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Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2022/2023

COURSE NAME	:	SENSORS AND ACTUATORS
COURSE CODE	:	BND 36103
PROGRAMME CODE	:	BND
EXAMINATION DATE	:	JULY/ AUGUST 2023
DURATION	:	3 HOURS
INSTRUCTION	1.	ANSWER **ALL** QUESTIONS.
	2.	THIS FINAL EXAMINATION IS CONDUCTED VIA **CLOSED BOOK.**
	3.	STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK.

THIS QUESTION PAPER CONSISTS OF **SEVEN (7)** PAGES

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Q1 (a) Describe the differences between analog and discrete sensors. For each type of sensors, provide an example.

(3 marks)

(b) Given the transfer function of the temperature sensor is $44.5\ mV/^0C$

(i) Determine the change in output voltage when the temperature increases by 10 °C.

(2 marks)

(ii) Calculate the expected value of the temperature if the output voltage measured to be $8.86\ V$.

(2 marks)

(c) Digital-to-analog converter (DAC) has a reference voltage of $100\ V$ and has 6-bit precision. Three successive sampling instances 0.5 seconds apart have the output from data register as shown in **Table Q1(c)**. Compute the analog output voltage that corresponding to each binary data.

(6 marks)

(d) Analyze and compare the performance of two different analog-to-digital converters (ADCs) with varying resolutions. ADC A has a 10-bit resolution, and ADC B has a 12-bit resolution. The input voltage range for both ADCs is from $0\ V$ to $5\ V$. For each ADC, calculate:-

(i) Quantization level and resolution.

(4 marks)

(ii) Quantization error.

(2 marks)

(iii) Dynamic range in dB.

(2 marks)

(e) Discuss the impact of higher resolution on quantization error and dynamic range in both ADCs.

(4 marks)

Q2 (a) Optical radiation is known to produce quantum effects. State **THREE (3)** effects which classified under the quantum effects.

(3 marks)

(b) Consider a photoelectric device intended for light detection.

(i) Assuming it is made of a potassium-coated surface with work function of $1.6\ eV$, determine the lowest wavelength that the device can detect. Given the Plank's constant is $4.1357\ x\ 10^{-15}\ eV$.

(2 marks)

(ii) Calculate the kinetic energy of an emitted electron under red light radiation at a wavelength of $620\ nm$.

(2 marks)

(c) The photoconductive sensor depicted in **Figure Q2 (c)** is made of Cadmium sulfide (CdS). Its dimensions are as follows: length of $4\ mm$, width of $1\ mm$, and thickness of $0.1\ mm$. The electron mobility in CdS is around $210\ cm^2/V_s$, while the hole mobility is $20\ cm^2/V_s$. The concentration of carriers in the absence of light, known as the dark concentration, is approximately $10^{16}\ carriers/cm^3$ for both electrons and holes. At a light density of $1\ W/m^2$ the carrier density increases by 11%:

(i) Calculate the conductivity of the material and the resistance of the sensor under dark conditions and under the given illumination.

(4 marks)

(ii) By assuming a rate of carrier generation due to light of $10^{15}\ carriers/\frac{s}{cm^3}$, estimate the sensitivity of the sensor to radiation at a wavelength of $300\ nm$.

(5 marks)

(d) A two parallel plate capacitors used as a fluid level sensor for application in small fuel tank shown in **Figure Q2 (d)**. Both plate immersed in the fuel so that the fuel fills the space between them up to the fluid level. The tank is $50\ mm$ high and the two plates are of that length as shown with $d = 1mm$. Given the width of the plate $w = 10\ mm$, vacuum permittivity, $\varepsilon_O = 8.854 \times 10^{-12} \text{F/m}$ and relative permittivity of the fuel, $\varepsilon_r = 15$. Analyse the figure and calculate:

(i) the total capacitance at empty level condition.

(3 marks)

(ii) the capacitance of the sensor if the fuel arises to the half level of the tank.

(4 marks)

(iii) the height of fuel, h if the C_h is increase to 0.05 nF.

(2 marks)

Q3 (a) The **Figure Q3 (a)** shows a resistance temperature detector (RTD) arranged in the Wheatstone bridge with each arm $100\ ohm$. If the temperature of the sensor changed such that the meter indicates $0.569\ V$ and the material has a temperature coefficient of $0.00395/^0C$ wheras the resistance at 0^0C is 100 Ω, determine:

(i) The sensor temperature.

(4 marks)

(ii) The power consumed in it.

(2 marks)

Hint: The condition of bridge balance is: $\frac{R_T}{R_1} = \frac{R_3}{R_2}$

(b) A truck scale is made of a platform and four compression force sensors, one at each corner of the platform. The sensor itself is a short steel cylinder, $20\ mm$ diameter. A single strain gauge is prestressed to 2 % strain and bonded on the outer surface of the cylinder. The strain gauges have a nominal resistance (before prestressing) of 350 Ω and a gauge factor of 6.9. The steel used for the cylinders has a modulus of elasticity (Young's modulus) of $30\ GPa$. Calculate:

(i) The maximum truck weight that the scale can measure.

(3 marks)

(ii) The change in resistance of the sensors for maximum weight.

(4 marks)

(iii) The sensitivity, S_0 of the scale assuming the response of the strain gauges is linear.

(3 marks)

(c) Consider the loudspeaker structure in **Figure Q3 (c)** with the following specifications: $I = 2\sin(2\pi ft)$, number of turns in the coil, $N = 100$, radius of the coil, $a = 40\ mm$, and magnetic flux density $B = 0.8\ T$. The radius of the cone is $b = 15\ cm$. Assuming that the magnetic flux density in the coil is constant at all times, determine:

(i) The maximum force on the coil.

(3 marks)

(ii) The maximum displacement of the cone, if the cone has a restoring constant, $k = 750\ N/m$. (This restoring constant is due to the attachment of the cone to the body of the loudspeaker and acts exactly as a spring constant to return the cone to its centered position).

(3 marks)

(iii) The maximum pressure the cone can apply.

(3 marks)

Q4 (a) Consider the fabrication of a MEMS sensor that has the following characteristics: a core made of a magnetic material (such as permalloy) and a 5-turn coil symmetrically wound around the core, connected to pads for external current supply. The coil is made of aluminum. Other materials must be chosen to accomplish the required functionality of the device. The dimensions are not important, but they must be compatible with MEMS fabrication methods. Propose the steps necessary to produce the device.

(10 marks)

(b) To produce an inkjet as part of an inkjet printing cartridge, a small cylindrical chamber is made and the ink is expelled through the action of a piezoelectric device. The arrangement is shown in **Figure Q4 (b)**, where the bottom of the chamber is sealed with a diaphragm and a piezoelectric disk is placed between the substrate and diaphragm. When a voltage V is applied, the piezoelectric disk expands (positive piezoelectric coefficient), decreasing the volume of the chamber and expelling the ink. The piezoelectric disk is made of PZT with a piezoelectric coefficient of $374 \times 10^{-12}\ C/N$, a relative permittivity of 1700, and a thickness of $25\ \mu m$. A voltage of 3.6 V is applied across the disk when operated. The upper and lower surfaces are coated with aluminum to allow connection of the voltage and to produce a uniform electric field intensity in the material. Assume the ink is water based and hence has the density of water ($1\ g/cm^3$).

(i) Calculate the mass of the ink expelled.

(9 marks)

(ii) Calculate the maximum force produced by the piezoelectric device and the peak pressure in the ink chamber.

(6 marks)

– END OF QUESTIONS –

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Table Q1 (c)

Output Values:	
Instant	Binary Data
1	101000
2	101010
3	101101

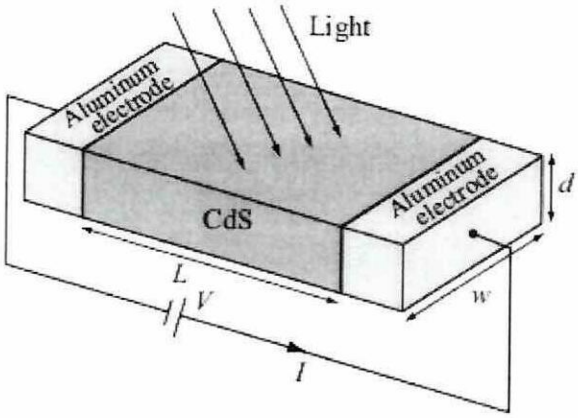

Figure Q2 (c)

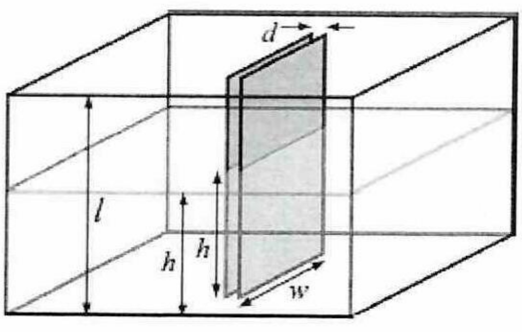

Figure Q2 (d)

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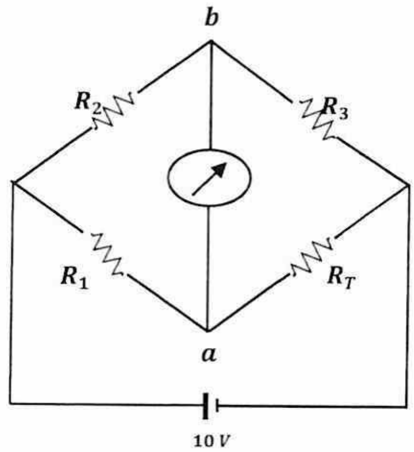

Figure Q3 (a)

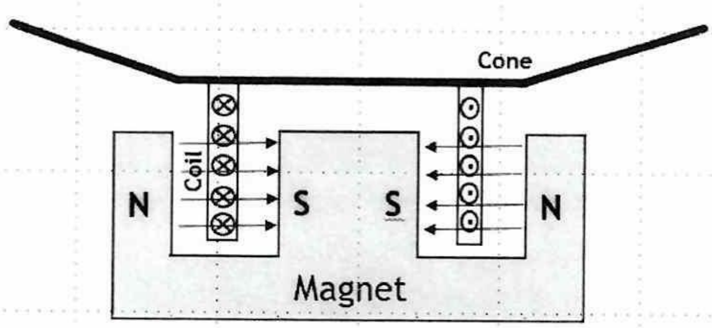

Figure Q3 (c)

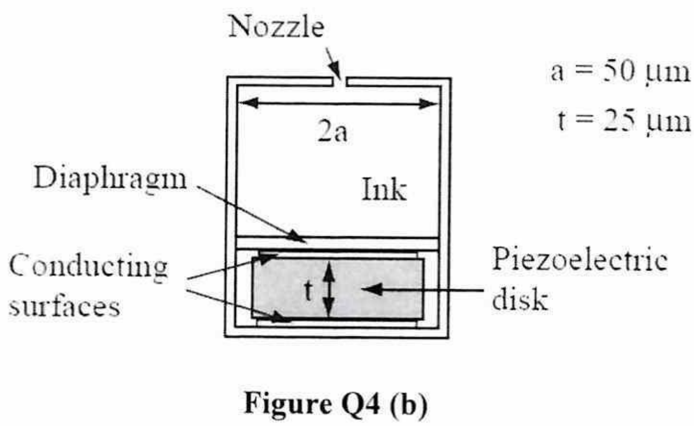

Figure Q4 (b)