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Motion and Vibration Measurements (1)

Measurement Techniques

Video prepared by:

ANEMS

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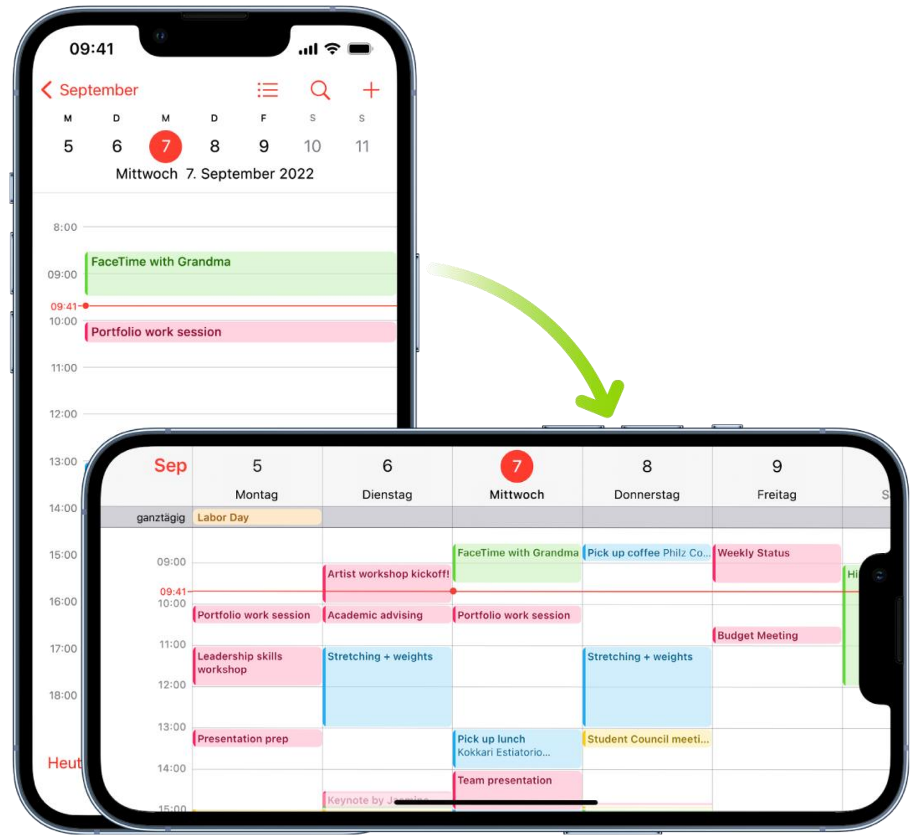
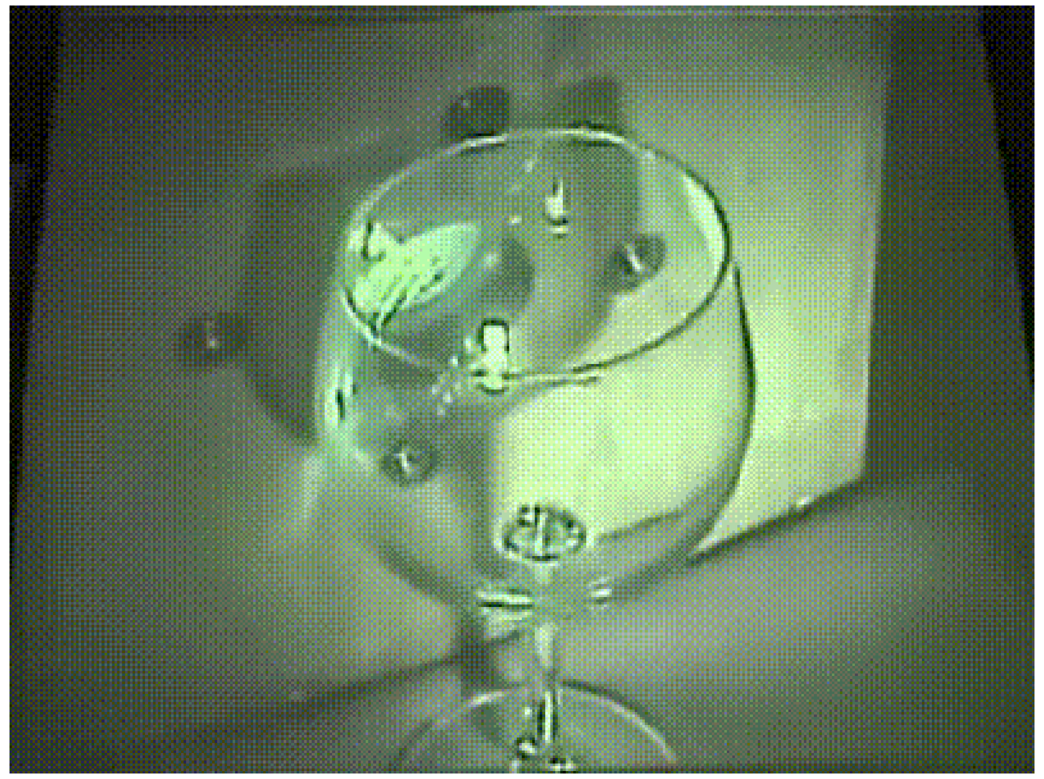
Introduction

- Importance of studying vibrations

Motion



Vibration



Different techniques

- Deformation
  - Strain Gauges
- Motion
  - Eddy Currents
- Velocity
  - Laser Doppler Vibrometer (LDV)
- Acceleration
  - Piezoresistive Accelerometers
  - Capacitive Accelerometers
  - Piezoelectric Accelerometers

Strain Gauges

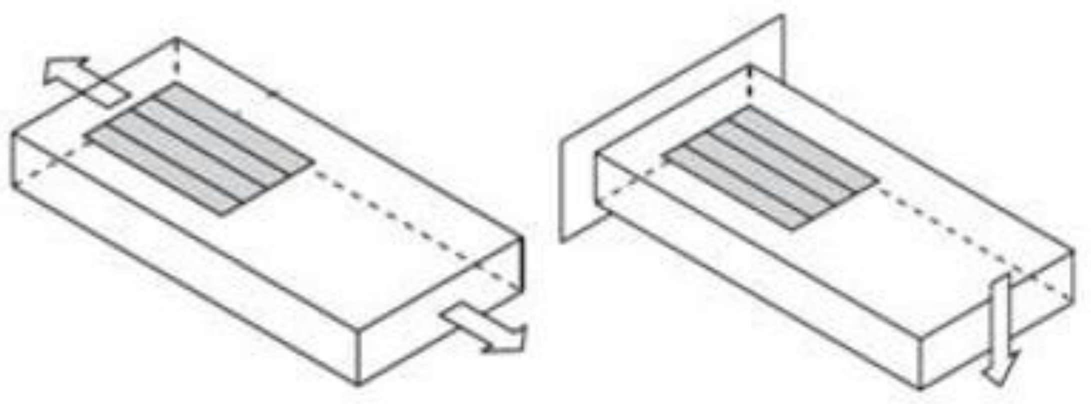
- Strain defined as the relative deformation of an object
- Strain can be caused by axial loading, bending, torsion…
- What happens if we strain an unclamped metal pad?
  - Elongation in the longitudinal direction and shrinking in the transversal one

  - As a consequence, the electrical resistance will change:

$$\boldsymbol{R = \rho \frac{L}{wt} \rightarrow \frac{\delta R}{R_0} = \frac{\delta L}{L} - \frac{\delta w}{w} - \frac{\delta t}{t}} = (\text{uniaxial}) = \boldsymbol{\varepsilon(1 + 2\nu)}$$

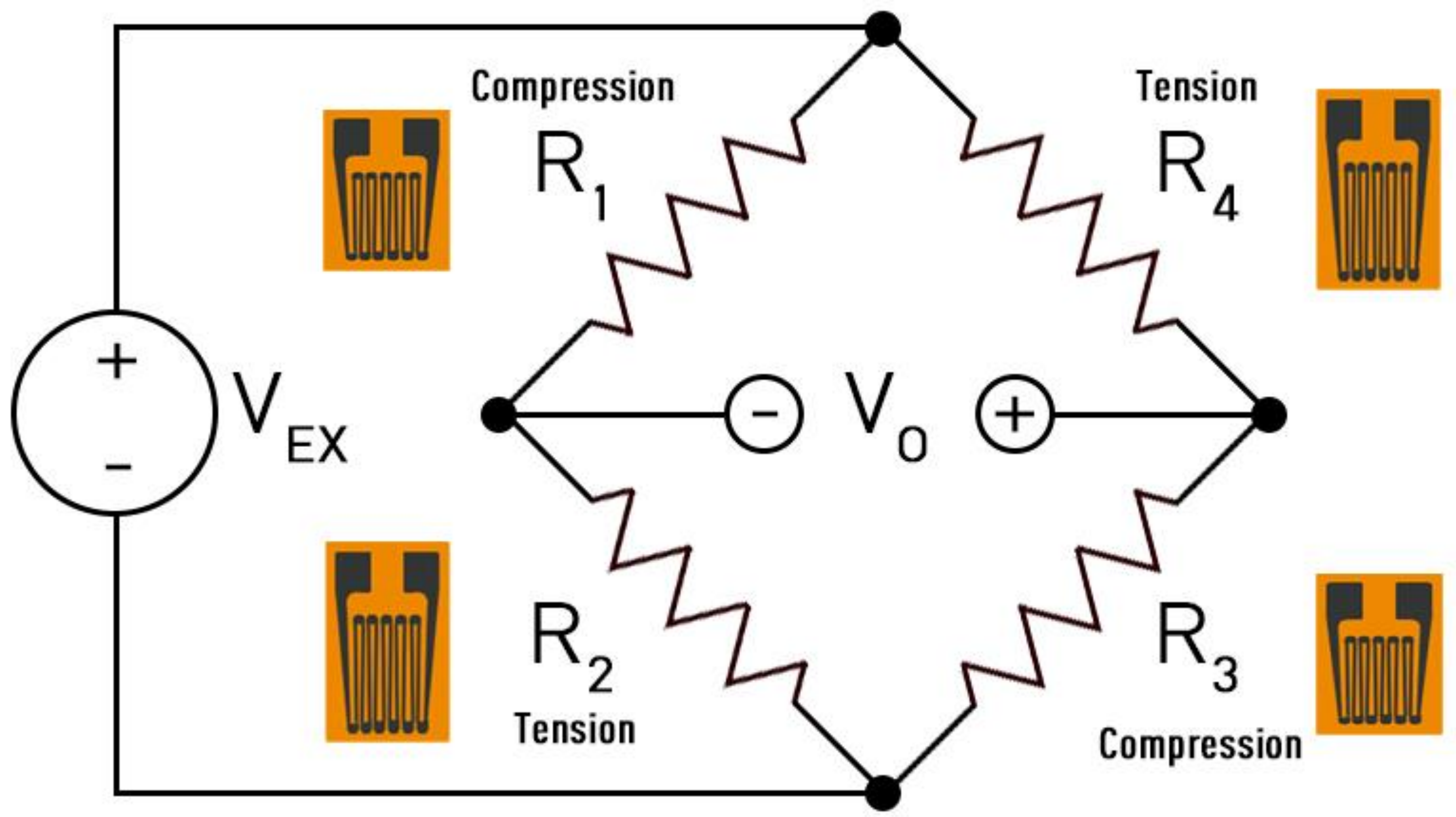
Strain Gauges

- Deformation → Stress/strain → Change in resistance

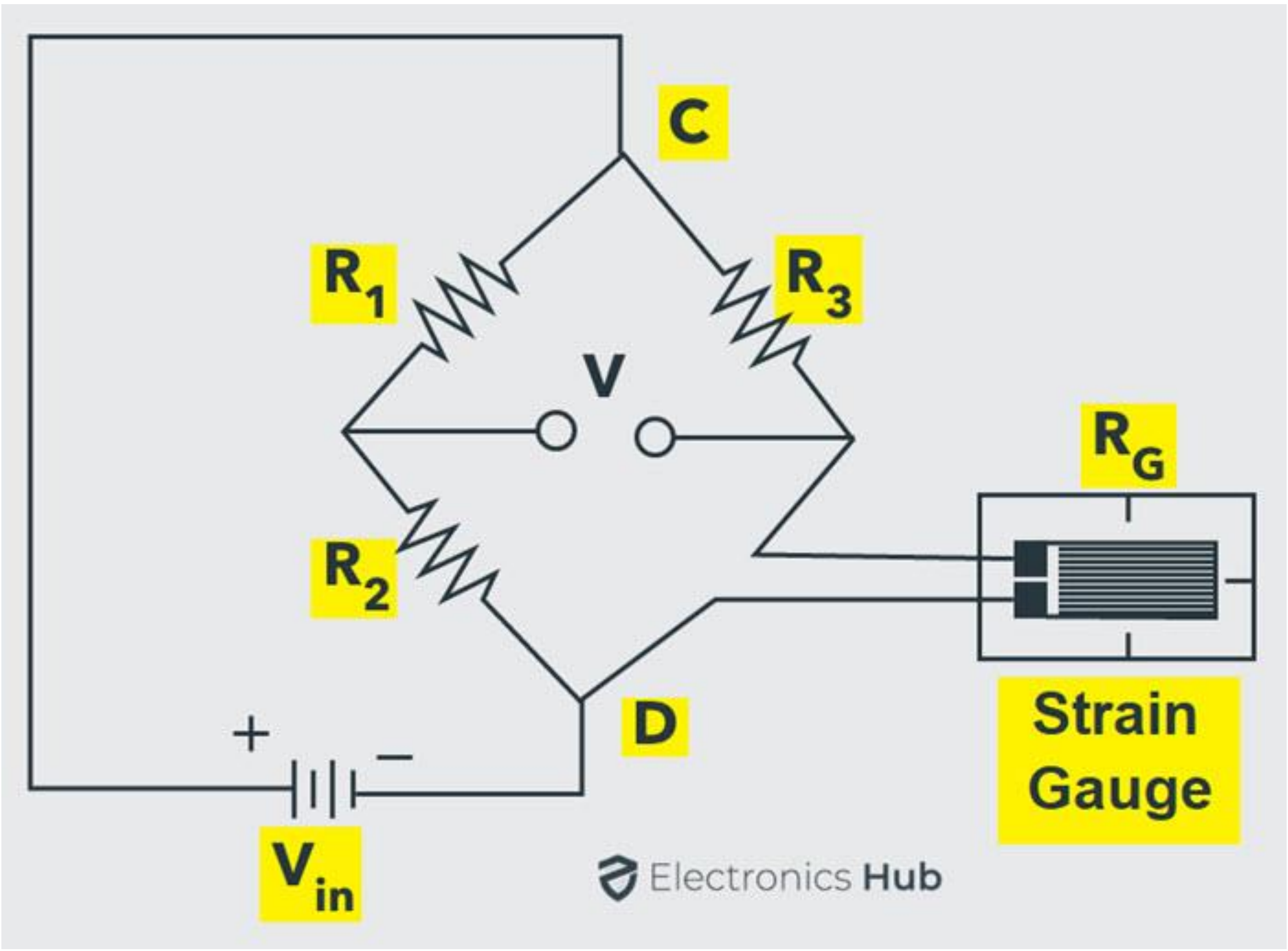


A single strain gauge can detect different strains

- To measure resistance, we typically convert it to voltage
- Wheatstone Bridge



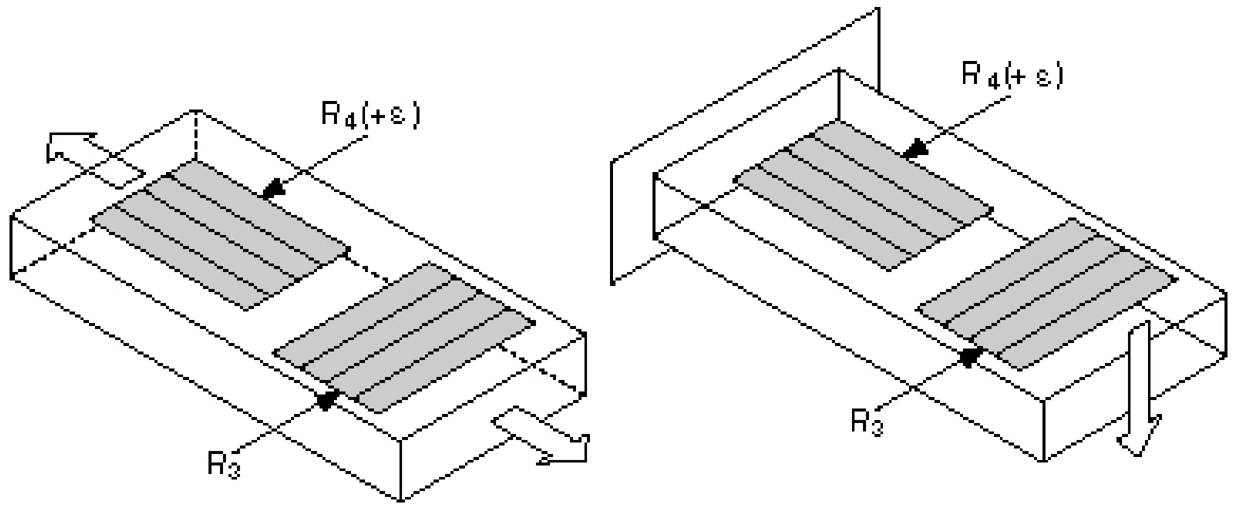
$$\frac{\delta V}{V_{bias}} = \frac{\boldsymbol{\delta R}}{\boldsymbol{R_0}}$$



$$\frac{\delta V}{V_{bias}} = \frac{1}{4}\frac{\boldsymbol{\delta R}}{\boldsymbol{R_0}}$$

Strain gauges

- Applications:
  - Structural health monitoring
  - Vehicle testing
  - Components of accelerometers and pressure sensors (see later)
- Advantages
  - Accuracy and lifetime stability
- Disadvantages
  - Fixing/gluing technique of gage to structure is critical, paramount for performance
  - Require compensation of temperature as it affects resistance



From ni.com, dummy gauge for temperature compensation

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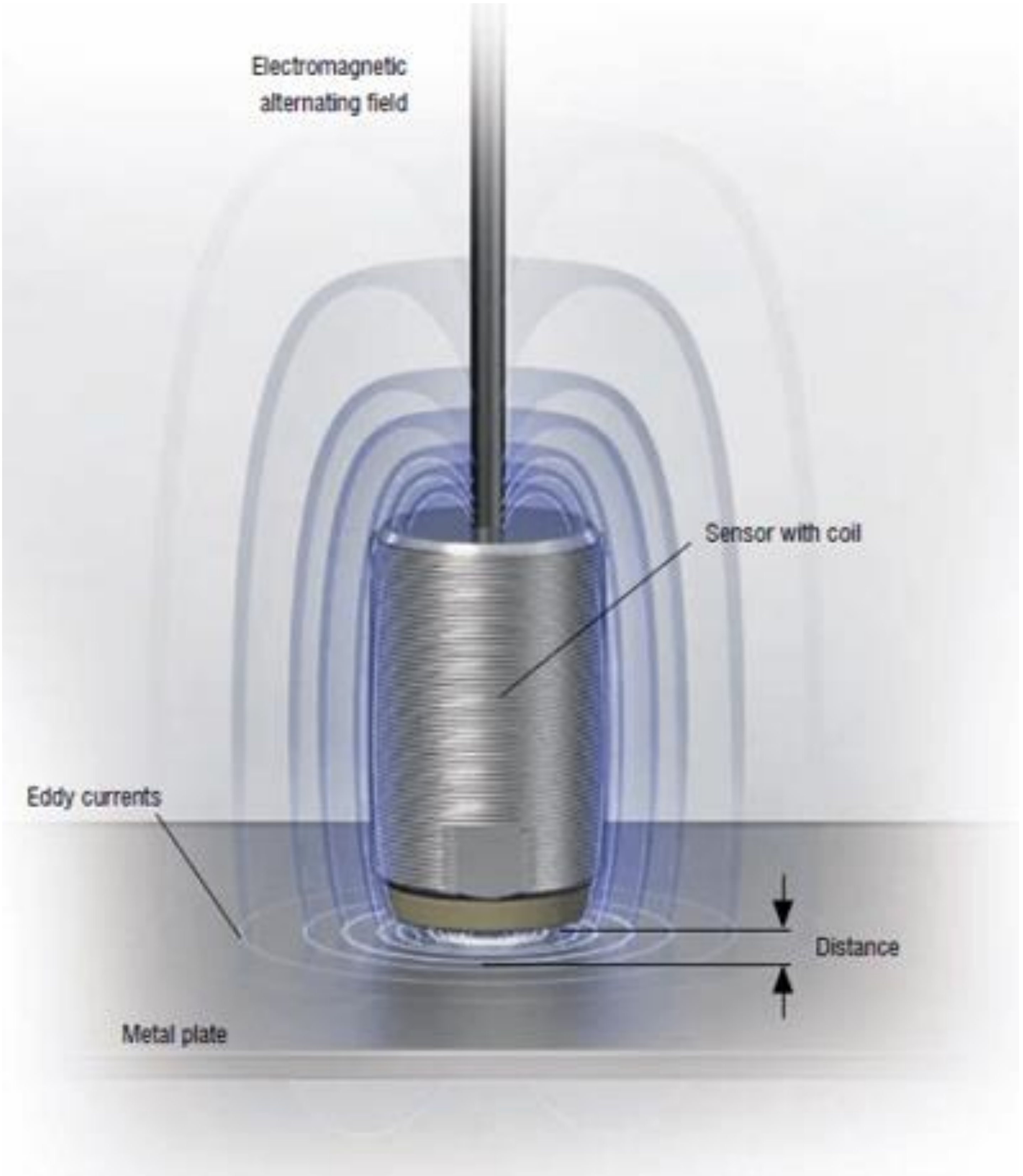
Eddy Currents

- Changing magnetic field induces loops of electrical current within conductors, called eddy currents.



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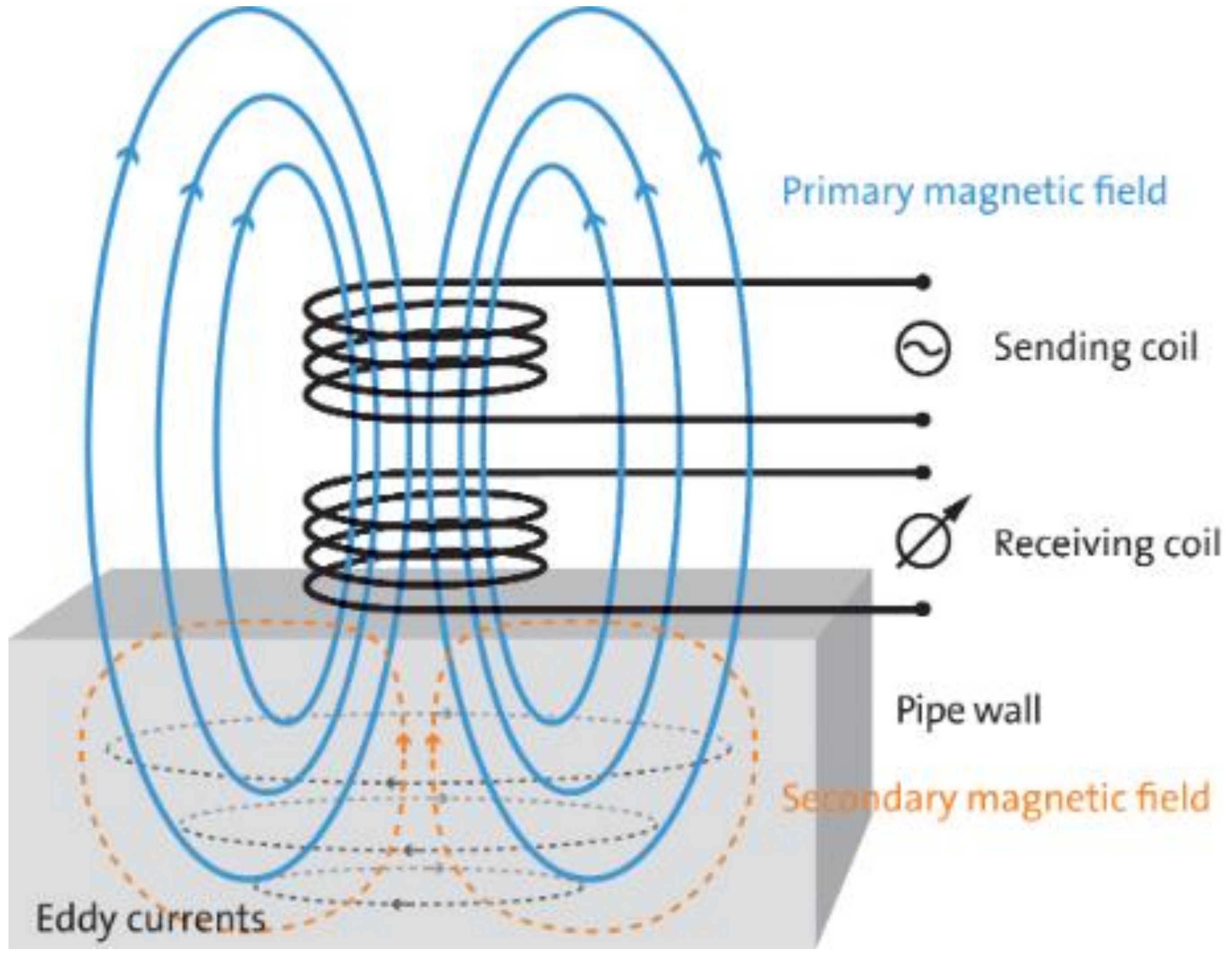
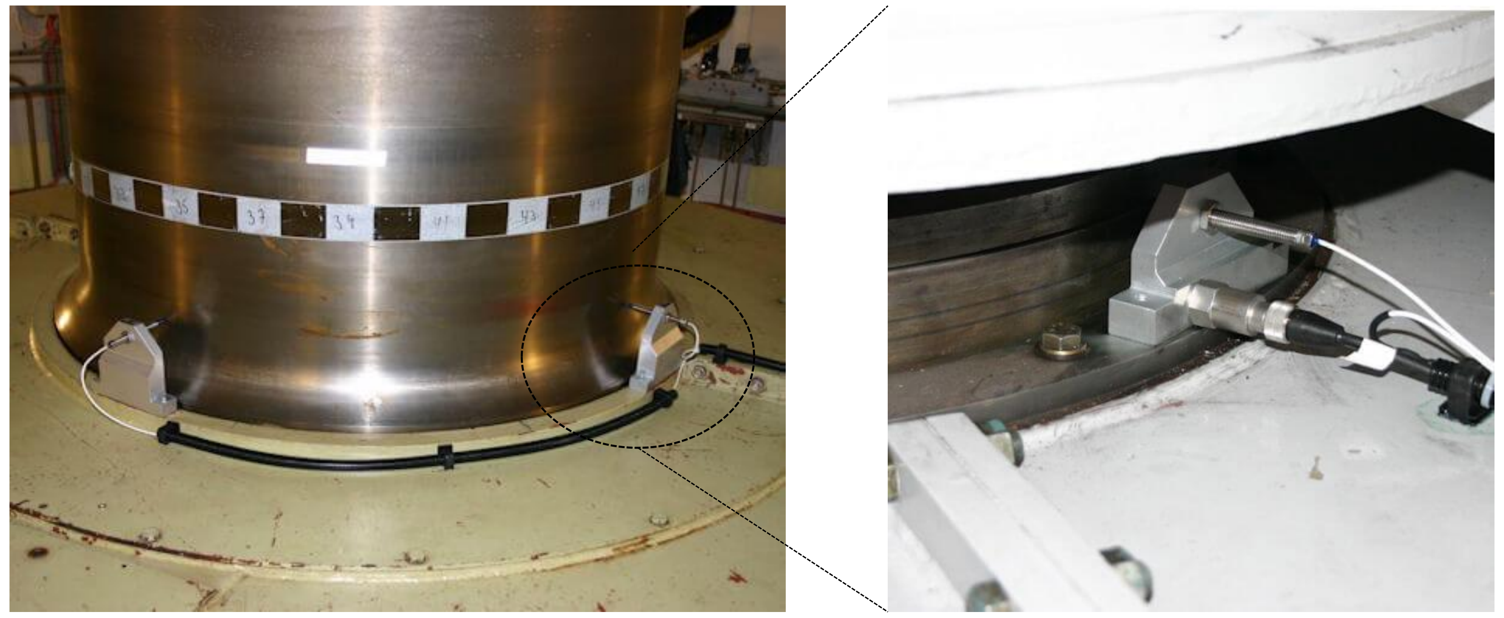
Eddy Current Sensor

- Generates high-frequency magnetic field by flowing high-frequency current to a coil inside a sensor head.
- When a measuring object (conductor) come close to the magnetic field, eddy current is generated on the surface of the measuring object.
- This local electric current in turn induces a magnetic field in the opposite direction of the magnetic field of the coil and impedance of the sensor coil is reduced.



Eddy Current Sensor

- Advantages
  - They have relatively high temperature stability.
  - They are resistant to pressure, dirt and oil.
  - They can operate at high pressures.
  - They are one of the best wear-free, non-contact sensors for measuring displacement and position in harsh environments.
- Applications
  - Vibration measurement in steel galvanizing plants
  - Measurement of cylinder position movement in an internal combustion engine



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Velocity – Laser Doppler Vibrometer (LDV)

- Most common method to measure velocity is through the Doppler effect
- The frequency emitted by a moving object depends on its velocity

$$f = \left(\frac{c \pm v_r}{c \pm v_s}\right) f_0$$

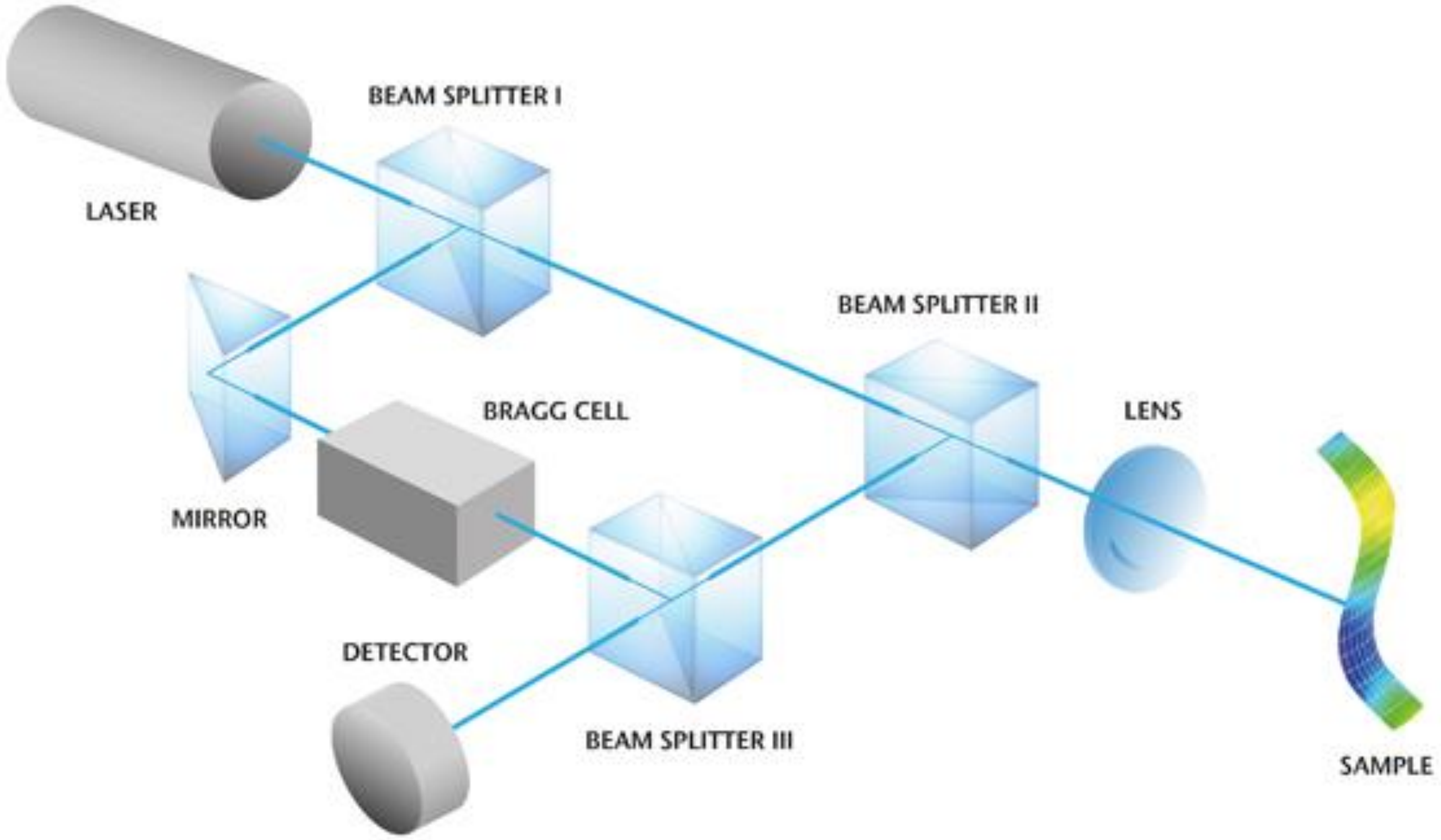
f: measured frequency
c: speed of propagation of waves
v_r: velocity of receiver
v_s: velocity of source
f_0: emitted frequency

- Speed radar:
  - Electromagnetic signal bounces off a moving target
  - Returned signal has a change of frequency depending on the velocity of the target

wikipedia.org

Velocity – Laser Doppler Vibrometer (LDV)

- Measurement of the velocity of a point of interest focusing a laser



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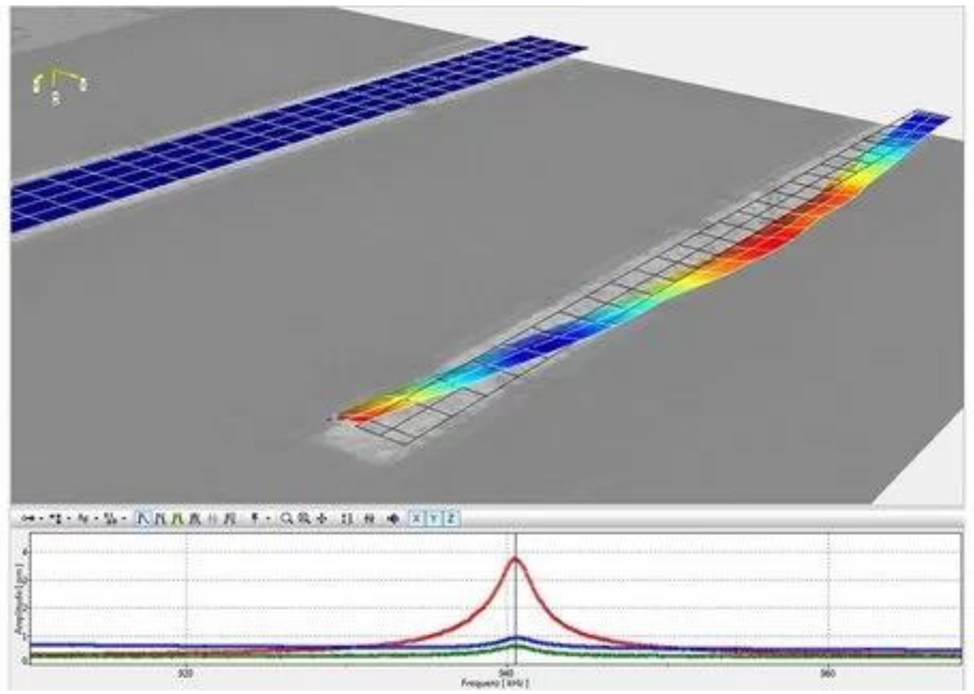
Velocity – Laser Doppler Vibrometer (LDV)

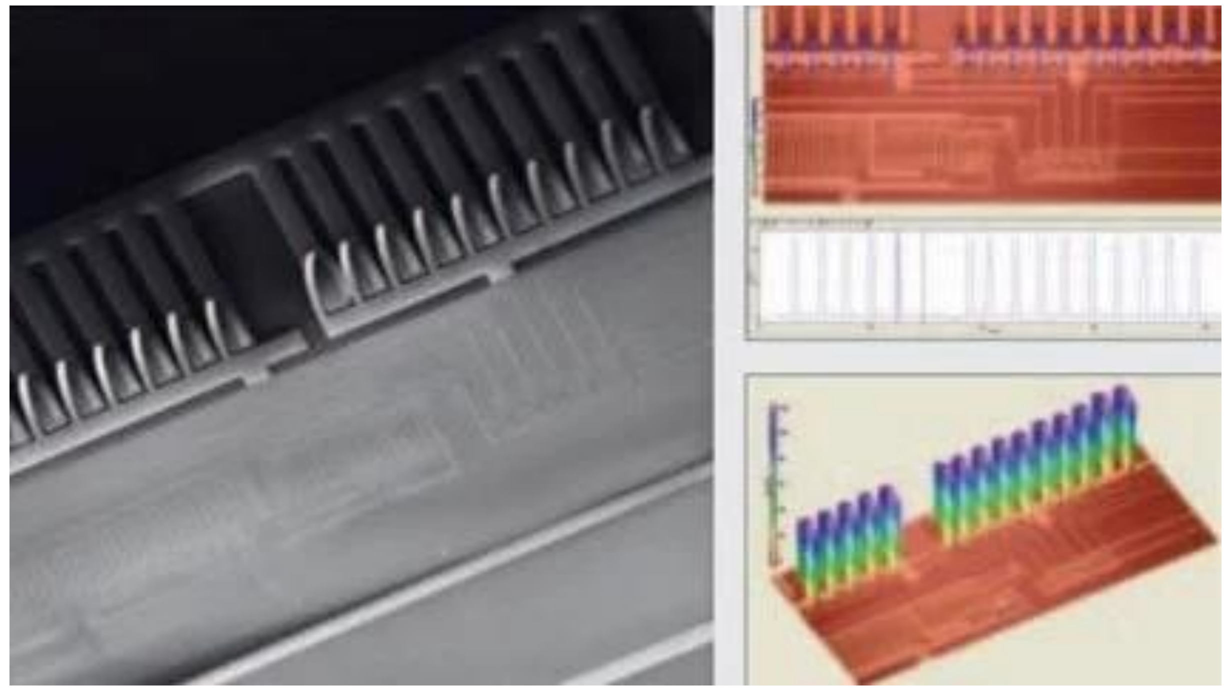
- Advantages:
  - High sensitivity
  - Non-contact method
  - Environment flexibility (device in air, vacuum, water, etc…)
  - No mass loading

- Limitations:
  - Single-axis measurements (out-of-plane)
  - Complex setup
  - Portability
  - Need reflective surface

LDV applications

- Aerospace and automotive
  - Characterization of turbines vibrations, wings bendings, wheels deflections, etc...
- Acoustics
  - Study of loudspeaker performance, deformation of instruments
- Micro and Nanotechnology
  - Model validation, prototype testing, reliability testing
  - Resonating devices





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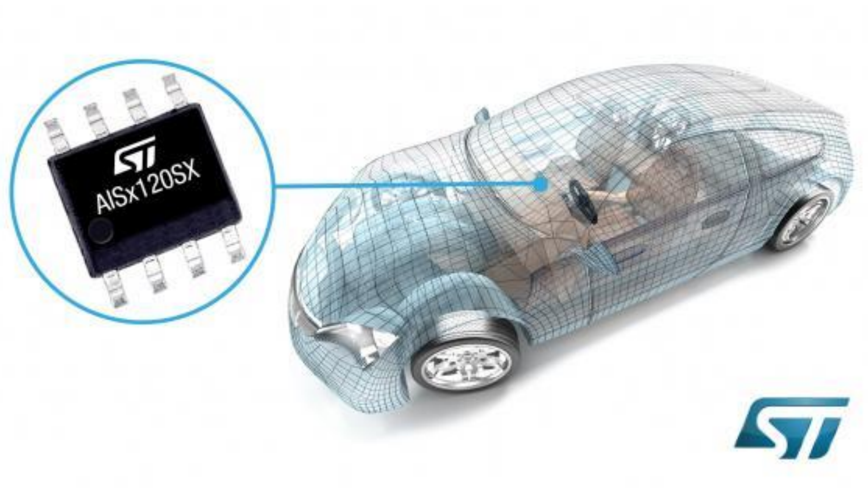
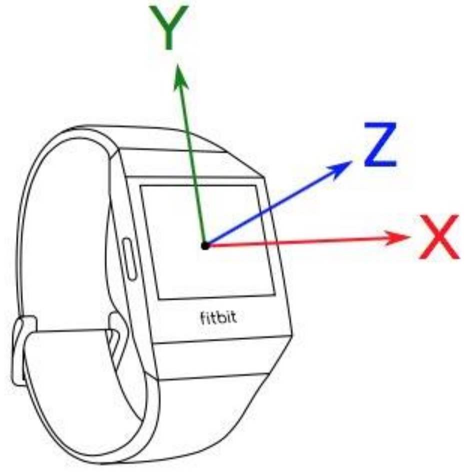
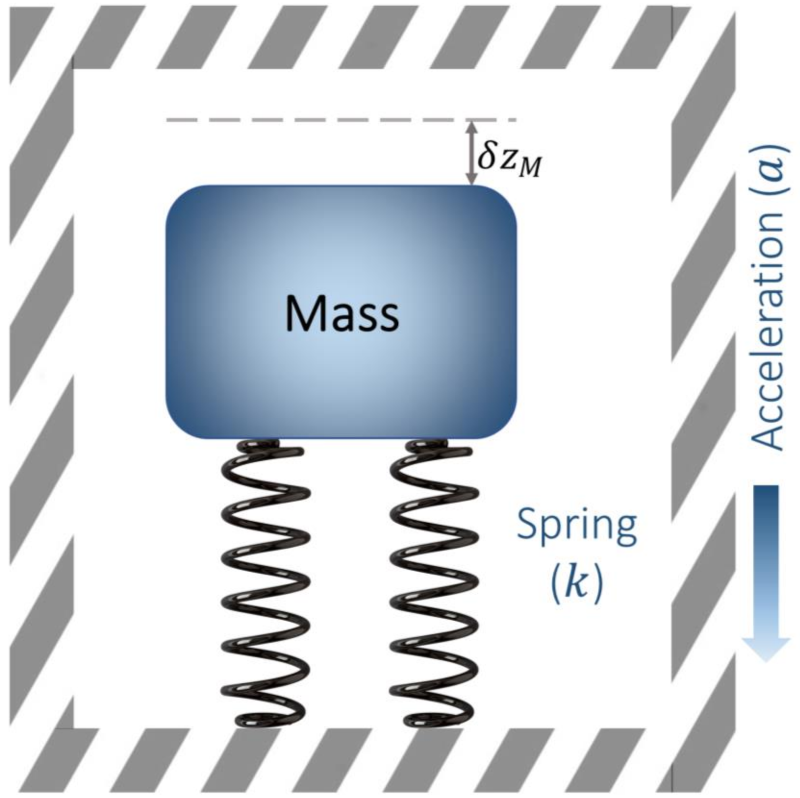
Accelerometers

- Most common method for monitoring vibrations and motion is to use inertial sensors.
- Uses in:
  - Vehicle safety
  - Smartphones and Wearable devices
  - Seismic
  - Navigation
  - Monitoring of vibrations in machinery
- Accelerometer types:
  - Capacitive
  - Piezoresistive
  - Piezoelectric





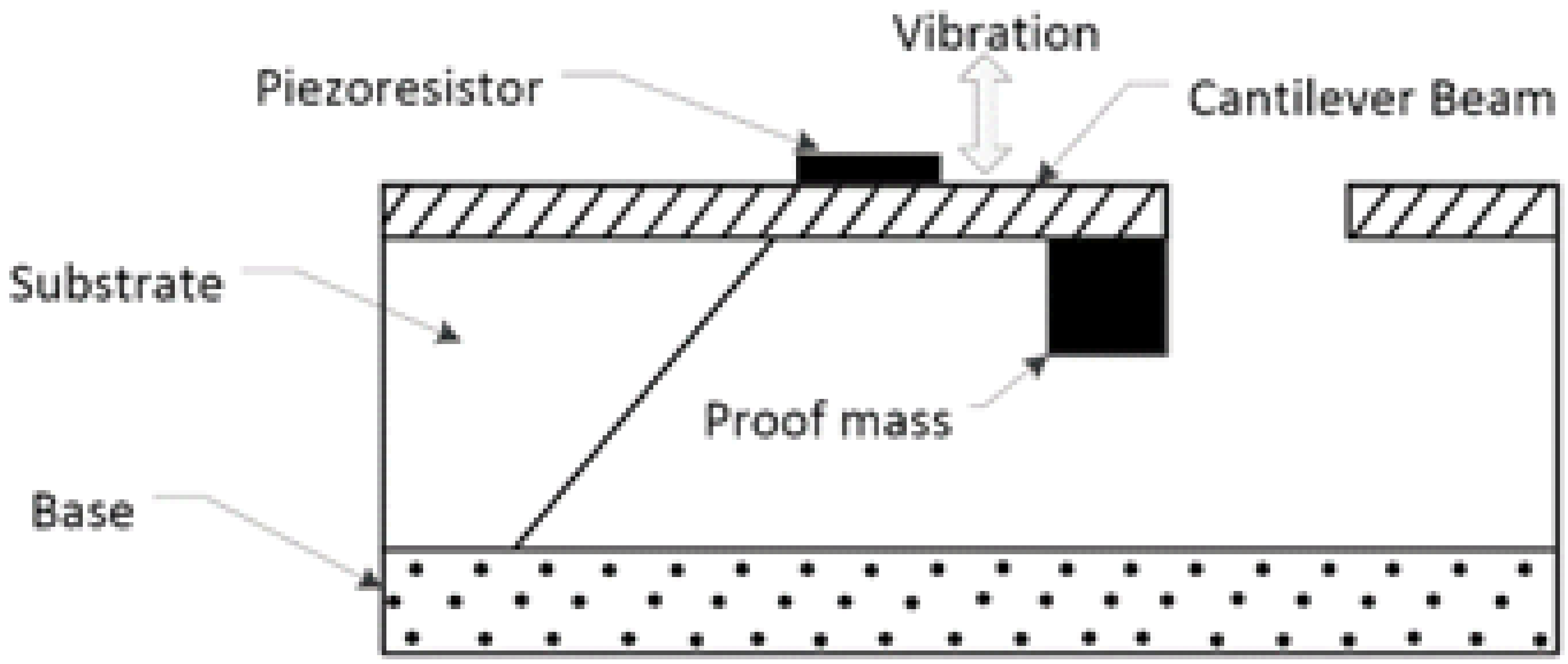
Vibworks Collector Analyzer



Piezoresistive accelerometers

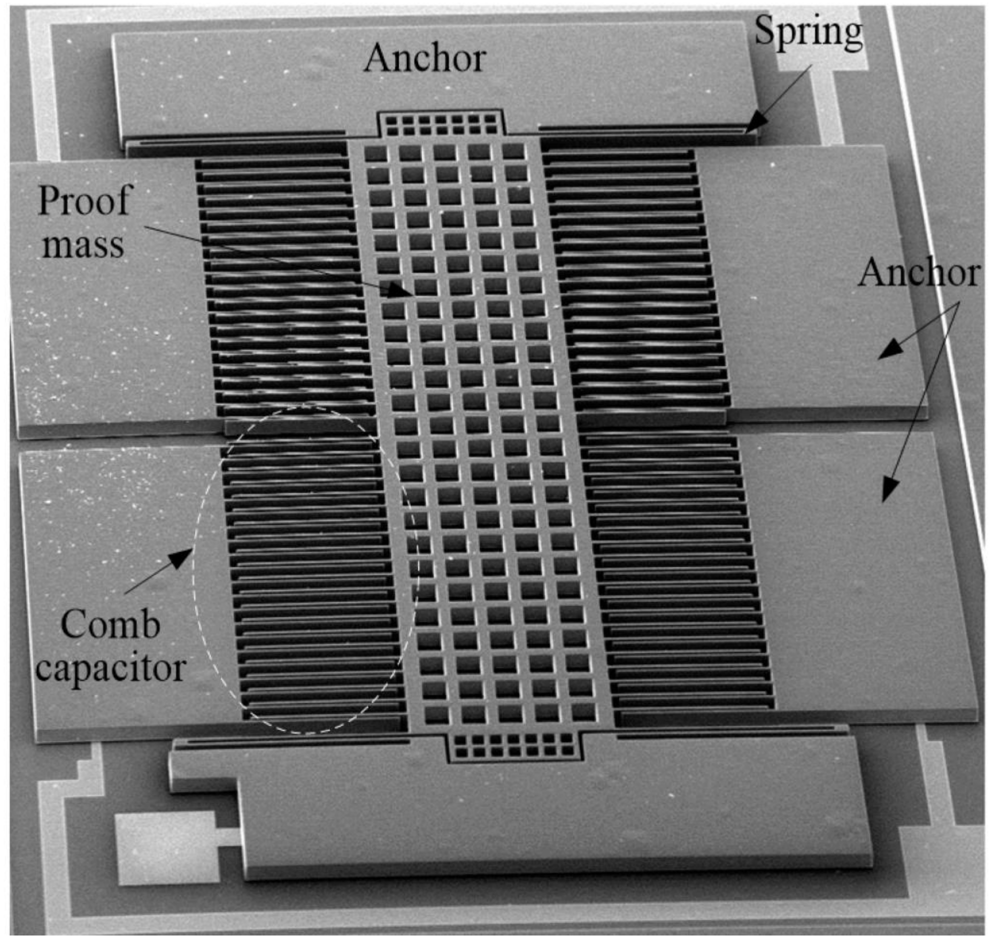
- Measure the resistance changes in the strain gauges that are part of the spring system of the accelerometer.

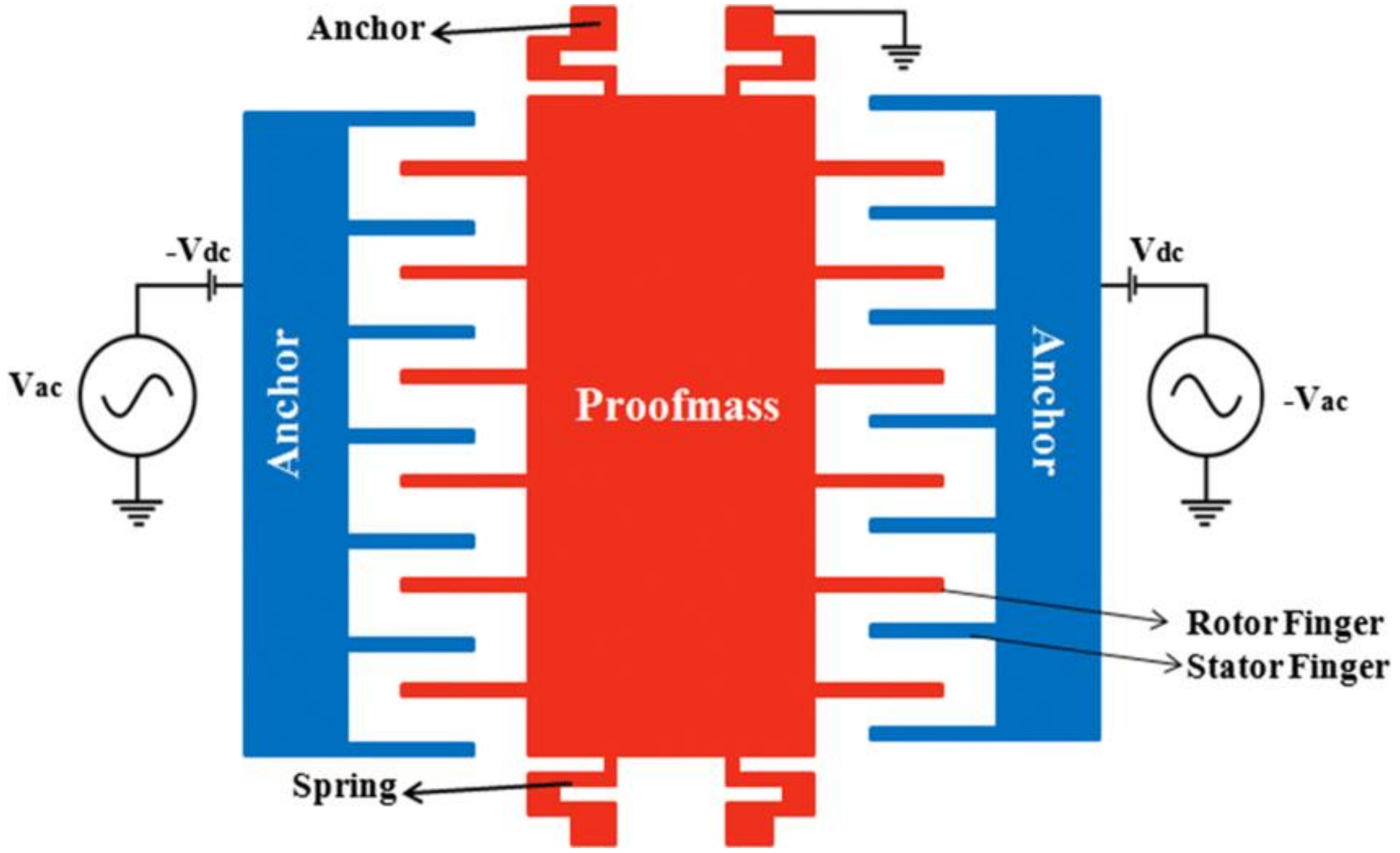
- Advantages:
  - Simple design structure
  - Easy readout
  - Measurement of slow changes in signal
- Disadvantages:
  - Needs temperature compensation
  - Large and bulky
  - Low sensitivities – Good for shock measurements (crash tests)



Capacitive Accelerometers

- Measure the change in capacitance in a comb structure when the proof mass moves under acceleration.
- Most common technology in commercial applications: smartphones.
- Advantages:
  - High sensitivity
  - Low noise
  - Temperature stability
  - Self-test
  - Good DC performance
- Disadvantages:
  - Susceptible to electromagnetic interferences

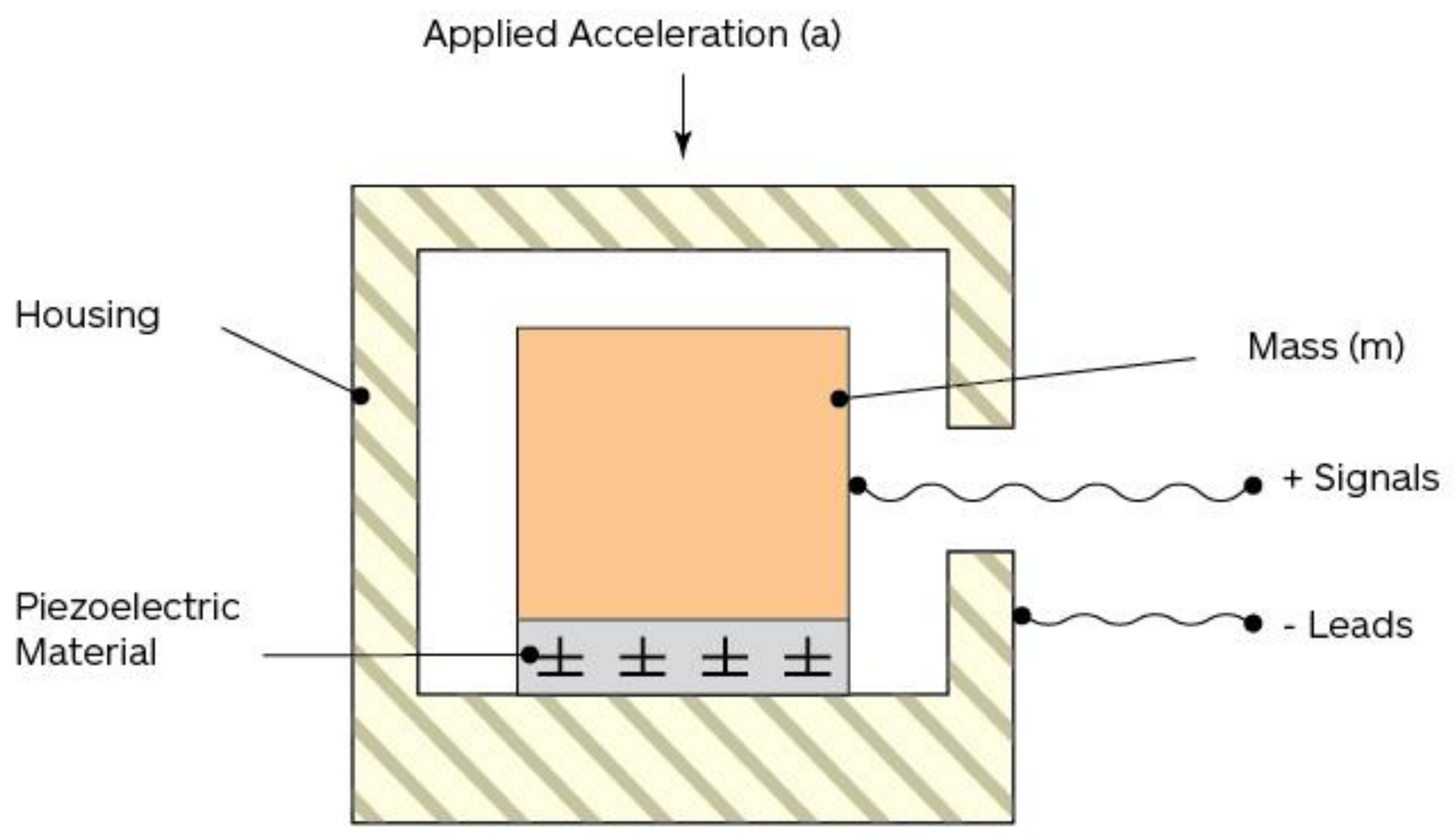




Piezoelectric accelerometers

- Proof mass compresses a piezoelectric element, creating a proportional signal.

- Advantages:
  - High frequency
  - High transient response
  - High output
  - Self-powered
- Disadvantages:
  - Bad low-frequency response
  - Device size is large



A basic diagram of a piezoelectric accelerometer.
Image credit: PCB Piezotronics

Summary of properties

Parameter	Piezoelectric	Piezoresistive	Capacitive
Gravitational component	No	Yes	Yes
Bandwidth	Wide	Low to moderate	Wide
Impedance	High	Low	Very high
Signal level	High	Low	Moderate
Ruggedness	Good	Moderate	Good
Cost	High	Low	High

Adapted from Wong *et al.*, 2007 [15].

Types of measurements

- Vibration (Piezoelectric accelerometer):
  - Object executes an oscillatory motion around a position of equilibrium.
  - Transportation, aerospace and industrial environments
- Shock (Piezoresistive accelerometer):
  - Transient excitation of a structure that generally excites structure's resonances
  - Explosion, hammer striking and object, vehicle crash.
- Motion (Capacitive accelerometer):
  - Slow-moving event lasting from < 1 s to several minutes.
  - Movement of a robotic arm or an automotive suspension.
- Seismic (Capacitive accelerometer):
  - Low-frequency vibration that requires low-noise, high-resolution accelerometer.
  - Motion of bridges, floors and earthquakes.

How to choose accelerometer?

- What is the amplitude of the vibration?
  - Dynamic range: maximum amplitude the accelerometer can measure before clipping the output signal. (Typically specified in g's)
- What is de frequency range?
  - Depends on the mass and the resonance frequency.
  - Frequency range where the output is within a specified deviation

Capacitive	Piezoresistive	Piezoelectric
15 Hz to 3000 Hz	Hundred Hz to > 130 kHz	few Hz to 30 kHz

- Environmental conditions:
  - Temperature, humidity, Electromagnetic interferences?
- Communication interface

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Thank You for listening this long!!

Any questions:

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