ENGINEERING
TEXAS A&M UNIVERSITY

ENGR/PHYS 217

Introduction to the Course; Measurement

Howdy! Welcome to today's class. Please download the current version of these slides from Canvas and open the downloaded file in MS PowerPoint. We will start today's discussion in a few moments.

Agenda for today:

Introduction to the Course

- Introduction
- Team forming and seating plan
- The course
- Canvas
- Syllabus
- A brief account of history of Electricity and Magnetism

Measurement

- What is 'measurement'? Why do we perform measurements?
- Six categories of physical quantities
- How do we perform measurement?
  - Natural senses (sight, touch, hearing, smell, taste, space, others)
  - Sensors/transducers
- How is outcome of measurement used?
  - Data collected and stored for further processing
  - Data collected and used directly in a control system
  - Data collected to generate other data that is used for visualization or in a control system
- Examples of sensors/transducers
- Need for ADC (analog to digital conversion)
- Two major components of a measurement system
  - Sensor
  - ADC
- Data Acquisition System (DAQ)
- How is 'analog to digital conversion' performed?
- 'Range' and 'resolution' of a measurement system
- How do we report outcome of a measurement?
  - Single measurement
    - With an analog device
    - With a digital device
  - Repeated measurements

Welcome!

- Introduction

Welcome!

- Team forming
- Seating plan

Agenda for today

- Introduction
- The course
- Canvas
- Syllabus
- A brief account of history of Electricity and Magnetism
- Measurements, and Analog to Digital Conversion (ADC)
- DAQ

The course

- Electricity and Magnetism are important across many fields of engineering
- We will also cover some material you will use throughout your curriculum and later in your profession

The course

- 6 labs
- 14 class meetings in Spring or Fall; 10 in Summer
  - Refer to Canvas section website for topics to be covered every week
  - Cover various aspects of Electricity and Magnetism (E&M)
  - Engineering Ethics
  - Project Management
  - Art and Engineering

The course

- Class discussions
  - Pre-class learning by completing assigned reading and activities
  - There will be associated assessment (weekly tests)
    - Typically there will be two weekly tests, one pre-class test and one post-class test
  - Keep careful track of due dates
  - Submit to section website
- **There will be an in-person proctored final exam** on class discussion material during finals period in the classroom
  - Time/date depends on section
  - Refer to Final Examination Schedules on Aggie One Stop (Please note: The exam schedule may be adjusted later in the semester)
- This is an in-person class; there is generally no streaming – no Zoom
- If you are sick, please get a medical excuse letter; or get another evidence if you have another valid excuse

- Labs grade will be determined from lab reports
  - Submit to multisection website
  - Remember: You need either an RJ45 port on your laptop, or an adapter

Canvas

- Go to canvas.tamu.edu, and log in.
- Two sites:
  - Canvas section website
  - Canvas multisection website

Syllabus

- Read the syllabus carefully and thoroughly

A brief account of history of Electricity and Magnetism

Magnetism – a brief account of history

- 2000 BC – Magnets (lodestones) discovered in China and Greece or Turkey
- 400 BC – Compasses made from lodestones by Chinese
- 1819 – Hans Christian Oersted observed movement of compass needle in the vicinity of current carrying conductor
- 1831 – Michael Faraday and Joseph Henry showed that relative movement between a conductor and a magnet causes a current in the conductor
- 1873 – James Clark Maxwell formulated laws of electromagnetism

Electricity – a brief account of history[1]

- 600 BC - Thales of Miletus, a Greek philosopher, discovered that, when rubbed by fur, amber[2] attracted feathers
- 17th Century – the term electric was used and it was realized that there are two types of electricity
- 18th Century – Benjamin Franklin made considerable contributions to the human knowledge about electricity
- 19th Century – Electric power generation

[1] Further reading:
- https://nationalmaglab.org/education/magnet-academy/history-of-electricity-magnetism/timeline
- https://www.magcraft.com/history-of-magnetism-and-electricity
- https://www.sutori.com/en/story/electricity-and-magnetism-timeline--ueXDJxZUJgpU1xqQdBHP3bzS

[2] Elektron is the Greek word for amber, fossilized tree resin used as gemstone.

Measurements, and Analog to Digital Conversion (ADC)

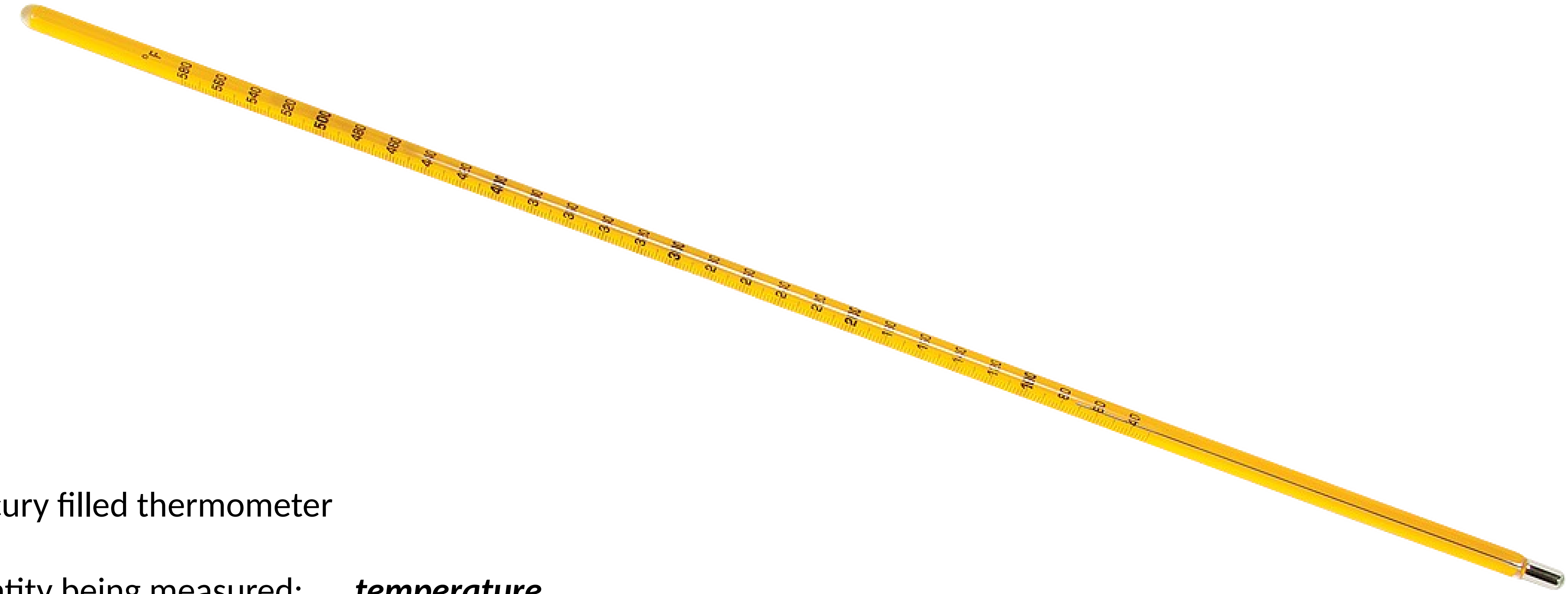
Measurement

- *Measurement*, in physical sciences or engineering, is observation of a physical quantity.
- *Unit* is a standard of comparison, e.g. foot, kilogram, newton.
- *Numerical value* of the observation is determined using a unit for that quantity.
- *Observed value* in a measurement is different from the *true value*, in almost all cases.
- *Error* is the difference of observed value and true value.
- *Measurement error*, in almost all cases, is not known.

Measurement - TL:DR

- Many measurements look at changes in **electrical characteristics** due to changes in other physical quantities
  - physical quantities: **mechanical, thermal, magnetic, chemical, radiation** (e.g. light), and **electrical**
  - electrical properties: **Voltage, Resistance, Capacitance, Inductance,** and **others**
    - An object with specific material and geometry can exhibit changes in these properties in relation to changes in other physical quantities.
    - In PHYS 207, you should have learnt or are going to learn about these properties
- For measurements, we use sensors and transducers
- Sensors and transducers – measure change in some physical quantity; output in the form of a physical quantity that is different from the one measured

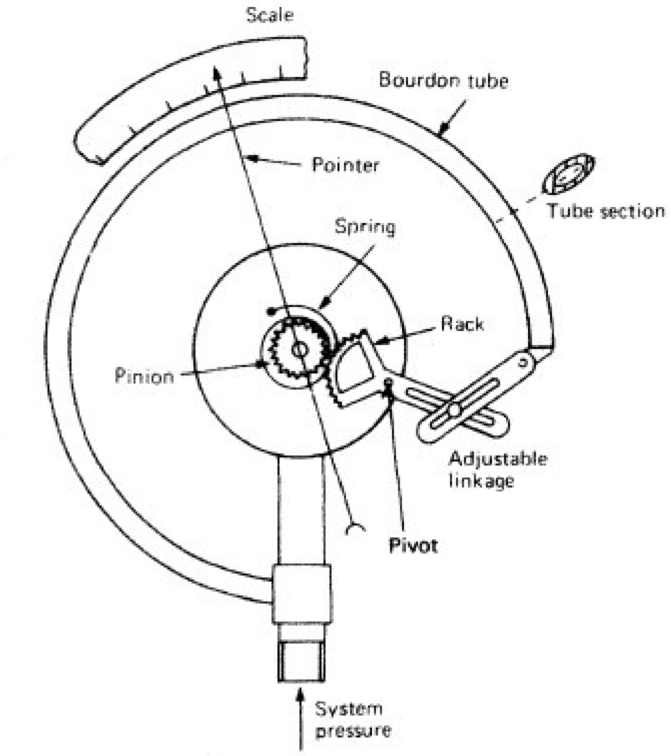
Measurement - Examples



Mercury filled thermometer

Quantity being measured: ***temperature***
Output quantity: ***length of mercury column***

Measurement - Examples



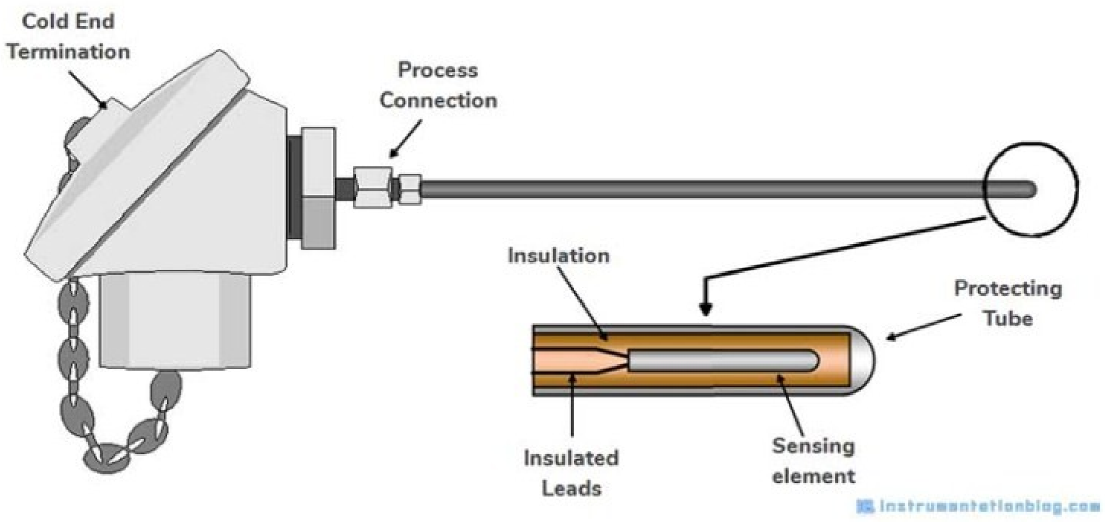
Bourdon tube pressure gauge

Quantity being measured: ***pressure***

Output quantity: ***position of needle on a scale***

http://www.machineryspaces.com/Bourdon-tube-pressure-gauge.html

Measurement - Examples



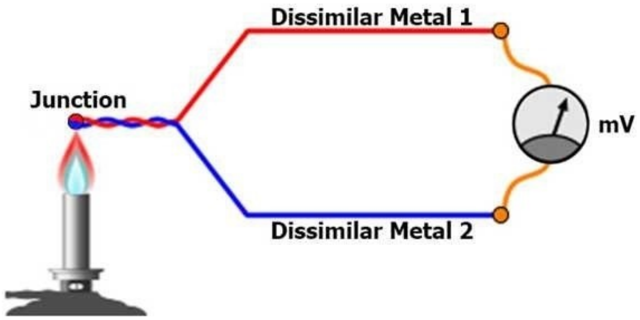
Thermistor

Quantity being measured: ***temperature***
Output quantity: ***voltage***

Resistance Temperature Detector (RTD)

Quantity being measured: ***temperature***
Output quantity: ***voltage***

Measurement - Examples



Thermocouple
Consists of two dissimilar wires; voltage difference across the two wires depends on the temperature at their junction

Quantity being measured: ***temperature***
Output quantity: ***voltage***

Pressure Transducer/Transmitter

Quantity being measured: ***pressure***
Output quantity: ***voltage***

Measurement - TL:DR

- Most of the time the output of sensors or transducers is changes in **voltage**

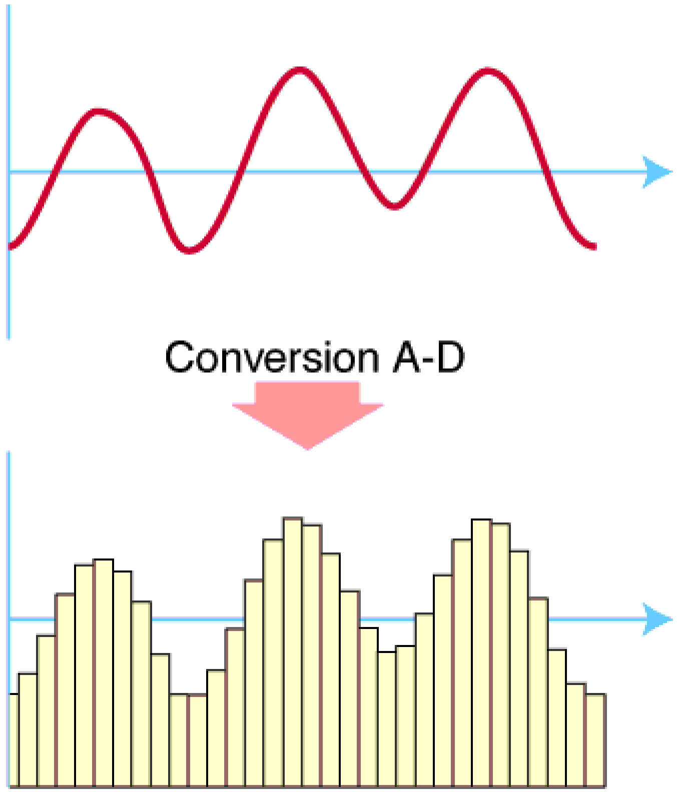
What is voltage?

- **Voltage** between two points is the difference of electric potential between the points.
- **Electric potential** is the **electric potential energy** of a unit positive charge.
- Therefore, voltage between two points is the change in potential energy of a unit (positive) charge when it is moved from one point to the other.
- Units of electrical potential are **Volts**
- ***We will have more detailed discussion on voltage in subsequent classes.***

Measurement - TL:DR

- We need to convert changes in voltage which are analog (continuous) values to digital (discrete) values, since computers are digital
  - Analog to Digital Converters (ADCs) are used for this purpose
  - A good tutorial is available here: https://www.electronics-tutorials.ws/combination/analogue-to-digital-converter.html

Analog to Digital Conversion



Analog or continuous signal

Digital or discrete signal – the closer the discrete values the higher the resolution

Reference: https://en.wikipedia.org/wiki/File:Conversion_AD_DA.png

Example

- Let's say we have a 4-bit ADC.
- It can represent discrete numbers:

0	8
1	9
2	10
3	11
4	12
5	13
6	14
7	15

Ok, what does this have to do with resolution?

Example

- By knowing the **range** and **number of bits** of an ADC, we can figure out:
  - the resolution of the ADC and
  - the discrete voltage values that can be output by this ADC.
- Assume we have a 4-bit ADC with an output range of 5 V. There are 16 possible outputs. We let each output represent an equal part of the range between 0 and 5 V.
- 5 V/15 = 1/3 V;
  - this is the **width for each sub range** or **resolution of the ADC**

Example

- We can now map analog values to digital (discrete) values:

	Output is 0
	Output is 1
	Output is 2
	Output is 14
	Output is 15

Why does resolution of an ADC matter?

- Sensitivity of a sensor/transducer is the change in the output signal (usually in volts) per unit change in the physical quantity being measured.
- If you use too large a range, or too small a number of bits, you won't be able to see changes in the signal from the sensor, or measure changes in the physical quantity being measured.
- Pick your ADC to match what you expect input from sensor to be.

How ADCs work

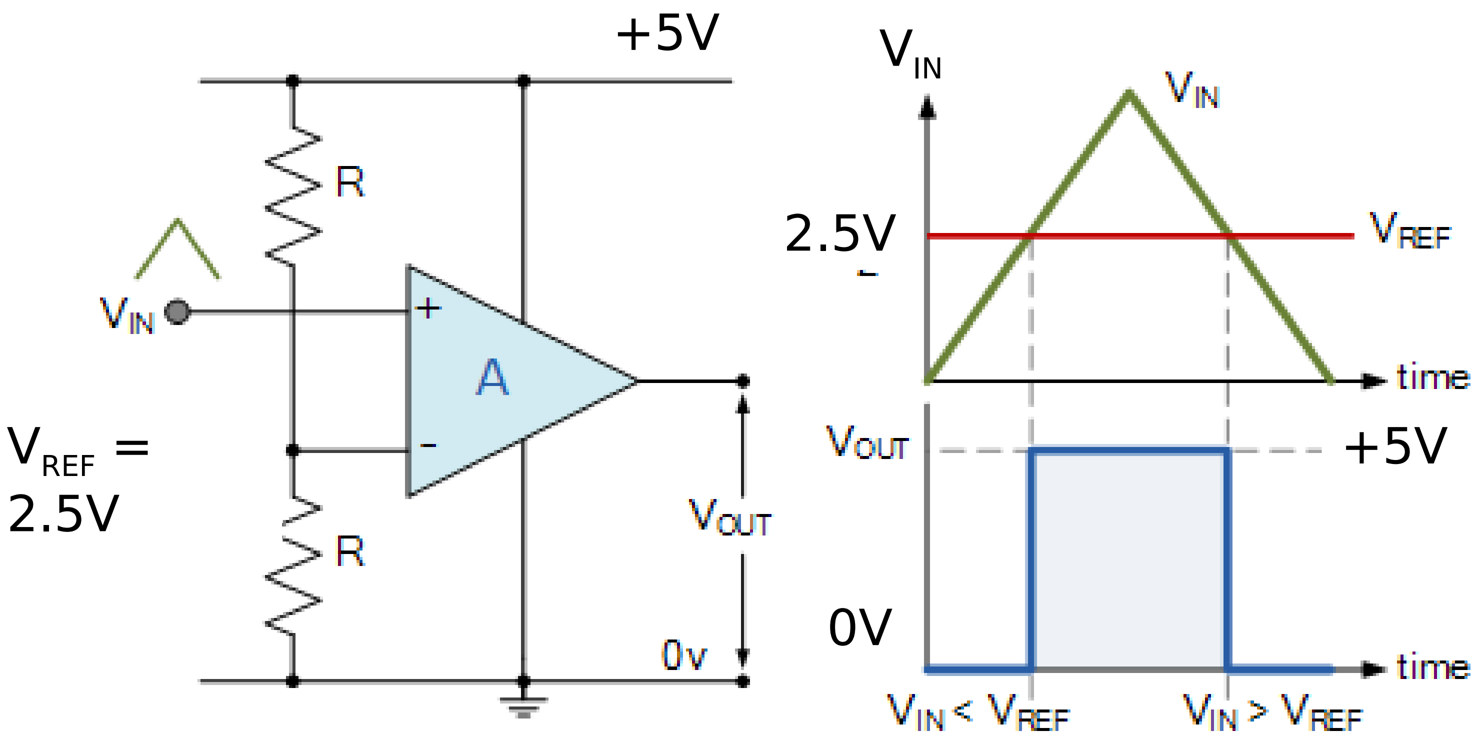
- There is a number of different types of ADCs, but most work using a circuit called a *voltage comparator.* A voltage comparator has two voltage inputs A and B. If A>B, the comparator returns A. If A<B, the comparator returns B.

How ADCs work

Voltage comparator compares two electric potential values.

In the shown example,

- $V_{out} = 5\ V$ if $V_{in} > V_{REF}$
- $V_{out} = 0\ V$ if $V_{in} < V_{REF}$



How ADCs work – Flash ADC

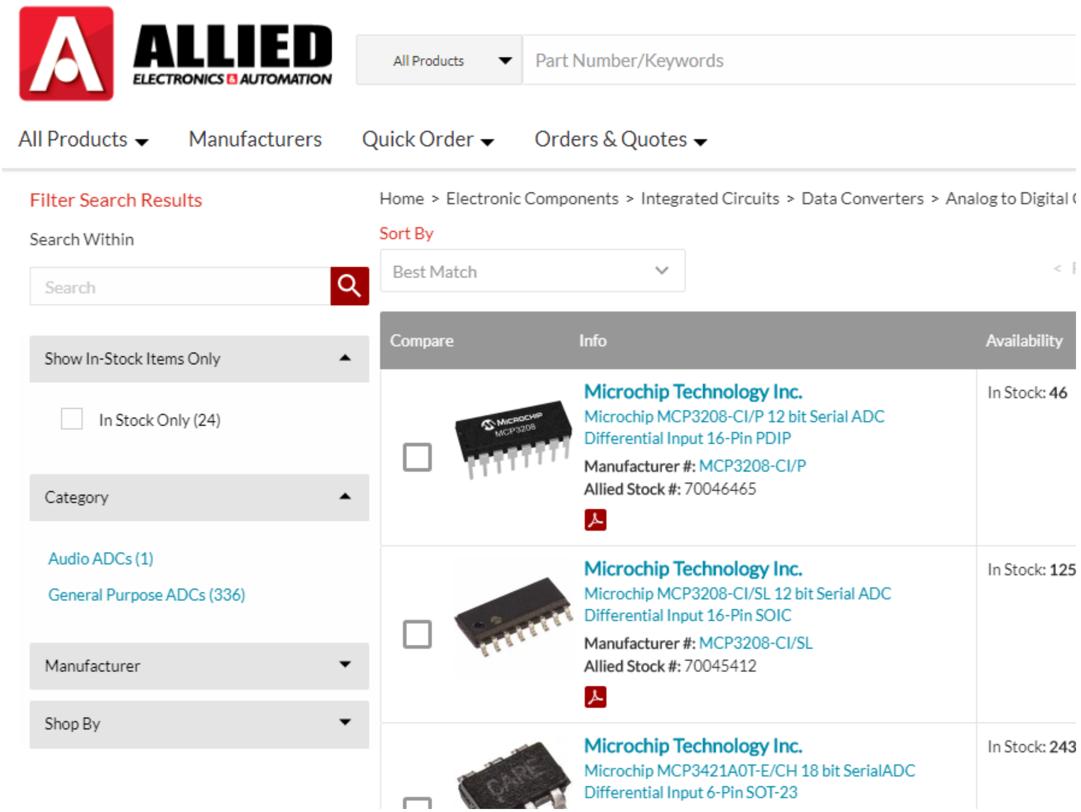
- n = number of bits – use ~ comparators
- Advantage – very fast
- Disadvantage – expensive, not cost-effective for n > 8

How ADCs work – Successive approximation

- Successive approximation
  - Idea – set a reference voltage in the comparator, compare with the unknown measurement voltage
  - If unknown voltage is less, output the corresponding discrete voltage value
  - If no, increase the reference voltage, and compare again
- Advantage – cheaper
- Disadvantage – slower

Analog to Digital Converters (ADCs)

- There are many, many, many chips which do analog to digital conversion
- They are also often built into modern microprocessors, so you don't even need to include one



Characteristics of an ADC

Choice of an ADC for a given measurement application is based on the following characteristics:

- Speed
- Resolution
  – Output Range
  – Number of bits
- Differential or single ended
- Sponge Bob or Patrick

(Just checking if you're paying attention)

Speed

- Speed is measured in samples per second – units are Hertz = 1/second
- For television, telephones, communications in general, we want millions of samples per second – mega Hertz – MHz
- For our labs, don't need that speed (usually) – we get by with thousands of samples per second – kilo Hertz - kHz

Range

- An ADC will typically have an input range (maximum voltage difference)
- Values can only be read in this range
- Values above or below the range will be “clipped”
- IMPORTANT: going too far outside range can damage equipment!

Examples

- You have an ADC with a range of ±5 V relative to ground. (Ground voltage is taken as 0 V).
- Your voltage input is 7.2 V above ground
- Your ADC returns a reading of 5 V, since 7.2 V is out of range

Examples

- You have an ADC with a range of ±5 V relative to ground.
- Your voltage input is 1.3 V below ground
- Your ADC returns a reading of -1.3 V since it is within the range

Dealing with range

- You can often use *signal conditioning* to make readings of out-of-range values, or make readings which use more of the range
- Signal conditioning is an advanced topic, so we won't discuss too much how to actually do it, but you should understand the basic principle

Example

- The signal entering a radio is 0.1 mV. You pass the signal through an amplifier circuit that raises it to the 1 V range

Data Acquisition System (DAQ)

- A data acquisition system is a collection of software and hardware that allows one to measure … physical characteristics of something in the real world (source: Wikipedia)
- Data Acquisition Systems (DAQ) are extensively used in physical sciences and engineering
- A typical DAQ consists of sensors, actuators, ADC, and a computer to run the associated software
- A sensor/transducer measures a physical quantity (temperature, pressure, light, etc.); the output of the transducer is analog voltage.
- Transducer is coupled with an ADC that converts (or maps) analog values of voltage into digital values. The output from an ADC is still voltage, but in digital form.

Data Acquisition System (DAQ)

- ***Sensitivity of a sensor****/transducer* is the change in output voltage of the sensor for a unit change in the physical quantity being measured.
- ***Resolution of an ADC*** is the difference of two consecutive discrete output voltage values.
  – Resolution of an ADC is usually specified in terms of bits – e.g. a 10 bit ADC, a 14 bit ADC, a 24 bit ADC.
  – The number of bits tells you the number of possible binary numbers the device can output

- ***Resolution of a measurement system*** is the smallest measurable change in the physical quantity being measured.

Data Acquisition System (DAQ)

– Units of sensitivity would be , , etc.

[1] Refer to this page for further reading:
https://www.ni.com/en-us/innovations/white-papers/13/sensor-terminology.html#:~:text=Dynamic%20Linearity-,Sensitivity,input%20of%20physical%20parameter%20that%20will%20create%20a%20detectable%20output%20change.,-In%20some%20sensors

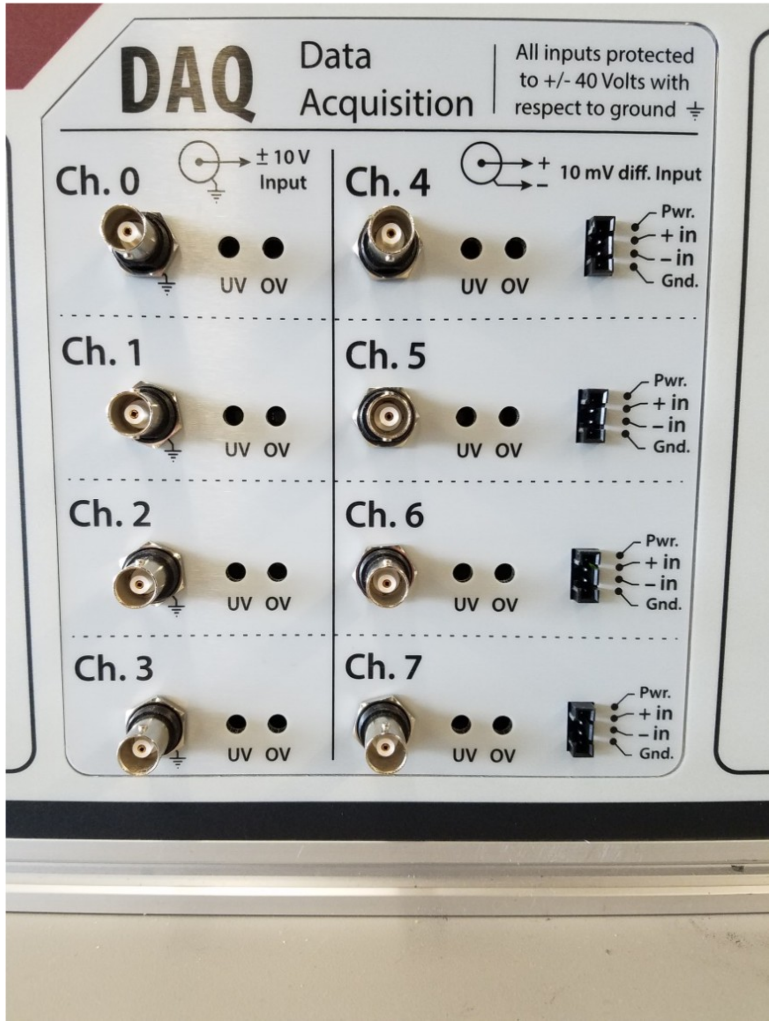
Lab Visualization Studio is a DAQ

- For an introduction to Lab Visualization Studio, watch the video posted in Canvas.

FYI Our DAQ has a 12-bit ADC

This should be sufficient to do the measurements you need in this class.

This information will also give you some idea of how accurate your measurements can be.



I’ve got 12-bits, baby!

Example

- The Type K thermocouple has a sensitivity of about , i.e. for each degree difference in the junction temperature, the output changes by 41 V.
- The output from the sensor is fed into an ADC.
- If you have a 16-bit ADC, what is the smallest temperature change you can detect if the ADC range is 10 V?
- (Students should try before revealing answer)

Answer

- so we can split the range into 65535 subranges
- Each subrange is 10 V/65535 = 0.0001526 V (rounded) or 152.6 . This is the resolution of the ADC.

- Each subrange represents . This is the resolution of the measurement system.

- So we can comfortably detect changes of

Voltage measurement using an analog meter

An analog voltmeter measures voltage by position of a needle on a scale.

A current carrying coil placed in electromagnetic field experiences electromagnetic torque which is proportional to the current passing through the coil.

We have more accurate means now…

You can buy this for $5-$10 at Amazon

It is based on technology your instructor used when he was young

Measurement - Precision

- Least Count – the smallest possible measurement
- In a single measurement (with an electronic instrument or a gauge with graduations) precision is of the Least Count – this is '***precision of the instrument***'
- For example, if the reading in a single measurement using the gauge shown here is 62 psi, we report it as 62 ± 1 psi; 62 psi is the best estimate; ± 1 psi is the precision

Precision with repeated measurements

- We talk about '***precision of measurement***', when we take multiple measurements
- When a number of measurements are taken the measurement can be reported as an interval estimate
- interval estimate = best estimate ± precision
- Precision is also called uncertainty or variation
- Whenever we report an interval estimate a confidence level is also reported
- The set of measurements is called a data sample
- Sample mean, , is the best estimate

Estimating uncertainty with repeated measurements

- For repeated, independent measurements, we can use statistics to get uncertainty
- There will be more detailed discussion on this in a subsequent class

Standard error

- We know how to get mean and standard deviation from n independent measurements
- We can now estimate the experimental error for our best estimate (the mean) as

- This quantity is called standard error of the mean. We use it as variation, precision, or uncertainty.

Interval estimate

-
- Confidence level is 68%
- This means the true value of the physical quantity being measured is contained by the interval with a probability of 0.68.

Adjournment

- Read assigned material ahead of the class; come prepared for effective class discussion
- Typically there will be a pre-class test on the assigned reading and a post-class test on the overall learning during a week
- Please make sure to:
  - Catch up on the current week's assigned reading
  - Complete the assigned reading for the next week
  - Keep careful track of all assessments' due dates

- Questions?