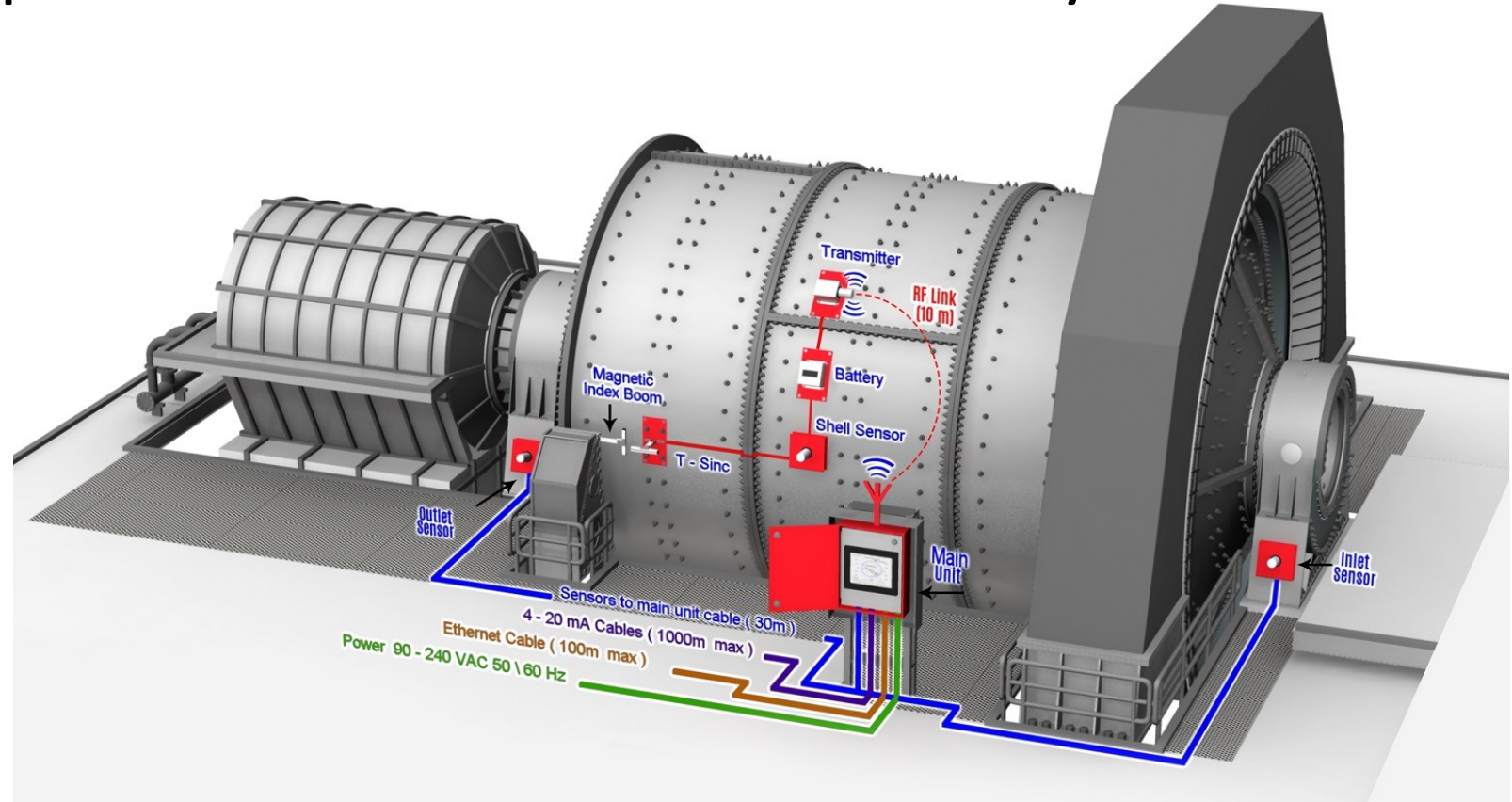


# Hardware Components of Embedded Systems

ET2223 Microprocessors, Microcontrollers, and Embedded Systems

# Hardware Components of Embedded Systems

- Electronic
- Electrical
- Electro-mechanical
- Mechanical

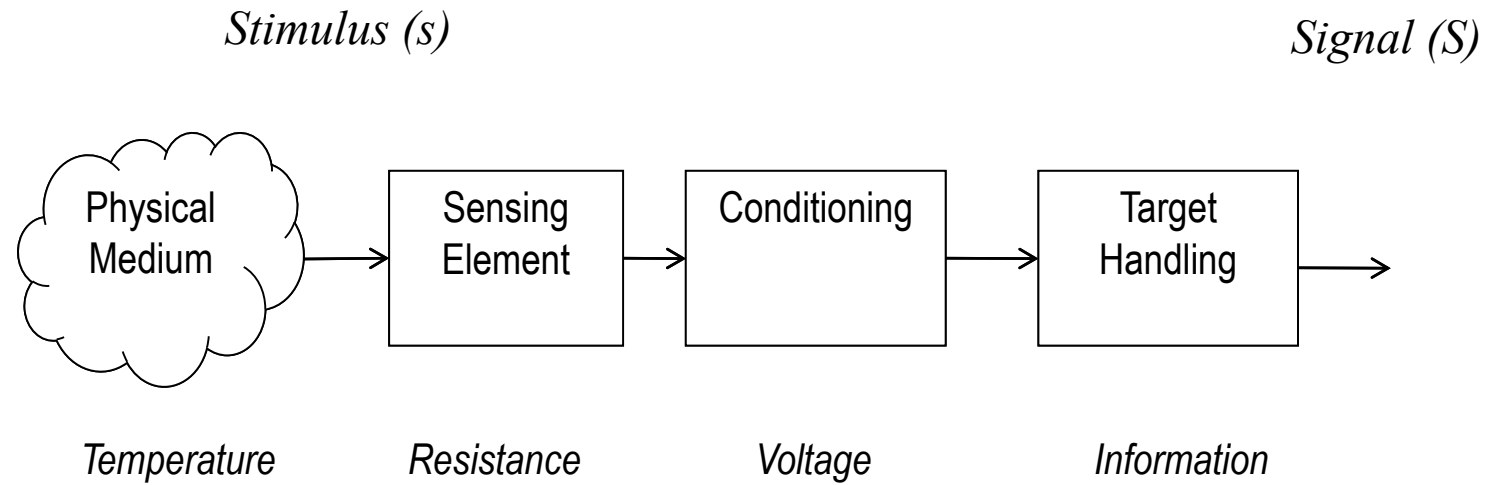


The following content is based on *Introduction to Transducers, Sensors, and Actuators*  
– Southwest Center for Microsystems Education (SCME), University of New Mexico

# Sensors

- A sensor is a device that receives and responds to a signal.
- This signal must be produced by some type of energy, such as heat, light, motion, or chemical reaction.
- Once a sensor detects one or more of these signals (an input), it converts it into an analog or digital representation of the input signal.
- Sensors detect by receiving a signal from a device such as a transducer, then responding to that signal by converting it into an output that can easily be read and understood.

# Sensors



# Transfer Function

- $S=f(s)$ 
  - $S$  = output signal;
  - $s$  = stimulus;
  - $f(s)$  = functional relationship
- For binary sensors:
  - $S = 1$  if  $s > 0$  and  $S = 0$  if  $s < 0$ .
- The ideal functional form for an analogue measuring device is a simple proportional relationship, such as:
- $S=C+ms$ 
  - $C$  = output value at a stimulus value of zero
  - $m$  = constant of proportionality (sensitivity)

# Example

- The output voltage of a particular thermocouple sensor is registered to be 42.3 mV at temperature 105°C.
- It had previously been set to emit a zero voltage at 0°C.
- Since an output/input relationship exists between the two temperatures, determine
  1. the transfer function of the thermocouple, and
  2. the temperature corresponding to a voltage output of 15.8 mV.

# Solution

$$S = C + ms$$

$$42.3 \text{ mV} = 0 + m(105^\circ\text{C}) = m(105^\circ\text{C})$$

$$\text{or } m = 0.4028571429$$

$$S = 0.4 \text{ (s)}$$

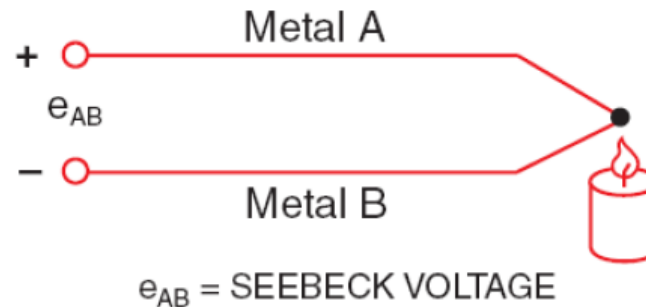
$$15.8 \text{ mV} = 0.4 \text{ (s)}$$

$$15.8 / 0.4 = s$$

$$s = 39.22^\circ\text{C}$$

# Thermal Sensors

- Thermometer – measures absolute temperature
- Thermocouple gauge– measures temperature by its affect on two dissimilar metals
- Calorimeter – measures the heat of chemical reactions or physical changes and heat capacity



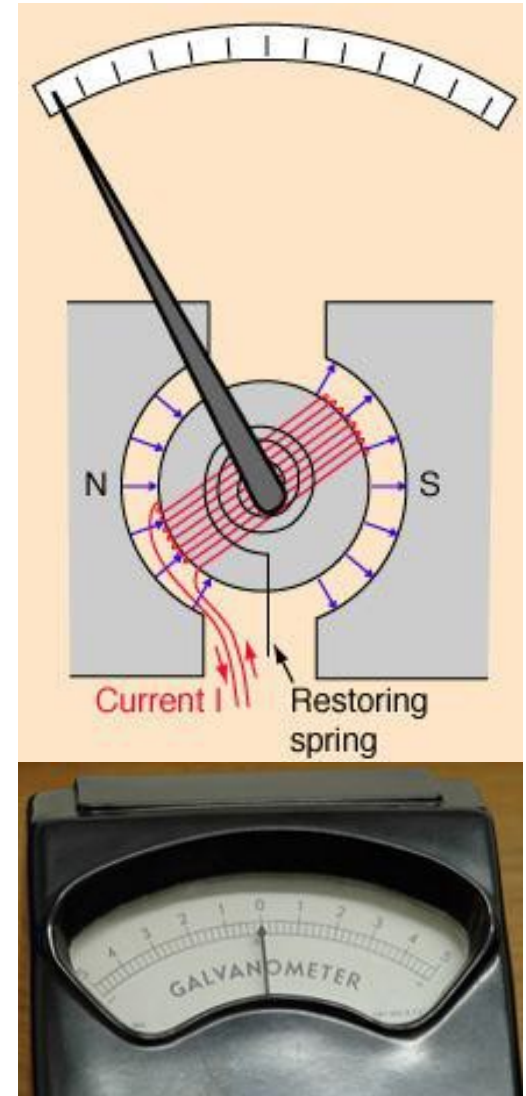


# Mechanical Sensors

- Pressure sensor – measures pressure
- Barometer – measures atmospheric pressure
- Altimeter – measures the altitude of an object above a fixed level
- Liquid flow sensor – measures liquid flow rate
- Gas flow sensor – measures velocity, direction, and/or flow rate of a gas
- Accelerometer – measures acceleration

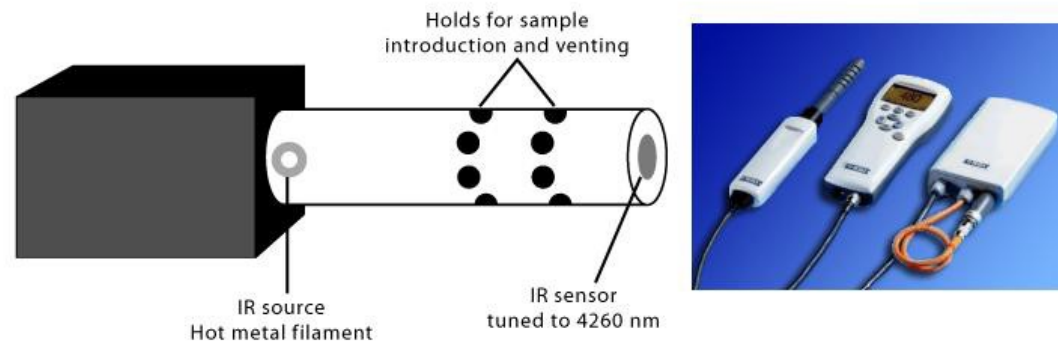
# Electrical Sensors

- Ohmmeter – measures resistance
- Voltmeter – measures voltage
- Galvanometer – measures current
- Watt-hour meter – measures the amount of electrical energy supplied to and used by a residence or business



# Chemical Sensors

- Chemical sensors detect the presence of certain chemicals or classes of chemicals and quantify the amount and/or type of chemical detected.
  - Oxygen sensor – measures the percentage of oxygen in a gas or liquid being analysed
  - Carbon dioxide detector – detects the presence of CO<sub>2</sub>



# Other Types of Sensors

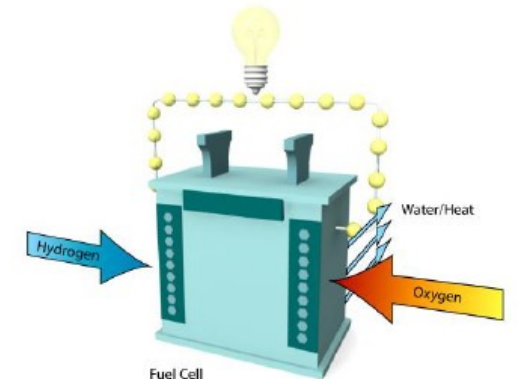
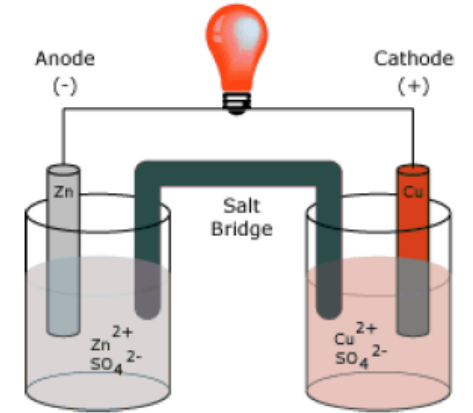
- Optical
  - Light sensors (photodetectors) – detects light and electromagnetic energy
  - Photocells (photoresistor) – a variable resistor affected by ambient light intensity
  - Infra-red sensor – detects infra-red radiation
- Acoustic
  - Seismometers – measures seismic waves
  - Acoustic wave sensors – measures the wave velocity in the air or an environment to detect the chemical species present
- Other
  - Motion – detects motion
  - Geiger counter – detects atomic radiation

# Transducer

- A transducer is any device which converts one form of energy into another.
- Examples:
  - A microphone converts sound into electrical impulses and a loudspeaker converts electrical impulses into sound (i.e., sound energy to electrical energy and vice versa).
  - A solar cell converts light into electricity and a thermocouple converts thermal energy into electrical energy.
  - An electric motor is a transducer for conversion of electricity into mechanical energy or motion.

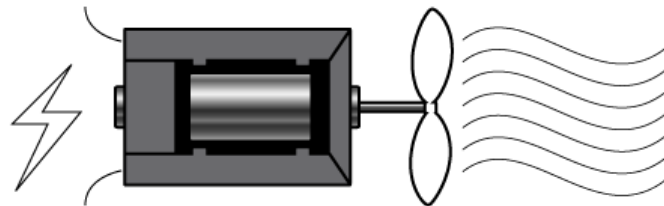
# Electrochemical Transducers

- Some common electrochemical transducers include the following:
  - pH probe – Converts chemical energy into an electrical energy
  - Molecular electric transducer – Converts motion in an electrolytic solution into electrical energy
  - Battery – Converts chemical energy directly into electrical energy
  - Fuel cell – Converts the energy from a reaction within a fuel cell to electrical energy



# Electromechanical Transducers

- Electromechanical Transducers – (Some are also called actuators)
  - Strain gauge – Converts the deformation (strain) of an object into electrical resistance
  - Galvanometer – Converts the electric current of a coil in a magnetic field into movement
  - Generators – Converts mechanical energy (motion) into electrical energy
  - Motor – Converts electrical energy into mechanical energy



A motor converts electrical energy into mechanical energy

# Electroacoustic, Electromagnetic, and Electrostatic Transducers

- Common electroacoustic transducers:
  - Loudspeaker – Converts an electrical signal into sound
  - Microphone – Converts sound waves in air into an electrical signal
  - Hydrophone - Converts sound waves in water into an electrical signal.
- Common electromagnetic transducers:
  - Magnetic cartridge – Converts motion in a magnetic field into an electrical energy
  - Generator – Converts motion in a magnetic field into electrical energy
- Common electrostatic transducers:
  - Electrometer – Converts static or energy from a vibrating reed into electricity
  - Van de Graaf generator – Converts static into high voltage (*see figure below*)



# Other Types of Transducers

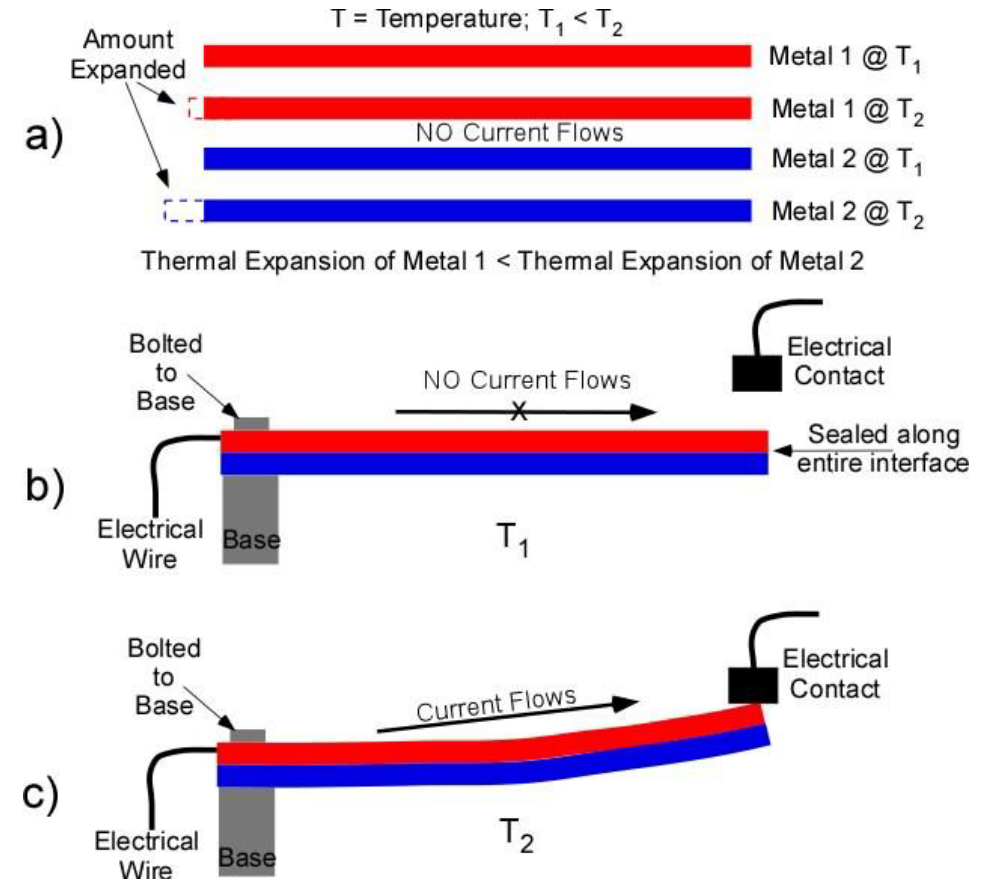
- Photoelectric Transducers:
  - Cathode ray tube (CRT) –Converts electrical signals into light energy for a visual output
  - Light bulb –Converts electrical energy into visible light and heat (*explained in next section*)
  - Laser diode – Converts electrical energy into light energy
  - Photodiode - Converts light energy into electrical energy
- Thermoelectric Transducers:
  - Thermocouple – Converts heat energy into electrical energy
  - Temperature sensitive resistor (Thermister) – a variable resistor affected by temperature changes (heat energy to electrical energy)

# Actuator

- An actuator is a device that actuates or moves something. An actuator uses energy to provide motion.
- Therefore, an actuator is a specific type of a transducer.
- Which of the previously mentioned examples is an actuator?

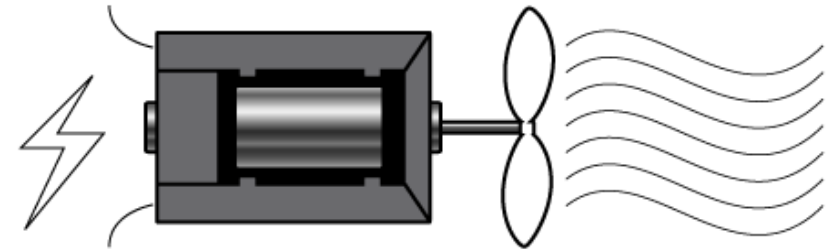
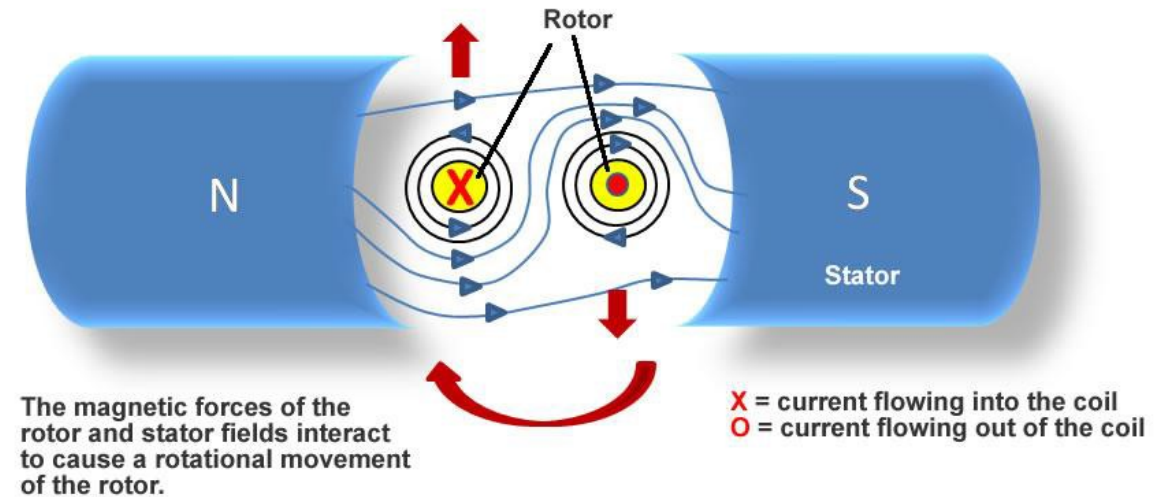
# Thermal Actuators

- One type of thermal actuator is a bimetallic strip.
- This device directly converts thermal energy into motion.
- This is accomplished by utilizing an effect called thermal expansion.



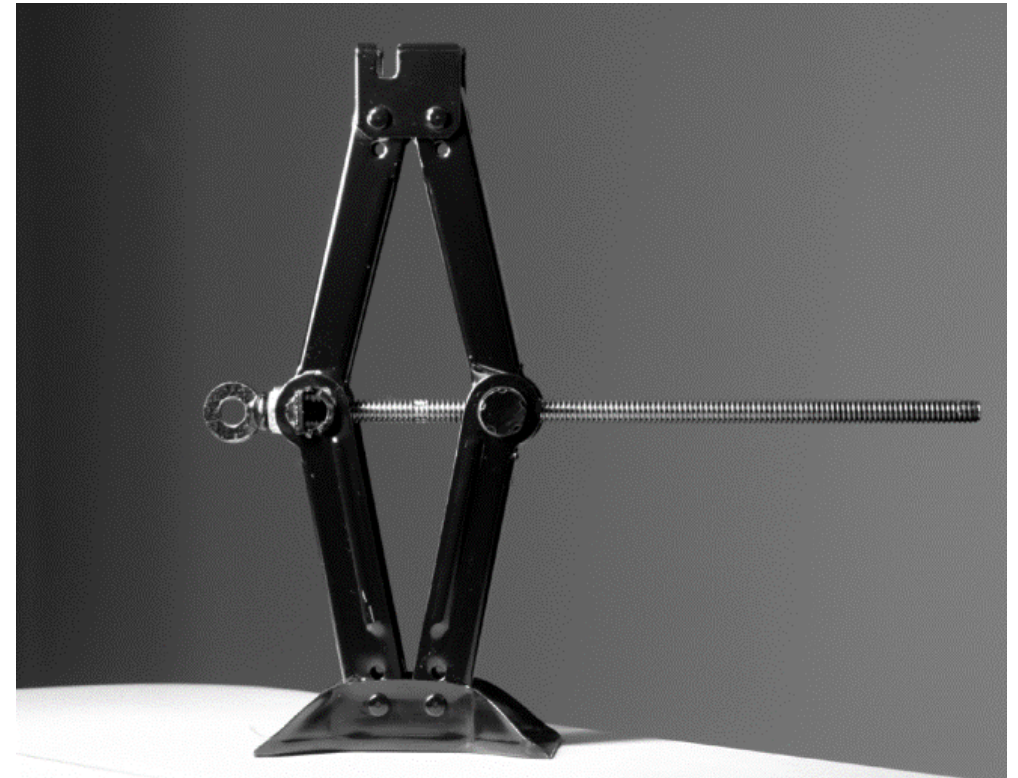
# Electric Actuators

- Electric motors – An electric motor is an actuator that transforms electrical energy into mechanical energy or motion.
  - DC servomotors
  - AC motors
  - Stepper motors
- Solenoids



# Mechanical Actuators

- Mechanical actuators convert a mechanical input (usually rotary) into linear motion.
- A common example of a mechanical actuator is a screw jack.
- Mechanical actuators can produce a rotational output with the proper gearing mechanism.



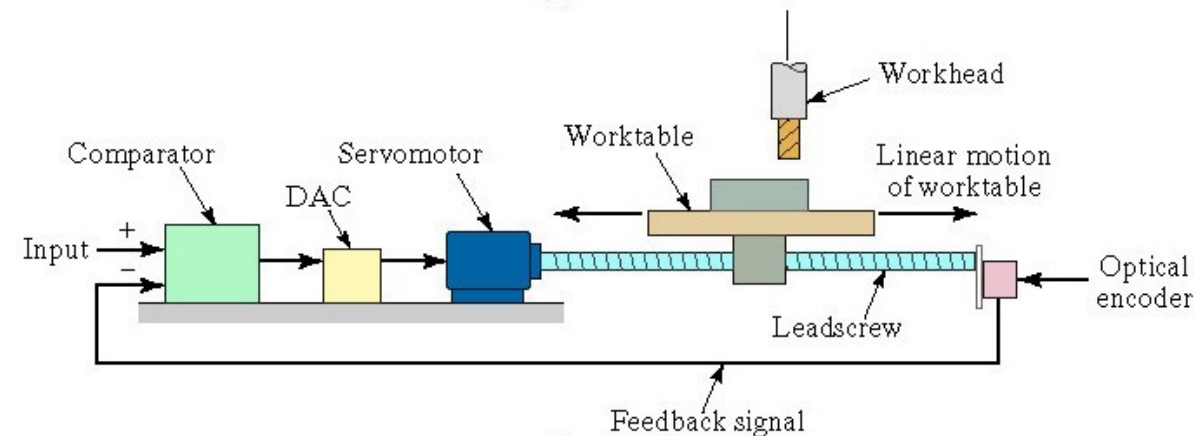
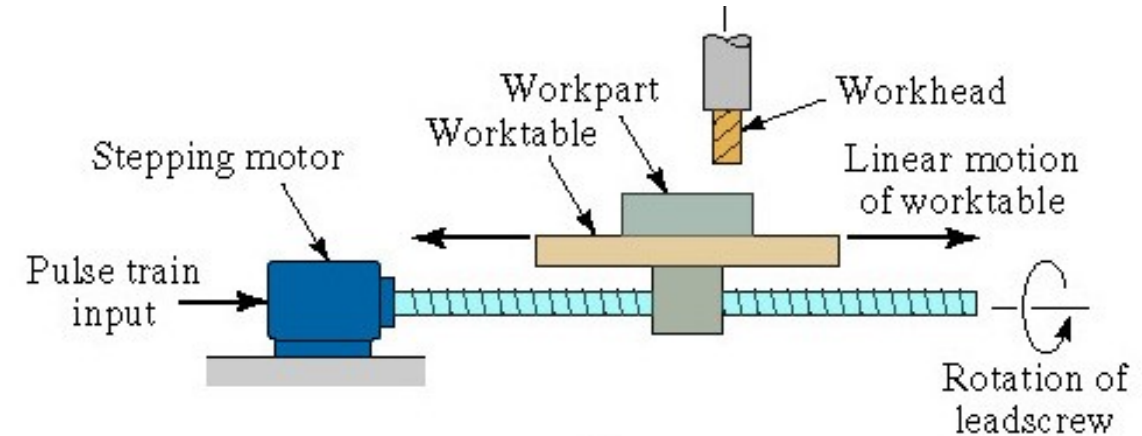
# Other Actuators

- Hydraulic actuators
  - Use hydraulic fluid to amplify the controller command signal
- Pneumatic actuators
  - Use compressed air as the driving force

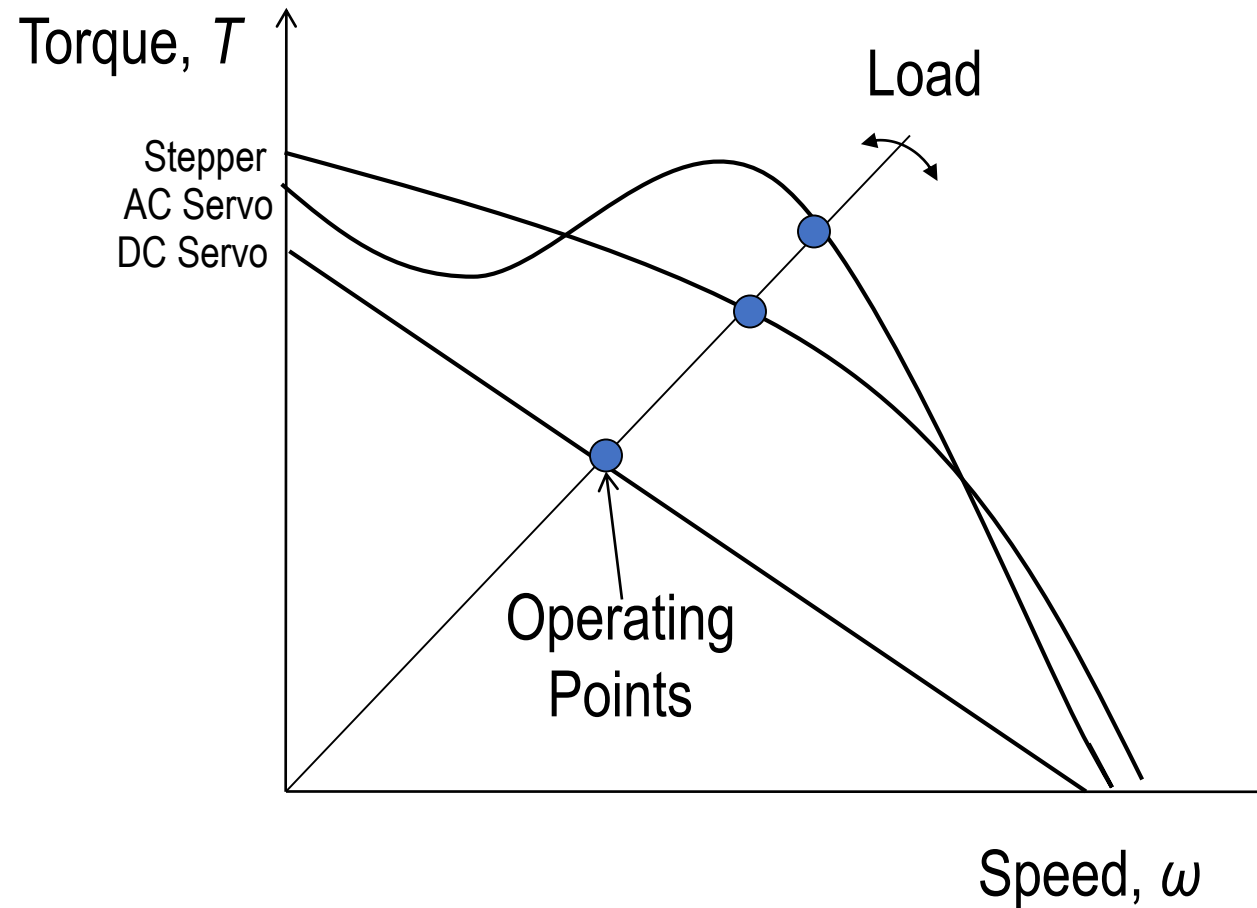


# Servo Motors and Stepper Motors

- Steppers typically use 50 to 100 pole brushless motors while typical servo motors have only 4 to 12 poles.
  - A pole is an area of a motor where a North or South magnetic pole is generated either by a permanent magnet or by passing current through the coils of a winding.
- Steppers don't require encoders since they can accurately move between their many poles whereas servos, with few poles, require an encoder to keep track of their position.
- Steppers simply move incrementally using pulses [open loop] while servo's read the difference between the motor's encoder and the commanded position [closed loop], and adjust the current required to move.



# Torque-Speed Curve





# Stepper Motors

- **Step angle** is given by:  $\alpha = \frac{360}{n_s}$ 
  - where  $n_s$  is the number of steps for the stepper motor (integer)
- **Total angle** through which the motor rotates is given by:  $A_m = n_p \alpha$ 
  - where  $n_p$  = number of pulses received by the motor.
- **Angular velocity** is given by:  $\omega = \frac{2\pi f_p}{n_s}$ 
  - where  $f_p$  = pulse frequency
- **Speed of rotation** is given by:  $N = \frac{60 f_p}{n_s}$

# Example

- A stepper motor has a step angle =  $3.6^\circ$ .
  1. How many pulses are required for the motor to rotate through ten complete revolutions?
  2. What pulse frequency is required for the motor to rotate at a speed of 100 rev/min?

# Solution

$$(1) 3.6^\circ = 360 / n_s; \quad 3.6^\circ (n_s) = 360; \quad n_s = 360 / 3.6 = 100 \text{ step angles}$$

$$(2) \text{ Ten complete revolutions: } 10(360^\circ) = 3600^\circ = A_m$$

$$\text{Therefore } n_p = 3600 / 3.6 = 1000 \text{ pulses}$$

Where  $N = 100 \text{ rev/min}$ :

$$100 = 60 f_p / 100$$

$$10,000 = 60 f_p$$

$$f_p = 10,000 / 60 = 166.667 = 167 \text{ Hz}$$

# Summary

- A sensor is a device that receives and responds to a signal.
  - This signal must be produced by some type of energy, such as heat, light, motion, or chemical. Once a sensor detects one or more of these signals, it converts it into an analog or digital representation of the input signal.
- A transducer is a device which converts one form of energy into another.
  - Transducers are used in all aspects of life to measure changes in the environment, to enhance everyday applications, and to learn more about the world around us.
- An actuator is a device that converts energy into motion.
  - Therefore, it is a specific type of a transducer. When the output of the transducer is converted to a readable format, the transducer is called a sensor.

# Common Sensors and Transducers

Quantity being Measured	Input Device (Sensor)	Output Device (Actuator)
Light Level	Light Dependant Resistor (LDR) Photodiode Photo-transistor Solar Cell	Lights & Lamps LED's & Displays Fibre Optics
Temperature	Thermocouple Thermistor Thermostat Resistive Temperature Detectors	Heater Fan
Force/Pressure	Strain Gauge Pressure Switch Load Cells	Lifts & Jacks Electromagnet Vibration

# Common Sensors and Transducers

Quantity being Measured	Input Device (Sensor)	Output Device (Actuator)
Position	Potentiometer Encoders Reflective/Slotted Opto-switch LVDT	Motor Solenoid Panel Meters
Speed	Tacho-generator Reflective/Slotted Opto-coupler Doppler Effect Sensors	AC and DC Motors Stepper Motor Brake
Sound	Carbon Microphone Piezo-electric Crystal	Bell Buzzer Loudspeaker