS, the newcomer in the Astrix family with more than 6 million hours of cumulated successful flight history in orbit, arises from the needs of the new compact satellite platforms for small, light, low-power, and cost-efficient equipment: 100 x 100 x 100 mm, 1.4 kg and 7 W (see figure 1). It is qualified for a large range of missions, including the demanding GEO 15 years + electric orbit rising.

Astrix NS is a compact solid state 3-axis gyroscope with shared communication and power electronic boards. Its optical architecture corresponds to the architecture of iXblue high performances FOG that has been improved for more than 25 years [4] [5]. It is available at a competitive price thanks to the use of COTS EEE parts that are carefully space-qualified. For Astrix NS, this critical activity of space qualification of the components is undertaken by Airbus Defence & Space. It guarantees a high reliability for all space environments including severe levels of radiations.

Astrix NS reuses many materials and components from the Astrix family that have demonstrated their reliability for space use. It is especially true for the optical part of the gyroscope: the same rad-hard fibers designed and manufactured by iXblue [2], a compact version of the same optical components. The patented core closed feedback loop is the same as in all iXblue products. The coil diameter was reduced to 40mm ensuring high performances while keeping the overall system very compact.

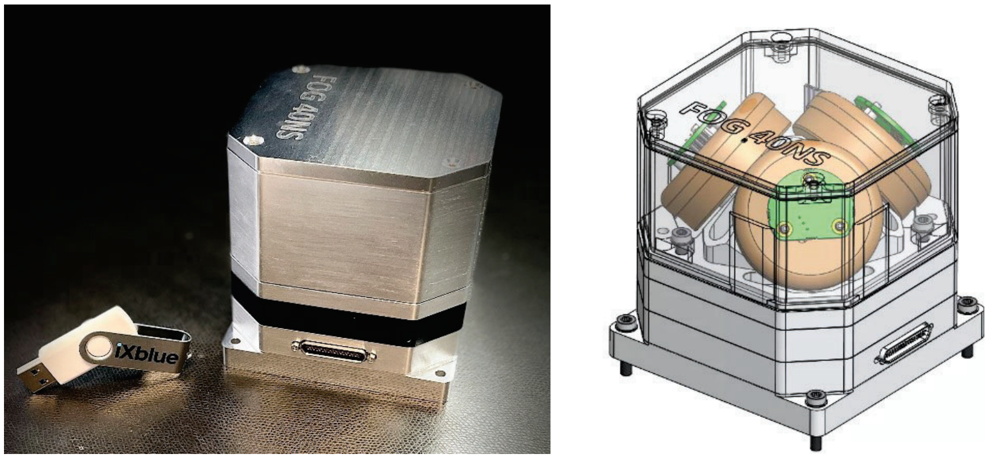

Figure 1: Astrix NS and its mechanical design

Astrix NS consists of two main parts, as illustrated in Figure 2 with the green-dashed boxes:

- Three Sagnac interferometers.

Each of them is composed of an optical fiber coil ended by an integrated optical circuit (IOC). These Sagnac interferometers measure the rotation rate around the fiber optic coil axis.

The 3 Sagnac interferometers are arranged on a symmetrical pyramid with orthogonal sensitive axis. This architecture is similar to Astrix 1090 and also to iXblue inertial systems for launchers. This solid heritage guarantees a very good robustness to vibrations and shocks. This pyramidal architecture also ensures a homogeneous behavior of the three sensors to mechanical and thermal variations.

- Three electronic boards, based on a mix of space qualified EEE COTS parts and rad-hard EEE parts:
    - An optronic board with the light source and the optical detection
    - A digital board to extract the inertial information from the optical signal coming out of the Sagnac interferometers.
    - An interface board to manage communication with the platform and ground tests systems and to do power distribution.

These two parts are mechanically assembled in one shielding case (see Figure 1).

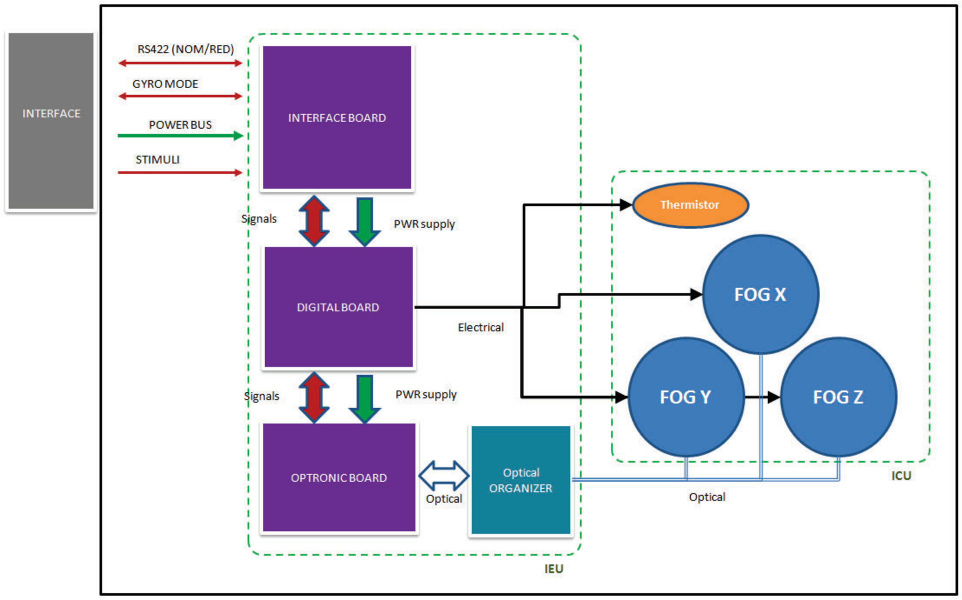

Figure 2: System architecture

To offer a compact and reliable FOG with the highest cost/performances ratio on the market, iXblue reuses the bricks that made the Astrix series successful and combines them with a COTS approach for the EEE components. This approach was presented at the AAS GN&C conference [3].

Table 1. Astrix NS main inertial performances

Parameter	Capability
Dynamic range	> 60 °/s
Bandwidth @ -3dB (Factory Configurable anti-aliasing filter)	up to 250 Hz
Bias stability over 1h (steady temperature)	< 0.02 °/h
Scale factor stability (all effects)	200 ppm @ 3σ
Angular Random Walk (ARW) standard	< 0.005 °/√h
Angular Random Walk (ARW) high performance	< 0.0025 °/√h
Consistent data availability	< 1s
No other noise contributors for FOG technology like AWN, flicker noise…	

Table 2. Astrix NS main features

Parameter	**Capability**
Dimension	100 x 100 x 100 mm
Weight	1.4 kg
Supply Voltage	20 to 51 VDC
Power Consumption	< 7W BOL
Communication	RS422/RS485 (full duplex/half duplex)

The characteristics of Astrix NS make it a highly versatile gyroscope that has been designed to fit both AOCS propagation during an extended attitude sensor blackout, pointing accuracy and high-speed fine guidance for agile spacecrafts.

2. ASTRIX NS' ANGULAR ACCURACY

For Astrix NS, the angular knowledge error is mainly due to the angular random walk (ARW) noise as there is negligible Rate Random Walk (RRW) and Angular White Noise (AWN) as can be seen in Figure 3 with a linear Allan variance from 1mHz to 250 Hz. It allows real-time analysis of reaction wheel and cryocooler induced microvibrations. Signal latency is expected under 2 milliseconds which is compatible with high frequency LOS loops.

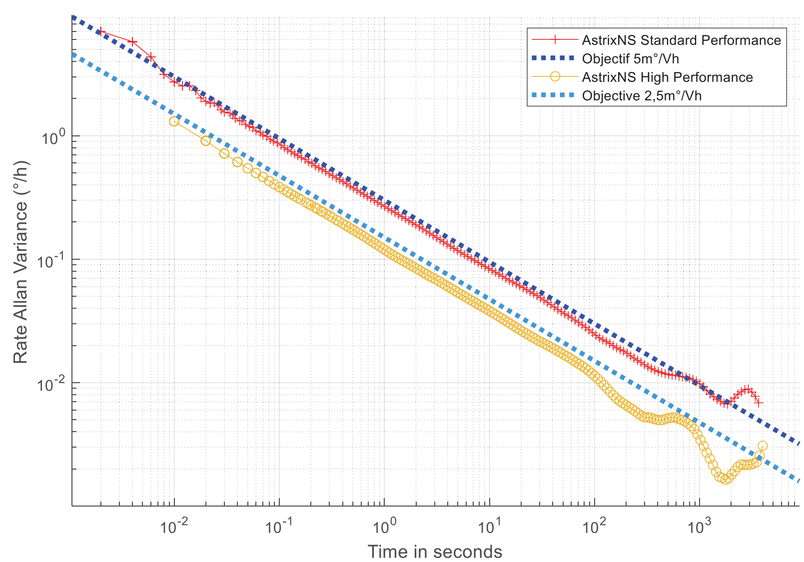

Figure 3: Allan variance of Astrix NS standard and high performance versions

In this paper, we present the pointing measurement results for Astrix NS standard version i.e. with a 5 m°/√h ARW. For the high performance Astrix NS (2.5 m°/√h ARW), the results would be twice better. It will be demonstrated and published in a future paper.

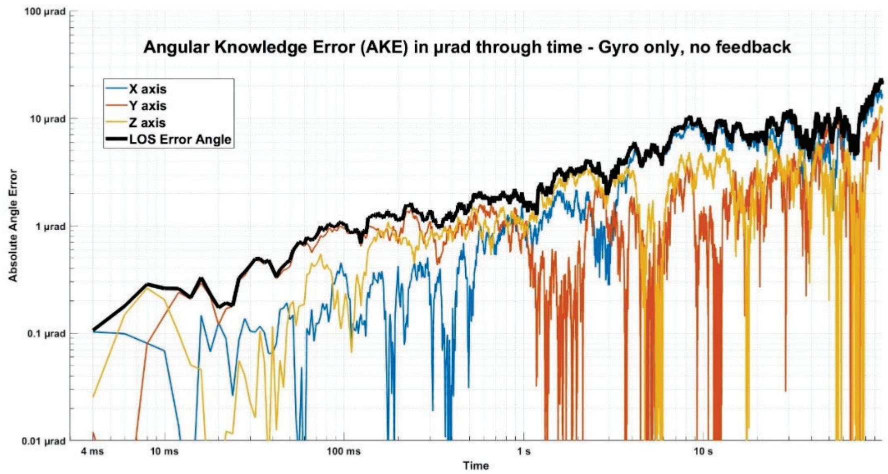

Figure 4: Angular error recording through time during a single experiment. The three colored light lines show the measurement for the three axes of the gyroscope. The black bold curve shows the 3D error.

The Astrix NS short time angular accuracy evolves roughly as the square root of time, as can be seen in Figure 4 with the black bold curve. If this experiment is repeated several times, for each duration, we observe a nearly gaussian distribution of angular error as can be seen in Figure 5.

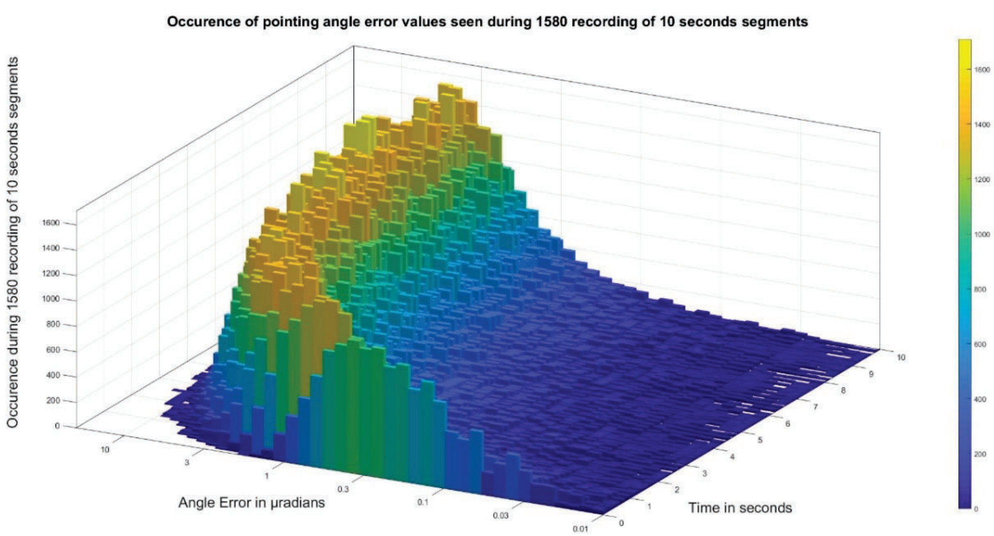

Figure 5: Distribution of measured pointing performances of one axis of an Astrix NS through time. Each "slice" of time distribution has a gaussian shape (skewed by the log axis representation in this figure)

To monitor more easily the evolution of the distribution through time we plot the distribution values at the 10th, 50th, 90th and 99,7th percentiles as shown on Figure 6.

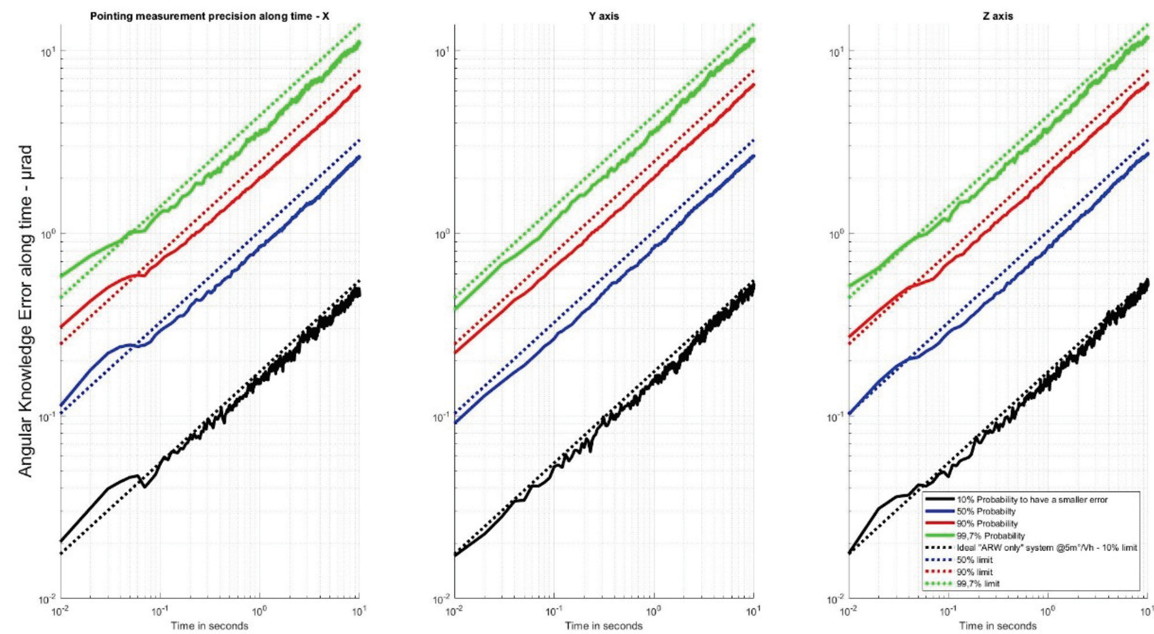

Figure 6: Measured pointing performance of Astrix NS at 100 Hz for the three axes. From left to right: x-axis, y-axis and z-axis. Each color represents the maximal error inside a 10% to 99,7% confidence rising through time. For example, there is a 90% probability (red curve) to have an error inferior to 2 µrad after 1 second of pure inertial propagation on one axis. Dash lines are theoretical systems made of only pure 5 m°/√h Angular Random Walk noises (the commercial specification of the standard Astrix NS).

In the representation of Figure 6, theoretically perfect systems with only pure white noise would results in straight parallel lines (dashed lines on Figure 6). A spectral anomaly in the noise spectrum or an electronic defect in the gyroscope would cause the temporal evolution to display bumps and peaks. In Astrix NS case, we don't observe any significant and annoying bumps which demonstrates that the design is sound.

The really meaningful error is the three-dimensional angular error which is a combination of the three orthogonal physical sensors. The noise of the three fiber gyroscope axes of Astrix NS are uncorrelated which is a favorable case for better three-dimensional performances. For uncorrelated variables, the three gaussian distributions of pointing performances combine according to a third order Chi Square Law, squeezing the error distribution of the real three-dimensional error. On Figure 7, the excellent superposition of the dashed curves (theoretical third order Chi Square Law values) and the plain curves (measured value) demonstrates this point.

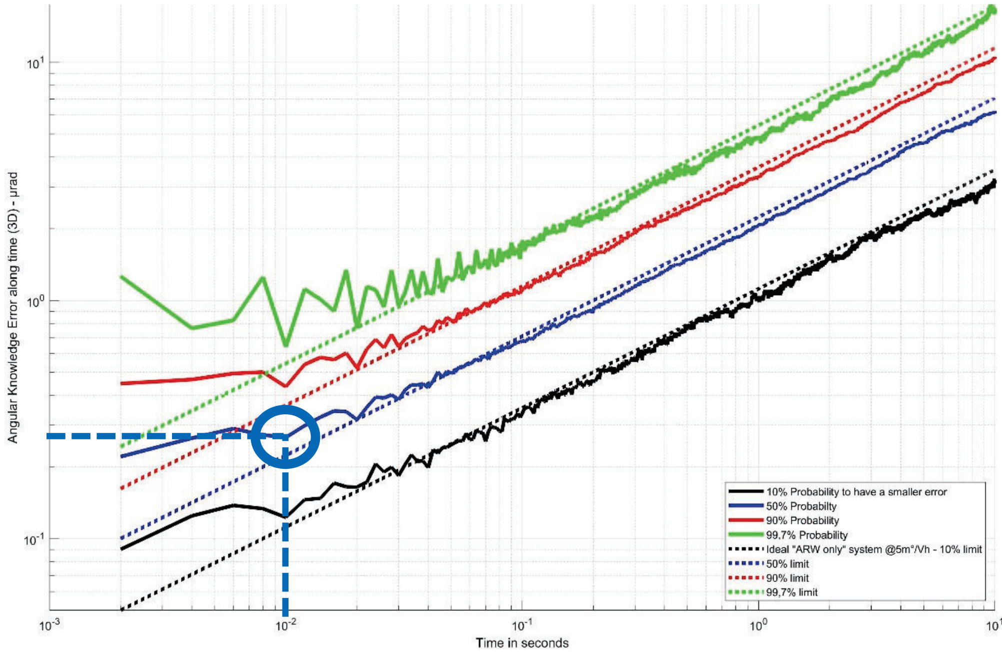

Figure 7: Measured pointing accuracy of the standard performance Astrix NS (3 gyroscopes axis with a 5 m°/√h specification – 500 Hz). Each color represents the maximal error - from 10% to 99,7% - rising through time. The dotted lines are theoretical behavior for a pure 5m°/√h noise through the third order chi square law formula. The blue circle and perpendicular dashed lines explicit a mean error at 10 milliseconds under 0.3 µrad. A high performance Astrix NS (2.5 m°/√h ARW) would be twice better with an error divided by 2.

Depending on the specific mission and on the architecture of the satellite, the relevant duration and the needed angular knowledge error vary. For instance, significant micro-vibrations in orbit have been measured on laser com satellites [6] and induced micro-vibrations linked to control moment gyroscopes (CMGs) or cryocooler are a concern [7]. As an example, we underline (blue circle on Figure 7) that for a duration of 10 milliseconds, the pointing error will be below 0.3 µrad with a probably of 50%.

We believe that with such high angular precision at 500 Hz in a 100 x 100 x 100 mm cube, Astrix NS can be used inside the telescope itself and monitor some of the telescope structural deformations to improve the satellite performances.

Finally, the space qualification of Astrix NS is planned for Q1 2023 and the first flight models delivery will be made in S2 2023.

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