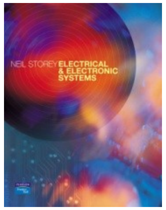
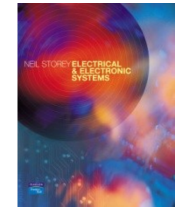



# Sensors

- Introduction
- Describing Sensor Performance
- Temperature Sensors
- Light Sensors
- Force Sensors
- Displacement Sensors
- Motion Sensors
- Sound Sensors
- Sensor Interfacing





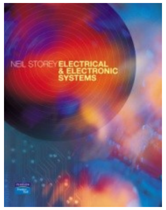

# Introduction

- 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 sensors in this lecture and at actuators in the next lecture

- 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

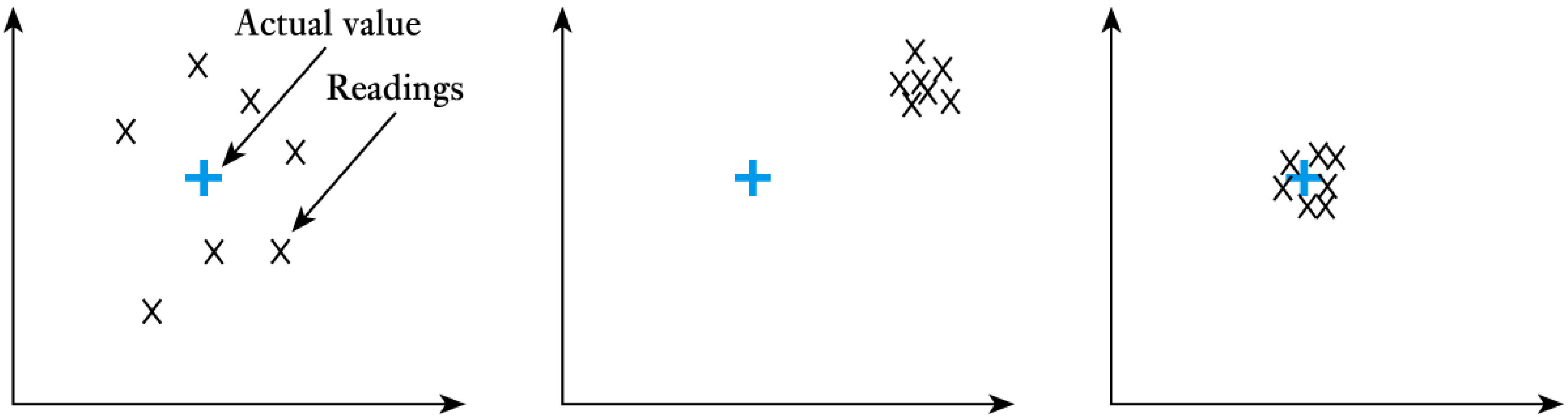




# Describing Sensor Performance

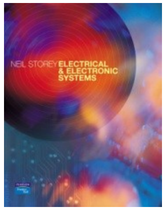
- **Range**
  - maximum and minimum values that can be measured
- **Resolution or discrimination**
  - smallest discernible change in the measured value
- **Error**
  - difference between the measured and actual values
    - random errors
    - systematic errors
- **Accuracy, inaccuracy, uncertainty**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

- **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

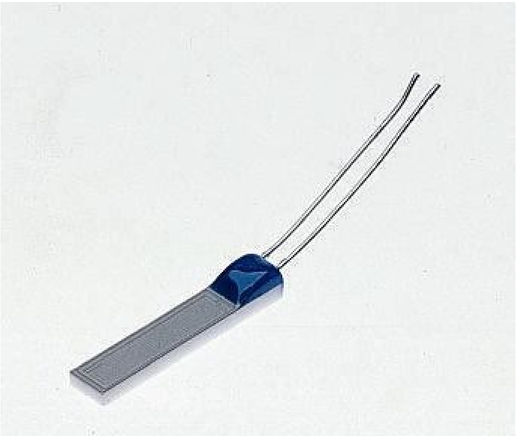
- **Linearity**
  - – maximum deviation from a ‘straight-line’ response
  - – normally expressed as a percentage of the full-scale value
- **Sensitivity**
  - – a measure of the change produced at the output for a given change in the quantity being measured



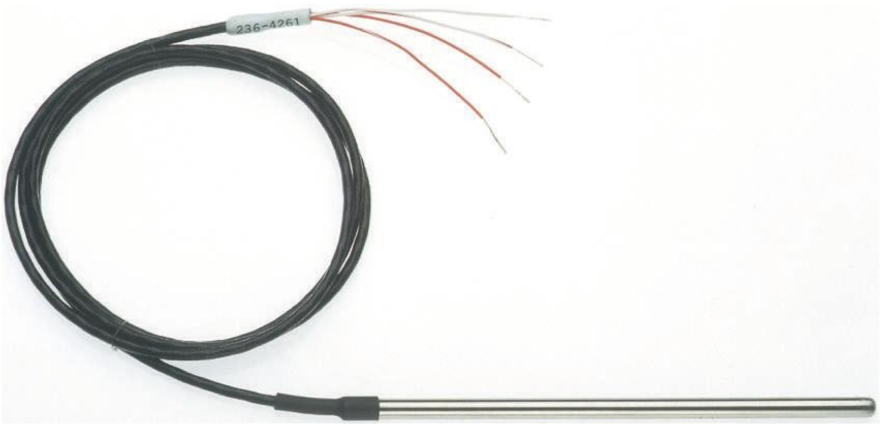



# Temperature sensors

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

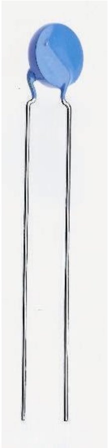


A typical PRT element




A sheathed PRT

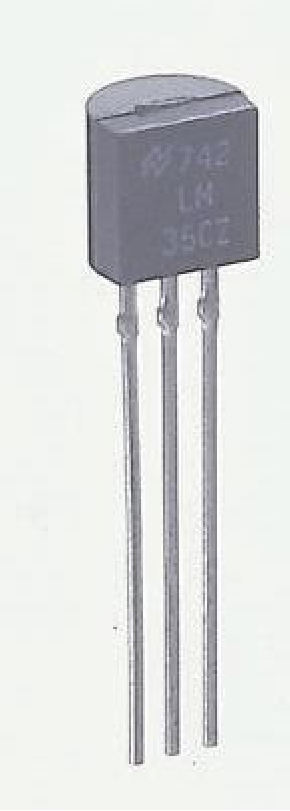
- **Thermistors**
  - use materials with a high thermal coefficient of resistance
  - *sensitive* but highly *non-linear*



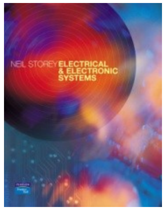
A typical disc thermistor

A threaded thermistor

- ***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



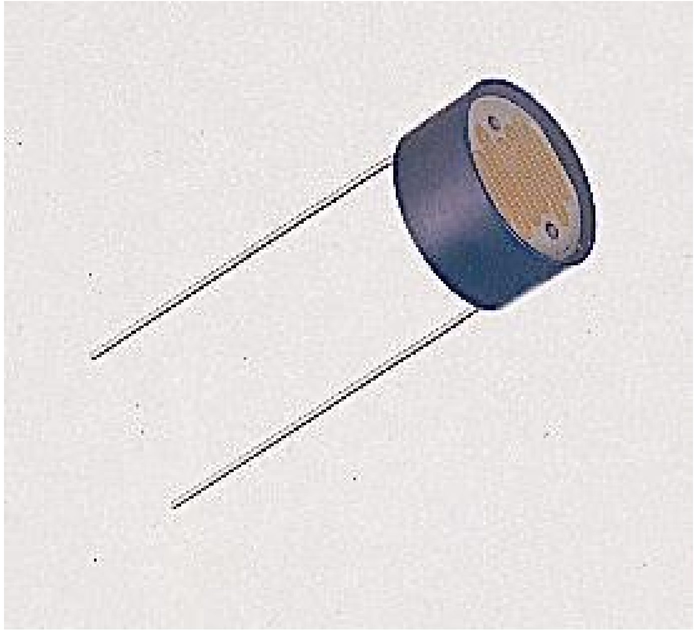


# Light Sensors

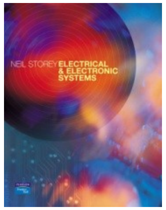
- **Photovoltaic**
  - light falling on a *pn*-junction can be used to generate electricity from light energy (as in a solar cell)
  - small devices used as sensors are called **photodiodes**
  - fast acting, but the voltage produced is *not* linearly related to light intensity

A typical photodiode

- **Photoconductive**
  - such devices do not produce electricity, but simply change their resistance
  - photodiode (as described earlier) can be used in this way to produce a linear device
  - 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)

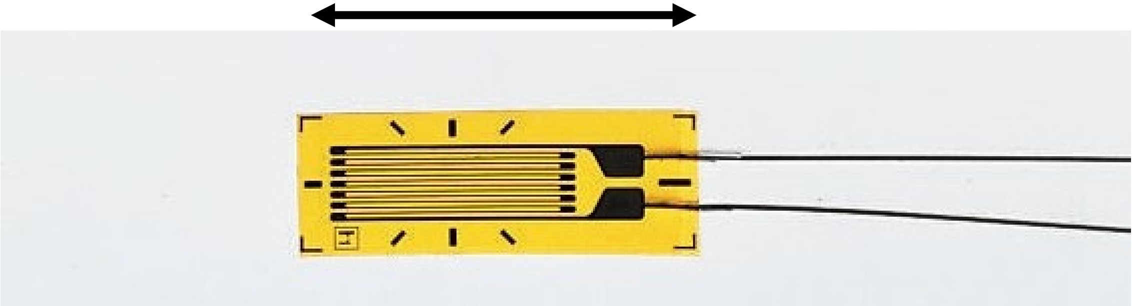




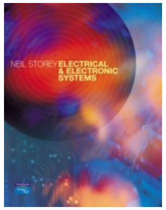

# Force Sensors

- **Strain gauge**
  - stretching in one direction increases the resistance of the device, while stretching in the other direction 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

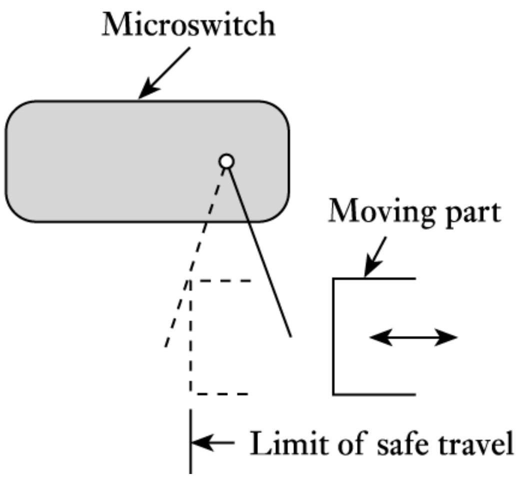
- **Potentiometers**
  - resistive potentiometers are one of the most widely used forms of position sensor
  - can be angular or linear
  - consists of a length of resistive material with a sliding contact onto the resistive track
  - when used as a position transducer a potential is placed across the 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

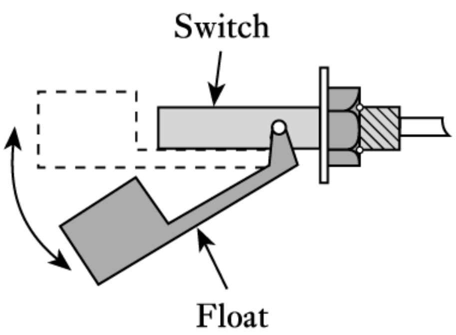
- coil inductance is greatly affected by the presence of ferromagnetic materials
- here the proximity of a ferromagnetic plate is determined by measuring the inductance of a coil
- we will look at inductance in later lectures

Inductive proximity sensors

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

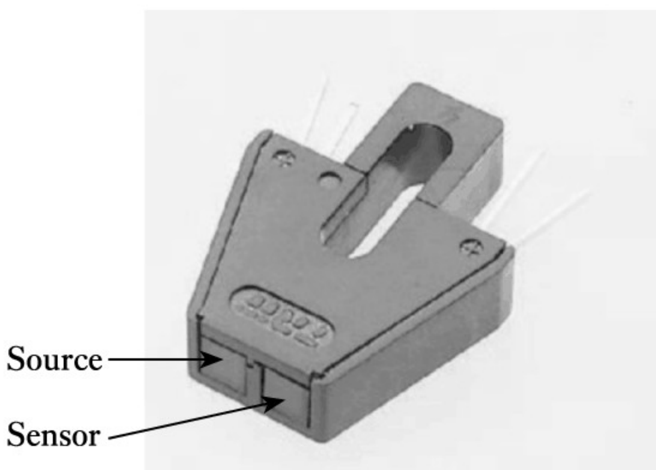



A limit switch

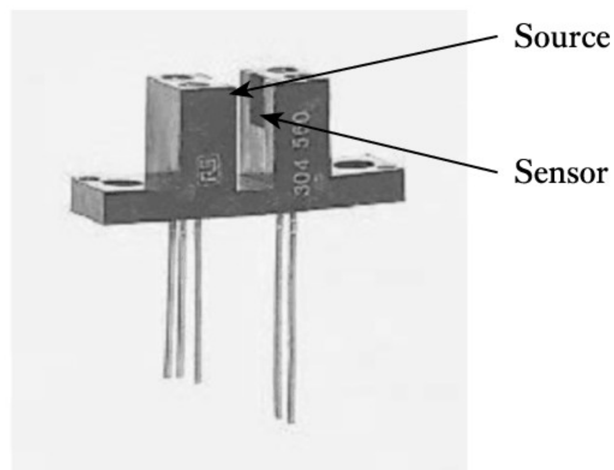



A float switch

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



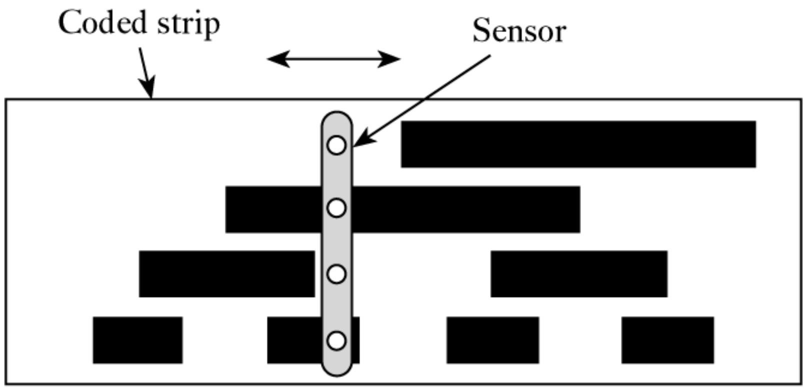

A reflective opto-switch




A slotted opto-switch

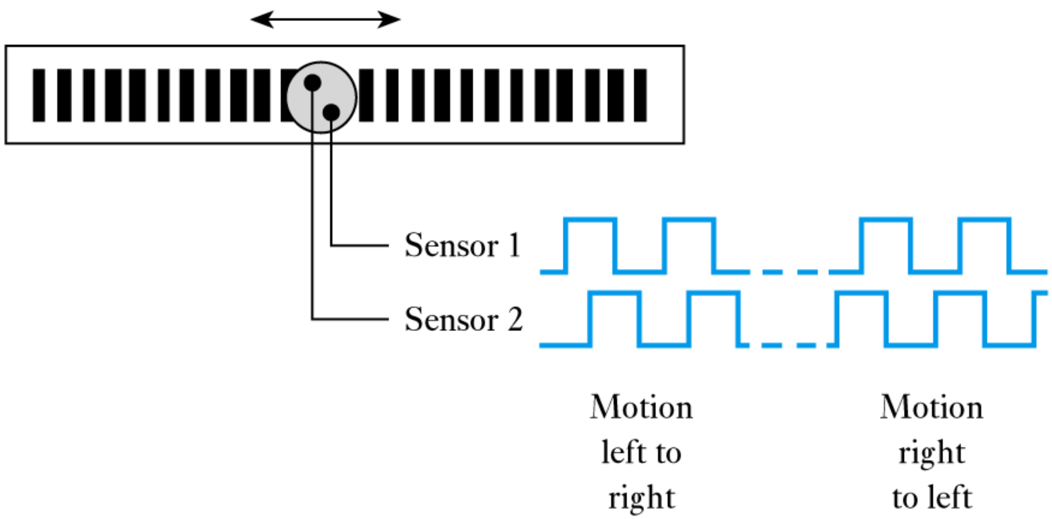
## Absolute position encoders

– 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

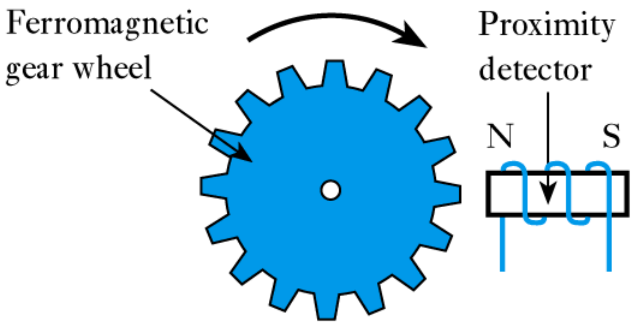


## Incremental position encoder

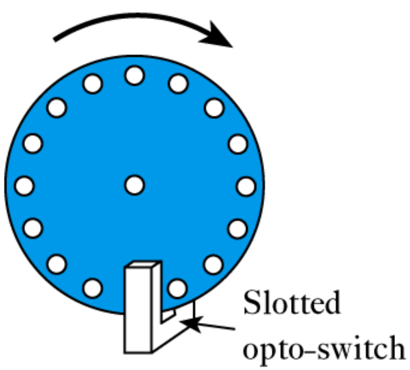
- uses a single line that alternates black/white
  - two slightly offset sensors produce outputs as shown below
  - detects motion in either direction, pulses are counted to determine absolute position (which must be initially reset)



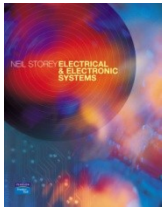

- **Other counting techniques**
  - several methods use counting to determine position
    - two examples are given below




Inductive sensor




Opto-switch sensor



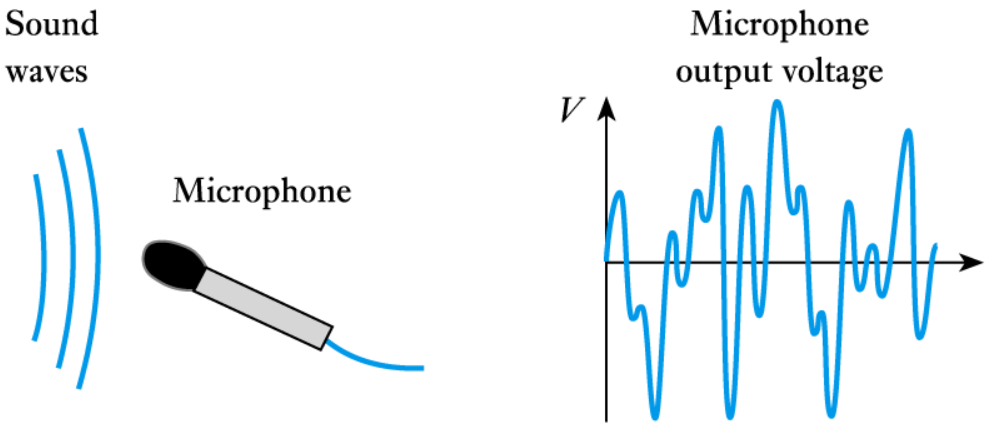


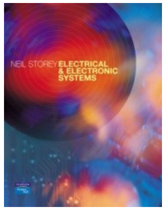
# Motion Sensors

- 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 – we will discuss electromagnetism later

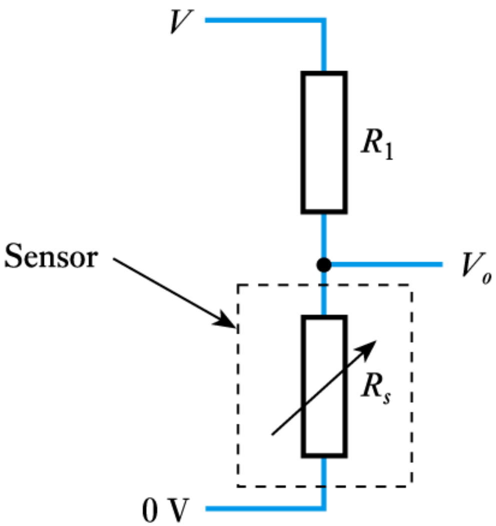




# Sensor Interfacing

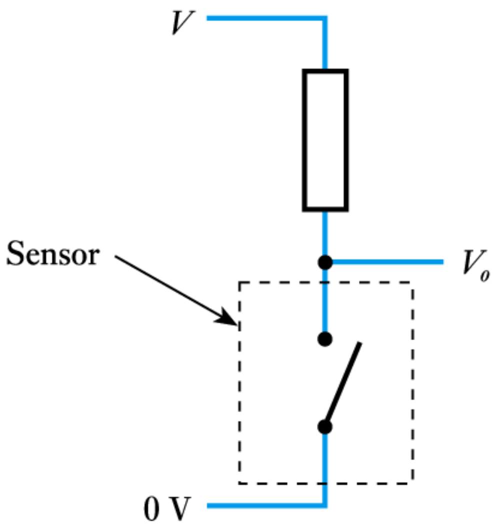


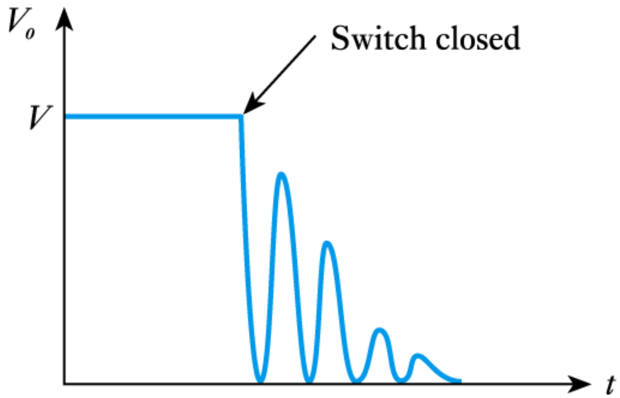
- **Resistive devices**
  - can be very simple
    - e.g. in a potentiometer, with a fixed voltage across the outer terminals, the voltage on the third is directly related to position
    - where the resistance of the device changes with the quantity being measured, this change can be converted into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




(a)

- **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**



- **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

# 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
- Some sensors produce an output that is linearly related to the quantity being measured, others do not
- Interfacing may be required to produce signals in the correct form