IFA511 Komunikasi Antar Perangkat
(Internet of Things - IoT)
Lecture 5

Sensing

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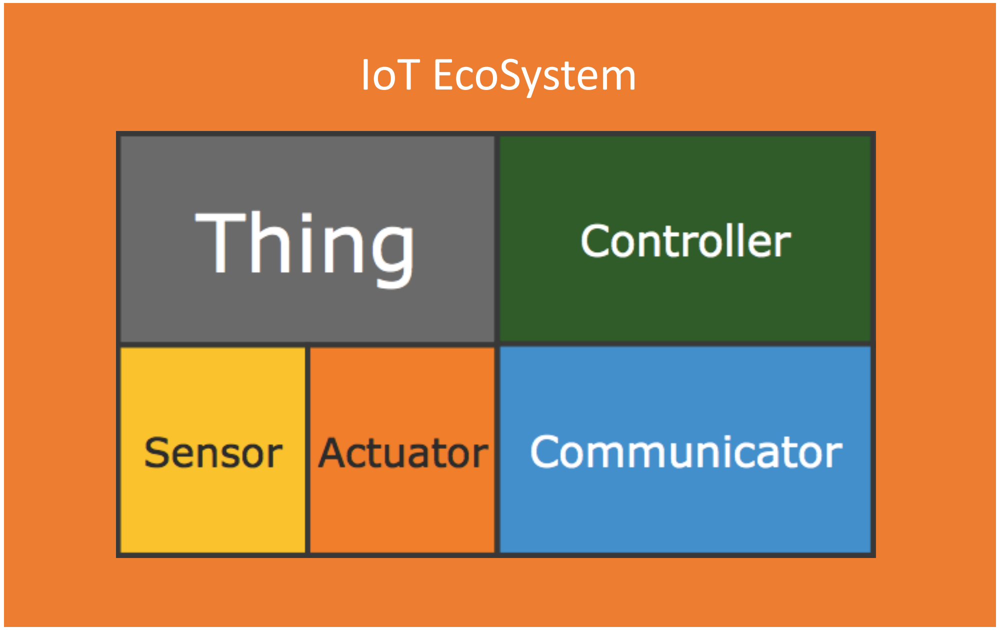
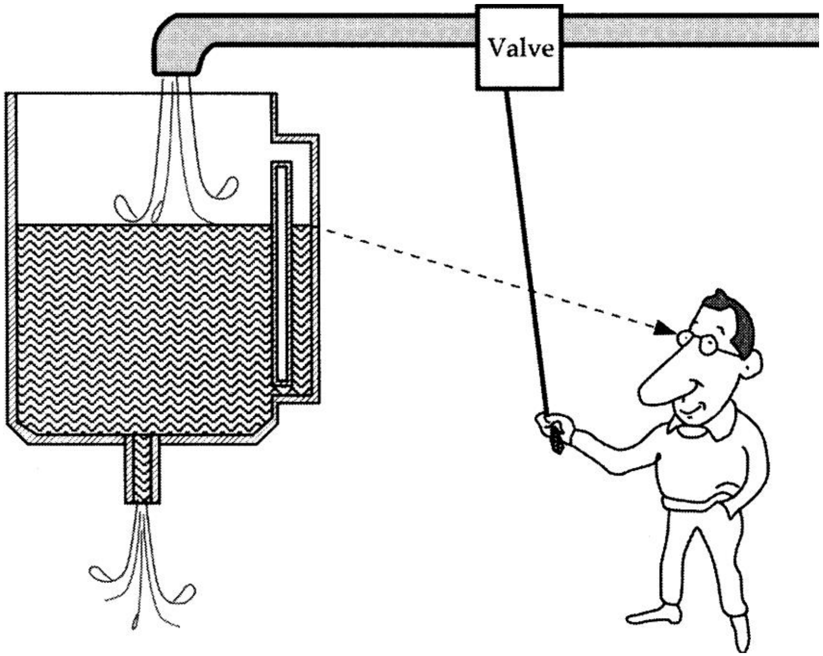
Components of an IoT Device

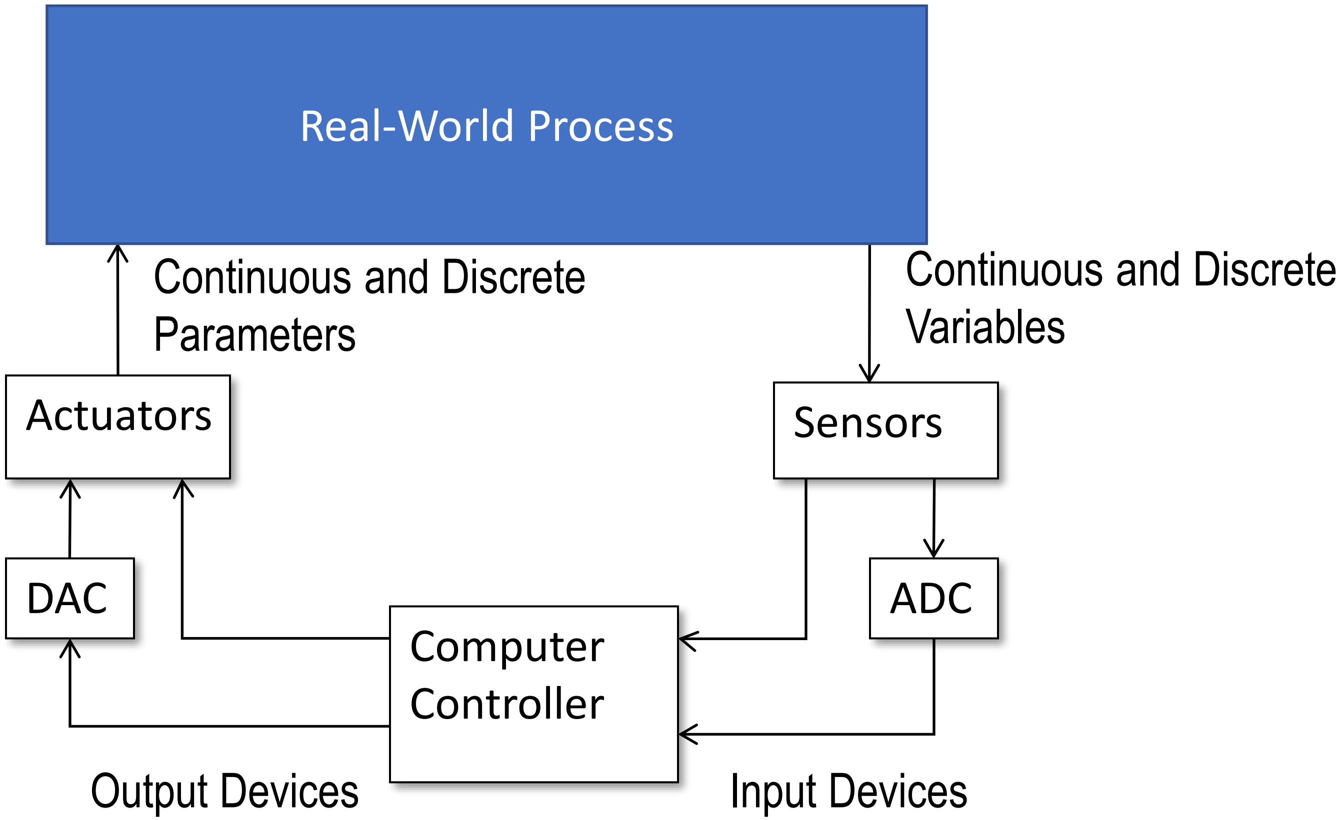


Sensors

- A sensor is a device that receives a stimulus and responds with an electrical signal.



Computer Process Control System

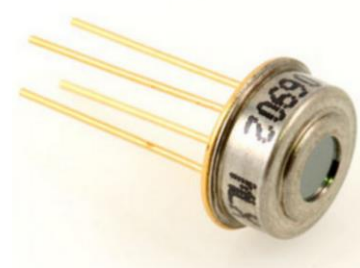


What is a Stimulus?

- Motion, position, displacement
- Velocity and acceleration
- Force, strain
- Pressure
- Flow
- Sound
- Moisture
- Light
- Radiation
- Temperature
- Chemical presence

Visual Sensor

Ultrasound Sensor



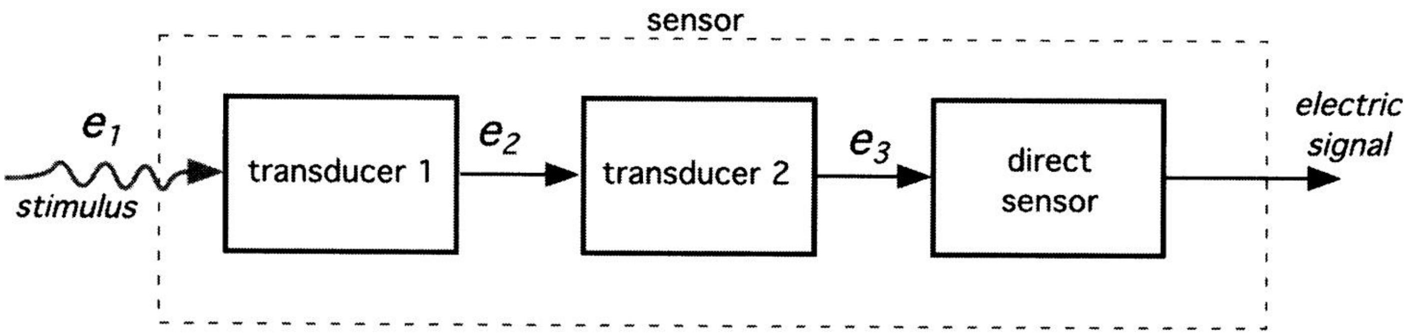
Infrared Sensor

What is a Response?

- When we say electrical we mean a signal which can be channeled, amplified, and modified by electronic devices:
  - **Voltage**
  - **Current**
  - **Charge**

Sensor as Energy Converter

- This conversion can be direct or it may require transducers



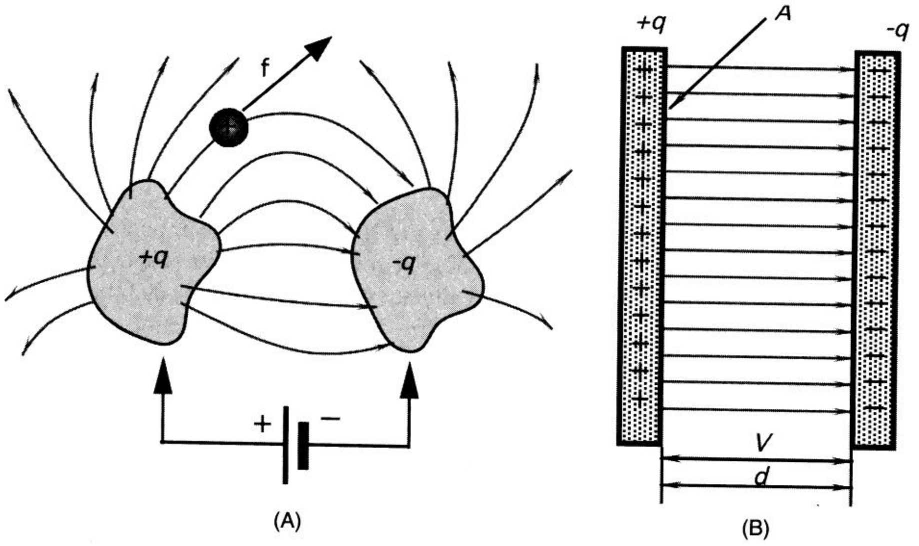
- Example:
  - A chemical sensor may have a part which converts the energy of a chemical reaction into heat (transducer) and another part, a thermopile, which converts heat into an electrical signal

Physical Principles of Sensing

- Charges, fields, & potentials
- Capacitance
- Magnetism
- Induction
- Resistance
- Piezoelectric effect
- Seebeck and Peltier effects
- Thermal properties of materials
- Heat transfer
- Light

Capacitance

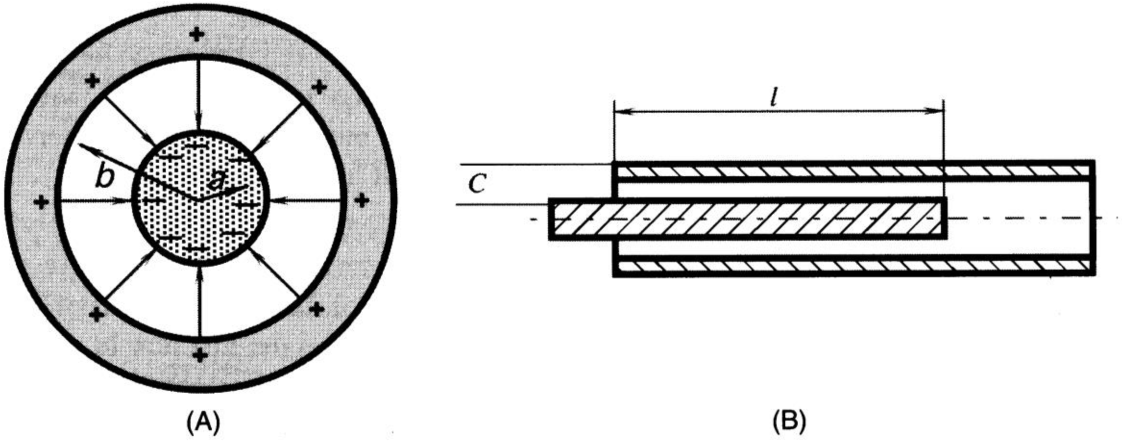
- Two isolated conductive objects of arbitrary shape, which can hold an electric charge, are called a capacitor
  - An electric field is developed between the two conductors



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

Capacitor as Displacement Sensor

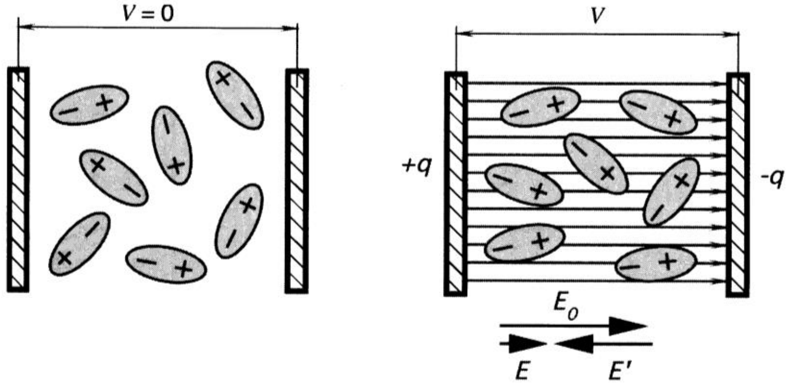
- If the inner conductor can be moved in and out, the measured capacitance will be a function of *l*



$$C = \frac{2\pi\varepsilon_0 l}{\ln(b/a)}$$

Dielectric Constant

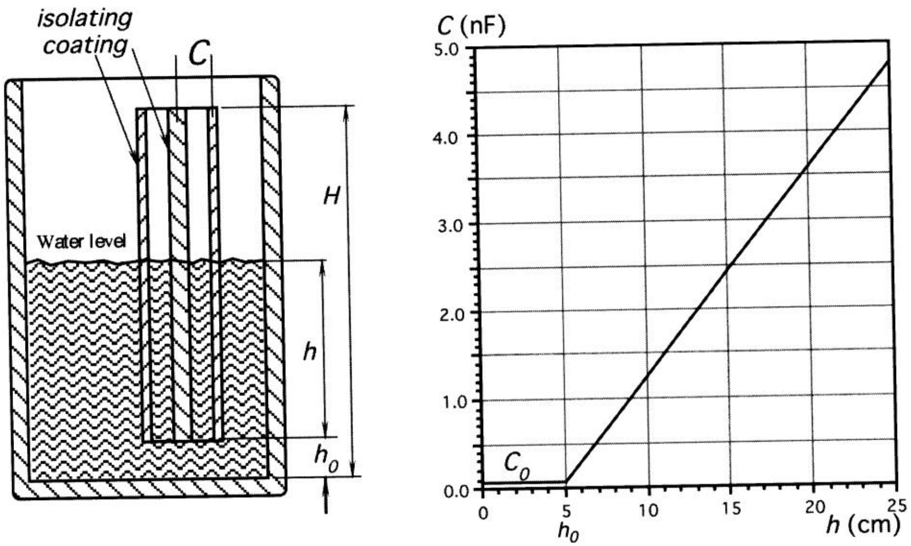
- The material between the plates of the capacitor can also be used to sense changes in the environment.
  - When vacuum (or air) is replaced by another material, the capacitance increases by a factor of κ, known as the dielectric constant of the material
  - The increase in C is due to the polarization of the molecules of the material used as an insulator



$$C = \kappa \frac{q}{V} = \frac{\kappa \varepsilon_0 A}{d}$$

Example – A Water Level Sensor

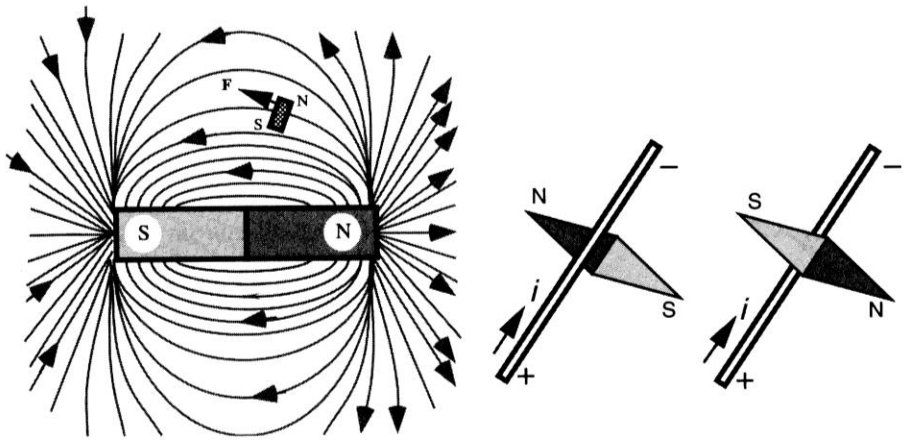
- The total capacitance of the coaxial sensor shown below is the capacitance of the water-free portion plus the capacitance of the water-filled portion; as the level of the water changes, the total capacitance changes



Magnetism

- There are two methods of generating a magnetic field:
  - permanent magnets (magnetic materials)
  - magnetic field generated by a current

Force is generated on a test magnet in the field of magnetic materials.



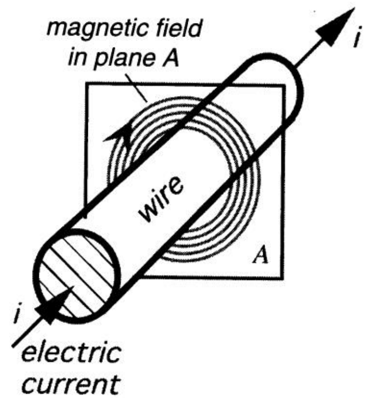
(A) (B)

A compass needle will respond to the magnetic field generated by a current.

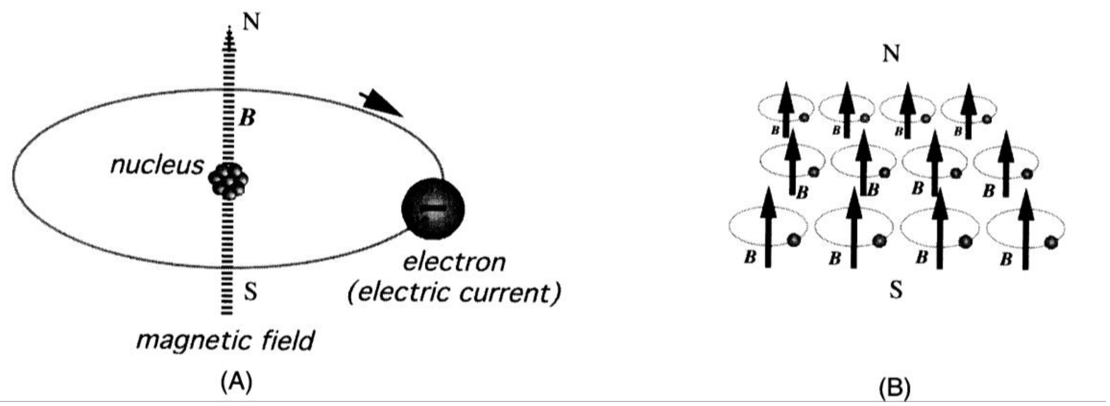
Magnetic field, **B**

“flux” is the field density, Φ_B

Sources of Magnetic Fields



Electric current sets a circular magnetic field around a conductor.

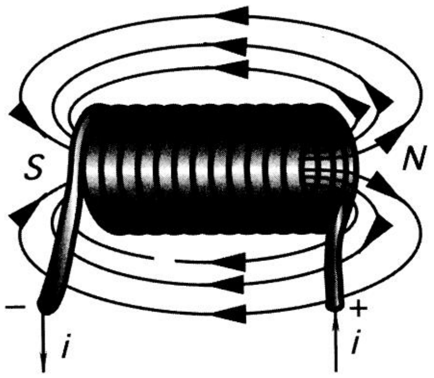


Moving electron sets a field, superposition of field vectors results in a combined magnetic field of a permanent magnet.

Magnets are useful for fabricating magnetic sensors for the detection of motion, displacement, and position.

Induction

- A phenomenon related to magnetism is induction, the generation of voltage from a *changing* magnetic field
  - If the coil has no magnetic core, the flux is proportional to current and the voltage proportional to *di/dt*

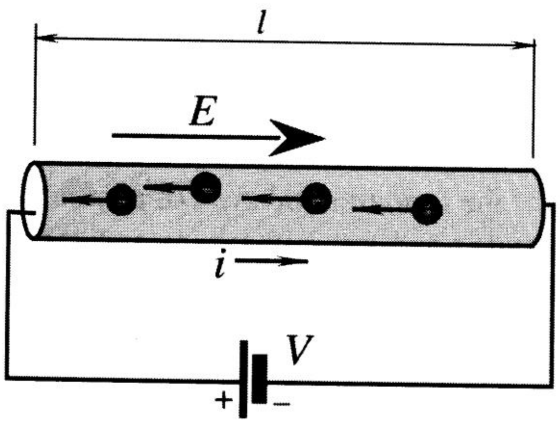


(A)

$$v = -\frac{d\left(n\Phi_B\right)}{dt} = -\frac{dLi}{dt} = -L\frac{di}{dt}$$

Resistance

- If we apply a battery across two points of a piece of material, an electric field will be set up where *E=V/l*



$$R = \frac{V}{i}$$

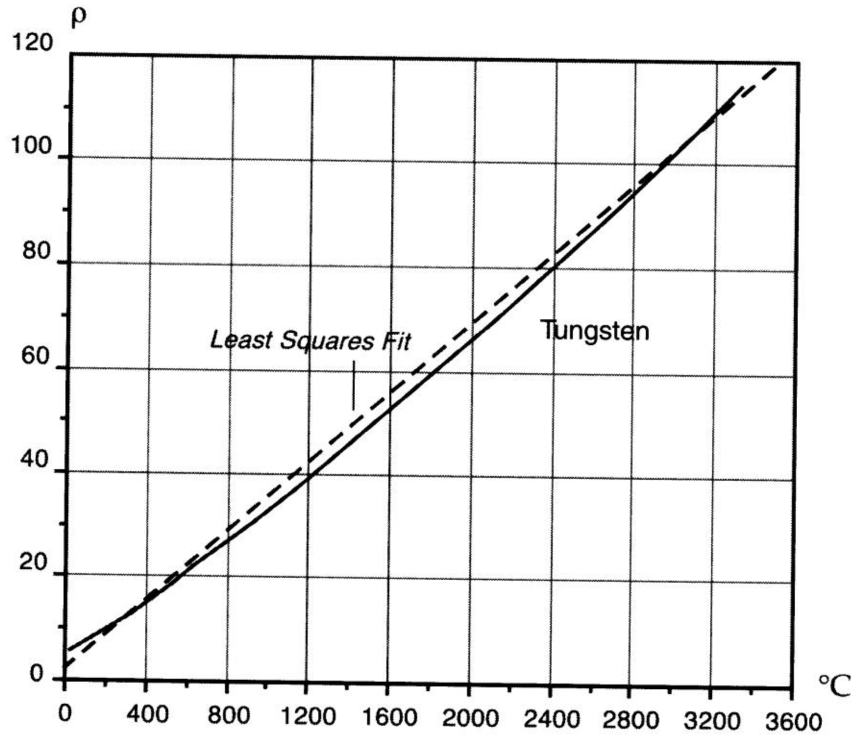
$$\rho = \frac{E}{j} = \frac{V}{l} \cdot \frac{1}{(i/a)} = \frac{Va}{li}$$

$$R = \frac{Va}{il} \cdot \frac{l}{a} = \rho \frac{l}{a}$$

The tendency of the material to resist the flow of electrons is called its <u>resistivity</u>, ρ, and we say that the material has a particular electrical <u>resistance</u>, *R*.

Sensitivity of Resistance

- To Temperature:



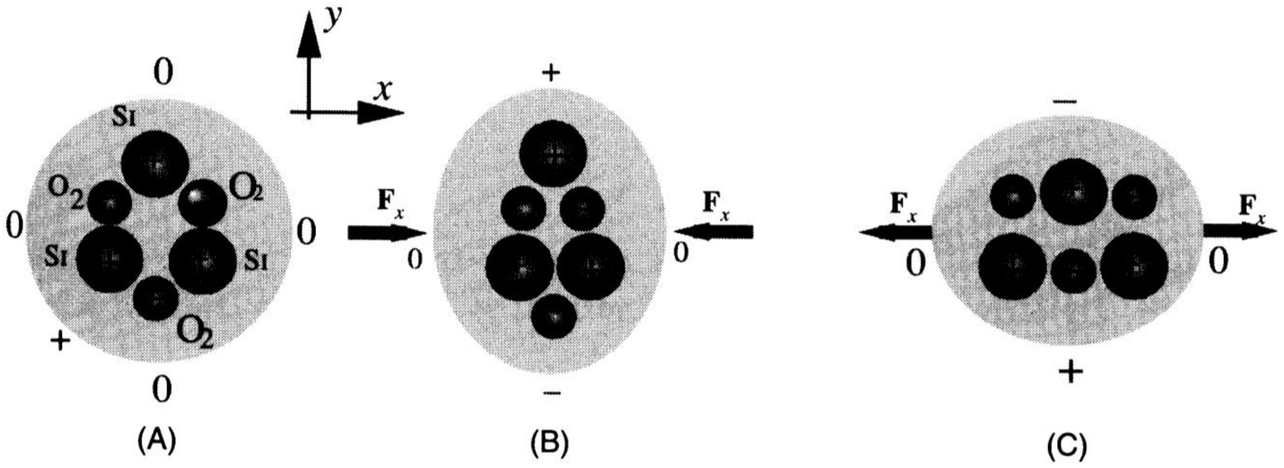
Specific resistivity of tungsten as a function of temperature.

$$\rho = \rho_0\left[1 + \alpha\left(t - t_0\right)\right]$$

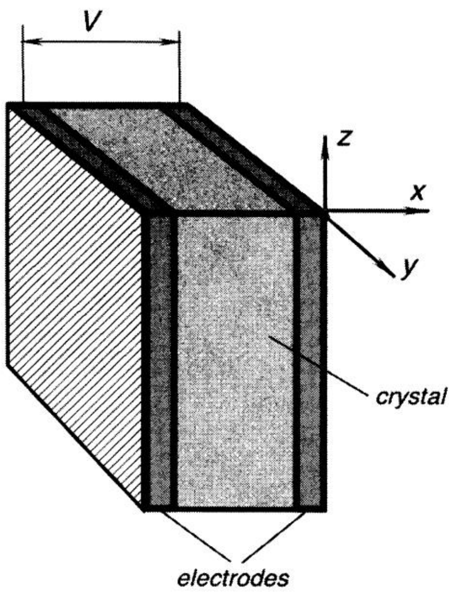
α is the temperature coefficient of resistivity.

The Piezoelectric Effect

- The piezoelectric effect is the generation of electric charge by a crystalline material upon subjecting it to stress



Piezoelectric Sensor

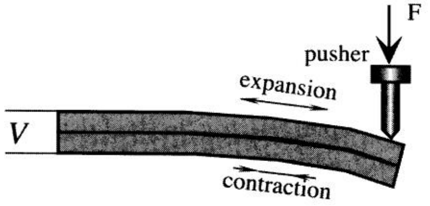


Piezoelectric crystals are direct converters of mechanical energy into electrical energy.

Because a crystal with deposited electrodes forms a capacitor the voltage developed can be expressed as:

$$V = \frac{Q_x}{C} = \frac{d_x}{C} F_x$$

Where d_x is the piezoelectric coefficient in the x direction and F_x is the applied force in the x direction.



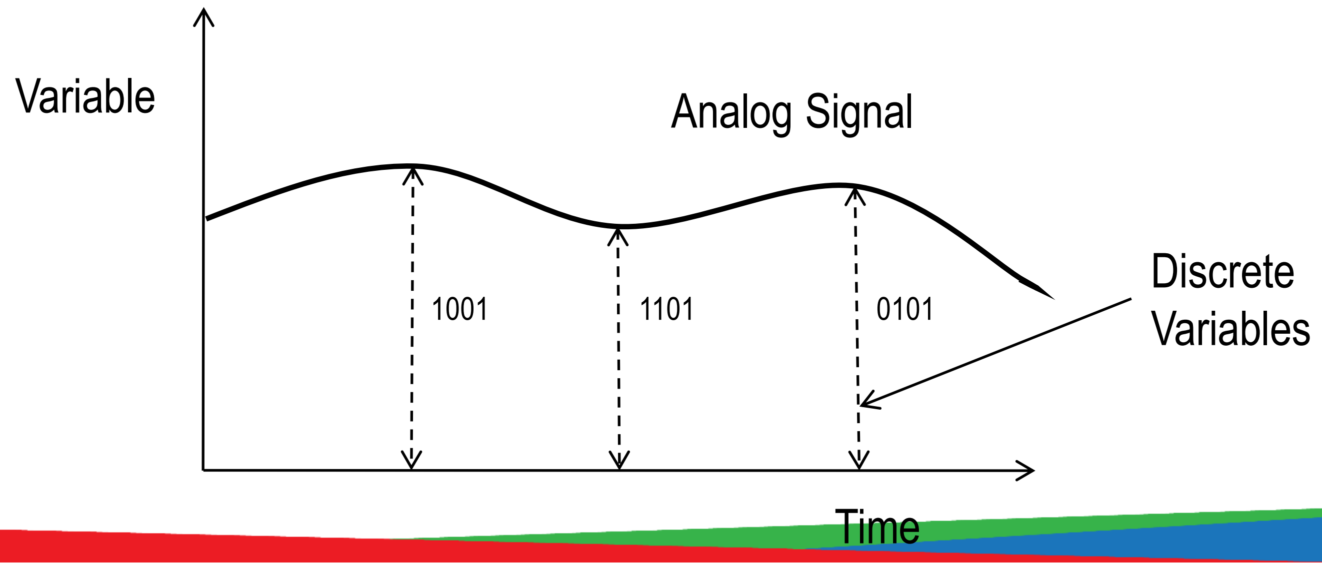
Laminated 2-layer piezoelectric sensor

Signal Conditioning

- Filter for expected frequency regime
- Subtract DC offset (“zeroing”)
- Amplify or attenuate signal (“scaling”)
- Linearize relationship between measured and observed electrical parameter
- Analog-to-Digital (and Digital-to-Analog) conversion

Analog-to-Digital Conversion

- **Sampling** – converts the continuous signal into a series of discrete analog signals at periodic intervals
- **Quantization** – each discrete analog is converted into one of a finite number of (previously defined) discrete amplitude levels
- **Encoding** – discrete amplitude levels are converted into digital code



Features of an ADC

- **Sampling rate** – rate at which continuous analog signal is polled (e.g., 1000 samples/sec)
- **Quantization** – divide analog signal into discrete levels
- **Resolution** – depends on number of quantization levels
- **Conversion time** – how long it takes to convert the sampled signal to digital code
- **Conversion method** – means by which analog signal is encoded into digital equivalent
  - Example: Successive approximation method

Successive Approximation Method

- A series of trial voltages are successively compared to the input signal whose value is unknown
- Number of trial voltages = number of bits used to encode the signal
- First trial voltage is 1/2 the full scale range of the ADC
- If the remainder of the input voltage exceeds the trial voltage, then a bit value of 1 is entered, if less than trial voltage then a bit value of zero is entered
- The successive bit values, multiplied by their respective trial voltages and added, becomes the encoded value of the input signal

Sensor Types: HW & SW

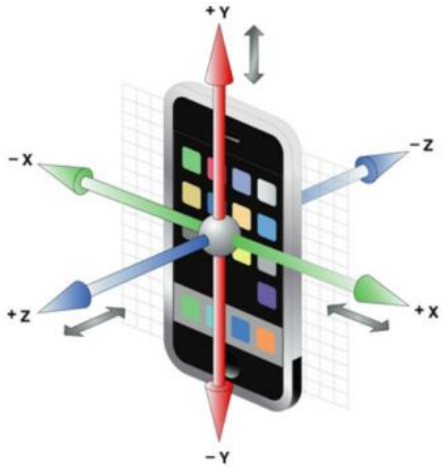
- **Hardware**-based sensors
  - Physical components built into a device
  - They derive their data by directly measuring specific environmental properties
- **Software**-based sensors
  - Not physical devices, although they mimic hardware-based sensors
  - They derive their data from one or more hardware-based sensors

Sensor List of Smartphones

Sensor	Function Type	Software-based or Hardware-based
Accelerometer	Motion Sensor	Hardware-based
Gyroscope	Motion Sensor	Hardware-based
Gravity	Motion Sensor	Software-based
Rotation Vector	Motion Sensor	Software-based
Magnetic Field	Position Sensor	Hardware-based
Proximity	Position Sensor	Hardware-based
GPS	Position Sensor	Hardware-based
Orientation	Position Sensor	Software-based
Light	Environmental Sensor	Hardware-based
Thermometer	Environmental Sensor	Hardware-based
Barometer	Environmental Sensor	Hardware-based
Humidity	Environmental Sensor	Hardware-based

Sensor: Motion and Orientation

- Most of the sensors use the same **coordinate system**
- When a device's screen is facing the user
  - The X axis is horizontal and points to the right
  - The Y axis is vertical and points up
  - The Z axis pints toward outside of the screen face



Sensor: Accelerometer

- Measure proper acceleration (acceleration it experiences relative to free fall)
- Units: g

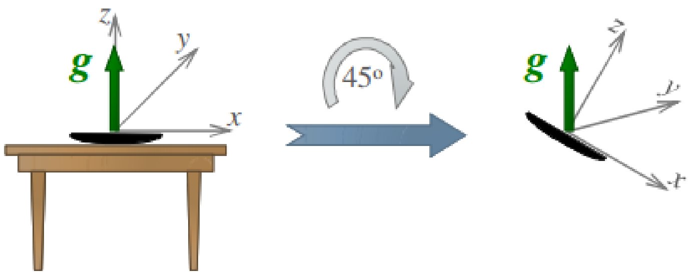
Example	G Force
Standing on earth at sea level	1g
Bugatti Veyron from 0 to 100 km/h (2.4s)	1.55g
Space Shuttle, maximum during launch and reentry	3g
Formula 1 car, peak lateral in turns	5-6g
Death or serious injury	50g
Shock capability of mechanical Omega watches	5000g

Sensor: Accelerometer

- Acceleration is measured on 3 axes
- Note that the force of gravity is always included in the measured acceleration
  - When the device is sitting on the table stationary, the accelerometer reads a magnitude of 1g
  - When the device is in free fall, the accelerometer reads a magnitude of 0g
- To measure the real acceleration of the device, the contribution of the force of gravity must be removed from the reading, for example, by calibration

Sensor: Accelerometer

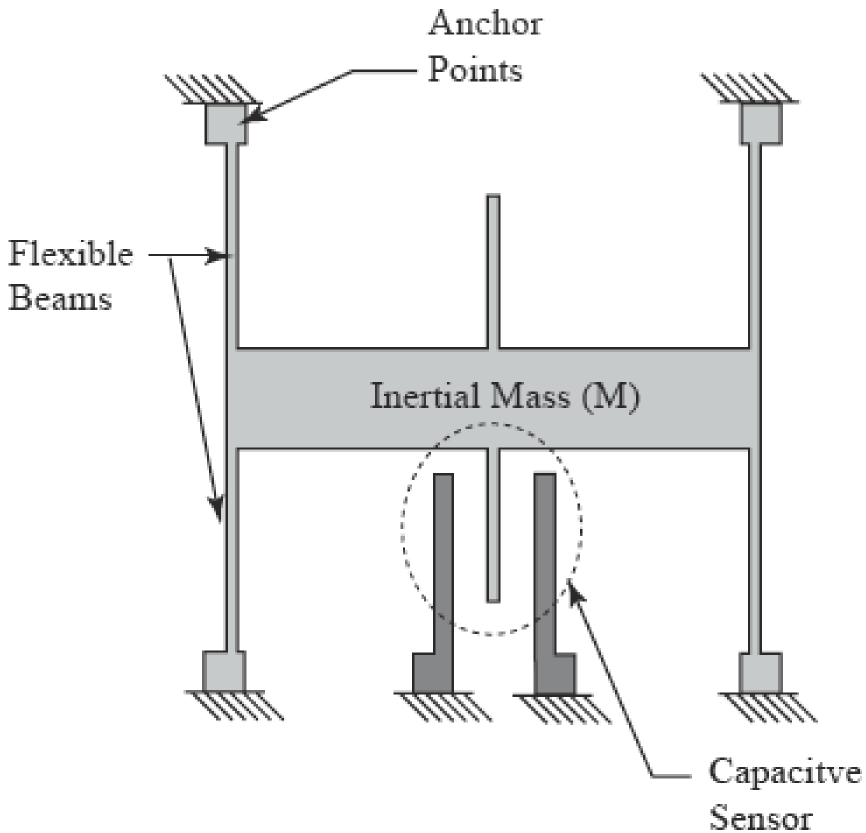
- When the device is lying flat
  - gives +1g (gravitational force) reading on Z axis
- Stationary device, after 45 degree rotation
  - Same magnitude, but rotated



$$a_x = a_y = 0$$
$$a_z = g$$

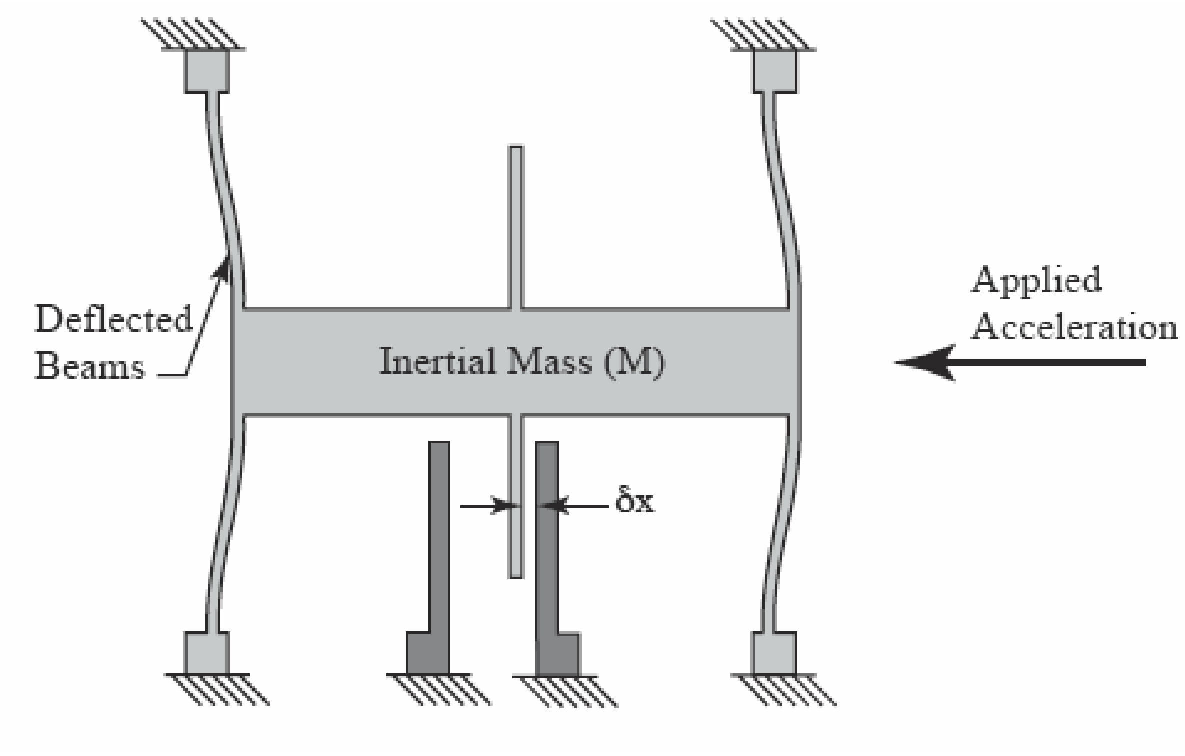
$$a_y = 0$$
$$a_z = -a_x = g/\sqrt{2}$$

Accelerometer: Inner Working (1 of 2)



It consists of beams and a capacitive sensor with some anchor points

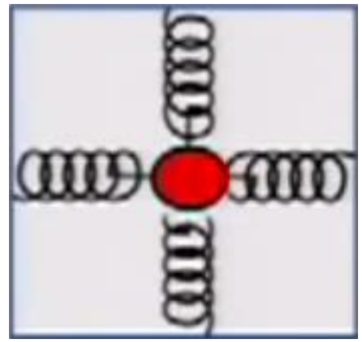
Accelerometer: Inner Working (1 of 2)

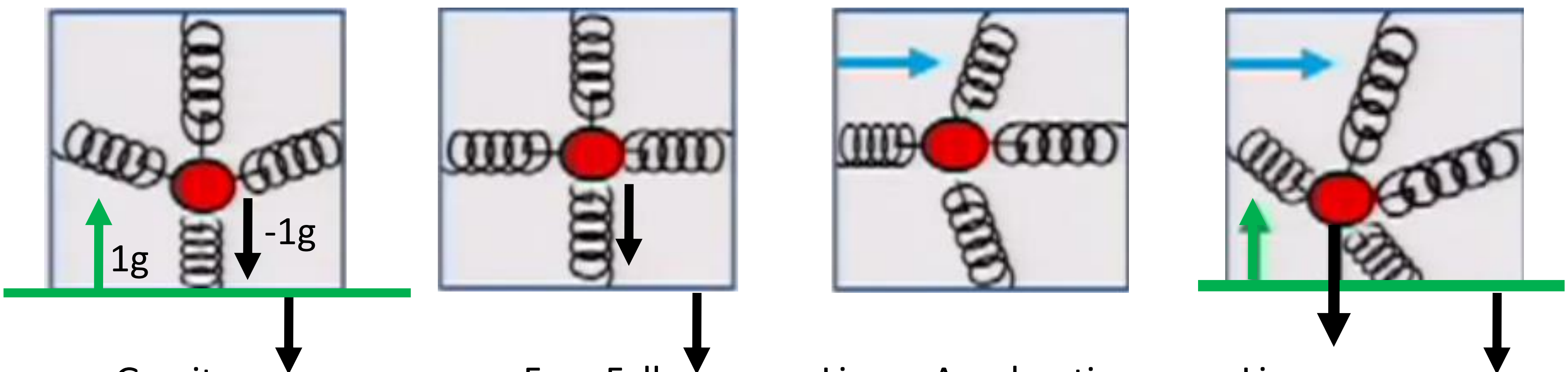


On applying the acceleration, the beams deflect and cause the change in capacitance.

Accelerometer

Mass on spring





Gravity

$1g = 9.8 m/s^2$

Free Fall

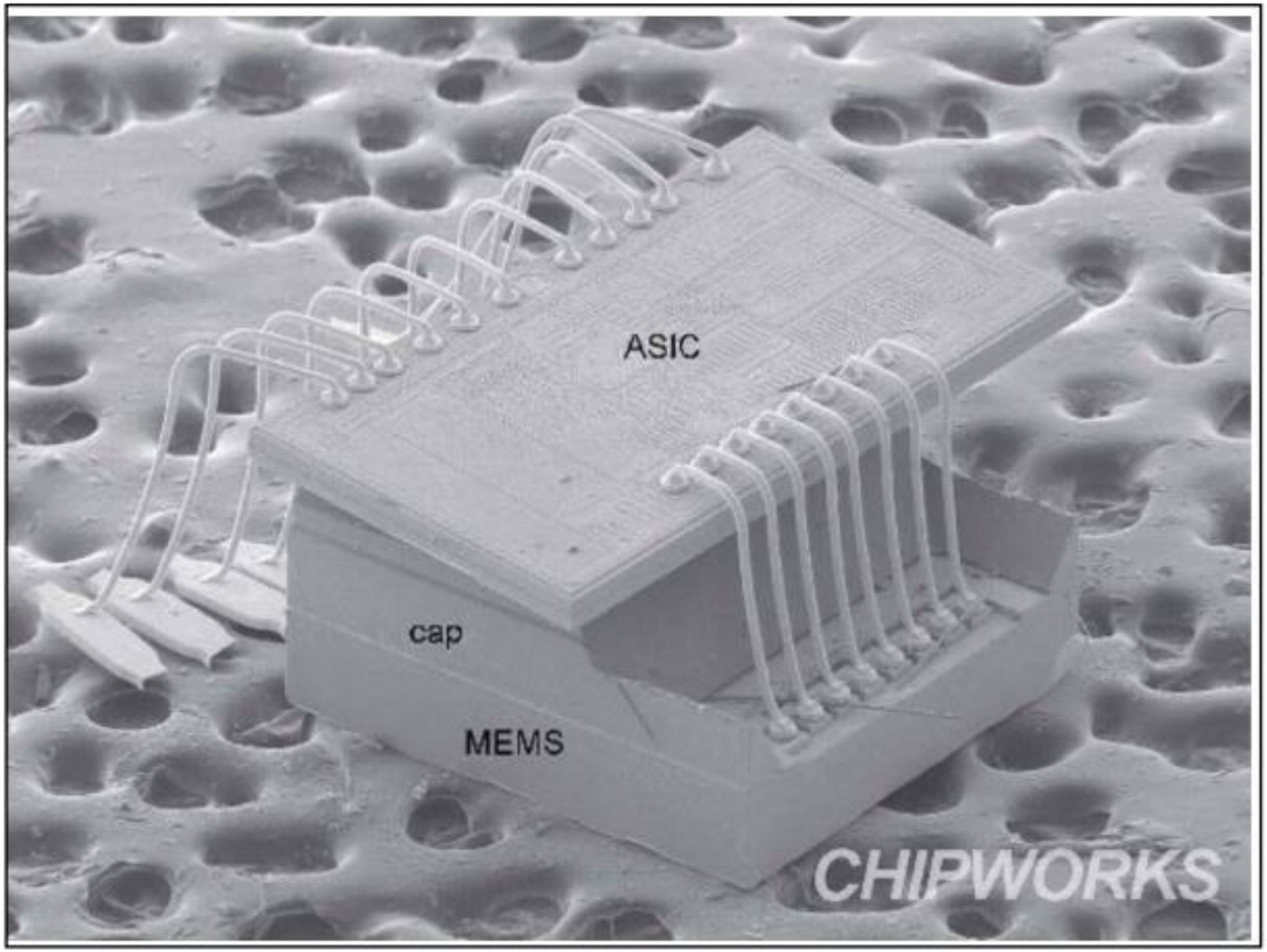
Linear Acceleration

Linear Acceleration plus gravity

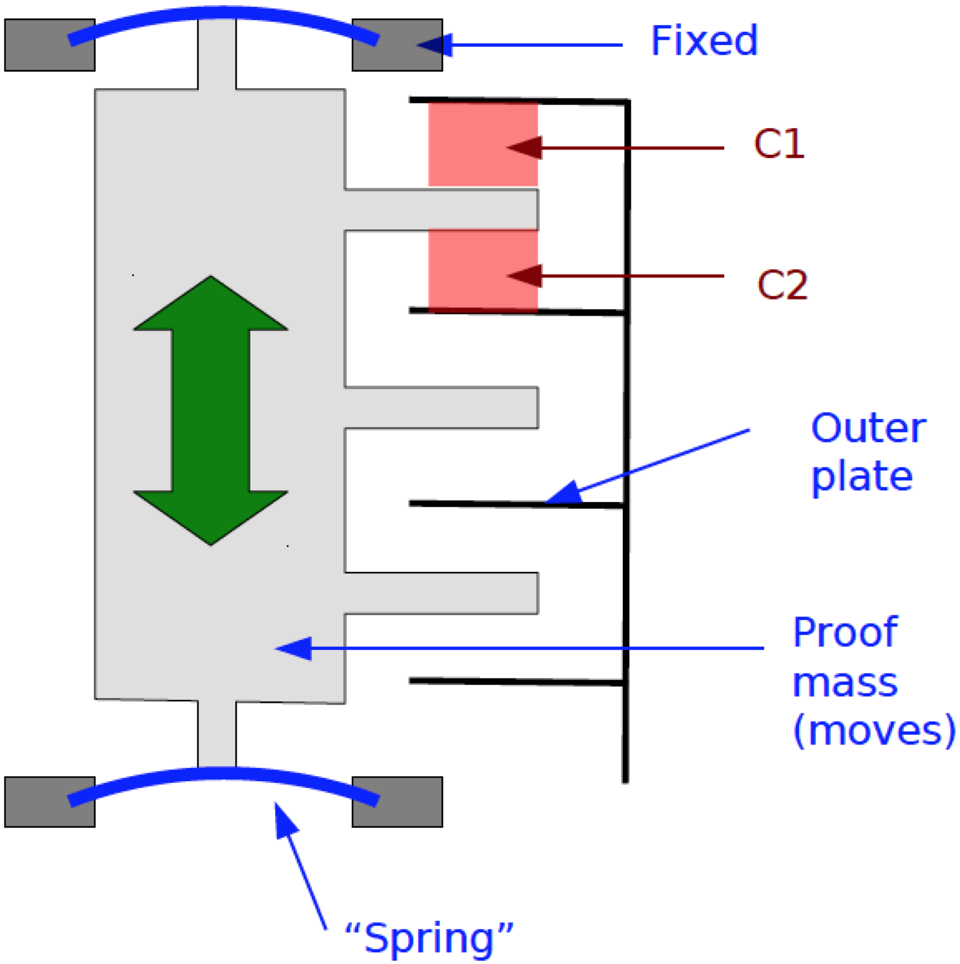
Smartphones: MEMS Sensors

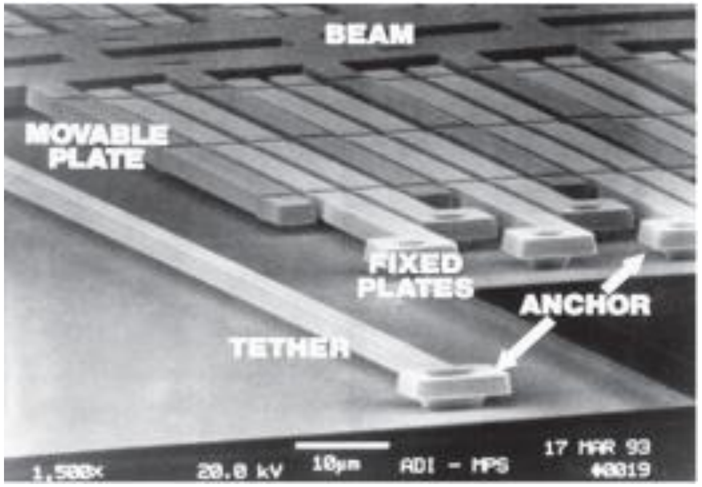
- Micro Electro-Mechanical Systems
- Term coined in 1989
- Describes creation of mechanical elements at a scale more usually reserved for microelectronics
- MEMS use cavities, channels, cantilevers, membranes, etc. to imitate traditional mechanical systems
- Small enough to be integrated with the electronics

MEMS Accelerometer



MEMS Accelerometer





- Have a proof mass between springs and a series of ‘plates’
- Measure deflection via capacitance changes
- 1-D only

Sensor: Gravity

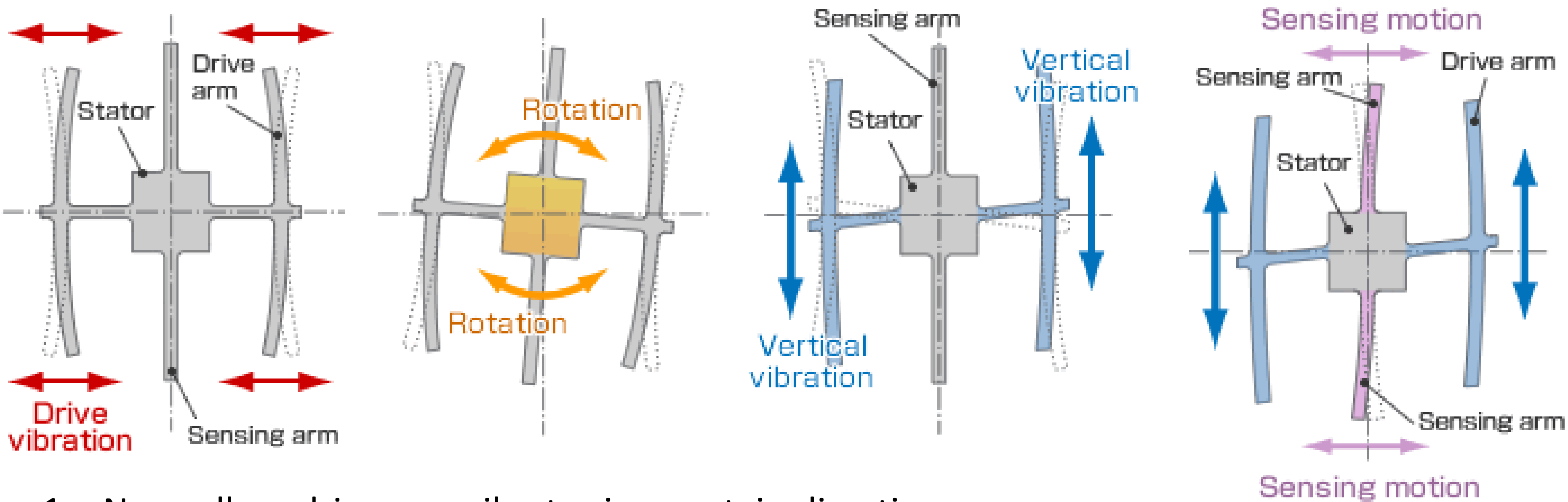
- Gravity sensor is not a separate hardware
- It is a virtual sensor based on the accelerometer
- It is the result when real acceleration component is removed from the reading

Sensor: Gyroscope

- Measures the rate of rotation (angular speed) around an axis
- Speed is expressed in rad/s on 3 axis
- When the device is not rotating, the sensor values will be zeros
- It gives us 3 values
  - Pitch value (rotation around X axis)
  - Roll value (rotation around Y axis)
  - Yaw value (rotation around Z axis)

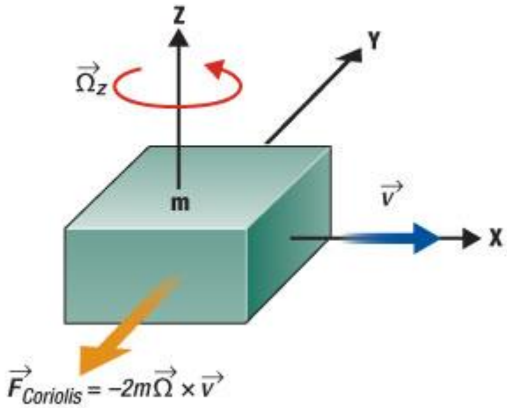
- Gyroscope is error prone over time
- As time goes, gyroscope introduces drift in result
- By sensor fusion (combining accelerometer and gyroscope), results can be corrected and path of movement of device can be obtained correctly

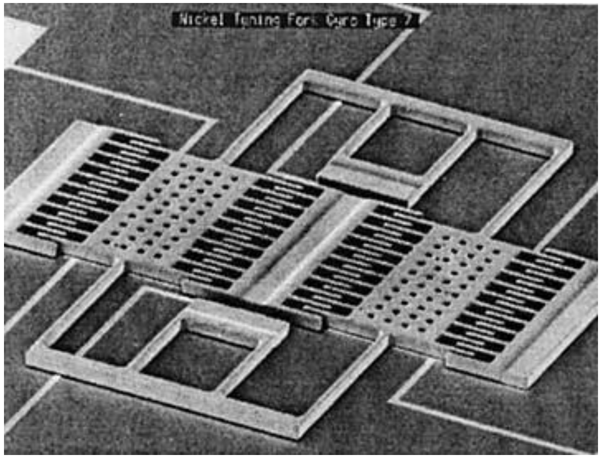
Gyroscope

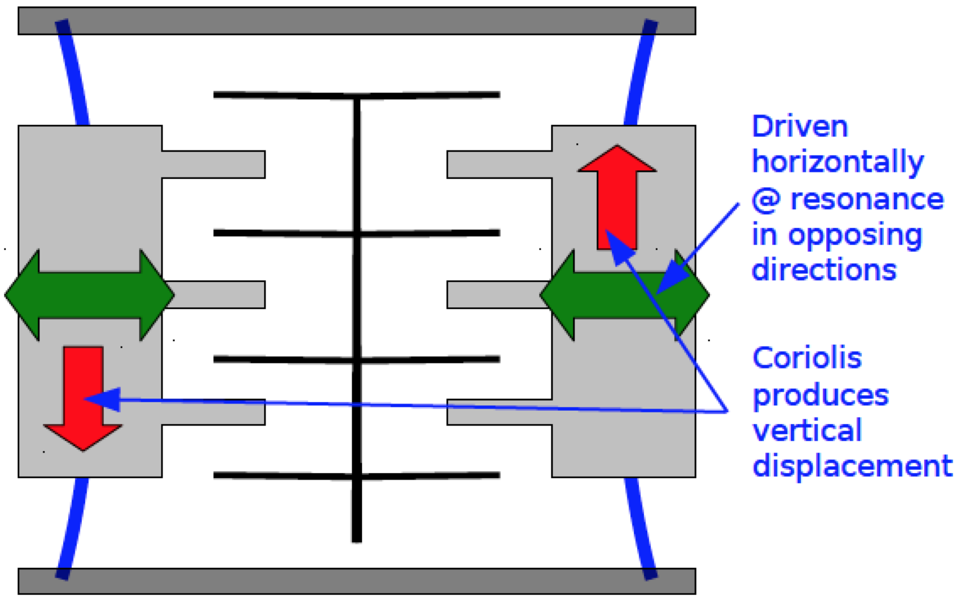


1. Normally, a drive arm vibrates in a certain direction.
2. Direction of rotation
3. When the gyro is rotated, the Coriolis force acts on the drive arms, producing vertical vibration.
4. The stationary part bends due to vertical drive arm vibration, producing a sensing motion in the sensing arms.
5. The motion of a pair of sensing arms produces a potential difference from which angular velocity is sensed. The angular velocity is converted to, and output as, an electrical signal.

MEMS Gyroscope







- Based on measuring Coriolis force as experienced by a moving object in a rotating frame of reference
- Many implementations, but the “tuning fork” method is most common

Accelerometer vs. Gyroscope

- Accelerometer
  - Senses linear movement: not good for rotations, good for tilt detection
  - Does not know difference between gravity and linear movement
- Gyroscope
  - Measures all types of rotations
  - Not movement
- A+G = both rotation and movement tracking possible

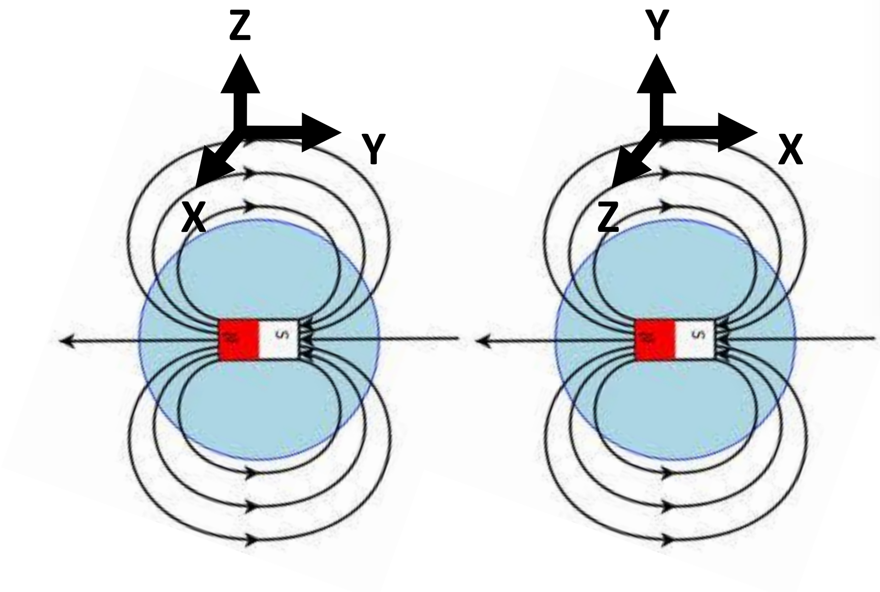
Sensor: Magnetic Field

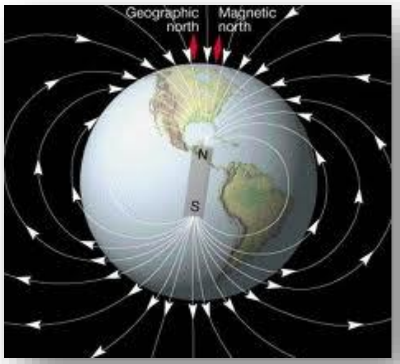
- Measures direction and strength of earth's magnetic field
- Strength is expressed in tesla (T)

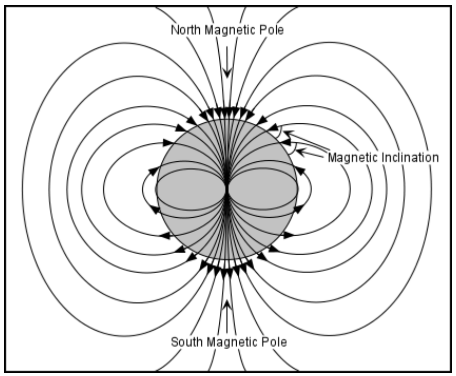
Example	Field strength
Earth's magnetic field on the equator (0° latitude)	31μT (0.00031T)
Typical fridge magnet	5mT (0.005T)
Strong neodymium magnet	1.25T
MRI system	1.5T – 3T

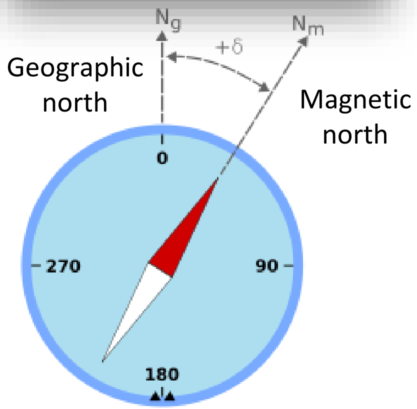
Compass

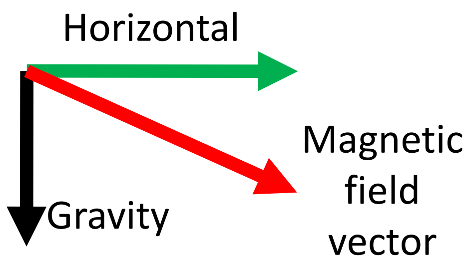
- Magnetic field sensor (magnetometer)











Magnetic declination

Magnetic inclination

MEMS Compass

- Most use Lorentz Force
- A current-carrying wire in a magnetic field experiences a perpendicular force