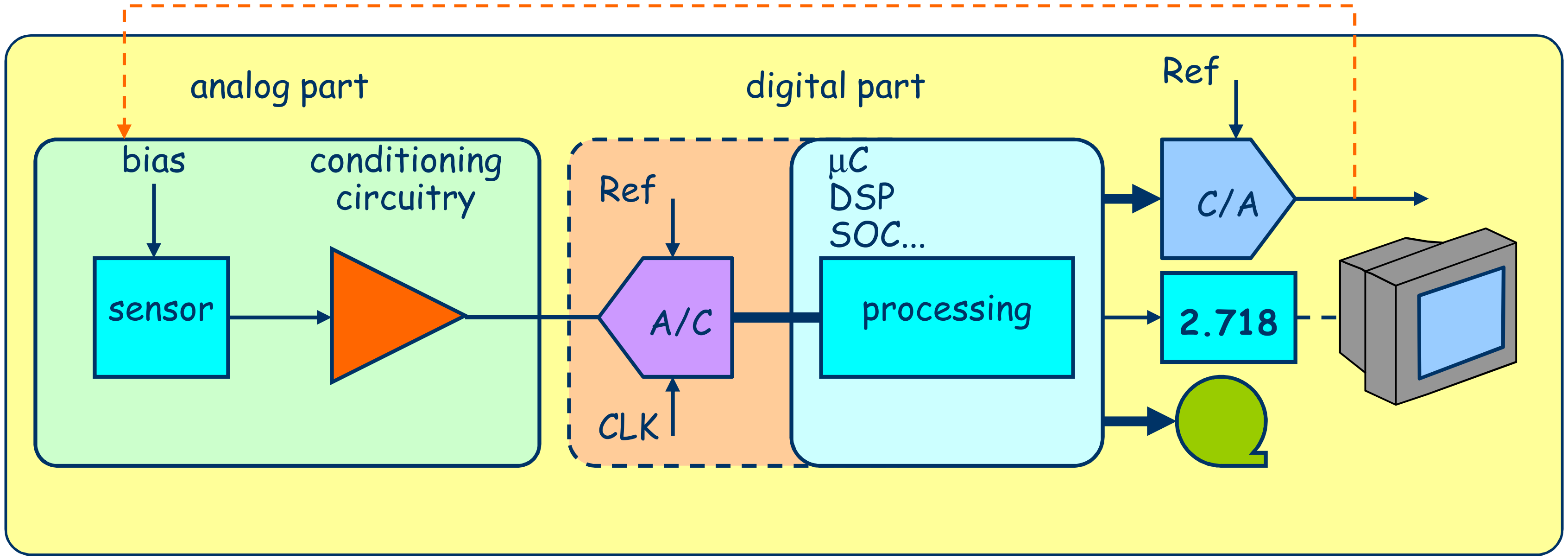
Measurement of non-electrical quantities

Measurement chain



Sensor

a converter that measures a physical quantity, converting it into a signal convenient for an observer or some data acquisition system.

Transducer

a device, converting one form of energy (eg. mechanical, thermal, electromagnetic etc.) into other form (often of electrical nature), convenient for transmission, presentation or processing.

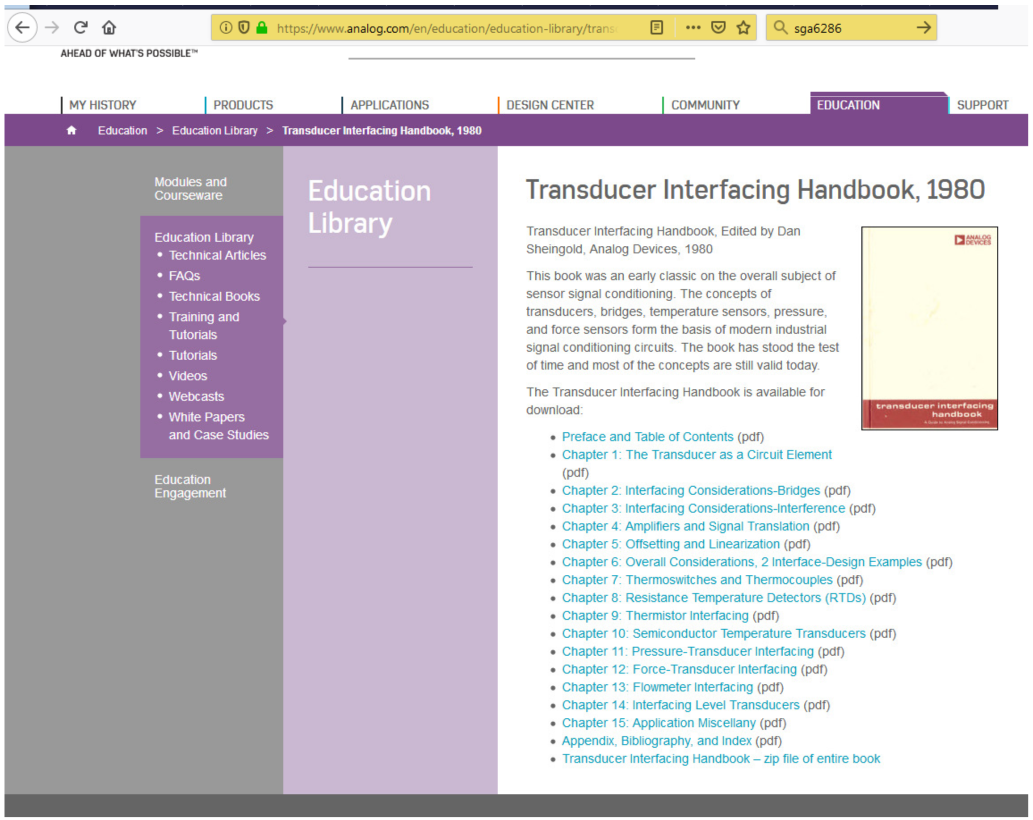
Which quantities can be measured...

...almost all

- temperature (thermistor, termocouple)
- force, tention (tensometer)
- pressure (tensometer transducer)
- displacement (potentiometer, LVDT transformer)
- flow of substance (anemometer)
- speed, speed of rotation (gyroscope)
- acceleration
- distance
- vibrations (piezoelectric effect)
- humidity
- chemical composition
- time
- ....

- ECG signals
- HRM
- gesture, position
- smoke/particles detections ...

https://www.analog.com/en/education/education-library/transducer-interfacing-handbook.html



Strain gauge (gage), tensometer

$$R = \frac{\rho \cdot l}{S}$$

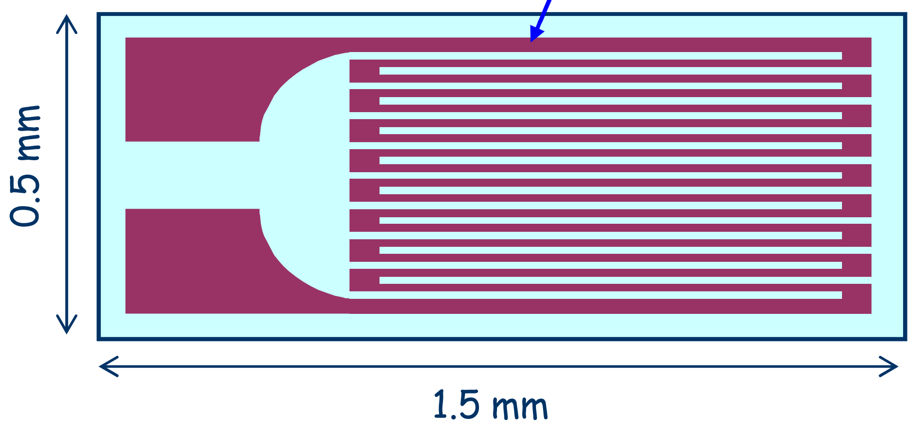
$$\Delta R = \frac{\partial R}{\partial l}\Delta l + \frac{\partial R}{\partial S}\Delta S + \frac{\partial R}{\partial \rho}\Delta \rho$$

$$\frac{\Delta R}{R} = G_f \frac{\Delta l}{l}$$

Practical realisation

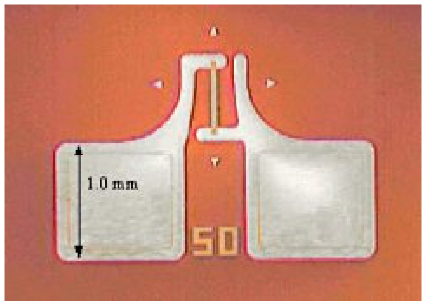
foil strain gauge

foil ~5µm
Cu, Ni, Fe, Pt,...



G_f~2

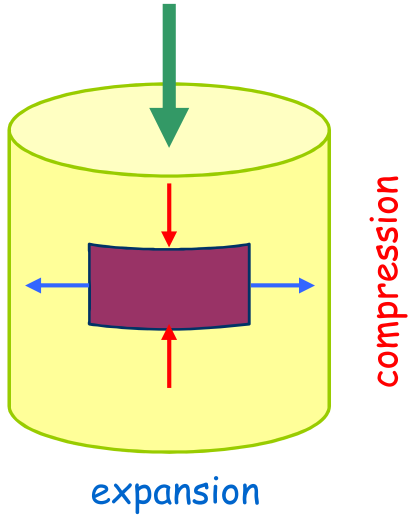
semiconductor strain gauge

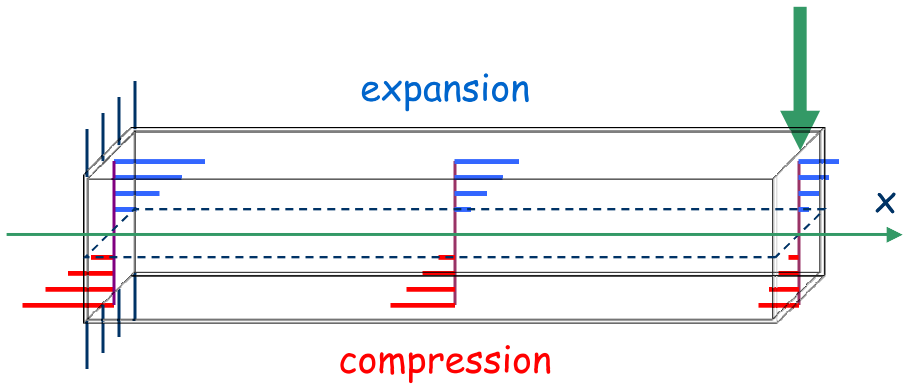


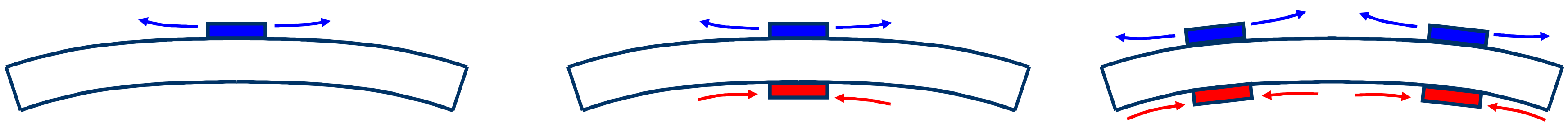
source: sensormag.com

G_f~-100 (Si)

Strain measurement (force, mass, pressure, tension...)



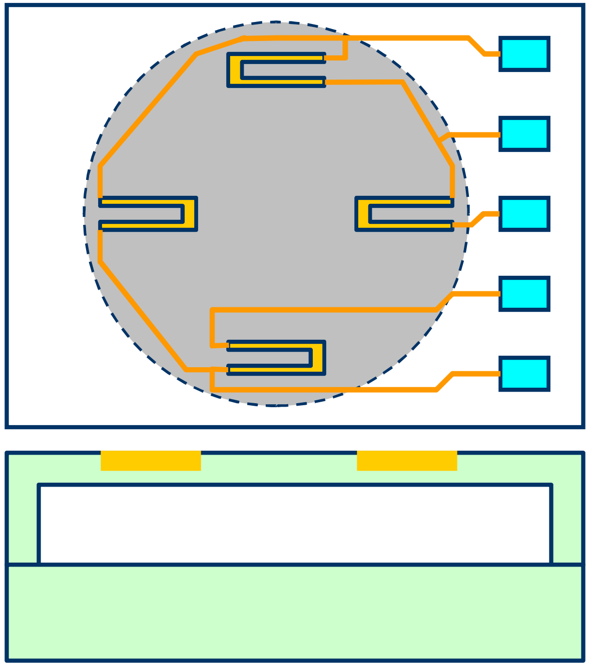


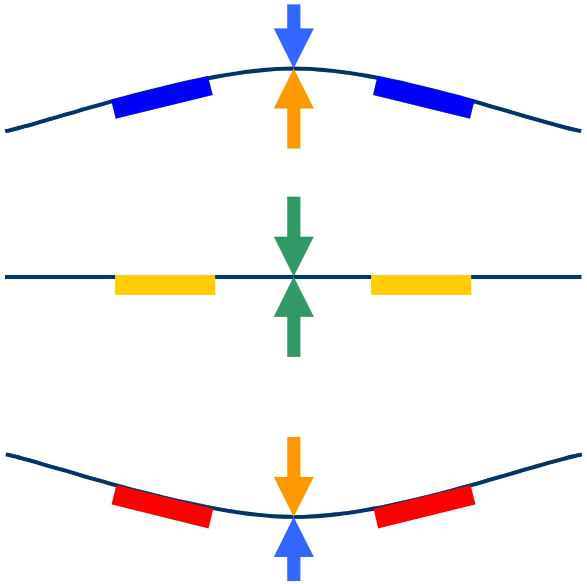


$$\frac{\Delta R}{R} = G_f \frac{\Delta l}{l} \Rightarrow \Delta R = R \cdot G_f \frac{\Delta l}{l}$$

$\Delta l/l \sim 0.4 \div 1\%$
$R = 1\ k\Omega$
$\Delta R \sim 8 \div 20\ \Omega$ (assuming $G_f = 2$)

Pressure transducer



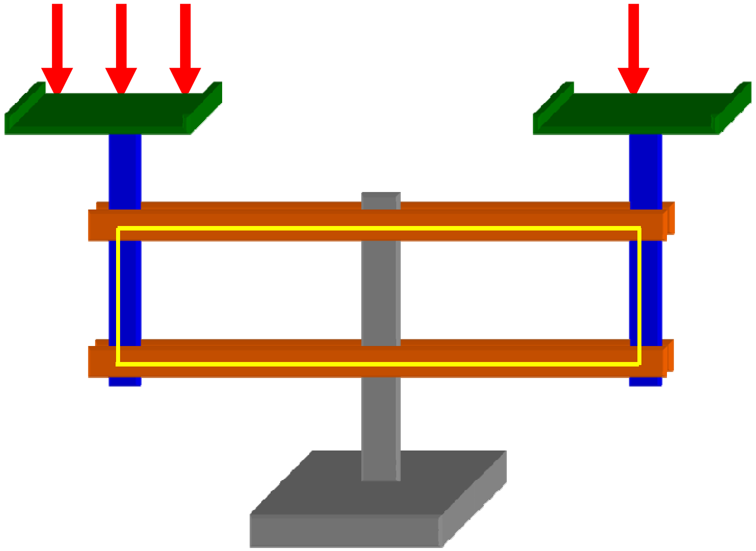


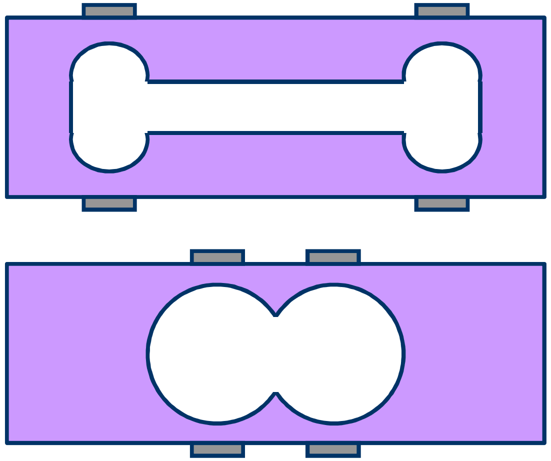
MPX2300 (Freescale)

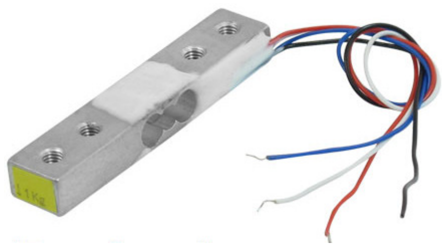
sensitivity 5 μV/V/mmHg
U_{FS} = 3 mV

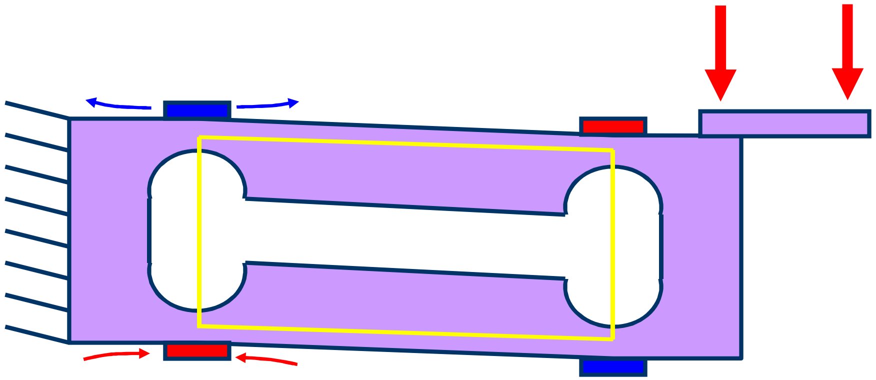
A weighting scale

Roberval mechanism (Gilles Personne de Roberval, 1602–1675)









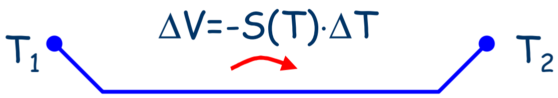
sensitivity 0.5 - 1 mV/V/FL (full load)

FL: ranges from grams to tons

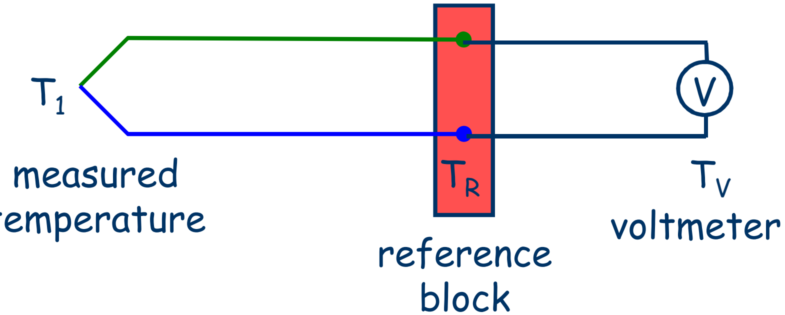
Temperature measurement

Thermocouple – thermoelectric effect

Seebeck effect (Thomas J. Seebeck, 1821)

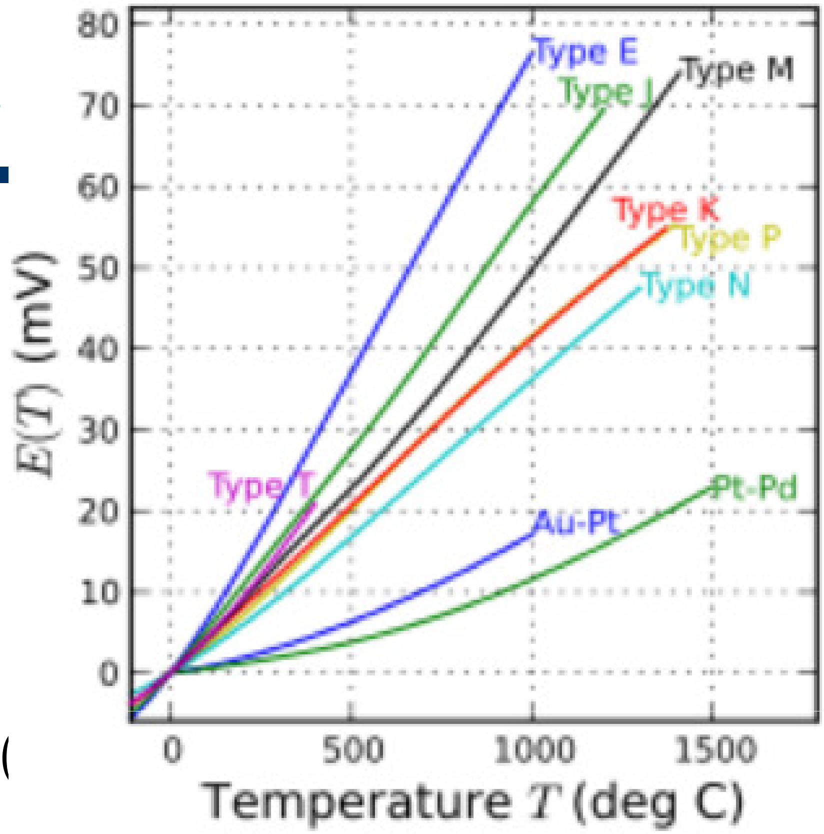


Standard measurement setup



$$V_T = \int_{T_R}^{T_1} (S_A($$

$$= E(T_1) - E(T_R)$$



Possible solutions

- cold junction, aka „ice bath”
- compensated cold junction
- hot junction (rare)

Standard thermocouple junctions

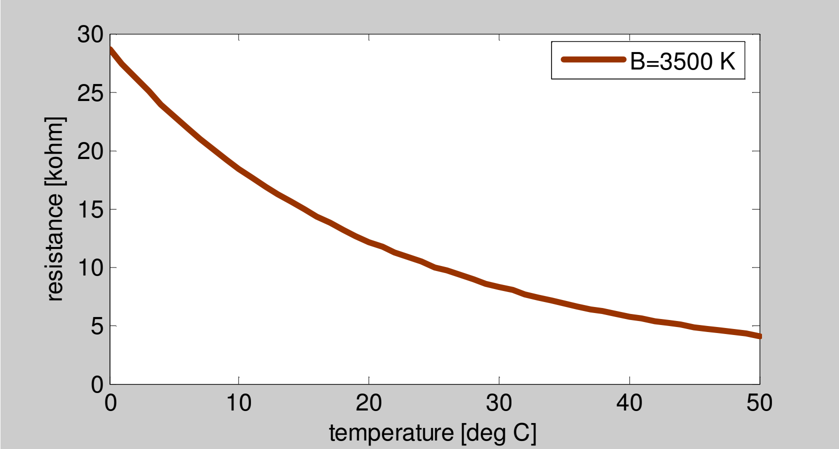
type	junction	range [°C]	sensitivity [µV/ °C]
K	chromel/alumel	-200 ÷ 1200	39
E	chromel/constantan	0 ÷ 900	76
J	iron/constantan	-200 ÷ 760	55
T	copper/constantan	-200 ÷ 400	45

Temperature measurement

Thermistor

Steinhart-Hart equation $$a + b\ln R_T + c(\ln R_T)^3 = T^{-1}$$

For NTC thermistors $$R_T = R_0 \exp\left[B\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

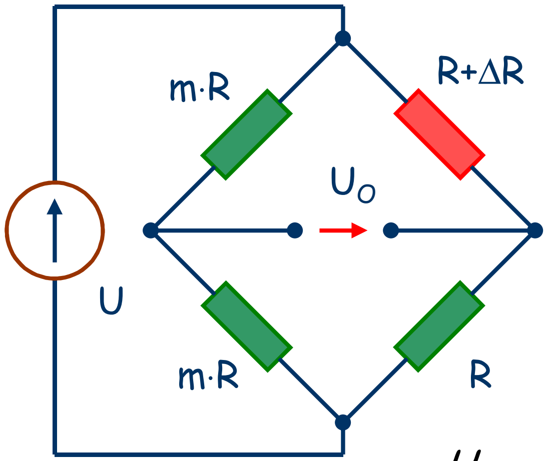
Resistive thermometer detector RTD (William Siemens, 1871)

$$R_T = R_0\left(1 + C_1T + C_2T^2 + C_3T^3 + \ldots\right)$$

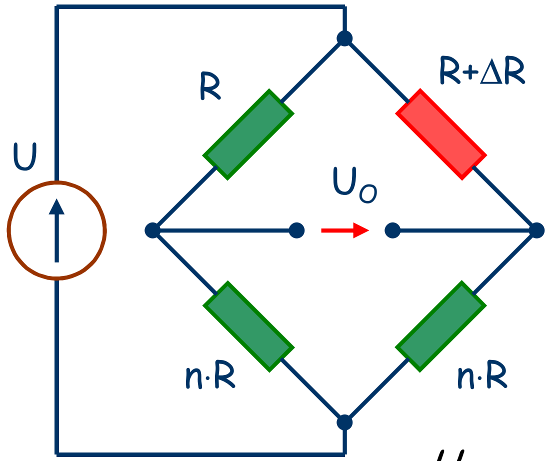
Pt-100 sensor – 100 Ω @ 0°C; C_1~0.75 Ω/°C



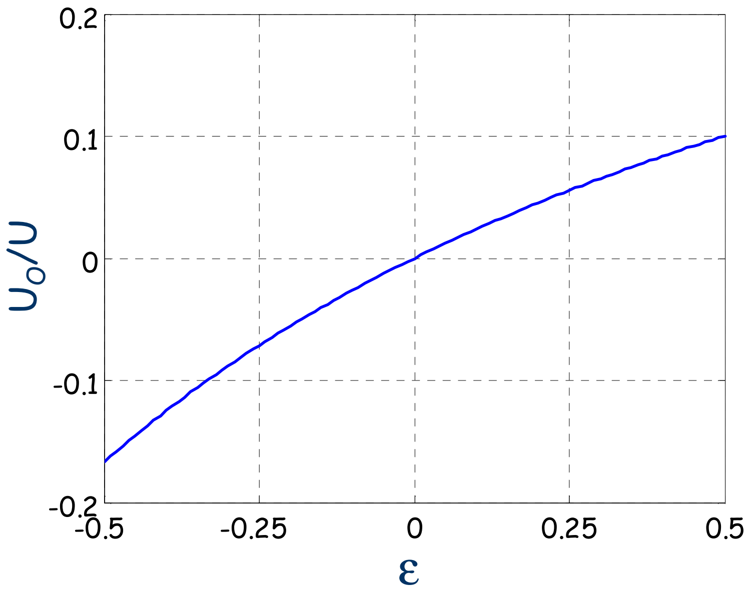
Unbalanced bridge – linearity problem

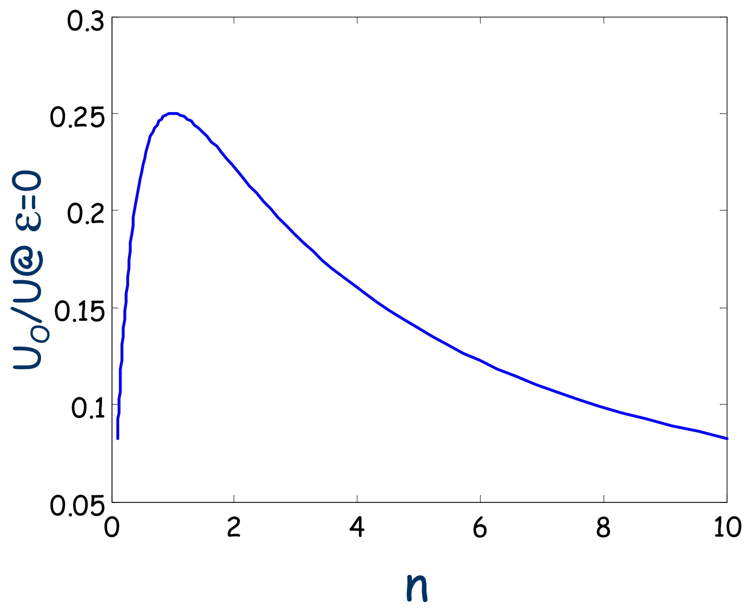


$$\frac{U_O}{U} = \frac{\varepsilon}{2(2+\varepsilon)}$$

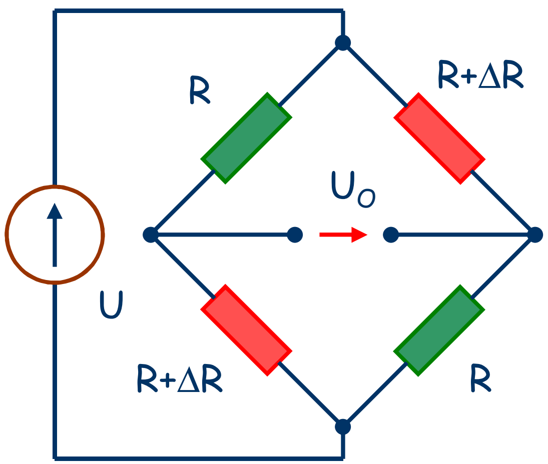


$$\frac{U_O}{U} = \frac{n \cdot \varepsilon}{(n+1)^2 + (n+1)\varepsilon}$$

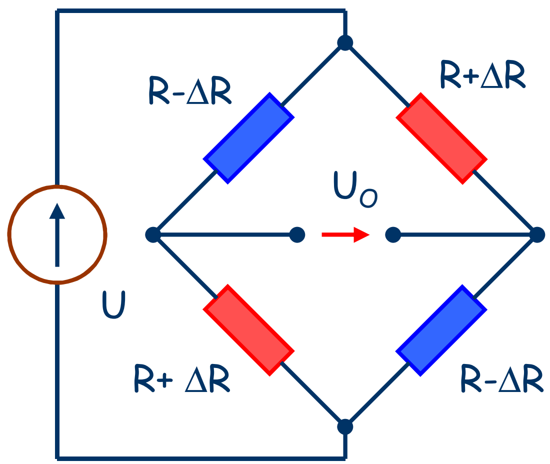




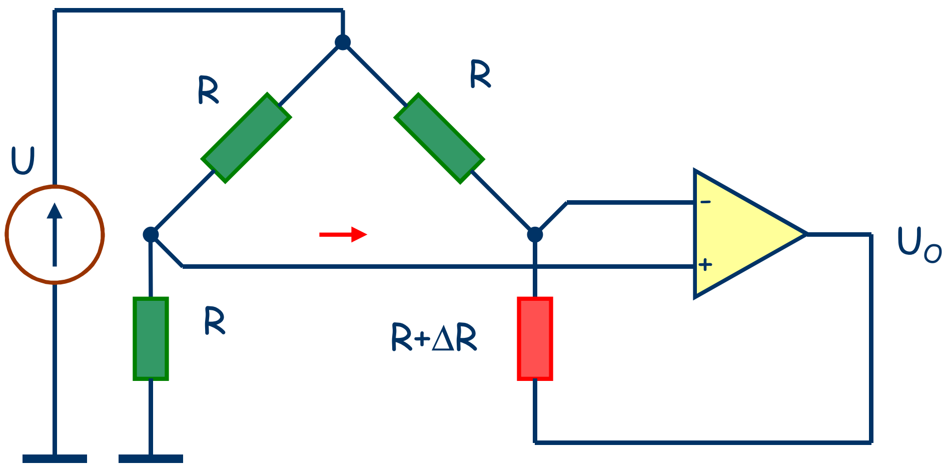
Methods of bridge linearisation



$$\frac{U_O}{U} = ??$$



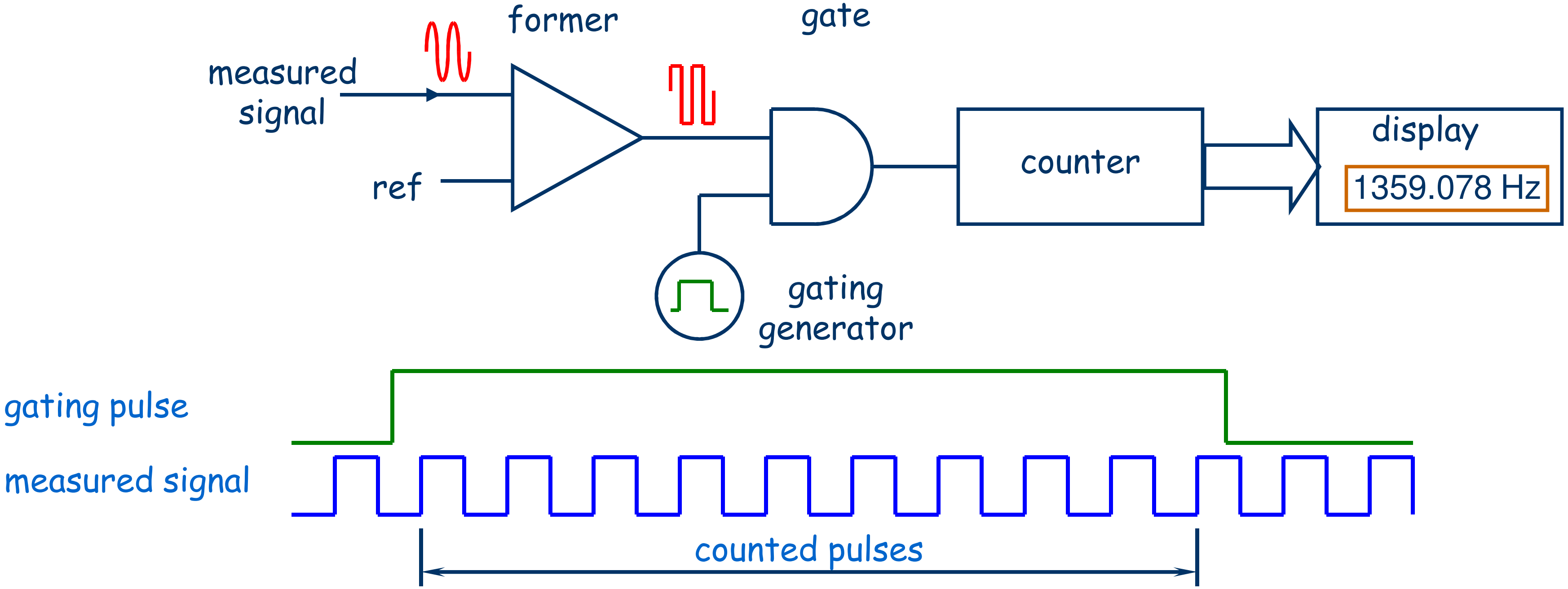
$$\frac{U_O}{U} = ??$$



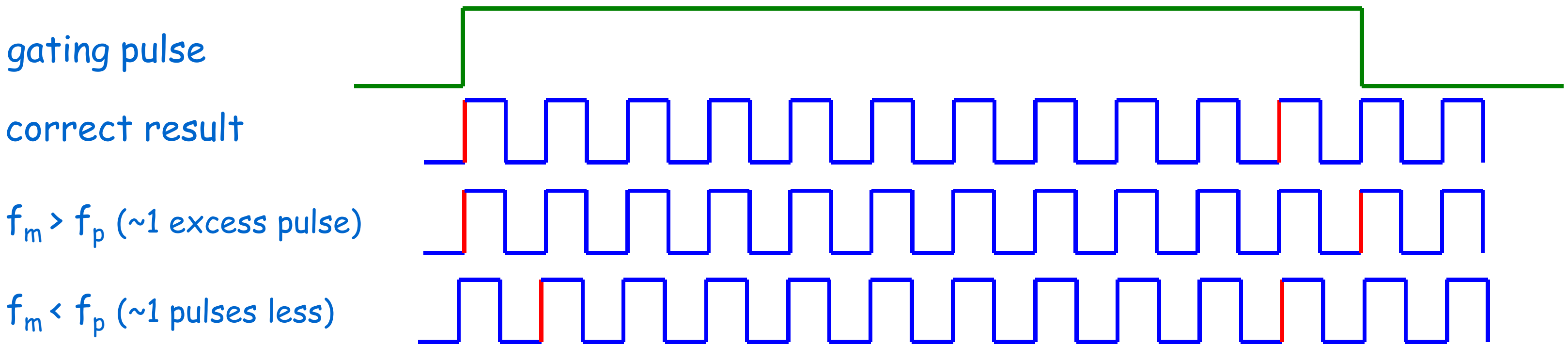
$$\frac{U_O}{U} = -\frac{\varepsilon}{2}$$

Frequency

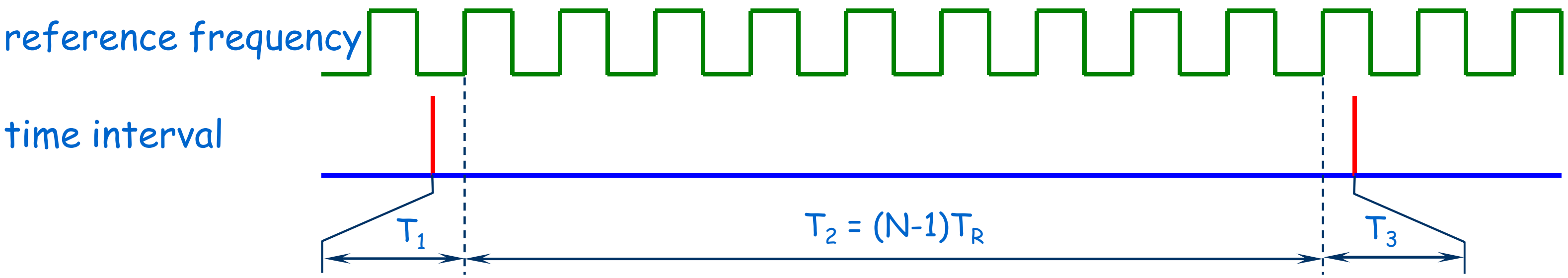
Frequency measurement



What is a „true" ferquency value?



Time interval/frequency measurement

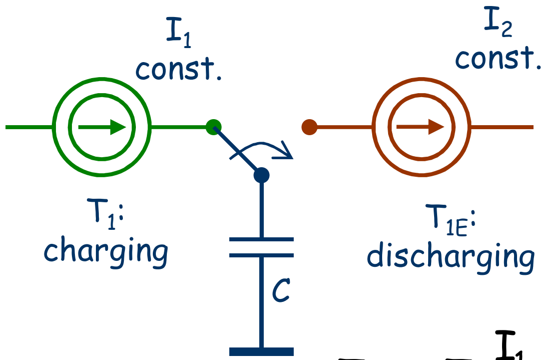


$$T = T_1 + T_2 + T_3$$

$$f = 1/T$$

How to determine the „tails"?

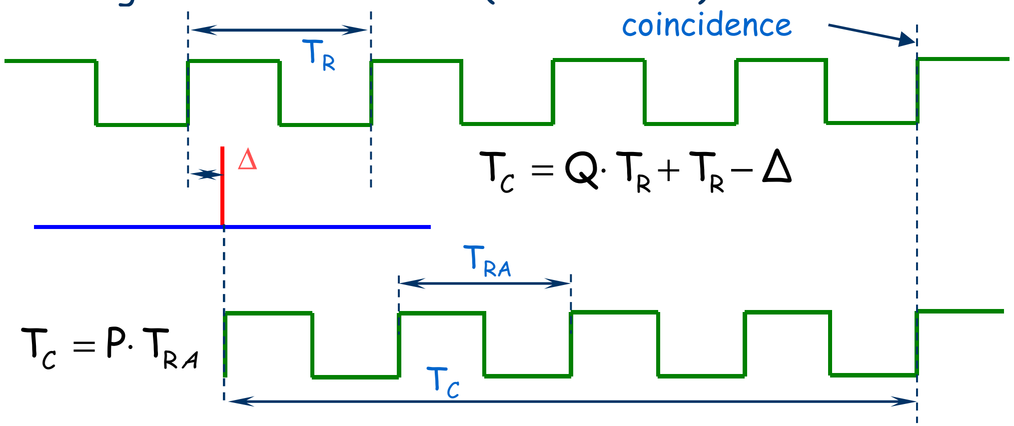
„analog" method



$$T_{1E} = T_1 \frac{I_1}{I_2}$$

$$I_2 < I_1 \rightarrow T_{1E} > T_1$$

digital vernier method (coincidence)



$$T_C = Q \cdot T_R + T_R - \Delta$$

$$T_C = P \cdot T_{RA}$$

$$\Delta = (Q+1) \cdot T_R - P \cdot T_{RA}$$

$$T_{RA} < T_R \rightarrow P = Q + 1$$

$$\Delta = (Q+1) \cdot (T_R - T_{RA})$$

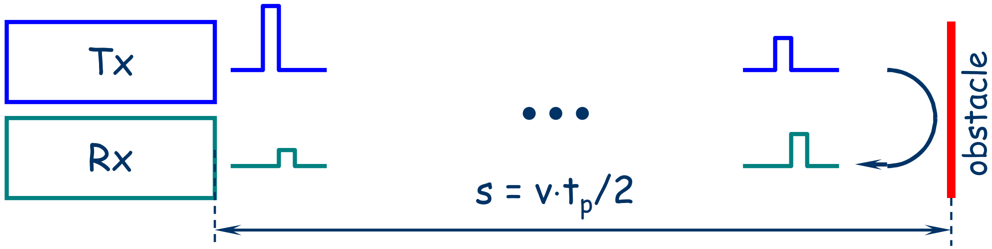
$$\Delta = T_R \cdot (Q+1) \cdot \left(1 - \frac{A}{B}\right)$$

eg.: $A/B = 9/10$

$$\Delta = \frac{1}{10} T_R \cdot (Q+1)$$

Distance measurement (ranging)

1. Pulse „reflectometric" method



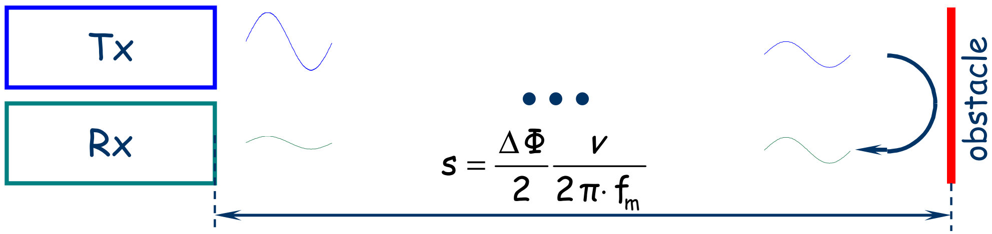
measurement resolution:
- wavelength λ,
- time interval measurement: $\Delta s = 0.5v\Delta t_p$

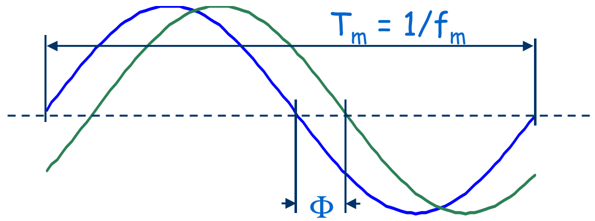
acoustic waves:
- $v \cong 300$ m/s
- @ 100 kHz → $\lambda \cong 3$mm
- T = 10 μs
- resolution limit – wavelength
- ...but there are other problems...

optical waves:
- $v \cong 3\cdot10^8$ m/s
- @ $\lambda \cong 700$ nm → 430 THz
- T ≅ 2.3 fs
- resolution limit – technical capabilities of time interval measurement

$\Delta t_p = 10$ ns → $\Delta s = 1.5$ m...

2. „Coherent" method → phase shift measurement of CW signal





$$\Delta\Phi = 2s\cdot\beta = 2s\frac{2\pi}{\Lambda_m} = 2s\cdot 2\pi\frac{f_m}{v}$$

measurement resolution – phase shift

$v \cong 3\cdot10^8$ m/s
$f_m = 100$ MHz

$\Delta\Phi = 1°$ → $\Delta s \cong 4$ mm...