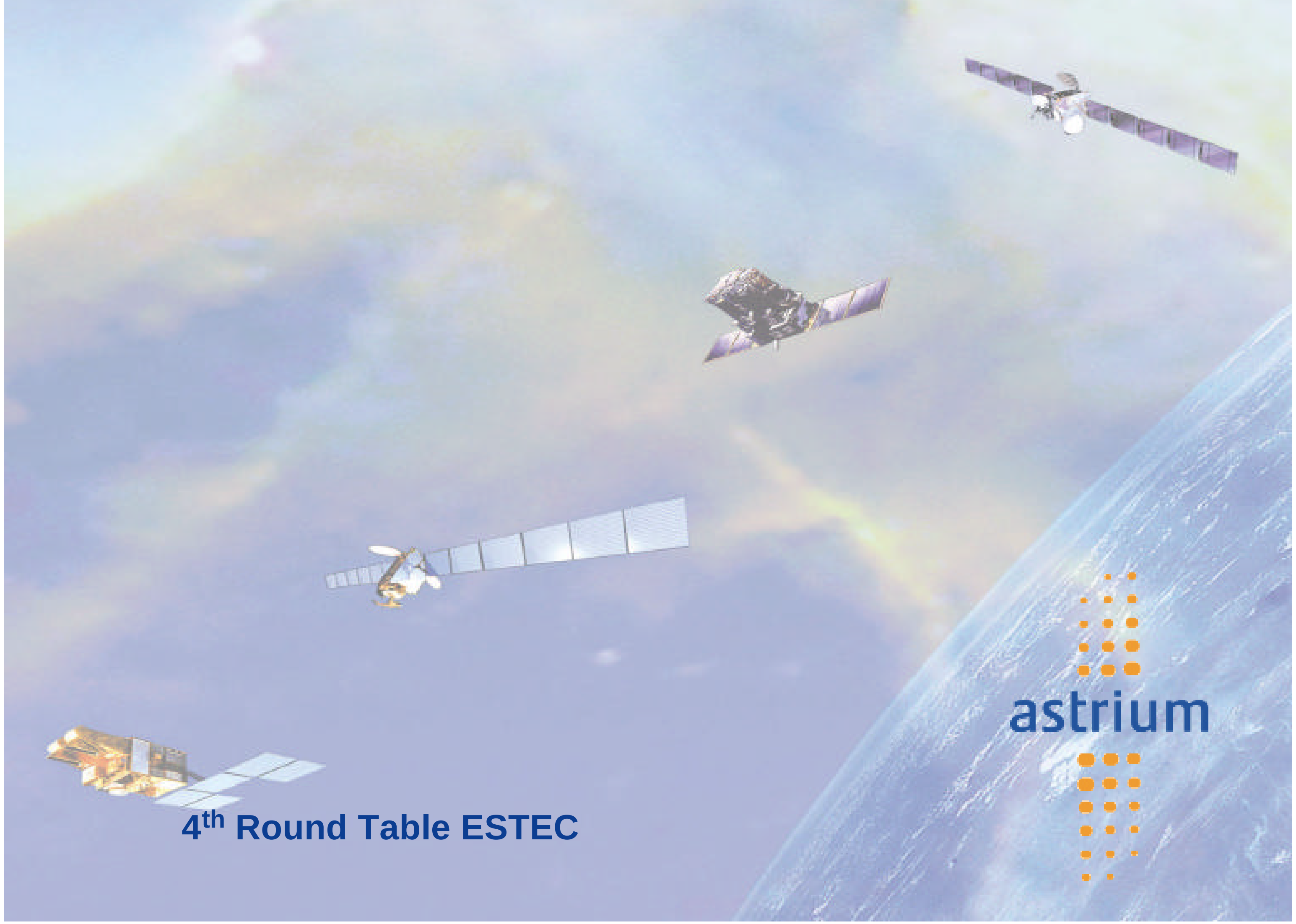
MEMS for space applications: a reliability study



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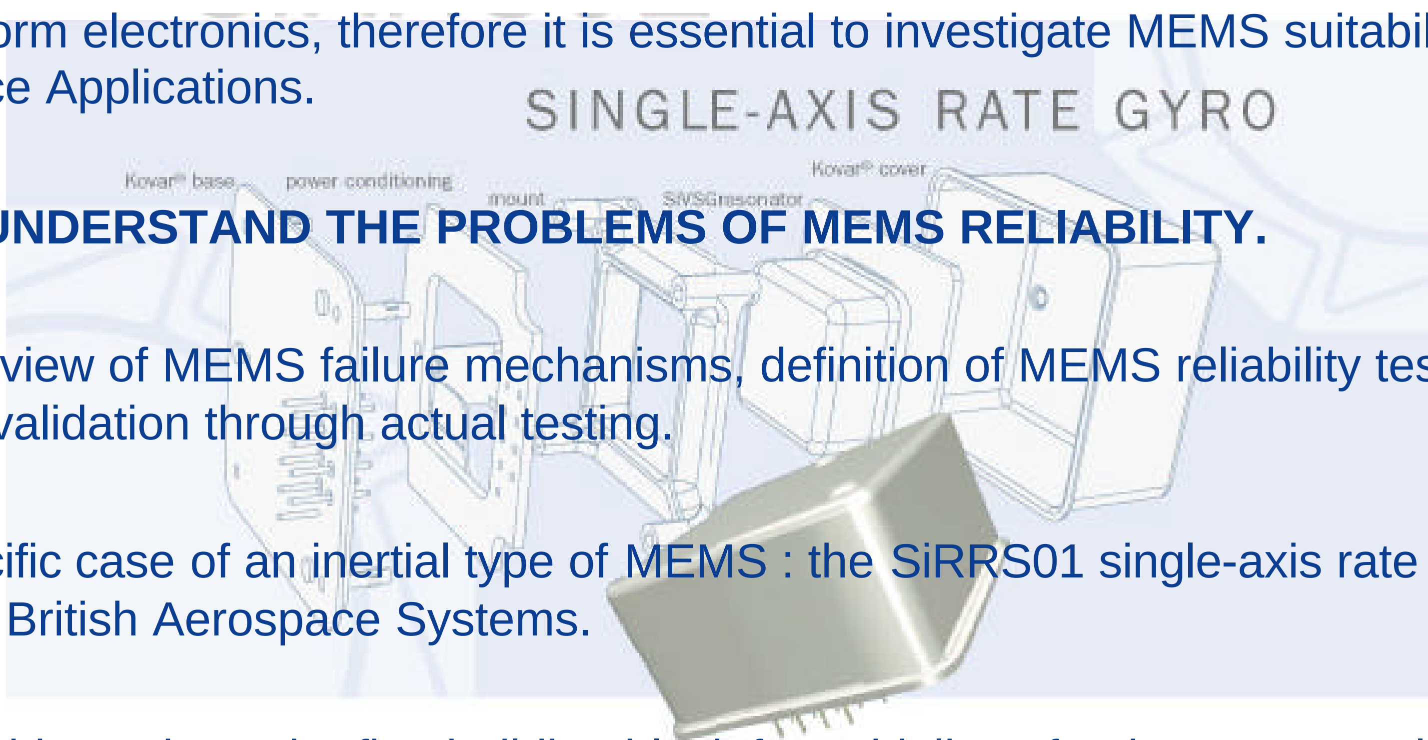
Objectives of the reliability study

- The use of MEMS is one possible step forward towards the miniaturisation of space platform electronics, therefore it is essential to investigate MEMS suitability for Space Applications.



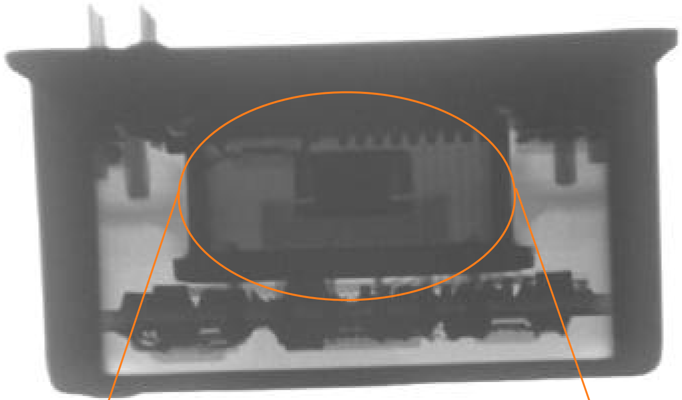
- **TO UNDERSTAND THE PROBLEMS OF MEMS RELIABILITY.**

- Overview of MEMS failure mechanisms, definition of MEMS reliability test methods and validation through actual testing.

- Specific case of an inertial type of MEMS : the SiRRS01 single-axis rate sensor from British Aerospace Systems.

- Use this study as the first building block for guidelines for the space evaluation of MEMS

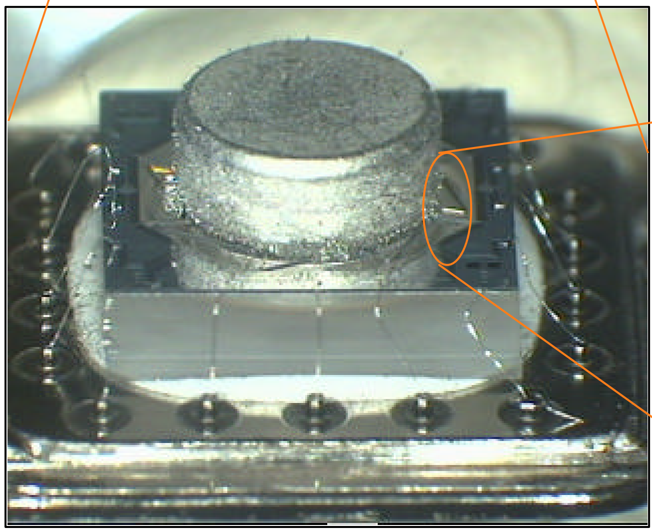
SiRRS01 single-axis rate gyro

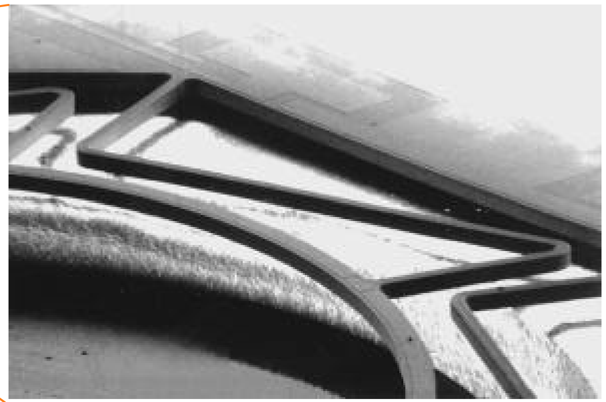


✓ Gyro made of a mechanical part, the ‘sensor head’, and an ASIC to put the gyro into vibration, control the vibration and measure the rate of turn.

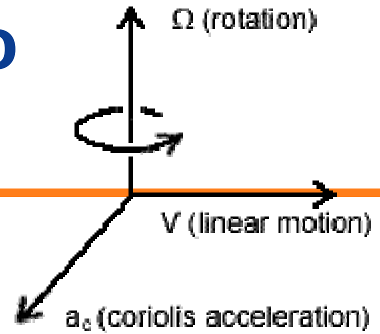
✓ Vibrating Structure Gyro based on the coriolis effect.

✓ ‘Deep trench etching’ process enabling the production of the tiny micromachined silicon ring.

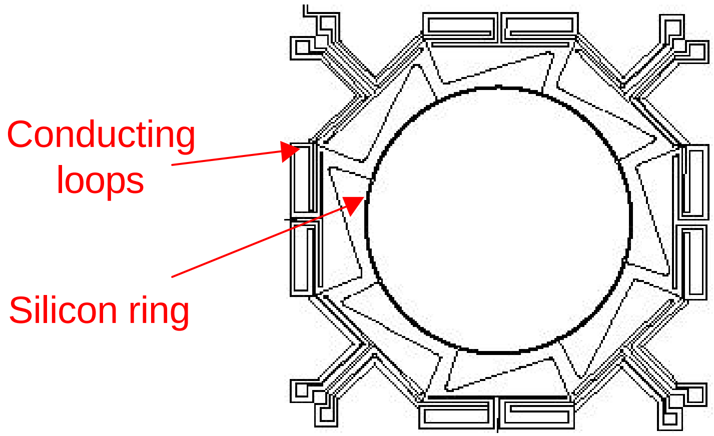


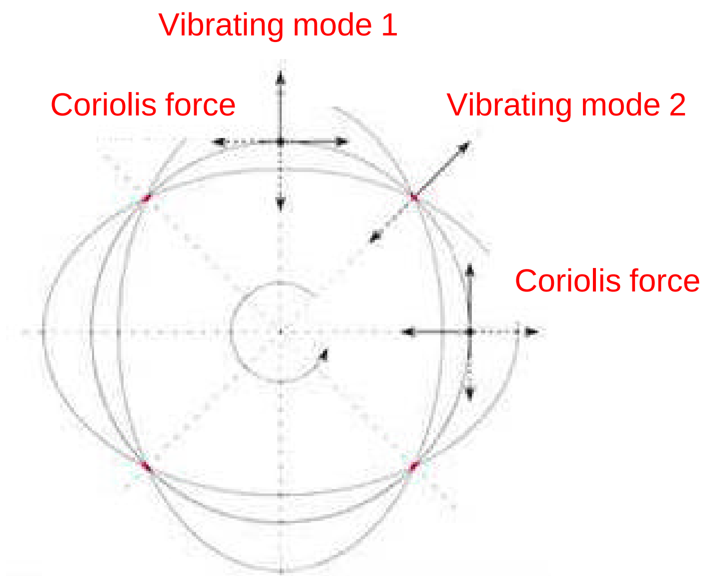


Working principle of the SiRRS01 gyro

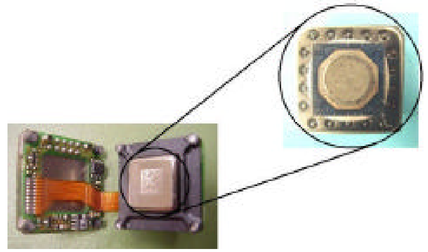


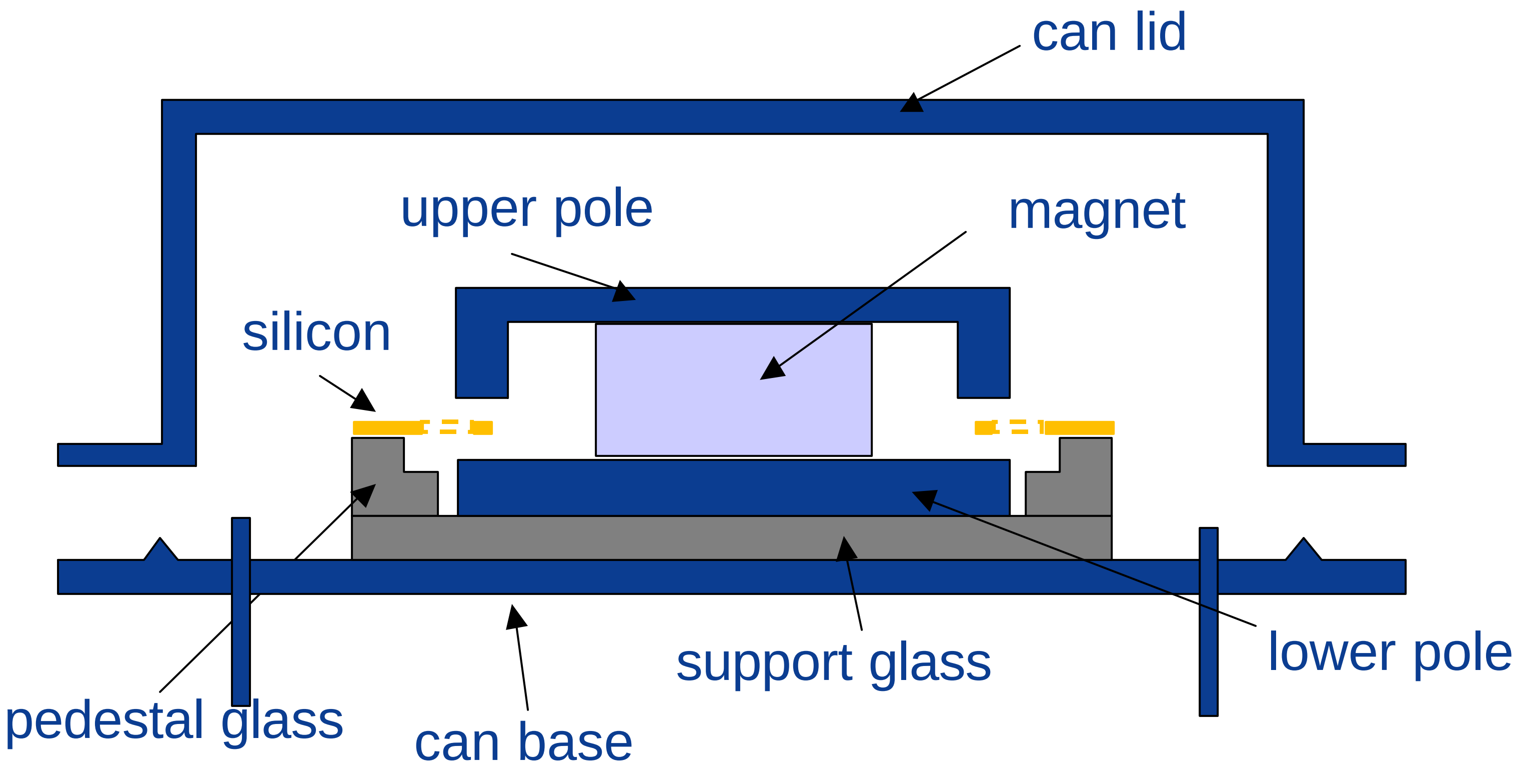
- ✓ **Based on the Coriolis Effect: Coriolis acceleration experienced by a particle undergoing linear motion in a rotating frame of reference.**
- ✓ **Resulting acceleration directly proportional to the rate of turn.**
- ✓ **Vibratory motion coupled from a primary vibrating mode into a second mode when sensor experiencing angular rate.**





Construction of the SiRRS01 gyro





- ✓ **Bulk micro-machining technology: silicon etched to create the sensor ring**
- ✓ **Silicon-on-insulator (SOI) substrate: silicon anodically bonded to a glass support**

Functional testing: specification and measurements

Scale factor **18.2mV/°/s** **1% linearity**

Gyro set on a 2-axis table and put into rotation : measurements performed for 6 input speed values, between +/- 30°/s, and 6 temperature values from –

Bias stability **+/-0.3°/s (ambient temperature)**

Gyro set on a 2-axis table and kept fixed with the sensitive axis in vertical position : measurements performed for 6 temperature values from –40°C to 75°C.

Angular Random Walk **0.2°/Ö hr**

Measured through Allan variance

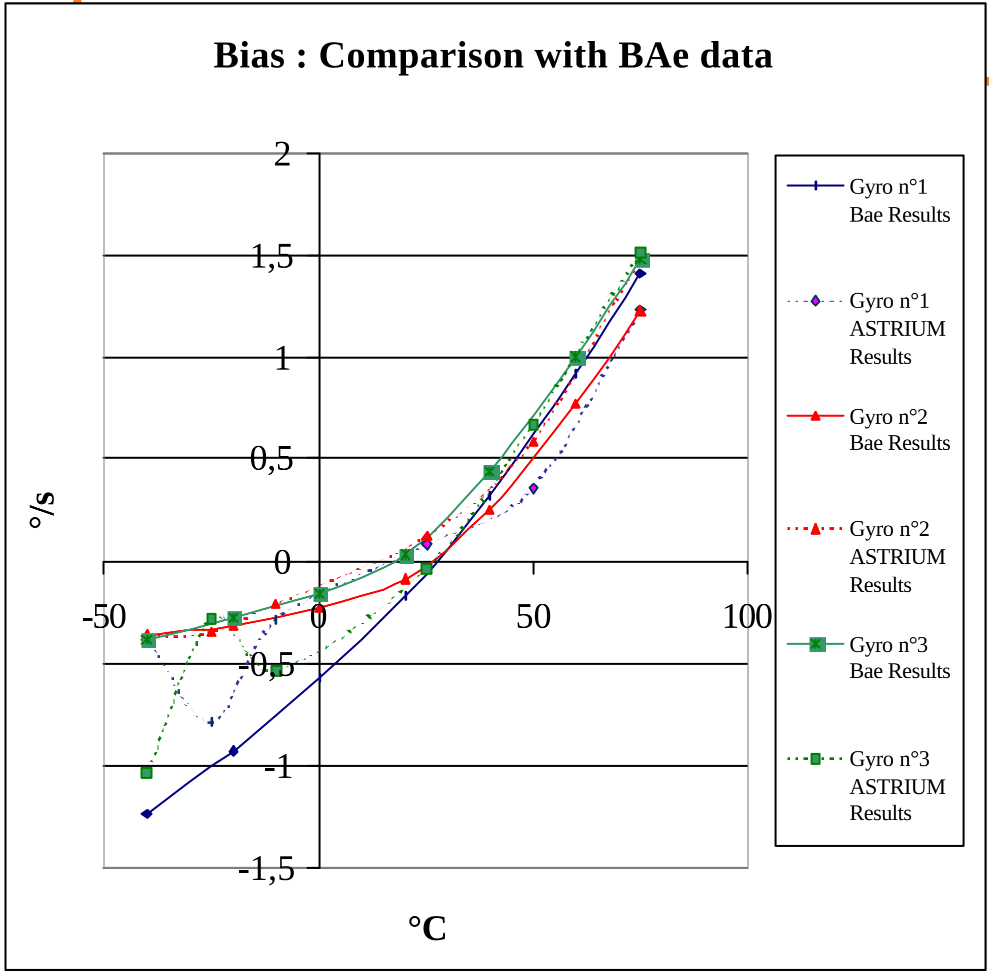
Gyro mounted on a fixed support. While keeping the gyro fixed, the measurements are acquired during 12 hours at ambient temperature.

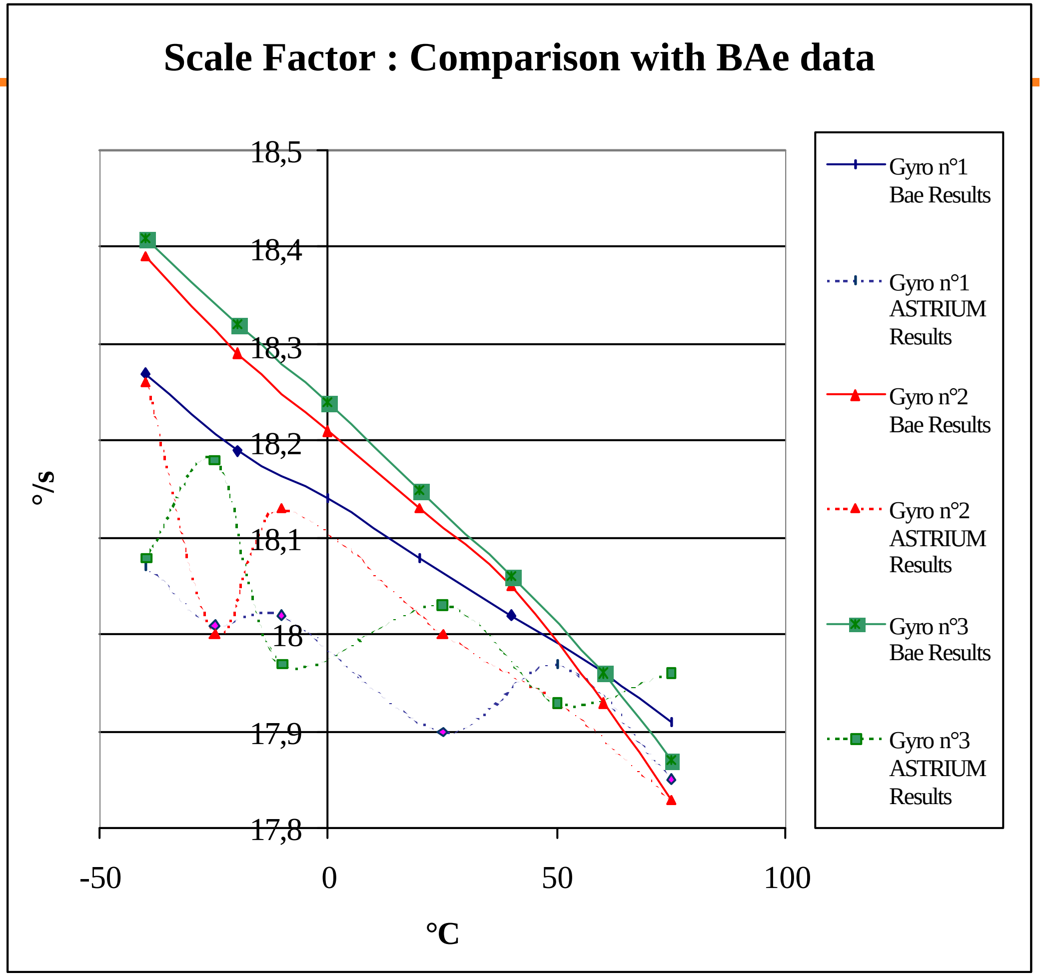
Bias repeatability **0.1°/s**

Gyro set ON and OFF : measurement of bias stability.

Gyro mounted on a fixed support. While keeping the gyro fixed, the measurements are acquired during 5 successive periods of 10 min. The gyro is set ON and OFF between each period.

Functional testing: Astrium measurements





- Gyros show a rather stable behaviour over temperature
- Higher value of ARW (0.7°/Öhr instead of 0.2°/Öhr)

Approach for investigation of potential failure mechanisms

- MEMS process combines ***micro-machined technologies*** for the ***mechanical part*** and traditional ***integrated circuit technologies*** for the ***electronics part***.

- Reliability of MEMS devices depends on the reliability of the traditional integrated electrical circuitry, the reliability of the ***miniature mechanical structure*** and the ***interactions between both systems.***

SiRRS01 GYRO:

List of materials used: Si / Glass / PolySi / Al / Fe

List of MEMS elements: Vibrating structure / Springs

Destructive Physical Analysis (DPA) to understand the structure and links between elements and sometimes evidence weakness points: Humidity / Spokes to watch up (holes cut in the spokes)

Potential failure mechanisms on SiRRS01 gyro

Focus made on the sensor head : {silicon ring / metallic resonator / glass bonded}

Sensor head

Fatigue

Not expected in glass and Si: brittle materials

Yes in coatings and polySi

Fracture

Single-crystalline Si (anisotropic material)

Stiction / Wear

No surfaces in contact

Delamination

At interfaces such as Can base/ support glass

Dampening effects

Not operating at resonant frequency and hermetically sealed

Radiation

Expected to be sensitive

Particulates

Dust particles from iron can

Temperature changes

Mechanical properties affected ?

Tests versus failure mechanisms

➢ SiRRS01 silicon rate sensor more sensitive to fracture and delamination.

➢ **Thermo-mechanical** tests and even life-test may evidence these failure mechanisms.

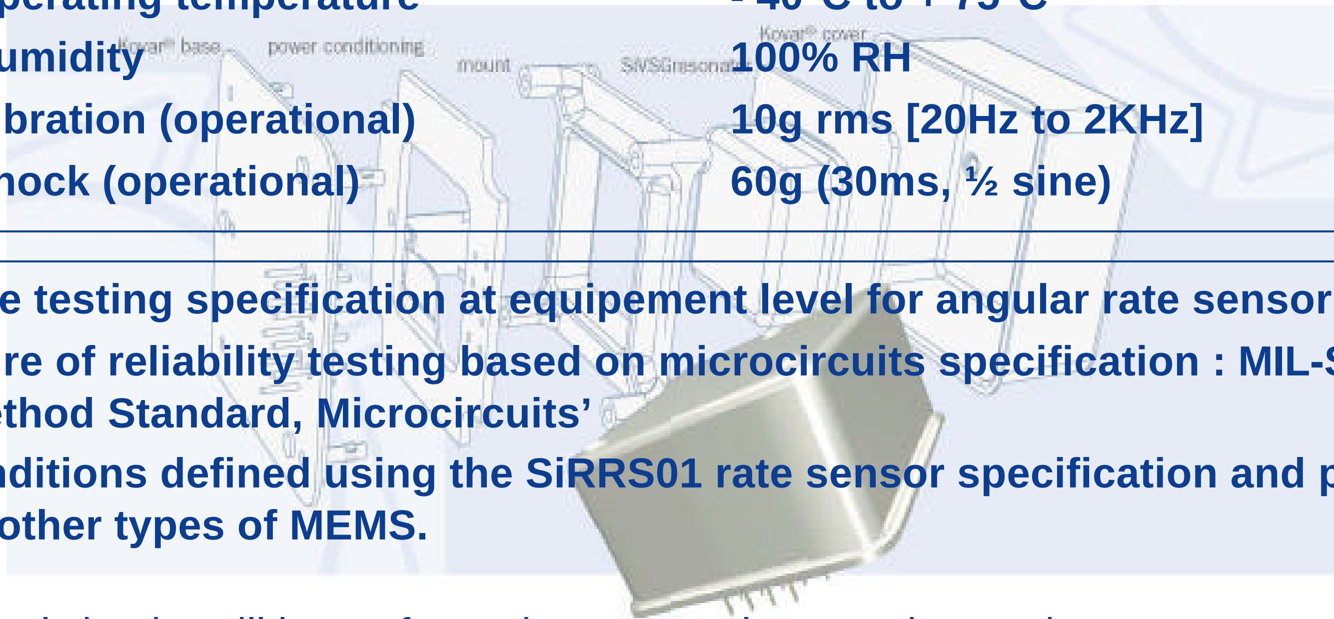
- Shocks and temperature testing may induce fracture and delamination
- Shocks could lead to early end of life of the structure, and vibrations too
- Symmetry of the ring design offer excellent rejection of linear vibration.

➢ Electronics in a closed loop around the sensing part may prevent the system from reaching its functional limits even under harsh conditions.

- The possibility to perform radiation testing on isolated sensor head is under investigation

Performance and reliability testing

Operating temperature	**- 40°C to + 75°C**
Humidity	**100% RH**
Vibration (operational)	**10g rms [20Hz to 2KHz]**
Shock (operational)	**60g (30ms, ½ sine)**

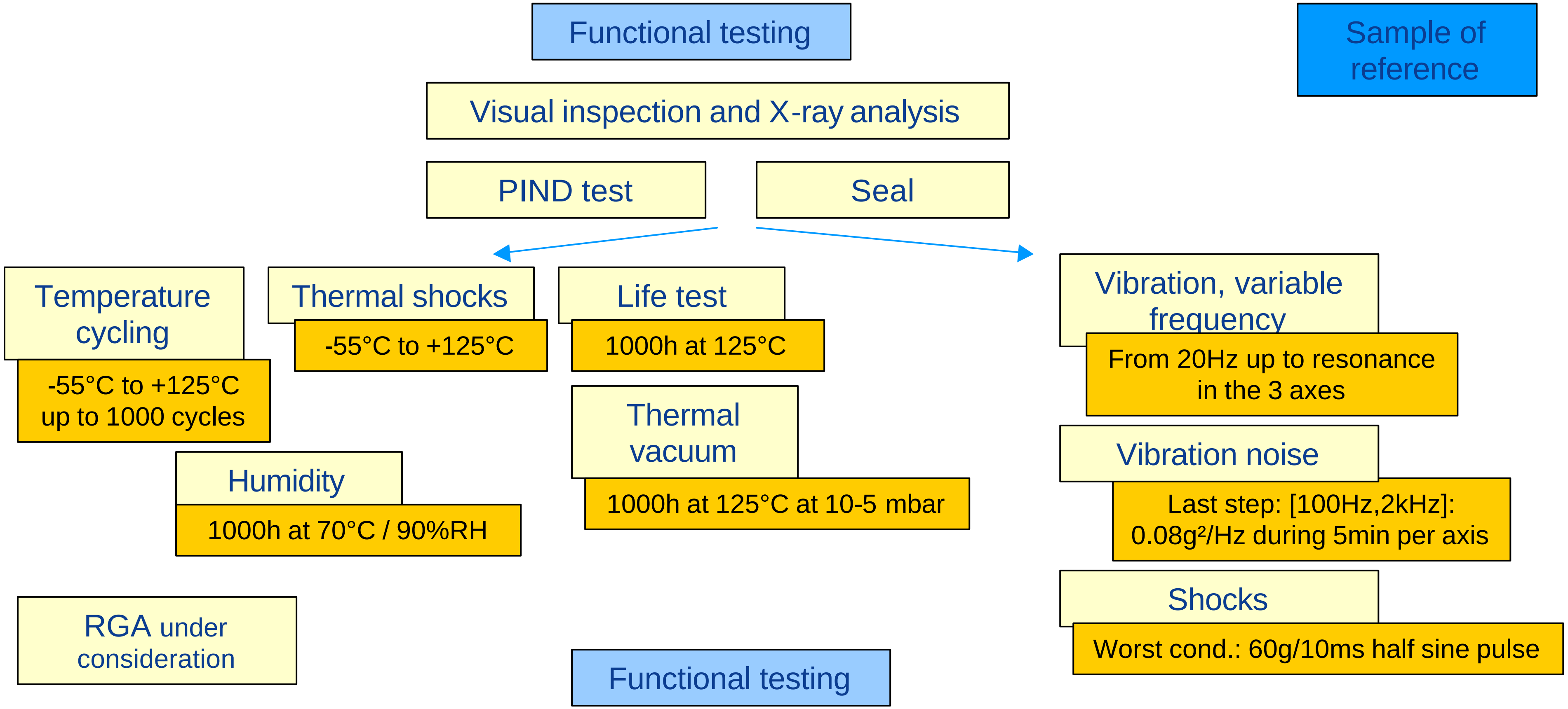


- **No space testing specification at equipement level for angular rate sensors.**
- **Procedure of reliability testing based on microcircuits specification : MIL-STD-883E ‘Test Method Standard, Microcircuits’**
- **Test conditions defined using the SiRRS01 rate sensor specification and published data on other types of MEMS.**

- Mechanical shocks will be performed on a sample up to destruction.
- Failure Analysis will be performed when encountering anomalous parameter measurements or destructive events.

- Limited number (7) of gyros including a reference sample to perform reliability testing.
- Sensor and electronics kept together in the same package during tests.

Test plan



- **Basic performances (Bias / Bias repeatability / Noise) to be performed between each tests.**
- **3 gyros will undergo temperature testing and 3 others mechanical testing.**

Conclusion

- SiRRS01 Angular Rate Sensor from BASE = vibrating gyro based on Coriolis effect.
- Functional testing (Bias / Bias repeatability / Scale factor / Noise / ARW) performed by Astrium. Higher value of Angular Random Walk found. Additional discussion with manufacturer required for better understanding.
- Thermo - mechanical tests expected to evidence fracture and delamination which are considered to be the most likely failure mechanisms for the sensor structure.
- Reliability testing on-going at CNES. Radiation test planned at ESA.
- Results expected to help in the definition of draft guidelines for the evaluation of MEMS.