# Current and Future Performance of Si-MEMS Quad Mass Gyro (QMG) System

THE VALUE OF PERFORMANCE.

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# Flat is not Dead

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# Current Status of SoA MEMS Gyros

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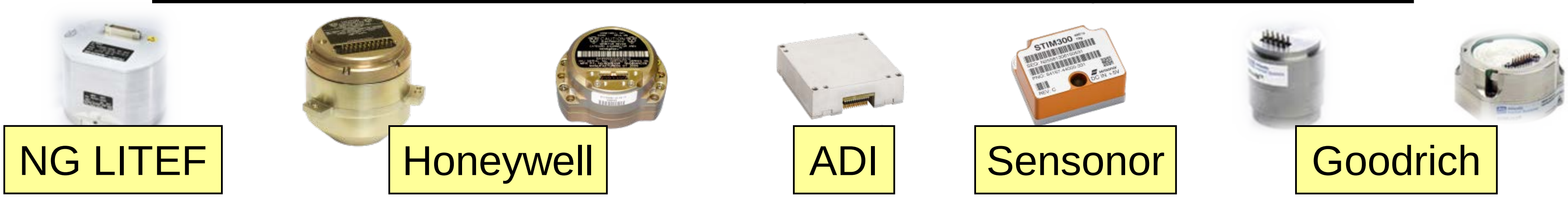
| MEMS gyro parameter (SoA production IMUs) | Tactical grade | Inertial / azimuth grade |
|---|---|---|
| Bias in-run, ***°/hr*** | ***1*** | ***0.01*** |
| Bias composite, ***°/hr*** | ***10*** | ***0.01*** |
| ARW, ***°/√hr*** | ***0.1*** | ***0.001*** |
| Rate Noise, ***°/hr/√Hz*** | ***5*** | ***0.05*** |
| Scale factor, ***ppm*** | ***>100*** | ***1*** |




100x improvement in MEMS gyro performance required for Navigation / Azimuth grade applications.



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# Two Classes of Coriolis Vibratory Gyros

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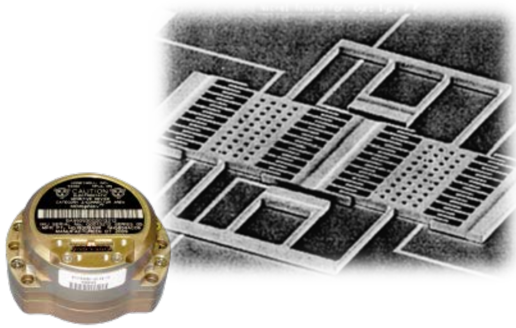
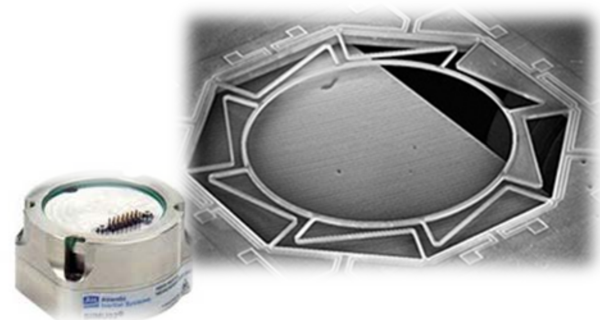
| IEEE STD 1431 | Class I | Class II |
|---|---|---|
| Modal symmetry (not axial) | ✗ | ✓ |
| Whole angle, self-calibration | ✗ | ✓ |
| MEMS implementation | lumped masses | ring, disk, (shells in R&D) |
| Angle gain, drive amplitude | ✓ | ✗ |
| Modal mass, decay time (Q) | ✓ | ✗ |
| Defining examples | Draper/ Honeywell | BAE/ AIS/ Goodrich/ UTC |

Tactical grade HG-1930 and SiIMU02 are dominant production SoA MEMS IMUs since ~2000.





**Revolutionary potential: mode-symmetric tuning fork with low ARW of Class I and good stability of Class II.**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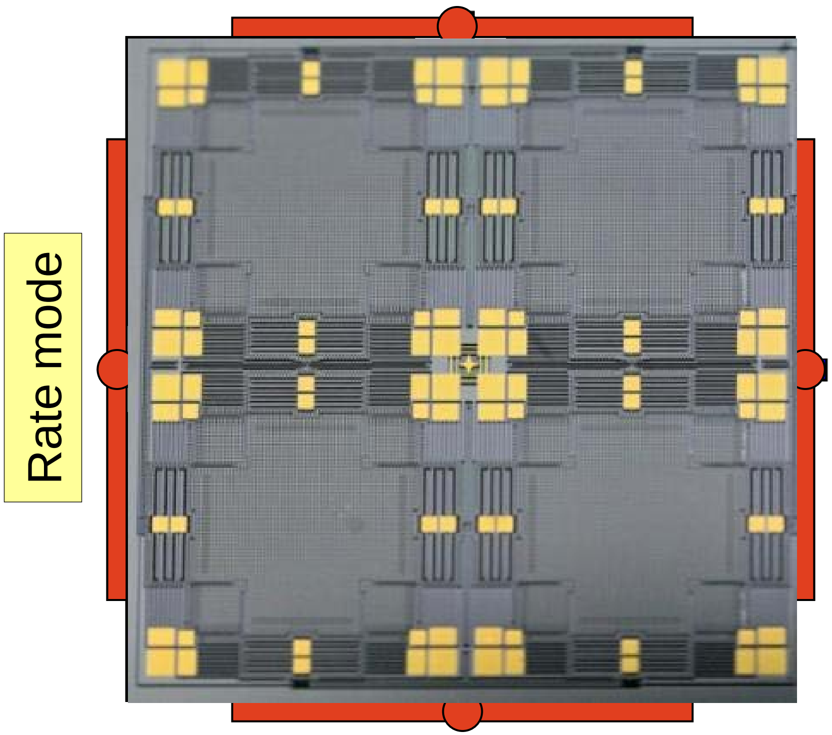
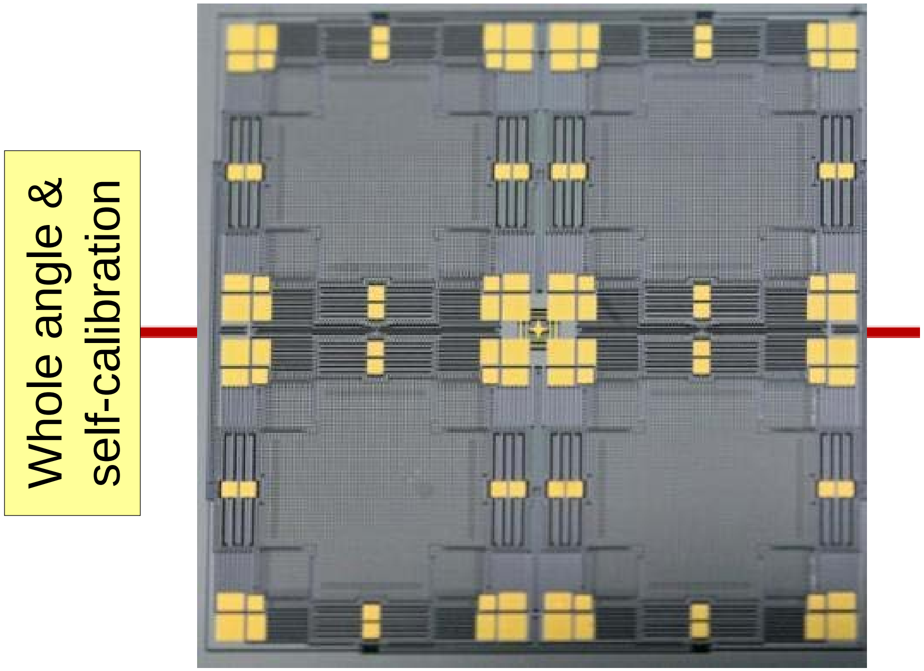
# Quad Mass Gyro (QMG)

- 4 tines, 20 levers
- Symmetry, balance

- No anchor loss, TED limited ***Q*>*1 M***
- Measured ***Tau*=*3 min*** and ***Q*>*1 M***




Quad Mass Gyro: Class II tuning fork CVG with Q>1 M, whole angle, and self-calibration.



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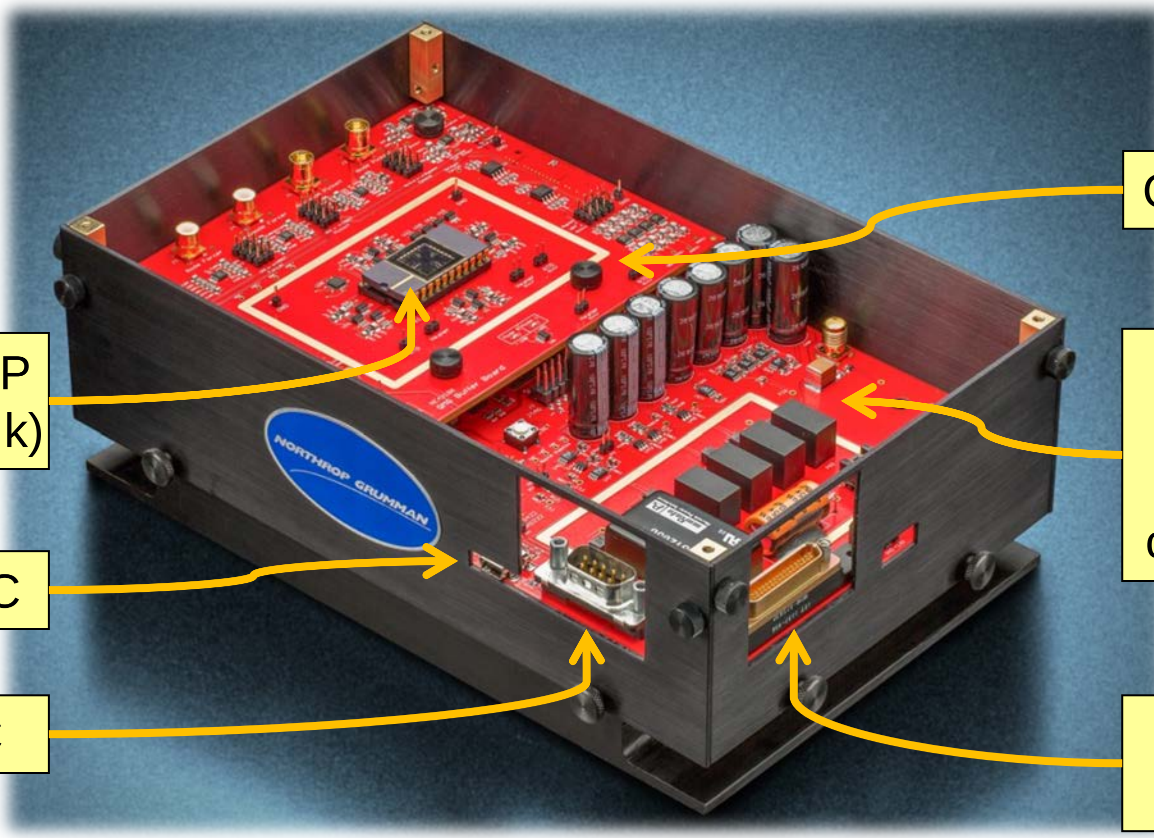
# Resonator Alone Does Not Gyro Make

- Rate mode, whole angle, mode reversal, carouseling
- All closed loop




Gyro buffer card

QMG in cer. DIP (no getter, Q=1 k)

Motherboard (DSP, FPGA, power, and communication)

USB port to PC

RS 232 to PC

PALADIN connector

Stand alone, turn key gyro suite; DARPA PALADIN compatible. Adaptable to other CVGs through analog card interchange.





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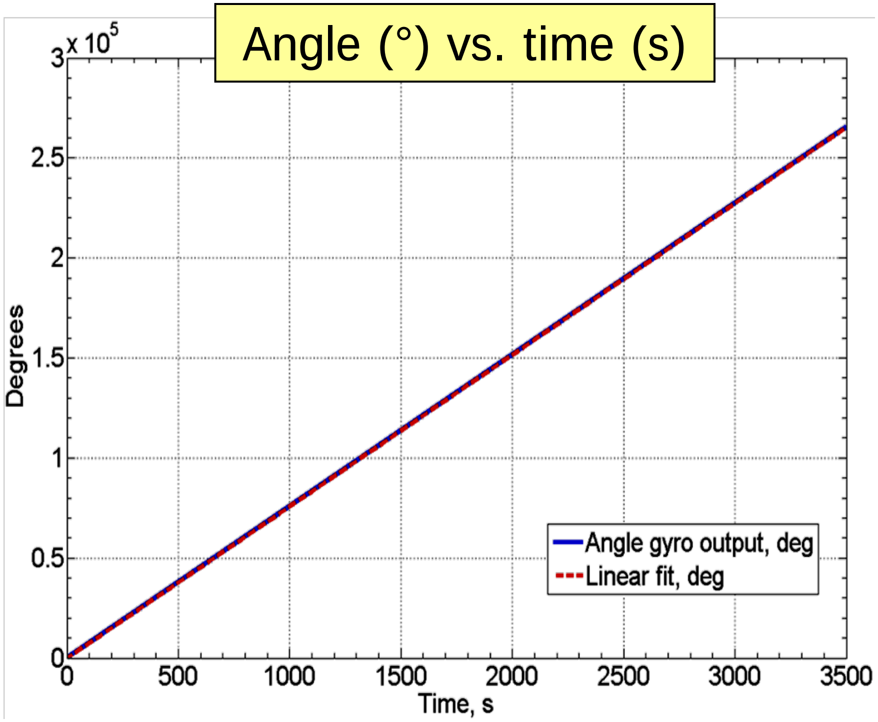
# Whole Angle QMG Performance

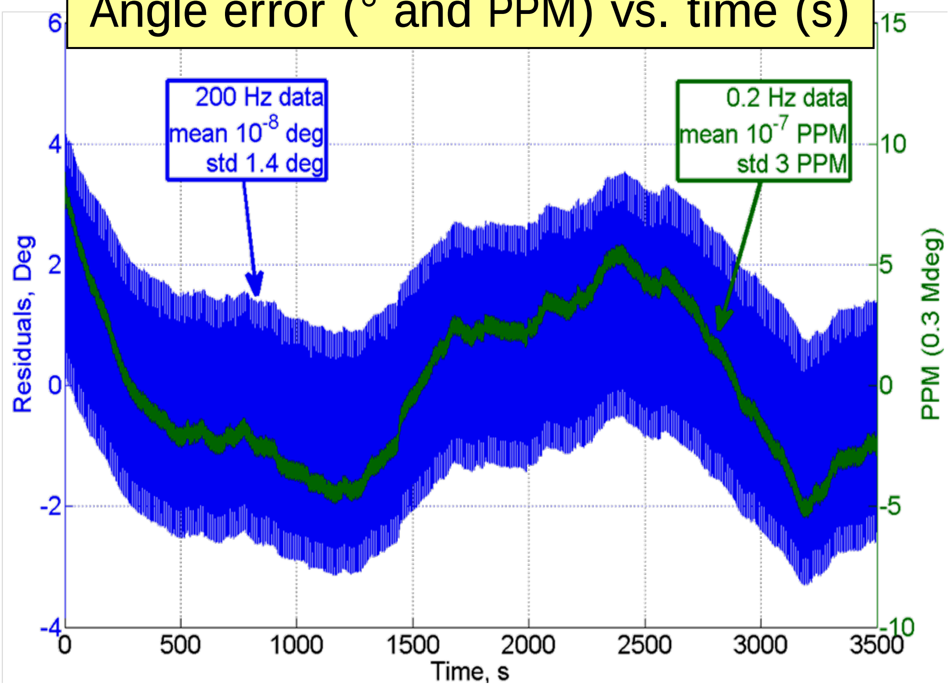
- QMG without getter
- ***Q=1 k***, ***tau=0.1 sec***

- ***1 hr*** at ***100 °/s*** for ***.3E6 °***
- All closed loop operation

Angle (°) vs. time (s)




Angle error (° and PPM) vs. time (s)




**Whole Angle with *3 PPM* error demonstrated on QMG (despite low Q package without getter). *18,000 °/s* range.**



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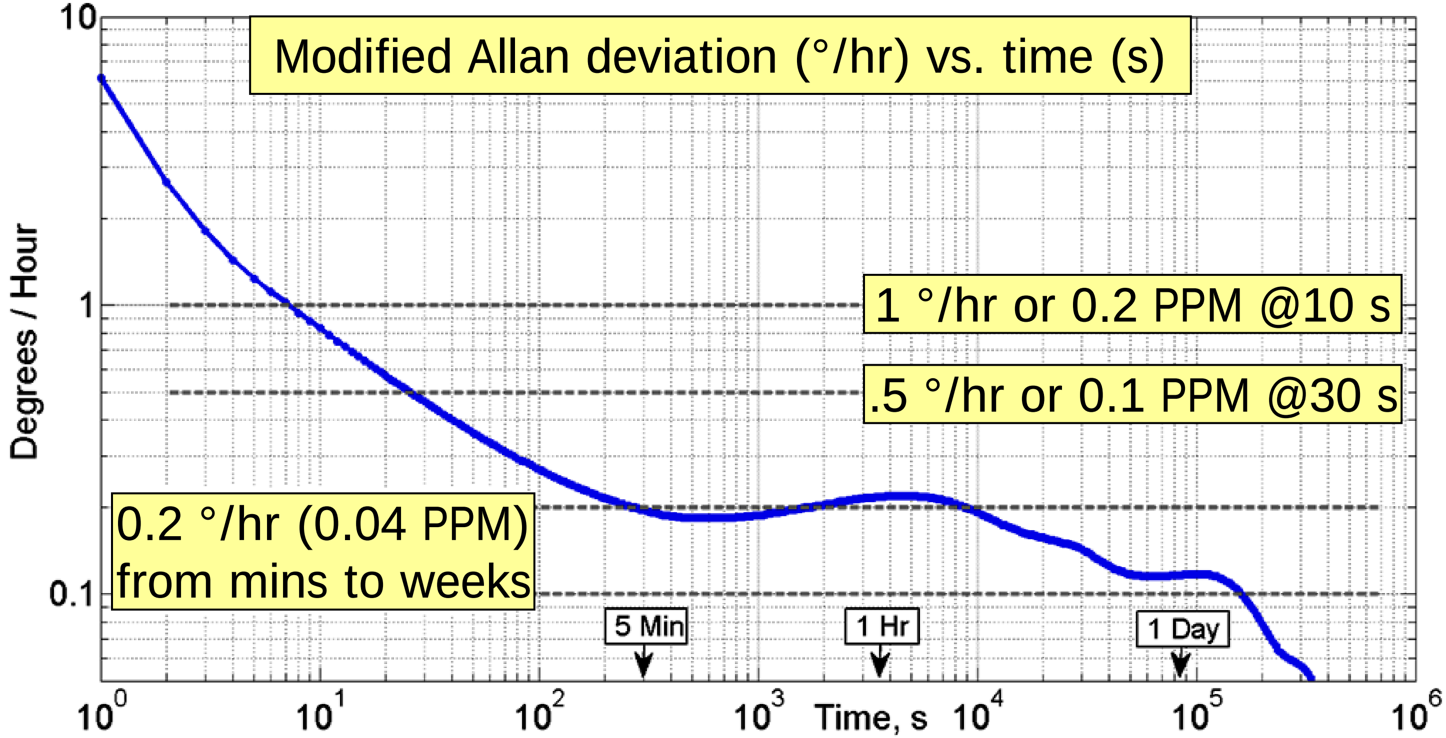
# Rate Mode QMG Performance

- QMG without getter
- ***Q=1 k***, ***tau=0.1 sec***

- ***½ month*** in-run experiment
- All closed loop with self-cal.




***0.2 °/hr*** or ***0.04 PPM*** bias stability over weeks.
Full scale of ***1350 °/s***, dynamic range >***145 dB***.



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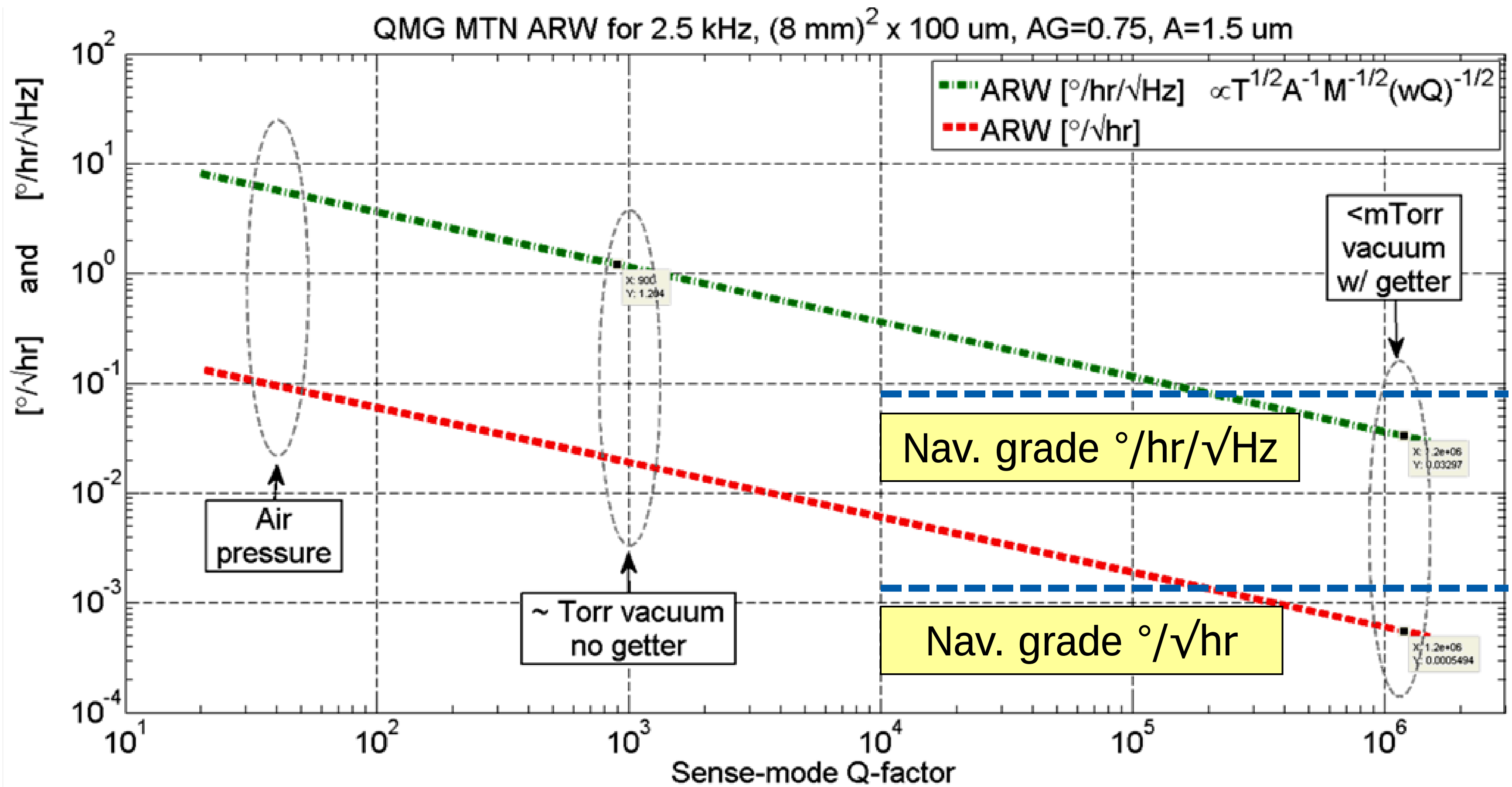
# QMG Noise Scaling: Effect of Mass and Q-Factor




**Angle Random Walk ∝ Mass$^{-½}$ * (Frequency * Q-factor)$^{-1/2}$**

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# Navigation Grade QMG Capability

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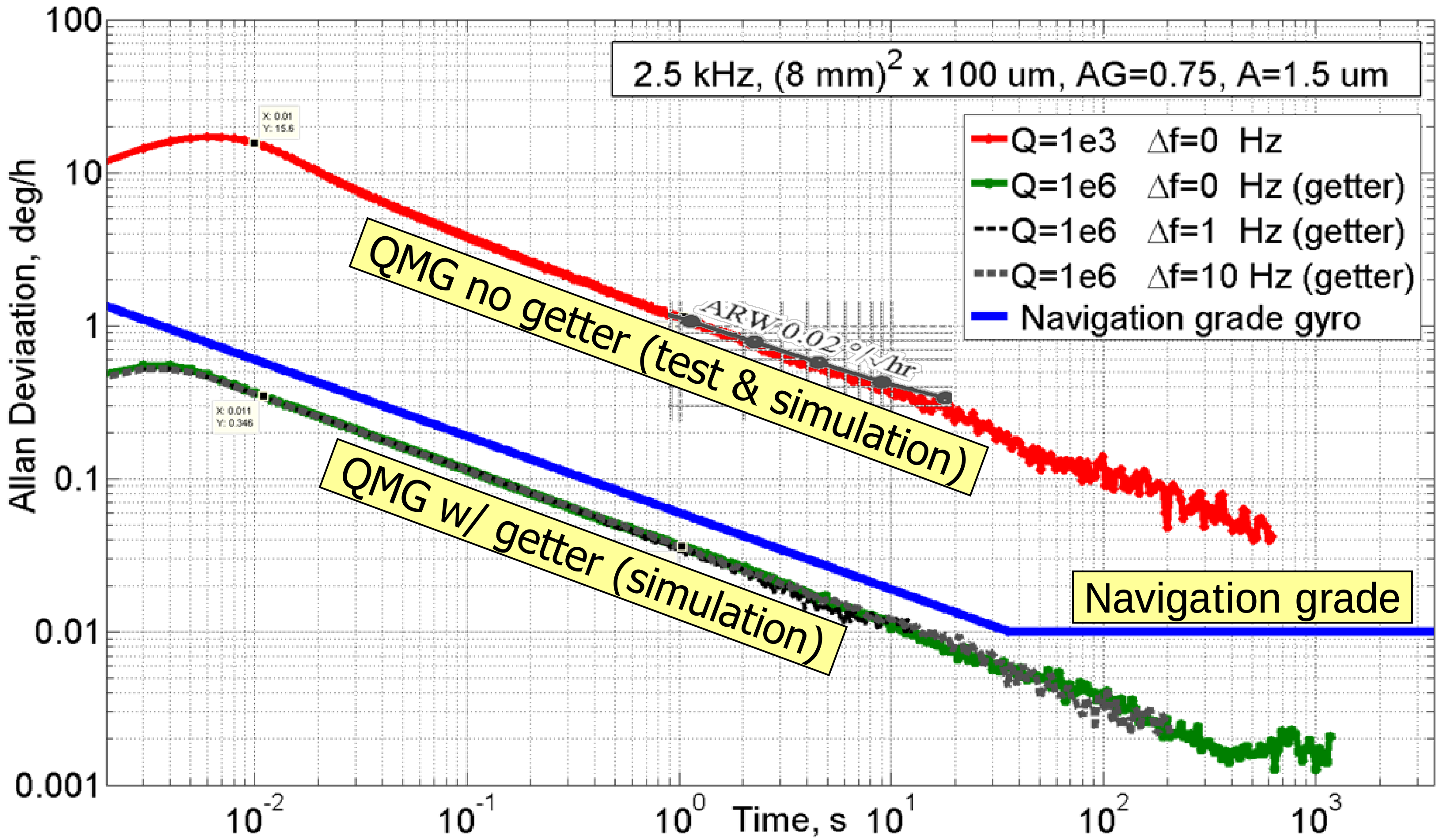


***Q=1 M*** QMG with getter packaging beats navigation grade ARW of ***<0.05 °/hr/√Hz*** with room for more improvement.





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# Quad Mass Gyro (QMG) Conclusions

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**QMG** – a clear path to Navigation / Azimuth grade Si-MEMS

- Ultra-low dissipation due to mechanism design
- Mode symmetry enables whole angle, self-cal.
- Wide range in rate mode due to large capacitance
- Mature silicon technology, no exotic fabrication

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