Measurement Systems

Measurement Instruments

Applied Mechatronics

Module 2.1

by Wolfgang Neff

Metrology (1)

- Definition
  - Science of Measurement
- Measurement
  - Determination of a physical quantity
  - Measured value
    - Magnitude
    - Unit

Metrology (2)

- International System of Units

Base quantity	Base unit	Symbol
Time	Second	s
Length	Meter	m
Mass	Kilogram	kg
Electric Current	Ampere	A
Temperature	Kelvin	K
Amount of Substance	Mole	mol
Luminous Intensity	Candela	cd

Metrology (3)

- Derived Units

Quantity	Standard unit	Symbol	Derivation
Area	Square Meter	m^2	
Speed	Meter per Second	m/s	
Force	Newton	N	$kg \cdot m/s^2$
Work	Joule	J	$N \cdot m$
Power	Watt	W	J/s
Voltage	Volt	V	W/A
Resistance	Ohm	Ω	V/A

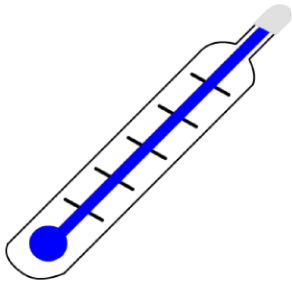
Metrology (4)

- Metric prefixes

Text	Symbol	Factor	Power
mega	M	1 000 000	10^{6}
kilo	K	1 000	10^{3}
(none)	(none)	1	10^{0}
milli	m	0.001	10^{-3}
micro	µ	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pico	p	0.000 000 000 001	10^{-12}

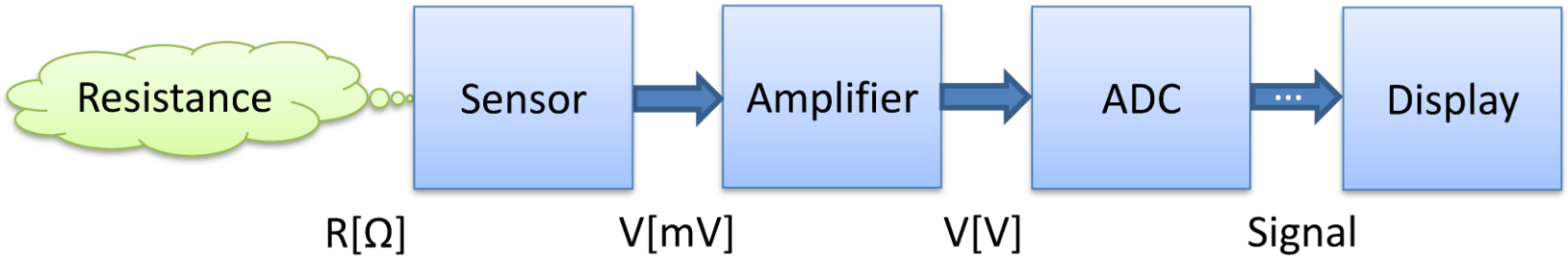
Metrology (5)

- Types of Measurement
  - Direct Measurement
    - Measurement by comparing
      - Length: Yardstick
      - Weight: Beam balance
  - Indirect Measurement
    - Measurement of a physical effect
      - Liquid expansion thermometer
      - Spring balance



Metrology (6)

- Measurement Chain
  - Often measurement cannot be done in one step
  - Several measuring devices are required
  - They form a measurement chain
  - The elements are called transfer elements



Metrology (7)

- Measurement Chain (continued)
  - Measurement Amplifier
    - See AMEC Module 5.3
  - Analog-to-Digital Converter
    - See NWES Module 4.2.6

Instruments (1)

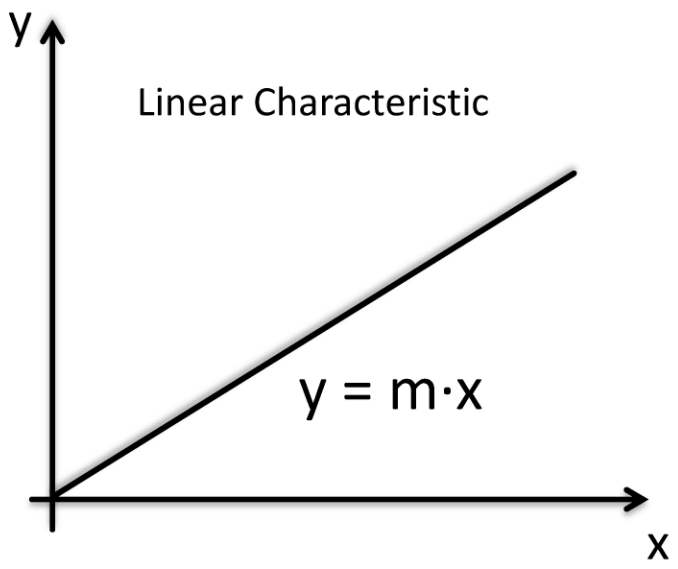
- Types
  - Passive and Active
    - Passive: no external power source needed
      - Liquid expansion thermometer
    - Active: external power source needed
      - Digital thermometer
  - Analog and Digital
    - Analog: result is indicated
    - Digital: result is a number

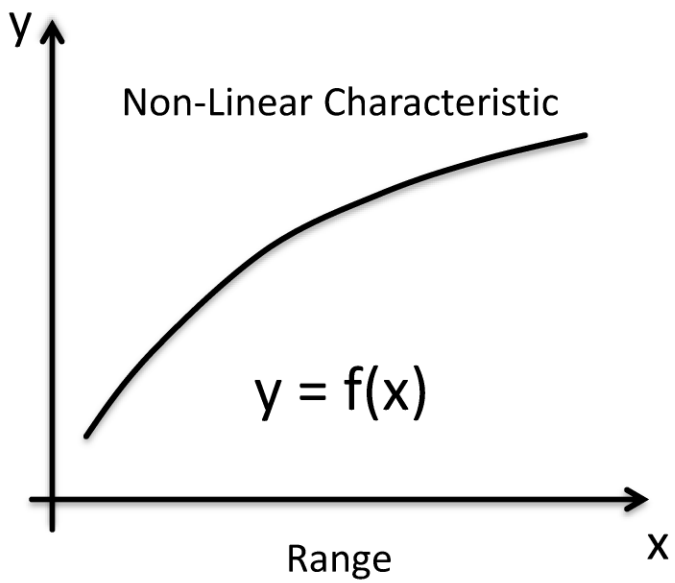
Instruments (2)

- Calibration
  - Comparison with a calibration standard
  - Adjustment of the measuring instrument
- Static Characteristics
  - Range
    - Minimum and maximum possible measured value.
  - Resolution
    - Minimum observable change of measured value.

Instruments (3)

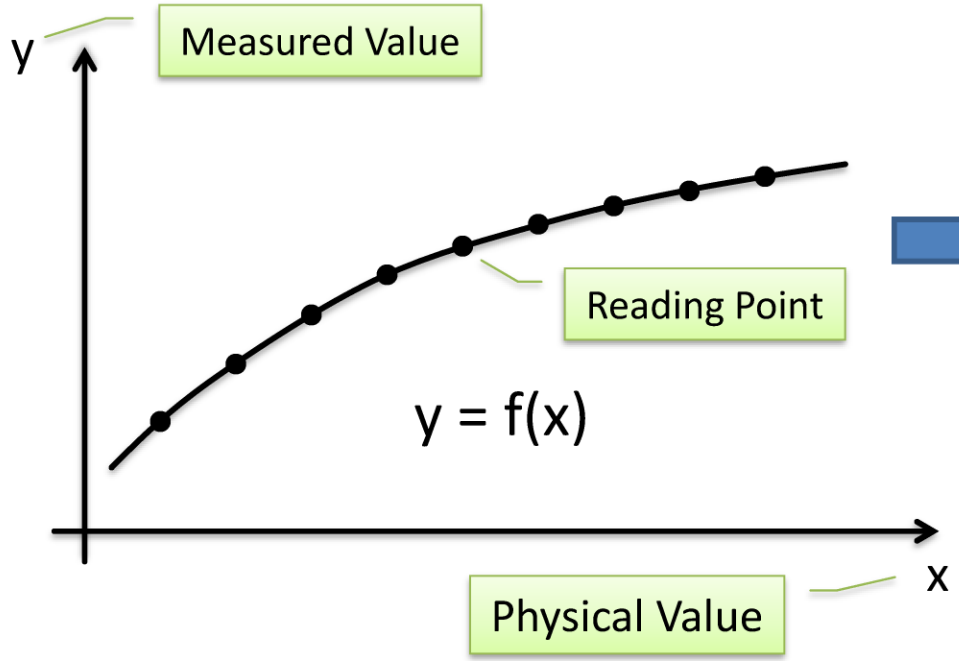
- Static Characteristics (continued)
  - Linearity





Instruments (4)

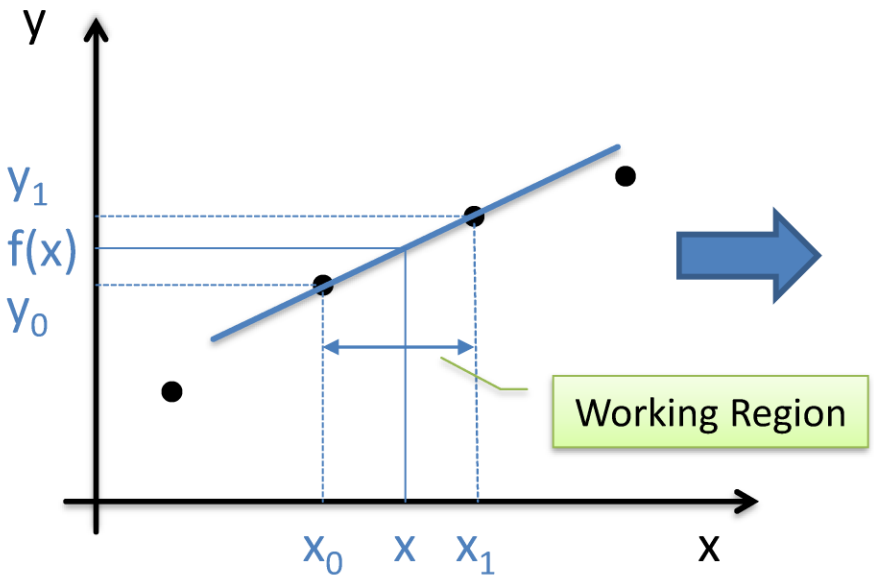
- Static Characteristics (continued)
  - Table of Values



x	y
10	12.41
20	20.75
30	28.77
40	33.95
50	37.49
60	41.10
70	43.92
80	45.47
90	46.87

Instruments (5)

- Static Characteristics (continued)
  - Linearization of a Working Region

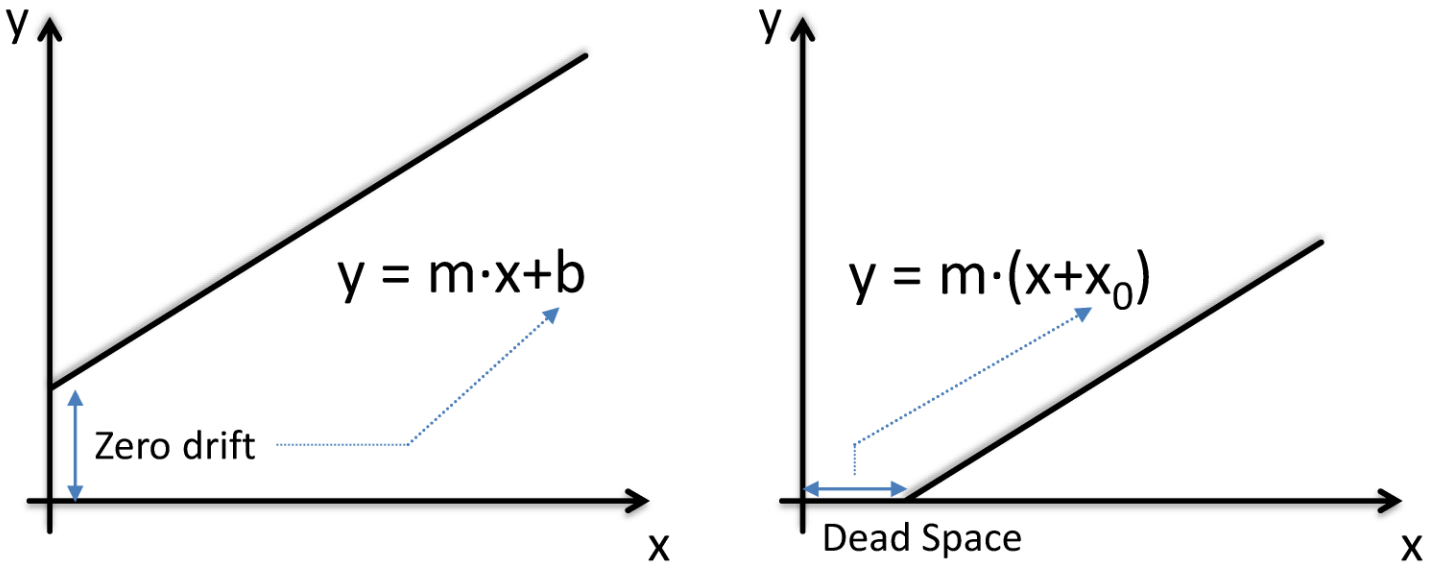


$$f(x) = y_0 + \frac{y_1 - y_0}{x_1 - x_0}(x - x_0)$$

Linear Interpolation

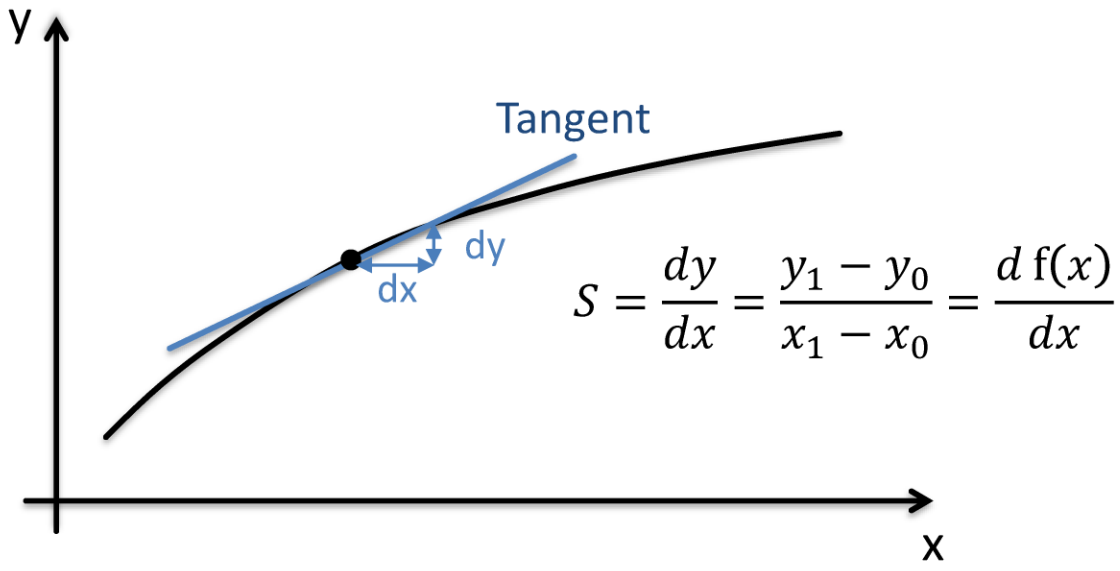
Instruments (6)

- Static Characteristics (continued)
  - Zero Drift and Dead Space



Instruments (7)

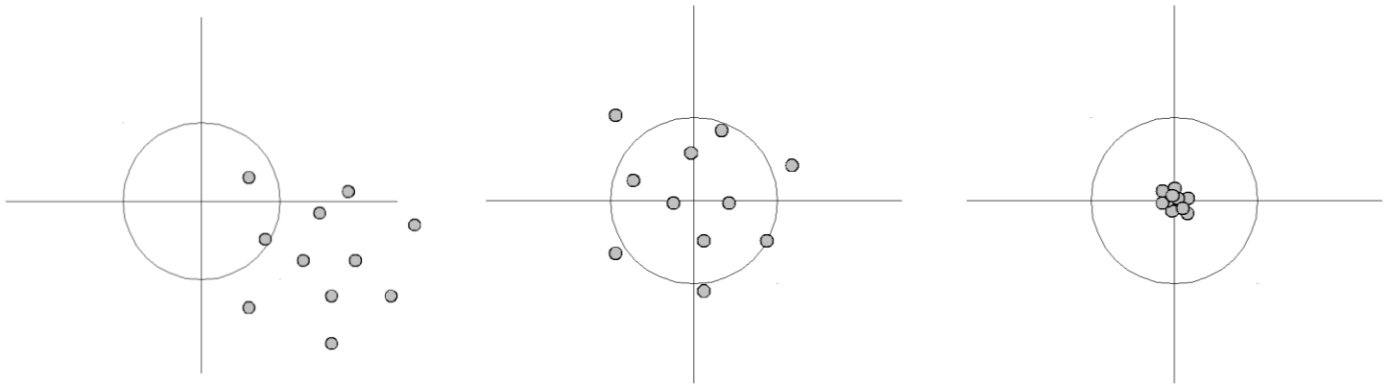
- Static Characteristics (continued)
  - Sensitivity



$$S = \frac{dy}{dx} = \frac{y_1 - y_0}{x_1 - x_0} = \frac{d\,\mathrm{f}(x)}{dx}$$

Instruments (8)

- Static Characteristics (finished)
  - Accuracy and Precision



Low Precision
Low Accuracy

Low Precision
High Accuracy

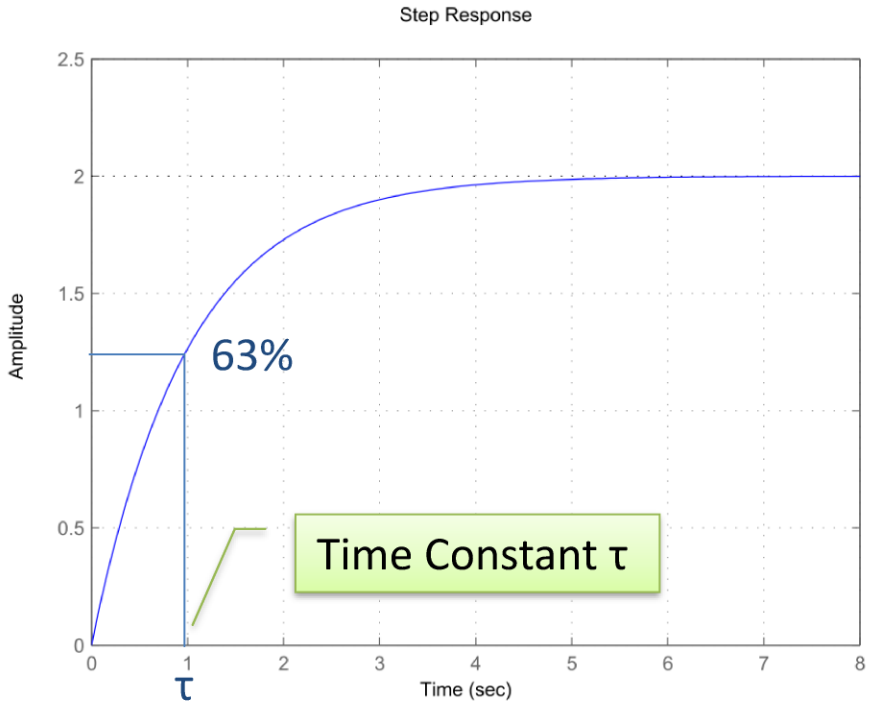
High Precision
High Accuracy

Instruments (9)

- Dynamic Characteristics
  - Measured quantity changes
  - Instrument tries to follow
  - Time needed to attain a steady value
    - Energy stored in instrument
      - Load of capacitor
      - Tension of a string
      - Heat capacity of a sensor
    - Energy has to resettle

Instruments (10)

- Dynamic Characteristics (continued)
  - First order instruments



Charging Curve of a Capacitor

$$V_c = \left(1 - e^{-\frac{t}{R \cdot C}}\right) \cdot V$$

$$V_c = \left(1 - e^{-\frac{t}{\tau}}\right) \cdot V$$

Time Constant

$$\tau = R \cdot C$$

Charge if $t = \tau$

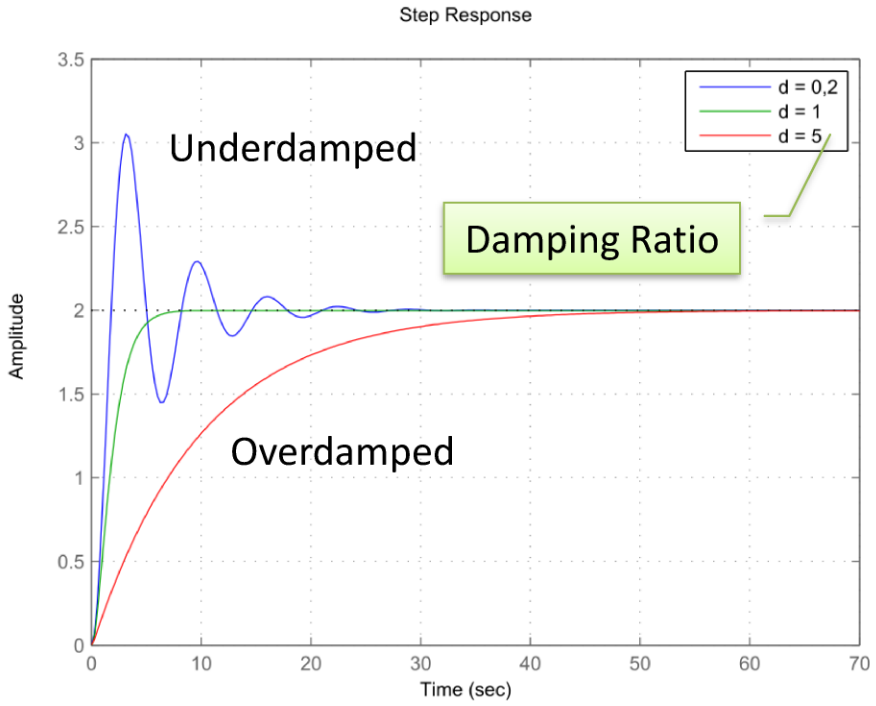
$$V_c = \left(1 - e^{-\frac{\tau}{\tau}}\right) \cdot V$$

$$\frac{V_c}{V} = 1 - e^{-1}$$

$$\frac{V_c}{V} = 0.632 \ldots$$

Instruments (11)

- Dynamic Characteristics (finished)
  - Second order instruments



Damping

Decay of oscillations

Damping Ratio

Describes damping

- $\zeta = 0$: Undamped
  Oscillates for ever
- $\zeta < 1$: Underdamped
  Oscillations decay
- $\zeta = 1$: Critically damped
  Edge case (desired)
- $\zeta > 1$: Overdamped
  No oscillations

Selection (1)

- Selection Criteria
  - Instrument Characteristics
    - Accuracy
    - Resolution
    - Sensitivity
    - Durability
    - Dynamic Behavior
      - Speed of measurement

Selection (2)

- Selection Criteria
  - Operating Conditions
    - Ambient Temperature
    - Exposure of Radiation
    - Mechanical Stress
    - Humidity
    - Vandalism
    - Interfaces

Selection (3)

- Selection Criteria
  - Costs
    - Purchasing Costs
    - Maintenance Costs
    - Cost per Year
      - $Cost_{Year} = \frac{Cost_{Purchase} + Cost_{Maitenance}}{Expected\ Live\ Time}$
- Rule of Thumb
  - Select the minimum characteristics necessary

Addendum

- Further Information
  - [BRI13] Ch. 8 Messtechnik
- Bibliography
  - [BRI13]: BRIEGLER, ADOLF and others, 2013, Elektrotechnik Fachkunde 1. Wien : Jugend & Volk. ISBN 978-3-7100-2911-0.