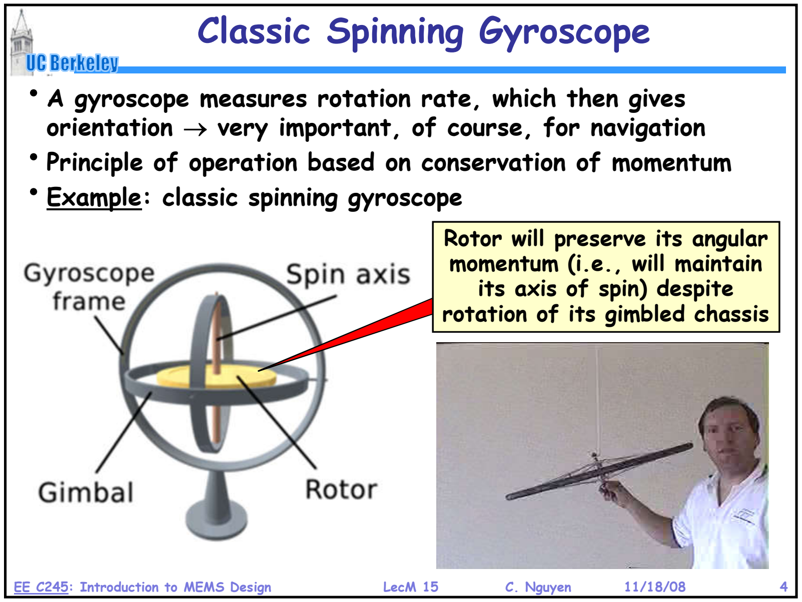
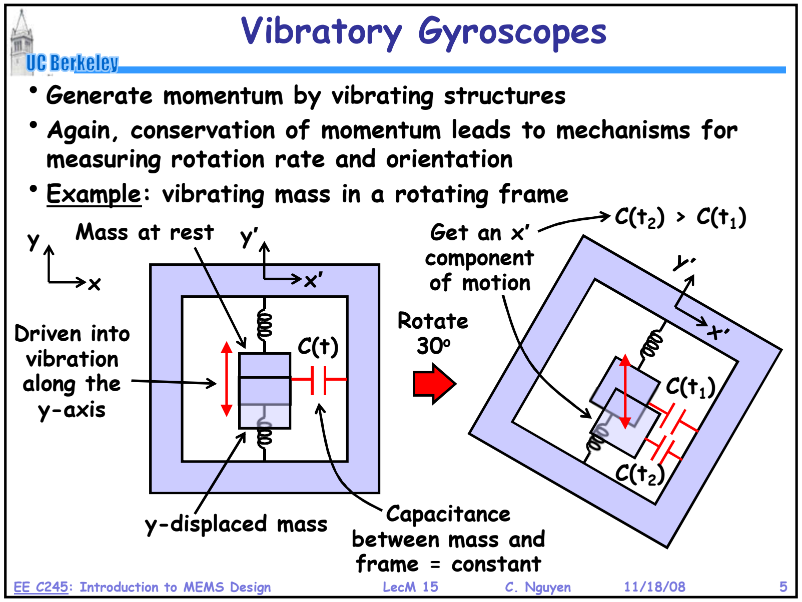


## Classic Spinning Gyroscope

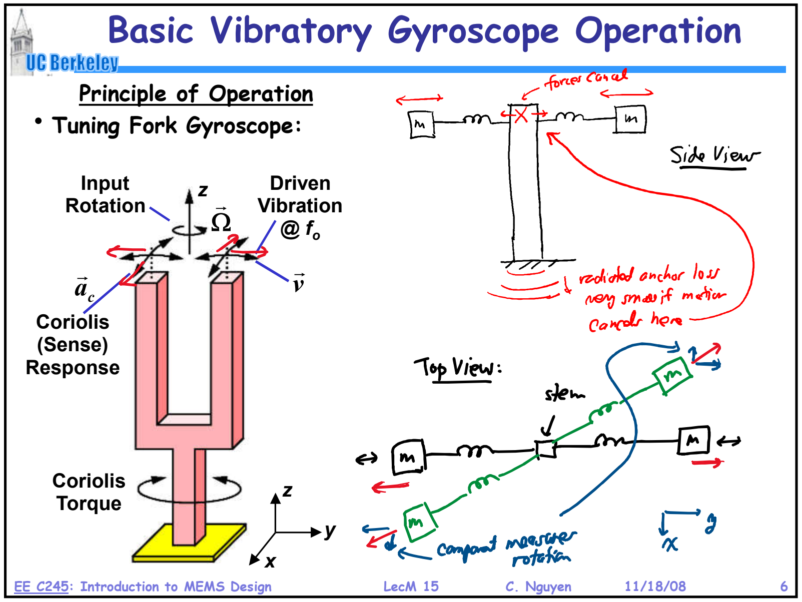
- A gyroscope measures rotation rate, which then gives orientation → very important, of course, for navigation
- Principle of operation based on conservation of momentum
- Example: classic spinning gyroscope

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



## Vibratory Gyroscopes

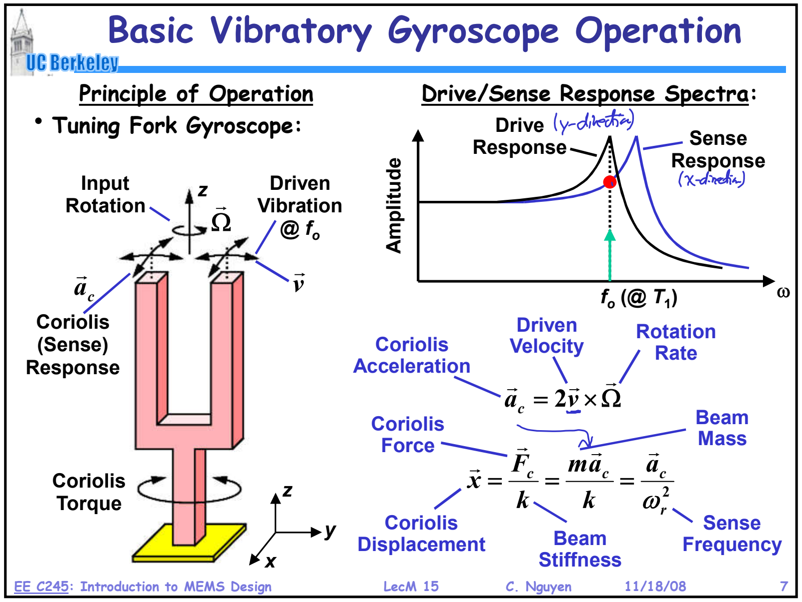
- Generate momentum by vibrating structures
- Again, conservation of momentum leads to mechanisms for measuring rotation rate and orientation
- Example: vibrating mass in a rotating frame



## Basic Vibratory Gyroscope Operation

Principle of Operation

- Tuning Fork Gyroscope:



## Basic Vibratory Gyroscope Operation

Principle of Operation

- Tuning Fork Gyroscope:

Drive/Sense Response Spectra:

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

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

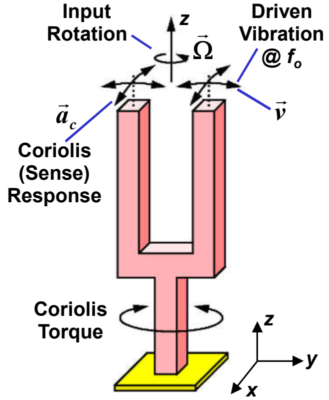
## Vibratory Gyroscope Performance

**Principle of Operation**

- Tuning Fork Gyroscope:

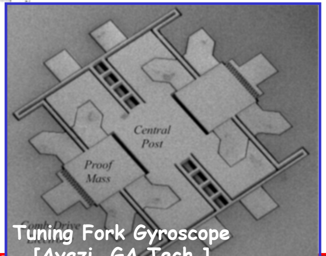
$$\vec{x} = \frac{\vec{F}_c}{k} = \frac{m\vec{a}_c}{k} = \frac{\vec{a}_c}{\omega_r^2} \qquad \vec{a}_c = 2\vec{v}\times\vec{\Omega}$$

Beam Mass
Beam Stiffness
Sense Frequency
Driven Velocity

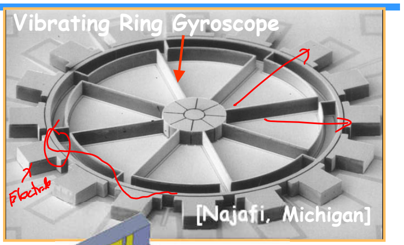


- To maximize the output signal x, need:
  - Large sense-axis mass
  - Small sense-axis stiffness
  - (Above together mean low resonance frequency)
  - Large drive amplitude for large driven velocity (so use comb-drive)
  - If can match drive freq. to sense freq., then can amplify output by Q times →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

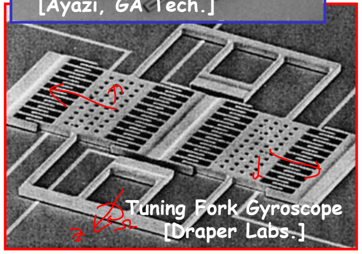
## MEMS-Based Gyroscopes



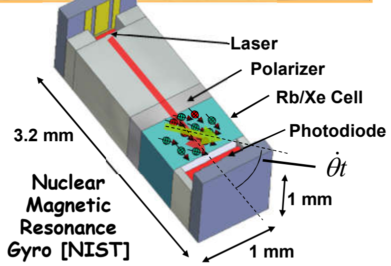
Tuning Fork Gyroscope [Ayazi, GA Tech.]



Vibrating Ring Gyroscope [Najafi, Michigan]

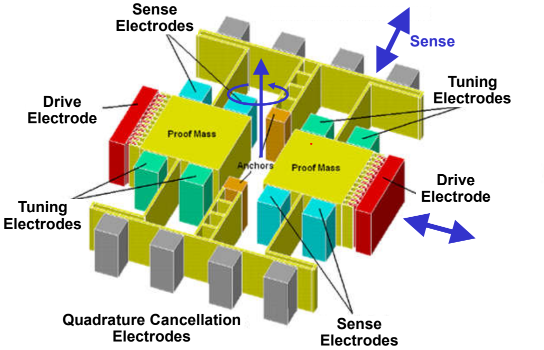


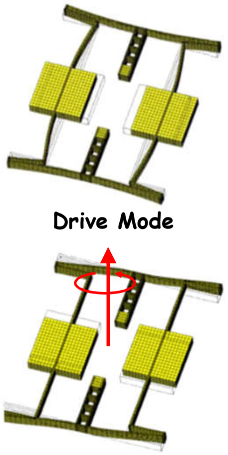
Tuning Fork Gyroscope [Draper Labs.]



Nuclear Magnetic Resonance Gyro [NIST]

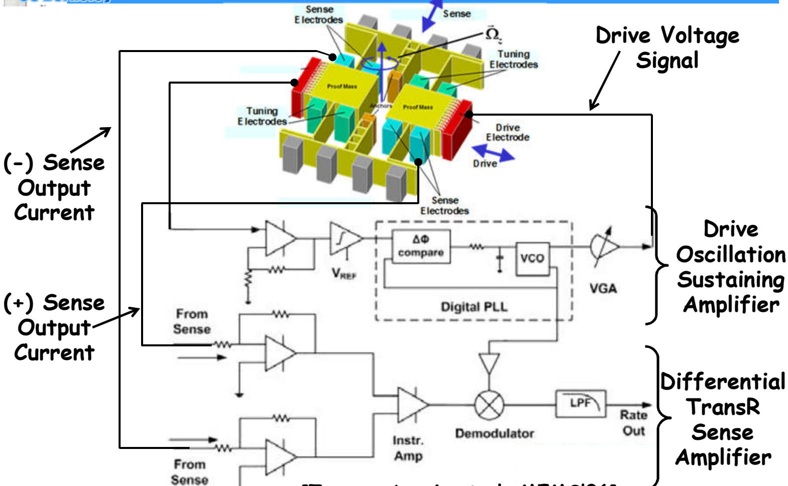
## MEMS-Based Tuning Fork Gyroscope





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

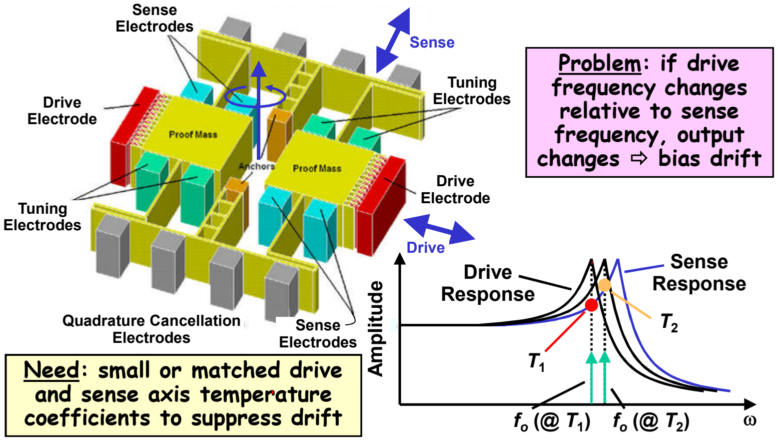
## MEMS-Based Tuning Fork Gyroscope



[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



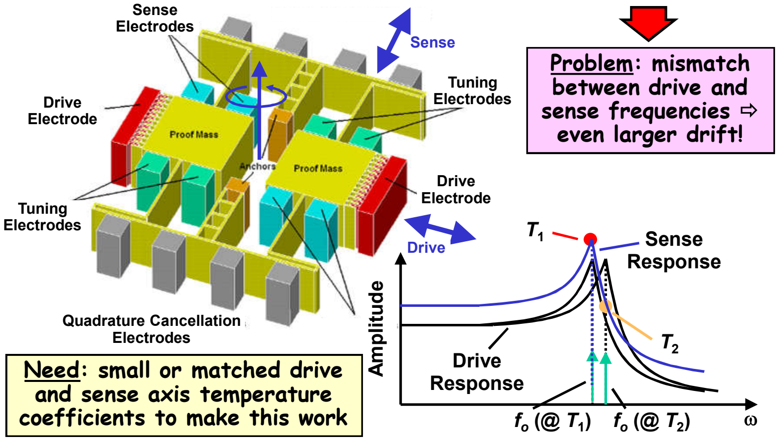
**Problem**: if drive frequency changes relative to sense frequency, output changes ⇨ bias drift

**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

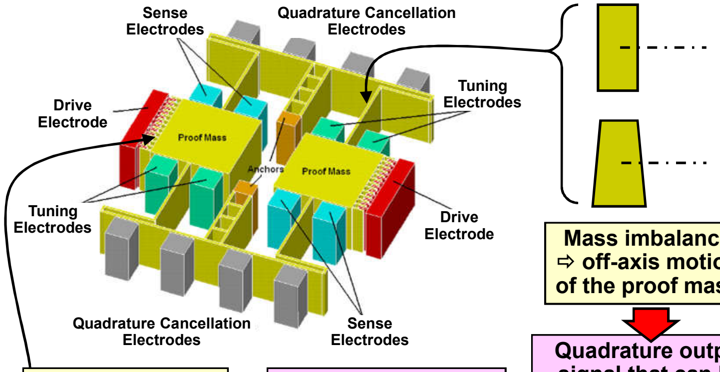
**Problem**: mismatch between drive and sense frequencies ⇨ even larger drift!



**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

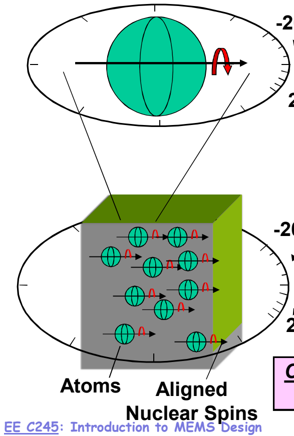
Quadrature output signal that can be confused with the Coriolis acceleration

Drive imbalance ⇨ off-axis motion of the proof mass

Output signal in phase with the Coriolis acceleration

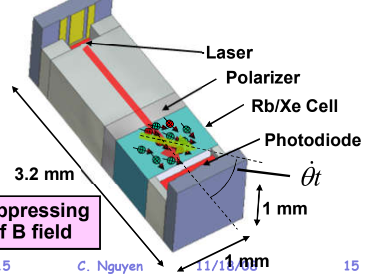
## Nuclear Magnetic Res. Gyroscope

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

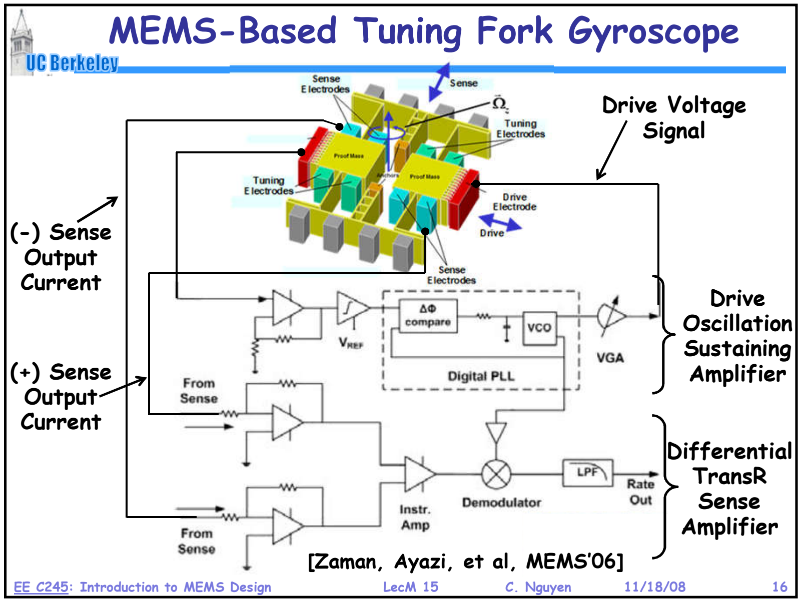


Better if this is a noble gas nucleus (rather than e-), since nuclei are heavier ⇨ less susceptible to B field

***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

Drive Voltage Signal

(-) Sense Output Current

(+) Sense Output Current

Drive Oscillation Sustaining Amplifier

Differential TransR Sense Amplifier

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

EE C245: Introduction to MEMS Design LecM 15 C. Nguyen 11/18/08 16