ASTRIX NS : A SMALL, ACCURATE, VERSATILE AND COST-EFFICIENT FIBER OPTIC GYROSCOPE

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PAPER

In the early 2000s, Airbus Defence and Space and iXblue, with CNES and ESA support, developed a family of gyroscopes for space applications. This family of products, called "Astrix", is based on the solid-state Fiber-Optic Gyroscope (FOG) technology and offers high performance and high reliability solutions for a large variety of space missions.

Astrix NS, the newcomer in the Astrix family, 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. It is qualified for a large range of missions, including the demanding GEO 15 years + electric orbit rising. Its performances, such as an ARW at 5m°/√h or 2.5m°/√h, a scale factor life stability at 200 ppm and a bias stability at 0.02°/h, allow Astrix NS to be used in a large range of missions: telecommunication, Earth observation and scientific missions.

Astrix NS represents a breakthrough among the current space gyroscopes avail-able as it not only offers high inertial performances but also 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 un-dertaken by Airbus Defence & Space. It guarantees a high reliability for all space environments including severe levels of radiations.

The space qualification of Astrix NS is planned for Q4 2022, and the first flight model delivery is Q2 2023.

The latest environmental test results from the Engineering Models as well as the reliability analysis, confirming the promising design analyses, will be presented in this paper.

1 INTRODUCTION

Astrix NS is a 3-axis space gyroscope based on iXblue solid state fiber-optic technology that is at the heart of all the Astrix gyroscopes: Astrix 200, Astrix 120 and Astrix 1090. They have been co-designed with Airbus Defence & Space and are in production since 2007. To date, 170 FOG axes are in flight, cumulating a total of more than 6 000 000 hours in space No failure has occurred and Astrix gyroscopes exhibit excellent results and robustness [1]. Astrix products have been used for science, telecommunication, Earth observation and interplanetary missions.

In 2020, iXblue started the development of a new gyroscope in line with the ongoing New Space revolution: Astrix NS.

In this paper, we present the architecture of the product, the operational safety analysis as well as the latest environmental tests results obtained on the Engineering Models in the frame of Astrix NS critical design review.

The inertial performance, the qualification's environments and the EEE parts selection and qualification process were already presented and published earlier this year [2].

2 ASTRIX NS SYSTEM OVERVIEW and PERFORMANCE

2.1 FOG architecture inherited from the Astrix family

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 by its Research and Development team for more than 25 years [3] [4].

Astrix NS reuses as much as possible 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, a compact version of same optical component technology. 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.

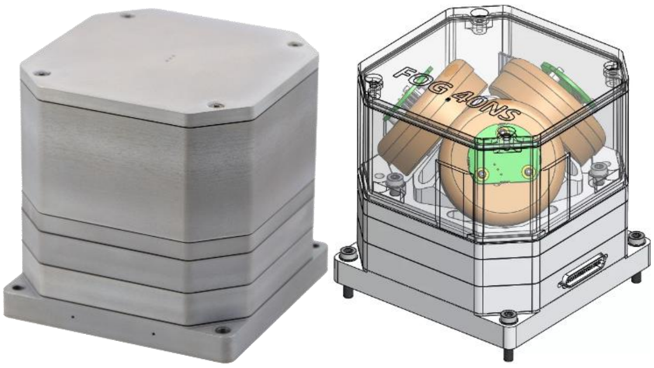


Figure 1: On the left Astrix NS picture and on the right Astrix NS mechanical design

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 radhard 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).

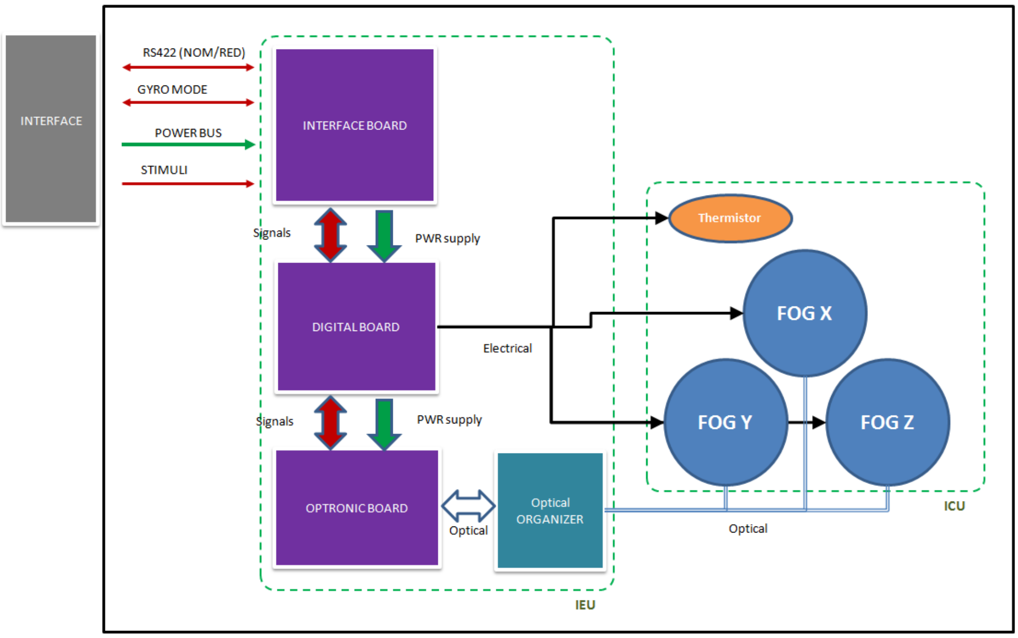


Figure 2: System architecture

The processing functions of Astrix NS are based on an FPGA performing FOG signal processing as well as the TM/TC protocol management. It also implements very efficient Built In Test, which greatly helps the spacecraft on-board computer in its Fault Detection Isolation and Recovery task.

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 earlier this year [2].

2.2 Main features and performance

Astrix NS offers two levels of ARW performance while keeping the same mechanical, electrical and TM/TC interfaces. The standard level at 0.005 °/√h and the high-performance level at 0.0025 °/√h for the most demanding projects like Earth observation and many scientific missions.

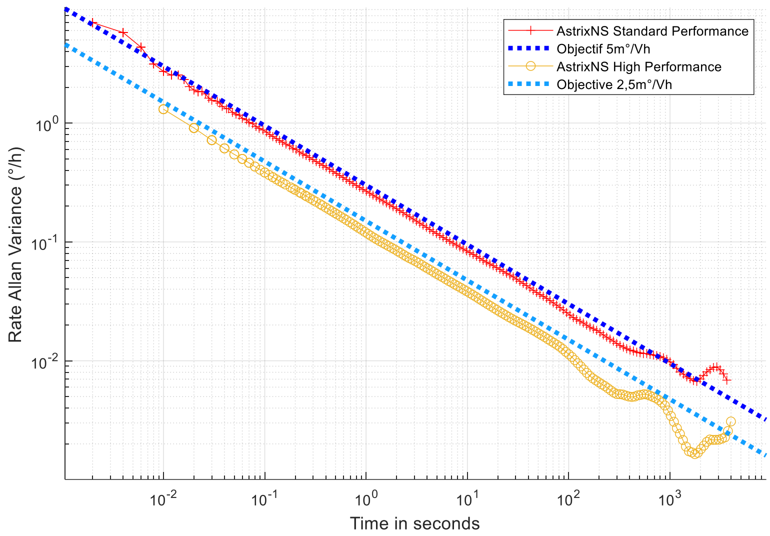


Figure 3: Allan variance of Astrix NS standard and high performances versions

Thermal scale factor error is expected to be below 200 ppm after modeling which is the case on the Engineering Model as can be seen in Figure 4 during thermal cycling with 100°/s rotation rate and 100°/s² acceleration. Raw scale factor (top graph) and the residual after ideal thermal modeling (bottom graph) are represented.

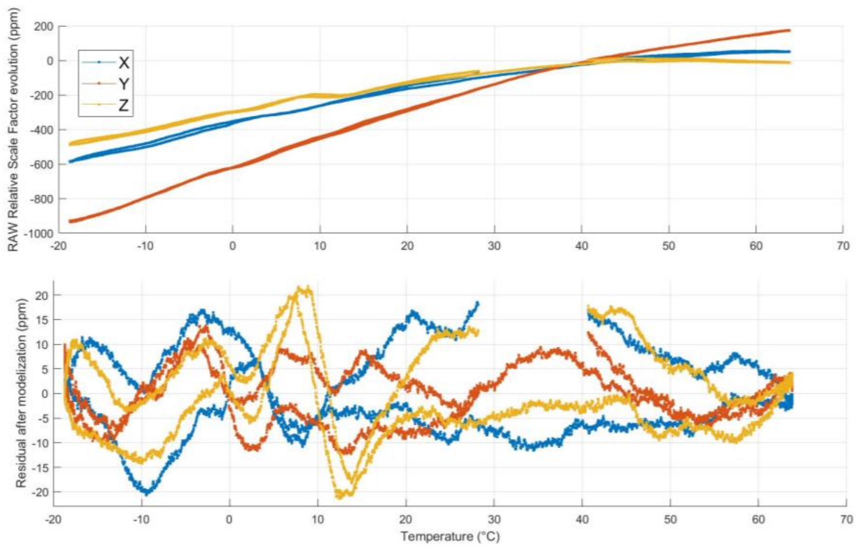


Figure 4: Internal raw scale factor evolution depending on temperature (above) and after thermal modeling (below)

All the other important inertial performances are summarized in the table below. The performances are specified at end of life.

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 100x 100 mm
Weight	1.4 kg
Supply Voltage	20 to 51 VDC
Power Consumption	< 8 W (< 7W BOL)
Communication	RS422/RS485 (full duplex/half duplex)

2.3 A wide range of applications

The characteristics of the Astrix NS make it a highly versatile gyro 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.

Thanks to the transfer function, the spectral noise flat up to 250 Hz, the microsecond time tag precision, and the internal rotation LSB at 2.10-10 radian without speed saturation, Astrix NS is perfectly suited for accuracy in high-frequency scenario. Therefore, micro-vibrations due to pumps or solar panels can be tracked and corrected for pointing accuracy, and movements smaller or faster than the star tracker limit can be addressed.

Its rotation rate dynamic range and absence of saturation make it a great choice for planetary exploration and atmospheric re-entry when coupled with three accelerometers to achieve a complete, compact, and cost-effective IMU [5].

Finally, Astrix NS reaches full performance very quickly when switched on in vacuum. It can also survive more than 12.000 ON/OFF operations during its entire lifetime. Thanks to these two features combined this gyro is a real asset for small satellite power saving strategies.

3 LATEST INFORMATION on ASTRIX NS DEVELOPMENT

For Astrix NS critical design review, a comprehensive list of tests (Inertial, Mechanical, Thermal, Electrical) and of studies (Radiation, Thermal, Mechanical, Operational safety) were conducted. All tested models are based on the EM 2 design presented at the preliminary design review i.e. close from the final design. For instance, we are using the final FPGA and both the EEE components and the mechanical design are representative.

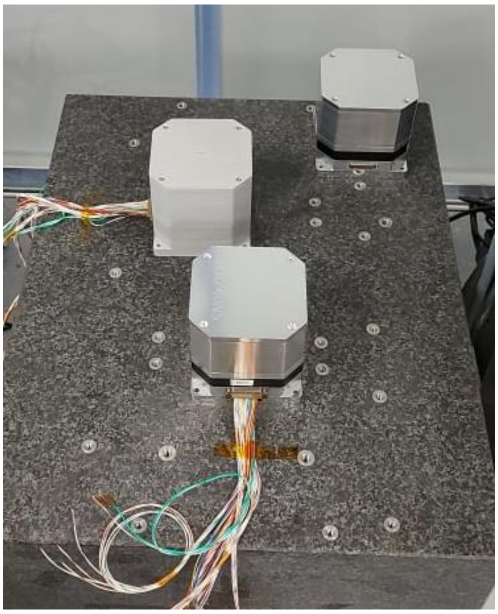


Figure 5: 3 EM 2 engineering models that were used during the tests.

A first fold of results focusing on inertial performances tests and radiation studies was presented at AAS GN&C earlier this year [2]. In this paper, we focus on the results obtained since this publication.

3.1 Mechanical environments test campaign

Astrix NS successfully withstood qualification level for sine vibrations and random vibrations along its 3 axes.

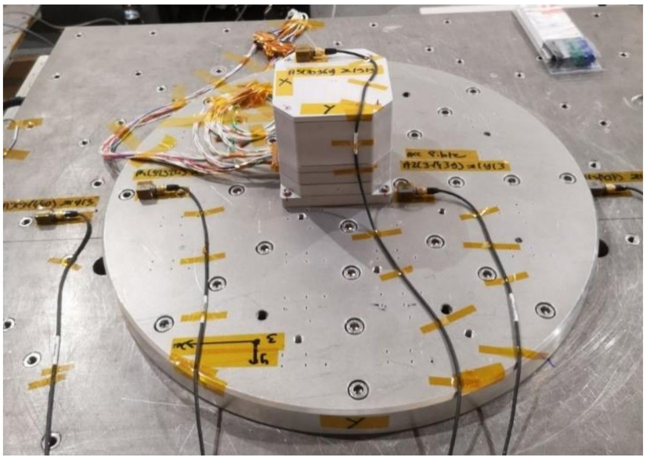


Figure 6: Picture of Astrix NS tested along the horizontal axis

Table 3: Random vibration level. Both “shall” and “should” levels were tested.

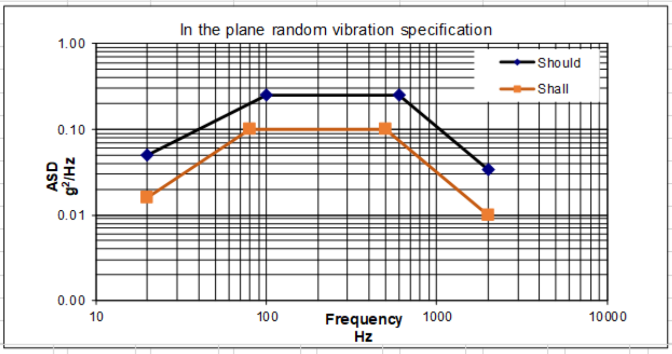
In the plane

Should

FREQ(Hz)	ASD(g²/Hz)	dB/Oct	Grms
20	0.05	*	*
100	0.25	3	3.5
600	0.25	0	11.7
2000	0.03	-5	16.2

Shall

FREQ(Hz)	ASD(g²/Hz)	dB/Oct	Grms
20	0.02	*	*
80	0.10	4	1.8
500	0.10	0	6.7
2000	0.01	-5	9.5



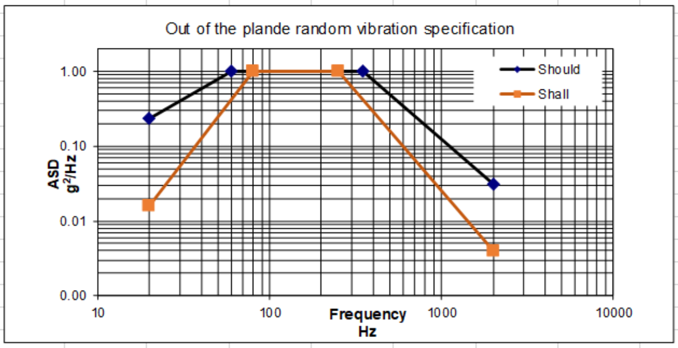
Out of the plane

Should

FREQ(Hz)	ASD(g²/Hz)	dB/Oct	Grms
20	0.23	*	*
60	1.00	4	4.9
350	1.00	0	17.7
2000	0.03	-6	24.6

Shall

FREQ(Hz)	ASD(g²/Hz)	dB/Oct	Grms
20	0.02	*	*
80	1.00	9	4.5
250	1.00	0	13.8
2000	0.00	-8	18.3



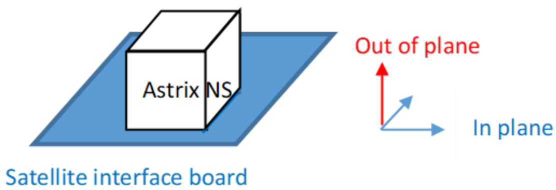


Table 4: Sine vibration levels

Shall withstand	5-20 Hz	20-100 Hz	100-140Hz
Acceleration	Maximum of the test bench *	25g	7g

After vibration, we observe:

- No visible damage
- No sliding
- No screw loosening (all screws were marked before vibration for control purpose)
- No relative critical frequency drift over 5%
- No performance-loss (see Figure 7 below)

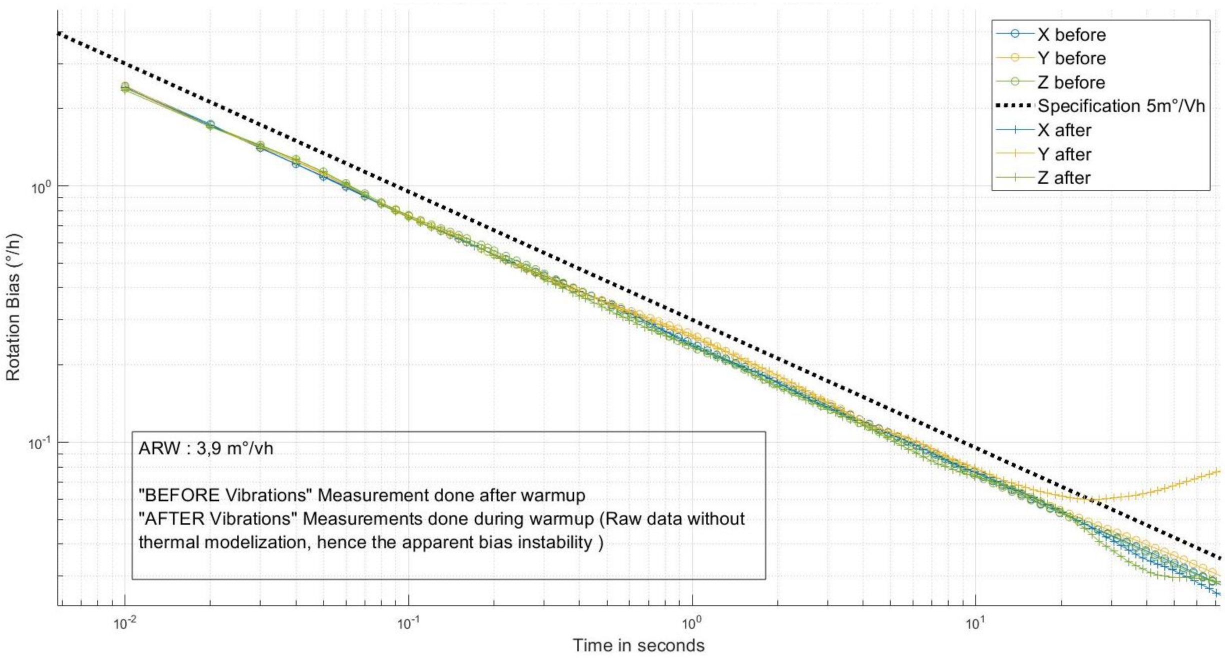


Figure 7: Allan variances of the three axes before and after vibrations (sin + random). They are superimposed. The increase at long integration time comes from the absence of thermal model and the fact that the second set of measures are recorded during warmup. They are not linked to the vibration tests.

A low-level sine frequency sweep was also carried out to determine the resonance frequencies of the system and establish a reference to compare the system's health status before and after harsh tests. Indeed, a shift in position or amplitude of the system's resonances could indicate mechanical damage.

The low-level sine signal has an amplitude of 0.5g and the frequencies are swept at 1 oct/min, from 5 Hz to 2000 Hz.

The first critical frequency was measured around 1kHz, in accordance with the mechanical simulations conducted earlier this year [2].

Astrix NS Engineering model compliance against the shocks environmental specification is being evaluated at the time of the paper submission. Test results will be presented in the poster.

Table 5. Shocks qualification levels

Freq (Hz)	Shock Response Spectra Q=10 (SRS) (g)
100	50
1000	2000
10000	2000

3.2 Thermal design test campaign

The temperature distribution of Astrix NS has been measured in medium vacuum and compared against the thermal simulation done earlier this year. The system displays excellent thermal dissipation capability. Indeed, at full power:

- On average, the structure is 5 °C warmer than the baseplate

- There is no point on the structure where the temperature is 6 °C warmer than the baseplate
- None of the critical electronic components probed are 15°C warmer than the baseplate. This low heating distribution will improve the components lifetime.
- The tests conducted agree with the thermal simulation done earlier in the development.

Figure 8: Astrix NS in the vacuum chamber for thermal tests

3.3 Operational safety analysis

The evaluation and the validation of Astrix NS operational safety are defined through the following requirements:

- Conformity to the technical requirements of Astrix NS in all applicable environments.
- Reliability (including lifetime aspects)
- Compliance with the rules of component load rates
- Robustness of performance against worst-case operating conditions
- Operational availability i.e. mainly sensitivity of components to Single Event Phenomenon (SEP)
- Safety during implementation for ground integration and testing.

Regarding reliability, Astrix NS targets a reliability level below or equal to 700 fits for LEO mission 7 years and for GEO mission 15 years. iXblue uses the FIDES reliability method (version 2009) to make the fits calculation.
This reliability calculation is currently in progress and is expected to be finished for the conference.
All the activities for evaluating operational safety and reliability are carried out by Airbus Defense and Space (Elancourt) together with iXblue. This partnership is a guarantee of quality and seriousness as Airbus has a strong expertise regarding the FIDES method.

4 ACKNOWLEDGMENTS

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5 REFERENCES

[1] Paveau A et al. *Robustness of Astrix fiber optic gyros in space radiative environment*, AAS-17-111

[2] Bonnefois J.J. et al. *ASTRIX NS: A SMALL, ACCURATE, VERSATILE AND COSTEFFICIENT FIBER OPTIC GYROSCOPE, AAS 22-037*

[3] Lefevre H. et al. *The fiber optic gyro 'adventure' at Photonetics, iXsea and now iXblue*, Proc. SPIE 11405, Optical Waveguide and Laser Sensors, 1140505 (13 May 2020)

[4] Lefevre H. *The fiber optic gyroscope*, Third Edition

[5] Eurisa, European IMU for space navigation, https://eurisa-h2020.eu/