UNIVERSITY OF SWAZILAND
MAIN EXAMINATION, MAY 2014

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) Draw and briefly explain a block diagram of a generalized instrumentation system.

(8 marks)

(b) A load cell to be used to measure weight in the range 0 to 12 kg is tested and gave the following output voltages.

Weight, kg	0.0	2.0	4.0	6.0	8.0	10.0	12.0
Output, mV	3.12	3.65	4.24	4.86	5.36	6.02	6.65

(i) Calculate the sensitivity and zero offset of the load cell.

(5marks)

(ii) The output of this load cell is to be fed into an ADC which has an input analogue signal range of 0 V to 5 V. Design a suitable circuit to interface the load cell to the ADC.

(12 marks)

QUESTION 2 *(25 marks)*

Consider the three-opamp configuration of an instrumentation amplifier (IA) shown in Fig. Q2. The amplifier is used for amplifying the output of a differential pair of electrocardiograph skin electrodes fed in as signal inputs v_1 and v_2. The opamps A1, A2, A3 may be assumed to be ideal.

(a) If the IA is required to have as high a CMRR as possible, derive relevant expressions differential gain **G1** of the first stage (consisting of opamps A1 and A2) and differential gain **G2** of the second stage (consisting of opamp A3). *(10 marks)*

(b) You are required to design the IA given the following specifications:

Minimum differential signal from the input probes is 0.5 mV
Maximum differential signal from the input probes is 4.0 mV
Minimum peak output voltage required from the IA is 0.5 V
Differential gain **G2** of the second stage is 10 times the differential gain **G1** of the first stage
$R_7 = 100\ \text{k}\Omega$, $R_1 = 10\ \text{k}\Omega$ and $R_3 = 10\ \text{k}\Omega$

(i) Calculate the values of resistors R_2, R_4, R_5, and R_6. *(10 marks)*

(ii) If the amplifiers are capable of producing an output voltage of amplitude to within 1 V of the power supply voltage without saturation, what should be the supply voltage for the amplifiers to operate without clipping the signal. *(3 marks)*

(iii) How can the CMRR of the amplifier you designed be maximized during implementation? *(2 marks)*

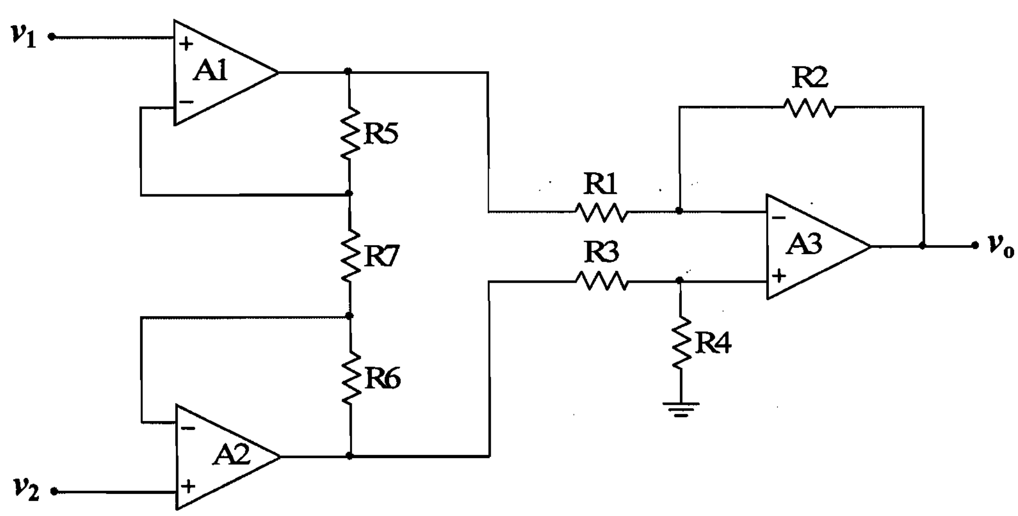

Fig.Q2

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

(a) A temperature sensor with a sensitivity of 10 mV/ °C is to be used in a digital thermometer with a range of 0°C to 100°C with a resolution of 0.5 °C or better. The ADC to be used has a full scale analogue input range of 0 to 6 V.

(i) Determine the number of bits required in the ADC. *(3 marks)*

(ii) Design an appropriate signal amplifying circuit for the sensor. *(5 marks)*

(iii) What actual voltage and temperature changes does the least significant digit represent? *(2 marks)*

(b) An ultrasonic transmitter and receiver for measuring the depth of a liquid in a tank is mounted 0.4 m above the highest level of liquid in the tank. The bottom of the tank is 6 m below the highest level of liquid. The depth of liquid in the tank is measured by evaluating the time taken for a transmitted ultrasonic pulse to return to the receiver. A counter operating at an appropriate clock frequency is used for evaluating the time. Assume that the speed of sound in air is 331.5 m/s

(i) If the resolution of the depth measurement is required to be 1 cm, determine the number of bits required in the counter. *(5 marks)*

(ii) When measuring the ultrasonic pulse is sent at the same time as the counter is preloaded with a number representing a full tank. The counter counts down until the transmitted pulse is received back. The counter reading should then indicate the depth of liquid in cm. Determine the required clock frequency and the number which should be preloaded on the counter. *(10 marks)*

QUESTION 4 ***(25 marks)***

(a) A strain gauge of nominal resistance 240 Ω and gauge factor 2.1 is bonded lengthwise to a steel beam of length 16 cm and cross-section 12 mm by 5 mm. For steel Young's Modulus $E = 20.7 \times 10^{10}$ N/m^2 and temperature coefficient $\alpha = 0.003925$ / °C. A force of 20 kg is applied lengthwise to the beam.

(i) Calculate the change in length of the beam. *(4 marks)*

(ii) If the strain gauge experiences a change in temperature of 15 °C, compare the change in resistance due strain with the change of resistance due to temperature. *(6 marks)*

(iii) Explain how you would use circuit arrangements to compensate for the effect of temperature change when measuring strain. *(5 marks)*

(b) Briefly describe one method of measuring flow of a liquid. *(4 marks)*

(c) Explain why three or four leads are normally used for connecting a Resistance Temperature Detector (RTD) to a circuit. *(6 marks)*

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

(a) Explain why temperature compensation is used in temperature measurements using thermocouples. *(5 marks)*

(b) Design a fourth order equal-component Sallen-Key lowpass filter with a cut-off frequency of 1.2 kHz. You given that for a 4^{th} order Sallen-Key **equal-component filter** K=1.152 and 2.235. *(10 marks)*

(c) Design a circuit to transmit a 0 to 5 V analogue signal over a 4 mA to 20 mA current transmission loop. Assume that load is floating and that amplifiers saturate at ±10 V. What are limits of the load resistance at the receiver? *(10 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)**