UNIVERSITY OF SWAZILAND
SUPPLEMENTARY/RESIT EXAMINATION, JULY 2018

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.

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THIS PAPER HAS SIX(6) PAGES INCLUDING THIS PAGE

QUESTION 1 *(25 marks)*

(a) Explain the meaning of the following terms:

(i) Measurement. *(2 marks)*

(ii) Instrument. *(2 marks)*

(iii) Accuracy *(2 marks)*

(iv) Precision *(2 marks)*

(v) Triple point. *(2 marks)*

(b) An instrumentation amplifier circuit is shown in **Fig. Q.1b**. For this amplifier.

(i) Derive an expression for the output voltage v_o as a function of the resistors and input voltages, v_1 and v_2. *(10 marks)*

(ii) If $R_1 = R_3 = 10\ \text{k}\Omega$ and $R_2 = R_G = 5\ \text{k}\Omega$ determine the ouput voltage v_o when the input voltages are: $v_1 = 4.97\ \text{V}$ and $v_2 = 5.03\ \text{V}$. *(5 marks)*

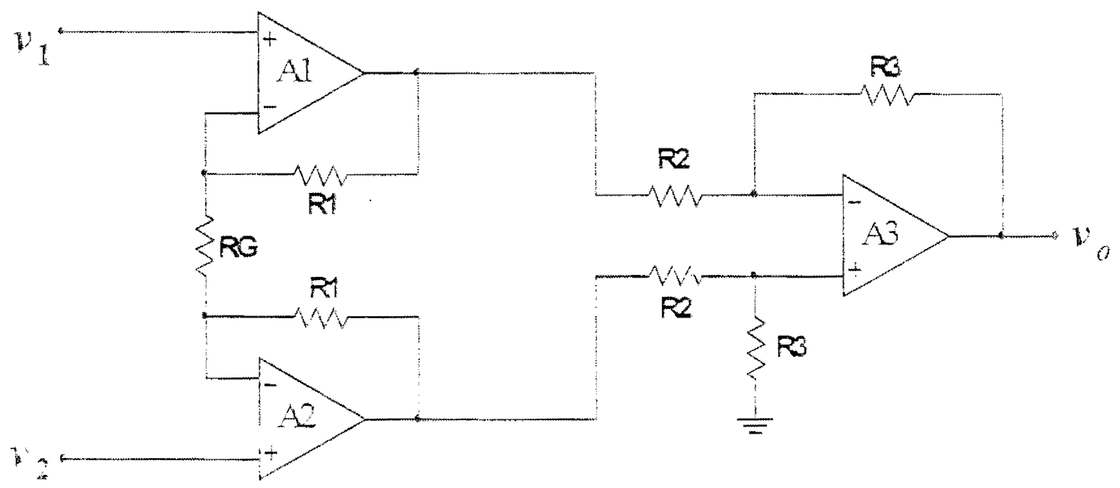


Fig. Q1.b

QUESTION 2 *(25 marks)*

(a) Explain what is meant by cross-sensitivity of a sensor and give one practical example of it. *(4 marks)*

(b) An ADC has an input range **0 to 5.00 V**.

(i) If its resolution is **20.8 mV**. How many bits would be required to represent its output? *(3 marks)*

(ii) If its output is **24 bits**, what would be the required resolution? *(3 marks)*

(iii) Comment on the realization and construction challenges in the case (ii) above. *(3 marks)*

(c) A solid state temperature sensor has a first-order order response with a time constant of 3.5 s. The sensor is initially in steady state in an ambient temperature of $20°C$. The sensor is then suddenly immersed, at $t = 0$, into a bath of liquid at temperature of $50°C$.

(i) Find the output voltages of the sensor after **0.5 s**, **4.8 s** and **8.5 s** *(8 marks)*

(ii) If we wish to read the bath temperature to an accuracy of at least **1%**, how long should we wait before taking a reading? *(4 marks)*

QUESTION 3 *(25 marks)*

(a) Explain why bridge circuits are commonly used in sensor conditioning circuits.

(4 marks)

(b) For the strain gauge sensor bridge circuit shown in Fig. Q.3b, show that

$$V_o = \frac{1}{2}\left(\frac{\Delta R}{R}\right)V_{EX}$$

(6 marks)

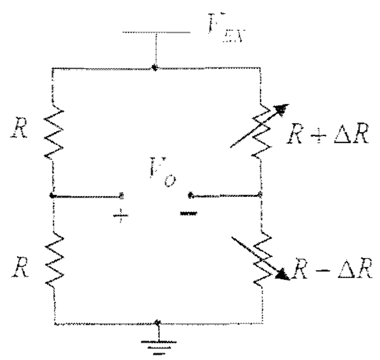


Fig. Q.3b

(b) With the aid of an illustration, show how the strain gauges in Fig Q3.b would mounted on the horizontal beam in **Fig Q.3c** in order to measure force. Show also how the strain gauges would be connected together the resistors to form the bridge circuit. *(5 marks)*

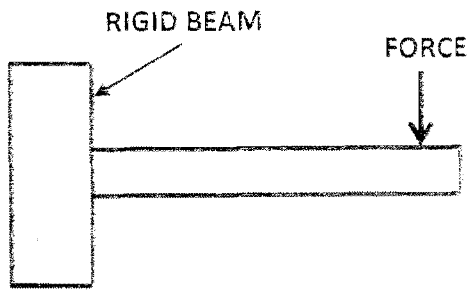


Fig. Q.3c

(d) A weigh bridge is made up with two matching strain gauges as shown in the bridge circuit of **Fig. Q.3b**. The strain sensitivity of each strain gauge is given as 0.62 **microstrain per kg** (με/kg) and the **gauge factor is 2.1**. For a bridge excitation voltage of **12 V**, determine the sensitivity of the bridge circuit to mass (i.e. in **μV/kg**). *(6 marks)*

(e) With the aid of an illustration, explain why some load cells based on strain gauges have six wire leads. *(4 marks)*

QUESTION 4 *(25 marks)*

(a) An instrument system consists of a pressure transducer with input range $0-600$ **kPa** and output range $0-25$ **mV**. The output of the transducer is connected to a voltage-to-current converter which converts the transducer output to a loop current in the range $4-20$ **mA**. An analogue milliammeter indicates the measured pressure in kPa.

(i) Draw a neat labelled block diagram of the instrument system indicating the ranges of the input and output of each block. *(2 marks)*

(ii) What is the overall sensitivity of the instrument system? *(2 marks)*

(iii) Determine the equation connecting the voltage-to-current converter output to its input. *(5 marks)*

(iv) What pressure is indicated when the milliammeter current is 16 mA? *(4 marks)*

(v) Explain why the loop current range starts from 4 mA instead of 0 mA. *(2 marks)*

(b) A PTAT sensor is a two terminal temperature sensing device in which the current through the device is proportional to absolute temperature. The AD590 is one such device and it has a specification of 1 **μA/K** for any supply voltage from 4 V to 30 V. The device is used in the circuit shown in Fig. Q.4b.

(i) Find the range of voltage indicated as V_{Temp} for temperature variation from 0°C to 100°C. Note that $0°K = -273.15°C$. *(3 marks)*

(ii) Design an opamp-based circuit which would convert the temperature range 0°C to 100°C to analogue signal 0 to 5 V. *(7 marks)*

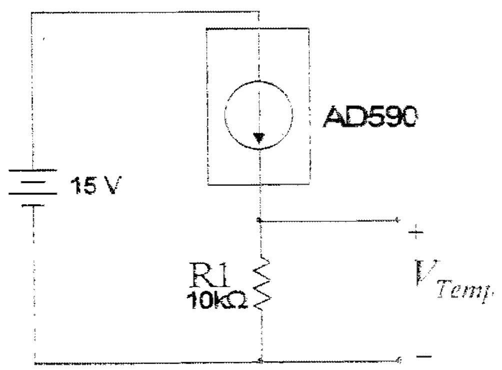


Fig. Q.4b

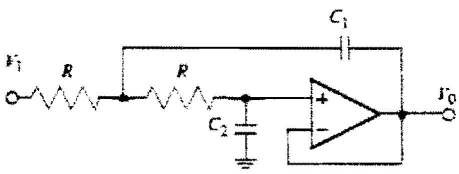
QUESTION 5 *(25 marks)*

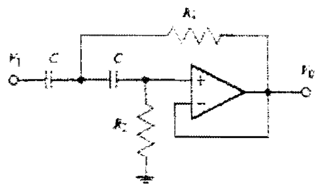
(a) The gain response function, $(|G| \text{ vs } f)$, of an n-pole Butterworth low pass filter with cut off frequency f_c is given by $\left|\frac{v_o}{v_{in}}\right| = \frac{1}{\sqrt{1+\left(\frac{f}{f_c}\right)^{2n}}}$.

In a digital sampling system, an interference signal at a relative frequency of $3f_c$ is to be attenuated by at least **50 dB** using a Butterworth anti-aliasing filter. Determine the **minimum order** of the Butterworth filter. *(10 marks)*

(b) Use the data given below to design a **4-pole**, **Butterworth low-pass** active filter with cut off frequency of **800 Hz.** *(15 marks)*

The following data applies to a unity gain Sallen-Key Lowpass and Highpass Configuration active filters. Notice resistors are equal in lowpass and capacitors are equal in Highpass.





	Butterworth		Transitional		Bessel		Chebyshev (0.5 dB)	
Poles	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
2	1.414	0.707	1.287	0.777	0.907	0.680	1.949	0.653
4	1.082	0.924	1.090	0.960	0.735	0.675	2.582	1.298
	2.613	0.383	2.206	0.472	1.012	0.390	6.233	0.180
6	1.035	0.966	1.060	1.001	0.635	0.610	3.592	1.921
	1.414	0.707	1.338	0.761	0.723	0.484	4.907	0.374
	3.863	0.259	2.721	0.340	1.073	0.256	13.40	0.079
8	1.019	0.981	1.051	1.017	0.567	0.554	4.665	2.547
	1.202	0.832	1.191	0.876	0.609	0.486	5.502	0.530
	1.800	0.556	1.613	0.615	0.726	0.359	8.237	0.171
	5.125	0.195	3.373	0.268	1.116	0.186	23.45	0.044

Source: Brian K. Jones, *Electronics for Experimentation and Research*, Prentice Hall, Englewood Cliffs, NJ. 1986. By permission of Prentice-Hall International (UK) Ltd, London.

Where for **Lowpass:** $RC_1\omega_c = k_1$ and $RC_2\omega_c = k_2$. Higher-order filters use cascaded stages.

For **Highpass:** $R_1C\omega_c = 1/k_1$ and $R_2C\omega_c = 1/k_2$. Higher-order filters use cascaded stages.