PHYSICS 352 - 2009
Part 2

Measurement, Instrumentation

&

Experiment Design

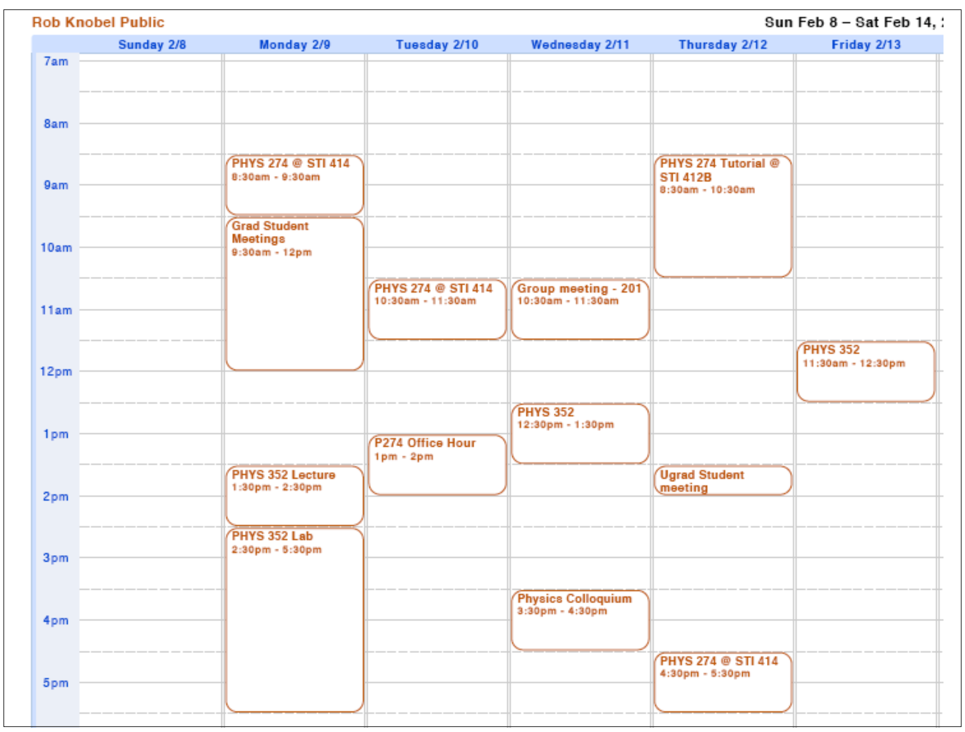
Outline

- Measurement
- Transducers
- Noise, amplifiers
- Filtering
- Signal Processing

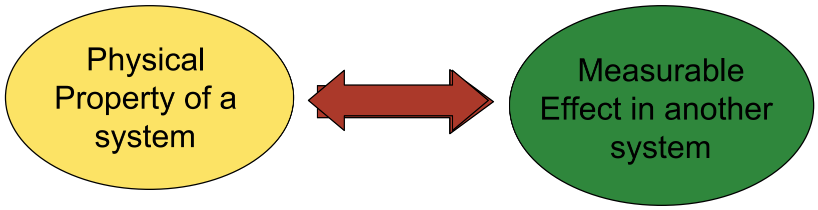
MainReference: "Measurement, Instrumentation and Experiment Design in Physics and Engineering"
Michael Sayer, Abhai Mansingh

Format of this half of course

- Office hours: To be determined
  - – Other times by appointment or by luck
- Homework Assignments: ~ 4 assignments
- Design Project (assigned later this week)
- Final Exam: In exam period, covers only 2nd half of course



Measuring Device



Examples: In a thermometer,

Temperature → Thermal Expansion

In a photomultiplier

Light → electric current

Any such measurement *must* affect the original system (eg. Absorb light or heat)

Instrumentation

In modern instrumentation, we don't want to simply sit in front of an instrument recording numbers in a lab book or sketching - use the power of electronics and computers

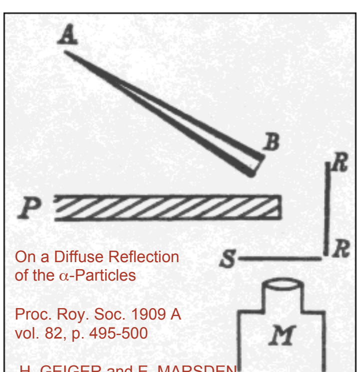


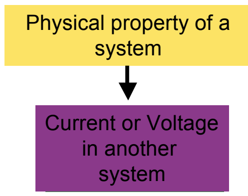
FIG. 1.

Scattering Experiment:

Geiger & Marsden watched scintillation of alpha particles hitting a ZnS screen (S) when scattering off the reflector (R). Painstaking work. Discovered the nucleus…

A few years later, Geiger invented his "tube".

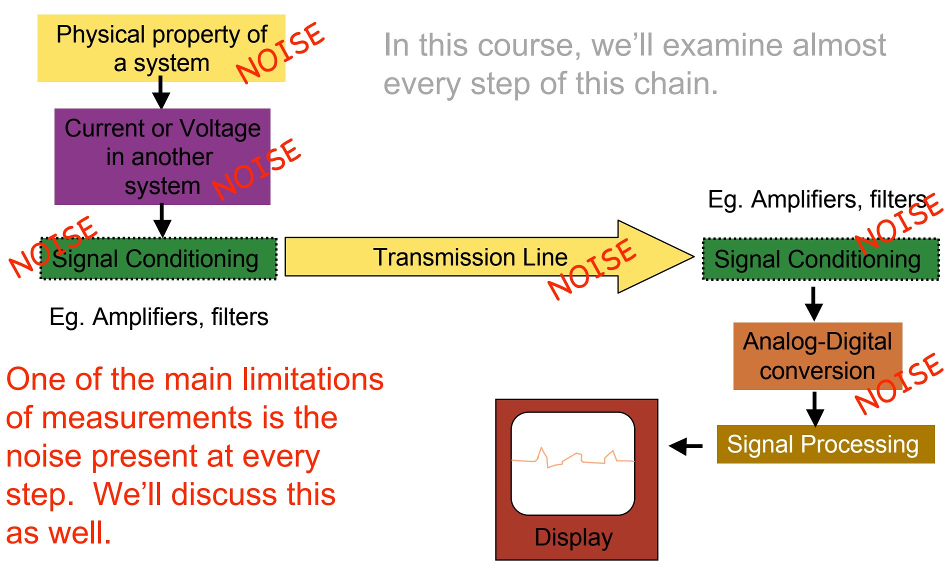
Measurement System



To take advantage of the power of electronics, use a transducer - a device which converts a measured physical effect into a signal measured by electronics (normally a voltage or current).

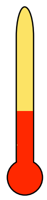
Measurement System

In this course, we'll examine almost every step of this chain.



One of the main limitations of measurements is the noise present at every step. We'll discuss this as well.

Transducer Examples - Temperature



Liquid-in-glass thermometer:

-Rely on thermal expansion of liquids with temperature.[Physical Property]

Works between freezing and boiling point of the liquid [Range of the transducer]

Slow due to thermal conductivity of glass and heat capacity of fluid
[Response time]

Calibration done by fixed points, and relies on thermal expansion being linear…

Transducer Characteristics

- **Accuracy:** The conformity of a measured value to an accepted standard or true value. The accuracy defines the limits that the errors will not exceed when operated in the stated conditions.
- **Resolution:** The smallest difference between measured values that can be discriminated. For a digital display, it corresponds to the last stable digit.
- **Calibration:** A transducer gives a response that is measured, but the calibration converts the response to a measurement of the property of interest. For a liquid-in-glass thermometer, the response is the height of liquid, calibration by measurement with standards converts this to temperature.

Transducer Characteristics -2

- Repeatability: The agreement among a number of consecutive measurements for identical conditions and approached from the same direction.
- Reproducibility: The agreement among a number of measurements for the same value of the input over a period of time and approached from either direction.
- Hysteresis: The difference in measured values for the same input when approached from increasing and decreasing input directions.

Transducer Characteristics -3

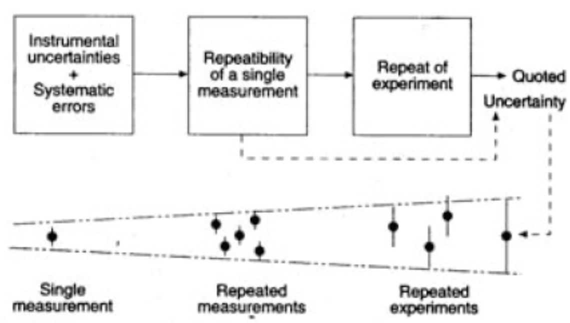


Fig. 1.6 The progression in the uncertainty from that of a single measurement to that for a system.

If all systematic uncertainties and extraneous variables are controlled, then repeatability = reproducibility…
For some experiments this can be difficult or impossible (eg. biology or astronomy)

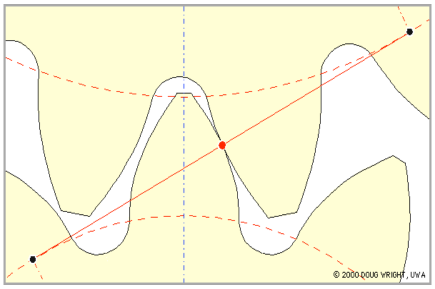
Hysteresis

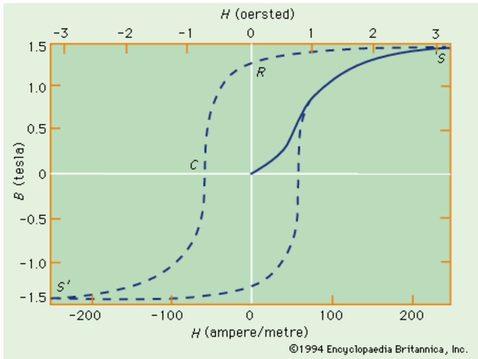
Hysteresis can occur in a number of situations, some are inherent in the system and others are due to defects in the system and should be avoided:

•Ferromagnetism

•Ferroelecticity

•Gear Backlash





Transducer Characteristics - 4

•Linearity error: the deviation of the transducer output for varying input from a straight line. A highly linear transducer will not deviate much (normally expressed as a percentage of the full scale output).

•Sensitivity: the ratio of the change in the magnitude of the output to the change in the input after steady state has been reached.

A highly linear transducer would require fewer calibration points. Strong nonlinearity can lead to very high sensitivity (eg. Some resistance thermometers)

Dynamic Transducer Characteristics

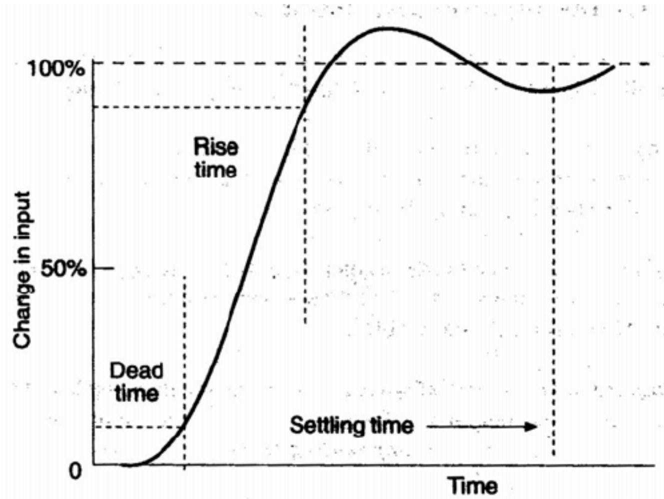


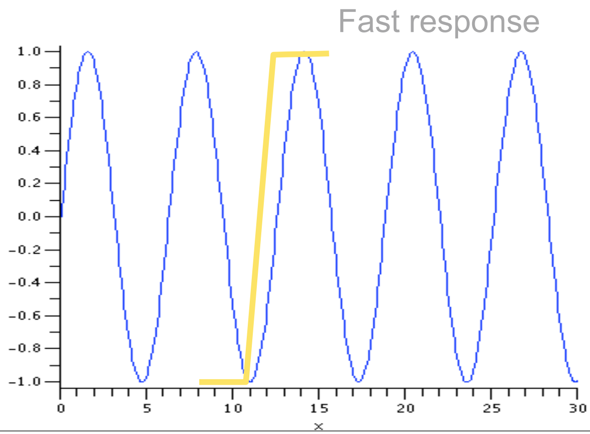
Fig. 2.4 The time response of an instrument after a change in the measured parameter.

Dynamic Transducer Characteristics - 2

- Response time: the time interval between a change in the input and the time the transducer reads a new equilibrium value. This can be further specified in terms of:
- Dead time (τ_D): the time during which a variation in a signal cannot be detected due to some characteristic of the transducer.
- Rise time (τ_R): the time taken by the transducer to respond to a step change in the input. Often the time between 10% and 90% of the final value is used.
- Settling time (τ_S): the time required to attain a stable reading within a stated percentage of its equilibrium output. Often taken to be the time of the first minimum in the oscillation.

Dynamic transducer characteristics - 3

For a sinusoidally varying input, there will be a maximum (and often minimum) frequency at which the transducer can respond:



Dynamic transducer characteristics - 3

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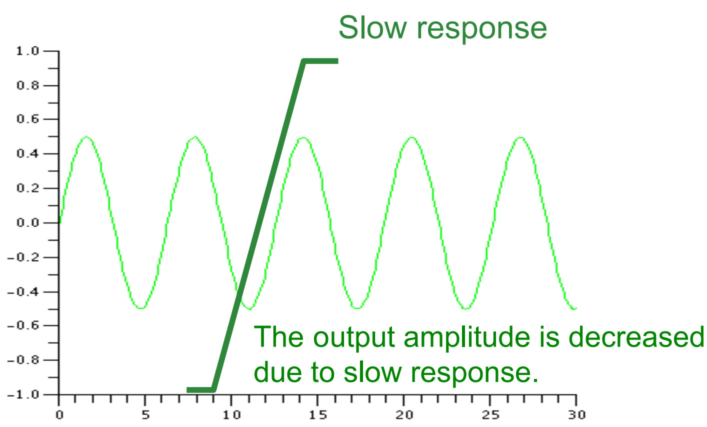

Dynamic transducer characteristics

Often the frequency at which the output signal is decreased to 1/2 of the nominal output is the quoted value (“corner frequency”), or 3dB point

(since -3 decibels ≈ 1/2).

The bandwidth of the transducer (or system) is the difference between the low frequency and high frequency at which the transducer can operate.

More on this later…

Transducer Characteristics Again

- Noise: (in the transducer) consists of fluctuating signals generated in the transducer which contribute to the output, but aren’t correlated to the input. Such signals may be intrinsic (eg. thermal fluctuations) or be generated by the environment (eg. electromagnetic pickup).
- Threshold: the minimum value for which a measurable response is produced. This may be set by the operator, or related to the noise in the transducer.
- Noise floor: the low limit of what can be measured due to noise in the transducer

Transducer Characteristics

- Saturation level: the maximum input level before significant non-linearities in the output appear.
- Maximum input: The highest input signal which gives a calibrated output. This level can be set due to saturation, damage to the transducer, safety or other limits.
- Dynamic range: the ratio of the maximum input signal to the noise floor or threshold. Often reported in decibels:

$$DR = 10 \log_{10}(Max/Min)$$