DIGITAL ASSIGNMENT-1

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18BIS0008

ECE3032

SLOT: F1

SENSOR TECHNOLOGY

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MEMS- (Micro-electro-mechanical Systems):

As the name infers, Microelectromechanical Systems (MEMS) is the innovation that consolidates electrical and mechanical frameworks at a miniaturized scale. Basically, any gadget created utilizing photograph lithography-based procedures with micrometer (1μm=10−6m) scale highlights that use both electrical and mechanical capacities could be viewed as MEMS.

Gyroscopes:

In most straight forward terms, the gyroscope is the sensor that measures the rate of rotation of an object. The name "gyroscope" originated from L'eon Foucault, consolidating the Greek word "skopeein" which means to see and the Greek word "gyros" which means rotation, during his experiments to measure the revolution of the Earth. The earliest gyroscopes, for example, the Sperry whirligig, and numerous cutting-edge spinners use a pivoting energy wheel connected to a gimbal structure. In any case, turning wheel whirligigs accompanied numerous impediments, essentially concerning bearing rubbing and wear.

Types of Gyroscopic sensors:

1) **Vibrating gyroscopes (MEMS technology)**

Example: Hemispherical Resonator Gyroscope (HRG) ,Tuning-Fork Gyroscopes

Based on "**Coriolis effect**" - Linear Vibrating gyroscopes

"**Gyroscopic Precession**" - Torsional Vibrating gyroscopes

2) **Optical gyroscopes**
   Example: Fiber-Optic Gyroscope (FOG)and Ring Laser Gyroscope (RLG)
   Based on " **Sagnac effect**"

***MEMS Gyroscopes are generally Vibrating gyroscopes either Linear or Torsional type.**

***MEMS Gyroscopes can be fabricated either on insulator or on glass with silicon.(i.e., SOI = Silicon On Insulator, SOG = Silicon On Glass)**

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STMicroelectronics is a French-Italian multinational electronics and semiconductor manufacturer and it is Europe's largest semiconductor chip maker based on revenue. Usually called ST.

“L3G4200D” is a MEMS Gyroscopic sensor which is ultra-stable 3-axis digital output gyroscope manufactured by STMicroelectronics.

Description

- ⇨ The L3G4200D is a low-power 3-axis angular rate sensor able to provide unprecedented stability of zero rate level and sensitivity over temperature and time.
- ⇨ It includes a sensing element and an IC interface capable of providing the measured angular rate to the external world through a digital interface.
- ⇨ The sensing element is manufactured using a dedicated micro-machining process developed by STMicroelectronics to produce inertial sensors and actuators on silicon wafers.

SPECIFICATIONS:

- **L3G4200D has a full scale ⬄ ±250/±500/±2000dps(degrees per second)**
- **I^{2}C/SPI digital output interface**
- **Data output ⬄ 16 bits**
- **Temperature ⬄ 8 bits**
- **Two digital output lines ⬄ interrupt and data ready**
- **Integrated low- and high-pass filters ⬄ user selectable bandwidth**
- **Wide supply voltage ⬄ 2.4 V to 3.6 V**
- **Embedded power-down and sleep mode**
- **Embedded temperature sensor**
- **High shock survivability**
- **Extended operating temperature range ⬄ -40 °C to +85 °C**
- **Low voltage compatible IOs ⬄ 1.8 V**

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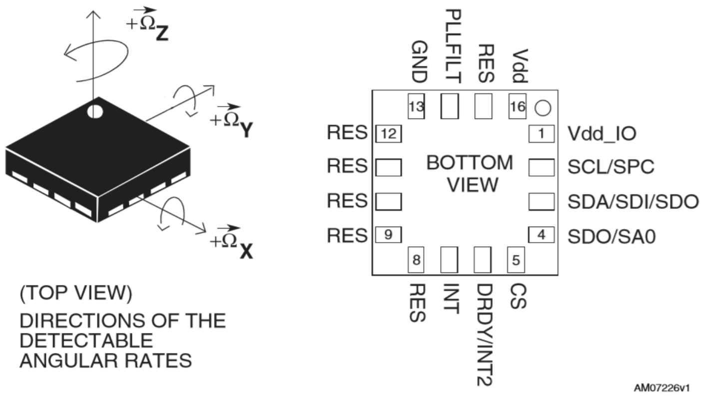
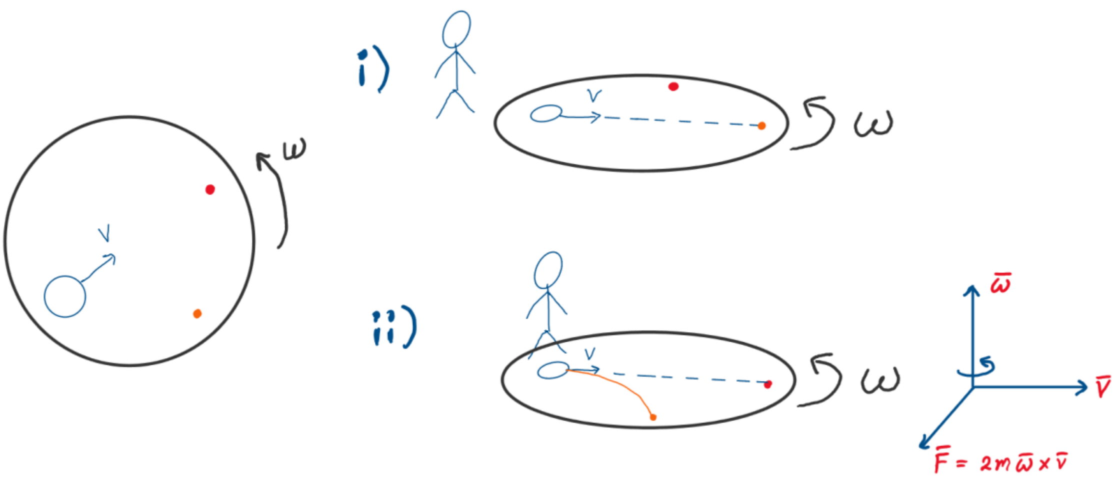
PIN DIAGRAM OF L3G4200D



BASIC WORKING PRINCIPLE OF MEMS GYROSCOPE: (z axis)

1) MEMS Gyroscope works based on the physical phenomenon called "Coriolis effect".
2) **Coriolis effect:**
   It is effect caused by Coriolis force which is an inertial or fictitious force that acts on objects that are in motion within a frame of reference that rotates with respect to an inertial frame.



Case(i) is inertia frame or reference frame ⇔ the ball appears to move in a straight line as seen by the observer in inertia frame.
Case(ii) is non-inertia frame (rotating frame) ⇔ the ball appears to move in a curve path as seen by the observer in non-inertia frame.

3) MEMS Gyroscopes are also called as Vibrating MEMS Gyroscopes, because it involves vibration of the "Proof mass" back and forth.
4) ***The basic components present in MEMS Gyroscopes are***

⇨ ***Proof mass (a freely movable mass)***

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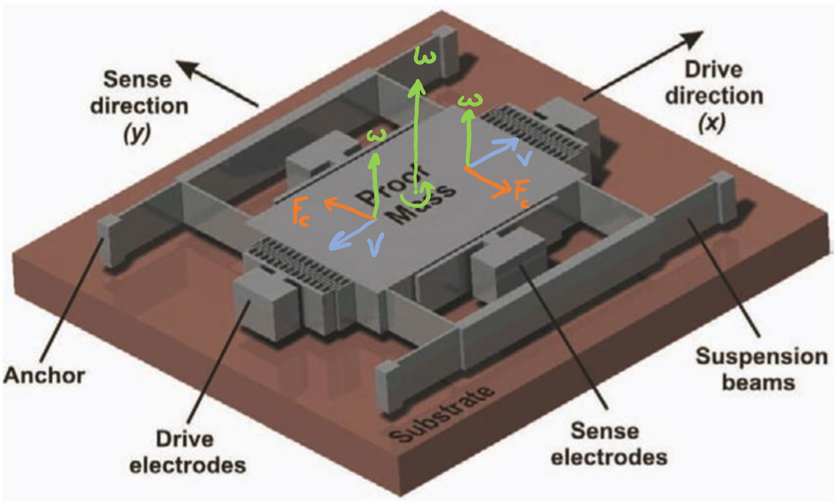
- ⇨ ***Drivers (which vibrate the proof mass)- by electrostatic forces***
- ⇨ ***Sense-mode (senses the Coriolis force as a change in capacitance)***

5) By giving a sinusoidal voltage to the Drivers or the Drive-mode, which in turn vibrates the proof mass has it is connected to it by comb like structures.
6) If the MEMS IC experiences a rotating motion with an angular velocity then the Coriolis forces induced on the vibrating proof mass is detected by the sense-mode.
7) And the strength of the sinusoidal voltage that sense-mode receives will determine the magnitude of the Coriolis force which in turn tells the angular velocity of rotation, since
   |Coriolis force|= 2mωV (where m=mass, ω=angular velocity, V=velocity of object)
8) By increasing the DOF (degrees of freedom) we can measure the **ω** in all directions and with high accuracy.



This is a "Linear Vibrating MEMS Gyroscope".

9) Drive – mode ⬄ electrostatic forces
   Sense – mode ⬄ capacitance

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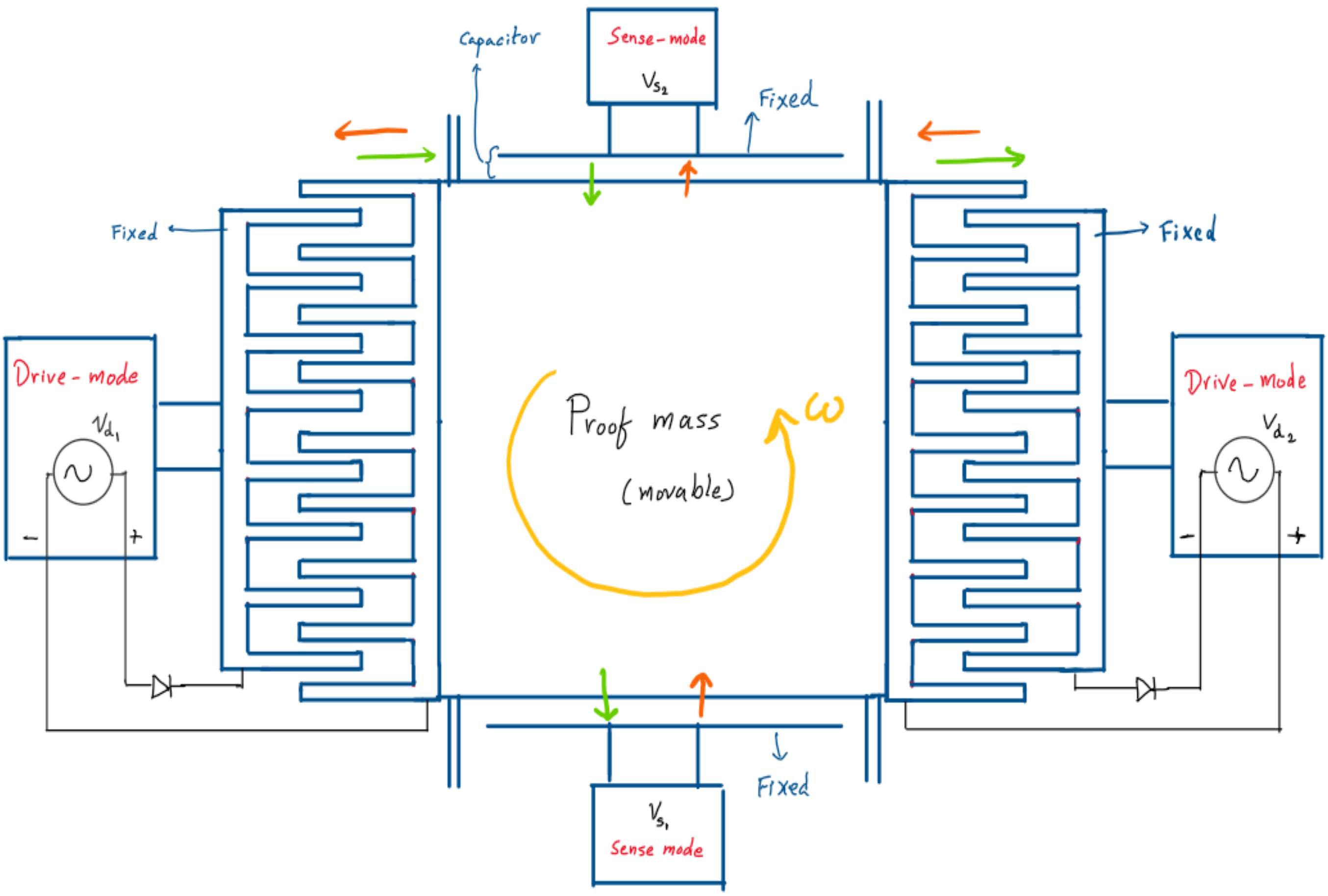
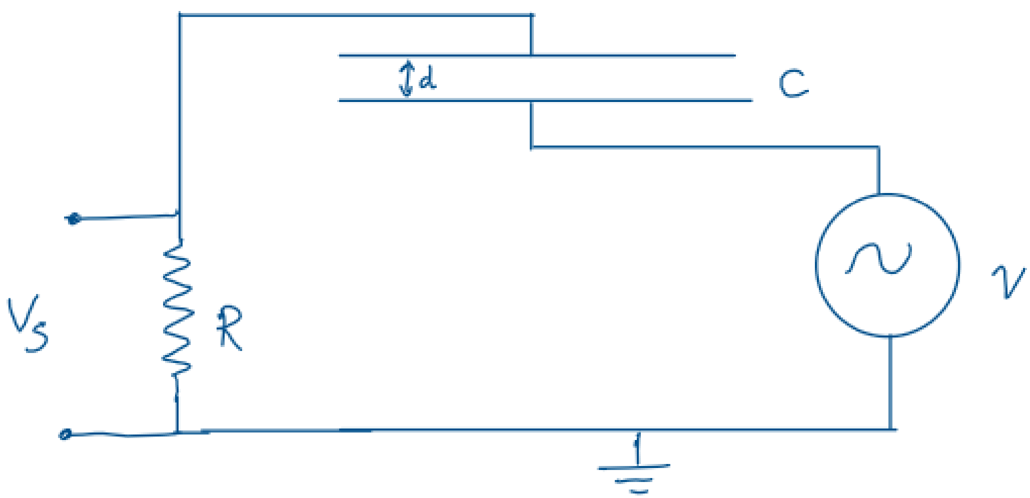


10) By including the diodes both drivers can't be on at the same time this makes the proof mass vibrate back and forth in a sinusoidal pattern of displacement in drive direction.

11) And by using sense circuit we can measure the angular velocity based on Coriolis effect.

<u>Sense-mode circuit</u>



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$$V_s = V\left(\frac{R}{R+jX_c}\right)$$

where $X_c = \frac{1}{C\omega} \Rightarrow \Delta X_c = -\frac{1}{C^2\omega}\Delta C$

$$V_s = V\frac{R}{\sqrt{R^2+X_c^2}} \Rightarrow \Delta V_s = \frac{-VRX_c}{(R^2+X_c^2)^{3/2}}\Delta X_c$$

$$\Rightarrow \Delta V_s = \frac{VRX_c^2}{(R^2+X_c^2)^{3/2}} \cdot \frac{\Delta C}{C}$$

$$\therefore \Delta V_s = \alpha V(t) . \Delta C \qquad \left(\because \Delta C = -\frac{\varepsilon A}{x^2}\Delta x\right)$$

$$\Rightarrow \frac{dV_s}{dt} = \alpha V(t)\frac{dC}{dt} = -\frac{\varepsilon A \alpha}{x^2} V(t)\frac{dx}{dt}$$

$$\Rightarrow \frac{d^2V_s}{dt^2} = \beta\frac{dV}{dt}.\frac{dx}{dt} + \beta V(t).\frac{d^2x}{dt^2}$$

$$\left(\because a = \frac{d^2x}{dt^2} = \frac{F}{m}\right)$$

$$\Rightarrow \frac{d^2V_s}{dt^2} = \beta\frac{dV}{dt}.\frac{dx}{dt} + \beta V(t)\frac{F}{m}$$

$$\Rightarrow \frac{d^2V_s}{dt^2} \propto \frac{F}{m} \qquad (\because F_{coriolis} = 2m\omega v)$$

$$\Rightarrow \frac{d^2V_s}{dt^2} \propto 2\omega v$$ ($\because$ v - velocity of proof mass vibrating)

$$\Rightarrow \boxed{\frac{d^2V_s}{dt^2} \propto \omega \text{ (angular velocity)}}$$

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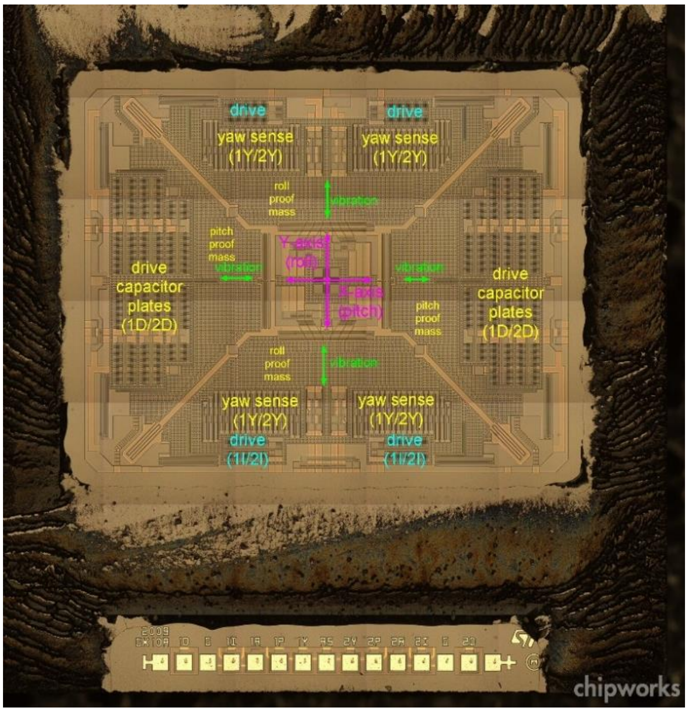
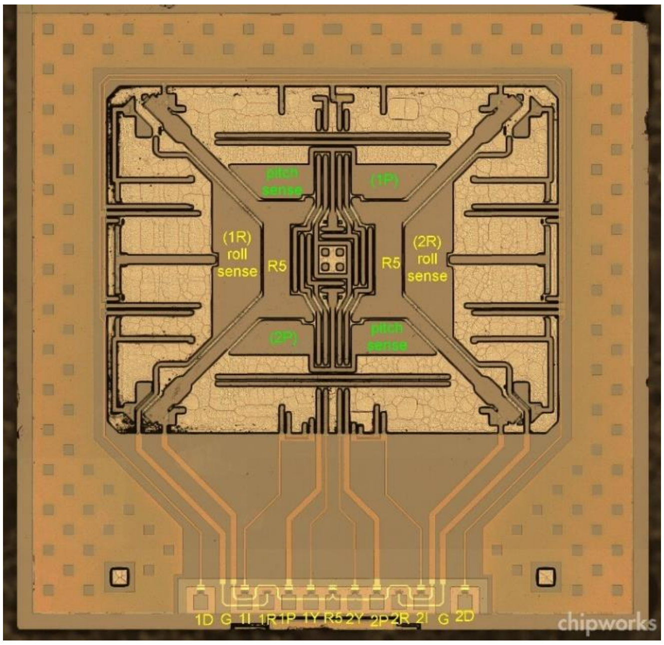
WORKING OF L3G4200D MEMS GYROSCOPE (x, y, z axis)

1) **It consists of 'four proof mass' in the shape of a trapezium which lie in XY- plane.**
2) **It consists of 3 pairs of sense-modes in order to measure angular velocity in three axis x, y and z.**
3) **It has a drive-mode that will vibrate the 4 proof masses in and out.**

TOP VIEW of L3G4200D MEMS die

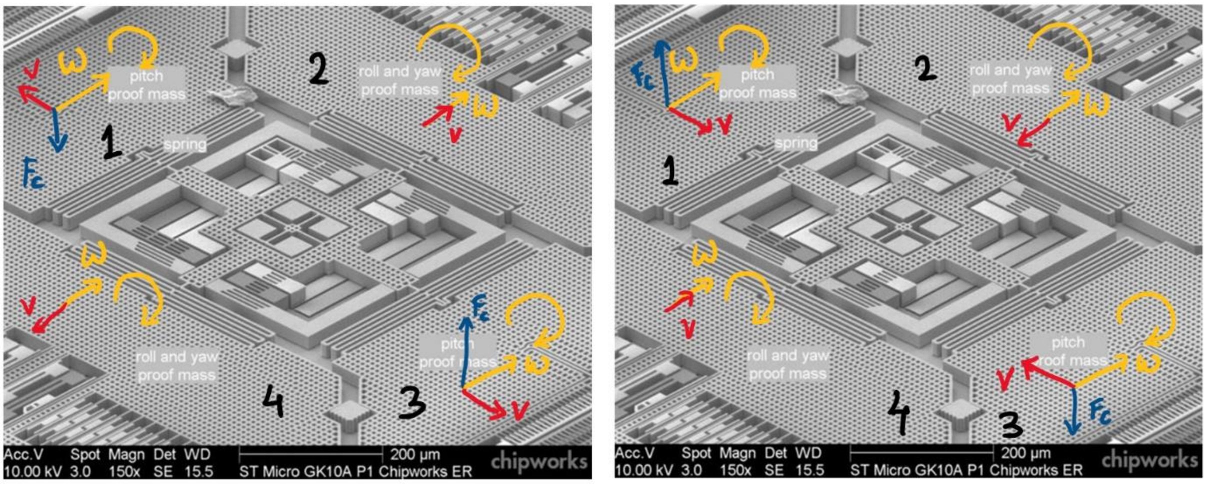


SENSE- MODE OF L3G4200D die (senses x , y rotation)



4) MEASURING THE X-AXIS ROTATION (PITCH)

This is (ST Micro GK10A P1 Chipworks ER) present in L3G4200D MEMS Gyroscope.



i) Here the MEMS IC is rotating along x-axis, so the angular velocity vector in along x-axis.

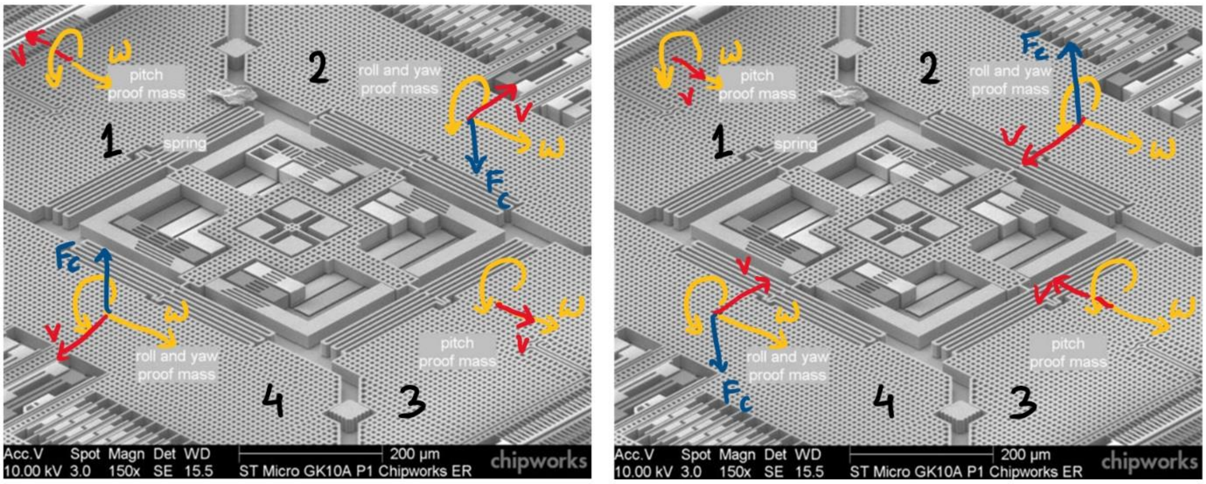
ii) While moving out the 1 and 3 proof masses experience the Coriolis forces in -z and z direction respectively.

iii) While moving in the 1 and 3 proof masses experience the Coriolis forces in z and -z direction respectively.

iv) 2 and 4 proof masses does not experience any Coriolis force because both velocity and angular velocity vectors are along the same axis.

v) The pitch sense-mode measures the induced Coriolis force on 1 and 3 proof masses by measuring change in capacitance between the proof masses on the sense-mode plate underneath the proof masses.

5) MEASURING THE Y-AXIS ROTATION (ROLL)



i) Here the MEMS IC is rotating along y-axis, so the angular velocity vector in along y-axis.

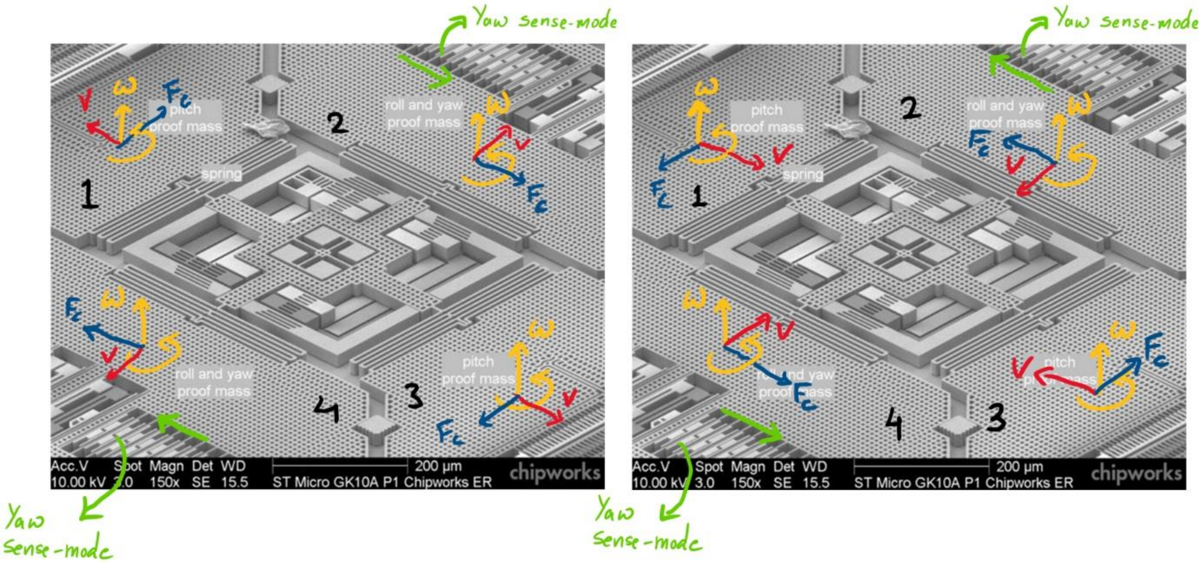
ii) While moving out the 2 and 4 proof masses experience the Coriolis forces in -z and z direction respectively.

iii) While moving in the 2 and 4 proof masses experience the Coriolis forces in z and -z direction respectively.

iv) 1 and 3 proof masses does not experience any Coriolis force because both velocity and angular velocity vectors are along the same axis.

v) The roll sense-mode measures the induced Coriolis force on 2 and 4 proof masses by measuring change in capacitance between the proof masses on the sense-mode plate underneath the proof masses.

6) **<u>MEASURING THE Z-AXIS ROTATION (YAW)</u>**



i) Here the MEMS IC is rotating along z-axis, so the angular velocity vector in along z-axis.

ii) While moving out the 1 and 3 proof masses experience the Coriolis forces in x and -x direction respectively and 2 and 4 proof masses experience the Coriolis forces in y and -y direction respectively.

iii) While moving out the 1 and 3 proof masses experience the Coriolis forces in -x and x direction respectively and 2 and 4 proof masses experience the Coriolis forces in -y and y direction respectively.

iv) 1 and 3 proof masses are not connected to any yaw sense mode so, their movement is not useful for measurement.

v) The yaw sense-mode (present in XY-plane) measures the induced Coriolis force on 2 and 4 proof masses by measuring change in capacitance between the combs of proof masses on the sense-mode combs which are in XY-plane.

7) In this way the L3G4200D measures rotation along x, y and z axis.

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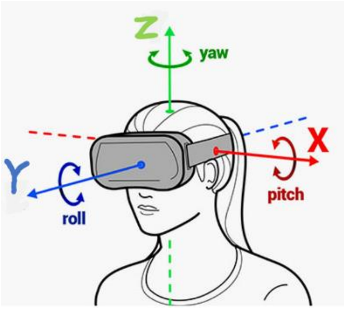
APPLICATIONS

This is MEMS gyroscope used in iPhone 4.

■ Used in input devices ⇔ Gaming and virtual reality devices
■ Motion control with MMI (man-machine interface)
■ GPS navigation systems
■ Appliances and robotics

Gaming and virtual reality devices:

i) In Virtual reality devices or VR devices these MEMS gyroscope is used to know the orientation of the device in 3D space.
ii) By knowing the orientation of the device, the VR can be used to view street views in google maps, 360-degree videos and some VR games.
iii) In gaming controllers like PS3 motion controller MEMS Gyroscope is used to control the character motion in the games like cricket games and tennis games.



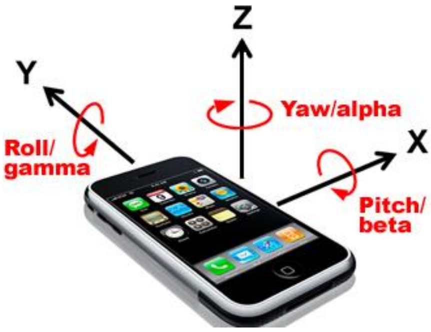
GPS navigation systems

i) GPS- Global Positioning System in satellites use Gyroscope to measure angular velocity of the satellites around earth.
ii) Using this, devices can measure your location with the satellites using a **GPS**.
iii) These MEMS Gyroscopes are in airplanes and helicopters which helps them to fly in controlled manner and also used in navigation used in military applications.

Appliances and robotics

i) In smart phones MEMS Gyroscope is used to know the orientation of the phone.

ii) And can be used in mobile gaming and Auto rotation features in mobiles.
iii) Can be used in digital levelers to measure ground levels.
iv) In industries the industrial robots can be equipped with MEMs Gyroscope to know their orientation and by knowing this robots can adjust themselves.
v) Industrial robotic arms have MEMS gyroscopic sensor and therefore they align things with high accuracy in industrial manufacturing process like assembly line in car manufacturing etc.



<u>Motion control with MMI (man-machine interface)</u>

i) Human-machine interface (HMI) – otherwise called User Interface (UI), Operator Interface Terminal (OIT) or Man-Machine Interface (MMI) – includes equipment and programming answers for data trade and correspondence between frameworks/machines and a human administrator.
ii) HMIs can be found in numerous areas, for example, versatile handheld gadgets, machines, brought together control rooms, just as manufacturing plant floor machines and procedure control.
iii) Applications incorporate mechanical and building robotization, computerized signage, vending machine, medicinal, car, and appliances.