UNIVERSITY OF SWAZILAND
MAIN EXAMINATION, MAY 2015

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

TITLE OF PAPER:	**INSTRUMENTATION SYSTEMS**
COURSE NUMBER:	**EE521**
TIME ALLOWED:	**THREE HOURS**

INSTRUCTIONS:

1. There are five questions in this paper. **Answer any FOUR questions.**
2. Each question carries 25 marks.
3. Marks for different sections are shown on the right hand margin.
4. Show the steps clearly in all your calculations including any assumptions made. This is because marks may be awarded for method and understanding, even in the event of incorrect answers.
5. A table of standard values of 1% tolerance resistors and a table of common capacitor values are attached at the end of the question paper for your use in designs.

THIS PAPER IS NOT TO BE OPENED UNTIL PERMISSION HAS BEEN GIVEN BY THE INVIGILATOR

THIS PAPER HAS SEVEN (7) PAGES INCLUDING THIS PAGE

QUESTION 1 *(25 marks)*

(a) What is meant by each of the following terms as used in the specification of a sensor

(i) Accuracy *(1 mark)*

(ii) Resolution *(1 mark)*

(iii) Sensitivity *(1 mark)*

(iv) Dynamic range *(1 mark)*

(v) Linearity *(1 mark)*

(b) A first order Butterworth **high-pass** RC filter must reduce the amplitude of a 50 Hz

For a first order Butterworth HP filter $\left|\frac{v_o}{v_{in}}\right| = \frac{f / f_c}{\sqrt{1+(f/f_c)^2}}$

interference signal down to 0.8% of its original value.

(i) Specify the filter cut-off frequency, *(6 marks)*

(ii) Find the attenuation in dB of a 10-kHz signal passed through the filter. *(2 marks)*

(iii) If a capacitor of 10 nF is used in realizing this filter, specify the value of resistor to be used with the capacitor. *(2 marks)*

(c) Four similar strain gauges are mounted on a metal beam, two on top of the beam and two on the bottom surface. The gauges have a nominal resistance of 120 Ω and a gauge factor 2.1. In order to measure the bending stress on the beam the gauges are connected to form a **full bridge** circuit.

(i) Sketch a diagram illustrating how the four strain gauges should be connected to form a bridge of maximum sensitivity. You must specify exactly where the top gauges and bottom gauges go in your bridge. *(4 marks)*

(ii) The bridge is excited with an excitation current of 100 mA. Calculate the sensitivity of the bridge in Volts per unit micro strain. *(6 marks)*

QUESTION 2 ***(25 marks)***

A measurement system consists of two submersible sensors, one for measuring depth in a liquid and the other the temperature of the liquid are tied together and used to measure the temperature profile of water contained in an open tank at various depths. The depth sensor has a **zero-order response** while the temperature sensor has a **first order response** with a time constant of 20 s. It is known that the temperature T_x in ^{0}C at depth *x* metres is given by the equation

$$T_x = T_o - 0.5x$$

where T_o is the temperature at the surface of the water. The temperature at the surface of the water is 25.0 ^{0}C and the sensors are initially floating on the surface with the instrument output readings in steady state. At time $t = 0$ s the sensors are lowered (submerged) at a constant rate of 0.1 m/s.

(a) Show that the temperature reported by the temperature sensor at time t is given by

$$20\frac{dT_R}{dt} + T_R = T_x = 25 - 0.05t$$ *(5 marks)*

(b) Show that the solution to the above response equation is

$$T_R = 26 - 0.05t - e^{-t/20}$$ *(8 marks)*

(c) Hence draw a table showing the temperature reported by the measurement system every 10 s of travel for the first 50 s and the error (to 2 dec. places) in each reported temperature measurement. *(8 marks)*

(d) If the tank was very deep say 100 m (Note that the same measurement could be carried out in the ocean), what would be the error in the temperature measurement? *(2 marks)*

(e) Suggest a simple way in which the accuracy of the measurement of this temperature profile could be improved. *(2 marks)*

QUESTION 3 ***(25 marks)***

A photovoltaic diode is to be used to measure light intensity in the range 4 to 20 mW/cm^2. Measurements show that its **unloaded** output voltage ranges from 0.16 to 0.55 V over this range of intensity. When loaded with a 120 Ω load it delivers a current of 0.4 to 2.5 mA over the same range of intensity.

(a) Determine the range of the short-circuit current of the photovoltaic cell. *(10 marks)*

(b) If the short circuit current of the photovoltaic diode is linearly related to light intensity, develop a signal conditioning circuit to provide a linear output voltage from 0.3 V to 5 V as the solar radiation intensity varies from 4 to 15 mW/cm^2. *(15 marks)*

QUESTION 4 *(25 marks)*

(a) In preparation for trouble shooting the opamp circuit shown in Fig. Q4a, voltages at certain nodes need to be worked out. The nodes 0, 4, 7 and 10 have been given as having voltages 0 V, 440 mV, 10 mV and 10 V respectively. Work out the voltages expected at the nodes 5, 6, 3, 2, 1, 9, 8 and 11 assuming that all the opamps are ideal. *(10 marks)*

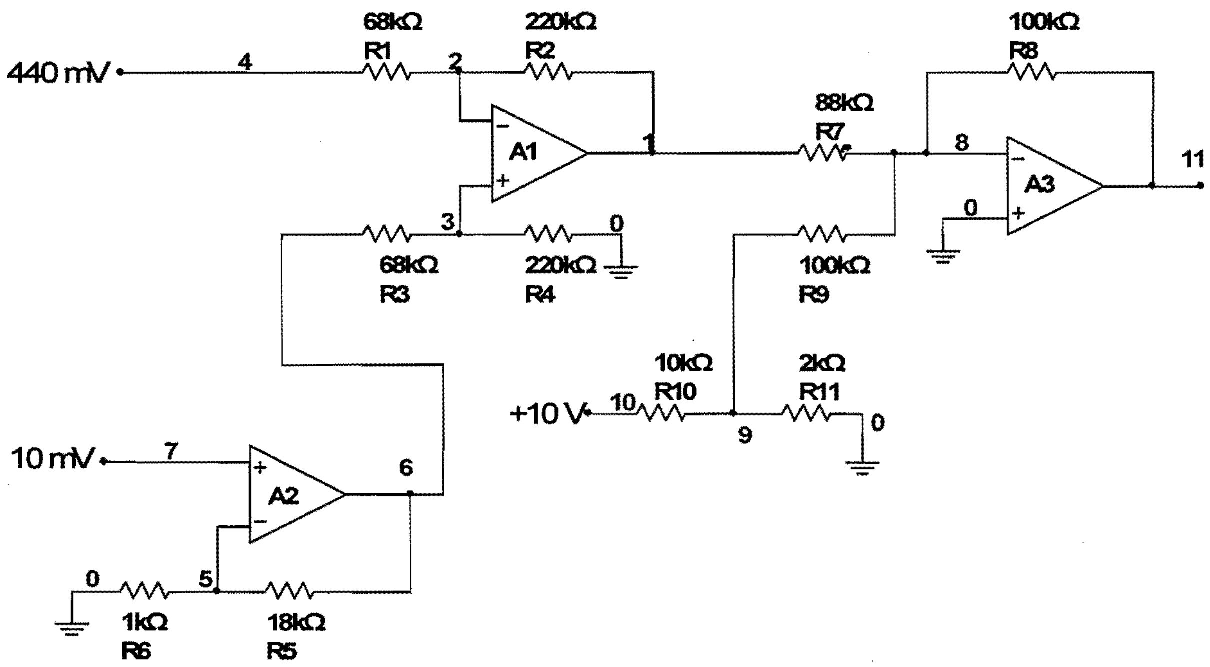

Fig. Q 4a

(b) Design a circuit to transmit a 0 to 4 V analogue signal over a 4 mA to 20 mA current transmission loop. Assume that **load is floating** and that the amplifiers used saturate at ±13 V. What are limits of the load resistance at the loop receiver? *(15 marks)*

QUESTION 5 ***(25 marks)***

A thermistor is used to measure the air temperature (which is around 23 °C) using the bridge circuit shown in Fig. Q5. The bridge is connected to an instrumentation amplifier which amplifies according to the equation $V_o = 6(V^+ - V^-)$. The thermistor has a resistance $R_T =$ 10.0 kΩ at temperature T = 23 °C and is assumed to have a linear response around 23 °C so that $\frac{dR_T}{dT} = -300\ \Omega/°C$.

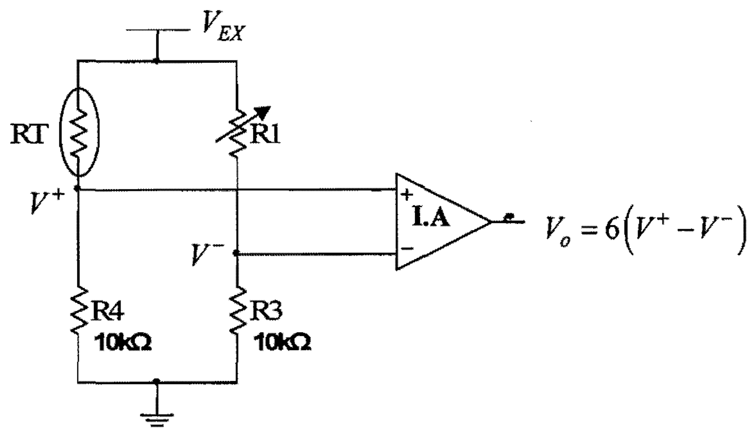

Fig.Q5

In order to study the effect of self-heating, two experiments described below are performed.

(a) **Experiment 1**

With excitation $V_{EX} = 1$ V and the thermistor immersed in water at 23 °C, R_1 is adjusted until $V^+ - V^- = 0.000$ V. Assume that the quantity of water is large enough to ensure that its temperature does not change due to self-heating of the thermistor. For this experiment:

(i) What are the values of R_1 and R_T? *(2 marks)*

(ii) What is the power dissipation in the thermistor? *(5 marks)*

(b) **Experiment 2**

Without changing the value of R_1 and with the excitation still at $V_{EX} = 1$ V, the thermistor is removed from the water and moved to air which is at 23 °C and after a while the instrumentation amplifier output voltage increases to 0.060 V. For this experiment:

(i) What is the new value of R_T? *(4 marks)*

(ii) At what temperature is the thermistor? *(4 marks)*

(iii) What is the power dissipation in the thermistor? *(5 marks)*

(iv) Find the thermal dissipation coefficient of the thermistor in W/°C? *(5 marks)*

= = = = = END OF QUESTION PAPER, ATTACHMENT FOLLOWS = = = = =

VALUES OF STANDARD 1% TOLERANCE RESISTORS

100	140	196	274	383	536	750
102	143	200	280	392	549	768
105	147	205	287	402	562	787
107	150	210	294	412	576	806
110	154	215	301	422	590	825
113	158	221	309	432	604	845
115	162	226	316	442	619	866
118	165	232	324	453	634	887
121	169	237	332	464	649	909
124	174	243	340	475	665	931
127	178	249	348	487	681	953
130	182	255	357	499	698	976
133	187	261	365	511	715	
137	191	267	374	523	732	

COMMON STANDARD VALUES OF CAPACITORS

10	**15**	**22**	**33**	**47**	**68**	**pF**	**Non-polarized**
100	**150**	**220**	**330**	**470**	**680**	**pF**	**Non-polarized**
1	**1.5**	**2.2**	**3.3**	**4.7**	**6.8**	**nF**	**Non-polarized**
10	**15**	**22**	**33**	**47**	**68**	**nF**	**Non-polarized**
100	**150**	**220**	**330**	**470**	**680**	**nF**	**Non-polarized**
1	**1.5**	**2.2**	**3.3**	**4.7**	**6.8**	**µF**	**Non polarized /Polarized**
10	**15**	**22**	**33**	**47**	**68**	**µF**	**(Polarized)**
100	**150**	**220**	**330**	**470**	**680**	**µF**	**(Polarized)**
1000	**1500**	**2200**	**3300**	**4700**	**6800**	**µF**	**(Polarized)**

Zero order response $a_o s_o = b_o s_i$

First order response $a_1 \frac{ds_o}{dt} + a_o s_o = b_o s_i$ or $\tau \frac{ds_o}{dt} + s_o = Ks_i$