Interim Exam 1
5AIB0 Sensing, Computing, Actuating
15-5-2018, 14.00-15.00
Location Paviljoen M23

Name: ______________________________

ID: ______________________________

- This interim exam consists of 1 question for which you can score at most 50 points. The final grade for this interim exam is determined by dividing the number of points you scored by 5.
- 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.

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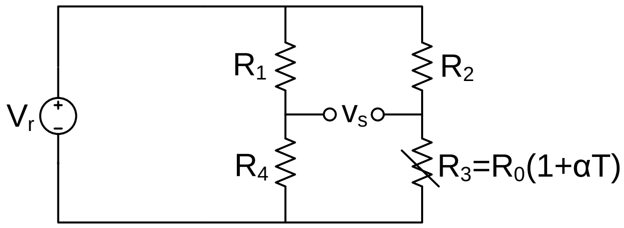
Exercise 1: temperature sensor **(50 points)**

A resistive temperature detector (RTD) can be used to measure the temperature of an object. Figure 1 shows a bridge circuit with an RTD which is exposed to a temperature T. This temperature will be in the range [-30°C, 80°C]. The RTD is a PT100 sensor with $R_0 = 100\ \Omega$ and $\alpha = 0.004/°\text{C}$ at 0°C.



Figuur 1: Bridge circuit with a RTD temperature sensor.

(5p) (a) Show that output voltage v_s of the sensor circuit is equal to:

$$v_s = -\frac{k\alpha T}{(k+1)(k+1+\alpha T)}V_r$$

, with $k = R_1/R_4 = R_2/R_0$.

(7p) (b) What ratio k should the resistors R_2/R_0 have to ensure that the non-linearity error is less then 0.8% of the reading while maximizing the sensitivity?

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(7p) (c) Assume that $k = 38.7$. Assume further that the dissipation constant of the environment $\delta = 1$ mW/K. What value should the supply voltage V_r have to keep the self-heating below 0.002% of the full-scale output (FSO)?

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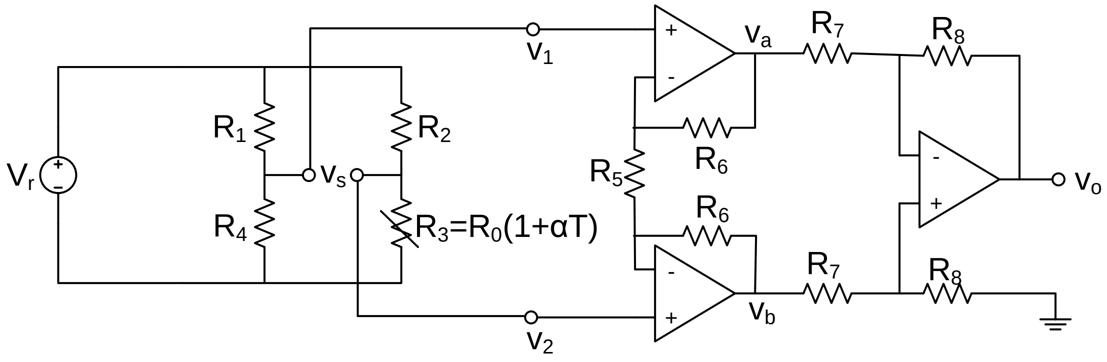

Figuur 2: Sensor circuit connected to instrumentation amplifier.

(8p) (d) The sensor circuit from Figure 1 is connected to an instrumentation amplifier (see Figure 2). Show that the output voltage v_o of the circuit shown in Figure 2 is equal to:

$$v_o = \left(1 + \frac{2R_6}{R_5}\right)\frac{R_8}{R_7}\frac{k\alpha T}{(k+1)(k+1+\alpha T)}V_r$$

Exercise continues on next page

(5p) (e) Assume that the resistors R_6, R_7, and R_8 are all equal to 150 kΩ, $k = 38.7$, and $V_r = 4.3$ V. What resistance should the resistor R_5 have to ensure output of the circuit is equal 4.0 V at 80°C?

(5p) (f) Does this instrumentation amplifier suffer from a loading effect when it is connected to the sensing circuit? Explain you answer.

(5p) (g) 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.

Exercise continues on next page

(8p) (h) Give a definition (maximal 100 words) for the following terms:

- Transducer
- Sensor
- Sensitivity of a sensor
- Transfer function 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: $|H(f)| = \frac{1}{\sqrt{1+\left(\frac{f}{f_n}\right)^{2n}}}$

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