Informative Exam
5AIB0 Sensing, Computing, Actuating
26-5-2020, 13.30-14.30

Name: ______________________________

ID: ______________________________

- This interim exam consists of 1 question for which you can score at most 45 points. The final grade for this interim exam is determined by dividing the number of points you scored by 4.5.
- 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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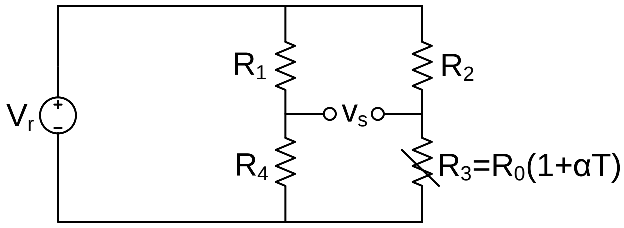
Exercise 1: temperature sensor **(45 points)**

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 $\alpha = 0.004$/°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 $k = R_1/R_4 = R_2/R_0$.

(5p) (b) Has the sensor output voltage v_s a non-linearity error in terms of the temperature T? (Explain your answer)

(5p) (c) Show that the relative non-linearity error in the output voltage v_s is equal to:

$$\epsilon = \left| \frac{-\alpha T}{k + 1 + \alpha T} \right|$$

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(5p) (d) 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?

(5p) (e) Explain how the self-heating effect causes an error in the resistance of the RTD.

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(5p) (f) 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 0.2% of the full-scale output (FSO)?

(5p) (g) The circuit in Figure 1 uses three fixed resistors and one RTD. What would be the advantage when the fixed resistor R_1 in Figure 1 is replaced with an RTD similar to the RTD used for R_3?

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(5p) (h) 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.

(5p) (i) What is the essential difference between an active and a passive 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: $\pi_{AB}(T) = T \cdot (\alpha_A - \alpha_B) = -\pi_{BA}(T)$