SILICON SENSING®

Inertial Technology For North Finding

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Silicon Sensing is a joint venture between Atlantic Inertial Systems and Sumitomo Precision Products

To be the leading provider of affordable, high performance, high integrity MEMS inertial products and foundry services

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SILICON SENSING®

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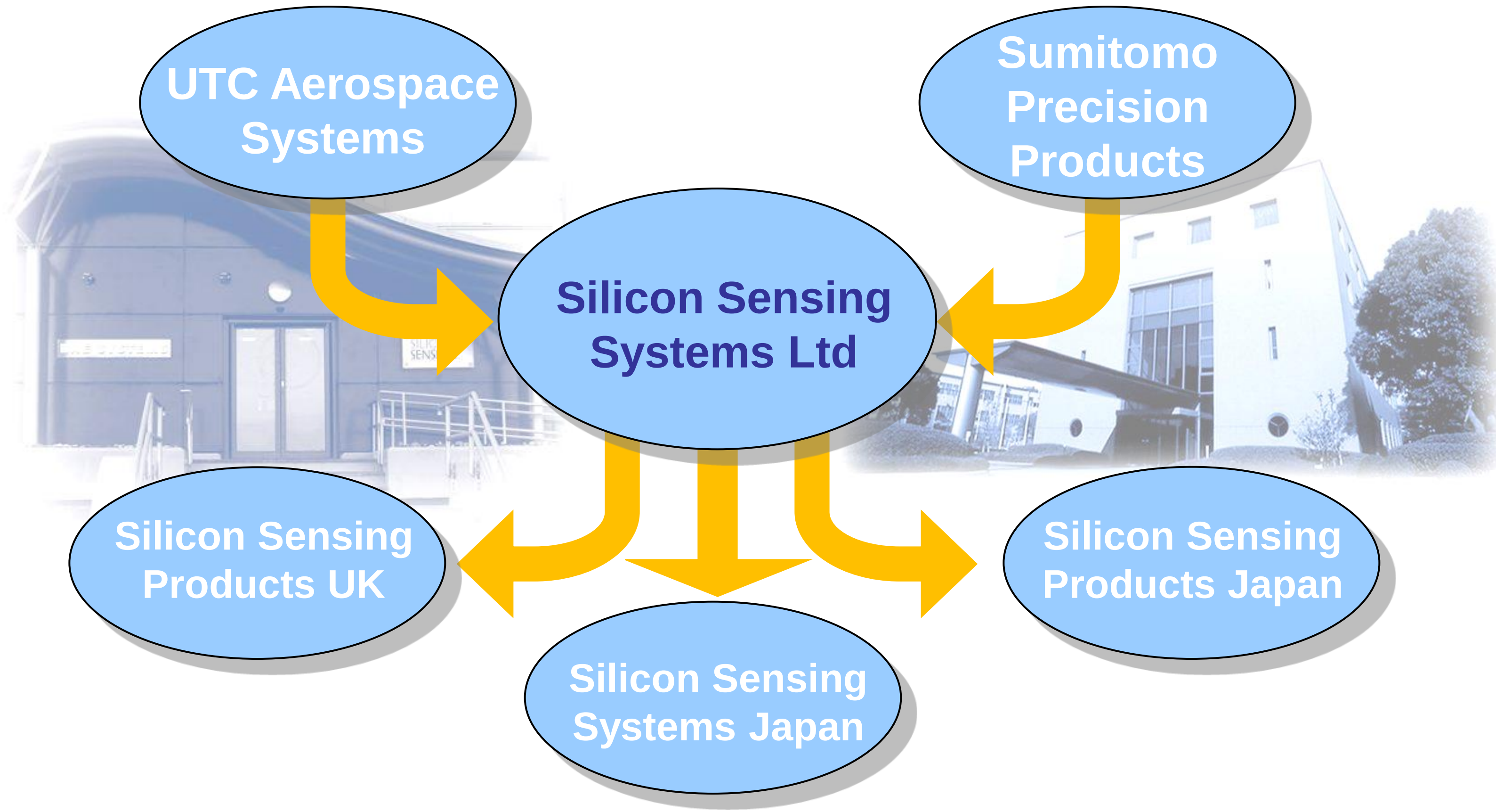
A UTC/SPP Joint Venture Company

UTC Aerospace Systems

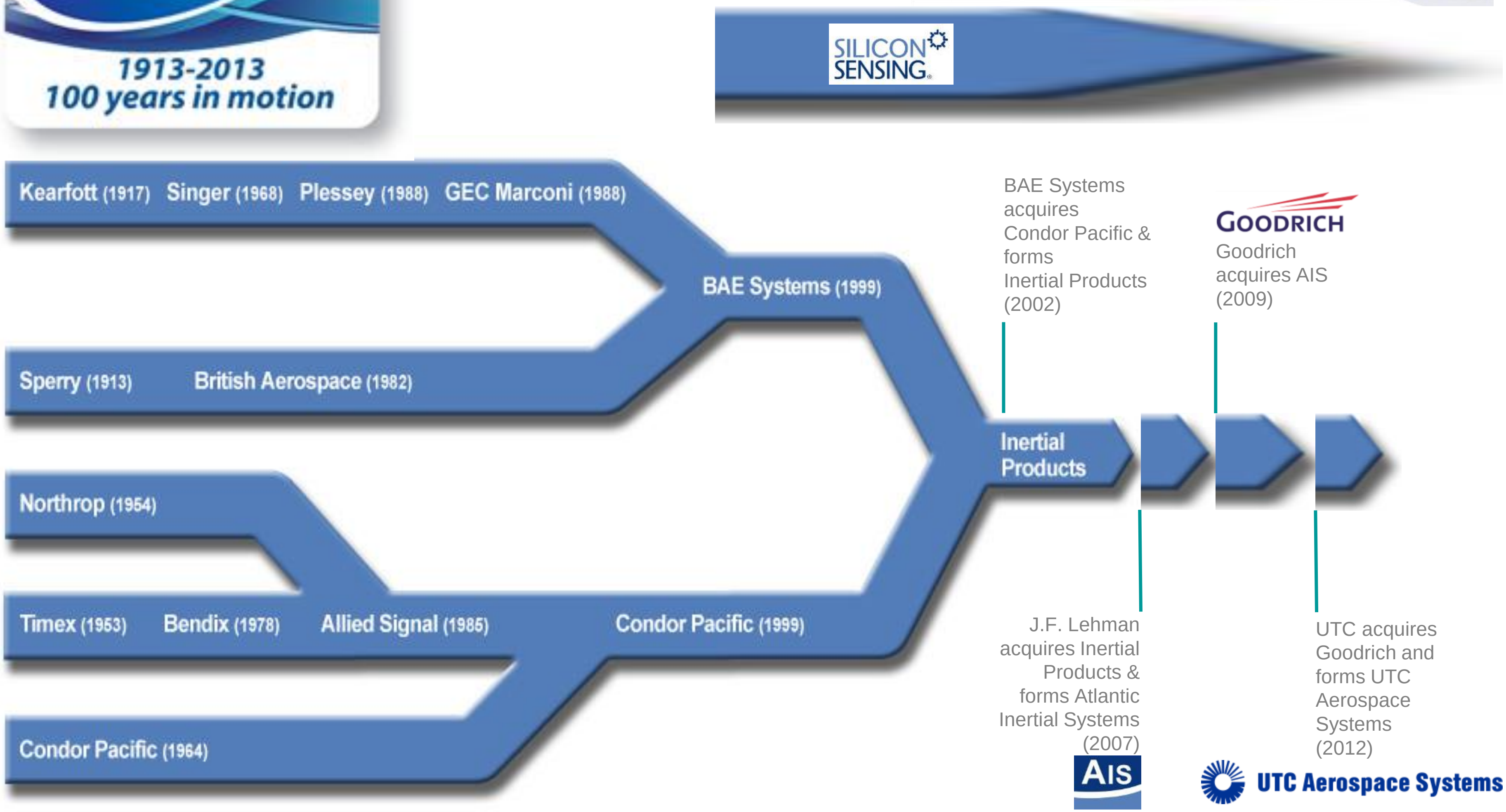
SPP



Who we are

The Gyro™
1913-2013
100 years in motion

SILICON SENSING®



What a gyroscope does

- Angular rate sensors, are used whenever rate of turn sensing is required without a fixed point of reference. This separates gyros from any other means of measuring rotation, such as a tachometer.
- Traditionally, gyros (gyroscopes) were much like the children's toy – a spinning mass supported such that its position in inertial space remains fixed and allowing rotation of its support structure to be measured.
- The world of inertial sensors has turned on its head with the emergence of 'solid state' non-rotating rate sensors, still colloquially known as gyros. Their construction in silicon (or sometimes quartz) explains their other descriptive name of 'MEMS' (Micro-machined Electro-Mechanical Systems) devices.
- MEMS gyros emerged through the need to overcome the biggest problems associated with traditional spinning wheel gyros – mechanical issues such as fragility, reliability, stiction, wear, backlash and overall life.
- Based on a vibrating element, MEMS gyros sense rotation rate through a phenomenon known as coriolis.

Current Product Range

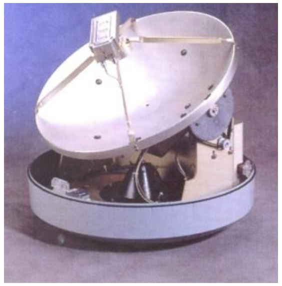
- **Single Axis Gyroscopes**
  - PinPoint®
  - CRS09/CRS39
  - CRH01
  - CRG20
  - CRS03/CRS07
- **Combination Sensors**
  - Orion ®
- **Accelerometers**
  - Gemini ®
- **Multi-axis**
  - DMU02

Applications

- **Platform Stabilisation:**
  Camera Stabilisation
- **Antennas**
- **Agriculture Spray Booms**
  Cranes
- **Fork Lift Trucks**

- **Vehicle Dynamic Measurements**
- **Proving and Qualification**
- **Motorsport**
  Black box/accident recorders
- **Lean Angle Measurement**
  Ride monitoring

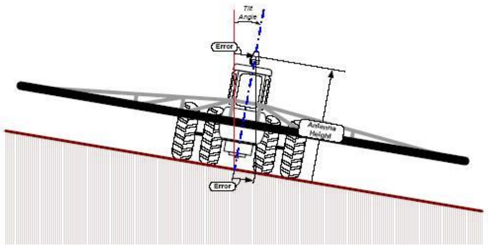
- **Flight Instruments and Avionics**
- **AHRSs, VRUs, VRSs**
  Autopilots
  UAVs



Applications

- **GPS Integration and Augmentation:**
  - **Autosteer – Precision Agriculture**
  - **Auto-helms**
  - **Tilt Compensation – Precision Agriculture**
  - **Navigation**
- **Guidance Navigation and Control:**
  - **Vehicle Navigation**
  - **Position Monitoring**
  - **Surveying**
  - **Vehicle Guidance and Control**
- **Rail:**
  - **Surveying and Track Condition Monitoring**

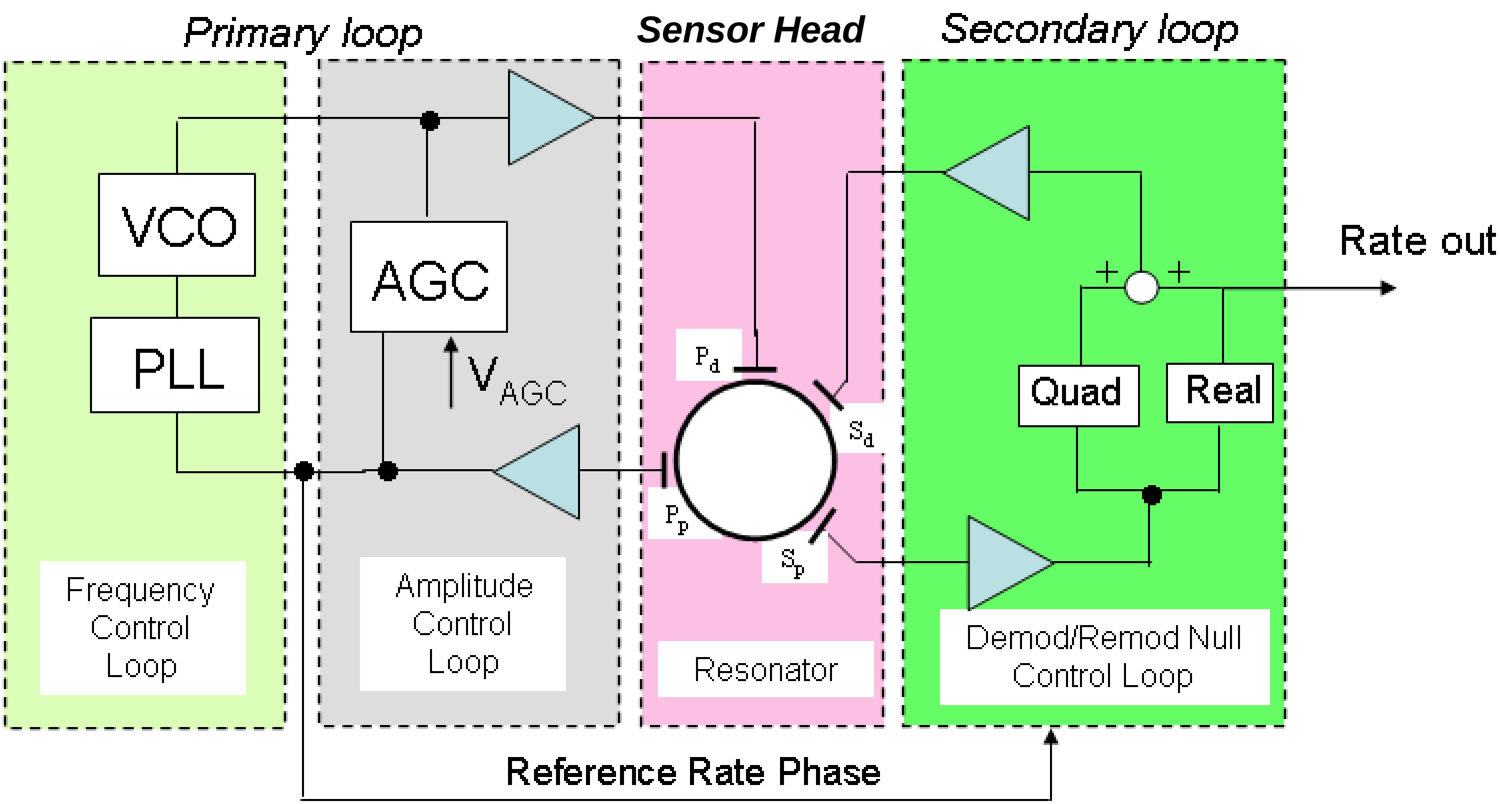
CenterLine® Guidance Lightbar



Applications

- **Automotive:**
  - **Black box/accident recorders**
  - **Navigation**
- **Technical Toys**
  - **Model Helicopters**
  - **Robotics**
  - **Education Kits**
  - **Inverted Pendulum**
- **Plant and Power Equipment:**
  - **Power Tools, safety and control**
  - **Lawn Mowers**
  - **Domestic/Industrial Robots**
  - **Torque Wrenches**
  - **Robotic Vacuum Cleaners**

A Vibrating Structure Gyroscope, VSG



A Gyroscope consists of a vibrating structure plus controlling electronics.

Vibrating Structure Gyro (VSG) Technology

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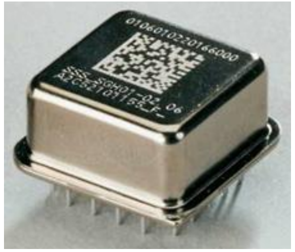
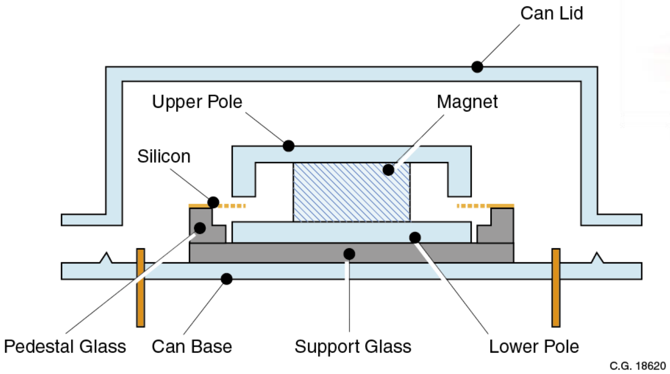
VSG 1 1985 | VSG 2 1995 | VSG 3 1998 | VSG 4 2006 | **VSG5 2010**

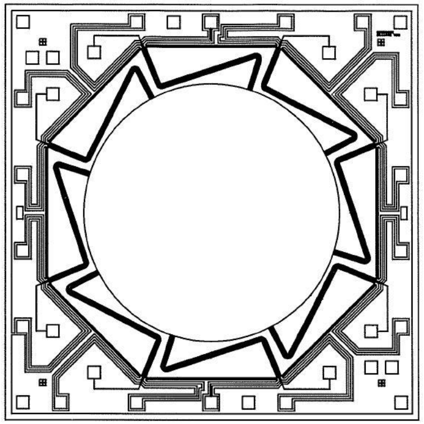
- Silicon Sensing's gyroscopes are Vibrating Structure Gyroscopes, VSGs
- These VSGs use shell (cylinder or ring) structures and work on the Coriolis principle where forces are observed when a linear motion occurs in a rotating frame.
- The closed loop technology provides excellent scale factor and performance over wide rate and temperature ranges.
- The technology has a very rugged design and construction and delivers superior performance than its competitors using other structures (e.g. tuning fork).

"Evolution not Revolution"

SGH01 Head

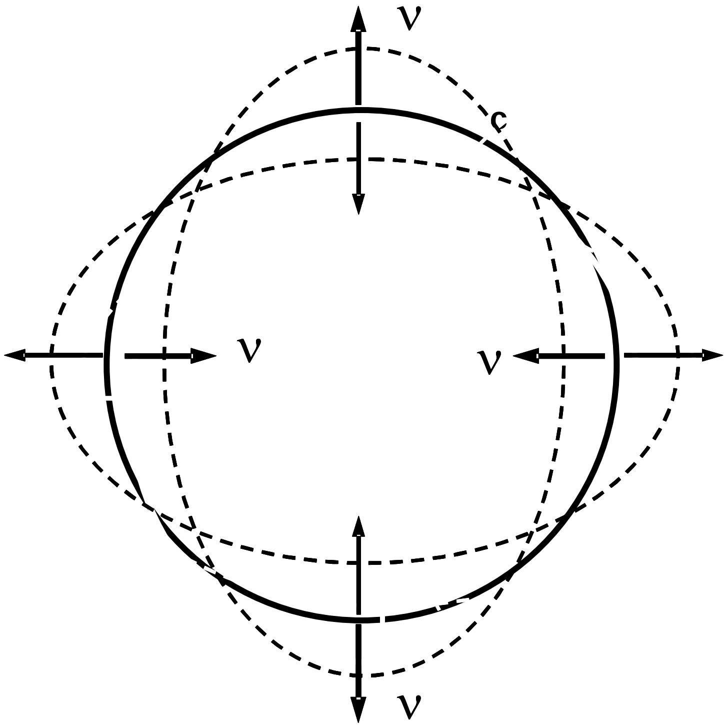


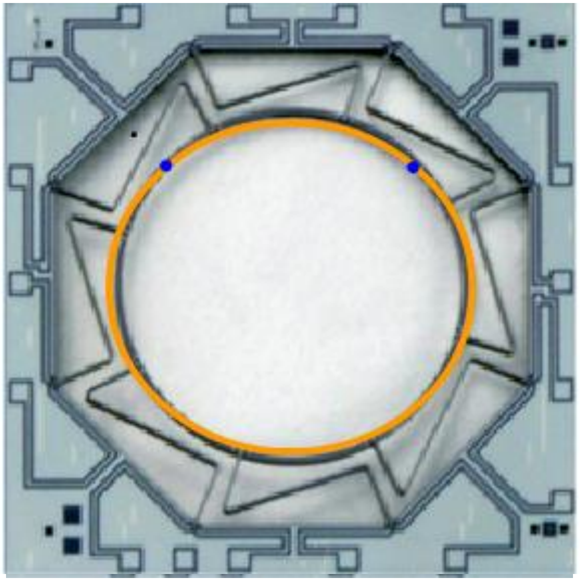




- Deep trench etched in bulk silicon
- Stable and robust crystalline silicon - 100µm thick
- Planar construction
- Single crystal pane
- Stability of key parameters (fn, f1-f2, Q1-Q2)
- 8 dog Legs to support the vibrating ring.
- Ring diameter: 6mm
- Leg width: 60µm
- Each leg carries three electric tracks

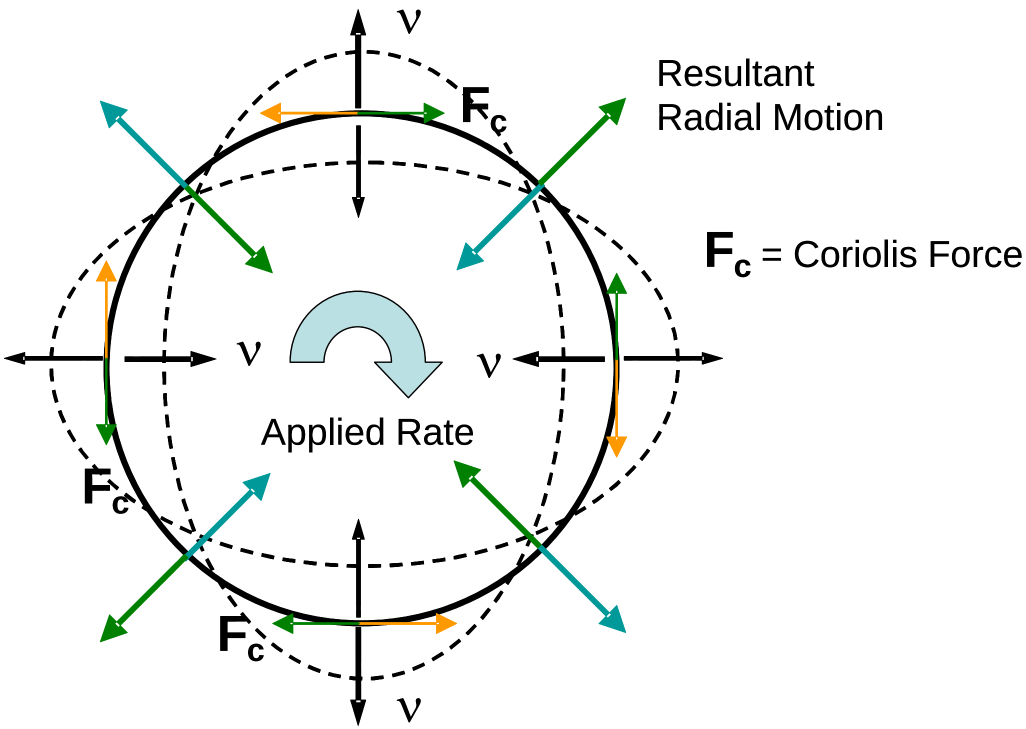
How the VSG works

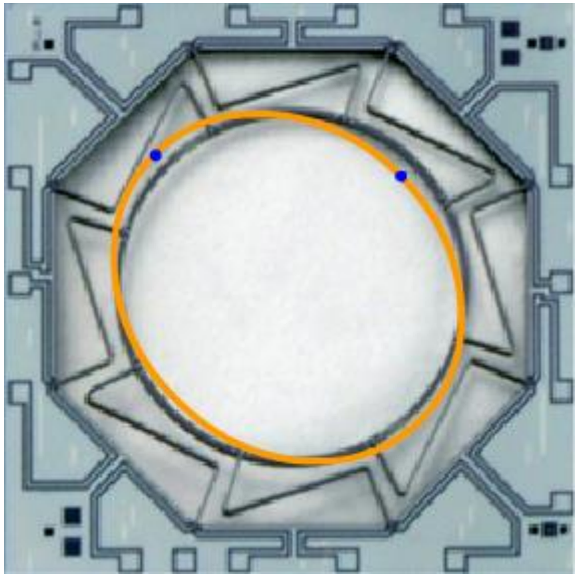




No angular rate applied

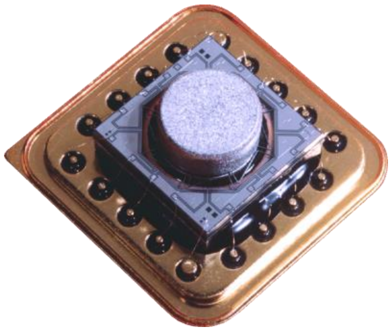
How the VSG works

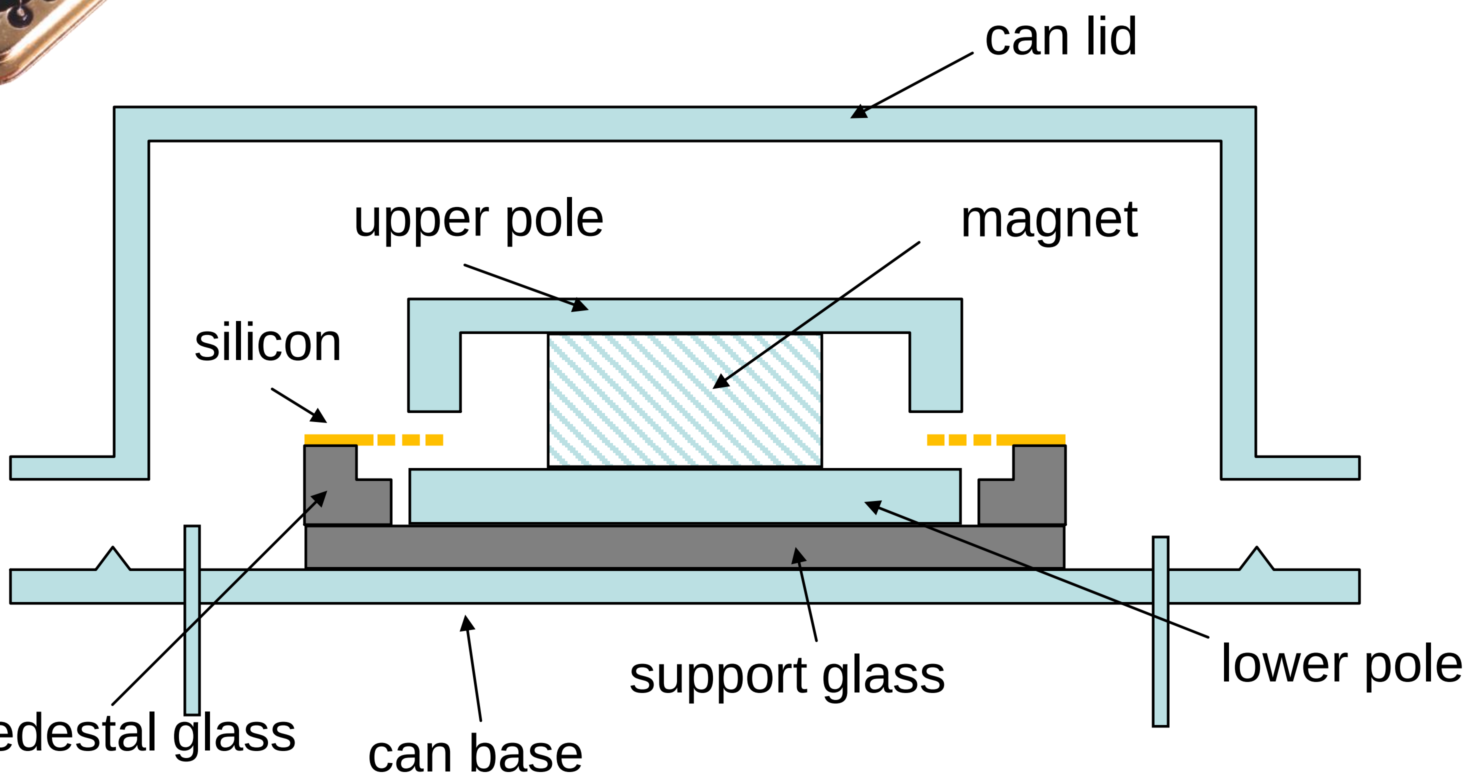




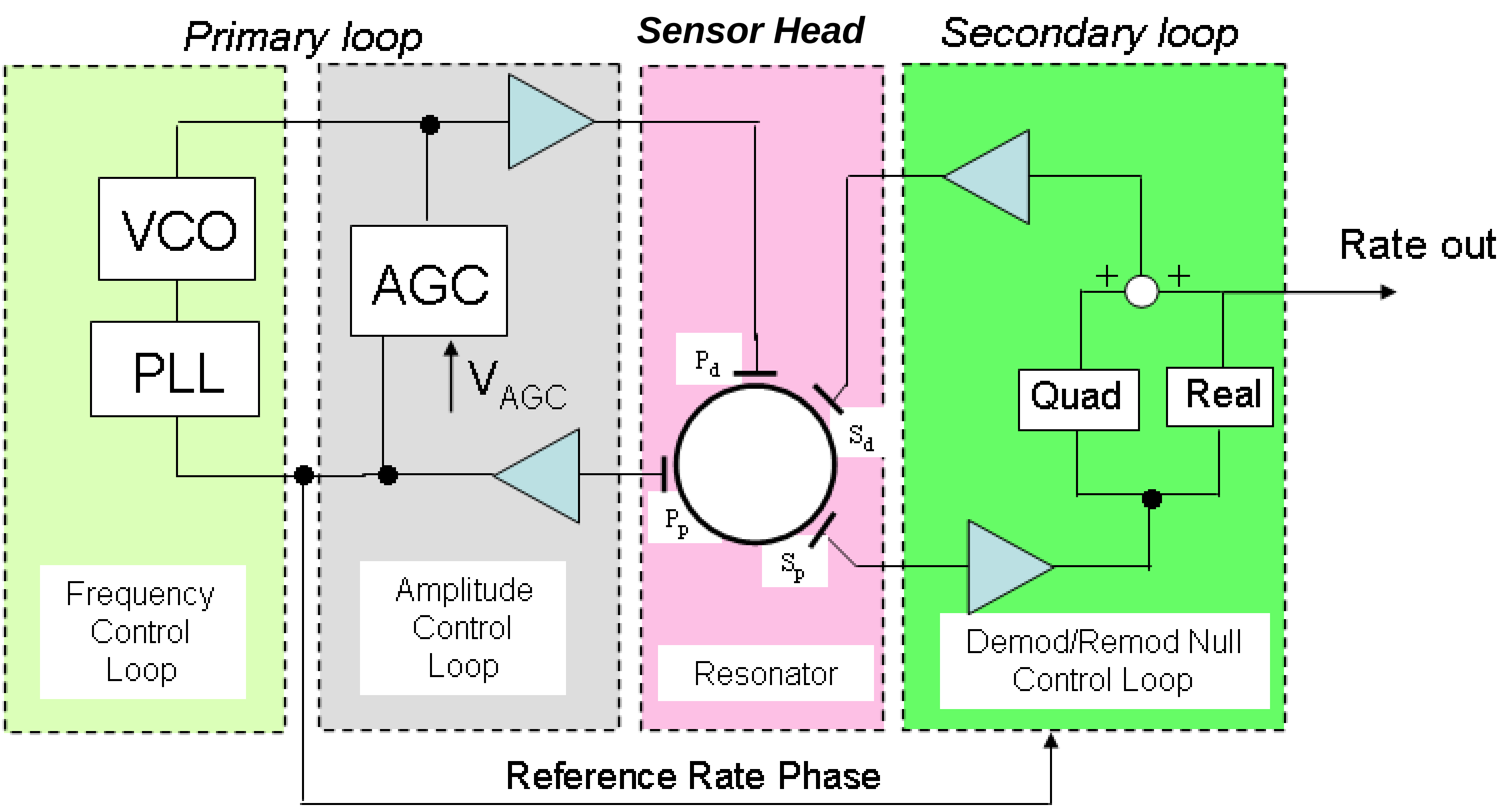
With angular rate applied

VSG3 Sensor Head Construction





Electronic Control Closed Loop Operation



Electronic control loop and the sensor head needed to make a gyroscope.

High Performance MEMS Gyroscopes

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CRS09

CRS39-01
CRS39-03

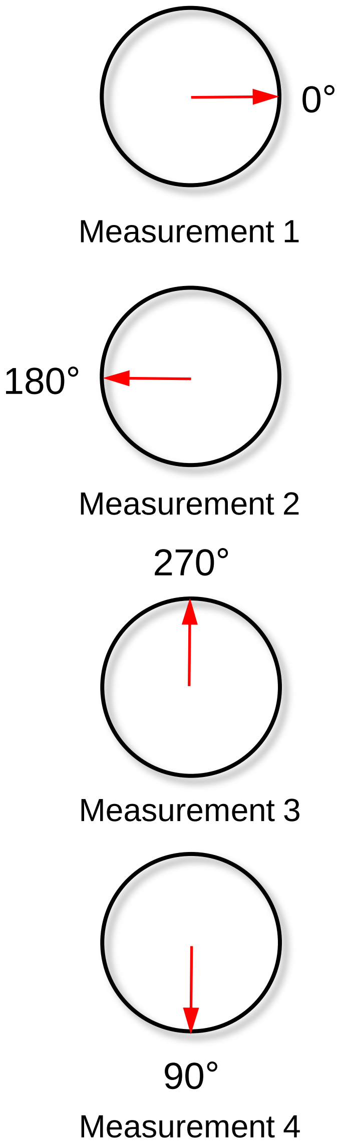
CRS39-02

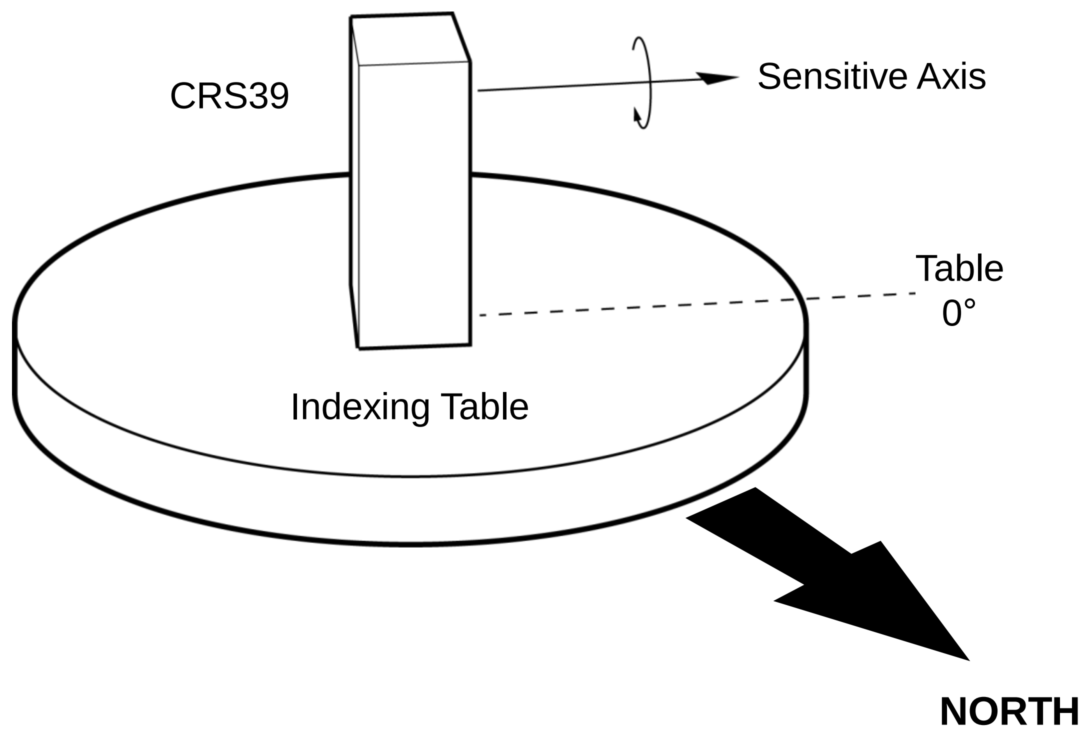
- **CRS09**
  - **Rate Ranges ± 100º/s and ± 200º/s**
  - **Bias Instability ~ 0.6º/h**
- **CRS39-01 (unpackaged) CRS39-02 (packaged)**
  - **Rate Range ± 25º/s**
  - **Bias Instability ~ 0.3º/h typical**
- **CRS39-03 (unpackaged)**
  - **Rate Range ± 25º/s**
  - **Bias Instability ~ 0.08º/h typical**
- **CRH01 and CRH02**
  - **Rate Range ± 25º/s ± 100º/s ± 200º/s and ± 400º/s**
  - **Bias Instability ~ 0.2º/h (CRH01), ~ 0.1º/h (CRH02) typical**

CRH01
CRH02

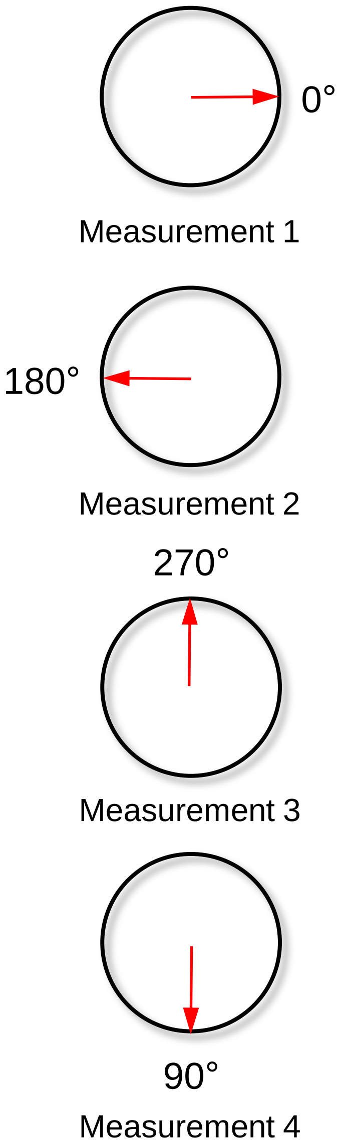
- **CRH01**

North Finding – Indexing Technique.





North Finding – Indexing Technique.



$$\text{Heading} = \text{ATAN2}\ \frac{(\text{Meas1} - \text{Meas2})}{(\text{Meas3} - \text{Meas4})}$$

where

Meas1 = EarthRate1+FixedErrors1+VariableErrors1

Meas2 = EarthRate2+FixedErrors2+VariableErrors2

Meas3 = EarthRate3+FixedErrors3+VariableErrors3

Meas4 = EarthRate4+FixedErrors4+VariableErrors4

but

EarthRate2 =-EarthRate1 and EarthRate4 = -EarthRate3

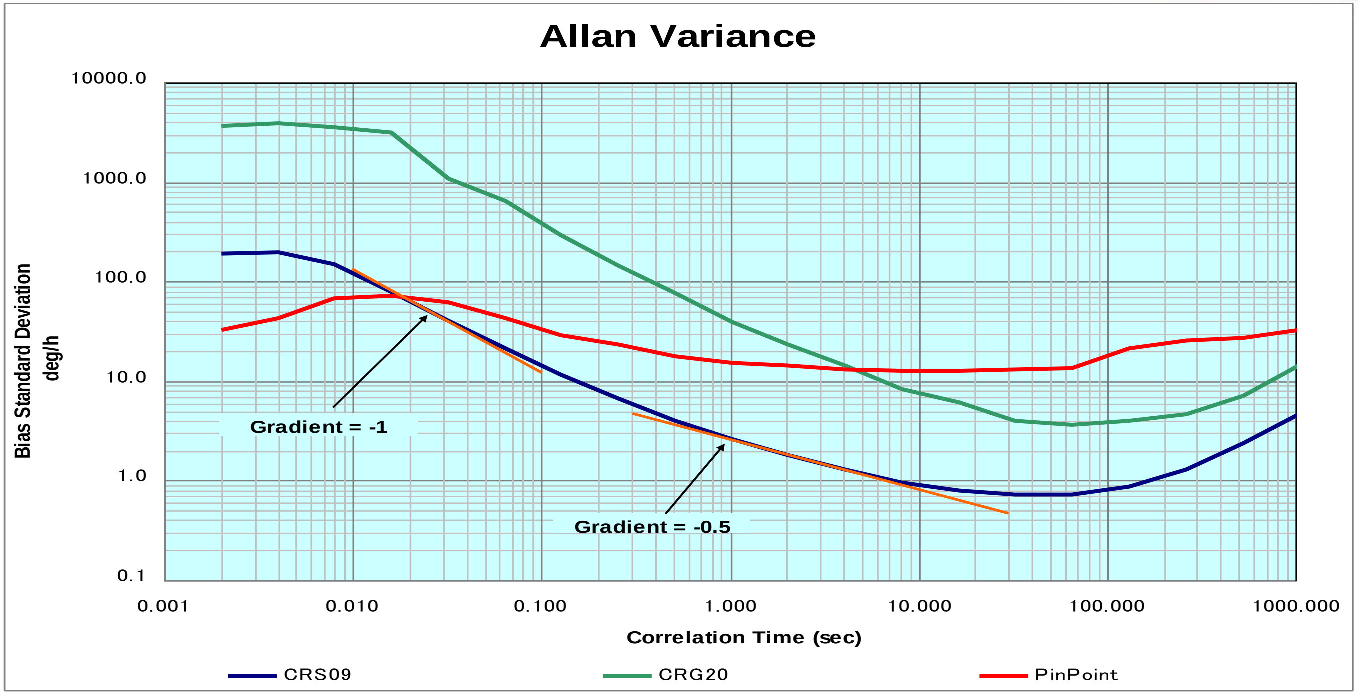
FixedErrors2=FixedErrors1 and FixedErrors4=FixedErrors3

therefore

(Meas1 – Meas2) = 2xEarthRate1 + ΔVariableErrors12

(Meas3 – Meas4) = 2xEarthRate3 + ΔVariableErrors34

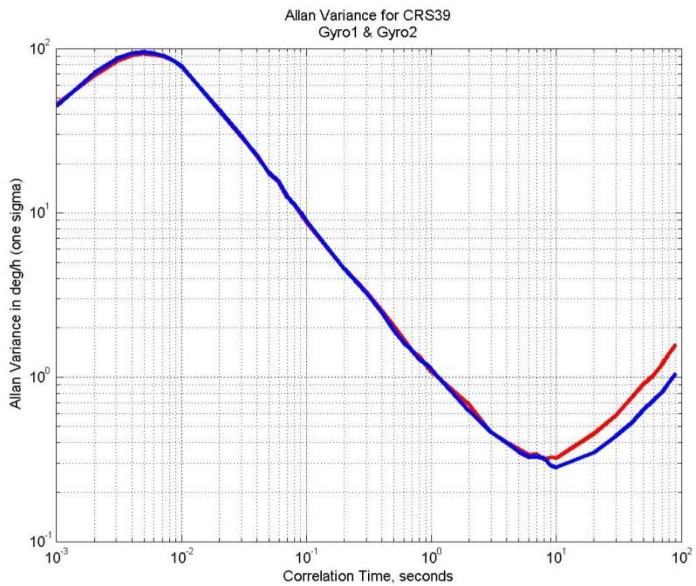
Bias Instability and Angle Random Walk



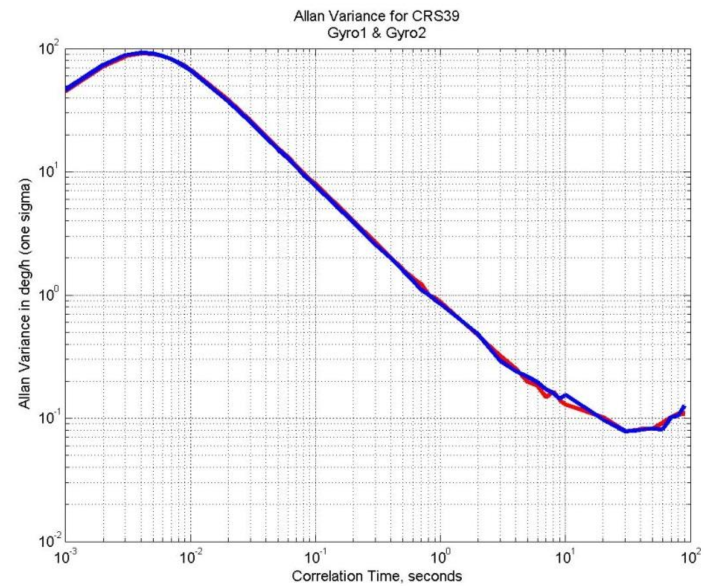
- The standard deviation of the bias changes between successive averages is plotted against the averaging period (or Correlation Time).
- Raw noise from the gyroscopes can be seen at the sampling frequency (there is no averaging here) at the left side of the chart, i.e. at 0.002 seconds above.
- Angle Random Walk can be calculated from the point where the -0.05 Gradient for a particular plot intercepts the 1 second point and then divided by 60. For the CRS09 above, the gradient intercepts at 2.8 deg/h, giving an ARW = 0.047 deg/√h.
- Bias Instability is read from the lowest part of the plots, 0.6 deg/h for CRS09.

CRS39: Allan Variance.

CRS39-01



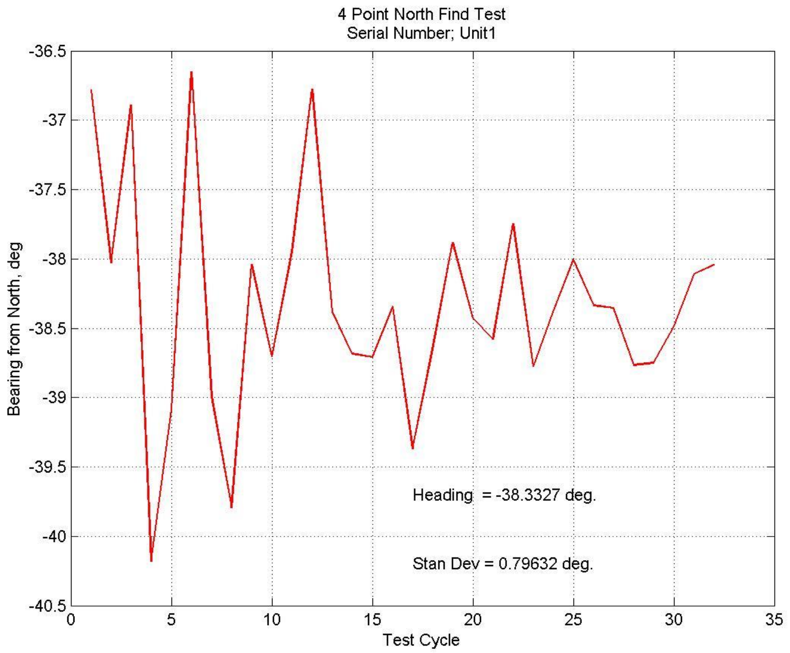
CRS39-03

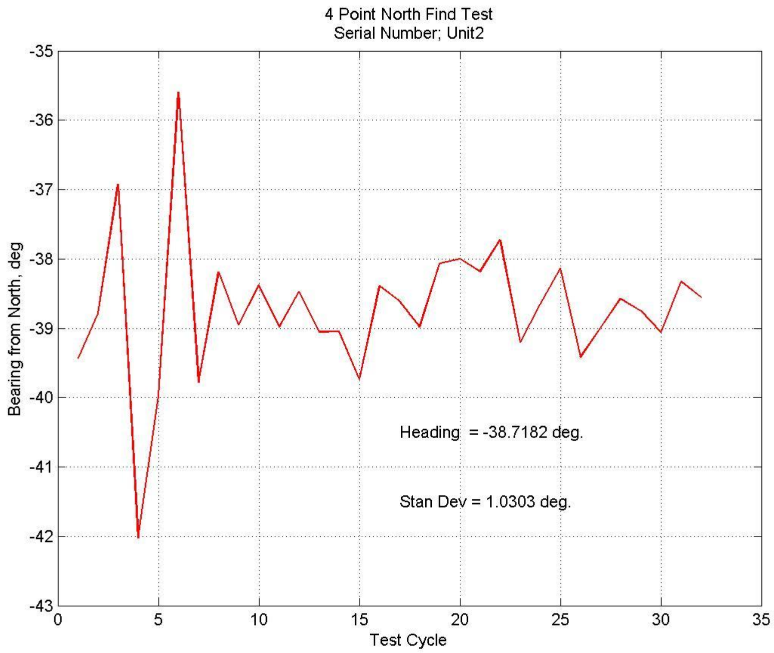


Bias instability improved from 0.3º/h to 0.08º/h

Angle Random Walk improved from 0.013º/√h to 0.0083º/√h

North Finding Accuracy – Raw Measurements





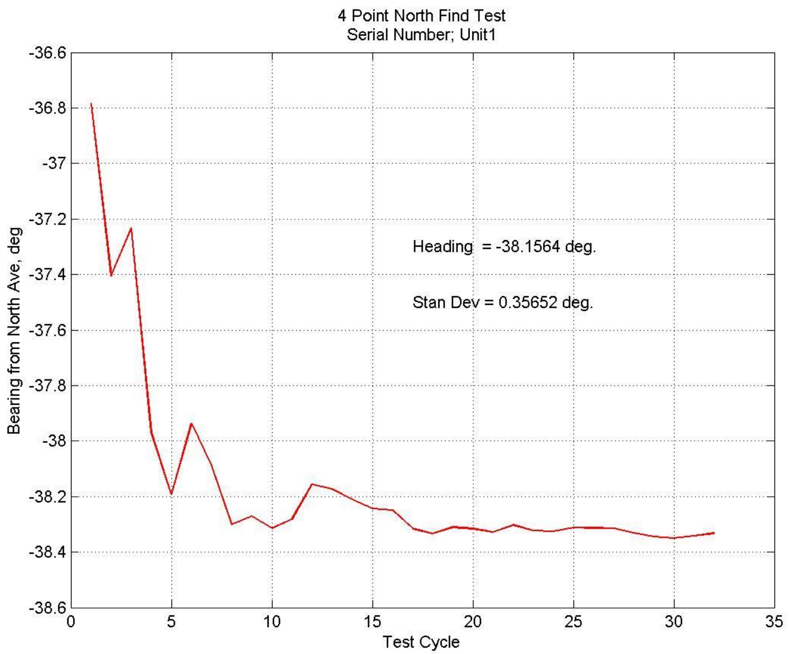
Single Measurements Unit 1.

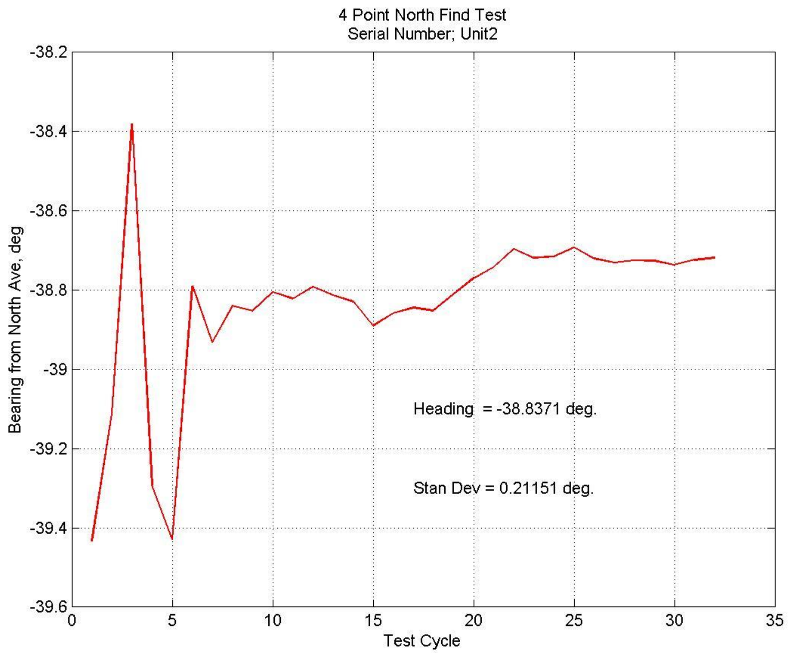
Single Measurements Unit 2.

North Finding Accuracy – Improvements

- Use more than one device
  - Use n devices to get $\sqrt{n}$ improvement factor.
- Use multiple measurements
  - Use n measurements to get $\sqrt{n}$ improvement factor.
- Ensure the device is warmed up
- Stable temperature improves bias instability.

North Finding Accuracy – Averaged

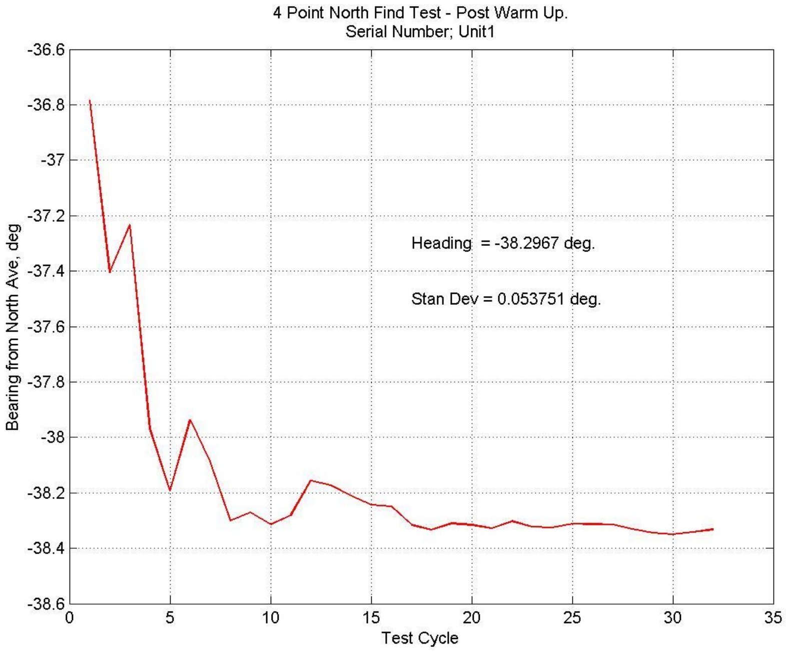


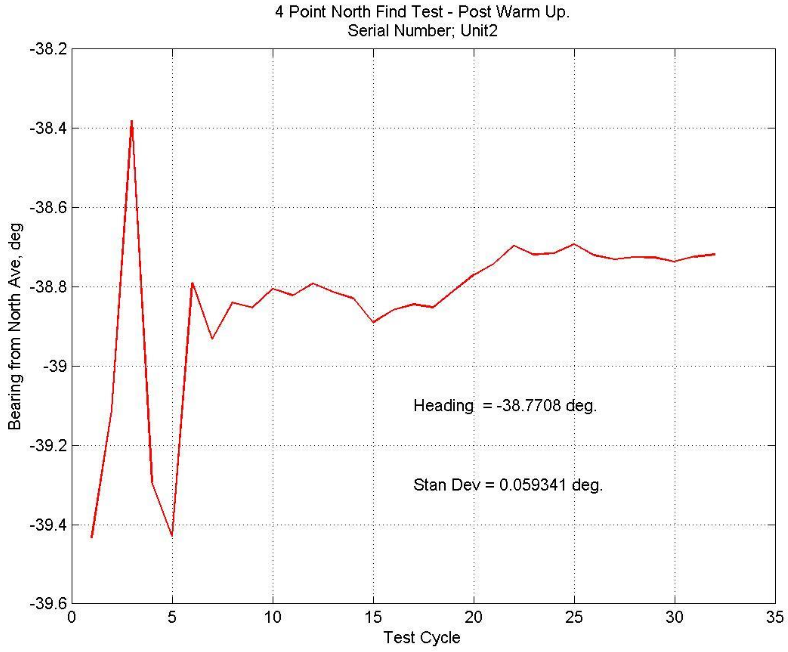


Single Measurements.

Averaged Measurements.

North Finding Accuracy – After Warm Up.





Averaged Measurements Unit 1

After Warm Up.

Averaged Measurements Unit 2

After Warm Up.

Summary

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Questions/Discussion

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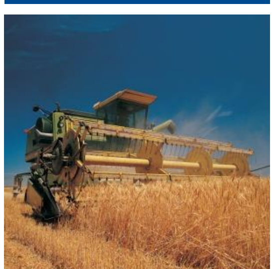



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