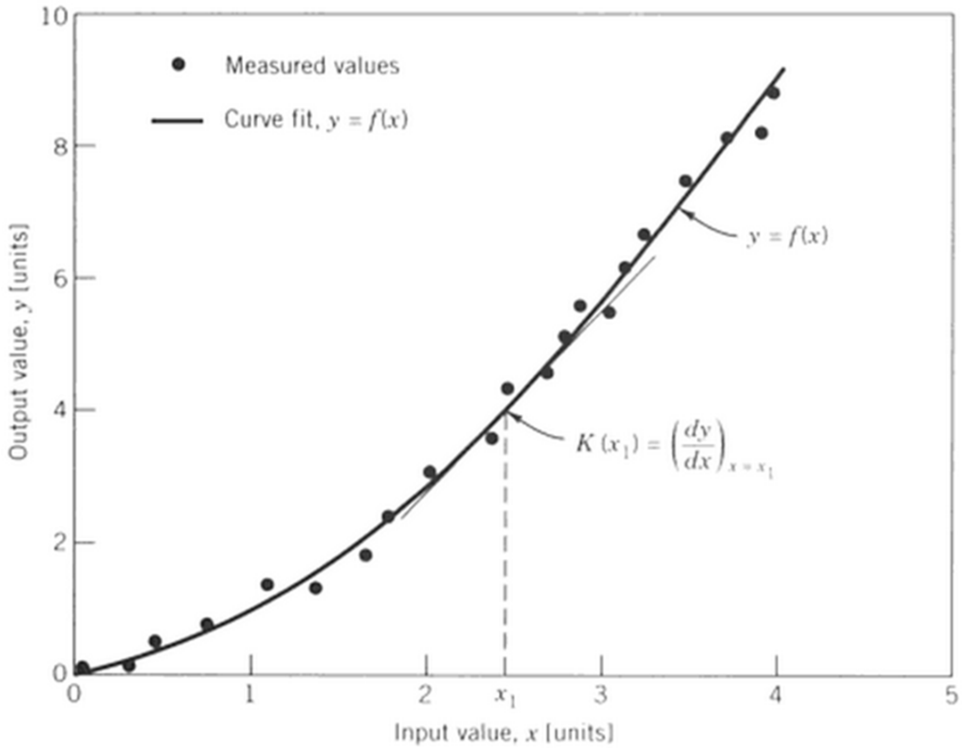
Instrumentation & Measurements
MECH 430

Chapter 1
Introduction

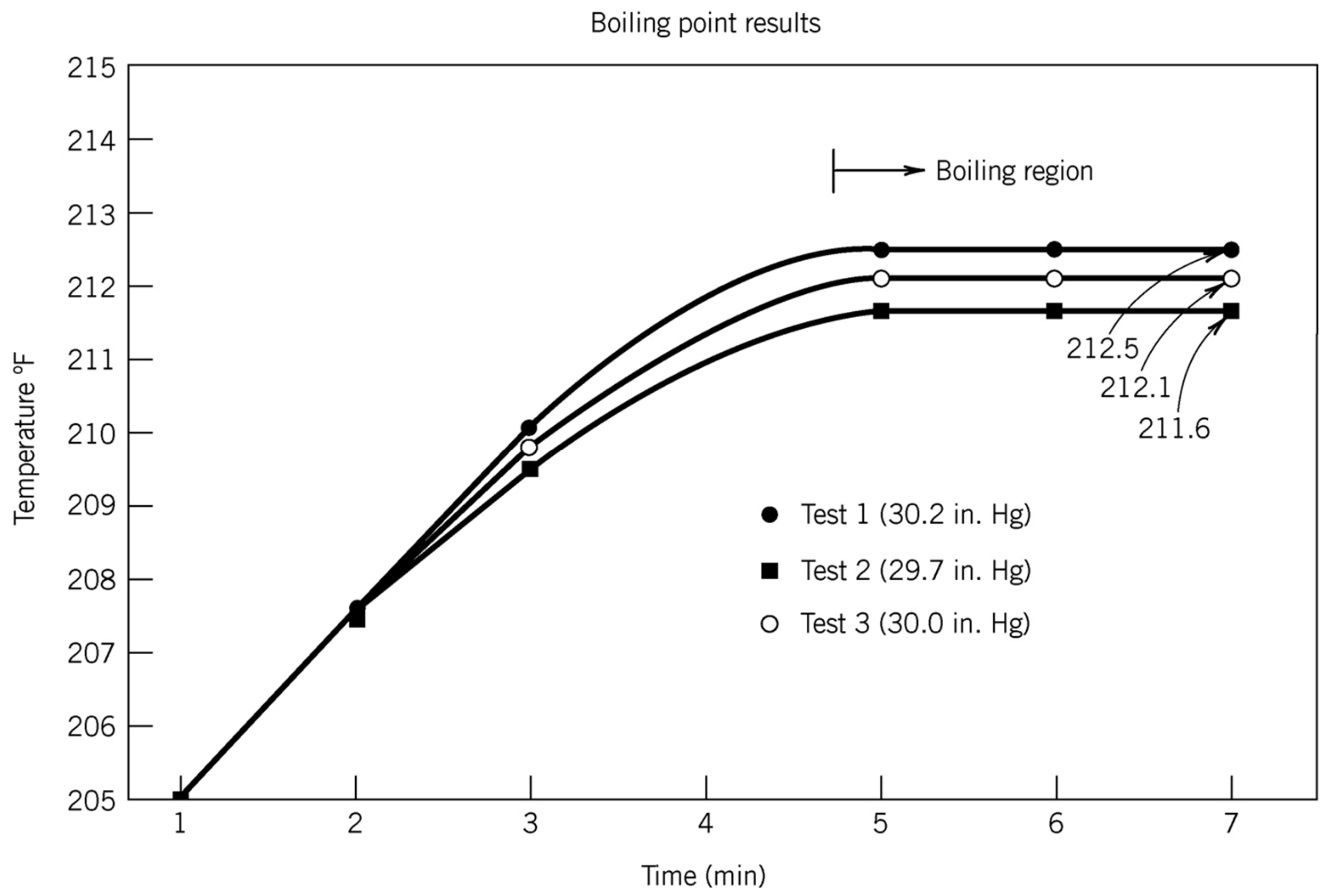


Experimental Test Plan

- Parameter design plan
  - What needs to be measured?
  - What conditions or parameters should I keep track of?
- System and tolerance design plan
  - How trustworthy are my numbers?
  - Do I have enough resolution?
- Data reduction design plan
  - Do I understand the results?
  - How should I present my findings?

Variables

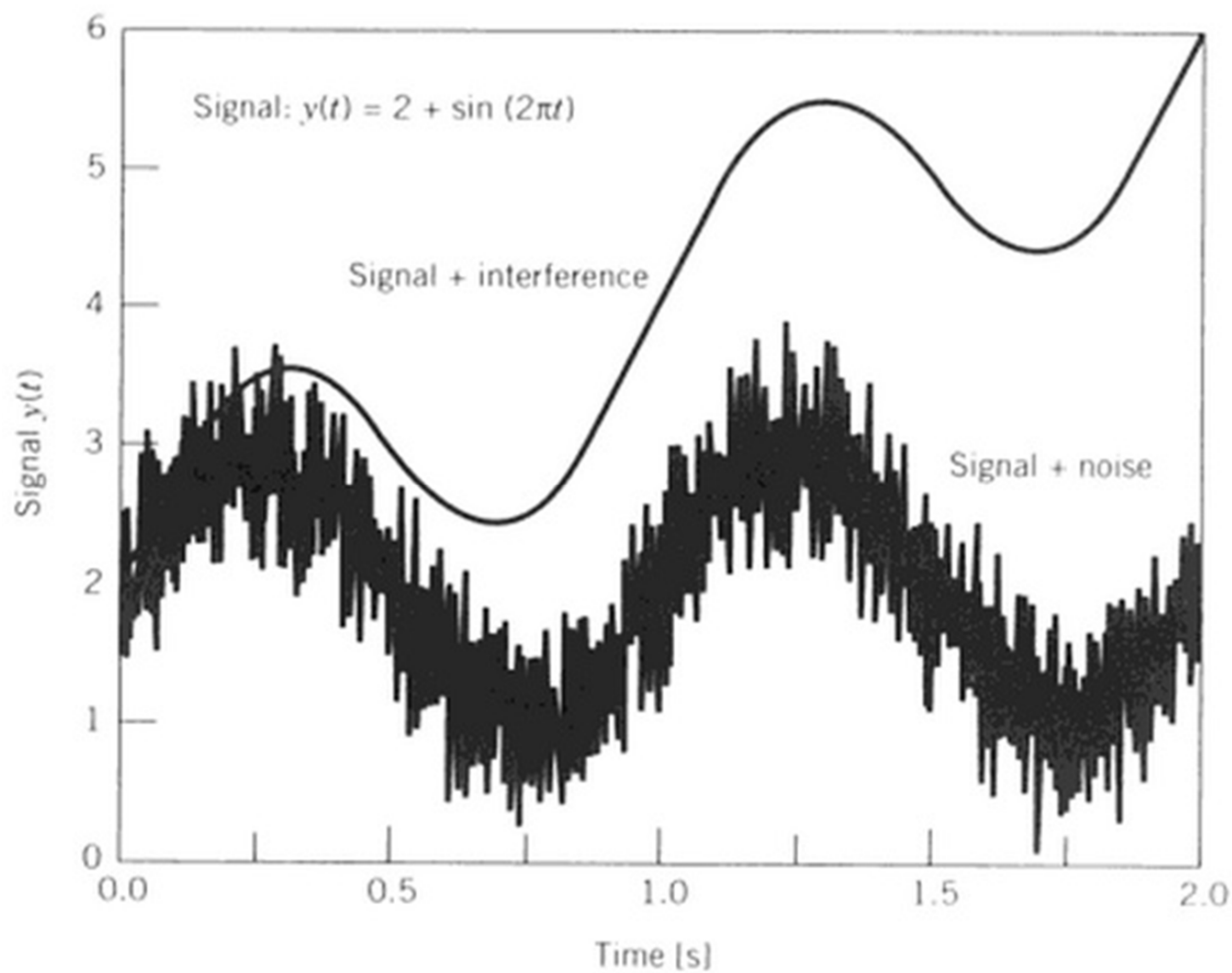
- Independent variables vs. dependent variables



Noise and Interference

- How external variables affect the measured data
- *Noise* is a random variation that affects the variable that is being measured
- *Interference* is a deterministic effect on the variable being measured, usually unwanted effect.

Noise and Interference



Calibration

- *Calibration* is the process of ensuring that the equipment and artifacts that are being used in the experimental setup are "in spec"
- "Calibration is a comparison of measuring equipment against a standard instrument of higher accuracy to detect, correlate, adjust, rectify and document the accuracy of the instrument"

  Source: Calibration: A Technician's Guide, Mike Cable
- Calibration consists of comparing the output of the instrument or sensor under test against the output of an instrument of known accuracy when the same input (the measured quantity) is applied to both instruments.

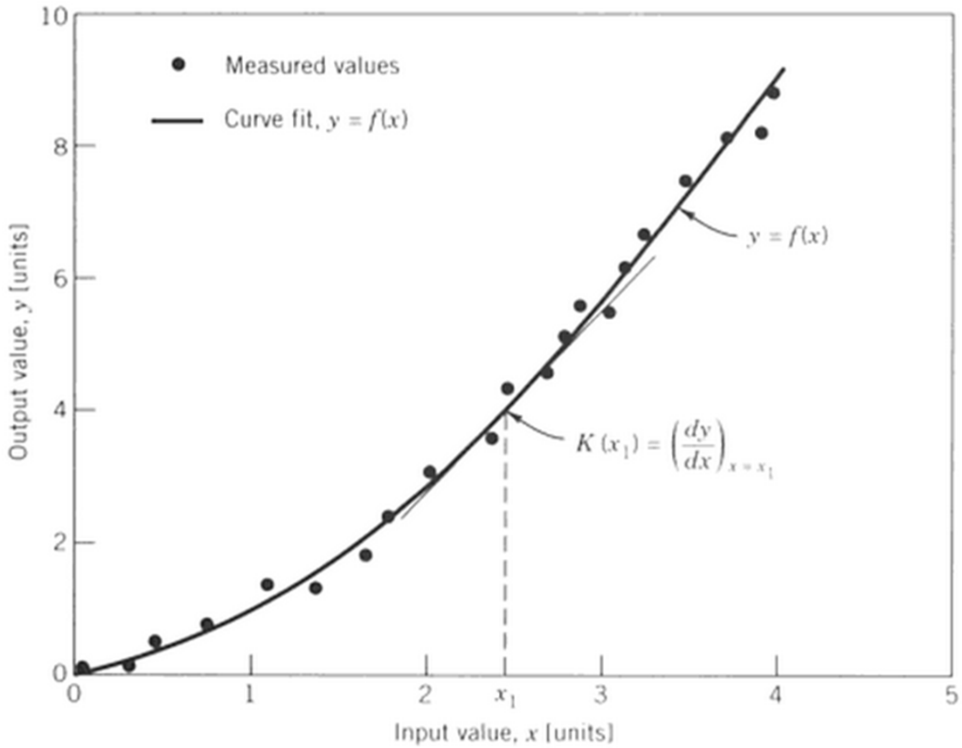
Calibration

- Instruments used as a standard in calibration procedures are usually chosen to be of greater inherent accuracy than the process instruments that they are used to calibrate.
- Any instrument that is used as a standard in calibration procedures must be kept solely for calibration duties and must never be used for other purposes.

1.4 Calibration

- *Calibration* applies a known input to the measurement system for the purpose of observing the output value.

•Keeping all sensor inputs constant except the one studied.
•Varying this input slowly in the up and down directions (these are known inputs).
•Recording the sensor output for each of the inputs.
•Repeat this process for every point of interest.



Calibration

- http://www.omega.com/ppt/pptsc.asp?ref=CL1000&Nav=temk06

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- Soft Carrying Case, Power Cord and Complete Operator's Manual Included
- Built-in Digital 1/32 Temperature Controller

View related products - Calibration Equipment

Sensor Characteristics

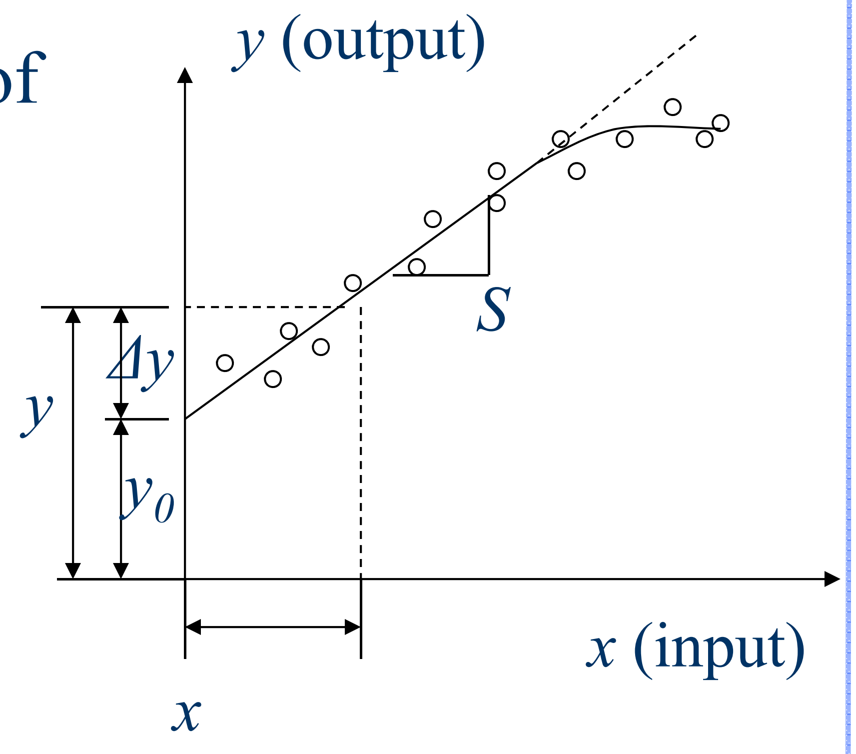
- Sensitivity
- Full scale input
- Full scale output
- Resolution
- Accuracy
- Precision
- Drift
- Gain
- Linearity
- Threshold
- Saturation
- Repeatability
- Reproducibility

Sensitivity

- *Sensitivity* is the smallest detectable change in output of the sensor (y), to a change in the input (x), evaluated at a specific input (x_a):

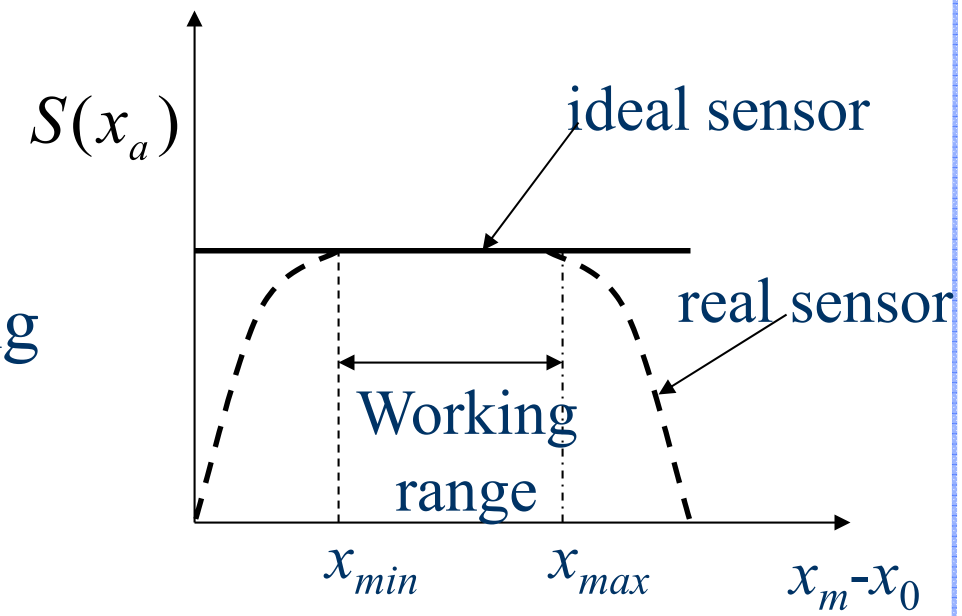
$$S(x_a) = \left.\frac{dy}{dx}\right|_{x=x_a}$$

- For linear sensors, S is constant and represents the slope of the input-output curve



Sensitivity

- Sensor sensitivity can be constant over the working range.

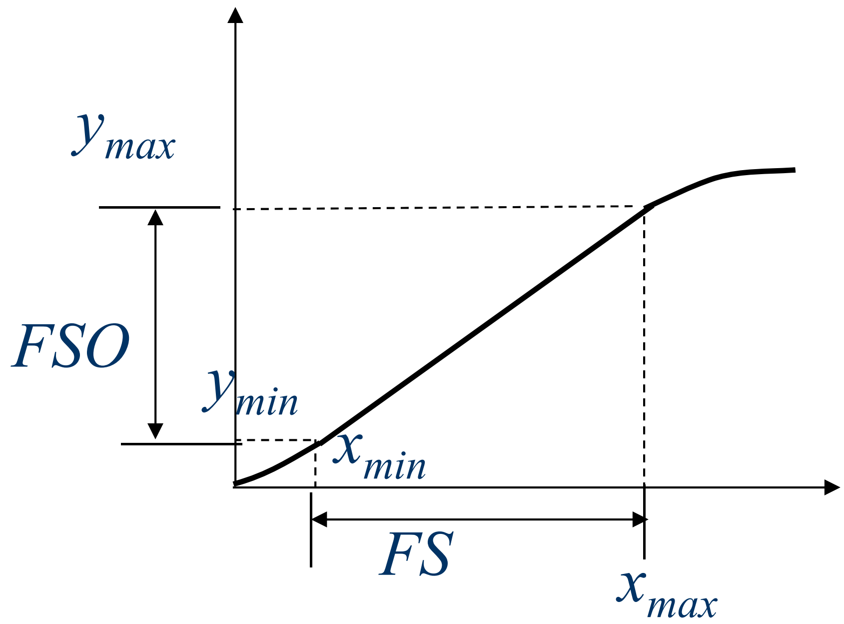


$$S(x_a) = \left.\frac{dy}{dx}\right|_{x=x_a}$$

Range - Full scale input

- Full-Scale input (FS) specifies the range of values that the sensor can convert.

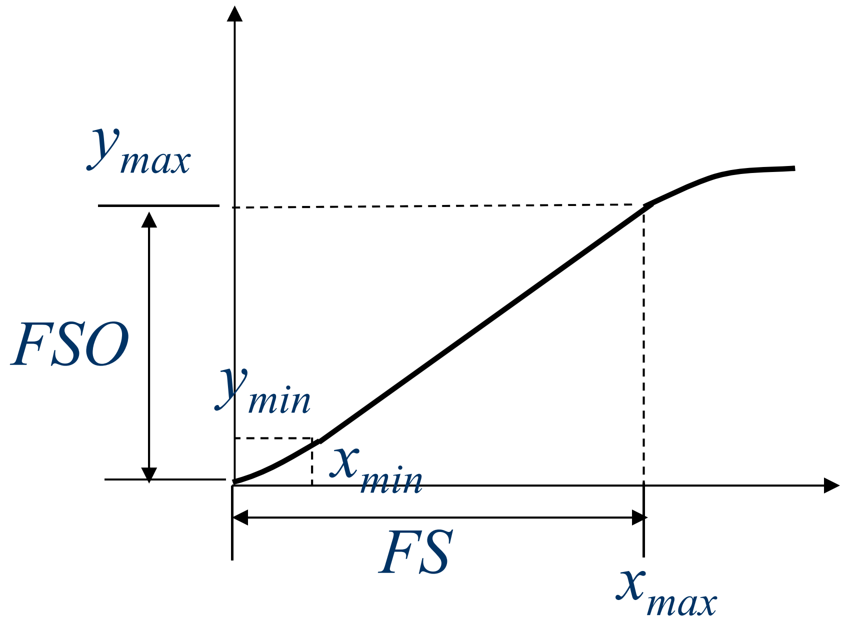
$$FS = x_{\max} - x_{\min}$$



- For example, a pot used to measure angular position of a shaft may be limited to the range $0<\theta<270^o$.

Range - Full scale output

- Full-Scale Output (FSO) is the <u>range</u> of values that can be measured with the instrument.



$$FSO = y_{\max} - y_{\min}$$

Example

SIEMENS HQEU

Building Technologies

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HVAC Products – Catalog

HVAC Products – Catalog > 11 - Sensors - Symaro™ > Humidity and temperature > Room sensors QFA.. > QFA20..

Product Search

Search

↑ One level up

→ Room sensors QFA..
- → QFA20..
- → QFA31..
- → QFA31..D
- → QFA41..
- → QFA41..D

Room sensor for rel. humidity / temperature

Product no.	Documents
QFA20..	

For relative humidity and temperature

Attribute	Value
Operating voltage	AC 24 V, DC 13.5...35 V
Measuring range, humidity	0...95 % r.h.
Measurement accuracy	At 0...95 % r.h. and 23 °C: ±5 %, At 30...70 % r.h. and 23 °C: ±3 %
Time constant	Humidity <20 s, Temperature <8.5 min
Connection, electrical	Screw terminals
Type of fixing	Screws
Signal output humidity	DC 0...10 V
Degree of protection	IP30
Dimensions (W x H x D)	90 x 100 x 36 mm

Products

Product no.	Stock no.	Description	Price
QFA2060D	BPZ:QFA2060D	Room sensor for humi...	236.00 EUR
QFA2000	BPZ:QFA2000	Room sensor for humi...	181.00 EUR
QFA2020	BPZ:QFA2020	Room sensor for humi...	186.00 EUR
QFA2060	BPZ:QFA2060	Room sensor for humi...	191.00 EUR

Example

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HVAC Products – Catalog

HVAC Products – Catalog > search: qfa > QFA4160D

Product Search

qfa Search

↑ One level up

→ Room sensors QFA..
→ QFA20..
→ QFA31..
→ QFA31..D
→ QFA41..
→ QFA41..D

Room sensor for humidity (DC 0..10V) and temperature (DC 0..10V) with calibration certificate, with display

Product no.	Price	Documents	Stock no.
QFA4160D	776.00 EUR	🗎	BPZ:QFA4160D

Humidity 2%, Temperature Certified Room Temperature Sensor with diaplay, 0 to 10 Volts

Attribute	Value
Operating voltage	AC 24 V, DC 13,5...35 V
Measuring range, temperature	0...50 °C, -35...35 °C, -40...70 °C
Measuring range, humidity	0...100 % r.h.
Measurement accuracy	Humidity at 0...100 % r.h. and 23 °C: ±2 % r.h., Temperature, at 15...35 °C: ±0.6 K, Temperature, at 40...70 °C: ±0.8 K
Time constant	Humidity: <20 s, Temperature: <8.5 min
Connection, electrical	Round connector
Signal output temperature	DC 0...10 V
Signal output humidity	DC 0...10 V
Degree of protection	IP65
Dimensions (W x H x D)	80 x 144 x 39 mm

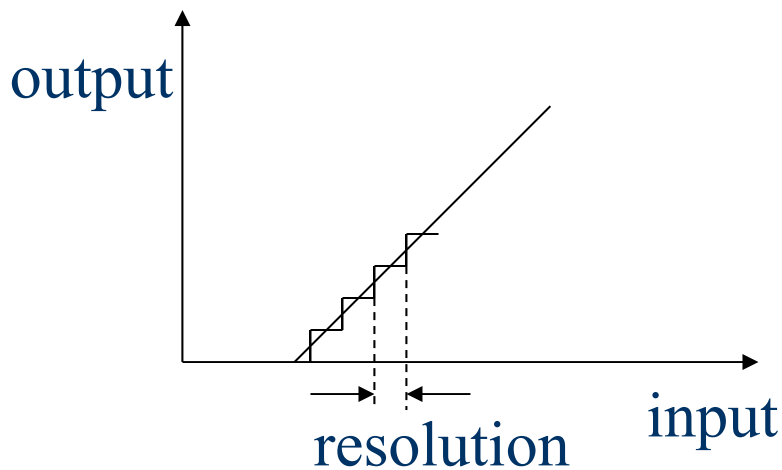
Accessories

Produc...	Stock no.	Description	Doc
AQF4150	BPZ:AQF4...	Exchangeable measuring tip,...	🗎

Resolution

- *Resolution* is the minimum change of the input to produce a detectable change in the output. It is quantified by the smallest scale increment of the output readout indicator.

Ex: a thermometer that displays 2 decimal places has a 0.01°C resolution



Error, True Value

- The Error is the difference between the output or *Measured Value* and the *True Value*
- The true value is the value obtained by a perfect measurement
- This true value is theoretical!

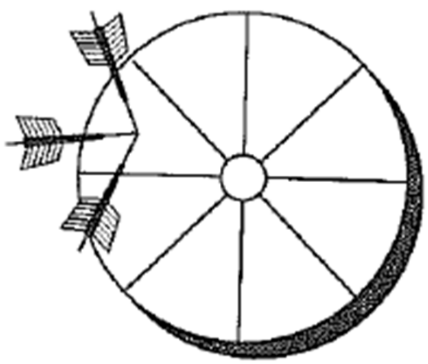
Accuracy

- *Accuracy* is the **closeness** of a measurement to the *true* value of the measurand.
- It is often quoted as a percentage of the full scale value
- This true value is theoretical and in practice a value is considered true if it exhibits an uncertainty small enough to be appropriate for a given purpose.
- Sensor accuracy is determined through *static calibration*.

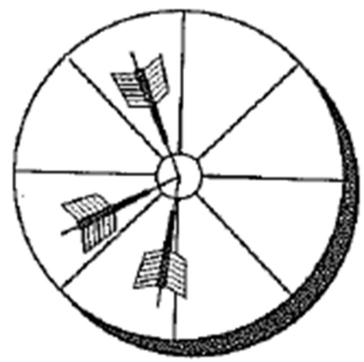
Precision

- *Precision* is the quality that characterizes the capability of a measuring instrument of giving the same reading when repetitively measuring the same quantity under the same prescribed conditions.
- When considering precision, there is no regard for the coincidence or discrepancy between the result and the true value.

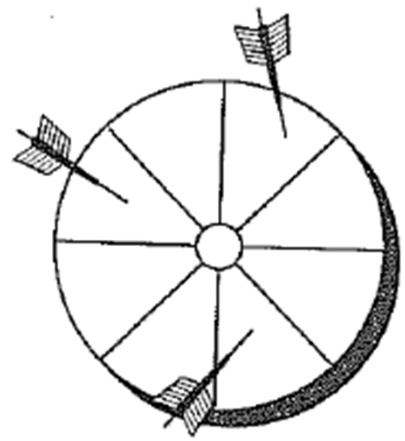
Accuracy vs. Precision



1) High precision (repeatability), low accuracy



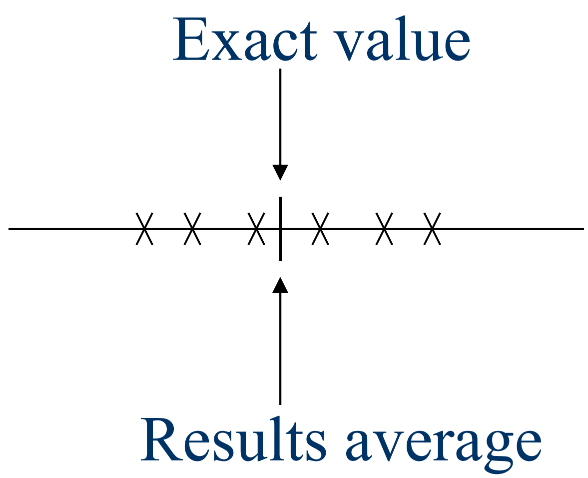
2) High precision (repeatability), high accuracy



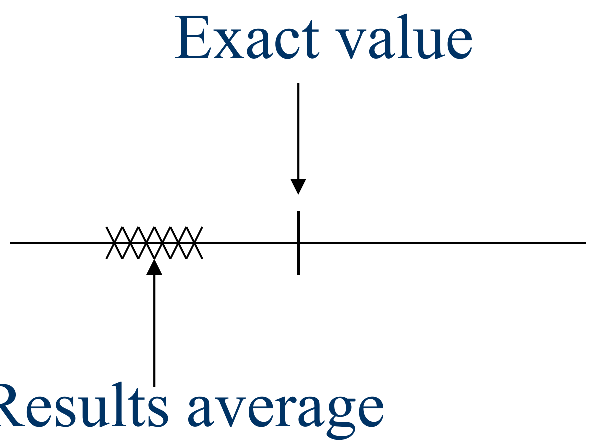
3) Low precision (repeatability), low accuracy

Precision vs. Accuracy

- Precision is a necessary but not sufficient condition for accuracy.



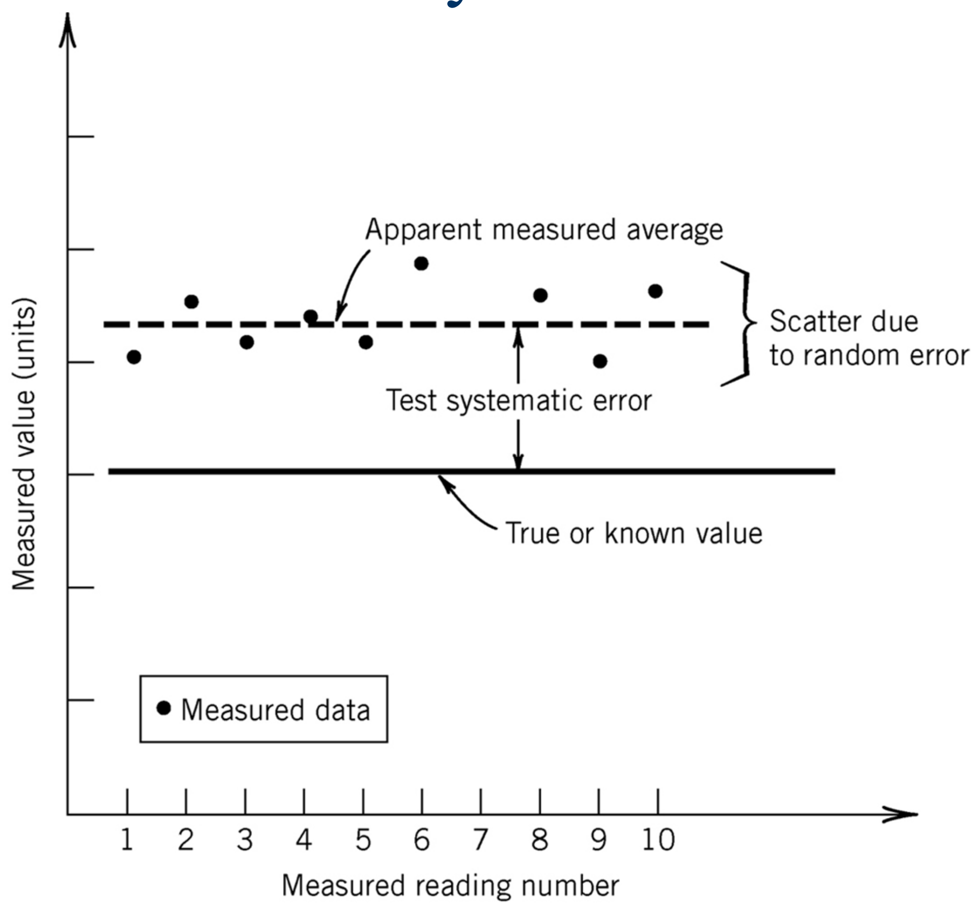
1) High accuracy, low precision



2) Low accuracy, high precision

Precision vs. Accuracy

- Effects or random and systematic errors on calibration

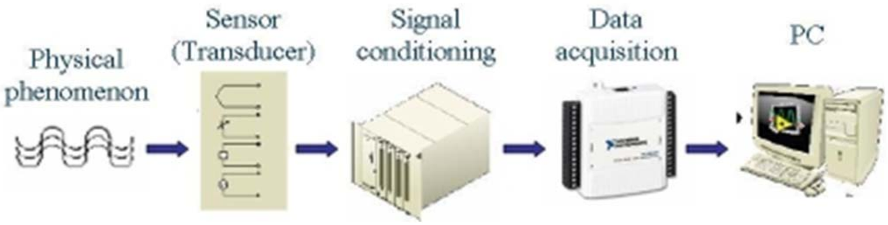


Overall accuracy

- To determine the <u>*overall accuracy*</u> of a measurement system, combine all sources of error using the <u>*Square-Root-of-the-Sum-of-the-Squared*</u> (SRSS) method .
- If the sources of error include:
  - DAQ system (noise, aliasing),
  - External sensor or signal sources,
  - Connected wires,
  - Signal conditioning.

Example

- Given:
  - A1 = ±0.025% (Sensor)
  - A2 = ±0.01% (Wiring)
  - A3 = ±0.05% (Signal conditioning)
  - A4 = ±0.005% (A/D converter)

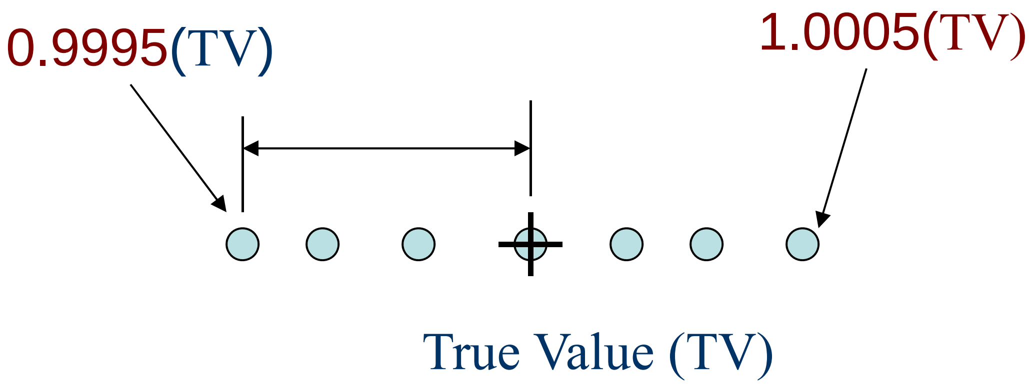


- The system accuracy is therefore:

$$A_{system} = \sqrt{(A_1)^2 + (A_2)^2 + (A_3)^2 + (A_4)^2} = \pm 0.057\%$$

Overall accuracy

- When one states an accuracy of 0.05% (0.0005)



How to express values vis-à-vis accuracy

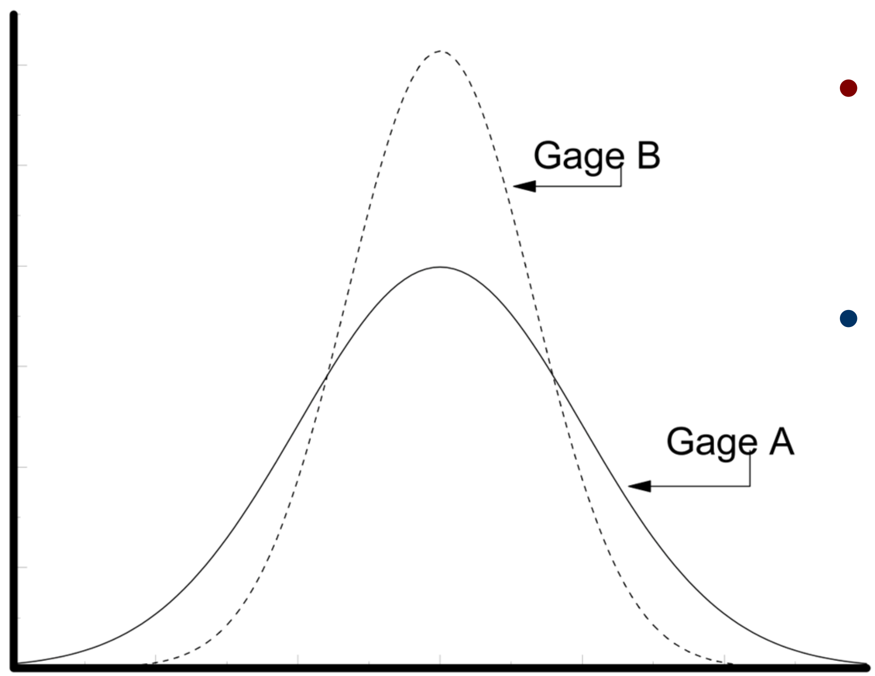
- The measured value and its error are expressed with consistent numerical values.
- An acceptable expression is:
  - $20^{o}C \pm 1^{o}C$
- Incorrect expressions:
  - $20^{o}C \pm 0.1^{o}C$
  - $20.5^{o}C \pm 1^{o}C$

Repeatability

- *Repeatability* of a measurement system is the closeness of agreement between successive results obtained with:
  - The same method and person,
  - Under the same conditions,
  - In a short time interval.
- For example if a pressure sensor has a repeatability of 0.1Pa at 95%, it means that there is a 95% chance that two consecutive readings will not differ more than 0.1Pa.
- Precision and repeatability are sometimes used interchangeably.

Repeatability

- Consider the Probability Density Functions (PDF) from the measurements of the thickness of a piece of metal using two gages A and B.



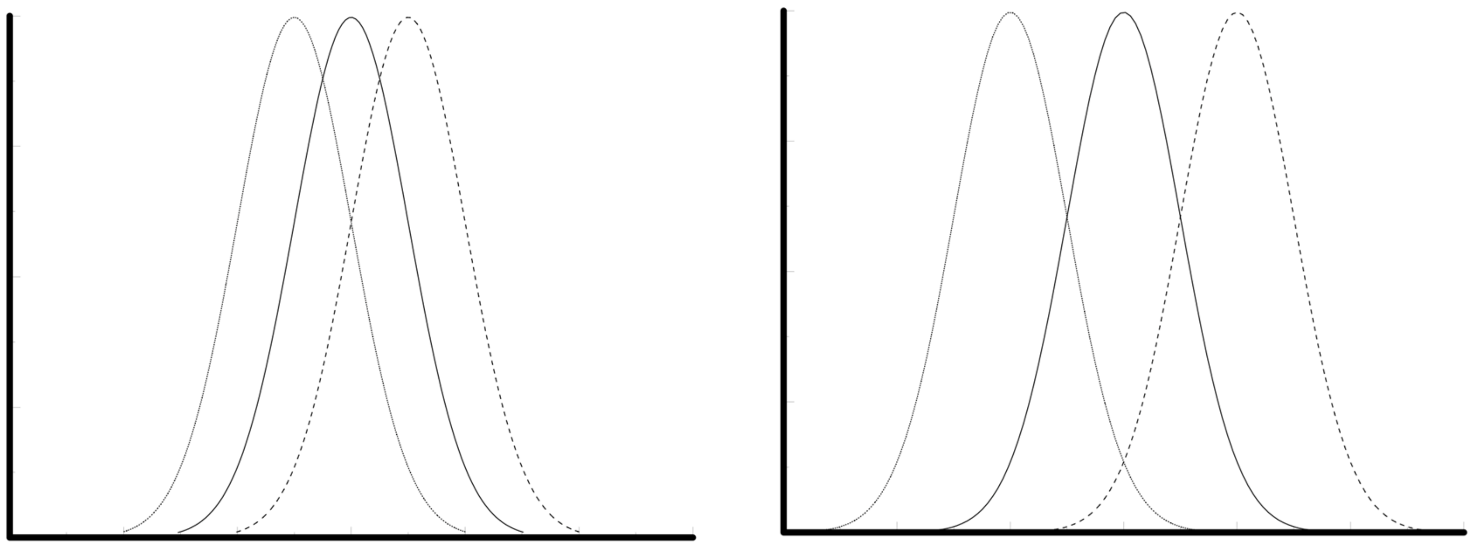
- We say Gage A has a higher repeatability (as a value) than Gage B
- Gage B is more repeatable than Gage A

Reproducibility

- *Reproducibility* is the closeness of agreement between a successive set of long-term results, or results performed by different people or performed with different instruments in different laboratories.
- Think about it as the variability in the average values obtained by several operators while measuring the same item.
- The quantitative value of reproducibility is the minimum value that exceeds, with a given probability, the absolute value of the difference between two single measurement results under the above-mentioned conditions.

Reproducibility

- Consider the Probability Density Functions (PDF) from the measurements of the thickness of a piece of metal by 3 operators.



Reproducibility (as a value) is higher in the right chart

Repeatability and Reproducibility

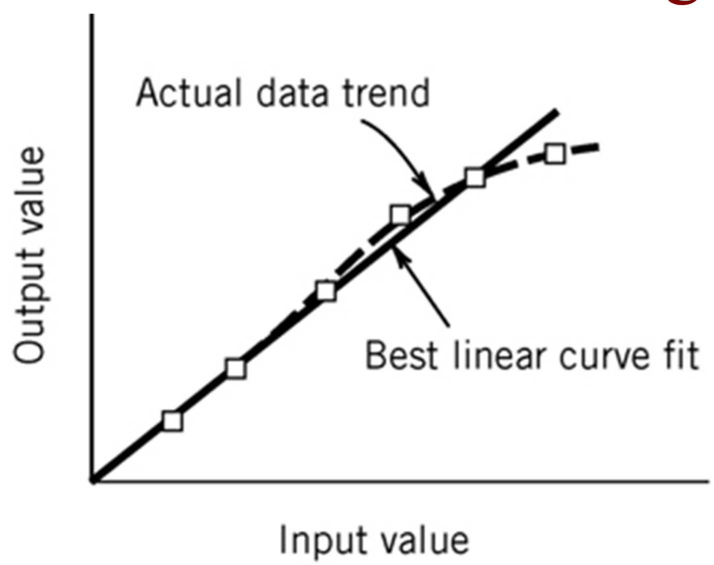
- Repeatability and reproducibility describe the spread of output readings for the same input.
- This spread is referred to as repeatability if the measurement conditions are constant and as reproducibility if the measurement conditions vary.

Drift

- When a sensor output changes with time (for constant input), it is said there are instabilities and that the sensor *drifts*.
- Zero drift describes output variation when the input is zero.
- *Scale factor drift* describes sensitivity changes with time.

Linearity

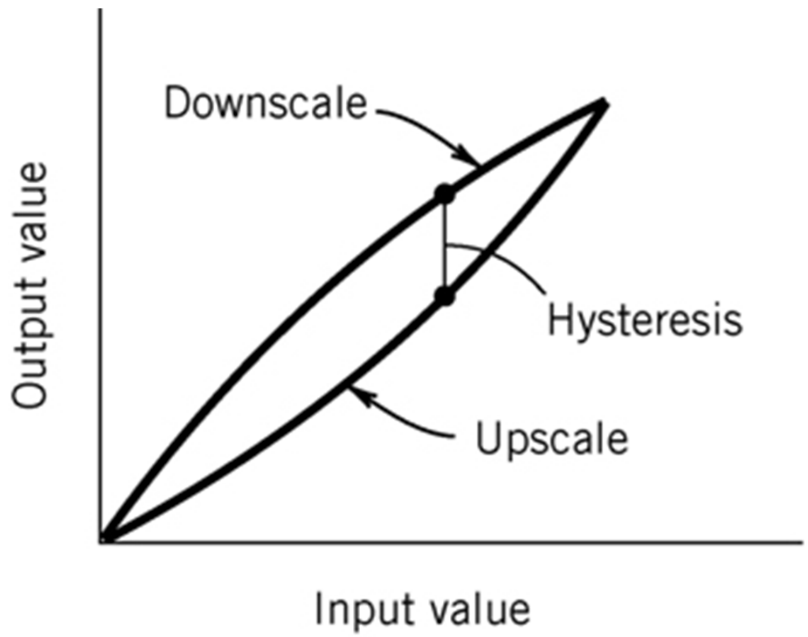
- Linearity describes the closeness of the response curve to a straight line.
- Linearity indicates to what extent the sensor's sensitivity is constant in its full range.



(b) Linearity error

Hysteresis

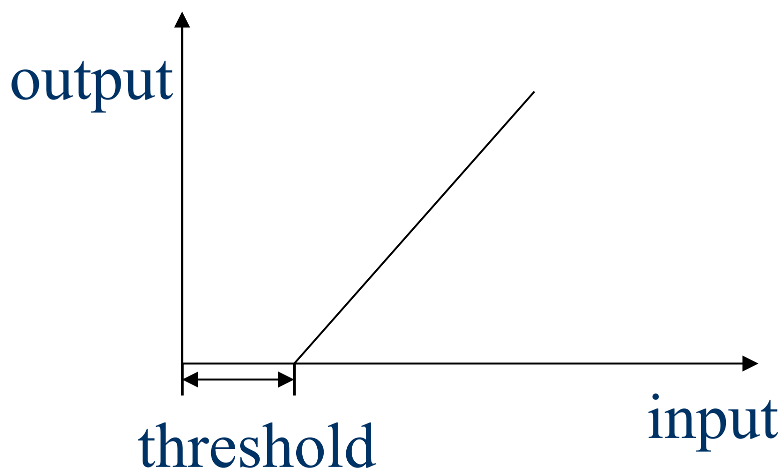
- It refers to difference between an upscale sequential test and a downscale sequential test.



(a) Hysteresis error

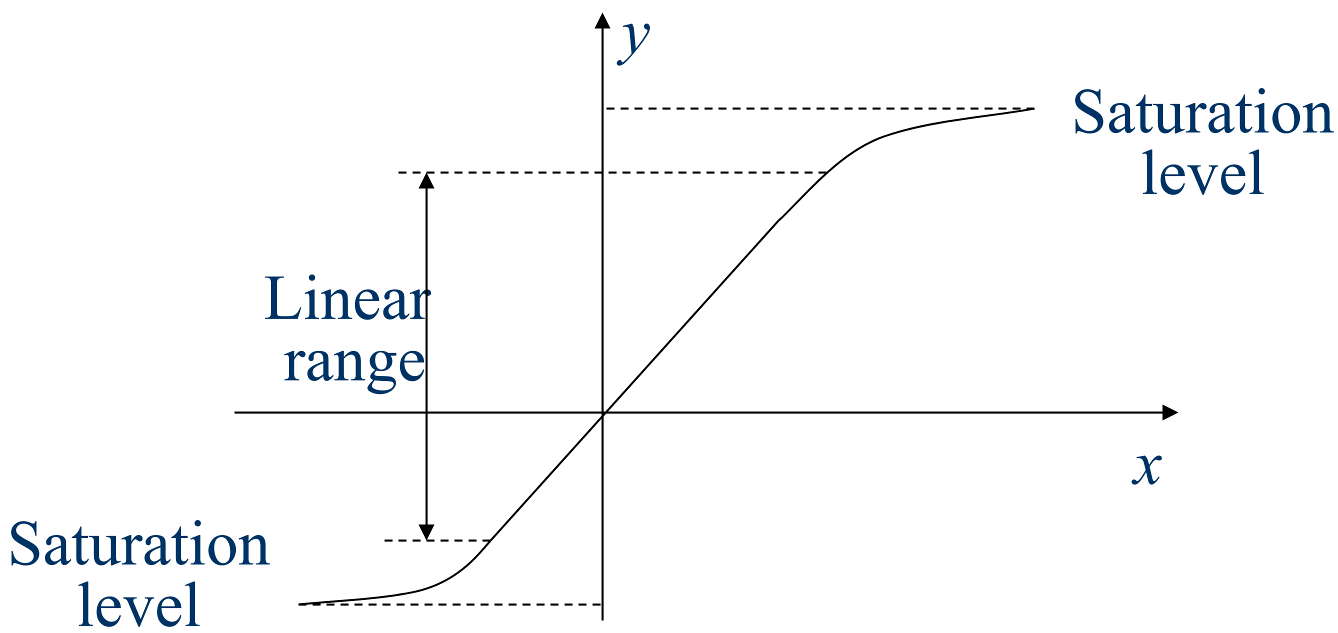
Threshold

- The Threshold is the minimum value of input needed to activate the sensor output.
- When the input increment is from zero, then the resolution is called *threshold*.



Saturation

- *Saturation* is one form of nonlinear response. It emanates from causes such as magnetic saturation, plasticity in mechanical components, or non-linear deformations in springs.



1.5 Standards, dimensions, units

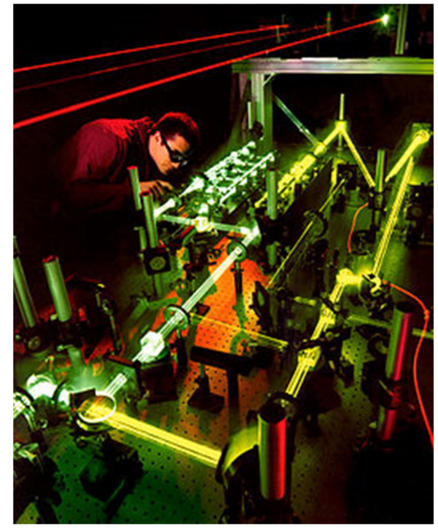
- When a measurement system is calibrated it is compared to reference value called a *standard*.
- A *dimension* defines a physical variable that is used to describe some aspect of a physical system (*e.g.*, mass, length, time).
- A *unit* is a quantitative measure of a dimension (*e.g.*, kilogram, meter, second).
- A *primary standard* defines the value of a unit. The unit will be described by a unique number understood throughout the world.

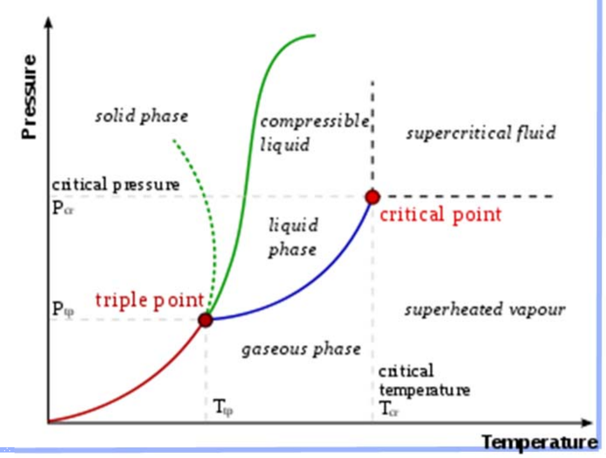
Primary standards

- Mass: The dimension is defined by the kilogram. A bar (90% platinum, 10% iridium by mass) kept in the International Bureau of Weights and Measures (IBWM) in Sevres, France is the primary standard for mass.
- Time: The dimension is defined by the unit of a second. It is the time elapsed during 9,192,631,770 periods of radiation emitted between two excitation levels of the fundamental state of cesium-133. The Bureau International de l'Heure (BIH) used to maintain the primary standard for time but in 1987 the IBWM took over this responsibility.

Primary standards

- Length: the primary standard for the meter is the length traveled by light in 1/299,792,458 of a second. This number is derived from the velocity of light in vacuum (299,792,458m/s).
- Temperature: the primary standard for the Kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.





Hierarchy of Standards

- Primary standards are impractical as standards for normal calibration use. They serve as a reference for exactness.
- Thus, there exist a hierarchy of reference and secondary standards used to duplicate the primary standards.

Hierarchy of Standards

- Primary standard
- National reference standard (Designated Laboratories)
- Transfer standard (*e.g.*, NIST*)
- Local standard (*e.g.*, university)
- Working standard (*e.g.*, university)
- Local instruments (*e.g.*, multimeter)

* NIST: National Institute of Standards and Technology

Example - Temperature

Level	Standard Method	Error [^{o}C]
Primary	Fixed thermodynamic point	0
Transfer	Platinum resistance thermometer	$\pm$0.005
Working	Platinum resistance thermometer	$\pm$0.05
Local	Thermocouple	$\pm$0.5

Primary & derived units

- Primary:
  - Length (m) [L]
  - Mass (kg) [M]
  - Time (s) [T]
  - Temperature (K) [ɵ]
  - Current (A) [I]
  - Substance (mol) [N]
  - Light Intensity (Candela) [Iv]
- Derived:
  - Force (N) $[M][L][T]^{-2}$
  - Voltage (V)
  - Resistance (Ω)
  - Capacitance (F)
  - Inductance (H)
  - Pressure (Pa) $[M][L]^{-1}[T]^{-2}$
  - Energy (J)
  - Power (W)

Named units derived from SI base units

Name	Symbol	Quantity	Expression in terms of SI base units
hertz	Hz	frequency	s^{-1}
radian	rad	angle	dimensionless
steradian	sr	solid angle	dimensionless
newton	N	force, weight	$m \cdot kg \cdot s^{-2}$
pascal	Pa	pressure, stress	$m^{-1} \cdot kg \cdot s^{-2}$
joule	J	energy, work, heat	$m^{2} \cdot kg \cdot s^{-2}$
watt	W	power, radiant flux	$m^{2} \cdot kg \cdot s^{-3}$
coulomb	C	electric charge or electric flux	$s \cdot A$
volt	V	voltage, electrical potential difference, electromotive force	$m^{2} \cdot kg \cdot s^{-3} \cdot A^{-1}$
farad	F	electric capacitance	$m^{-2} \cdot kg^{-1} \cdot s^{4} \cdot A^{2}$
ohm	Ω	electric resistance, impedance, reactance	$m^{2} \cdot kg \cdot s^{-3} \cdot A^{-2}$
siemens	S	electrical conductance	$m^{-2} \cdot kg^{-1} \cdot s^{3} \cdot A^{2}$
weber	Wb	magnetic flux	$m^{2} \cdot kg \cdot s^{-2} \cdot A^{-1}$
tesla	T	magnetic field strength, magnetic flux density	$kg \cdot s^{-2} \cdot A^{-1}$
henry	H	inductance	$m^{2} \cdot kg \cdot s^{-2} \cdot A^{-2}$
degree Celsius	°C	temperature	$K - 273.15$
lumen	lm	luminous flux	$cd \cdot sr$
lux	lx	illuminance	$m^{-2} \cdot cd \cdot sr$
becquerel	Bq	radioactivity (decays per unit time)	s^{-1}
gray	Gy	absorbed dose (of ionizing radiation)	$m^{2} \cdot s^{-2}$
sievert	Sv	equivalent dose (of ionizing radiation)	$m^{2} \cdot s^{-2}$
katal	kat	catalytic activity	$s^{-1} \cdot mol$

http://en.wikipedia.org/wiki/Derived_units