Accelerometers

An accelerometer is a device that measures acceleration, *which is the rate of change of velocity of an object.*

It detects changes in motion or orientation and is widely used in various applications, ranging from consumer electronics to aerospace systems.

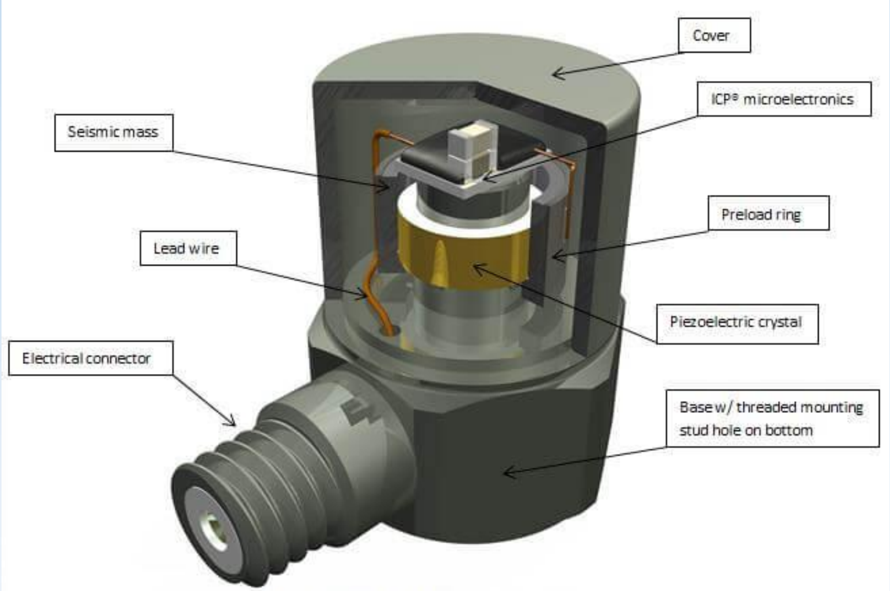
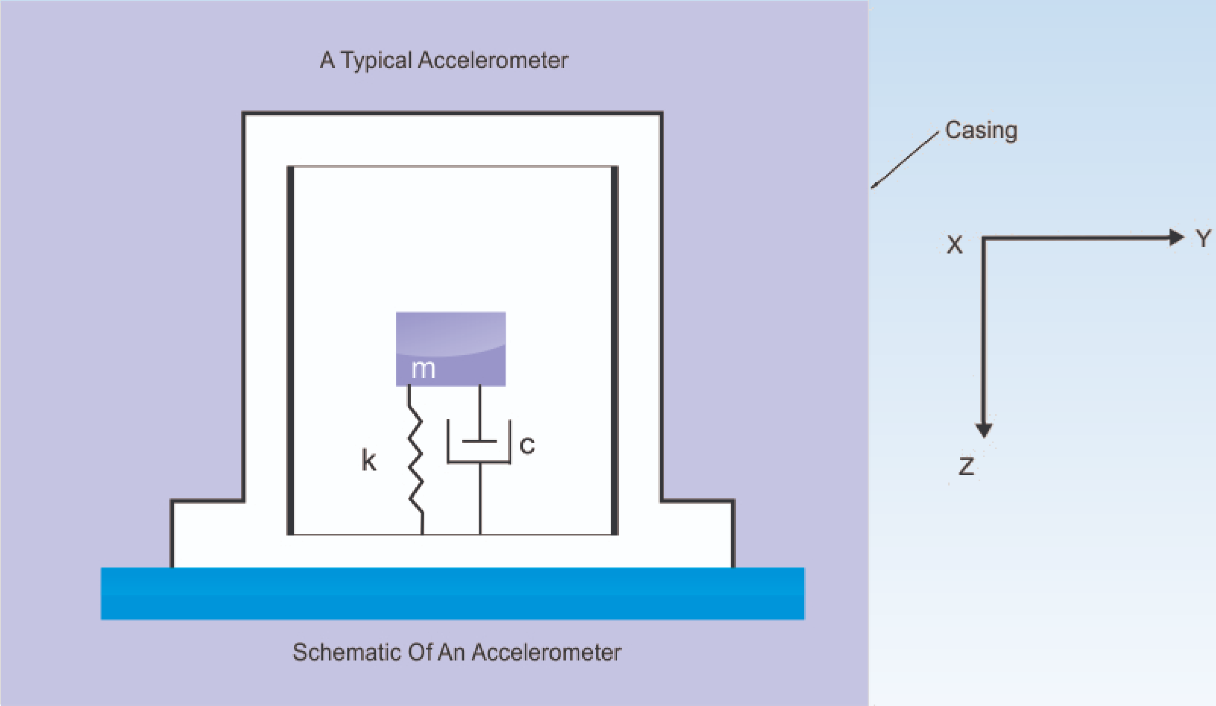


Figure 1: Typical ICP® Accelerometer

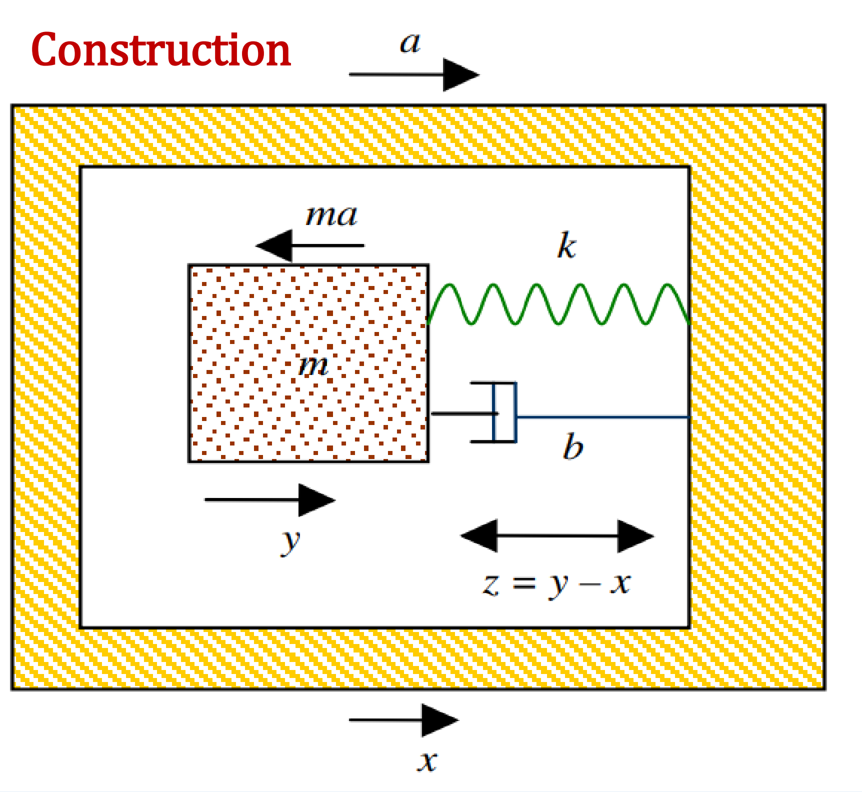
Accelerometers

Key Functions:

- Measure acceleration forces (static like gravity or dynamic due to movement).
- Detect orientation, tilt, vibration, and shock.



Accelerometers

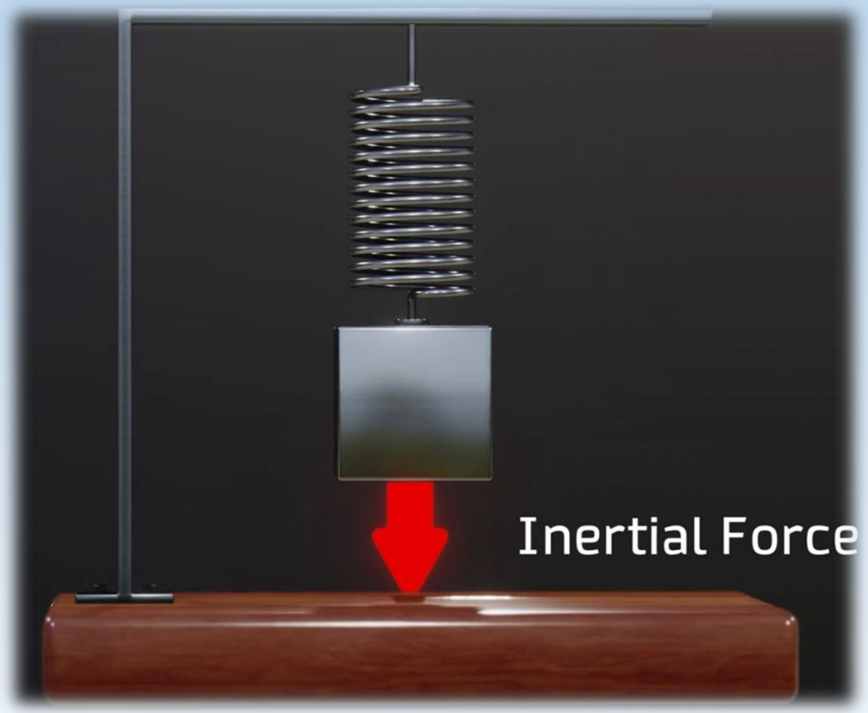


Accelerometer comprises

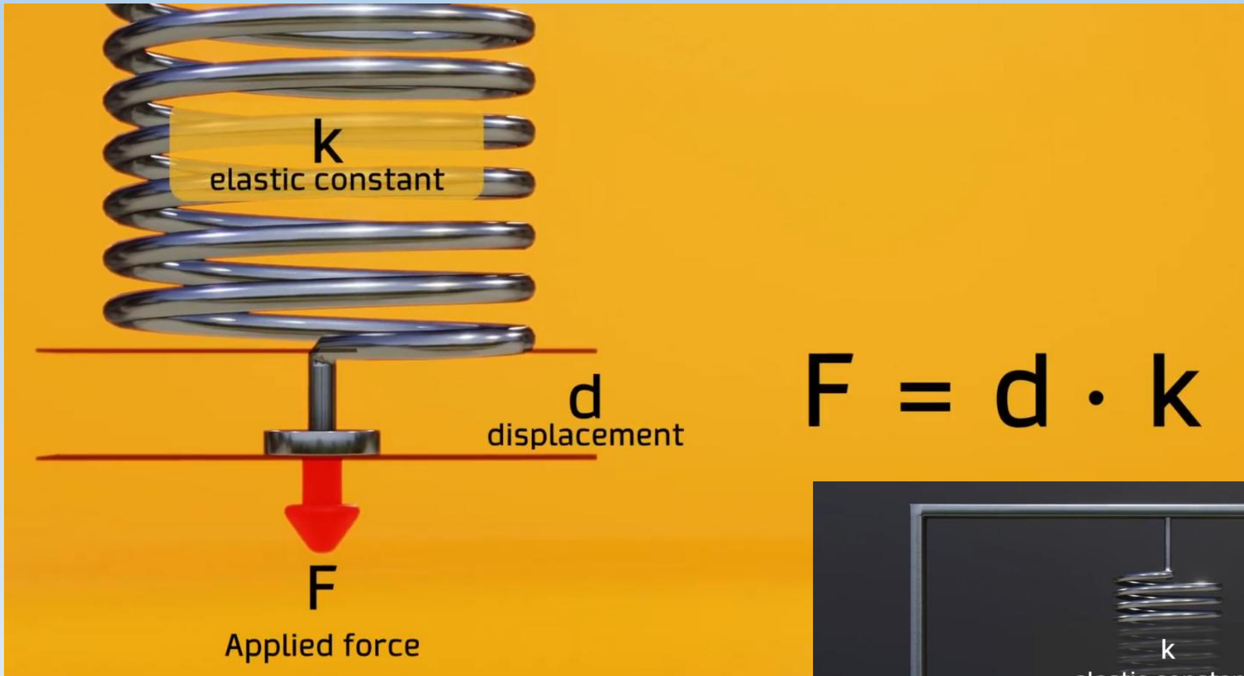
- spring,
- damper,
- seismic mass, and
- displacement sensor arranged within a housing attached to a base.

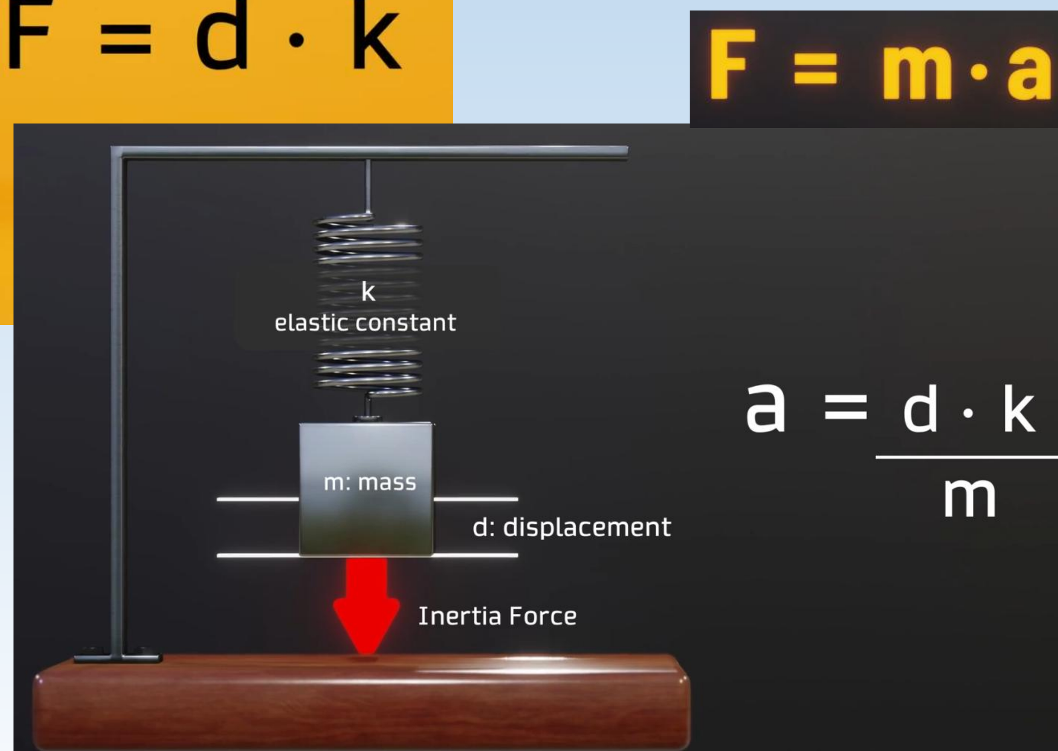
In operation, the base is mounted on the vibrating structure to be measured, and the relative displacement between the seismic mass and the base is recorded by the displacement sensor.

Accelerometers



Accelerometers





Accelerometers

Accelerometers

F = m·a

Measuring acceleration

- Newton's second law

$$m\ddot{x}_m = F_s - mg$$

- and for a spring we know

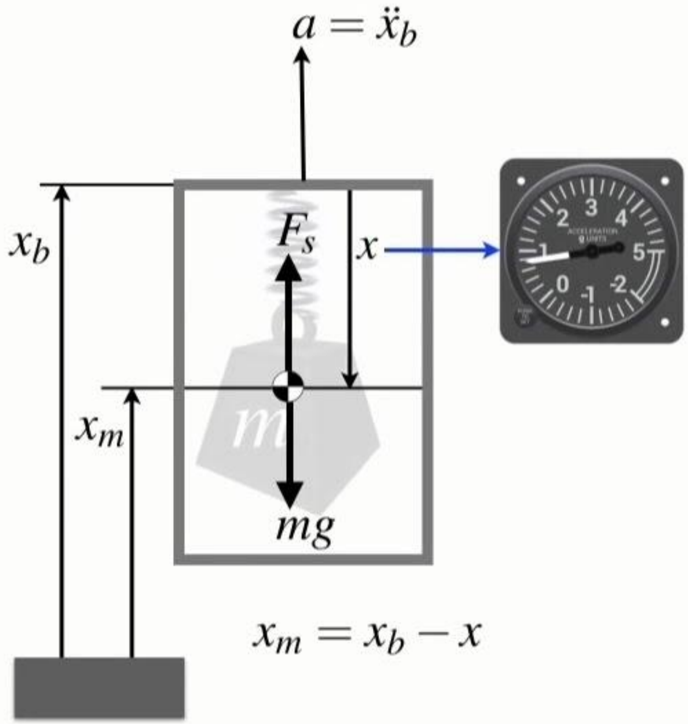
$$F_s = kx$$

- so acceleration is proportional to spring extension

$$m(\ddot{x}_b - \ddot{x}) = kx - mg$$

$$m(a - \ddot{x}) = kx - mg$$

$$x = \frac{m}{k}(a + g)$$



Accelerometers

Main Types of Accelerometers

1.**Capacitive** – Use changes in capacitance between microstructures to detect motion (common in MEMS devices).

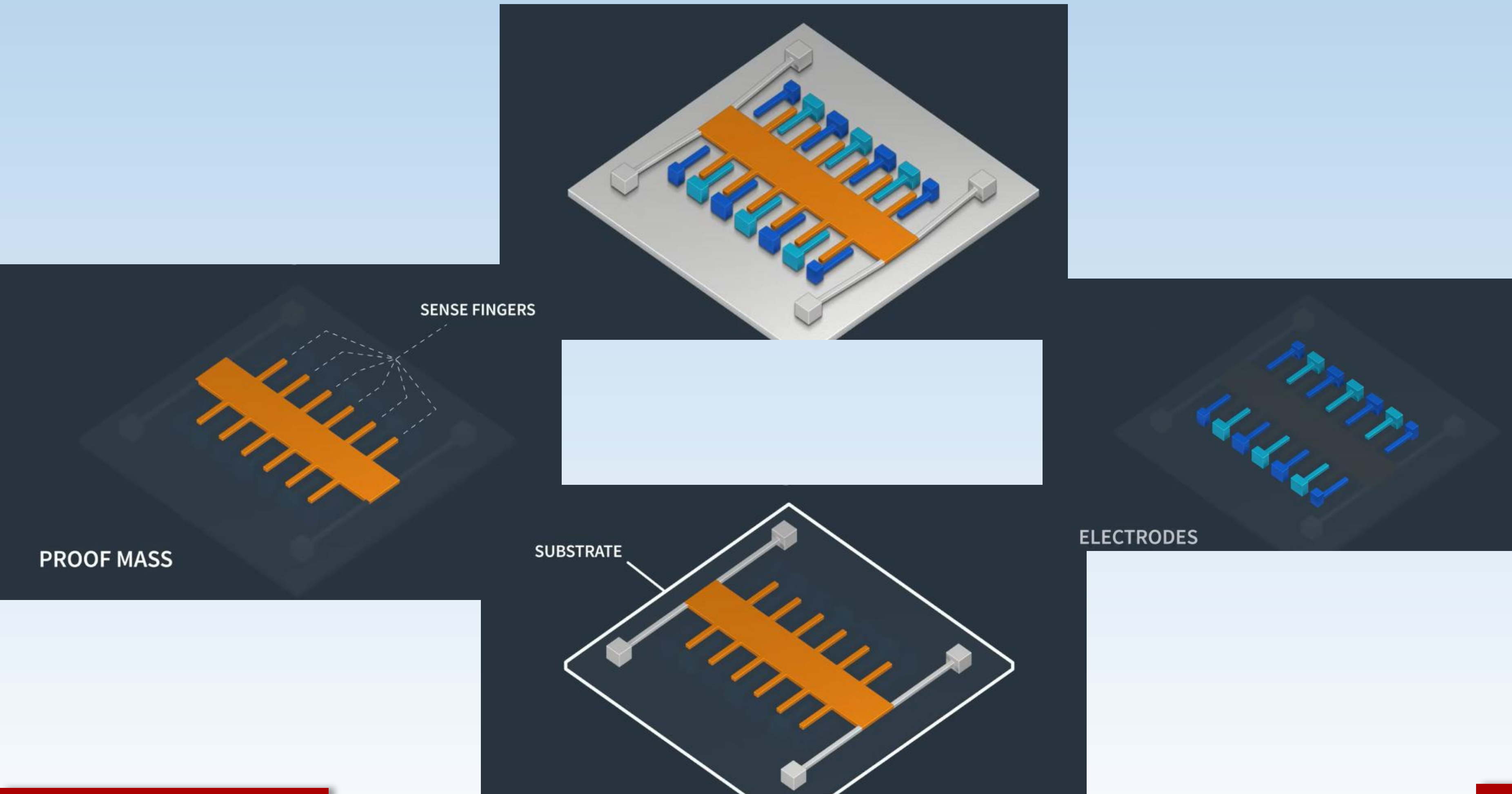
2.**Piezoelectric** – Use materials that generate electrical charge when mechanically stressed (ideal for dynamic/vibration sensing).

3.**Piezoresistive** – Detect changes in resistance when stressed.

4.**Hall effect-based** – Measure displacement of a mass within a magnetic field.

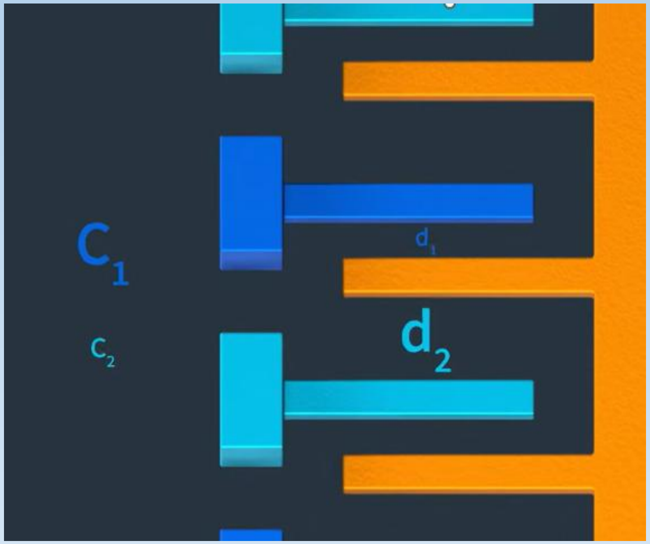
Accelerometers

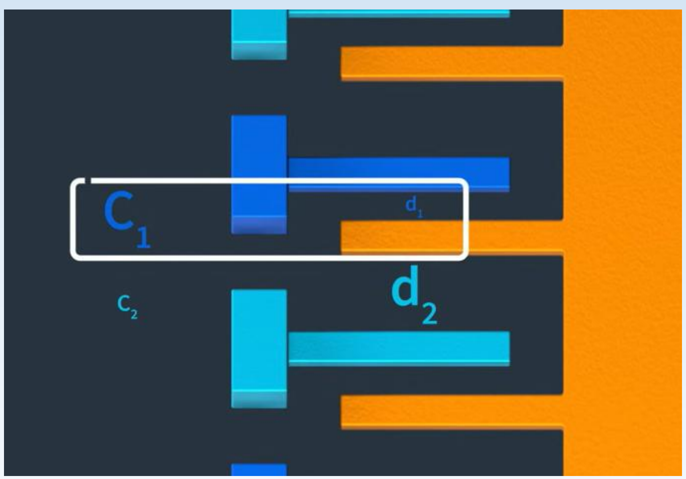
Capacitive – Use changes in capacitance between microstructures to detect motion (common in MEMS devices). 10^{-6} m

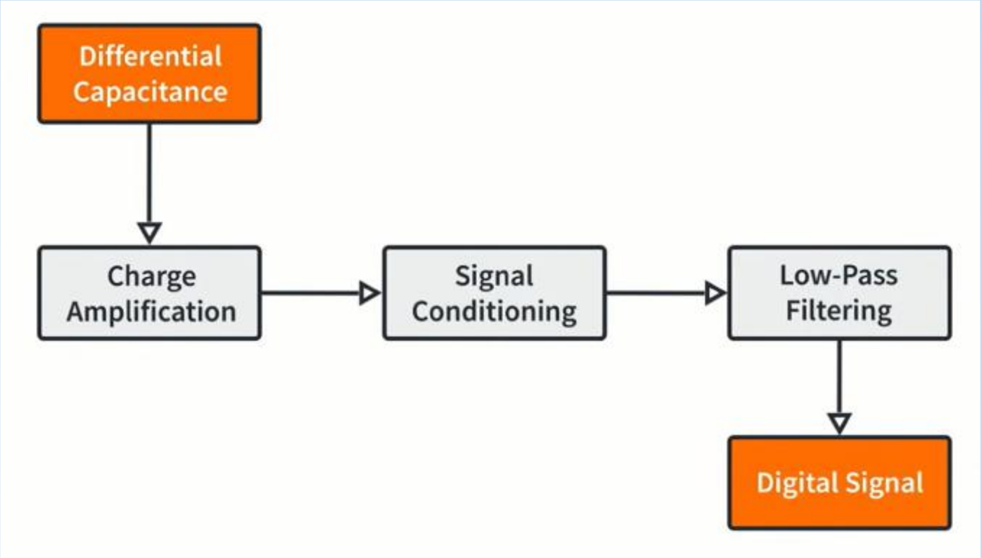


Accelerometers

$$C = \frac{\varepsilon A}{d}$$

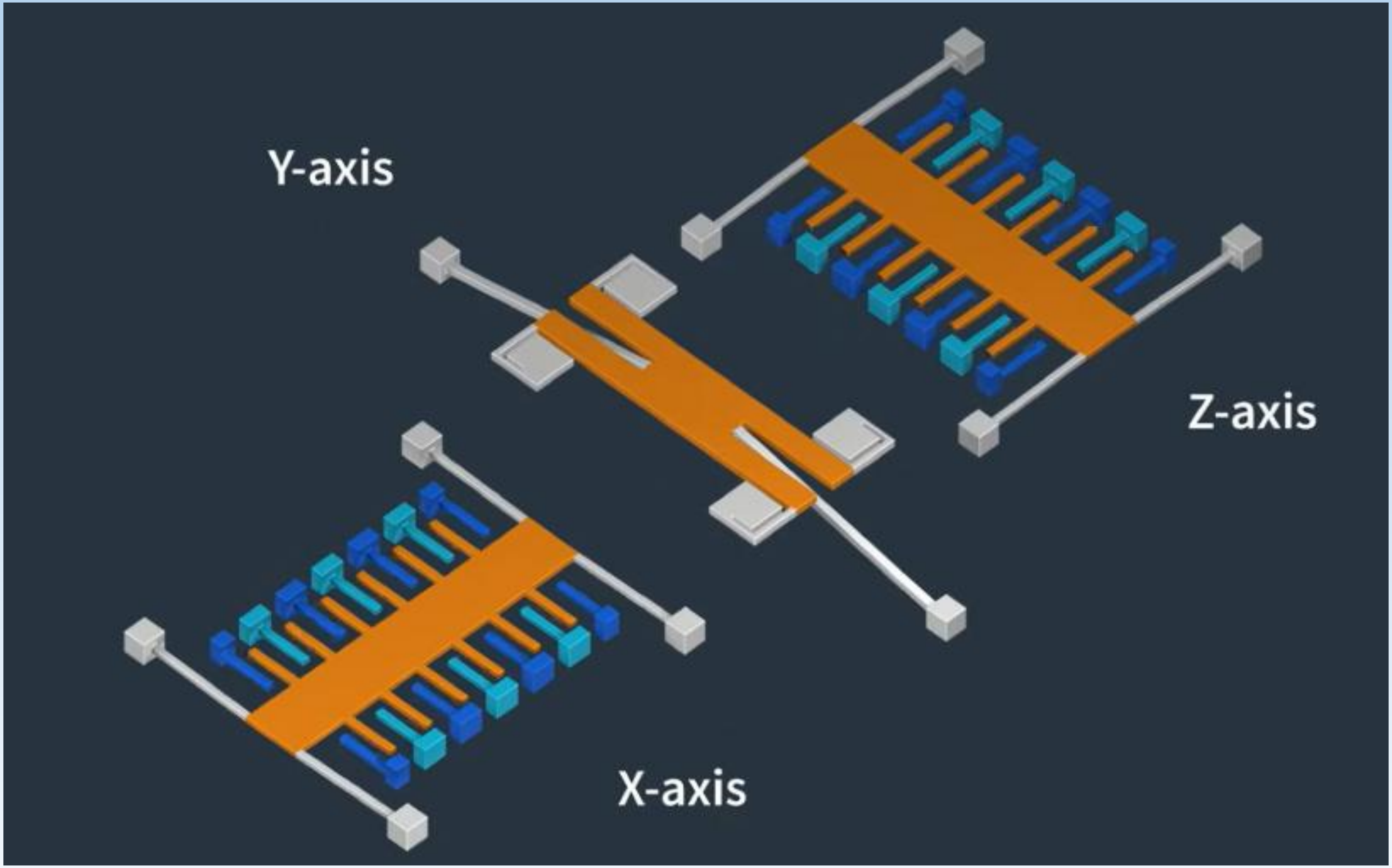






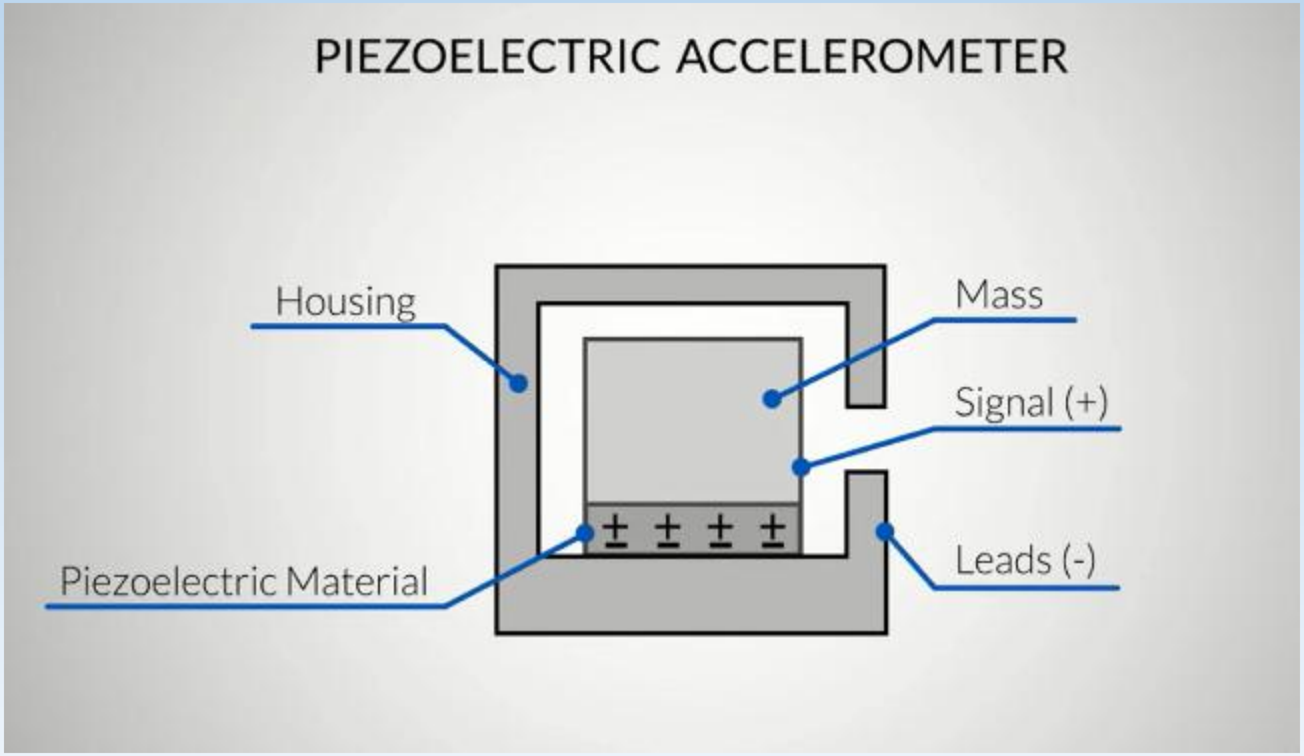
Accelerometers

$$C = \frac{\varepsilon A}{d}$$



Accelerometers

Piezoelectric – Use materials that generate electrical charge when mechanically stressed (ideal for dynamic/vibration sensing).



Accelerometers

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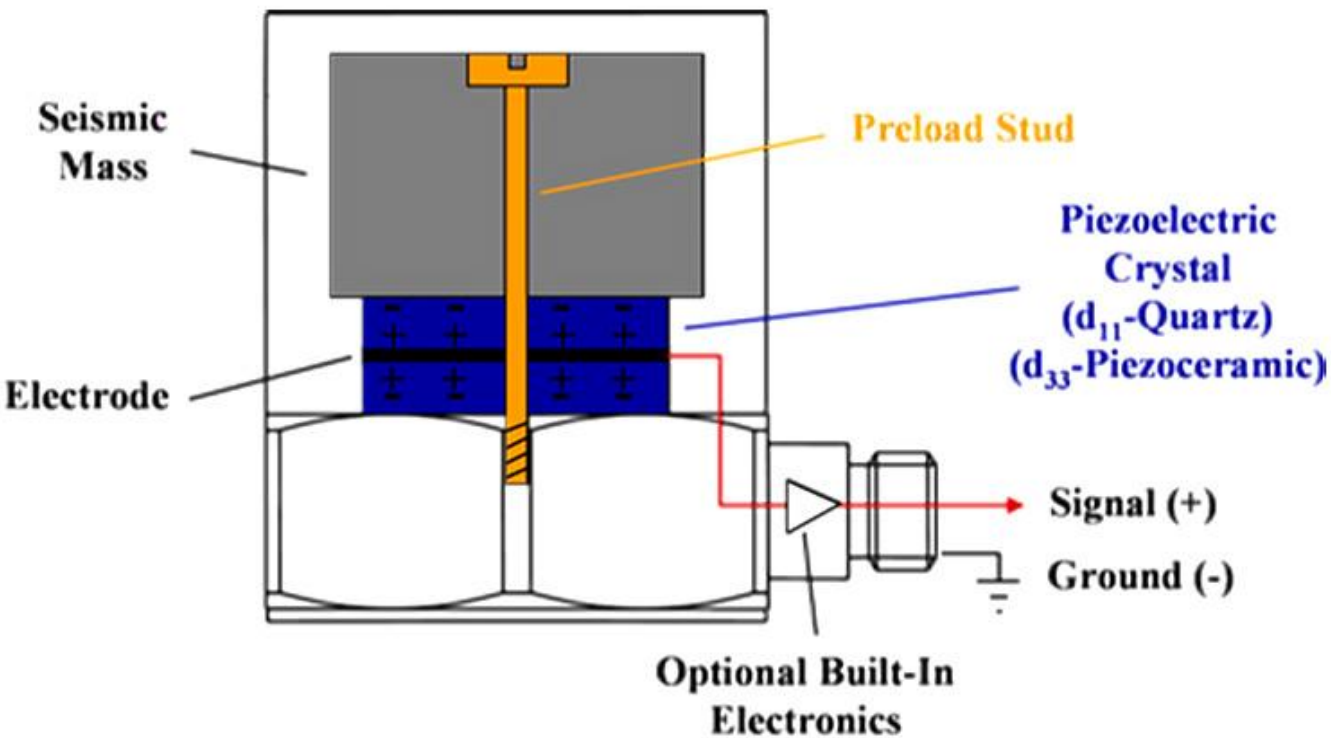
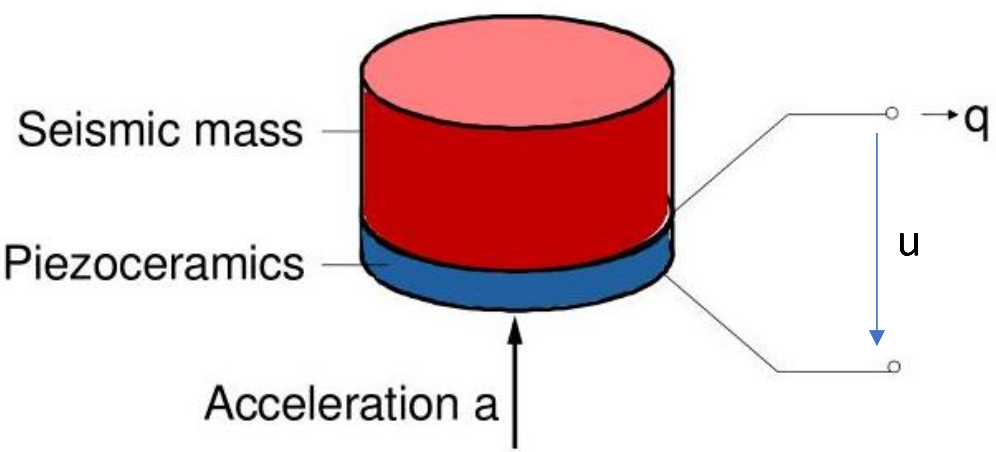


Accelerometers

Piezoelectric – Use materials that generate electrical charge when mechanically stressed (ideal for dynamic/vibration sensing).

Piezoelectric Accelerometer

- A piezoelectric accelerometer consists of a piezoelectric material and a seismic mass.
- The charge output is proportional to acceleration.



Voltage sensitivity:

$$B_{ua} = \frac{u}{a}$$

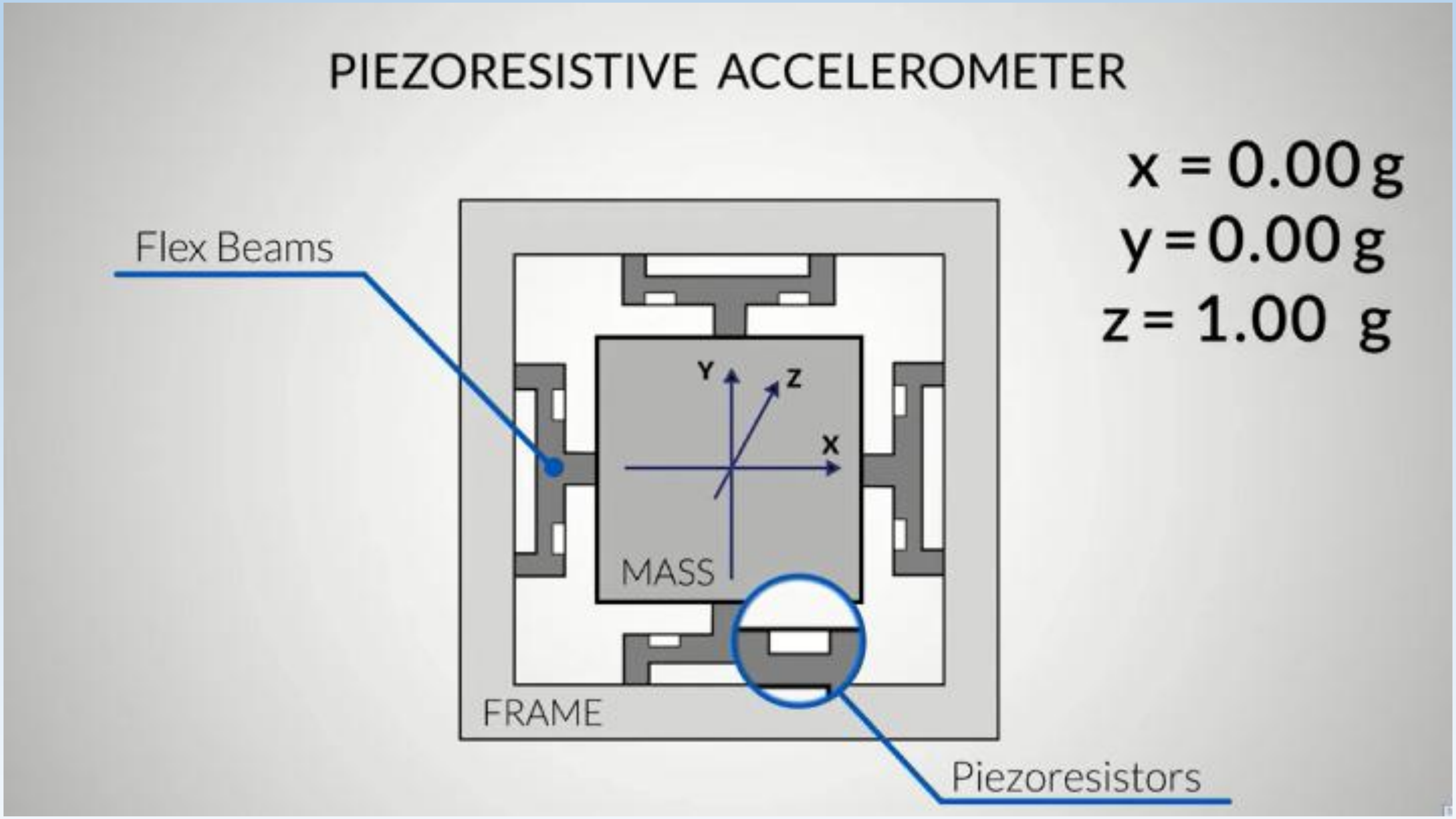
$$\boxed{F = m \cdot a}$$

charge sensitivity:

$$B_{qa} = \frac{q}{a}$$

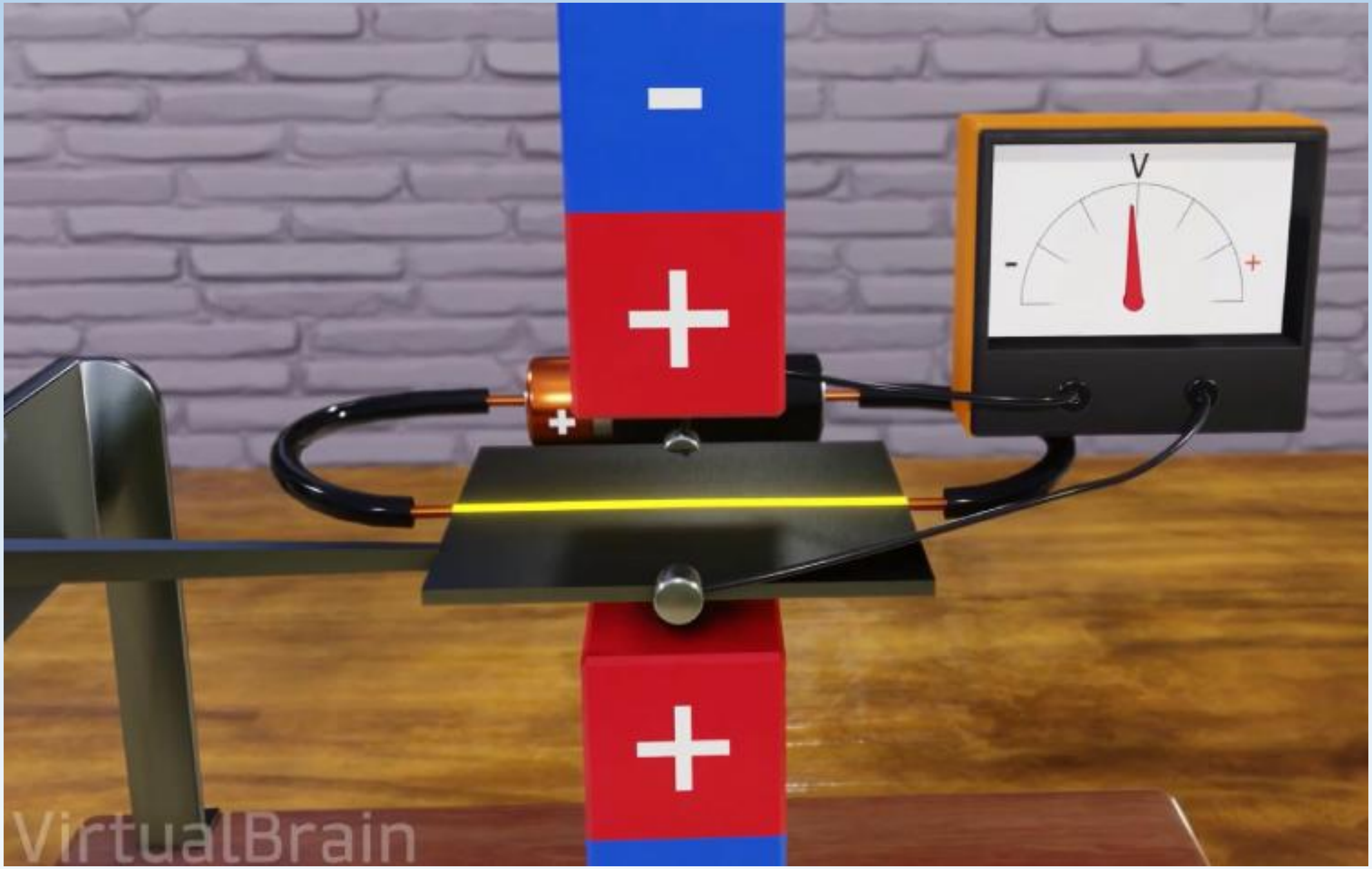
Accelerometers

Piezoresistive – Detect changes in resistance when stressed



Accelerometers

Hall effect-based – Measure displacement of a mass within a magnetic field.



Accelerometers

- **Applications:**

- **Consumer electronics**: smartphones (screen rotation, step counting), game controllers.

- **Automotive**: airbag deployment systems, crash detection.

- **Aerospace and defense**: navigation systems, vibration monitoring.

- **Medical devices**: fall detection, activity monitoring.

- **Vibration monitoring in rotating machinery** – Detect imbalance, misalignment, or bearing faults in motors, pumps, turbines, etc.

- **Seismic monitoring** – Measure ground movement during earthquakes for structural response studies

Accelerometers

Comparison with piezoelectric accelerometers:

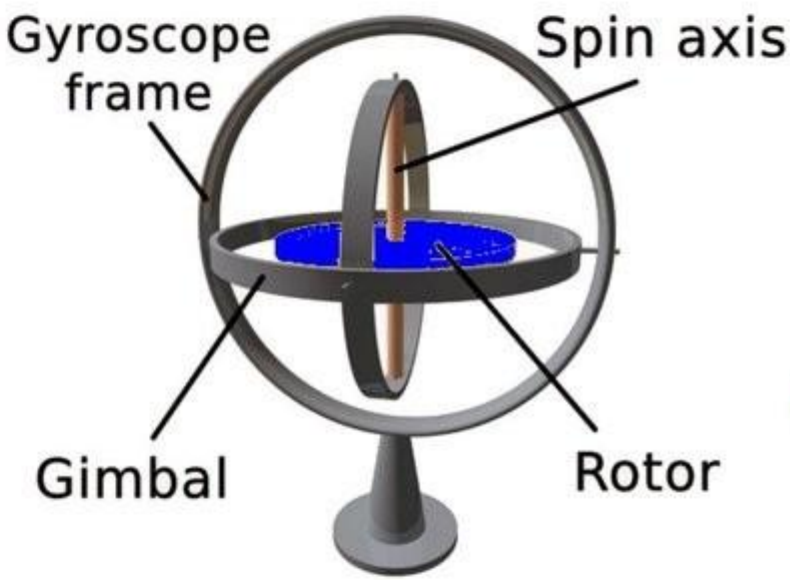
Sensor Type	Advantages	Disadvantages
Piezoresistive (strain gauge)	• Measures static acceleration • Robust	• Limited resolution • Only up to some kHz • Power supply required
Electrodynamic	• Measures static acceleration	• Only for low frequencies
Capacitive	• Measures static acceleration • Cheap manufacturing by semiconductor process	• Low resolution • Fragile

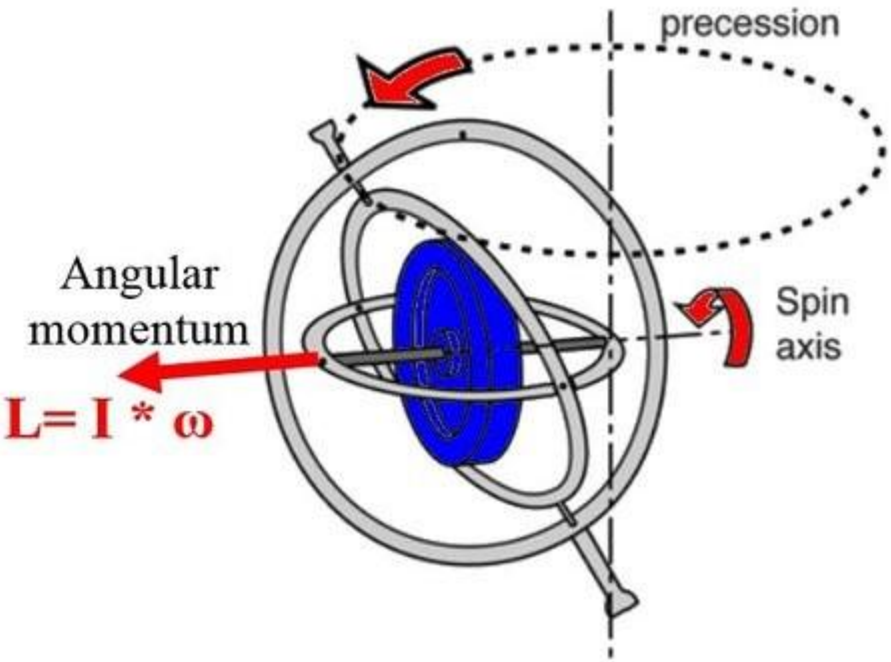
Advantages of Piezoelectric Accelerome

- Extremely wide dynamic range, almost free of noise - suitable for shock measurement as well as for almost imperceptible vibration
- Excellent linearity over full dynamic range
- Wide frequency range, high frequencies can be measured
- Compact yet highly sensitive
- No moving parts – long service life
- Self-generating - no external power required

Gyroscopes and precession

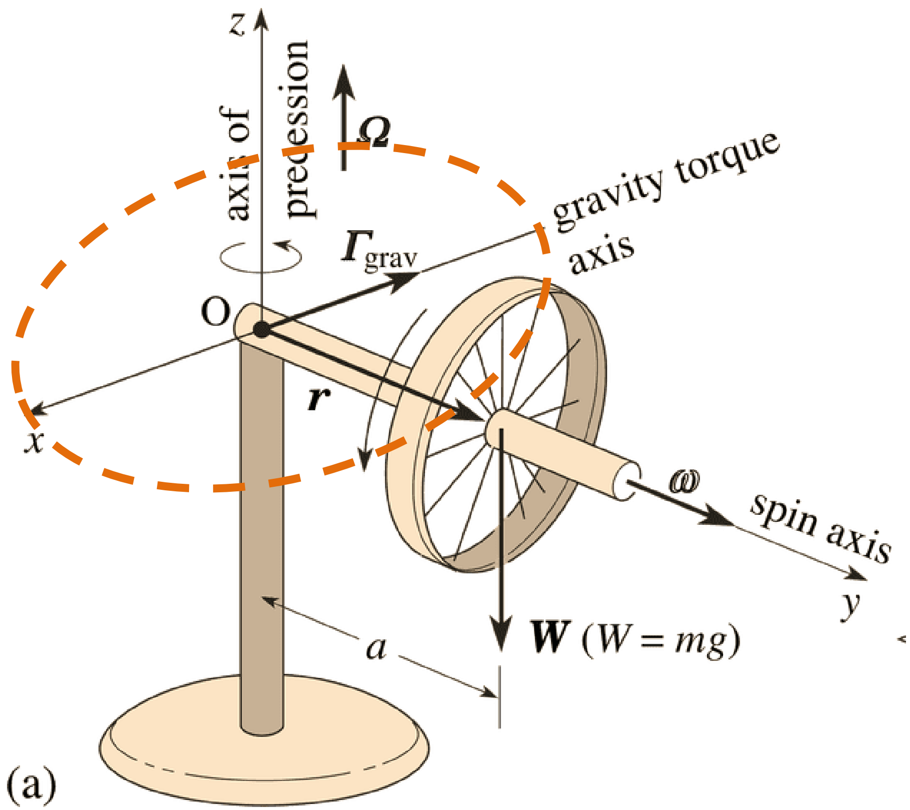
Gyroscopes and precession

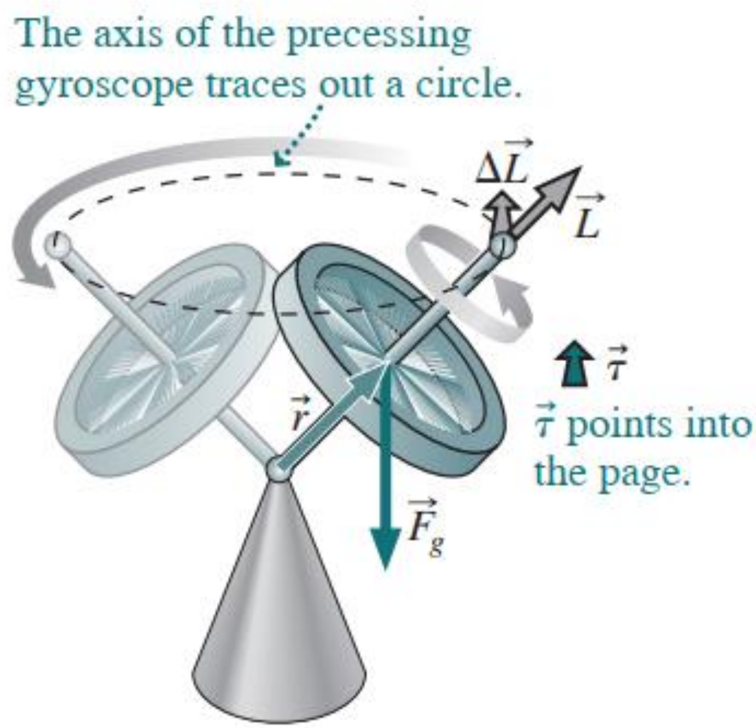




GYROSCOPE is **a wheel or disk mounted to spin rapidly about an axis** and also free to rotate about another axes

Gyroscopes and precession

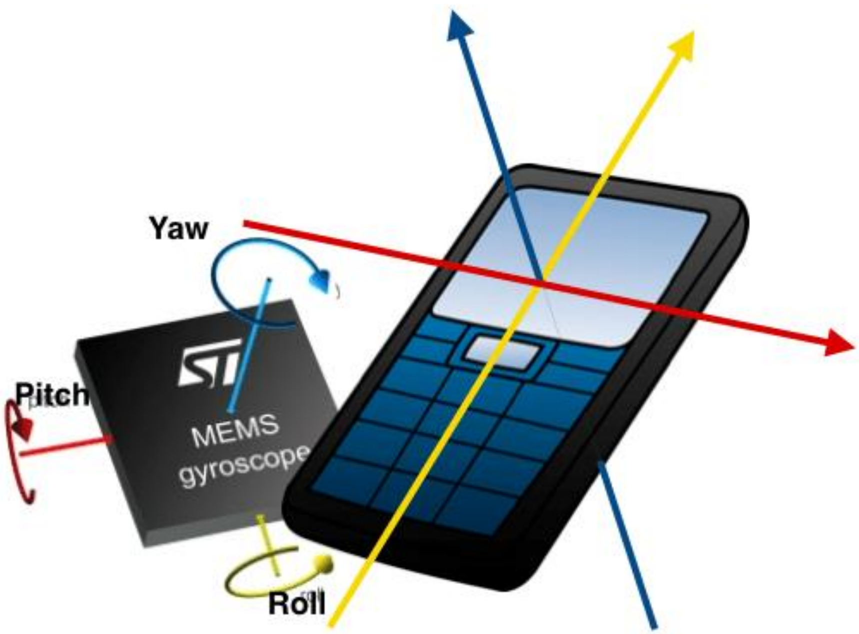




If an external torque is applied, the rotation axis undergoes a circular motion known as **precession**.

Gyroscopes and precession

smartphone, it, too, contains gyroscopes.
They're used to determine the phone's orientation in space; among other uses, they tell the phone how to orient its display.



(a) (b)

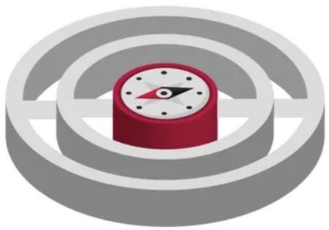
FIGURE 11.9 (a) Smartphone displaying data from its internal gyroscopes, indicating the phone's orientation and its rate of change. Graph at top shows that the phone was recently reoriented. (b) Micro photo of a MEMS gyro like those used in smartphones. The entire structure is only about 0.5 mm across.

Gyroscopes and precession

Applications of Gyroscope

Following are the main applications of gyroscopes.

- **In heading indicators in airplanes and rockets**:
- **Gyrocompass**:
- **With accelerometers**:
- **Consumer Electronics**:
- **In cruise ships**:
- **Drones**



Gyrocompass