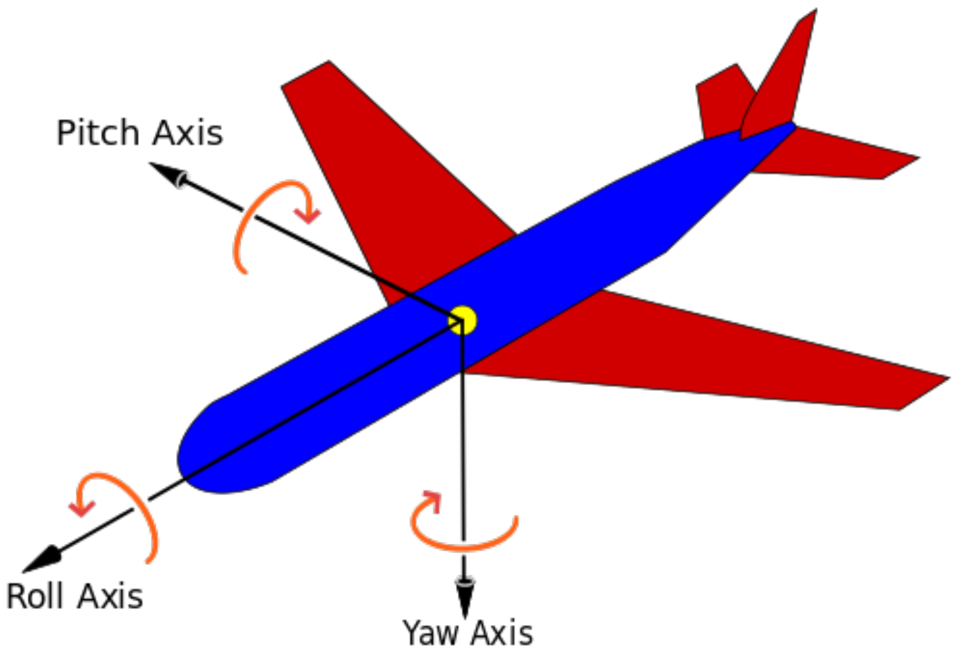
MEMS Gyroscopes – Draft lecture notes

The Gyroscope is an instrument capable to measure or maintain orientation in space in three dimensions, regardless of the orientation or of the rotation of the mounting.

For this reason, gyroscopes (or gyros) are traditionally used in navigation, when the geomagnetic field is absent (as in space) or disturbed (as in a plane, o in a tunnel).

Typical uses now are in stabilization devices, robotics, tunnel mining, weapon navigation and stabilization, and in all situations in which GPS systems do not work, as for example indoor, in space, or in bad weather.



Source: Wikipedia
https://upload.wikimedia.org/wikipedia/commons/thumb/c/c1/Yaw_Axis_Corrected.svg/500px-Yaw_Axis_Corrected.svg.png

The principle of operation is based on the **conservation of angular momentum:**
"The total angular momentum of a system with respect to a fixed point is constant if no external forces act on the system".

Traditional Gyroscopes are based on a rotating disk or a rotating sphere. Several example were build in the 1800. This is a photo of a gyroscope fabricated in 1852 by Leon Foucault, who was the first to call it gyroscope:

Source: Wikipedia - https://en.wikipedia.org/wiki/File:Foucault%27s_gyroscope.jpg

In the beginning of the XX century, the gyroscope was broadly used as naval and aircraft stabilizer. Later, also to provide inertial navigation systems to ballistic missiles, and in antiaircraft or anti-missile systems.

MEMS Gyroscopes are based on vibrating masses (are vibration gyro) and have appeared in 1997 for dynamic control of automobiles (Robert Bosch Corporation).

Now they are in most tablets and smartphones, to provide orientation along 3 axes, typically in the same package of the 3 axis accelerometer.

Let us look at the principle of operation of a MEMS Gyroscope:

The physical mechanism is based on the **Coriolis force,** an inertial force **(**in Italian “forza apparente”) that acts on a body in a rotating reference frame.

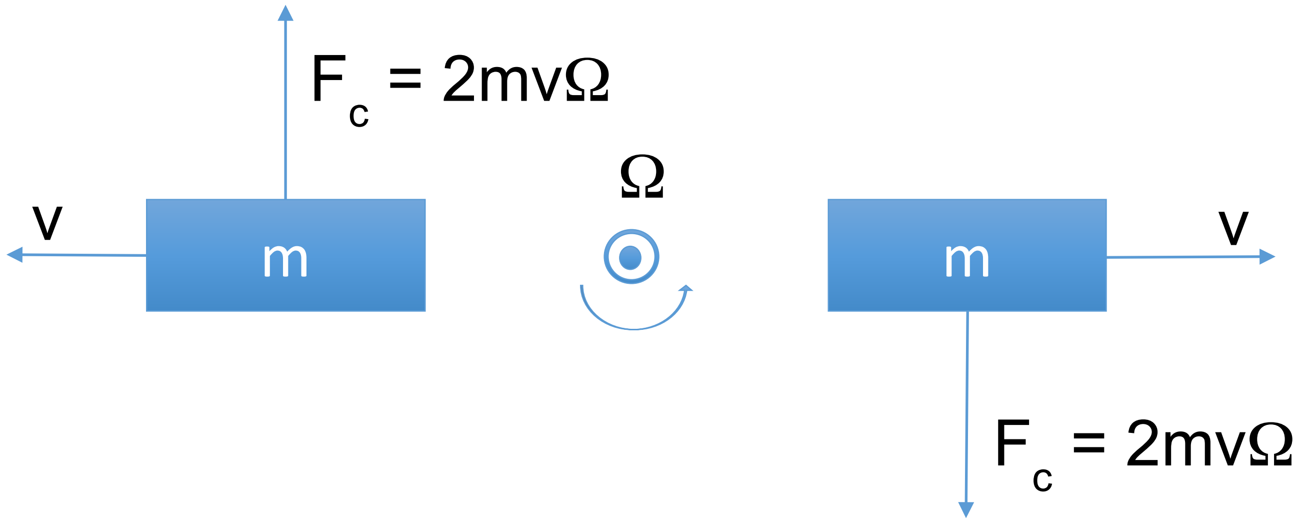
The mathematical expression was discovered by Coriolis in 1835 and is

$$\overrightarrow{a_c} = 2\vec{v}\wedge\vec{\Omega}$$

where $\vec{\Omega}$ is the angular velocity of the reference frame with respect to a fixed reference frame, $\vec{v}$ is the velocity of the body and $\overrightarrow{a_c}$ is the Coriolis acceleration in the rotating reference frame.

[example on the blackboard or youtube video]

Example of a 1 axis accelerometer

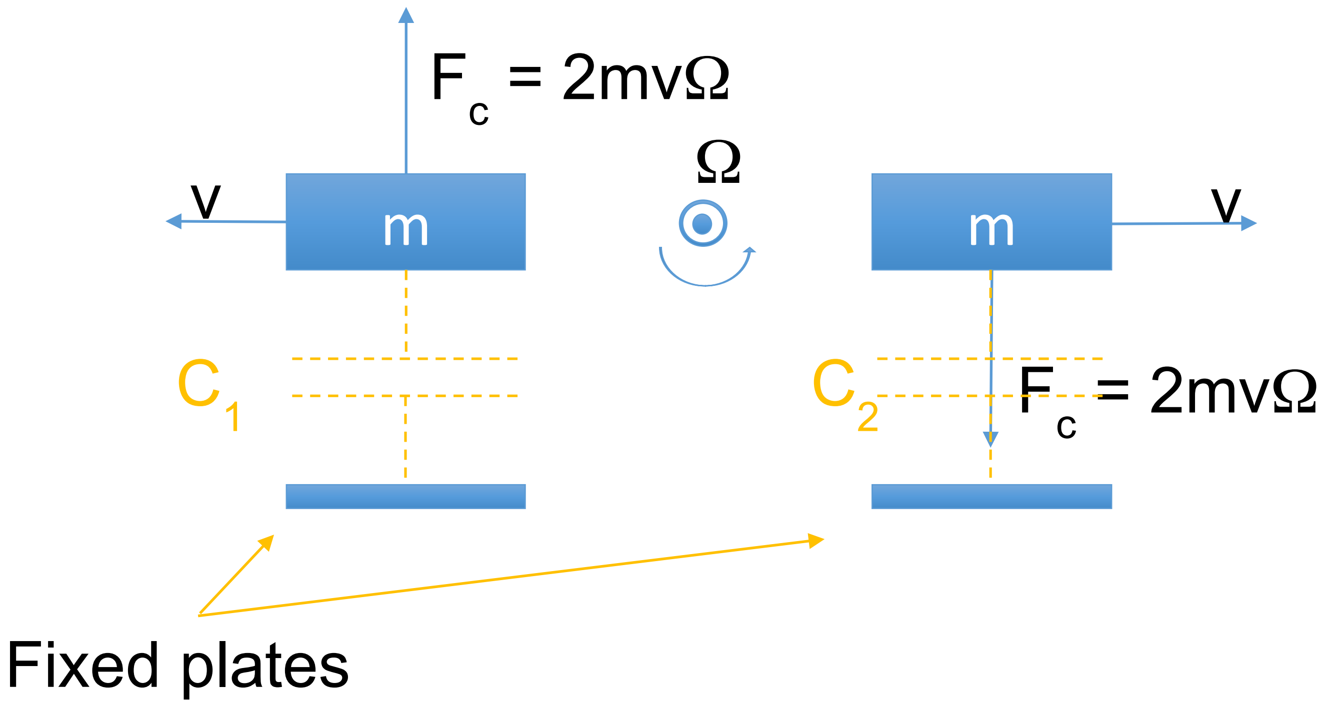


Let us assume that the structure rotates with angular velocity W in the plane, as indicated in the figure.

Then we have two masses m, vibrating along the direction connecting them, with instant velocity v.

The Coriolis force on each of the masses act as in the Figure. We can measure the Coriolis force as we measure the acceleration in an accelerometer, i.e., by transforming it in a displacement (using a spring) and by measuring the displacement as a difference of capacitances.

In order to do that, we need to fixed plates, and we need to sense the capacitance difference $\Delta C = C_1 - C_2$



This differential structure is required in order to eliminate the effect of a linear acceleration (because a linear acceleration would have the same effect on both capacitances and therefore ΔC would be zero.

The complete MEMS structure is the following