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Lecture 4: Sensors

IAT 267 Introduction to Technological Systems
Fall 2011

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Announcements

- Quiz for Week 4 will be available this Friday.
  - This quiz covers lecture material.

- Assignment 1 due next Wednesday.

Topics

- Physical principles
- Quality parameters of a sensor system
- Voltage divider circuit
- RFID

Physical Principles

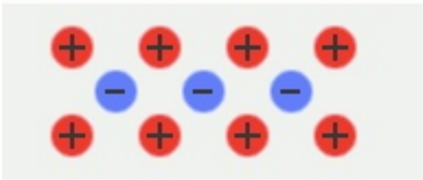
- Piezoelectric effect
- Thermocouple (Seebeck effect)

Piezoelectric Effect

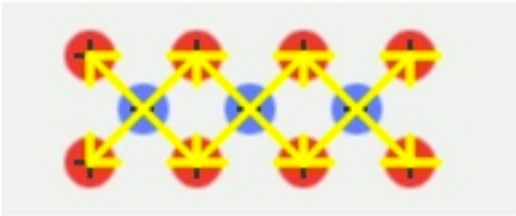
- Piezoelectricity (also called the **piezoelectric effect)** is the appearance of an electrical potential (a voltage, in other words) across the sides of a crystal when it is subjected to mechanical stress.

How Piezoelectricity Works

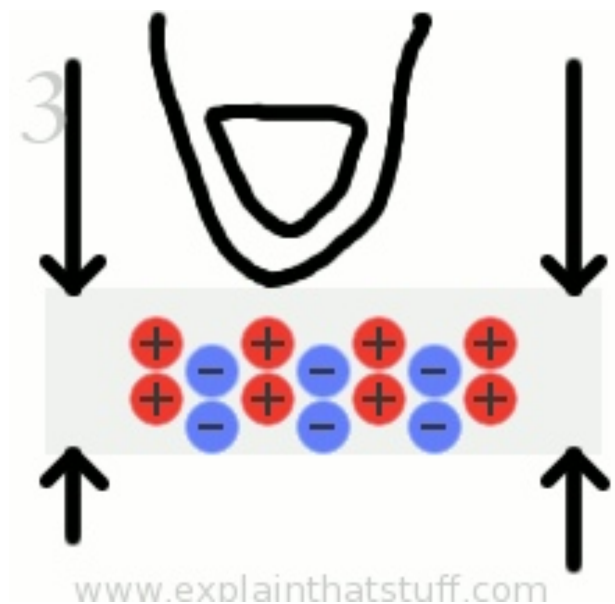
- Normally, the charges in a piezoelectric crystal are exactly balanced, even if they're not symmetrically arranged.

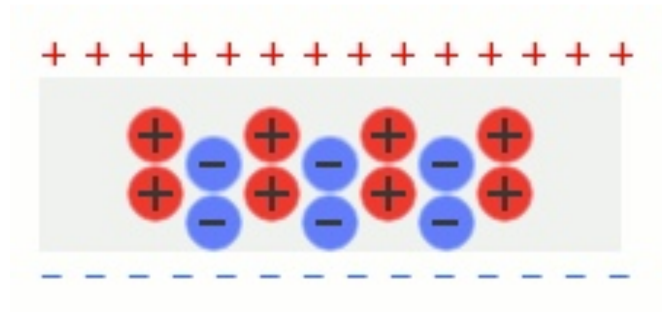


- The effects of the charges exactly cancel out, leaving no net charge on the crystal faces. (More specifically, the electric dipole moments—vector lines separating opposite charges—exactly cancel one another out.)



- If a mechanical distortion is applied to the crystal, it forces the charges out of balance.
- Now the effects of the charges (their dipole moments) no longer cancel one another out and net positive and negative charges appear on opposite crystal faces.
- By mechanically distorting the crystal, a voltage is produced across its opposite faces—piezoelectricity!

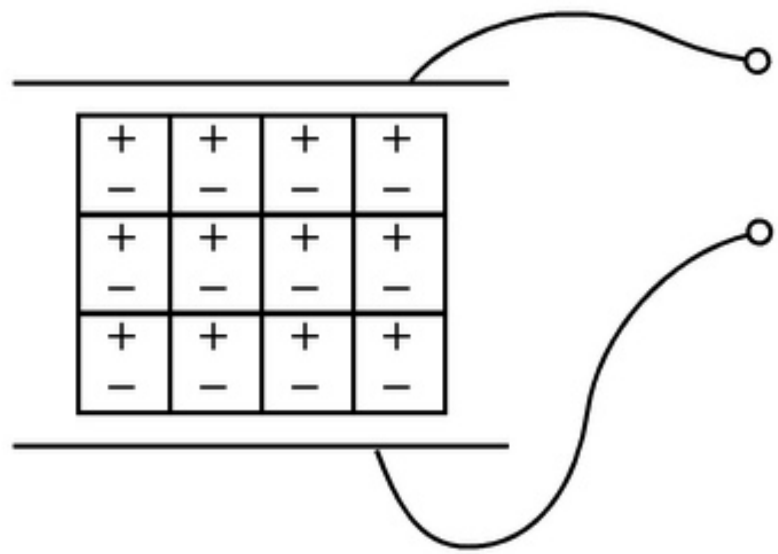




Images from www.explainthatstuff.com

Piezoelectric Sensor

- Two metal plates are used to sandwich the crystal making a capacitor.
- As mentioned previously, an external force causing a deformation of the crystal results in a charge which is a function of the applied force.
- In its operating region, a greater force will result in more surface charge.



Thermocouple – Seebeck Effect

- Thermocouples are the most popular temperature sensors.
- They are cheap, interchangeable, have standard connectors and can measure a wide range of temperatures.
- The main limitation is accuracy, system errors of less than 1°C can be difficult to achieve.

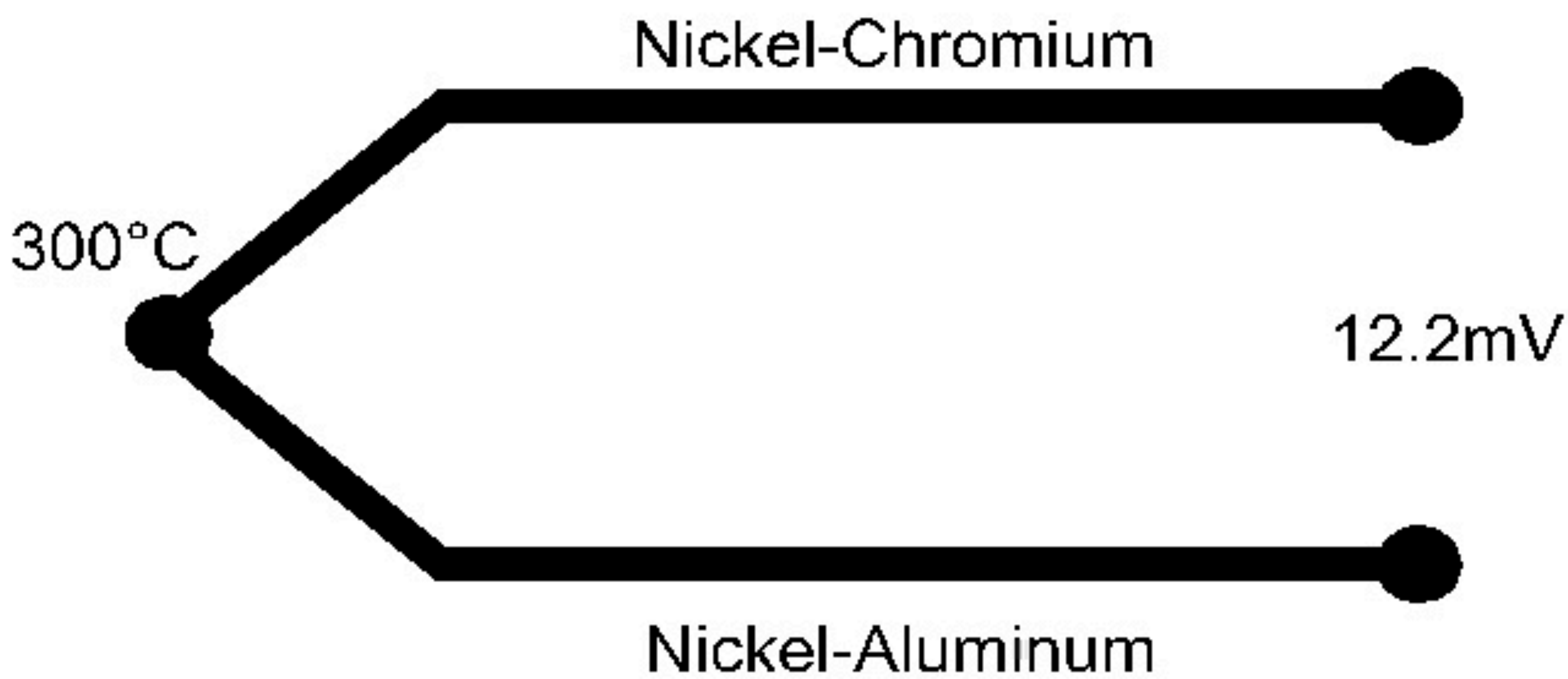
Seebeck Effect

- In 1822, an Estonian physician named Thomas Seebeck discovered (accidentally) that the junction between two metals generates a voltage which is a function of temperature.

- Thermocouples rely on this Seebeck effect.

- Although almost any two types of metal can be used to make a thermocouple, a number of standard types are used because they possess predictable output voltages and large temperature gradients.

K-type Thermocouple



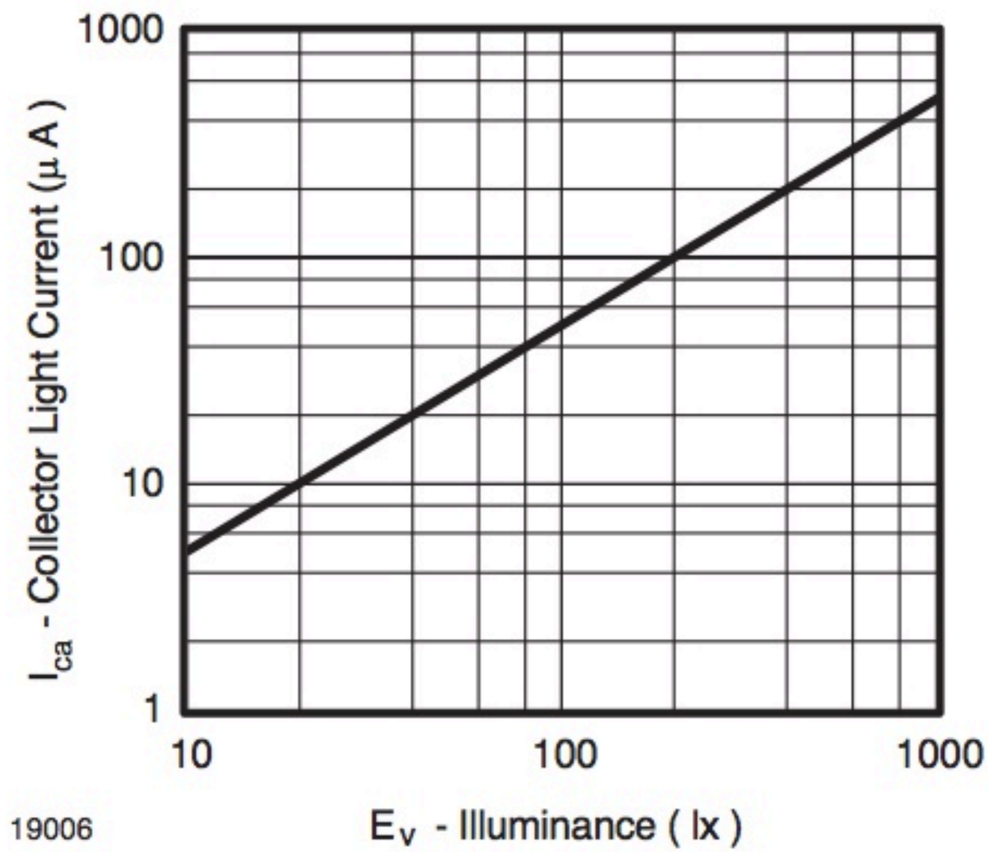
Choosing the right sensor

- Decide first what parameters of the external environment are important for our application (e.g.: temperature, humidity, pressure, light, etc).
- Determine what kind of sensor is optimal for measuring that parameter.
- Decide also on the basis of **quality parameters**.

Quality parameters of a sensor system(1)

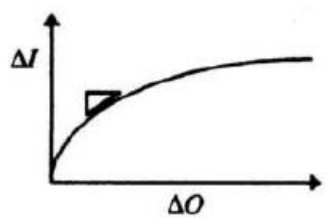
- **Transfer Function**
  - the functional relationship between physical input signal and electrical output signal
  - for expensive sensors which are individually calibrated, this might take the form of the certified calibration curve

Transfer Function



Quality parameters of a sensor system(2)

- **Sensitivity**
  - is defined in terms of the relationship between input physical signal and output electrical signal
  - the sensitivity is generally the ratio between a small change in electrical signal to a small change in physical signal.
  - Example: a thermometer would have "high sensitivity" if a small temperature change resulted in a large voltage change.



Sensitivity $S = \frac{\Delta O}{\Delta I}$

Quality parameters of a sensor system (3)

- **Accuracy:** is a measure of difference between the measured value and actual value. Generally defined as percentage of actual value.

- **Precision**: is the ability of an instrument to reproduce a certain set of readings within a given deviation.

- **Repeatability**: is the ability to reproduce the output signal exactly when the same measured quantity is applied repeatedly under the same environmental conditions.

Quality parameters of a sensor system(4)

- **Range & span** : is defined as the limits between which inputs can vary. Span is maximum value minus the minimum value of the input.

- **Stability (drift):** is the ability to give same output when a constant input is measured over a period of time. Drift is expressed as percentage of full range output.

Sensor Range

- Temperature sensor from Novar Controls:

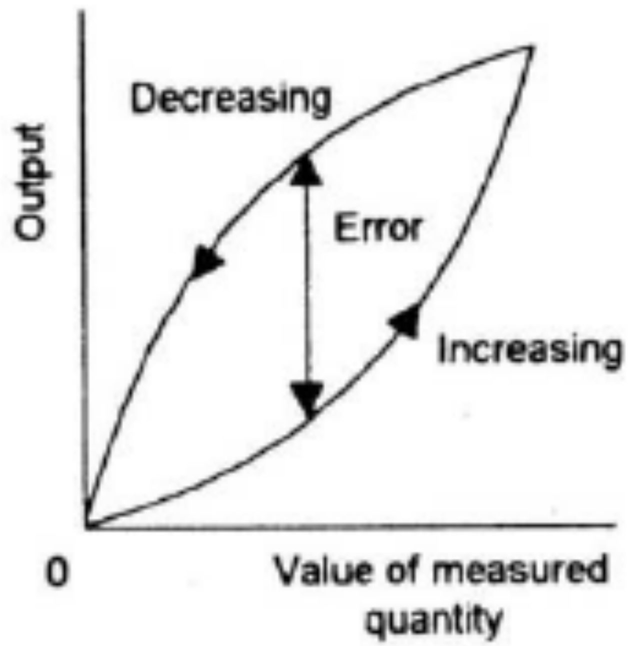
Outdoor Temperature Sensor (EP/2)

For use with the EP/2, Savvy™ and Lingo™. Precision sensor consisting of an environmentally sealed, metal enclosure equipped with a 20-foot, shielded cable.

Model:	***Measurement Range:***
EP2-OTS	*-40° to 120° F (-40° to 49° C).*

Quality parameters of a sensor system
(5)

- **Hysteresis**:
  – Different output for increasing and decreasing value of input



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Example: Humidity Sensor

Sensor Performance

Relative Humidity

Parameter	Condition	min	typ	max	Units
Resolution [1]		0.4	0.05	0.05	%RH
		8	12	12	bit
Accuracy [2] SHT10	typical		±4.5		%RH
	maximal	see Figure 2			
Accuracy [2] SHT11	typical		±3.0		%RH
	maximal	see Figure 2			
Accuracy [2] SHT15	typical		±2.0		%RH
	maximal	see Figure 2			
Repeatability			±0.1		%RH
Hysteresis			±1		%RH
Non-linearity	linearized		<<1		%RH
Response time [3]	τ (63%)		8		s
Operating Range		0		100	%RH
Long term drift [4]	normal		< 0.5		%RH/yr

Quality parameters of a sensor system(6)

- **Noise:**

  – All sensors produce some output noise in addition to the output signal. In some cases, the noise of the sensor is less than the noise of the next element in the circuit, or less than the fluctuations in the physical signal, in which case it is not important.

  – Many other cases exist in which the noise of the sensor limits the performance of the system based on the sensor.

Sources of Sensor Error

- Error = the difference between the measured value and the true value.

- Types of errors:
  - Insertion errors
  - Application errors
  - Characteristic errors
  - Dynamic errors
  - Environmental errors

Application Errors

- Operator-caused
  - numerous types are possible.

- Errors seen in temperature measurements:
  - incorrect placement of probe
  - erroneous insulation of the probe from the measurement site

- Application errors can also involve incorrect placement of a transducer

Insertion Errors

- Occur when the act of inserting a sensor into the system changes the parameter of being measured
  - using a transducer that is too large for the system (e.g. pressures)
  - one that is too slow for the dynamics of the system
  - or a sensor that self-heats to the extent that excessive thermal energy is added to the system.

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Characteristic Errors

- Defined as those that are inherent in a device itself
  - the difference between the ideal, published characteristic transfer function of the device and the actual characteristic.

Dynamic Errors

- Many sensors are characterized and calibrated in a static condition, which means using an input parameter that is either static or quasi-static in nature.

- Dynamic errors will appear when the input parameter is rapidly changing.

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Environmental Errors

- Derive from the environment in which the sensor is used.
- They most often include temperature, but may also include vibration, shock, altitude, chemical exposure or other factors.
- These most often affect the characteristic errors of the sensor, so they are often lumped together with that category in practical application.

Sensor output

- Sensor output is generally in the form of **resistance change** or **voltage change** or **capacitance change** or **current change** when input quantity is changed.

- An appropriate circuit is required to measure the above changes.

Digital Sensors

- A digital sensor's output can only be in one of two possible states.

- It is either ON (1), often +5V or OFF (0), 0V. Most digital sensors work with a threshold.

- If the incoming measurement is below the threshold, the sensor will output one state, if it is above the threshold, the sensor will output the other state.

Analog Sensors

- In contrast to a digital sensor, an analog sensor's output can assume any possible value in a given range.

- Very often the output of an analog sensor is a **variable resistance** that can be used to control a voltage.

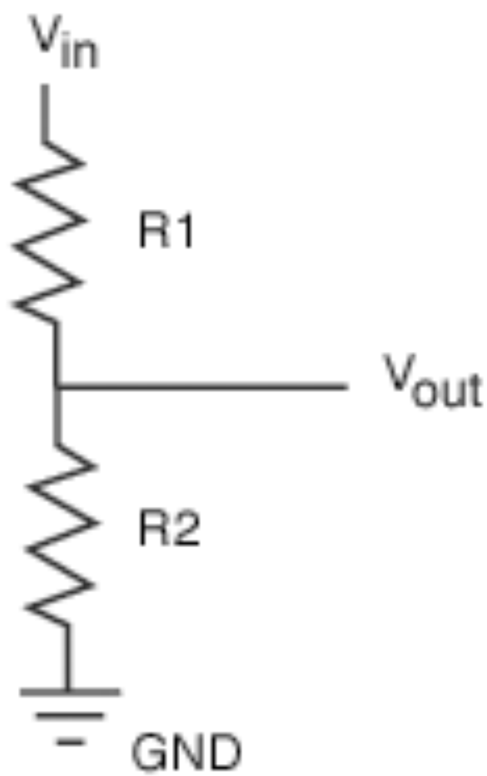
- Rather than only being able to toggle between two states, the analog sensor can output an almost infinite range of values.

Voltage Divider and Analog Sensors

- Analog sensors, such as the light sensor in our lab kit often work like a variable resistor the resistance of which is directly influenced by the condition it measures (in the case of the light sensor it is the amount of light).

- Often a **voltage divider circuit** is used to turn the changing resistance of the sensor into a proportional change of voltage that can be understood better by ICs/ microcontrollers that you might want to connect to the sensor.

Voltage Divider Principle



based on Ohm's Law:

$$I = \frac{V_{in}}{R1 + R2}$$

$$V_{out} = I \times R2 = \frac{R2}{R1 + R2} V_{in}$$

RFID

- **R**adio **F**requency **Id**entification

- Automatic identification procedures exist to provide information about people, animals, goods and products
  - Barcode labels: based on optical principles
    - Inadequate in an increasing number of cases
      - Low storage capacity
      - Cannot be reprogrammed

- Alternative solution to barcode labels is to store data in a silicon chip (telephone chip cards, bank cards,etc)
  - Disadvantage: impractical mechanical contact

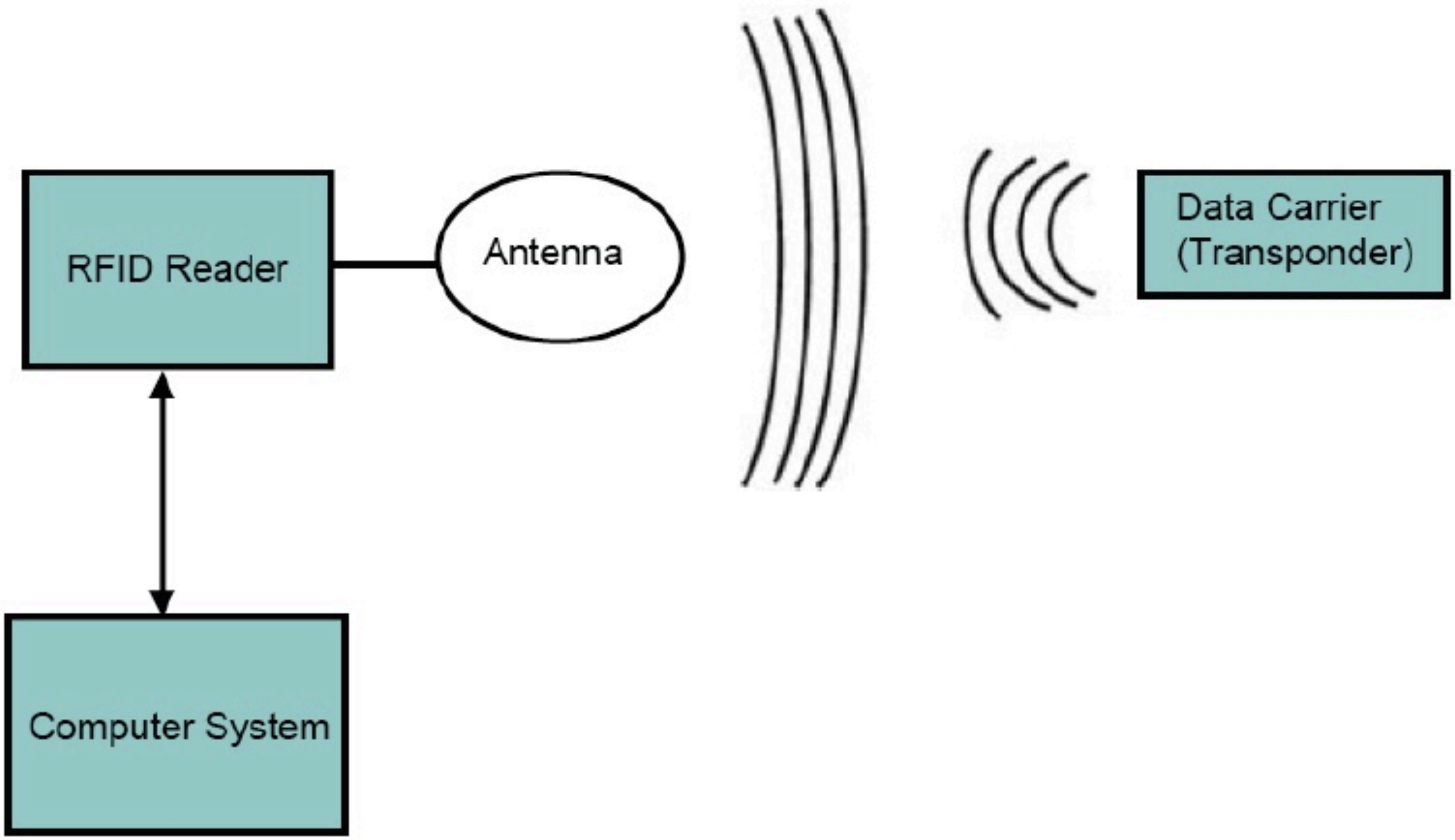
- RFID: contactless in regards to transfer of data and power

RFID ("Smart Labels")

- Identify objects from distance
- Small IC with RF-transponder
- Wireless energy supply
- ~1m
- Cost ~$0.1 ... $1
- Consumable and disposable
- Flexible tags
- Laminated with paper

Chip (without antenna): ~ 2 mm x 2 mm x 10 µm (fits into 80 µm thick paper!)

RFID System



RFID Reader
Antenna
Data Carrier
(Transponder)
Computer System

RFID System

- An RFID system is always made up of two components:
  - the **transponder**, which is located on the object to be identified
  - the **detector reader,** which, depending upon design and the technology used, may be a read or write/read device

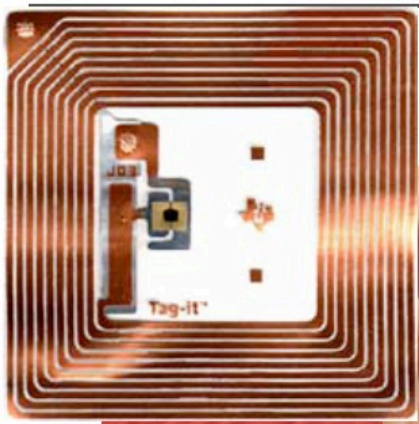
RFID Reader and Transponder

- Reader transfers energy to the transponder by emitting electromagnetic waves through the air.
- Transponder uses RF energy to charge up.
- Transponder receives command/data signal and responds.
- Reader receives transponder's response and processes it, i.e.sends it to a computer system.

RFID Transponder (Tag)

- Comprised of a chip and antenna mounted onto a substrate or an enclosure.
- The chip may consists of a **processor, memory and radio transmitter.**
- The transponder communicates via radio frequency to a reader, which has its own antennas.
- Transponders are also known as smart or radio tags.
- The memory will vary, depending on the manufacturer, from just a few characters to kilobytes

RFID tags



The black specks in the bottle are ultra-miniature RFID chips

Types of RFID Tags

- Transponders can be:
  - **Read Only (R/O)**: are pre-programmed with a unique identification.
  - **Read Write (R/W)**: for applications that require data to be stored in the transponder and can be updated dynamically.
  - **Write Once Read Manytimes (WORM)**: will allow for an identification number to be written to the transponder once. The information is stored in the memory, it cannot be changed but the transponder can be read many times.

RFID Technologies

- The two most common types of RFID technologies are:
  - **Active RFID transponders**
    - Are self powered and tend to be more expensive than passive.
    - Having power on board allows the tag to have greater communication distance and usually larger memory capacity.
  - **Passive RFID transponders**
    - Are available with chips and without chips, they have no internal power source, therefore require external power to operate.
    - The transponder is powered by an electromagnetic signal that is transmitted from a reader. The signal received will charge an internal capacitor on the transponder, which in turn will then supply the power required to communicate with the reader.

Frequency and Applications

- Today, most implementations involve **passive technology.**

- There are different frequency bands which passive technology operates within:
  - **Low frequency (LF) passive RFID**
  - **High frequency (HF) passive RFID**
  - **Ultra High frequency (UHF) passive RFID**

- One frequency does not fit all types of applications.

Frequency and Applications

- LF:
  - Range varies from a few cm to a couple of meters depending on the size of the transponders
  - Not very affected by surrounding metals or water
  - Expensive ($ 2.00 - $17.00 CDN)
  - Only read one tag/transponder at a time
- HF
  - More affected by metals than LF
  - Faster communication
  - Read range < 1m
  - Cheap(er) ($0.70 - $0.80)
  - Reads multiple tags

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RFID Frequencies cont.

- UHF
  - Longer read distance (1-10 m)
  - Does not work well with liquids (humidity)
  - Long read distance is a disadvantage in applications where security and privacy are issues
    - Banking
    - Access control

RFID Advantages

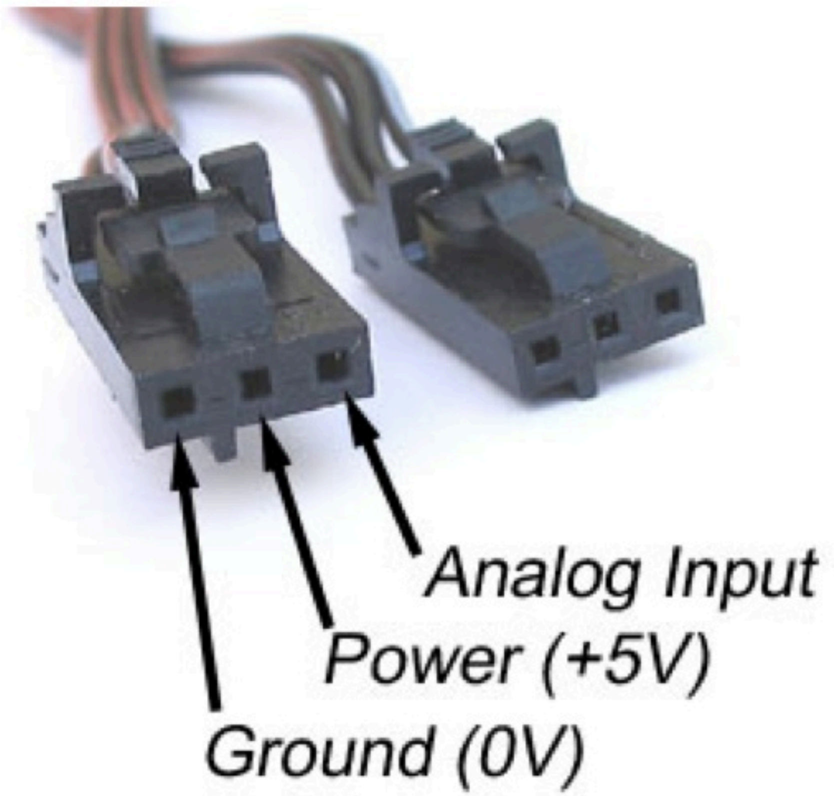
- No line of sight required.
- Multiple items can be read with a single scan.
- Each tag can behave like a portable database.
- Hidden data source.
- Virtually unlimited lifetime
- Tags can be read from great distances.

RFID Advantages

- Can be combined with current barcode technology
- Can take many shapes and survive climactic and harsh conditions
- Data on the tag can be modified
- Unique permanent ID embedded

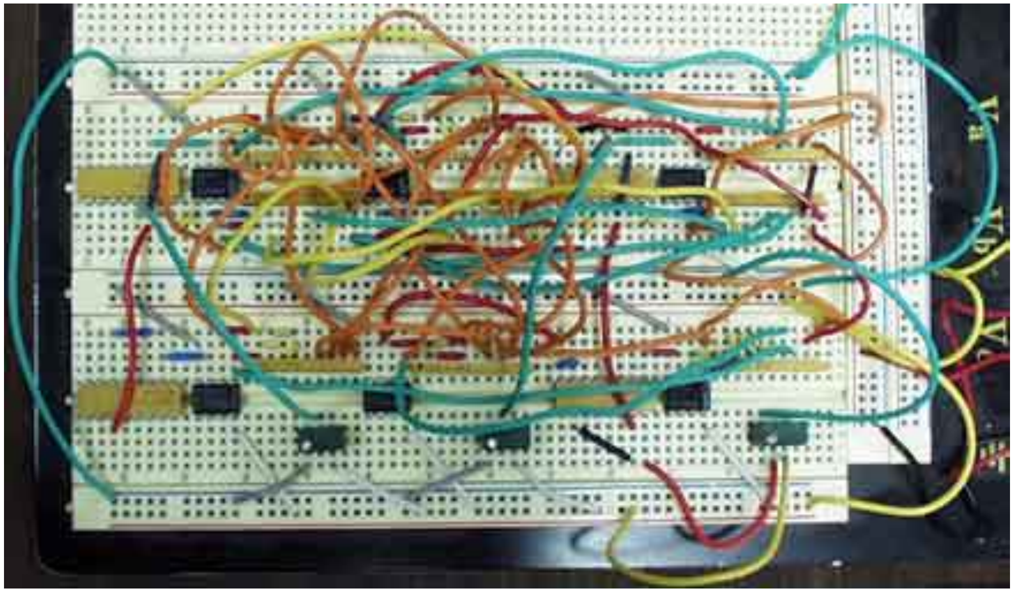
Sensors in the Lab

- How to connect:



Breadboard

- Keep it organized
- Verify the circuit before applying power
- To make it easy to verify and follow connections, try to keep the wires flat on the breadboard - not like this:



Thank you

Questions?