Electronic Circuits
Elektronik Devreler

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Sensors and actuators

- Introduction
- Describing sensor performance
- Sensors
- Actuators
- Laboratory measuring equipment.

Introduction

- To be useful, systems must interact with their environment. To do this they use sensors and actuators.
- Sensors and actuators are examples of **transducers.**

A transducer is a device that converts one physical quantity into another.

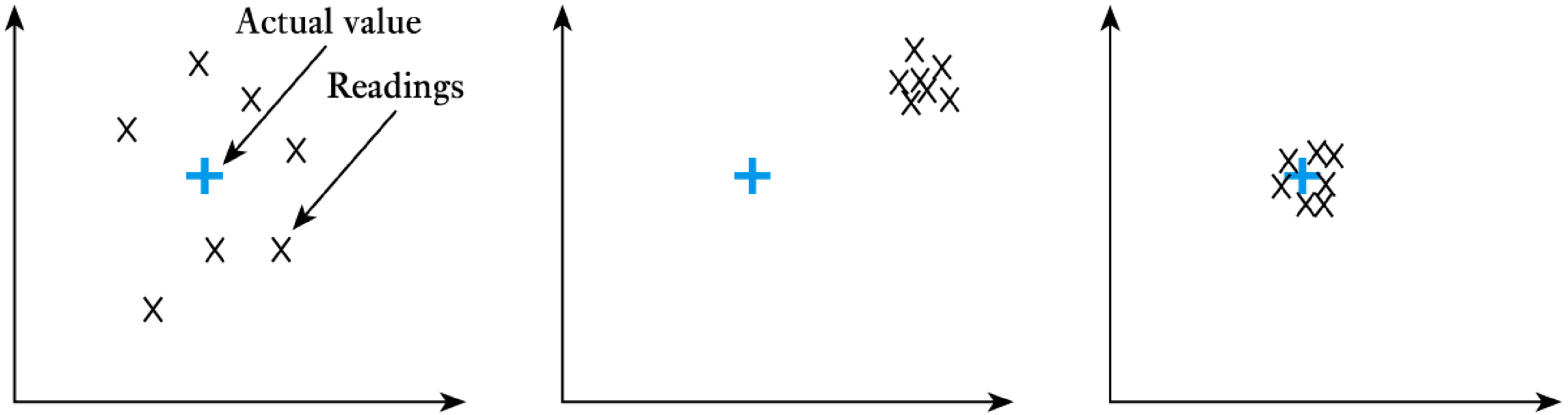
  - examples include:
    - a mercury-in-glass thermometer (converts temperature into displacement of a column of mercury)
    - a microphone (converts sound into an electrical signal).
- We will look at both sensors and actuators in this lecture.

Describing sensor performance

- **Range**
  - maximum and minimum values that can be measured.
- **Resolution or discrimination**
  - smallest discernible change in the measured value.
- **Error**
  - difference between the measured and actual values.
    - random errors
    - systematic errors
- **Accuracy, inaccuracy, uncertainty**
  - accuracy is a measure of the maximum expected error.

Describing sensor performance (contd.)

- **Precision**
  - a measure of the lack of random errors (scatter)



(a) Low precision, low accuracy

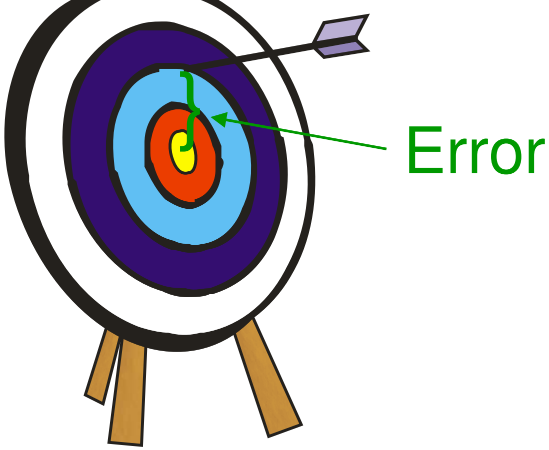
(b) High precision, low accuracy

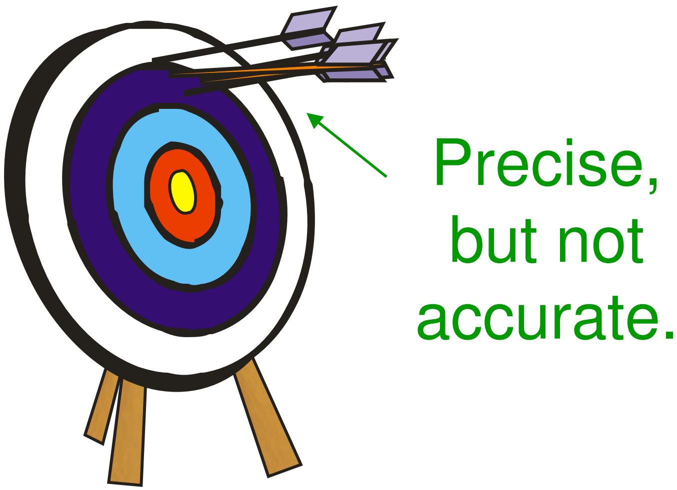
(c) High precision, high accuracy

Error, Accuracy, and Precision

Experimental uncertainty is part of all measurements. **Error** is the difference between the true or best accepted value and the measured value. **Accuracy** is an indication of the range of error in a measurement.

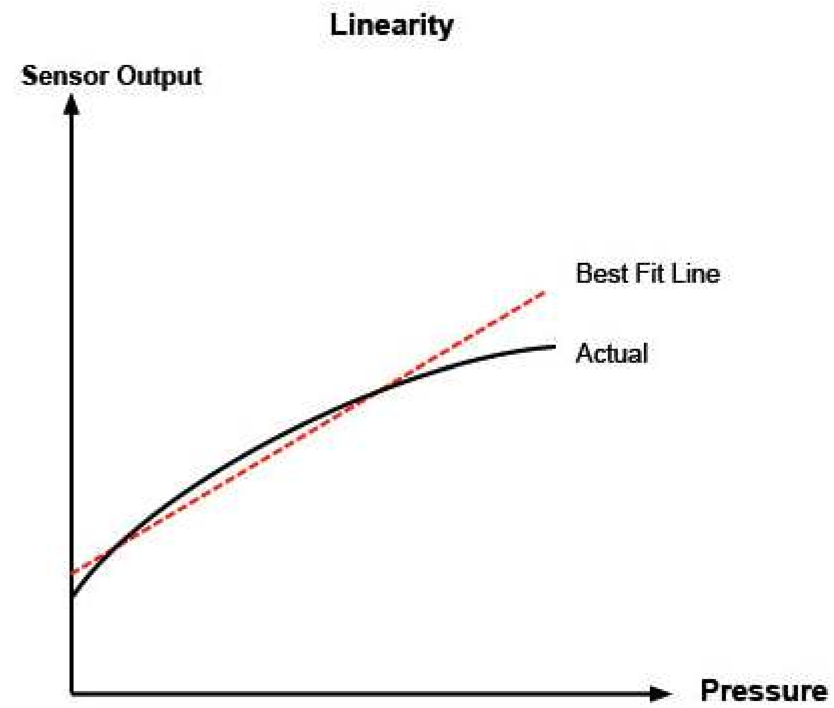
Precision is a measure of repeatability.





Describing sensor performance (contd.)

- **Linearity**
  – maximum deviation from a 'straight-line' response



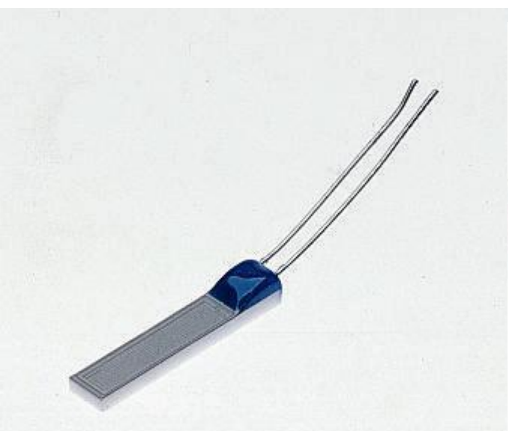
- **Sensitivity**
  – a measure of the change produced at the output for a given change in the quantity being measured.

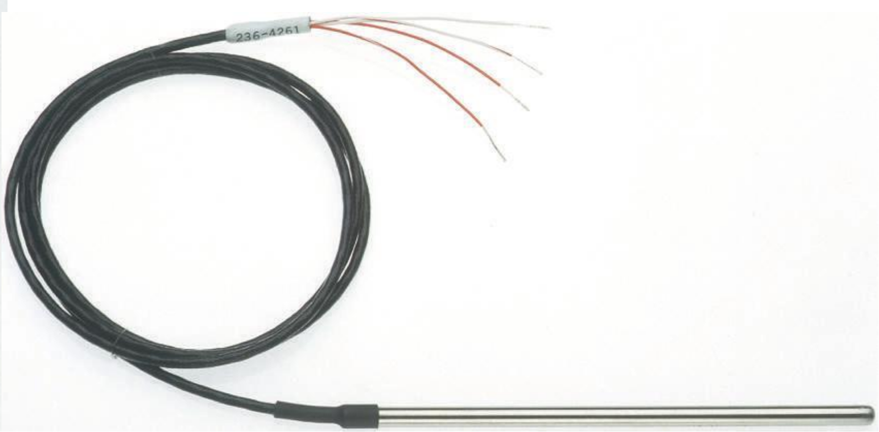
Sensors

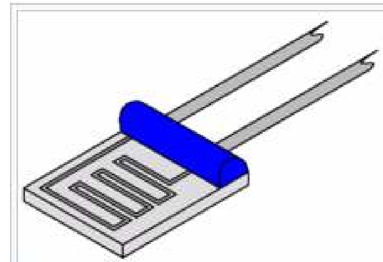
- Almost any physical property of a material that changes in response to some excitation can be used to produce a sensor.
  - Widely used sensors include those that are:
    - resistive
    - inductive
    - capacitive
    - piezoelectric
    - photoresistive
    - elastic
    - thermal.
  - In this lecture we will look at several examples.

Temperature sensors

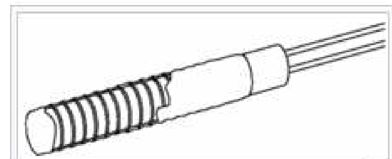
- **Resistive thermometers**
  - typical devices use platinum wire (such a device is called a platinum resistance thermometers or PRT)
  - *linear* but has poor *sensitivity.*







Thin-film PRT



Wire-wound PRT

Coil-element PRT

Temperature sensors (contd.)

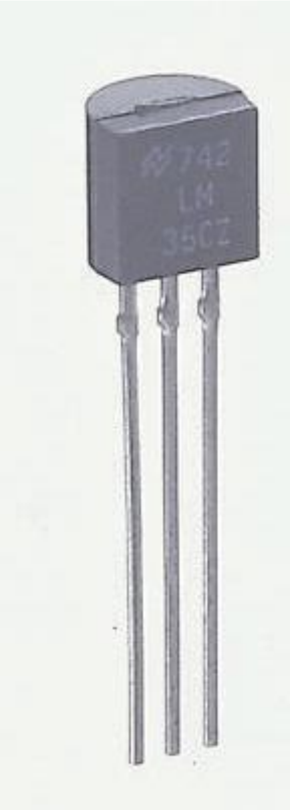
- **Thermistors**
  - use materials with a high thermal coefficient of resistance
  - *sensitive* but highly *non-linear*.

A typical disc thermistor

A threaded thermistor

Temperature sensors (contd.)

- *pn* **junctions**
  - a semiconductor device with the properties of a diode (we will consider semiconductors and diodes later)
  - *inexpensive*, *linear* and *easy to use*
  - *limited temperature range* (perhaps -50°C to 150°C) due to nature of semiconductor material.



pn-junction sensor

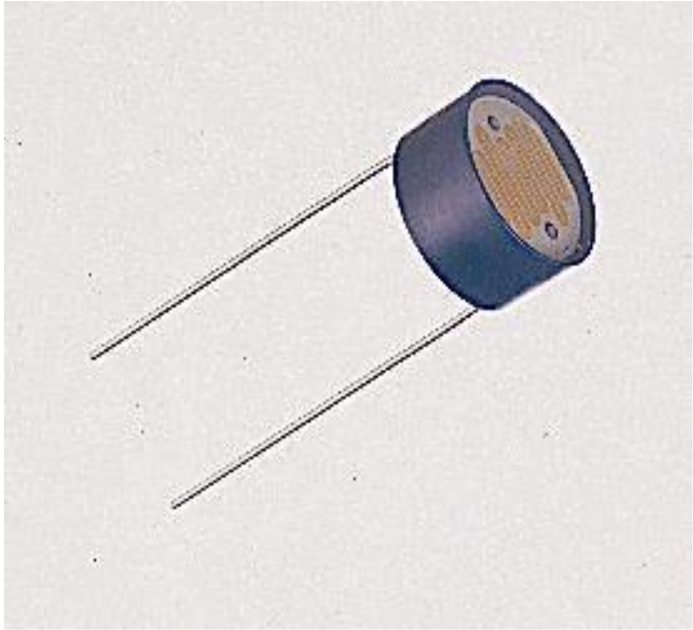
Light sensors

- **Photovoltaic**
  - light falling on a *pn*-junction can be used to generate electricity from light energy (as in a solar cell).
  - small devices used as sensors are called **photodiodes.**
  - fast acting, but the voltage produced is *not* linearly related to light intensity.

A typical photodiode

Light sensors (contd.)

- **Photoconductive**
  - such devices do not produce electricity, but simply change their resistance.
  - photodiodes (as described earlier) can be used in this way to produce linear devices.
  - phototransistors act like photodiodes but with greater sensitivity.
  - light-dependent resistors (LDRs) are slow, but respond like the human eye.

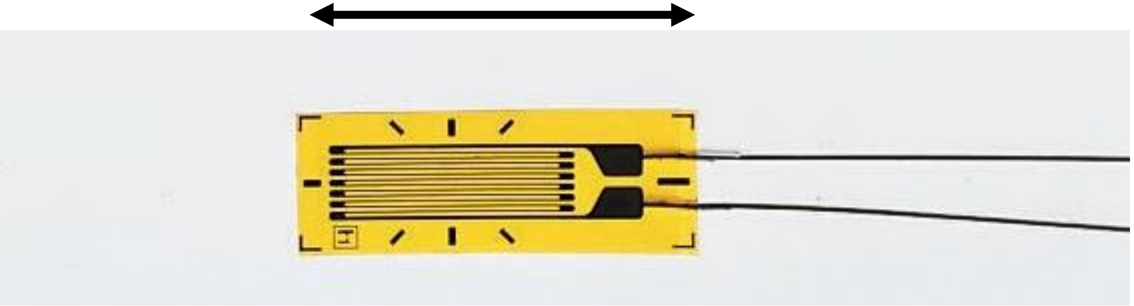


A light-dependent resistor (LDR)

Force sensors

- **Strain gauge**
  - stretching in one direction increases the resistance of the device, while stretching perpendicular to this has little effect
  - can be bonded to a surface to measure strain
  - used within load cells and pressure sensors.

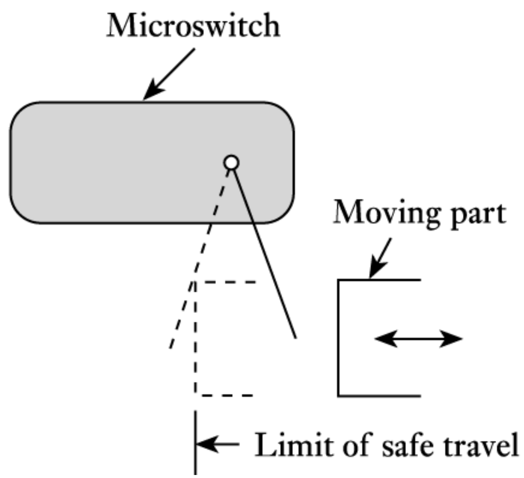
Direction of sensitivity



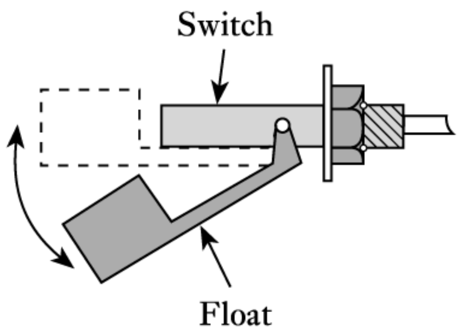
A strain gauge

Displacement sensors (contd.)

- **Switches**
  - simplest form of *digital* displacement sensor
    - many forms: lever or push-rod operated microswitches, float switches, pressure switches, etc.



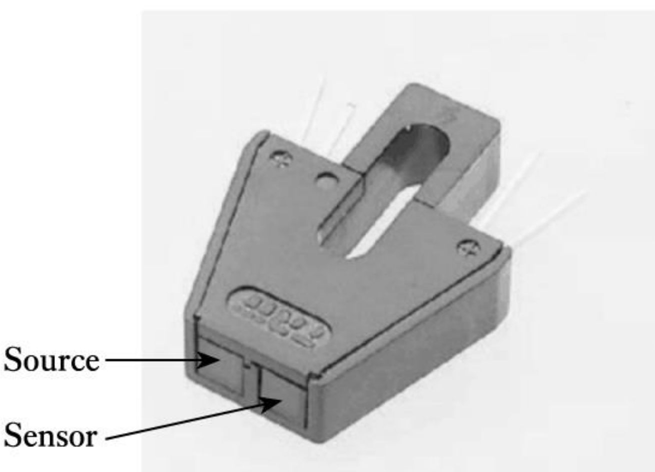
A limit switch



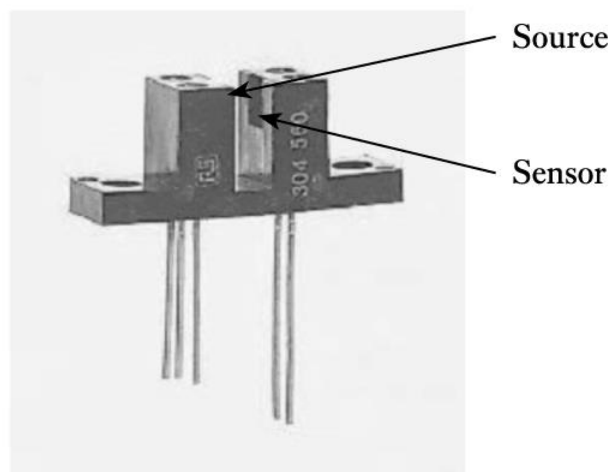
A float switch

Displacement sensors (contd.)

- **Opto-switches**
  - consist of a light source and a light sensor within a single unit.
    - 2 common forms are the reflective and slotted types.



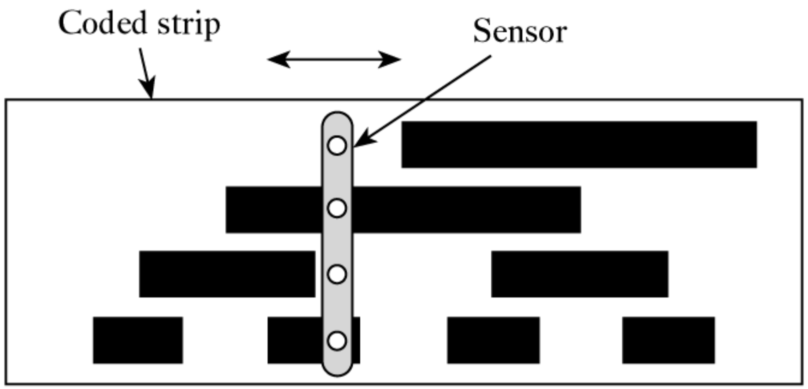
A reflective opto-switch



A slotted opto-switch

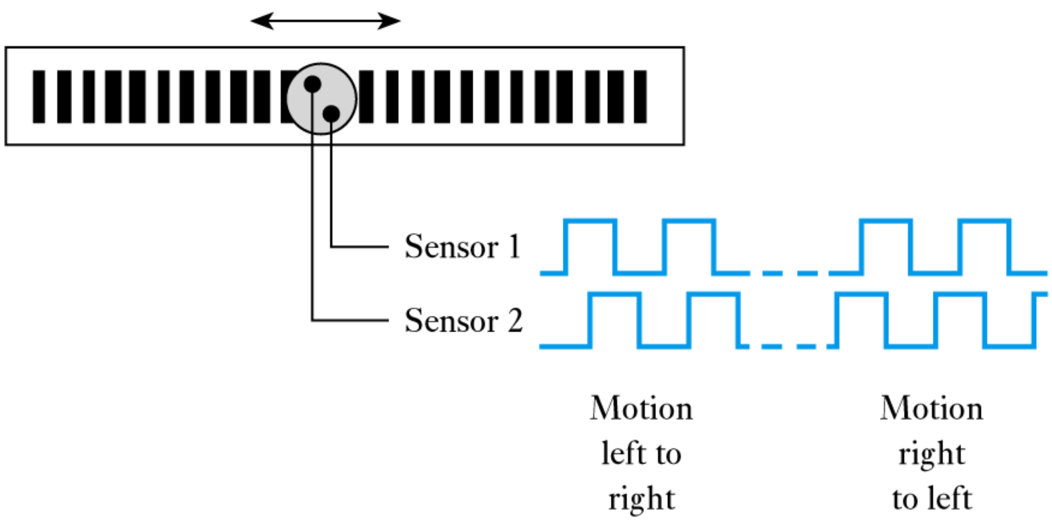
Displacement sensors (contd.)

- **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 below.
    - It is arranged so that the combination is unique at each point.
    - Sensor is an array of photodiodes.



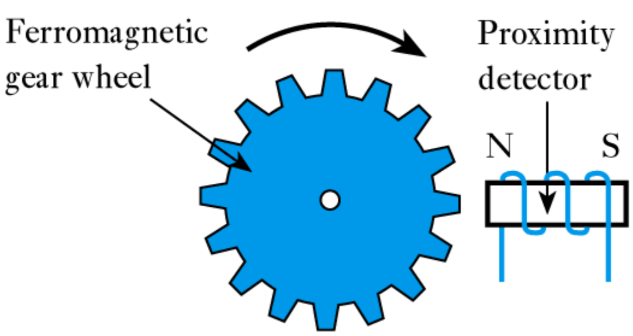
Displacement sensors (contd.)

- **Incremental position encoder**
  - uses a single line that alternates black/white
    - two slightly offset sensors produce outputs as shown below
    - detects motion in either direction, pulses are counted to determine absolute position (which must be initially reset).

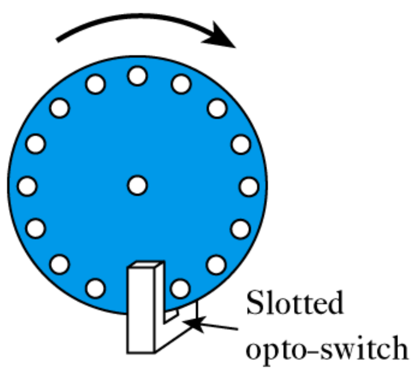


Displacement sensors (contd.)

- **Other counting techniques**
  - several methods use counting to determine position
    - two examples are given below.



Inductive sensor



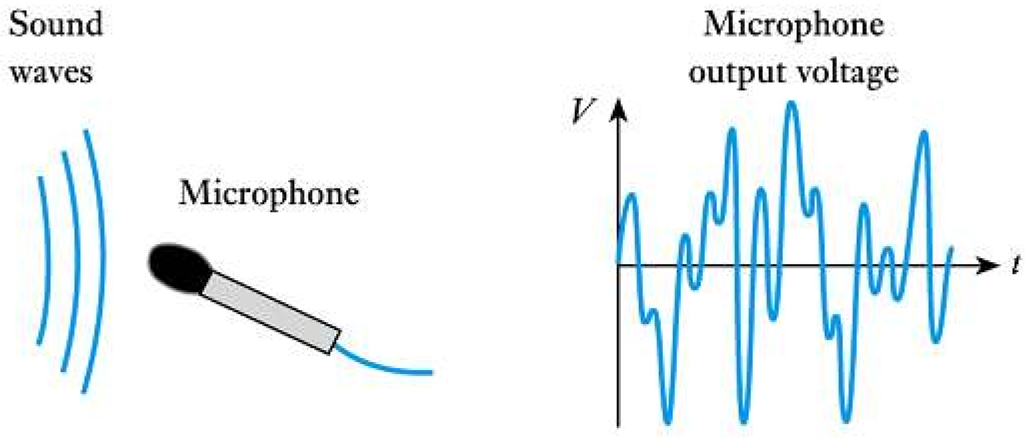
Opto-switch sensor

Motion sensors

- Motion sensors measure quantities such as velocity and acceleration.
  - Can be obtained by differentiating displacement
  - Differentiation tends to amplify high-frequency noise.
- Alternatively can be measured directly
  - some sensors give velocity directly
    - e.g. measuring *frequency* of pulses in the counting techniques described earlier gives speed rather than position.
  - some sensors give acceleration directly
    - e.g. accelerometers usually measure the force on a mass.

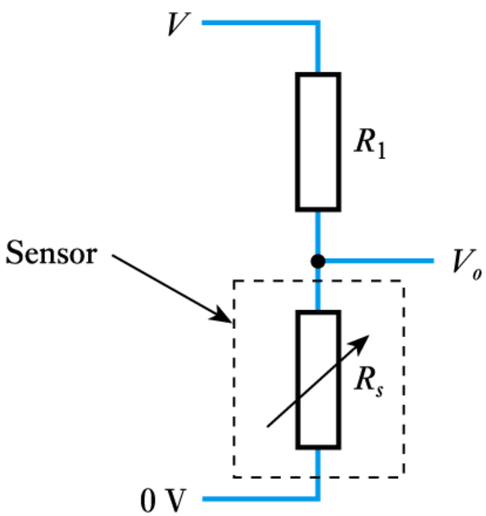
Sound sensors

- **Microphones**
  - a number of forms are available
    - e.g. carbon (resistive), capacitive, piezoelectric and moving-coil microphones
    - moving-coil devices use a magnet and a coil attached to a diaphragm.



Sensor interfacing

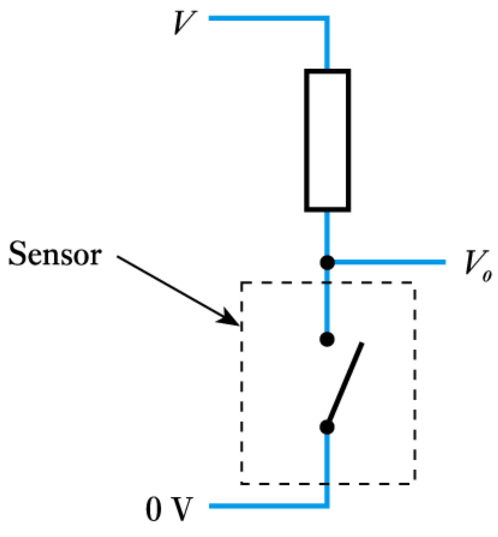
- **Resistive devices**
  - can be very simple
    - e.g. in a potentiometer, with a fixed voltage across the outer terminals, the voltage on the third is directly related to position
    - where the resistance of the device changes with the quantity being measured, this change can be converted into a voltage signal using a potential divider – as shown
    - the output of this arrangement is *not* linearly related to the change in resistance.

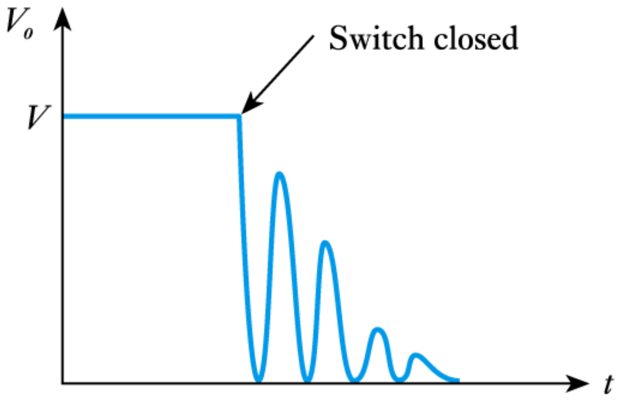


(a)

Sensor interfacing (contd.)

- **Switches**
  - switch interfacing is also simple
    - can use a single resistor as below to produce a voltage output
    - all mechanical switches suffer from **switch bounce.**





Sensor interfacing (contd.)

- **Capacitive and inductive sensors**
  - Sensors that change their capacitance or inductance in response to external influences normally require the use of alternating current (AC) circuitry.
  - Such circuits need not be complicated.
  - We will consider AC circuits in later lectures.

Actuators

- In order to be useful an electrical or electronic system must be able to affect its external environment. This is done through the use of one or more **actuators.**
- As with sensors, actuators are transducers, which convert one physical quantity into another.
- Here we are interested in actuators that take electrical signals from our system and from them vary some external physical quantity.

Heat actuators

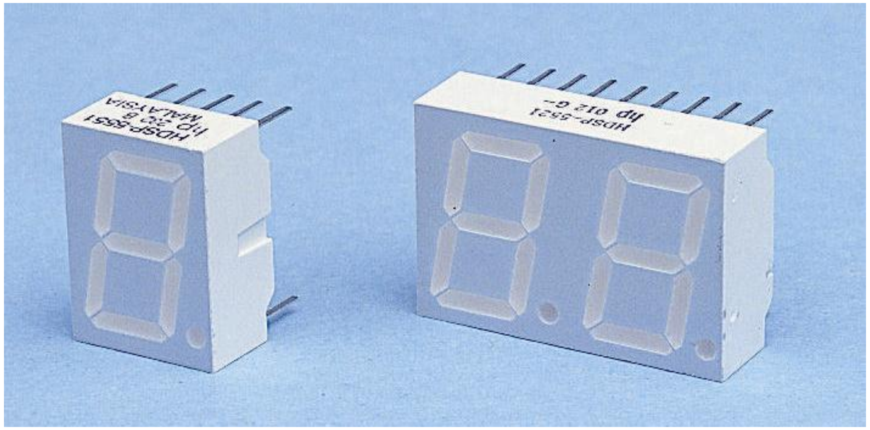
- Most heat actuators are simple **resistive heaters.**
- For applications requiring a few watts ordinary **resistors** of an appropriate power rating can be used.
- For higher power applications there are a range of **heating cables** and **heating elements** available.

Light actuators

- For general illumination it is normal to use conventional **incandescent light bulbs** or **fluorescent lamps.**
  - power ratings range from a fraction of a watt to perhaps hundreds of watts
  - easy to use but relatively slow in operation
  - unsuitable for signalling and communication applications.

Light actuators (contd.)

- **Light-emitting diodes (LEDs)**
  - produce light when electricity is passed through them.
  - a range of semiconductor materials can be used to produce light of different colours.
  - can be used individually or in multiple-segment devices such as the seven-segment display shown here.



LED – seven-segment displays

Light actuators (contd.)

- **Liquid crystal displays**
  - consist of 2 sheets of polarised glass with a thin layer of oily liquid sandwiched between them.
  - an electric field rotates the polarization of the liquid making it opaque.
  - can be formed into multi-element displays (such as 7-segment displays).
  - can also be formed into a matrix display to display any character or image.

A custom LCD display

Light actuators (contd.)

- **Fibre-optic communication**
  - used for long-distance communication
  - removes the effects of ambient light
  - **fibre-optic cables** can be made of:
    - **optical polymer**
      - inexpensive and robust
      - high attenuation, therefore short range (up to about 20 metres)
    - **glass**
      - much lower attenuation allowing use up to hundreds of kilometres
      - more expensive than polymer fibres
  - light source would often be a **laser diode.**

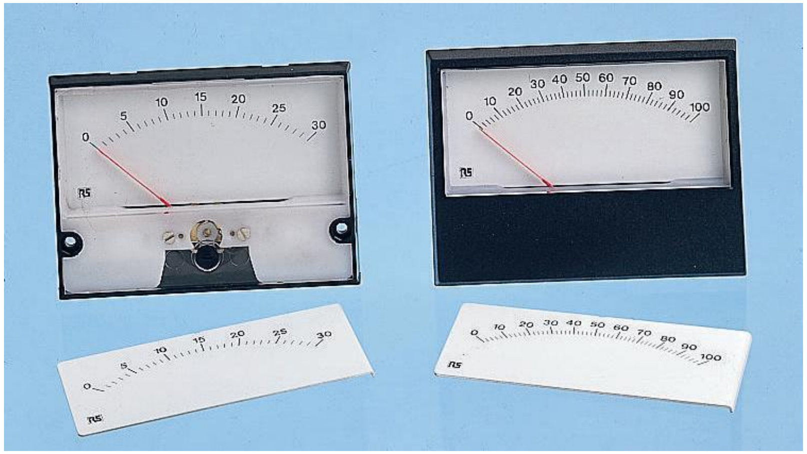
Force, displacement and motion actuators

- **Solenoids**
  - basically a coil and a ferromagnetic ‘slug’
  - when energised the slug is attracted into the coil
  - force is proportional to current
  - can produce a force, a displacement or motion
  - can be linear or angular
  - often used in an ON/OFF mode.

Small linear solenoids

Force, displacement and motion actuators (contd.)

- **Meters**
  - moving-iron
    - effectively a rotary solenoid plus spring
    - can measure DC or AC
  - moving-coil
    - most common form
    - deflection proportional to average value of current
    - full scale deflection typically 50 μA – 1 mA



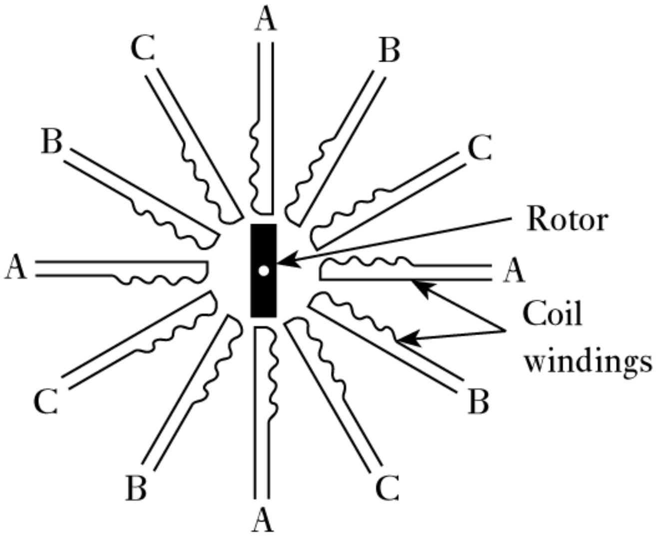
Moving-coil meters

Force, displacement and motion actuators (contd.)

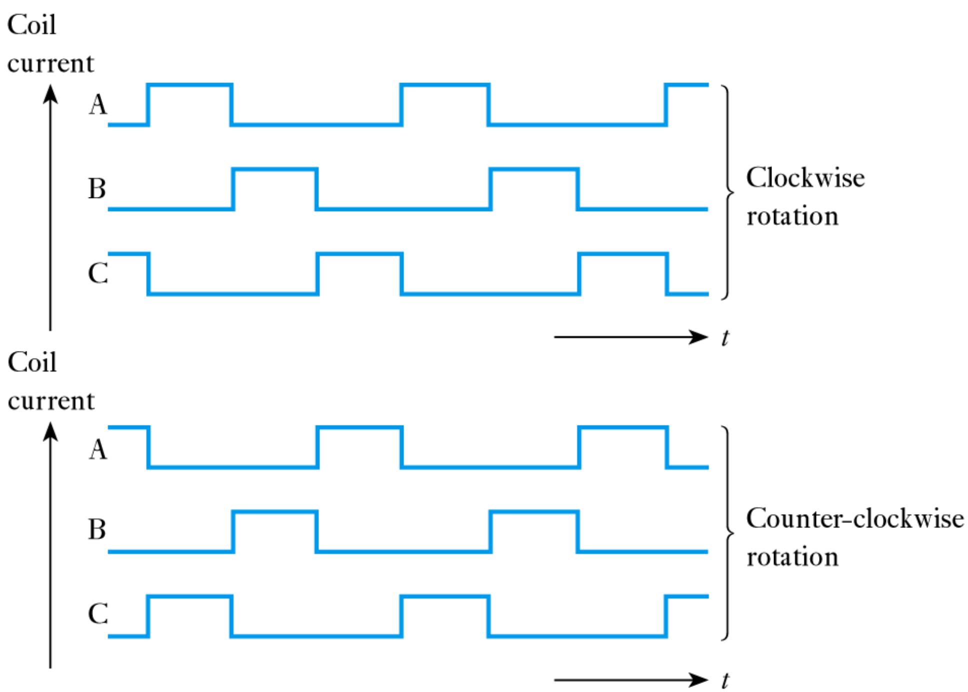
- **Motors**
  - three broad classes
    - **AC motors**
      - primarily used in high-power applications
    - **DC motors**
      - used in precision position-control applications
    - **Stepper motors**
      - a digital actuator used in position control applications.

Stepper motors

- **Stepper motors**
  - a central rotor surrounded by a number of coils (or windings)
  - opposite pairs of coils are energised in turn
  - this ‘drags’ the rotor round one ‘step’ at a time
  - speed proportional to frequency
  - typical motor might require 48-200 steps per revolution.



Stepper motors (contd.)



Stepper-motor current waveforms

A typical stepper-motor

Sound actuators

- **Speakers**
  - usually use a permanent magnet and a movable coil connected to a diaphragm.
  - input signals produce current in the coil causing it to move with respect to the magnet.
- **Ultrasonic transducers**
  - at high frequencies speakers are often replaced by **piezoelectric actuators**
  - operate over a narrow frequency range.

Actuator interfacing

- **Resistive devices**
  - Interfacing involves controlling the power in the device.
  - In a resistive actuator, power is related to the voltage.
  - For high-power devices the problem is in delivering sufficient power to drive the actuator.
  - High-power electronic circuits will be considered later.
  - High-power actuators are often controlled in an ON/OFF manner.
  - These techniques use **electrically operated switches**
    - discussed in later lectures.

Actuator interfacing (contd.)

- **Capacitive and inductive devices**
  - Many actuators are capacitive or inductive (such as motors and solenoids).
  - These create particular problems – particularly when using switching techniques.
  - We will return to look at these problems when we have considered capacitors and inductors in more detail.

Laboratory measuring instruments

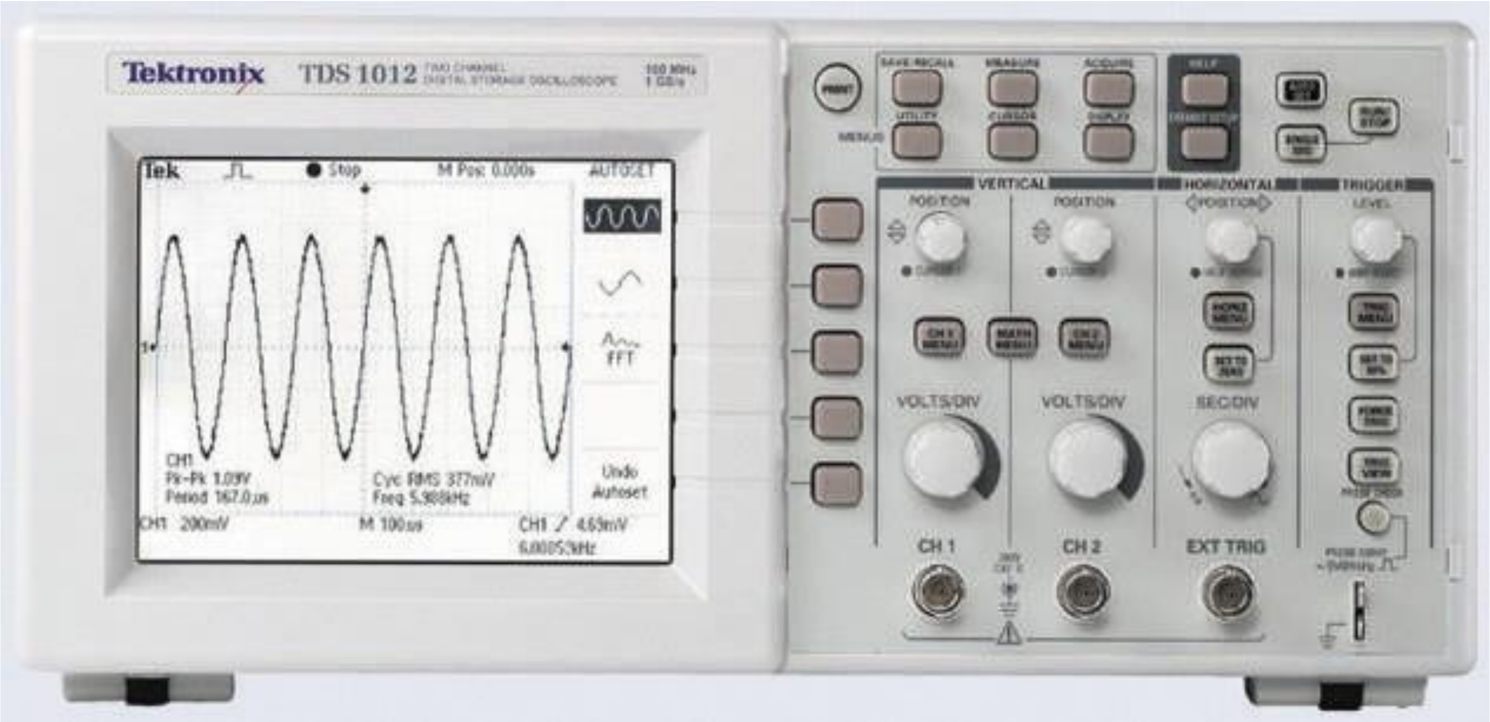
- Often the object of sensing a physical quantity is to **measure** it.
- Here we will look at three forms of measuring instrument:
  - analogue oscilloscope
  - digital oscilloscope
  - digital multimeter.

Analogue oscilloscope (contd.)

- A typical analogue oscilloscope

Digital oscilloscope (contd.)

- A typical digital oscilloscope



Digital multimeters (contd.)

- Measurement of voltage, current and resistance is achieved using appropriate circuits to produce a voltage proportional to the quantity to be measured.
  - In simple DMMs alternating signals are rectified as in analogue multimeters to give their average value which is multiplied by 1.11 to directly display the r.m.s. value of sine waves.
  - More sophisticated devices use a **true r.m.s. converter,** which accurately produces a voltage proportional to the r.m.s. value of an input waveform.

A typical digital multimeter

Key points

- A wide range of sensors is available.
- Some sensors produce an output voltage related to the measured quantity and therefore supply power.
- Other devices simply change their physical properties.
- Interfacing may be required to produce signals in the correct form.
- Most actuators take power from their inputs in order to deliver power at the output – the efficiency is often low.
- We often sense quantities in order to measure them – there are a number of standard measuring instruments.