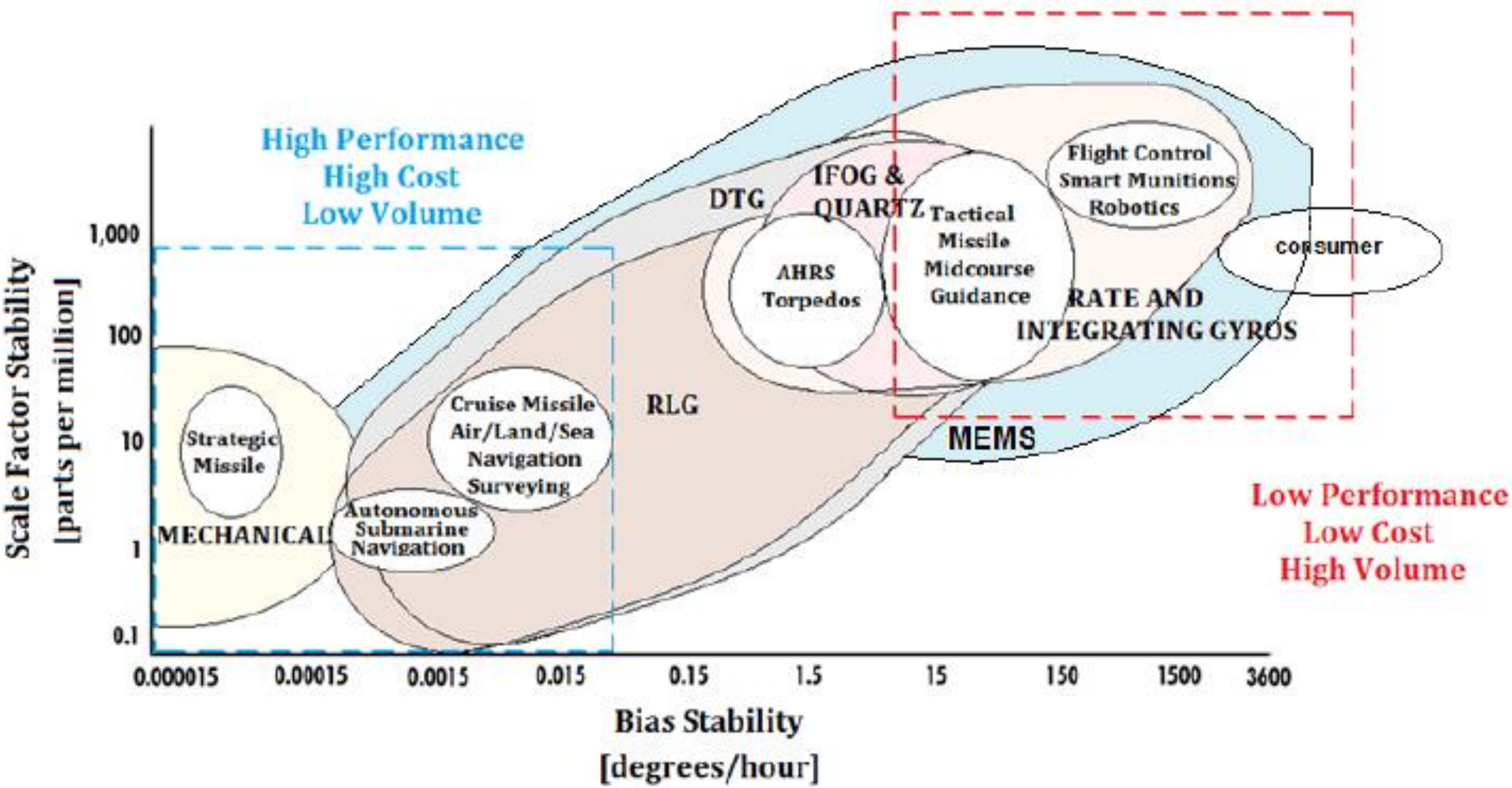
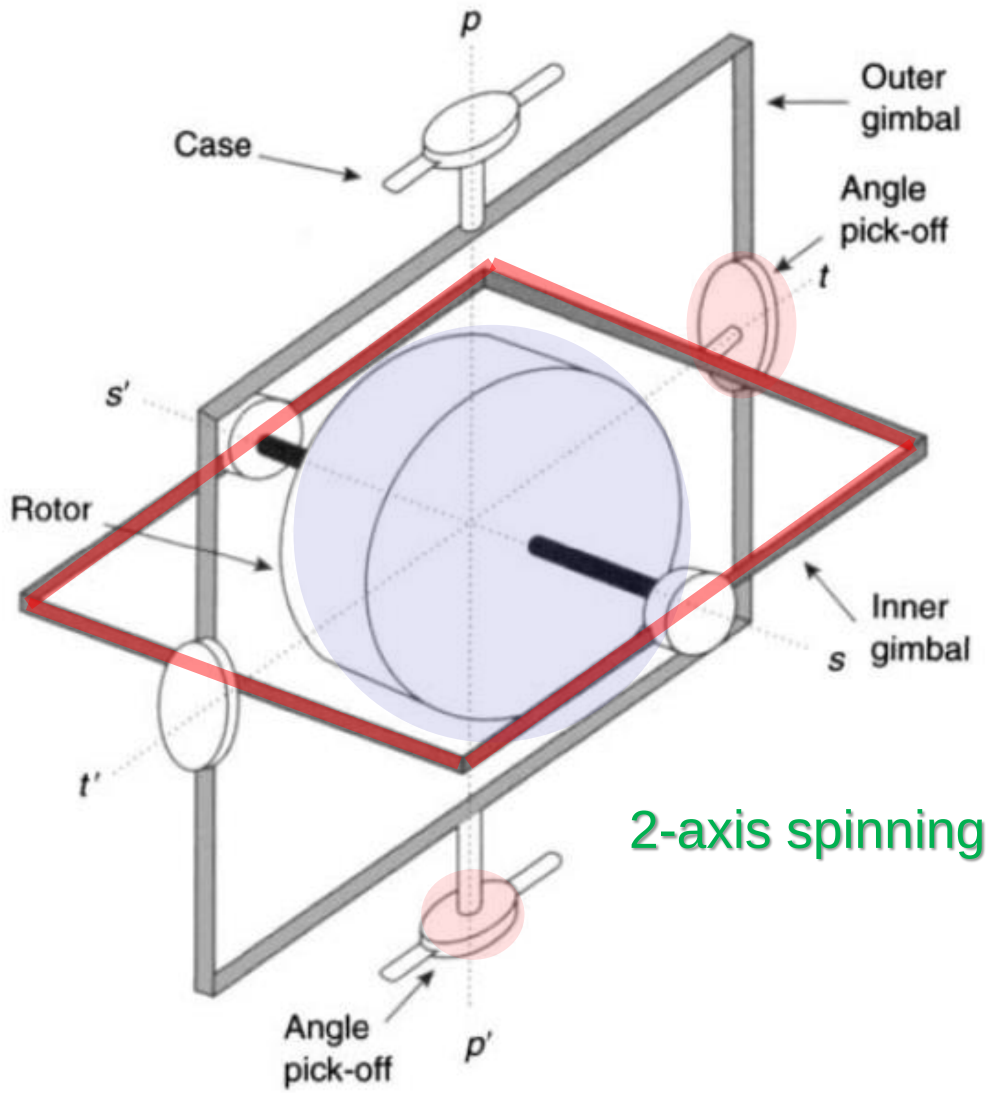
AE 242
Aerospace Measurements Laboratory

Gyroscope



High Performance
High Cost
Low Volume
Low Performance
Low Cost
High Volume
Scale Factor Stability
[parts per million]
1,000
100
10
1
0.1
Bias Stability
[degrees/hour]
0.000015
0.00015
0.0015
0.015
0.15
1.5
15
150
1500
3600
Strategic Missile
MECHANICAL
Autonomous Submarine Navigation
Cruise Missile Air/Land/Sea Navigation Surveying
RLG
DTG
IFOG & QUARTZ
AHRS Torpedos
Tactical Missile Midcourse Guidance
Flight Control Smart Munitions Robotics
consumer
RATE AND INTEGRATING GYROS
MEMS

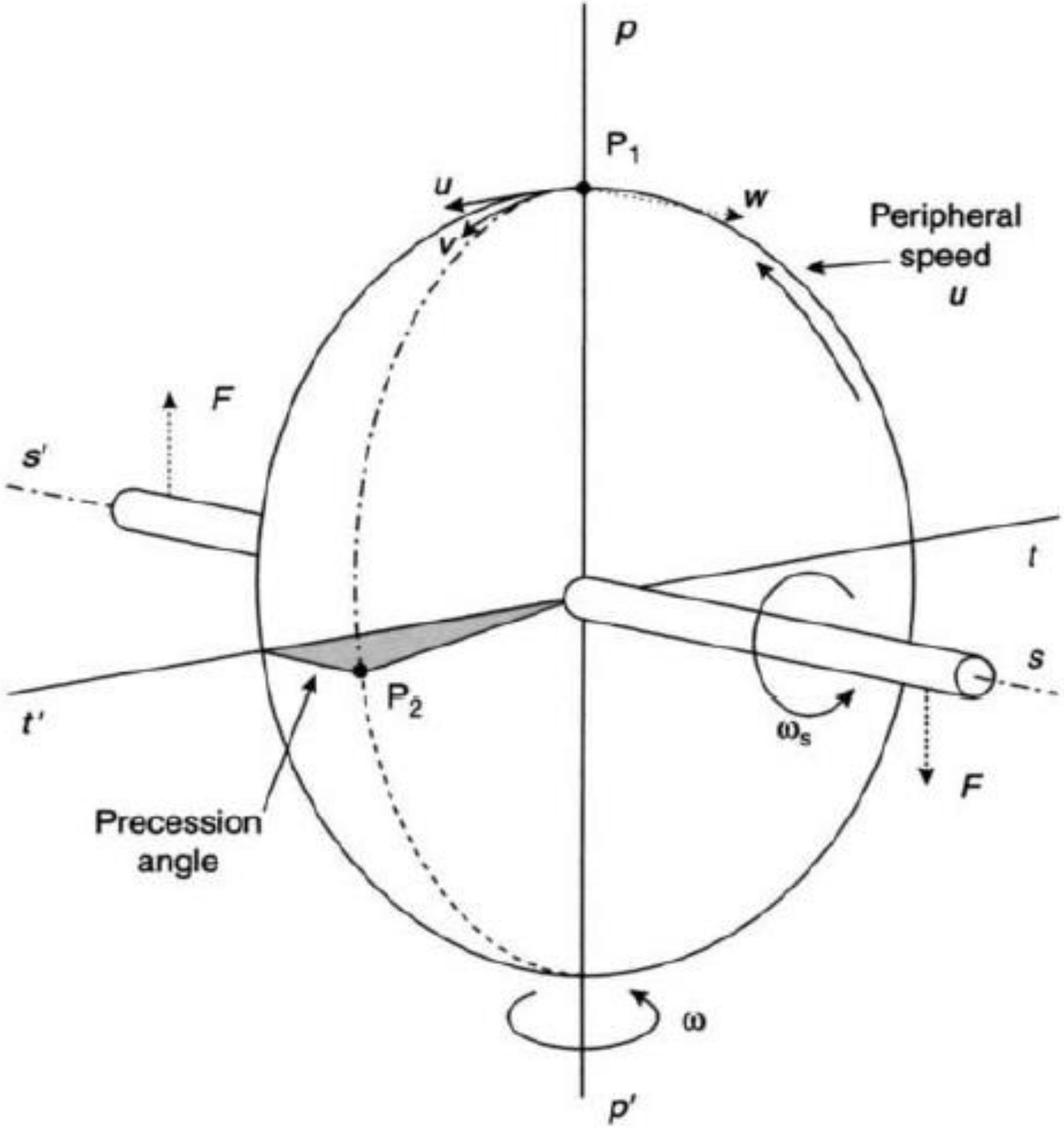
Gyroscope - Mechanical



2-axis spinning mass gyroscope

Strapdown Inertial Navigation Technology, D.H. Titterton, J.L. Weston

Gyroscope - Mechanical



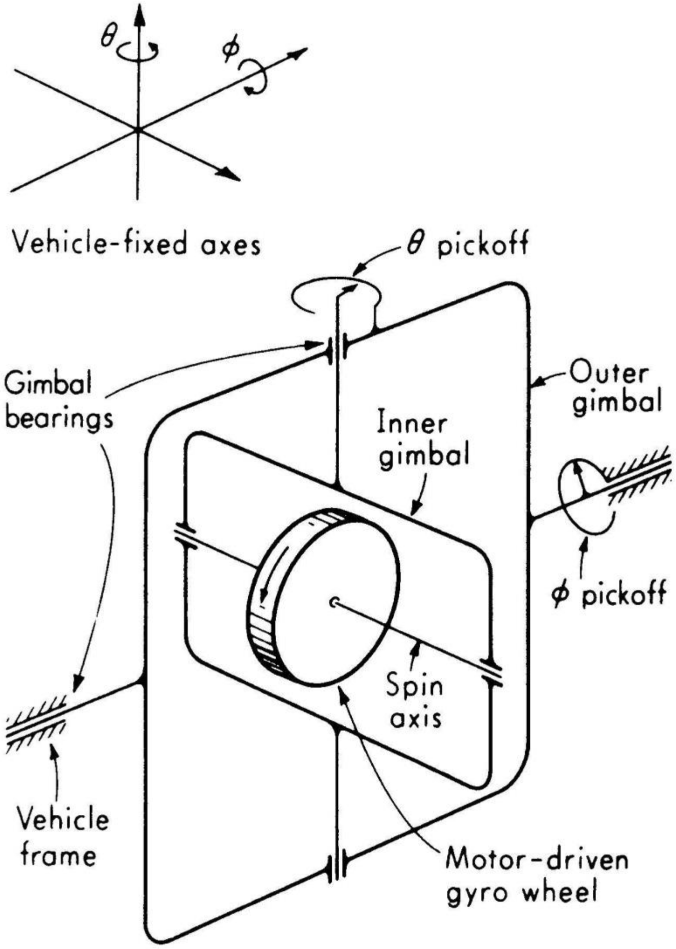
s-s' – Spin axis

F-F – Applied impulse

p-p' – Precession axis

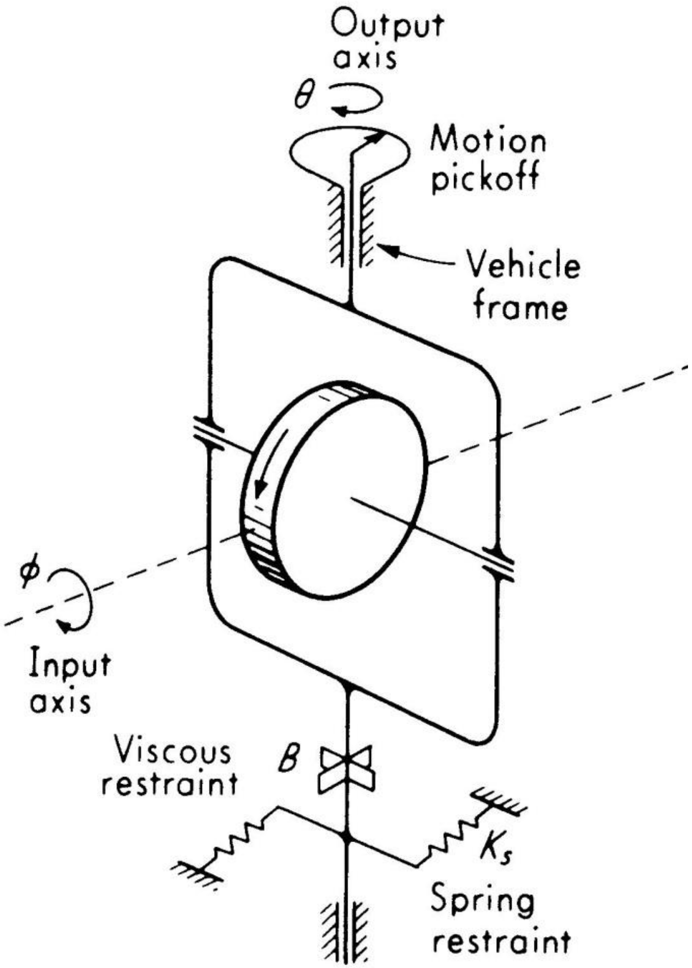
Gyroscope - Mechanical

Spinning mass axis always point to a fixed direction in the space. Using free gyroscope two motions can be detected. This system directly gives the rotation angle. Coupling between two axis exist and it is dominant at large angles.

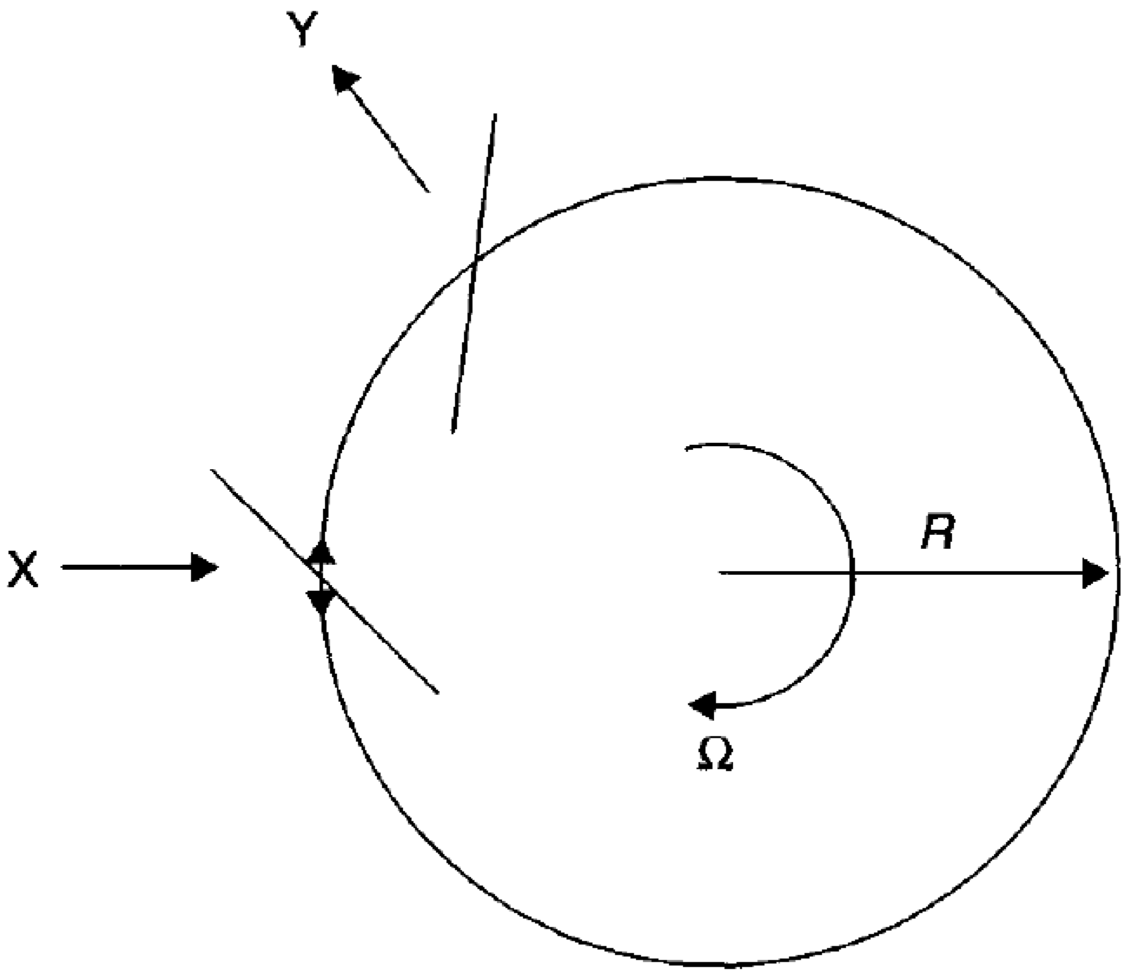


Gyroscope - Mechanical

When the axis is constrained, torque will be applied by the spinning mass to restore the position. Used for measurement of angular rates. For high sensitivity large mass at large speed is required. Generally gyros are built to measure motion in one axis to remove the coupling effect.



Gyroscope - Optical

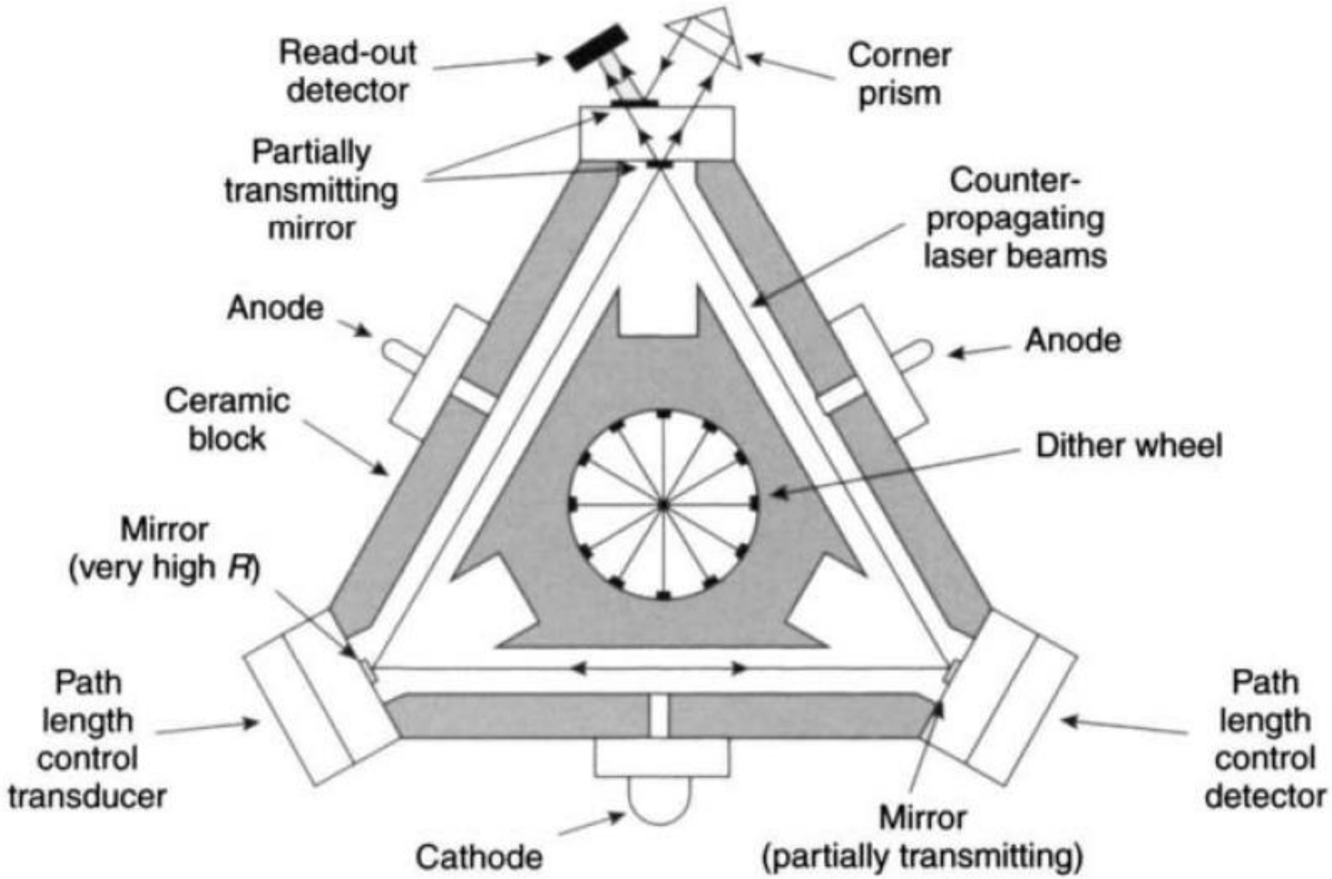


$$t = \frac{2\pi R}{c}$$

Light (laser) moves in two different direction. When body is stationary, light take equal time to reach start point.

When body is rotating light takes different time to reach the start point, called as Sagnac effect

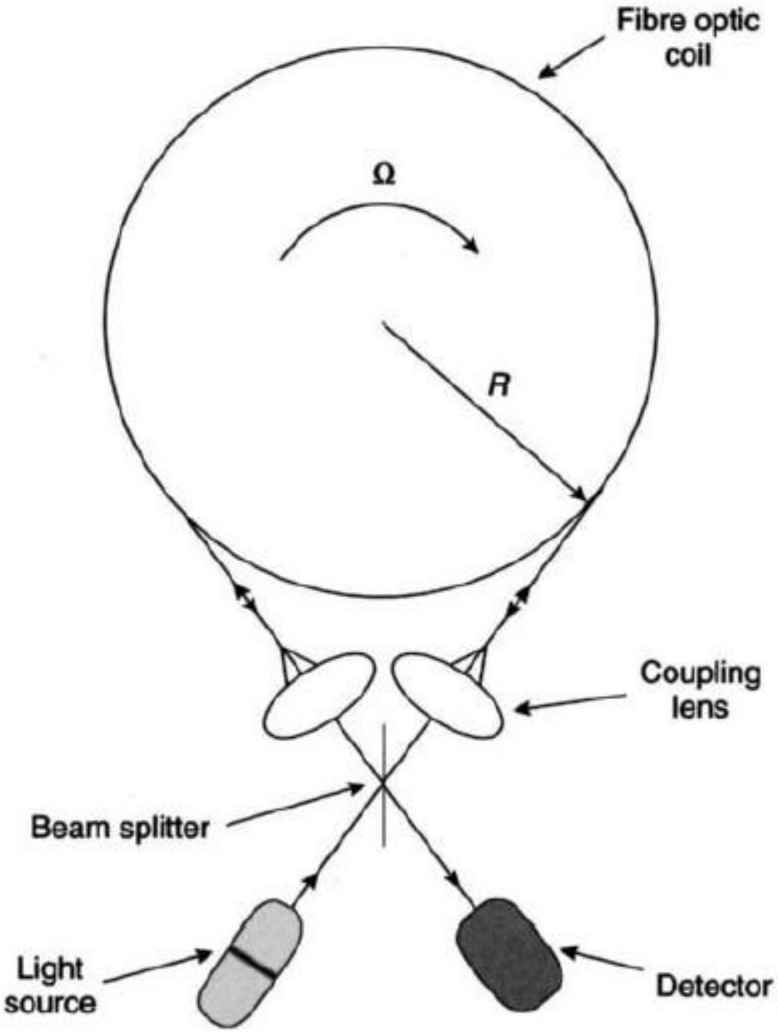
Gyroscope - Optical



Light (laser) resonates inside the tube. Creates standing waves when stationary. Under rotation, frequency of the resonance is different in two direction, this is proportional to angular rate, this is detected for measurement of angular rate.

Ring Laser Gyroscope (RLG)

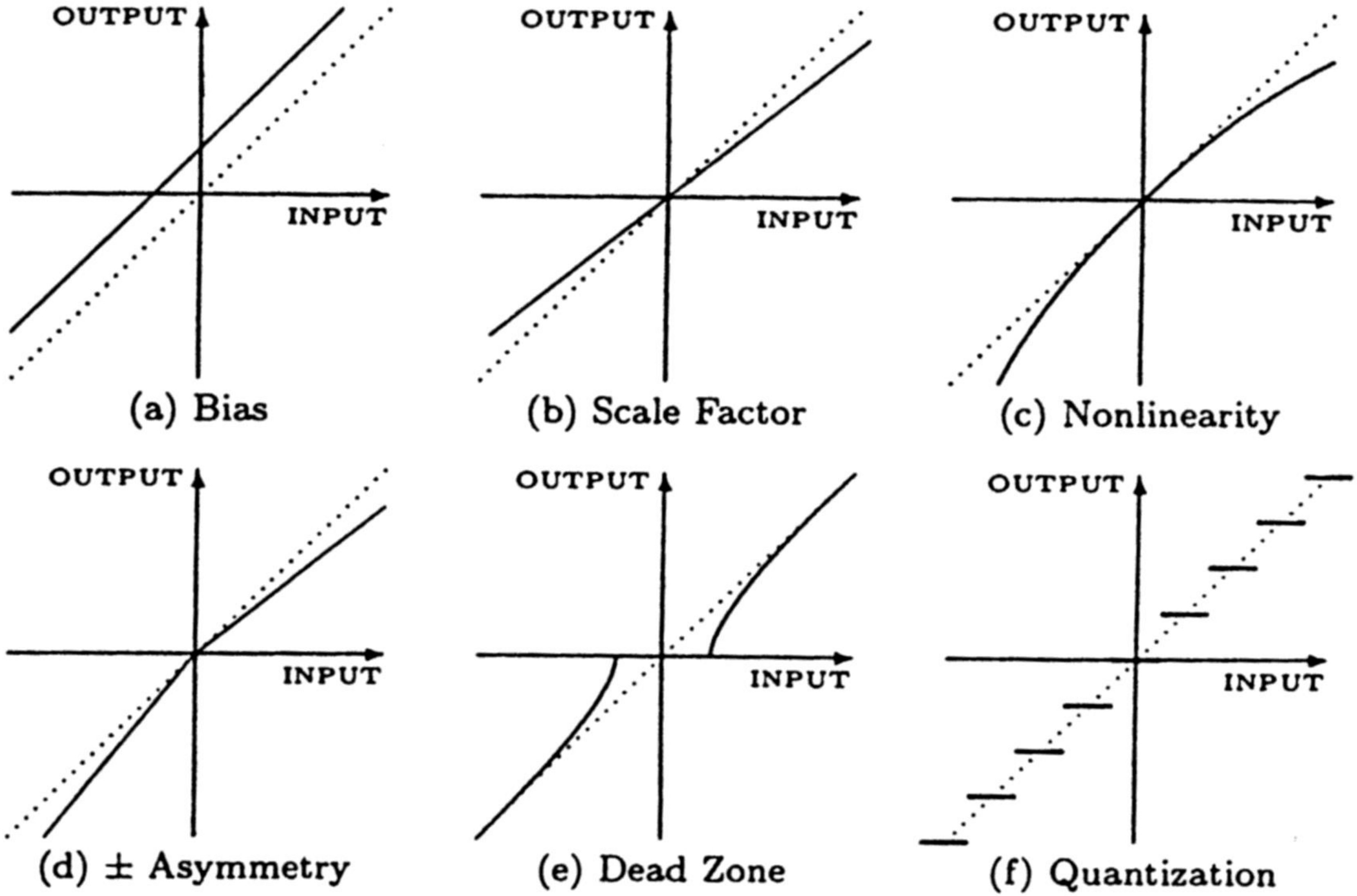
Gyroscope - Optical



Light (laser) is split and sent in two different direction. Light travels through same distance and medium before meeting at start point. Phase between two beam will depend on the body motion. Phase difference will depend on the magnitude of rotation (angle measurement)

Fiber Optic Gyroscope (FOG)

Common error models

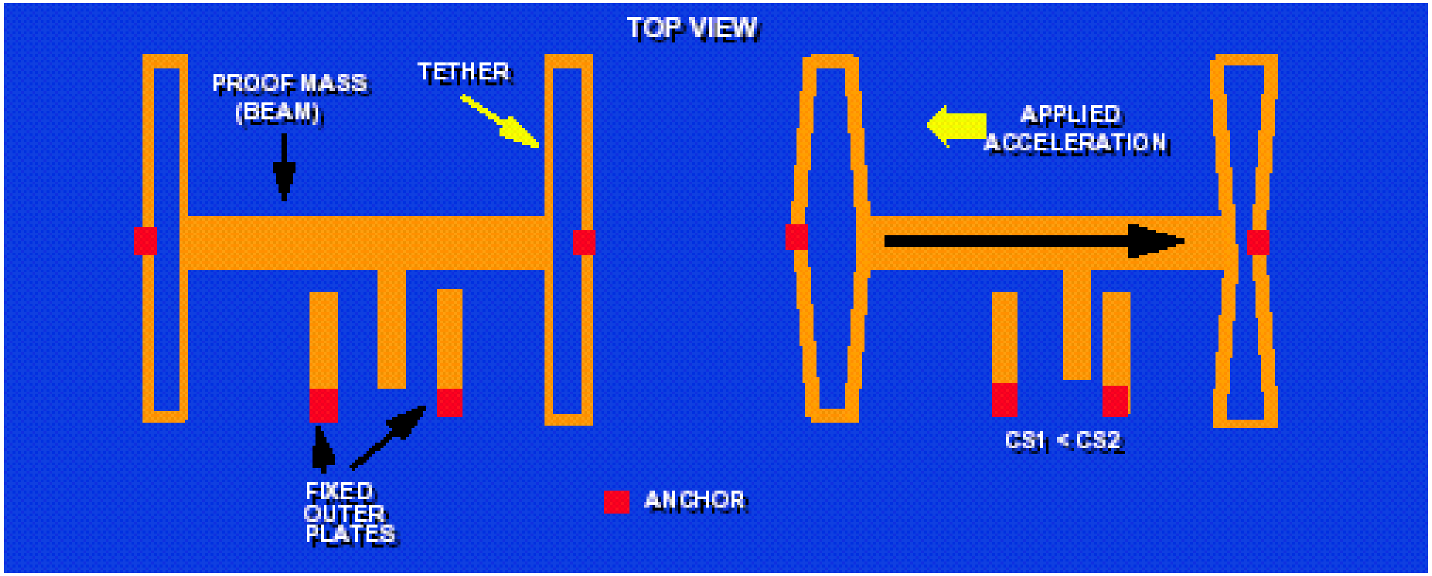


MEMS based sensors

Micro Electrical Mechanical Systems

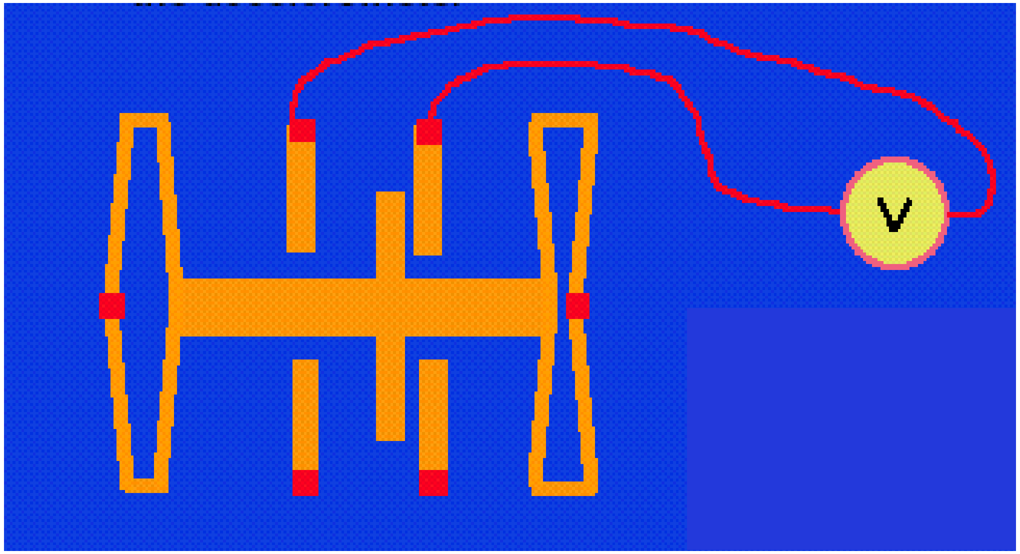
Practice of making and combining miniaturized mechanical and electrical components

MEMS based Single Chip acceleration Sensor



Sensor forms Differential Capacitor, circuitry to measure change in capacitance, it is also the part of the sensor package.

Self Test Operation



Extra fixed outer plates are added which when excited, force the proof mass to move. So it can electronically test the accelerometer.

Interesting Facts

0.1μgrams Proof Mass

0.1pF per side for the Differential Capacitor

20aF (10^{-18}f) least detectable Capacitance change

Total Capacitance change for Full Scale is 10fF

1.3μm gaps between Capacitor Plates

0.2A minimum detectable beam deflection

1.6μm between suspended beam and substrate

10 to 22 kHz resonant frequency of beam

Advantages

Low cost (can even be made “disposable”)

FFTs can be used to increase the performance

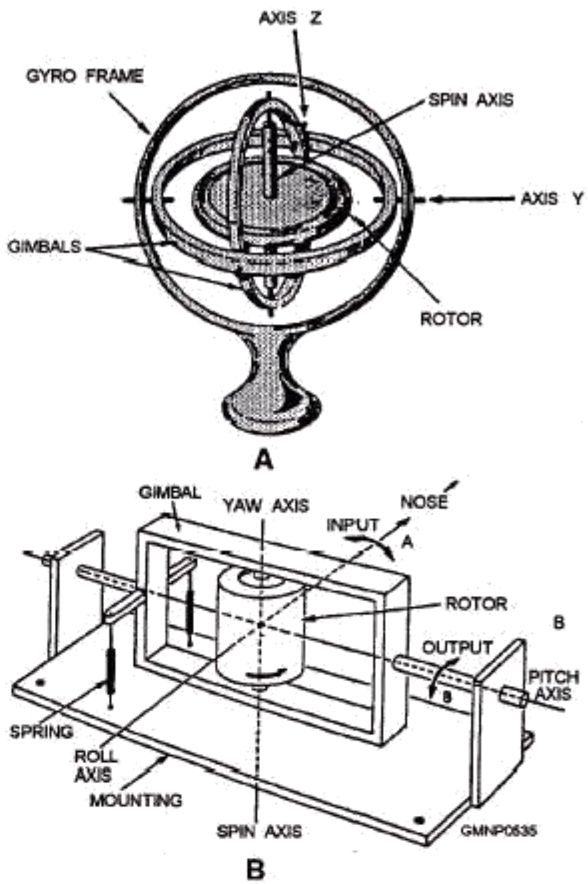
Onboard signal conditioning. No charge amplifiers required.

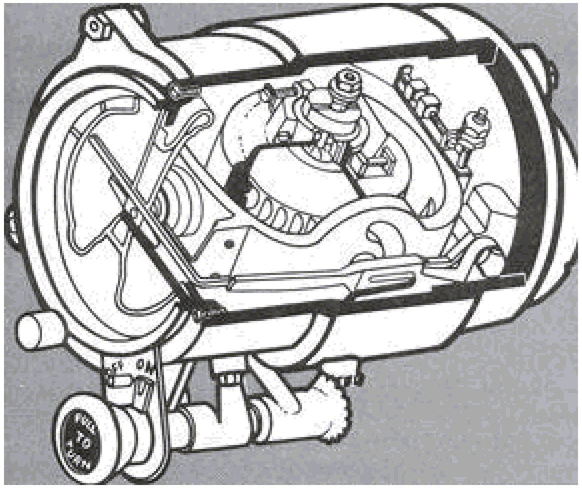
Disadvantages

Performance still below that of more expensive sensors

May not be available in industrial hardened packages

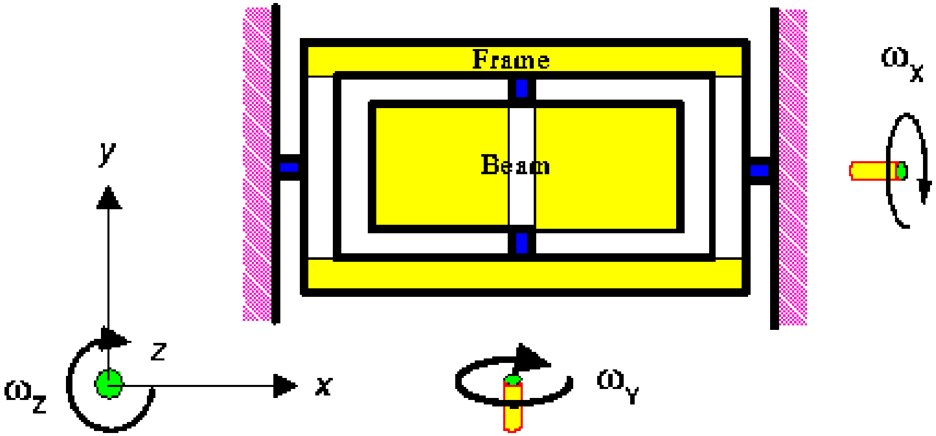
–Angular Rate Sensor





–Mechanical - Spinning mass

Angular Rate Sensor



- Two masses supported by torsional springs
- Electrical excitation to oscillate in rotating mode around x axis
- If rotated about *z* axis, coriolis force about y axis
- Motion of beam mass is sensed
- Structure enclosed in low pressure chamber and remaining gas in air gaps cause damping

Gyroscopes - Comparison

- Conventional
  - Bulky
  - Power hungry
  - Mechanical wear and tear
  - Highly accurate
  - Expensive

- MEMS based
  - Miniaturised
  - Low power consumption
  - Less moving parts
  - Accuracy not up to inertial class
  - Less weight
  - Low cost