ELECTRONICS & DEFENSE

MINIATURIZED HIGH-PERFORMANCE MEMS ACCELEROMETER

SAFRAN

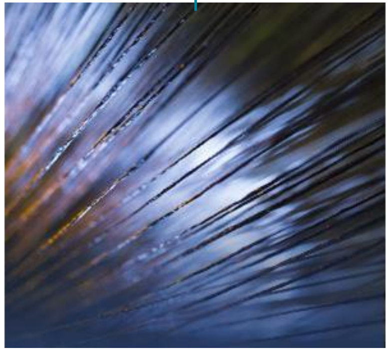
ThalesAlenia Space
a Thales / Leonardo company

Safran Group
Overview

76 800
Employees

12,000+
Employees involved in R&D

€15,3
Billion in revenues in 2021



€1.43
Billion invested in R&D in 2021

3 fields
- Aircraft propulsion
- Aircraft and defense equipment
- Aircraft interiors

- Engines
- Landing Systems
- Nacelles
- Electrical Wiring

No.3
Aerospace company worldwide (excluding aircraft manufacturers)

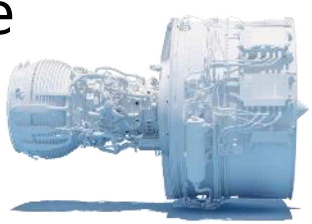
Safran Electronics and Defense

a world leader in our core markets

No.1 worldwide

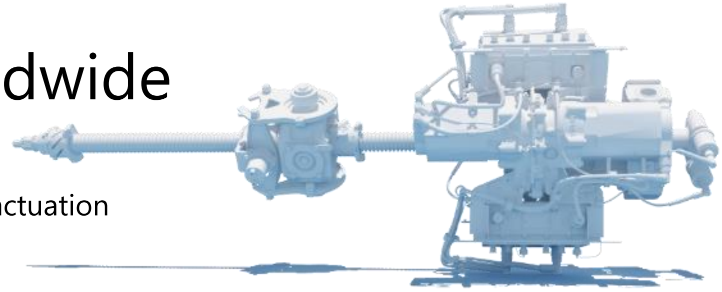
FADEC (*) for civil aircraft

* Full Authority Digital Engine Control



No.1 worldwide

Electromechanical actuation for flight controls



No.1 in Europe

Inertial navigation systems

No.2 worldwide

Cockpit panels

No.2 worldwide

Flight data monitoring

Safran Sensing Technologies

High-Performance MEMS

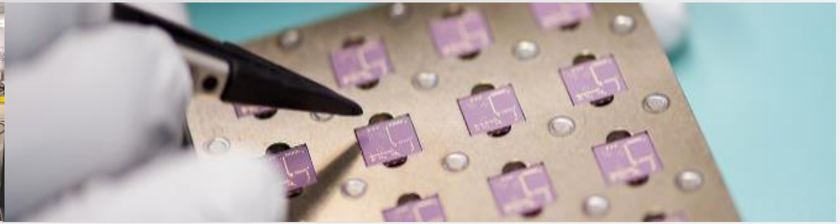
- **Leader in high-perf. MEMS sensors**
- **25+ Years experience in MEMS**
- **Proprietary 6’’ Wafer foundry**
- **Located in:**
  Yverdon, Switzerland
  Horten, Norway

20+ Millions
MEMS produced

110
Employees

85 patents

20% R&D

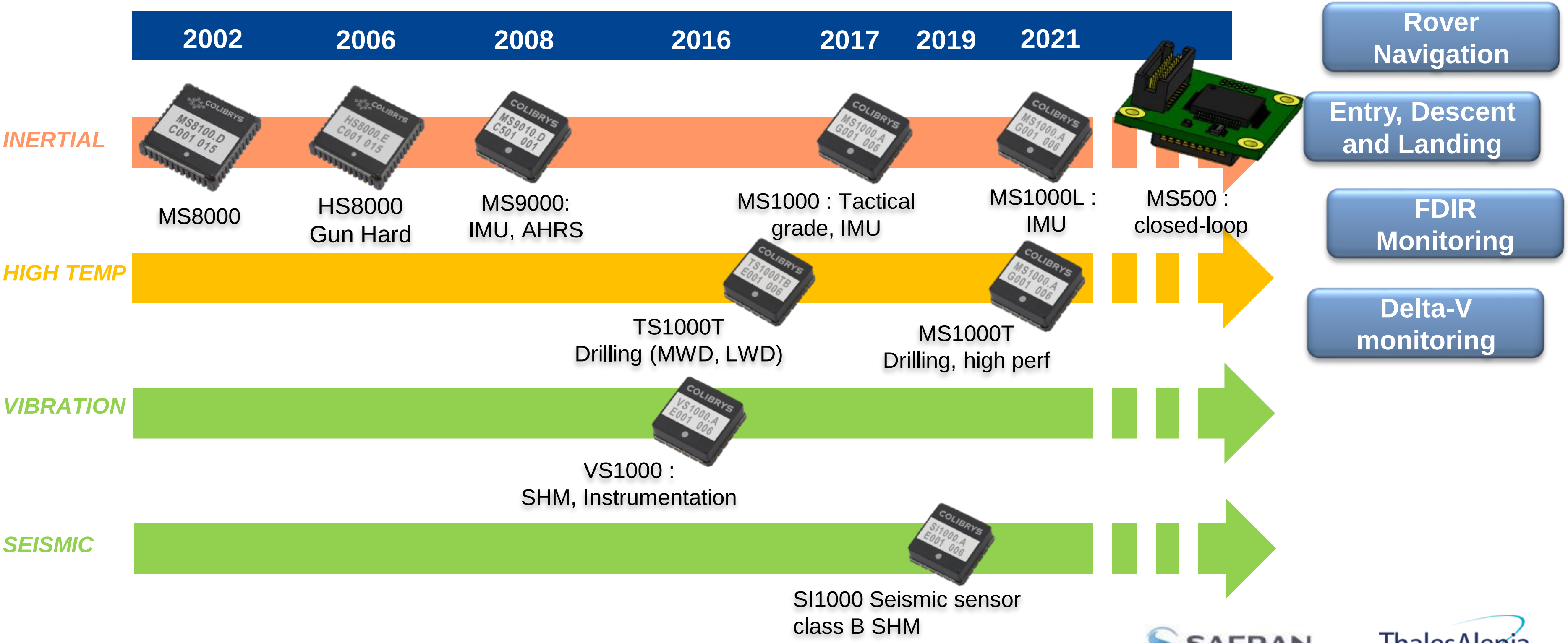


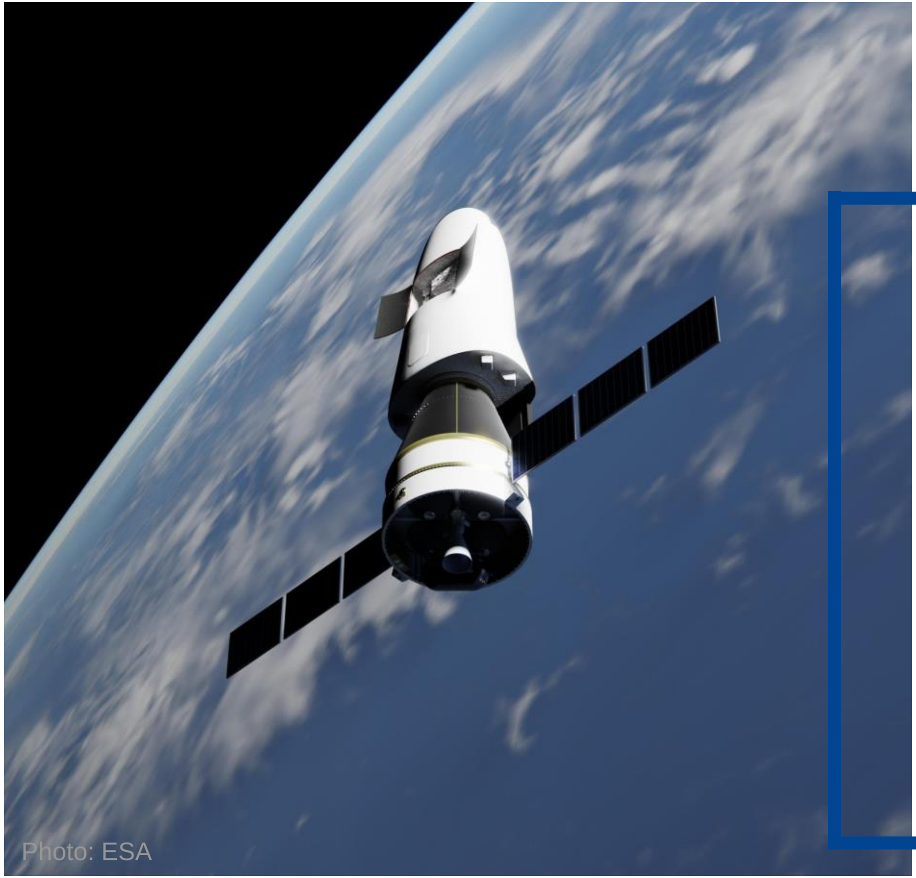
The strategic partner for MEMS in Safran, Safran Sensing Technologies is a worldwide leader in high-end inertial MEMS

Safran Sensing Technologies Switzerland

Product Mapping

Potential Space application for MEMS accelerometers





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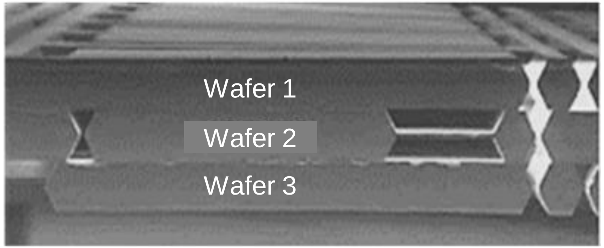
BACKGROUND INFORMATION

MEMS Accelerometer
Transducer

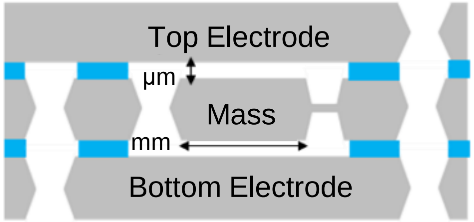
Capacitive Accelerometer

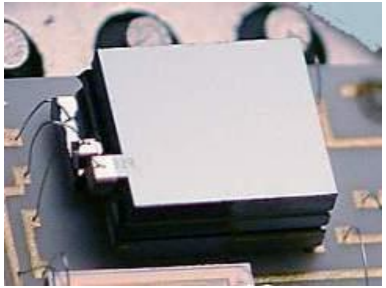
- 3-wafer bonded stack
- Suspended Proof-Mass between fixed electrodes → Pair of variable capacitors
- Accel. $\xrightarrow{\text{Spring}}$ Position $\xrightarrow{\text{Electrodes}}$ Δcapacitance

- Key Specifications:
  - Bias (K0): Signal Output @ zero input
  - Scale Factor (K1): Output sensitivity



SEM cross-section



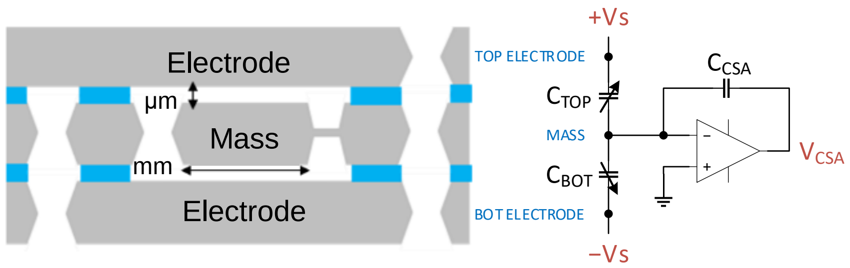


Open Package

MEMS Accelerometer
Readout Electronics

Readout Electronics: Charge-Sense Amplifier

- Differential Charging of MEMS Capacitors $+q = \Delta C \cdot V_S$
- Amplifier equalizes charge on center node $-q = C_{CSA} V_{CSA} \rightarrow V_{CSA} = -\frac{\Delta C}{C_{CSA}} V_S$



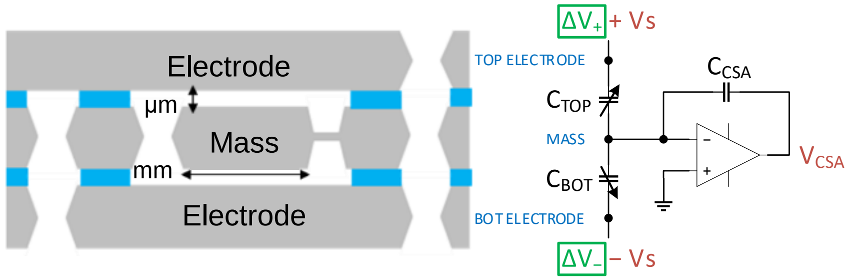
Note: V_S modulated @ high frequency (outside MEMS bandwidth)

MEMS Accelerometer

Force Feedback

Force Feedback Electronics (Closed-Loop):

- Controller input: Mass position
- Controller output: Acceleration
- Feedback Mechanism: Electrostatic Force
  - $\Delta V_+ > \Delta V_-$ → push mass up
  - $\Delta V_+ < \Delta V_-$ → push mass down



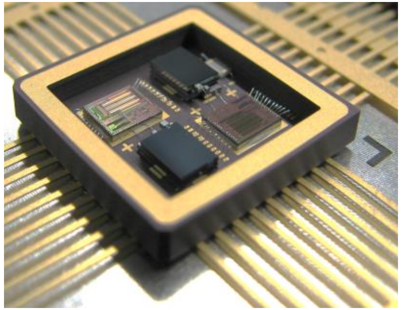
Aerospace MEMS Accelerometer
Program History

SA0120 open-loop accelerometer

- Adapted from 1000-series sensor
  - 2-channel sensor (1 gee & 20 gee) → Better Spec. Coverage
- Rad-Hard electronics (digital, transistors in ASIC)
- Full performance characterized

- Lessons learned:
  - Excellent spec. coverage → attractive SWaP-C (MEMS)
  - 2-Ch → Enlarged package → degraded thermal performance
  - Radiation → Scale Factor shift

SA0120



Aerospace MEMS Accelerometer
SA500 Closed-Loop Sensor

SA500 closed-loop accelerometer

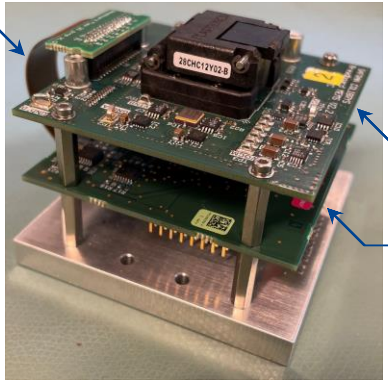
- Adapted from 500-series sensor (20 gee)

- Improved MEMS die
  - Reduced bias error
- Closed-Loop Architecture
  - Improved Performance (1-Ch)
  - Reduced scale factor error

- Targeted Improvement:
  - Bias (K0) Error vs. Temperature: < 300 μgee $[-40°C, +85°C]$
  - Scale Factor (K1) Error post-rad: < 300 ppm $[\text{TID: } 50\ krad\ ]$

- Note: Breadboard model
  - Socket for MEMS
  - Discrete ICs for analog circuit

SA500



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PERFORMANCE TESTING

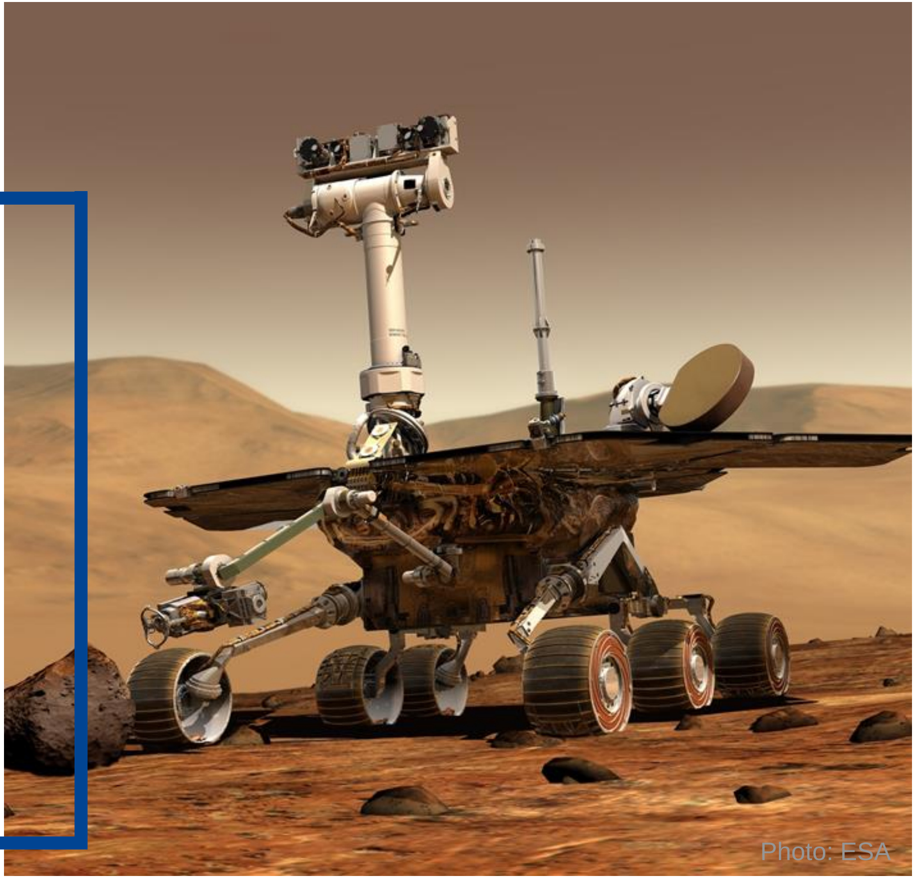
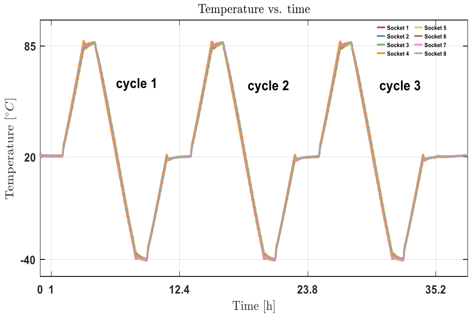


Photo: ESA

Performance Characterization
Activities

Thermal Test
- MEMS + Electronics in Oven



Radiation Test
- MEMS only (ICs & MCU not Rad-Hard)

Thermal performance testing

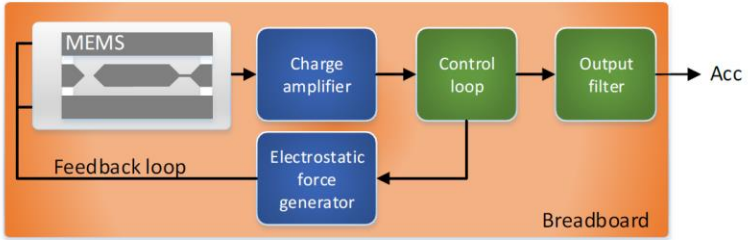


Figure 7: Accelerometer breadboard with individual package MEMS sensor and discrete electronic components

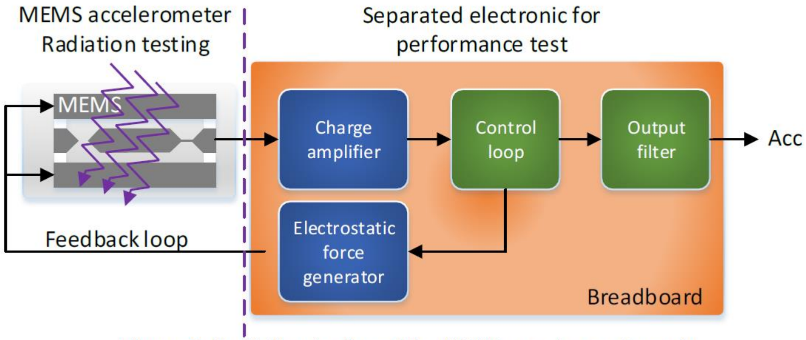
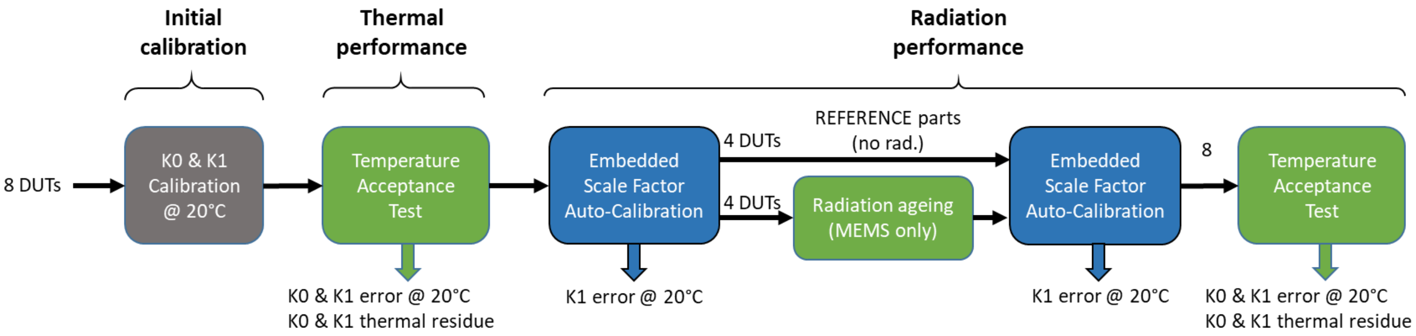


Figure 6: Radiation testing of the MEMS accelerometer only

Performance Characterization
Objective & Test flow

Objectives: Demonstrate
- Improved Thermal Bias (K0) Error
- Improved Radiation Scale Factor (K1) Error
  - Embedded K1 Auto-Calibration

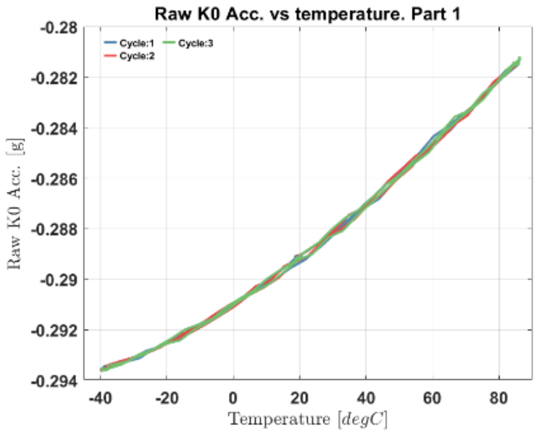


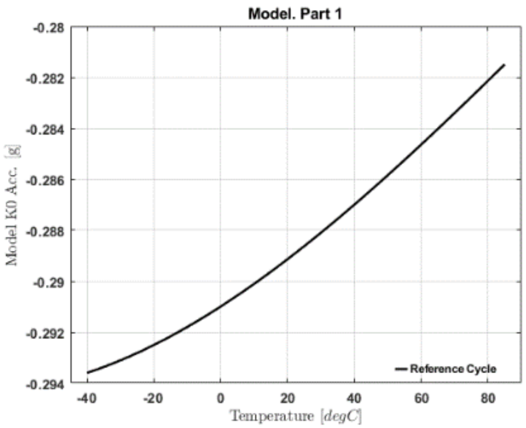
Performance Characterization

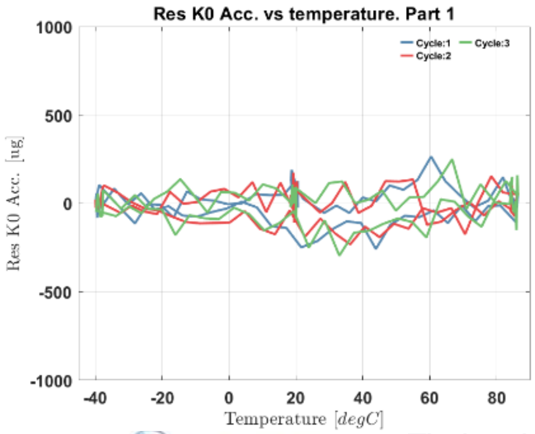
Temperature Acceptance Test: Data Extraction

Process:

- Measure Acceleration
- Separate into +1g & -1g
- Calculate $\boldsymbol{K_0}$ & $\boldsymbol{K_1}$ → plot vs. Temperature
- 3rd order polynomial fit, extract: nominal values ($\boldsymbol{K_0}$ & $\boldsymbol{K_1}$ calibration), TC & residue





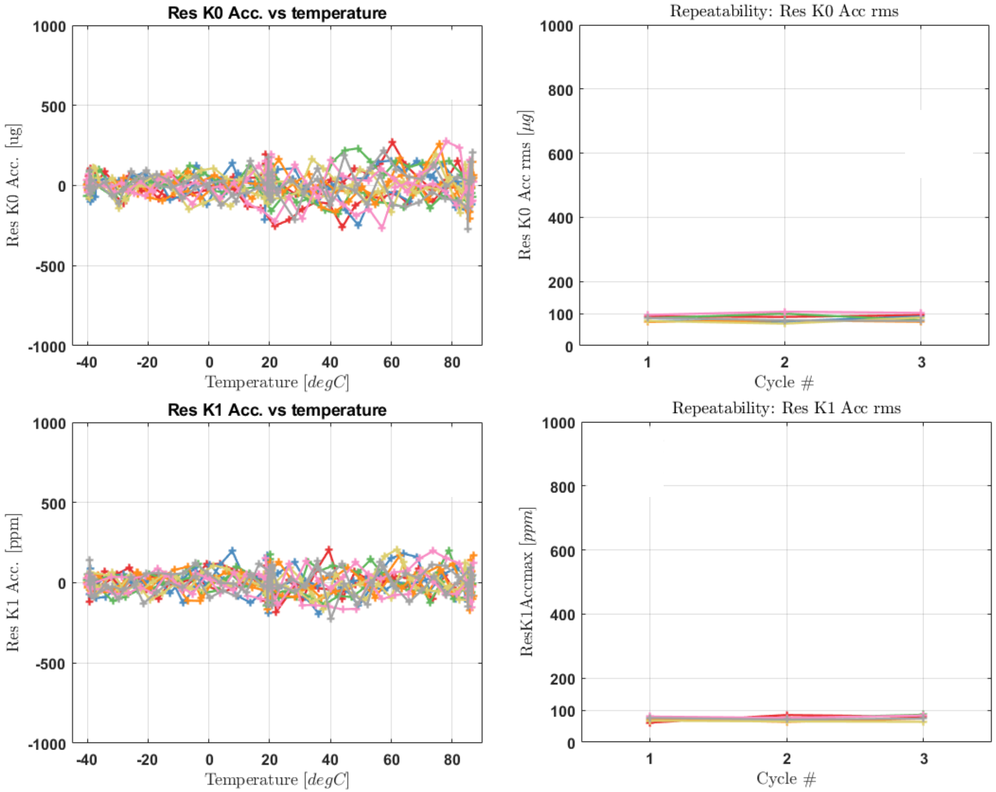


Performance Characterization

Improved thermal bias performance

Bias (K0) Residue: 100 µgee (rms)

Scale Factor (K1) Residue: 90 ppm (rms)

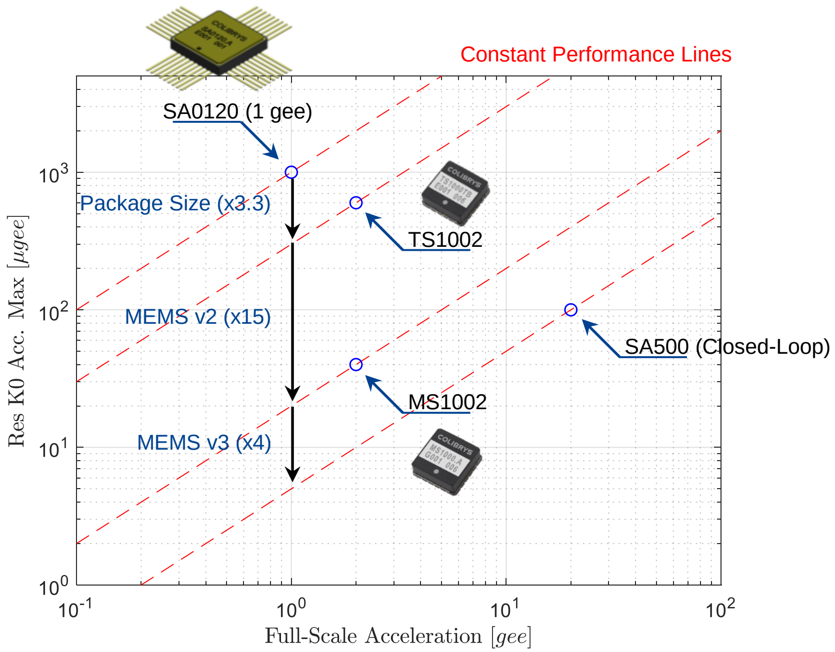


Performance Characterization

Summary: Improved thermal bias performance

Total improvement: ***x200***

- Smaller Package x3.3
- Improved MEMS die v2.0 x15
- Improved MEMS die v3.0 x4

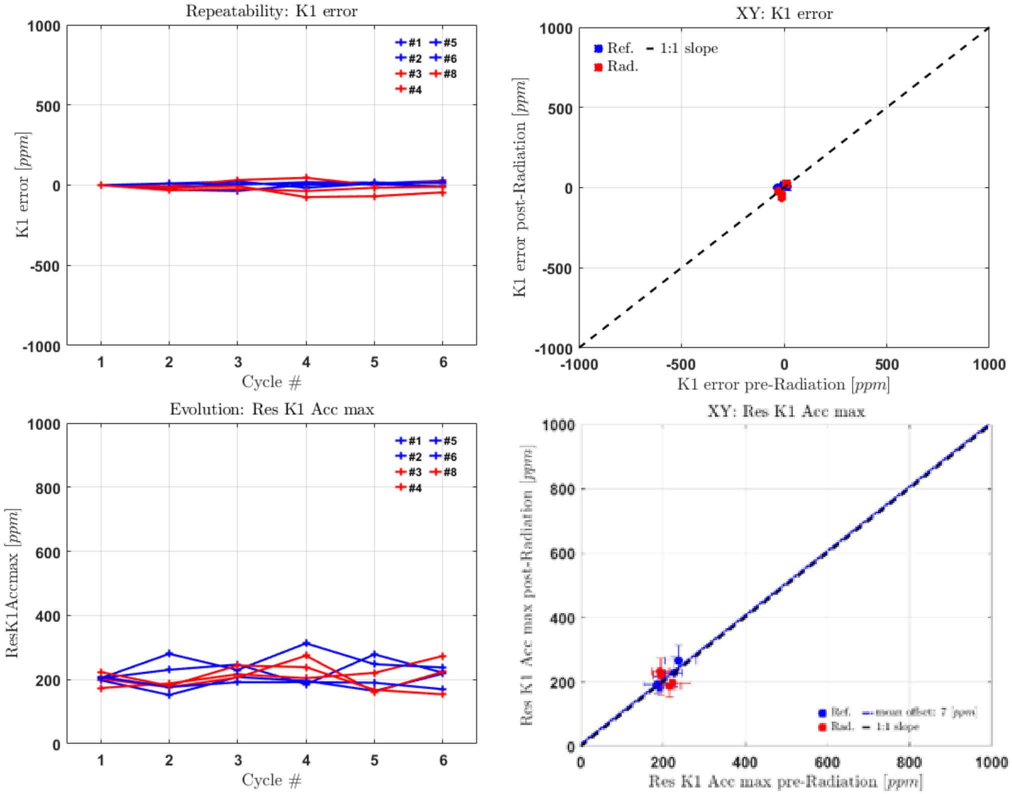


Note: K0 error approx. proportional to FS accel.

De-risking closed-loop breadboard
Post radiation Scale factor

Scale factor error (20°C): ***no change***

Scale factor Residue: ***no change***



De-risking closed-loop breadboard

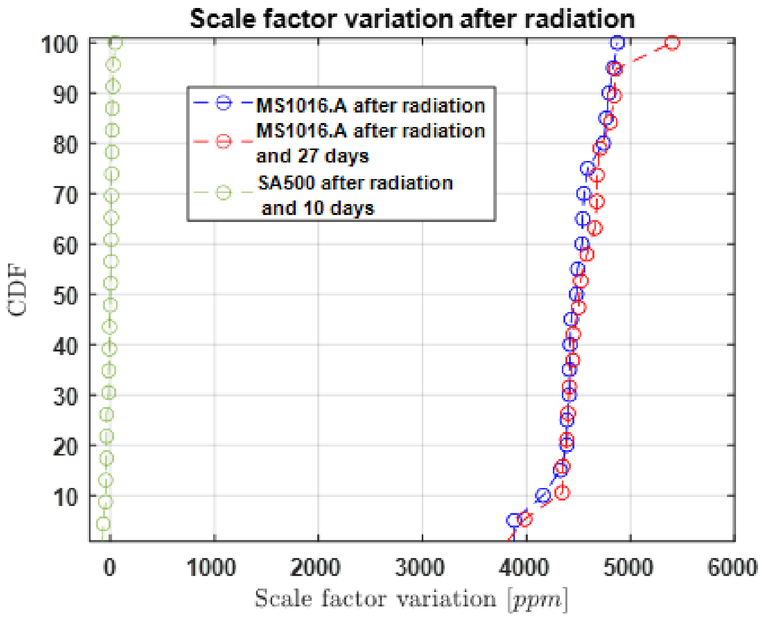
Summary: Improved post-radiation scale factor performance

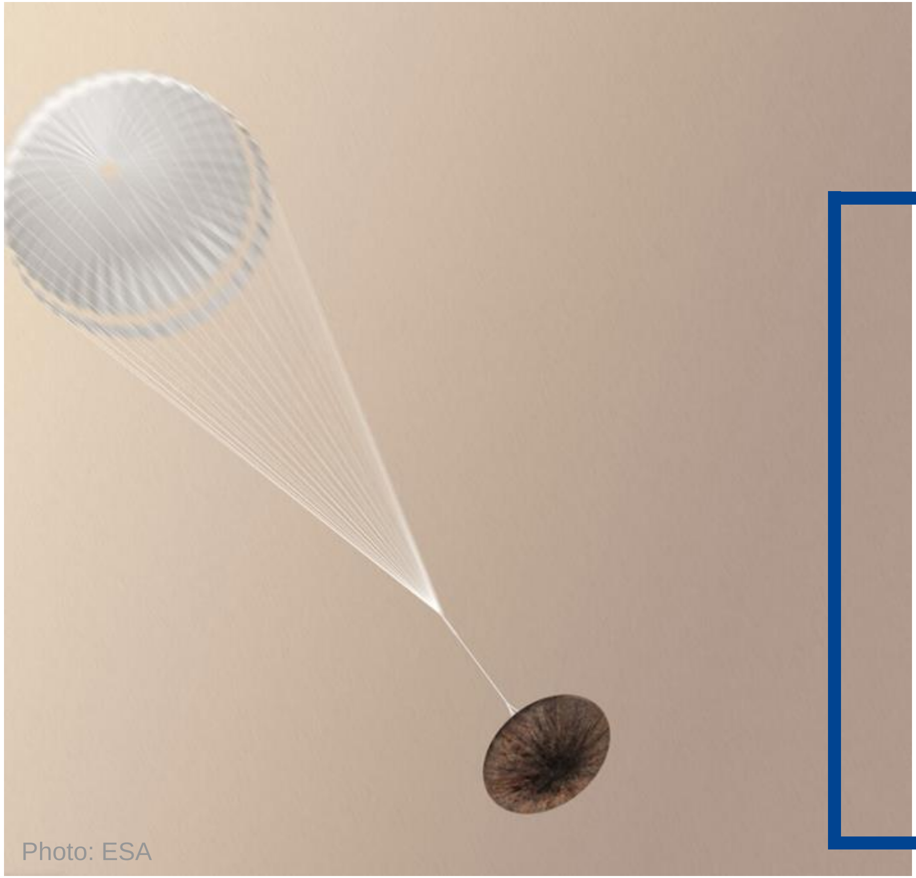
Open-Loop Sensors (SA0120, TS1000 & MS1000)

4500 ppm shift @ 50 krad
In-Spec @ ~3-4 krad

Closed-Loop Sensor (SA500)

- MEMS K1 Radiation ageing: ***none***
- Embedded K1 auto-calibration: Validated
  - Correct analog circuit shifts (e.g., voltage reference).





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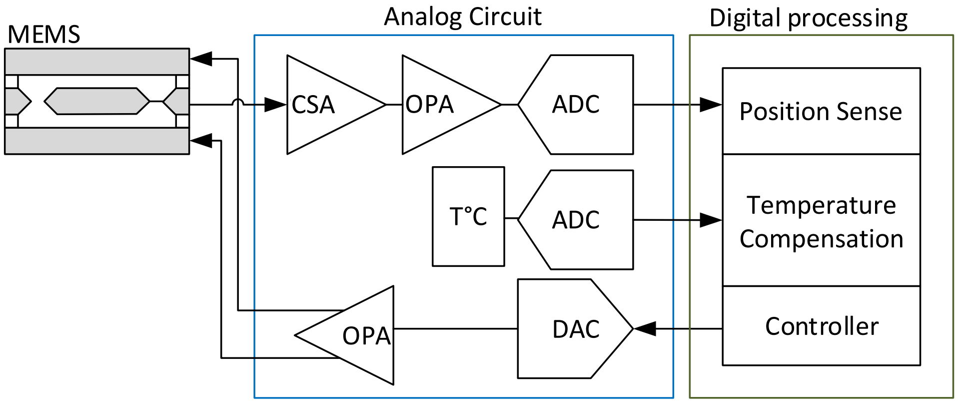
PRODUCT ARCHITECTURE & DEVELOPMENT LOGIC

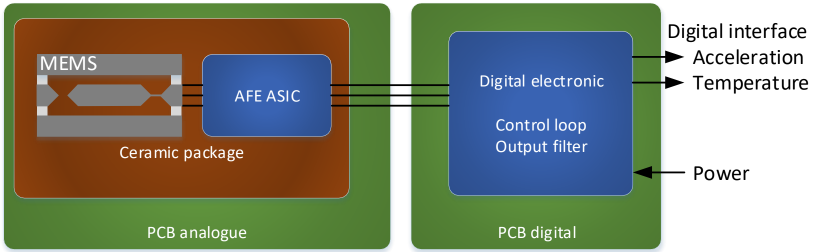
Product architecture & development logic

Product architecture SA500

Functions

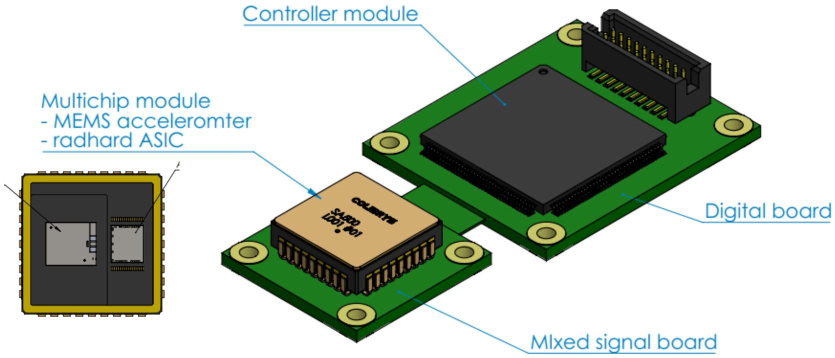


Integration



Product architecture & development logic

Product architecture: SA500 vs. MS500



- **Next Step: Multichip Module**
  - MEMS + rad-hard ASIC (analog circuit)
  - J-lead Ceramic LCC package

- **Client Interface**
  - SPI comm. (accel., temperature, status)
  - Digital inputs (e.g. auto-calibration)
  - +3.3V digital (MCU)
  - +3.3V analog (DAC, ADC)
  - ±15V analog (Feedback, CSA)

- **Development Logic**
  - Maintain BOM commonality (same MCM)
  - Only MCU changes (rad-hard)

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