Sensors

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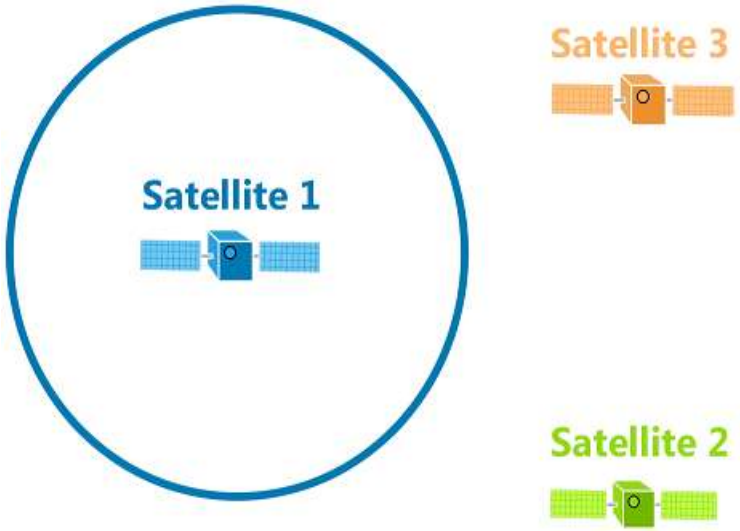
Introduction

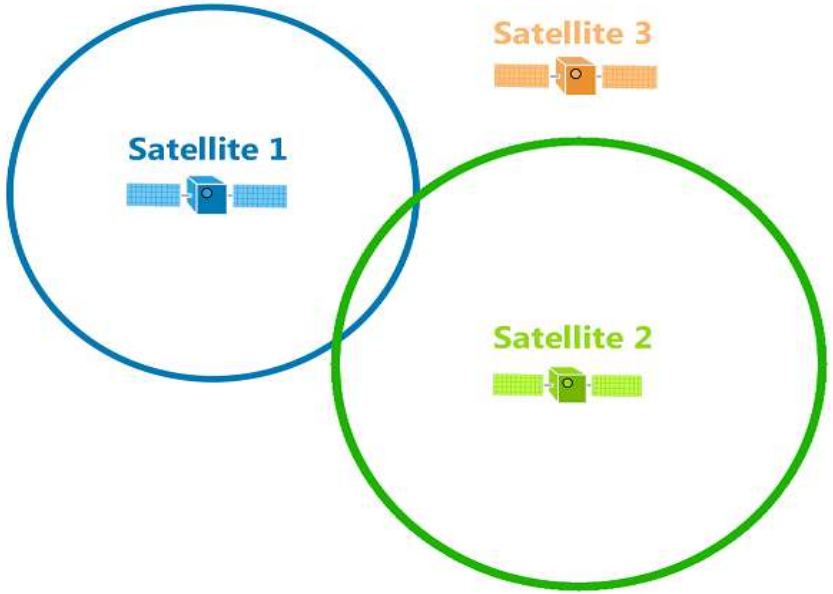
- Sensors inform electrical systems about the world around them.
- we focus only on sensors that are directly connected to, or are part of, an embedded device.
- Sensors can deliver
  - qualitative information (*water level above threshold?* – yes/no)
  - quantitative, absolute readings
    - sensitivity and resolution of a sensor

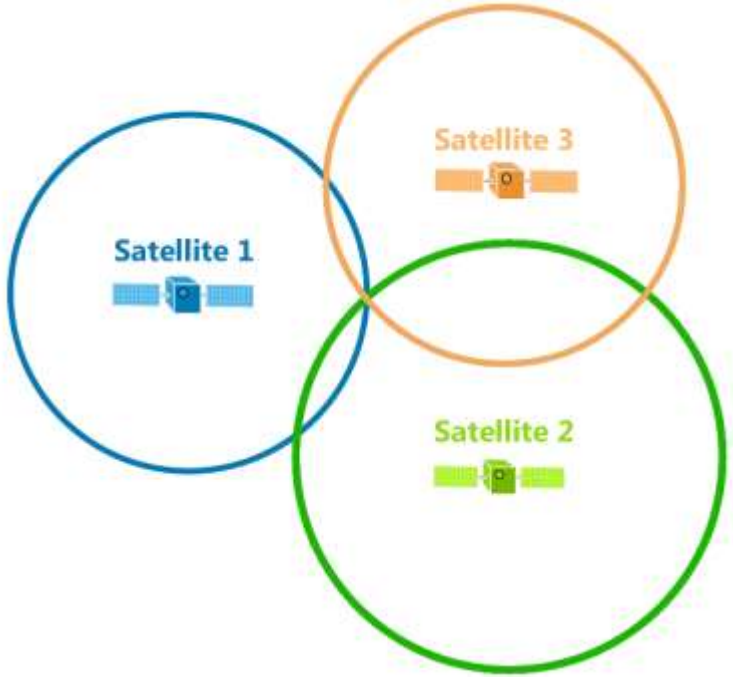
Location

- Localization technologies are divided into global and indoor localization systems.
- Global navigation satellite systems (GNSSs)
  - unobstructed line-of-sight connections between the satellites and their respective receiver
- Indoor positioning systems (IPSs)
  - locally deployed anchor points such as WiFi routers or Bluetooth beacons
- The key principle behind both technology types is signal tri- or multilateration
  - Given the distances d_1, d_2, d_3, …, d_n to three or more points in space, it is possible to infer a unique position from the intersection of the spheres of radius d_1, d_2, d_3, …, d_n around these points.

Trilateration







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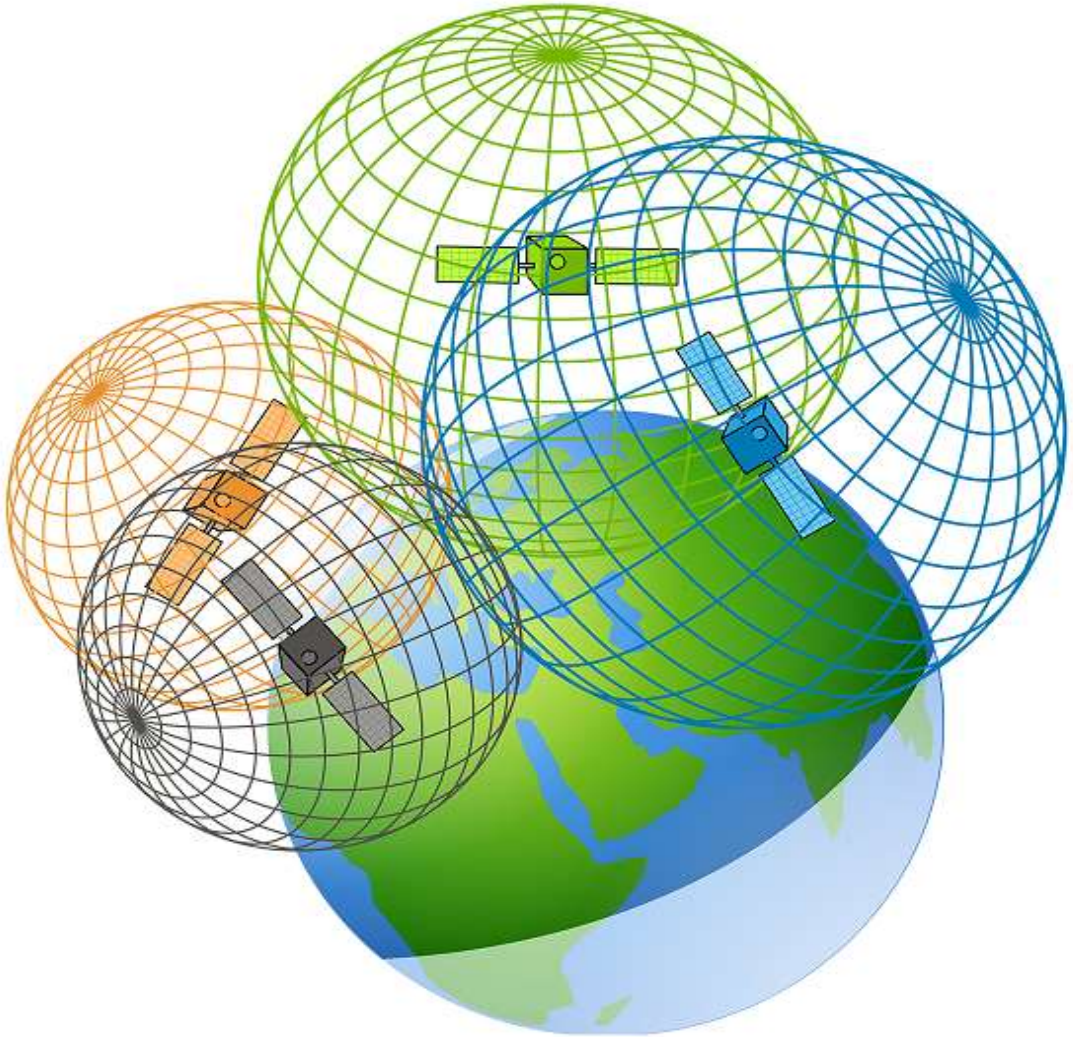


Global Localization

- The four main GNSSs are:
  - GPS (31 Satellites)
  - GLONASS (26 Satellites)
  - Galileo
  - BDS

- Different GNSSs differ in the way they generate time-aligned messages, and how their respective messages are being encoded and transmitted.
- The messages of different GNSSs can be combined suggesting a resolution in the centimeter range
- GPS receivers have become cheap commodities.

Indoor Localization

- Received Signal Strength Indication (RSSI) as a metric
- RSSI values can vary significantly between even nearby positions
- Depending on the number of base stations, the resolution of RSSI-based solution is
  - 2m to 5m for WiFi
  - sub-1m range for Bluetooth

- Fingerprinting
  - We can establish a database of RSSI value sets for each position and use the measured RSSI values for a quick lookup.
  - Resolution better than 1m

Indoor Localization

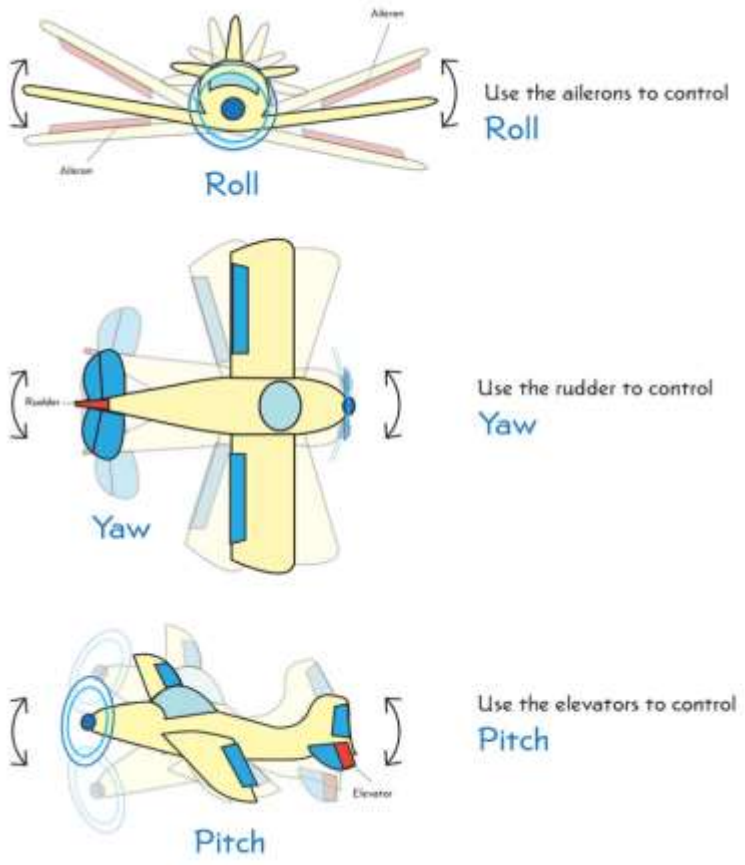
- Specialized WiFi and Bluetooth devices, it is possible to determine the time-of-flight differences that the signal requires between a point of interest and several base stations.
- Base stations with antenna arrays (minimally three; in practice up to eight) can determine the angle-of-arrival.
- Eddystone By Google
- iBeacon By Apple
- kontakt.io

PHYSICAL TRIGGERS

- Physical triggers are those that are based on the fundamental gravitational and electromagnetic forces: kinetic force, light and sound, temperature, and current.
- **Motion** is the positional change of an object.
- **Acceleration** is the change of displacement of an object over time.

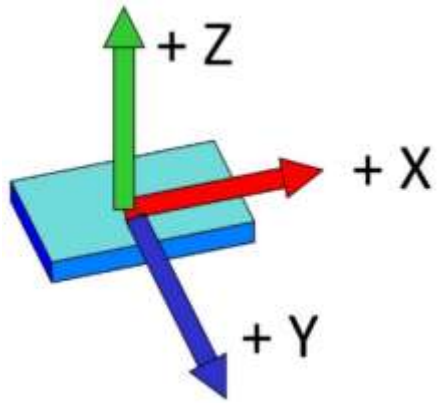
Motion of an object

- **Translation** (Δ)
  - Up or down
  - Left or right
  - Forward and backward
- **Rotation** (θ, relative to the forward/backward axis
  - **Pitch** (up or down)
  - **Roll** (left or right)
  - **Yaw** (rotating the forward/backward axis)



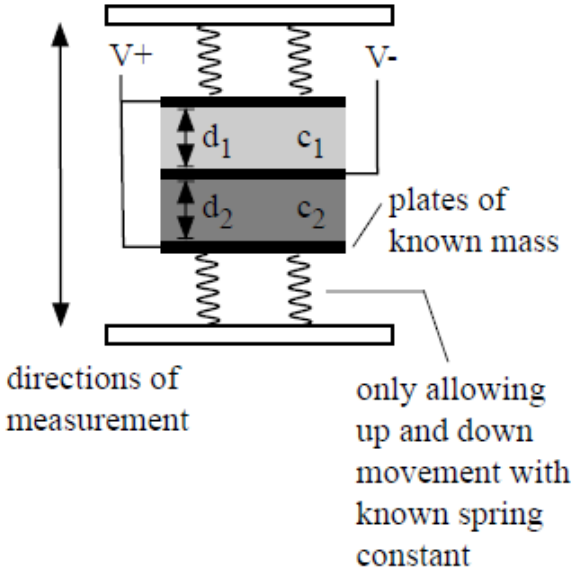
Accelerometer

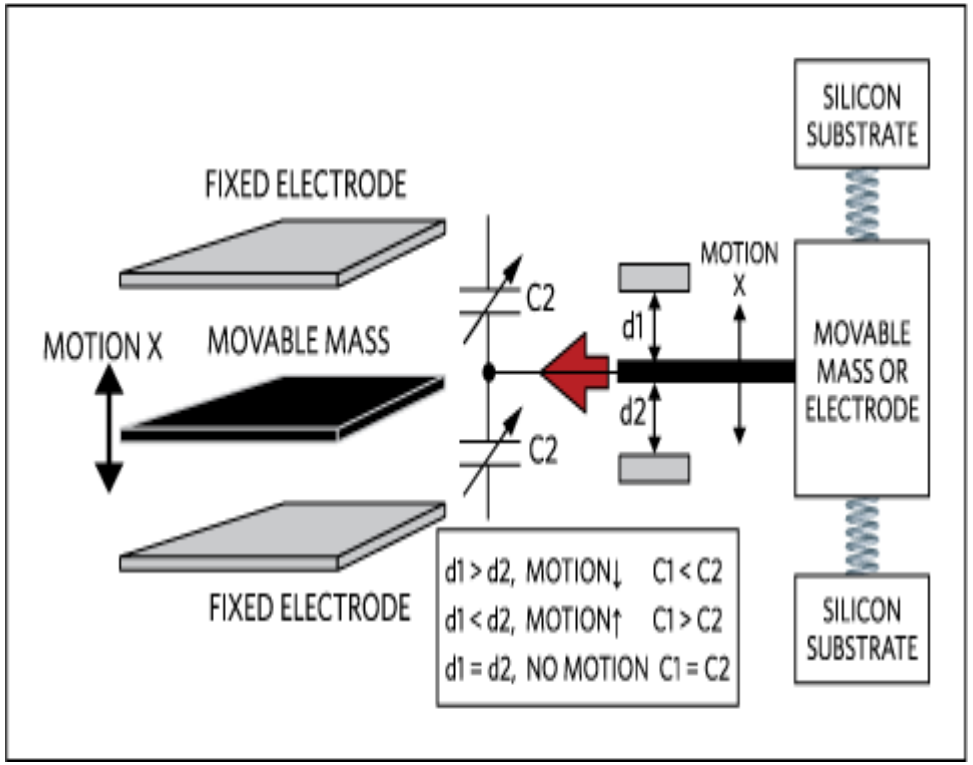
- An accelerometer determines motion in one direction



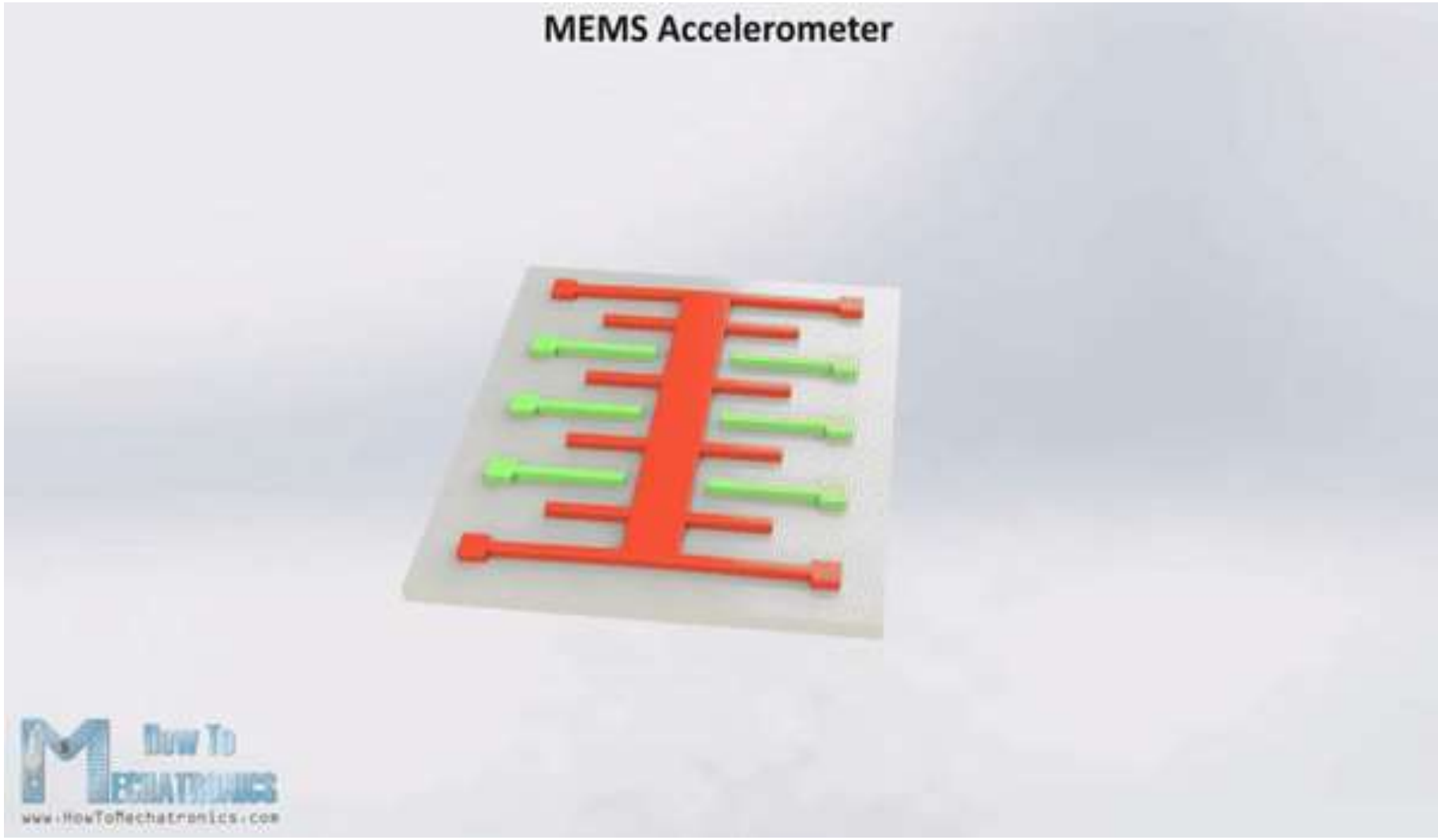
$$C = \varepsilon_0 \frac{A}{d}$$

$$\varepsilon_0 = 8.84 \times 10^{-12}$$





Accelerometer



Gyroscope

- The gyroscope is a device that is used for navigation and measuring angular velocity.

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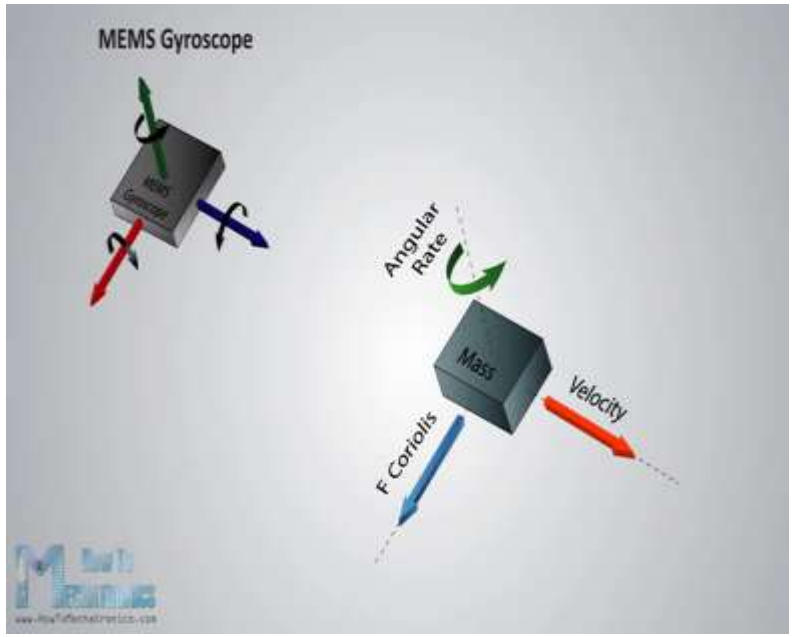
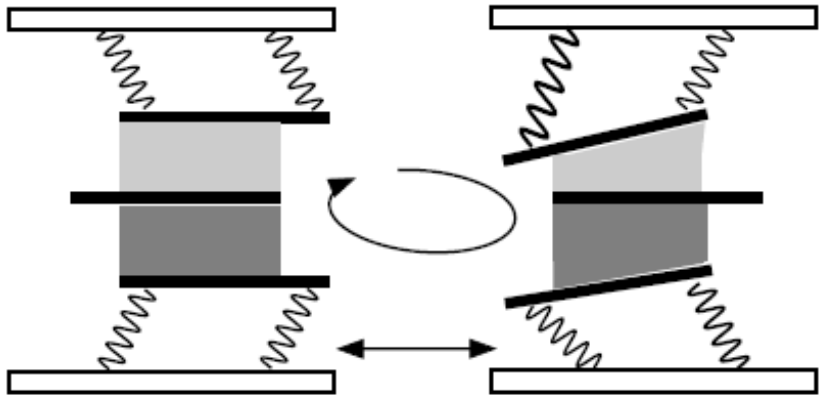
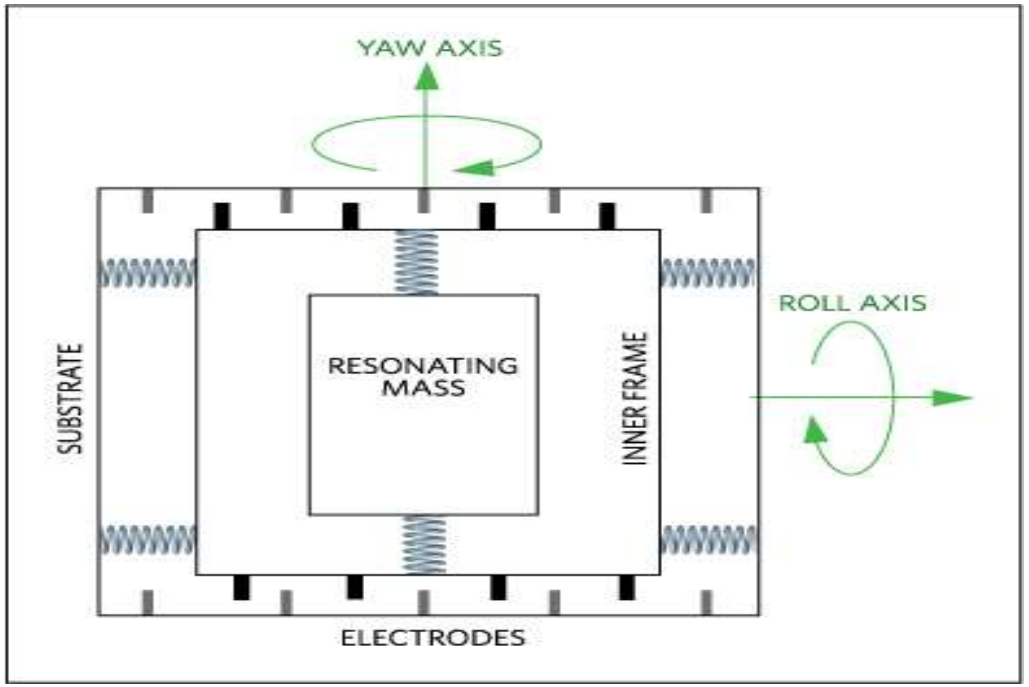
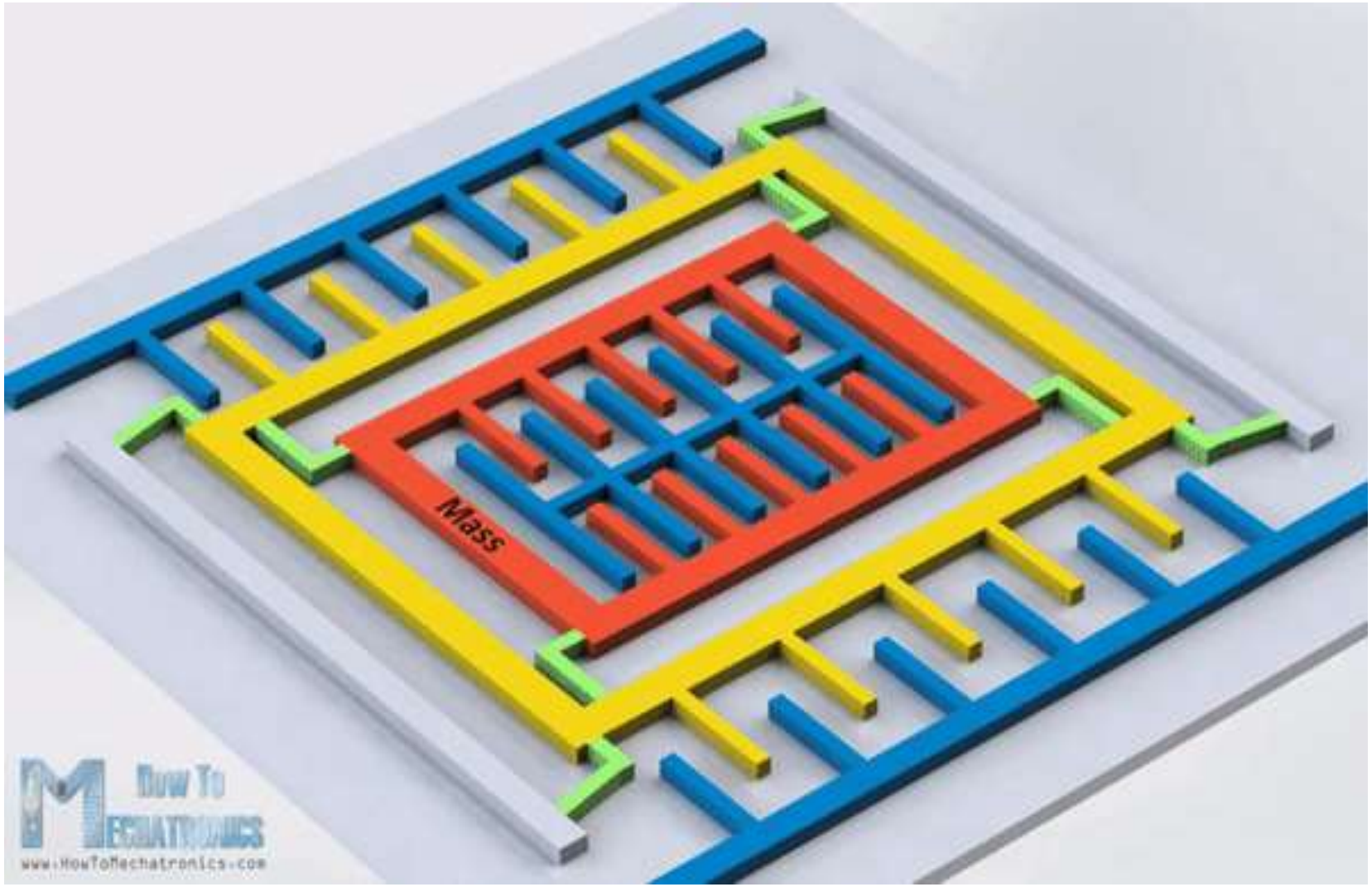




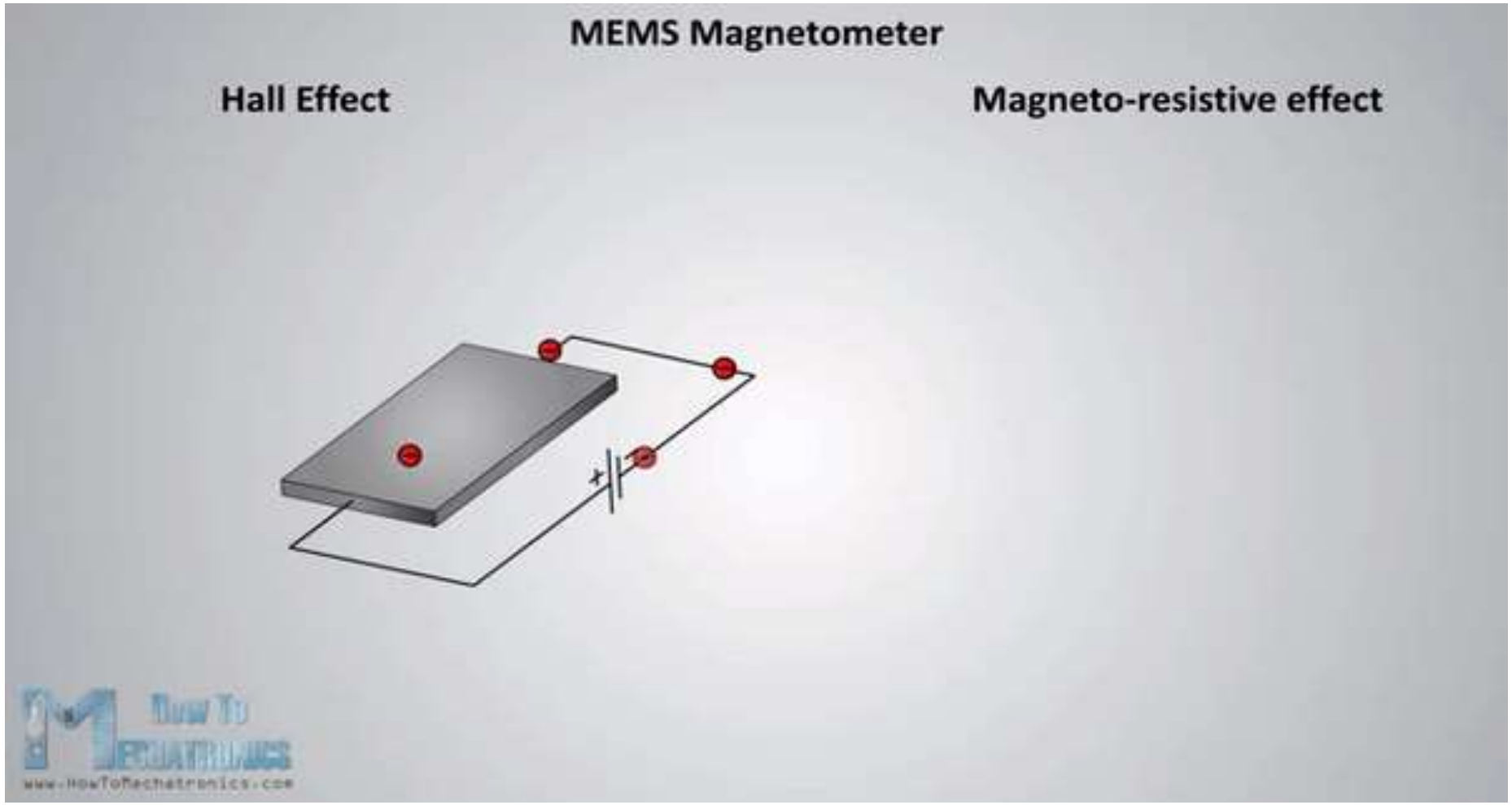
plates oscillate horizontally - angular disturbance produces different c_1/c_2 ratios



Gyroscope



Magnetometer



Light Sensor

- Visible light and near UV and infrared can be detected with a variety of simple electric components.
- Photoresistors on the basis of cadmium/sulfur (CdS) as well as lead/sulfur (PbS) see widespread use as light detectors.
- Both CdS and PbS-based components are not Restriction of Hazardous Substances Directive (RoHS)-compliant.
- To measure light quantitatively, both the overall intensity as well as the spectral intensity, differing over the frequency, is relevant.
- Most digital luminosity sensors are based on photo diode/amplifier/DAC integration.
- Color sensors are devices that follow the principle of luminosity sensors, but utilize filters to obtain different readings for red, green and blue

Temperature

- Temperature is the energy lost through the motion of particles.
- *Bandgap Temperature Sensor*
  - The forward voltage of a silicon diode is temperature-dependent
  - The increase in temperature gives rise to more charge carriers in a semiconductive polymer
  - A silicon diode is temperature-dependent

Temperature

- Temperature-dependent resistor (thermistor)
  - Thermistors are resistors that either see a decrease of resistance (negative temperature coefficient [NTC]) or an increase of resistance (positive temperature coefficient [PTC]) with rising temperature.
  - Both NTCs and PTCs show nonlinear behavior.
  - The Steinhart-Hart equation: $1/T=a+b.Ln(R)+c.Ln(R)^3$
  - NTCs are commonly used for measurement applications
  - PTCs more often see applications where a cutoff of electricity is beneficial above a certain temperature threshold.
  - are preferred over RTDs in the temperature range of -90 ^{C} to +130^C for their greater precision.

Temperature

- Resistance temperature detectors (RTDs)
  - RTDs utilize coils of elementary metal wire wrapped around a nonconductive core (coil-element) or meandering on a nonconductive surface (thin-film).

- As the material-specific conductivity is known per mass/volume and temperature, the resistance provides a good approximation of temperature

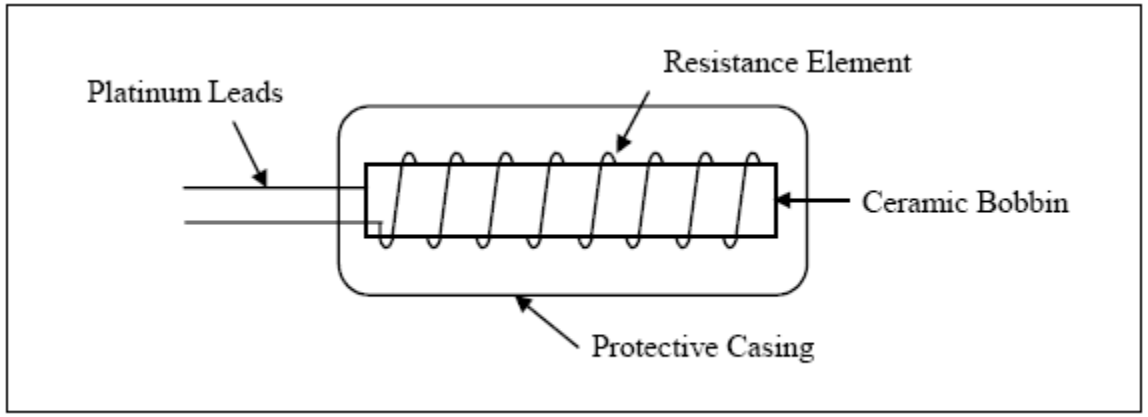
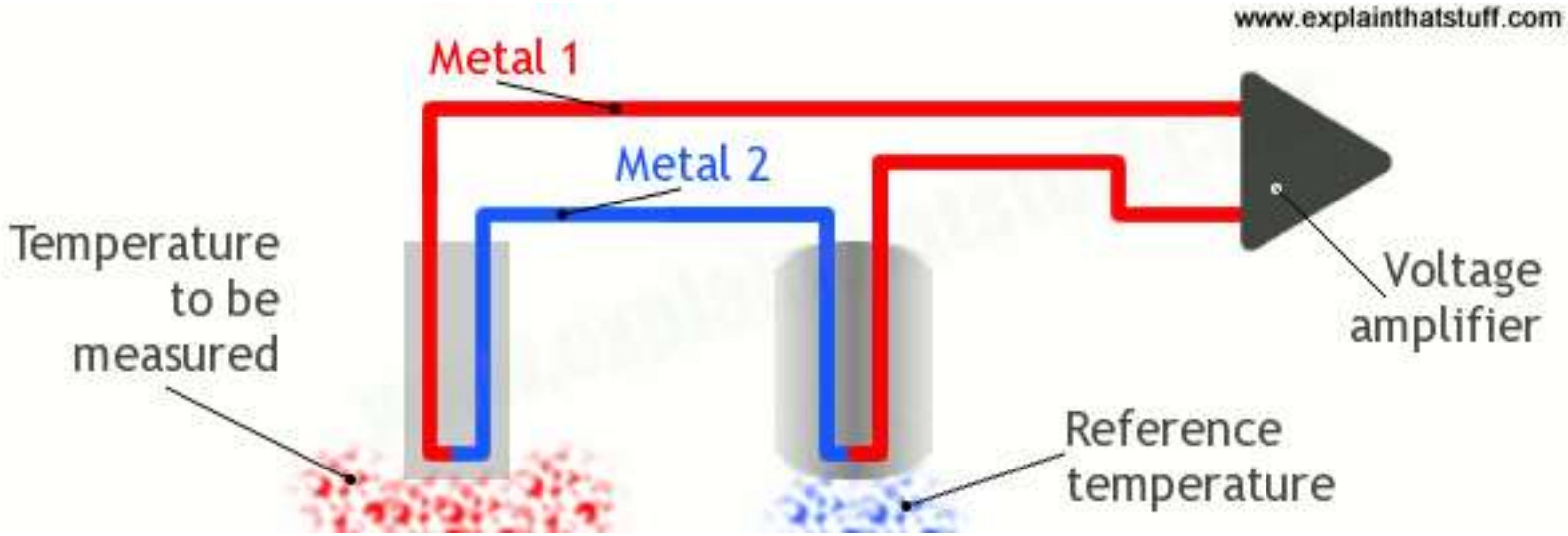


Figure 7-14. Typical RTD – resistance temperature detectors

Temperature

- Thermocouple
  - The Seebeck effect describes the electric potential difference that can be observed when two conductors of different material and different temperature are connected.
- Thermocouples keep part of the instrument at room temperature (reference temperature), and expose the other part of the instrument to the temperature that is to be measured.



CHEMICAL TRIGGERS

- Chemical sensors as those that recognize the presence of compounds (e.g., dust or smoke) and/or determine or quantitate their composition (e.g., the amount of nitric oxide in air).
- There are more than 100 million substances chemically their identification is sometimes trivial in the laboratory, there are massive constraints to our ability to detect and measure them electronically.
- An indirect proof for the presence of a particular substance
- Chemical sensors that are straightforward to use with conventional microcontrollers

Humidity

- Humidity describes the amount of water vapor in air, or the amount of water stored in soil.
- Capacitative sensors
  - Use a hygroscopic dielectric substance that mediates the flow of current between the two plates depending on the amount of water that is absorbed from the environment.
  - The change in the properties of the capacitor can be directly correlated with relative humidity, typically in the order of 0.2 pF to 0.5 pF per 1% relative humidity.
- Resistive sensors
  - Voltage required to establish a current between two probes separated by a gap with hygroscopic substance is being measured.
- More recently, frequency domain (FD), time domain transmission (TDT) and time domain reflectometry (TDR) sensors have seen applications in agriculture.
- TDT and TDR are based on the penetration of soil with electromagnetic waves.

pH and Other Ion-Specific Indicators

- The concentration of hydrogen-ions (H^+) determines the acidity or alkalinity of a solution.
- Measuring [H^+] is based on the potential difference determined with a standard hydrogen electrode (SHE).
- The SHE is a platinum electrode that mediates the redox reaction:

$$2\,H^+_{(solution)} + 2\,e^- \longrightarrow H_{2(gas)}$$

- The number of electrons that can be turned over in this reaction is directly dependent on the concentration of H^+ ions in the solution.

Sensor Modules Samples