High Performance Open Loop Accelerometer for Space Applications

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8th ESA Round Table on Micro and Nano Technologies for Space Applications

Topics

- Company Overviews
- Product Overview
- Requirements Specification
- Accelerometer Design, Prototyping and Test
- Accelerometer Performance
- Development Planning
- Conclusions and Future Work

High performance accelerometer for Space   Project Team

COLIBRYS

MEMS Detector design, development, prototyping and testing

sea

PCB design/prototyping/testing. IMU integration aspects.

Company - Colibrys (Switzerland) Ltd

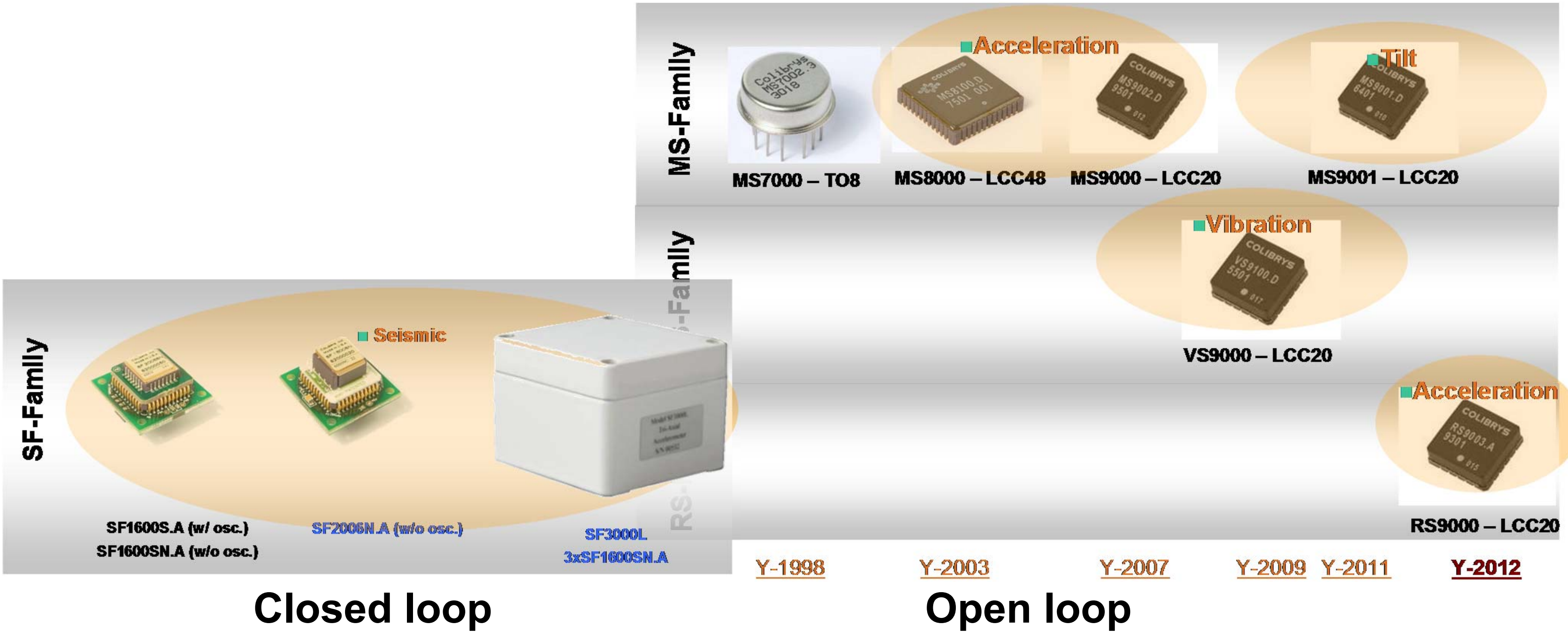
- **Colibrys created in 2001**
- **SME, 80 employees**
- **Development and manufacturing of MEMS based products**
- **Facilities in Neuchâtel Switzerland engineering and production**

Business sectors:

- **High performance accelerometers for Aerospace/ Defence, Industrial and Energy markets**
  - > 100’000 accelerometers manufactured /year
  - Harsh environment and safety critical applications
- **MEMS contract manufacturing**
  - Gaz sensors (automotive), optical telecoms components, pressure sensors, …

Company - Colibrys (Switzerland) Ltd

Accelerometer Products Families:



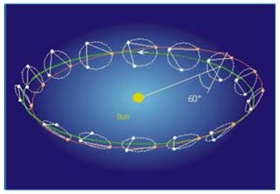
- Mature products, on the market since 14 years
- Open loop technology is basis for the space accelerometer

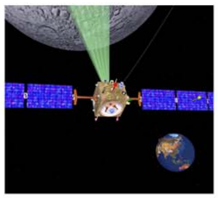
Company - Colibrys (Switzerland) Ltd

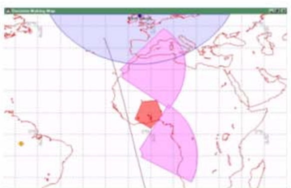
Applications

- **Inertial sensors**
  - High precision guidance or navigation over long time and/or distance independent of GPS
- **Tilt sensors**
  - High precision angle measurements with high resolution, low temperature sensitivity and long term stability
  - Platform stabilization, drilling
- **Vibration sensors**
  - Testing, monitoring and control of vibrations in structures for direct compensation, monitoring or preventive maintenance
- **Seismic sensors**
  - Earthquake detection systems, Structural health monitoring (buildings, bridges, dams), seismic imaging

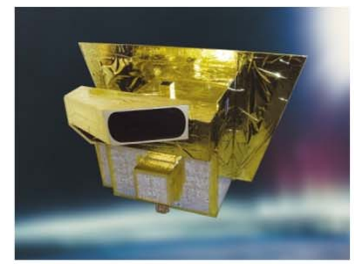
Company - SEA (Systems Engineering and Assessment Ltd)

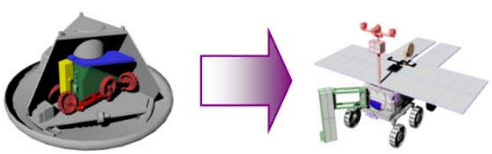


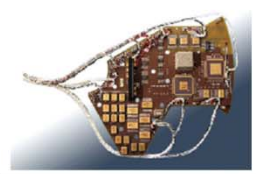




- SEA
  - Approx 250 employees; 80% professional engineers.
  - Offices in ***Bristol*** and Beckington, UK
- Space Systems
  - Instruments; sensors; electronics; (studies and flight units)
- Ground Systems
  - Radar transponders
- Non-space activities
  - Naval Systems
  - Airborne radars/equipment health monitoring
  - Traffic enforcement systems
  - Training systems for helicopters







Space IMU Requirements

- **MEMS Accelerometers in a European IMU Context**
  - A range of requirements have been identified for IMU capabilities for envisaged European space missions.
  - The number of IMUs required is currently quite small (<20 in 10 year period)
    - Althrough once a capability is available ways of using often follow.
  - There is not currently a consistent view on performance requirements for the driving planetary lander applications.
  - The highest variability is in the gyro requirements with competing IMU drivers across performance levels and power/mass/volume characteristics.

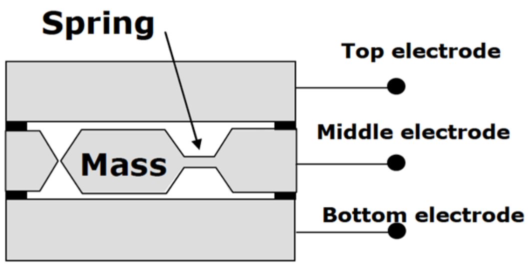
- **Implications for MEMS Accelerometer Development**
  - Component level capability targetted at:
    - Integration into stand-alone 3-axis accelerometer unit.
    - Integration with existing 3-axis space gyro (FOG to MEMS) to provide IMU unit.
    - Integration into existing spacecraft equipment (eg. OBC, RIU, etc) to provide and an efficient (reduced packaging, power conversion and data management) accelerometer function.
  - Testing at component and reference integrated (IMU) demonstration level.
  - Qualification at component level.

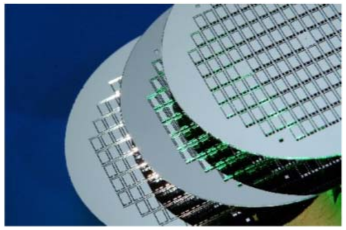
Towards MEMS accelerometer for Space

- **ESA ITT: Accelerometer for IMU feasibility demonstrator**
  - Requirements System Needs study
  - Development and characterisation of 1g and 20g sensors based on MEMS industrial accelerometer
  - Integration and characterisation in a space IMU
  - Project completed in 2012
  - Results:
    - demonstrated basic performance
    - Identified needed improvement: ASIC rad hardening, improvement on noise and nonlinearity
- **ESA ITT: Accelerometer to TRL5**
  - Project start September 2012 – project end July 2014
  - Design and manufacturing of a Radhard ASIC
  - Design, manufacturing and characterisation of a 1g & 20g Radhard accelerometer component
  - Goal: Component at TRL 5, with full specs for space (environment and performance)
- **Target applications:**
  - Aerobraking
  - Interplanetary burn control
  - Entry, Descent and Landing
  - Planetary Rovers Navigation

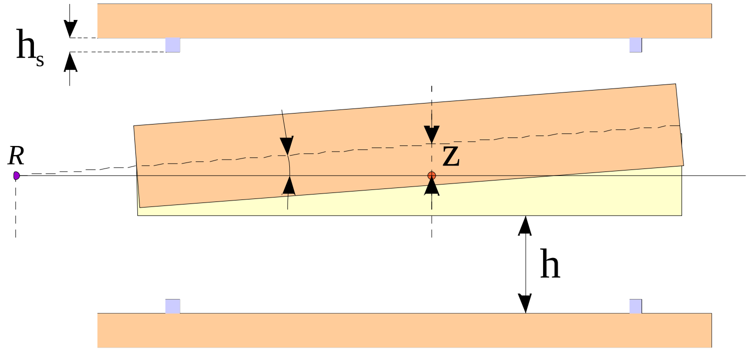
Capacitive MEMS accelerometer

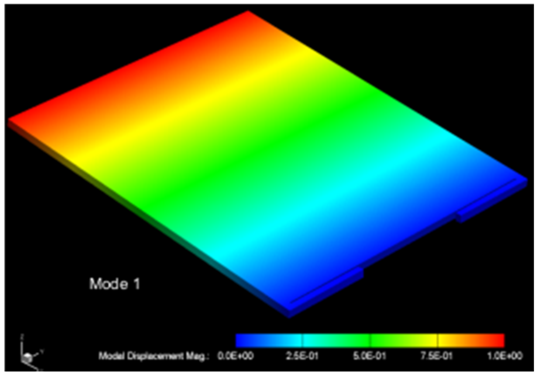
- MEMS capacitive accelerometer with suspended proof-mass configuration





- Analytical model → Transfer function and electro-mechanical model
- FEM model → resonance frequency and shock resistance

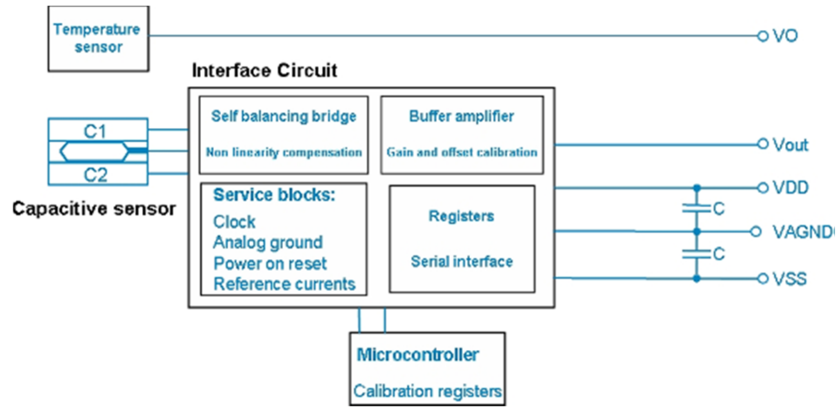


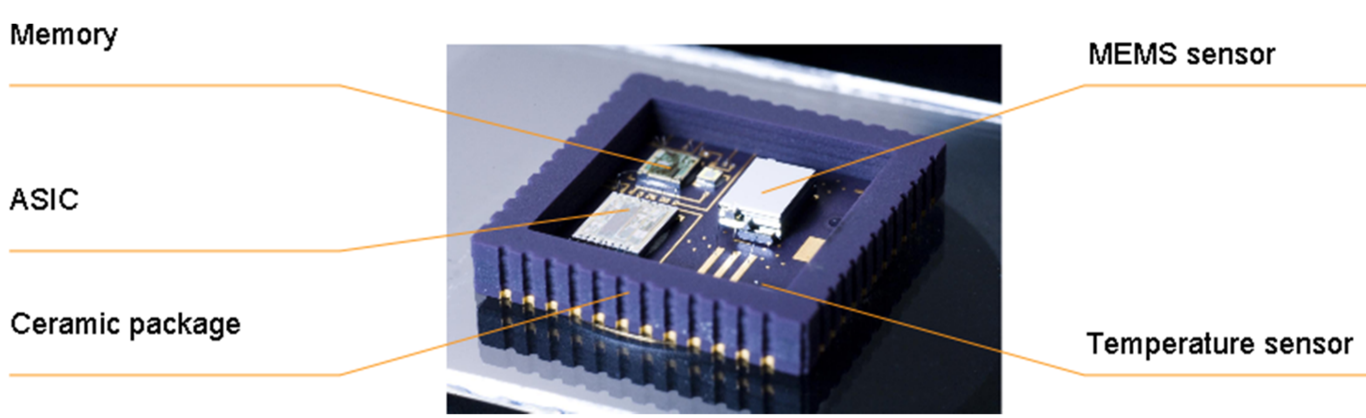


- Out of plane capacitive MEMS approach advantages vs SOI
  - Larger gain provided by a larger capacity change per mass displacement (large surface (< 3 mm^2) and small gap (2 µm)
  - Lower Brownian noise due to larger mass

Accelerometer Principles of Operation

- **Open loop ASIC & proximity electronic**
  - MEMS sensor: acceleration → capacitance change
  - Electronics:
    - C to V conversion (Self-balancing capacitor bridge)
    - Gain, scale factor (SF) and non linearity calibration
    - Calibration data stored in Memory
    - Temperature sensor



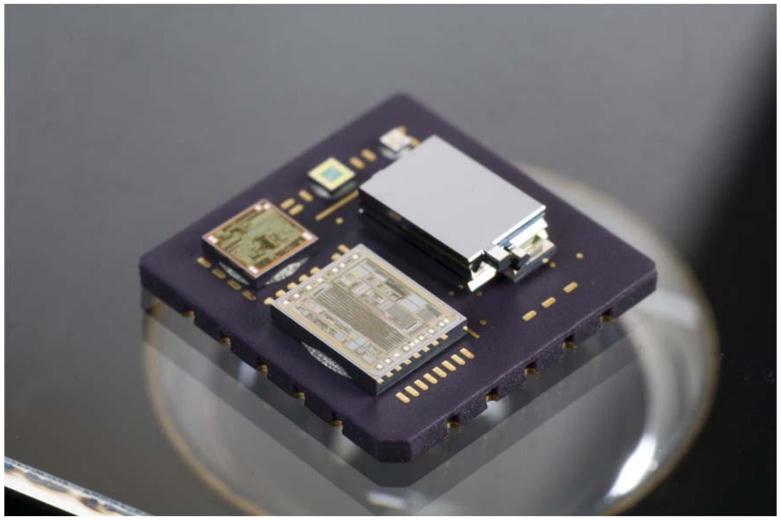


Trade off MEMS open loop vs. closed loop

- **System complexity / reliability**
  - Open loop: low complexity: MEMS +ASIC
  - Closed loop: high complexity: MEMS+ ASIC+ FPGA+ precision oscillator, Operates with high order sigma delta loop: powerful concept but complex
- **Maturity (for navigation and guidance application)**
  - Open loop: well established, proven in many products
  - Closed loop: under development for inertial applications
- **Power**
  - Open loop: single 3.3V, power < 10 mW
  - Closed loop, multiple supplies: 3.3V, 20V (for electrostatic motor), Power ~100 mW
- **Performance**
  - Open loop meets requirements for space applications
  - Closed loop has better performance for linearity and noise at the cost of higher complexity electronics
- **Driving factors for choice of open loop: Reliability, Complexity and Technology Maturity**

ESA Project Accelerometer for IMU feasibility demonstrator

- **Open loop accelerometer based on industrial ASIC**
- **Dedicated MEMS sensor**
  - 1g MEMS sensor
  - 20g MEMS sensor
- **Standard industrial package design for harsh environment**
- **Extended measurement and characterization with respect to Space specifications (no radiation)**



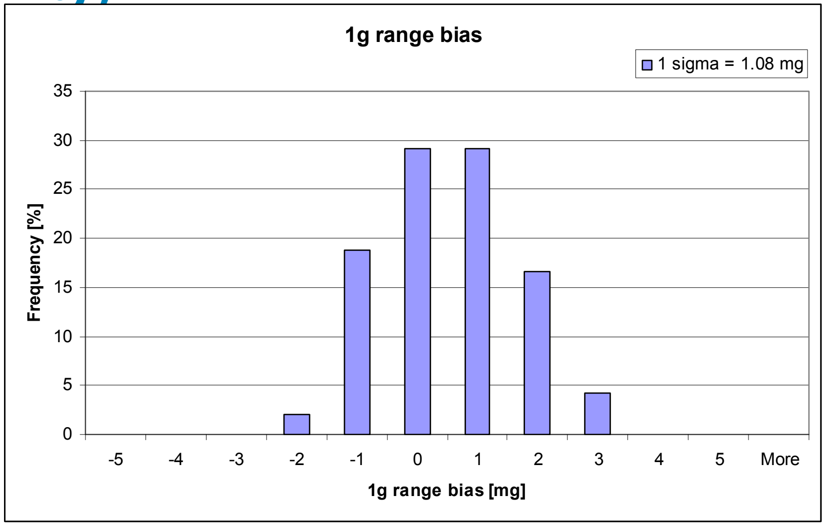
Accelerometer demonstrators– Obtain results

Test Description / parameter	Measured Results	
Measurement range	± 1g	±20g
Output	2V/g	0.1V/g
Output bandwidth	> 150Hz	> 427Hz
Latency	< 1.2ms @ 100Hz	< 0.5ms @ 100Hz
Resolution	< 0.5mm/s² @ 10Hz	< 14.3 mm/s² @ 10Hz
Axis misalignment		< 0.8° (1σ)
Absolute bias	< 1.1mg (1σ)	< 68mg (1σ)
Short term bias stability	< 12.5 µg (1σ)	< 0.16 mg (1σ)
Scale factor calibration tolerance	< ±1.5mV/g	< ±1mV/g
Scale factor stability	< 97.8 ppm (1σ)	
White noise	<14µg/√Hz @ 10Hz	<0.53mg/√Hz @ 10Hz
Flicker noise	< 7µg [100s]	
Nonlinearity		< 0.5%
Vibration rectification		83.6µg/g² rms
Mass	1.64g	
Dimensions	14.48 x 14.48 x 3.79 mm³	

Bias Performance (absolute and stability)

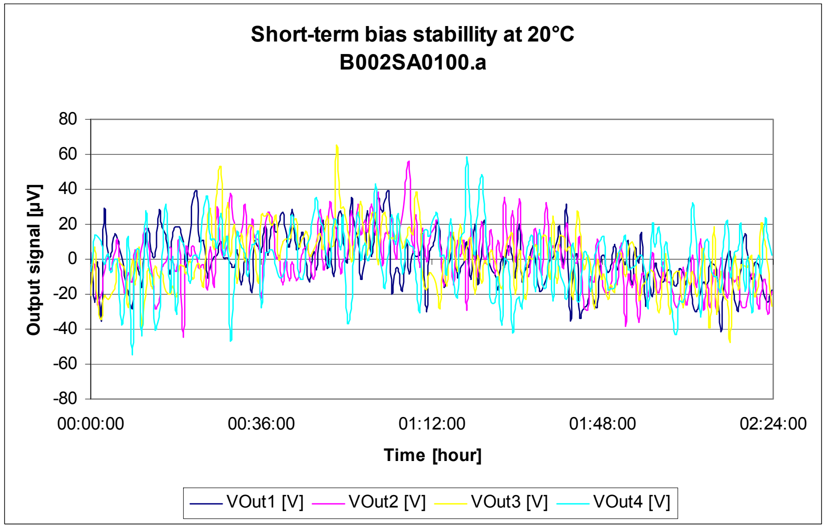
Absolute

- Calibration made on the ASIC PGA stage
- < 3mg on 1g sensor (< 80mg on 20g)



Stability

- Short-term (2h): < 12.5ug (1 sigma) from -35°C to 65°C
- 1 day: < 55ug (max)



Allan Variance Analysis 1g

Allan Variance measurements realised in different configuration

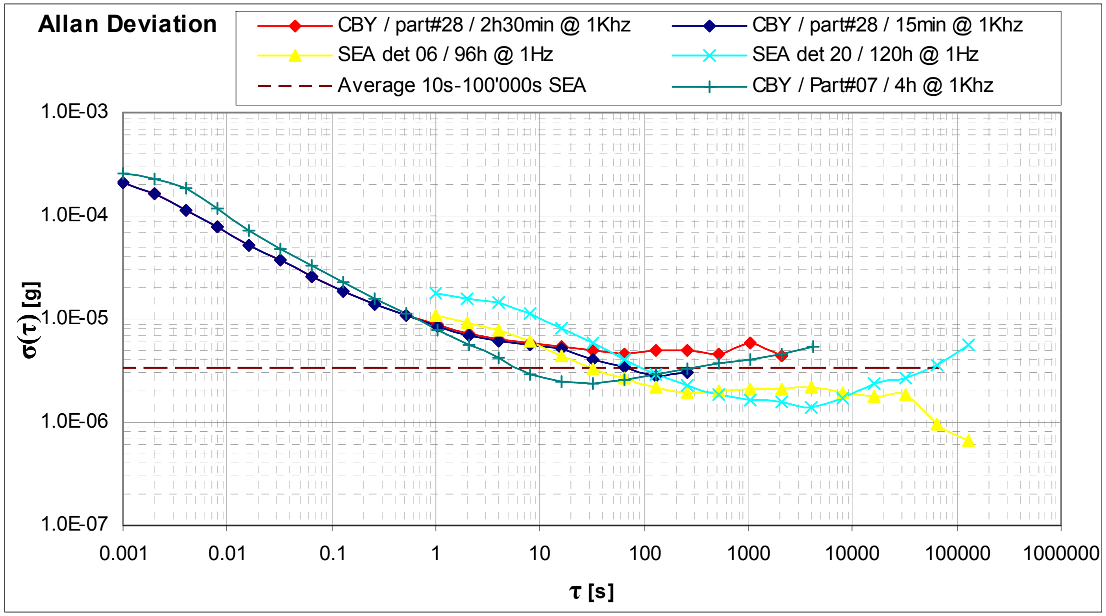
- **Detector level**
- **PCB level (include proximity electronic)**
- **high frequency (white noise)**
- **low frequency (long term stability)**

Bias instability (10-10’000s)

- **3.24µg**

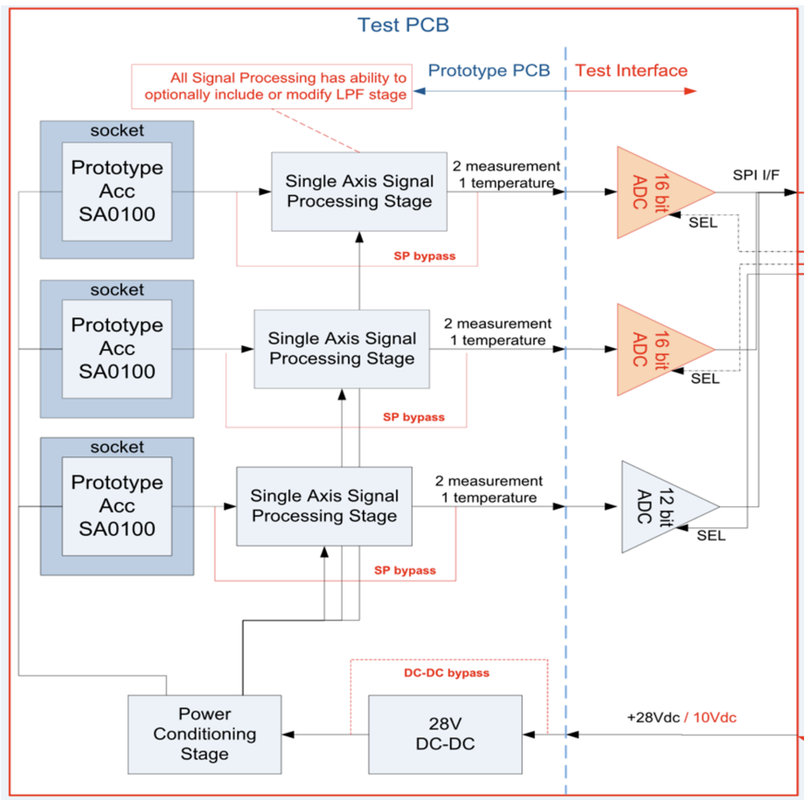
random walk @ T=1s

- **7.04µg**



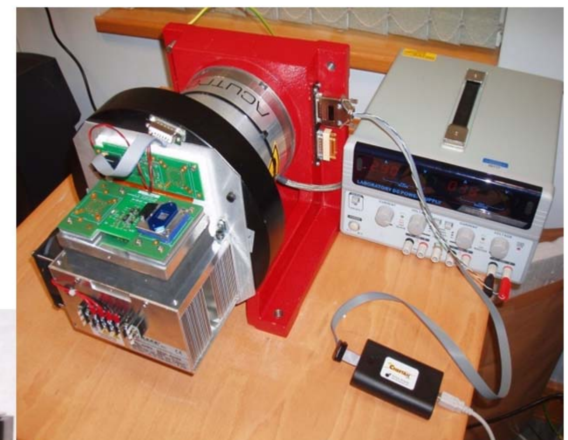
IMU demonstrators– Obtain results

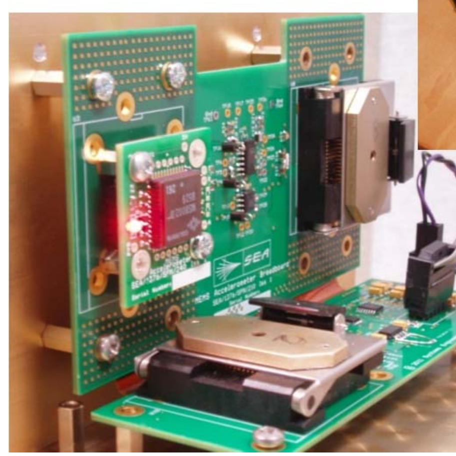
- **Prototype Detectors – Integrated testing at SEA and ESA**
  - Prototype detectors (1g and 20g) tested in a representative flight electronics.
  - Confirmation of key component level results
  - Guide for downstream IMU/component integration



Flight Representative

Front-End Electronics

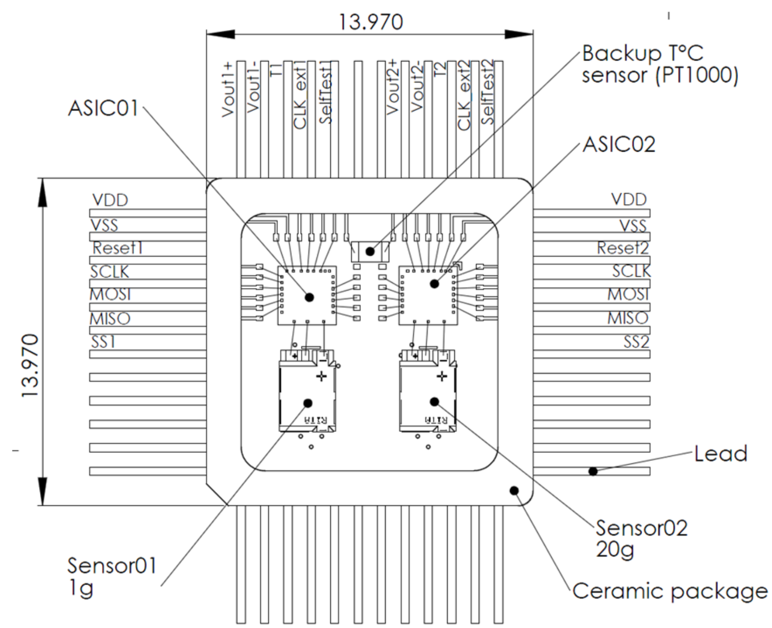




Acutronic Rate Table with Peltier cooler for Thermal-Tumble Test

ESA Project: Accelerometer to TRL5 - Approach

- New ASIC (open loop) with Identified performance improvements
- 1g and 20g out of plane capacitive sensor
- Planned dedicated package for dual sensor



Accelerometer to TRL5 – Performance and planning

- **Expected improvements**
  - Radhard tolerant → development of a Radhard ASIC
  - Improve performance → lower noise, improve NL and improve bias stability
- **Planning**
  - ASIC and package design 2013
  - Accelerometer components 2014
    - include characterization and radiation tests
- **Outlook:**
  - MEMS based accelerometers are bound to replace the traditional electromechanical devices (e.g. QA3000)
    - Smaller, more robust, lower power, lower cost, non-ITAR
  - Enabling technology allowing to address applications that are not possible today
    - Basis for low power, lightweight IMU's for mass and power constrained missions such as planetary landers and rovers

Thank you!