High Performance MEMS Gyroscope for Space – Future Roadmap

esa 9th esa round table on micro and nano technologies
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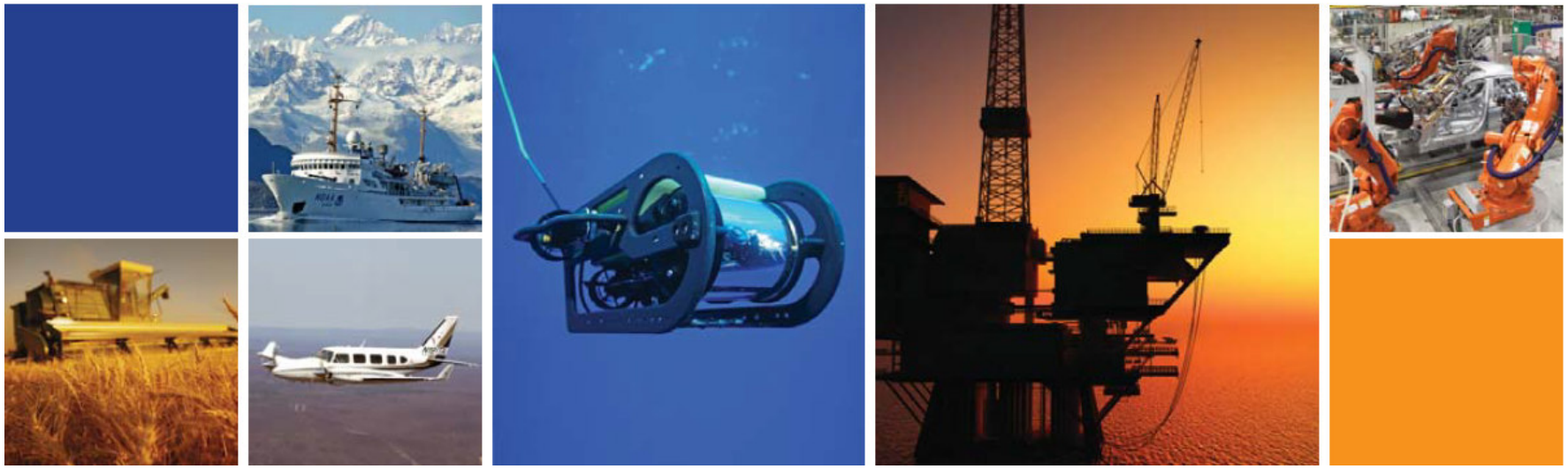
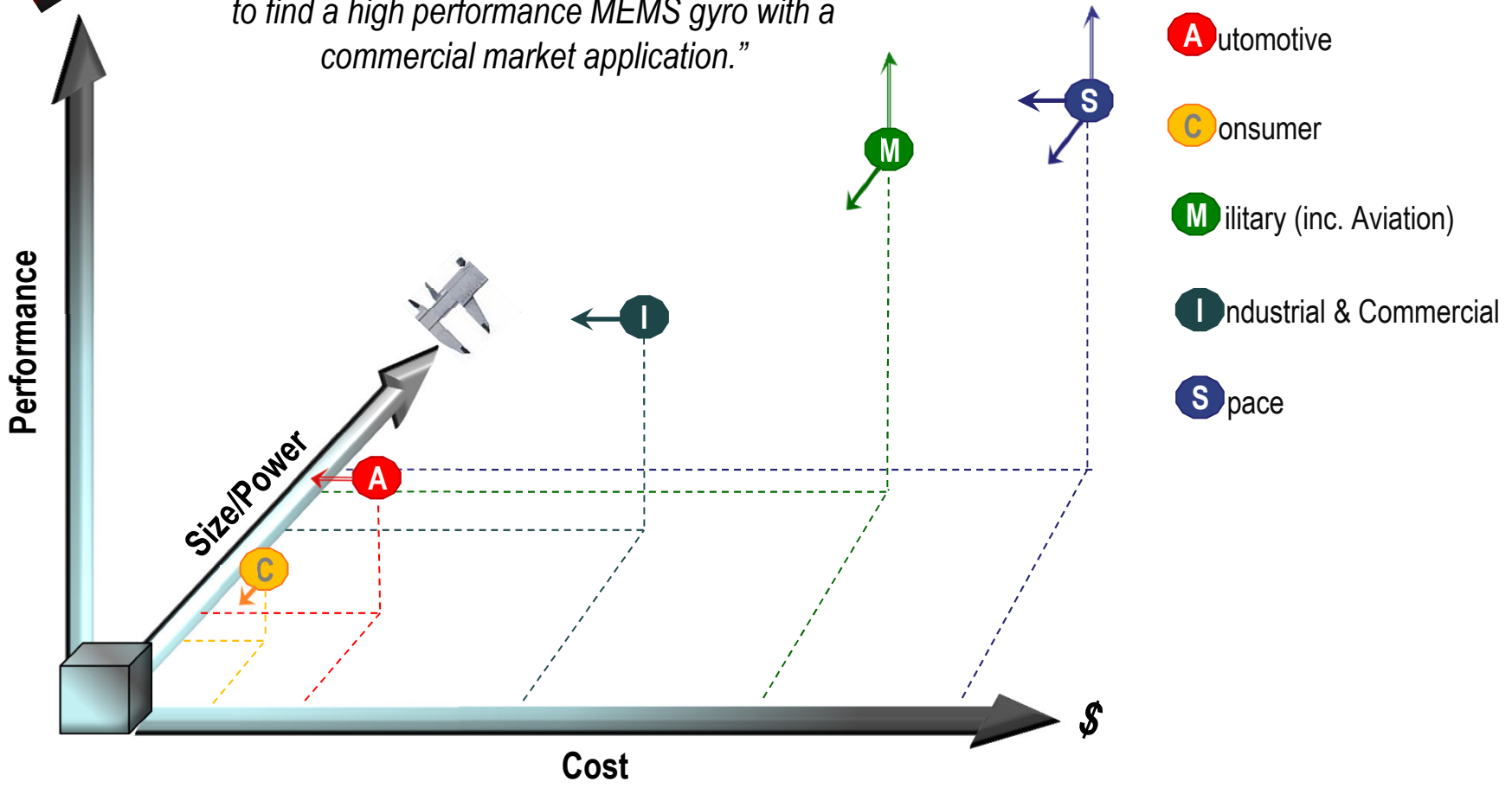
European Space Agency



Contents

MEMS Gyro Market Drivers

"Market forces and the high level of investment needed for MEMS mean the relatively small space market for MEMS gyros is commercially unappealing. The challenge is for the space market to find a high performance MEMS gyro with a commercial market application."



Advantages & Disadvantages of MEMS

Pros -

- Mass produceable
- Low cost
- Small and robust
- High reliability
- Low power consumption
- Ease of integration

Cons –

- Performance…..

Space Application Requirements

FDIR
Bias Stability: 5-50°/hr
SFerror: 2,000-5,000 ppm

Planetary Rovers
Bias Stability: 5-10°/hr
SFerror: 1,000-2,000 ppm

Planetary Landers
Bias Stability: <1°/hr
SFerror: <200 ppm

Spacecraft AOCS
Bias Stability: <1°/hr
SFerror: <200 ppm

Space Gyro Classes:
Coarse (10°/hr)
Medium (1°/hr)
Fine (<<1°/hr)

Functional Requirements:

- 1-10 Hz bandwidth
  - 100 Hz for Landers
- Rate or incremental angle
- MEMS detector only package or die

Environmental Requirements:

- Radiation Tolerance
  - TID: 100 Krads
  - SEL: 80 MeV.mg/cm^2
- Thermal: -40 to +80°C
- Shock: 2,000g

Vibrating Structure Gyro Evolution

(Strictly speaking; a Coriolis Shell Resonating solid-state angular rate sensor)

Over 20 million supplied

<0.9ppm in 3yr warranty

SGH01
SGH02
SGH03

CRG20

pinpoint® CRM100 CRM200

orion™ CMS300 CMS390

VSG 1 1985

VSG 2 1995

VSG 3 1998

VSG 4 2006

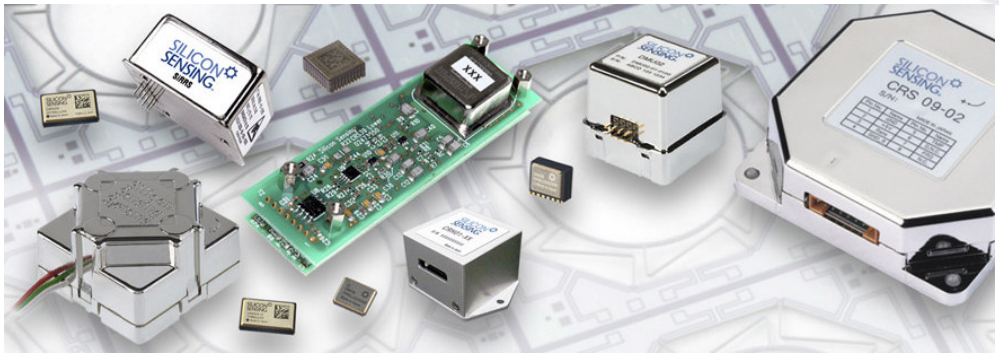
VSG 5 2010

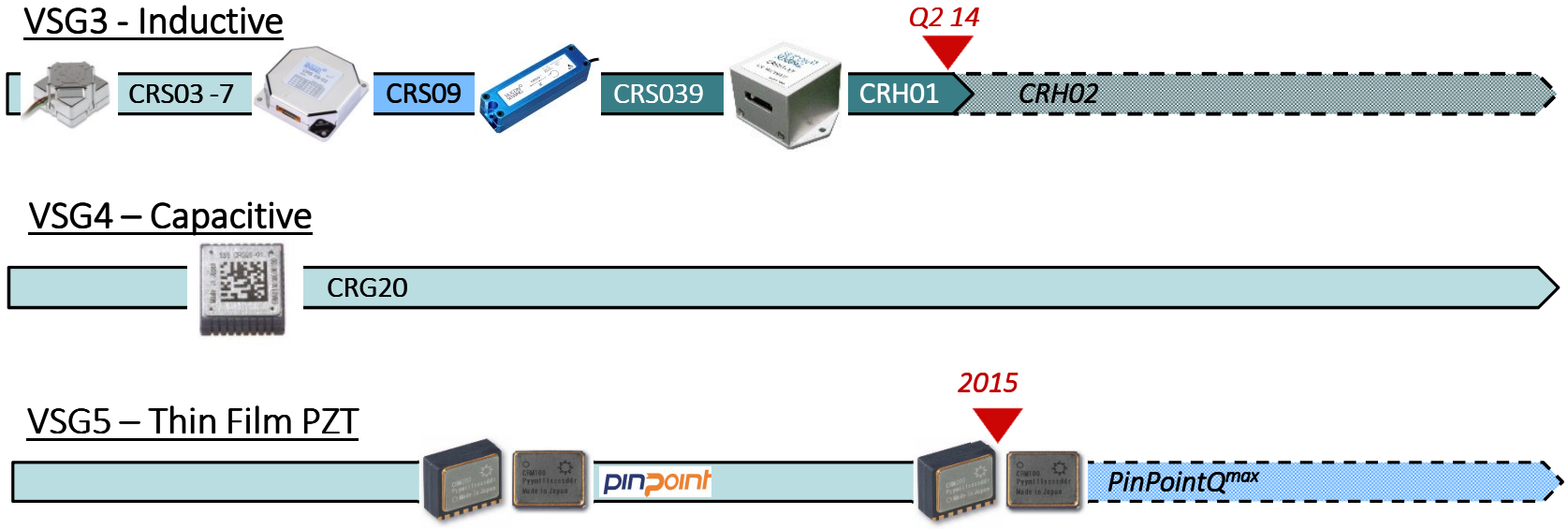
Ceramic Cylinder	Metal Ring	Silicon MEMS Ring		
		VSG3 - Inductive	VSG4 - Capacitive	VSG5 - PZT

MEMS Gyro Product Roadmap

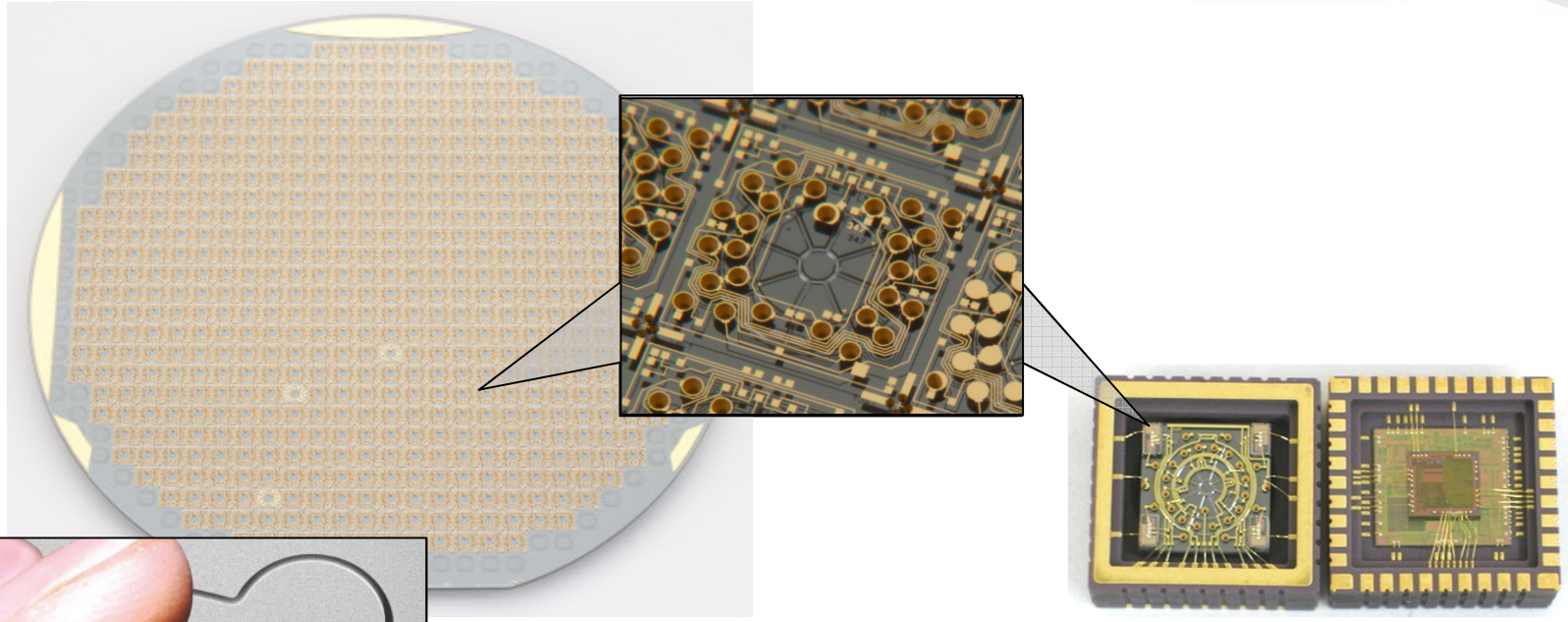
Optimised products designed to cover a wide range of automotive, commercial, industrial and aerospace applications –

3 different MEMS VSG technologies
6 MEMS detector designs
8 Gyro module types
30 different available part numbers
Over 20,000,000 units in service



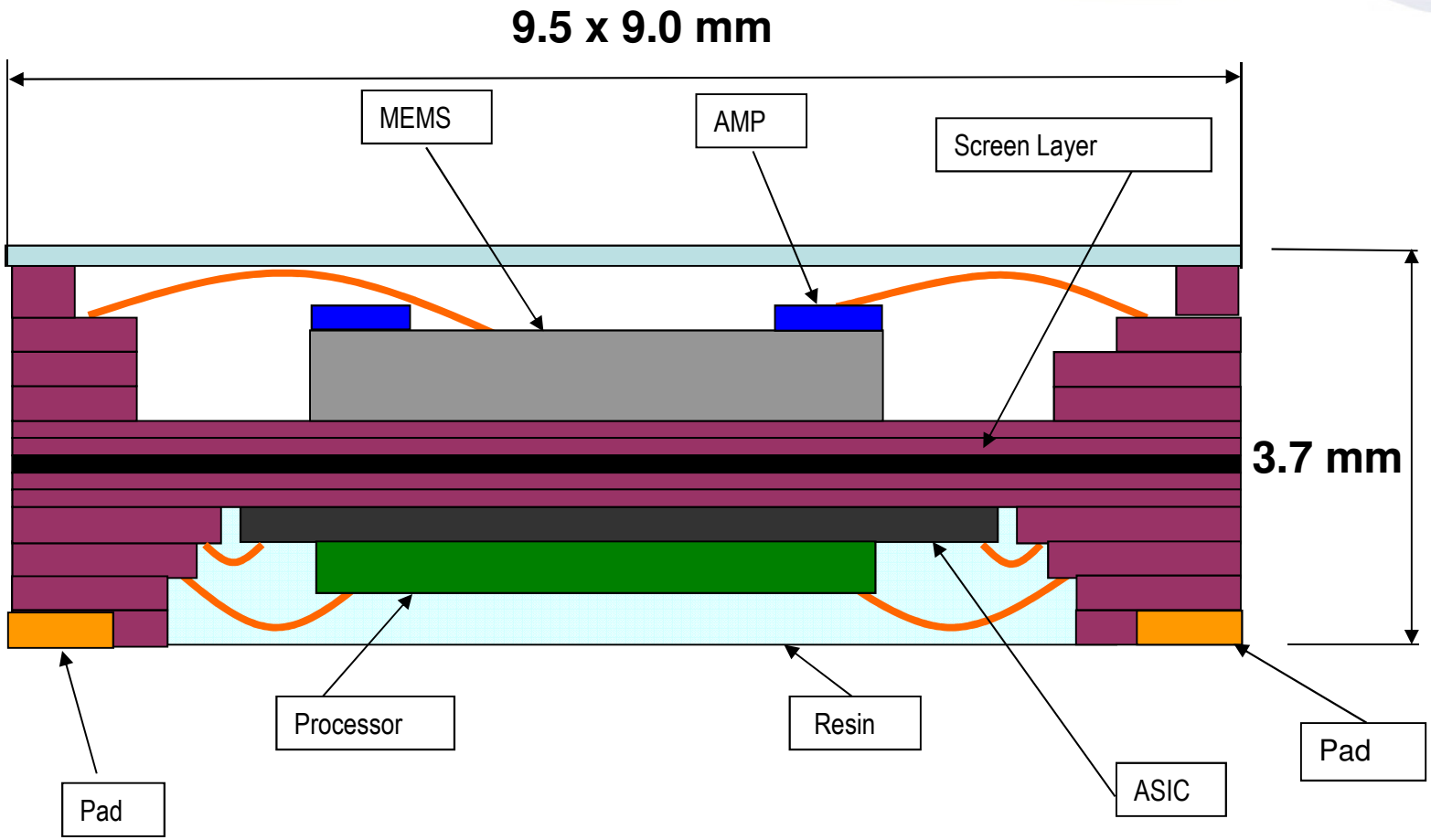


Capacitive VSG4 Gyro - MEMS

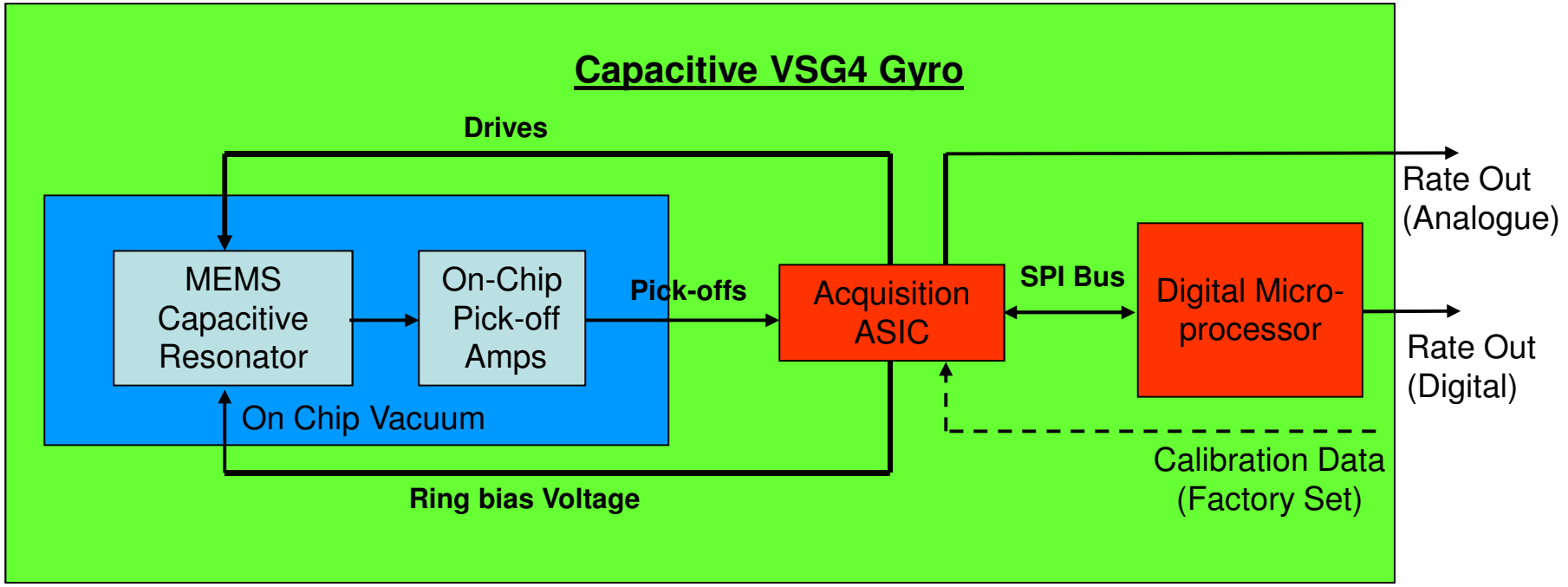


- CRG20 Product
- VSG4 technology
- 3mm Ø Si resonating ring
- Complete single package digital gyro
- Multi chip ceramic package containing MEMS, ASIC and microprocessor
- Over 100,000 units sold
- Automotive, aviation and general industrial applications

Capacitive Gyro - Construction

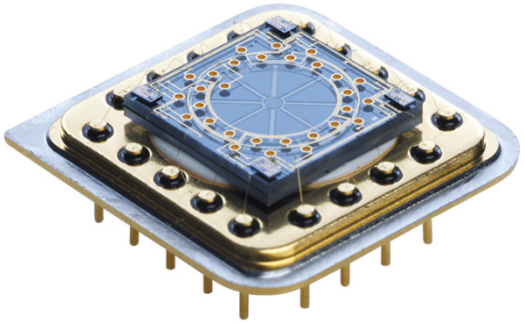


Capacitive Gyro – Block Diagram



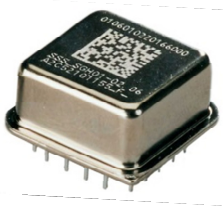
SGH15 Capacitive MEMS Gyro

SGH15 MEMS

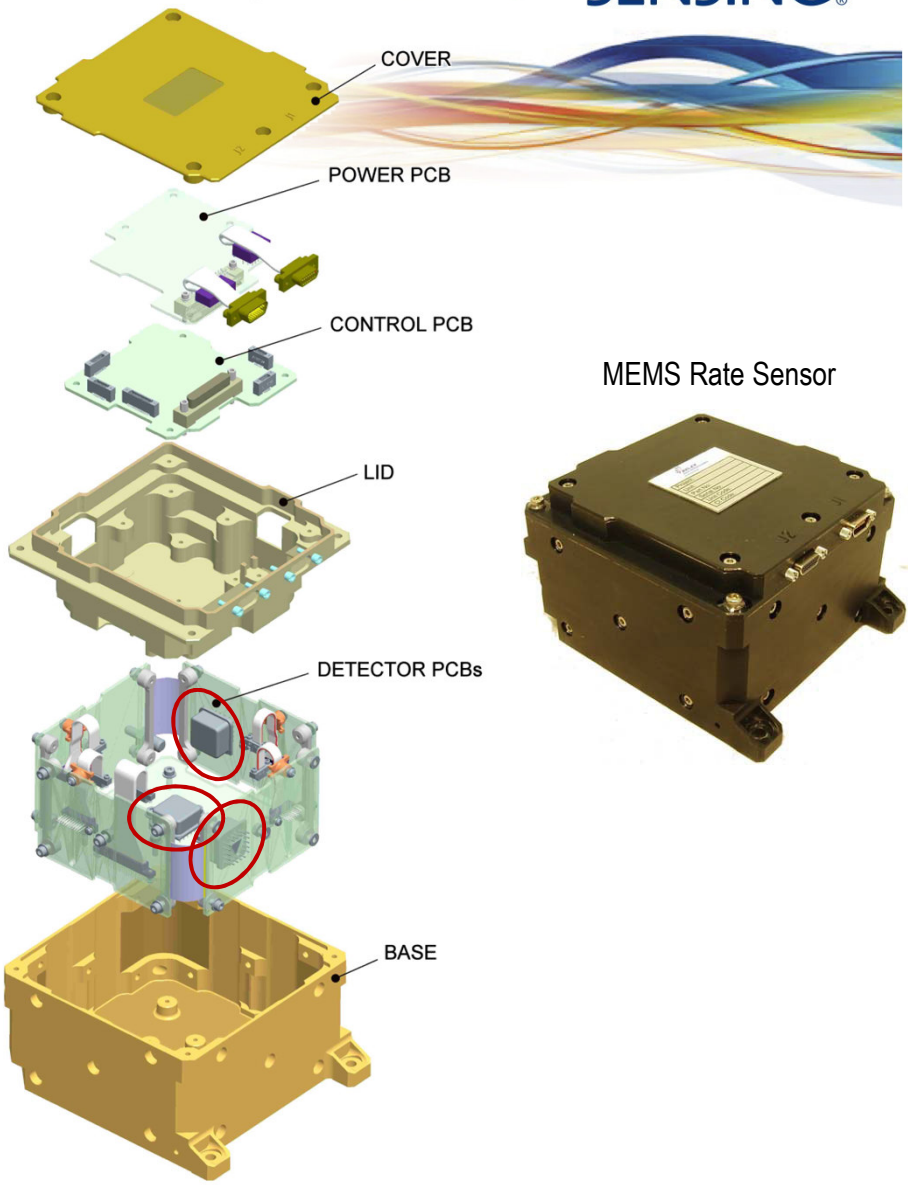


- 8mm Ø ring resonating ring for best performance
- Proven architecture -
  - Glass package
  - Vacuum sealed
  - On chip pick-off amps

SGH15 MEMS Rate Detector



- Hermetically sealed (welded) Kovar base & lid (from VSG3)



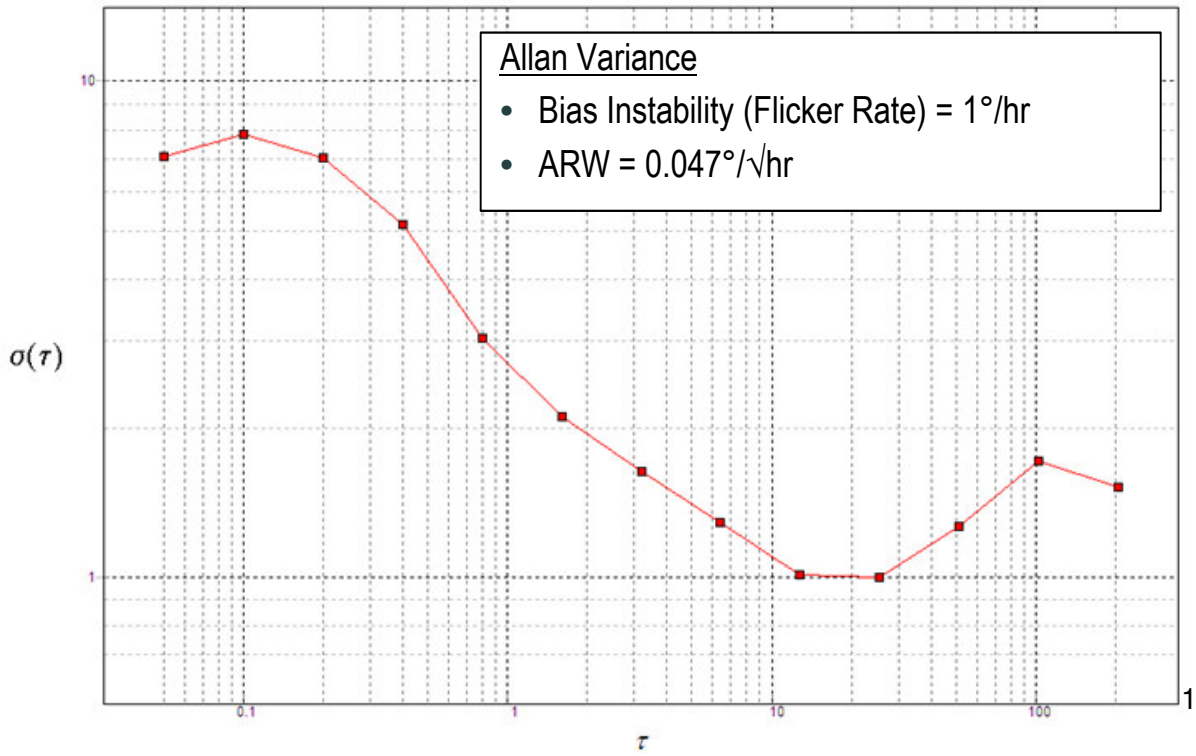
MEMS Rate Sensor

"SGH15 is a unique detector design applicable only to the current space programmes – the latest Inductive VSG3 detector (SGH03) outperforms SGH15 and has a wider commercial market beyond space applications"

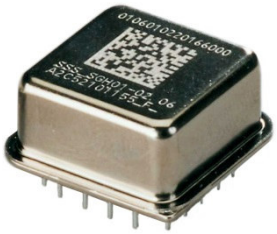
SGH15 Performance

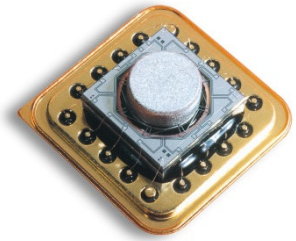
Requirement

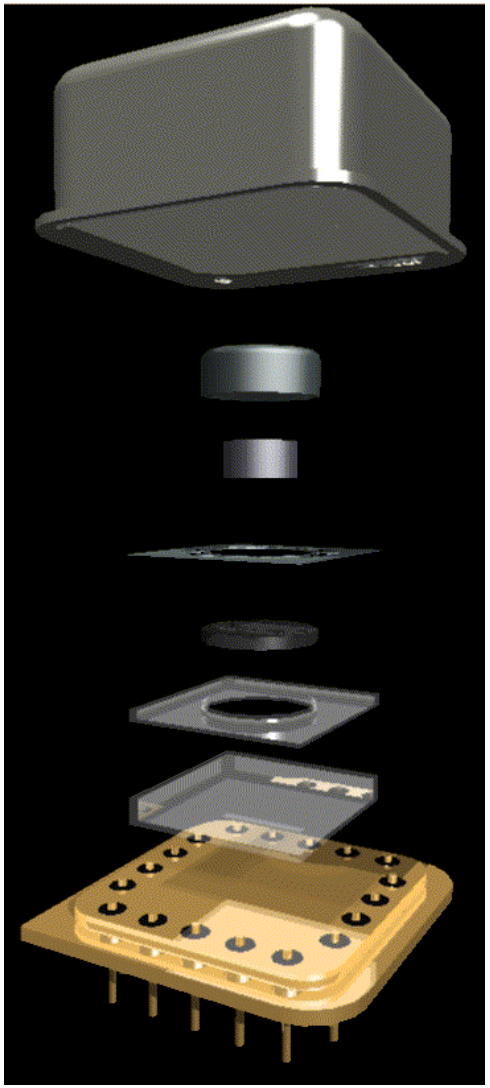
Sensor Type Mass Power	3 axis rate sensor < 0.8kg 5.1W
Bandwidth	10 Hz (max)
Measurement Output Rate	2 - 20 Hz (settable), 0 Hz = no output
Switch-on to Switch-on Change	< 10 deg/hr (with off time constraints)
Angular Rate Bias	10 - 20 deg/hr
Rate Bias Drift	5 - 10 deg/hr over 24 hours with ±10°C
Scale 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

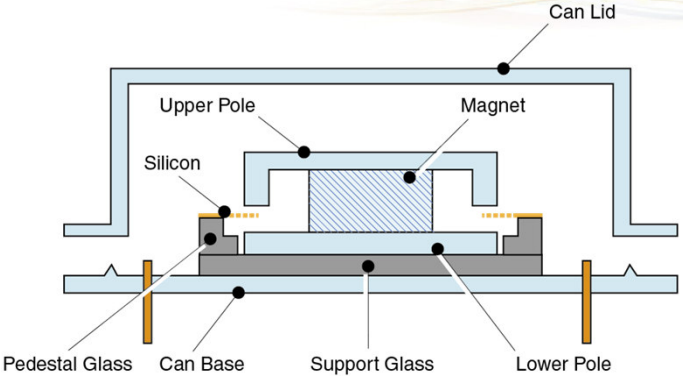


Inductive MEMS Gyro Detector

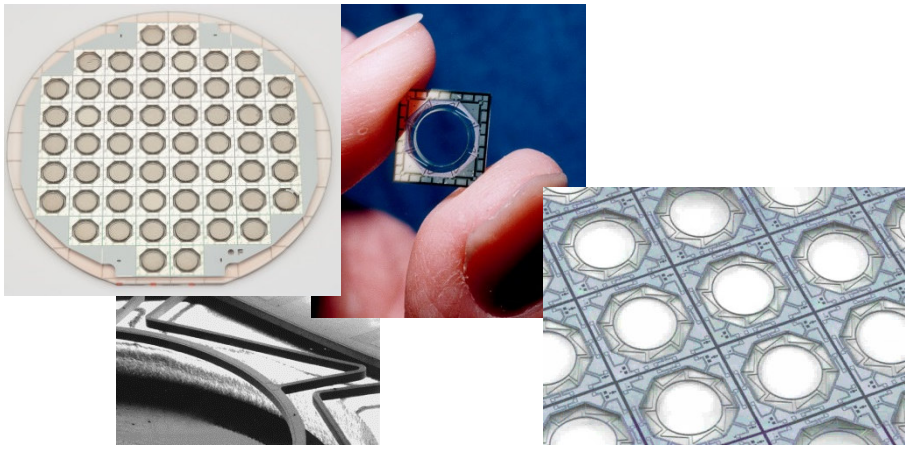




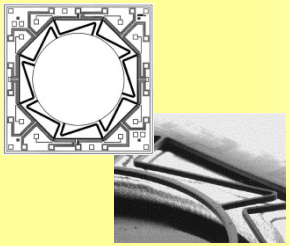
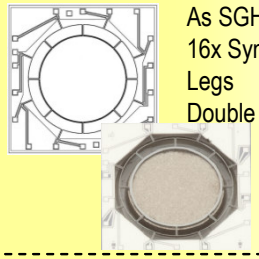
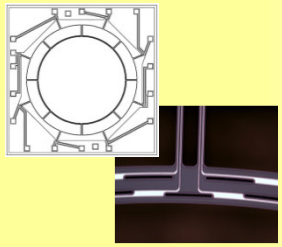
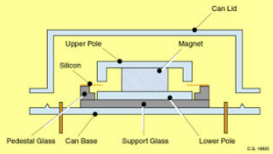




- 4” x 100µm Si Wafer
- 6mm Ø ring
- 10mm sq gyro die
- 52 die per wafer



MEMS Gyro Detector Roadmap

	1999	2009	2014
	SGH01		
	➢ Designed for automotive ➢ Over 20 million produced ➢ 0.9ppm reliability ➢ Still in production	**SGH02** ➢ Reduced mechanical coupling ➢ Reduced thermo-mechanical stress ➢ Reduced ΔF ➢ Reduced Quad Bias TC ➢ Improved gains ➢ Improved S:N ➢ Reduced drive-to-gain cross-talk	***SGH03 (VSG3Q^{max})*** ➢ *Increased Q* ➢ *Reduced fluid damping* ➢ *Reduced 'intrinsic' damping* ➢ *Improved MEMS mechanical isolation* ➢ *Reduced moisture content* ➢ *Improved mode frequency matching*
MEMS	 DRIE 10mm sq x 100µm 6mm Ø ring 8x Asymmetric Legs Single loops	 As SGH01, with 16x Symmetric Legs Double loops	 *As SGH02, with* *Slotted ring*
Assembly	 Glass supported Anodic bonding Permanent magnet Metal poles Die bonded Wire bonding	As SGH01	*As SGH02, with* *Octagonal glass* *Undercut pole support*
Package	 Kovar base & lid Glass-metal pinouts Welded hermetic Atmos N_2 @ 1bar	As SGH01	*As SGH02, with* *N_2 @ high vacuum* *Getter integrated*

Inductive Gyro Module Roadmap

VSG3 Gyro MEMS

Control Electronics (Analogue)

Digital Interface

Module

SGH01 → SGH02 (NL2T) → *SGH03 (VSG3Q^{max})*

ASIC → Discrete → Enhanced → *Optimised*

ADC

CRS03 -7 & RRS01 — 7 -14°/ hr

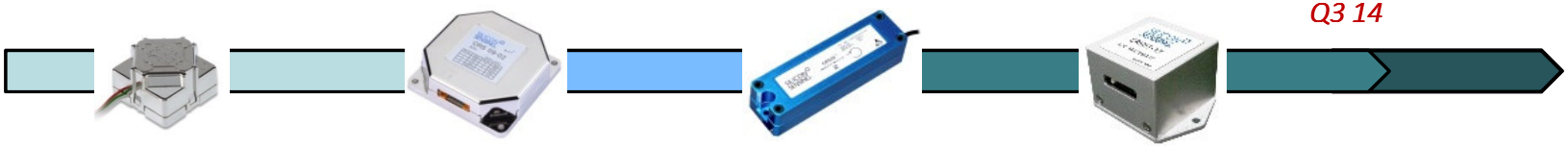
CRS09 — 0.7°/ hr

CRS39-01/-02 & CRH01 — 0.2°/ hr

Q1 14

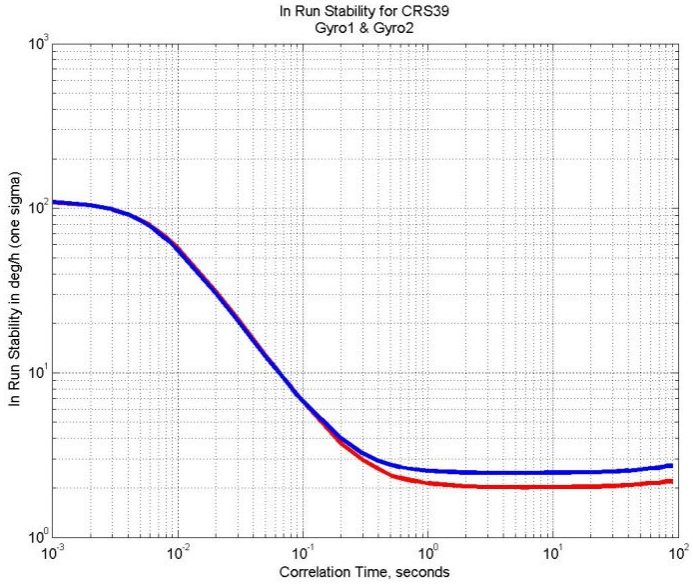
CRS39-03 & CRH02 — <0.1°/ hr

Q3 14

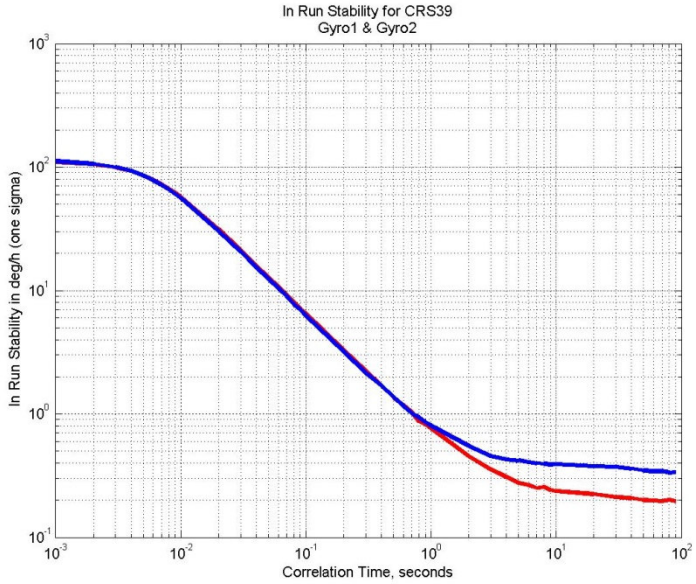


SGH03– In-run Bias

SGH02



SGH03

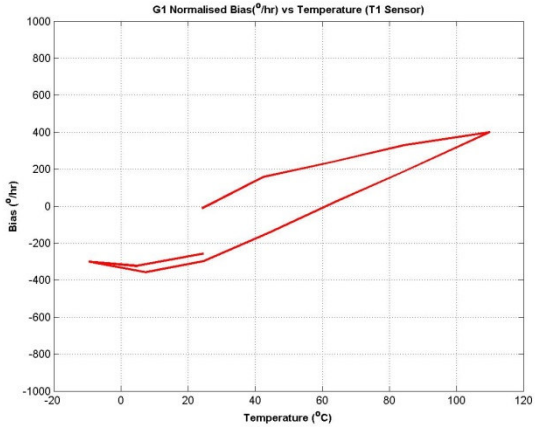


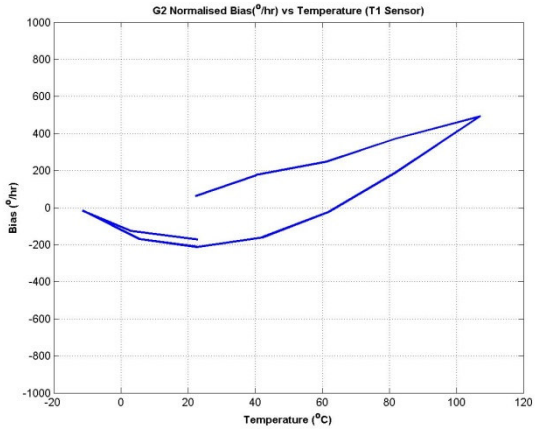
Bias Stability improved from 2º/hr to 0.2º/hr.
(Note scale change).

Angular Rate Bias	10 - 20 deg/hr
Rate Bias Drift	5 - 10 deg/hr over 24 hours with ±10°C

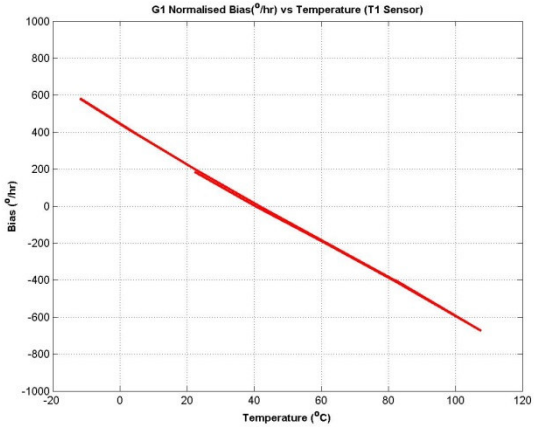
SGH03 – Bias Hysteresis

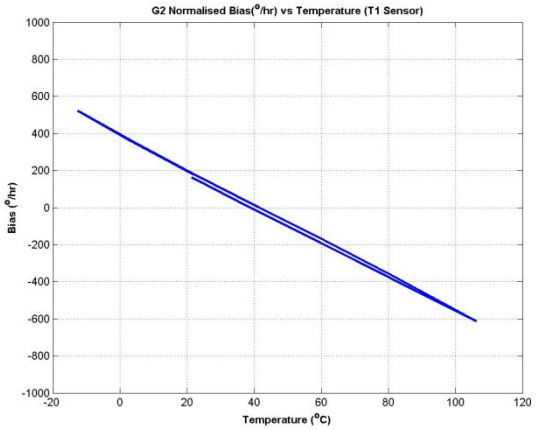
SGH02





SGH03

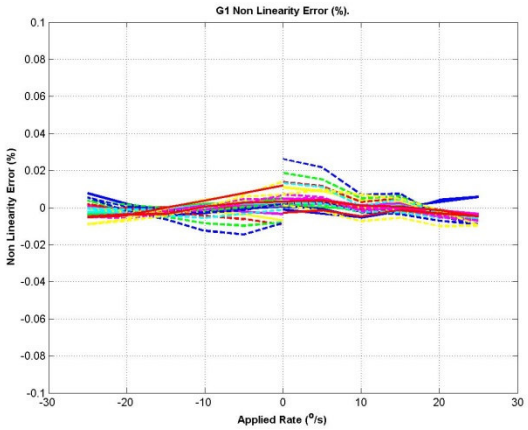


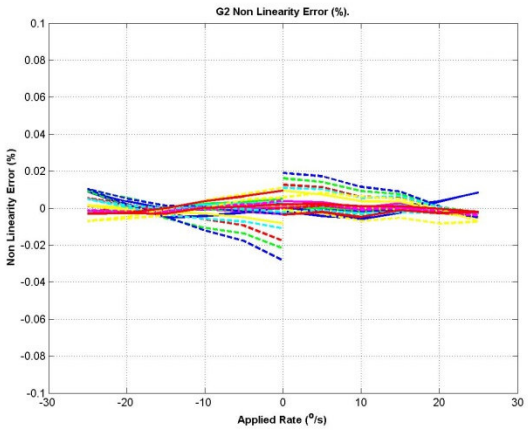


Bias Hysteresis improved from ±180°/hr to ±7.5°/hr

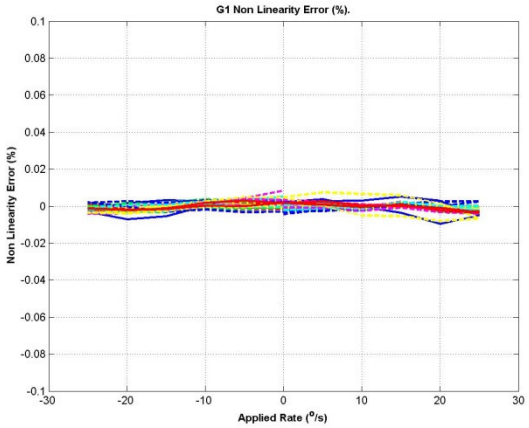
SGH03 - SF Linearity

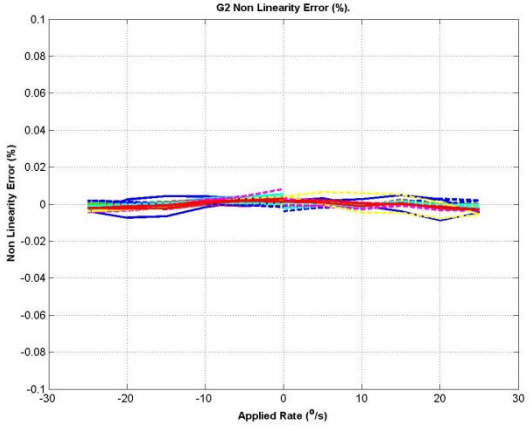
SGH02





SGH03



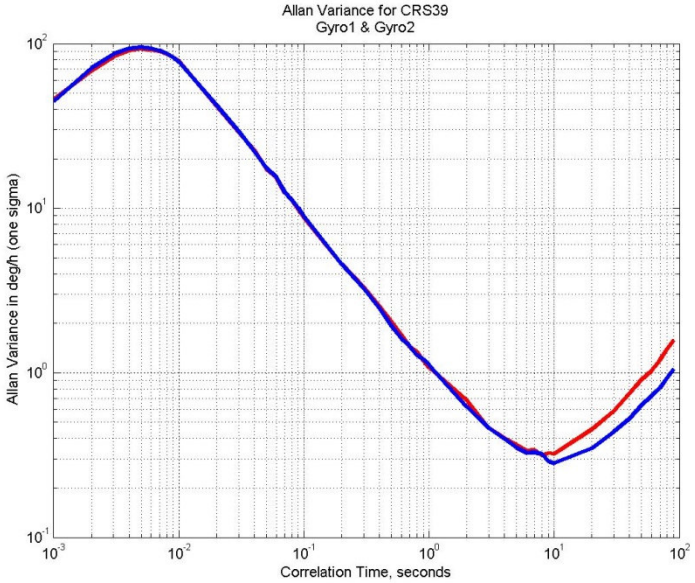


Non-linearity improved (<1,000ppm) due to improved bias stability, lower noise and improved linearity

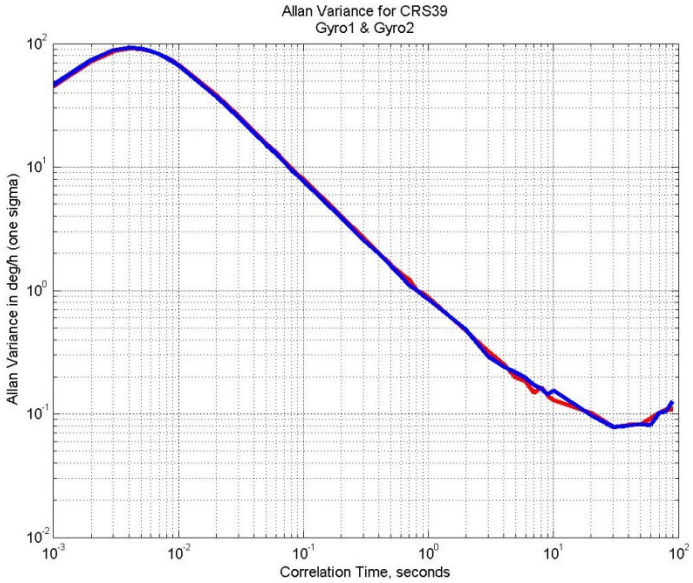
Scale Factor Linearity	< 2000 ppm over input range

SGH03 – Allan Variance

SGH02



SGH03



Angle Random Walk improved from 0.013°/√hr to 0.0083°/√hr

Bias Instability (NER) improved from 0.2°/hr to 0.08°/hr

SGH15

- *ARW = 0.047°/√hr*
- *Bias Instability (Flicker Rate) = 1°/hr*

Linearity	Input range
Angular Random Walk	0.1 - 0.2 deg/√hr
Noise Equiv't Rate	< 1 deg/hr (defined as flicker rate)

Conclusion

- The SGH15 Capacitive VSG4 MEMS detector has proved the feasibility of MEMS gyroscope suitability for space use
- The roadmap for MEMS space gyros will need to focus on cost reduction, without compromising performance and functionality
- Trends and drivers in the MEMS gyroscope market mean there is a weak commercial argument for investment in a unique space MEMS gyro – the key is to find and adapt a high performance commercial MEMS gyro for use in space
- Much has changed in the market since the SGH15 MEMS gyro detector was first conceived, and other viable alternatives now exist
- Free of the constraints of the automotive market Silicon Sensing has evolved its Inductive VSG3 MEMS detector technology and the latest generation (SGH03) could potentially meet the mid-term performance-v-cost objectives for future space MEMS gyros