Imperial College London

Topic 16

Sense

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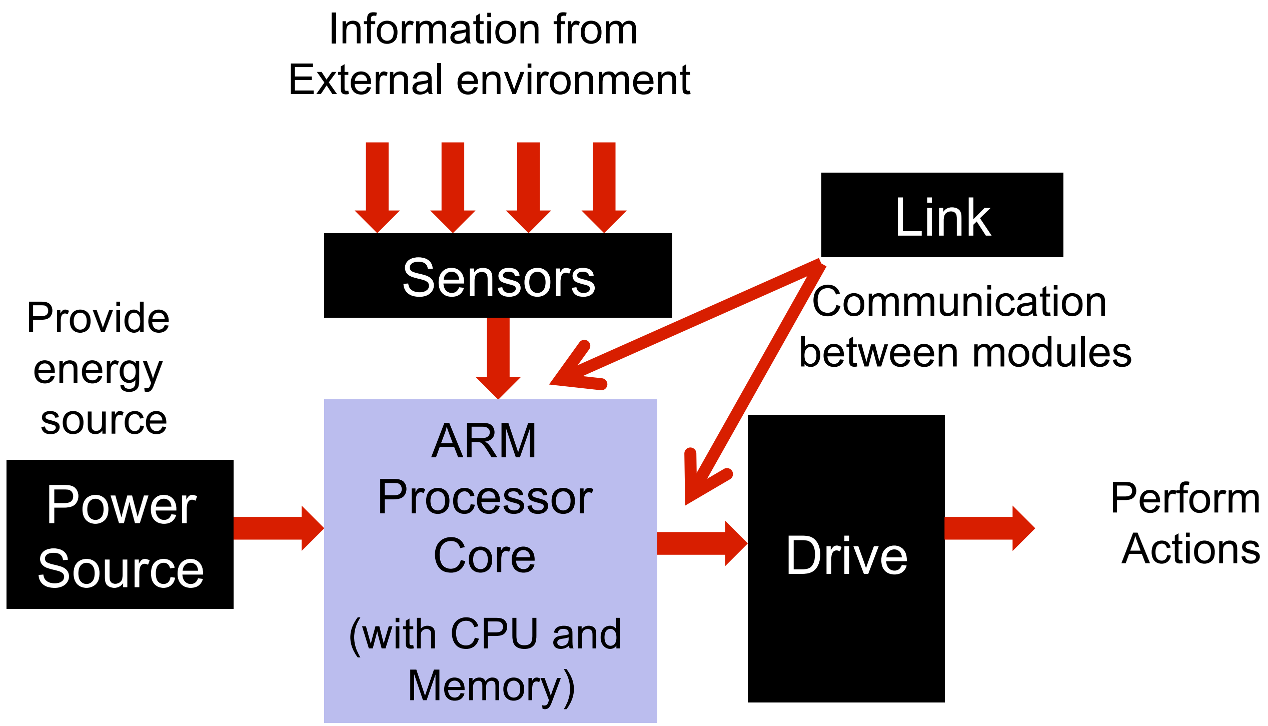
A holistic view of our electronic system



- Although central to our system is the microcontroller (the ESP32), for our system to do anything useful, we need four other elements:
  - **Sense** – to gather information from the environment
  - **Drive** – to provide means of doing things, e.g. motor, actuator and display
  - **Link** – the means for passing information between components
  - **Source** – the source of energy to power the whole system

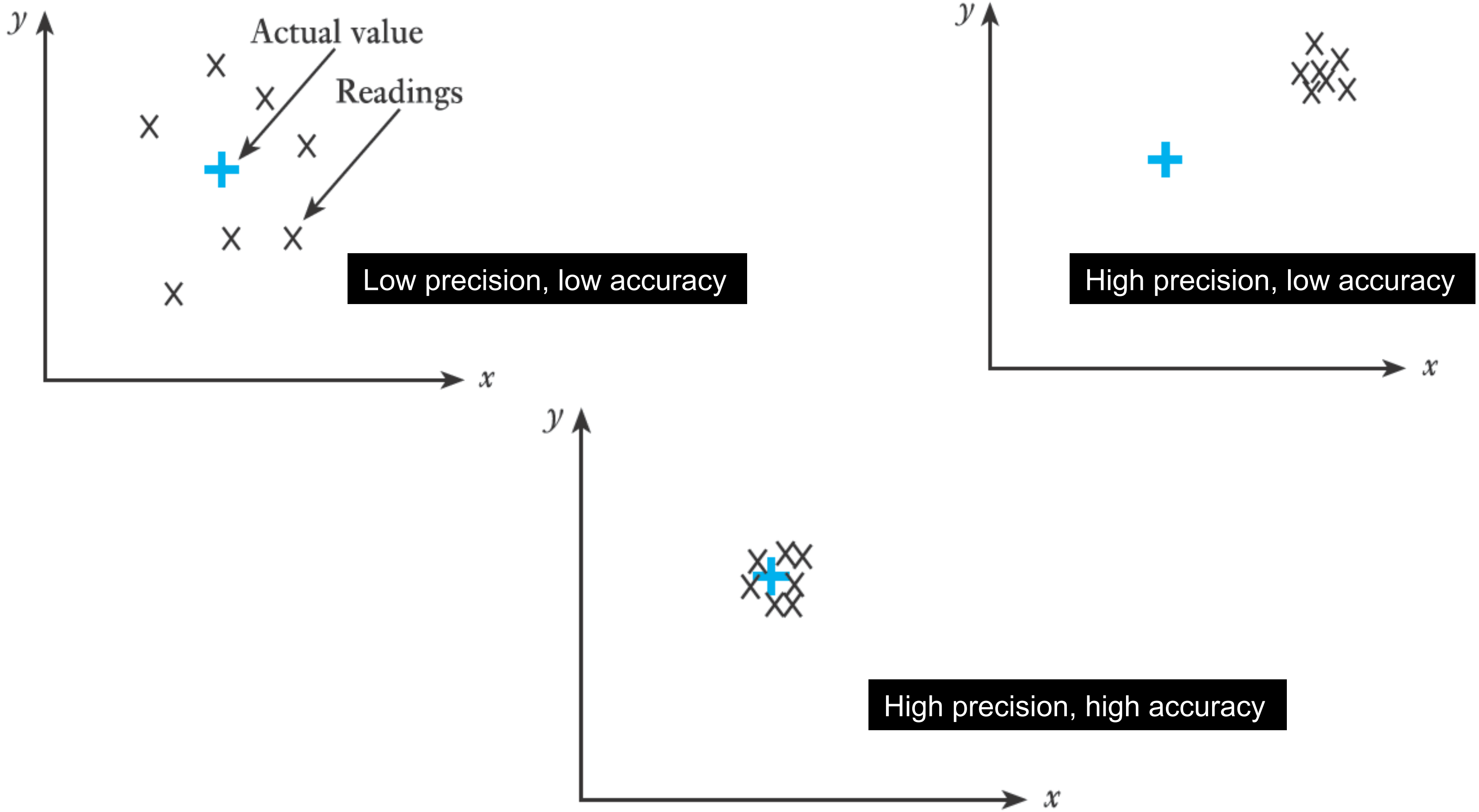
Sensors

- To be useful, systems must interact with their environment. To do this they use sensors and actuators, which are examples of transducers.
- A transducer is a device that converts one physical quantity into another.

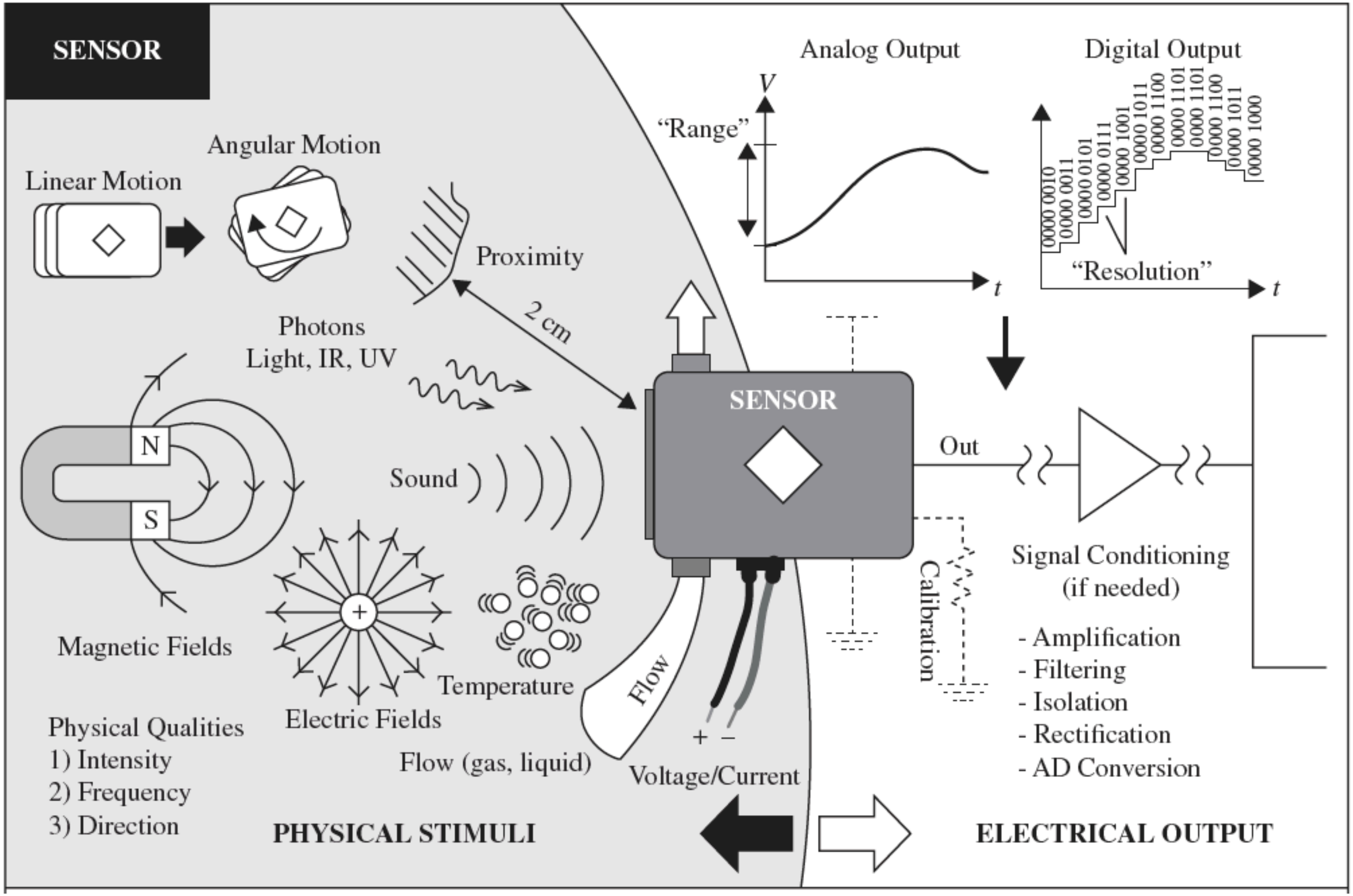
- The important parameters of senor performance are:
  - **Range** – maximum and minimum values that can be measured
  - **Resolution** – smallest discernible change in the measured value
  - **Error** – difference between the measured and actual values, which can be random errors or systematic errors
  - **Accuracy** – accuracy is a measure of the maximum expected error
  - **Precision** – a measure of the lack of random error (scattering)
  - **Linearity** – maximum deviation from a 'straight-line' response, normally expressed as a percentage of the full-scale value
  - **Sensitivity** – a measure of the change produced at the output for a given change in the quantity being measured

The Difference between precision and accuracy

- Precision and Accuracy describe two very different properties as illustrated in the graphs here:



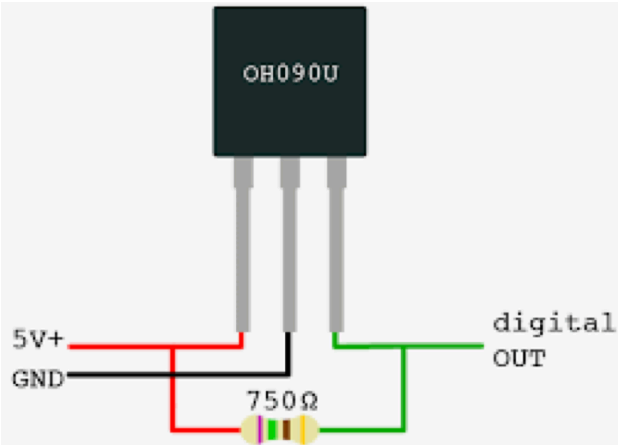
Overview of sensor and its interface

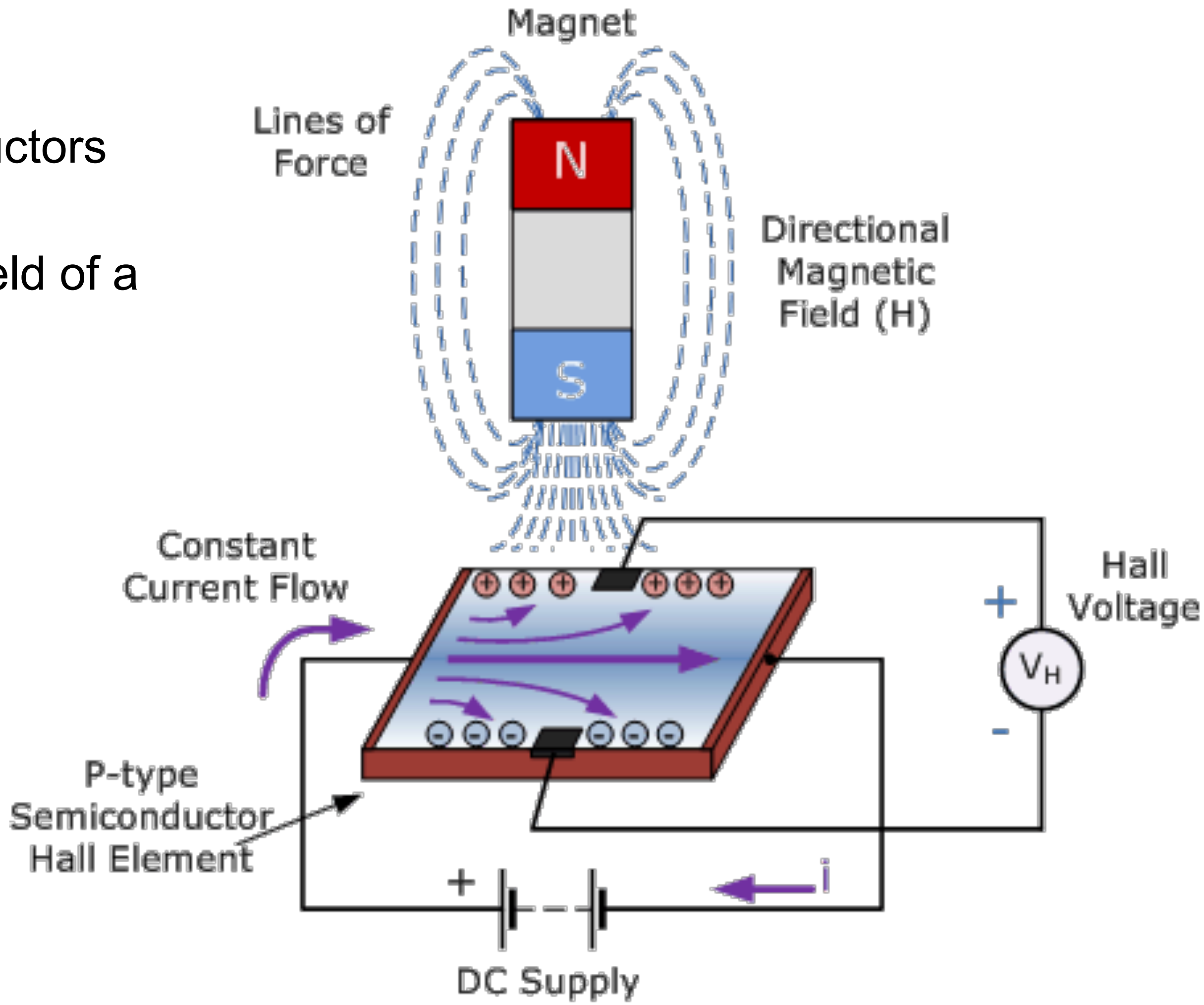


Magnetic Field sensor – Hall Effect

Hall effect sensor

- Manufactured similar to transistors in semiconductors
- Create a voltage in the presence of magnetic field of a certain pole
- Simple, cheap, reliable





A video about Hall Effect sensor

Displacement Sensing – Resistive, Inductive, Switch

Potentiometers

- Resistive potentiometers are one of the most widely used forms of position sensor
- Can be angular or linear
- Consists of a length of resistive material with a sliding contact onto the resistive track
- When used as a position transducer a potential is placed across the two end terminals, the voltage on the sliding contact is then proportional to its position an inexpensive and easy to use sensor

Inductive proximity sensors

- Coil inductance is greatly affected by the presence of ferromagnetic materials
- The proximity of a ferromagnetic plate is determined by measuring the inductance of a coil
- Inductance changes resonant frequency of a LC tuned circuit – hence easy to detect if something is near.

Digital displacement senor

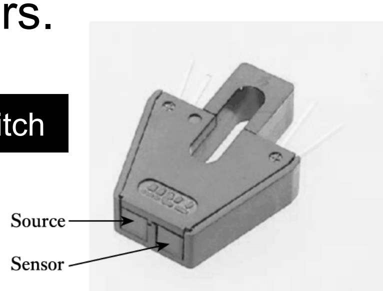
- Fancy name for a switch!
- Needs contact
- Easy to understand and implement - cheap

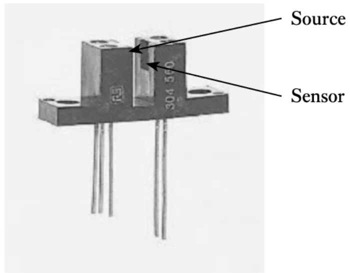
Displacement Sensing – Optical

Optical switches

- Consist of a light source and a light sensor within a single unit.
- Typically using light emitting diode (LED) and light sensitive diodes (or photodiodes) as transducers.

Reflective optical switch

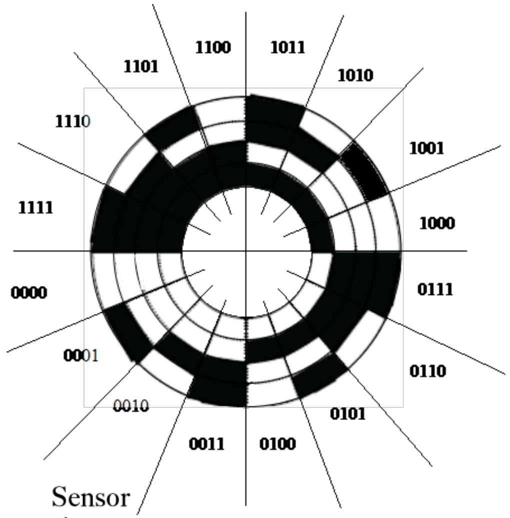


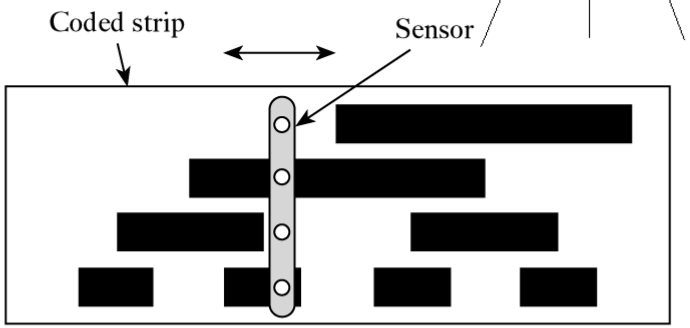


Slotted optical switch

Absolute position encoders

- A pattern of light and dark strips is printed on to a strip and is detected by a sensor that moves along it.
- The pattern takes the form of a series of lines as shown here.
- Or as a disk with black/white pattern in grey code (neighbourouring code only change by 1 bit).
- The combination is unique at each location.
- Sensor is an array of photodiodes.

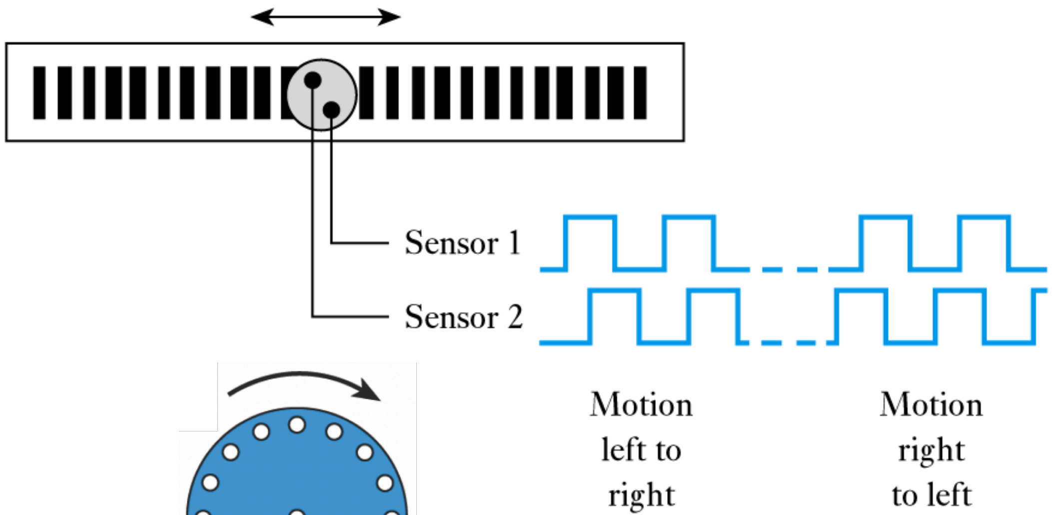




Displacement Sensing – with and without direction

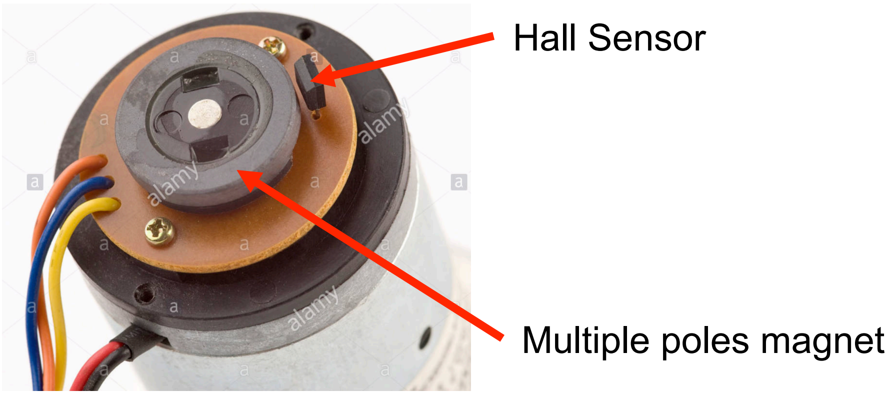
Incremental position encoder

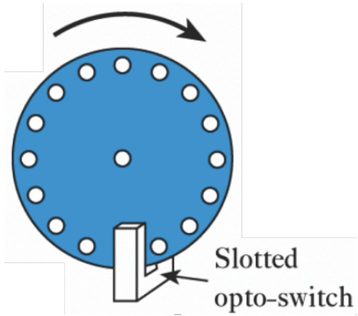
- Uses a single line or a circular disk with alternating black/white bars (or slots)
- Can use simple slotted optical switch with a disk with slot and counter pulses – no direction.
- To know the direction, use two slightly offset sensors produce outputs as shown below. This detects motion in either direction, pulses are counted to determine absolute position (which must be initially reset)



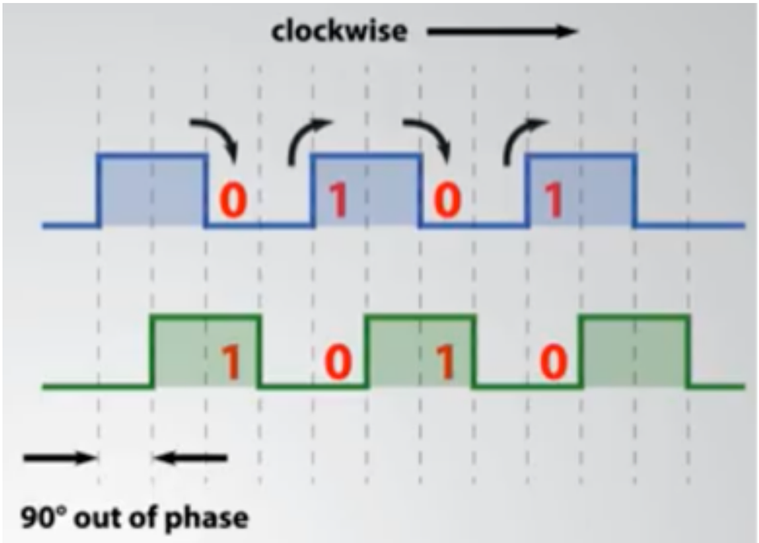
Hall effect sensor

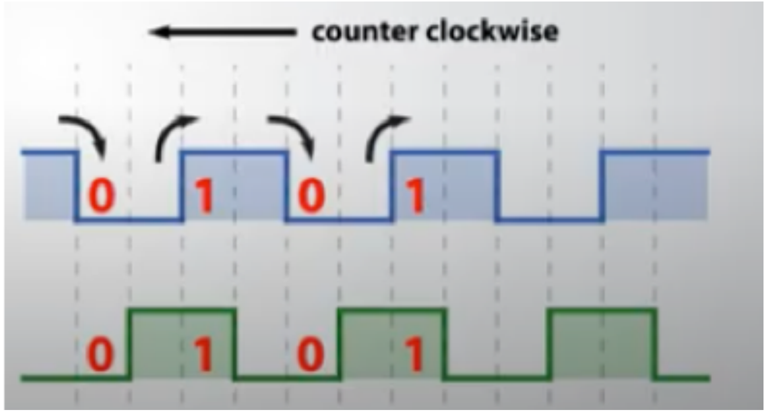
- We also use Hall Effect sensors to detect rotational displacement as shown here.



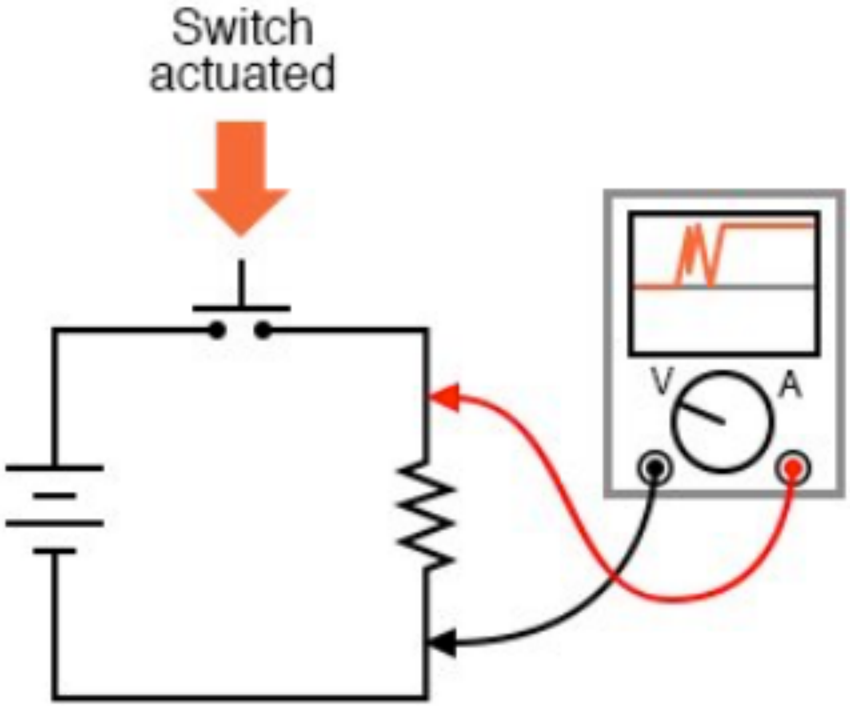


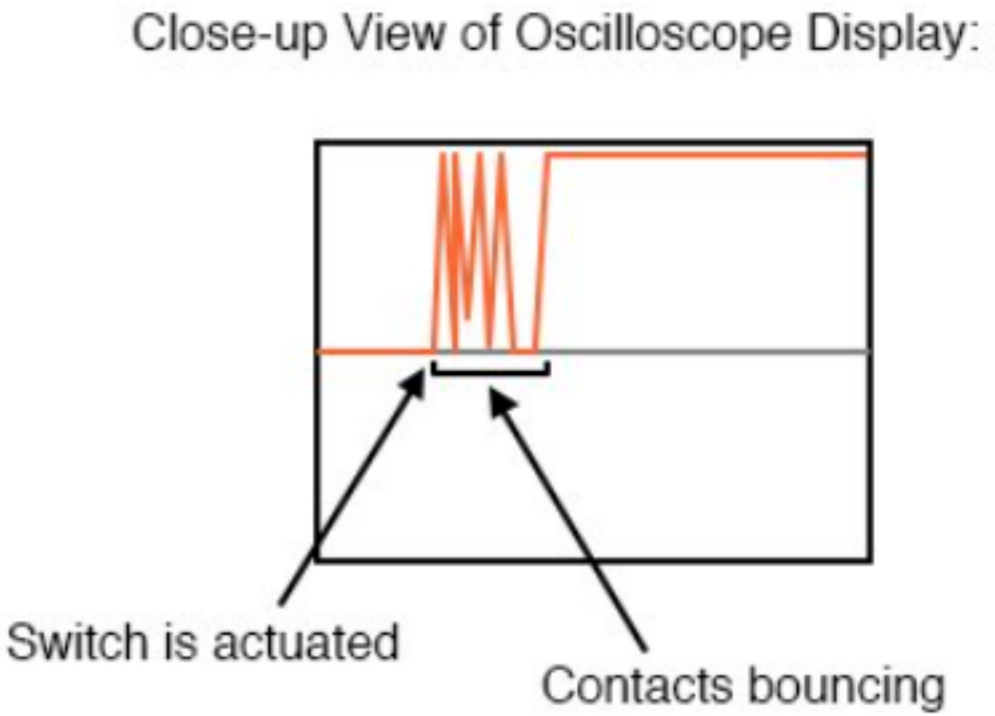
KY-040 Rotary Switch





Contact Bound in switches

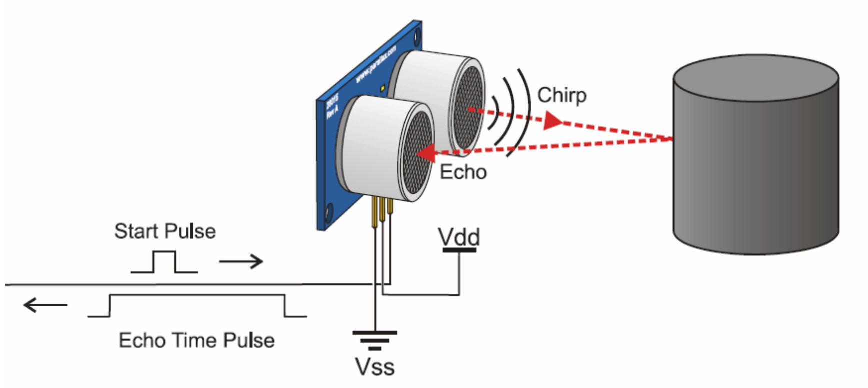


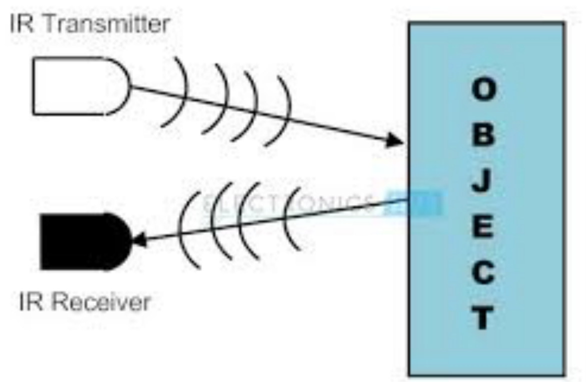


Distance Sensing – Echo location

Time-of-Flight Sensors

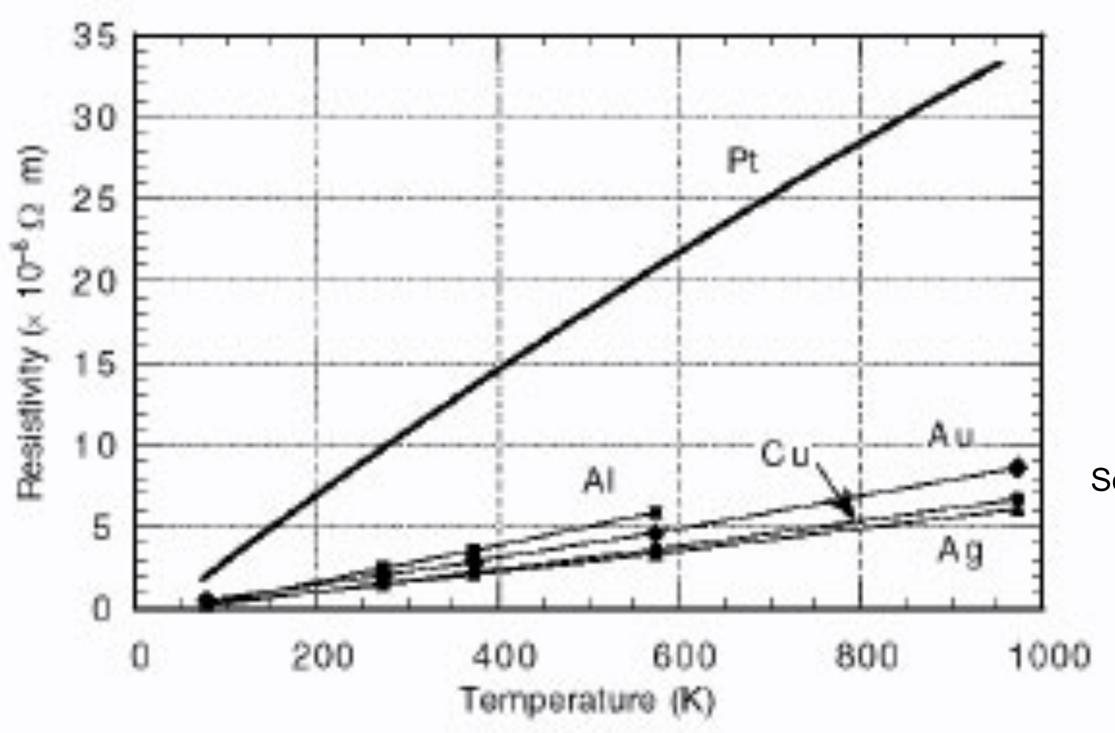
- Almost all distance sensors are based on time-of-flight principle.
- A source signal is sent as a burst of pulses, and the echo is detected.
- Distance is derived using the delay time between the source signal and the detection of the echo signal.
- Ultrasound is often used as a cheap and low accuracy time-of-flight sensor. Its effectiveness depends on the object surface property and orientation. Good for robot cars, but not for industrial applications.
- Instead of ultrasound, one could use infra red sources. Usually good for short distance (a few cm).
- Laser sensors are commonly used for industrial applications, due to their robustness, accuracy and low sensitivity to surface reflectivity and orientation.
- An alternative is to use infrared transmitter/receiver as you did in Lab 4.





Temperature Sensing - PRT

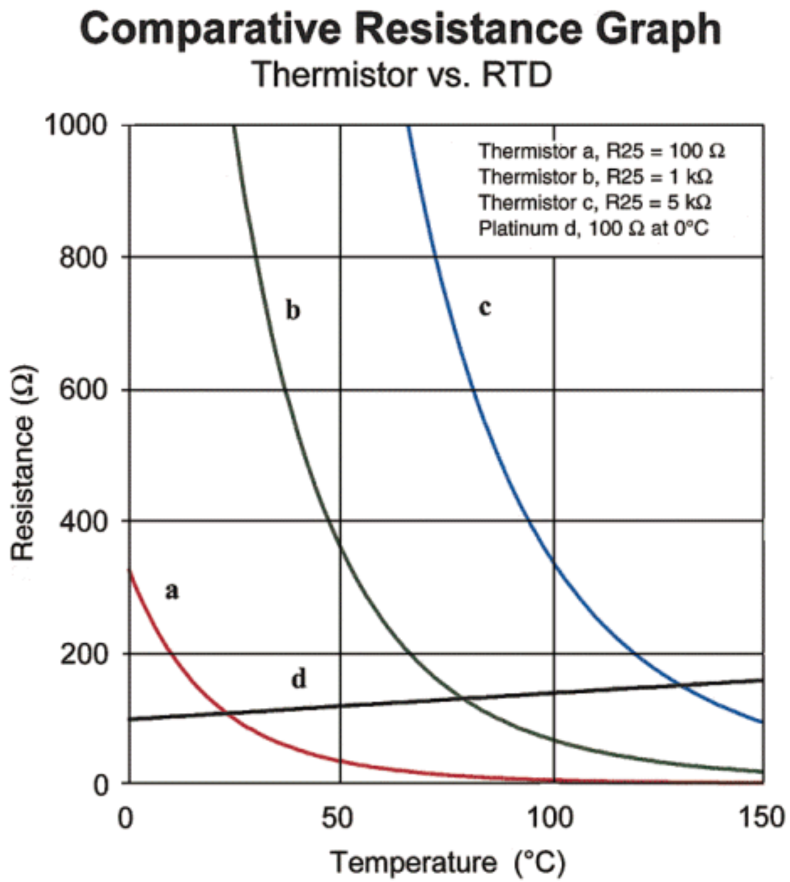
- Platinum Resistive Thermometers (PRT) - devices using platinum wire whose resistance changes with temperature
- Shown here is a plot of resistivity vs temperature characteristics for five different metals. It shows platinum has the highest sensitivity.
- PRT has good *linearity* but has poor *sensitivity* when compared to other types of temperature sensors.
- It works up to high temperature.



Source: NPL

Temperature Sensing - Thermistors

- Thermistors are made of semiconductors whose resistance varies with temperature.
- They have higher sensitivity than platinum wire, as shown in the graph here. (R25 means resistance at 25 ºC.)
- They are highly non-linear, therefore requires the intelligence of a microprocessor for calibration and correction.
- They have limited operating temperature range.
- They are widely available and cheaper than PRT.
- They can have positive or negative temperature coefficients.



Source: Sensors online

Temperature Sensing – pn junction

- pn junction diode is made of silicon semiconductor materials
- A diode only conducts current in one direction (when a positive end known as anode to negative end known as cathode), when V_D exceeds some threshold.
- When a diode is conducting, it is being forward biased.
- The diode voltage V_D changes by around -2mV/ºC – hence we can use this to measure temperature.

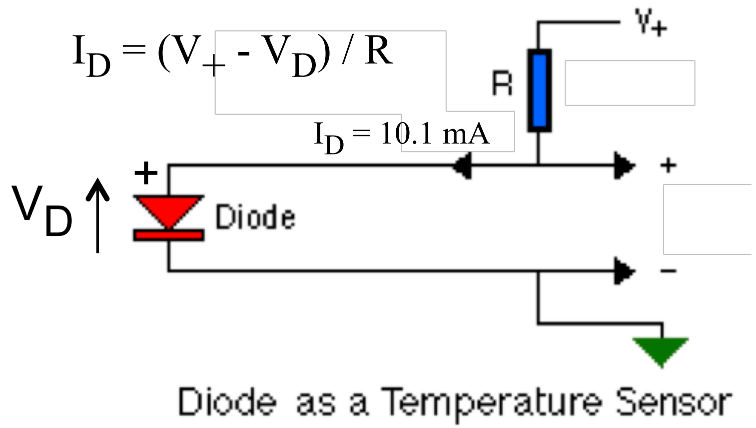
Advantage:

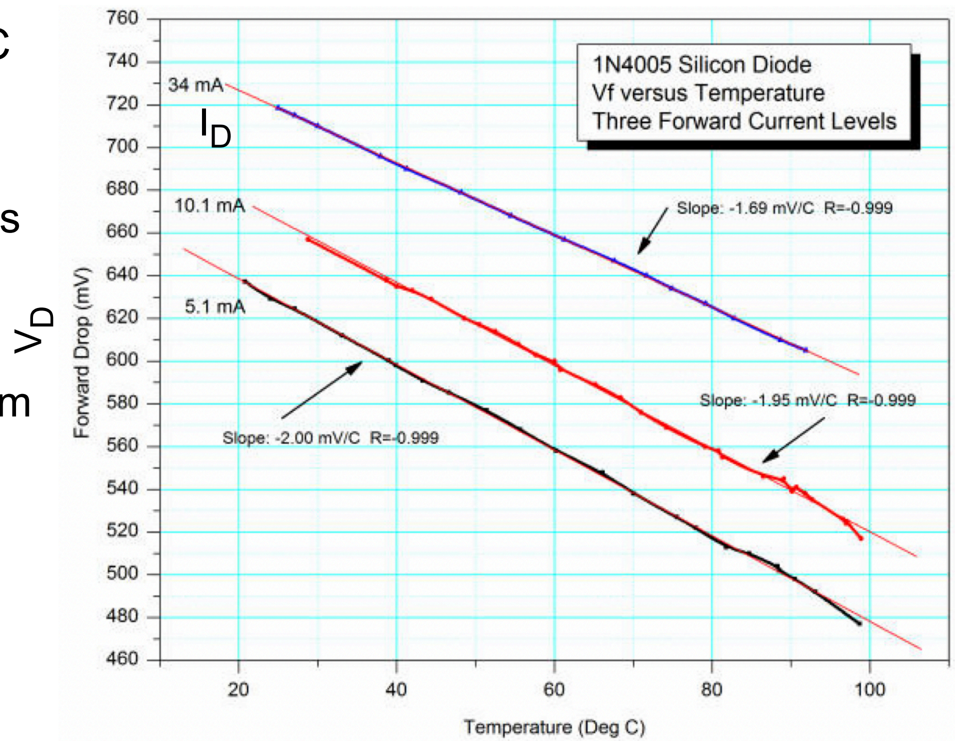
- Cheap or free – already available inside chips

Disadvantages:

- Limited operating range
- V_D varies with current through diode, and from device to device – difficult to do accurate absolute measurements

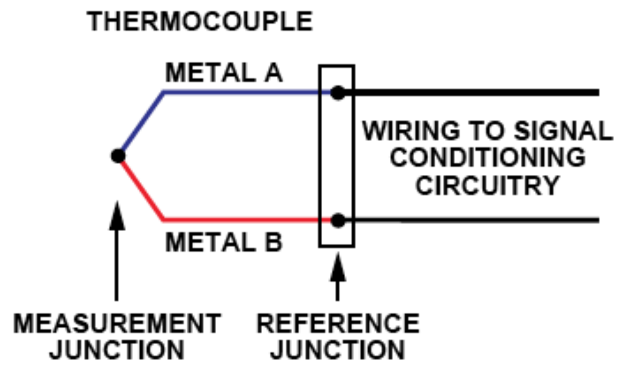
- Generally useful to detect overheating – found in almost all semiconductor chips now (e.g. Pentium or ARM processors)

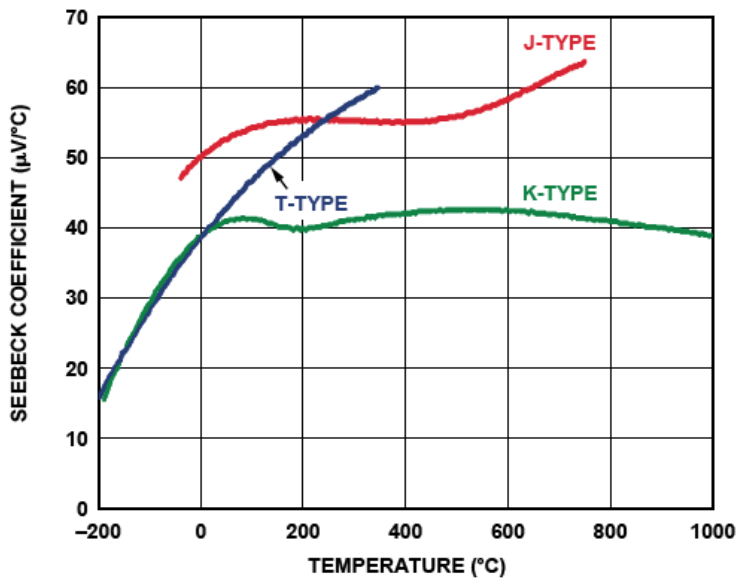




Temperature Sensing – Thermocouples

- Thermocouples are made with joining two types of metals.
- A voltage is developed at the junction of the two metals, and the voltage is temperature dependent.
- This coefficient (dV/dT) is known as Seebeck coefficient (the person who discovered this property).
- Advantages are:
  - High operating range: -200ºC to +2500ºC
  - Robust: just two wires wielded together!
  - Rapid response: small, low heat capacity, msec
  - No self-heating: passive device, not energised
- Disadvantages are:
  - Produces very small voltage – hence expensive signal conditioning
  - Highly non-linear, needs calibration/correction
  - Can corrode
  - Low accuracy – around ±1 to 2 ºC



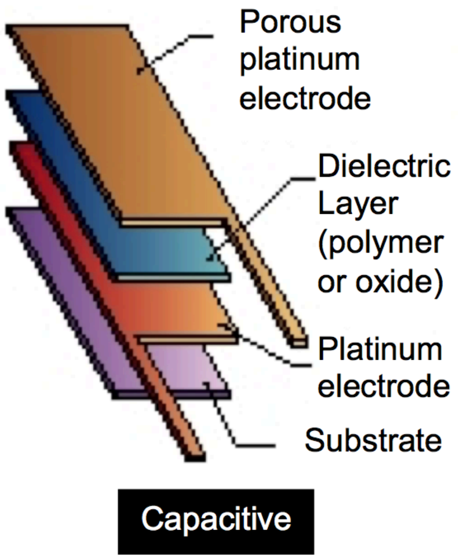


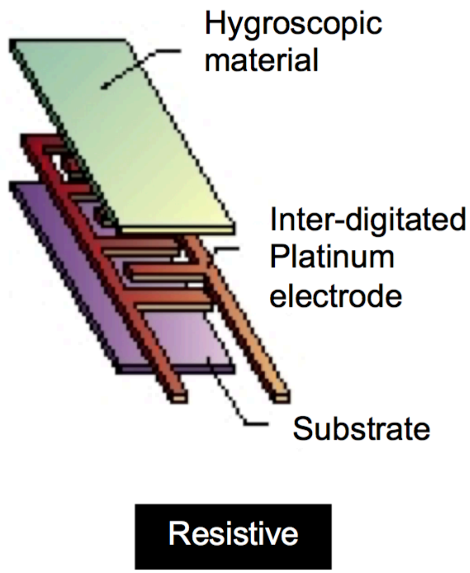
Source: Analog Devices

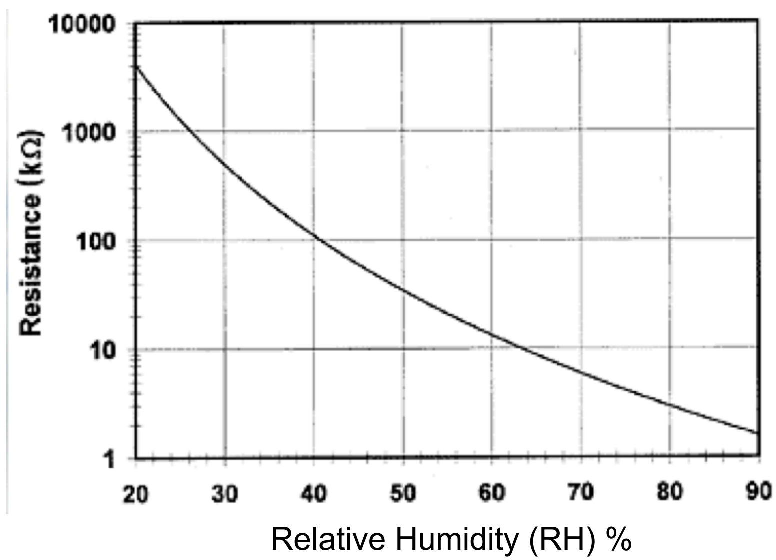
Humidity Sensing – Capacitive and Resistive

- **Capacitive Humidity Sensors** – measured relative humidity through change in capacitances.
- Transducer is made of thin film of polymer or metal oxide deposited between two conducting electrodes.
- Sensing surface protected against contamination with porous metallic material.
- Change in capacitance is typically 0.2 to 0.5 pF/ºC and quite linear.
- Has low response time, typically in 10's of seconds.

- **Resistive Humidity Sensors** – based on interdigitated electrode with a deposition of a hydroscopic polymer coating on top.
- Resistance changes as an inverse exponential with humidity.
- Response time is also in 10's of seconds.

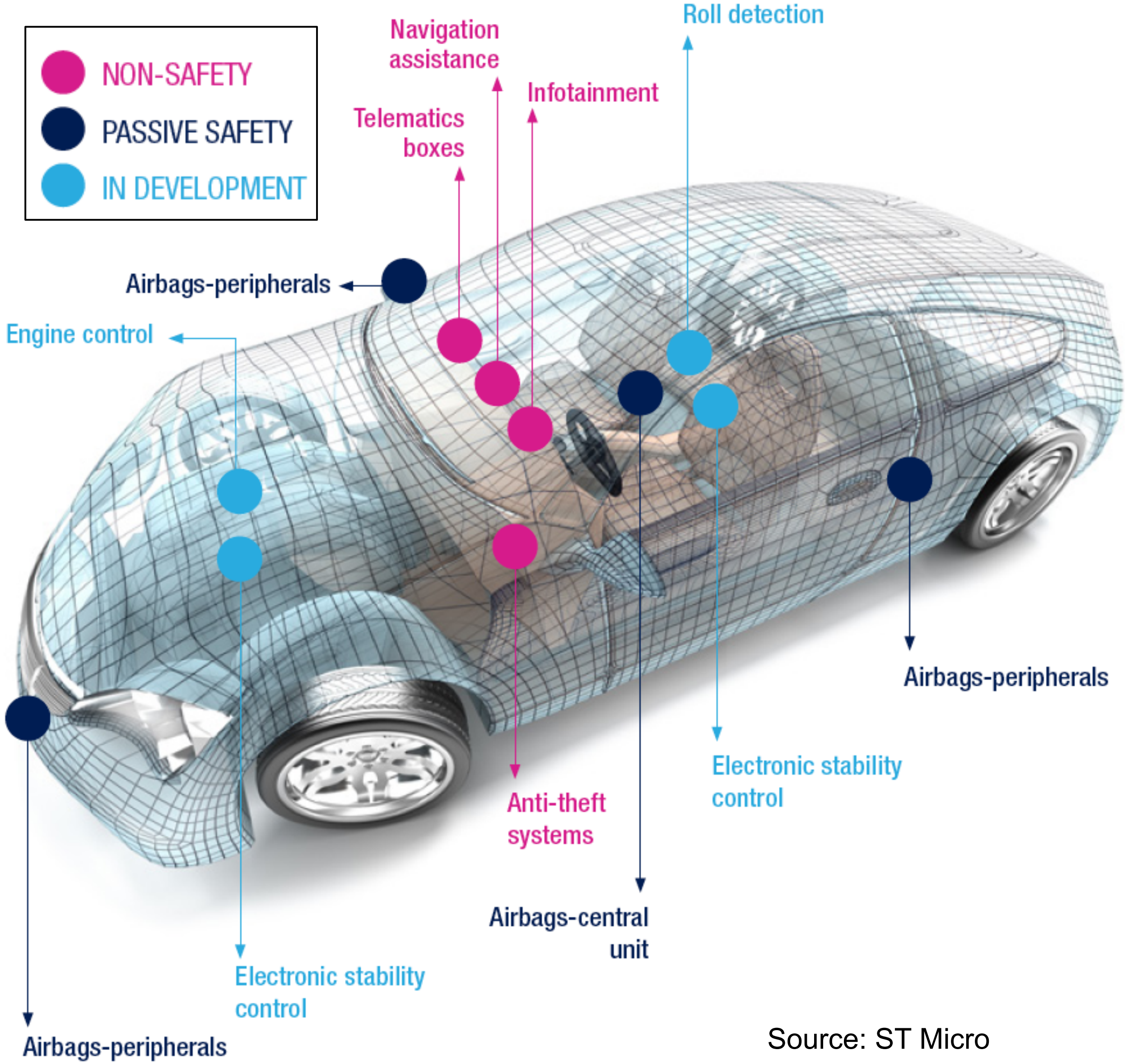






Introduction to Micro-ElectroMechanical Systems

- Combine electronics with mechanical functions on an integrated circuit.
- Often use same silicon process as making chips.
- Grew since the 80's, and now dominate the sensor area.
- Cars now have MANY sensors made from MEMS.

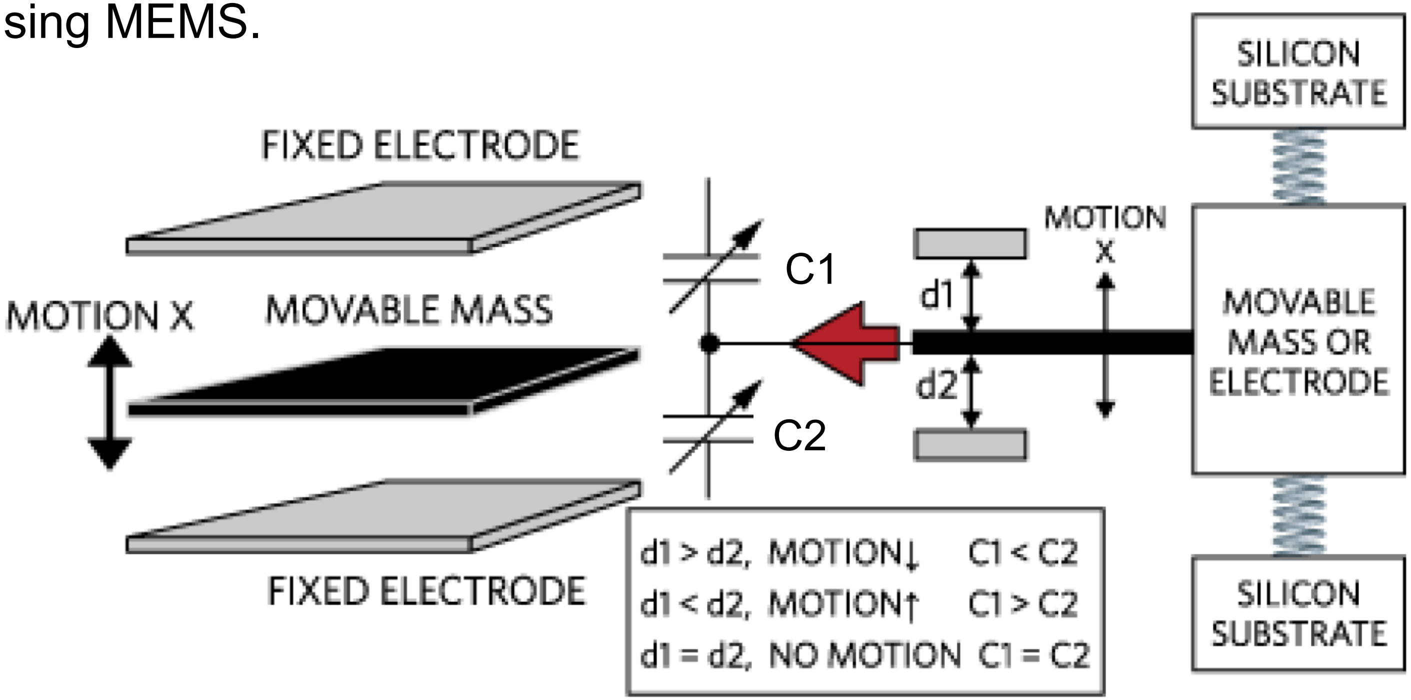


Source: ST Micro

Motion Sensing – Accelerometer

Basic Principle

- Newton's 2nd Law of motion: F = mass x acceleration.
- Sense acceleration is really sensing the force on a mass.
- Use capacitive sensing with MEMS.
- Acceleration causes mass to move.
- Mass pivoted on springs anchored one side as shown.
- Implemented using MEMS.

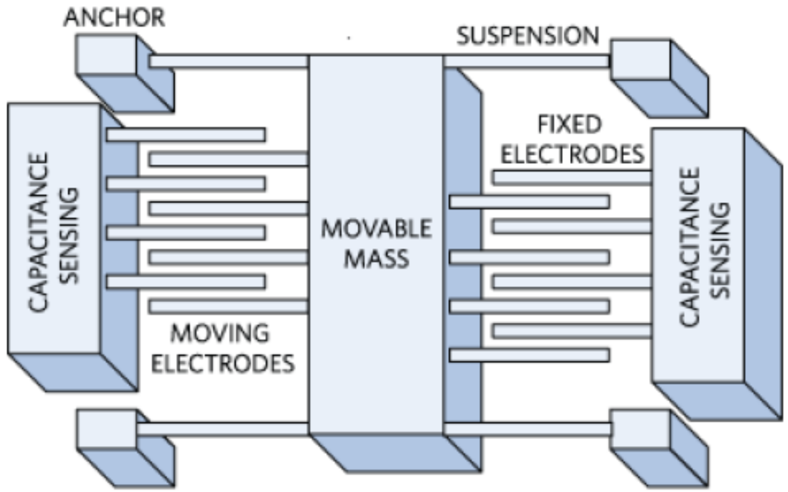


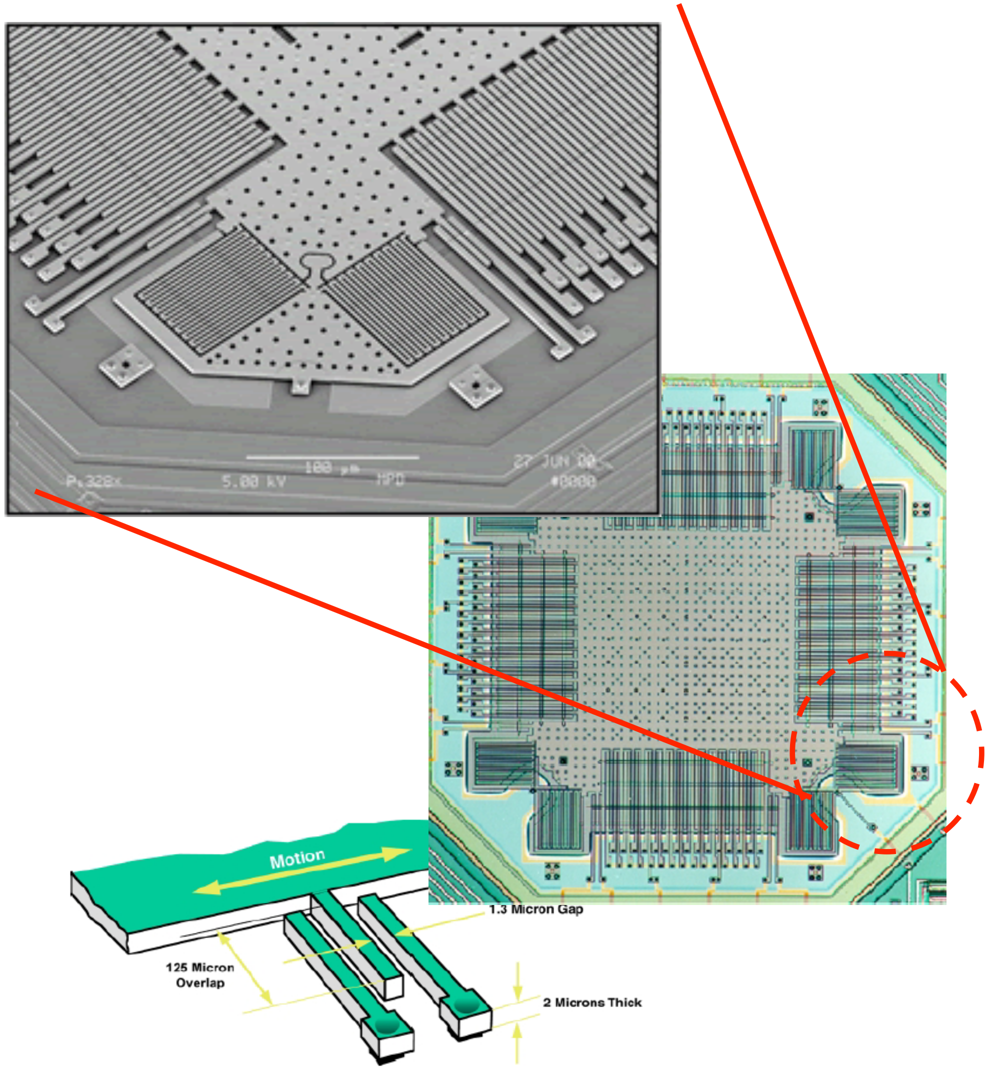
Source: Maxim Integrated

Motion Sensing - MEMS accelerometers

Capacitive MEMS accelerometer

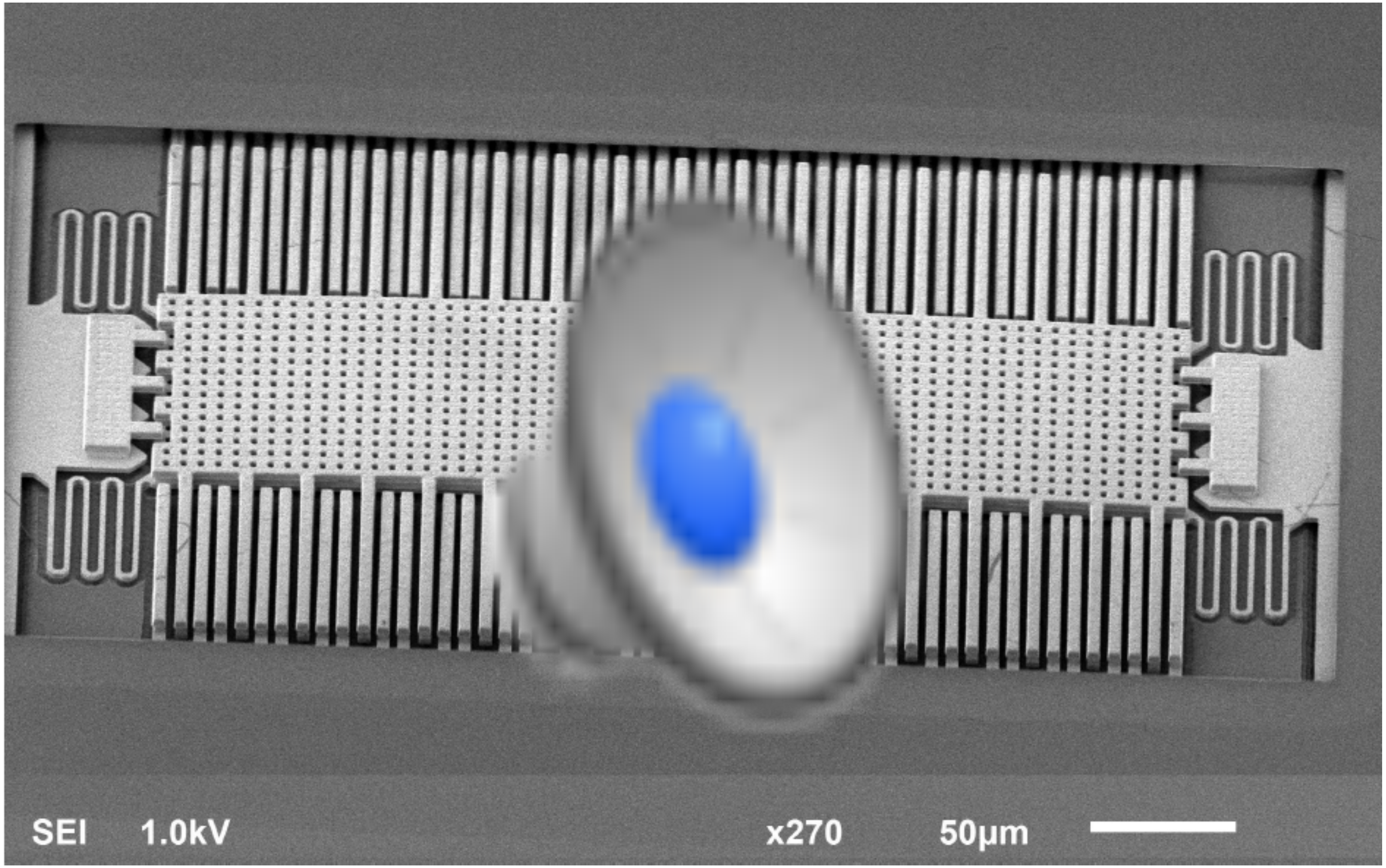
- The displacement of the movable mass (micrometer) is caused by acceleration.
- It creates an extremely small change in capacitance for proper detection. Therefore practical sensors use multiple movable and fixed electrodes, all connected in a parallel configuration as shown.





Source: Analog Devices

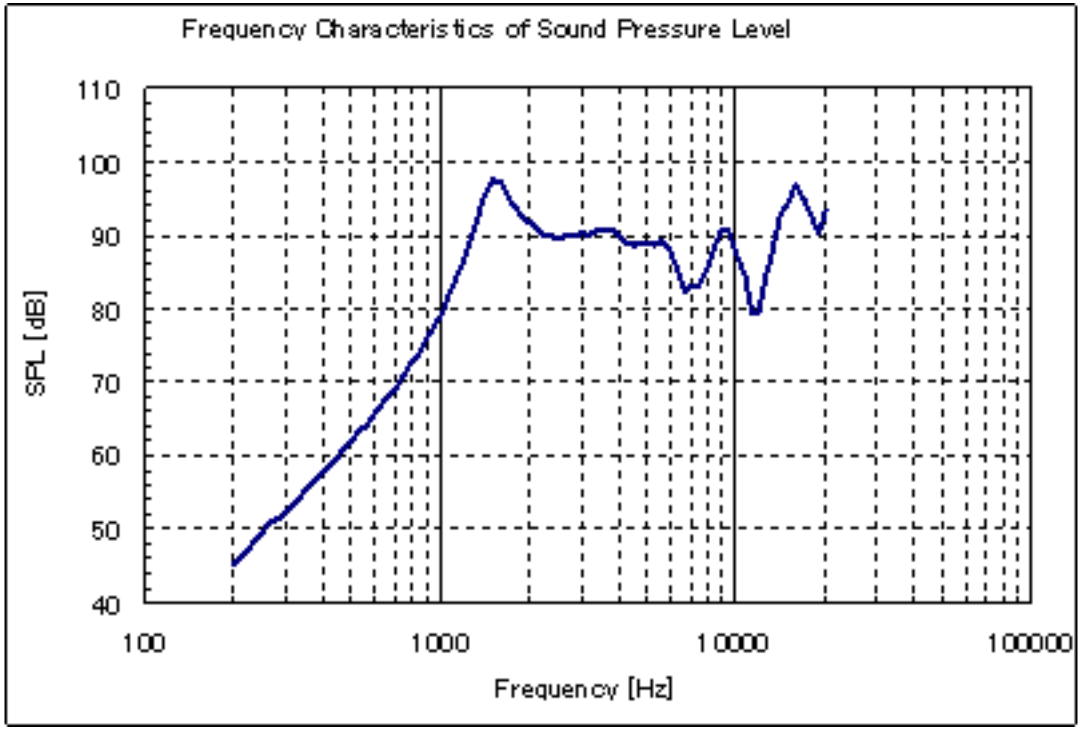
A short video on “MEMS Accelerometer”

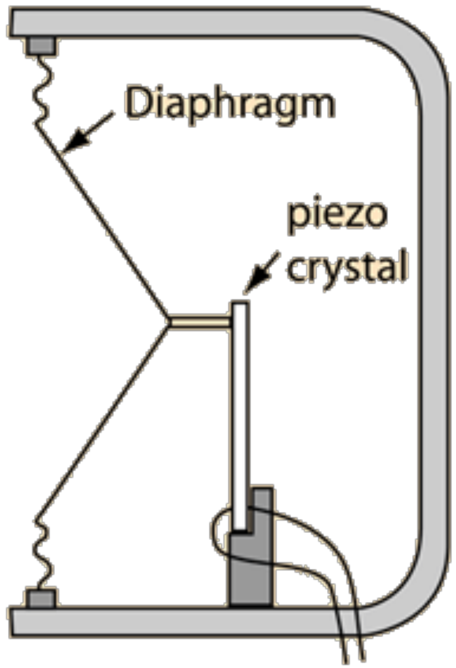


A scanning electron microscope photo of a lateral accelerometer
Piotr Michalik et al, IEEE Senors, Nov 2015

Pressure Sensing - Piezoelectric

- There are many types of pressure sensors: resistive, inductive and those that are based on piezoelectric materials.
- Here we will only consider those that are based on piezoelectric, because this is a type of materials that can be found in other types of sensors.
- Some microphones are also made of piezoelectric materials. Piezoelectric microphones turn sound pressure into electrical voltage.

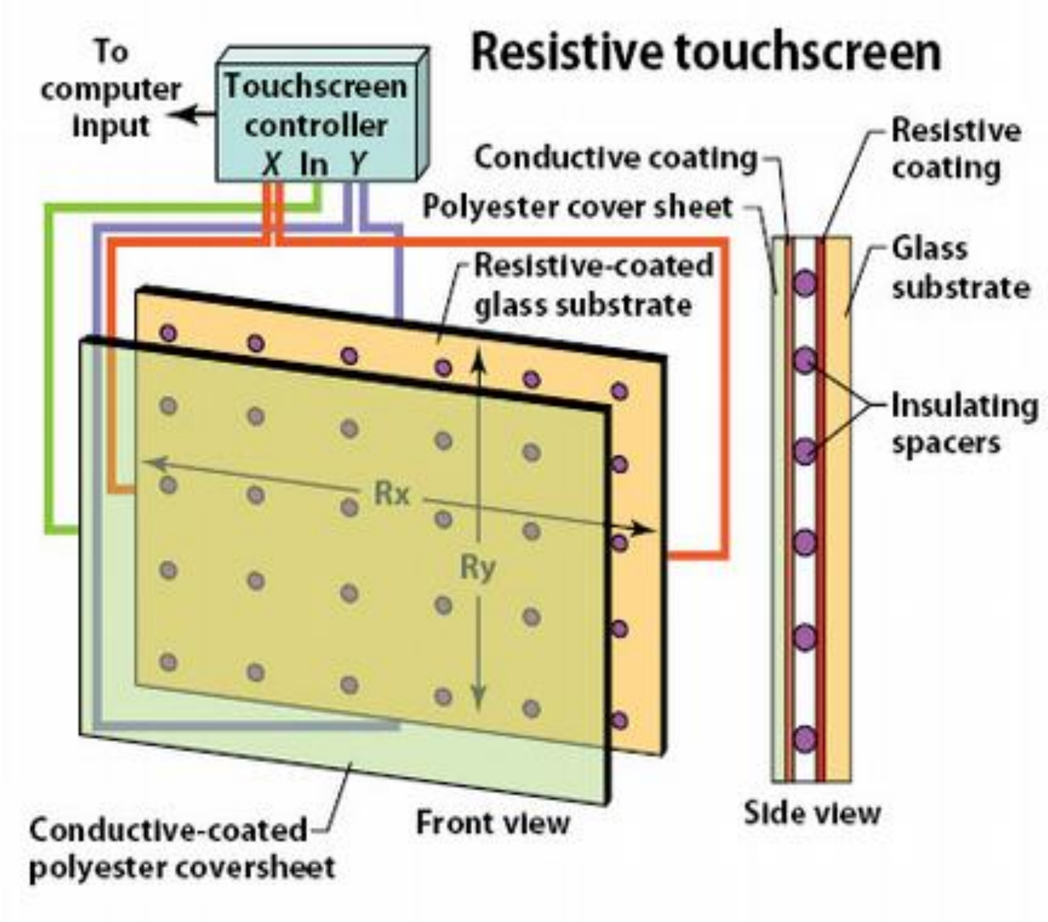




Touch Sensing - Resistive

- Composed of multiple layers separated by thin spaces
- Using indium tin oxide (ITO) layers – optically transparent, electrically conductive

- Contact made when pressed.
- Uniform voltage on first screen for X and second screen for Y
- Resistive screen works well with and without a stylus
- Low cost and rugged
- Generally cannot detect more than one touch point



Touch Sensing - Capacitive

- Becoming popular is capacitive touch sensing.
- Capacitor is formed with conductive coating (ITO) and insulator layer (glass or air).
- There are two types of capacitive touch sensors: surfaced and projected.

Surface type

- Only one side of the glass is coated
- Electrodes are at the edges
- Capacitor is formed ONLY after touch with finger – you are the earth terminal, completing the circuit
- Single touch only and limited resolution
- Contact location determine X, Y coordinate

Multi-touch Sensing – Projected Capacitive

- Has two parallel ITO layers and two sheets of glass
- Capacitor array distributed on the surface at many locations
- Touching changes the electrostatic field at the location of touch, changing many capacitances through field **projection** through glass
- Measure capacitance distribution, and can therefore work out **all** touch locations