Low-Noise MEMS Gyroscope System for Navigation

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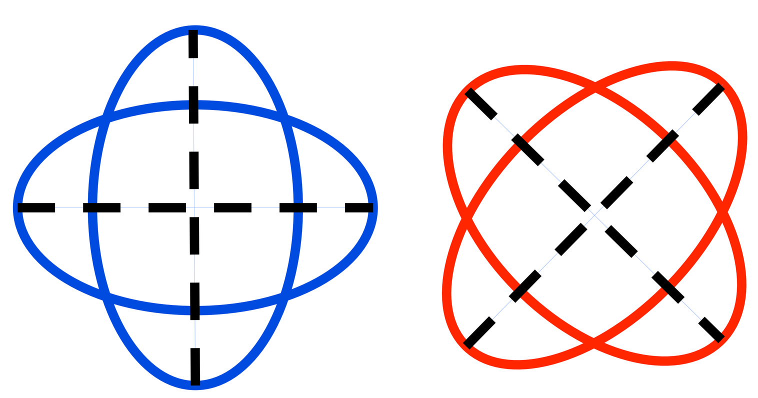
Motivation

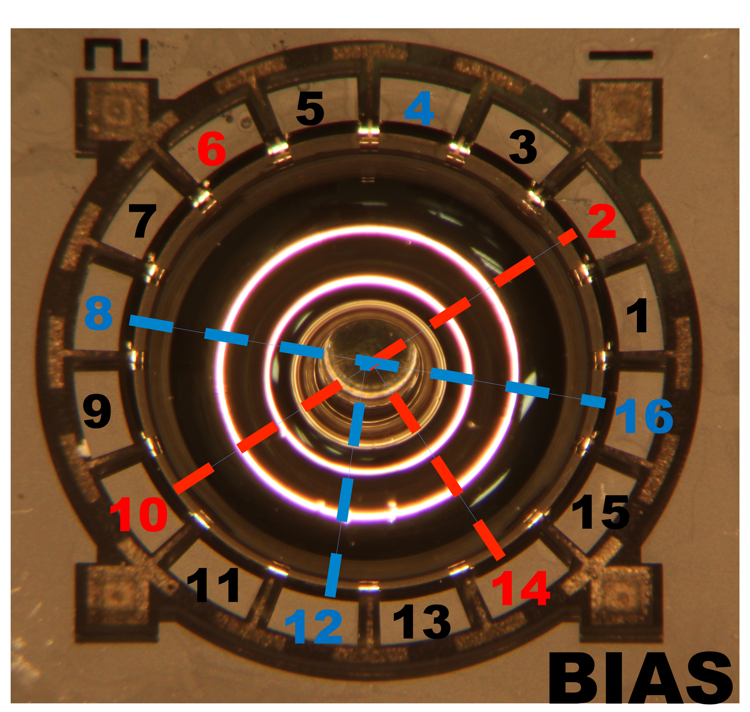
- Develop an accurate rotation sensor which fits in a volume of 10 mm^3
- Applications
  - GPS-free inertial navigation
  - Active vehicle safety systems
  - Robotics and autonomous vehicles
  - Health monitoring systems
- Mechanical damping (Q) determines gyroscope fundamental noise floor
- Inherent sensor noise from fabrication mismatch is reduced using closed-loop control
- Low-noise interface circuit is necessary to push accuracy towards theoretical limits

Gyro Characterization

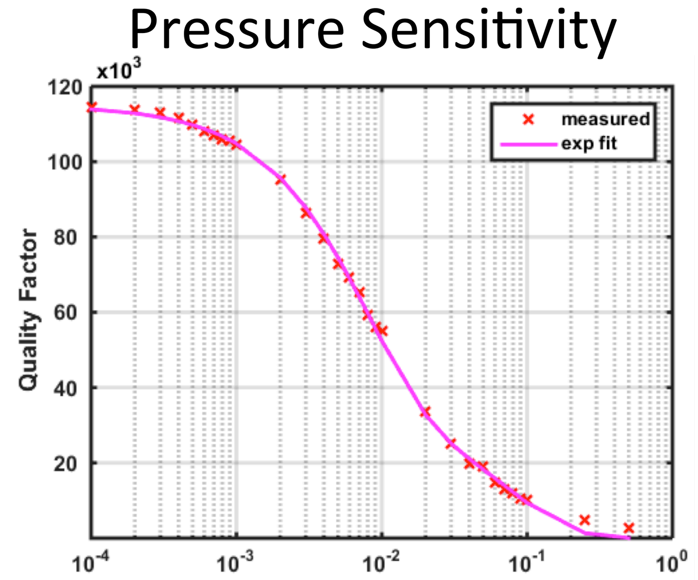
Quality Factor $(Q)=\pi f \tau$



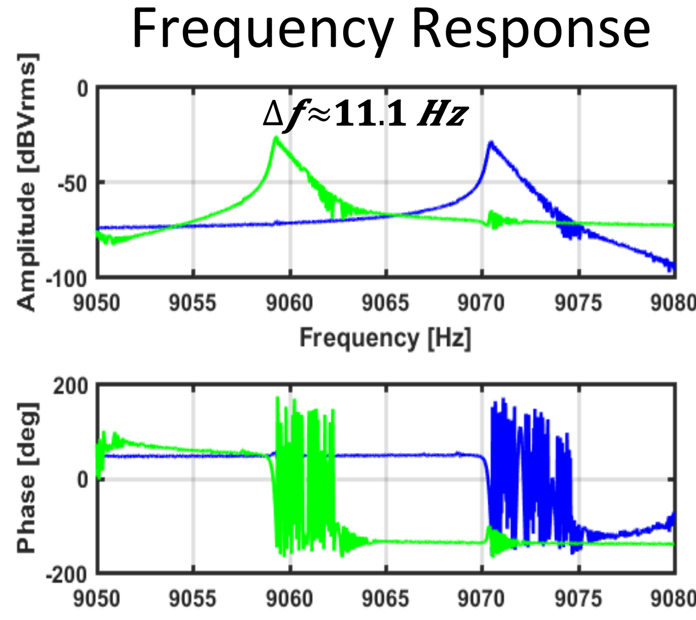
Drive Mode Sense Mode



Pressure Sensitivity



Frequency Response



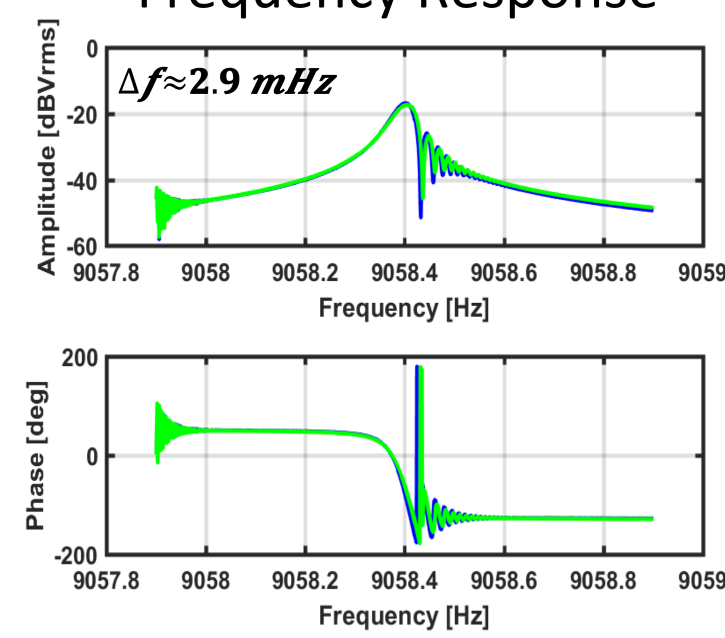
Angle Random Walk Equation

$$ARW \approx \sqrt{\frac{k_B T \omega_2}{A^2 M \omega_1^2 Q_2}\left(1+\frac{(\Delta\omega)^2}{\gamma^2}\right)} \times 3437.7\ {}^\circ/\sqrt{hr}$$

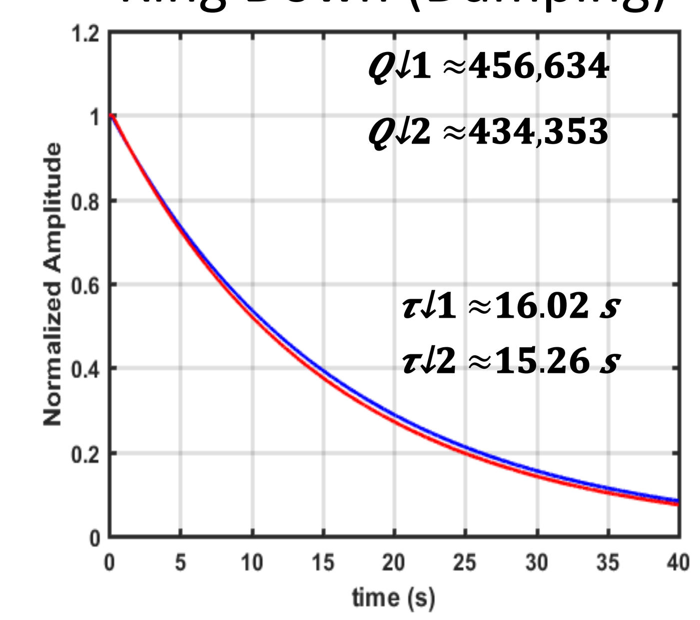
Control Approach

Mode Matching

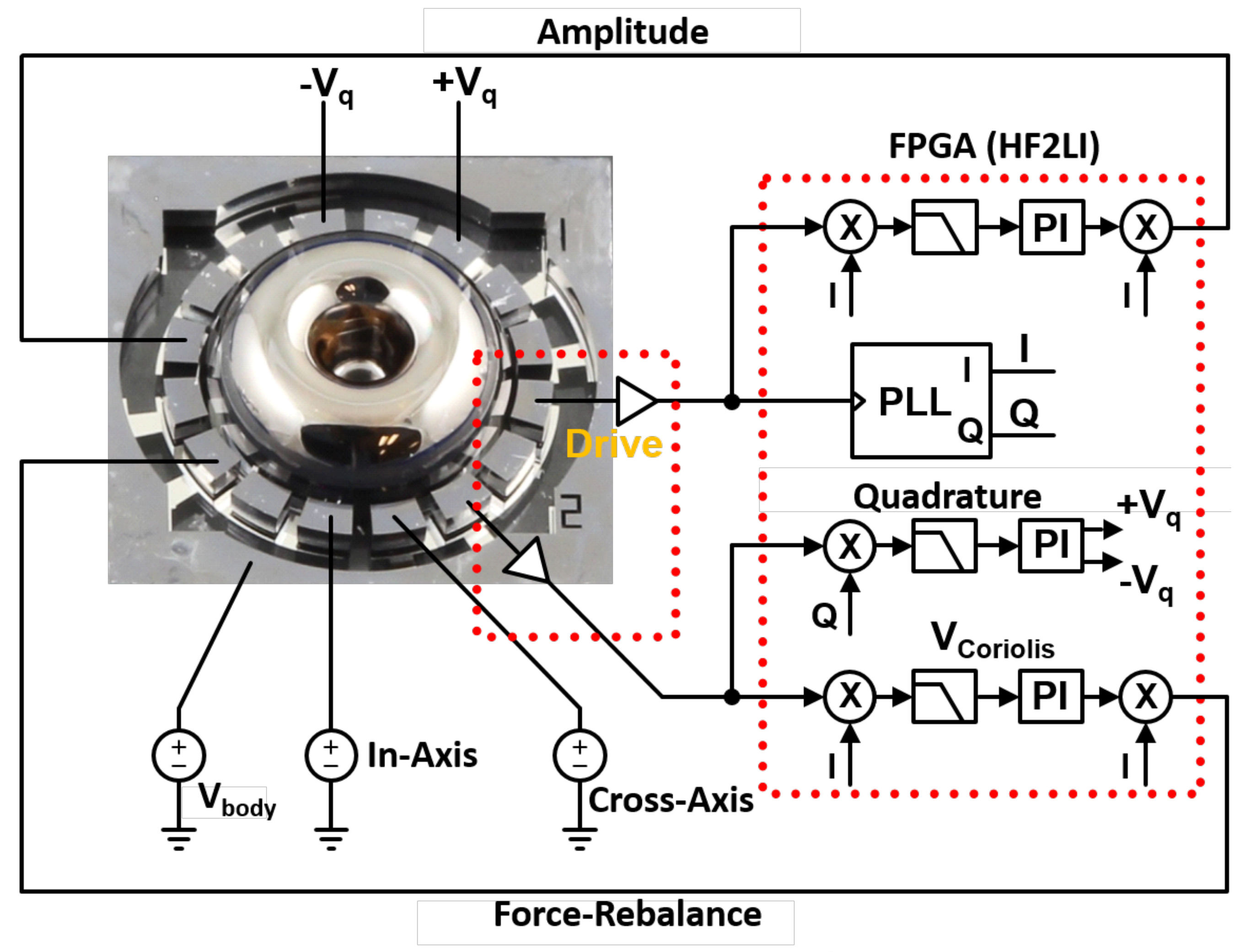
Frequency Response



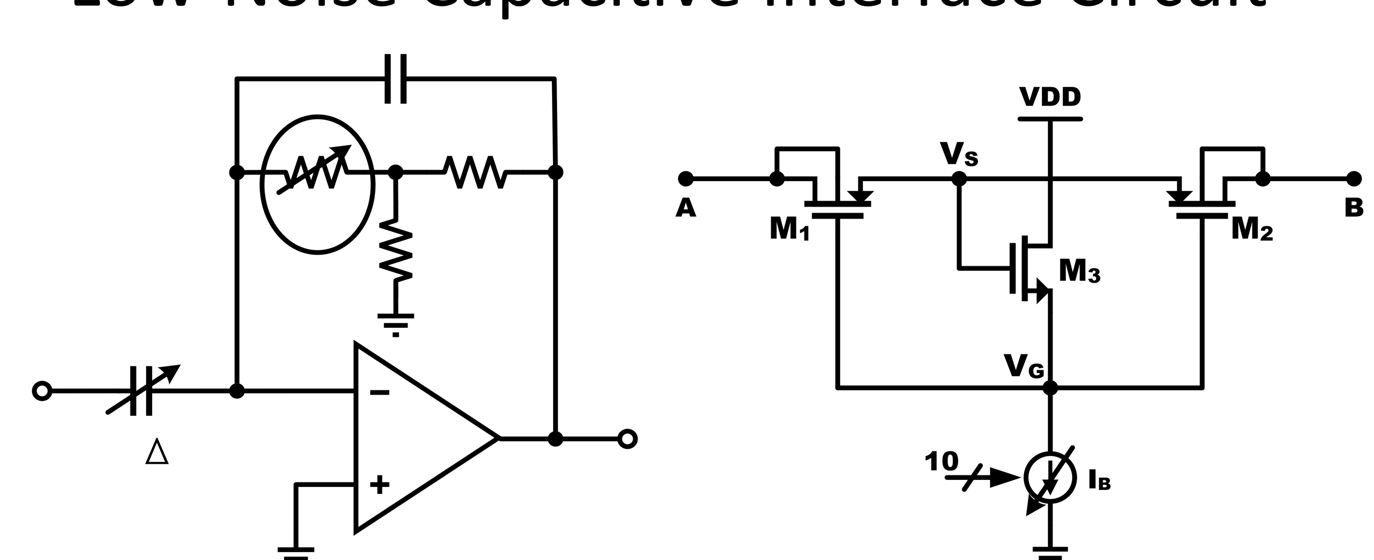
Ring Down (Damping)



Force Rebalance Control



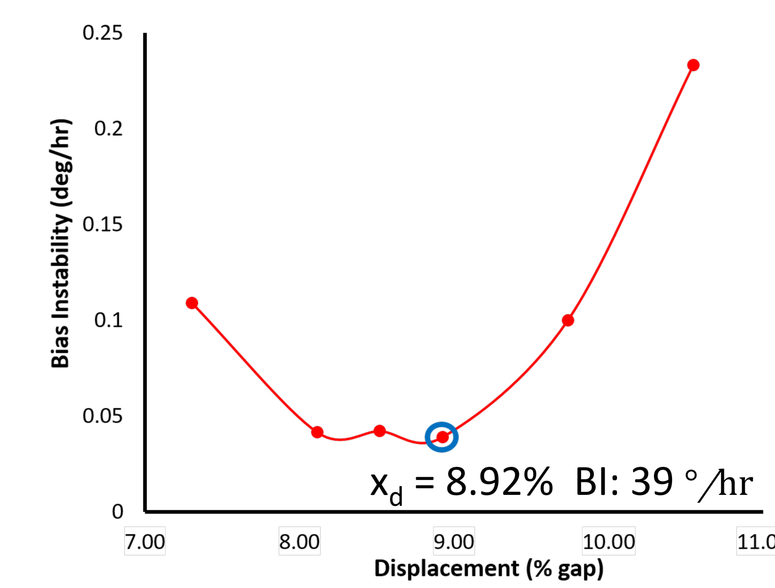
Low-Noise Capacitive Interface Circuit



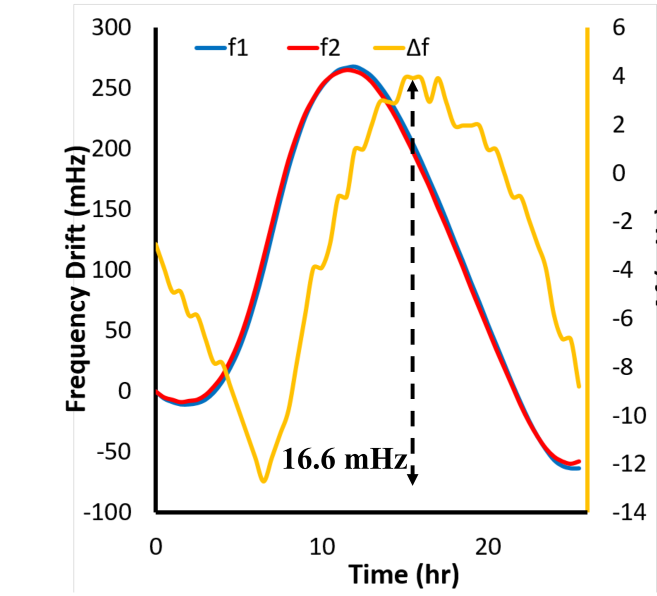
Reference	This Work	[1]	[2]	[3]
Front-End Architecture	TIA	TIA	CSA	CSA
Input Current Noise $(fA/\sqrt{Hz})$	5.12	88	-	-
Min. detectable ΔC $(zF/\sqrt{Hz})$	0.45	20	220	12
Technology (μm)	0.18	0.6	0.35	3

Experimental Results

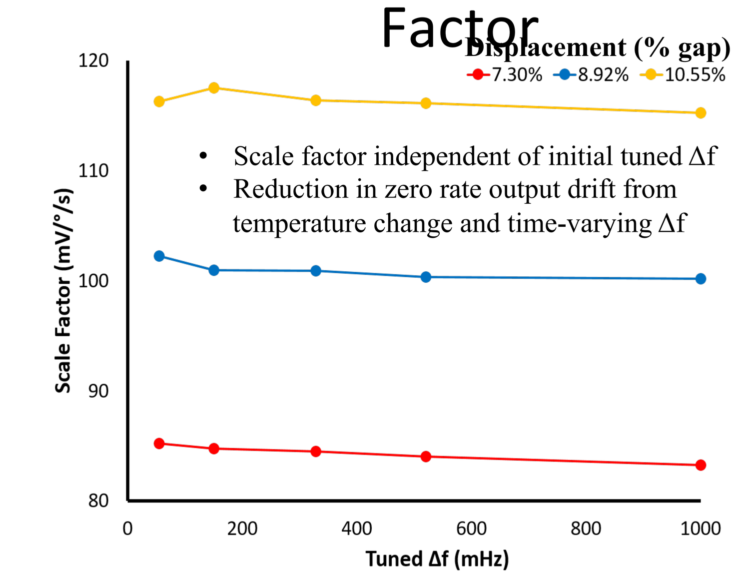
Gyro Bias Instability



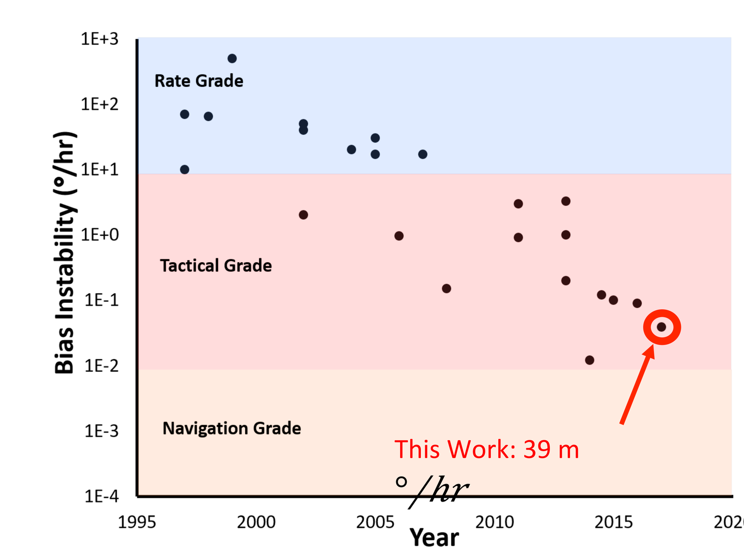
Temperature Sensitivity



Force Rebalance Scale Factor



MEMS Gyro Comparison



Reference	This Work	[4]	[5]	[6]
Bias Instability $(m{}^\circ/hr)$	39	12	90	100
ARW $(m{}^\circ/\sqrt{hr})$	8.7	2.3	15	15
Quality Factor	450k	80k	1.6M	50k

- Reduced angle random walk (ARW) and bias instability attributed to reduced front-end noise, mode matching, and increased quality factor
- Future work will compensate for long-term drift in quality factor and resonant frequency due to temperature drift and structural asymmetry

Acknowledgments

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References

[1] A. Sharma et al., “A Sub-0.2 deg/hr bias drift micromechanical silicon gyroscope with automatic CMOS mode-matching”, in IEEE JSSC, vol. 44, no.5, pp. 1593-1608, May 2009.
[2] L. Aaltonen and K.A. I. Halonen, “Pseudo-Continuous-Time Readout Circuit for a 300 deg/s capacitive 2-axis micro gyroscope,” in IEEE JSSC, vol. 44, no. 12, pp. 3609-3620, Dec. 2009.
[3] J. A. Geen, S. J. Sherman, J. F. Chang and S. R. Lewis, "Single-chip surface micro-machined integrated gyroscope with 50deg/h Allan deviation," in *IEEE JSSC*, vol. 37, no. 12, pp. 1860-1866, Dec 2002.
[4] A. D. Challoner et al., "Boeing Disc Resonator Gyroscope," *2014 IEEE/ION PLANS 2014*, Monterey, CA,USA.
[5] S. Askari *et al.*, “Near-Navigation Grade Quad Mass Gyroscope with Q-Factor Limited by Thermo-Elastic Damping,” *2016 Hilton Head Conference*
[6] Silicon Sensing Systems, “CRS39 Technical Data Sheet”, 2016.

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