Lecture

Sensor Technology

EE 570: Location and Navigation

Lecture Notes Update on February 25, 2014

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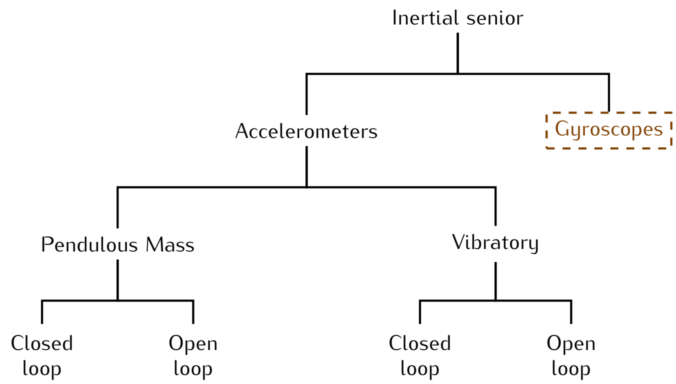
.1

1 Overview

Accelerometers



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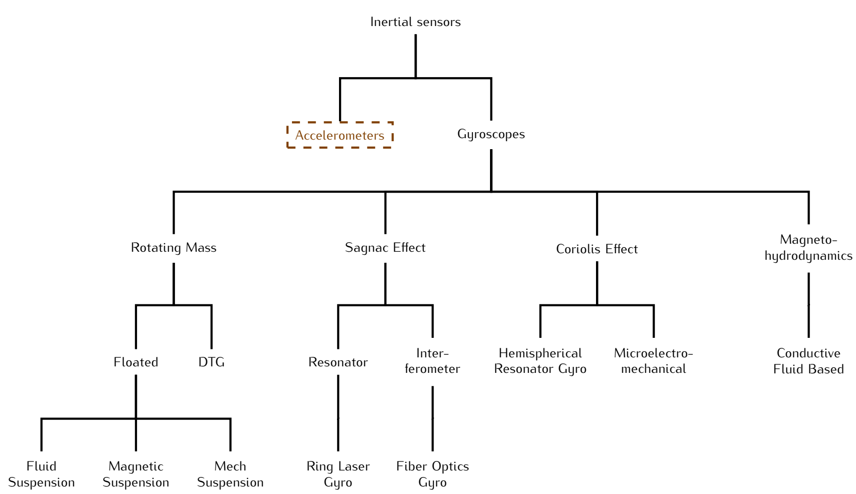
Accelerometers



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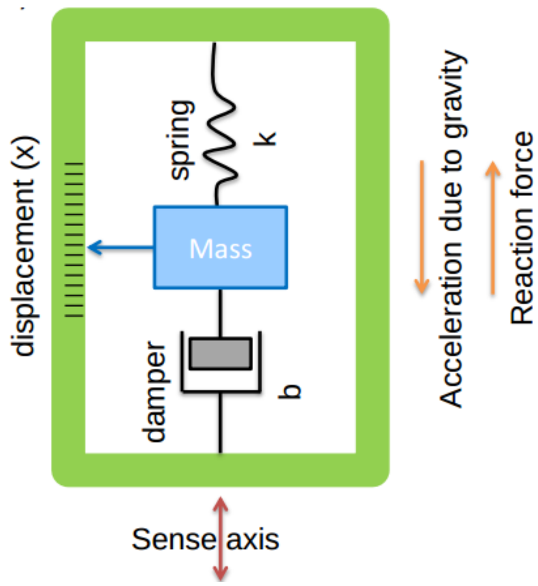
2 Accelerometers

Pendulous Mass

- A mass, a suspension system, and a sensing element
- Displacement $\propto$ applied force resolved along the senstive axis
- Modeled as basic 2^{nd} order system $f = m\ddot{x} + b\dot{x} + kx$
- In steady state $m\ddot{x} \approx -kx$, hence, $SF = \frac{x}{\ddot{x}} = -\frac{m}{k}$



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Pendulous Mass — Closed-loop

- Generates a force to null the displacement
- Improved linearity

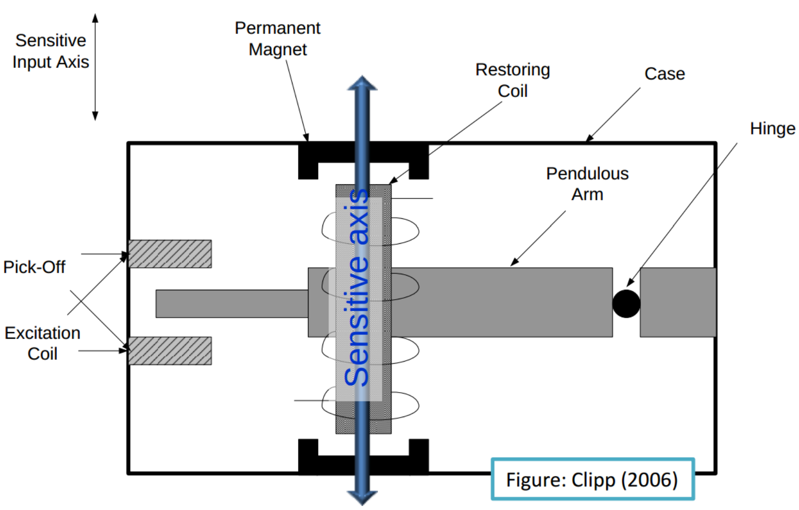

Figure: Clipp (2006)

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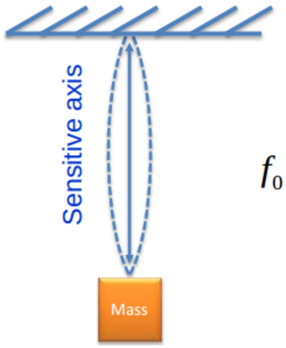
Vibratory

- Vibrating Beam Accelerometer (VBA)
- Acceleration causes a change in resonance frequency



$$f_0 = k\sqrt{Tension}$$

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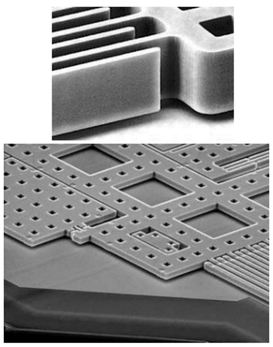
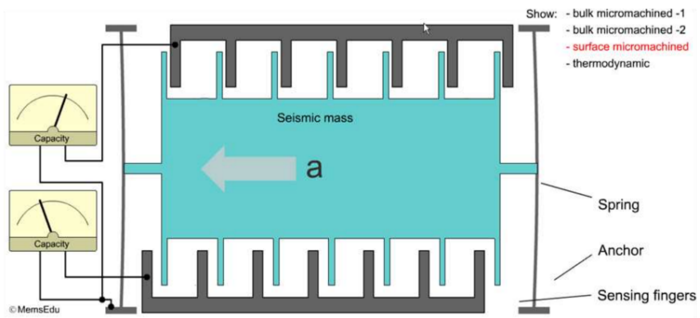
MEMS Accelerometer





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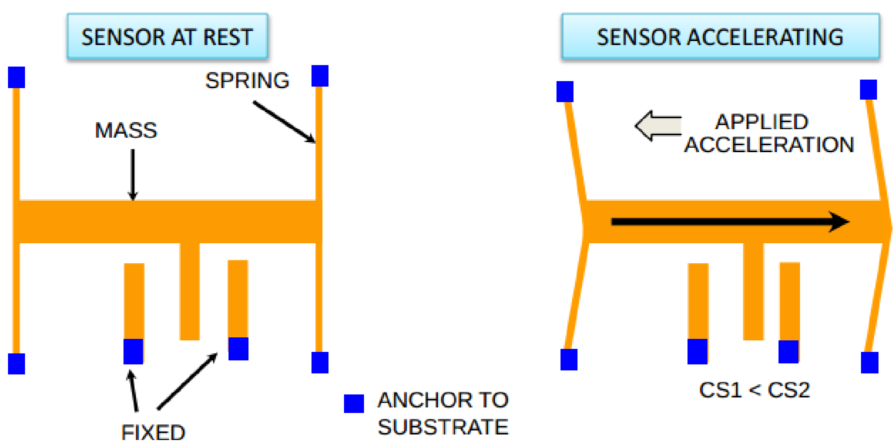
MEMS Accelerometer

- Spring and mass from silicon and add fingers make a variable differential capacitor
- Change in displacement ⇒ change in capacitance



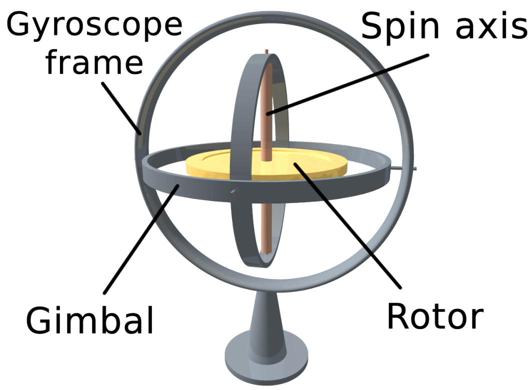
.8

3 Gyroscopes

Rotating Mass Gyroscopes

- Conservation of angular momentum
- The spinning mass will resist change in its angula momentum

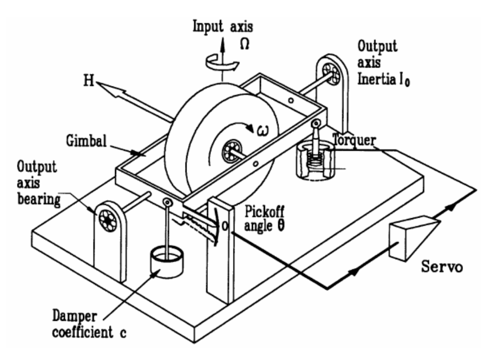
- Angular momentum
  - $H = I\omega$=(Inertia $\times$ angular velocity)
- By placing the gyro in a pair of frictionless gimbals it is free to maintain its inertial spin axis
- By placing an index of the x-gimbal axes and y-gimbal axis two degrees of orientational motion can be measured

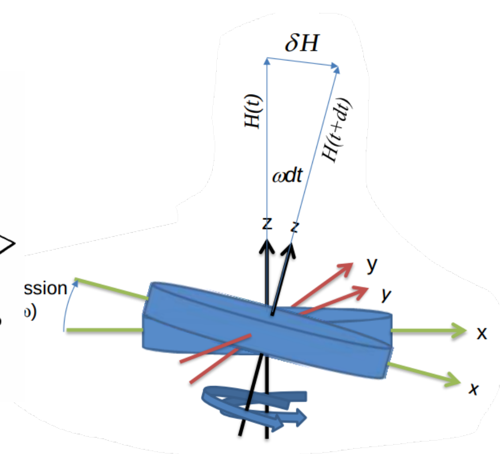


.9

Rotating Mass Gyroscopes

- Precession
  - Disk is spinning about z-axis
  - Apply a torque about the x-axis
  - Results in precession about the y-axis
    - $-\tau = \omega \times H$





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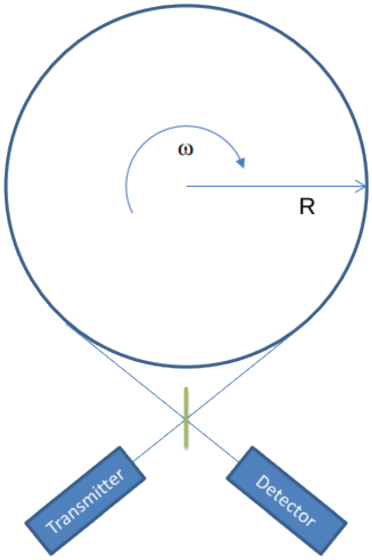
Sagnac Effect Gyroscopes

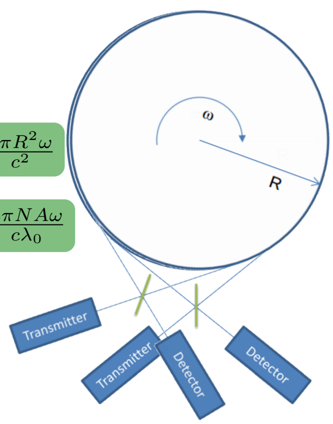
- Fiber Optical Gyro (FOG)
  - Basic idea is that light travels at a constant speed
  - If rotated (orthogonal to the plane) one path length becomes longer and the other shorter
  - This is known as the Sagnac effect
  - Measuring path length change (over a dt) allows ω to be measured



.11

Sagnac Effect Gyroscopes

- Fiber Optical Gyro (FOG)
  - Measure the time difference between the CW and CCW paths
  - CW transit time = t_{CW}
  - CCW transit time = t_{CCW}
  - $L_{CW} = 2\pi R + R\omega t_{CW} = ct_{CW}$
  - $L_{CCW} = 2\pi R - R\omega t_{CCW} = ct_{CCW}$
  - $t_{CW} = 2\pi R/(c - R\omega)$
  - $t_{CCW} = 2\pi R/(c + R\omega)$ $\Rightarrow \Delta t \approx \frac{4\pi R^2\omega}{c^2}$
  - With N turns $\Delta t \approx \frac{N4A\omega}{c^2}$
  - Phase $\phi_c \approx 2\pi\Delta t f_c = 2\pi\Delta tc/\lambda_0 = \frac{8\pi NA\omega}{c\lambda_0}$

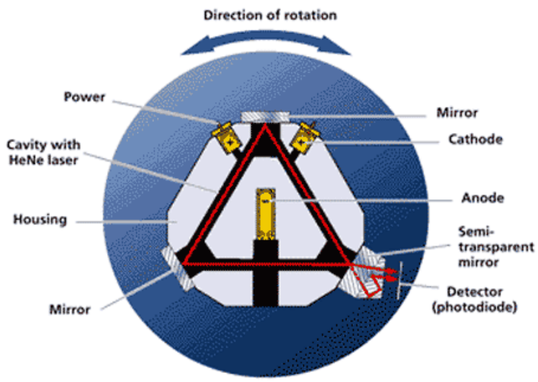


.12

Sagnac Effect Gyroscopes

- Ring Laser Gyro (RLG)
  - A helium-neon laser produces two light beams, one traveling in CW direction and the other in the CCW direction
  - When rotating
    - The wavelength in direction of rotation increases (decrease in freq)
    - The wavelength in opposite direction decreases (increase in freq)
    - Similarly, it can be shown that

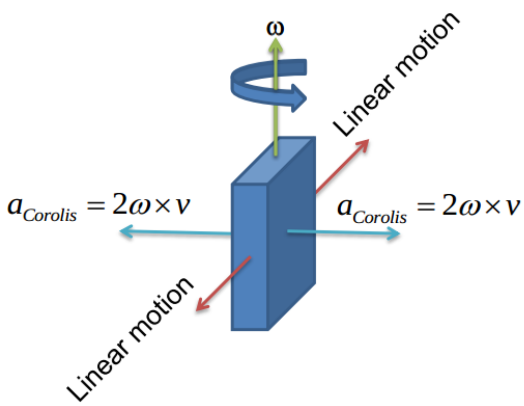
$$\Delta f \approx \frac{4A\omega}{\lambda_0}$$



.13

Gyroscopes: Coriolis Effect

- Vibratory coriolis angular rate sensor
  - Virtually all MEMS gyros are based on this effect



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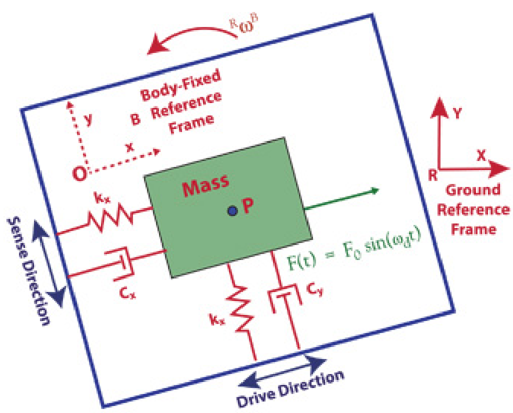
Gyroscopes: Coriolis Effect

- Basic planer vibratory gyro



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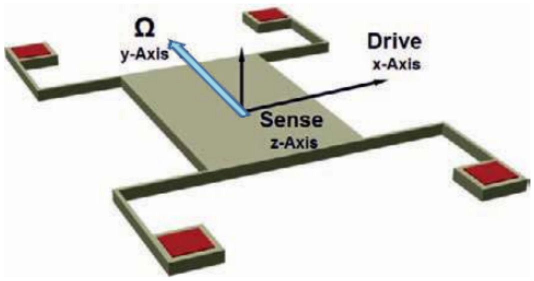
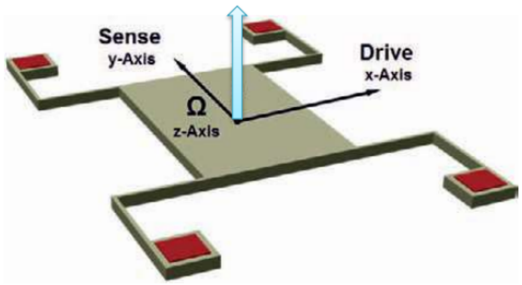
Gyroscopes: Coriolis Effect



In plane sensing



Out of plane sensing

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.16

4 Summary

Summary

- Accelerometers
  - Measure specific force of the body frame *wrt* the inertial frame in the body frame coordinates
    - Need to subtract the acceleration due to gravity to obtain the motion induced quantity
  - In general, all points on a rigid body do **NOT** experience the same linear velocity
- Gyroscopes
  - Measure the inertial angular velocity
    - Essentially, the rate of change of orientation
  - All points on a rigid body experience the same angular velocity

.17