7th ESA Round Table on MNT for Space Applications

The Qualification and Market Entry of the SiREUS MEMS Coarse Rate Sensor for Space Mission Applications

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Content

- **The background route to SiREUS**
  - Teaming and UK capabilities
  - Principles of operation
  - Programme plan
  - SiREUS configuration
- **Challenges overcome during development**
  - Non - MEMS, qualification and manufacturing
  - Characteristics of MEMS sensors
  - Pre-calibration of the detector
  - Product assurance of MEMS
- **Results**
  - In orbit performance on Cryosat-2
  - EQM testing
  - SiREUS performance achievements
- **Summary**
- **Next steps**

The background route to SiREUS

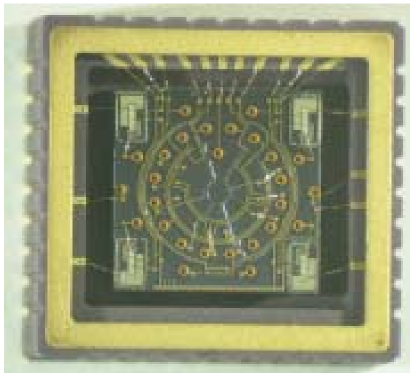
- **Presentation take to story forward from previous presentations**
  - 4^{th} MNT (2003) – Overview of basic technology
  - 6^{th} MNT (2007) – Status of development and Cryosat-2 FExp
  - 7^{th} MNT (2010) – Update of product development with results

- **Development of gyro technologies by the ESA harmonisation roadmap**
  - to supply reliable, low cost, coarse sensors that enable robust, simple building blocks in AOCS systems

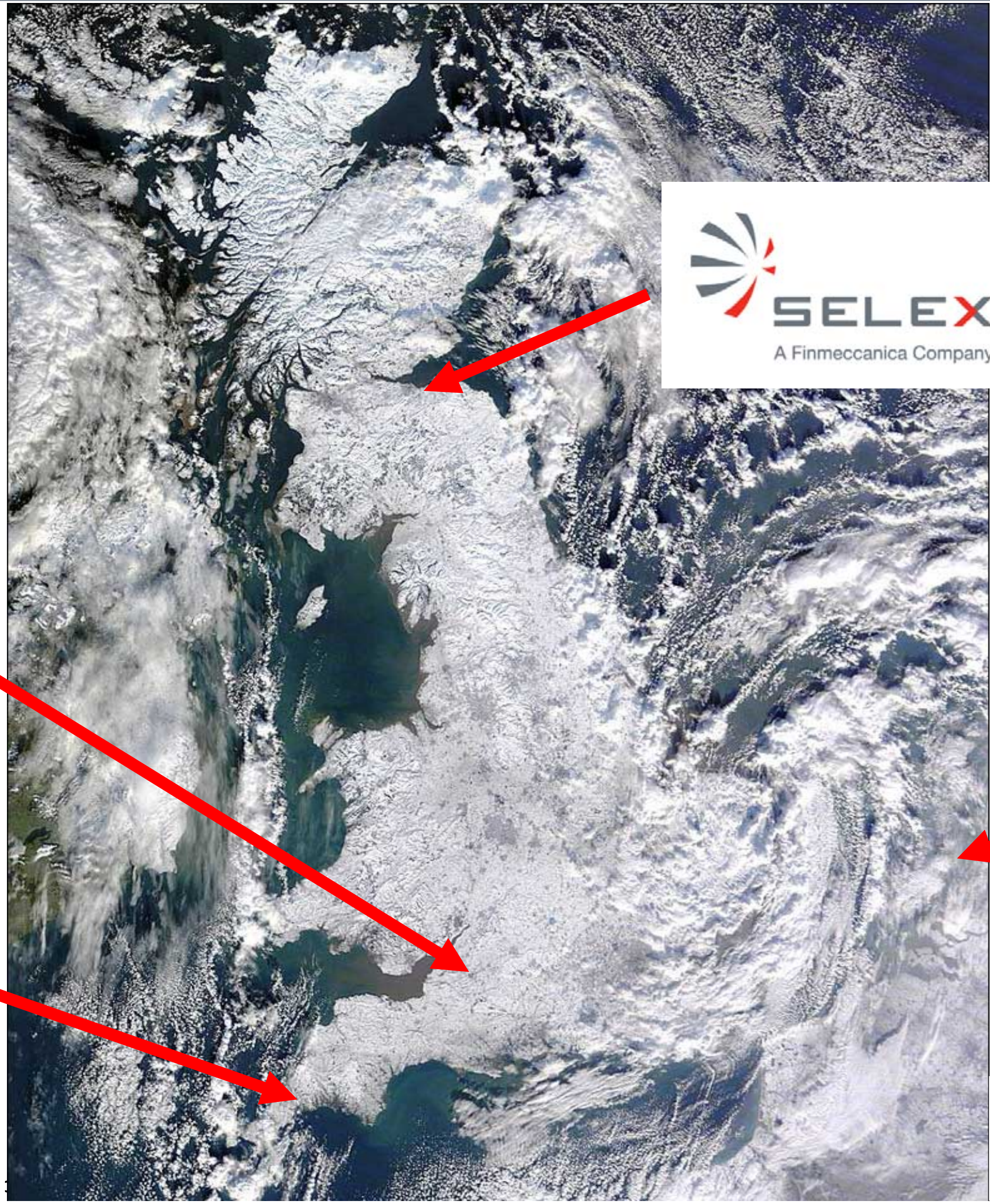
- **Evolution of MEMS Coriolis gyro technology in the UK showed potential for spin-in to the Space sector**

- **Definition of market requirements for a Coarse Rate Sensor led to a viable investment case**

- **Competitive procurement won by a UK consortium of three companies.**
  - MEMS Rate Sensor (MRS) development programme leads to SiREUS (**EU**ropean **Si**licon **R**ate **S**ensor)



The development team



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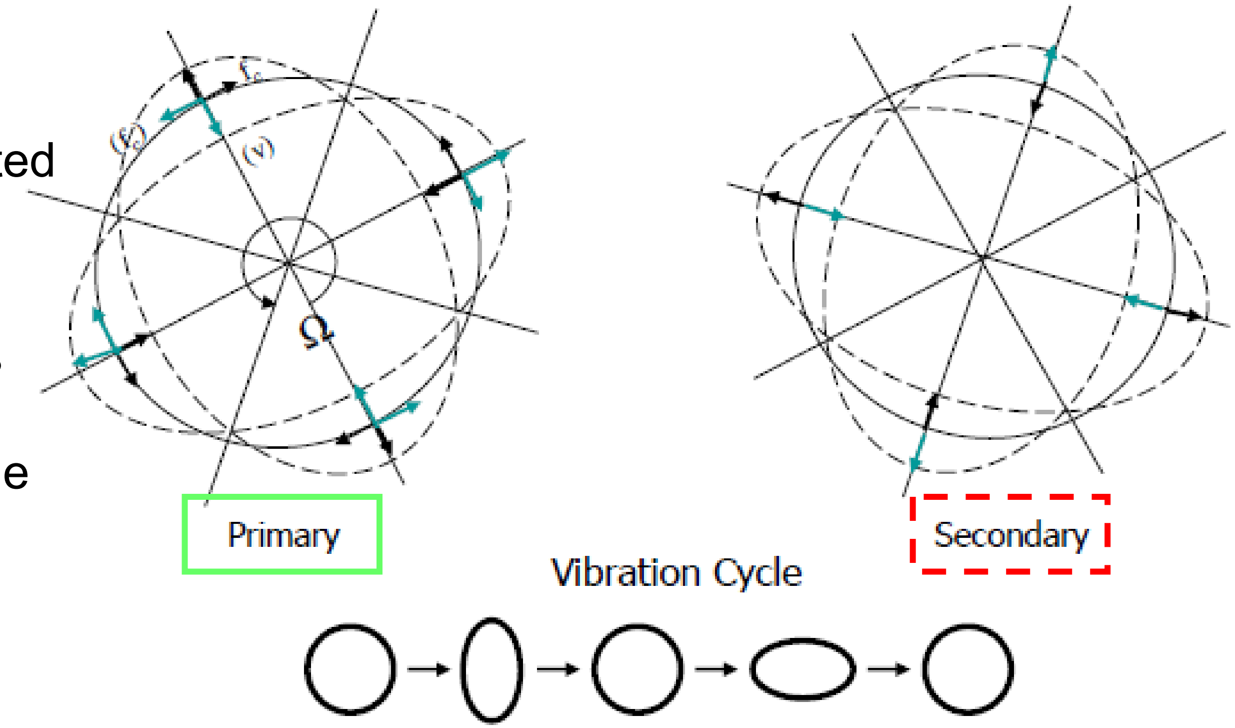
Teaming and UK Capabilities

- **A planar ring structure, etched from silicon, held in a resonating state by a primary drive current.**

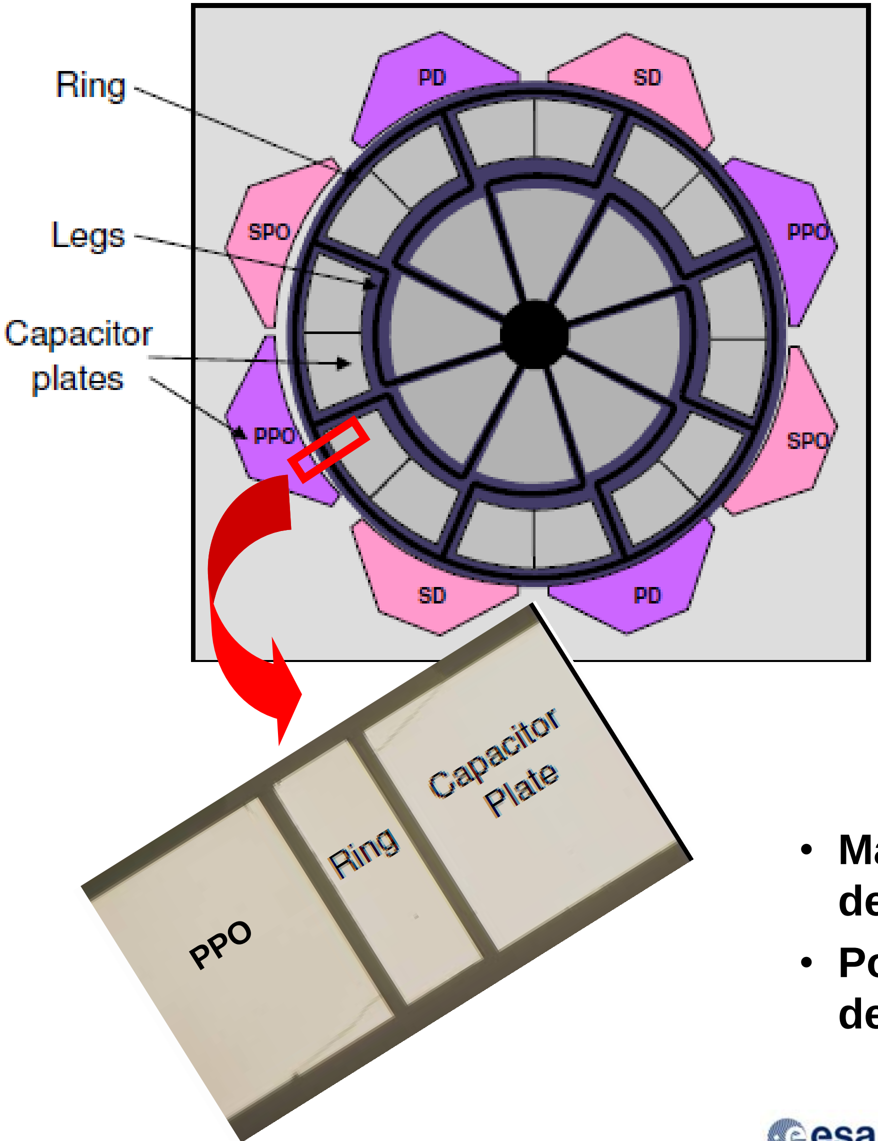
- Primary mode is excited at constant amplitude

- Rotation around z-axis couples energy to **Secondary mode** – the Coriolis acceleration

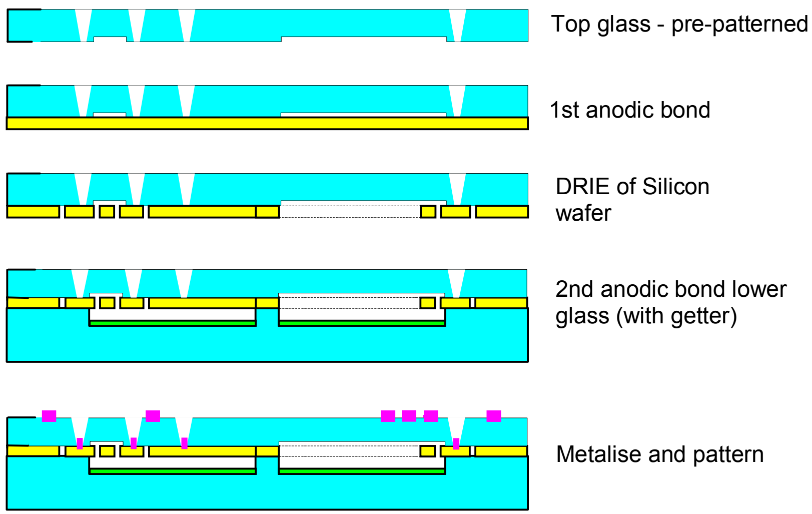


- **Angular rate is determined from the shift in the secondary current required to null the Coriolis effect.**

Application of MEMS gyros



- **Planar ring with 8 support legs in a vacuum cavity**
- **Discrete capacitor plates positioned around the ring**



- **Mass, stiffness, geometry and characterisation determined during precision manufacture**
- **Power, balancing forces and control feedback determined by electronic design**

Programme Plan

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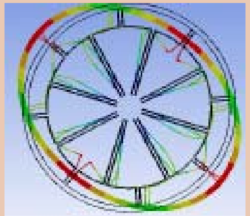
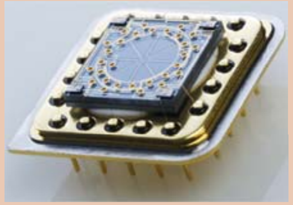
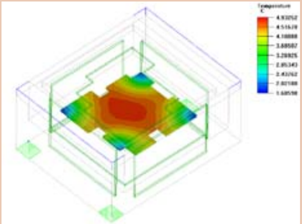
Phase 1

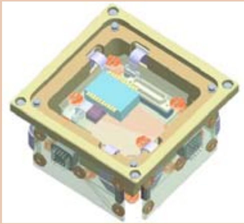
Detector prototype development



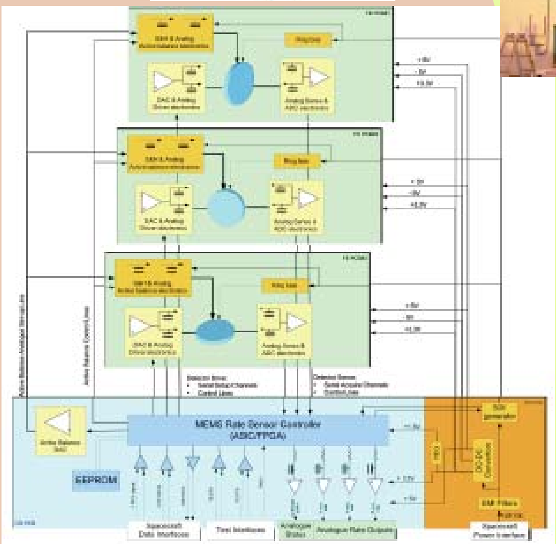


Preliminary Mechanical, Thermal Design





Electronic design
Bread boarding
Characterisation and test



Phase 2

Detailed design

Detector performance Improvement

Algorithm development

Cryosat-2 FExp

Electronic integration

Testing

Qualification

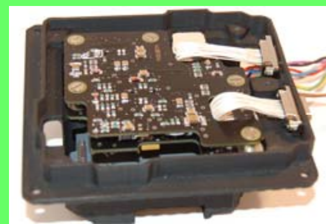
Phase 3

Detector and Unit Productionisation

Detector evaluation programme

Europeanisation

- (ITAR Free) Power Supply



Europeanisation

- (ITAR Free) ASIC

Δ Qual activities

Further

SiREUS – Configuration

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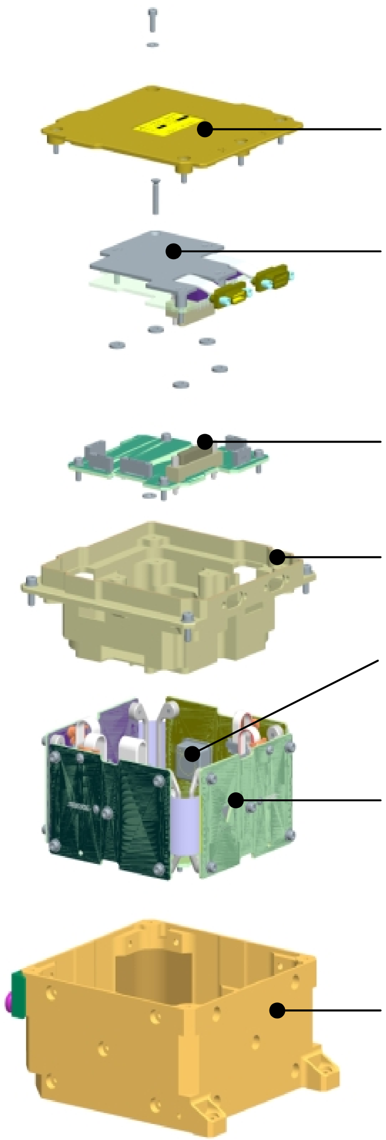
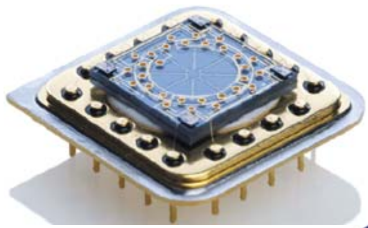




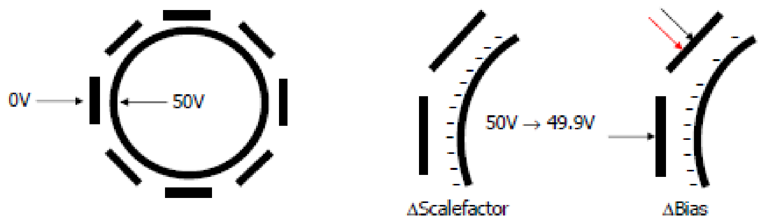
Sensor Type **Mass** **Power**	3 axis rate sensor < 0.8kg 5.1W
Bandwidth	10 Hz (max)
Measurement Output Rate	2 - 20 Hz (settable), 0 Hz = no output
Switch-on to Switch-on Change	< 10 deg/hr (with off time constraints)
Angular Rate Bias	10 - 20 deg/hr
Rate Bias Drift	5 - 10 deg/hr over 24 hours with ±10°C
Scale Factor Linearity	< 2000 ppm over input range
Angular Random Walk	0.1 - 0.2 deg/√hr
Noise Equiv't Rate	< 1 deg/hr (defined as flicker rate)
Interface **Rad Tolerance**	Analogue, RS422 100krads, 18 yr GEO

Several challenges overcome during the development and qualification

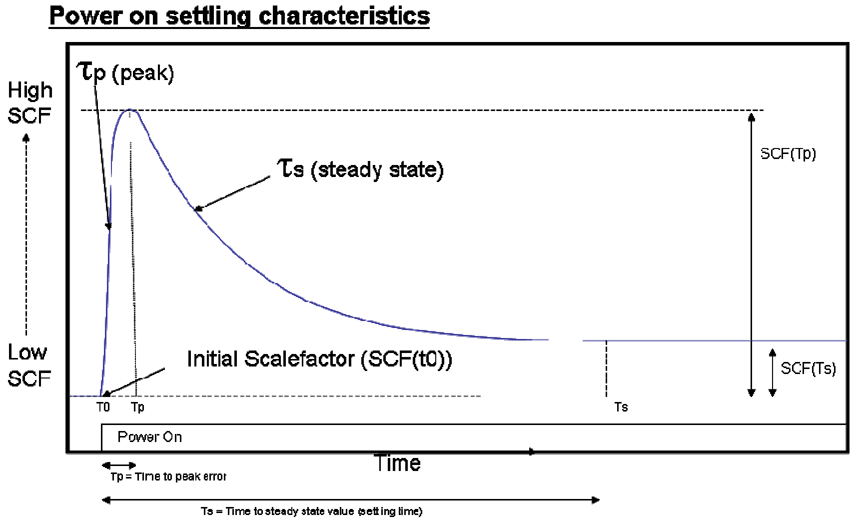
- **Non – MEMS issues**
  - Power supply start-up and temperature dependency
  - Parts supply and component obsolescence
- **Rapid supply to mission**
  - Lessons-learnt feedback into design from Cryosat-2 FExp development
- **Environmental qualification**
  - Initial thermal restriction on baseline PSU limits upper performance temperature
  - FPGA mounting at high g levels. Solved by Structural Model tests, and specification agreed with ESA
- **Manufacturing of MEMS for Space**
  - Commercial performance is a long way from Space requirements
  - High volume reliability and repeatability with low volume batches
  - Trade-offs and design tolerances
  - Design right, processes right, electronic integration right
- **Cost containment**
  - High reliability and ITAR free……

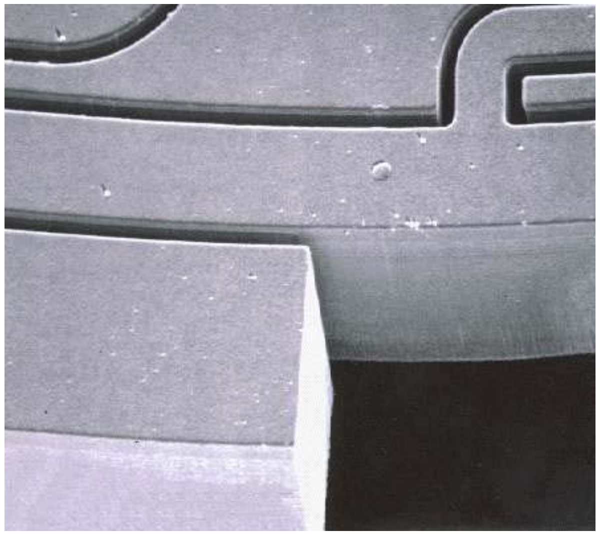
Characteristics of capacitive MEMS-based sensors

- **Move to volume production line**
  - Change in performance stabilisation
- **Cause / affect**
  - Migration of charged species to capacitor plate surfaces



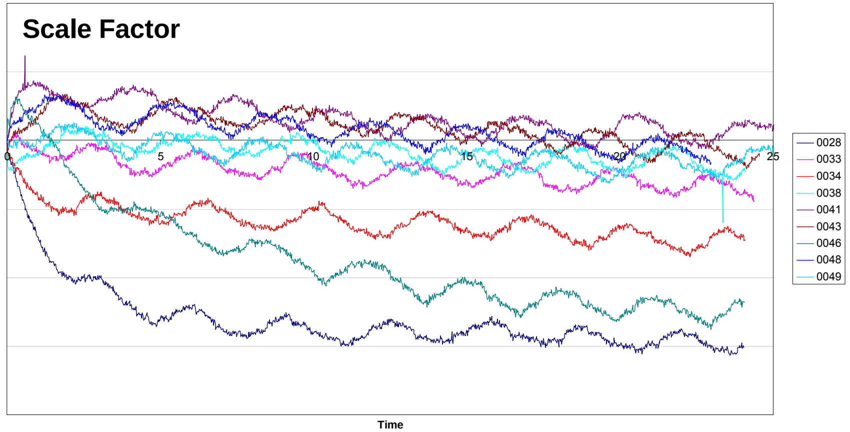
  - Initial drift in scale factor and bias on start
- **Solution**
  - Review of detector design and iteration of manufacturing processes
  - Refined calibration and characterisation during system integration
  - Fundamental, device and unit level management of system

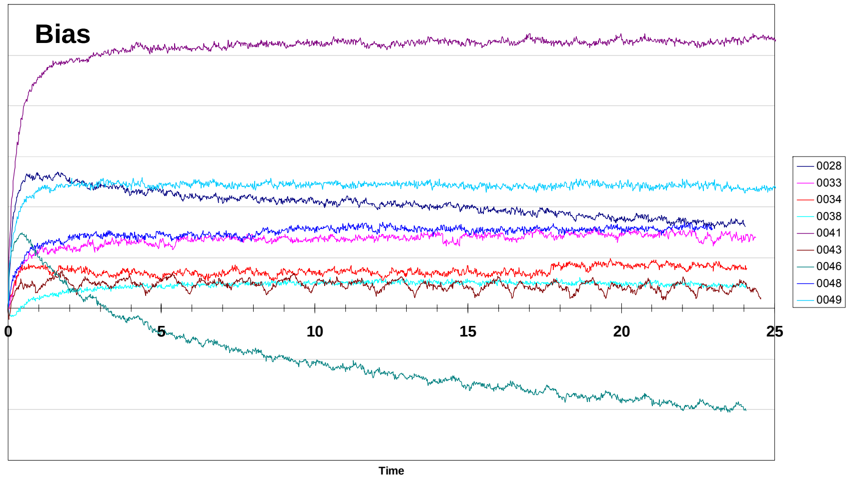




Pre-calibration of detector

- **Detectors are assessed for scale factor and bias stability prior to system-level calibration**
  - Uncalibrated detector performance specification agreed
- **Scale factor within specification of < 2000ppm**
- **Bias within specification of 10 - 20 deg / hr**
- **Close integration with electronics provides opportunities for better performance than seen pre-calibration**
- **Further activities identified to remove even this small residual error**





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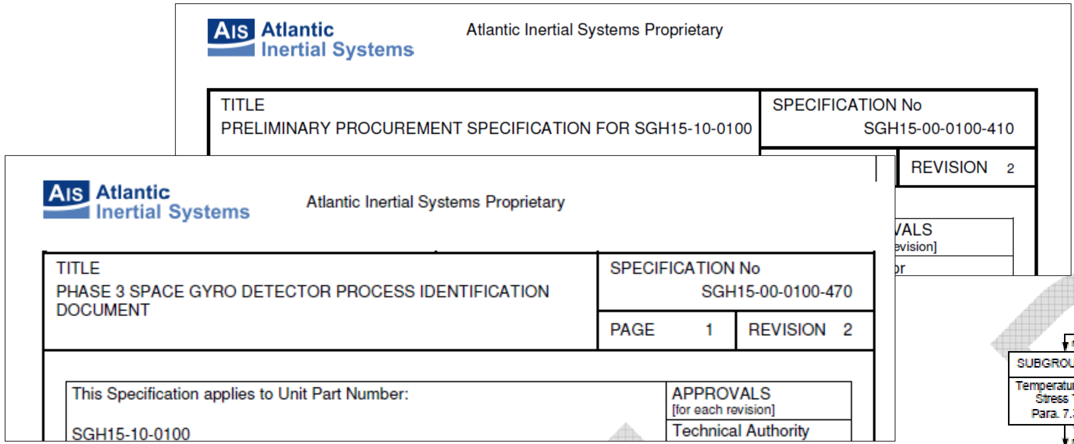
- **Agreed procurement specification**
- **MEMS Evaluation Flowchart adapted ESCC 2269000 and developed for Phase 3**
- **Development of PAD and PID for MEMS detector**


AIS Atlantic Inertial Systems — Atlantic Inertial Systems Proprietary

TITLE	SPECIFICATION No
PRELIMINARY PROCUREMENT SPECIFICATION FOR SGH15-10-0100	SGH15-00-0100-410
	REVISION 2

AIS Atlantic Inertial Systems — Atlantic Inertial Systems Proprietary

TITLE	SPECIFICATION No	
PHASE 3 SPACE GYRO DETECTOR PROCESS IDENTIFICATION DOCUMENT	SGH15-00-0100-470	
	PAGE 1	REVISION 2

This Specification applies to Unit Part Number:	APPROVALS [for each revision]
SGH15-10-0100	Technical Authority

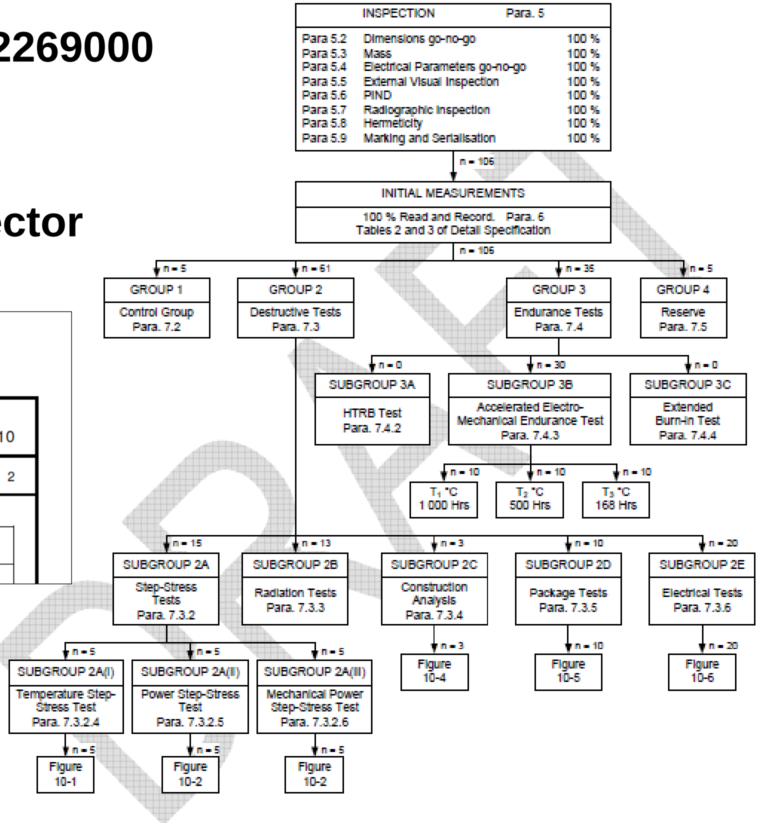
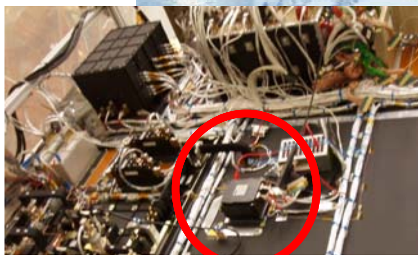
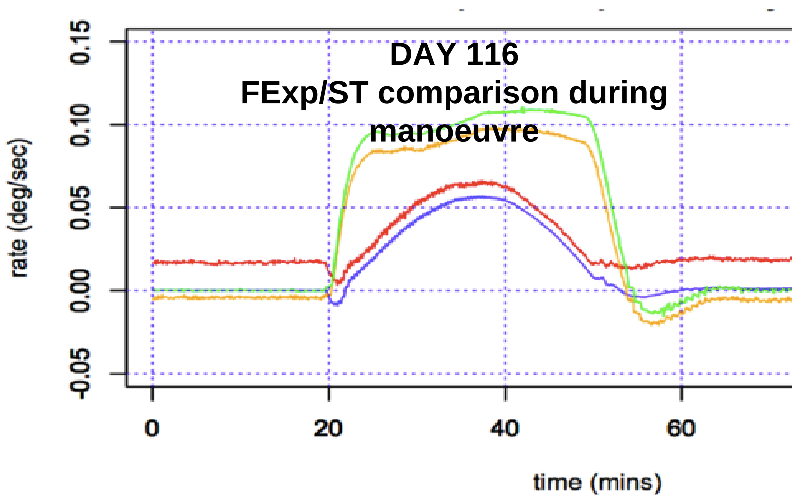


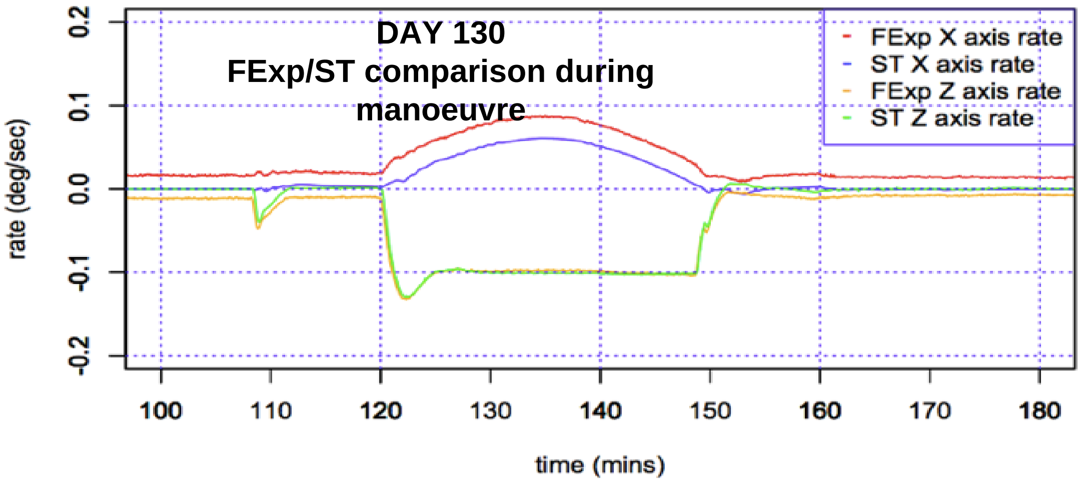
Figure 9-1 Evaluation Test Programme (Chart I)

In-orbit performance on Cryosat-2

- **Launched 8 April 2010**
- **Early-build detectors, and system configured for limited functionality**
  - Only X and Z axes operative
  - Known anomaly on Y axis before launch
- **FExp X and Z rates verified against Star Tracker inertial measurement**



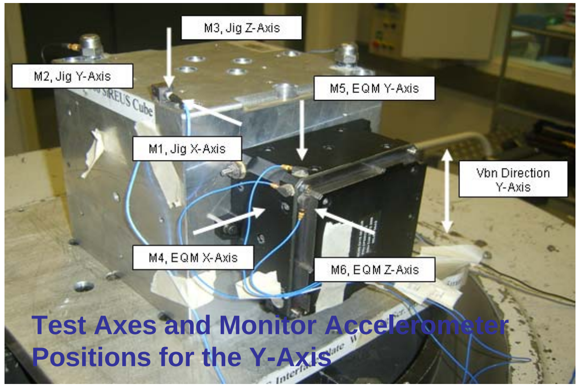




EQM testing

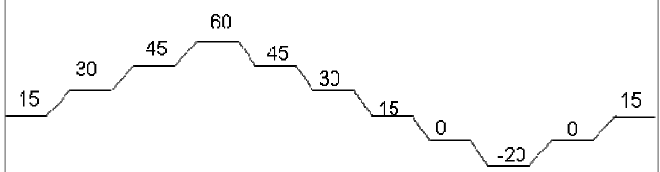
- **Physical Properties**
- **Functional Test**
- **Calibration and Check (Thermal) Tests**
- **Performance (Thermal and Rate) Tests**

- **Environmental**
  - Vibration Tests
  - Shock Tests
  - Thermal Vacuum Tests
  - EMC/ESD Tests



Test Axes and Monitor Accelerometer Positions for the Y-Axis

Calibration and Check (Thermal) Tests
Performance (Thermal and Rate) Tests



For setting detector compensation parameters

SINE VIBRATION to
5 to 14Hz @ 50mm pk-pk displacement
14 to 100 Hz @ 20g, At 3 octaves/minute

RANDOM VIBRATION

20-100Hz	+3dB/octave
100-300Hz	1.1g2/Hz
300-2KHz	-5dB/octave
Overall	25.1 grms

THERMAL VACUUM (Deg C)

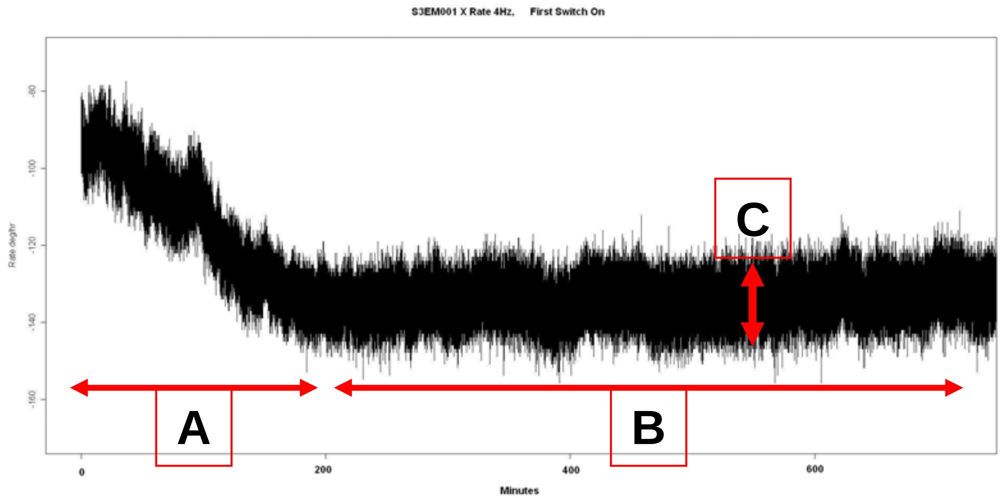
PSU	Phase 2	Phase 3
T min	-40	-40
T max	+60	+75

SHOCK

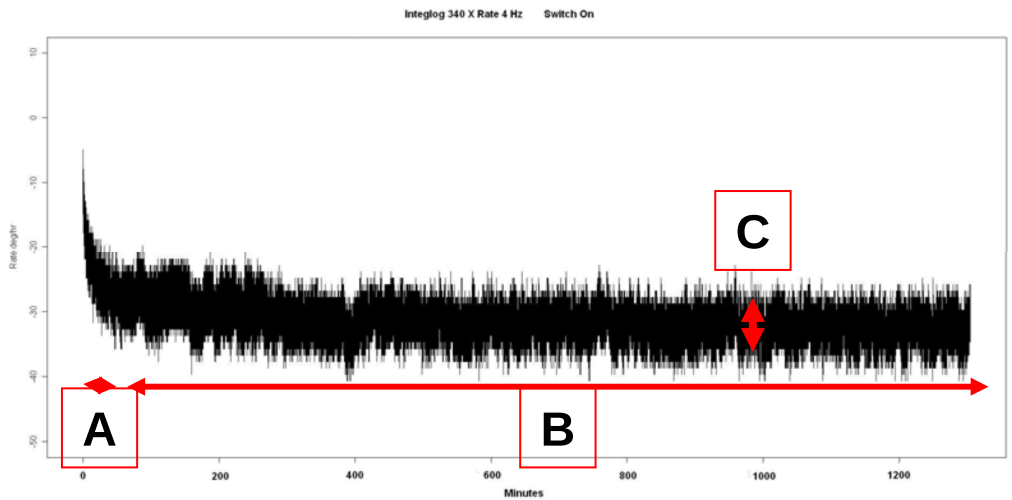
Each of the 3 axis	– 1000g
	-- 1500g

Lansmont Drop Test facility
-- = Delta qual level

SiREUS performance achievements



- **At initial unit switch-on with base parameters - UNCOMPENSATED**
  - A = Stabilisation time in 200 mins
  - B = Quite noisy rate, but the average is well behaved
  - C = Steady output at ~20 deg/ hr



- **CALIBRATED switch on post compensation**
  - A = Stabilisation time in 30 mins
  - B = Less noisy rate, but the average is well behaved
  - C = Steady output at ~10 deg/ hr

SiREUS performance achievements

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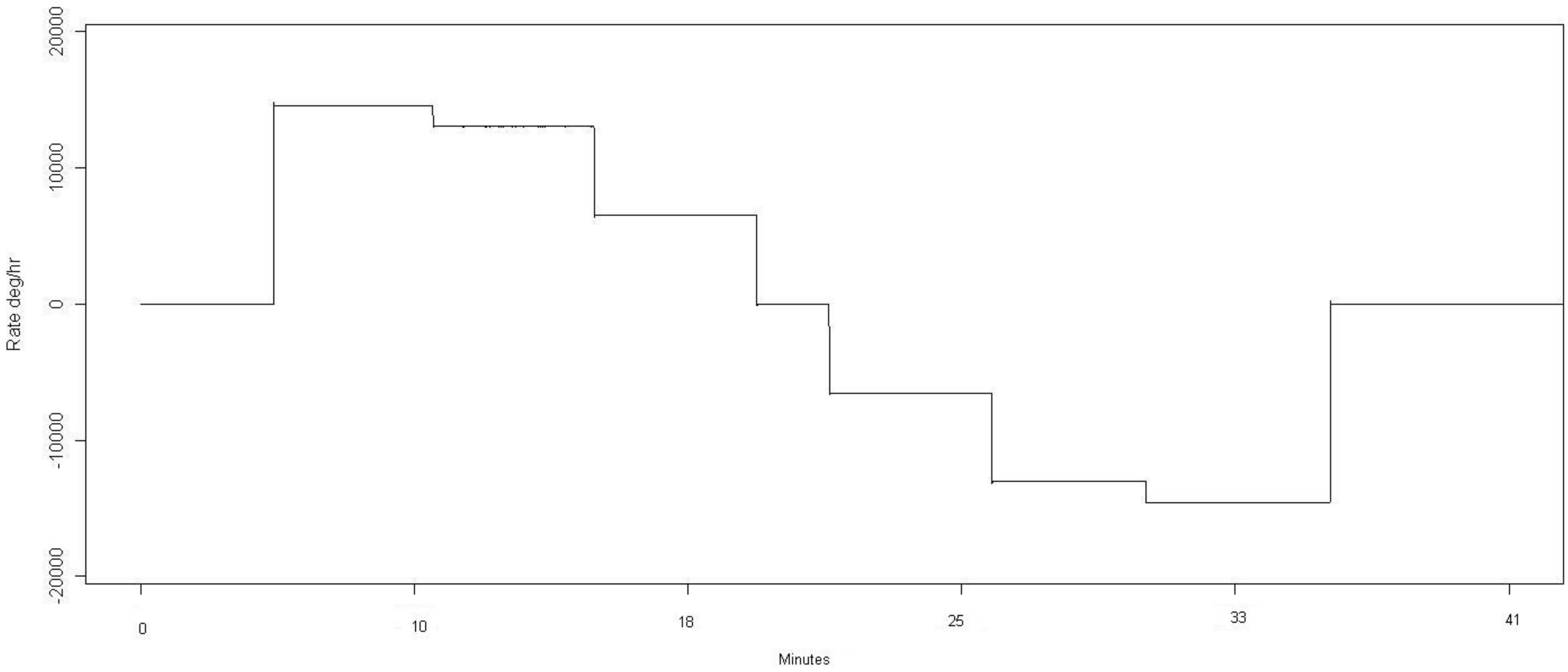
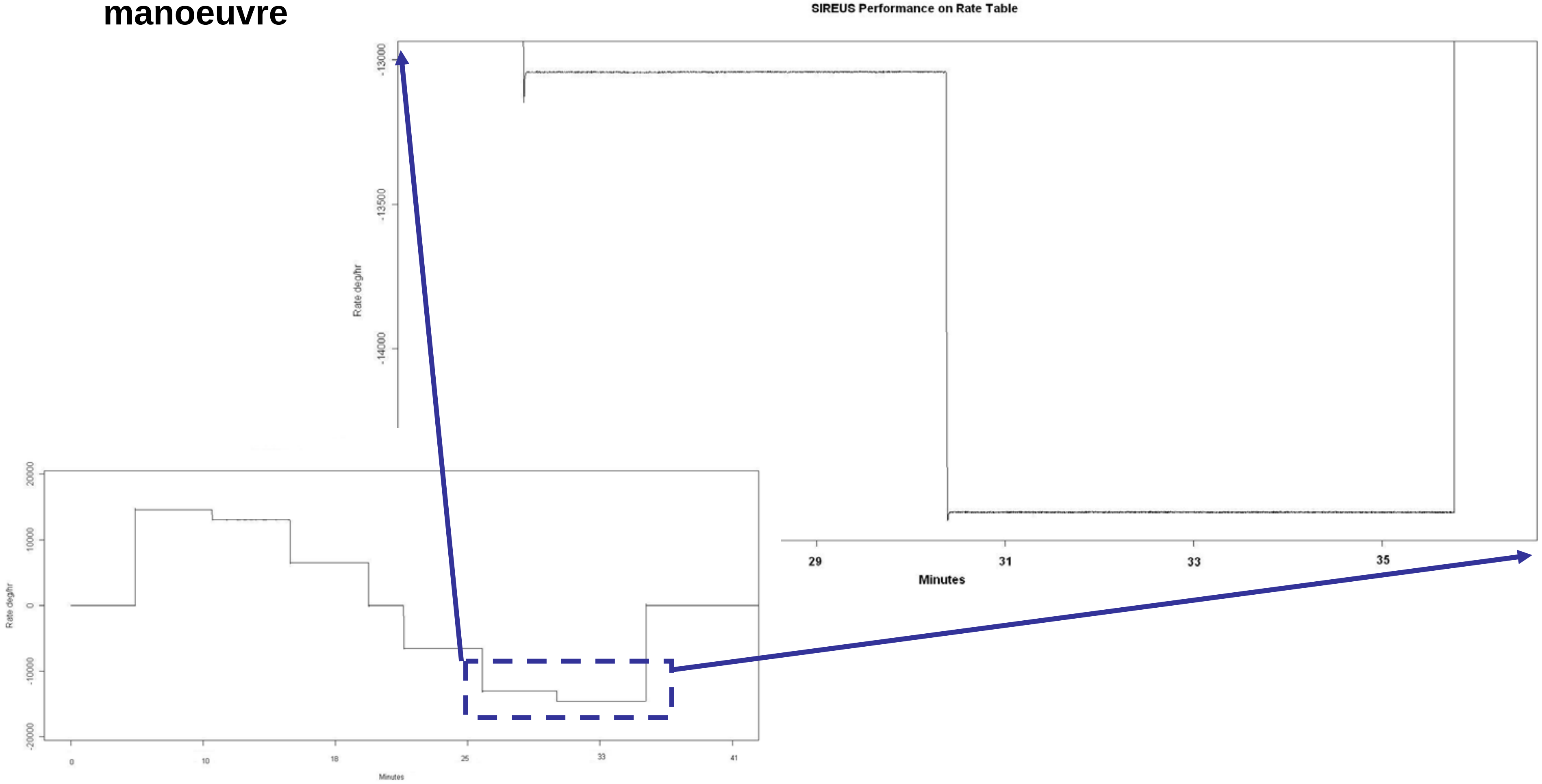
- **CALIBRATED unit undertaking slew manoeuvres while on rate table at 20C**



- **Closer inspection of performance during manoeuvre**



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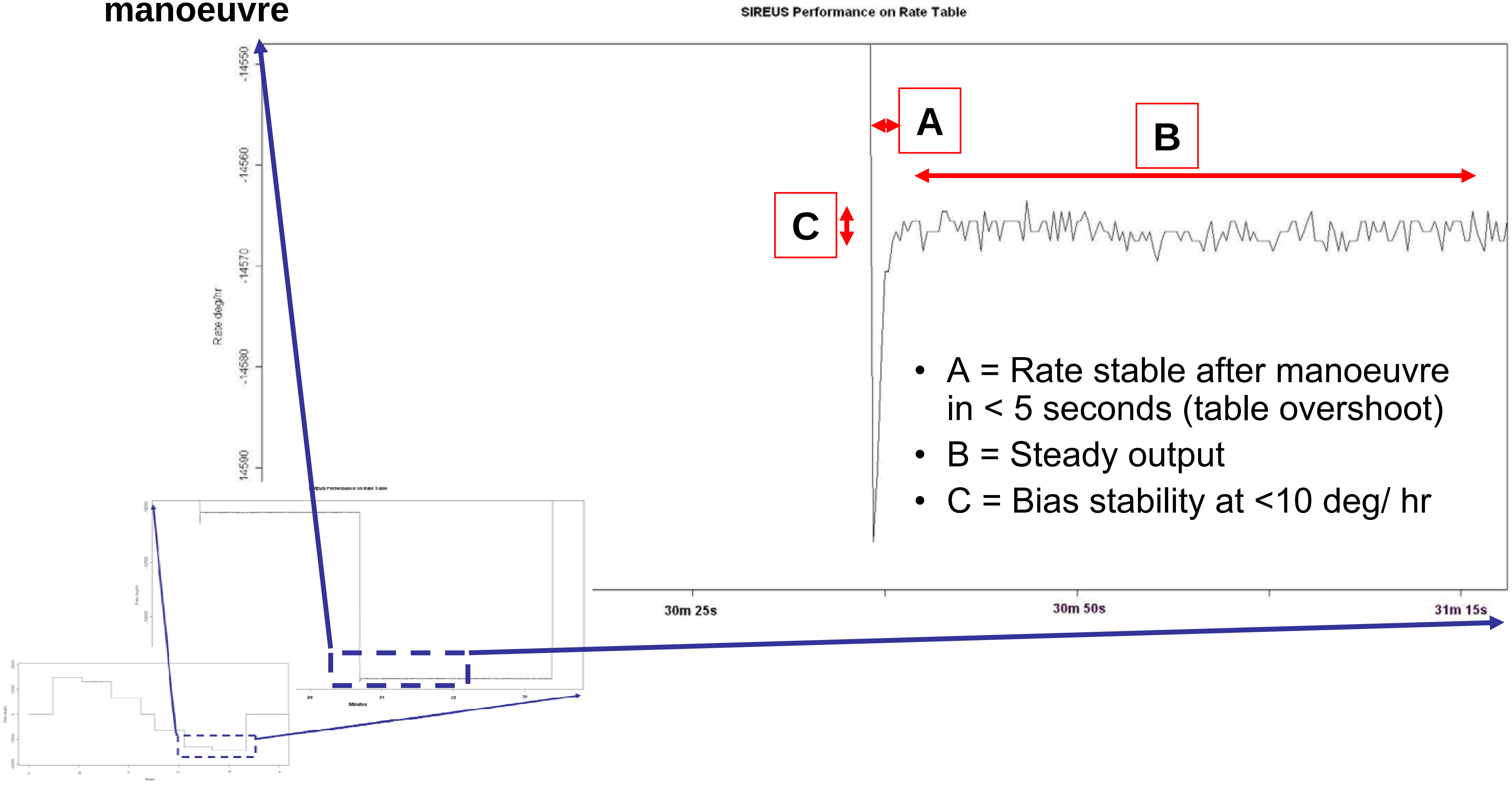


- A = Rate stable after manoeuvre in < 5 seconds (table overshoot)
- B = Steady output
- C = Bias stability at <10 deg/ hr

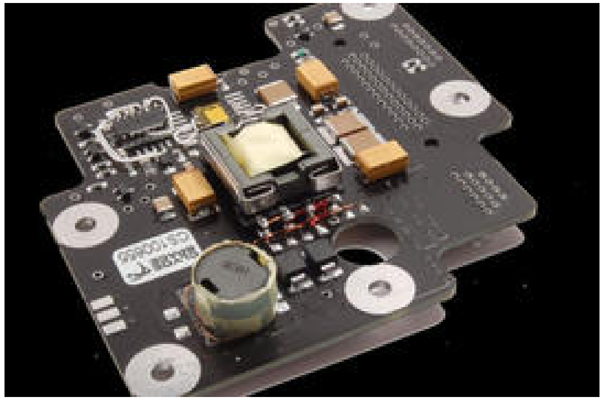
Summary

- **Assembly of UK team with ESA guidance and support**
  - careful consideration of internal capabilities and those of all suppliers helps to ensure that the process ‘challenges’ are shared around equitably.

- **Preparing MEMS for Space**
  - Adaptation of terrestrial MEMS technology and processes for space-grade instruments
  - Several new developments
    - Space-grade electronics to accompany the detector
    - refinement of compensation loops to obtain optimum detector performance
    - Compact housing with high environmental capability
  - Delivery of FExp to Cryosat-2 programme – now operational in-orbit
  - Detailed design, build and test of SiREUS MEMS Qualification Model

- **The MEMS detector is not standalone**
  - requires close integration
  - control electronics
  - test and calibration procedures
  - there are inevitably trade-offs to be made, for example, between the MEMS fabrication tolerances and the precision of the electronics

The next steps



- **Post qualification upgrades**
  1. **ITAR-free PSU**
     - Higher efficiency
     - Greater capability
     - Fits within existing housing

  Progress
  -Design Completed
  - EQM PSU in build

  2. **Replacement of FPGA by ITAR-free ASIC**
     - Multi-Project Wafer approach for European-sourced ASIC
     - Same package style as present FPGA
     - Functionality/capability improvements available

  Progress:
  - PDR held with ESA
  - Logic review with Atmel next

- **Further evaluation testing planned at ESA and at Astrium**

  Progress:
  - Pending

- **Further miniaturisation, performance improvement, integration for explorers & Smallsats…?**
- **SiREUS selected on Sentinel-3A/3B, Gokturk, Orbital Sciences and TechDemoSat**

SiREUS – Part of the Family

Contacts and acknowledgements

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Acknowledgements

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