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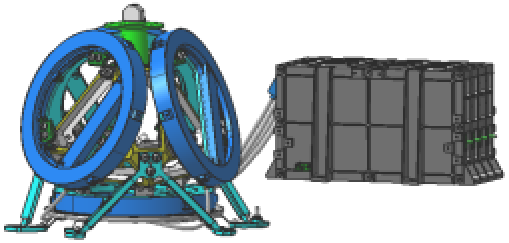

Fiber Optic Gyroscopes for Space Application

Thomas Buret

iXSpace Project Manager

IXSPACE S.A.S.

Outline

Company Profile

Introduction to FOG technology

FOG technology Qualification to Space environment

- Building the Qualification Plan
- Procurement scheme
- Qualification test sequence

Conclusion

Company Profile

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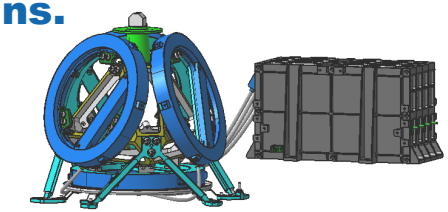
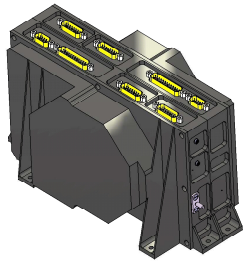
- **iXSpace develop with EADS Astrium a family of ITAR free Inertial Measurement Units (ASTRIX):**
  - based on the Fiber Optic Gyro (FOG) technology of iXSEA
  - under CNES and ESA funding budget
  - covering a large range of space applications from LEO scientific missions to Telecom missions.



- **Mission**
  - **Astrix 200 (0,001°/h) :**
    - Pleiades : Earth Observation
    - Aeolus : Atmospheric Wind Profile
  - **Astrix 120 (0,01°/h) :**
    - Planck : Cosmic Background radiation
  - **Astrix 120 HR (0,1°/h) :**
    - Galileo ?



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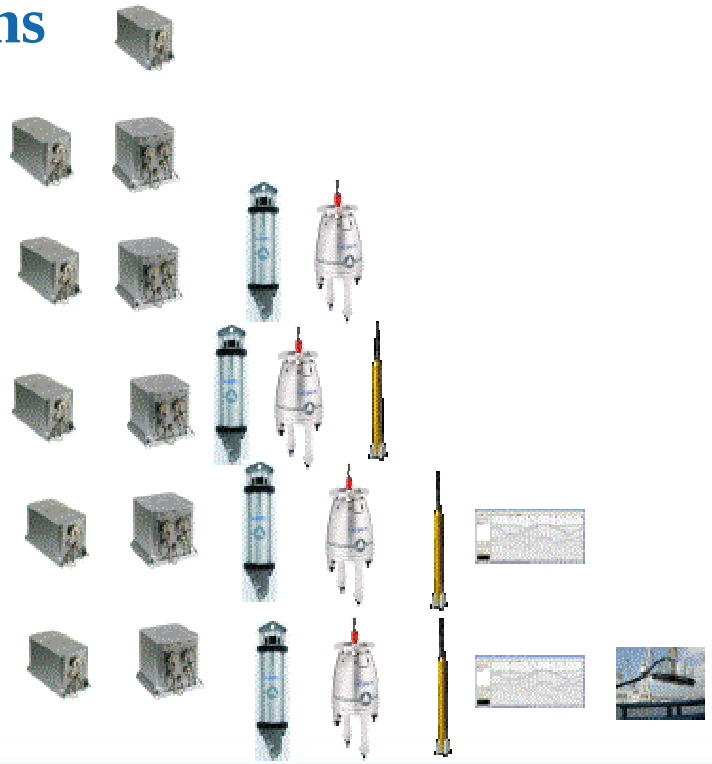
Company Profile

- **iXSpace:**
  - **100% Subsidiary of iXSea, Founded in 2004**
  - **Benefits from iXSea leadership on FOG technology**
  - **Benefits from iXSea 25 years expertise on Fiber Optic Component**
- **iXSea :**
  - **World leader in**
    - navigation and positioning
    - Imagery and survey systems
    - Moorings and construction equipment
  - **170 employees**

Brief history of the company

- 1978 - Creation of Photonetics
- 1985 - Development of FOG techno.
- 1998 - Introduction of Octans
- 2000 - Creation of iXSea
- 2002 - Merger with Oceano
- 2003 - Merger with Geomag
- 2004 - Merger with TEI SA
- 2004 - Merger with Eramer



Introduction to FOG Technology

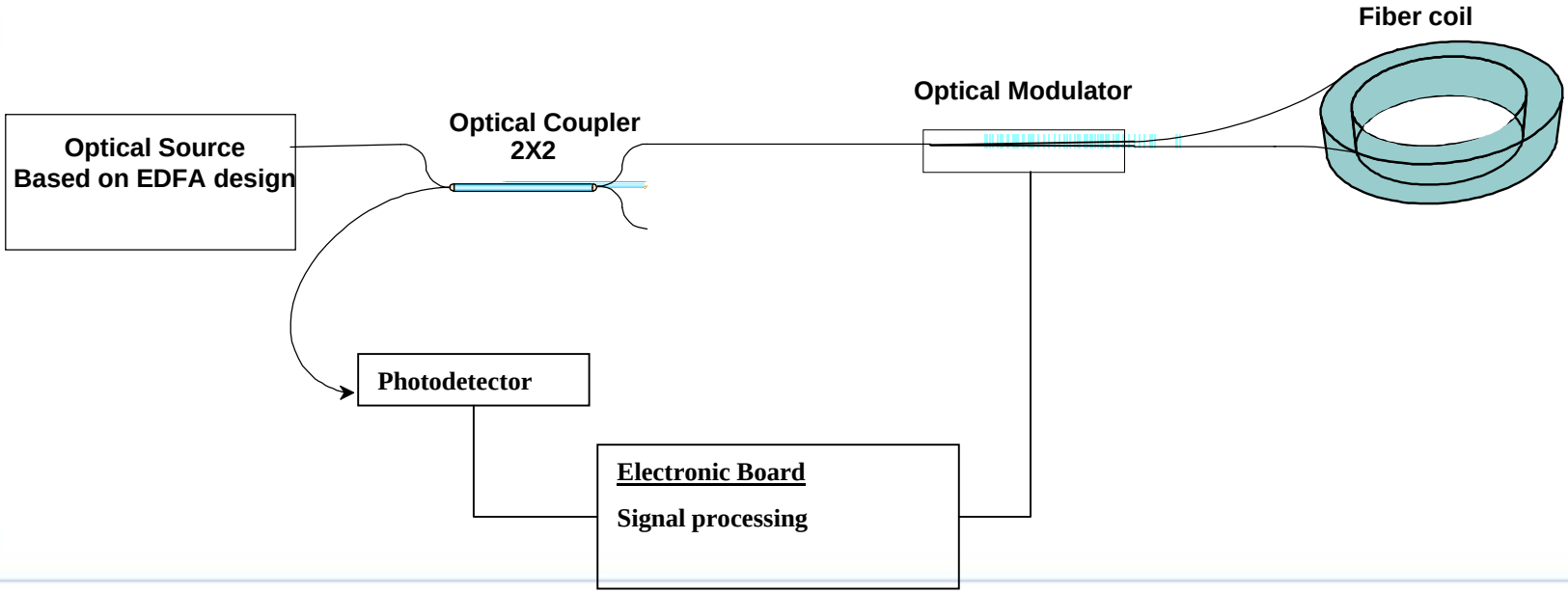
- Gyroscopes are rotation rate sensors
- Gyroscopes can be classified according to performance and mission :

100 °/h	10 °/h	1 °/h	0,1 °/h	0,01 °/h	0,001 °/h
Robotic Car industry	Helicopter stabilization	Central of attitude and heading	Gyrocompas Telecommunication Satellites	Scientific Satellite Avionic Rockets Ship and submarines	Observation Satellites Military Submarine and Battleship

- Ixsea FOG production line has produced 2000 axis for various applications in the high performance field

Introduction to FOG Technology

- **A FOG is based on the Sagnac Effect which produces, in a ring interferometer, a phase difference between two counter propagative waves.**



Introduction to the technology

- **FOG Key advantage for space application:**
  - **High inertial performance**
  - **High reliability : solid state technology, no moving parts**
  - **High versatility: from Telecom Mission to Earth Observation with the same design**
- **Development main challenge :**
  - **Demonstrate the equipment performance while respecting space design constraints**
  - **Qualify the FOG Technology to Space Environment**

Qualification of the Technology

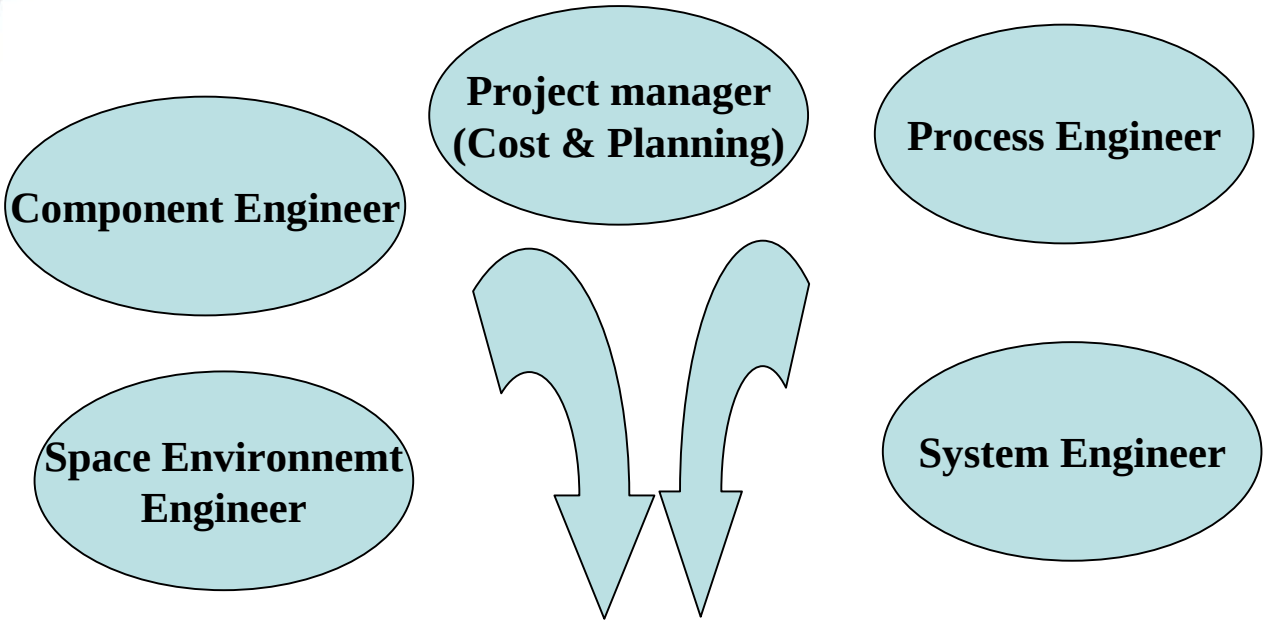
- **Electronic qualification :**
  - **standard process (space EEE parts; specific manufacturing rules)**
- **Optical qualification :**
  - **Variety of optical device**
    - **Opto-Electronics Parts:**

      Pump laser diode; Optical detector PINFET;IOC (Integrated Optical Component)
    - **Passive Optical Components:**

      Optical isolator; Optical coupler;Bragg grating
    - **Fiber Optic:**

      Erbium doped fiber (for FOG Source); fiber Coil (for Sagnac Interferometer)
  - **No space qualified alternative : COTS qualification**
  - **Batch procurement and qualification**

Building the Qualification Plan
A Teamwork



Qualification Plan

- **Procurement scheme**
- **Elements to be tested (components, sub assembly, system)**
- **Test sequence**
- **Parameter to monitor**

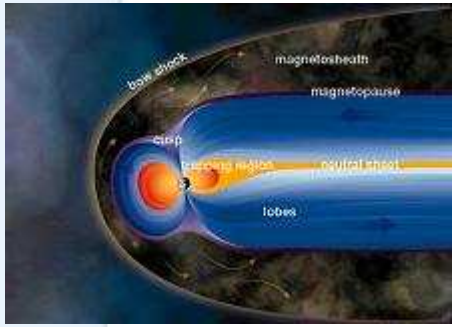
Building the Qualification Plan
A Teamwork

- **System Engineer**
  - **Defines which parameter to monitor to assure that the equipment will function properly. (Wavelength stability, Optical power)**
- **Component Engineer.**
  - **Components Risks management Matrix**
    - Available information : Qualification status (Tellcordia; by similarity technology or materials Flowchart of production.)
    - Evaluation Test (construction analysis,radiation test)
- **Process Engineer.**
  - **Process Risk management Matrix (operator dependant, repeatability..)**

Building the Qualification Plan
A Teamwork

- **Space Environment experts**

The ASTRIX products family aims at covering a large range of space applications from LEO scientific missions to Telecom missions.



- **Radiative environment (cumulated dose, dose rate)**
- **Mechanical environment**
- **Thermal Environment**
- **Ageing : Mission life time (5 to 15 years)+Storage**

Qualification plan
Procurement Scheme

- **Procurement set up**
  - **Selection of component (preliminary testing, constructional analysis)**
  - **Procurement Specification**
  - **Definition of lot for each part (batch of fiber, wafer)**

- **Component Manufacturing**

  Inspection before encapsulation when needed (performed on PINFET)

- **Upscreening**

Procurement Scheme
Construction Analysis

- **External Visual Inspection & X-Rays**

Identify packaging issues

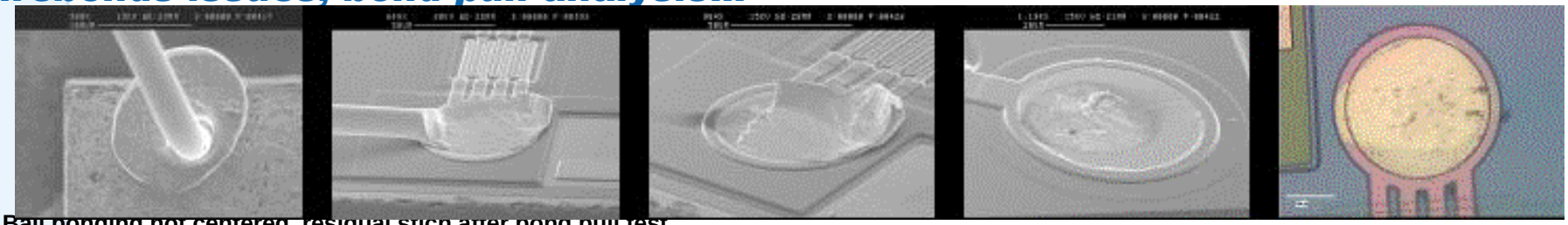
Ex : Pump Laser Diodes (butterfly), PINFET (DIL14)& Isolator (tube)

Solder joints for the output optical pigtail

Output optical pigtail

- **Seal test (gross and fine leak)**
- **PIND Test**
- **Internal Visual Inspection (Optical, MEB)**

Wirebonds issues, bond pull analysis…



Ball bonding not centered, residual stich after bond pull test…

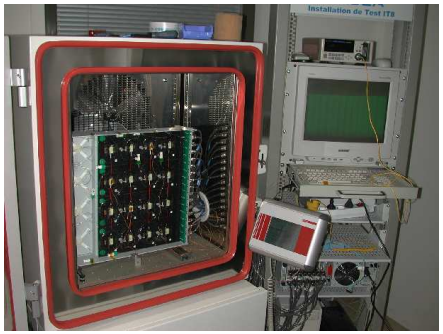
- **Micro-section & Material Identification**

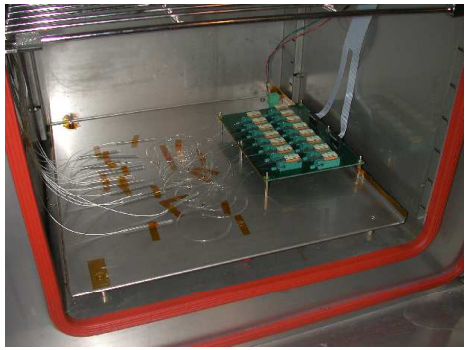
Output optical pigtail : transmission axis cut

Procurement Scheme

UpScreening

- **Based on :**
  - Our knowledge about parts and manufacturer's process
  - Astrium experts inputs
  - Some manufacturing tests can be considered as upscreening
- **PINFET and Pump Laser Diode**
  - Thermal cycling (10 cycles, [-40℃;+85℃], 10℃/min)
  - Burn In (85℃ during 168h for PINFET & 70℃ during 240h for Laser)
- **Passive Optical Components : Bragg, Isolator & Coupler**
  - Thermal cycling (10 cycles, [-40℃;+85℃], 10℃/min)





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Sub assembly tested and key parameter

Selection criteria

How to translate equipment performance and qualification

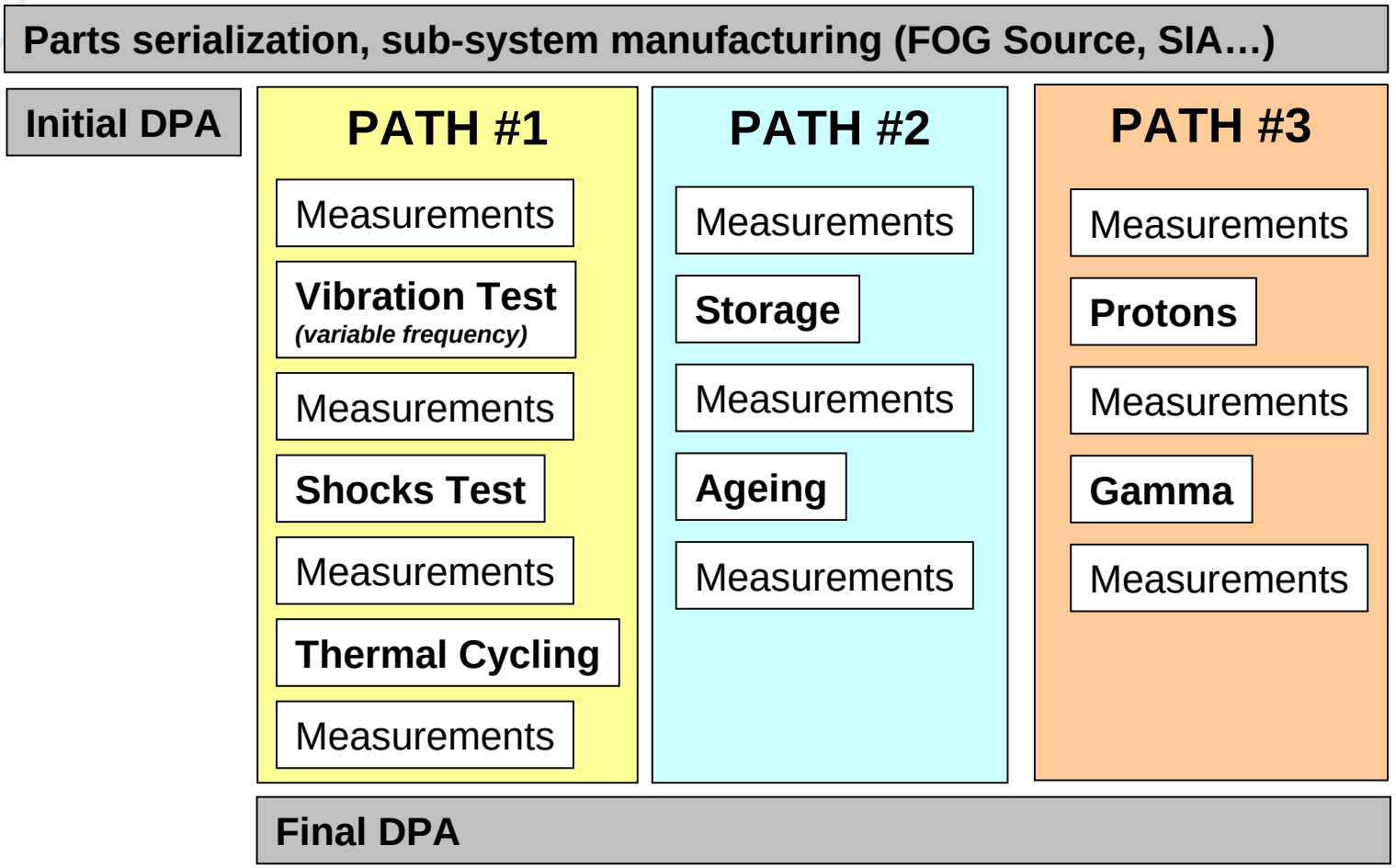
System engineer : ⇒ entire equipment

Component & Process Engineer : ⇒ qualify every Component & Process separately

Environmental test, WCA, evaluation feedback…

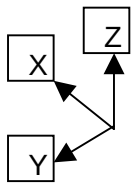
- **FOG Source**
  - Optical Power vs Pump Current (value @nominal current), Spectrum drift
- **Pump Laser Diode**
  - Threshold Current (Max value & drift), Optical Power vs Pump Current (value @nominal current)
- **SIA and Optical Fiber**
  - Optical transmission drift
- **PINFET**
  - Output Voltage Signal vs Optical Input Signal, Max and min values
- **IOC**
  - Optical transmission drift

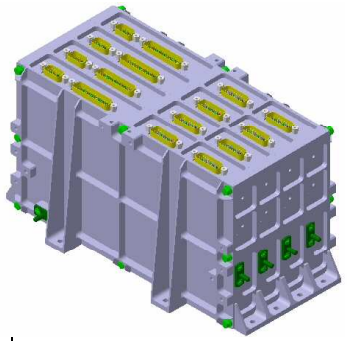
Environmental Test Sequence

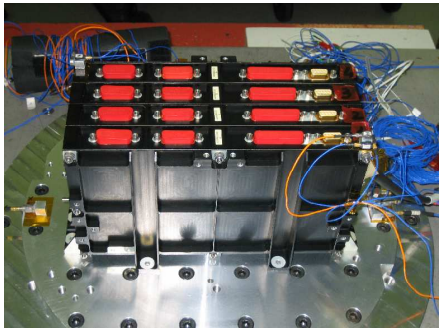


Sine & Random Vibration

- **FEM**
  - Out of plane : axis Z
  - In plane : axis x and y







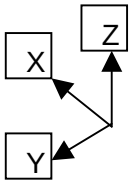
Axis	Frequency (Hz)	Qualification level
Perpendicular to the mounting plane (Z axis) **29.95 gRMS**	20-90	+ 3dB/ oct
	90-350	1.0 g^2/ Hz
	350-560	-8dB/oct
	560- 2000	- 3 dB/oct

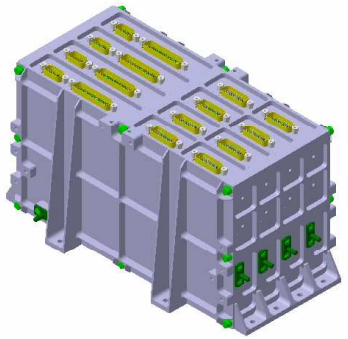
- **Qualification successful (July 2005)**
  FOG Source & PINFET: nominal working

- **SIA (October 2005)**

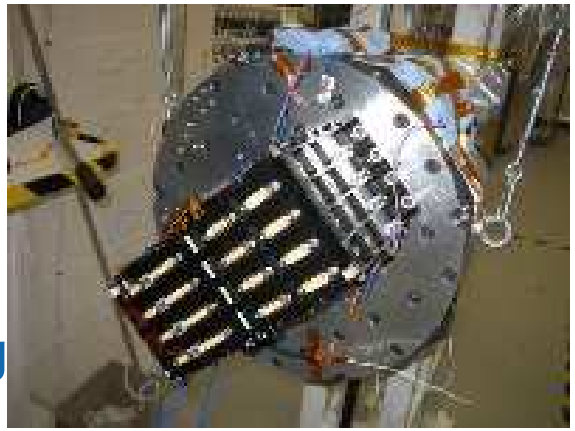
Path #1 : Mechanical & Thermal Cycling Qualification

- **Shocks**
  - **FEM**
    - **Out of plane : axis Z**
    - **In plane : axis x and y**





Axis	Frequency (Hz)	Acceleration (g)
Perpendicular to the mounting plane (Z axis)	100	40
	1200	1200
	1200	1200



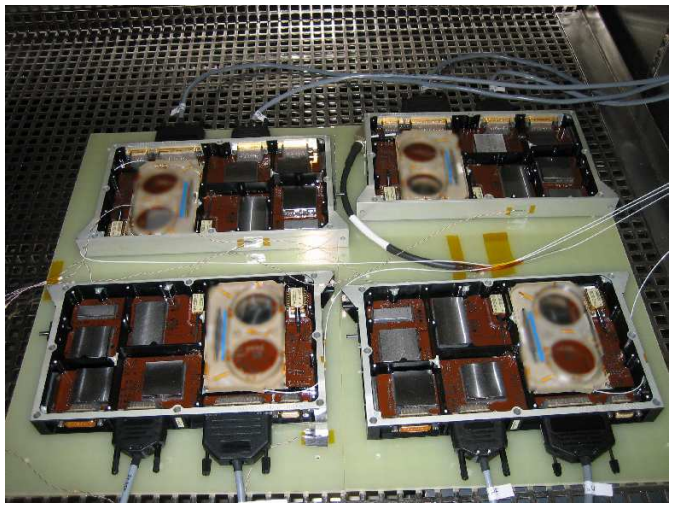
    - **Qualification successful (July 2005)**
      FOG Source & PINFET: nominal working
  - **SIA (October 2005)**

Path #1 : Mechanical & Thermal Cycling Qualification

- **FEM* : Thermal Cycling**
  - **500 cycles : [-40°C;+85°C], 10°C/min**

With measurements at 20, 100, 200, 300, 400 & 500 cycles

- 20 cycles = Parts Qualification Level
- 200 cycles = Bonding Process Qualif Level
- 500 cycles = Parts Report Qualif Level



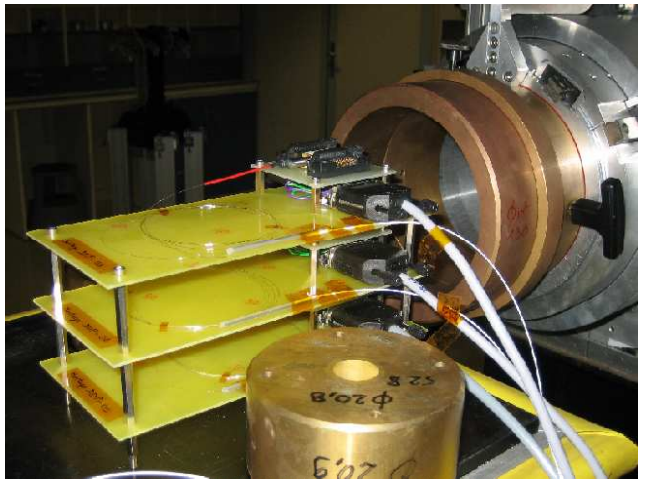
***FEM : Flight Electronic Model (FOG Source + PINFET)**

Path #2 : Storage & Ageing Qualification

- **FOG Source** (under progress)
  - Storage (not polarized) 500h, 85°C
  - Ageing (polarized) 2000h, 70°C
- **Pump Laser Diodes** (under progress)
  - Thermal Vacuum Test (70°C, Pressure < 10^{-4} atm, 2000h, polarized parts)
- **PINFET** (under progress)
  - Storage (not polarized) 500h, 85°C
  - Ageing (polarized) 3000h, 85°C
- **IOC** (October 2005)
  - Storage (not illuminated) 500h, 85°C
  - Ageing (illuminated) 2000h, 85°C

Path #3 : Proton & Gamma Qualification

- **Proton Dose Qualification**
  - **Pump Laser Diode**
    - » *60MeV, 1.8e^{11}p/cm²*
  - **PINFET**
    - » *30 & 100MeV, 1.6e^{11}p/cm²*



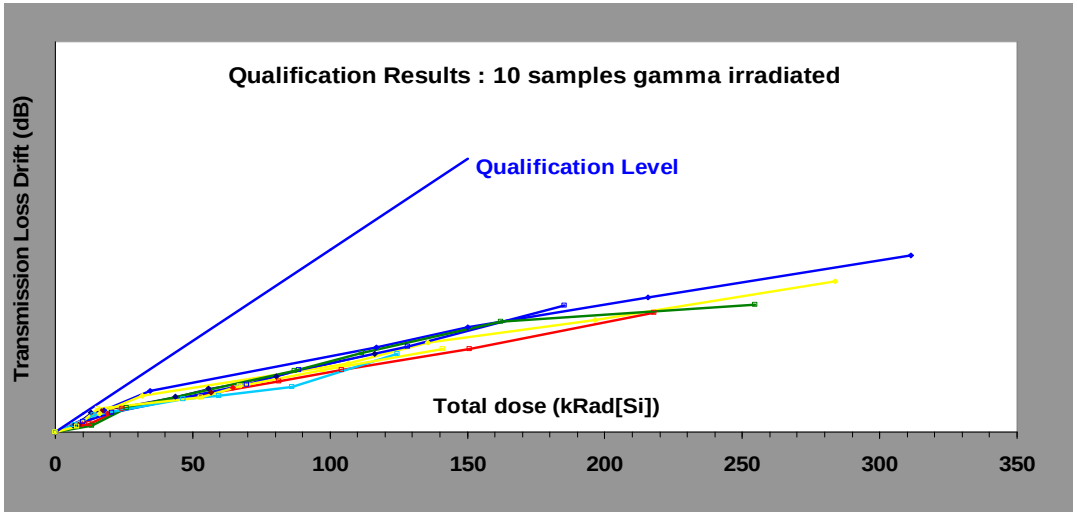
No drift during Proton Irradiation Test

- **IOC & FOG Source : test for the end of 2005.**

Path #3 : Proton & Gamma Qualification

Total Ionising Dose Qualification

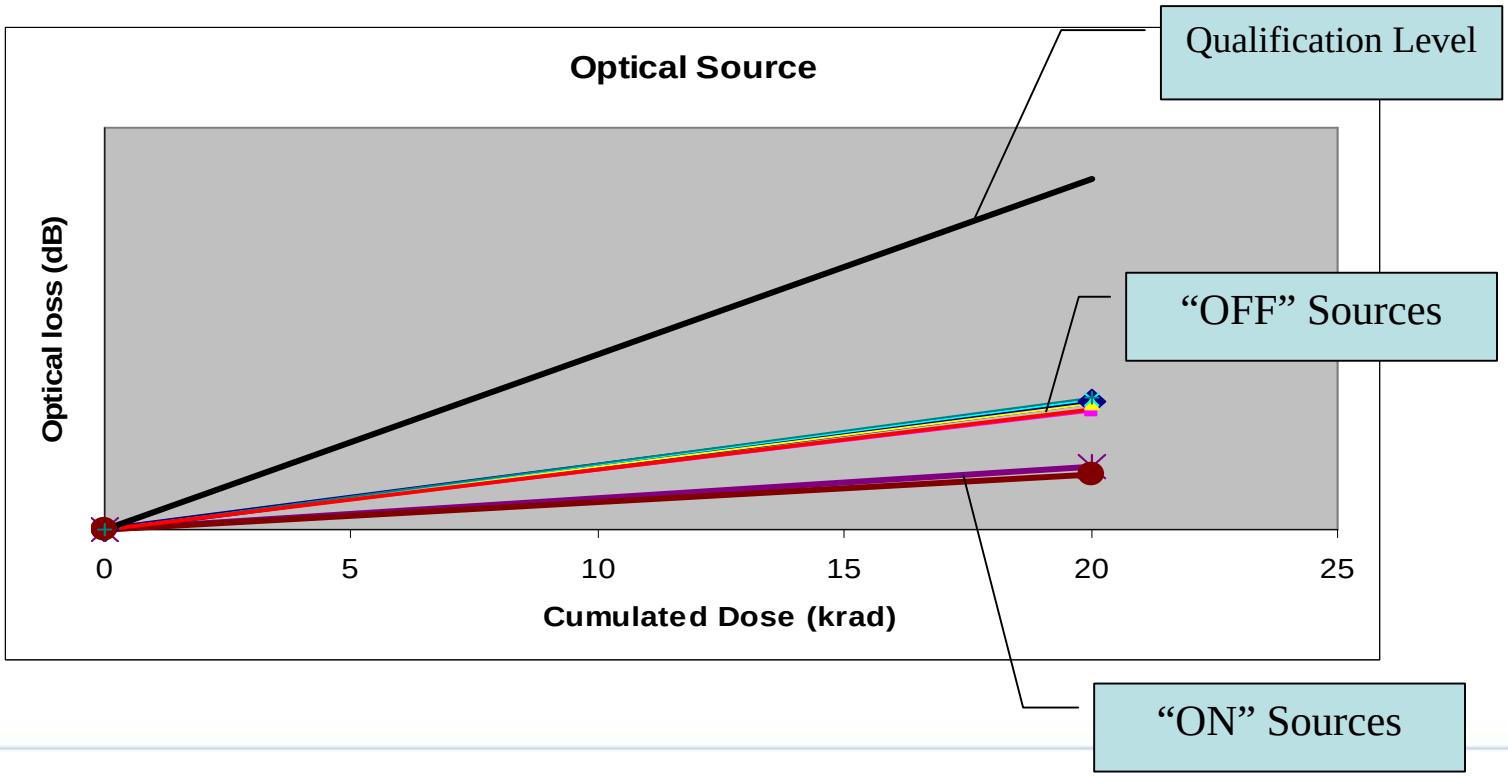
- **Coil Fiber (Up to 300krad, variable dose rate: 50rad/h up to 250rad/h)**



- **IOC (500krad, ~300rad/h) *under progress***
  - Steps : 10krad, 300krad & 500krad
- **PINFET (120krad, 200rad/h et 50rad/h) *under progress***
  - Steps : 15krad, 75krad & 120krad

Path #3 : Proton & Gamma Qualification

- **FOG Source (120krad, ~300rad/h)** ***under progress***
  - **Steps : 15krad, 75krad & 120krad**



Space Models

- **FOG 200**
  - **Prototype : performances obtained**
  - **Engineering Qualification Model**
    - Manufactured, under Test
    - Overall environment qualification
  - **First FM by mid 2006**

- **FOG 120**
  - **First FM delivery by mid November 05 (Planck)**
- **FOG 120HR**
  - **EQM by mid 2006**

Conclusion

- **Qualification Successful so far**
- **Risk management very different from terrestrial activities : *a qualification has to be successful***
- **Procurement is a lengthy process**
  - **Gathering information**
  - **Batch definition**
- **Take Advantage of both side Expertise :**
  - **iXSpace as Fiber Optic Components and FOG technology experts.**
  - **EADS Astrium as Space Qualification Experts.**