Universidad Carlos III de Madrid
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Electronic Instrumentation

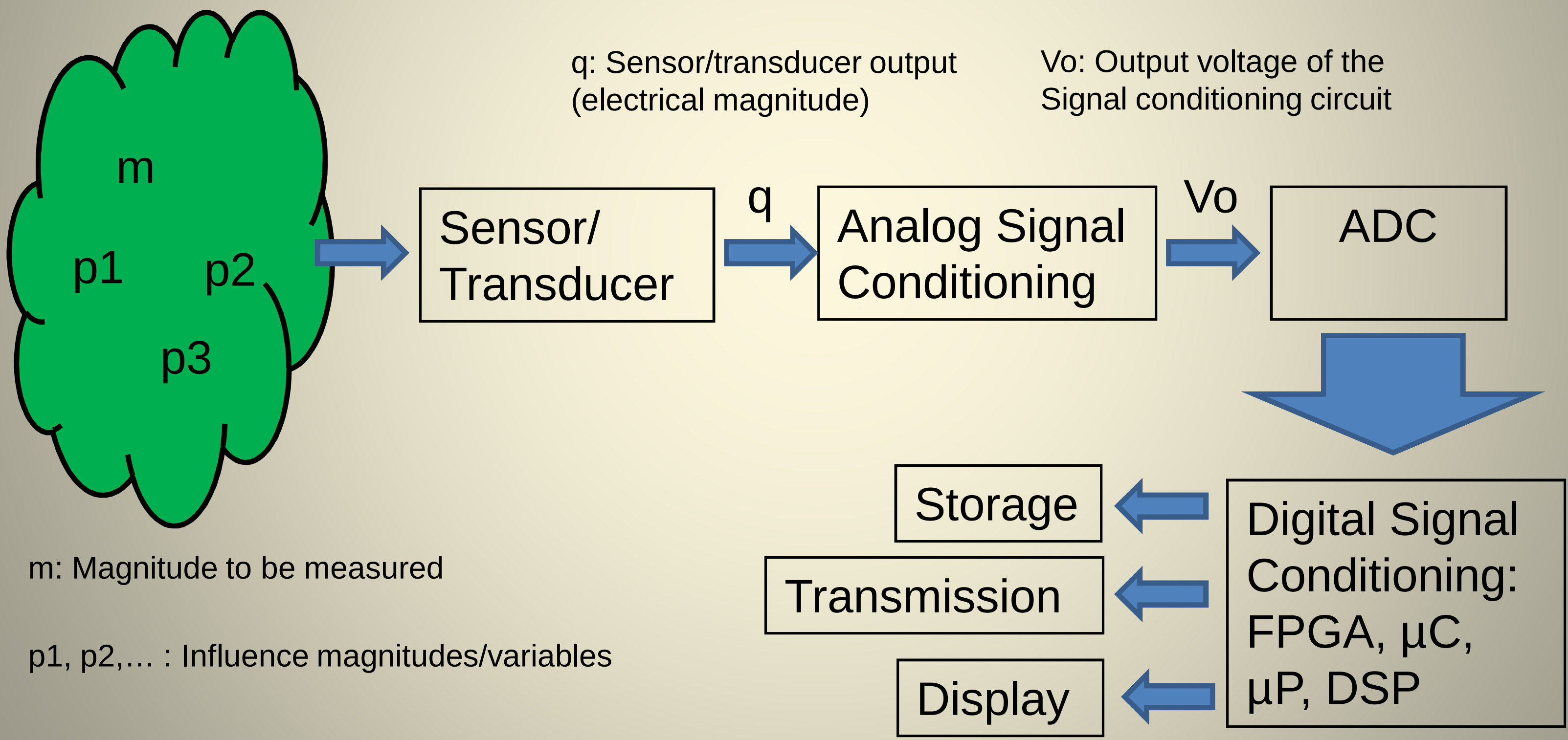
Chapter 1

Introduction

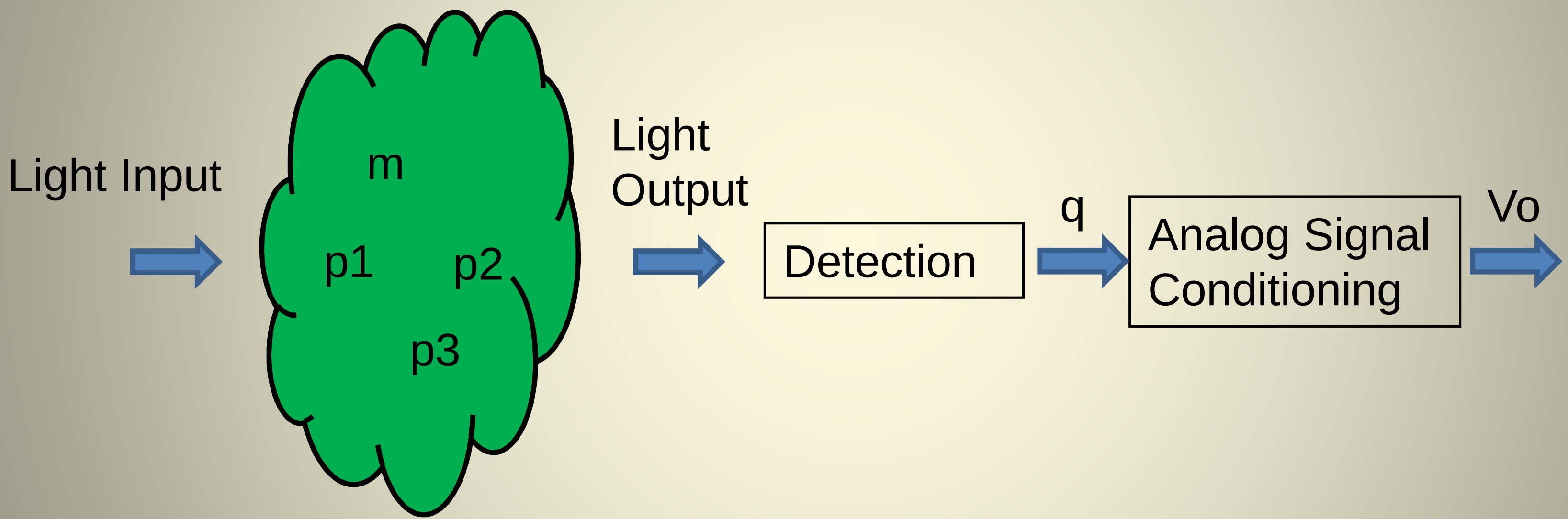
Chapter 1. Introduction

- Basic Architecture for an Electronic/Optoelectronic Instrumentation Measurement System. Definitions.
- Sensors and Categories of Sensor by Input Mechanisms
- Characterization of Sensors and Measurement Systems
    - Calibration Curve/Transfer Function
    - Static Characteristics
    - Dynamic Characteristics
- Errors in Measurements
- Summary

Basic Architecture for an Electronic Instrumentation Measurement System



Basic Architecture for an Opto-Electronic Instrumentation Measurement System



- Light Input from a Semiconductor laser diode or LED (sometimes not necessary).
- "Optical Signal conditioning" sometimes present (eg. Interferometer).
- Output from detector can be either a current (photodiode) an impedance change (photoconductor) or a voltage (photovoltaic sensor).
- The information from the interest magnitude can be either in the amplitude, phase, polarization or wavelength of the light.

Sensors

A sensor is a device that receives a stimulus and responds with an electrical signal

- There is always a form of energy conversion associated to the transduction process.
- A sensor can be a *simple* sensor or can be a *complex* system.
- Sensors can be classified in many ways depending on the criteria chosen:
    - Field of applications
    - Conversion Phenomena
    - Specification
    - Other

Categories of Sensor Input Mechanisms

- Resistive Sensors
- Variable Inductance/Magnetic Coupling Sensors
- Capacitive Sensors

} Passive Sensors

- Voltage Generating Sensors
- Current Generating Sensors/optical Sensors

} Active Sensors

- Other Sensors

Characterization of Sensors and Measurement Systems

- Transfer Function:

$$q = f(m, x_1, x_2, x_3, \dots)$$

- Calibration Curve (static):

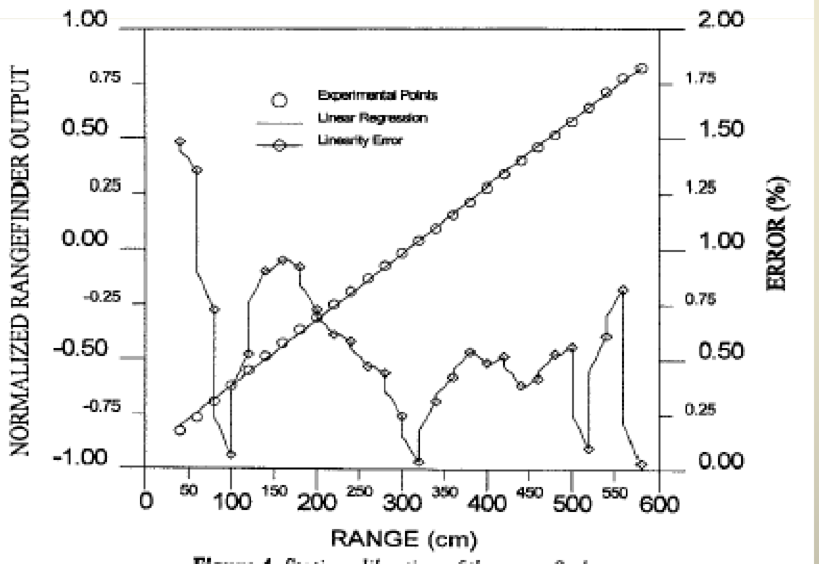
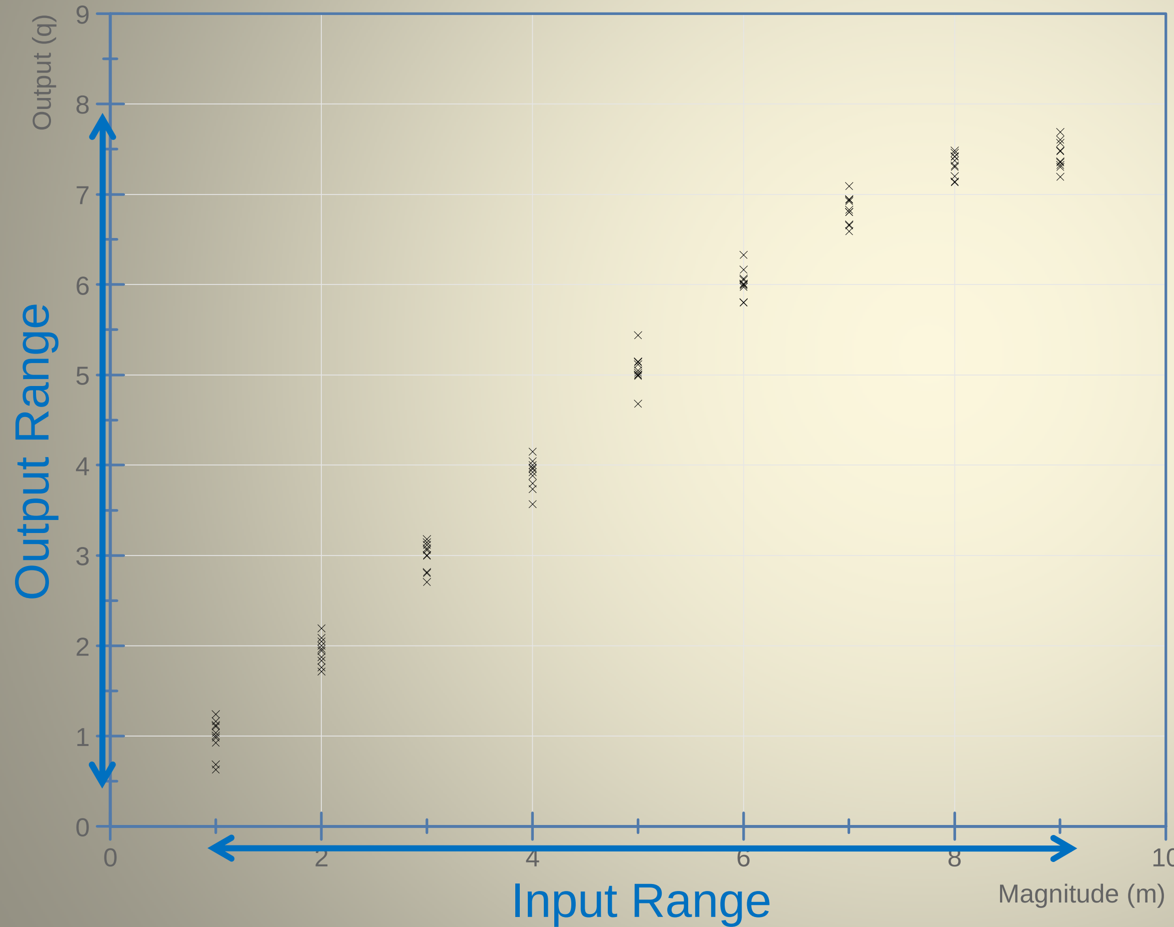


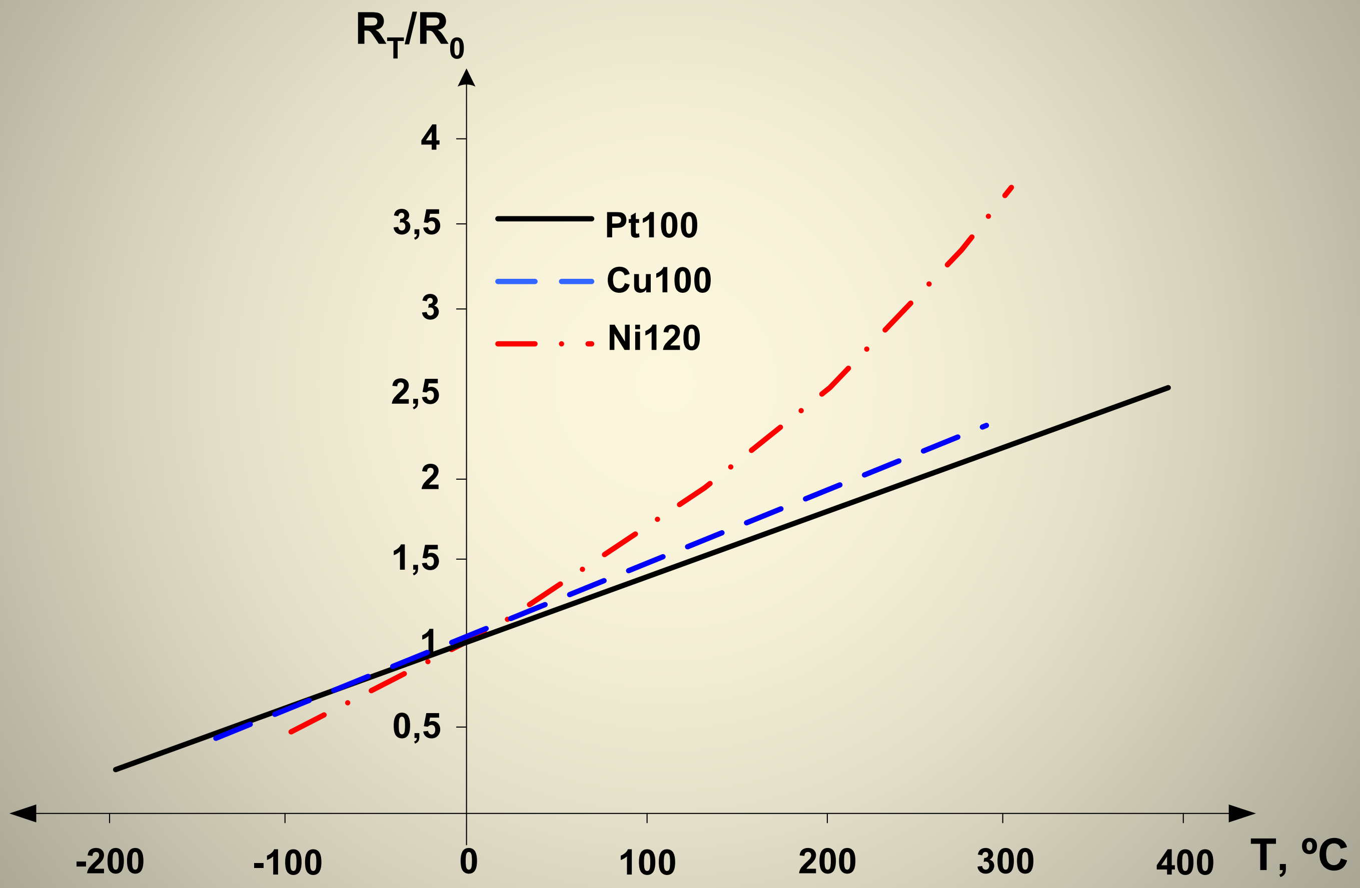
Figure 4. *Static calibration of the rangefinder.*

Calibration Curve

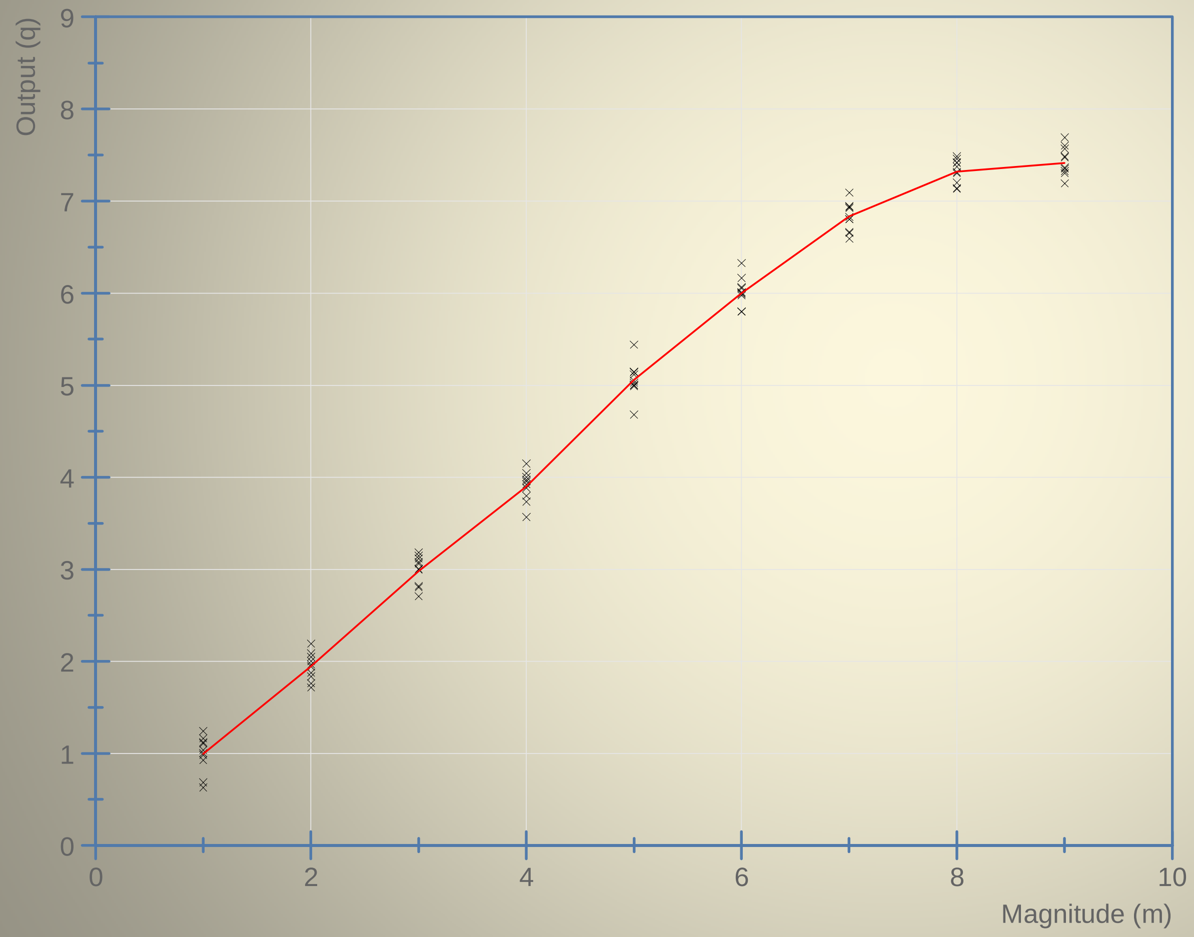


- Input Range
- Output Range
- Span
- Full Scale Input
- Full-Scale Output

Calibration Curve: Example



Sensitivity

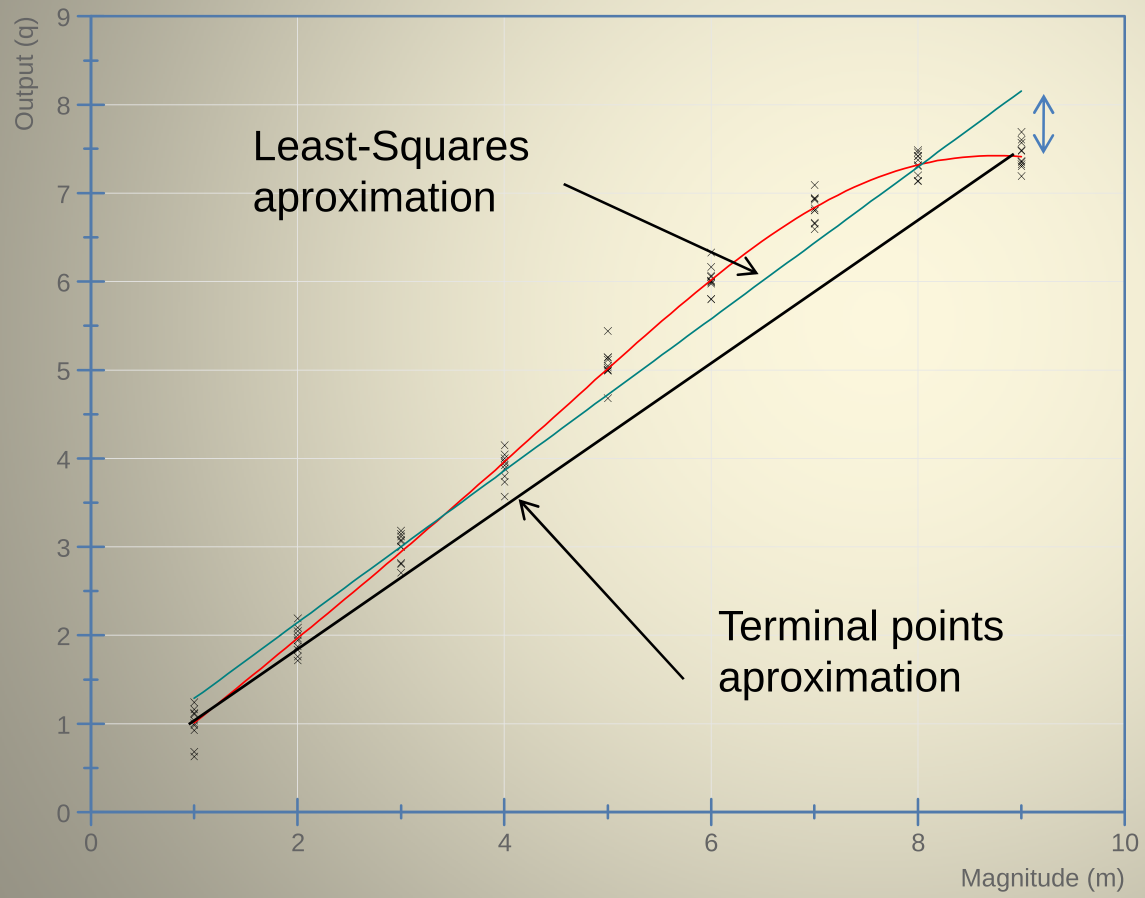


- Definition:

$$S = \frac{\Delta q}{\Delta m}$$

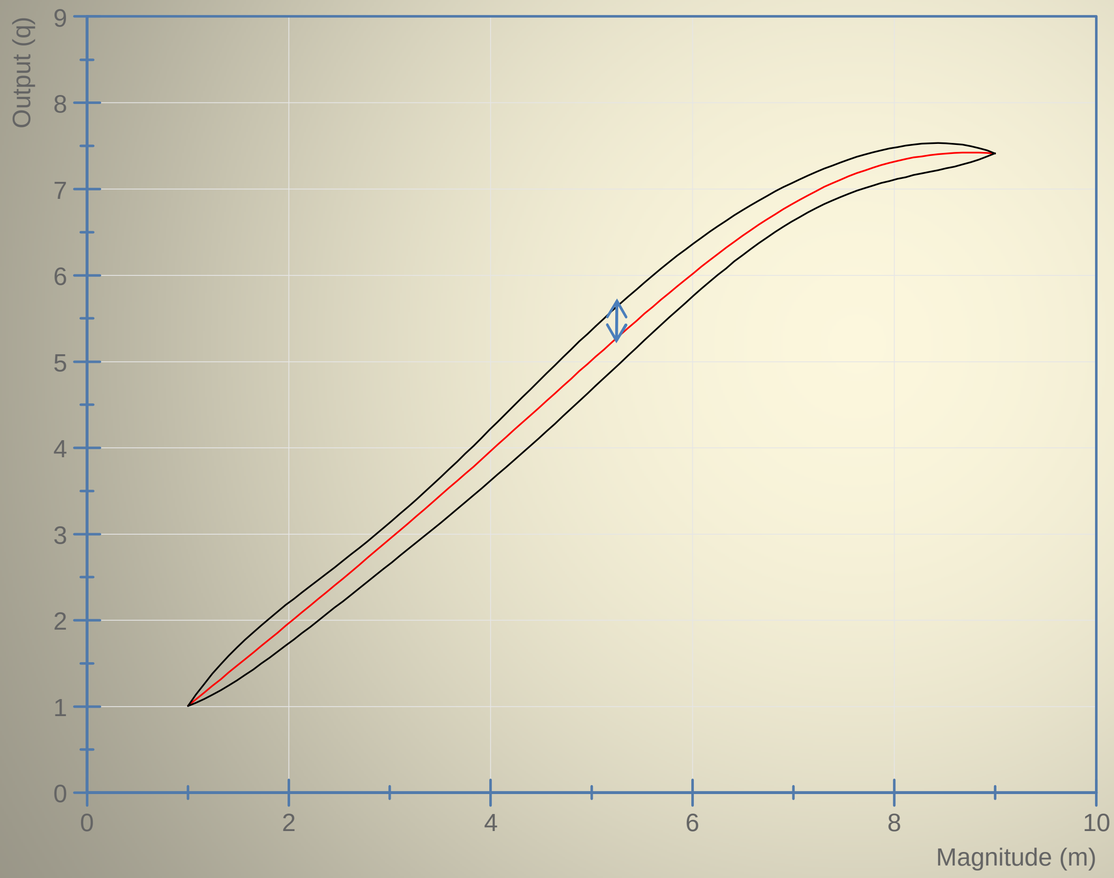
- Local Value
- UNITS!!
- Slope of the transfer function (local)

Non-Linearity



- •Associated to a linear approximation of the transfer function.
- •IMPORTANT: Different linear aproximations may be used, leading to different non-linearity error values
- •Maximum deviation from the nonlinear transfer function (usually in percent of FS value)

Hysteresis

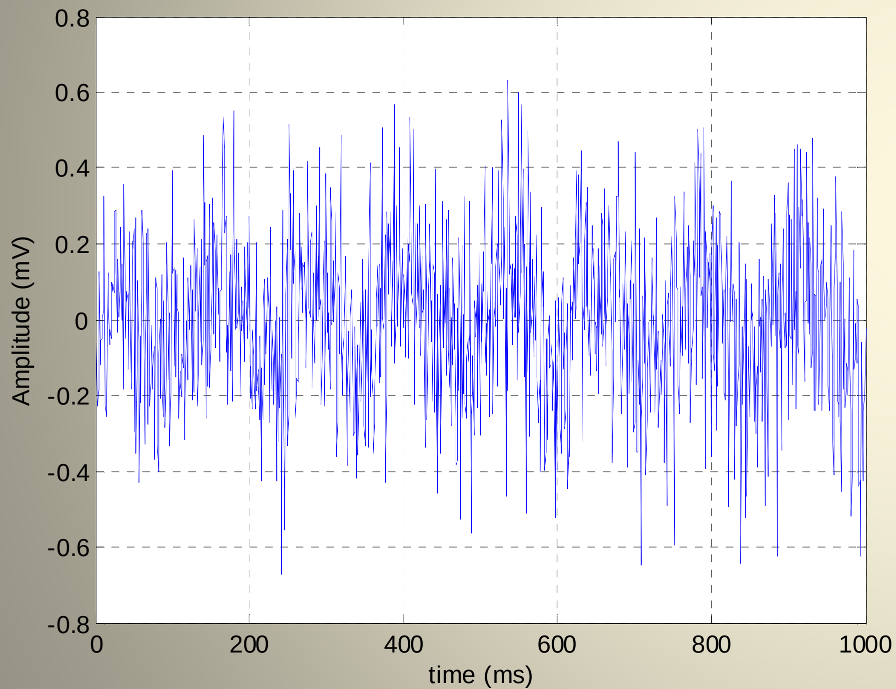


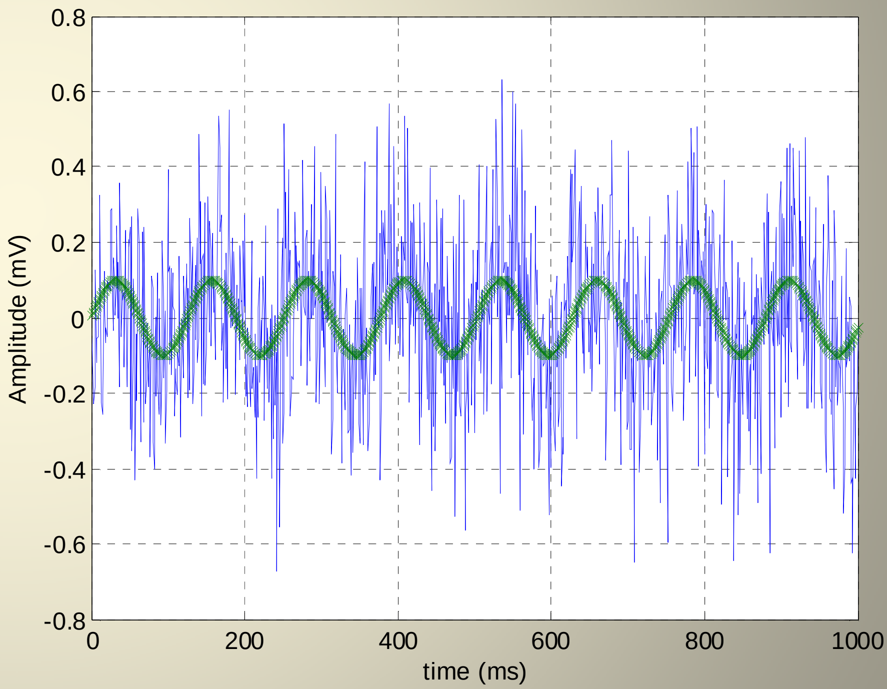
- Deviation of the sensor's output at specified point when it is approached from the opposite directions (usually in percent of FS value)

- Typical causes of Hysteresis are friction and structural changes in the materials

Resolution

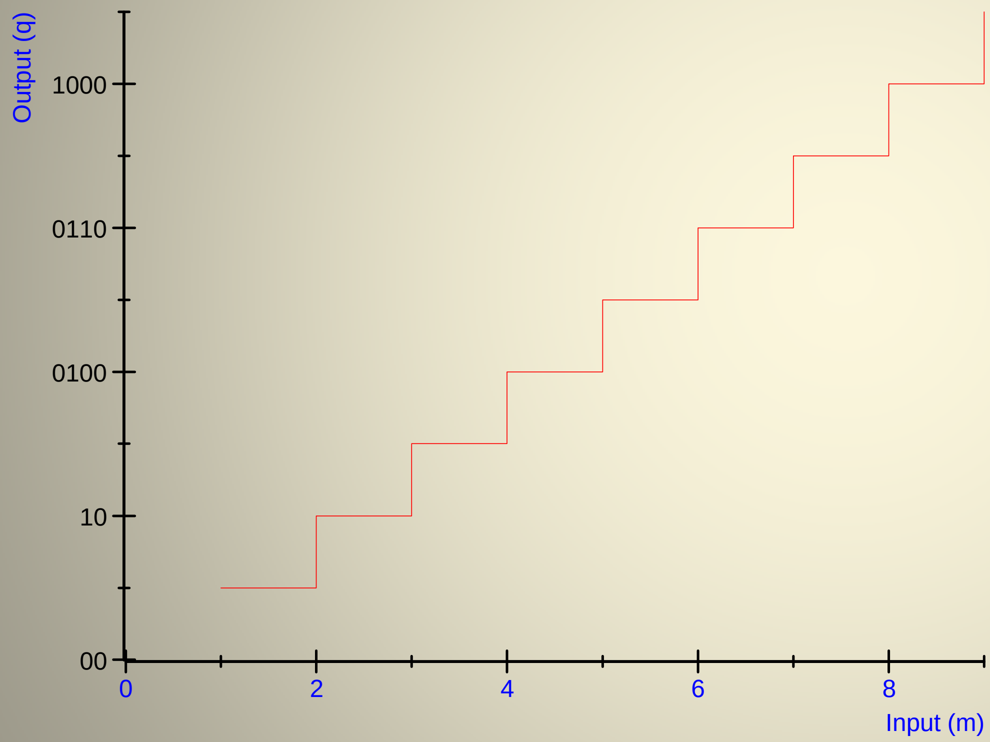
- Resolution: The smallest increment of the input that can be sensed.
- Important: For sensors with a continuous response some texts talk about *infinitesimal resolution.* That does not mean “infinite Resolution”.





Limited by the Signal-to-Noise ratio (S/N=0dB)

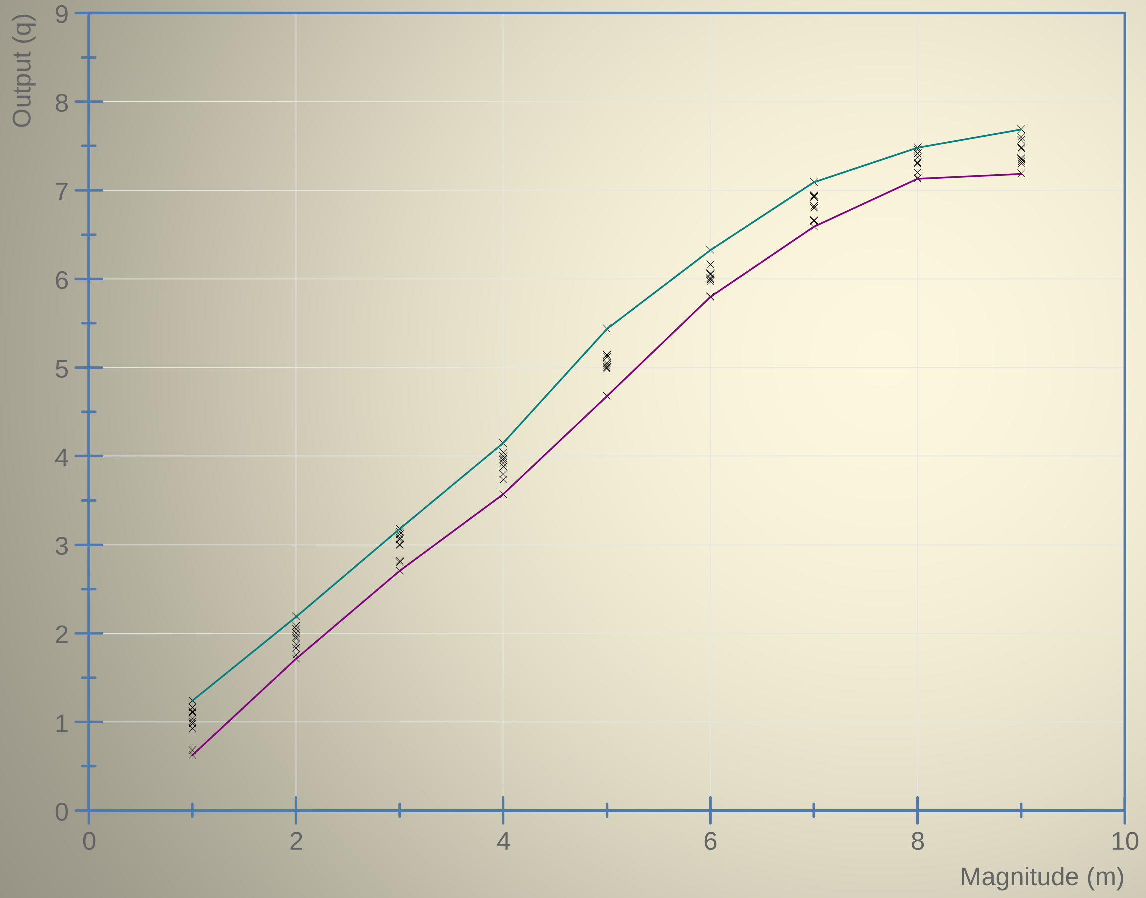
Resolution



- In sensors with discrete response (after ADC conversion for exampled), the minimum resolution achievable is usually limited by A/D quantization error (step size).

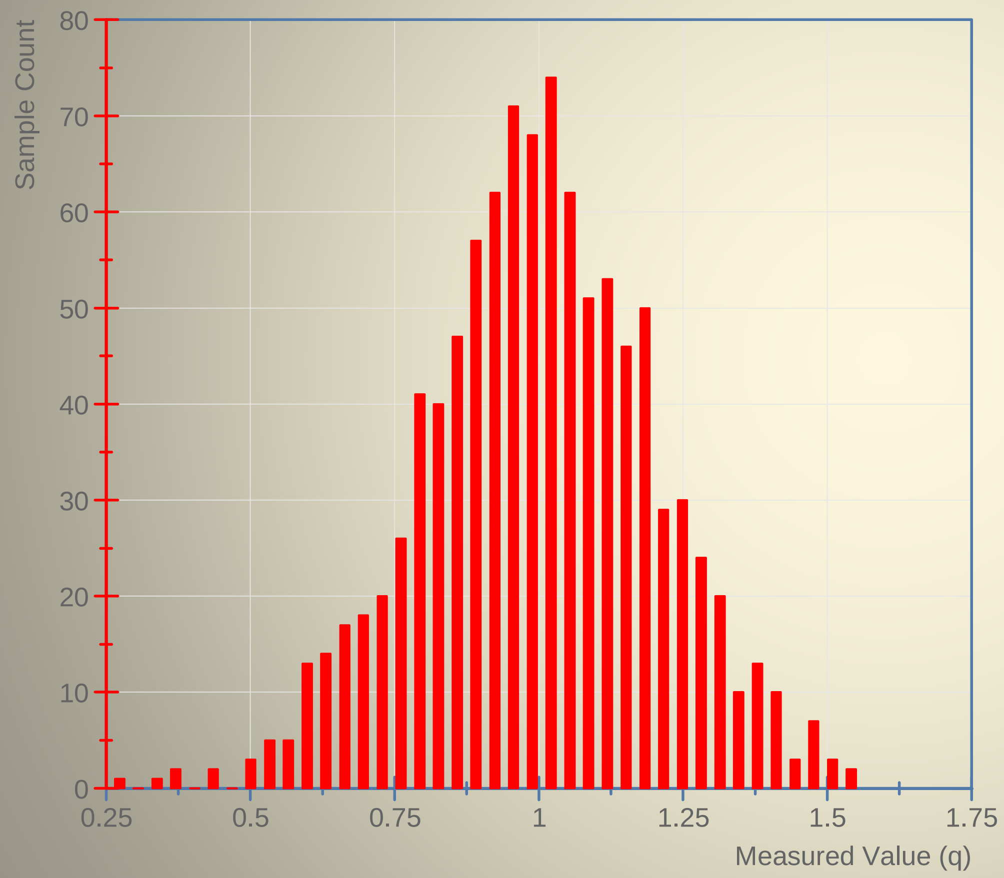
- NOTE: that only will be true if the resolution asociated to the SN ratio at the ADC input is lower than the ADC's resolution.

Precision/Accuracy



- Precision: consistency of the measurement. It is associated to the capacity of the sensor to give the same output (measurement) under the same input (Stimulus).
- In modern sensors uncertainty is preferred asociated to the Limiting error of the measurement (to be discussed later)

Precision



- Precision of the n^th measurement

$$P_N = 1 - \left[\frac{X_N - \bar{X}}{\bar{X}}\right]$$

- Where:

$$\bar{X} = \frac{1}{N}\sum_{1}^{N} X_N$$

NOTE

• Precision: Quality of the system to give always the same output under the same stimulus (input)

• Accuracy: Error between the measurement and the *true* value (Y): i.e. conformance between the measurement and the standard.

$$\varepsilon_N = X_N - Y$$

Accurate Measurements require the use of a precision measurement system which is calibrated against a certified, accurate standard

Other Parameters

- Stability: Quality of the system to maintain its characteristics under changes of the measurement conditions (e.g. Temperature) or aging. Usually characterized through drifts in the calibration curve (offset & sensitivity drifts).

- Dead Band: Insensitivity of a sensor in a specific range of input signals.

- Those related to the physical/electronic characteristics of the sensor/transducer:

  - Output Impedance
  - Excitation (Power supply)
  - Weigh
  - *……*

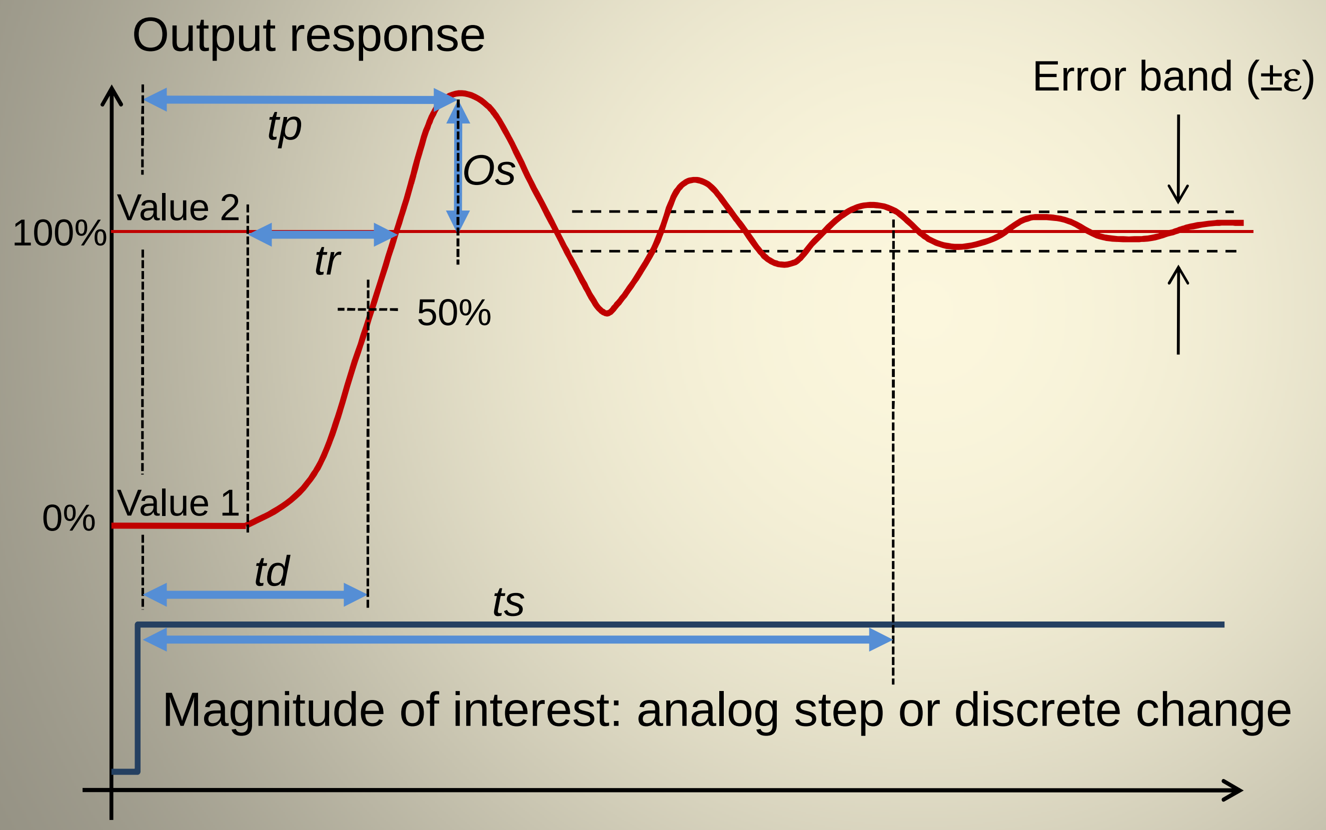
Example of Datasheet

Dynamic Characteristics

- Dynamic Transfer Function: $V(t) = f\left[m(t),\ldots\right]$
- Transient Response:
  - Previous characteristics assume a steady state. The time response shows the behavior of the sensor or the instrumentation system to the changes in the magnitude of interest by observing the signal output with time. The step response is used as a basic test and for characterizing the system.
  - Basic parameters are: *overshoot* in the under-damped response, *peak time, settling time* that is the time to reach and thereafter remain within a prescribed percentage of the steady-state value (5%), *rise time* and *delay.*
- Frequency Response:
  - Range of work frequencies, bandwidth and types of pass-band.
  - Some cases don´t respond to a constant. Even more, narrow-band ones.
  - Dynamic sensitivity for the amplitude. Don´t forget the phase.

Parameters of the time response

Step response

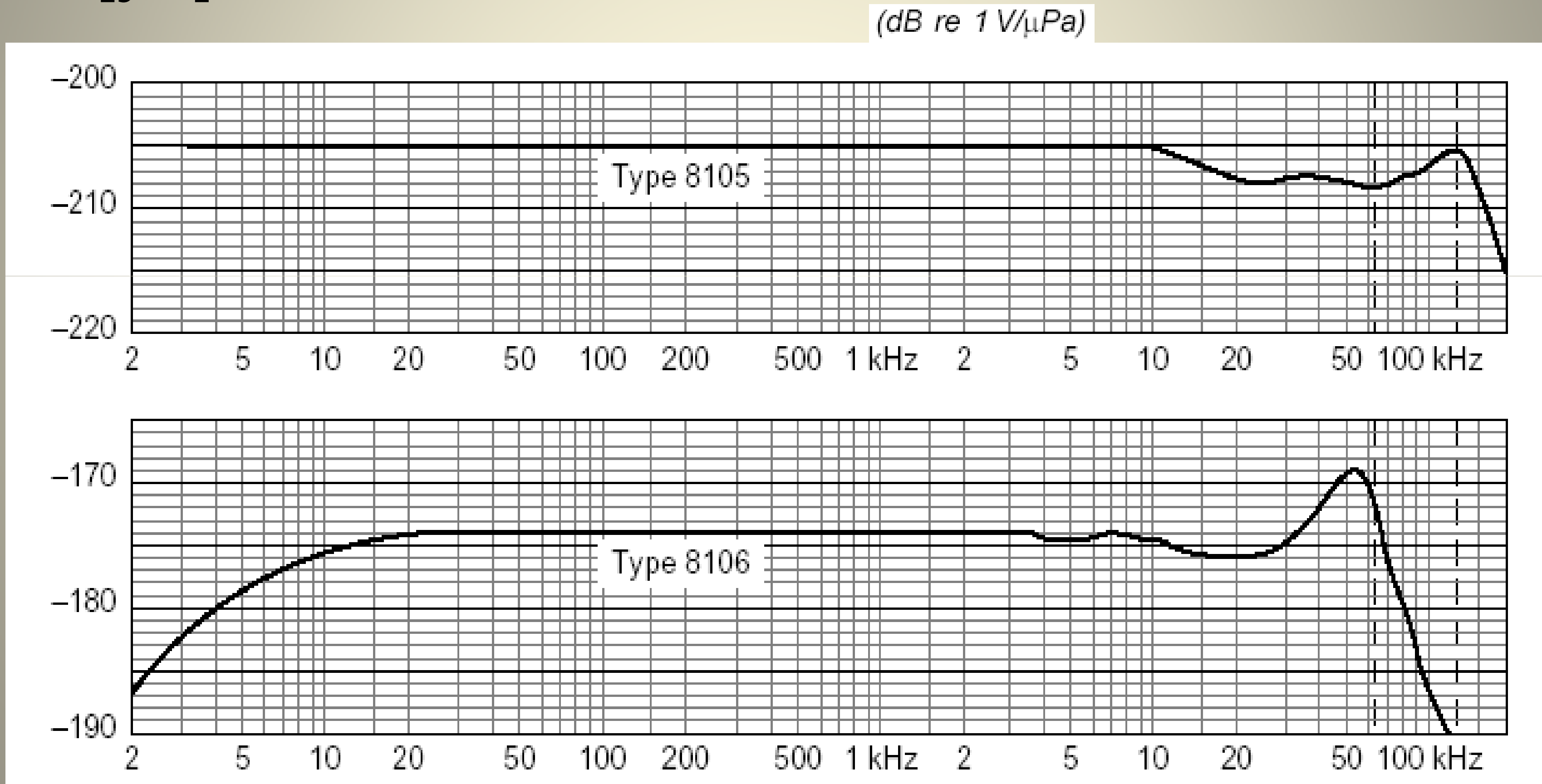


- *Os: overshoot*
- *ts: settling time*
- *tr: rise time*

  $t_{10\text{-}90}$
- *td: delay*
- *tp: peak time*

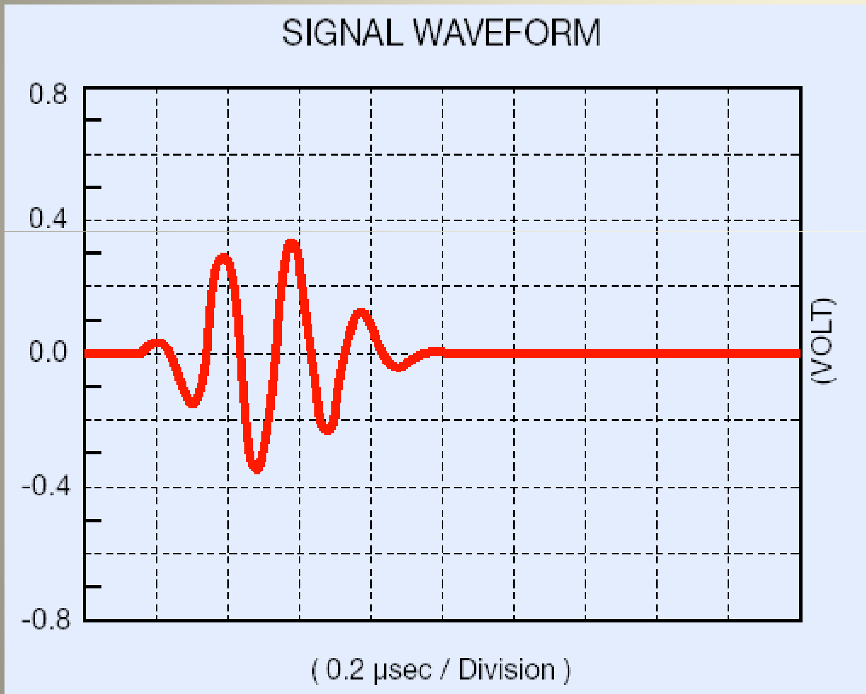
Frequency response

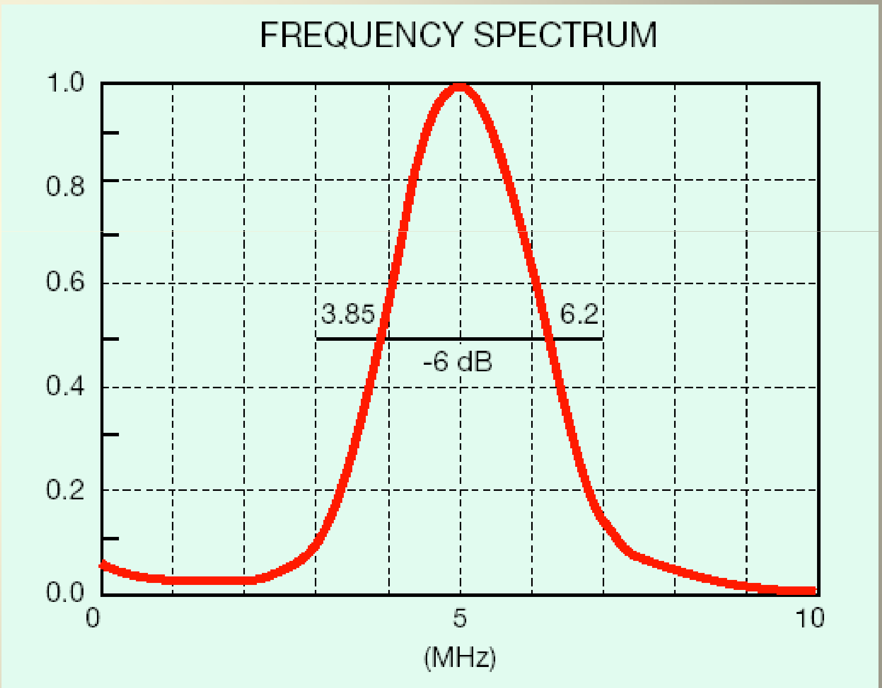
$F[j\omega]$ Dynamic sensitivity: sensitivity for each frequency input



Dynamic Characteristics

- Step Response:
- Frequency Response: $F[j\omega]$





Errors in Measurements

All measuring instruments should be regarded as guilty until proven innocent (P.K. Stein)

Sources/Classification of Errors

- Systematic Errors
- Random Errors (Noise/Interference)
- Gross Errors (Northrop)/Human Errors (Stein)

Limiting Error (LE)

Limiting Error (guarantee error) describes the outer bounds of the expected worst case error

- It includes all source of errors (gross/human errors apart)
- Value given by designer/manufacturers to specify the precision (accuracy) of the instrument/sensor
- Related to uncertainty

Systematic Errors (I)

- The output of a sensor or a complete measurement system (Vo) will be function of the mesurand (q) and other, indirect factors, along with the characteristics of signal conditioning.

$$Vo = f(q, x_1, x_2, x_3, \dots)$$

- The influence of this factors in the final output is *deterministic.* Sources:
  - Signal conditioning and its imperfections.
  - Influence Variables.

Propagation of Systematic Errors

- As the influence of the different parameters is deterministic, the combined effect of errors (Δx_i) using the linear error-propagation law using Taylor series and removing all second and higher-order terms.

$$\Delta Vo = \sum_{i=1}^{n} \frac{\partial f}{\partial x_i} \Delta x_i$$

- Usually is expressed in relative error.

Example

- Let’s calculate the LE in the calculation of the DC power in a resistor from the measurement of the current and its value:

$$P = I^2 R$$

$$\Delta P = 2IR\Delta I + I^2 \Delta R$$

$$\frac{\Delta P}{P} = 2\left|\frac{\Delta I}{I}\right| + \left|\frac{\Delta R}{R}\right|$$

- If we use a 2% precision multimeter and the value of the resistor is known to the 1%, the LE in the DC power calculation is 5%

Influence Variables

- The output of the sensor is related not only to the measurand value and the signal conditioning (former example), but to other environmental variables:
  - Temperature
  - Pressure
  - Vibration
  - ….
- The influence is also studied using the deterministic linear error propagation law that allows also for cancelation of effects (next chapter).

Random Errors (I)

- Associated to any measurement or electronic signal we find random, non-deterministic variations as the result of different sources:
    - Electronic noise (Johnson, shot,..)
    - Interference
- It is important to note that whilst some sources may well be truly random (noise), some can be rendered as systematic (interference) if enough effort is devoted to discover and model the sources. However, usually is easier to model them directly as noise.

Propagation of Random Errors

- In this case all the sources are independent and their influence are added to the *variance* of the final result.

$$\Delta Vo = \pm\sqrt{\sum_{i=1}^{n}\left(\frac{\partial f}{\partial x_i}\Delta x_i\right)^2}$$

- This quantity is usually expressed in terms of signal-to-noise ratio as will be discussed further .

Gross/Human Errors

- Humans are always part of an instrument chain as designers, manufacturers or observers.
- History is full of examples of errors due to wrong use of measurment units (SI vs Standard/Imperial)
- Instrumentation misuse, calculation errors and other human mistakes are the main source of wrong measurements!!!!

Summary

- The typical Architecture for an Electronic/Optoelectronic Instrumentation Measurement System has been presented, along with different sensor input mechanisms
- The Characterization of Sensors and Measurement Systems has been presented through the description of the Static and Dynamic Characteristics from the Calibration Curve/Transfer Function
- Errors in Measurements have been also described and classified as something inherent to every measurement.