# Interim Exam 1
# 5AIB0 Sensing, Computing, Actuating
# 11-5-2017, 10.45-11.45
# Location AUD 10

**Name:** ______________________________

**ID:** ______________________________

- This interim exam consists of two questions for which you can score in total at most 30 points. The final grade for this interim exam is determined by dividing the number of points you scored by 3.
- The solutions to the exercises should be clearly formulated and written down properly. Do not only provide the final answer. Explain your choices and show the results of intermediate steps in your computation.
- The use of a simple calculator is allowed. No graphical calculator or laptop may be used during the interim exam.

**Exercise 1: throttle position sensor** **(15 points)**

The driver of a car can control the power delivered by the engine through the throttle pedal. When moving this pedal, the driver changes the amount of fuel or the fuel/air mixture. This allows the driver to control the speed of the car. Traditionally, the throttle pedal has been connected with a carburetor valve using a so called bowden cable. Modern cars use a "drive-by-wire" system that replaces this cable with an electric system. These systems use a sensor to sense the position of the throttle pedal. One option would be to use a resistive displacement sensor such as the one shown in Figure 1. This sensor can be used to measure linear displacements of an object. The sensor consists of a variable resistor $R_T$, a fixed resistor $R_s = R_T/a = 1500\ \Omega$ and a constant voltage supply $V_r = 9$ V. The sensor is connected to a measurement circuit with a purely resistive impedance $R_m = R_T/b$ with a resistance of 3000 Ω. This measurement load causes a loading error in the output voltage $v_m$ of the sensor.

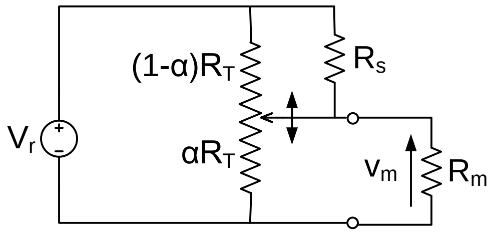


Figure 1: Displacementsensor with processing circuit.

(5p) (a) Show that the output voltage $v_m$ of the circuit shown in Figure 1 is equal to:

$$v_m = \frac{\alpha\left(1 + a\left(1-\alpha\right)\right)}{1 + \alpha\left(1-\alpha\right)\left(a+b\right)} V_r$$

**Exercise continues on next page**

(5p) (b) Show that the relative error in the output voltage of the sensor due to the loading circuit $R_m$ is equal to:

$$\epsilon = \left| \frac{\alpha\,(1-\alpha)\,b}{1+\alpha\,(1-\alpha)\,(a+b)} \right|$$

(5p) (c) A certain application requires that the relative error of the sensor at $\alpha = 0.75$ is not more then 3%. What value should the resistor $R_T$ to ensure that this constraint is met? (Hint: use $a = 2b$)

**Interim exam continues on next page**

**Exercise 2: climate control system** **(15 points)**

Automatic climate control systems are found in many cars that are sold nowadays. The system allows the driver or its passengers to set the desired in-door temperature. The climate control system will cool or heat the in-door air till the desired temperature is reached. The temperature inside the car is an important factor in the operation of the control system. Since this temperature is not known at the time the system is designed, it must be measured using a sensor. This sensor reading can then be processed by the control algorithm to compute the required actuation action (i.e., heat or cool the in-door environment).


Figure 2: Climate control.

The circuit in Figure 3 can be used to measure the in-car temperature. This circuit is designed to operate between -40°C and +40°C. The resistor $R_2$ is a temperature dependent resistor (RTD) of type PT100. The relation between temperature and resistance (transfer function) can be approximated with the following linear equation: $R_2(T) = R_0(1 + \alpha T)$, with $R_0$ equal to 100Ω and $\alpha = 0.004/°\text{C}$. The resistor $R_1$ has a fixed value ($R_1 = R_0 \cdot k$). The reference voltage $V_r$ is equal to 5 V. The RTD is surrounded by air with a dissipation factor $\delta = 20$ mW/K.

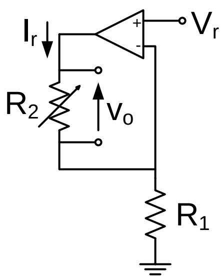


Figure 3: Temperature sensor.

(5p) (a) What resistance should the resistor $R_1$ have to ensure that the self-heating in the RTD $R_2$ is less then 0.1°C?

**Exercise continues on next page**

(5p) (b) What resistance should the resistor $R_1$ have to ensure a sensitivity of 1 mV/°C in the output voltage $v_o$?

(2p) (c) The operation of a temperature dependent resistor (RTD) is based on the thermo-resistive effect. Explain briefly (maximal 200 words) how this effect works in metals.

(3p) (d) Give a definition (maximally 100 words) for the following terms:

- Transducer
- Sensor
- Sensitivity of a sensor

# Formulae sheet

Characteristic temperature of material: $B_{T_1/T_2} = \frac{ln\left(\frac{R_2}{R_1}\right)}{\frac{1}{T_1}-\frac{1}{T_2}}$

Resistance: $R = \frac{m}{ne^2\tau}\frac{l}{A} = \rho\frac{l}{A}$

Strain: $\epsilon = \frac{dl}{l}$

Stress: $\sigma = \frac{F}{A} = E\frac{dl}{l}$

Poisson's ratio: $v = -\frac{dt/t}{dl/l}$

Change in specific resistance due to volume change (for metals): $\frac{d\rho}{\rho} = C\frac{dV}{V}$

Change in resistance due to strain: $\frac{dR}{R} = G\epsilon$

Capacitance of flat plate capacitor: $C = \frac{q}{V} = \epsilon_0\epsilon_r\frac{A}{d}$

Capacitance of cylindrical capacitor: $C = \frac{q}{V} = \epsilon_0\epsilon_r\frac{2\pi\cdot l}{ln(b/a)}$

Energy stored in capacitor: $E = \frac{C\cdot V^2}{2}$

Reluctance: $\Re = \frac{1}{\mu\mu_0}\frac{l}{A}$

Inductance: $L = \frac{N\cdot\Phi}{i} = \frac{N^2}{\Re}$

Flux: $\Phi = \mathbf{B}\times\mathbf{S}$

Magneto-motive force: $F_m = \Phi\cdot\Re = N\cdot i$

Amplitude response of Butterworth LPF: $|H\left(f\right)| = \frac{1}{\sqrt{1+\left(\frac{f}{f_n}\right)^{2n}}}$

Sideways force on electron moving through magnetic field: $\mathbf{F} = q\cdot\mathbf{v}\times\mathbf{B}$

Transverse Hall potential: $V_H = \frac{1}{N\cdot c\cdot q}\frac{i\cdot B}{d}sin(\alpha)$

Radius of warping of bimetal sensor: $r \approx \frac{2j}{3(\alpha_x-\alpha_y)(T_2-T_1)}$

Displacement of bimetal sensor: $\Delta = r(1-cos(\frac{180L}{\pi r}))$

Flow velocity and temperature difference: $v = \frac{K}{\rho}\left(\frac{e^2}{R_S}\frac{1}{T_s-T_0}\right)^{1.87}$

Voltage across P-N junction (quality factor 1): $V = \frac{kT}{q}ln\left(\frac{I}{I_0}\right)$

Saturation current through PN-junction (quality factor 1): $I_0 = BT^3e^{-E_g/kT}$

Thomson effect: $Q = I^2\cdot R - I\cdot\sigma\frac{dT}{dx}$

Peltier coefficient: $\pi_{AB}(T) = T\cdot(\alpha_A-\alpha_B) = -\pi_{BA}(T)$