# Interim Exam 1
# 5AIB0 Sensing, Computing, Actuating
# 3-5-2015, 14.00-15.00
# Location AUD 11

**Name:** ______________________________

**ID:** ______________________________

- This interim exam consists of 1 question for which you can score 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 continues on next page**

**Exercise 1: resistive pressure sensor** **(30 points)**

Strain gauges are used amongst others to measure pressure. Figure 1 shows one strain gauge that is attached to a thin metal strip (E = $250 \cdot 10^9$ N/m$^2$). When unloaded, the strain gauge has a resistance of $R_0 = 150\ \Omega$. The strain gauge has a gage factor of 2.50. To prevent damage to the strain gauge, the maximal current through it should be limited to 10 mA.

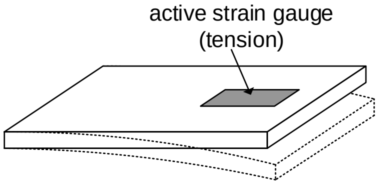


Figure 1: Metal strip with one active strain gauges.

The strain gauge is combined with three fixed resistors in a bridge circuit (see Figure 2) with a voltage supply $V_r$. The fixed resistors $R_1$ and $R_2$ have a resistance of $k \cdot R_0$, and the resistor $R_4$ has a resistance of 150 Ω. The electrical equivalent circuit of this sensor is shown in Figure 2.

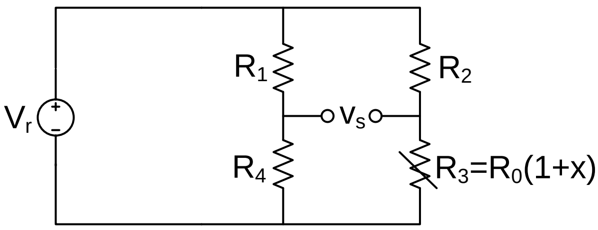


Figure 2: Bridge circuit with one strain gauge.

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

$$v_s = -\frac{kx}{(1+k)(k+1+x)} V_r$$

**Exercise continues on next page**

(5p) (b) Show that the relative non-linearity error in the output voltage of the sensor circuit is equal to:

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

(5p) (c) What is the change in the resistance of the resistor $R_3$ when a pressure of $100 \cdot 10^6\ N/m^2$ is applied to the metal strip?

**Exercise continues on next page**

(5p) (d) Assume that resistor $R_3$ has a resistance of 150.15 $\Omega$ when a pressure of $100 \cdot 10^6$ $N/m^2$ is applied to the metal strip. What resistance should the resistor $R_2$ have to minimize the non-linearity error to 0.01% of the reading when a pressure of $300 \cdot 10^6$ $N/m^2$ is applied to the metal strip?

(5p) (e) Assume that $k = 4$. 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 $x$?

**Exercise continues on next page**

(5p) (f) 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: $|H(f)| = \frac{1}{\sqrt{1+\left(\frac{f}{f_n}\right)^{2n}}}$

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