ENGG 6150

Bio-Instrumentation

Instrumentation Concepts and Systems

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or by email

Course content

Week	Lecture Topics
1	Overview of course content, instrumentation concepts and systems.
2	Review of basic sensors.
3	Chemical biosensors
4-5	Design and analysis of signal conditioning circuit, electrical safety
6-7	Amplifiers, biopotential electrodes and biopotential amplifiers
8-10	Clinical laboratory instrumentation and measurement
11-12	Technical Presentations

Grades Breakdown

Assessment	Weight	Due Date (tentative)
Assignment 1	10%	Feb. 19, 20
Assignment 2	10%	March 18, 20
Midterm Exam	25%	March 25, 20
Presentation	15%	April 8, 2020
Final Project Report	40%	April 15, 20

What is an Instrument?

- Instruments:
  Devices that can be used to make a measurement and give quantitative (or sometimes qualitative) results

- Biomedical Instruments:
  Devices that can be used to make measurements of biological or medical quantities and give quantitative (or sometimes qualitative) results

Examples of Familiar Biomedical Instrumentation

Clinical Thermometer

Stethoscope

What is Measurement?

- Measurement tells us about the property of different physical phenomena like
  - Weight,
  - Length,
  - Temperature,
  - Pressure.
  - Displacement, …etc.

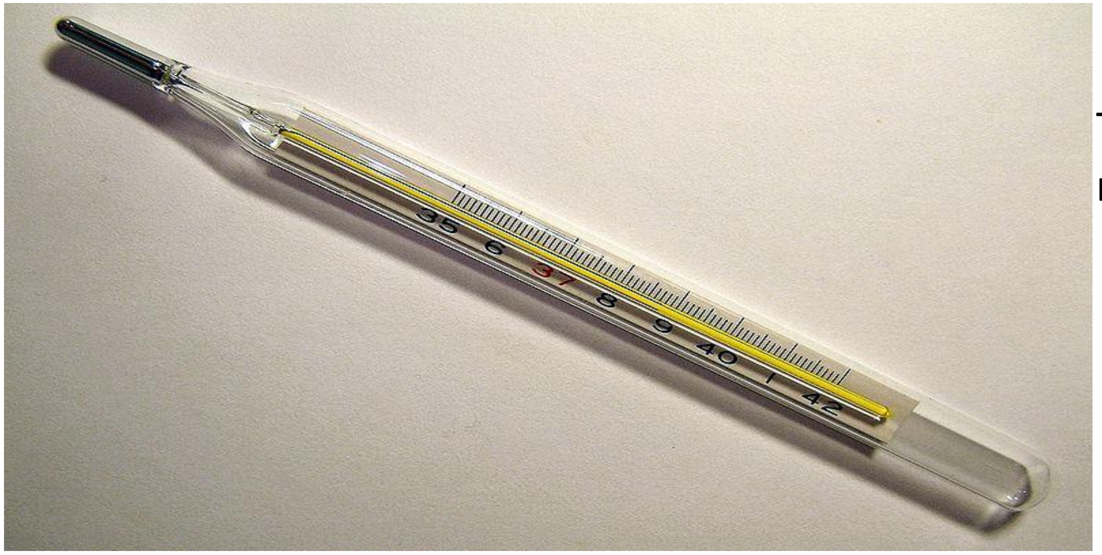
- Measurement describes various phenomena in quantitative terms.

Methods of Measurement

- Direct methods:
  - Unknown quantities are directly measured like measuring current using Ammeter, voltage using voltmeter and resistance using Ohmmeter.

- Indirect methods:
  - Unknown quantities are determined by measuring the functionally related quantity and then calculating the desired quantity like finding the resistance by measuring the voltage and current and then use Ohm law to find the resistance.

Direct Temperature Measurement
Clinical Mercury Thermometer

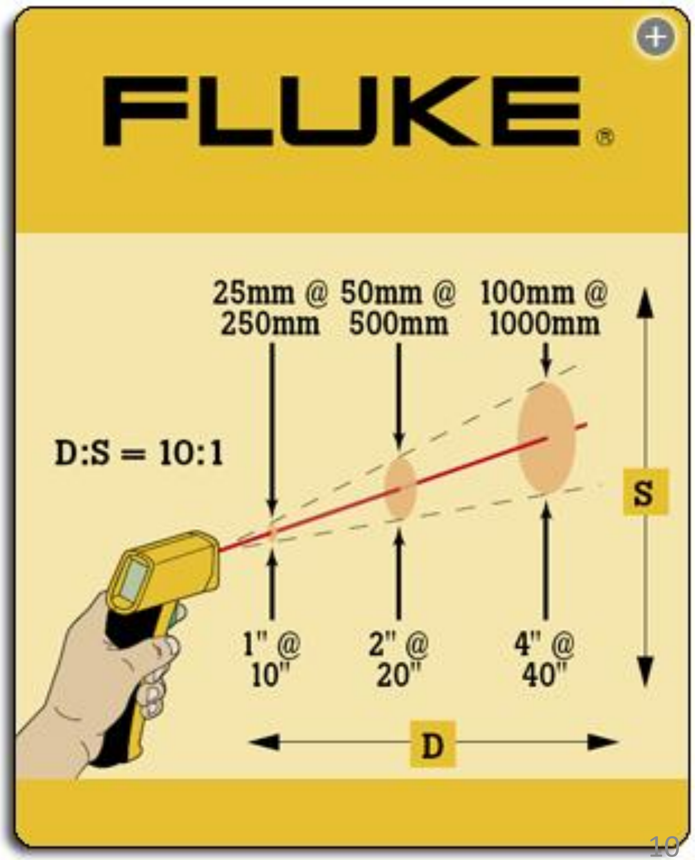


Temperature measurement range: 35 – 42 degrees C

Bulb is brought directly into contact with the body part or material whose temperature is to be measured, and as the mercury in the bulb exponentially changes to match this temperature, the mercury expands or contracts, pushing the very thin column of mercury up or down along a calibrated scale.

Indirect Temperature Measurement via "non-contact" Infrared (IR) Pyrometer)

Laser beam indicates middle of temperature measurement "spot". Radius of spot size is given by S = D/10.



Medical Instrumentation

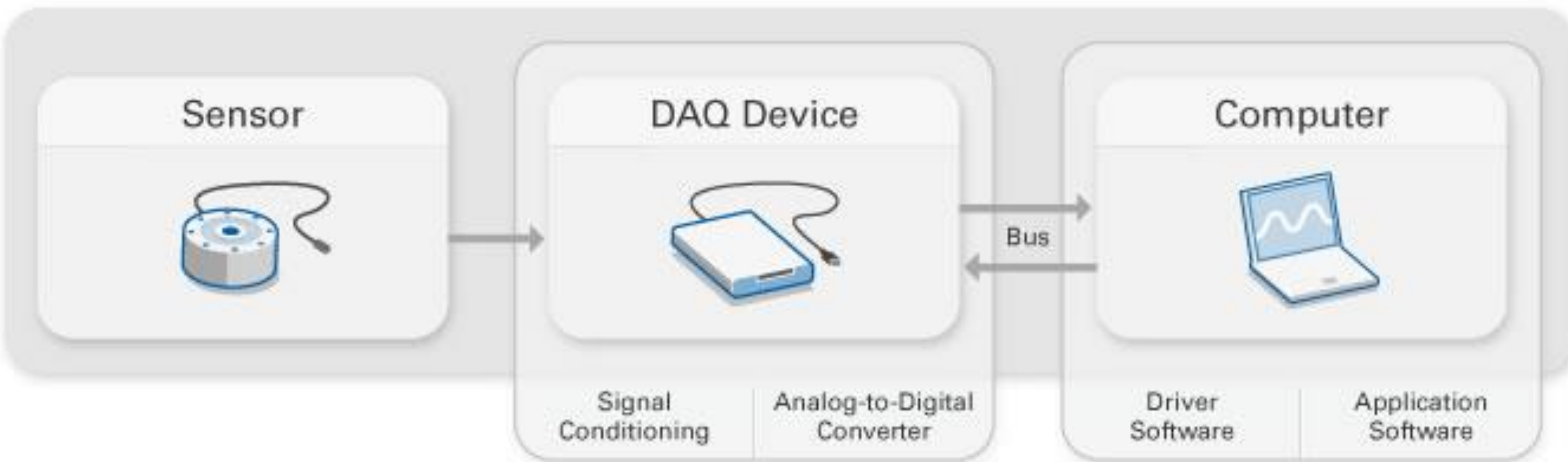
- Design of an instrument must match the following:
  - Measurement needs (environmental conditions, safety, reliability, etc)
  - Instrument performance (speed, power, resolution, range, etc)
- A medical device is:
  - "any item promoted for a medical purpose that does not rely on chemical action to achieve its intended effect"
    - [Medical Device Amendments (Public law 94-295)]
  - i.e., any electrical or mechanical device for medical applications

Medical Instrumentation

- Difference from any conventional instrument, medical instrument has
  - living tissue as the source of signals
  - energy is applied to the living tissue

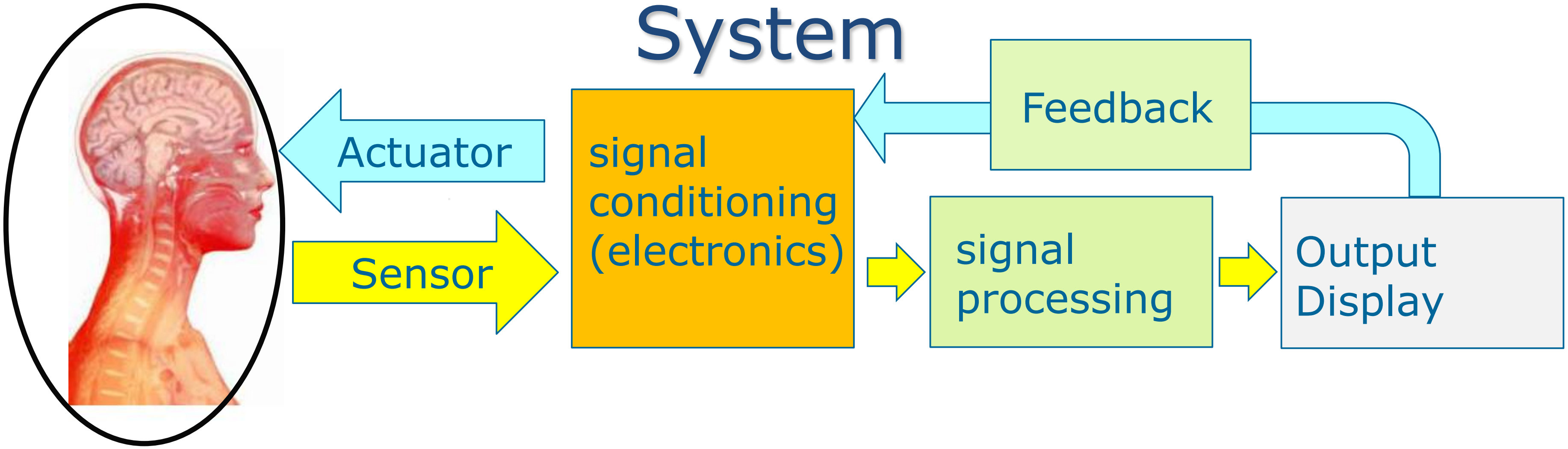
- Two important design requirements to meet in medical instrumentation that have strong impact are:
  - Reliability and Safety

General Instrumentation System



http://www.ni.com/data-acquisition/what-is/

General Medical Instrumentation System



- Measurand: Physical quantity, property or condition that the system measures
- Types of biomedical measurands ·
  - Internal – Blood pressure
  - Body surface – electro-cardio-gram (ECG) or electro-encephalo-gram (EEG) potentials
  - Peripheral – Infrared radiation
  - Offline – Extract tissue sample, blood analysis, or biopsy

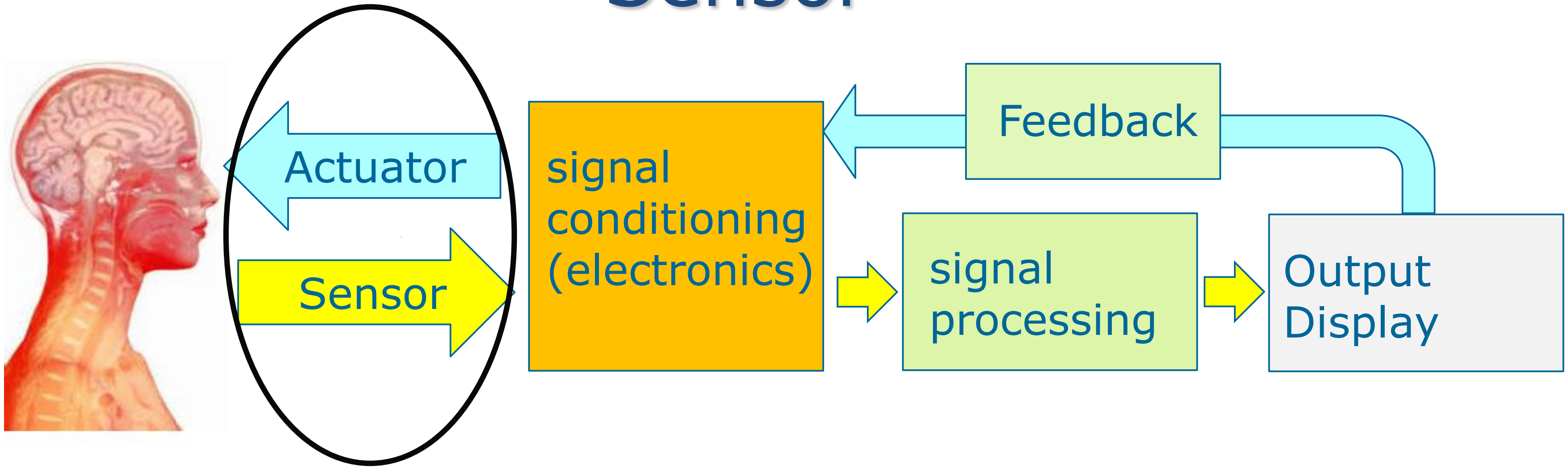
General Medical Instrumentation System

- Typical biomedical measurand quantities
  - Biopotential,
  - pressure,
  - flow,
  - dimensions (imaging),
  - displacement (velocity, acceleration and force),
  - impedance,
  - temperature
  - chemical concentration

Medical and Physiological Parameters

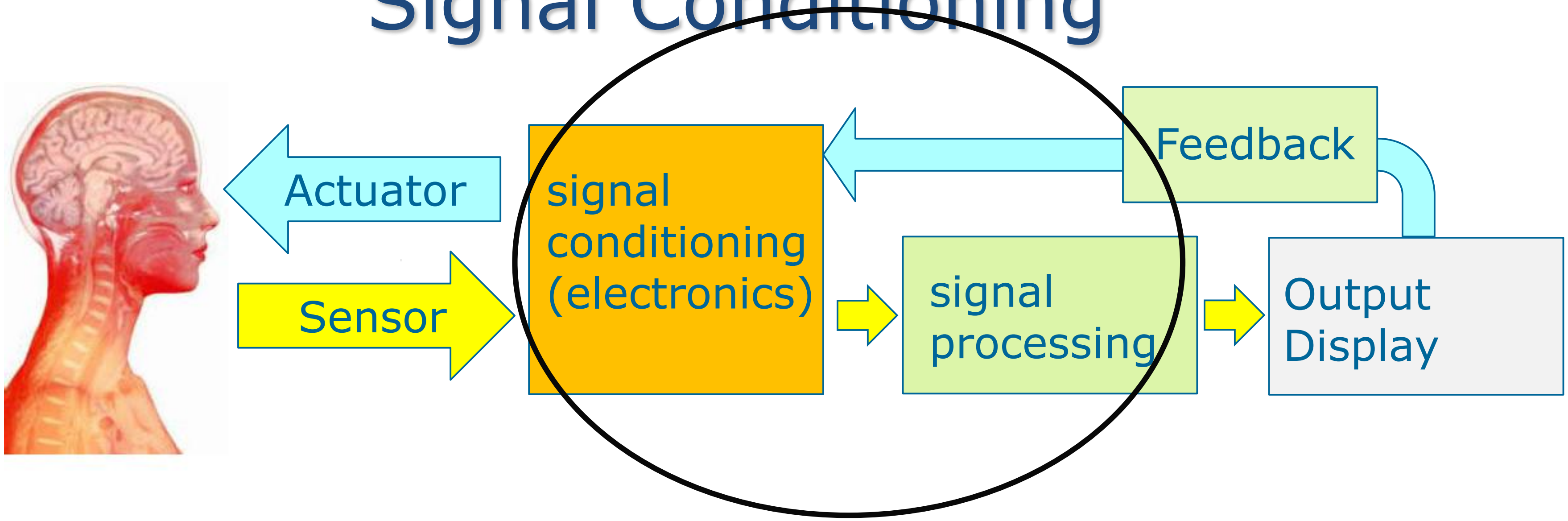
Parameter	Range	Frequency	Sensor
Blood flow	1-300 ml/s	dc – 20 Hz	Flowmeter (ultrasonic)
Arterial blood pressure	25-400mm Hg	dc – 50 Hz	Cuff, strain-gage
ECG	0.5 – 4 mV	0.01 – 250 Hz	Skin electrodes
EEG	5 – 300 microV	dc – 150 Hz	Scalp electrodes
EMG	0.1 – 5 mV	dc – 10,000 Hz	Needle electrodes
Respiratory rate	2 – 50 breaths/min	0.1 – 10 Hz	Strain-gage, nasal thermistor

Sensor



- A sensor converts physical measurand to another form of physical means
- Sensor requirements
  - Selective – should respond to a specific form of energy in the measurand
  - Minimally invasive (invasive = requiring entry into a part of the body) sensor should not affect the response of the living tissue

Signal Conditioning



- Signal Conditioning: Amplification and filtering of the signal acquired from the sensor to make it suitable for display
- General categories
  - Analog, digital or mixed-signal signal conditioning
    Time/frequency/spatial domain processing (e.g., filtering)
  - Calibration (adjustment of output to match parameter measured)
  - Compensation (remove of undesirable secondary sensitivities)

Sensors vs. Transducers

What is a sensor (transducer)?

- A sensor is a device which responds to a physical stimulus.
- A transducer is a device which changes one form of energy to another. It consists of two parts:
- Sensing element (detector, sensor).
- Transduction element.
- So, in electrical instrumentation, a transducer is a device that converts non-electrical quantities like temperature, force, displacement, thickness into electrical quantities like voltage and resistance.
- In conclusion, every transducer is a sensor but not every sensor is a transducer.

Transducers Types

Based on the output:

- Digital
- Analog

Based on principle of operation:

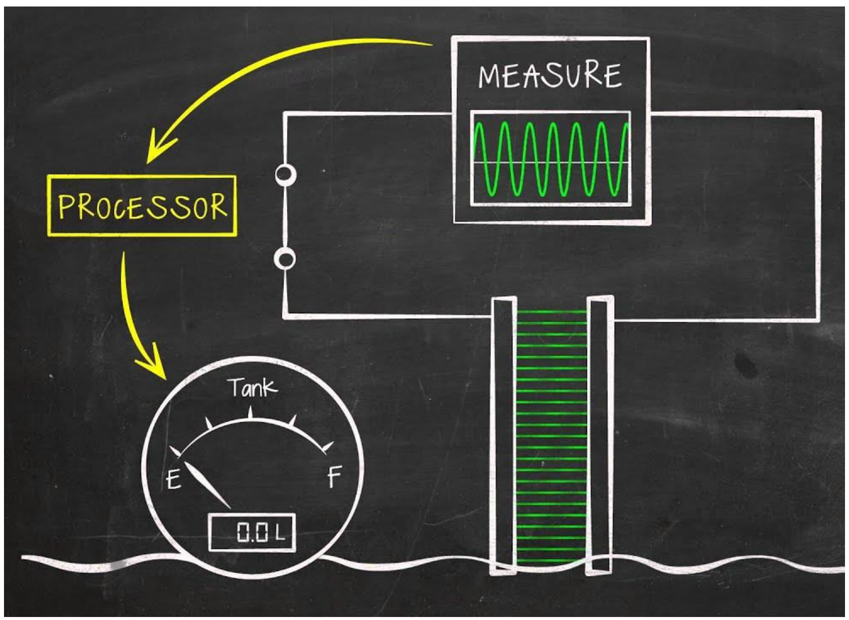
- Resistive
- Inductive
- Capacitive

Based on need for external supply

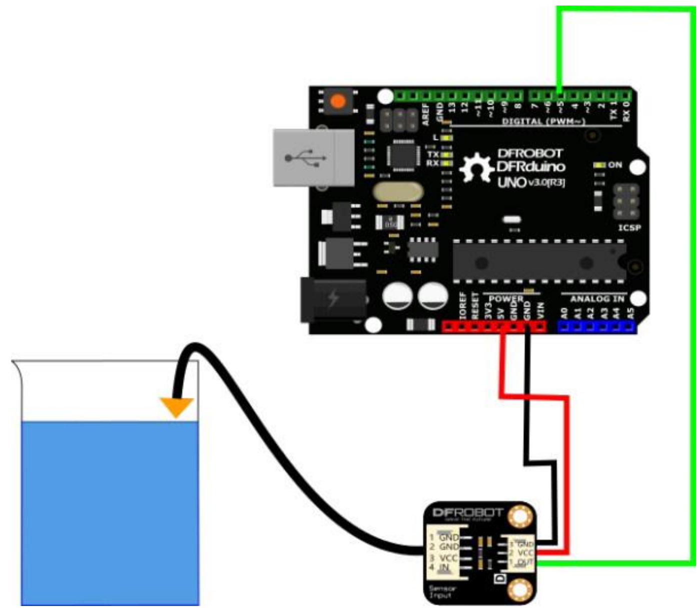
- Active (self generating)
- Passive (requires external voltage source)

Examples of transducers

- Water level sensor



Capacitive liquid level sensor.



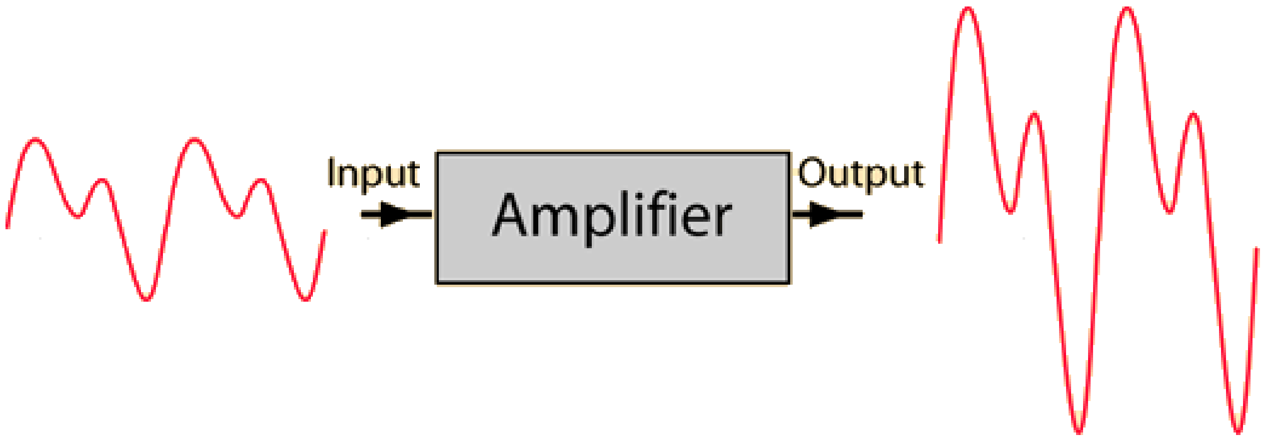
Photoelectric liquid level sensor.

Analog Signal Conditioning

- Practically all instrumentation systems require some type of analog signal conditioning between the analog input transducer and the data display, processing and storage systems.
- In its simplest form, analog signal conditioning can be voltage amplification.
- Analog signal conditioning may also involve linear filtering.

Analog Signal Conditioning

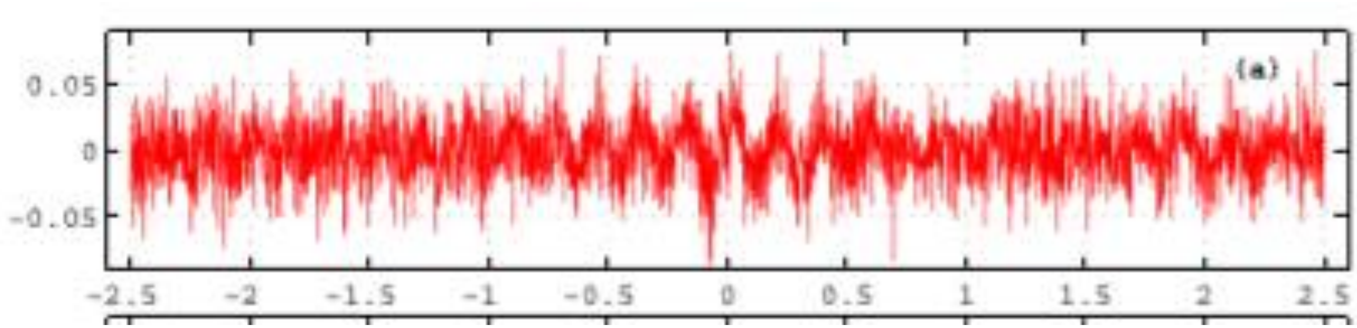
- Amplifier:

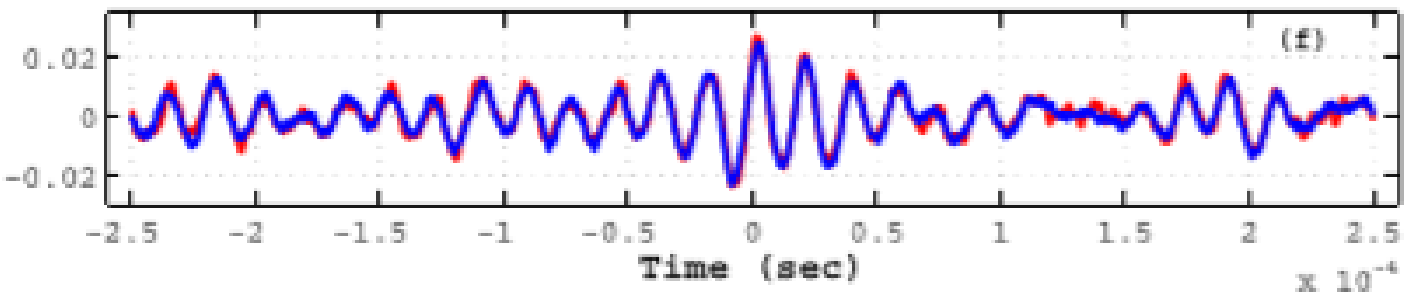


http://hyperphysics.phy-astr.gsu.edu/hbase/Audio/amp.html

Analog Signal Conditioning

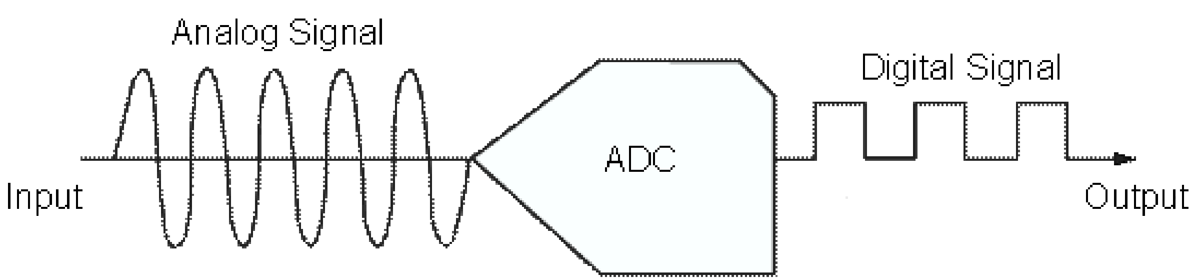
- Filter:



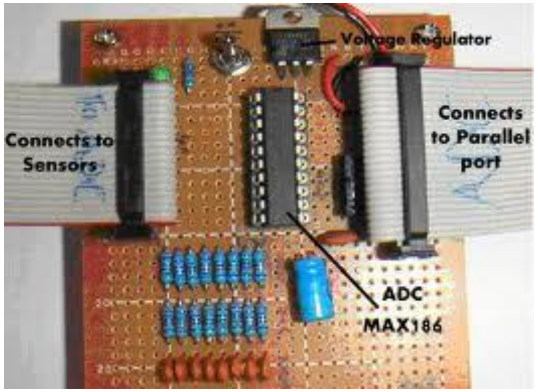


Analog to Digital Conversion

- Analog-to-Digital converters (ADC) translate analog signals, real world signals like temperature, pressure, …, into a digital representation of that signal.
- This digital representation can then be processed, manipulated, computed, transmitted or stored.



https://wiki.analog.com/university/courses/electronics/text/chapter-20

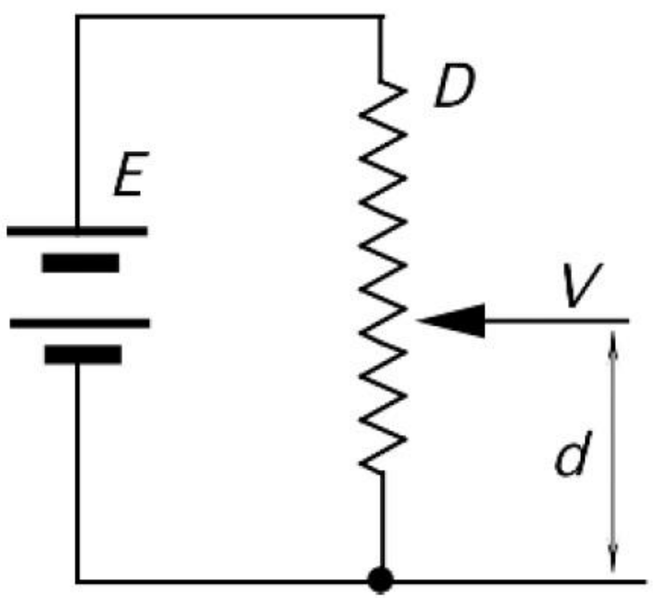


Computer Bus

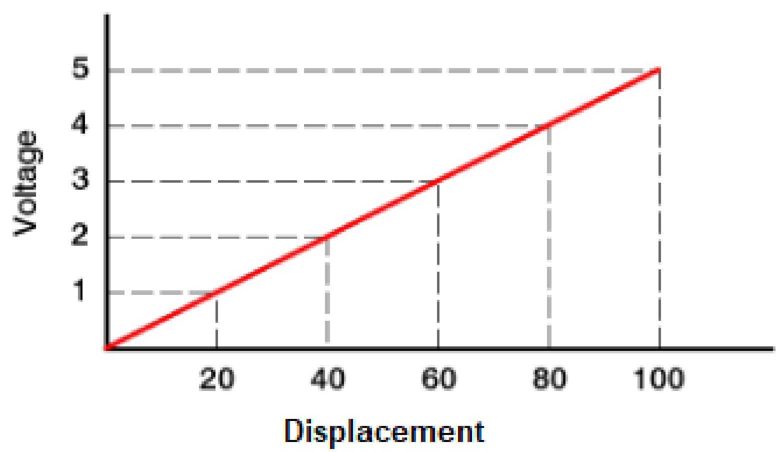
- DAQ devices connect to a computer through a slot or port.
- The computer bus serves as the communication interface between the DAQ and computer for passing instructions and measured data.
- Most common computer buses include USB, PCI, wireless, and Ethernet.

Instrument Characteristics

- Calibration Curve:
  - Example of a linear calibration curve: Potentiometer as linear displacement sensor

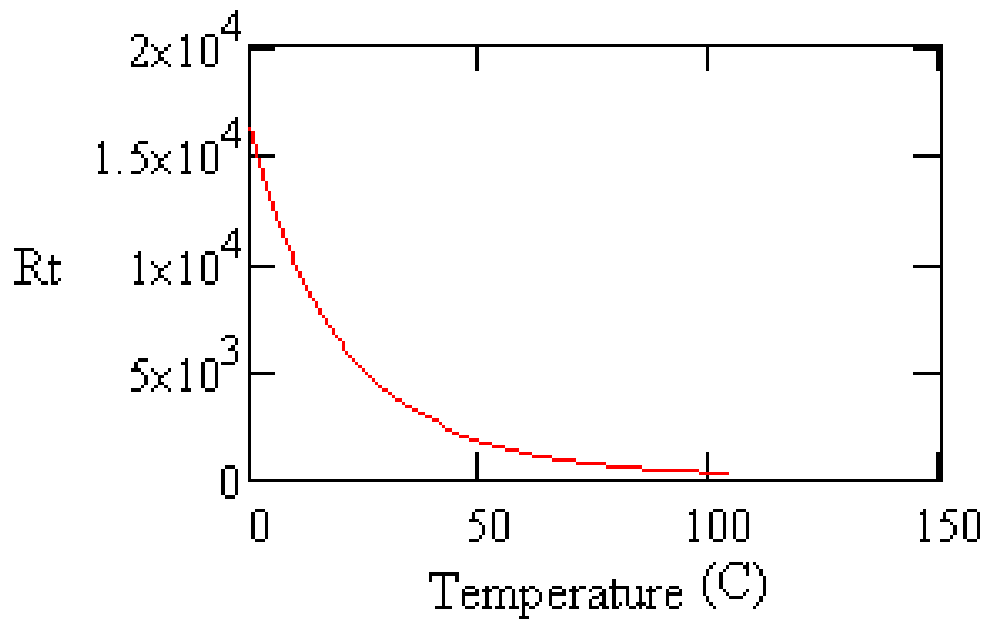


v = E (d/D)



Instrument Characteristics

- Calibration Curve:
  - Example of a non-linear calibration curve: Thermistor as a non-linear Temperature sensor

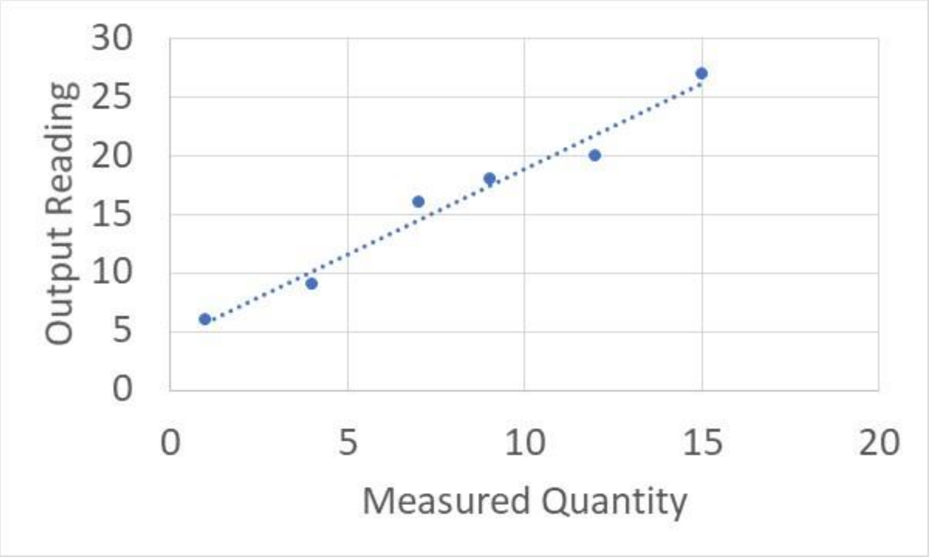


Instrument Characteristics

- The static characteristics of an instrument are concerned only with the steady state reading.
- Span:
  - If in a measuring instrument the highest point of calibration is X2 units and the lowest point X1 units.
  - The instrument span is given by: Span = (X2 – X1)
- Accuracy:
  - Accuracy means accurate within ± x% of instrument span at all calibration points of the scale.
  - When a temperature transducer with an error of ±1% indicates 100° C, the true temperature is somewhere between 99° C and 101° C.

Instrument Characteristics

- Linearity:
  - It is normally desirable that the output reading of an instrument is linearly proportional to the quantity being measured.
  - The non-linearity is defined as the maximum deviation of any of the output reading from this straight line and it is usually expressed as a percentage of full-scale reading



Instrument Characteristics

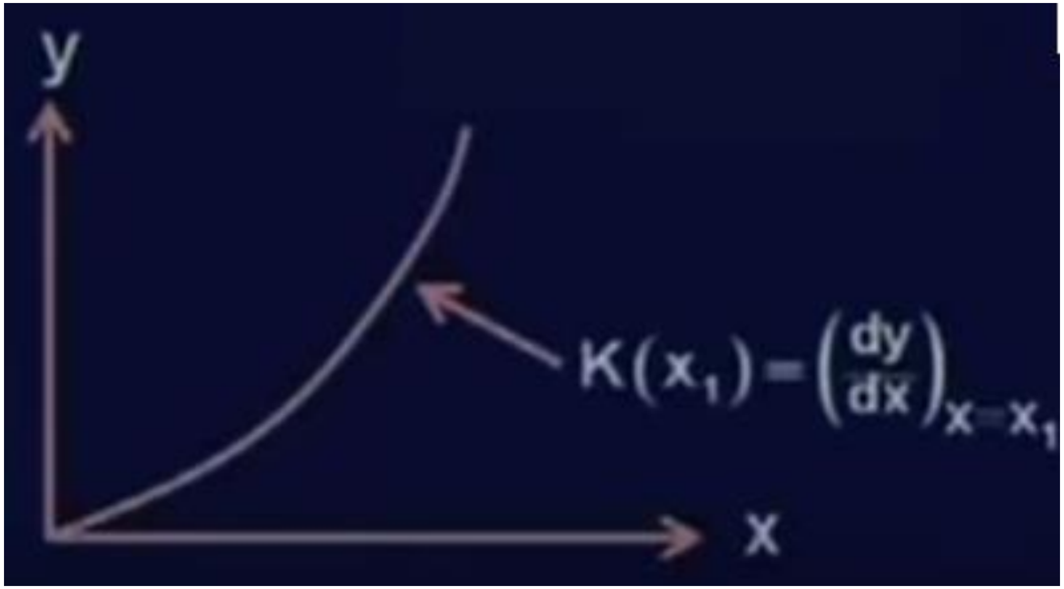
- Tolerance:
  - It describes the maximum deviation of a manufactured component from some specific value.
  - For an example, a resistor having a nominal value of 100 Ω and tolerance of 5% might have an actual value anywhere between 95 and 105 Ω.
- Repeatability or precision:
  - The repeatability of an instrument is the degree of closeness with which a measurable quantity may be repeatedly measured.

Instrument Characteristics

- Resolution:
  - The measurement resolution of an instrument defines the smallest change in measured quantity that causes detectable change in its output.
  - For example in a temperature transducer if 0.2 °C is the smallest temperature change that is observed, then the measurement resolution is 0.2 °C.
- Dead zone:
  - It is the largest value of a measured variable for which the instrument output stays zero.
  - Dead zone occurs due to factors such as static sensitivity in a transducer.

Instrument Characteristics

- Static sensitivity:
  - The slope of a static calibration curve, evaluated at the output when values at applied at the input
  - The slope of the calibration curve y=f(x)
  - An ideal sensor will have a large and constant sensitivity



Instrument Characteristics

- The dynamic characteristics of an instrument refer to the response of an instrument to continuously changing inputs.

- The dynamic response of an instrument to an input signal is typically modeled in terms of a zero, first or second order linear differential equations.

Instrument Characteristics

- Zero order instrument:
  - The simplest model for a measurement system is a zero order differential equation

$$y=Kx$$

  - An instrument can be modelled as a zero order instrument when its dynamic is very fast compared to the variation in its input signals.
  - An example is a potentiometer

Instrument Characteristics

- <u>First order instrument:</u>
  - For certain category of sensors, when the input changes suddenly, the output can’t change immediately.
  - For example, thermal loads when they are used in actuators, they tend to store the thermal energy resulting in exponential response.

Instrument Characteristics

- First order instrument:

  - The dynamic characteristics of a first order instrument is given by:

$$\tau \frac{dy}{dx} + y = Kx$$

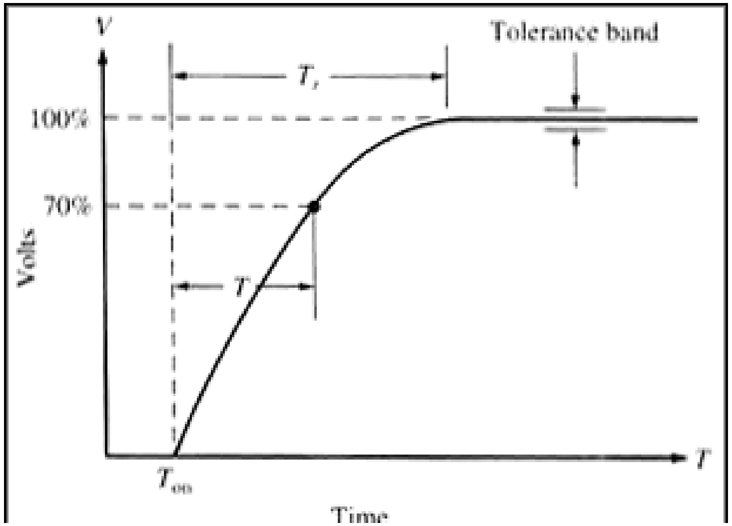
Where τ is the time constant
And let x be a step function, so:
$X = 0$, for $t<0$
$X = Xs$ for $t \geq 0$

Instrument Characteristics

- <u>First order instrument:</u>
  - The output will be given by the following equation:

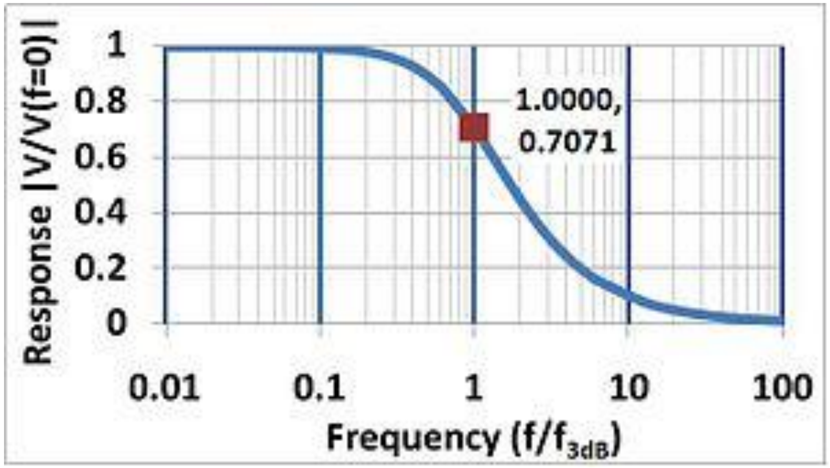
$$y = Kx_s\left(1 - e^{-\frac{t}{\tau}}\right)$$

  - Hence, the step response of the sensor will be as follows:



Instrument Characteristics

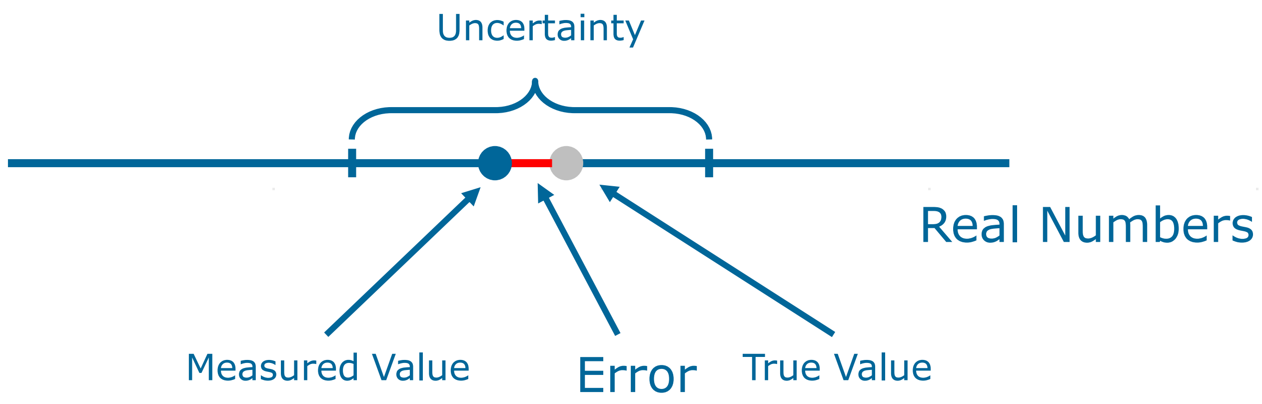
- First order instrument:
  - Periodic signals are encountered in many driving signals such as vibration analysis.
  - When a periodic signal such as sinusoidal is applied to a first order instrument, the frequency of the input signal influences the response of the measurement system.
  - The response will be as follows:



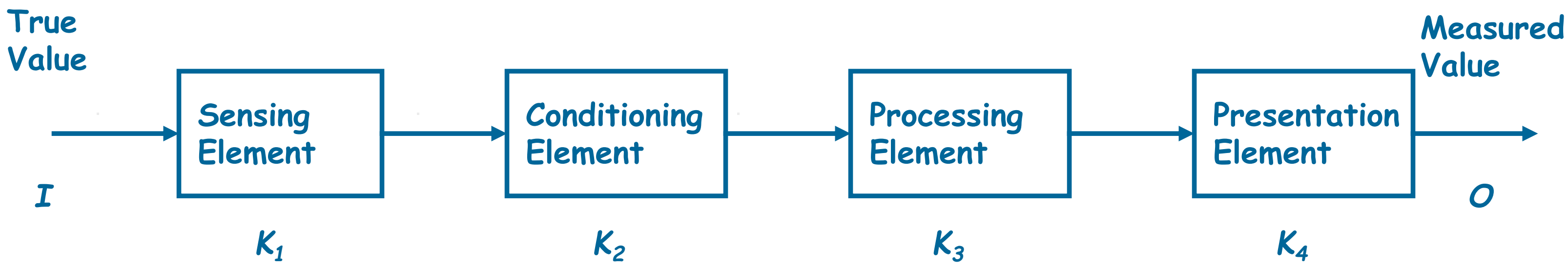
Measurement Errors

- A measurement is a physical quantity that has been observed and compared to a standard quantity, called a unit.

- There is always a level of uncertainty since the instrument used to make the measurement is imperfect.



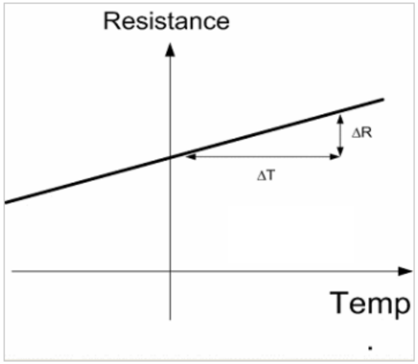
Measurement Errors

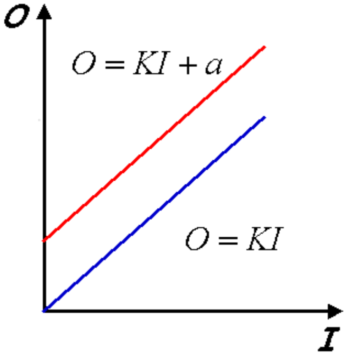


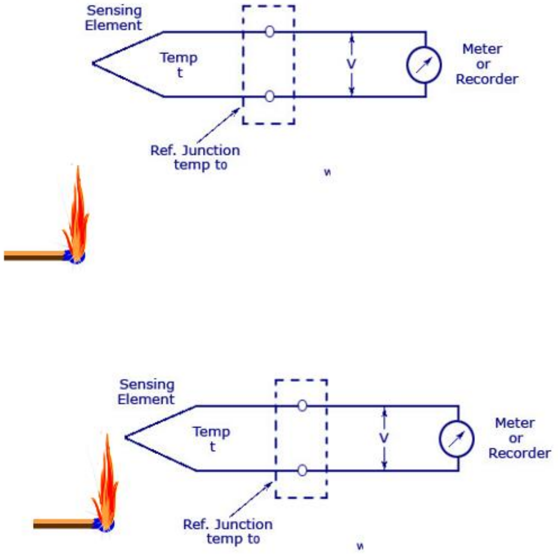
- None of the elements can be perfectly manufactured and integrated in the system, hence there will be sources of error.
- Error increases through different measurement elements from sensor element to output element.

Measurement Errors

- Systematic error is a consistent deviation in a measurement, also called a “bias” or an “offset”:
  - Natural error arises from environmental effects
  - Instrument error is caused by improper calibration
  - Personal error results from habits of the observer







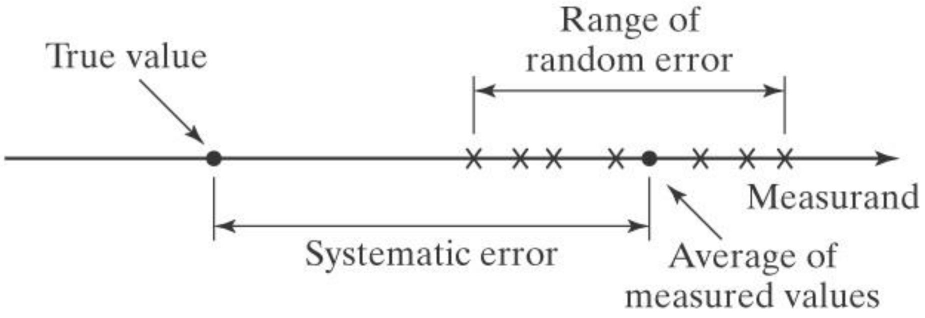
Measurement Error - Summary

Sources of errors

- Improper sensing position
- Improper element calibration
- Improper data acquisition method
- Improper sampling rate
- Elements non-linearity
- Environment effects

Characteristic of errors

- Systematic errors
- Random errors



Accuracy of measurement

- Accuracy – Closeness of agreement between measured value and true value – specify uncertainty in device specifications.

- Include both residual systematic and random errors in measurement system – specified as a % of full scale.

- For example, accuracy = ±5% of full scale for output with 0 to 5V range.

Uncertainty = ± 0.25V.