Interim Exam 1
5AIB0 Sensing, Computing, Actuating
8-5-2014, 9.00-10.00
Location AUD 3

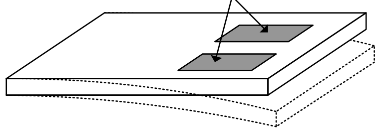
Name: ____________________

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.

Exercise 1: resistive pressure sensor **(50 points)**

Strain gauges are used amongst others to measure pressure. Figure 1 shows two strain gauges that are attached to a thin metal strip (E = $200 \cdot 10^9$ N/m^2). The strain gauges are combined with two resistors with a fixed value into a complete bridge. When unloaded, each strain gauge has a resistance of 200 Ω. The fixed resistors also have a resistance of 200 Ω. The strain gauges have a gage factor of 2.00. To prevent damage to the strain gauges, the maximal current through them should be limited to 25 mA.



Figuur 1: Metal strip with two active strain gauges.

The two strain gauges and the two fixed resistors are connected in a bridge circuit with a voltage supply V_r. The electrical equivalent circuit of this sensor is shown in Figure 2.

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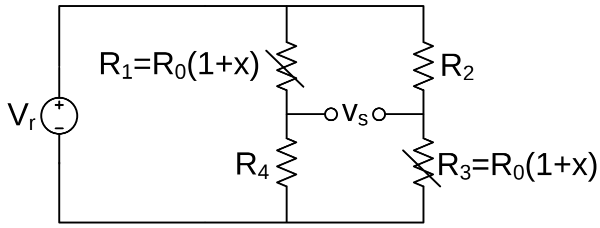

Figuur 2: Bridge circuit with two strain gauges.

(5p) (a) The sensor circuit in Figure 2 contains two active strain gauges. You can also design a pressure sensor with only one strain gauge and three fixed resistors. Mention at least one advantage of the circuit shown in Figure 2 compared to a solution with only one active strain gauge.

(6p) (b) Show that the output voltage v_s of the sensor circuit is equal to:

$$v_s = -\frac{x}{2+x} V_r$$

Exercise continues on next page

(6p) (c) What value should the voltage supply V_r have to maximize the sensitivity of the sensor circuit shown in Figure 2 for a change in x?

(6p) (d) The resistance of the strain gauges, $R(x)$, does not only depend on the deformation of the strain gauges, the resistance is also influenced by the temperature of the environment. This influence of the environmental temperature on the resistance can be seen as a thermal signal y. The resistance of R_1 and R_3 is then equal to $R_0(1 + x + y)$. Show that the absolute error in the output voltage of the circuit, v_s, due to the temperature dependency of the strain gauges is equal to:

$$\epsilon = \left| \frac{-2y}{(2 + x + y)(2 + x)} V_r \right|$$

(Assume that the temperature dependency of the fixed resistors R_1 en R_4 can be ignored.)

Exercise continues on next page

(6p) (e) Show that the output voltage v_s of the sensor circuit shown in Figure 2 is equal to -5.00 mV when a pressure of $100 \cdot 10^6\ N/m^2$ is applied to the metal strip and $V_r = 10$ V.[1]

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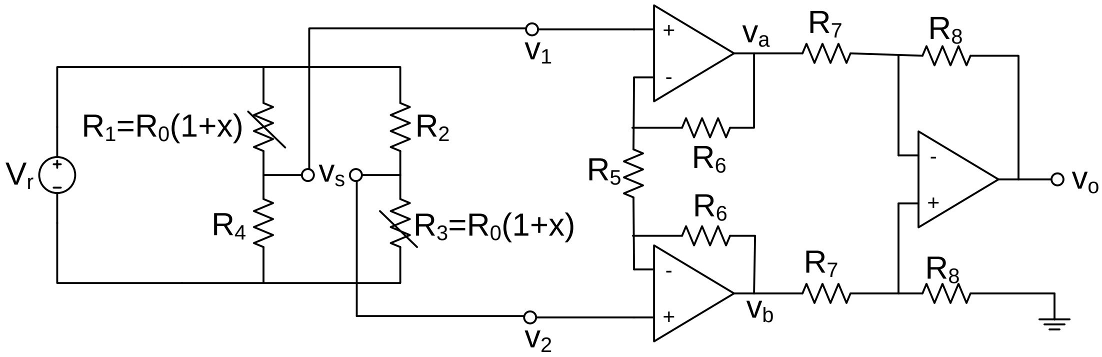
[1] You may ignore the error to the the thermal dependency of the resistors R_1 and R_3 in this and all all further questions of this exercise.

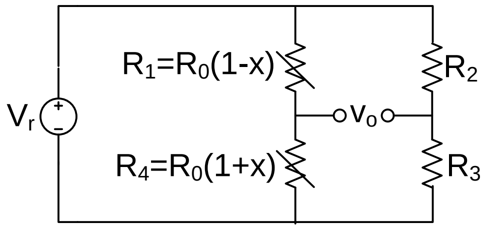


Figuur 3: Sensor circuit with processing circuit.

(8p) (f) The sensor circuit from Figure 2 is connected to an instrumentation aomplifier (see Figure 3). Show that the output voltage v_o of the circuit shown in Figure 3 is equal to:

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

Exercise continues on next page



Figuur 4: Alternative bridge circuit with two strain gauges.

(5p) (g) In stead of the sensor circuit from Figure 2 you may connect the alternative circuit from Figure 4 to the instrumentation amplifier from Figure 3. Mention at least one advantage of the sensor circuit from Figure 4 compared to the sensor circuit from Figure 2.

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