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FROM SPACE QUALIFIED FIBER OPTIC GYROSCOPE TO GENERIC FIBER OPTIC SOLUTIONS AVAILABLE FOR SPACE APPLICATION

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ABSTRACT

The aim of this article is to present how the qualification of the Fiber Optic Gyroscope technology from IXSEA has been achieved through the qualification of a large range of optical devices and related manufacturing processes. These qualified optical devices and processes, that are now fully mastered by IXSEA through vertical integration of the technology, can be used for other space optical sensors. The example of the SWARM project will be discussed.

1. IXSEA FIBER OPTIC GYROSCOPE TECHNOLOGY

Basically, a Fiber Optic Gyroscope (or FOG) is based on the Sagnac effect, which produces a phase difference $\Delta\Phi_s$ proportional to the rotation rate Ω in a ring interferometer [1]. In the FOG, the ring interferometer is a coil of optical fiber which can be several kilometres long. The phase shift depends on fiber coil dimensions following a simple law:

$$\Delta\Phi_s = 2\pi \frac{LD}{\lambda c}\Omega \qquad (1)$$

where L and D are the length and the diameter of the fiber coil, c is the speed of light in vacuum, λ is the mean wavelength.

This effect is very small, and in order to minimize all the others parasitic phase shifts, an all-guided Reciprocal Configuration is used [2].

The optimum configuration for a FOG offering best performances is shown in figure 1.

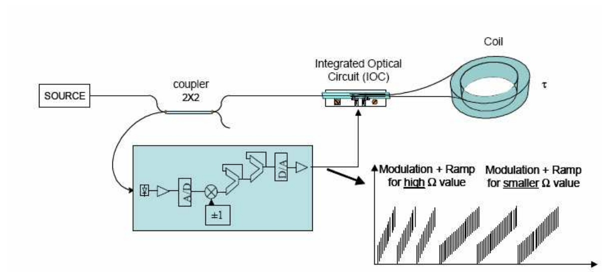


Fig. 1 FOG Optimum Configuration

By using this type of configuration, known as an 'all-digital closed-loop hybrid', the performance obtained makes it possible to attain the Holy Grail of rotation detection : stability better than 0.01 degree per hour.

The 'heart' of the system is a LiNbO3 Integrated Optical Circuit (IOC) which is altogether an Y-junction, a phase modulator and a highly efficient polarizer (>80dB!); it permits to inject light in the coil, to 'process' it and to filter it. The optical source is an erbium doped-fiber Amplified Spontaneous Emission (ASE) source, which provides an unpolarized light @1550nm with a wide spectrum (several nm). It is composed of a 980nm pump diode, Er-doped fiber, Fiber Bragg Grating (FBG) and Isolator. Last but not least, the photodetector is a PinFet with high sensitivity and low noise: the signal to be detected is as low as 10^{-5} µW!

2. THE ASTRIX PRODUCT FAMILY

EADS-Astrium and IXSPACE have achieved the industrialisation and the qualification of IXSEA space Fiber Optic Gyroscopes technology with the support of CNES and ESA. ITAR free ASTRIX™ Inertial Measurement Unit product family is now available, covering a large range of inertial performances (from 0.1°/h to 0.001°/h) and applications (Galileo, Planck, Pleiades) with more than 40 gyroscopes Flight Model already delivered by IXSPACE.

ASTRIX industrial Organization is as follows : IXSPACE manufacture the FOG channel that comprise the electronic board (delivered by ASTRIUM CRISA) and the optical interferometer. Each Gyroscopic Channel is then integrated on a tetrahedron or redundant axis structure to obtain an Inertial Measurement Unit : the ASTRIX^{TM} IMU.

Three families of IMU are now available : Astrix 200 (for 200 mm diameter fibre coil), Astrix 120 (for 120 mm diameter fibre coil) and 120 HR. These IMU are composed of FOG with the same electronic and optical source. The difference between Astrix 120 and 120 HR (for High Reliability) consists in quality level of electronic components, that shall cover 15 years operational Lifetime. The three configurations have been successfully implemented, and the required inertial performances have been demonstrated on Astrix 200 and 120 Flight Models.

The Astrix product family is shown in Figure 2

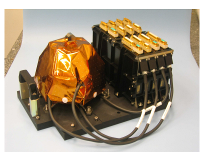
Astrix 200	Astrix 120	Astrix 120 HR
Redundant 3 axis Inertial angular rate detection (tetrahedron – 4 axes).	Redundant 3 axis Inertial angular rate detection (tetrahedron – 4 axes).	Redundant 1 axis Inertial angular rate detection
		
Coil Size : 5km Short term Bias stability: 0.001°/h Angular Random walk : 0.0002 °/√h Scale factor stability : 30 ppm	Coil Size : 1km Short term Bias stability: 0.01°/h Angular Random walk : 0.002 °/√h Scale factor stability : 100 ppm.	Coil Size : 1km Short term Bias stability: 0.02°/h Angular Random walk : 0.003 °/√h Scale factor stability : 100 ppm.
Budgets : 7 kg, 20 W. Customers: Earth Observation Satellite CNES (PLEIADES), ESA (AEOLUS) Operational Lifetime : 5 Years	Budgets : 7 kg, 20 W. Customers: Scientific Satellite ESA (PLANCK), Export Operational Lifetime : 5 Years	Budgets : 4 kg, 7W Customers: Telecommunication Satellite. ASTRIUM (COMS) Operational lifetime : 15 Years

Fig. 2 ASTRIX IMU product family

3. A LARGE RANGE OF OPTICAL DEVICES AND PROCESSES QUALIFIED FOR SPACE APPLICATION

The IFOG consists of a variety of optical devices: active optoelectronic component (laser diode, low noise photodetector, phase modulator), passive optical components (coupler, isolators, bragg grating) and special optical fibre (Erbium-doped fibre and fibre coil for the Sagnac interferometer).

These optical devices have been thoroughly tested under very harsh environment.

- mechanical tests (vibration to 25 grms and shock up to 1500g, 1ms) that cover mechanical stress experienced by the equipment during launching sequence.
- radiation tests (gamma ray cumulated dose up to 300krd and proton particle testing of 60 MeV, 1,8e11p/cm2). The effect of radiation tests on iFOG technology is induced by the creation of colored center in the fibre optic core, increasing the optical fibre insertion loss.
- thermal tests to demonstrate lifetime of five to fifteen years in orbit by thermal cycling (up to 500 [-40°C;+85°C]) and ageing testing (up to 3000 hours at 85°C).
- thermal vacuum testing.
- outgasing testing, as any outgasing could lead to critical pollution (telescopes are very sensitive to any deposition of organic material on optical surface)

The good results obtained are not that surprising as many components come from the submarine Telecom market, for which reliability under very long time (up to 25 years) is also a key issue. They demonstrate also some of the technology key advantages: no wear out effects due to moving parts or sealed packaging, lightweight component.

In fact the only weariness effect that has been observed is linked to radiation induced fibre optic darkening, that deteriorates the overall optical budget.

Typical radiation-induced optical attenuation is shown in figure 3

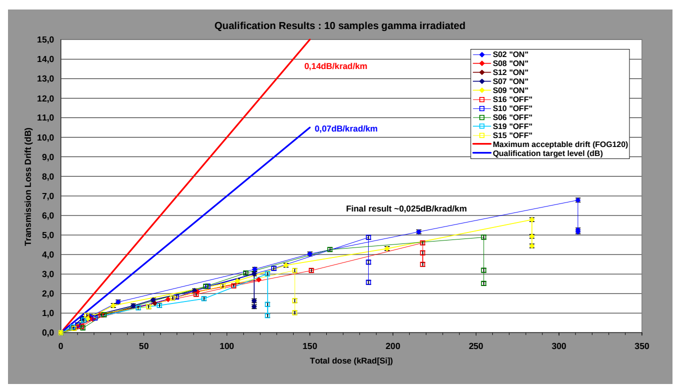


Fig.3 Fiber Optic radiation-induced loss

The long term availability of the optical devices is ensured by the vertical integration of the FOG technology. Every critical optical component is either manufactured by IXSEA (laser diode, low noise photo detector) or by a sister company (IXFIBER for special optical fiber such as Polarization Maintaining Fiber, or rare Earth doped Fiber). Critical manufacturing processes have been either internally developed or acquired and improved by IXSEA (coil winding process, Optical Assembly).

4. AVAILABLE SOLUTIONS FOR NEW APPLICATION: THE SWARM PROJECT EXAMPLE

The FOG qualification campaign has been a case study in many ways for any space qualification engineer. IXSPACE and EADS ASTRIUM had to tackle with strong budget constraints, while improving component quality, adapting key manufacturing process and qualifying a state of the art inertial sensor (0,001°/h rotation rate accuracy).
The lessons learned during the FOG qualification campaign can be extended to many other space applications as the constraints we had to face are indeed generic requirements to which every new optical sensor shall be confronted to during space qualification.

Taking advantage of its own expertise in the space field combined with IXSEA and IXFIBER expertise and manufacturing capacities, IXSPACE can design solutions in a large range of space applications requiring fiber optic technologies: opto-electronics components, sensors, fibre laser, assembly on mechanical and/or electronic board.

The first application of this know how outside the FOG is the SWARM project on which IXSPACE collaborates with the French Space Agency CNES and the CEA LETI. IXSPACE is in charge of the integration of the Ytterbium optical fibre laser used in the SWARM magnetometer. Some key components of the FOG technology such as IXSEA's 980nm Laser Diode have been used. Some key manufacturing processes that were qualified in the frame of the FOG technology qualification have been adapted to the application as well.

This Laser used for the pumping of the Helium cell of the magnetometer, is an athermal Bragg grating photo-written in an active Ytterbium fibre (LFA).
A pump Laser diode at 980nm is used in the pumping of the LFA through an optical Polarizing Maintaining Multiplexer.

This optical device comprises also an optical fibre photo-detector; an isolator for the back reflection ; an electro-optical modulator in the modulation of the Laser signal for the cell pumping. The commonalities with FOG optical configuration are obvious, and many informations from the FOG qualification campaign proved of great interest for this project.

The SWARM fiber laser is shown in Figure 4.

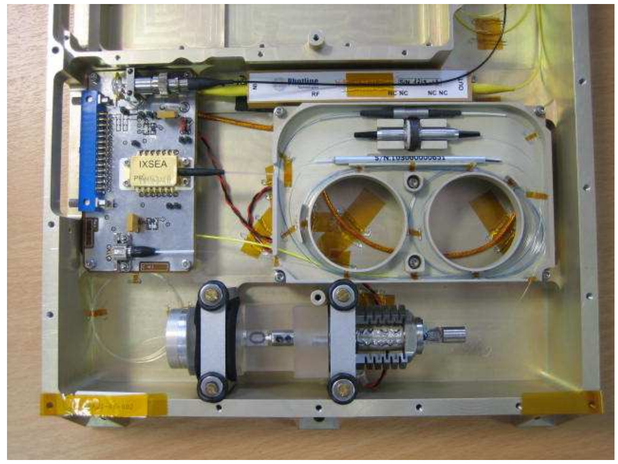


Fig. 4 SWARM Ytterbium fiber laser

5. CONCLUSION

A very large range of optical components, manufacturing processes as well as a very broad expertise have been built in the frame of the FOG qualification campaign. The SWARM project has demonstrated the interest of capitalising on this qualification Heritage.

6. REFERENCES

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