Digital Accelerometers and Magnetometers

Design Team 3

Introduction

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Accelerometers	
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Magnetometers	
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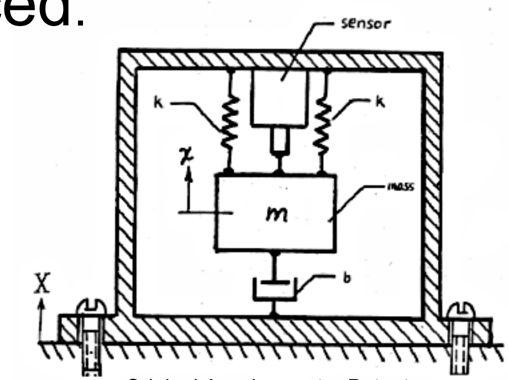
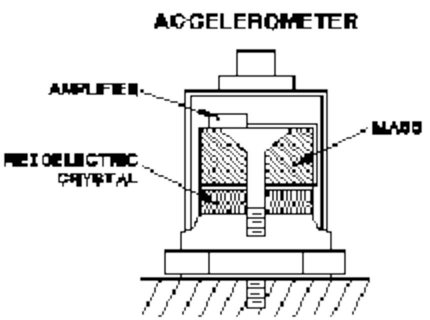
Accelerometers - History - Types

Accelerometers behave as a damped mass on a spring. Acceleration causes displacement of this "spring" proportional to the acceleration experienced.

- Original Invention
  - 1923 - Burton McCollum and Peter Orville
  - Commercialized in 1927
- Piezoelectric
  - 1943 - Used Rochelle salt
- Piezoresistive
  - 1959 - Warren P. Mason



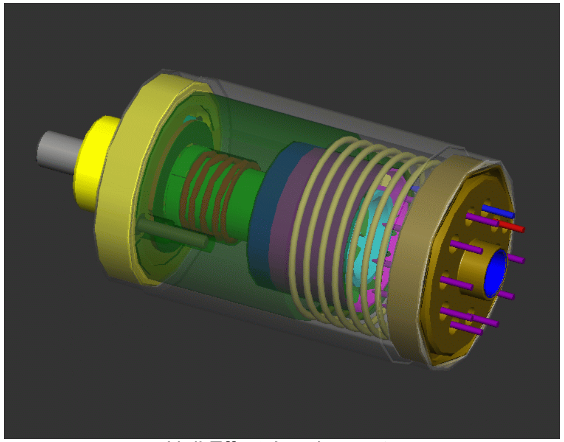
Original Accelerometer Patent



Piezo-based Accelertometers

Accelerometers - History - Types

- Hall Effect
  - 1961 - Heinz E. Kallmann
- Magnetoresistive
  - 1973 - Tetsuji Shimizu
- Capacitive
  - 1989 - Hitachi, Ltd.
- Digital Capacitive
  - 1994 - William C. Tang/Ford Motors


Hall Effect Accelerometer

Accelerometer - Applications

- Video games
- Hard drive protection
- Electronic Stability Package
- Vehicle crash detection
- Earthquake sensors

Accelerometer - Fundamentals

Acceleration: $a = \partial v / \partial t = \partial^2 x / \partial t$. At sea level we experience 32.2 ft/s^2 = 9.81 m/s^2 = 1g

Examples of g-forces:

This room = your weight = 1g

Space Shuttle reentry & launch = 3g

F-1 car cornering = 5g to 6g

Max experienced by a human* = 46.2g

Bugatti Veyron, 0 to 60mph in 2.4s= 1.55g

Top Thrill Dragster roller-coaster = 4.5g

Max for fighter jet pilots = 11g to 12g

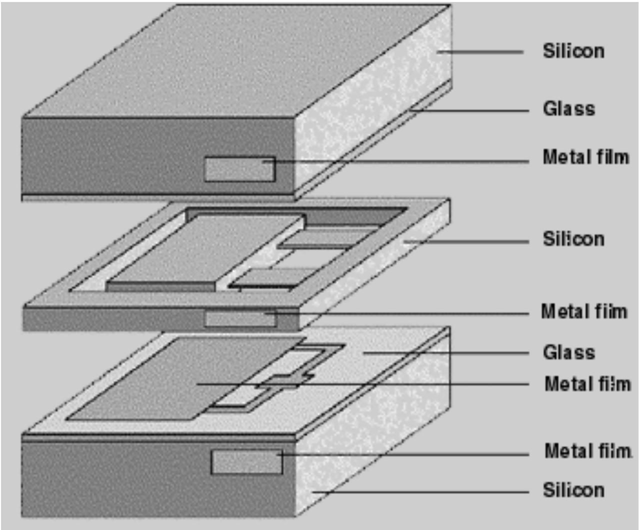
Death or extensive & severe injuries= +50g

Modern accelerometers are small microelectromechanical systems (MEMS) consisting of a cantilever beam with a proof mass. Thus they sense acceleration in only one direction.

* John Stapp on December 10th, 1954 in the rocket sled "Sonic Wind" going over 632 MPH and stopping over a water break.

Capacitive Accelerometer

Cantilever made of silicon, holding two plates suspended between energized reference rails. Our knowledge of the elasticity of silica is the basis of acceleration sensing.



Structure is symmetric, reducing temperature effects and providing more precise measurement. As the reference "mass" approaches one reference plate, the air-gap to the other reference plate increases.

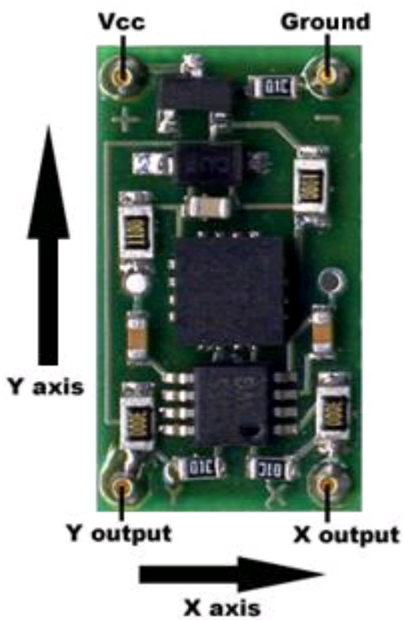
The device operates with a DC input voltage. $V_{OUT\text{-}DC}$ will change linearly to acceleration variations. $V_{out} = V_{g0} + V_{sens.}*G$; $V_{Sensitivity}=(V_{out,+1g} - V_{out-1g})/(2g)$

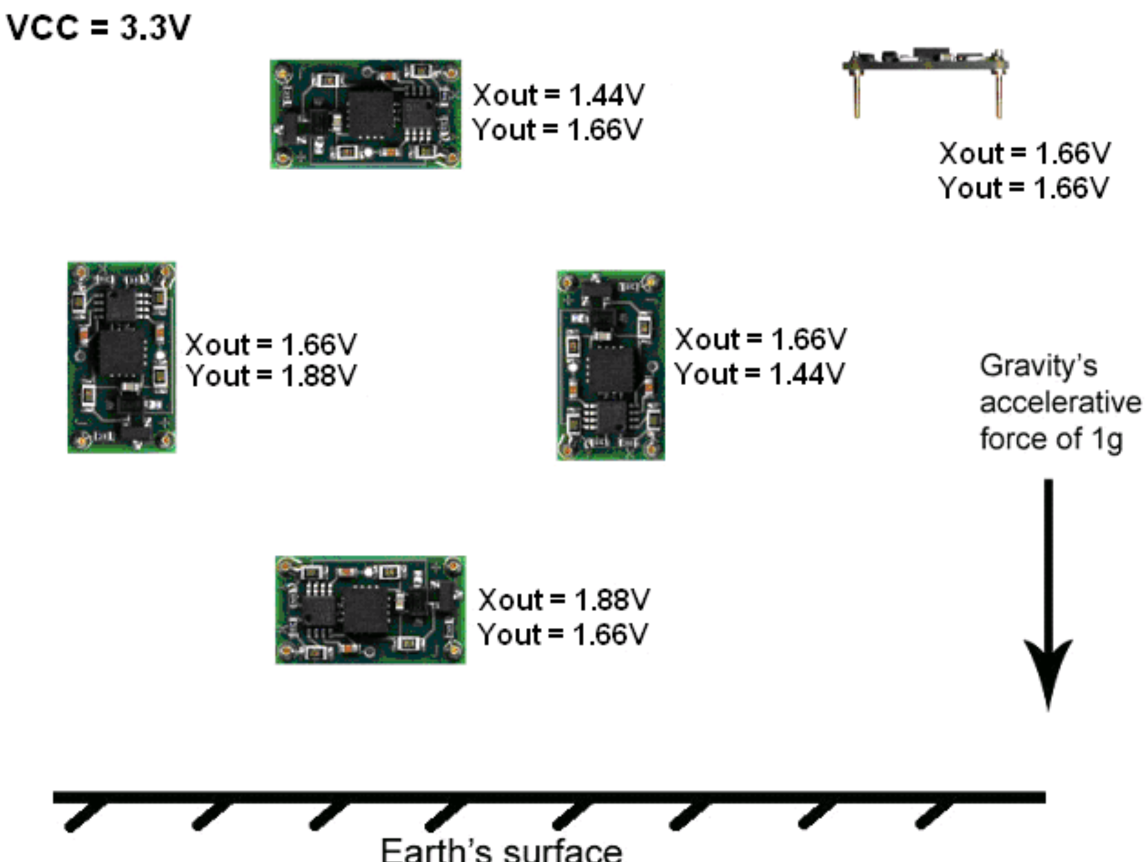
This design is cheap and usually accurate to +/- 0.01g, have a shock tolerance up to 200 Km/s^2 and sensitive to at least 1.5V/g with a V_{CC} of 5.0V.

Accelerometer - Examples

DE-ACCM6G Buffered ±6g Accelerometer

- Dimension Engineering
- Has ±6g sense range
- 222 mV/g sensitivity





Accelerometer - Examples

Acceleration to voltage example:

”What voltage will correspond to an acceleration of -0.5g?”

The 0g point is approximately 1.66V. Sensitivity is 222mV/g

$V_{out} = V_{g0} + V_{sens.}$*G.

-0.5g * 0.222mV/g = -0.111V

1.66V – 0.111V = 1.55V

Therefore you can expect a voltage of approximately 1.55V when experiencing an acceleration of -0.5g.

Accelerometer - Examples

Tilt to voltage example:

"I am making an antitheft device that will sound an alarm if it is tilted more than 10º with respect to ground in any direction. I have measured the 0g bias point to be 1.663V, and I want to know what voltage to trigger the alarm at."

Sin(10º) = 0.1736 so acceleration with a tilt of 10º will be 0.1736g

0.1736g * 0.222V/g = 0.0385V

1.663 + 0.0385 = 1.7015V

1.663 – 0.0385 = 1.6245V

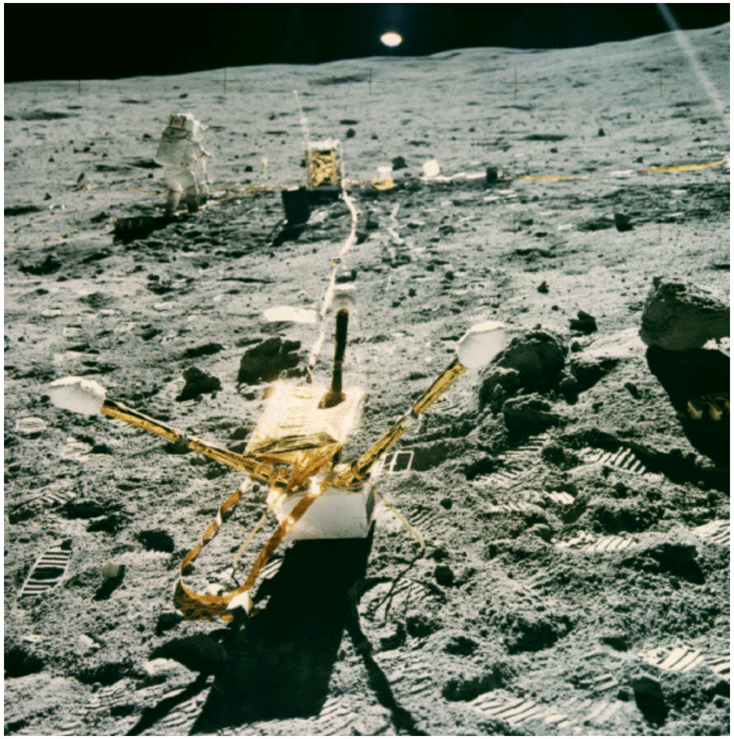
Sound the alarm when the voltage reaches more than 1.7015V or less than 1.6245V.

Magnetometers - Background

- Compass invented by the Chinese in the 4th century
- Carl Gauss invents the "magnometer" in 1833
- Two types of magnetometers
  - Scalar - measures the total strength of the magnetic field they are subject to
  - Vector - measure the component of the magnetic field in a particular direction, relative to the spatial orientation of the device

Magnetometer - Applications

Geology and planetary science



Magnetometer - Applications

Military applications

Magnetometer - Applications

Archaeology and salvage

Magnetometer - Applications

- Navigation
- Compass
- Mineral exploration
- Security
- Hard drives

Magnetometers - Principles of Operation

Hall Effect Magnetometer

Lorentz Force - $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$

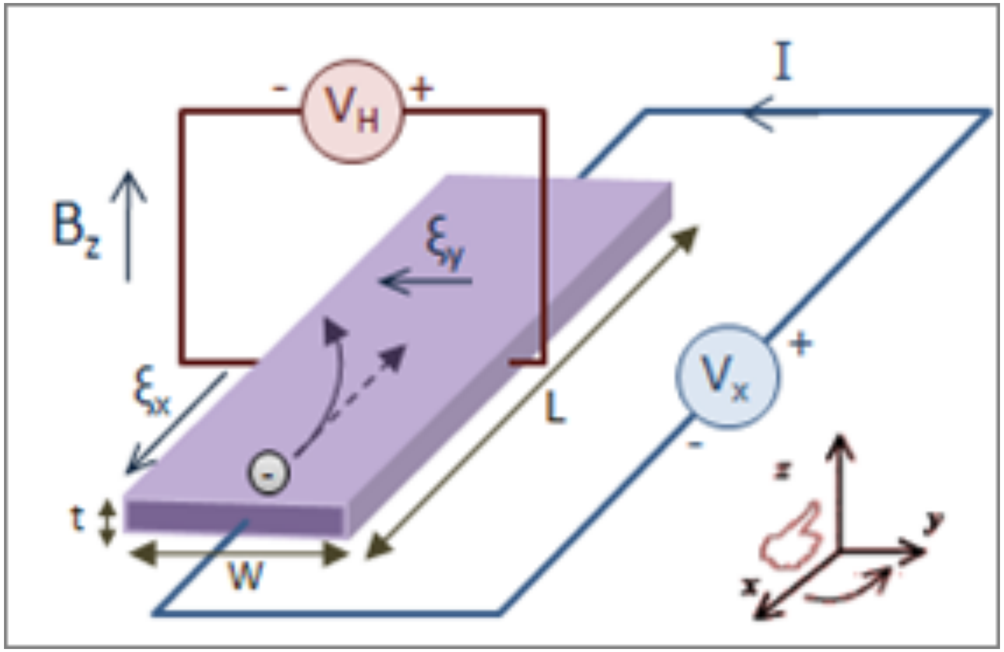
$$V_H = \frac{-IB}{ned}$$

Benefits-

- Solid-state
- Low Temperature Sensitivity
- Highly Linear
- Small
- Cheap

Drawbacks-

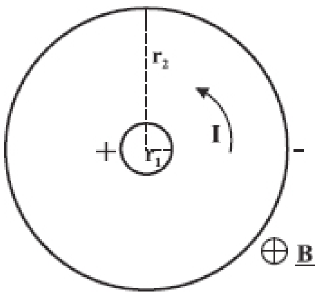
- Saturation limit
- Calibration Issues



Magnetometers - Principles of Operation

Ordinary Magnetoresistive Sensor

Corbino Disc

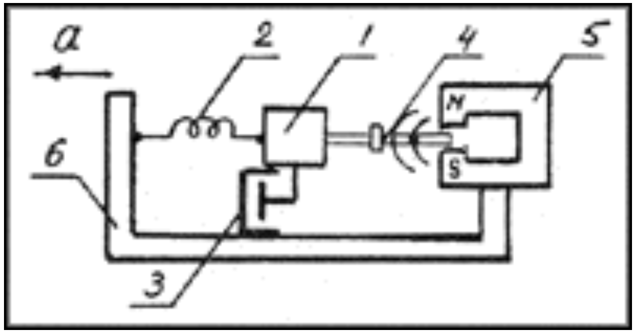


- Applied voltage creates a radial current
- Applied magnetic field creates a circular current
- This alters the path of an electron, making it travel in a spiral, increasing the length traveled and resistance

Quantum Mechanical Effects

- Anisotropic Magnetoresistance
- Giant/Colossal Magnetoresistance
- Tunneling Magnetoresistance

Magnetometer-based Accelerometer



Conclusion

- The history and applications of accelerometers
- Overview of G-Force
- Operation of Capacitive accelerometers
- Two types of magnetometers
  - Scalar
  - Vector
- Applications of magnetometers
- Operation of Hall Effect Magnetometer

Questions