UNIVERSITY OF RUHUNA

Faculty of Engineering

End Semester 3 Examination in Engineering: March 2026

Module Number: EE3203 Module Name: Electrical and Electronic Measurements(C-23)

[3 Hours]

[Answer **all questions**, each question carries 15 marks]

Q1 An instrumentation laboratory intends to design a versatile analog measuring instrument starting from a basic electromechanical movement. You are provided with a **bare Permanent Magnet Moving Coil (PMMC) movement** as shown in Figure Q1 a) and are required to systematically develop it into

1. A DC ammeter,
2. A DC voltmeter, and
3. An AC voltmeter.

During this development process, practical limitations and protection issues arise. You are required to resolve them using engineering knowledge.

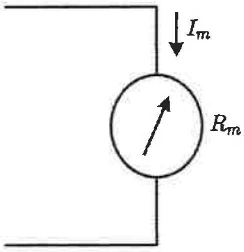

Figure Q1 a): PMMC movement.

Given Data of PMMC Movement shown in Figure Q1 a) is below

Flux density $(B) = 0.8\,T$ Internal resistance $(R_m) = 200\ \Omega$,
Number of turns $(N) = 100$ Full scale deflection current $(I_{fsd}) = 1.5\ mA$
Effective coil area $(A) = 3 \times 10^{-4}\ m^2$ Moment of inertia $(J) = 1.0 \times 10^{-6}\ kgm^2$
Spring constant $(k) = 2 \times 10^{-5}\ Nm/rad$ Damping constant $(D) = 3.5 \times 10^{-5}\ Nms/rad$

a) Starting from Lorentz force acting on a current-carrying conductor:

i) Derive an expression for deflecting torque (T_d) of the PMMC movement and state the assumption made during this derivation.

[2 Marks]

ii) Using steady state equilibrium conditions, obtain the relationship between deflection angle (θ) and current (I), and state the nature of its scale.

[1 Mark]

iii) Using the dynamic equation:

$$J\frac{d^2\theta}{dt^2} + D\frac{d\theta}{dt} + k\theta = T_d$$

I) Determine whether the given system is underdamped, overdamped, or critically damped.

II) State the practical importance of damping in pointer instruments.

[2 Marks]

b) The movement is now to be converted into a **25 A DC ammeter**.

i) Find the required shunt resistance and calculate the power dissipated in the shunt at full scale current.

[1.5 Marks]

ii) The instrument is provided with multiple current ranges using a selector switch. During switching, it is observed that the shunt momentarily disconnects while 25 A is flowing.

I) Determine the voltage that appears across the PMMC movement during this instant.

II) Compare this with its rated full-scale voltage and explain clearly why this may permanently damage the movement.

[1 Mark]

iii) Explain how to eliminate the problem in Q1). b) ii), considering the engineering principle behind it.

[1 Mark]

c) The same PMMC movement is now converted into a **300 V DC voltmeter**.

i) Find the required series resistance and determine the voltmeter sensitivity in Ω/V.

[1 Mark]

ii) The voltmeter is used to measure the voltage across a 40 kΩ load connected in series with a 60 kΩ resistor across a 300 V DC supply.

I) Calculate the measured voltage when the voltmeter is connected.

II) Determine the percentage loading error.

[2 Marks]

d) When the PMMC voltmeter is connected directly to a 50 Hz sinusoidal AC source, no steady deflection is observed.

i) Briefly explain the reason for this meter movement behavior.

[0.5 Marks]

ii) To enable AC measurement, diode circuit arrangement is introduced to above DC voltmeter configuration as shown in **Figure Q1 d)**, state two drawbacks of this arrangement.

[1 Mark]

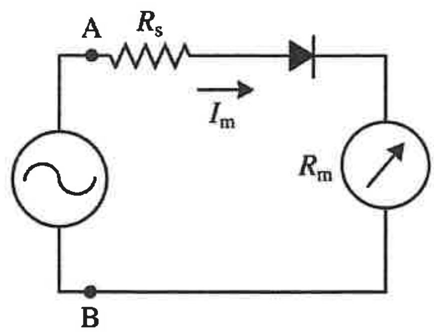

Figure Q1 d): Diode circuit arrangement.

iii) To overcome those drawbacks an electrodynamometer type instrument is suggested as an alternative for both AC and DC measurement. Briefly explain why it can measure both AC and DC quantities and state the nature of its scale.

[2 Marks]

Q2 You are an instrumentation engineer tasked with designing precise measurement setups for a variety of sensors and components in a newly established metrology lab. The lab's focus ranges from measuring very low resistances in power system shunts to characterizing capacitors for RF filters. Your fundamental understanding of bridge circuits will be the key to success in this task.

a) You begin by setting up a classic Wheatstone bridge to measure an unknown resistance R_x as shown in **Figure Q2 a)**.

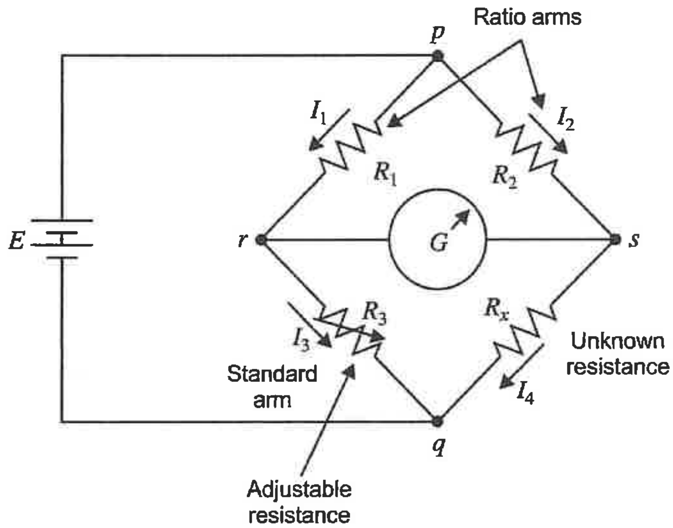

Figure Q2 a): A classic Wheatstone bridge.

i) State the primary advantage of using a bridge circuit for measurements over simpler methods like an Ohmmeter and multimeter.

[0.5 Marks]

ii) Derive the balanced condition for the Wheatstone bridge, clearly state the current relationships that lead to this condition.

[1 Mark]

iii) The beauty of a bridge circuit lies in its sensitivity to small changes in resistance. If the unknown resistance changes by a small amount ΔR_x (where $R_x \rightarrow R_x + \Delta R_x$), the bridge becomes unbalanced, producing a Thevenin voltage E_{Th} across the detector terminals. Show that for a small change ΔR_x, the Thevenin (open circuit) voltage developed is approximately:

$$E_{Th} = -\frac{ER_2\Delta R_x}{(R_2+R_x)^2}$$

(Assume that the bridge was initially balanced.)

[3 Marks]

iv) The galvanometer's deflection (θ) is given by $\theta = S_v E_{Th}$, where S_v is its voltage sensitivity. The bridge sensitivity (S_B) is defined as $S_B = \theta/(\Delta R_x/R_x)$. Using the expression for E_{Th} derived in Q2 a) iii), prove that the bridge sensitivity is:

$$S_B = -S_v E \frac{1}{\frac{R_2}{R_x} + \frac{R_x}{R_2} + 2}$$

[1.5 Marks]

b) While attempting to measure the resistance of a thick copper busbar (expected to be in the micro-ohm range) with your Wheatstone bridge, you encounter significant errors.

i) Briefly explain why the standard Wheatstone bridge fails for low-resistance measurements. What specific errors dominate in this scenario?

[1 Mark]

ii) To overcome this, you decide to use Kelvin Bridge. A simplified version of Kelvin Bridge circuit is shown in **Figure Q2 b)**. The unknown resistance R_x and the standard resistance R_3 are connected via a heavy connecting link of resistance R_{ab}. The galvanometer can be connected to a point 'c' on this dividing link, R_{ab} into R_{ac} and R_{cb}.given that at balance, $\frac{R_{ac}}{R_{ab}} = \frac{R_1}{R_1+R_2}$, Show clearly how the effect of the connecting link resistance R_{ab} is eliminated at balance condition.

[2 Marks]

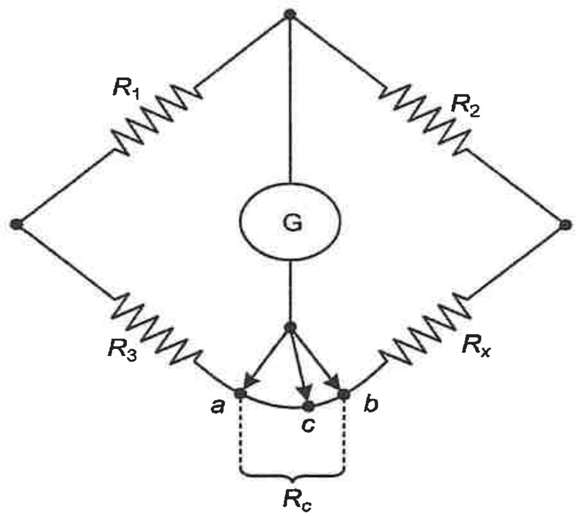

Figure Q2 b): A Kelvin Bridge circuit.

iii) With the aid of a diagram, briefly describe the concept of a four-terminal resistor and how it helps to mitigate the effect of lead and contact resistances.

[2 Marks]

c) Your lab now requires you to measure an unknown capacitor. You learn that AC bridges, which use a sinusoidal AC source and a detector are used for this purpose.

i) Draw the general block diagram of a 4-arm AC bridge. State the general balance condition in terms of impedances Z_1, Z_2, Z_3, and Z_4.

[0.5 Marks]

ii) Briefly explain what is meant by "dissipation factor" (D) of a capacitor.

[1 Mark]

iii) To measure a capacitor with significant losses (high dissipation factor), you are supposed to use **Schering Bridge as shown in Figure Q2 c)**. Derive the expressions for the unknown resistance r_s (which represents the loss) and the unknown capacitance C_x at balance.

[1.5 Marks]

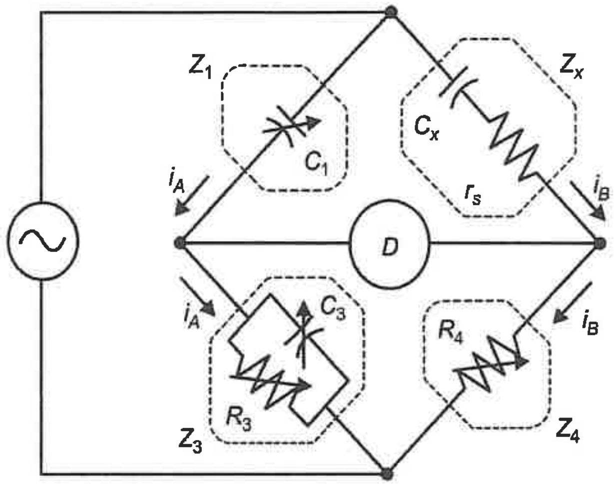

Figure Q2 c): A Schering Bridge Circuit.

iv) Hence, obtain an expression for the dissipation factor D of the unknown capacitor.

[1 Mark]

Q3 a) Briefly explain the operation of the following sections in the Cathode Ray Oscilloscope (CRO).

i) Electron gun section.

[1 Mark]

ii) Deflection section.

[1 Mark]

iii) Screen (phosphor screen) section.

[1 Mark]

b) i) Briefly explain the purpose of the time base (sweep generator) in an analog oscilloscope.

[1 Mark]

ii) Explain the effect of each of the following parameters on the deflection beam: deflection plate length, space between deflection plates, deflection potential, accelerating potential.

[2 Marks]

c) Draw the **Lissajous patterns** observed on a CRO for the following X:Y frequency ratios: 1:1, 1:2, 1:3, and 2:3. Label each pattern clearly.

[2 Marks]

d) i) What is the difference between passive probes and active probes?

[1 Mark]

ii) Describe the loading effect that occurs in a CRO and provide a solution to minimize it.

[1 Mark]

iii) What happens to the output waveform if the adjustable capacitor in a **10X** passive probe is set too HIGH? Draw the resulting output waveform.

[2 Marks]

e) i) Briefly explain the different types of spectrum analyzers available and their key features.

[1 Mark]

ii) Draw a labelled block diagram of a superheterodyne spectrum analyzer and briefly describe the function of each block.

[2 Marks]

Q4 A newly established research laboratory at the Faculty of Engineering, university of Ruhuna is setting up a test bench to characterize the performance of small DC motors. The team needs to accurately measure the input electrical parameters to the motor. Their setup consists of:

1. A (0 - 150 V) voltmeter, with a specified accuracy of ±1 % **of Full-Scale Reading (FSR)**. The voltmeter has 150 scale divisions, and an observer can reasonably estimate **one-tenth of a division.**
2. A (0 - 10 A) ammeter, with a specified accuracy of ±2 % **of the true value**.
3. The motor operates at a nominal voltage 120 V and draws a nominal current 8 A.
4. Additionally, they use a Resistance Temperature Detector (RTD) to measure the motor winding temperature. The RTD follows the linear approximation:

   $\mathbf{R_t = R_0\,(1 + \alpha T)}$, where:

   - R_0 = 100.00 Ω at 0°C (exact reference resistance)
   - α = 0.00385 Ω/Ω/°C (temperature coefficient)
   - T is the temperature in °C

During experiments, they encountered several measurement challenges. Furthermore, notice that the laboratory temperature fluctuates throughout the day, and taking multiple readings of the motor current at the same operating condition yield slightly different values each time.

Based on this scenario, answer the following questions.

a) i) Define **Resolution** as a static characteristic of an instrument. Calculate the resolution of the voltmeter in volts.

[1 Mark]

ii) Define **Sensitivity** of an instrument. If the voltmeter has a sensitivity of **20 Ω/V**, calculate its full-scale current.

[1 Mark]

iii) State the difference between **Range** and **Span**.

[1 Mark]

iv) Distinguish between **Absolute Error** and **% Limiting Error**. If a measurement yields a true value of 120 V and a measured value of 121.5 V, calculate both the absolute error and the % error.

[1 Mark]

b) i) Calculate the **Guaranteed Accuracy Error (GAE)** of the voltmeter.

[0.5 Marks]

ii) Calculate the **% Limiting Error** of the voltmeter when measuring the nominal voltage of 120 V. Also, calculate the % Limiting Error if the same voltmeter were used to measure 60 V. briefly explain the practical implication of this comparison.

[1 Mark]

iii) For the ammeter, convert its specified accuracy into **absolute error** when measuring the nominal current of 8 A. Calculate the % **Limiting Error** of the ammeter at this nominal current.

[1 Mark]

iv) The power consumed by the motor is given by **P = V × I**. Using the % Limiting Errors calculated above, determine the **resultant percentage limiting error** and the **resultant absolute error** in the power measurement.

[1.5 Marks]

c) i) One person of the team accidentally recorded 80 A instead of 8 A due to misreading the scale. Classify this type of error. List **two precautions** that can be taken to minimize such errors.

[1 Mark]

ii) The laboratory temperature fluctuates throughout the day, affecting the instrument readings. Classify this type of error and name the **specific sub-category** under which it falls. Suggest **one corrective measure** to eliminate or reduce this effect.

[1 Mark]

iii) Team takes **10 consecutive readings** of the motor current at the same operating condition and obtains: 7.95 A, 8.02 A, 7.98 A, 8.05 A, 7.92 A, 8.03 A, 7.97 A, 8.01 A, 8.03 A, and 8.04 A. Classify this type of error. What **statistical method** can be used to minimize the effect of these errors?

[1 Mark]

d) i) It is observed that the voltmeter reading at 120 V differs depending on whether the voltage is being increased from 0 V or decreased from 150 V. Name and define this **undesirable static characteristic**. Suggest **one possible cause** for this phenomenon in an analog voltmeter.

[1 Mark]

ii) With the few consecutive Readings of the RTD, it is calculated that the mean resistance of the temperature windings is 115.54 Ω, determine the corresponding temperature T with the **correct number of significant figures**, justifying your answer based on the significant figures of the input values.

[2 Marks]

iii) Considering the current readings that are given in Q4 c) iii), comment on whether the measurements are **precise, accurate, or both**, assuming the true current is 8.00 A. Justify your answer.

[1 Mark]