Introduction to MEMS

Accelerometers and Gyroscopes

What are MEMS (Micro Electro-Mechanical Systems):

- Microelectromechanical Systems are tiny integrated devices or systems that combine electrical and mechanical components.
- They range in size from micrometers to millimeters and can perform various sensing, control, and actuating functions.
- The fabrication of MEMS evolved from the process technology in semiconductor device fabrication, i.e. the basic techniques are deposition of material layers.

Importance

- **Integration**: MEMS integrate mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology.

- **Versatility**: MEMS can be used in a wide range of applications including automotive, medical, industrial, and consumer electronics.

Key Components

- **Sensors**: Convert physical parameters into electrical signals.
- **Actuators**: Convert electrical signals into mechanical movement.
- **Microstructures**: Support the sensor and actuator functions.

Fundamentals of MEMS Fabrication

- Silicon as a Substrate

Fabrication Techniques

- **Bulk Micromachining**: Involves etching away parts of the silicon substrate to form mechanical structures.
  - **Wet Etching**: Uses chemical solutions to remove material.
  - **Dry Etching**: Uses plasma to etch materials.

- **Surface Micromachining**: Involves adding layers to the silicon substrate and then etching them away to leave free-standing structures.

Deposition: Adding material layers using techniques like chemical vapor deposition (CVD).

Lithography: Patterning the deposited layers using photolithography.

Etching: Removing unwanted material to define structures

Advanced Fabrication Techniques

- **LIGA (Lithography, Electroforming, and Molding)**: Used for high-aspect-ratio microstructures.

- **DRIE (Deep Reactive Ion Etching)**: Allows for precise and deep etching of silicon.

Packaging and Assembly

- **Importance**: Protects MEMS devices from environmental factors and facilitates their integration into larger systems.
- **Techniques**: Wafer bonding, flip-chip bonding, and wire bonding.

MEMS Applications

- **Automotive**
  - **Airbag Sensors**: MEMS accelerometers detect rapid deceleration and trigger airbag deployment.
  - **Tire Pressure Monitoring**: MEMS pressure sensors monitor tire pressure.
- **Medical**
  - **Implantable Devices**: MEMS devices like drug delivery systems and pressure sensors for monitoring blood pressure.
  - **Lab-on-a-Chip**: Miniaturized devices that perform laboratory functions on a small chip.

- **Consumer Electronics**
  - **Smartphones**: MEMS accelerometers and gyroscopes for orientation detection and motion sensing.
  - **Wearables**: Fitness trackers and smartwatches using MEMS sensors for activity monitoring.

- **Industrial**
  - **Environmental Monitoring**: MEMS sensors for detecting temperature, humidity, and gases.
  - **Robotics**: MEMS sensors and actuators for precision control

Challenges

- **Miniaturization**: Further reducing the size of MEMS devices while maintaining performance.

- **Reliability**: Ensuring long-term reliability and durability in various environments.

- **Cost**: Reducing the cost of MEMS fabrication and packaging.

Future Trends

- **Integration with IoT**: MEMS devices will play a crucial role in the Internet of Things (IoT) by providing essential sensing and actuation capabilities.

- **Biomedical Advancements**: Development of advanced MEMS devices for more precise and effective medical treatments.

- **Nanoelectromechanical Systems (NEMS)**: Scaling down MEMS technology to the nanometer scale for enhanced performance and new applications

Accelerometer

- Comprises a mechanical sensing element and conversion of the signal from the mechanical to the electrical domain.
- Accelerometer is a device which can detect and measure acceleration.
- Accelerometer is rigidly attached to the body which acceleration is the subject of interest.

Proper Acceleration Vs Coordinate Acceleration

- Proper Acceleration – The acceleration of a body in its own instantaneous rest frame.
- Coordinate Acceleration – The acceleration in a fixed coordinate system.

An accelerometer measures proper acceleration.

Eg:– An accelerometer in free fall measures an acceleration equal to zero.

  - Any force that acts identically on the case and on the test mass results in an acceleration that is undetectable by the accelerometer.

Therefore gravity is not detectable.

Single- and multi-axis models of accelerometer are available to detect magnitude and direction of the proper acceleration, as a vector quantity, and can be used to sense orientation (because direction of the weight changes).

Proof mass (Seismic mass) is used in transducers as a sensing element.

Transducer – a device that converts energy from one form to another.

The ratio of change in acceleration (input) to change in the output signal. This defines the ideal, straight-line relationship between acceleration and output (x/a).

- Seismic mass is suspended by a spring.
- Acceleration, a causes a force, F to act on the mass,m

$$F = ma$$

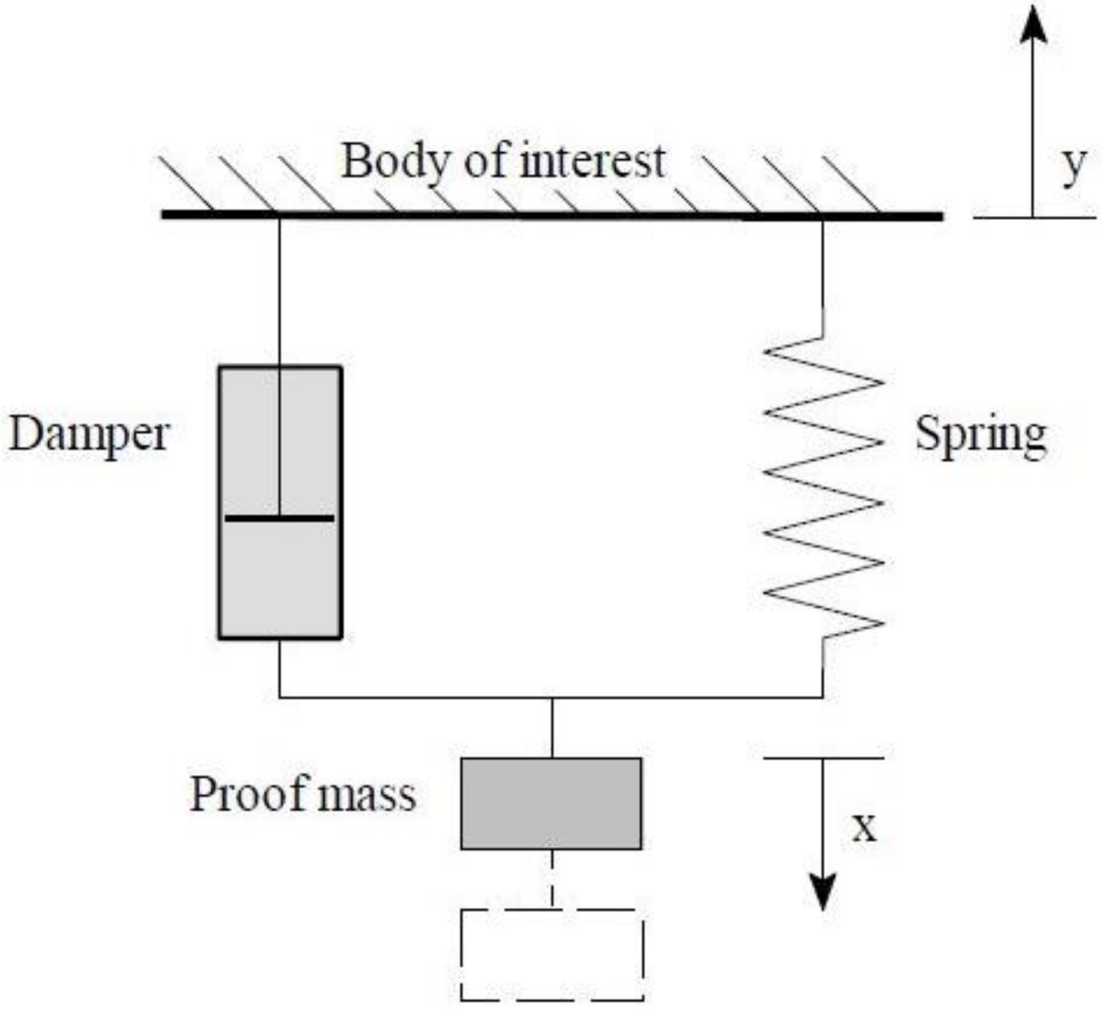
- As a result the mass will undergo a deflection x.

$$F = kx$$

$$a = \frac{kx}{m}$$

- Sensitivity of an accelerometer

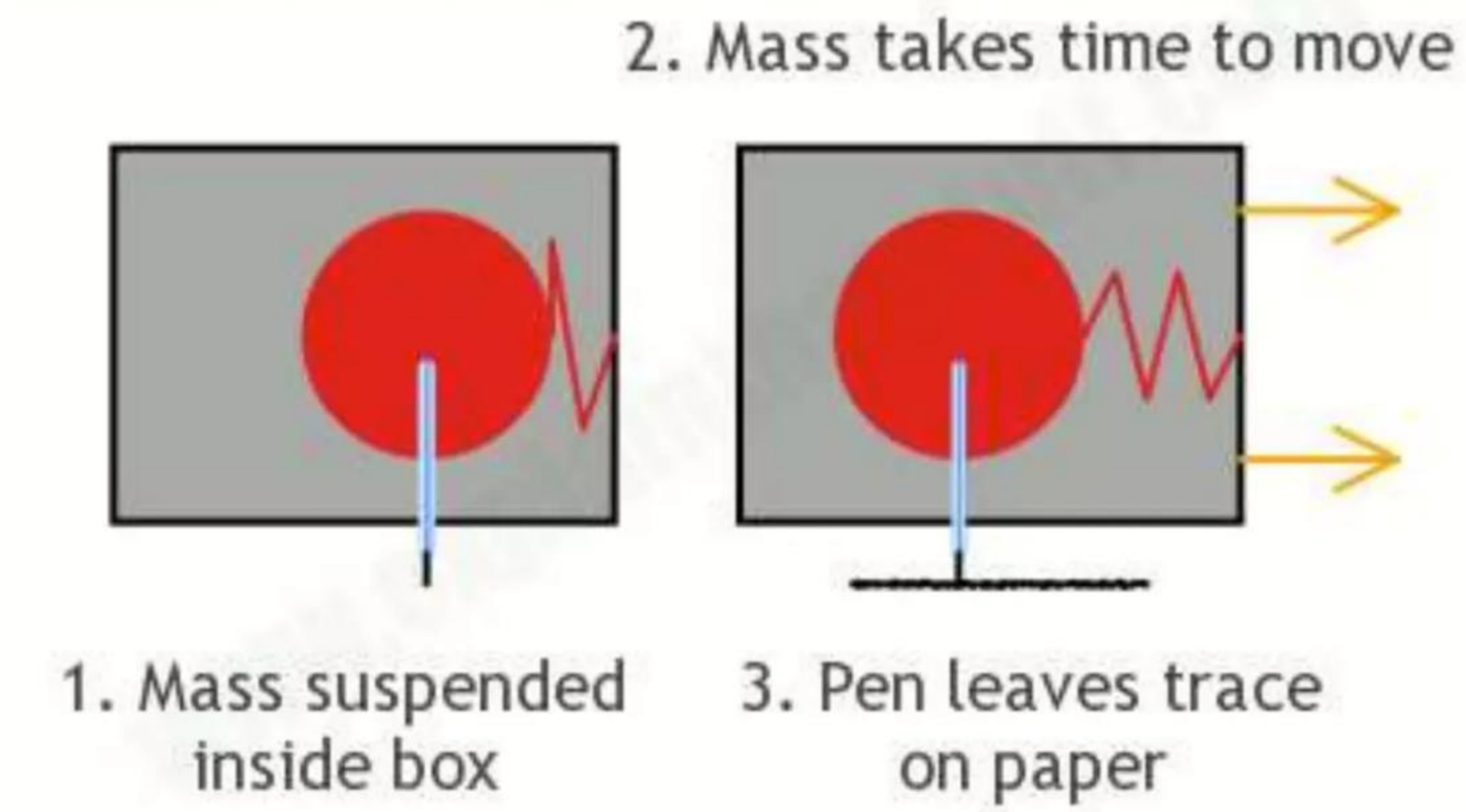
$$\frac{x}{a} = \frac{m}{k}$$



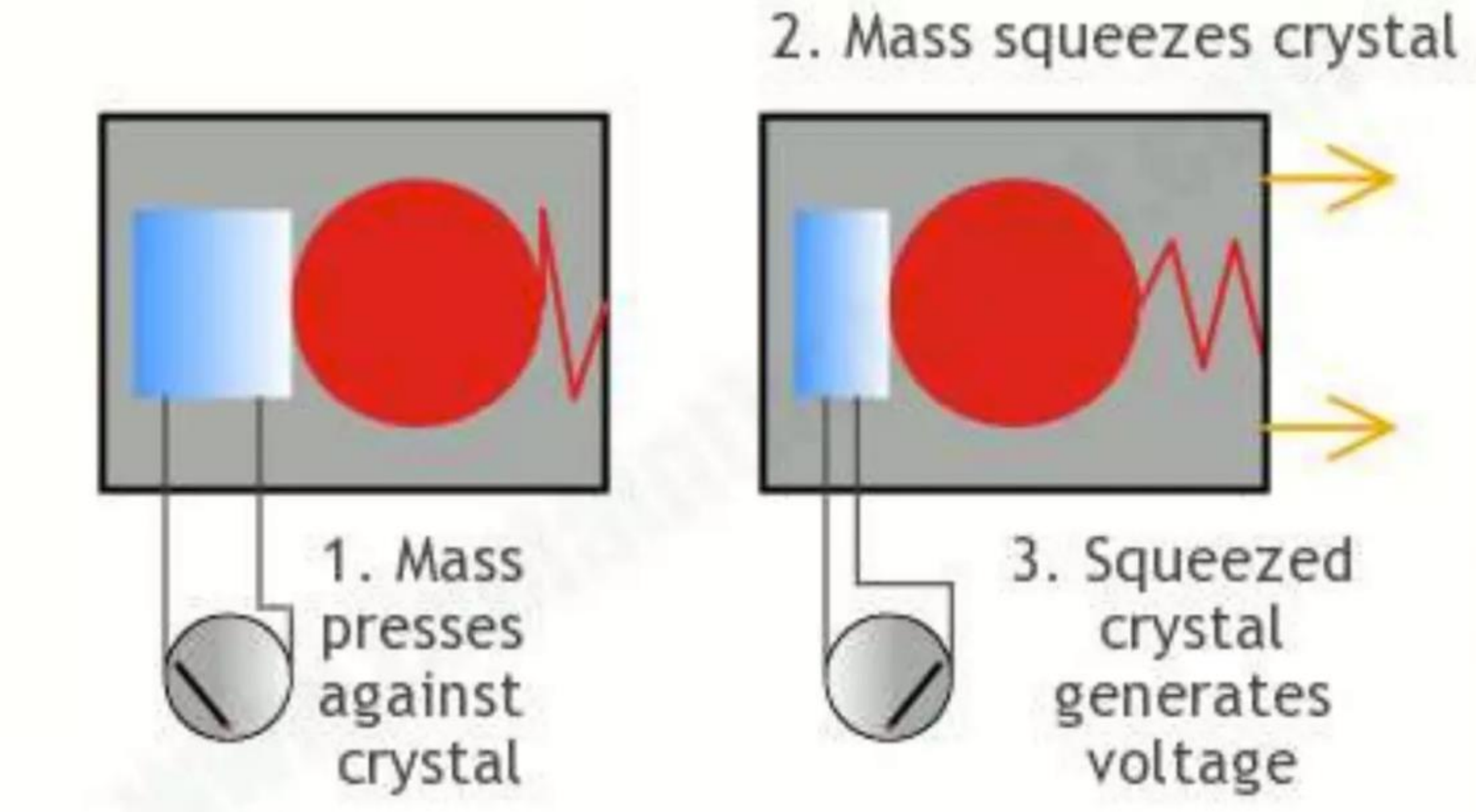
Types of accelerometers

- Capacitive accelerometers
- Piezoelectric accelerometers
- Piezo-resistive accelerometers
- Hall Effect accelerometers
- Magneto-resistive accelerometers
- Heat transfer accelerometers
- Heated Gas accelerometers
- Variable inductance accelerometers

Mechanical accelerometer



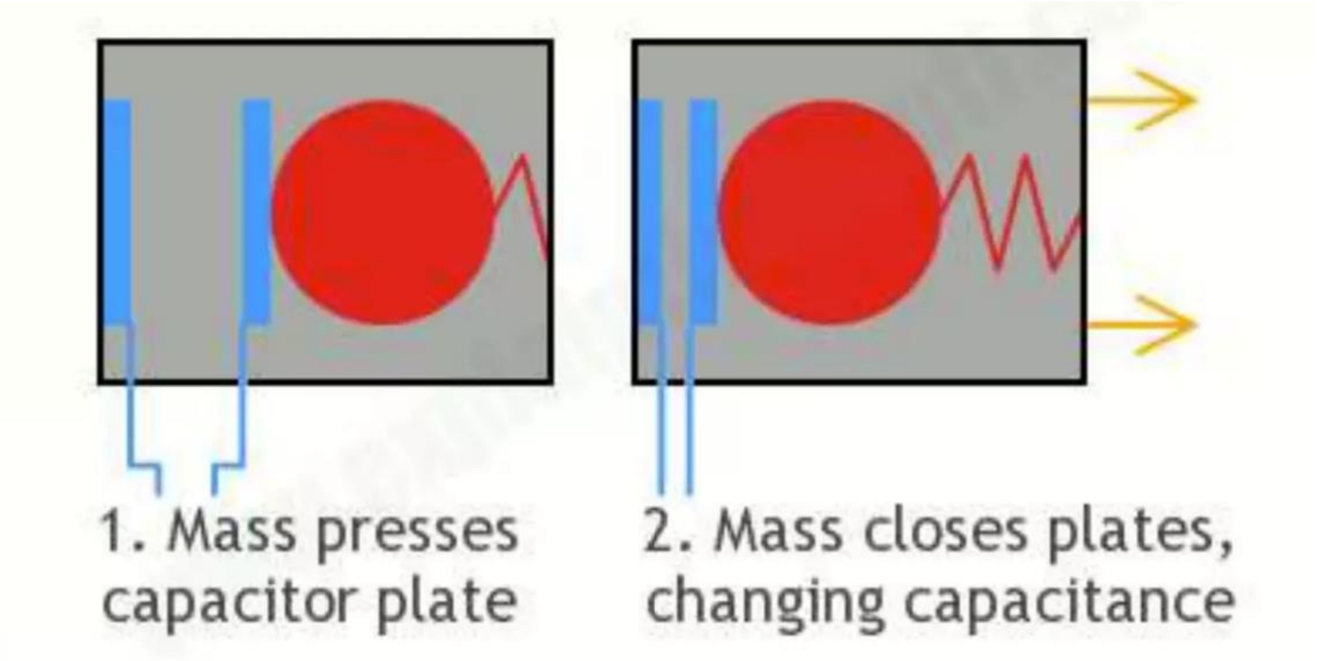
Piezoelectric accelerometers

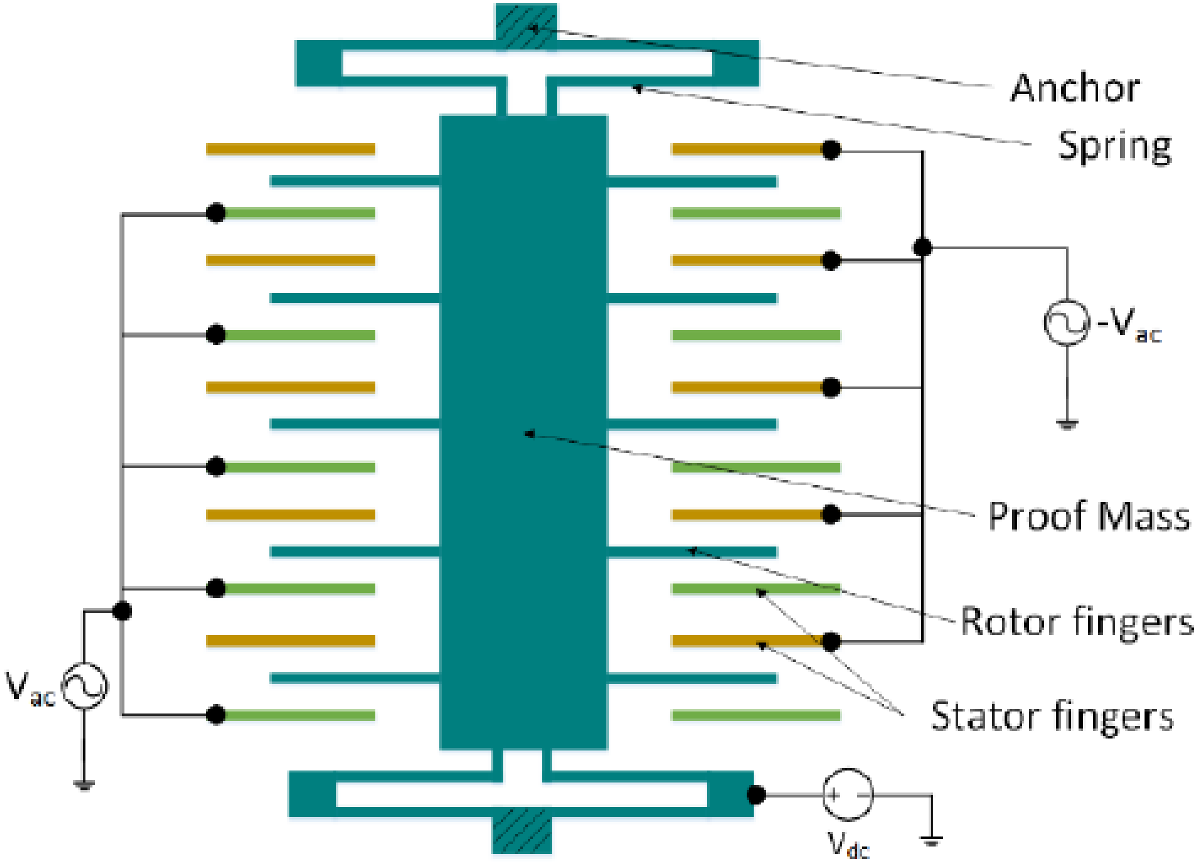


Capacitive accelerometers

Metal beam or micro machined feature produces capacitance.

Change in capacitance related to acceleration.





- The mass of the proof mass is approximately 0.1 µg.
- The smallest detectable capacitance change is ≈ 20aF (Atto Farads) and gaps between capacitor plates are approximately 1.3µm.

Working principle

- Piezoelectric accelerometers

  Piezoelectric crystal is attached to mass. Voltage output relates to acceleration.

- Piezo-resistive accelerometers

  Beam or micro machined feature, whose resistance changes with acceleration.

- Hall Effect accelerometers

  Motion converted to electrical signal by sensing the change in magnetic fields.

- Magneto-resistive accelerometers

  Material resistivity changes in presence of magnetic field.

- Heat transfer accelerometers

  Location of heated mass is tracked during acceleration by sensing temperature.

Applications of Accelerometers

- Inertial navigation systems for aircrafts and missiles.
- Used in smart phones and tablets to identify orientation.
- Detecting vibration in rotary machinery.
- Used in drones for flight stabilizing.
- Detect walking activity in cardiac rehabilitation.
- Crash detector in airbag.
- Examine the gesture for remote controller for video games.
- Active suspensions.
- Anti-lock braking systems.