Lecture 1 Instrument and Measurement Systems

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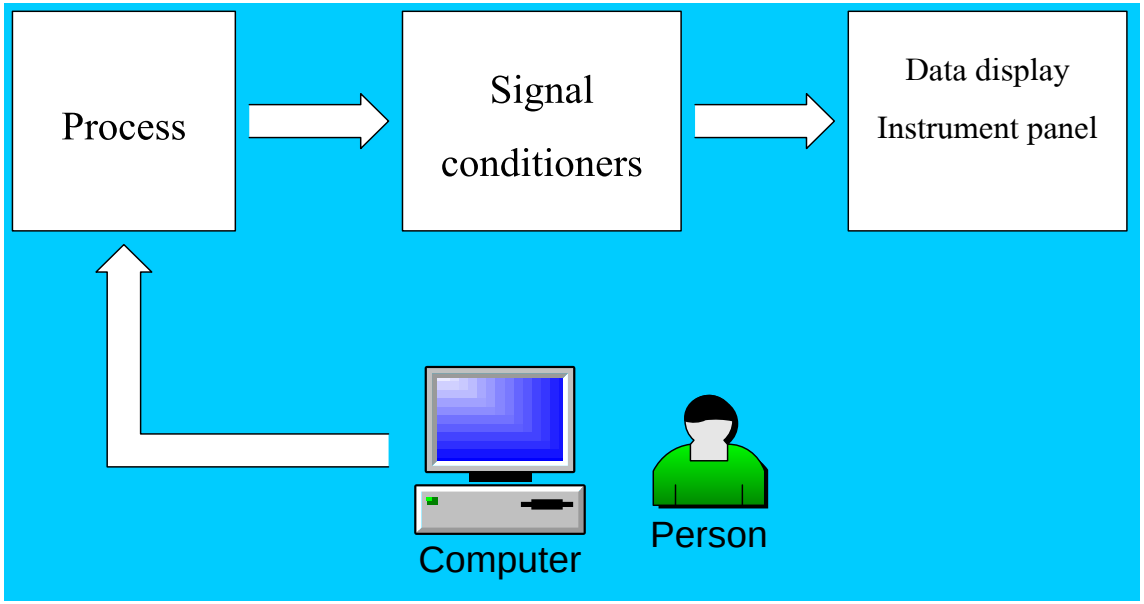
Introduction

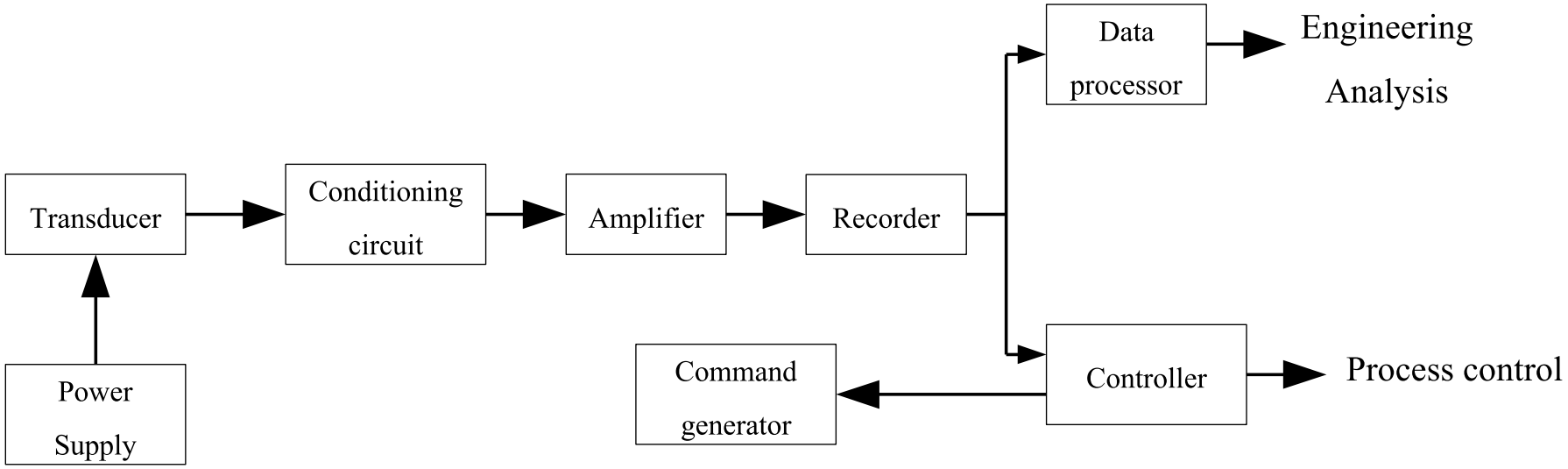
- Overview of Instrument and Measurement system
- Analog and digital instrument
- Measurement
  - Low voltage
  - High voltage
- Sensor and transducer

1. Process control system



ภาพที่ 1.1 Process control system

2. Electronic Instrument system



ภาพที่ 1.2 Electronic Instrument system in industrial

Analog and digital instrument

- Permanent-magnet Moving-Coil (PMMC)
- Analog multimeter
- Digital multimeter
- Watt hour meter
- Display Indicator
- Moisture meter

Multimeter

- Voltmeter
- Amp meter
- Ohmmeter
- Capacitance meter
- Inductance meter

ภาพที่ 1.3 analog and digital instrument

Multimeter

ภาพที่ 1.4 Analog high amp meter

ภาพที่ 1.5 Analog high amp meter

RPM meter

ภาพที่ 1.6 RPM meter application

- RPM meter in car
- PRM meter for speeded car

Mega Ohmmeter

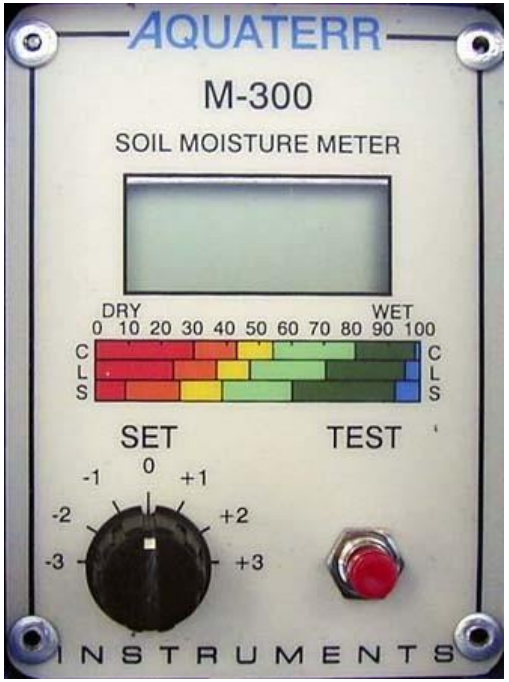
- Measure material high ohm
- Correct amp technics

ภาพที่ 1.7 แสดงตัวอย่าง Mega Ohmmeter

Moisture meter

ภาพที่ 1.8 แสดงตัวอย่าง Moisture meter

Moisture meter



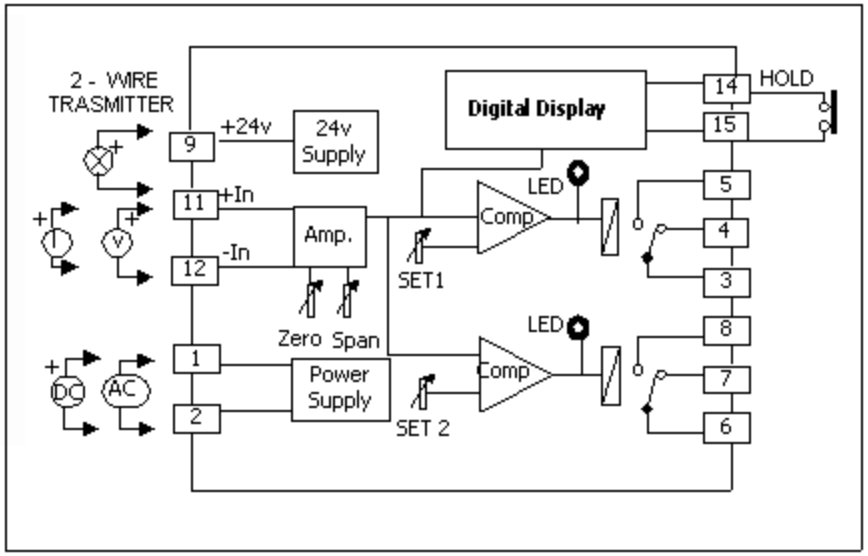
ภาพที่ 1.9 แสดงตัวอย่าง Moisture meter

Watt hour meter

ภาพที่ 1.10 แสดงตัวอย่าง Watt hour meter

- Watt hour meter
- Digital display

Display indicator



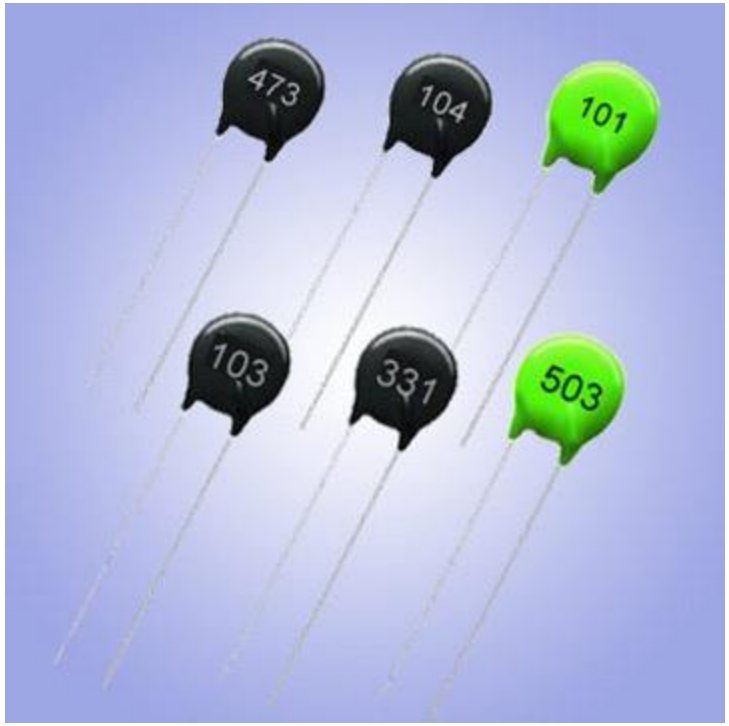
ภาพที่ 1.11 แสดงตัวอย่าง Display indicator

ภาพที่ 1.12 แสดง diagram Display indicator

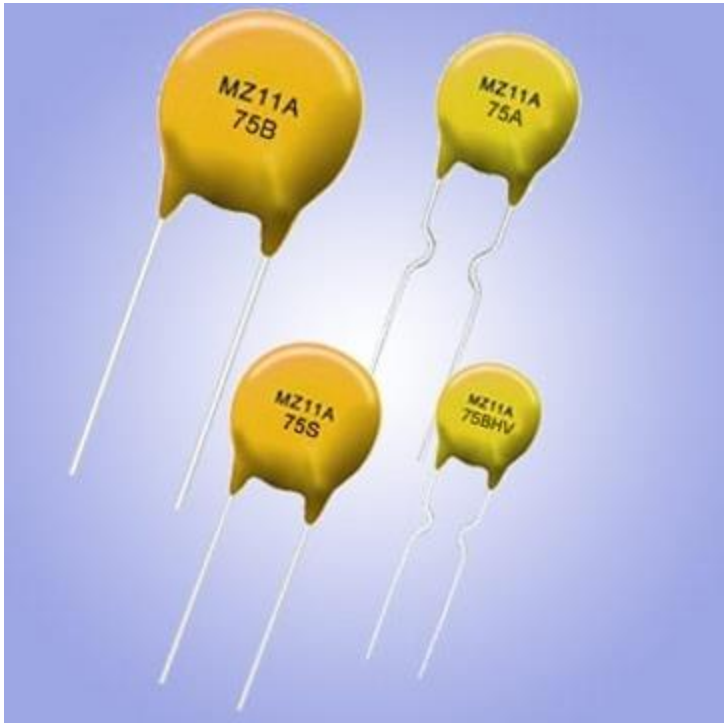
Sensor and Transducer

- Temperature to current conversion
- Temperature to voltage conversion
- Temperature relation resistance

Temperature relation resistance



ภาพที่ 1.13 NTC



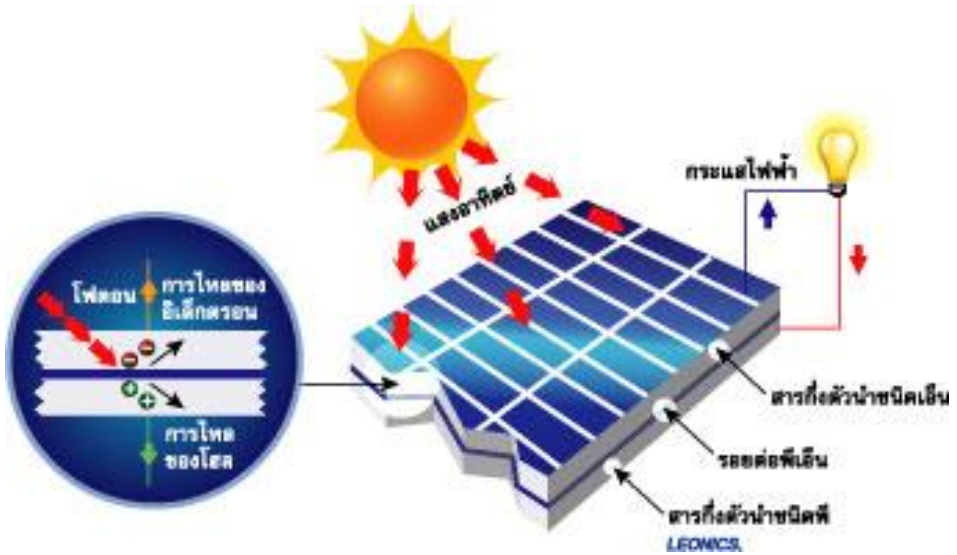
ภาพที่ 1.14 PTC

RTD and Thermocouple

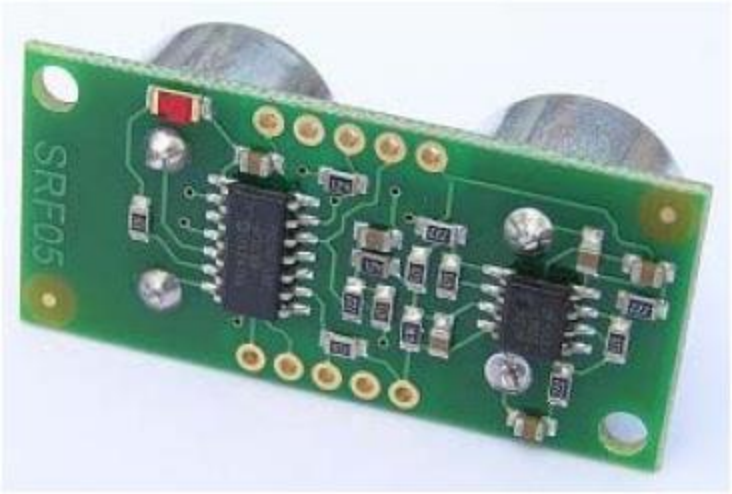
ภาพที่ 1.15 RTD

ภาพที่ 1.16 Thermocouple

PHOTOVOLTAIC or SOLAR CELLS

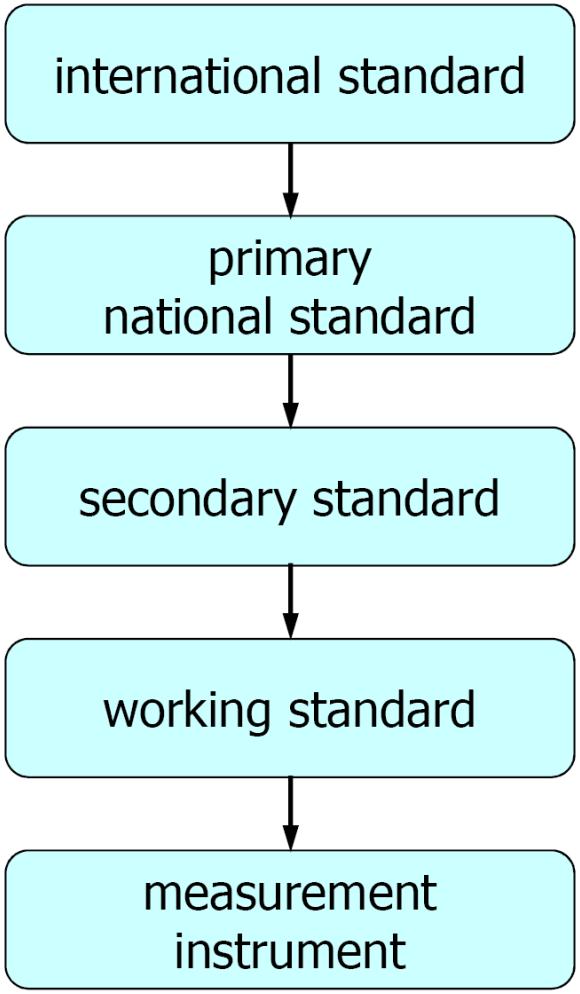


ภาพที่ 1.17 Photovoltaic or Solar cell


SRF05

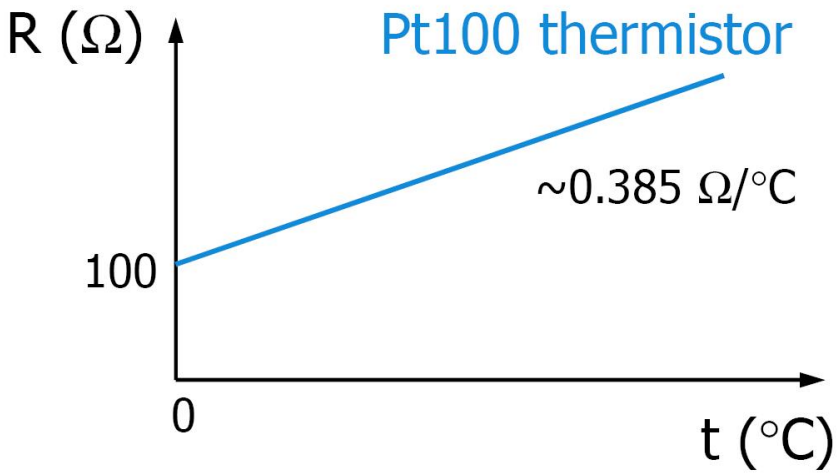
Calibration

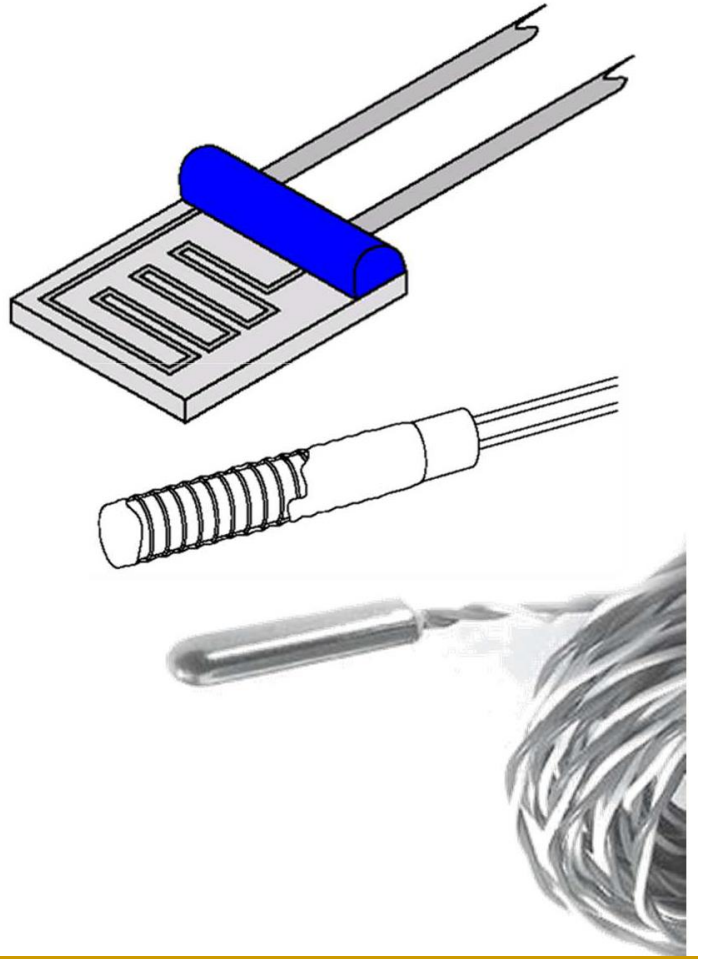
- **Calibration** makes a connection between
  - measurement values produced by a measurement instrument
  - corresponding values realized by standards
- **Calibration procedure**: comparison of an instrument with a (more accurate) measurement standard
- Calibration enables measurements which are **traceable** to standards
  - through an unbroken chain of comparisons
  - with associated specified uncertainties !



Example: calibration of a platinum thermometer

- PRT: platinum resistance thermometer
- typical **transfer**:

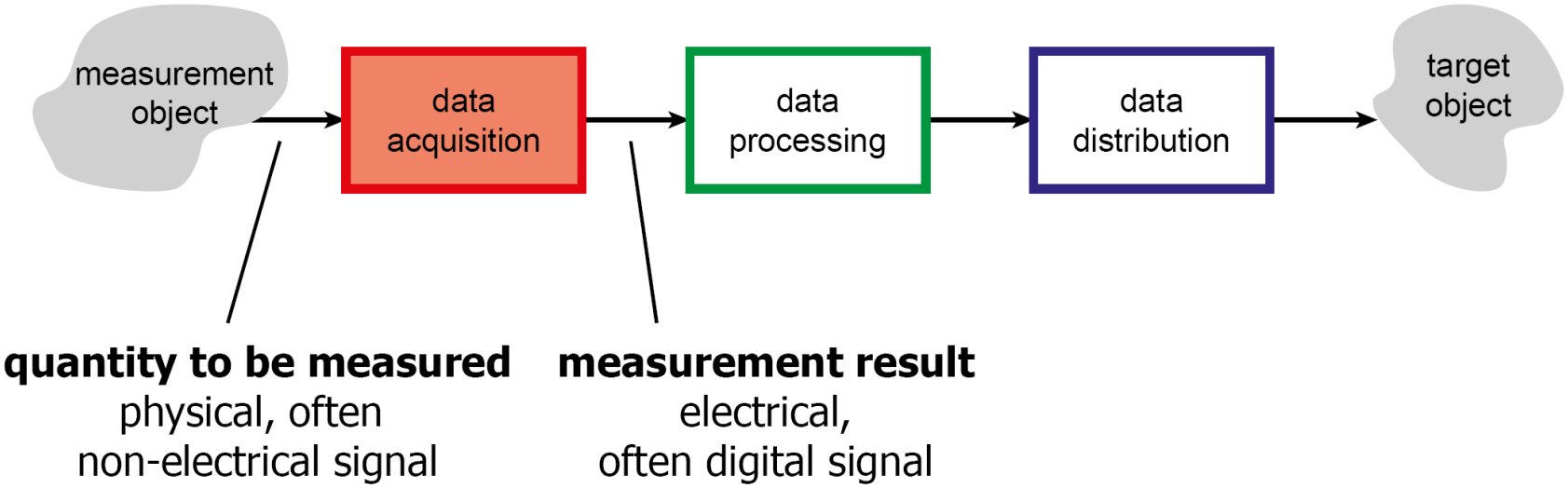




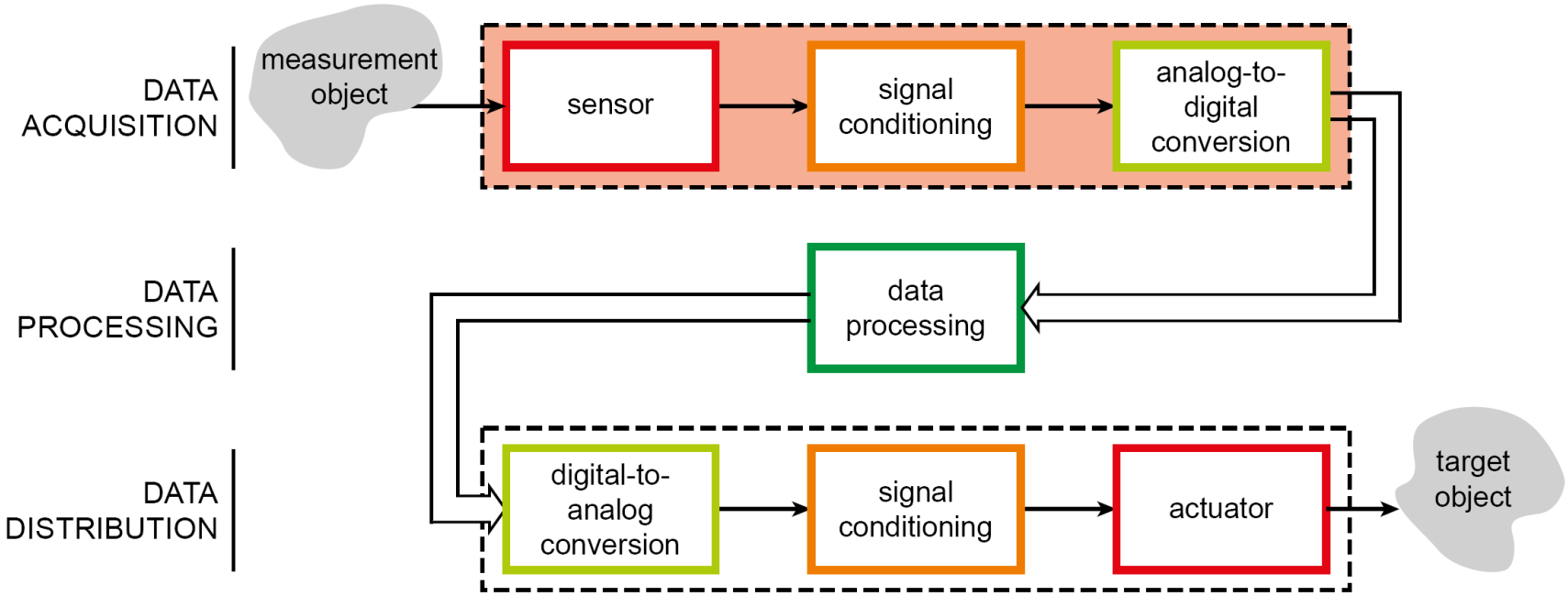
Example: calibration of a platinum thermometer

- Calibration procedure:
  - comparison to a more accurate reference thermometer (the working standard) at various calibration temperatures
    $\Rightarrow$ list of measured temperatures and resistance values with measurement uncertainty
  - determination of the coefficients of a formula that relates measured resistance to temperature
    $\Rightarrow R(t) = R_0 \, (\, 1 + A \cdot t + B \cdot t^2 \,)$
  - determination of the corresponding measurement uncertainty
- Next, when using the thermometer, this formula will be used to translate a measured resistance into temperature

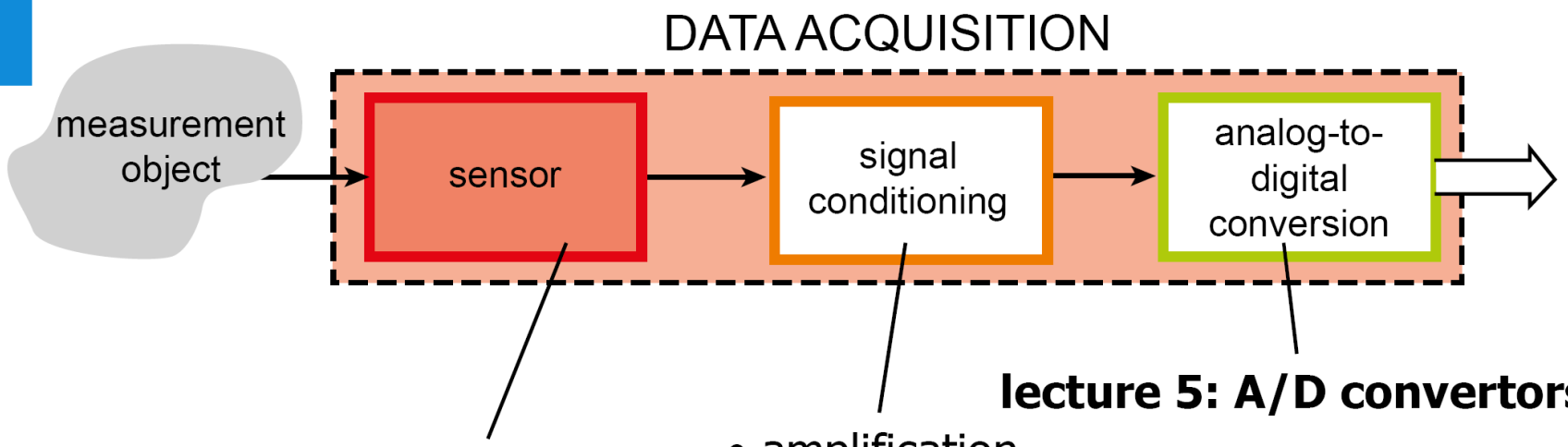
Structure of a measurement system



Structure of a measurement system



Structure of a measurement system



transduction of information from a (non-electrical) domain to the electrical domain

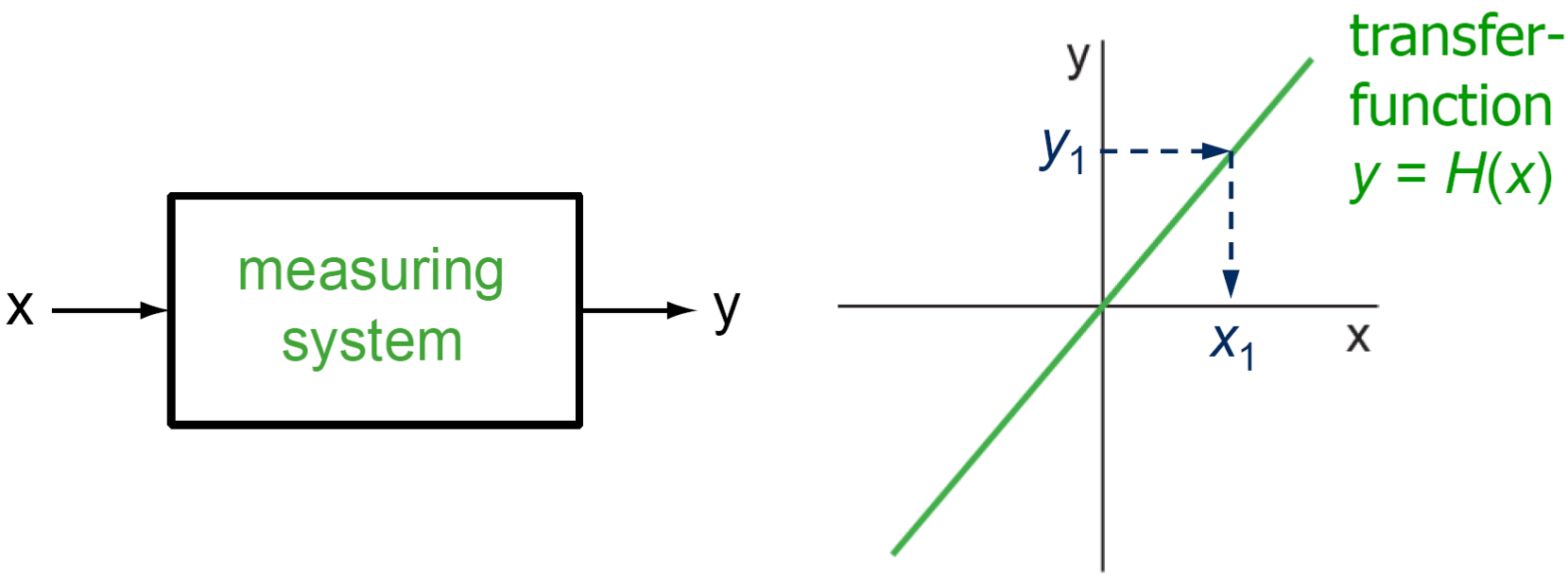
lecture 2: sensors

- amplification
- buffering (impedance transformation)
- filtering
- signal conversion (e.g. R $\rightarrow$ V)

lecture 3/4: sensor readout & instrumentation amplifiers

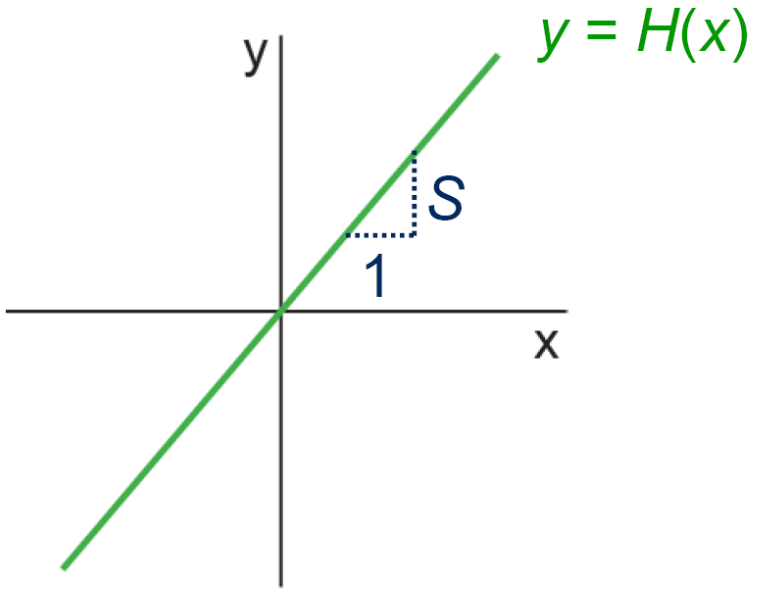
lecture 5: A/D convertors

Transfer of a measurement system



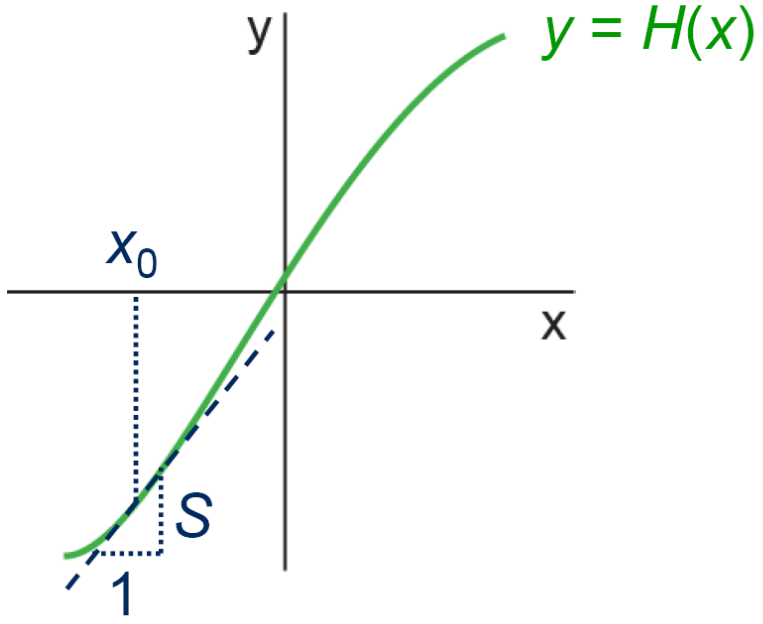
- Using the transfer function H, output signal (indication) y_1 can be translated back to a measurement value x_1

Sensitivity



- **Sensitivity**: $S = \Delta y / \Delta x$
- Ideal linear transfer: sensitivity $S = y / x$

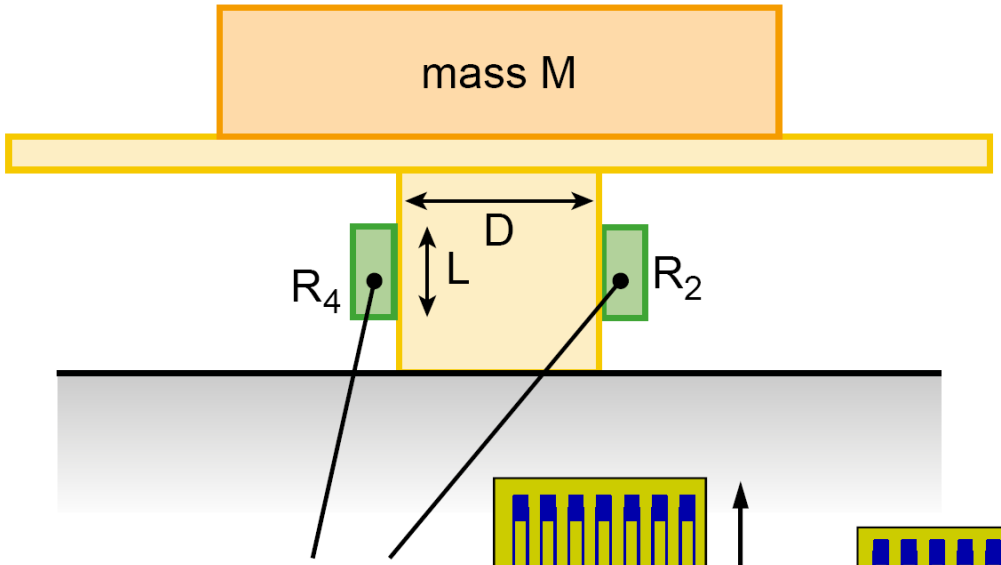
Differential Sensitivity



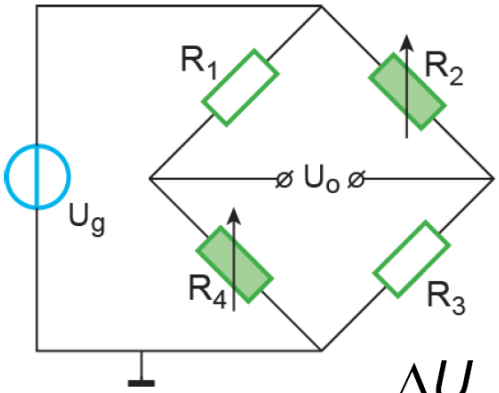
- Non-linear transfer
  ⇒ **differential** sensitivity round x_0:

$$S = \left.\frac{dy}{dx}\right|_{x=x_0} = H'(x_0)$$

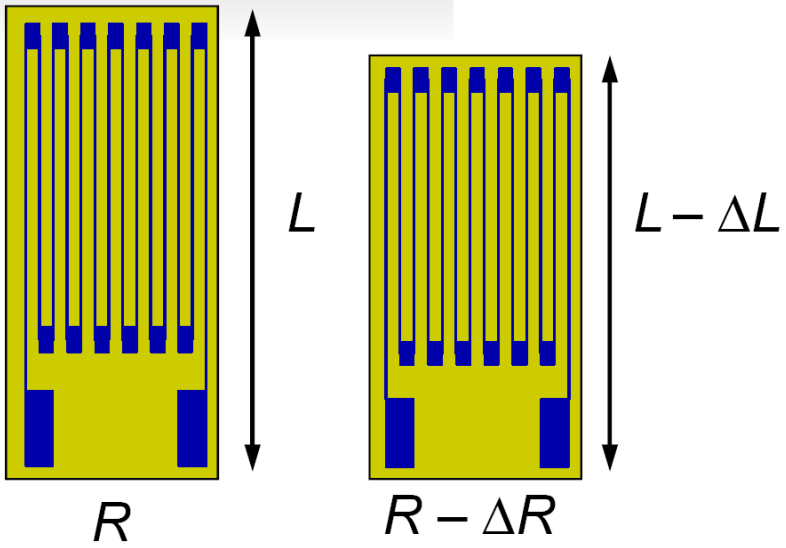
Sensitivity example: weighing scale



Strain gauges



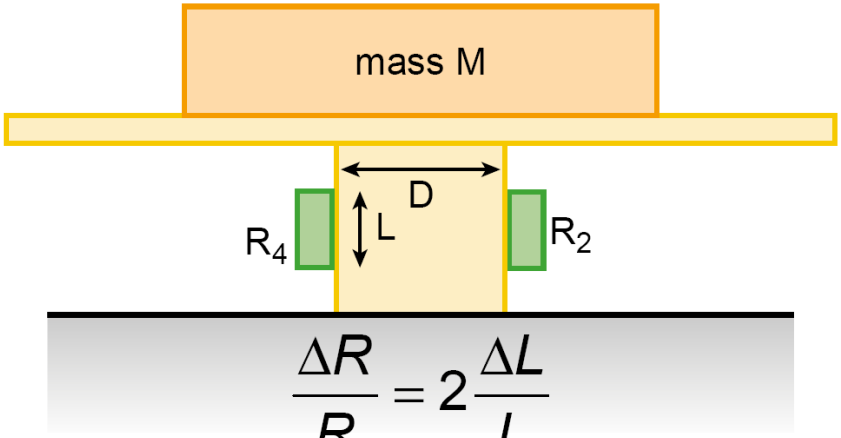
$$\Delta U_o \cong \frac{\Delta R}{2R} U_g$$



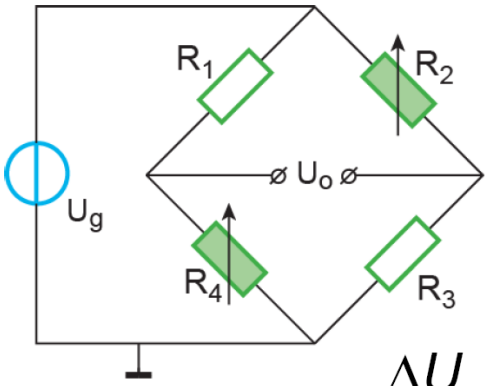
$$\frac{\Delta R}{R} = k \frac{\Delta L}{L}$$

gauge factor k
= 2 for metals

Sensitivity example: weighing scale



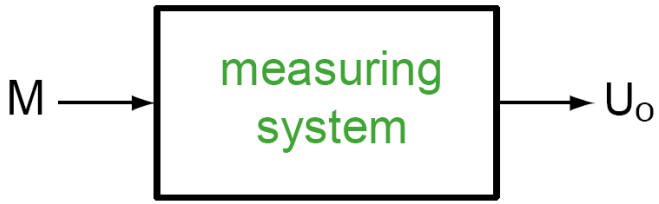
$$\frac{\Delta R}{R} = 2\frac{\Delta L}{L}$$



$$\Delta U_o \cong \frac{\Delta R}{2R} U_g$$

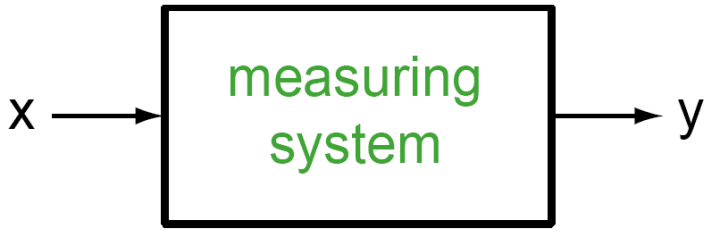
Given: the source voltage $U_g = 10\ \mathrm{V}$
the relative sensitivity of the length change is

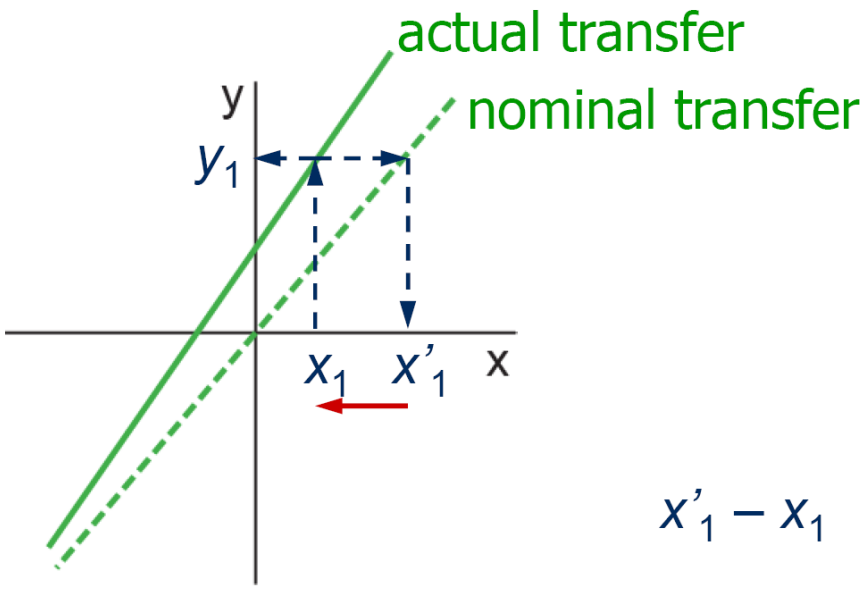
$$\frac{\Delta L / L}{\Delta M} = 6.2 \cdot 10^{-7}\ \mathrm{kg}^{-1}$$



Determine the sensitivity $S = \Delta U_o / \Delta M$ [V/kg] of the measurement system

Measurement errors due to deviations in the transfer





x_1 actual value of quantity to be measured

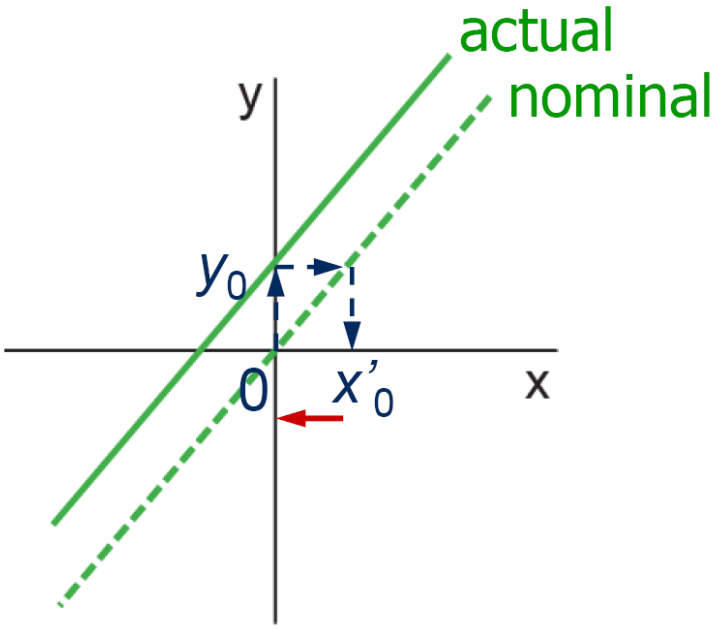
y_1 output signal of measurement system

x'_1 measured value determined based on nominal transfer

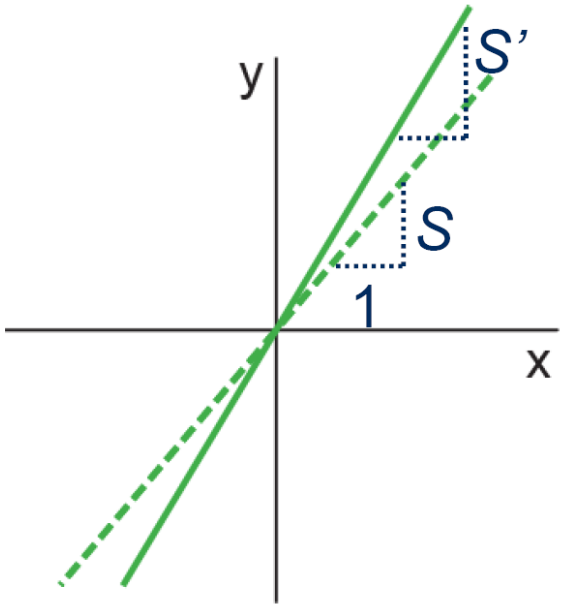
$x'_1 - x_1$ **measurement error**

Deviation in linear transfer

Offset error

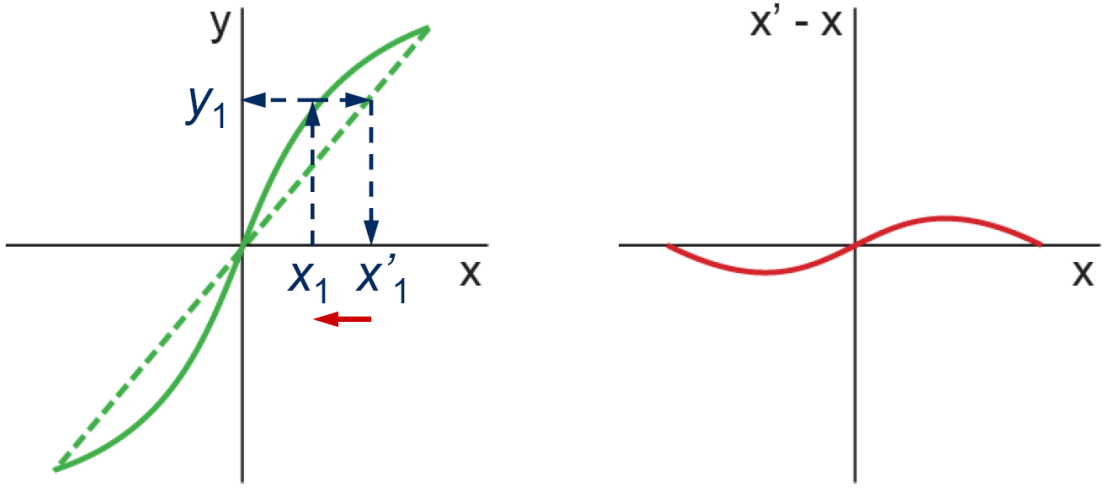


Gain error (sensitivity error)



Non-linearity

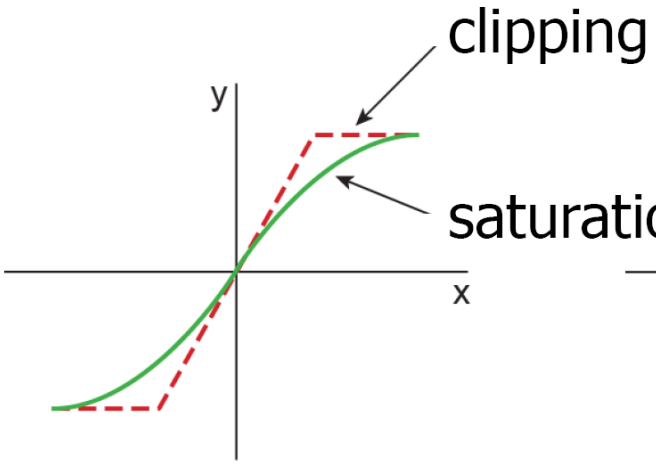
- A non-linear transfer will give measurement errors if the nominal transfer is assumed to be linear
- Integral non-linearity:



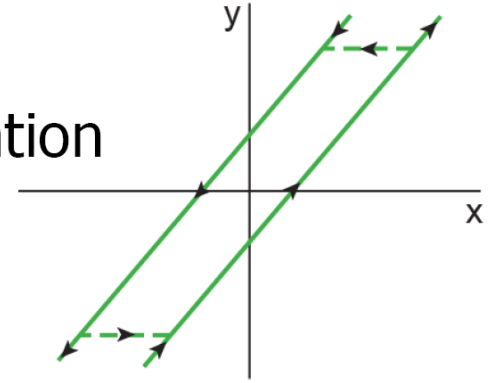
Ambiguity

- No one-to-one relation between the quantity to be measured x and the output signal y

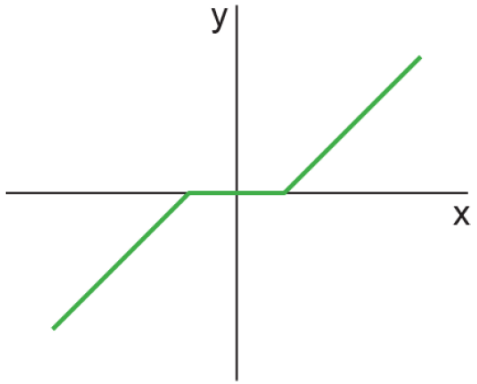
saturation



hysteresis



dead zone



Ambiguity

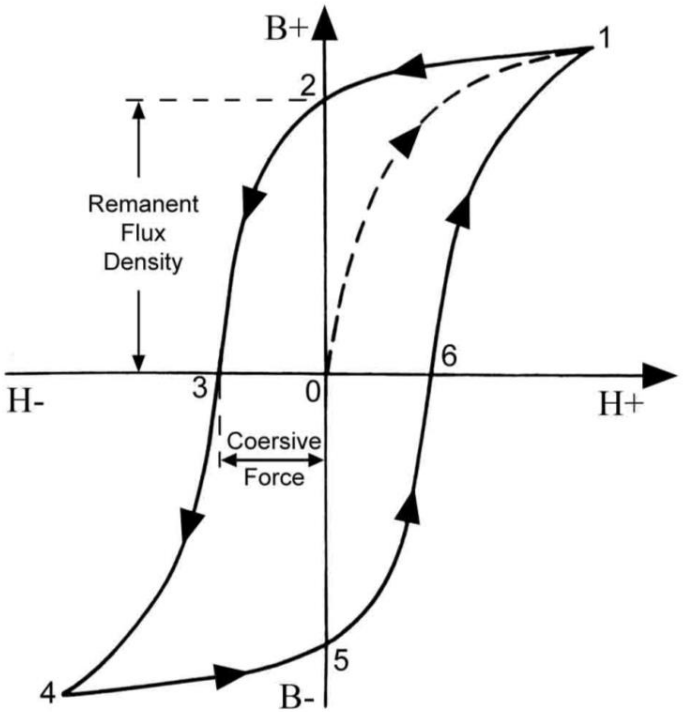
saturation
hysteresis
dead zone

- Moving coil meter with friction

Ambiguity

saturation
hysteresis
dead zone

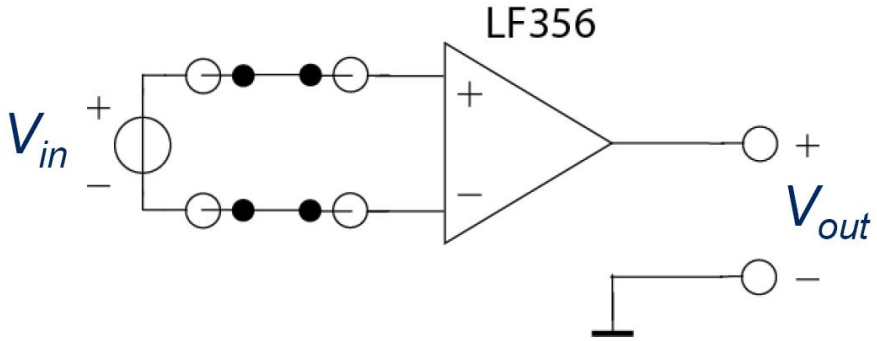
- Magnetisation of a ferromagnetic core



Ambiguity

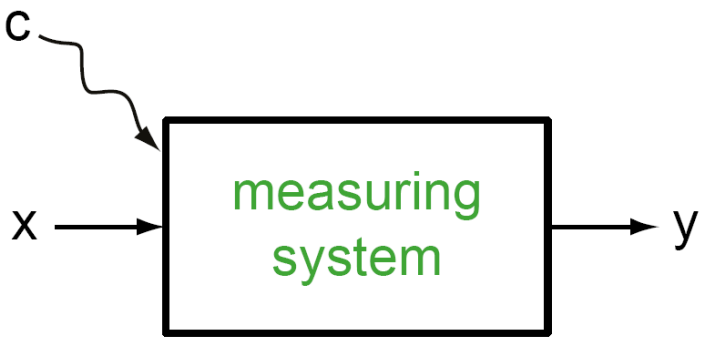
saturation
hysteresis
dead zone

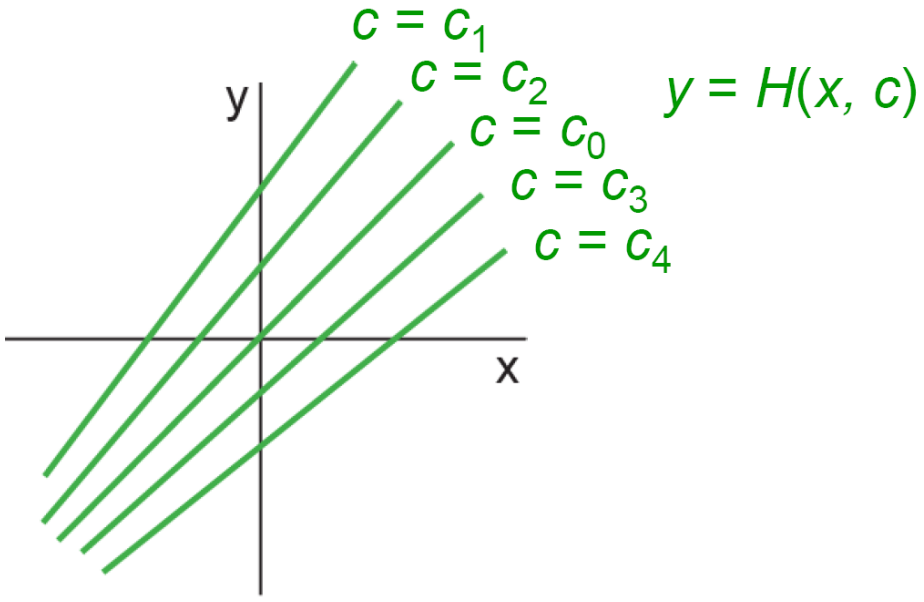
- Opamp



Cross-sensitivity

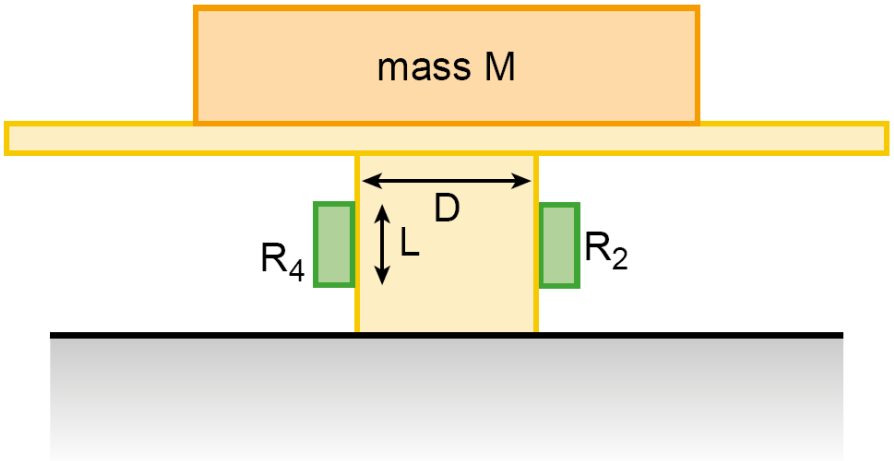
- Unwanted sensitivity to an **influence quantity** *c*

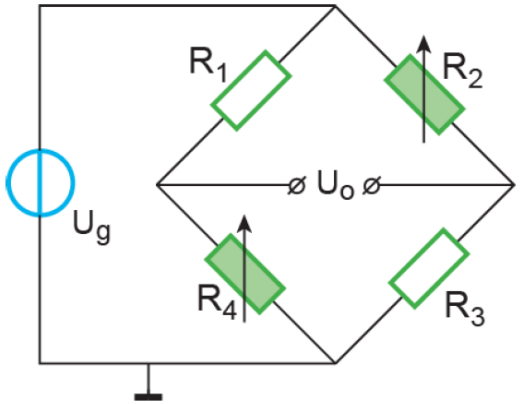




- Ideally: $S_c^y = 0$

Cross-sensitivity ex.: weighing scale

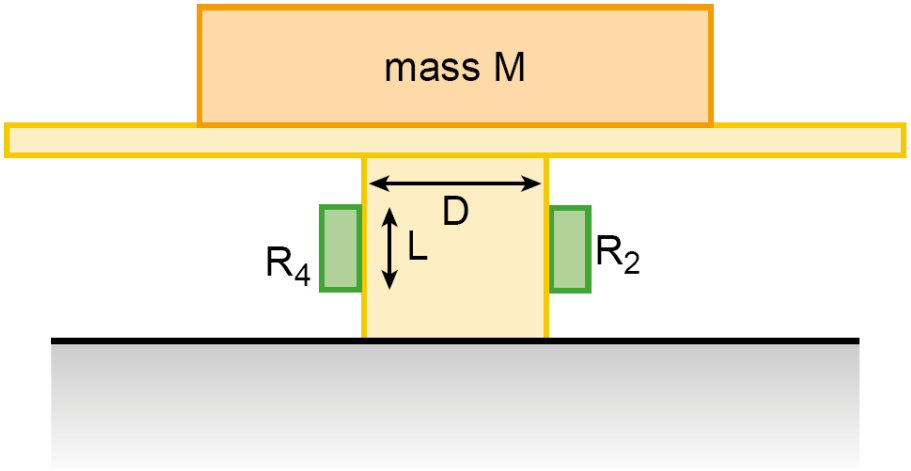


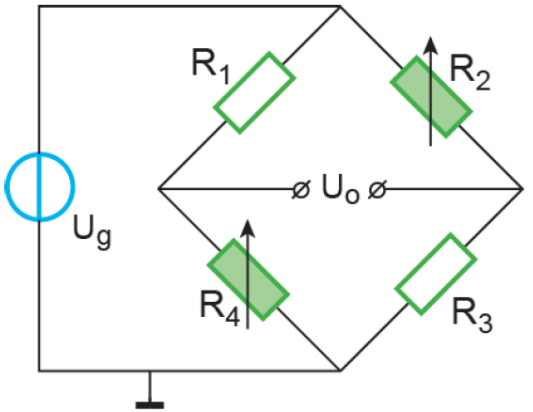


temperature-difference ΔT → resistance change $\Delta R/R$ → output voltage ΔU_o

- Temperature sensitivity resistors typically expressed as temperature coefficient: $\alpha = \frac{1}{R} \cdot \frac{dR}{dT}$ [K^{-1}] $\Rightarrow \frac{\Delta R}{R} = \alpha \cdot \Delta T$

Cross-sensitivity ex.: weighing scale



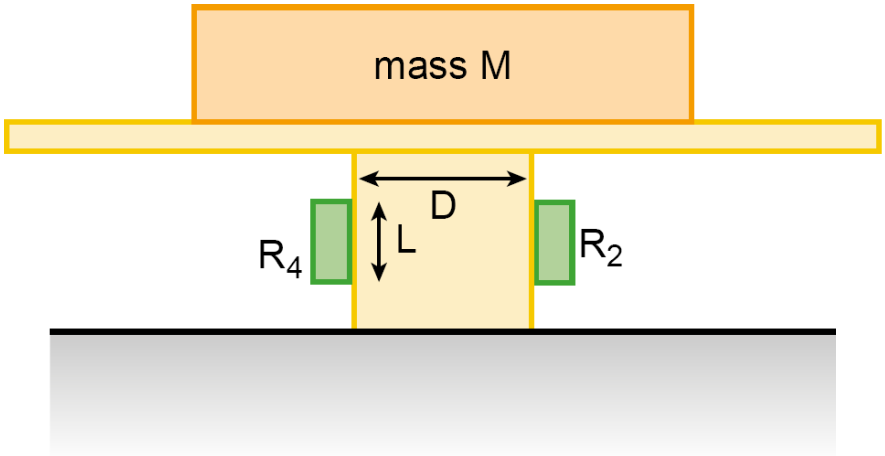


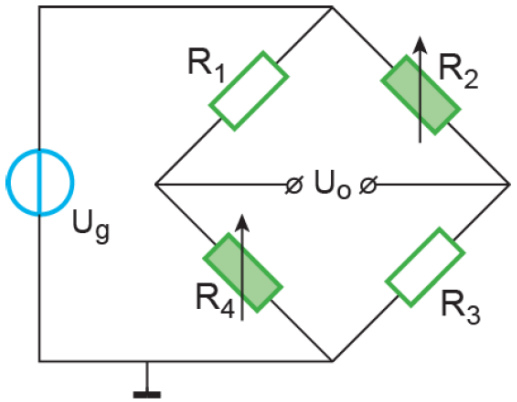
temperature-difference ΔT → resistance change $\Delta R/R$ → output voltage ΔU_o

$$\frac{\Delta R}{R} = \alpha \cdot \Delta T \qquad \Delta U_o \cong \frac{\Delta R}{2R} U_g$$

- Cross sensitivity: $S_{temp} = \frac{\Delta U_o}{\Delta T} = \frac{\alpha \cdot U_g}{2}$

Cross-sensitivity ex.: weighing scale



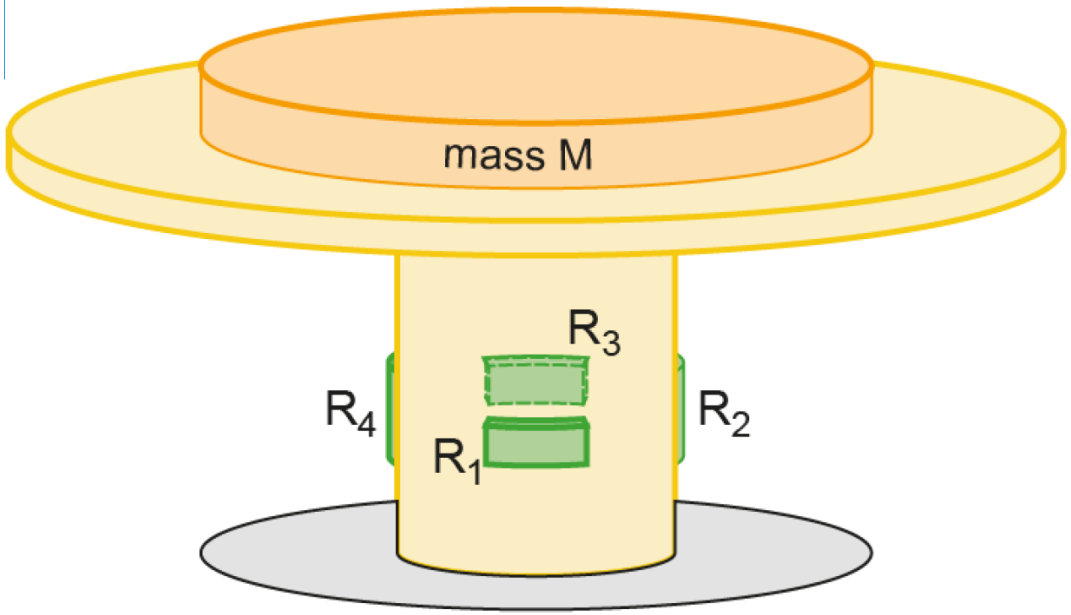


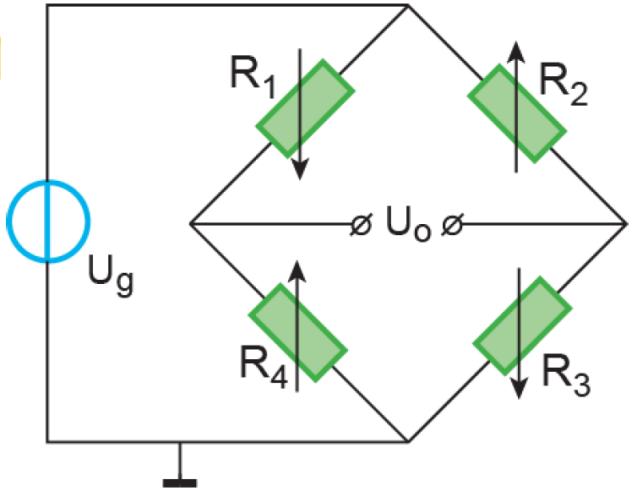
- Cross-sensitivity: $S_{temp} = \frac{\Delta U_o}{\Delta T} = \frac{\alpha \cdot U_g}{2}$

- Let: $\alpha = 2{,}0 \cdot 10^{-5}\,\mathrm{K}^{-1}$, $U_g = 10\,\mathrm{V} \Rightarrow S_{temp} = 0{,}10\,\mathrm{mV/K}$
- Compare to earlier found $S_{massa} = 6{,}2\ \mu\mathrm{V / kg}$

} error: 16 kg / K !!

Cross-sensitivity ex.: weighing scale





- **Compensation** for temperature differences:
  4 strain gauges mounted to the base ⇒ small ΔT

Measurement errors due to aging

- Measurement systems change over time
  ⇒ uncertainty increases
  ⇒ frequent calibration is needed

Accuracy Specifications ± (% of reading + % of range)

Function	Range[3]	24 Hour[2] 23°C ±1°C	90 Day 23°C ±5°C	1 Year 23°C ±5°C
DC voltage	100.0000 mV	0.0030 + 0.0030	0.0040 + 0.0035	0.0050 + 0.0035
	1.000000 V	0.0020 + 0.0006	0.0030 + 0.0007	0.0040 + 0.0007
	10.00000 V	**0.0015 + 0.0004**	**0.0020 + 0.0005**	**0.0035 + 0.0005**
	100.0000 V	0.0020 + 0.0006	0.0035 + 0.0006	0.0045 + 0.0006
	1000.000 V	0.0020 + 0.0006	0.0035 + 0.0010	0.0045 + 0.0010

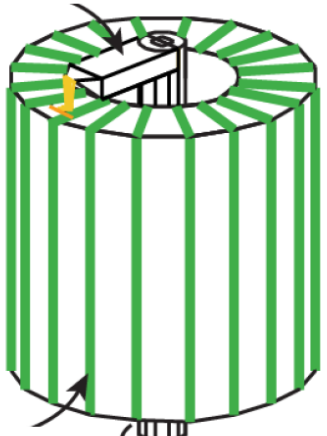
Resolution

- **Resolution:** smallest change in x that causes a noticeable change in y
- Expressed in two ways:
  - absolute: Δx
  - relative to the full scale: $\Delta x / x_{max}$
    often in bits: $- {}^2\log (\Delta x / x_{max})$
- Example: 4½-digit display, 200V range
  - $\Delta x = 0.01\,\text{V}$
  - $\Delta x / x_{max} = 0.01\,\text{V} / 199.99\,\text{V} = 5 \cdot 10^{-5}$
    in bits: $- {}^2\log (5 \cdot 10^{-5}) = 14.3$ bits

Resolution examples

- Resolution determined by sensor: wirewound potentiometer

sliding contact (wiper)

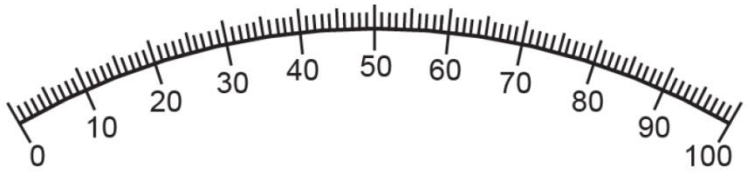


winding

1000 windings

Resolution examples

- Resolution determined by display:



Summary

- Measuring = determining the value of a quantity
  - measurement requires international standards
  - calibration is needed for traceable, comparable measurements
  - every measurement is subject to measurement uncertainty

- Measurement system: converts quantity to be measured x into usable output signal y (often electrical, digital)
  - Data acquisition: $x \rightarrow$ sensor $\rightarrow$ signal conditioning $\rightarrow$ ADC $\rightarrow y$
  - Characterized by transfer $y = H(x)$ with sensitivity $H'(x)$
  - Deviations in the transfer can lead to measurement errors: non-linearity, ambiguity, cross sensitivity, finite resolution

Thank you