Sensor and Actuator Networks

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HOCHSCHULE RHEIN-WAAL
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Exercise A.1.1: Units

1 gallon/23.5 miles

≈ 0.1 L/Km

An American manufacturer declares that a car consumes 1 gallon of gasoline per 23.5 miles. In the US, the price for one gallon is 2.30 USD. It also applies: 1 gallon = 3.79l; 1 mile = 1.609 km.

1. How many liters of gasoline does the car consume per 100 km? ≈10.023 L
2. How much does the gasoline cost in € for 100km at an exchange rate of 0.80€ / USD? 4.866 €

Exercise A.1.2: Units

1) 745.9 W

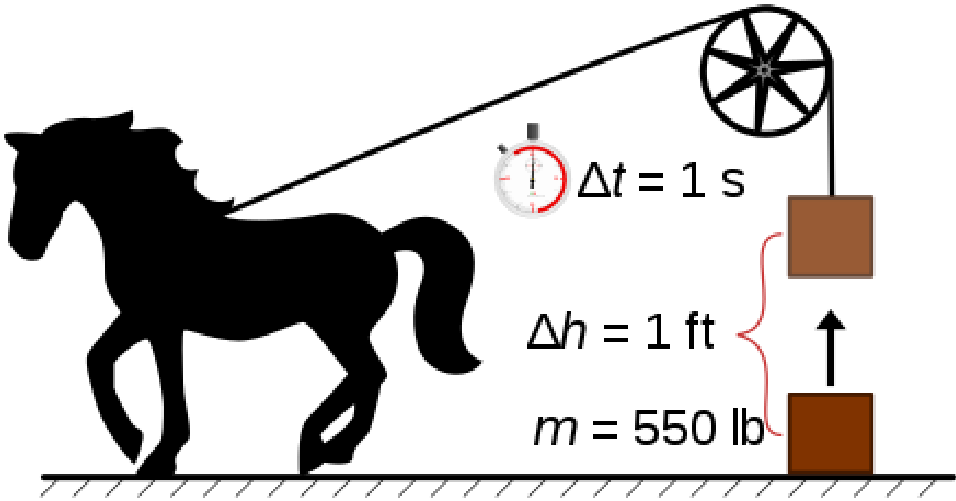
2) 1 hp

A typical horse is able to lift

mass ← 550 pounds (lb) by 1 foot in 1 second.

$$P = \frac{F \cdot l}{t} = \frac{mg \cdot l}{t}$$

1. Calculate the power of the horse in watts.
2. Express the power of the horse in mechanical (imperial) horsepower (hp).



Source: Wikimedia Commons

Exercise A.1.3: Units

Express the following measurands in SI base units (if necessary, as a power of ten):

Type	Measurand
Impulse	$I = 43\ N \cdot s$
Mass flow rate	$\dot{m} = 123.6\ mg/h$
Noise dose	$D_n = 8.23 \cdot 10^{-3}\ Pa^2 \cdot s$
Pressure	$p = 624\ Torr$

Exercise A.1.4: Measurement Uncertainty

For measuring the value of a resistance, you measure the current through and the voltage across the resistor with the following accuracies of the analog measuring equipment:

uncertainty

$p_i=0.2\%$ and $p_v=0.5\%$

current voltage

Calculate the combined measurement uncertainty.

$u_c = 0.54\%$

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Exercise A.1.5: Measurement Uncertainty

For the same resistor measurement as in exercise 3, you take a digital FLUKE 179 multimeter displaying a dc voltage U=8.74V and a dc current I=0.15A.

$U_u = 8.74V * 0.09\% + 2*0.01V = 0.027866\,V \Rightarrow P_v = \frac{0.027866\cancel{V}}{8.74\cancel{V}} * 100 = 0.3188\%$

1. Calculate the uncertainty of the voltage and current measurement as well as the combined uncertainty by using the electrical specifications on the two following slides.

$U_i = 150\,mA * 1\% + 3 * 0.1\,mA = 1.8\,mA \Rightarrow P_i = 1.2\%$

$U_c = \sqrt{P_v^2 + P_i^2} = 1.2416\%$

2. Calculate the resistor value and its uncertainty.

$R = \frac{U}{I} = 58.267\,\Omega$

combined uncertainty

$U_R = R * U_c = 58.267\,\Omega * 1.2416\% = 0.723\,\Omega$

Exercise A.1.5: Measurement Uncertainty

Models 175, 177 & 179
Users Manual

Function	Range [1]	Resolution	Accuracy ± ([% of Reading] + [Counts]) Model 175	Model 177	Model 179
AC Volts [2,3]	600.0 mV 6.000 V 60.00 V 600.0 V 1000 V	0.1 mV 0.001 V 0.01 V 0.1 V 1 V	1.0 % + 3 (45 Hz to 500 Hz) 2.0 % + 3 (500 Hz to 1 kHz)	1.0 % + 3 (45 Hz to 500 Hz) 2.0 % + 3 (500 Hz to 1 kHz)	1.0 % + 3 (45 Hz to 500 Hz) 2.0 % + 3 (500 Hz to 1 kHz)
DC mV	600.0 mV	0.1 mV	0.15 % + 2	0.09 % + 2	0.09 % + 2
DC Volts	6.000 V 60.00 V 600.0 V	0.001 V 0.01 V 0.1 V	0.15 % + 2	0.09 % + 2	0.09 % + 2 ×0.01V
	1000 V	1 V	0.15 % + 2	0.15 % + 2	0.15 % + 2
Continuity	600 Ω	1 Ω	Meter beeps at < 25 Ω, beeper turns off at > 250 Ω; detects opens or shorts of 250 µs or longer.		
Ohms	600.0 Ω 6.000 kΩ 60.00 kΩ 600.0 kΩ 6.000 MΩ 50.00 MΩ	0.1 Ω 0.001 kΩ 0.01 kΩ 0.1 kΩ 0.001 MΩ 0.01 MΩ	0.9 % + 2 0.9 % + 1 0.9 % + 1 0.9 % + 1 0.9 % + 1 1.5 % + 3	0.9 % + 2 0.9 % + 1 0.9 % + 1 0.9 % + 1 0.9 % + 1 1.5 % + 3	0.9 % + 2 0.9 % + 1 0.9 % + 1 0.9 % + 1 0.9 % + 1 1.5 % + 3
Diode test	2.400 V	0.001 V	1 % + 2		
Capacitance	1000 nF 10.00 µF 100.0 µF 9999 µF [4]	1 nF 0.01 µF 0.1 µF 1 µF	1.2 % + 2 1.2 % + 2 1.2 % + 2 10 % typical	1.2 % + 2 1.2 % + 2 1.2 % + 2 10 % typical	1.2 % + 2 1.2 % + 2 1.2 % + 2 10 % typical
AC Amps [5] (True RMS) (45 Hz to 1 kHz)	60.00 mA 400.0 mA 6.000 A 10.00 A	0.01 mA 0.1 mA 0.001 A 0.01 A	1.5 % + 3	1.5 % + 3	1.5 % + 3

1. All AC voltage and AC current ranges are specified from 5 % of range to 100 % of range.
2. Crest factor of ≤ 3 at full scale up to 500 V, decreasing linearly to crest factor ≤ 1.5 at 1000 V.
3. For non-sinusoidal waveforms, add -(2% reading + 2% full scale) typical, for crest factors up to 3.
4. In the 9999 µF range for measurements to 1000 µF, the measurement accuracy is 1.2 % + 2 for all models.
5. Amps input burden voltage (typical): 400 mA input 2 mV/mA, 10 A input 37 mV/A.

times the resolution

The result depends on the range

Exercise A.1.5: Measurement Uncertainty

Function	Range [1]	Resolution	Accuracy ± ([% of Reading] + [Counts]) Model 175	Model 177	Model 179
DC Amps[4]	60.00 mA 400.0 mA 6.000 A 10.00 A	0.01 mA 0.1 mA 0.001 A 0.01 A	1.0 % + 3	1.0 % + 3	1.0 % + 3
Hz (AC- or DC- coupled, V or A [2, 3] input)	99.99 Hz 999.9 Hz 9.999 kHz 99.99 kHz	0.01 Hz 0.1 Hz 0.001 kHz 0.01 kHz	0.1 % + 1	0.1 % + 1	0.1 % + 1
Temperature	-40 °C to +400 °C -40 °F to +752 °F	0.1 °C 0.1 °F	NA	NA	1 % + 10[5] 1 % + 18[5]
MIN MAX AVG	For DC functions, accuracy is the specified accuracy of the measurement function ± 12 counts for changes longer than 275 ms in duration. For AC functions, accuracy is the specified accuracy of the measurement function ± 40 counts for changes longer than 1.2 s in duration.				

1. All AC voltage and AC current ranges are specified from 5 % of range to 100 % of range.
2. Frequency is specified from 2 Hz to 99.99 kHz in Volts and from 2 Hz to 30 kHz in Amps.
3. Below 2 Hz, the display shows zero Hz.
4. Amps input burden voltage (typical): 400 mA input 2 mV/A, 10 A input 37 mV/A.
5. Does not include error of the thermocouple probe.

Exercise A.1.6: Measurement Uncertainty

With the same digital multimeter as in exercise A.1.5, you measure a voltage on the mains (in a private building in Germany). The display is showing 230.5V ac. 50 Hz

Calculate the uncertainty of your measurement.

$$U_v = 230.5V * 1\% + 3 * 0.1V = \pm 2.605V$$

$$P_v = \frac{2.605V}{230.5V} \times 100 = \pm 1.13\%$$

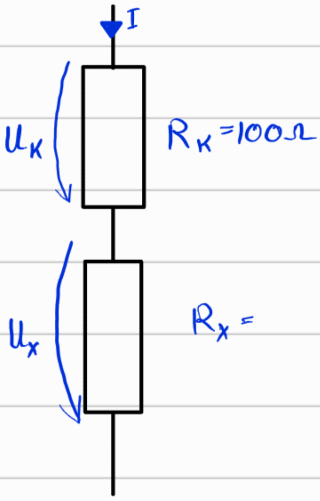
Exercises A.1. Measurement

Exercise A.1.7: Measurement Uncertainty

An unknown resistor R_x is connected in series with a known resistor R_k=100Ω (tolerance 0.5%). The same measuring current flows through both resistors. With an analog voltage meter (internal resistance can be assumed as infinite high, accuracy class 2%, voltage measuring range 0-10V), the voltage drops at the resistors are measured: U_x=8V, U_k=4V.

1. Define the formula for the calculation of R_x.

2. Calculate the worst case measuring error for R_x.



$$I = \frac{U_K}{R_K}, \quad I = \frac{U_x}{R_x} \quad \Bigg\} \quad \frac{U_K}{R_K} = \frac{U_x}{R_x} \Rightarrow R_x = U_x \cdot \frac{R_K}{U_K}$$

$$R_K = 100\,\Omega \pm 100\,\Omega * 0.5\,\%$$

$$\Rightarrow R_K = 100\,\Omega + 0.5\,\Omega$$

$$U_x = 8V \pm 0.2V$$

$$U_K = 4V \pm 0.2V$$

accuracy class * the maximum value in the voltage range $= 2\% * 10V = 0.2V$

$$R_{x,max} = \frac{U_{x,max}}{U_{K,min}} \cdot R_{K,max}$$

$$R_{x,max} = \frac{8.2V}{3.8V} * 100.5\,\Omega$$

$$R_{x,min} = \frac{U_{x,min}}{U_{K,max}} \cdot R_{K,min} = \frac{7.8V}{4.2V} * 99.5\,\Omega$$

Exercise A.1.8: Accuracy Classes

1. Name the accuracy class of the analog ampere meter shown on the right picture.

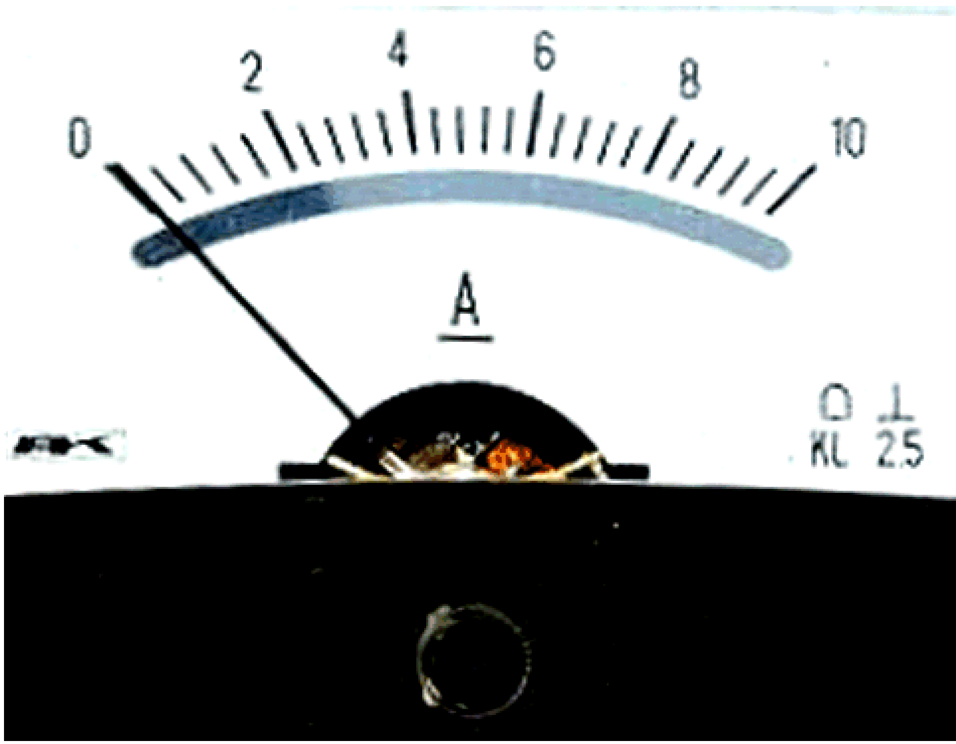
   2.5%

2. Name the measuring range.

   0 - 10 A

3. Calculate the maximum error value.

   2.5% x 10 A = 0.25 A



Source: Wikimedia Commons (Staro1)

Exercise A.1.9: Accuracy Classes

2.5%

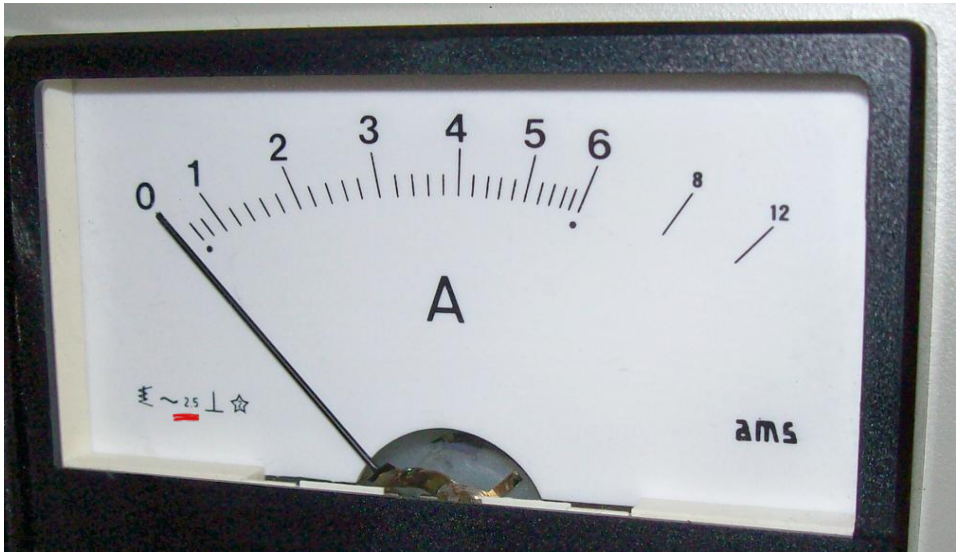
1. Name the accuracy class of the analog ampere meter shown on the right picture.

2. Name the measuring range.

   600 mA – 6 A

3. Calculate the maximum error value.

$\rightarrow 2.5\% * (6\,A) = \pm 150\,mA$



Source: Wikimedia Commons

Exercise A.2.1: Brinell Hardness Test

You will find a set of multiple choice questions with answers for the Brinell hardness test on:

https://www.sanfoundry.com/testing-materials-questions-answers-brinell-hardness-test/

Remark: There are some questions in the online-test whose answers are not part of the lecture‘s slides or videos. If the answers are not self-explaining, these questions can be discussed during the consultation hours (same for exercises A.2.2. to A.2.5.)

Exercise A.2.2: Ultrasonic Testing

You will find a set of multiple choice questions with answers dealing with ultrasonic testing on:

https://www.sanfoundry.com/casting-questions-answers-ultrasonic-inspection/

Remark: For questions 3, all four answers are correct (even ferrous materials can be tested by ultrasonic techniques within certain limits).

Exercise A.2.3: Magnetic Particle Testing

You will find a set of multiple choice questions with answers dealing with magnetic particle testing on:

https://www.sanfoundry.com/testing-materials-questions-answers-online-quiz/

Exercise A.2.4: Eddy Current Testing

You will find a set of multiple choice questions with answers dealing with eddy current testing on:

https://www.sanfoundry.com/testing-materials-questions-answers-eddy-current-inspection-ultrasonic-testing/

Exercise A.2.5: X-Ray Testing

You will find a set of multiple choice questions with answers dealing with x-ray testing on:

https://www.sanfoundry.com/testing-materials-questions-answers-radiographic-inspection/

Exercise A.3.1: Strain Gauge

A strain gauge has a resistance of 1000Ω (R_G) and a gauge factor of 2.2. It is bonded to an object to detect mechanical stress.

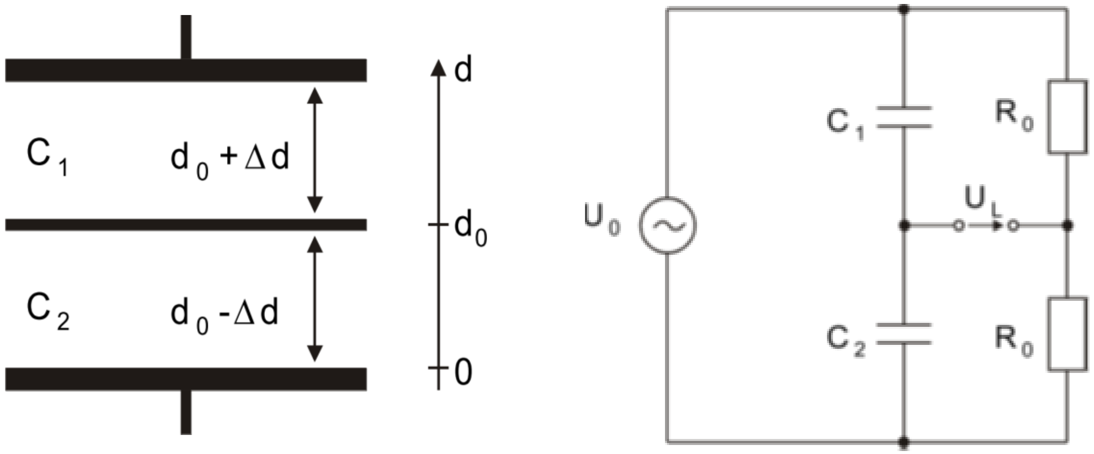
$$GF = \frac{dR/R_G}{\varepsilon}$$

1) Determine the resistance change of the strain gauge for a tensile strain of 2000με due to the change in size of the object. $dR = 2.2 * 1000\,\Omega * 2*10^{-3} = 4.4\,\Omega$

2) The relationship between change in resistance and displacement is $15\frac{\Omega}{mm}$. Determine the change in size of the object. $\Delta L = \frac{4.4\,\cancel{\Omega}}{15\,\cancel{\Omega}/mm} = 0.2933\,mm$

Exercise A.3.2: Differential Length Transducer

A differential length transducer should be used to measure small distance changes.



Express the bridge's output voltage U_L as a function of the distance change.

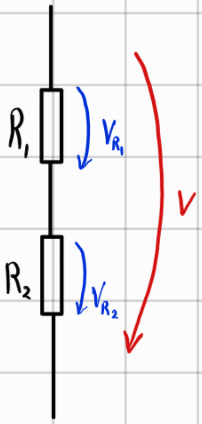
A.3.2:

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}$$

ε_0 & ε_r are constants

A is also constant is this case

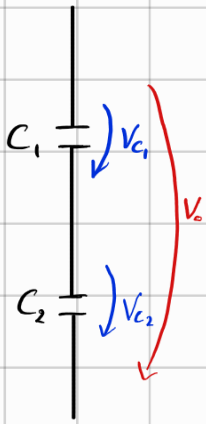
$$\boxed{Z_c = \frac{1}{2\pi f \cdot C} \qquad Z_L = 2\pi f \cdot L}$$



$$V_{R_2} = \frac{V_0 \cdot R_2}{R_1 + R_2}$$

$\because R_1 = R_2 = R_0$

$$\boxed{V_{R_2} = \frac{1}{2} V_0}$$



$$V_{C_2} = V_0 \cdot \frac{Z_{C_2}}{Z_{C_1} + Z_{C_2}}$$

$$V_{C_2} = V_0 \cdot \frac{\frac{1}{2\pi f C_2}}{\frac{1}{2\pi f C_1} + \frac{1}{2\pi f C_2}}$$

$$V_{C_2} = V_0 \cdot \frac{\cancel{2\pi f} C_1}{\cancel{2\pi f}(C_1 + C_2)}$$

$$V_{C_2} = V_0 \cdot \frac{\cancel{\varepsilon_0 \varepsilon_r} \cdot \frac{\cancel{A}}{d_1}}{\cancel{\varepsilon_0 \varepsilon_r} \cdot \cancel{A}\left(\frac{1}{d_1} + \frac{1}{d_2}\right)}$$

$$\boxed{V_{C_2} = \frac{d_2}{d_1 + d_2}}$$

from question:

$$\boxed{\begin{aligned} d_1 &= d_0 + \Delta d \\ d_2 &= d_0 - \Delta d \end{aligned}}$$

$$\boxed{V_{C_2} = \frac{d_0 - \Delta d}{2 d_0}}$$

$$\boxed{V_L = V_{C_2} - V_{R_2}}$$

$$\boxed{V_L = V_0 \left(\frac{d_0 - \Delta d}{2 d_0} - \frac{1}{2} \right)}$$

Exercise A.3.3: Variable Area Capacitor

A capacitor consists of two squarish conductive plates with an edge length of 20cm. The distance between the plates is 1cm, the relative permittivity of the dielectric between the plates is 1.

$A = 20\,cm \cdot 20\,cm = 400\,cm^2$, $\varepsilon_r = 1$, $d = 0.01\,m$, $\varepsilon_0 = 8.854 \times 10^{-12}\,\frac{F}{m}$

1) Determine the capacitance of the device for 100% overlap of the plates.

$C_1 = \varepsilon_0 \varepsilon_r \frac{A}{d} = 8.854 \times 10^{-12}\,\frac{F}{\cancel{m}} \cdot 1 \cdot \frac{0.04\,m^{\cancel{2}}}{0.01\,\cancel{m}} = 3.5416 \times 10^{-11}\,F$

$= 35.416\,pF$

$\rightarrow A_2 = 15\,cm \cdot 20\,cm = 300\,cm^2 = 0.03\,m^2$

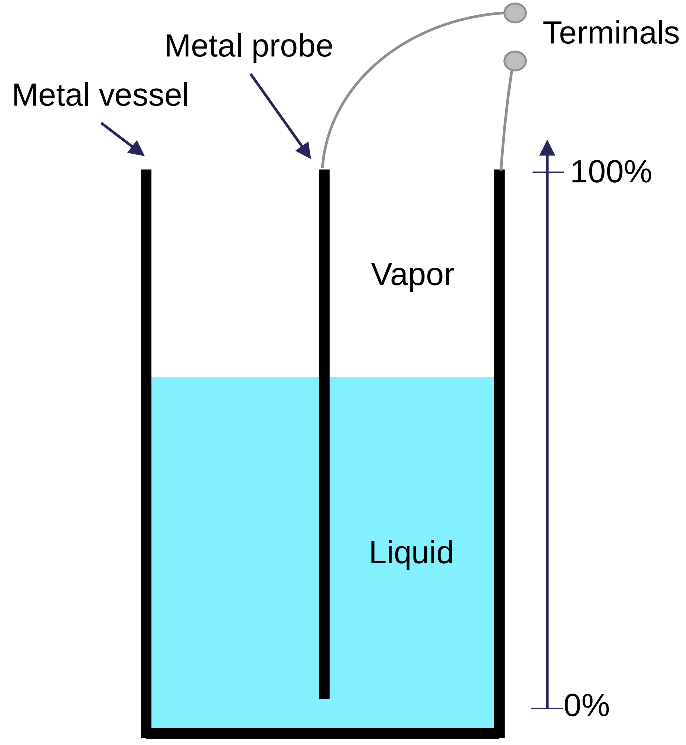
2) Determine the capacitance of the device if one plate is shifted 5cm horizontally in parallel to one edge of the plate.

$\frac{A_2}{A_1} = 0.75 \quad \therefore C_2 = 0.75 \cdot C_1 = 2.6562 \times 10^{-11}\,F$

$= 26.562\,pF$

Exercise A.3.4: Capacitive Level Measurement

The oil level in a metal vessel shall be measured. The oil has a relative ε_{Lr} permittivity of 2.2, for the vapor it is ε_{Vr} 1. The metal probe has a surface of 45cm x 10cm, whereas its thickness can be neglected. It is placed in the center of a metal vessel with a width of 30cm with no contact to the vessel.



$\varepsilon_0 = 8.854 * 10^{-12} \frac{F}{m}$

$\varepsilon_{Lr} = 2.2 \quad , \varepsilon_{vr} = 1$

$A = 45\,cm * 10\,cm = 0.045 m^2$

$d = \frac{30\,cm}{2} = 15\,cm$

0% Liq. : $C_1 = 2 * 8.854 * 10^{-12} \frac{F}{\cancel{m}} * 1 * \frac{0.045 \cancel{m^2}}{0.15 \cancel{m}} = 5.3124\ pF$

30% liq. : $C_2 = 2 * 8.854 * 10^{-12} \frac{F}{\cancel{m}} * \frac{0.045 \cancel{m^2}}{0.15 \cancel{m}} (0.3 * 2.2 + 0.7 * 1) = 7.225\ pF$

100% liq. : $C_3 = 2 * 8.854 * 10^{-12} \frac{F}{\cancel{m}} * 2.2 * \frac{0.045 \cancel{m^2}}{0.15 \cancel{m}} = 11.6873\ pF$

Exercise A.3.4: Capacitive Level Measurement

1) Calculate the capacities between the terminals for the liquid levels 0%, 30% and 100%.

2) Why is it not possible to measure the level of conductive liquids with such a capacitive level measurement system?

Because the conductivity of the liquid shorts circuit the capacitor/s.

Exercise A.3.5: Capacitive Touchscreens

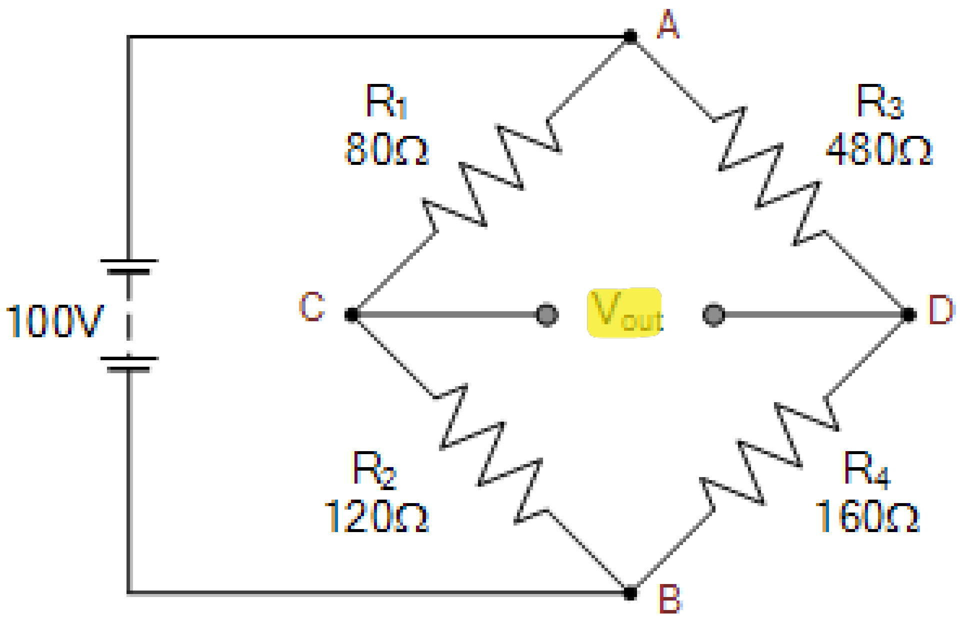
Why are surface capacitive touch screens typically used in large displays like for point of interests whereas projective capacitive touchscreens are typically used for smaller displays like in smart phones or tablets?

Surface capacitive touch screens is cheaper & accurate enough for large screens (lower resolution), whereas for smaller displays, projective capcitive touch is used.

Exercise A.3.6: Wheatstone Bridge

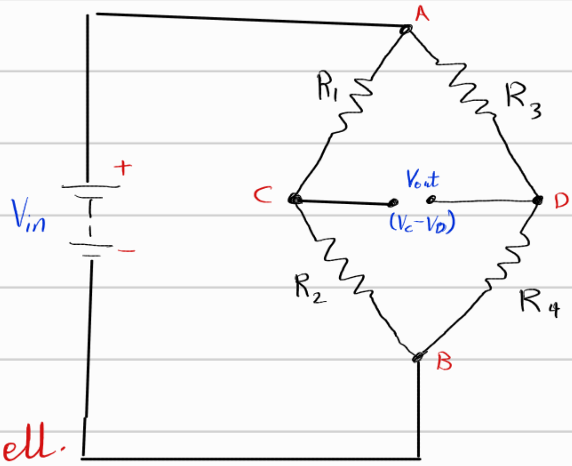
1. Calculate the output voltage V_{out} across the points C and D.

2. Calculate the value of the resistor R_4 to balance the bridge.



$$V_{out} = V_{in} * \frac{R_2}{R_1 + R_2} - V_{in} * \frac{R_4}{R_3 + R_4}$$

$V_{out} = 35\,V$



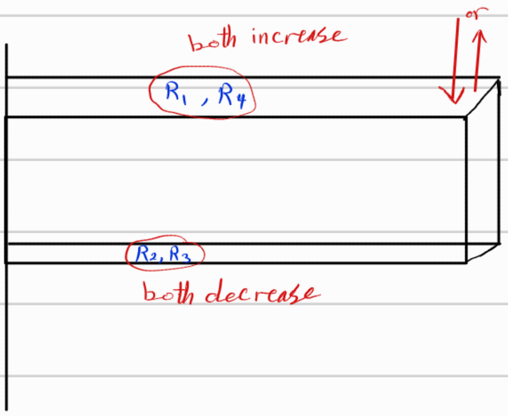
Balanced bridge (The sensor has no output signal)

$V_{out} = 0$

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

we could use this ratio as well.

or



$$V_{CB} = \frac{R_2}{R_1 + R_2} \cdot V_{in}$$

= for balanced bridge

$$V_{DB} = \frac{R_4}{R_3 + R_4} \cdot V_{in}$$

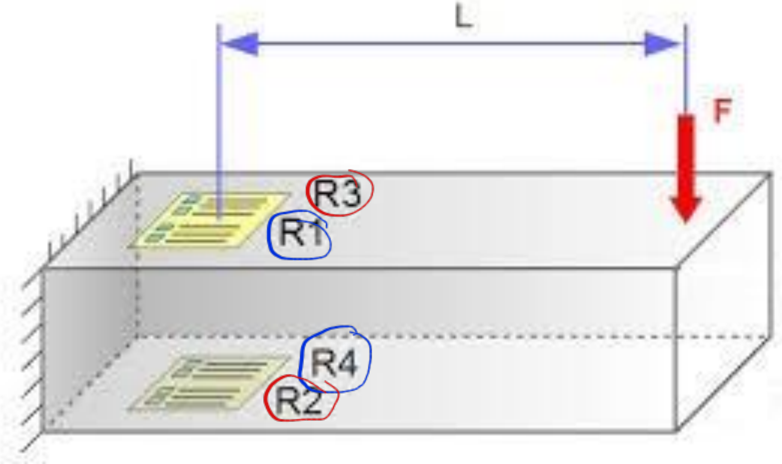
$R_4 = 720\ \Omega$

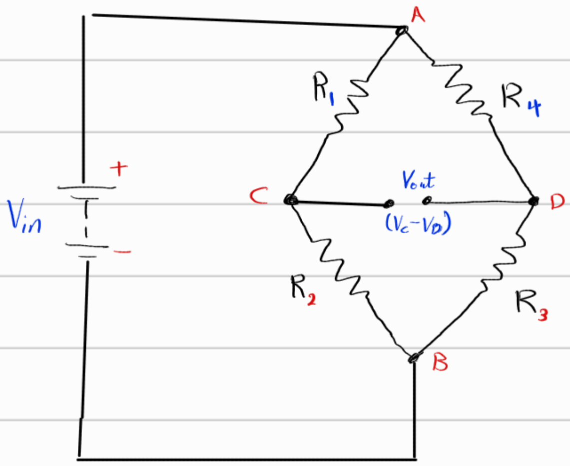
for a balanced bridge

Exercise A.3.7: Stress Measurement

You have a beam in bending as shown on the right picture with four strain gauges and an applied force F.

1. Draw a Wheetstone bridge and name the resistors in the bridge in order to get a maximum output voltage.




A
R_1
R_4
V_{in}
+
−
C
V_{out}
$(V_C - V_D)$
D
R_2
R_3
B

Exercise A.3.7: Stress Measurement

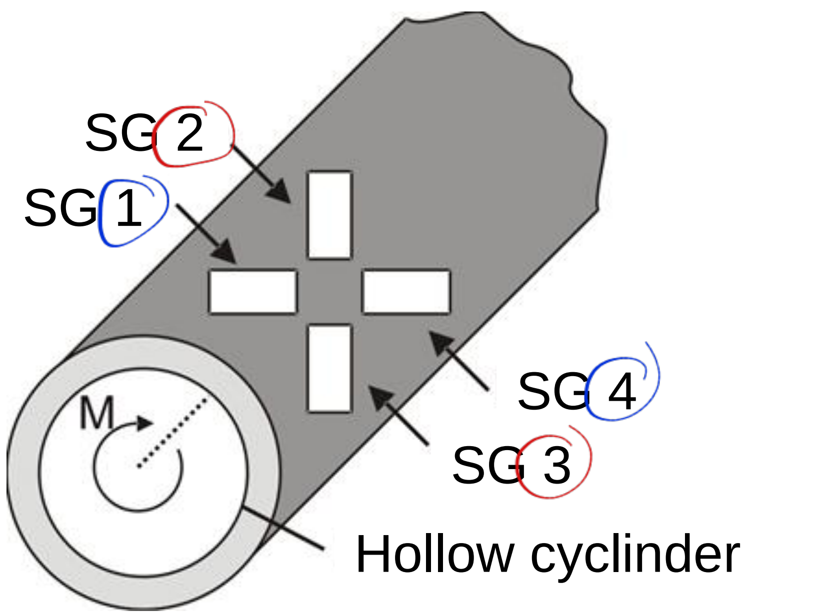
2. Add a voltage source and an instrumentation amplifier to your schematic of the Wheatstone bridge.

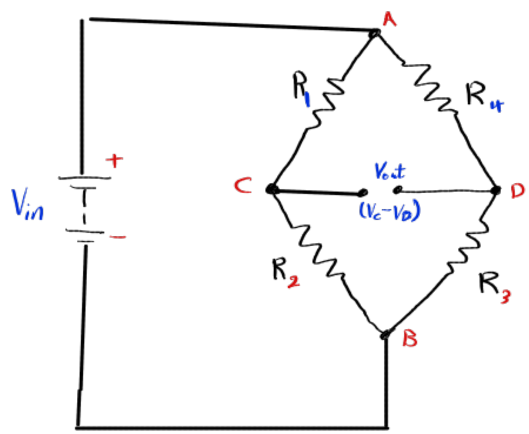
All strain gauges are identical (gauge factor GF=2). The supply voltage of the Wheatstone bridge is 3V dc. The maximal stress of the strain gauges is ±15mm/m. The input range of your analog to digital converter is 0..3V dc.

3. Calculate the resistor values of the instrumentation amplifier to achieve the maximum possible resolution of your measurement chain.

Exercise A.3.8: Torque Measurement

The torque of a combustion enginge shall be measured on a hollow cylinder with four strain gauges SG1 to SG4, mounted at an angle of ±45 degrees to the cylinder axis.





Exercise A.3.8: Torque Measurement

The mechanical stress for a hollow cylinder is given by

$$\varepsilon = \frac{2r_o \sin(2\alpha)}{\pi\left(r_o^4 - r_i^4\right)G} M$$

with

r_i	Inner radius of the cylinder
r_o	Outer radius of the cylinder
α	Relative angle of the strain gauge to the cylinder axis, ±45°
G	Shear modulus of the metal
M	Attacking moment

Exercise A.3.2: Torque Measurement

1. The two strain gauges 1 and 2 should first work in a half bridge. Which arrangement of the strain gauges in the half bridge makes sense? How does the bridge voltage depend on the moment? $V_{out} = V_s \cdot \frac{1}{2} \cdot GF \cdot \varepsilon - V_s \cdot \frac{1}{2}$

   Half bridge: $V_{out} = V_s (0.5 \cdot GF \cdot \varepsilon - 0.5) \approx 1.6 * 10^{-4} \cdot V_s$

2. Now the four strain gauges are used in a full bridge. How are they arranged in this bridge? How does the bridge voltage depend on the moment? What is the advantage of the full bridge compared to the half bridge?

Full bridge: $V_{out} = V_s \cdot \underbrace{GF}_{\text{Gage Factor}} \cdot \varepsilon \approx 3.1 * 10^{-4} \cdot V_s$

Exercise A.3.8: Torque Measurement

3. The following values are known for the measurement setup:

$$r_i = 20mm,\ r_o = 32mm,\ G = 22 * \ 10^{10}\frac{N}{m^2},\ M = 1500Nm\ ,$$
$$R_0(initial\ resistance\ of\ the\ strain\ gauge) = 350\Omega,\ GF = 2$$

How large are the resistance changes ΔR and the output voltage changes for a half-bridge as in task 1 and a full-bridge as in task 2?

Exercise A.3.9: Voltage Sensitivity of a Piezoelectric Crystal

A barium titanate crystal has a charge sensitivity of 150pC/N. The dielectric constant of the crystal is $1.25 \cdot 10^{-8}$F/m.

Calculate the voltage sensitivity of the crystal.

3.9 $S_v = 0.012 \ V \frac{m}{N}$

$$S_v = \frac{S_q}{K} = \frac{150 * 10^{-9} \ mC/N}{1.25 * 10^{-8} \ F/m} = 12 \ mV \cdot \frac{m}{N}$$

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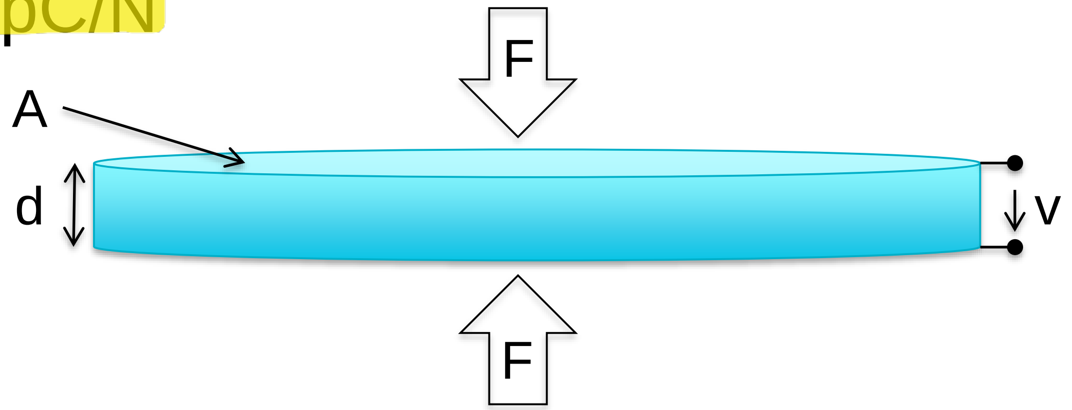
Exercise A.3.10: Piezo Electric Force Sensor

A piezo electric element made of quartz is used as a force sensor with the following parameters:

- charge sensitivity S_q=2.5pC/N
- Area A=10cm²
- Thickness d=0.885mm
- Dielectric constant ε_r=5



A force of F=1kN is suddenly applied.

Exercise A.3.10: Piezo Electric Force Sensor

Calculate the resulting piezo voltage v and the voltage sensitivity S_v (for ideal conditions, so e. g. the inner resistance of the crystal is not taken into account).

$$C = Q \cdot U$$

$$S_q = \frac{1\ Q}{A\ P}$$

$$P = \frac{F}{A}$$

$$U = 50\,V$$

$$S_v = \frac{1 \cdot U}{d \cdot P}$$

$$S_v = 0.057\,V \frac{m}{N}$$

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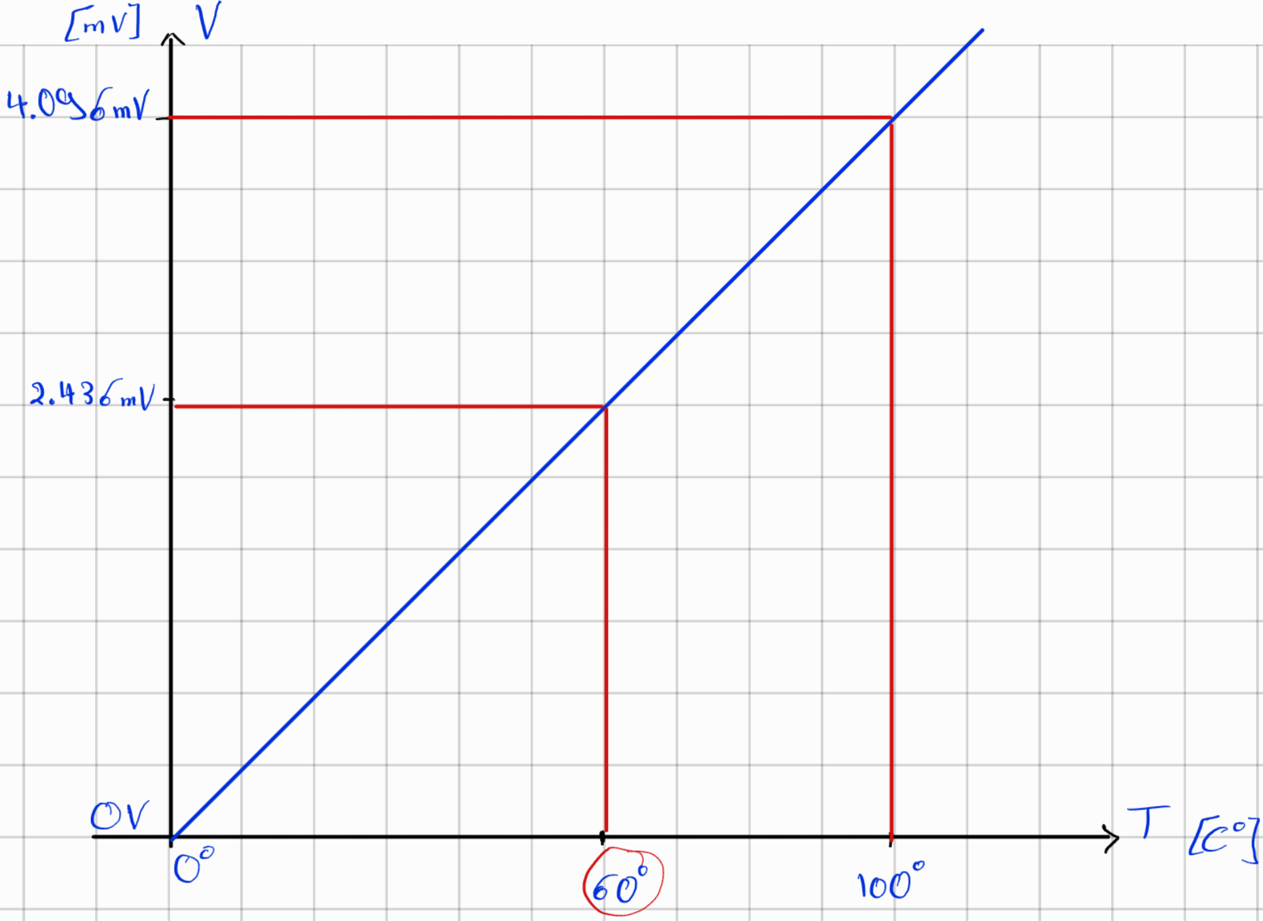
Exercise A.3.11: Thermocouple

You have type K class 1 thermocouple with an approximately linear function between E(0ºC)=0mV and E(100ºC)=4.096mV.

1. Calculate the temperature for a measured voltage of 2.436mV.

2. Name the maximum possible error of the thermocouple for this temperature.



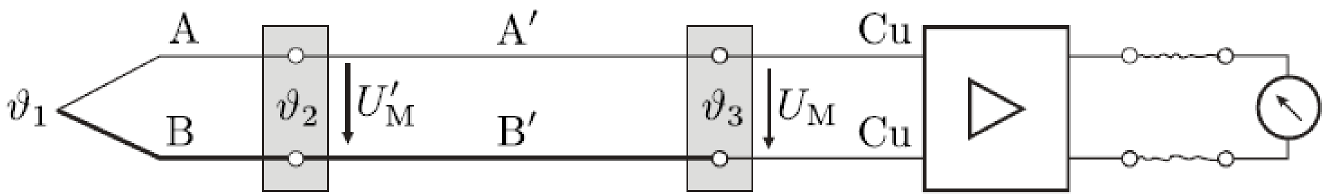
Error: $\pm 1.5°$ (from Tables or data sheet)

(Normed value)

Interpolation $\Rightarrow T_2 \approx 59.5\ °C$

Exercise A.3.12 : Thermocouple Configuration

A typical thermocouple configuration consists of short thermowires A and B and longer lines A‘ and B‘ made of other materials that are cheaper than the materials for the thermowires A and B.



Which general material property have the materials for A‘ and B‘ to fulfill and why? They have to be made from the same material/material with the same thermoelectric Properties.

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Exercise B.1: Pedelec

You have to chose an actuator for a pedelec (electrical bike).

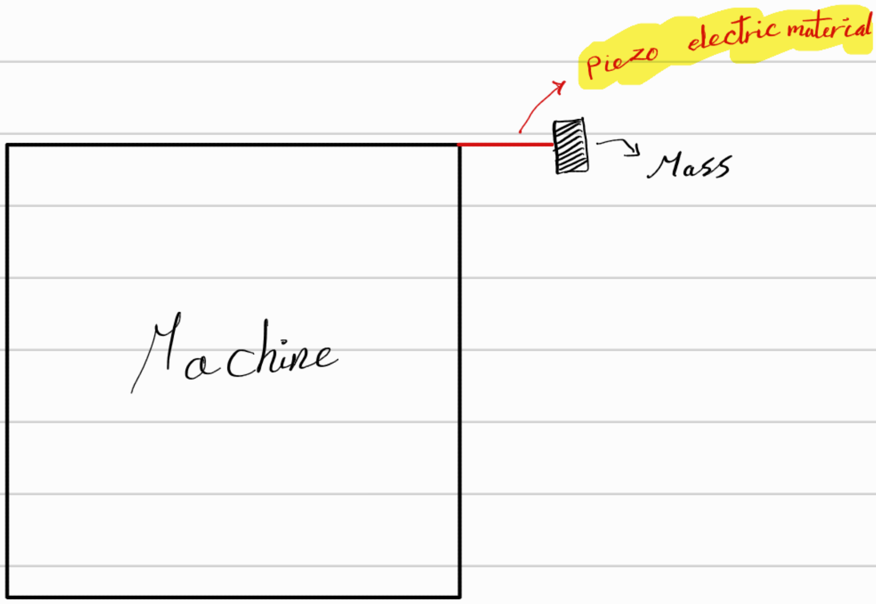
Which type of actuator would you chose and why? Name at least three advantages compared to other actuators which could be a <u>realistic</u> alternative.

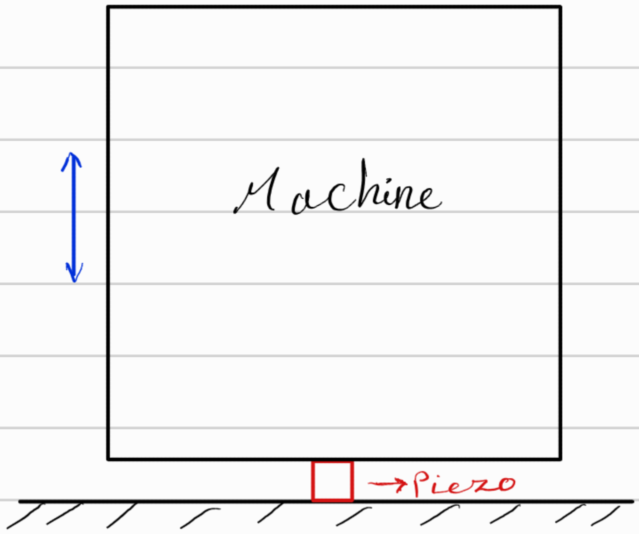
Source: Vogue

Exercise B.2: Energy Harvester (1)

Sensor nodes of wireless sensor networks are often powered by energy harvesters which derive (small amounts of) electrical energy from external sources. Imagine the case you have a vibrating machine with a given resonance frequency inside a dark building and you are responsible for the energy supply.

Sketch a possible energy harvester mechanism and explain its working principle.





either of these setups would do the work of transfering the motion (vipration) of the machine to electrical energy

Exercise B.3: Energy Harvester (2)

Imagine the case, that your machine from exercise B.2 is not vibrating, but it gets hot during operation.

Sketch again a possible energy harvester mechanism for this application and explain its working principle.

Thermocouple is generating very small voltage, so it's not used in here.

Thermoelectric cell (generator) ✓

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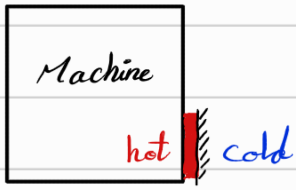
somewhere in the begining
of the slids

Thermo electric cell

TEC



one side $\longrightarrow$ other side
hot cold

Exercise B.4: Fuel Injection Valves

For the fuel injection in cars, more and more piezo electric valves are used instead of solenoid valves.

1. Name three technical advantages of the piezo electric valves. Faster, high pressure, dynamic injection pattern.

2. The driving circuit of a piezo electric valve is more complex than the driving circuit of a solenoid valve. Why?

   You need higher voltages for piezo compared to solenoid which only need small DC battery 10V
   more than 100V

Exercises B. Actuators

Exercise B.5: Fluidic and Electrical Actuators

Give an analogy of the force amplification in a hydraulic systems compared to an electrical system.

If you increase your voltage you decrease your current and vise-versa

Exercise B.6: Hydraulic Actuators

Explain why for most movements of an excavator hydraulic actuators are used instead of electro dynamic actuators.

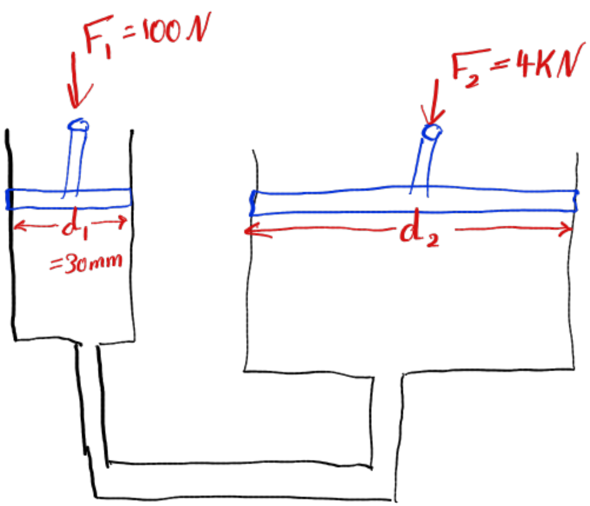
Source: Wikimedia Commons (btr)

We can generate higher forces/tourge with the same input power.

main advantage is the position of the pump in the back (more balance to the system)

Exercise B.7: Hydraulic Press

You have a hydraulic press and a jack cylinder with a diameter of 30mm and a force of 100N. Calculate the diameter of the working cylinder when a working force of 4000N is needed.



$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \Longrightarrow \frac{F_1}{F_2} = \frac{A_1}{A_2}$$

$$A_2 = A_1 \cdot \frac{F_2}{F_1}$$

$$\cancel{\frac{\pi}{4}} d_2^2 = \cancel{\frac{\pi}{4}} d_1^2 \frac{F_2}{F_1}$$

$$d_2 = \sqrt{(30\,mm)^2 \cdot 40} = 189.74\ mm$$

Exercise B.8: Hydraulic Car Hoist

A car with 1.5 tons shall be lifted 20cm with a hydraulic car hoist. $F_2 = m \cdot g$ h_2

$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \Rightarrow F_1 = d_1^2 \cdot \frac{m \cdot g}{d_2^2} = 408.75\,N$$

1) Which force is needed for the jack cyclinder (diameter d_1 20mm), when the working cylinder has a diameter of 120mm? d_2

2) Which way has the jack cylinder to pass?

$$\text{Volume 1} = \text{Volume 2} \Rightarrow A_1 \cdot h_1 = A_2 \cdot h_2$$

$$h_1 = \frac{d_2^2}{d_1^2} \cdot h_2 = 7.2\,m$$

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Exercise B.9: Medical Stents

Stents are used in medical applications to support the inner walls of arteries and veins.

1. What kind of actuator would you use for a self-expanding stent without any external power supply? shape-memory alloy actuator

2. Explain the working principle of such a stent, starting with the setting of the needed artery diameter to the finished insertion into the human body. It is placed inside the veins and then extends because of the higher temp. of the blood flow

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Exercise C.1: Representation of Numbers

Convert the following numbers

decimal

1. 187_D and 278_D into binary and hexadecimal
2. 123_D and 72_D into binary and octal
3. $101000101\,0010_2$ into decimal and hexadecimal
4. 0x55 and 0xDD into decimal and binary

$72 - 64$

$= 8 - 8 = 0$

$72_D \Rightarrow$

1			1			
64	32	16	8	4	2	1

Exercises C. Networks

Exercise C.2: File and Memory Sizes

A scientific experiment is generating 15 PB of data per year which have to be saved. What is the height of a stack of storage media when using:

- CDs (capacity 600MB = $600 \cdot 10^6$ Bytes, thickness 1.2mm)
- DVDs (capacity 4.3GB = $4.3 \cdot 10^9$ Bytes, thickness 1.2mm)
- Blu-rays (capacity 25GB = $25 \cdot 10^9$ Bytes, thickness 1.2mm)
- HDDs (capacity 2TB = $2 \cdot 10^{12}$ Bytes, thickness 2.5cm)

Calculate the solutions for the way a hardware manufacturer calculates (15PB = $15 \cdot 10^{15}$ Byte) and the operating systems calculates (15PB = $15 \cdot 2^{50}$ Byte).

Exercise C.3: Information Representation

The following data string is received and encoded in US-ASCII. Decode the string an represent it in latin characters (and control characters if necessary):

0x02	0x52	0x69	0x67	0x68	0x74	0x03
STX	R	i	g	h	t	EXT

Exercise C.4: Fundamentals of Data Transmission

For the following communication networks, indicate if

1. it is a serial or parallel interface.
2. it is a simplex, duplex or half-duplex communication.
3. it is a synchronous or asynchronous communication.

→ Serial, duplex, synchronous

→ serial, half-duplex, synchronous.

reciver → just reciving

→ just sending

CAN, SPI, I²C, space probe with a baseband radio transmitter

↳ serial, simplex, asynchronous.

transceiver → works in both directions

↳ Serial, half-duplex, asynchronous

Hint: Detailed information about the different busses are also available in part C "Networks" of this lecture.

Exercise C.5: Network Topologies

Describe the difference between the physical topology and the logical topology of a computer network.

How the wiring are set

How the data flow

Exercise C.6: Bit and Baud Rate

The minimum bit width of a bus system is 1µs. One symbol consists of eight data bits, one start bit and one stop bit. ⇒

amout of bit that can be transfered per second

1. Calculate the bit rate. ⟹ 1 Mbit/s
2. Calculate the baud rate. 1 symbol/10 µs = 1×10^5 baud = 100K baud

symbol/s

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Exercise C.7: Advantages of Layered Reference Models

Explain the two major advantages of using different layers to organize the communication in a network.

Exercise C.8: Hybrid Reference Model

Why is the hybrid reference model closer to reality, compared with the TCP/IP reference model and the OSI reference model?

Exercise C.9: Twisted Pair Cables

Explain the major advantage of using twisted pair cables and differential signals in terms of signal integrity.

Exercise C.10: Fiber Optical Cables

Name at least two advantages of fiber optical cables compared to electrical wires in terms of signal integrity.

Exercise C.11: Data Encoding

1. You have an asynchronous communication interface. Why is it in general useful to chose a data encoding which allows self-synchronization?

2. You have an asynchronous communication interface and you only transmit very short packets at low bit rates. Why it is acceptable to use a non-self-synchronizing data encoding in this particular case?

Exercise C.12: Manchester Code

1. Why does a Manchester code allows a clock synchronization and why does it suppress baseline wandering?

2. What is a drawback of the Manchester code?

Exercise C.13: 8B6T Encoding

1. Draw the bit sequence of the following bytes, encoded with 8B6T and using the voltage levels -1V, 0V, 1V:

   0x2E, 0x0F

1. Name three advantages and one disadvantage of the 8B6T encoding compared to other encodings like NRZ(I).

Exercise C.14: Byte Stuffing

The following payloads are processed by the Binary Synchronous Communication Protocol on the data link layer. This protocol uses the symbol DLE for byte stuffing. Modify the payloads by using byte stuffing for the ETX and DLE symbols.

Bit stuffing is diff. from byte //.

1. 0x54 0x30 0x21 0x03 0x77 0x77
2. 0x68 0x10 0x50 0x33 0x34 0x20
3. 0x44 0x20 0x10 0x03 0x5F 0x2C

Exercise C.15: Cyclic Redundance Check

Typical exam question

Bluetooth uses the generator polynomial

$$x^5+x^4+x^2+1.$$

$$1^5 + 1^4 + 0^3 + 1^2 + 0^1 + 1^0$$

Calculate the checksum for the bit sequence

then Polynomial division (XOR operation)

answer = 1010

1010100111011 1010 → now, it can be sent.

110101

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Exercise C.16: Error-Correction Codes

→ more effecient
→ less redundant inform-ation

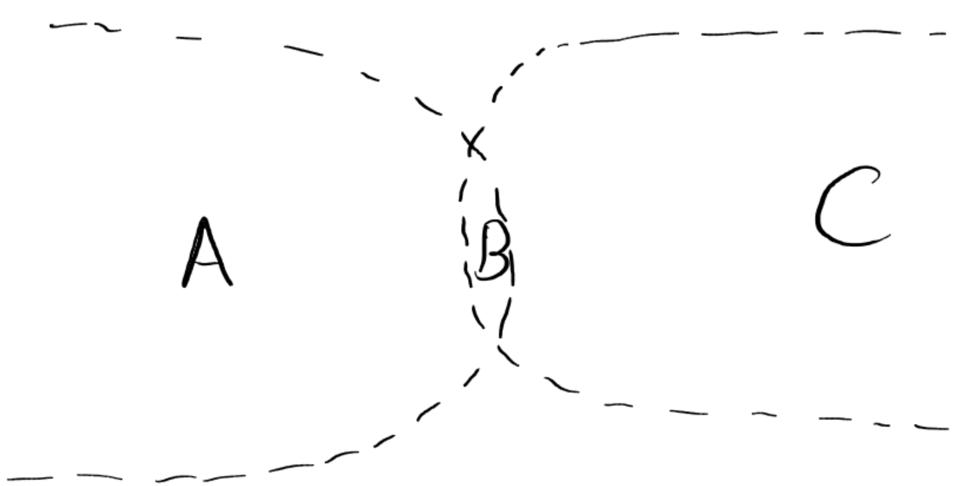
1. In many applications, only error-detection codes are used instead of error-correction codes. Why?

2. Name at least one application, where it is useful to choose an error-correction code.

In some application we need to correct the message directly, when you have no problem with redundant information.

Exercise C.17: CSMA/CD and CA

WLAN uses CSMA/CA instead of CSMA/CD, because with WLAN it is not possible to detect all collisions. Why it is not possible to detect all collisions?



we can't use a proto call, which based on collisions detection (wlan) rather, we use collisions avoidance proto call

Exercise C.18: CSMA/CA RTS/CTS

1. For which conditions, it is useful to use CSMA/CA RTS/CTS instead of CSMA/CA?

   It you are sending large packages.

2. Name a drawback of CSMA/CA RTS/CTS compared to CSMA/CA.

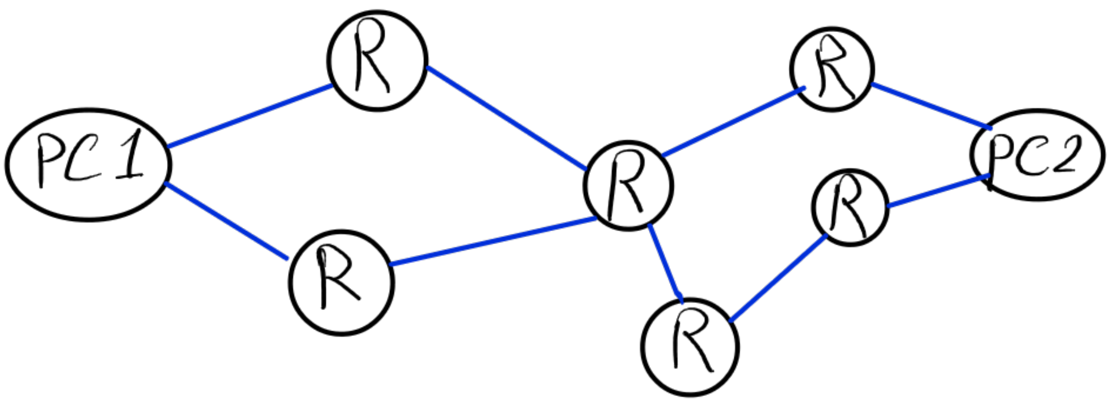
   Wasting some energy

Exercise C.19: Internet Protocol

The Internet Protocol (IP) is a connectionless protocol. Name one advantage and one disadvantage of the IP protocol.

(IP) doesn't have a specific defined path, multitask

disadv.: no acknowledgement it the person recieved



Exercise C.20: IPv4 Subnets

128

You have to set up a local network for 128 different devices +2 with one individual IP adress each.

Define the mask for the smallest possible subnet.

Decimal Mask	Binary Mask	Subnet Bits	Possible Subnets	Hosts Bits	Max Hosts
255	11111111	8	256	0	0
254	11111110	7	128	1*	0*
252	11111100	6	64	2	2
248	11111000	5	32	3	6
240	11110000	4	16	4	14
224	11100000	3	8	5	30
192	11000000	2	4	6	62
128	10000000	1	2	7	126
0	00000000	0	1	8	254

Exercise C.21: IPv4 Adresses

Exam question

The IP address is 193.99.144.85/27.

1100 0001.0110 0011.1001 0000.0101 0101

Calculate

1111 1111. 1111 1111. 1111 1111. 1110 0000

1. the subnet mask. 255.255.255.224

255x3:224

2. the subnet address.

64 (+1)

1100 0001.0110 0011.1001 0000.0100 0000

3. the broadcast adress.

1 1111

4. the range of host adresses.

95 (-1)

.0100 000

For the rang of hosts

65-94 is the range

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Exercise C.22: TCP vs. UDP

Explain, why UDP is often for video telephony and TCP for a webserver.

because it's better to ignoure a package if it didn't

Exercise C.23: IP Addresses, Port Numbers and Sockets

Explain the differences between an IP address, a port and a socket.

$$\underbrace{\underbrace{193.99.144.85}_{\text{IP address}}:\underbrace{8080}_{\text{Port}}}_{\text{Socket}}$$

Exercise C.24: CAN Bus Arbitration (1)

You have two CAN bus nodes with the IDs 15 and 16, starting a transmission at the same time. Which one will win the arbitration process and why?

Exercise C.25: CAN Bus Arbitration (2)

Why is it not allowed to have two CAN bus nodes connected to the same bus with the same IDs? What would be the consequence of two identical IDs?

Exercise C.26: CAN Bus Bit Stiffing

You have the following CAN bus frame. Add the stiffing bits.

After 5 consecutive 1s or 0s we stiff an opesite bit additionally after it.

Complete CAN Data Frame

		Arbitration Field										
		11 bit identifier										
	Start of Frame	ID 10	ID9	ID8	ID 7	ID 6	ID 5	ID 4	ID 3	ID 2	ID 1	ID 0
Data	0	0	0	0	0	0	0	1	0	1	0	0

	Control							Data							
				Data length code				1 to 8 bytes							
	RTR	IDE	Reser ved	DL 3	DL 2	DL 1	DL 0	D 7	D 6	D 5	D 4	D 3	D 2	D 1	D 0
Data	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1

	CRC Field (15 bits)														
	15 Bits														
	CRC14	CRC12	CRC11	CRC10	CRC9	CRC8	CRC7	CRC6	CRC5	CRC4	CRC3	CRC2	CRC1	CRC0	CRC Delimitter
Data	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1

			End of Frame						
			7 bits						
	Ack slot bit	Ack delimitter	D 6	D 5	D 4	D 3	D 2	D 1	D 0
Data	0	1	1	1	1	1	1	1	1

Exercise C.27: SPI Bus

You have a microcontroller (SPI master), wanting to send a command (0x01) and a 16bit data word to a SPI slave. The slave‘s SPI configuration is:

CPOL=0, CPHA=0, Little-Endian, MSB first.

Draw the timing diagram for SS, SCK, MOSI and MISO.