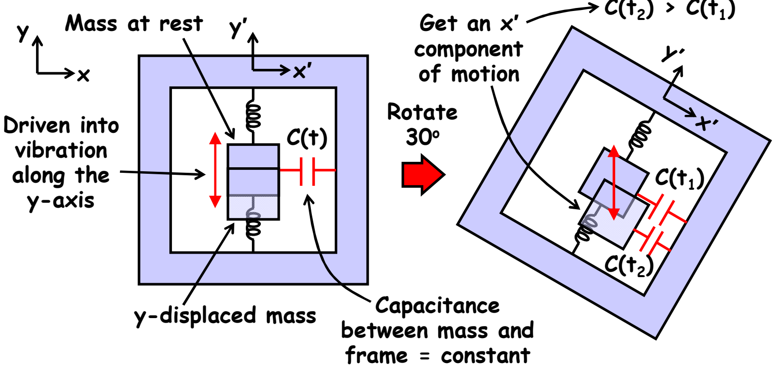
Vibratory Gyroscopes

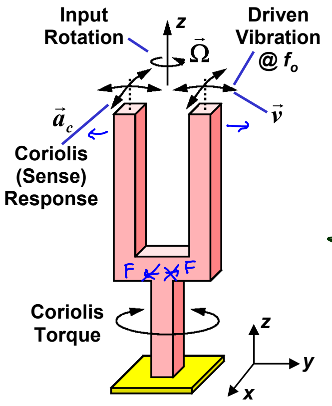
- Generate momentum by vibrating structures
- Again, conservation of momentum leads to mechanisms for measuring rotation rate and orientation
- **Example**: vibrating mass in a rotating frame

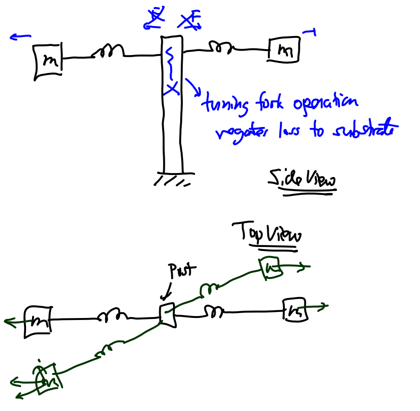


Basic Vibratory Gyroscope Operation

Principle of Operation

- Tuning Fork Gyroscope:

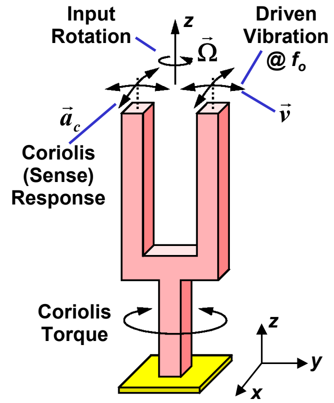




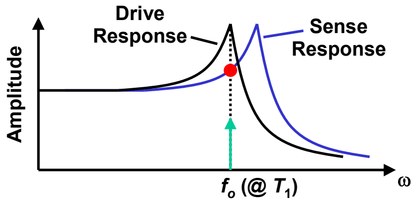
Basic Vibratory Gyroscope Operation

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 Force
Beam Mass

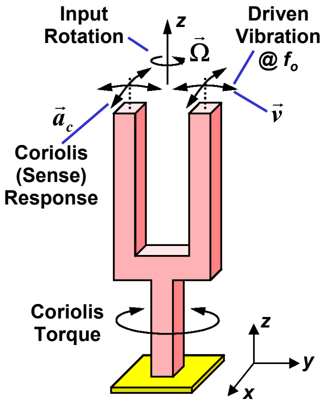
$$\vec{x} = \frac{\vec{F}_c}{k} = \frac{m\vec{a}_c}{k} = \frac{\vec{a}_c}{\omega_r^2}$$

Coriolis Displacement
Beam Stiffness
Sense Frequency

Vibratory Gyroscope Performance

Principle of Operation

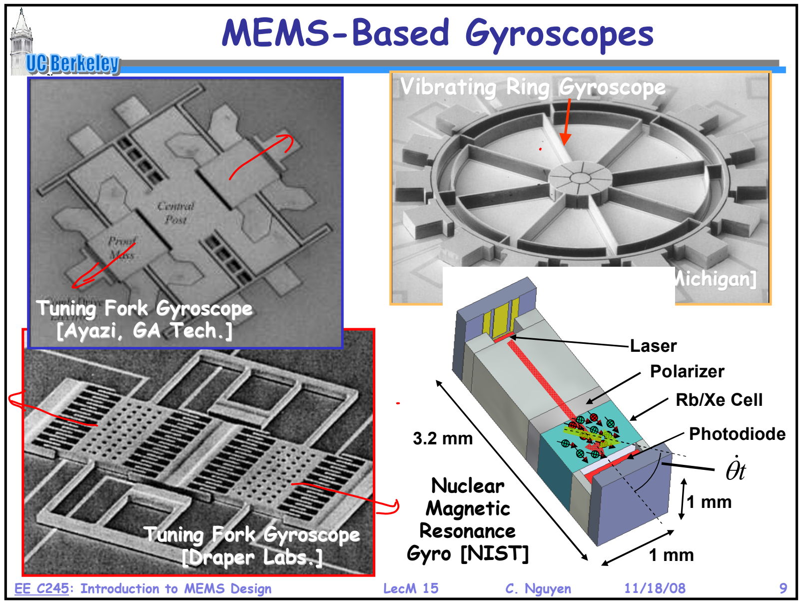
- Tuning Fork Gyroscope:



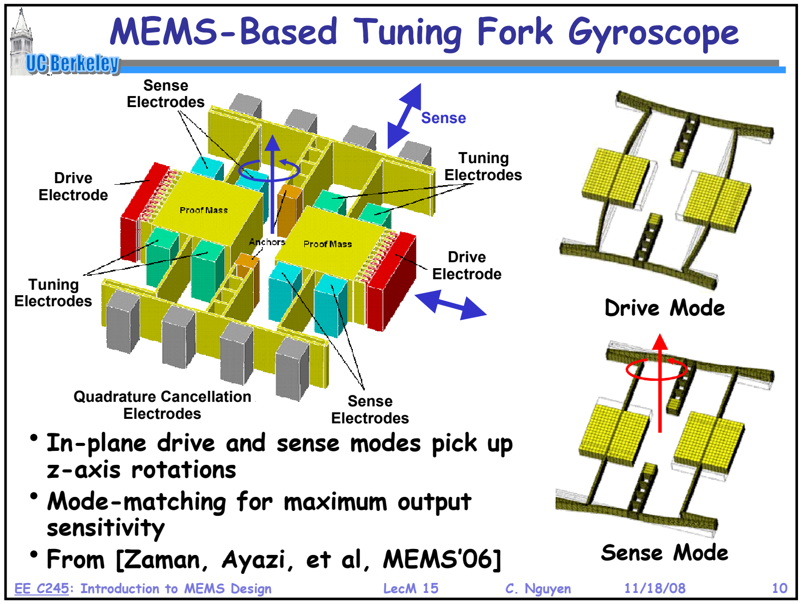
$$\vec{x} = \frac{\vec{F}_c}{k} = \frac{m\vec{a}_c}{k} = \frac{\vec{a}_c}{\omega_r^2} \qquad \vec{a}_c = 2\vec{v}\times\vec{\Omega}$$

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

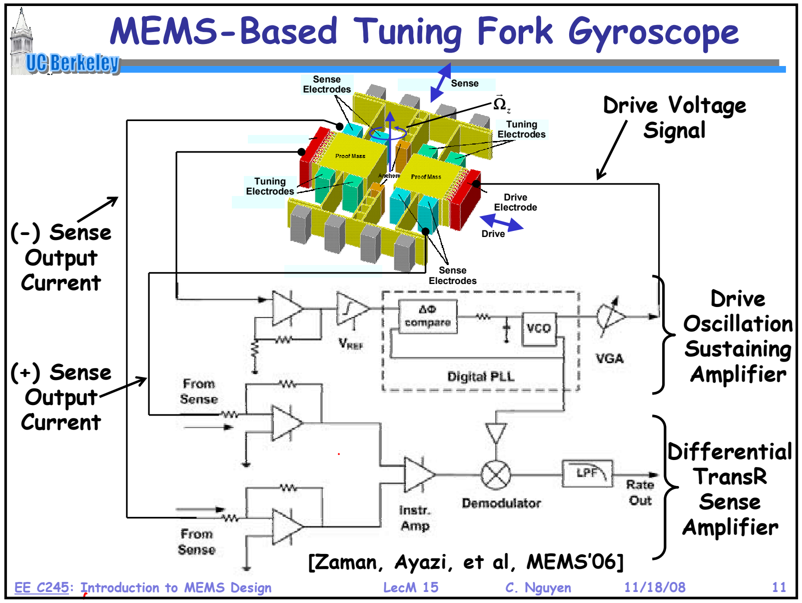


MEMS-Based Gyroscopes



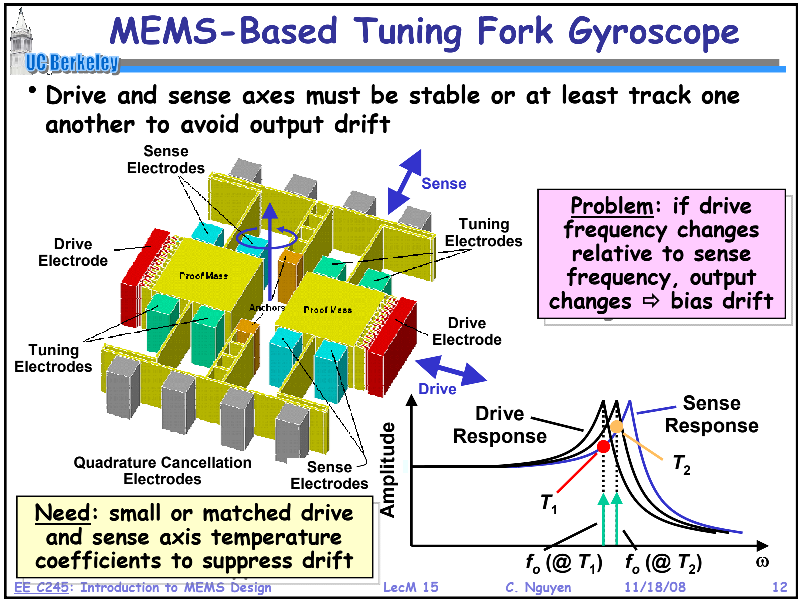
MEMS-Based Tuning Fork Gyroscope

- 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]

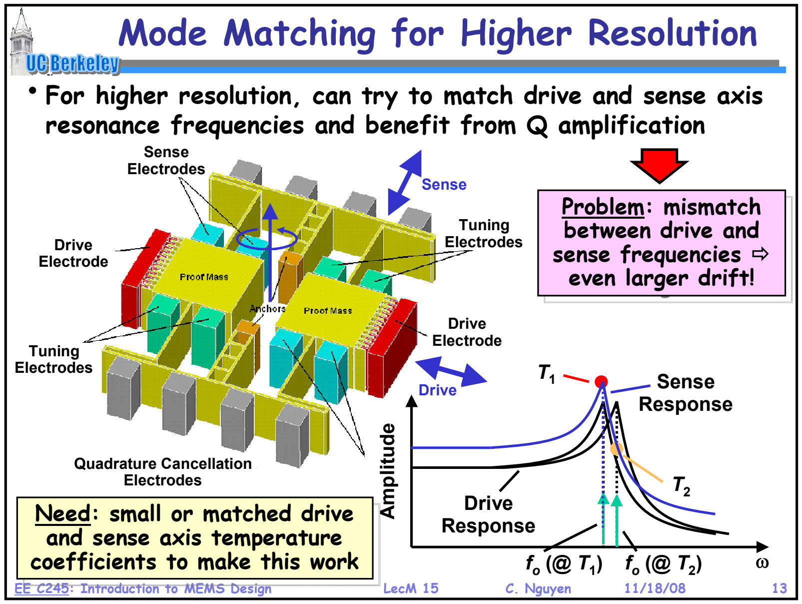


MEMS-Based Tuning Fork Gyroscope

- 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

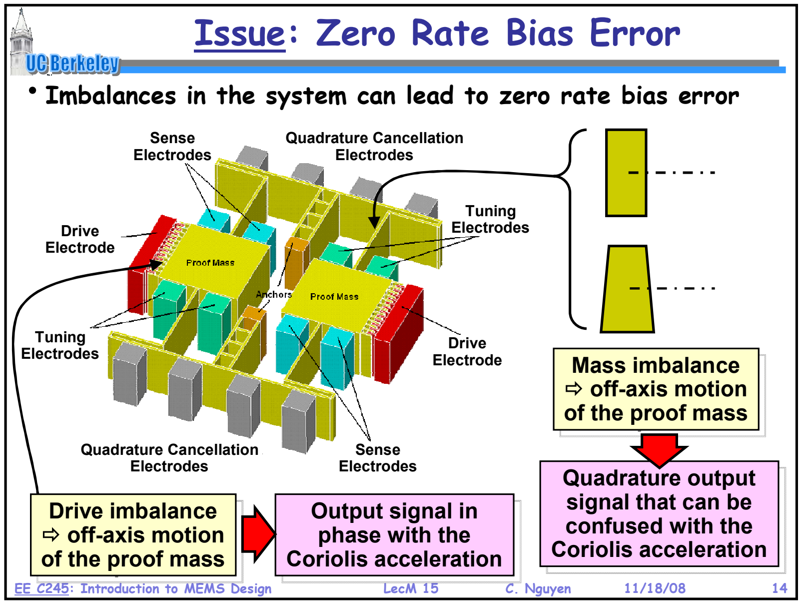


Mode Matching for Higher Resolution

- 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

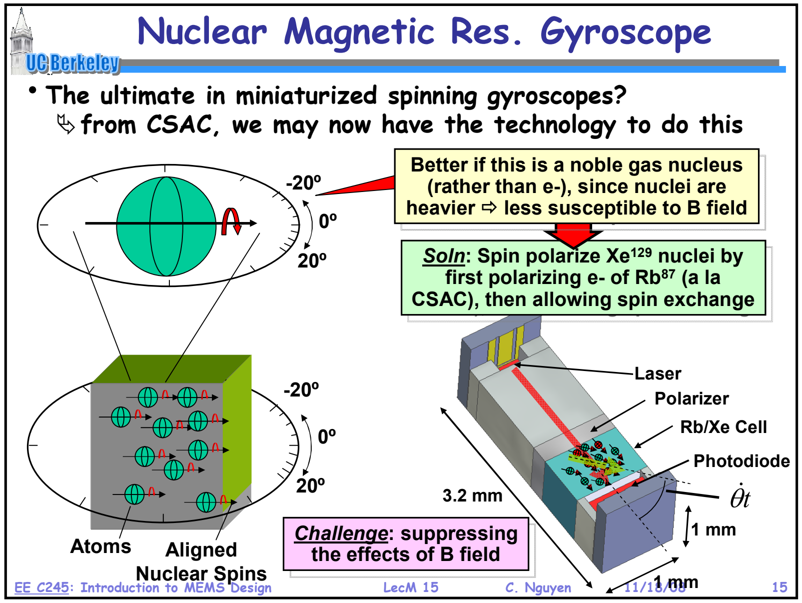
- Imbalances in the system can lead to zero rate bias error

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



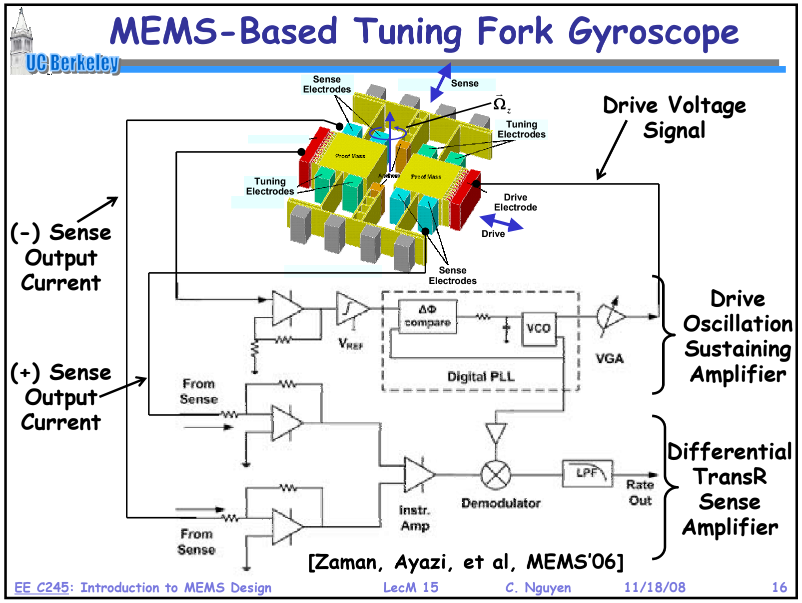
Nuclear Magnetic Res. Gyroscope

- 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

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