# Sensors

A high-level overview.

# Sensors

Anything that transduces physical characteristic to electrical information.

- Specifically discussed here:
  - Signals and op-amps for signal conditioning (brief review)
  - Terminology used to characterize and specify sensor performance
  - Commonly used sensors in mechatronics
  - Interfacing/signal conditioning circuits for sensors

# Sensors - Introduction

- Primary purpose of a sensor and its associated circuitry is to produce a measurable electrical signal correlated to the quantity it is intended to measure, also called measurand.

- Sensors are a category of transducer, a generic term used for devices that transform energy from one form to another.

- The job of the sensor is to translate a single physical parameter into a digital voltage, an analog voltage, or a voltage signal whose variations in the time encode its output.

# Sensor performance characteristics

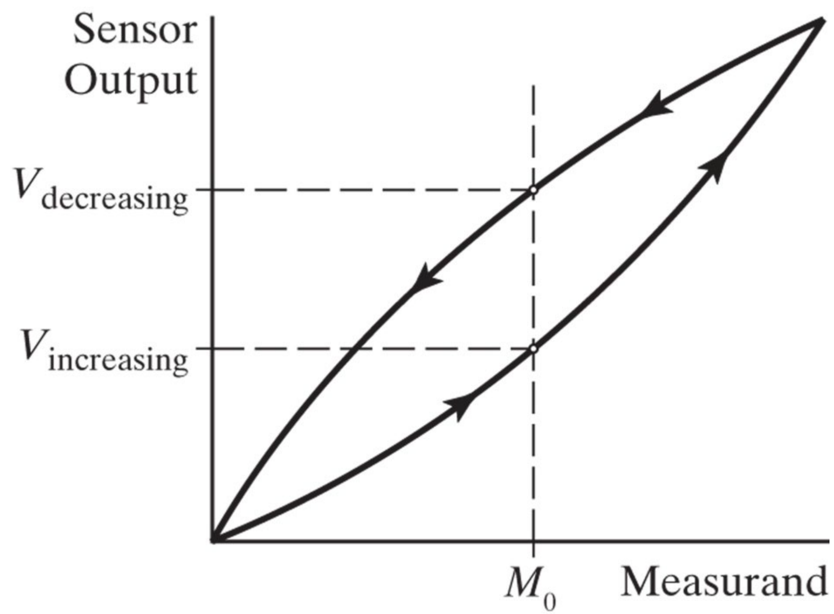
- **Transfer function:** Functional relationship between physical input and electrical output, presented by  a formula or a graph.
- **Sensitivity:** Ratio between change in output electrical signal to a given change in input physical signal (like a derivative of the transfer function).
- **Span or dynamic range:** Range of physical signals which may be converted to electrical signals by the sensor. Wide dynamic ranges sometimes get reported in units of dB.

# Sensor performance characteristics

- **Accuracy:** The largest expected error between actual and ideal output signal.
    - It is possible to substantially improve the accuracy of a sensor by calibrating it against a known standard. Sometimes there will be only offset error (single point calibration will take care of it). Sometimes there will be both offset and gain error (two point calibration will take care of it). Sometimes the output maybe nonlinear (requiring multi point calibration).
- Precision vs. Accuracy
- **Nonlinearity:** The maximum deviation from a linear transfer function over the specified dynamic range. Can be given in units of measured signal, or as a percentage of the F.S.O. (full-scale output)

# Sensor performance characteristics

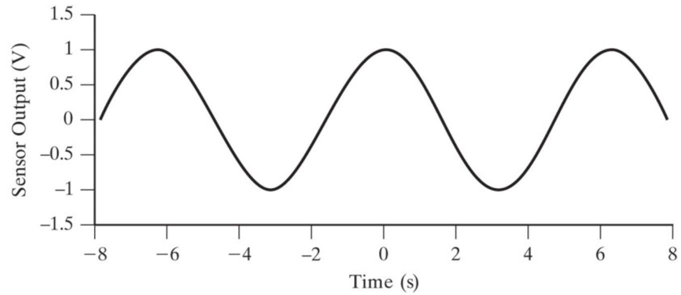
- **Hysteresis:** For a given value of the input physical signal, this is the difference between a sensor's output reading when approached from a previous reading below the new value and when approached from a previous reading above. Given in units of the physical variable.



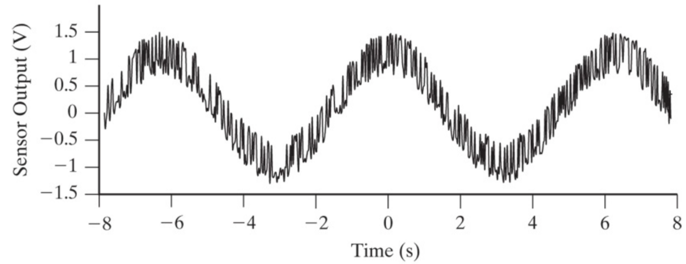
# Sensor performance characteristics

- **Noise:** A constituent of a sensor's output that does not contain information about the input physical signal. All sensors produce some noise in addition to their output signal. Many data sheets report RMS noise amplitude.



(a)

Low noise levels



(b)

High noise levels

# Sensor performance characteristics

- **Resolution:** The minimum detectable change in the measured quantity.
  - Usually in units of physical signal / sqrt(Hz). Actual resolution can be found by multiplying this with the square root of bandwidth.
- **Bandwidth:** The range of frequencies of an input physical signal that a sensor can detect.
  - All sensors have finite response times to instantaneous change in the physical signal. If a single frequency is reported, assumption is that the range starts from 0 Hz. Some sensors do not produce an output at DC (0 Hz), for them bandwidth will be stated as a range that starts from a non-zero frequency.

# Switches as sensors

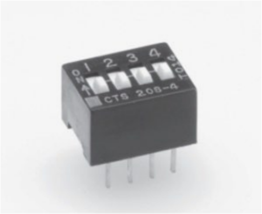
- Many types of switches exist: pushbutton, slide, toggle, rotary, knife, Hall, tactile, micro, lever, membrane, momentary, keyed, mercury, reed, etc.

(a) Toggle

(b) Slide

(c) Rocker

(d) Pushbutton

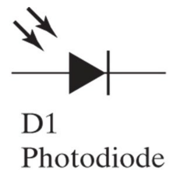


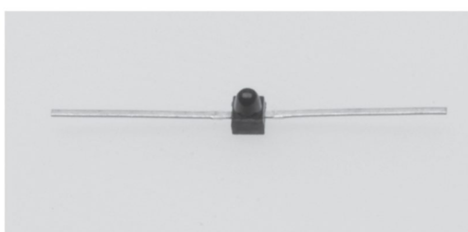
(e) DIP

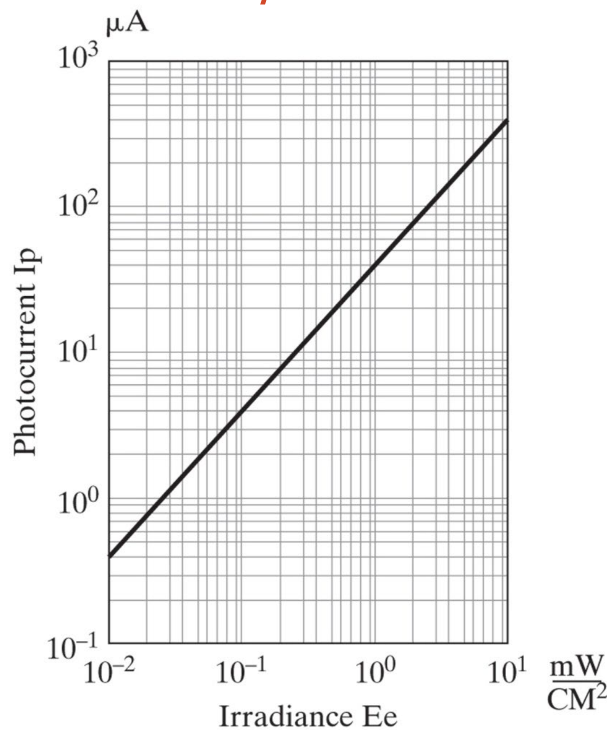
(f) Micro Switch, or Snap-Action Limit Switch

# Light sensors – photo-diodes

- Simplest light sensor. Needs to be zero biased or negative biased (usually 1V or so).

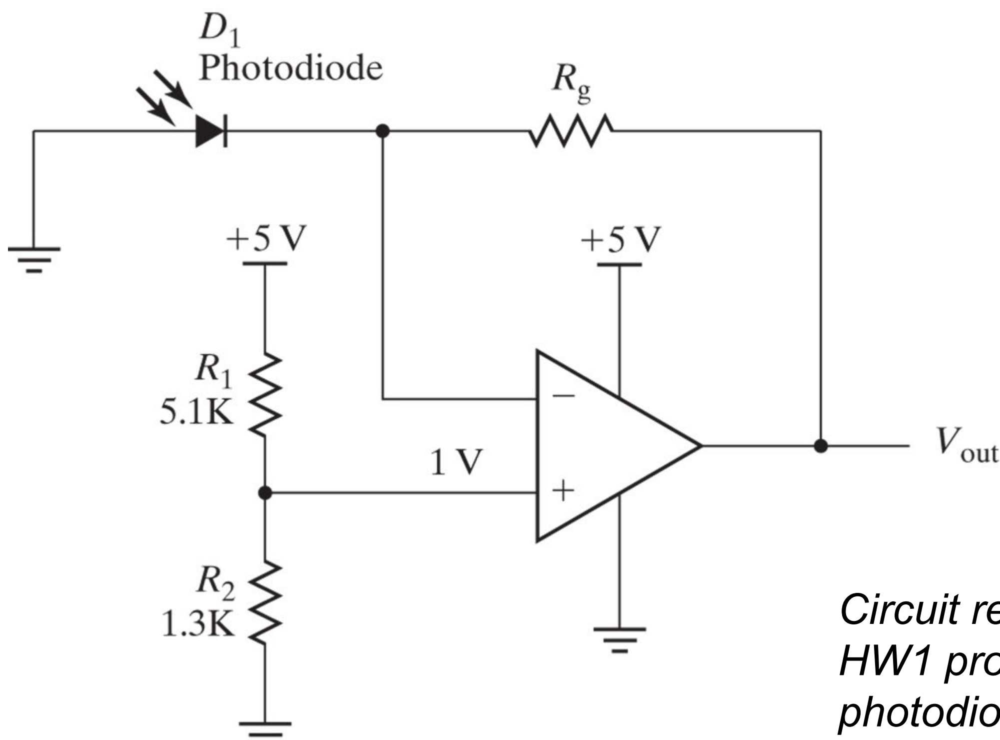




# Light sensors – photo-diodes

- A trans-resistive circuit can be used to translate the photo-current (the output of the photo-diode) into voltage.



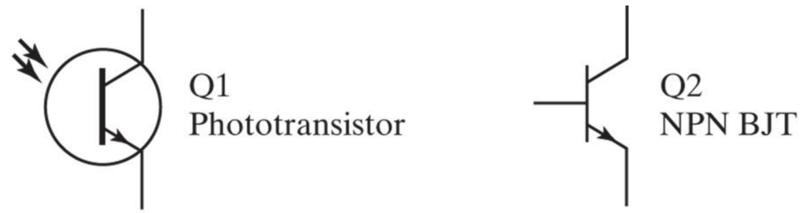

*Circuit relevant for HW1 problem with photodiode*

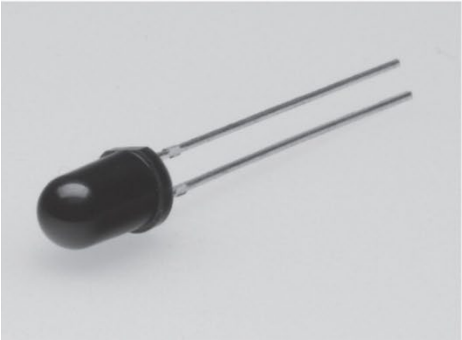
# Light sensors – photo-diodes

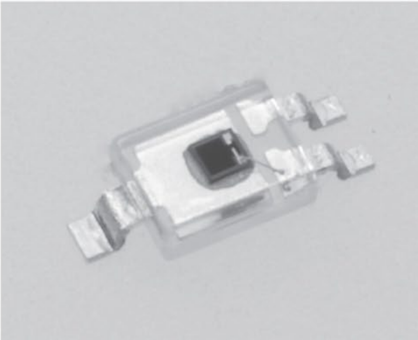
- Photo-diodes have very large dynamic range (example dynamic range for irradiance is 1000:1)
- Their output signal is very small (uA) and has a wide range. Considerable care is required for signal conditioning
- There is a small amount of current flow even when there is no light within the sensitivity range of the photo-diode (called dark current). It is temperature related and increases significantly with temperature.
- Response times of photo diodes are impressively quick. Example rise and fall time value is 50ns.
- Used very commonly in high speed applications (fiber-optic communications) and IR remote controls.

# Light sensors – photo-transistors

- Photo transistors provide an alternative when photo-diodes' low sensitivity becomes a problem.
- Much higher current outputs, but over a much narrower dynamic range, and with much slower response times



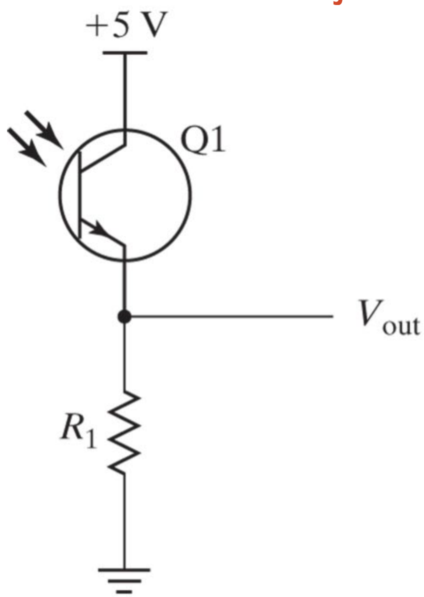


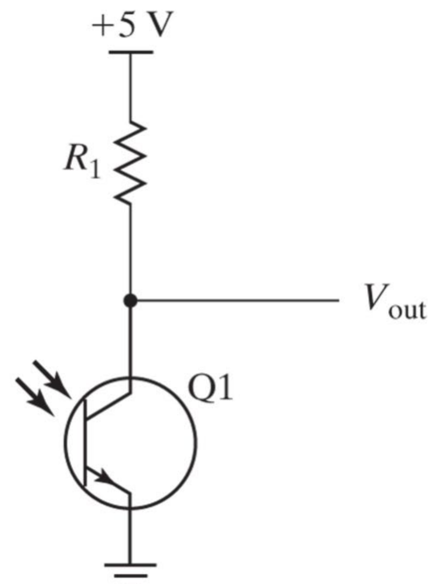
 

# Light sensors – photo-transistors

- If linearity of the output voltage is not a requirement, relatively simple circuits can ensure simple operation for: detecting whether a light is on or off, whether an object is in close proximity to a sensor, whether a beam of IR light is bouncing off a white object or black object.

Sourcing configuration

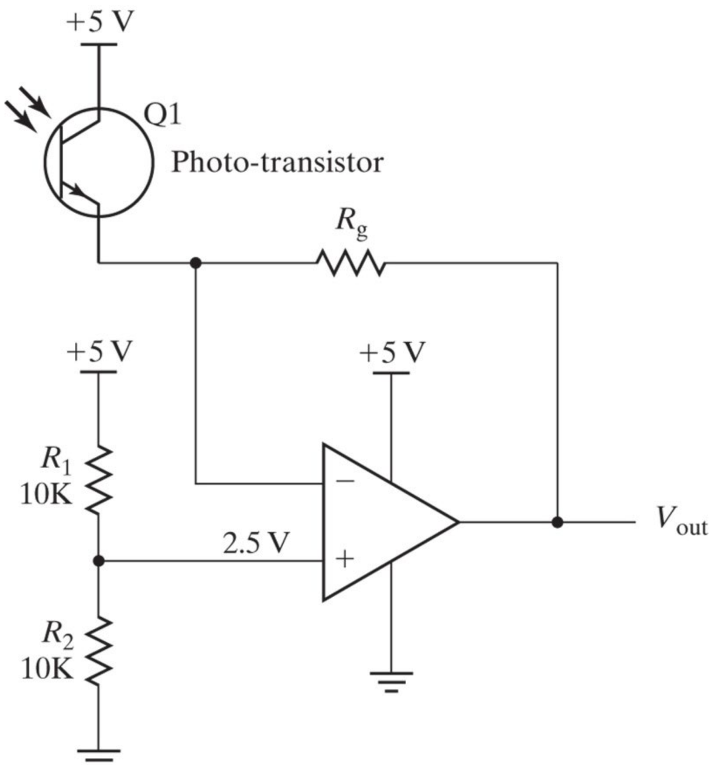


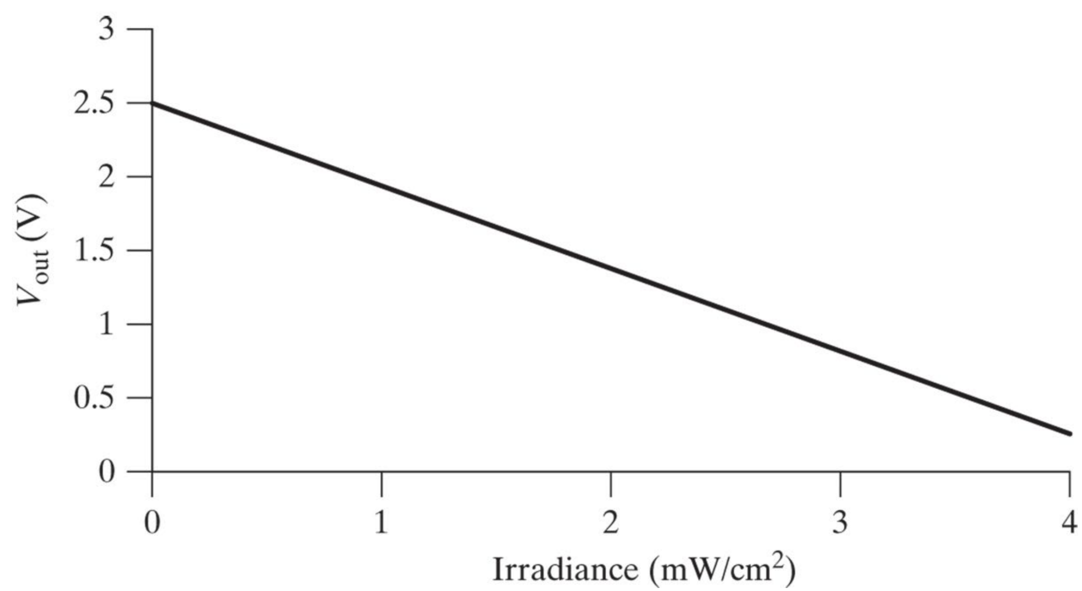




Sinking configuration

# Light sensors – photo-transistors

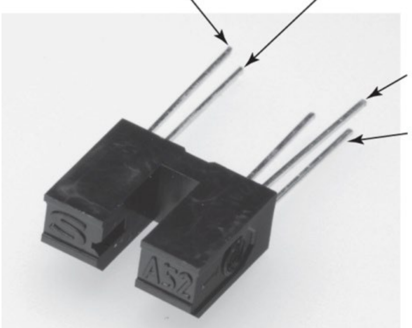
- For accurate measurement of irradiance, an interface circuit is required to ensure linear output. A trans-resistive circuit again is a good option.



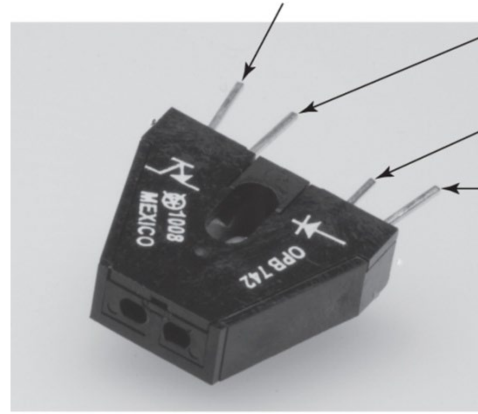



# Light sensors: emitter-detector pair modules

- Photo-transistors are often paired in a single package with IR LEDs.
- One common arrangement is an opto-interrupter.
- Another common configuration is reflective optical sensor. If reflectance characteristics of the object are known, relatively short distances can be measured accurately.



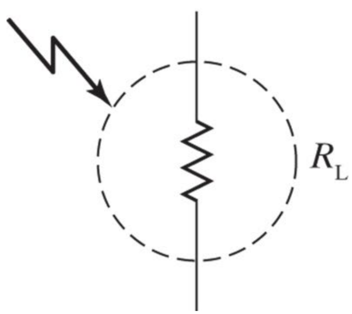

(a)

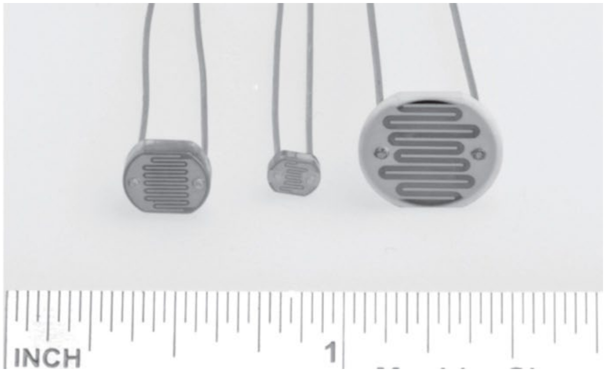



(b)

# Light sensors – photo-cells

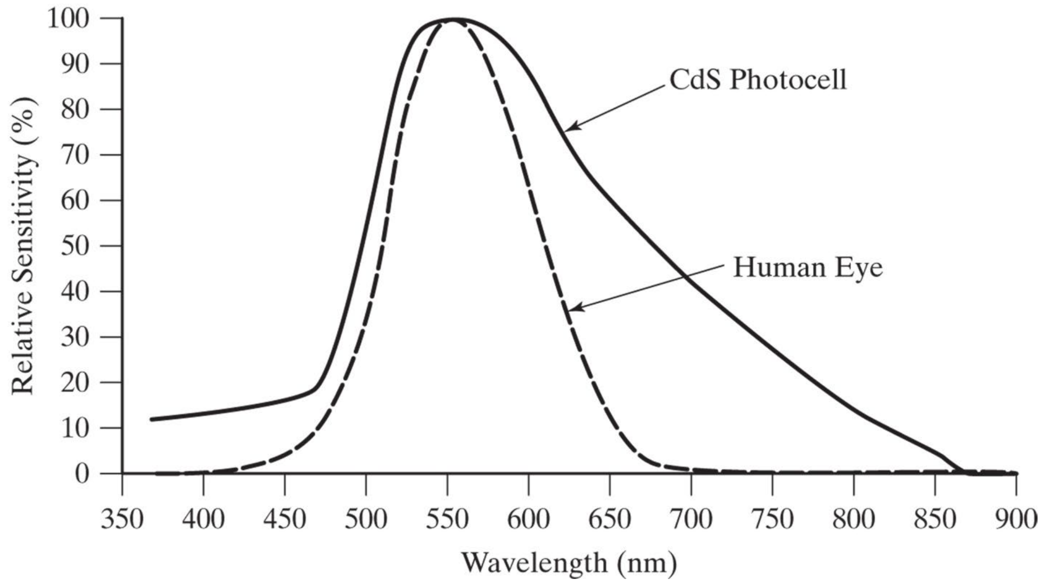
- For applications that require detecting light at wavelengths outside near IR spectrum, photo-diodes and photo-transistors may not have the appropriate spectral response.
- One common inexpensive solution is the photo-cell, whose resistance varies with amount of incident light across a spectrum detectable by human eye

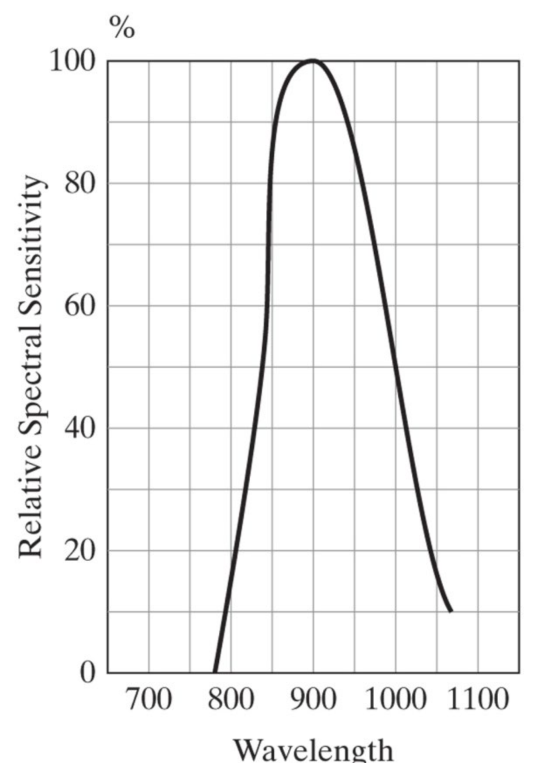


# Light sensors – photo-cells

- Spectral response of a typical CdS photo-cell compared with that of human eye (and also to that of a photo-diode, on the right).



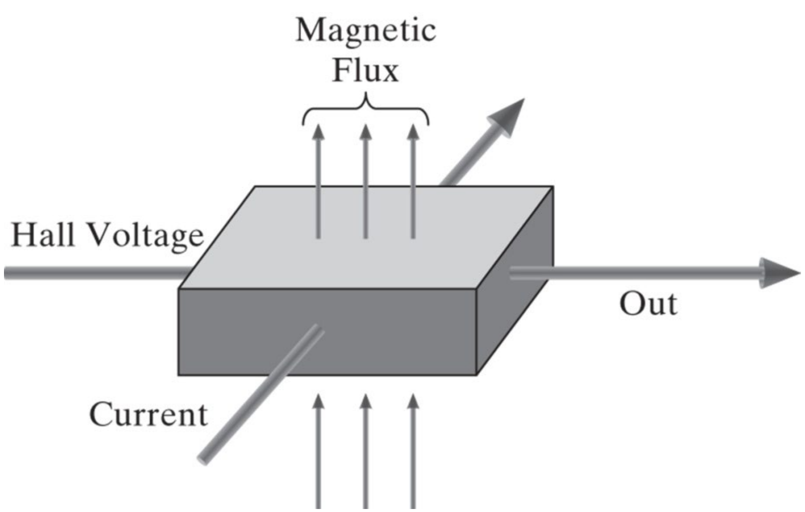



# Light sensors – photo-cells

- The weakness of photo-cells is their very slow response times. Rise time of 50ms and fall time of 25ms is typical.
- Compare to photo-diodes (10ns) and photo-transistors (10us).
- They are used in toys, street lights that automatically switch on/off, alarm systems, and light meters for photography.

# Magnetic field sensors

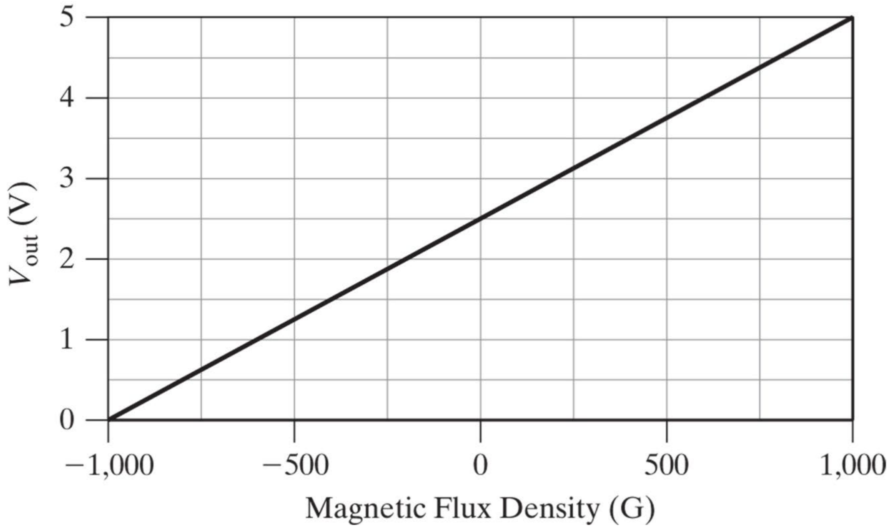
- Measurement of magnetic fields can be used to sense position, proximity or orientation.
- The Hall effect (discovered by Edwin Hall in 1879) is a phenomenon in which a magnetic field induces a measurable voltage across a conductor through which a current is flowing.



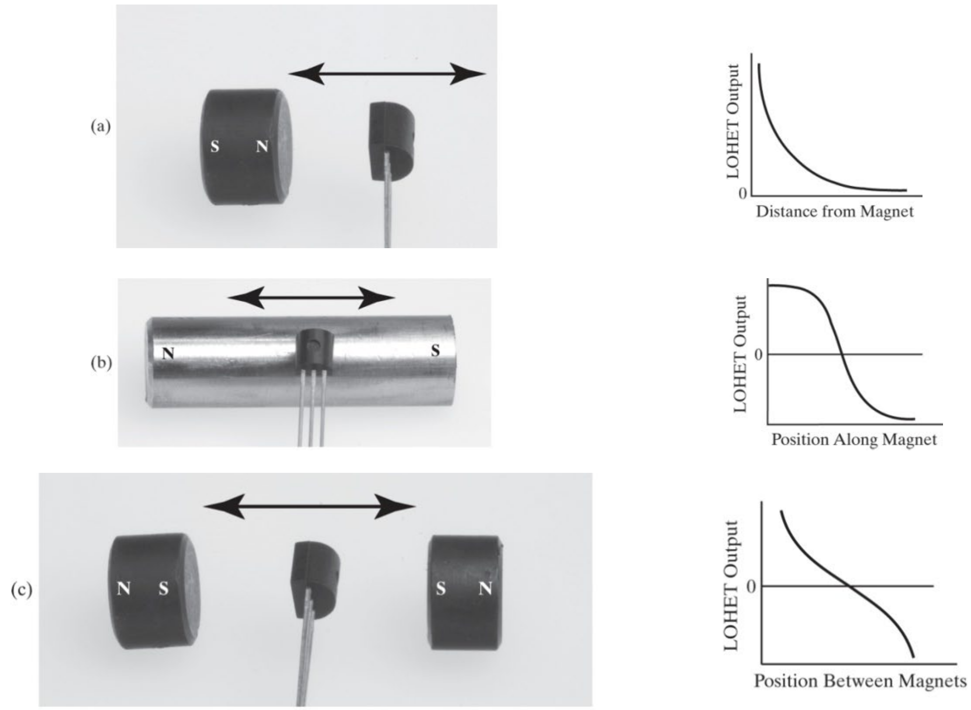
# Hall effect sensors

- Usually a Hall sensor and an amplifier is integrated in a single package, the result of which is a LOHET (linear output Hall effect transducer).
- Allegro A1386LLHL-T Hall effect sensor

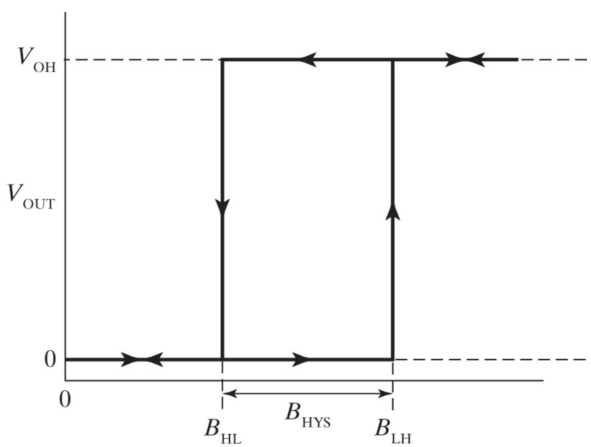
# Hall effect sensors

- Magnetic field strength is highly nonlinear with distance. The simplest arrangement does not work well.

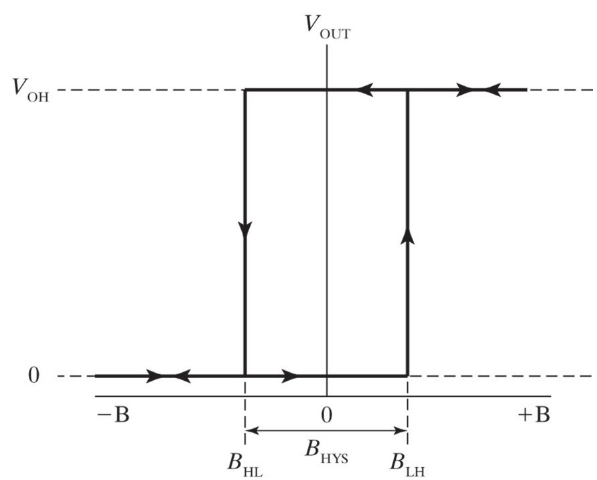


# Hall effect sensors

- Linear Hall sensors are useful in measuring angles and continuous rotation.
- Digital Hall sensors act as switches, turning on and off based on magnetic field levels. They are usually coupled with a Schmitt trigger.



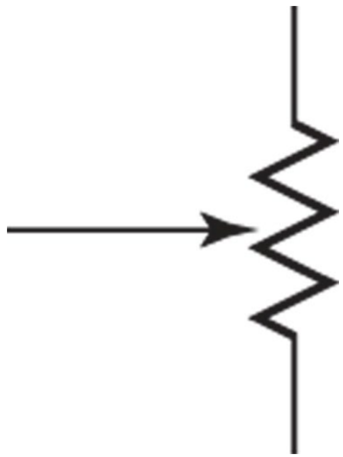
(a) Unipolar



(b) Bipolar

# Position sensors

- They measure distance from a sensor or the distance that something moved. Also called displacement sensors.
- A potentiometer (pot) is the simplest position sensor

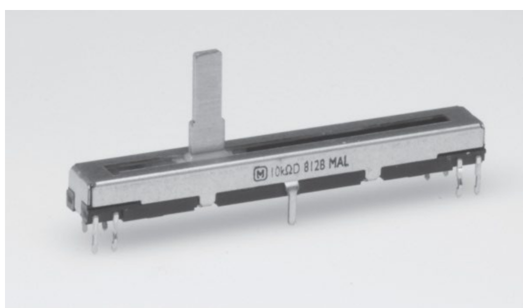


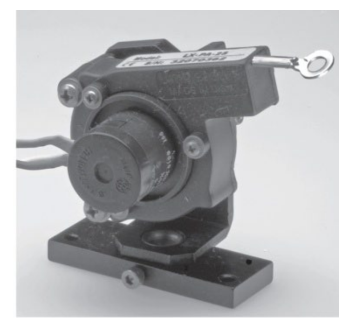
# Position sensors - Potentiometers

- They are not high-performance position sensors due to friction, and are subject to temperature effects, vibration and long-term drift resulting from wear and tear.
- They are often the first choice when the requirements are not highly demanding.


(a) Rotary potentiometer


(b) Linear potentiometer, or slide pot


(c) Joystick

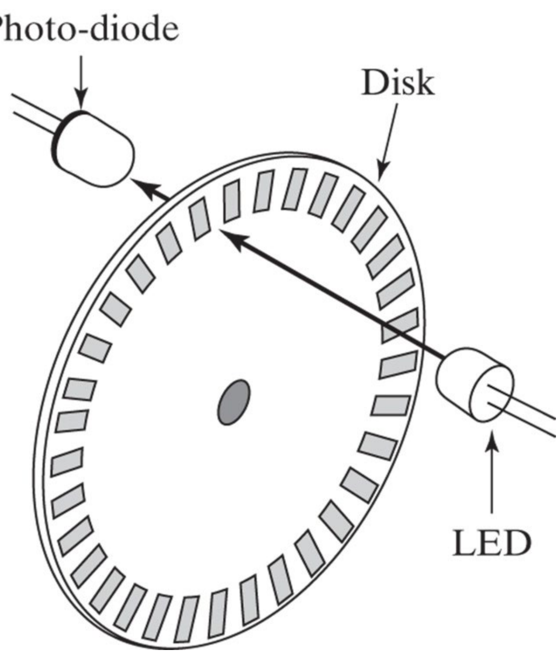

(d) Cable-driven linear displacement transducer, or string pot

# Position sensors - potentiometers

- Example application of "Midori Green Pot" potentiometer for position sensing and control
  - Monopropellant Powered Actuation – for prostheses
  - (Vanderbilt University, Dr. Michael Goldfarb)
  - (http://research.vuse.vanderbilt.edu/cim/research_monopropellant.html)

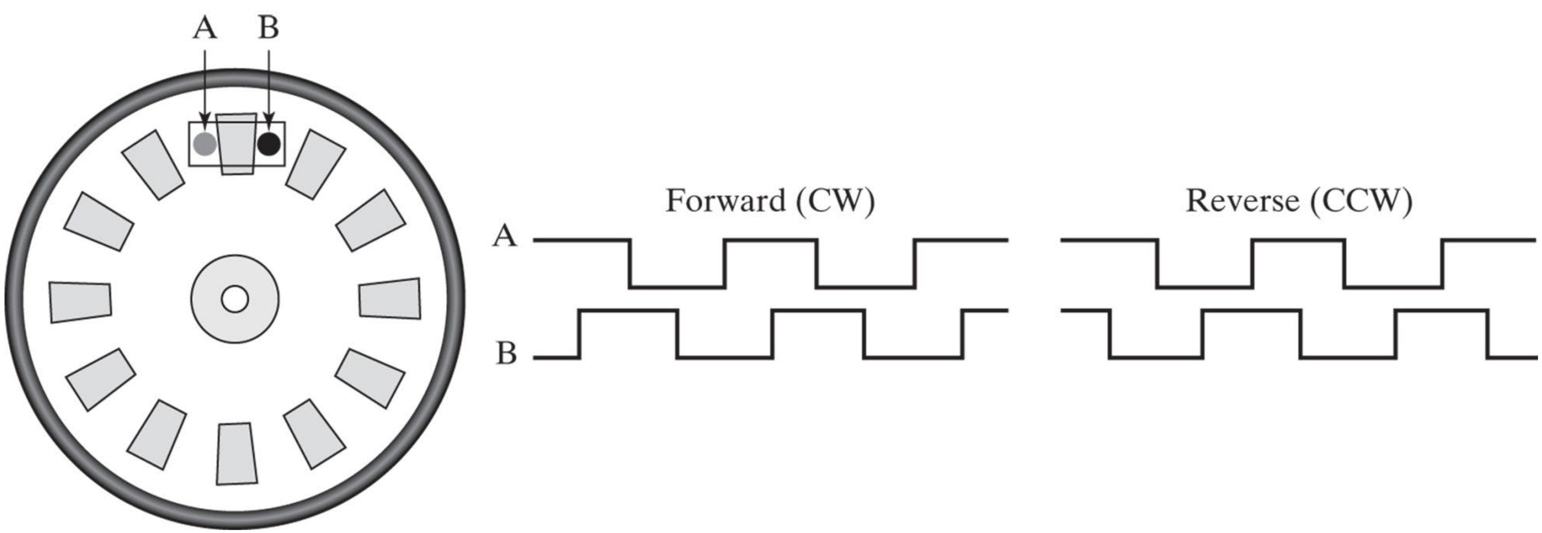
# Position sensors – optical encoders

- A very popular type of position sensor. Available in both absolute and relative versions.
- Most common configuration (incremental encoder):



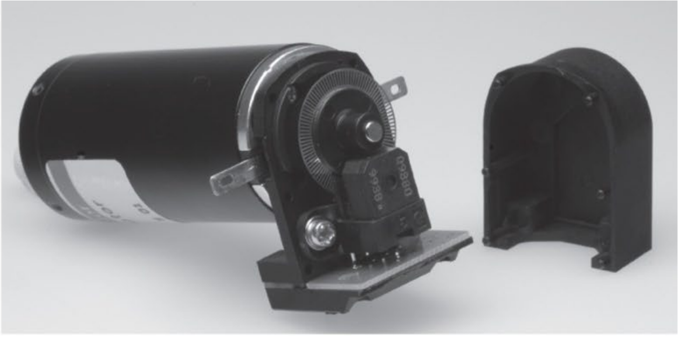
# Position sensors – optical encoders

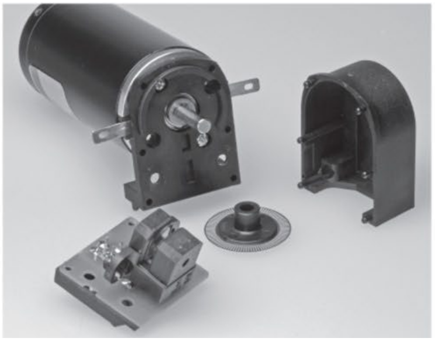
- Resolutions of 500 counts per turn or higher are readily available.
- Quadrature encoding can be used to determine direction of rotation. Also increases resolution by a factor of four as a bonus.



# Position sensors – optical encoders

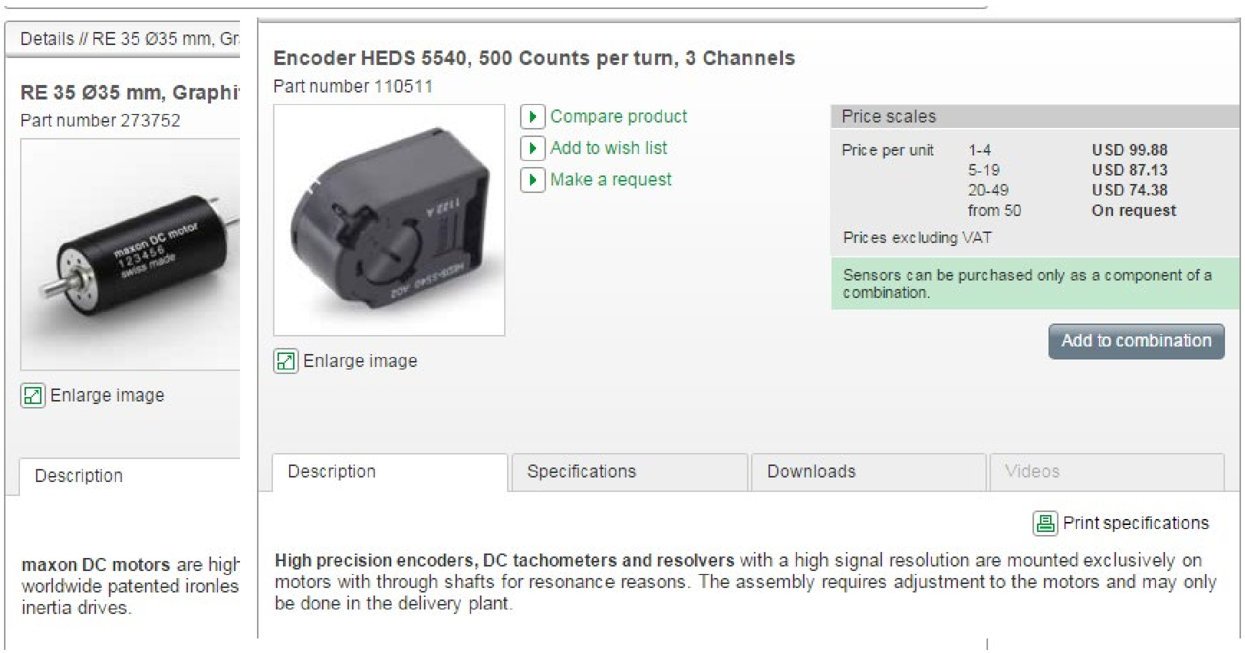
- Example optical encoder (from Maxon/Avago)





# Position sensors – optical encoders

- In many robotics applications, optical encoders are used.
- Motors can be purchased with coupled encoders.



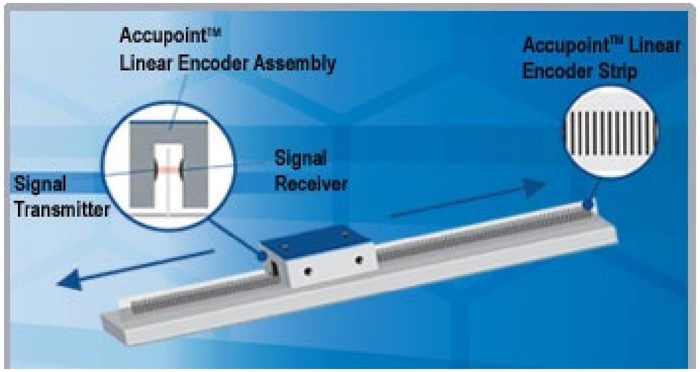
# Position sensors – optical encoders

- Digital encoders are preferred in most position measurement and control applications in industry due to
  - High resolution (very small amounts of movement can be sensed very accurately)
  - Virtually being noise-free (they have digital outputs that are robust against noise, unlike analog signals)
- There are also reflective optical encoders and magnetic encoders.

# Position sensors – optical encoders

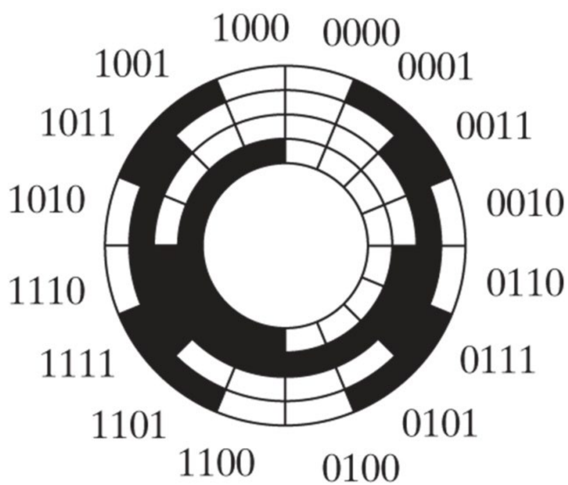
- Both rotary and linear optical encoders are available.



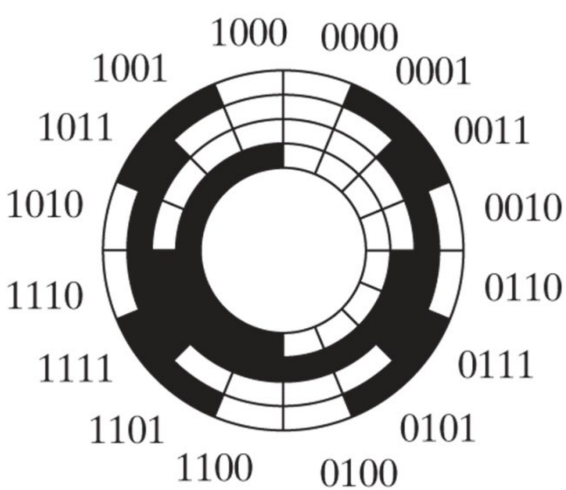
# Position sensors – optical encoders

- What if absolute position sensing is required (not incremental)?
- Absolute optical encoders have multiple tracks at separate radii, giving a unique digital code for a unique position.



# Position sensors – optical encoders

- Absolute encoders usually use Gray code encoding, instead of natural binary coding, to avoid problems that may arise from transitions in states for different tracks not happening exactly simultaneously



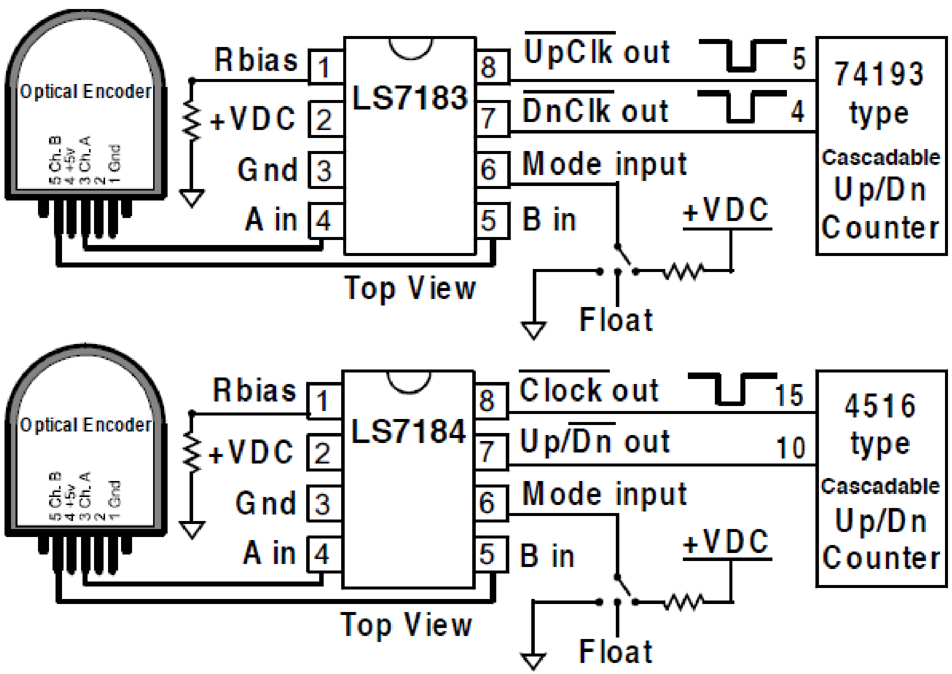

| Decimal number | Four-bit gray code | | | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 |
| 2 | 0 | 0 | 1 | 1 |
| 3 | 0 | 0 | 1 | 0 |
| 4 | 0 | 1 | 1 | 0 |
| 5 | 0 | 1 | 1 | 1 |
| 6 | 0 | 1 | 0 | 1 |
| 7 | 0 | 1 | 0 | 0 |
| 8 | 1 | 1 | 0 | 0 |
| 9 | 1 | 1 | 0 | 1 |
| 10 | 1 | 1 | 1 | 1 |
| 11 | 1 | 1 | 1 | 0 |
| 12 | 1 | 0 | 1 | 0 |
| 13 | 1 | 0 | 1 | 1 |
| 14 | 1 | 0 | 0 | 1 |
| 15 | 1 | 0 | 0 | 0 |

[http://www.emerald insight.com]

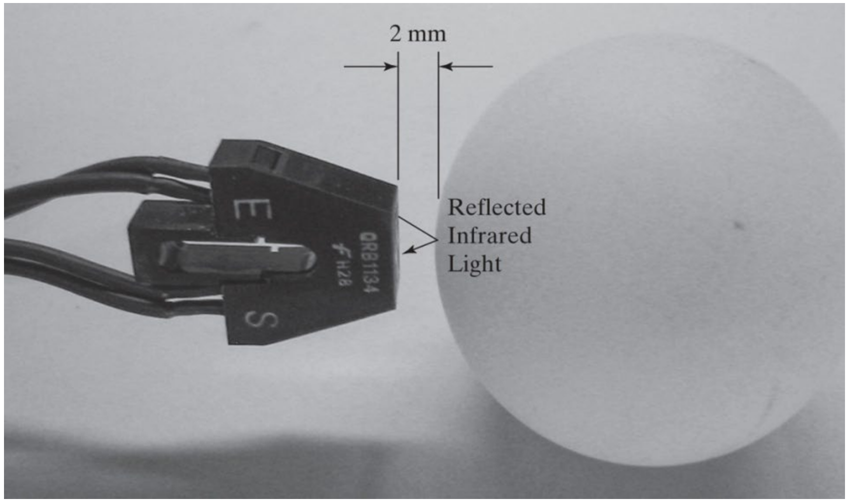
# Position sensors – decoders for incremental optical encoders

- Commercial decoders: LS7183 and LS7184
- Commercial decoder + counter: HTCL-2016

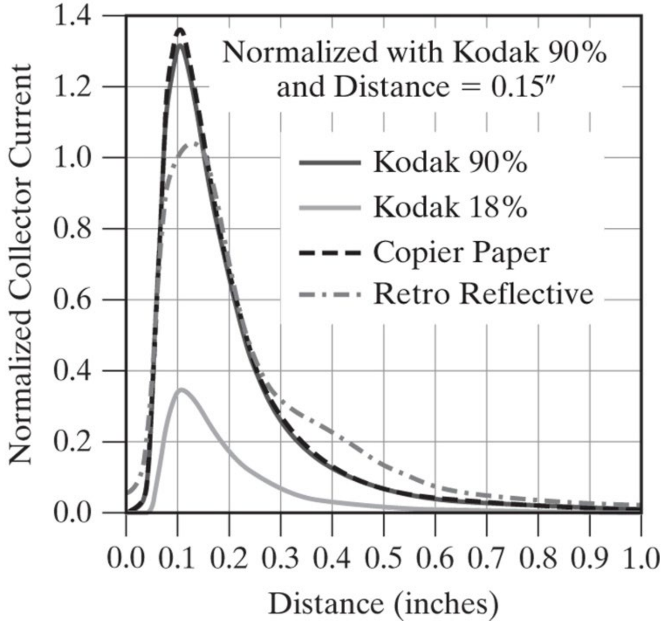


# Position sensors – reflective IR sensors

- Compact, inexpensive and useful in a wide variety of applications.
- Consistent but nonlinear response for a specific type of reflective surface.




Example response curve for OPTEK OPB700





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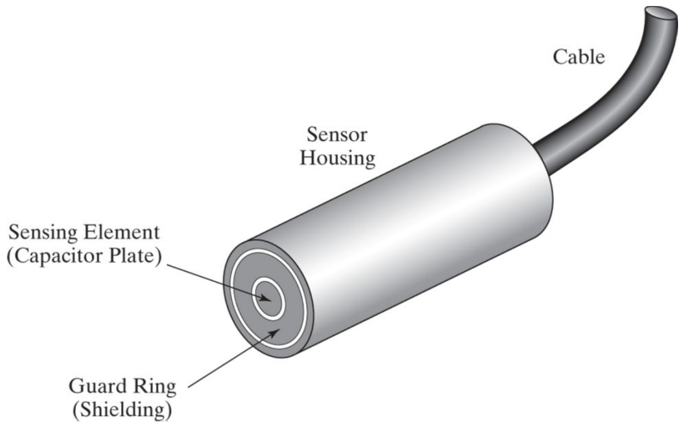
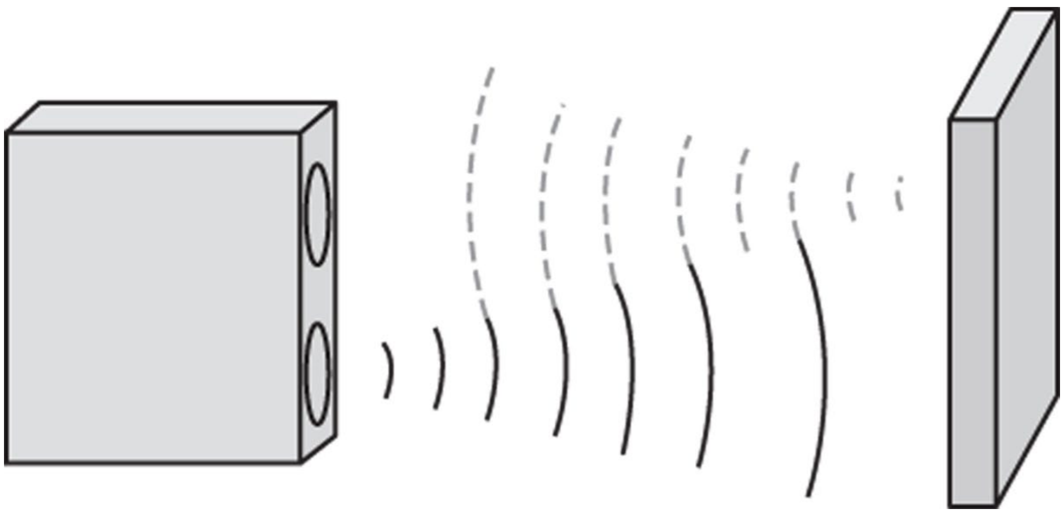
# Position sensors – capacitive displacement sensors

- When distance to an object is very small, capacitive displacement sensors provide a capability for achieving subnanometer resolution.
- Example commercial capacitive displacement sensor: less than 5mm in diameter, range of 0-10 um, 15 kHz bandwidth, 0.4nm resolution, 0.2% nonlinearity



# Position sensors – ultrasonic displacement sensors

- Ultrasonic range finders excel in larger distances, in the order of inches to meters.
- Time of flight between emission of a high frequency pulse of sound generated by a piezo or electrostatic element and the receipt of its reflection is measured.



# Position sensors – ultrasonic displacement sensors

- Examples with integrated electronics for readily conditioned output signal (either an analog voltage or a serial communication protocol)


(a) Parallax 28015 module

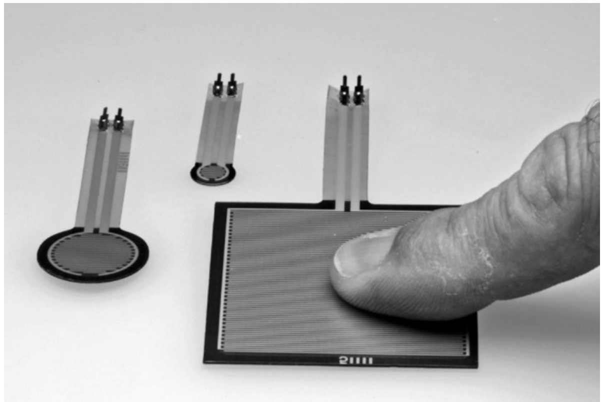
Range: 2 to 3 cm

(c) Maxbotix LV-EZ1 module

Range: 0 to 6.45m

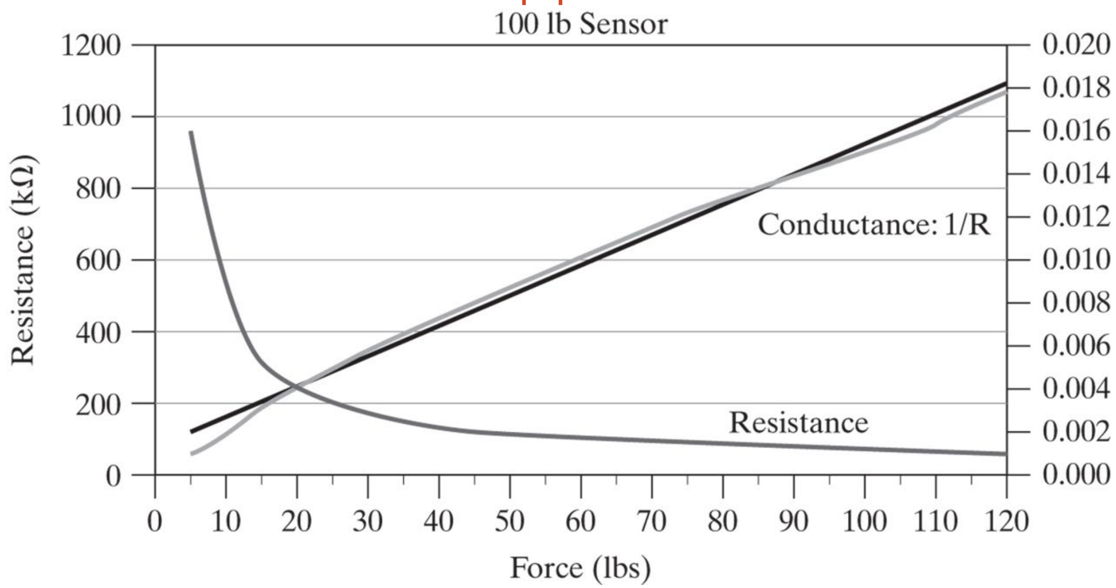
# Force sensors – force sensitive resistors

- An FSR is composed of a pressure sensitive ink sandwiched between flexible conductive layers.
- When the material is compressed, bulk resistance will be reduced.
- Often very thin and inexpensive. Example: Flexiforce sensors by Tekscan, Inc.



# Force sensors – force sensitive resistors

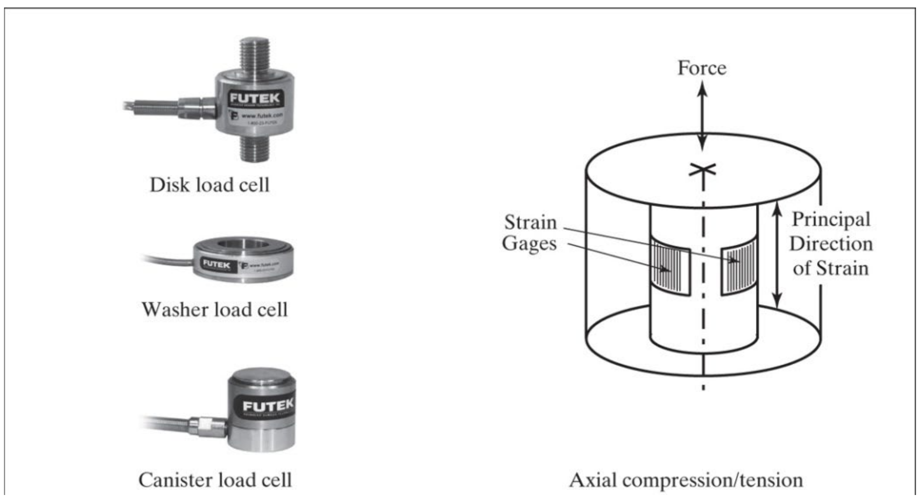
- Resistance versus force output is highly nonlinear, however conductance (1/R) versus force output is fairly linear.
- Repeatability, hysteresis and drift specifications are poor (especially when compared to load cells). They are NOT meant for instrumentation applications.

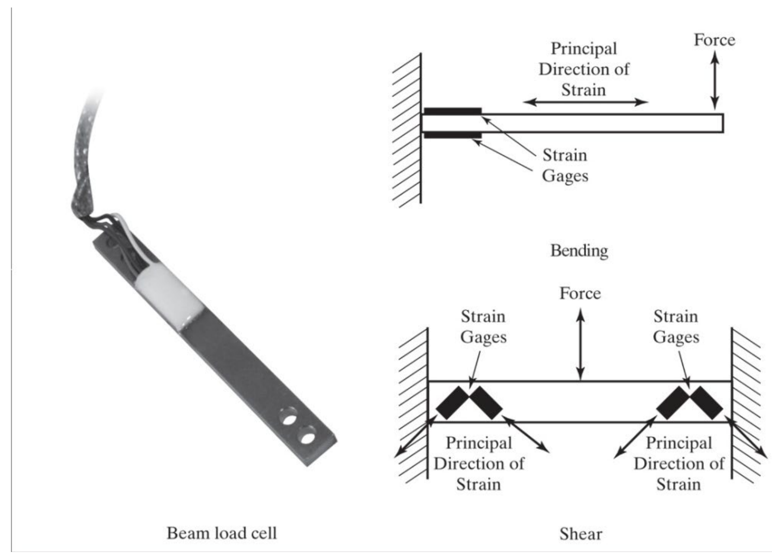


# Force sensors – load cells

- They measure force, precisely. They are usually expensive (one to several thousands of dollars)
- They contain a material that deforms under load, fitted with strain gages. All calibration and signal conditioning is taken care of so that you can read force or torque directly.



# Force sensors – load cells

- Application examples with force sensors in manufacturing (https://www.youtube.com/watch?v=4Ro6rQbePqE)

- Application examples with force sensors in haptics (https://www.youtube.com/watch?v=xQGkokPhzsg)

  (https://www.youtube.com/watch?v=Q4s__TXP9jI)