Aalto-yliopisto
Sähkötekniikan
korkeakoulu

Position, displacement and motion

ELEC-E5710 Sensors and Measurement Methods

J. Fraden, *Handbook of Modern Sensors,* Chapters 6, 7
J. S. Wilson, *Sensor Technology Handbook,* Chapter 15
https://www.te.com/usa-en/products/sensors.html

Position sensors

- Examples of use
  - Automotive
  - Power generation
  - Sub-sea / maritim
  - Hydraulics
  - Medical
  - Process controls
  - Factory automation
  - Security systems
  - Military / aerospace

Selecting position measuring sensor

- 1. How large is the displacement and of what type (linear, circular)?
- 2. What resolution and accuracy are required?
- 3. What is the measured object made of (metal, plastic, fluid, ferromagnetic, etc.)?
- 4. How much space is available for mounting the detector?
- 5. How much play is there in the moving assembly and what is the required detection range?
- 6. What are the environmental conditions (humidity, temperature, sources of interference, vibration, corrosive materials, etc.)?
- 7. How much power is available for the sensor?
- 8. How much mechanical wear can be expected over the lifetime of the machine?
- 9. What is the production quantity of the sensing assembly (limited number, medium volume, mass production)?
- 10. What is the target cost of the detecting assembly?

Technologies / Sensor types

- Limit switches
- Resistive position transducers (potentiometers)
- Magnetic sensors (Hall effect / magneto-resistive)
  - Inductive displacement sensor
  - LVDT, Linear variable differential transducer
  - Hall effect position sensors
  - Magnetoresistive position sensor
- Ultrasonic sensors
- Proximity sensors
- Photoelectric sensors
- Optical encoders
- Cable position transducer

Limit switches

- Target touches the switch causing contact / break of circuit
- Uses:
  - Identification of a target / position
  - Protection for malfunction
- Selection criteria
  - Actuator type
  - Circuitry
  - Ampere rating
  - Supply voltage
  - Housing material
  - Termination type

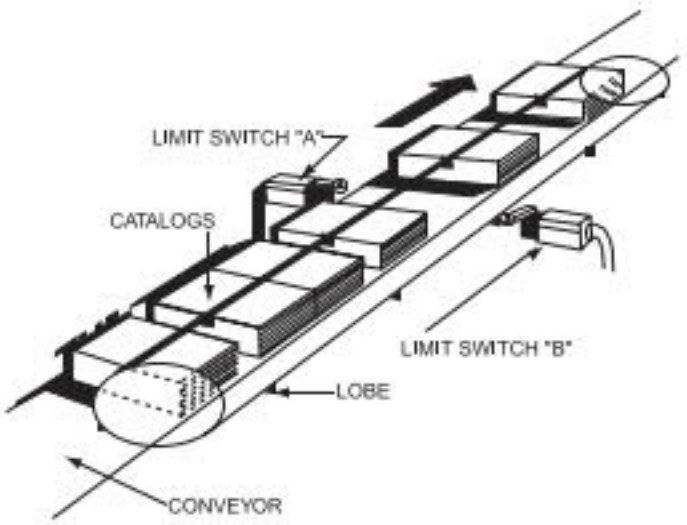


Figure 15.1.1: Limit switches on a conveyor.

Limit switches – examples of operation

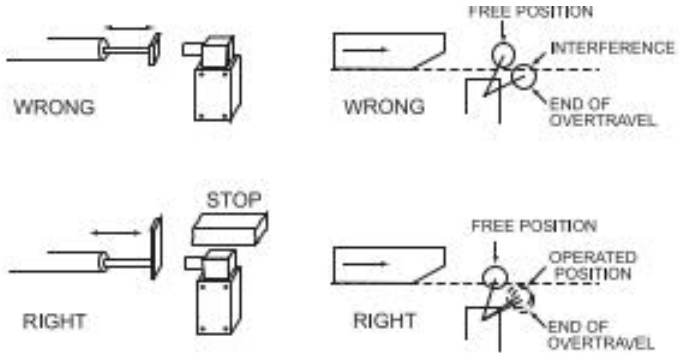


Figure 15.1.9: Operating mechanisms for limit switches should be designed so that under any operating or emergency conditions, the switch is not operated beyond its overtravel limit position. A limit switch should not be used as a mechanical stop.

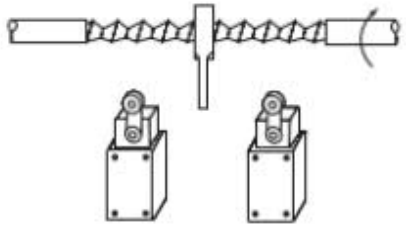


Figure 15.1.6: Where relatively slow motion operates a limit switch, you'll generally want to apply a snap-action switch.

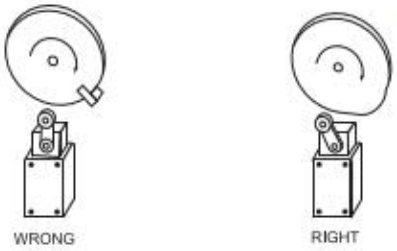


Figure 15.1.7: Where relatively fast motion operates the switch, cams should be arranged so that the switch does not receive a severe impact.

- Avoid mechanical impacts
- Limit free travel with mechanics, not the switch
- Make sure that the pulse is long enough

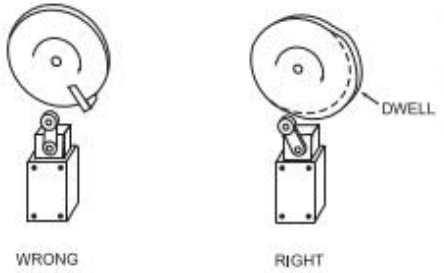
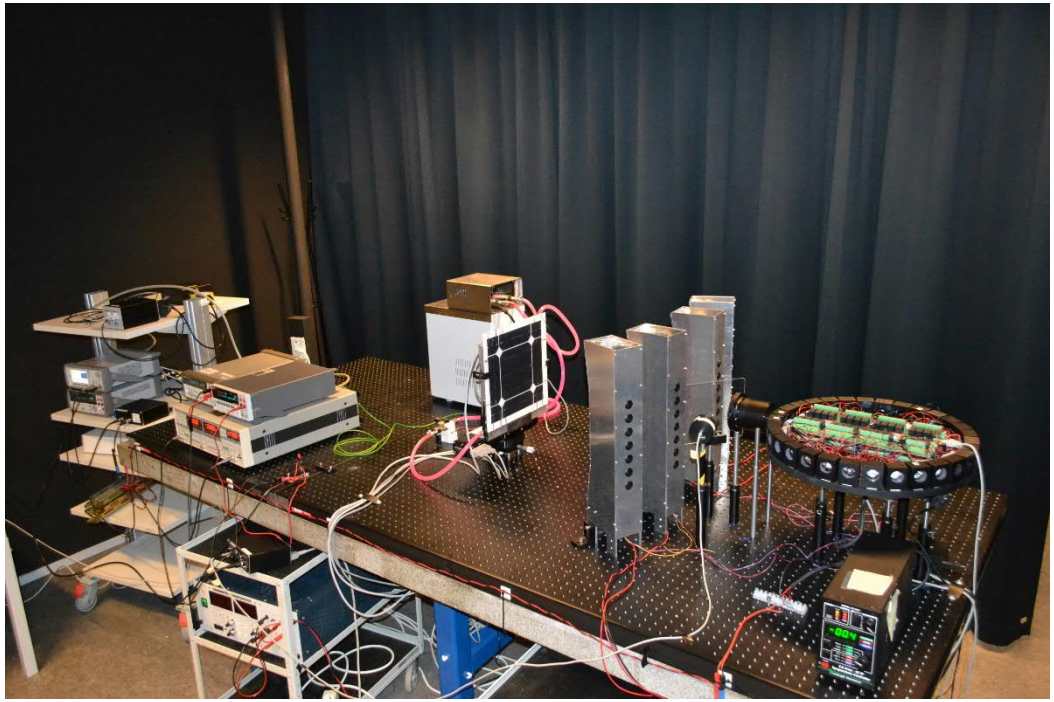


Figure 15.1.8: Where relatively fast motions are involved, cams should be designed such that the limit switch will be operated long enough to operate relays, valves, etc. as needed.

Examples of protection with limit switches

- Rotating assemblies with wires should always be protected with limit switches:
  - LED carousel
  - LED scanner
- Software crash may damage wiring



Resistive position transducers (potentiometers)

- Rotating / linear
- + low cost
- + simple operational and application theory
- + inherent absolute measurement even through power-off cycles
- + robust EMI emission/susceptibility performance.
- - Disadvantages include eventual wear-out due to the sliding contact wiper

Potentiometers – output types

- Resistor with varying middle slide
- Mostly used as voltage divider
- $U_{out} = U_{in}\, R_1 / (R_1+R_2)$
- Alternately, absolute resistor value (e.g. fuel meter, where changing resistor varies current through meter)

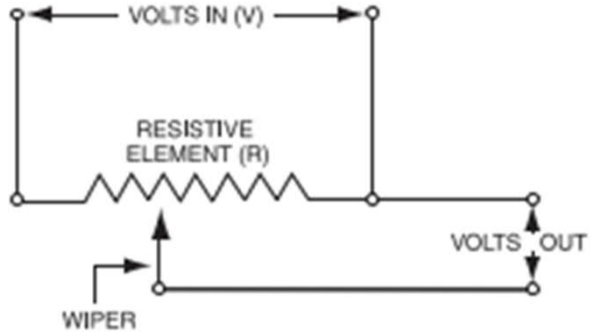
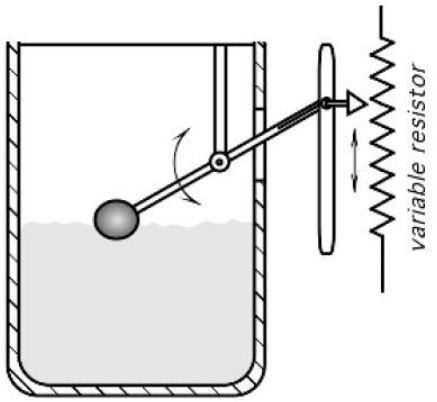


Figure 15.1.12: Potentiometer component.



Linear Displacement Sensors - Potentiometer

- Measurement range 12.5 mm – 750 mm
- Resistance 1.25 kΩ – 7.5 kΩ
- Linearity 0.04% - 1%
- Life expectancy 25 – 50 million cycles
- Resolution infinite
- Voltages up to 48 V
- Operating speed 5 – 10 m/s
- https://www.te.com/

Rotary Displacement Sensors - Potentiometer

- Range 45 – 72 000 º
- Operational voltage 3.3. – 48 V
- Output types
  - Resistance
  - 0 – 10 V
  - 4 – 20 mA
  - CAN

Cable-Actuated Position Sensors

- Rotary potentiometer operated with cable, return with spring
- Extends measurement capabilities up to 43 m!
- Analog outputs: 4-20mA, voltage divider, 0-5V, 0-10V, ±5 Vdc, and ±10 Vdc
- Digital outputs including: DeviceNet, Increnmental Encoder, and RS232
- Used e.g. in aeroplanes and International Space Station
- Light weight, compact

Figure 15.2.1: How CPTs work.

Capasitive position sensors

- Based on plate capacitor
- Object to be sensed can form one of the plates (conducting material)
- Object can also change permittivity between the plates (non-conducting material)
- May give distance to object or simply presence
- AC-operated kHz – MHz range

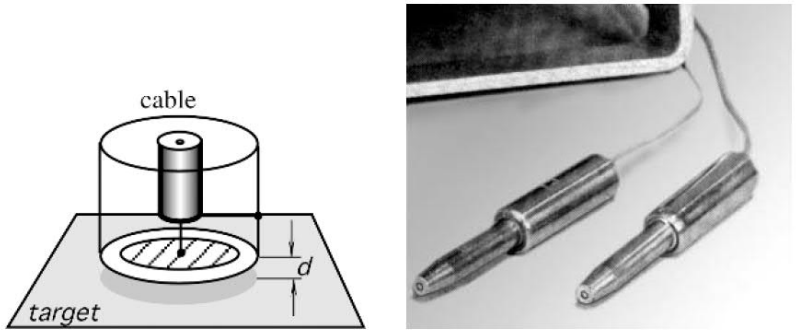


Fig. 7.6. A capacitive probe with a guard ring: (A) cross-sectional view; (B) outside view. (Courtesy of ADE Technologies, Inc., Newton, MA.)

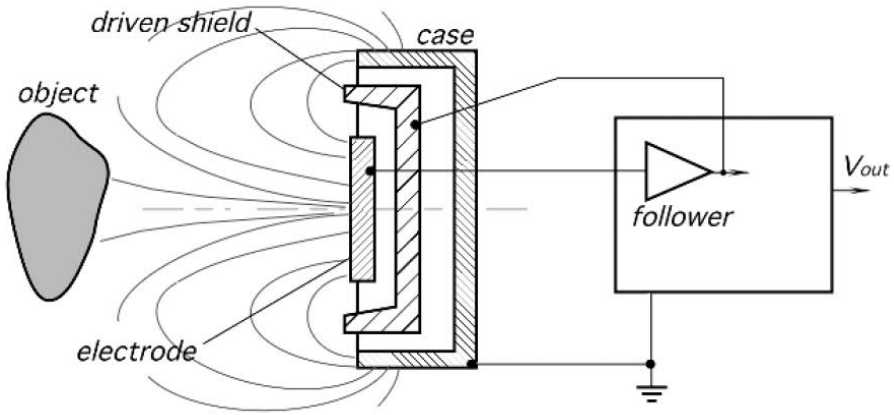


Fig. 7.7. Driven shield around the electrode in a capacitive proximity sensor.

Inductive and Magnetic Sensors

- Advantage of using magnetic field for sensing position and distance: any nonmagnetic material can be penetrated by the field with no loss of position accuracy.
- Stainless steel, aluminum, brass, copper, plastics, masonry, and woods can be penetrated
- magnetic sensors can work in severe environments and corrosive situations because the probes and targets can be coated
- Types: Hall effect, magneto-resistive, linear variable differential transformer, transverse inductive proximity sensor

linear variable differential transformer (LVDT)

- Transformer with one primary coil, and two secondary coils
- Moving core changes reluctance between the coils
- In the center position, secondary coils produce equal, but opposite signals -> zero output
- Changing the balance causes an output signal

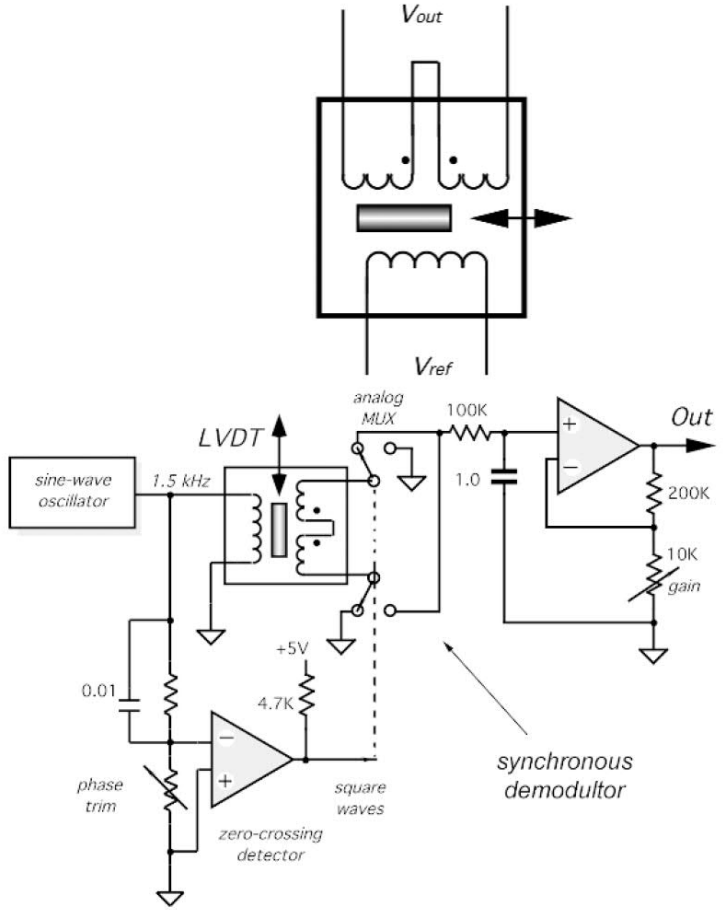
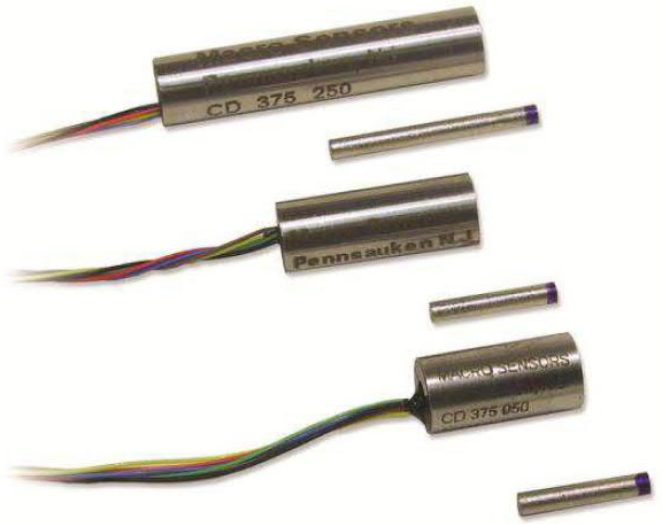


Fig. 7.10. A simplified circuit diagram of an interface for an LVDT sensor.

MINIATURE LVDT Position Sensors MACRO CD 375

- Range 0.63 mm … 25 mm
- Applications
  - Machine tools
  - Robotic grippers
  - Medical equipment
  - Valve position sensing
  - ATMs and copy machines
  - Pneumatic cylinder position
- Input Voltage 3.0 Vrms (nominal)
- Input Frequency 2.5 to 3.0 kHz
- Linearity Error < ±0.25% of FRO
- Repeatability Error < 0.01% of FSO
- Hysteresis Error < 0.01% of FSO



1) No or very little friction resistance
(2) hysteresis negligible
(3) Low output impedance
(4) Low susceptibility to noise and interferences
(5) Solid and robust
(6) infinitesimal resolution.

transverse inductive proximity sensor

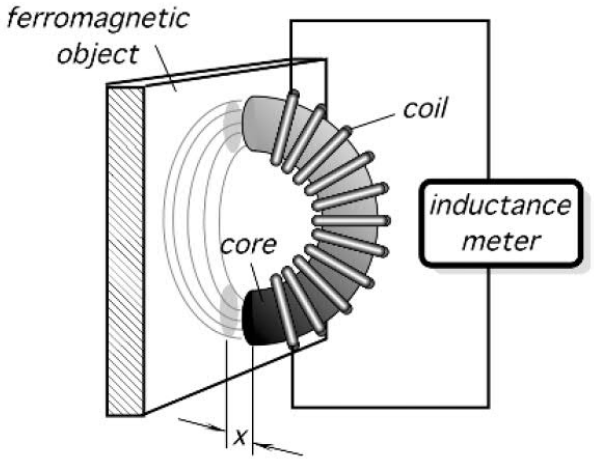


Fig. 7.12. A transverse inductive proximity sensor.

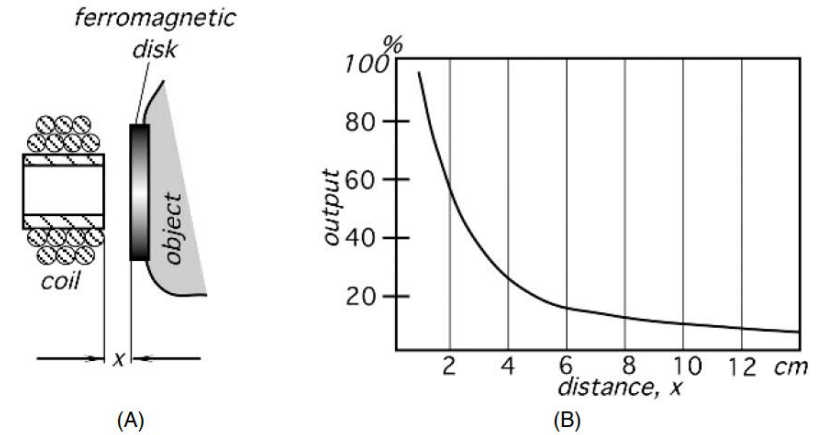
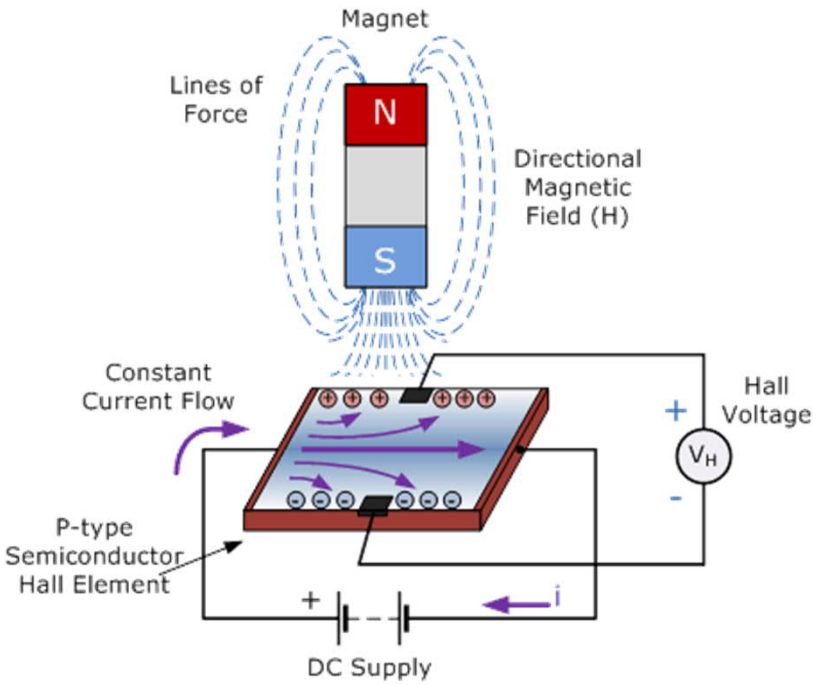


Fig. 7.13. Transverse sensor with an auxiliary ferromagnetic disk (A) and the output signal as function of distance (B).

- Detects ferromagnetic objects at short distances
- Ferromagnetic object changes the inductance of a coil which is measured
- Non-contact method, but only applicable to ferromagnetic materials (may be attached to the target), and signal is nonlinear

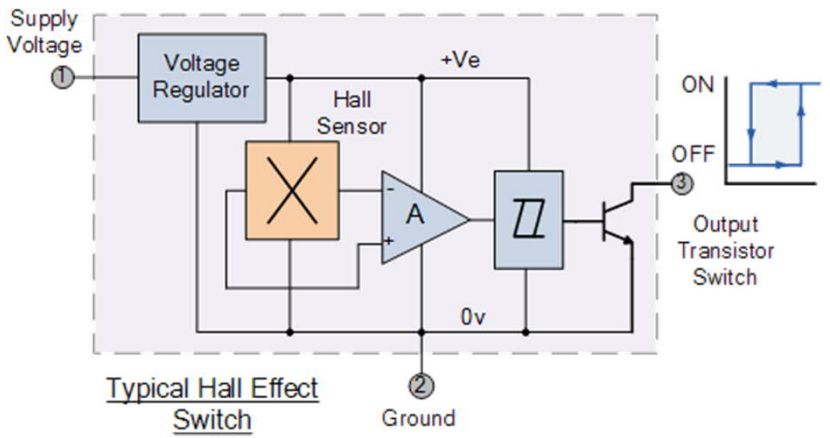
Hall effect position sensors

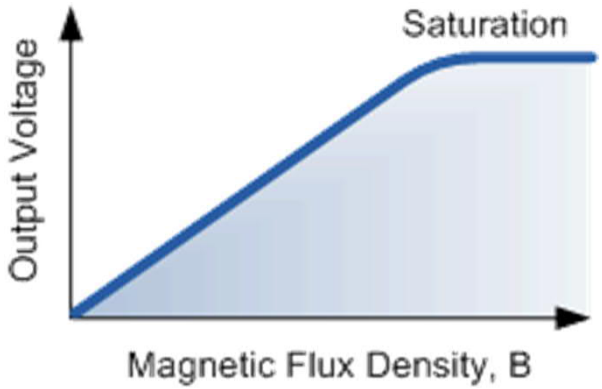
- Thin piece of rectangular p-type semiconductor material
  - gallium arsenide (GaAs),
  - indium antimonide (InSb)
  - or indium arsenide (InAs)
- Continuous current through the element
- Magnetic field causes measurable voltage perpendicular to current and magnetic field



Hall effect position sensors

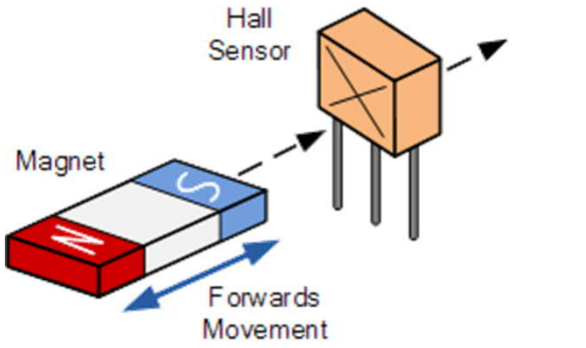
- Widely used position sensor
- CMOS technology
  - Cost effective
  - Integrated signal conditioning electronics
- Digital output with Schmitt trigger
- Analog output directly proportional to *B* and *I*, inversely proportional to thickness
- Needs magnet to detect
- Non-contact, linear

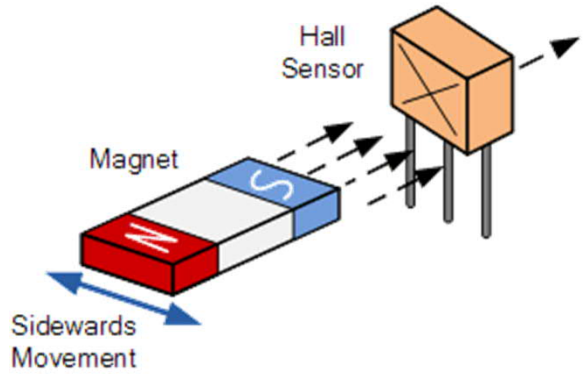




Application examples

- Head-on detection for distance
- Sidewards detection for counting magnets, e.g. in measuring rotation
- Non-contact measurement of currents in cables





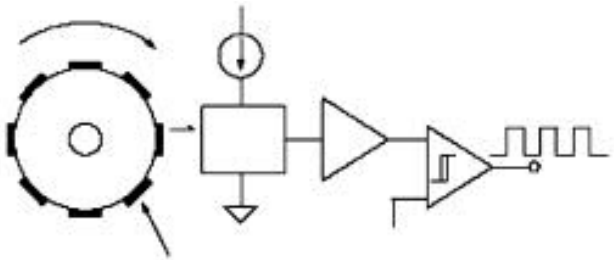


Figure 15.3.10: Hall effect sensor used as a rotation sensor.

Rotation measurent with Hall sensor

- Array of 4 Hall sensors
- Rotating magnet
- Signal conditioning electronics give orientation and angular velocity
- Non-contact, friction free measurement up to 30 000 rpm
- Array reduces sensitivity to external magnetic fields

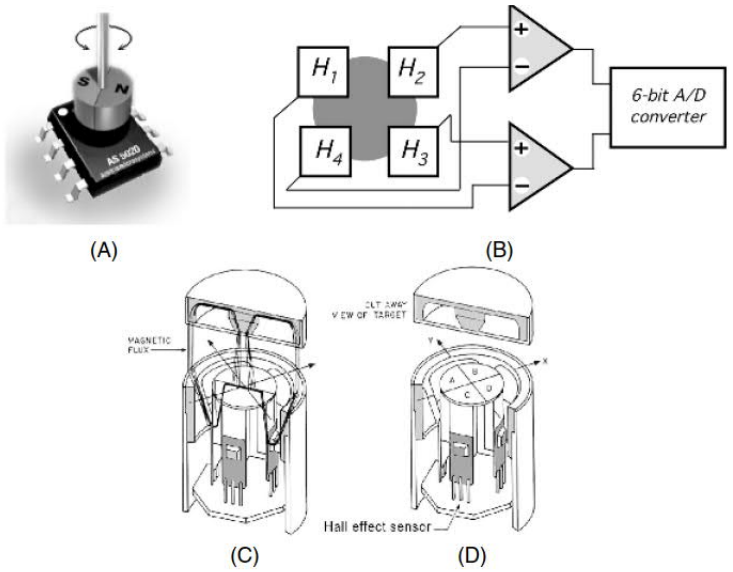


Fig. 7.17. Angular Hall sensor bridge (A) and the internal sensor interface (B) (Courtesy of Austria Micro Systems). A cut-away view (C) of the sensor with the target and the probe shows the magnetic flux paths. A cut-away view (D) shows four Hall effect sensors with four flux return paths.

Commercial Hall sensor

ANALOG DEVICES

Linear Output Magnetic Field Sensor

AD22151

FEATURES

Adjustable Offset to Unipolar or Bipolar Operation
Low Offset Drift over Temperature Range
Gain Adjustable over Wide Range
Low Gain Drift over Temperature Range
Adjustable First Order Temperature Compensation
Ratiometric to V_{CC}

APPLICATIONS

Automotive
- **Throttle Position Sensing**
- **Pedal Position Sensing**
- **Suspension Position Sensing**
- **Valve Position Sensing**

Industrial
- **Absolute Position Sensing**
- **Proximity Sensing**

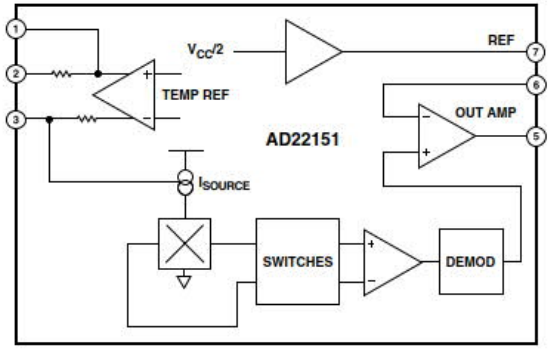
GENERAL DESCRIPTION

The AD22151 is a linear magnetic field transducer. The sensor output is a voltage proportional to a magnetic field applied perpendicularly to the package top surface.

The sensor combines integrated bulk Hall cell technology and instrumentation circuitry to minimize temperature related drifts associated with silicon Hall cell characteristics. The architecture maximizes the advantages of a monolithic implementation while allowing sufficient versatility to meet varied application requirements with a minimum number of components.

Principal features include dynamic offset drift cancellation and a built-in temperature sensor. Designed for single 5 V supply operation, the AD22151 achieves low drift offset and gain operation over –40°C to +150°C. Temperature compensa-

FUNCTIONAL BLOCK DIAGRAM



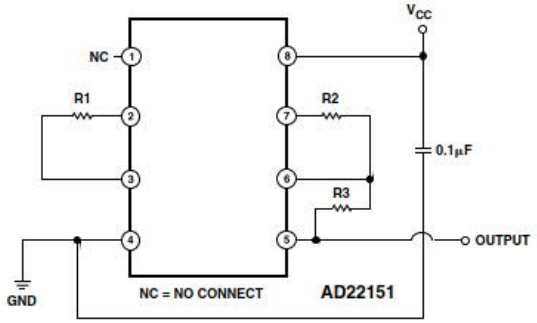


Figure 1. Typical Bipolar Configuration with Low (< –500 ppm) Compensation

Magnetoresistive sensor

- Quite similar to Hall sensor, and similar applications
- Made of a nickel-iron (Permalloy) thin film deposited on a silicon wafer and patterned as a resistive strip.
- Resistance of the thin film changes by 2 to 3% in the presence of a magnetic field.
- Bandwidth in the 1 to 5 MHz range (fast)
- Can use magnets as Hall sensors, but can also use Earth's magnetic field that is disturbed e.g. by an approaching vehicle.
- Vehicle detection up to 15 m (often used in traffic and toll way applications)

Vehicle Detection and Classification for Low-Speed Congested Traffic With Anisotropic Magnetoresistive Sensor

Bo Yang and Yiqun Lei

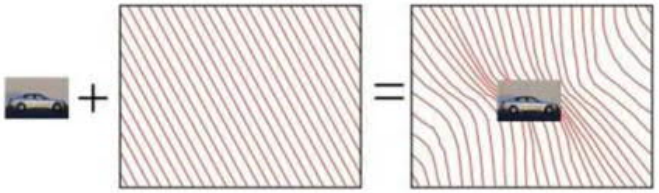


Fig. 1. The disturbance of of Earth's magnetic flux lines by a moving vehicle.

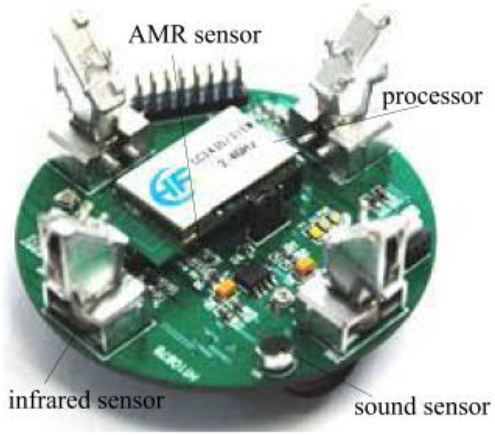


Fig. 2. Sensor node.

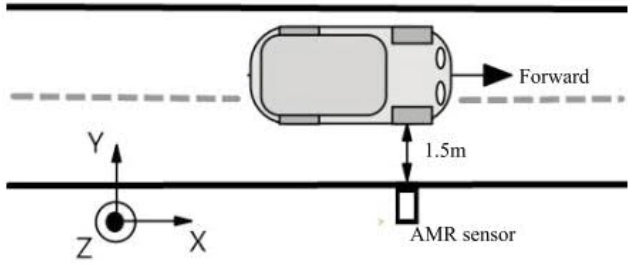


Fig. 4. Sensor installation diagram.

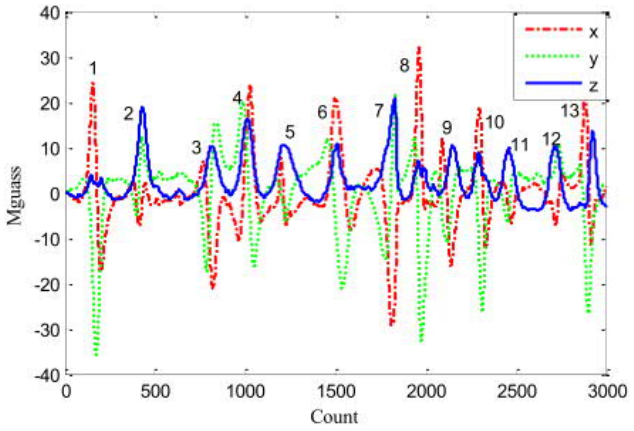


Fig. 5. Original magnetic signals of vehicles.

Commercial magnetoresistive sensor

ANALOG DEVICES

Integrated AMR Angle Sensor and Signal Conditioner

Data Sheet **ADA4571**

FEATURES

- High precision 180° angle sensor
- Maximum angular error of 0.5°
- Analog sine and cosine outputs
- Ratiometric output voltages
- Low thermal and lifetime drift
- SAR or Σ-Δ analog-to-digital converter (ADC) drive capable
- Magnetoresistive (MR) bridge temperature compensation mode
- Temperature range: −40°C to +150°C
- EMI resistant
- Fault diagnostics
- V_{DD} from 2.7 V to 5.5 V
- Minimum phase delay
- Qualified for automotive applications
- Available in an 8-lead SOIC package

APPLICATIONS

- Absolute position measurement (linear and angle)
- Brushless dc motor control and positioning
- Actuator control and positioning
- Contactless angular measurement and detection
- Magnetic angular position sensing

FUNCTIONAL BLOCK DIAGRAM

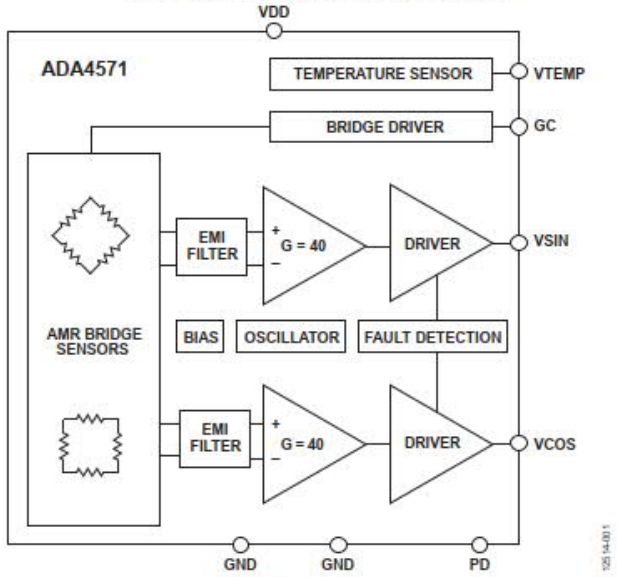


Figure 1.

GENERAL DESCRIPTION

The ADA4571 is an anisotropic magnetoresistive (AMR) sensor with integrated signal conditioning amplifiers and ADC drivers.

COMPANION PRODUCTS

ADCs: AD7265, AD7266, AD7866, AD7902

Proximity sensing with capasitive / magnetic sensors

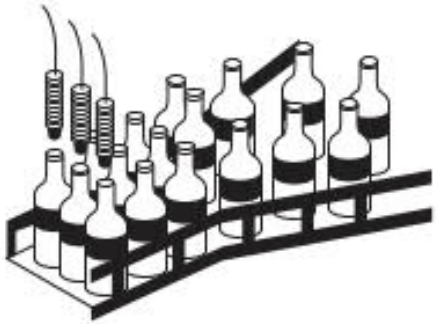


Figure 15.1.32:
Proximity sensors detect bottle caps.

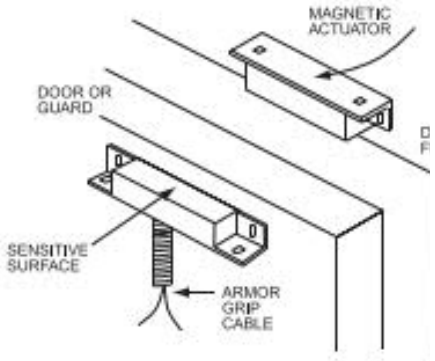


Figure 15.1.33:
A proximity sensor acts as a door guard.

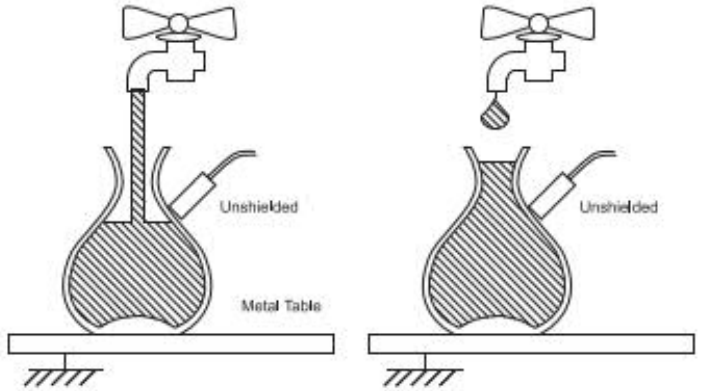
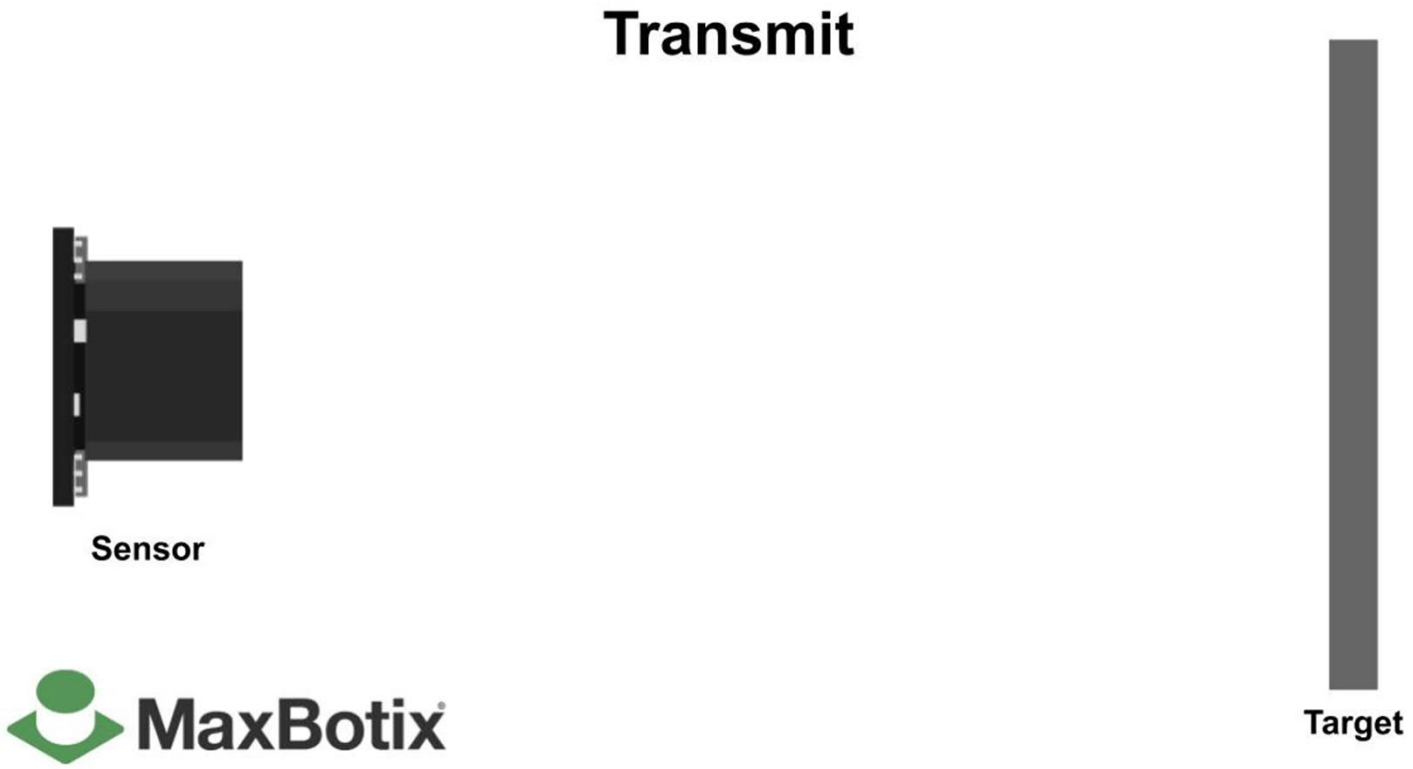


Figure 15.1.37: Once the ground electrode provided by the fluid is in place, the circuit closes and a signal results.

Ultrasonic sensor



- Ultrasonic (40 kHz) pulse is transmitted and reflects from target. Time of flight gives distance.

Ultrasonic sensor applications

- Automotive
- Industry
- Level sensing

Figure 15.1.25: Two ultrasonic sensors provide roll diameter and tension control by providing outputs directly proportional to distance and roll diameter.

Figure 15.1.30: Sensing range with maximum sensitivity.

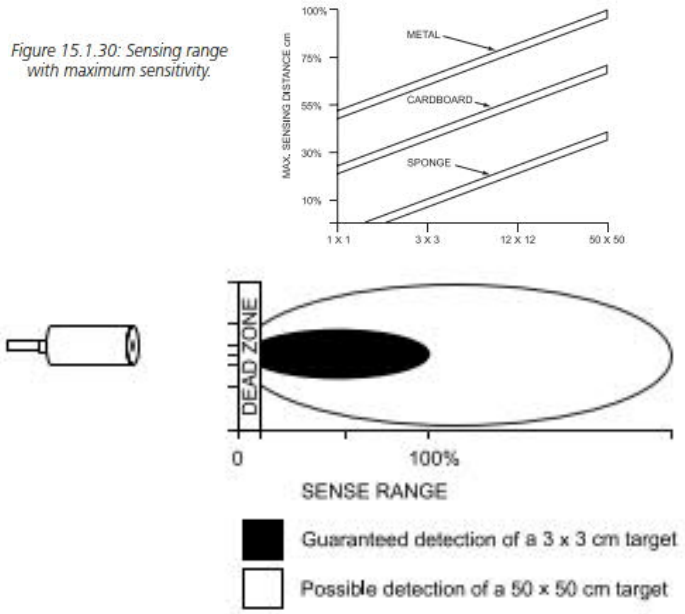


Figure 15.1.26: Ultrasonic sensors must be mounted outside of the dead zone.

Commercial ultrasonic sensor

- “**Acu-Trac™ Details**
- The Acu-Trac™ Fuel Level Sensor is a non-contact sensor that is a direct replacement for level sensors on tanks with depths up to ≤ 1.5 meters (59 inches). The Fuel Level Sensor offers a choice of outputs (analog current loop; ratiometric voltage; or non-ratiometric voltage).
- The Fuel level sensor has the additional capability of processing real-time fuel data and messaging on a J1708 data link for both on-vehicle and off-vehicle communications.
- The Fuel level sensor provides the user flexibility to program for tank configuration, digital filtering, sensor mounting offset, gauge drive output full and empty endpoints, and communication mode.
- **Product Overview**
- The Acu-Trac™ family of ultrasonic fluid level sensor is non-contact fluid level sensors that are a direct replacement for level senders on tanks with depths up to ≤ 3.0 m.”

Photoelectric sensors

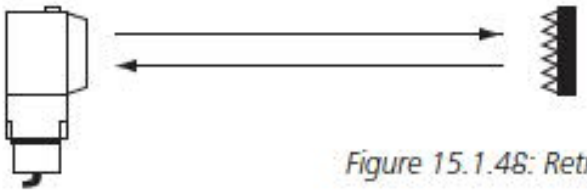


Figure 15.1.48: Retroreflective scanning.

Figure 15.1.53: Through scanning.

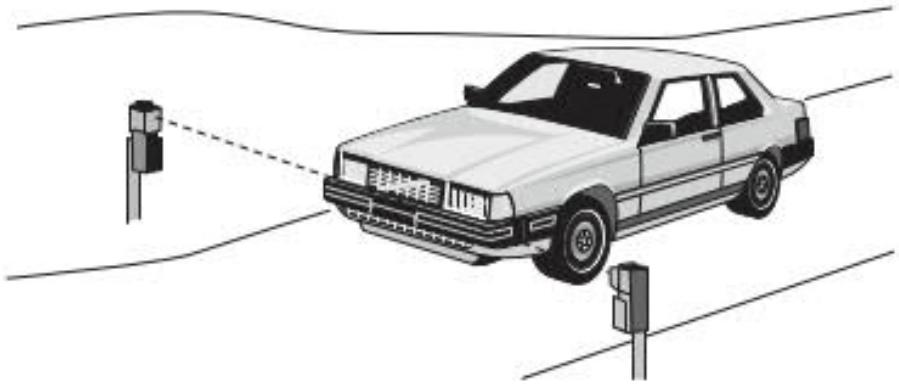
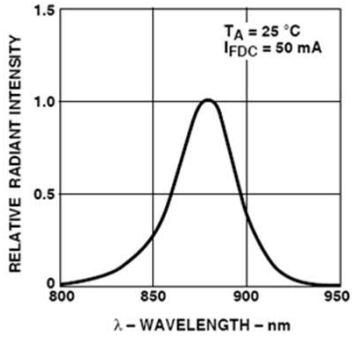


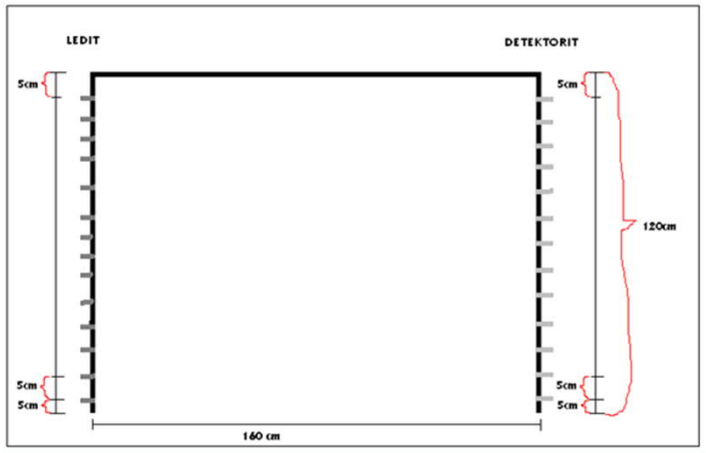
Figure 15.1.54: Long distance, harsh duty photoelectrics withstand outdoor environments to solve such applications as traffic control at toll ways and automatic security gates.

- LED and photodiode form an optical path. Target blocks the path, which causes signal

Application of photoelectric sensors: Detection of floor ball speed

- Two consecutive gates formed with LED's and photodiodes
- Ball causes notch in the gate signals
- Speed calculated from time difference
- Matched IR LEDs and PDs helps for stray light





Safety light curtains

- Special optical sensor used for safety applications
- A curtain is formed with LEDs (pulsed and coded) and photodiodes
- Detects if human enters a dangerous region
- https://www.youtube.com/watch?v=NUT98X1QQEs

Optical encoders

- Incremental optical encoder (left) is a disc divided into transparent and opaque sectors.
- Light source on one side of the disc, light sensor on the other
- Produces a stream of square wave pulses which, when counted, indicates the angular position.
- Resolution 100 - 65,000 1/round
- Second light source and sensor for the direction of rotation.
- Third light source and detector to sense a once-per-revolution marker.

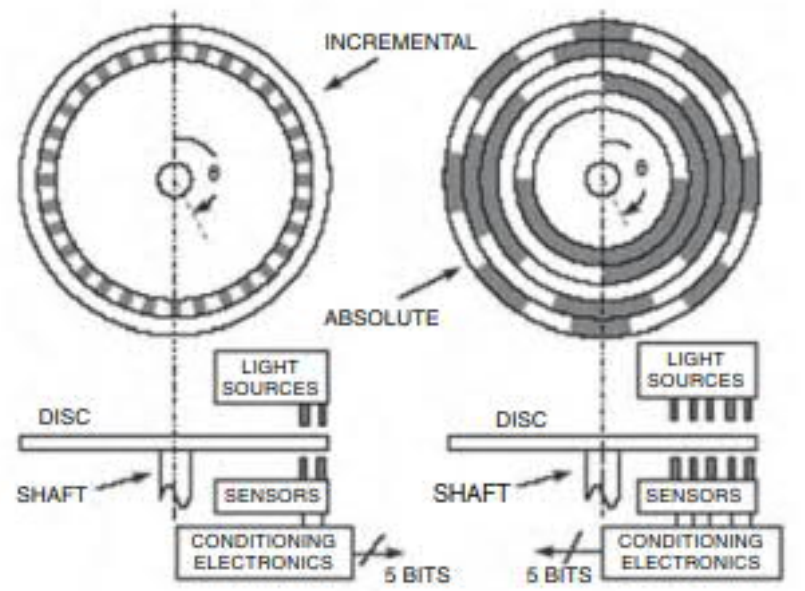


Figure 15.3.12: Incremental and absolute optical encoders.

- Limitation: if the encoder misses a pulse due to noise, power-cut, or dirt, the resulting angular information will be in error.
- Absolute encoder (right) overcomes this limitation

Questions

1. Free travel of a gas pedal of a car is 7 cm. Find a sensor that can be used to detect the position of the gas pedal? What is the output format of the sensor, and how does it attach mechanically?
2. Your company is manufacturing a surgical robot, whose arm twists 360 degrees. The twist angle has to be known as precisely as possible. Find a sensor that can measure this. How good precision can you accomplish? How does the sensor attach to the arm?
3. An industrial robot has been assembled on rails, where it can move 6 m. You need to determine its position. Find a sensor that can measure this rather long distance.

https://www.te.com/usa-en/products/sensors.html