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Exam - PoMS, 23/01/2015

- Write your answer of each question on a seperate sheet of paper.
- Write your **name** and **student ID** on each sheet.
- Pay attention to **units**. A numerical result without a unit will be considered wrong!
- **Motivate** all your answers.
- Only a **regular calculator** is allowed.
- This is NOT an open book exam.
- You are allowed to bring one A4 page with your own notes (one side only).
- You have **3 hours** to complete the exam.

Question 1: General (2 points)

a) Describe the working principle of a *thermocouple*. Describe a measurement setup using a Copper-Constantan thermocouple and a voltmeter. (1/2 pt)

b) Describe the technique of *Amplitude Modulation* (AM). Give an example application. (1/2 pt)

c) What is *reluctance* and explain qualitatively the working principle of a variable reluctance tachogenerator. (1/2 pt)

d) What is the working principle behind the *autocorrelation function* (ACF) and explain how and why it can be used to suppress white noise. (1/2 pt)

Question 2: A strain gauge (2 points+1/2 point bonus)

Strain e_L	-0.06	-0.03	0	0.03	0.06
Resistance R (Ω) at $T = 20$ °C (nominal condition)	92	96	100	104	108
Resistance R (Ω) at $T = 30$ °C	97	101	105	109	113

The table above shows the resistance, R, (output O) of a strain gauge as a function of the *strain*, e_L (input I). The resistance is measured at room temperature $T = 20$ °C (nominal condition) and at $T = 30$ °C.

a) What is the *gauge* (G) factor at the nominal temperature of $T = 20$ °C? (1/2 pt)

b) Determine the values of K_M, K_I, a, and K associated with the generalized model equation $O = (K + K_M \cdot I_M) \cdot I + a + K_I \cdot I_I$. Argue whether the environmental variable is modifying, interfering, or both modifying and interfering. (1 pt)

c) The strain gauge is embedded in a 1/4 Wheatstone (deflection) bridge. The other three (balance) resistances in the bridge are each R_0=100 Ω. The D.C. power supply of the bridge is V_S=12 V. Estimate and discuss the maximum non-linearity of the Thévenin output voltage (E_{Th}) of the bridge with respect to the strain e_L at $T = 20$ °C and for the range given in the table above. (1/2 pt + 1/2 pt bonus)

Question 3: A potentiometer (2 points)

A potentiometer has a total length of 10 cm and a resistance of 200 Ω.

a) Calculate the supply voltage so that the power dissipation is 1 W. (1/2 pt)

b) Draw the Thévenin equivalent circuit for an 8 cm displacement and calculate E_{Th} and R_{Th}. (1 pt)

c) The potentiometer is connected to a recorder with a resistance R_L. Find R_L such that the recorder voltage is 7% less than the open circuit voltage at an 8 cm displacement. (1/2 pt)

Question 4: A simple RC circuit (2 points+1/2 point bonus)

Figure 1 shows the schematics of an RC filter with R=100 Ω and C=1 μF. The input voltage is indicated as V. The voltage is transmitted to a recorder with an input resistance of R_L=10 kΩ.

a) Calculate the *static* loading effect. (1/2 pt)

b) Show that the dynamic part of the "source", ignoring the loading ($R_L \to \infty$), can be described as a first-order transfer function $G(s) = 1/(1+\tau s)$. Calculate the corresponding time constant, τ, and the bandwidth, ω_b. (1/2 pt)

c) Calculate the change in the time constant of the first-order transfer function due to the presence of the loading part (e.g. dynamic loading effect). (1/2 pt)

d) Calculate the response voltage (V_L) over R_L as a function of time in the case V increases suddenly (step function) from a steady state of 0 V to 10 V. In the case you got stuck in c), simply assume that $\Delta\tilde{V}_L = \Delta\tilde{V} \cdot K/(1+\tau' s)$ with K and τ' as constants. (1/2 pt)

e) Design an update of the RC filter using an ideal operational amplifier that would reduce the static and dynamic loading error without modifying the "source" and the "recorder". (1/2 pt bonus)

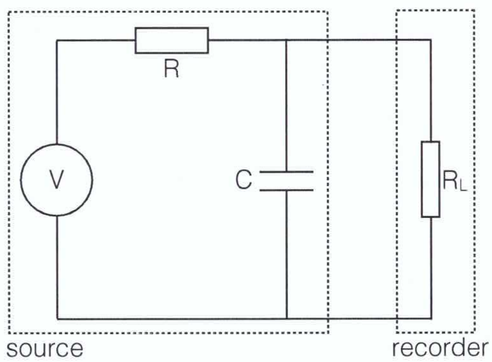

Figure 1: Figure corresponding to question 4.

Question 5: An oscillator (2 points)

Consider an oscillator with a variable reluctance displacement sensor as shown in Fig. 2. The sensor network has a transfer function $H(s)$ and the maintaining amplifier (not necessarily an operational amplifier) is represented by the transfer function $G(s)$. You can assume that no current flows into the negative terminal of the amplifier. The capacitor C=1 μF and the inductance L varies from 8 to 12 mH. The amplifier is designed such to maintain an oscillating output, V_O, with a frequency corresponding to the undamped natural frequency of the sensor.

a) Show that

$$H(s) = \frac{1}{LCs^2 + RCs + 1}. \quad (1/2 \text{ pt})$$

b) Calculate the frequency range of the oscillator. (1/2 pt)

c) What is the maximum allowed resistance R to obtain an underdamped response of $H(s)$ for the operational range of L? (1/2 pt)

d) Calculate the amplication and phase factor of $G(s)$ for L=10 mH. Take R=50 Ω. (1/2 pt)

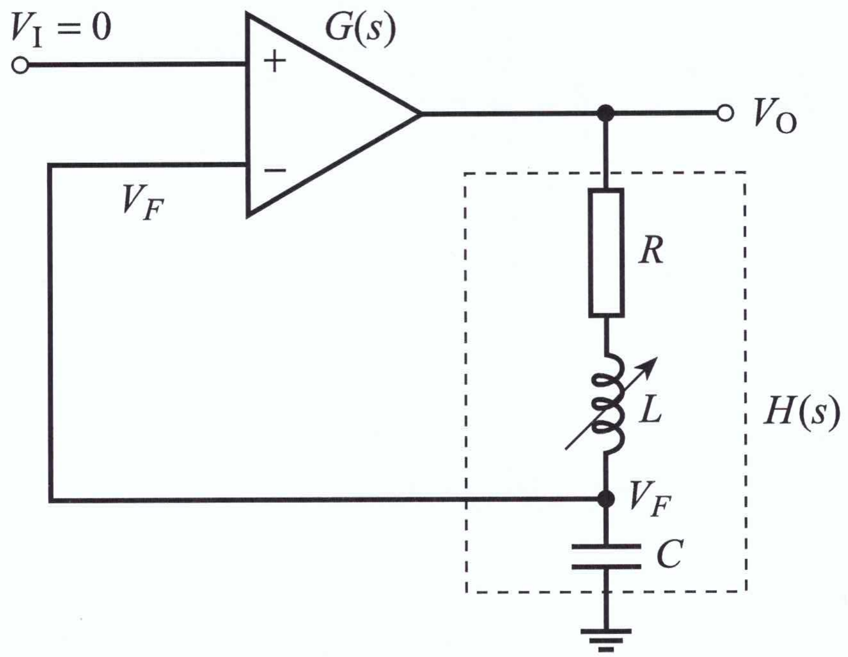

Figure 2: Figure corresponding to question 5.

Some useful expressions

- Laplace transformation:

$$\mathscr{L}(t^n\, e^{-\alpha t}) = \frac{n!}{(s+\alpha)^{n+1}}.$$

- First-order transfer function:

$$G(s) = \frac{1}{1+\tau s}.$$

- Second-order transfer function:

$$G(s) = \frac{1}{s^2/\omega_n^2 + 2\xi s/\omega_n + 1}.$$