CRS39 Technical Datasheet

Analogue Angular Rate Sensor

High Performance MEMS Gyroscope

CRS39-03

Features

- Proven and Robust silicon MEMS vibrating ring structure
- FOG-like performance
- DTG-like size and performance
- Low Bias Instability (0.1°/h)
- Excellent Angle Random Walk (0.01°/√h)
- Ultra-low noise (<0.006°/s rms, 10Hz)
- Optimised for low rate range environments (e.g. North Finding)
- Precision analogue output
- Wide range from -10°C to +110°C
- High shock and vibration rejection
- Three temperature sensors for precision thermal compensation
- MEMS frequency output for precision thermal compensation
- RoHS Compliant
- Packaged and unpackaged options

Applications

- Platform Stabilization
- Precision Surveying
- Downhole Surveying
- North Finding
- Maritime Guidance and Control
- Gyro-compassing and Heading Control
- Autonomous Vehicles and ROVs
- Rail Track monitoring
- Robotics

1 General Description

CRS39-03 provides the optimum solution for applications where bias instability, angle random walk and low noise are of critical importance.

At the heart of the CRS39-03 is Silicon Sensing's VSG3Q^{MAX} vibrating ring MEMS sensor which is at the pinnacle of 15 years of design evolution and the latest off a line which has produced over 30 million high integrity MEMS inertial sensors. The VSG3Q^{MAX} gyro sensor is combined with precision discrete electronics to achieve high stability and low noise, making the CRS39 a viable alternative to Fibre-Optic Gyro (FOG) and Dynamically Tuned Gyro (DTG).

CRS39 has been designed for mounting within a 25mm inside diameter cylinder.

Three on board temperature sensors and the resonant frequency of the MEMS enable additional external conditioning to be applied to the CRS39 by the host, enhancing the performance even further.

Typical applications include downhole surveying, precision platform stabilization, ship stabilization, ship guidance and control, autonomous vehicles and high-end AHRS.

CRS39-03 supersedes CRS39-01. It is a higher specification, 'drop-in' replacement.

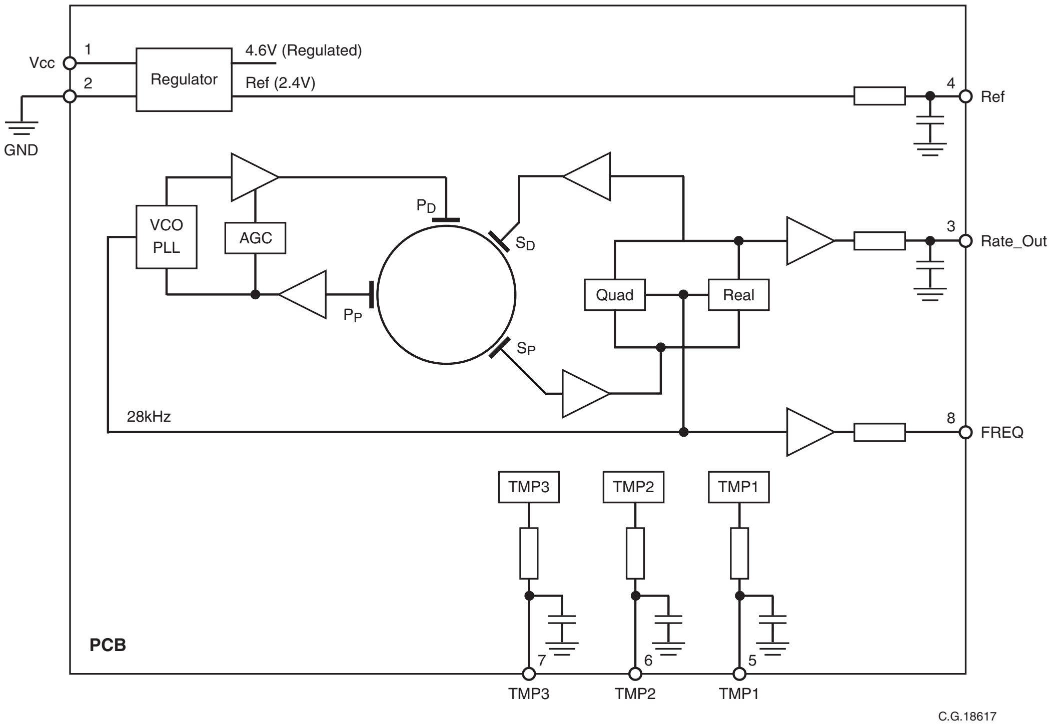
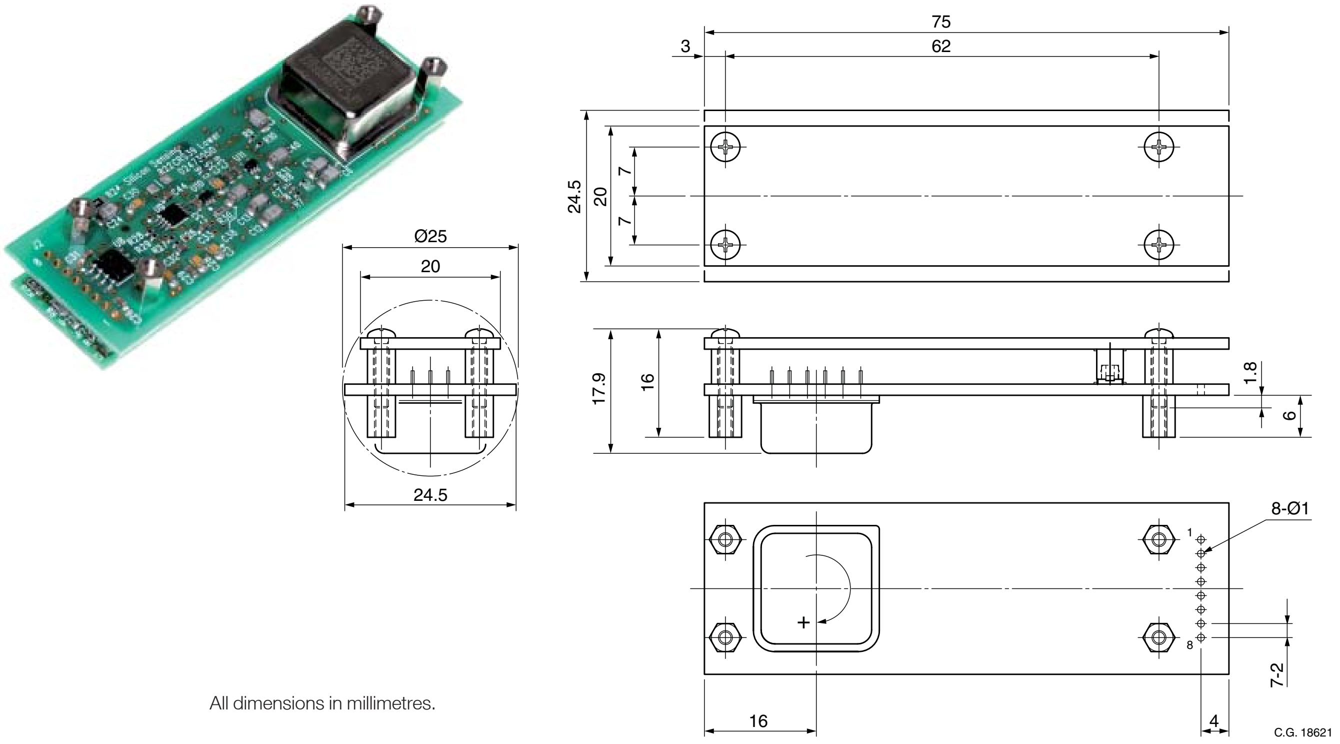


Figure 1.1 CRS39 Functional Block Diagram



All dimensions in millimetres.

Figure 1.2 CRS39-03 - Overall Dimensions

2 Ordering Information

Part Number	Package	Description	Overall Dimensions
			mm
CRS39-03-0100	Single - axis high performance MEMS gyro (unpackaged).	Bare PCB assembly is intended for mounting within the user's application such as a tube (25mm diameter), or other enclosure.	75 x 24.5 x 19.0

3 Specification

Unless otherwise specified the following specification values assume Vdd = 4.9 to 5.25 V over the temperature range -10 to +110°C.

Parameter	Minimum	Typical	Maximum	Notes
Angular Rate Range, °/s	<-25	–	>+25	–
Bias Setting Error, Volts	-0.10	±0.030	+0.10	Bias setting error at +45°C
Bias Variation Over Temperature, °/h	-500	±60	+500	Referenced to the setting point at +45°C
Bias Instability, °/h	–	0.10	–	As measured using the Allan Variance method, at constant ambient temperature
Angle Random Walk, °/√h	–	0.015	–	As measured using the Allan Variance method, at constant ambient temperature
Bandwidth, Hz.	15	25	35	-3dB point
Scale Factor, mV/°/s at +45°C	79.6	80.0	80.4	–
Scale Factor Error over Temperature, %	-1.0	±0.2	+1.0	Referenced to the setting point at +45°C
Scale Factor Non-Linearity Error, % of Full Scale	–	0.006	0.05	–
Noise to 10Hz, °/s rms	–	0.006	0.01	–
Wideband Noise, °/s rms	–	0.03	0.05	–
Start Up Time, seconds	–	–	1.0	Full performance will require additional time for thermal stability
Cross Axis Sensitivity, %	-3.5% (-2.0°)	±1.2% (0.7°)	+3.5% (+2.0°)	–

4 Power Requirements

Parameter	Minimum	Typical	Maximum	Notes
Supply Voltage, Vdd, Volts	4.9	5.0	5.25	Minimum of 4.9V is required for internal regulation
Current, mA	–	80	100	–
Noise 13.5kHz to 14.5kHz	–	–	0.5mV	Power supply ripple (pk - pk)
Noise 40.5kHz to 43.5kHz	–	–	5.0mV	Power supply ripple (pk - pk)

5 Frequency and Temperature Output Characteristics

Parameter	Minimum	Typical	Maximum	Notes
Frequency output, kHz	27.0	28.0	29.0	This signal is 2x resonant frequency of the MEMS structure and can be used to measure the MEMS temperature
Resonant Frequency Temperature Coefficient, Hz/°C	-0.90	-0.80	-0.70	–
TMP1, 2 and 3, Volts at +45°C	-1.16	-1.06	-0.96	Referenced to Ref.
Temperature Sensor Temperature Coefficient, mV/°C	-13.7	-11.7	-9.7	LM20B temperature sensor

6 Operating and Storage Environmental

Parameter	Minimum	Typical	Maximum	Notes
Operating Temperature Range °C	-10	–	+110	–
Non-operating Temperature Range °C	-40	–	+130	–
Operational Shock, g	–	–	250	For 1.7ms half-sine
Powered and Non-operational Shock Survival, g	–	–	1,000	For 1.0ms half-sine

Note: The shape of the CRS39-03 can make it susceptible to resonances when used in an environment with high shock or vibration levels. In these circumstances, it is recommended that additional supports along the edges of the PCB are provided.

7 Typical Performance Characteristics

Graphs showing typical performance characteristics for CRS39 are below.
Note: Typical data is with the device powered from a 5.0V supply, unless stated otherwise.

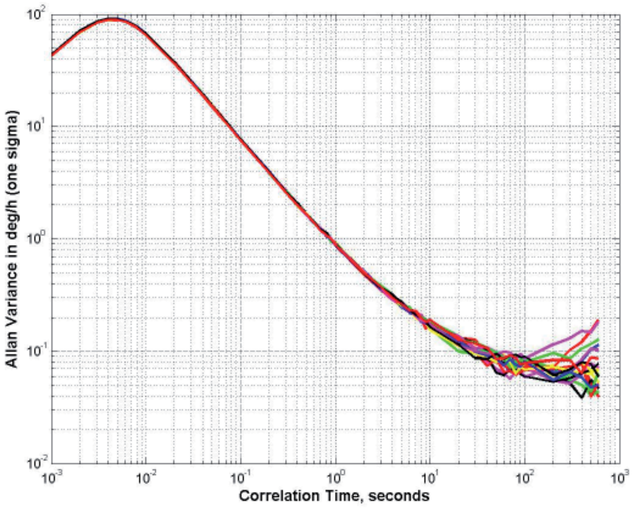


Figure 7.1 CRS39-03 Allan Variance

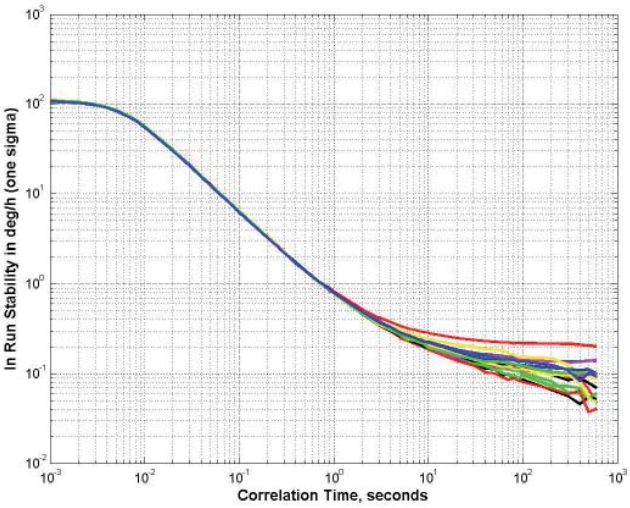


Figure 7.2 CRS39-03 In-Run Stability

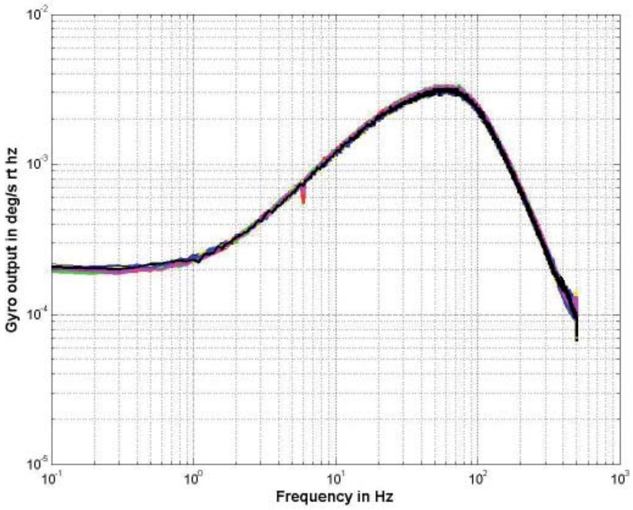


Figure 7.3 CRS39-03 Spectral Characteristics

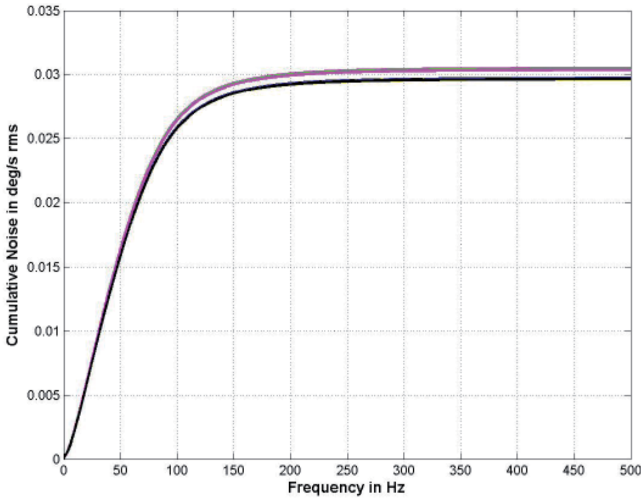


Figure 7.4 CRS39-03 Cumulative Noise

Typical Performance Characteristics Continued

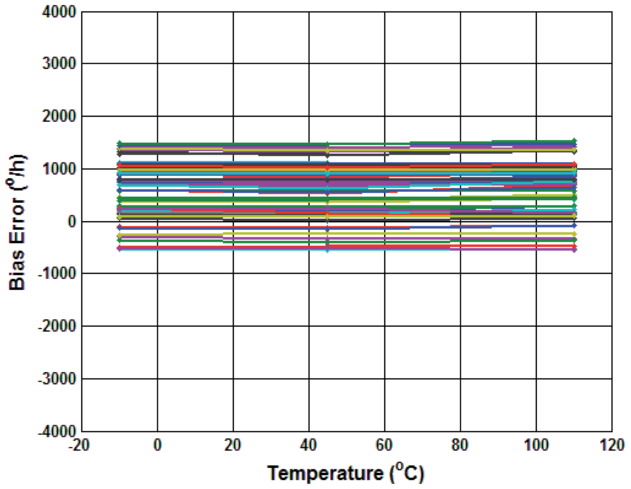


Figure 7.5 CRS39-03 Bias Error (dph) vs Temperature

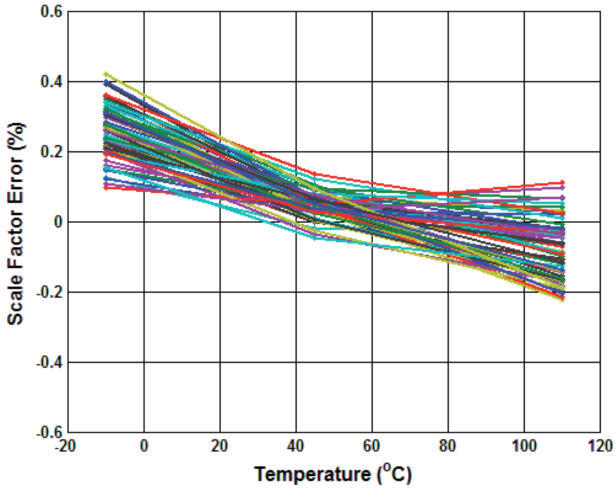


Figure 7.6 CRS39-03 Scale Factor Error (%) vs Temperature

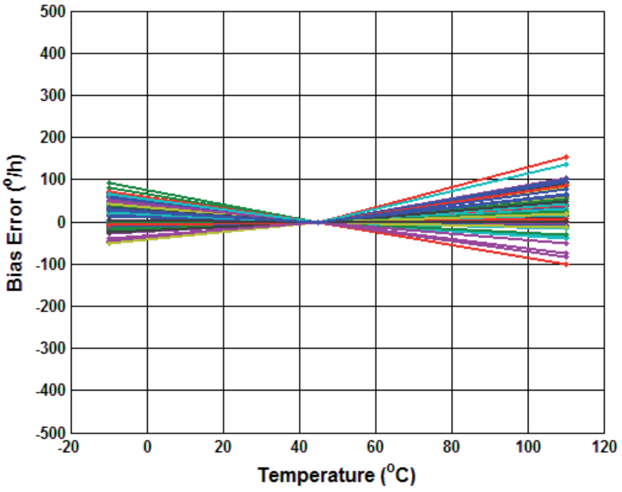


Figure 7.7 CRS39-03 Normalised Bias Error (dph) vs Temperature

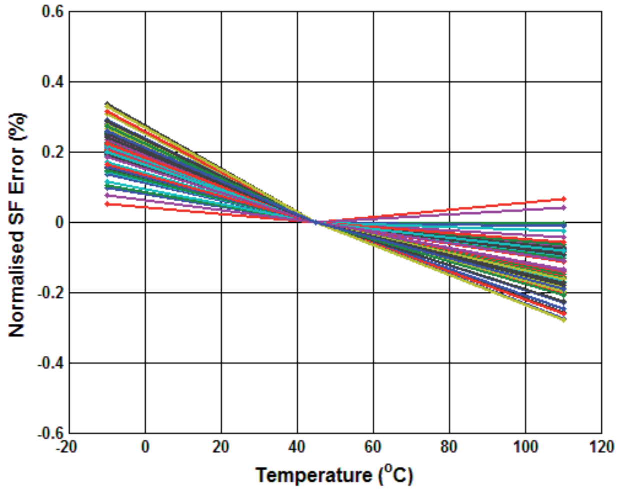


Figure 7.8 CRS39-03 Normalised Scale Factor Error (%) vs Temperature

Typical Performance Characteristics Continued

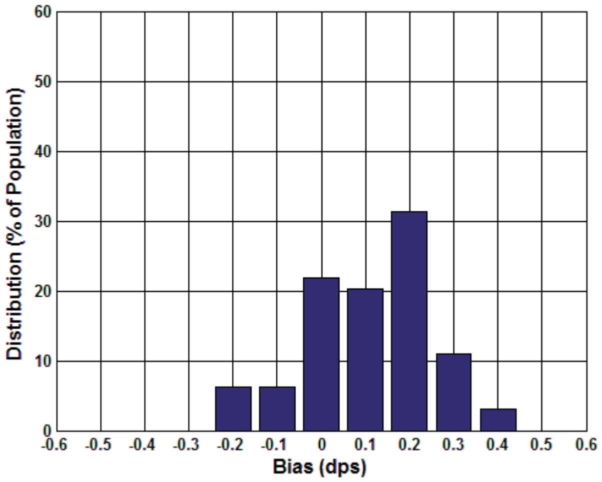


Figure 7.9 CRS39-03 Bias Setting Distribution (dps) at 45°C

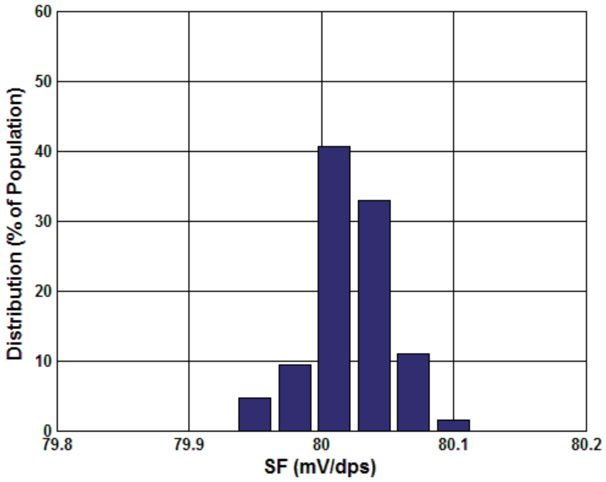


Figure 7.10 CRS39-03 Scale Factor Setting Distribution at 45°C

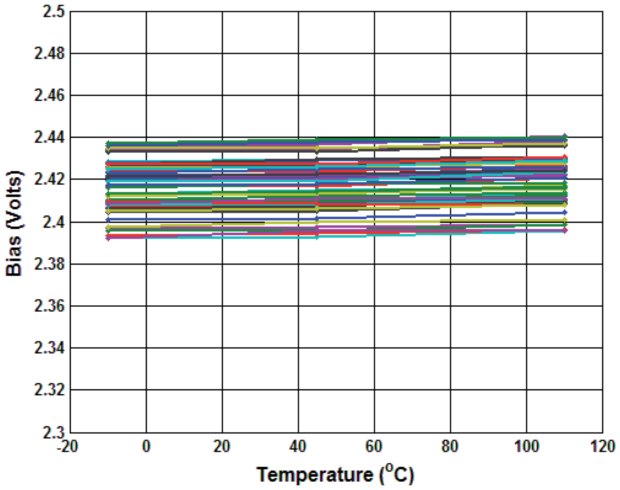


Figure 7.11 CRS39-03 Bias (Volts Single Ended) vs Temperature

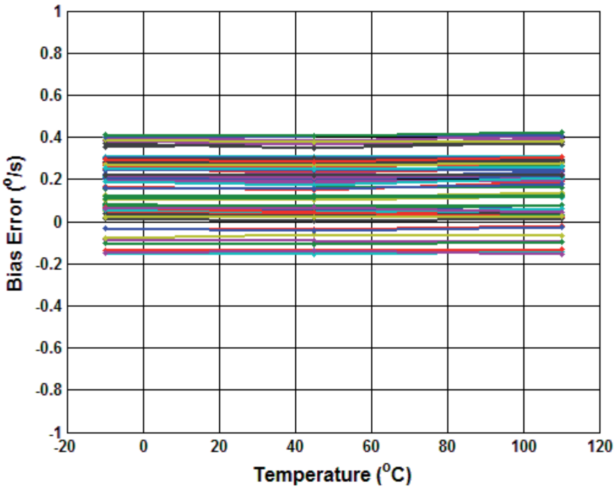


Figure 7.12 CRS39-03 Bias Error (dps) vs Temperature

Typical Performance Characteristics Continued

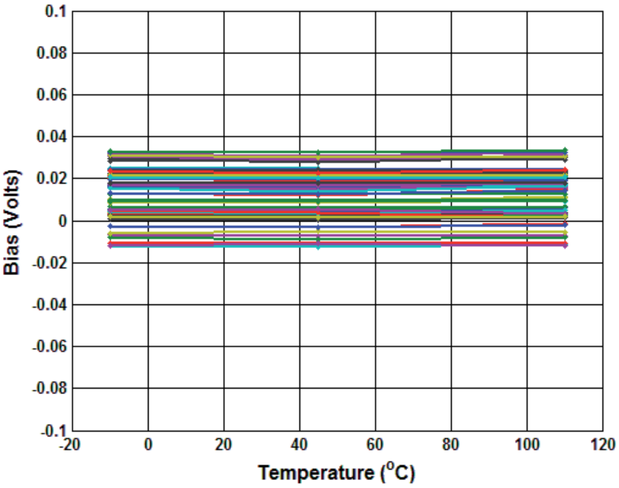


Figure 7.13 CRS39-03 Bias (Volts ref VRef) vs Temperature

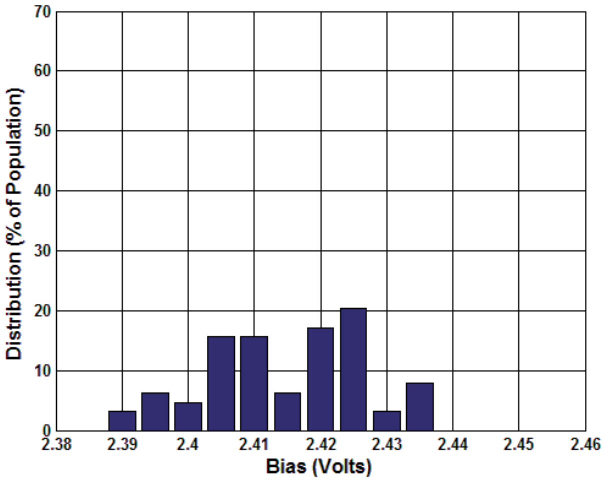


Figure 7.14 CRS39-03 Bias Setting Distribution (Volts) at 45°C

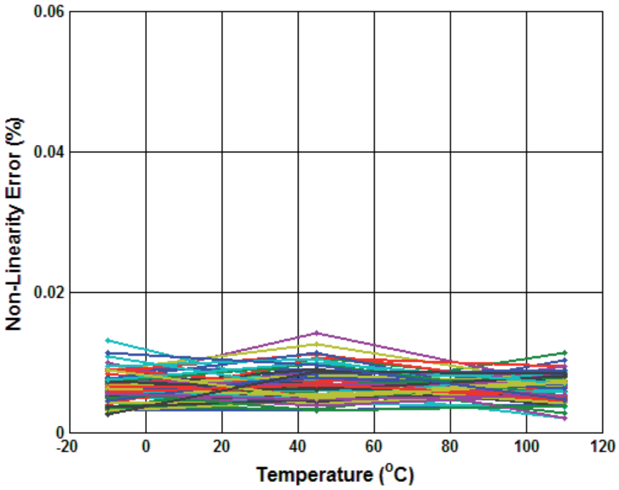


Figure 7.15 CRS39-03 Non-Linearity Error (%) vs Temperature

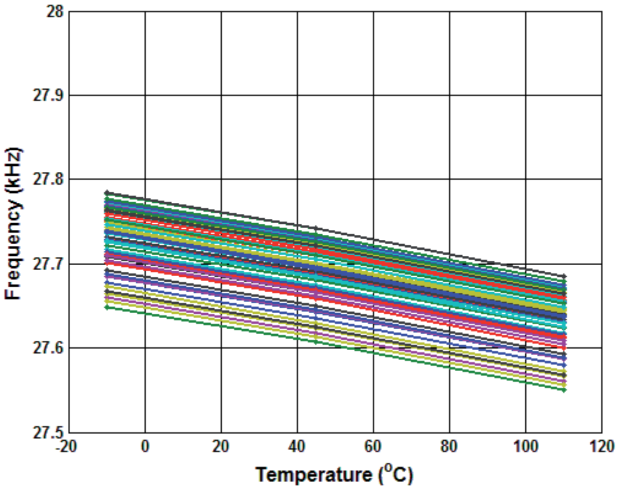


Figure 7.16 CRS39-03 Ring Frequency (%) vs Temperature

Typical Performance Characteristics Continued

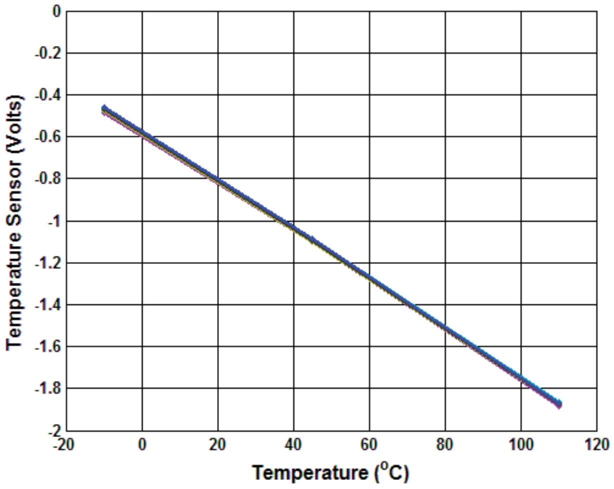


Figure 7.17 CRS39-03 Temperature Sensor (Volts ref VRef) vs Temperature

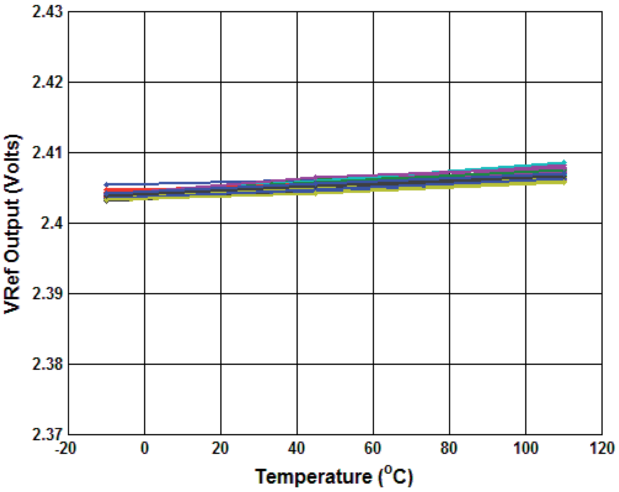


Figure 7.18 CRS39-03 VRef (Volts) vs Temperature

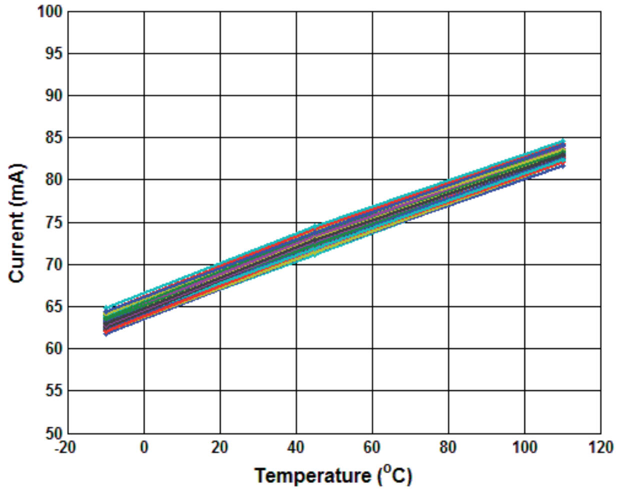
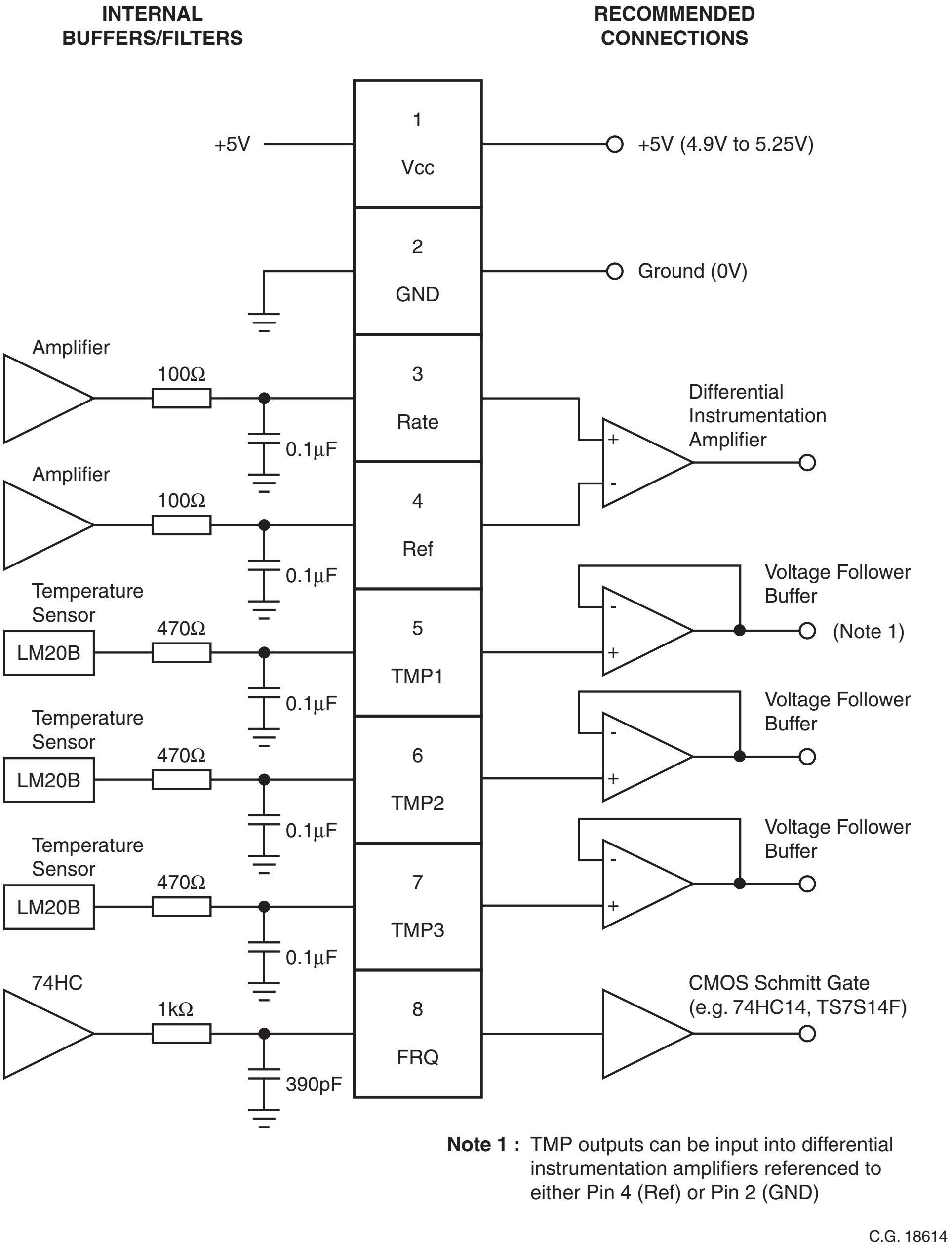


Figure 7.19 CRS39-03 Current Consumption (mA) vs Temperature

8 Interfacing



Note 1 : TMP outputs can be input into differential instrumentation amplifiers referenced to either Pin 4 (Ref) or Pin 2 (GND)

Figure 8.1 Recommended Interfacing

The table below provides connection details.

PCB Pin Number	Name	Comment
1	Vcc	Power Rail: 4.90 to 5.25 Volts, at 80mA approx. (200mA inrush)
2	GND	Power Supply and Signal Ground, 0 Volts.
3	Rate_Out	Angular Rate output. Nominally centred at Ref (2.40 Volts) for zero angular rate. Scale Factor is 80 mV/°/s. Nominal rate range is ± 25°/s
4	Ref	Voltage reference. Nominally fixed at 2.40 Volts. This reference is derived from a precision voltage reference integrated circuit and is used as the reference for the analogue electronics
5	TMP1	Temperature sensor output. A National Semiconductor LM20B is used to measure the temperature. TMP1 is located on the PCB, and is the furthest temperature sensor from the sensor head
6	TMP2	Temperature sensor output. A National Semiconductor LM20B is used to measure the temperature. TMP2 is located on the PCB, and is the temperature sensor midway between TMP1 sensor and the sensor head
7	TMP3	Temperature sensor output. A National Semiconductor LM20B is used to measure the temperature. TMP3 is located on the PCB, and is the temperature sensor on the under side of the sensor head
8	FREQ	This is CMOS Digital (74HC series) compatible digital output at two times the frequency of the sensor head

8.1 Temperature Sensors

The temperature sensors all use the LM20B device, internally connected as shown in Figure 8.2.

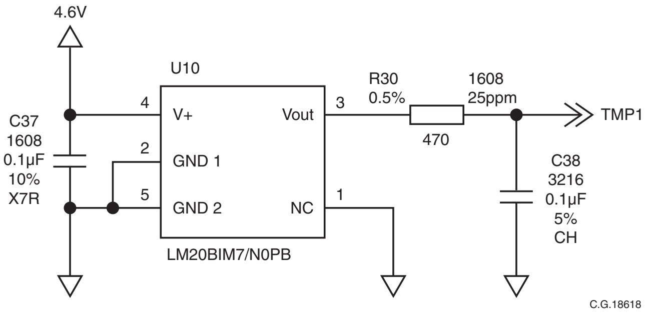


Figure 8.2 Temperature Sensors

The output at 0°C is typically +1.864V with respect to GND. The temperature coefficient is typically -11.7 mV/°C.

The output can be measured with respect to GND or can be put through a differential input instrumentation amplifier, referenced to the Ref pin, in which case the offset at 0°C is typically -0.536V. At +45°C, the output is typically -1.06V with respect to Ref. The temperature sensors are not intended for use as a thermometer, since they are not calibrated on the Celsius scale. They are intended only as a temperature reference for thermal compensation techniques.

8.2 Rate and Ref Outputs

Both the Rate and the Ref outputs are passed through a simple RC low pass filter before the output pins. The resistor value is 100 ohms. The capacitor value is 0.1μF.

It is recommended that the Rate Output (signal High or +) is differentially sensed using a precision instrumentation amplifier, referenced to the Ref output (signal Low or -).

The Offset of the instrumentation amplifier should be derived from the host stage (e.g. derived from the ADC Ref Voltage) or from the signal ground if the following stage is an analogue stage.

8.3 Frequency Outputs

This is CMOS Digital (74HC series) compatible digital output at two times the frequency of the sensor head. It is provided to give an indication of the temperature of the MEMS sensor head. The nominal frequency is 28KHz with a typical temperature coefficient of -0.8Hz/°C.

The signal is protected with a 1Kohm resistor before being output from the CRS39. It is recommended that this signal is buffered with a CMOS Schmitt Gate such as 74HC12, or TC7S14F. The signal can be used to accurately measure the temperature of the MEMS structure.

An example of measuring the MEMS temperature is to use a precision crystal oscillator (operating at a very high frequency, for example 20, 40 or 60MHz) to measure the frequency of the ring by measuring the time (oscillator clock cycles) to count to a defined number of ring cycles.

9 Glossary of Terms

ADC	Analogue to Digital Converter
ARW	Angular Random Walk
BW	Bandwidth
C	Celsius or Centigrade
DAC	Digital to Analogue Converter
DPH	Degrees Per Hour
DPS	Degrees Per Second
DRIE	Deep Reactive Ion Etch
EMC	Electro-Magnetic Compatibility
ESD	Electro-Static Damage
F	Farads
h	Hour
HBM	Human Body Model
Hz	Hertz, Cycle Per Second
K	Kilo
MEMS	Micro-Electro Mechanical Systems
mV	Mili-Volts
NEC	Not Electrically Connected
NL	Scale Factor Non-Linearity
PD	Primary Drive
PP	Primary Pick-Off
RC	Resistor and Capacitor filter
s	Seconds
SF	Scale Factor
SMT	Surface Mount Technology
SOG	Silicon On Glass
SD	Secondary Drive
SP	Secondary Pick-Off
T.B.A.	To Be Announced
T.B.D.	To Be Described
Wrt	With respect to
V	Volts

10 Part Markings

CRS39-03 is uniquely identified by the part markings on the SGH03 sensor; the large through-hole metal can device. These markings consist of the following information.

SGH03 Part Number
SGH03-11

SGH03 Manufacturing Code
0300000VVXX00YYMMPPWWWCCCCSSS

Content	Detail	No of Digits	Cumulative Digits
0300000VV	Product variant	9	9
XX	Relates to the revision level of the product specification e.g. issue 04 = ‘04’	2	11
00	Product variant	2	13
YY	Year - the last two digits of the year of manufacture 2008 will be shown as ‘08’	2	15
MM	Month - the numerical value of the month of manufacture where: ‘01’ equates to January, and ‘12’ equates to December	2	17
PP	Production Line - at present there is only one line at SSP, Japan, this will be denoted as site ‘01’	2	19
WWW	Wafer Lot Number equates to the production lot number, as defined in manufacturing, consisting of 3 numerical digits	3	22
CCCC	Counter is the series number of the unit within the production batch, driven by the sequence off the production line	4	26
SSS	Supplier’s internal coding	3	29

The SGH03 Part Number and Manufacturing Code is also stored in the 2D Data Matrix Code printed on the sensor.

11 Silicon MEMS Ring Sensor (Gyro)

At the heart of the CRS39-03 is Silicon Sensing’s VSG3Q$^{\text{MAX}}$ vibrating ring MEMS sensor which is at the pinnacle of 15 years of design evolution and the latest off a line which has produced over 30 million high integrity MEMS inertial sensors. The VSG3Q$^{\text{MAX}}$ gyro sensor is combined with precision discrete electronics to achieve high stability and low noise, making the CRS39-03 a viable alternative to Fibre-Optic Gyro (FOG) and Dynamically Tuned Gyro (DTG).

The silicon MEMS ring is 6mm diameter by 100µm thick, fabricated by Silicon Sensing Systems using a DRIE (Deep Reactive Ion Etch) bulk silicon process. The ring is supported in free-space by sixteen pairs of ‘dog-leg’ shaped symmetrical legs which support the ring from the supporting structure on the outside of the ring.

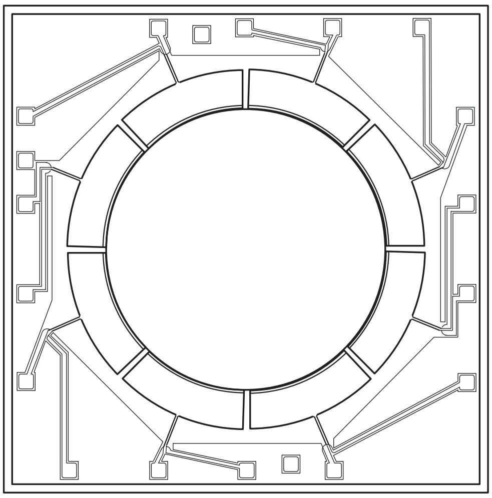


Figure 11.1 Silicon MEMS Ring

The bulk silicon etch process and unique patented ring design enable close tolerance geometrical properties for precise balance and thermal stability and, unlike other MEMS gyros, there are no small gaps to create problems of interference and stiction. These features contribute significantly to CRS39’s bias and scale factor stability over temperature, and vibration immunity. Another advantage of the design is its inherent immunity to acceleration induced rate error, or ‘g-sensitivity’.

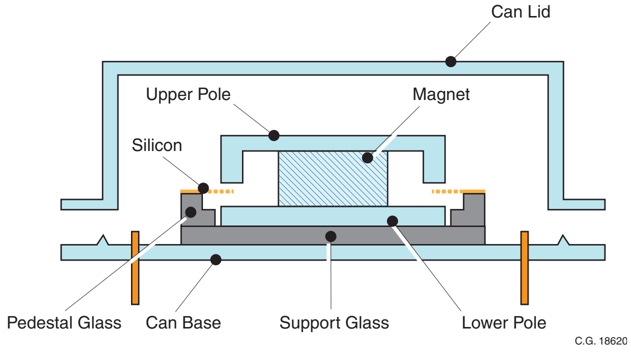


Figure 11.2 MEMS Sensor Head

The ring is essentially divided into 8 sections with two conductive tracks in each section. These tracks enter and exit the ring on the supporting legs. The silicon ring is bonded to a glass pedestal which in turn is bonded to a glass support base. A magnet, with upper and lower poles, is used to create a strong and uniform magnetic field across the silicon ring. The complete assembly is mounted within a hermetic can with a high internal vacuum.

The tracks along the top of the ring form two pairs of drive tracks and two pairs of pick-off tracks. Each section has two loops to improve drive and pick-off quality.

One pair of diametrically opposed tracking sections, known as the Primary Drive PD section, is used to excite the cos2θ mode of vibration on the ring. This is achieved by passing current through the tracking, and because the tracks are within a magnetic field causes motion on the ring. Another pair of diametrically opposed tacking sections is known as the Primary Pick-off PP section is used to measure the amplitude and phase of the vibration on the ring. The Primary Pick-off sections are in the sections 90° to those of the Primary Drive sections. The drive amplitude and frequency is controlled by a precision closed loop electronic architecture with the frequency controlled by a Phase Locked Loop (PLL), operating with a Voltage Controlled Oscillator (VCO), and amplitude controlled with an Automatic Gain Control (AGC) system. The primary loop therefore establishes the vibration on the ring and the closed loop electronics is used to track frequency changes and maintain the optimal amplitude of vibration over temperature and life. The loop is designed to operate at about 14kHz.

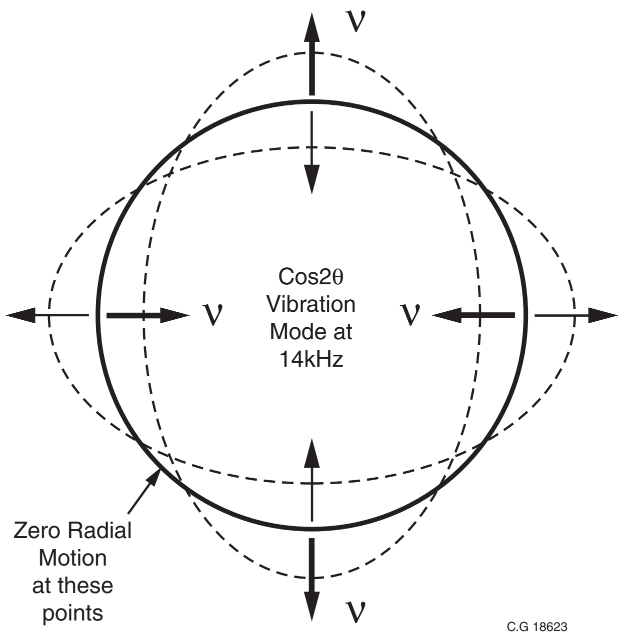


Figure 11.3 Primary Vibration Mode

Having established the cos2θ mode of vibration on the ring, the ring becomes a Coriolis Vibrating Structure Gyroscope. When the gyroscope is rotated about its sense axis the Coriolis force acts tangentially on the ring, causing motions at 45° displaced from the primary mode of vibration. The amount of motion at this point is directly proportional to the rate of turn applied to the gyroscope. One pair of diametrically opposed tracking sections, known as the Secondary Pick-off SP section, is used to sense the level of this vibration. This is used in a secondary rate nulling loop to apply a signal to another pair of secondary sections, known as the Secondary Drive SD. The current applied to the Secondary Drive to null the secondary mode of vibration is a very accurate measure of the applied angular rate. All of these signals occur at the resonant frequency of the ring. The Secondary Drive signal is demodulated to baseband to give a voltage output directly proportional to the applied rate in free space.

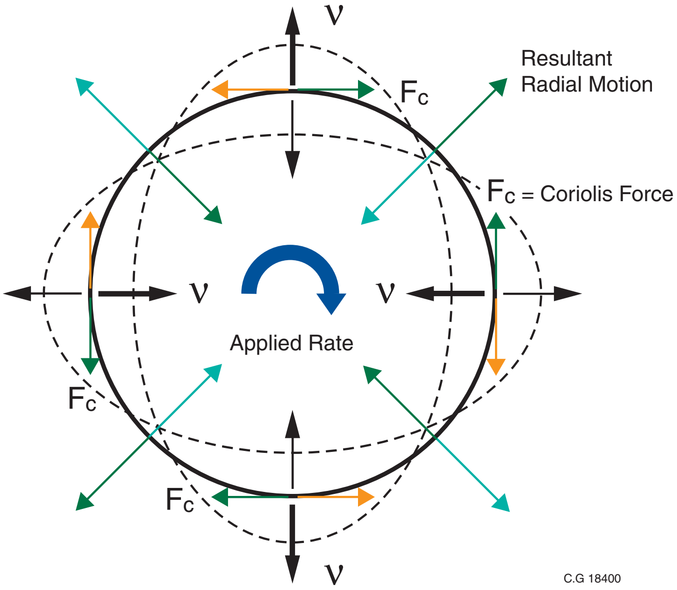


Figure 11.4 Secondary Vibration Mode

The closed loop architecture on both the primary and secondary loops result is excellent bias, scale factor and non-linearity control over a wide range of operating environments and life. The dual loop design, introduced into this new Sensor Head design, coupled with improved geometric symmetry results in excellent performance over temperature and life. The discrete electronics employed in CRS39, ensures that performance is not compromised.

Notes

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