UNIVERSITY OF SWAZILAND
MAIN EXAMINATION, DECEMBER 2016

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.
5. Linear graph paper is provided.
6. Sheets showing useful data are attached at the end.

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

THIS PAPER HAS EIGHT (8) PAGES INCLUDING THIS PAGE

QUESTION 1 ***(25 marks)***

(a) Define the following performance terms as used in measurement:

(i) linearity

(ii) resolution

(iii) precision

(3 marks)

(b) List three dynamic and three environmental performance characteristics which would influence the choice of a transducer for a particular application. *(3 marks)*

(c) Explain how does the response of a first order system to a step input differs from its response to a ramp input? *(5 marks)*

(d) In an experiment to calibrate a pressure transducer the following data were obtained for pressure increasing and pressure decreasing:

Applied pressure (bar)	0	1	2	3	4	5	6	7
Output for pressure increasing (mA)	4.0	6.8	9.4	12.0	14.0	16.0	18.0	20.0
Output for pressure decreasing (mA)	4.0	5.8	7.8	9.6	12.4	15.0	17.6	20.0

(i) Plot the data and estimate the maximum hysteresis. *(4 marks)*

(ii) We wish to derive a linear calibration graph for the transducer. Suggest how to derive it and plot the resulting calibration graph. *(5 marks)*

(iii) What is the sensitivity of the calibrated transducer? *(3 marks)*

(iv) Express the maximum error of the calibrated transducer as a percentage of the output span. *(2 marks)*

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

(a) Derive an expression for the overall gain of the instrumentation amplifier circuit shown in Fig. Q2a.

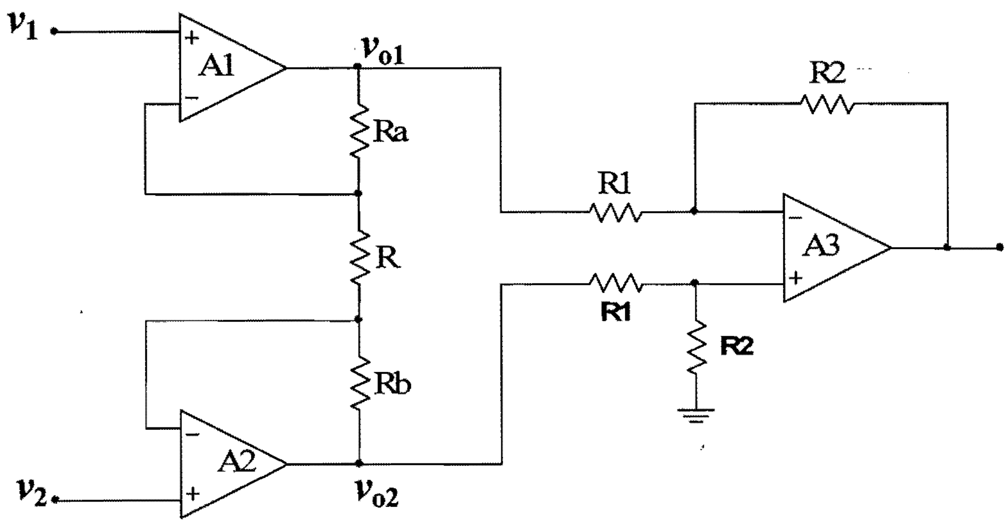


Fig. Q2a

(b) A block diagram of a measurement system using a thermocouple is shown in Fig.Q2b. A voltage dependent on the temperature difference between the cold and hot junctions appears at the thermocouple outputs. This voltage varies by 41.0 μV for every °C temperature difference and may be assumed constant throughout the range of measurement. A digital output display shows the temperature in °C and is driven by an analog to digital converter (ADC). The ADC converts a signal from 0 to 10 V to an 8-bit digital value. The maximum temperature difference to be measured is 1000 °C

(i) Determine the range of voltage is produced by the thermocouple? *(3 marks)*

(ii) Design an instrumentation amplifier which converts the output from the thermocouple to that required to fully utilize the full range of the ADC. *(13 marks)*

(iii) Determine the resolution of the measurement system. *(3 marks)*

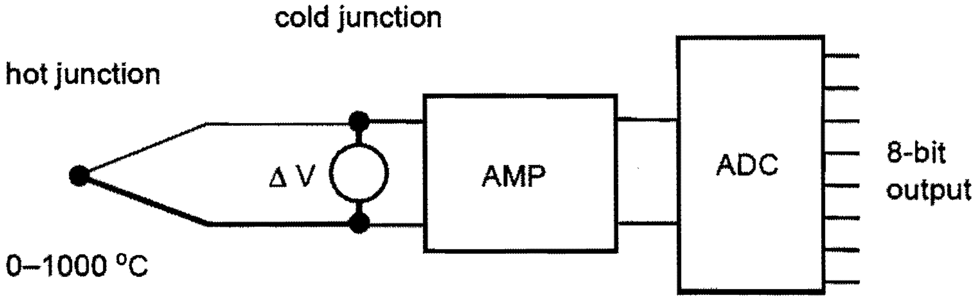


Fig.Q2b

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

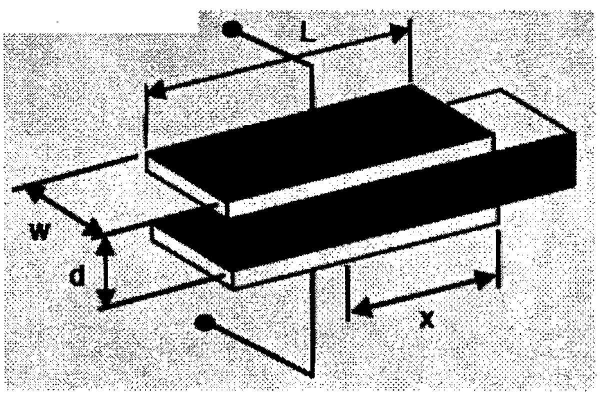
(a) An infrared gas analyser is used to measure the concentration of carbon monoxide (CO) in the exhaust gases of a motor vehicle. Before the measurement is taken, purified air containing no CO is introduced and the "zero" is adjusted for 0 mV on the output display. Then, a calibrated mixture of CO and air at 400 ppm is introduced and the span adjusted to give 400 mV on the output. The exhaust gas is then sampled by the instrument and the reading is 350 mV. It is discovered later that the concentration of the calibrated mixture was in error and should have been 410 ppm. Assuming that the response of the instrument is linear, determine a corrected value for the measured concentration. *(7 marks)*

(b) A photodiode has a sensitivity of 9 nA/lux at 560 nm and an area of 40 mm^2. Express its detectivity in A/W. you are given that 1 lux = 1 lumen/m^2 and a radiant flux of 1 W at 560 nm produces 685 lumens. *(6 marks)*

(c) A variable dielectric capacitive displacement sensor consists of two square metal plates of sides $W = L = 5$ cm separated by a gap d of 1 mm. A sheet of dielectric material 1 mm thick and the same area as the plates can be slid between them. If the dielectric constant of air is $\varepsilon_r = 1$ and that of the dielectric material is $\varepsilon_r = 4$,

(i) Calculate the capacitance of the sensor when the input displacement $L - x = 2.0$ cm. *(6 marks)*

(ii) Determine the sensitivity of the sensor. *(6 marks)*



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

(a) Figure Q4 shows a temperature measurement system employing a two-wire 100Ω RTD R_{Th} excited by a constant current source. The RTD has a sensitivity of 0.385 Ω/°C.

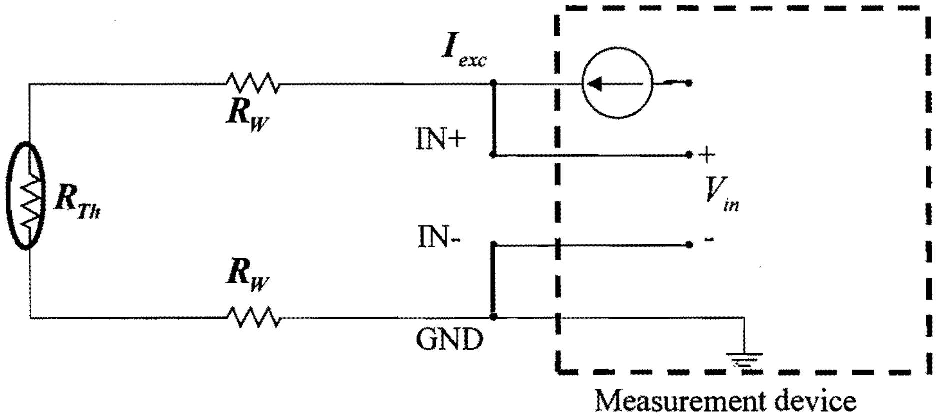


Fig Q4

(i) If the lead resistance of each wire is 0.4 Ω, what error in the temperature measurement is produced by the lead resistance for every degree change in temperature? *(5 marks)*

(ii) With the aid of diagrams explain how this measurement can be made more accurate using a four-wire RTD connection. *(5 marks)*

(iii) If the self-heating coefficient of the RTD is 0.2 °C/mW and the excitation current is 0.85 mA, calculate the temperature error contributed by self-heating. *(5 marks)*

(iv) How can the errors due to self-heating be reduced? *(5 marks)*

(b) Explain the effect of temperature and pressure in the measurement of humidity. *(5 marks)*

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

(a) Distinguish between the following terms as used in communication between measurement devices:

(i) Half duplex and full duplex communication

(ii) Asynchronous and Synchronous transmission

(iii) Balanced and unbalanced interfaces

(6 marks)

(b) A filter with Chebychev response is desired for anti-aliasing. It suggested that a fourth order filter with a cut-off frequency 120 Hz be used. Futhermore it is decided that no further gain is required in the filter so a unity-gain version with a ripple amplitude of 0.5 dB be used. Design the filter using Sallen-Key configurations. *(10 marks)*

(c) Design a circuit to transmit -1 V to 4 V analogue signal over a 4 mA to 20 mA current transmission loop. Assume that load is grounded and that amplifiers saturate at ±10 V. What are limits of the load resistance at the receiver? *(9 marks)*

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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)**

	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 $RC_2\omega_c = k_2$.

For **Highpass:** $R_1C\omega_c = 1/k_1$ and $R_2C\omega_c = 1/k_2$.

Higher-order filters use cascaded stages.