



MERU UNIVERSITY OF SCIENCE AND TECHNOLOGY

P.O. Box 972-60200 – Meru-Kenya.

Tel: +254(0) 799 529 958, +254(0) 799 529 959, +254 (0)712 524 293

Website: www.must.ac.ke Email: info@mucst.ac.ke

UNIVERSITY EXAMINATIONS 2024/2025

THIRD YEAR, FIRST SEMESTER EXAMINATION FOR THE DEGREE OF BACHELOR
OF TECHNOLOGY IN ELECTRICAL AND ELECTRONICS ENGINEERING

EET 3303: INSTRUMENTATION AND MEASUREMENT

DATE: JANUARY 2025

TIME: 2 HOURS

INSTRUCTIONS: Answer Question ONE and any other TWO questions.

: Start each question on a fresh page

QUESTION ONE (30 MARKS)

- (a) Define the terms instrumentation and measurement and briefly explain their significance in the field of engineering and science. (2 Marks)
- (b) Using a suitable diagram, explain in detail the elements of a generalized instrumentation system. (5 Marks)
- (c) A technician is troubleshooting a temperature control system in a manufacturing plant. The system is using a thermocouple to measure temperature and a PID controller to regulate a heating element. The technician notices that the controller is constantly adjusting the heating element, but the actual temperature is fluctuating wildly. What are some possible causes of this issue, and how could the technician diagnose and resolve it? (4 Marks)
- (d) Define the following terms:
 - i. Physical quantity (1 Mark)
 - ii. Accuracy (1 Mark)
 - iii. Precision (1 Mark)
- (e) A quartz piezoelectric crystal having a thickness of 2mm and a voltage sensitivity of 0.055V-m/N is subjected to a pressure of 1.5MN/m².



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ISO/IEC 27001:2013 CERTIFIED

- i. Calculate the voltage output. (2 Marks)
 - ii. If the permittivity of quartz is 40.6×10^{-12} F/m, calculate its charge sensitivity. (2 Marks)
- (f) Define the term signal conditioning and explain the role of signal conditioning circuits in measurement and instrumentation systems. (3 Marks)
- (g) A four-arm bridge network consists of a fixed resistor R_1 in arm AB, a variable resistor R_2 in series with a variable capacitor C_2 in arm BC, a fixed resistor R_3 in arm CD, and a coil with unknown resistance R and inductance L in arm DA. When the bridge is balanced, the following values are given: $R_1=1k\Omega$, $R_2=2.5k\Omega$, $C_2=4000$ pF, $R_3=3k\Omega$, and the supply frequency is 1.6 kHz. Determine the unknown values of R and L of the coil. (4 Marks)
- (h) A force of 50N is applied to a wire of length 2m, causing it to stretch and increasing its length by $\Delta L=0.001$ m. If the Young's modulus of the material is $E=70$ GPa, calculate:
 - i. The strain in the wire (1 Mark)
 - ii. Stress in the wire due to the applied force. (1 Mark)
- (i) A manufacturing plant has recently upgraded its production line by integrating advanced instrumentation technologies. Discuss the advantages of implementing advanced instrumentation in the manufacturing process. (3 Marks)

QUESTION TWO (15 MARKS)

- (a) A researcher measures the length of a metal rod, known to be 100 cm, and records the following measurements (in cm) from five trials: 98, 99, 101, 102, and 100. In this context, discuss how the concepts of accuracy and precision relate to the recorded measurements. (4 Marks)
- (b) Figure Q2 (b) shows an illustration of an instrumentation amplifier. Explain how it works and derive the equation for the output voltage. (5 Marks)

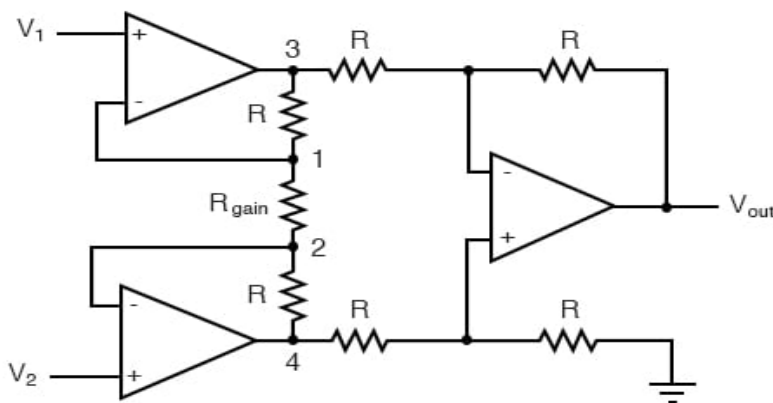


Figure Q2(b)

- (c) Using a suitable illustration, explain the working principle of a 4-bit Binary Weighted Digital-to-Analogue Converter and derive the expression for the output voltage. (6 Marks)

QUESTION THREE (15 MARKS)

- (a) Using a suitable illustration, explain in detail the Hall Effect principle and state any three applications of Hall Effect sensors. (5 Marks)
- (b) Consider a piezoelectric crystal with specific properties: the piezoelectric constant d is $2 \times 10^{-12} \text{ C/N}$, the relative permittivity ϵ_r is 5, the permittivity of free space ϵ_0 is $8.854 \times 10^{-12} \text{ F/m}$, the area A is $1 \times 10^{-4} \text{ m}^2$, and the thickness t is $1 \times 10^{-3} \text{ m}$. An applied force F of 10 N is exerted on the crystal. Calculate:
- The voltage sensitivity. (2 Marks)
 - The stress. (1 Mark)
 - The output voltage. (1 Mark)
- (c) A Maxwell-Wien Bridge is used for the measurement of an unknown resistance R_x and inductance L_x . Given the circuit configuration in Figure Q3 (c):
- Derive the balance condition for the Maxwell-Wien Bridge. (2 Marks)
 - Calculate the values of R_1 and L_1 if $R_2=1.5\text{k}\Omega$, $R_3=1\text{k}\Omega$, $C_3=100\mu\text{F}$ and $R_4=1\text{k}\Omega$ when the bridge is balanced. (2 Marks)
 - Calculate the Q factor of the coil at a frequency of 1000 Hz. (2 Marks)

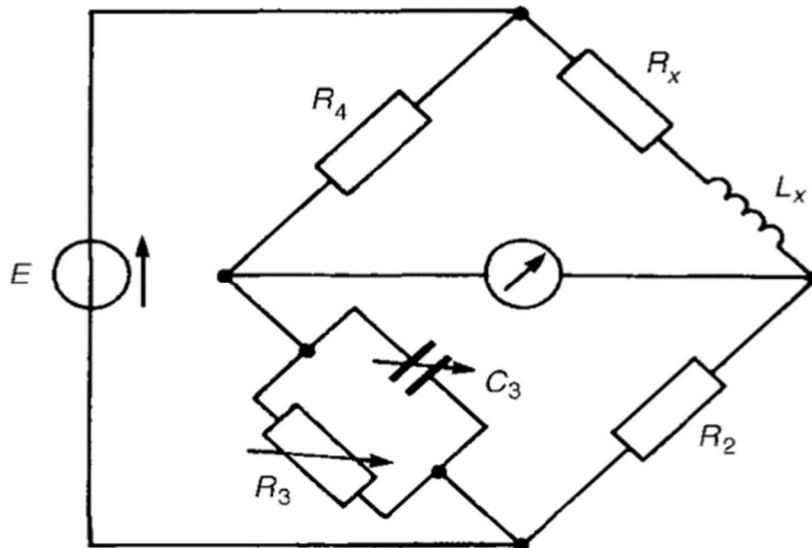


Figure Q3 (c)

QUESTION FOUR (15 MARKS)

- (a) Using clearly labeled sketches, briefly explain three factors that affect the change of capacitance in a capacitive transducer and list any three applications of a capacitive transducer. (5 Marks)
- (b) Differentiate between the following terms:
- i. Reproducibility and repeatability (2 Marks)
 - ii. Range and span (2 Marks)
- (c) A conductor wire has an initial length $L=2$ m, a cross-sectional diameter $D=0.5$ mm, and a resistivity $\rho=1.68 \times 10^{-8} \Omega\text{m}$. A force of 50 N is applied to the wire, causing it to stretch and increase its length by $\Delta L=0.001$ m. The material of the wire has Young's modulus, $E=70$ GPa, and the gauge factor of the strain gauge is $G=2$.
- i. Calculate the original resistance R of the wire. (1 Mark)
 - ii. Determine the strain and stress in the wire due to the applied force. (2 Marks)
 - iii. Calculate the change in resistance ΔR of the wire. (2 Marks)
 - iv. Determine the new resistance of the wire after the force is applied. (1 Mark)

QUESTION FIVE (15 MARKS)

- (a) A 4-bit Digital-to-Analog Converter (DAC) has an input voltage range of 0V to 8V.
- i. Calculate the resolution of the DAC. (1 Mark)
 - ii. If the DAC operates at a clock frequency of 500 kHz, calculate the total conversion time for a 6-bit DAC. (1 Marks)
- (b) Distinguish between passive and active transducers and give 2 examples for each. (4 Marks)
- (c) Using a suitable illustration, explain the working principle of a resistive potentiometer and derive the relationship between output voltage and length of the potentiometer. (4 Marks)
- (d) In designing a new environmental monitoring system for a smart city, engineers must choose the appropriate transducer to accurately measure various parameters, such as temperature, humidity, and air quality. Briefly explain five factors that the engineers should consider when selecting a transducer for this environmental monitoring application. (5 Marks)