EE C245 – ME C218
Introduction to MEMS Design
Fall 2010

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Lecture Module 15: Gyros, Noise, & MDS

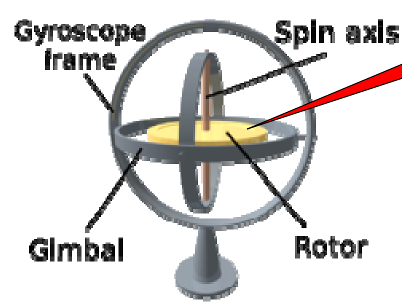
Lecture Outline

- Reading: Senturia, Chpt. 14, Chpt. 16, Chpt. 21
- Lecture Topics:
  - Gyroscopes
  - Gyro Circuit Modeling
  - Minimum Detectable Signal (MDS)
    - Noise
    - Angle Random Walk (ARW)

Gyroscopes

Classic Spinning Gyroscope

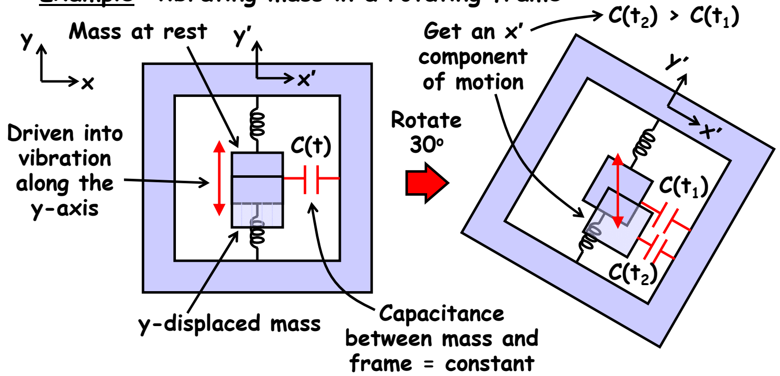
- A gyroscope measures rotation rate, which then gives orientation → very important, of course, for navigation
- Principle of operation based on conservation of momentum
- Example: classic spinning gyroscope



Rotor will preserve its angular momentum (i.e., will maintain its axis of spin) despite rotation of its gimbled chassis

Vibratory Gyroscopes

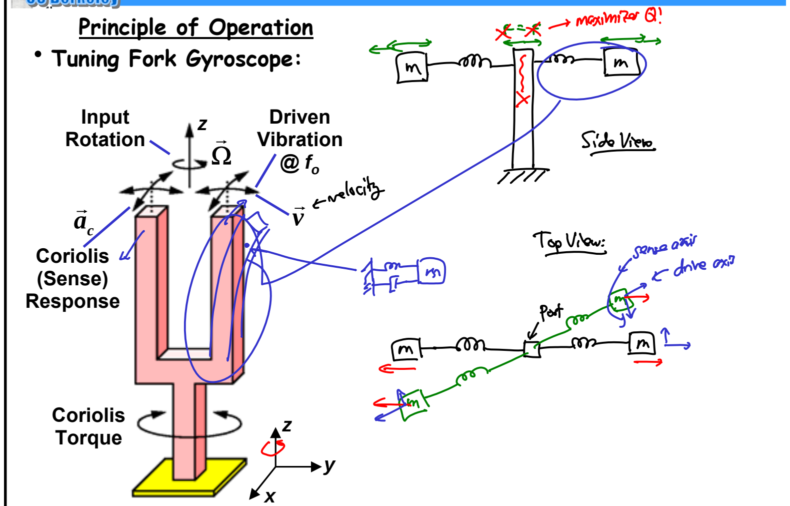
- Generate momentum by vibrating structures
- Again, conservation of momentum leads to mechanisms for measuring rotation rate and orientation
- Example: vibrating mass in a rotating frame



Basic Vibratory Gyroscope Operation

Principle of Operation

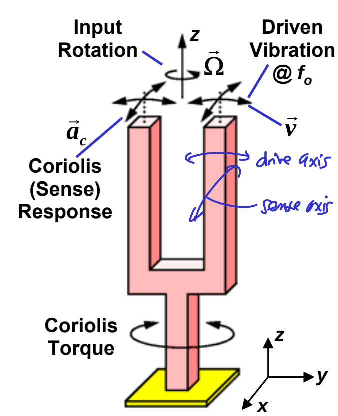
- Tuning Fork Gyroscope:



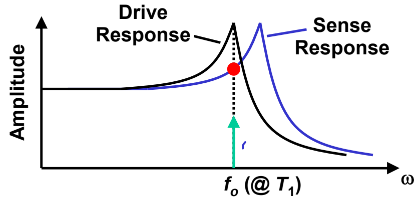
Basic Vibratory Gyroscope Operation

Principle of Operation

- Tuning Fork Gyroscope:



Drive/Sense Response Spectra:



Coriolis Acceleration, Driven Velocity, Rotation Rate:

$$\vec{a}_c = 2\vec{v} \times \vec{\Omega}$$

Coriolis Displacement, Coriolis Force, Beam Mass, Beam Stiffness, Sense Frequency:

$$\vec{x} = \frac{\vec{F}_c}{k} = \frac{m\vec{a}_c}{k} = \frac{\vec{a}_c}{\omega_r^2}$$

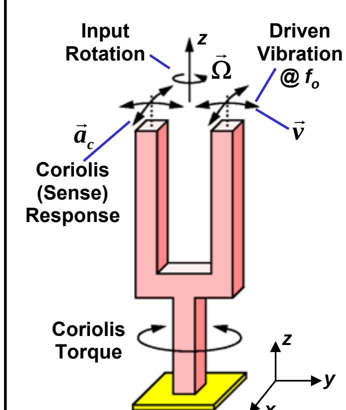
Vibratory Gyroscope Performance

Principle of Operation

- Tuning Fork Gyroscope:

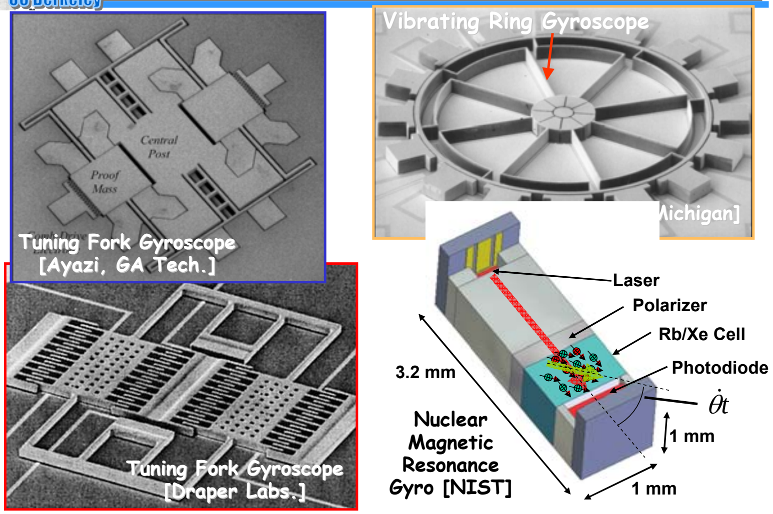
$$\vec{x} = \frac{\vec{F}_c}{k} = \frac{m\vec{a}_c}{k} = \frac{\vec{a}_c}{\omega_r^2} \qquad \vec{a}_c = 2\vec{v} \times \vec{\Omega}$$

(Beam Mass, Beam Stiffness, Sense Frequency, Driven Velocity)

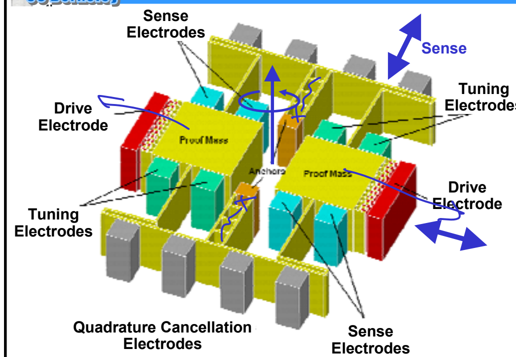


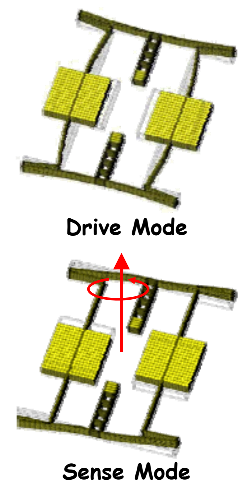
- To maximize the output signal x, need:
  - Large sense-axis mass
  - Small sense-axis stiffness
  - (Above together mean low resonance frequency)
  - Large drive amplitude for large driven velocity (so use comb-drive)
  - If can match drive freq. to sense freq., then can amplify output by Q times → $x_s = \frac{QF_c}{k_s}$

MEMS-Based Gyroscopes



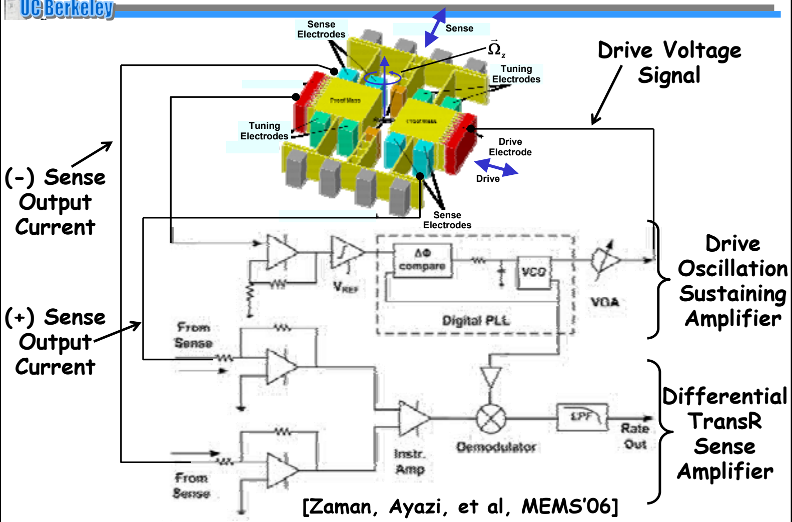
MEMS-Based Tuning Fork Gyroscope





- In-plane drive and sense modes pick up z-axis rotations
- Mode-matching for maximum output sensitivity
- From [Zaman, Ayazi, et al, MEMS'06]

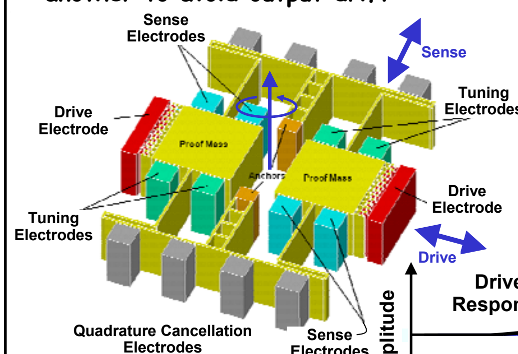
MEMS-Based Tuning Fork Gyroscope



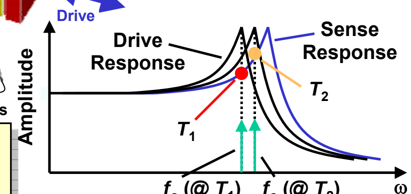
[Zaman, Ayazi, et al, MEMS'06]

MEMS-Based Tuning Fork Gyroscope

- Drive and sense axes must be stable or at least track one another to avoid output drift



Problem: if drive frequency changes relative to sense frequency, output changes ⇨ bias drift



Need: small or matched drive and sense axis temperature coefficients to suppress drift

Mode Matching for Higher Resolution

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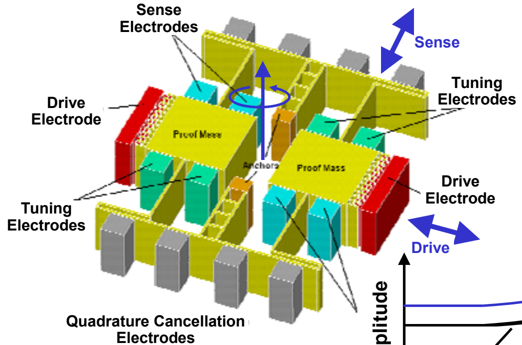
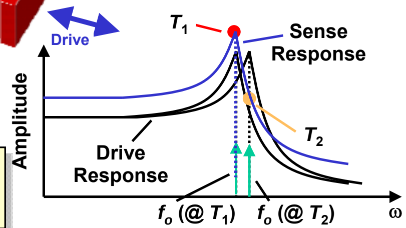
- For higher resolution, can try to match drive and sense axis resonance frequencies and benefit from Q amplification



Problem: mismatch between drive and sense frequencies ⇨ even larger drift!



Need: small or matched drive and sense axis temperature coefficients to make this work

Issue: Zero Rate Bias Error

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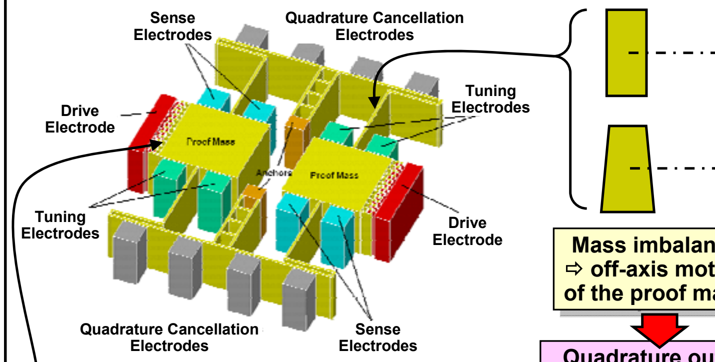
- Imbalances in the system can lead to zero rate bias error



Mass imbalance ⇨ off-axis motion of the proof mass

Quadrature output signal that can be confused with the Coriolis acceleration

Drive imbalance ⇨ off-axis motion of the proof mass

Output signal in phase with the Coriolis acceleration

Nuclear Magnetic Res. Gyroscope

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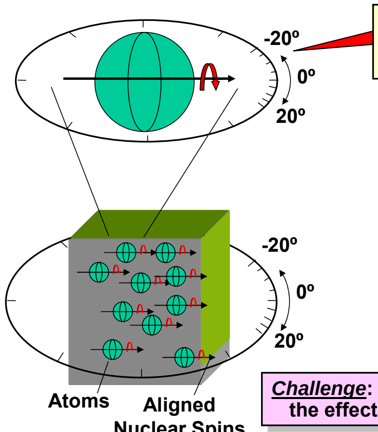
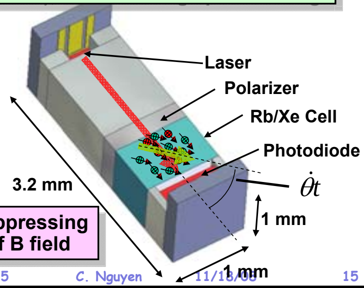
- The ultimate in miniaturized spinning gyroscopes?
  ⇘ from CSAC, we may now have the technology to do this

Better if this is a noble gas nucleus (rather than e-), since nuclei are heavier ⇨ less susceptible to B field

Soln: Spin polarize Xe^{129} nuclei by first polarizing e- of Rb^{87} (a la CSAC), then allowing spin exchange





Challenge: suppressing the effects of B field

MEMS-Based Tuning Fork Gyroscope

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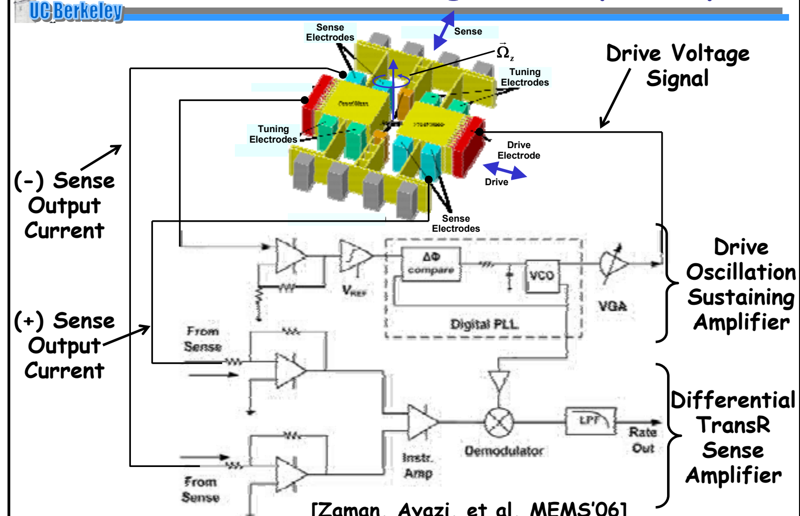

[Zaman, Ayazi, et al, MEMS'06]