



**NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY**

**FACULTY OF APPLIED SCIENCES**

**DEPARTMENT OF APPLIED PHYSICS**

**BSc. (HONS) DEGREE IN APPLIED PHYSICS PART II**

**BSc. (HONS) DEGREE IN RADIOGRAPHY PART I**

**INSTRUMENTATION PHYSICS**

**SPH 2203 / SPH 1205**

**First Semester Examination Paper**

**October 2024**

This examination paper consists of 5 pages

**Time Allowed: 3 hours**

**Total Marks: 100**

**Special Requirements: Table of Laplace functions and corresponding time functions**

**Examiner's Name: Mr. N Sibanda**

**INSTRUCTIONS**

**ANSWER ALL PARTS OF QUESTION 1 IN SECTION A AND ANY THREE QUESTIONS FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS.**

**MARK ALLOCATION**

QUESTION	MARKS
1	40
2	20
3	20
4	20
5	20
6	20
<b>Maximum possible mark</b>	<b>100</b>

Permeability of Free space

$$\mu_0 = 4\pi \times 10^{-7} \text{ Hm}^{-1}$$

Boltzmann Constant

$$k_B = 1.38 \times 10^{-23} \text{ JK}^{-1}$$

## SECTION A

- 1 (a) An instrument can be *precise* but not *accurate*. Explain. [2]
- (b) i. Is a thermocouple a sensor or a transducer? Explain your reasoning. [2]  
ii. Calculate the resistance of a thermistor at 45°C given  $R_{25^{\circ}\text{C}} = 12 \text{ k}\Omega$  and  $\beta = 3\,570 \text{ K}$ . [2]
- (c) A piezoelectric transducer can be used as a transceiver. Explain how the principle of piezoelectricity and inverse piezoelectricity can be used in fetal heart detection. [3]
- (d) Draw a block diagram of a general measurement system and explain the functions of each block. [4]
- (e) Distinguish between static and dynamic characteristics of a measurement system. [2]
- (f) Name and explain any two error reduction techniques that can be done on an element of a measurement system. [4]
- (g) i. Define Johnson noise for a resistive sensor. [2]  
ii. Calculate Johnson noise for a resistive sensor whose resistance is  $67 \text{ }\Omega$  at  $23 \text{ }^{\circ}\text{C}$ . The frequency range of the input signal is from 120 kHz to 140 kHz. [2]
- (h) Determine the natural angular frequency and damping factor for a second-order system with input  $y$  and output  $x$  and described by the differential equation:  
$$0.02 \frac{d^2x}{dt^2} + 0.20 \frac{dx}{dt} + 0.50x = y$$
 [4]
- (i) In signal processing elements give reasons why it is necessary to convert analogue signals into digital signals? [2]
- (j) With the aid of a well-labelled diagram explain how a semiconductor detector is used to measure radiation. [4]
- (k) For a measurements system with negative feedback, show that the overall transfer function is given by:  
$$\frac{Y(s)}{X(s)} = \frac{G(s)}{1 + G(s)H(s)}$$
 [4]  
where symbols have their usual meaning.
- (l) Giving examples, define passive and active sensing elements. [3]

## SECTION B

- 2 (a) A force measurement system consists of four elements with sensitivities  $10^{-2}$ ,  $5 \times 10^{-2}$ ,  $10^3$  and 1.9. Find the system error for a true value input of 10 kN. [2]
- (b) You are required to design a digital thermometer, which will measure temperature in a water bath and numerically display the value. The required temperature range is from 10 °C to 87 °C.
- Draw the block diagram of the instrument, briefly describing the function of each block. [6]
  - Give a detailed explanation of the selected temperature sensor including how the sensor measures temperature. [4]
- (c) A 5.5 MHz ultrasound is used to detect blood flow. For blood flowing at 48 cm/s toward the ultrasound source, find the Doppler shift frequency at an angle of 30°. (Take the speed of sound in blood as 154 000 cm/s). [4]
- (d) For a typical microcontroller system used in data processing, define the
- input/output interfaces, [2]
  - memory. [2]
- 3 (a) The 4 – 20 mA current loop is a popular medium for industrial signal transmission. Suggest two reasons for its popularity. Explain how a two-wire current loop system can utilize the signal wire pair to supply power to sensors. [4]
- (b) Design a reactive deflection bridge that incorporates a variable reluctance push-pull displacement sensor. [4]
- (c) Variable reluctance push-pull displacement sensor is used to measure displacement. The total distance between the two ferromagnetic cores is 5 cm, the radius of each core is 4 cm and  $\mu_0 = 1.3 \times 10^7 \text{ H}^{-1}$ . The sensor is incorporated into the deflection bridge of question 3(b) with  $V_s = 15 \text{ V}$ .
- Calculate the constants  $k$  and  $\alpha$  for the sensor. [4]
  - Calculate  $E_{Th}$  if the measured displacement is 2 cm. [3]
- (d) Including relevant equations and diagrams, explain the principle of operation of the differential capacitive displacement sensor and its applications. [5]

- 4 (a) For a pitot-static tube show that  $v = [2(P_1 - P_s)/\rho]^{1/2}$ . [5]
- (b) i. Describe the principle of operation of an electromagnetic flowmeter. [5]  
 ii. An electromagnetic flowmeter is used to measure the volume flow rate of a conducting fluid in a circular pipe of radius 0.10 m. Calculate the average velocity of the fluid if the magnetic field is 0.15 T and the voltage appearing across the measurement electrodes is 0.8 V. [4]
- (c) Write explanatory notes on scintillation detectors. [6]
- 5 (a) With the aid of a traceability ladder, define calibration and explain the importance of calibration for a company that manufactures cement. [4]
- (b) Figure 1 shows a resistive deflection bridge incorporating four active strain gauges  $R_1, R_2, R_3$  and  $R_4$ .  $R_1$  and  $R_3$  are in tension ( $T$ ) and,  $R_2$  and  $R_4$  are in compression ( $C$ ).

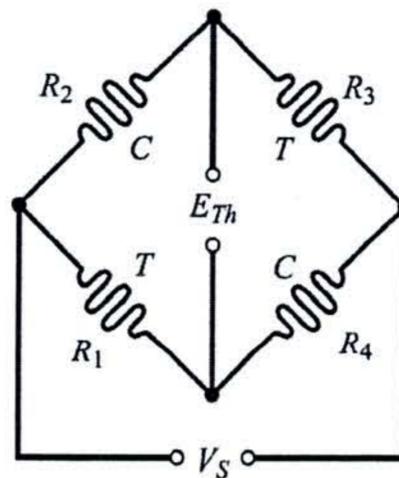


Figure 1: Resistive deflection bridge

For this type of deflection bridge, show that:

$$E_{Th} = V_s G_e, \quad [6]$$

where symbols have their usual meaning.

- (c) A venturi is used to measure the flow of oil through a horizontal pipe. The pipe has a diameter of 120 mm and the venturi constriction has a diameter of 40 mm. The pressure difference between the constriction and the pipe flows is measured and found to be 800 Pa. If the oil has a density of  $820 \text{ kg/m}^3$ , what is the flow rate of the oil? Assume there are no losses. [6]
- (d) With the aid of a well-labelled diagram, define the following types of signals:  
 i. deterministic and [2]  
 ii. random signals. [2]

- 6 (a) i. What is a transfer function  $G(s)$  of an element? [2]
- ii. Derive a transfer function of a thermocouple that has a steady state gain of  $40 \mu\text{V}/^\circ\text{C}$ , and a time constant of 10 s. The thermocouple is subjected to a step input of  $100^\circ\text{C}$ . [4]
- iii. Solve the equation you have derived in 6(a)(ii). [2]
- (b) A platinum-resistant thermometer is used to interpolate between the triple point of water ( $0^\circ\text{C}$ ), the boiling point of water ( $100^\circ\text{C}$ ) and the freezing point of zinc ( $419.6^\circ\text{C}$ ). The corresponding resistance values are  $100.0 \Omega$ ,  $138.5 \Omega$  and  $253.7 \Omega$ . The algebraic form of the interpolation equation is:
- $$R_T = R_0(1 + \alpha T + \beta T^2)$$
- where  $R_T \Omega =$  resistance at  $T^\circ\text{C}$ ,  $R_0 \Omega =$  resistance at  $0^\circ\text{C}$  and  $\alpha, \beta$  are temperature coefficients of resistance. Find the
- i. numerical form of the interpolation equation. [5]
- ii. resistance of this thermometer when it is immersed in warm water at  $75^\circ\text{C}$ . [1]
- (c) Write explanatory notes on the following data presentation elements:
- i. light emitting diodes, [3]
- ii. liquid crystal displays. [3]

**\*\*\* END OF EXAMINATION PAPER \*\*\***