First Semester Examination
2023/2024 Academic Session

Februari 2024

**EMC 301 – Measurement & Instrumentation**
***(Pengukuran dan Instrumentasi)***

Duration: 3 hours
*(Masa: 3 jam)*

Please check that this examination paper consists of EIGHT (8) pages of printed material before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi LAPAN (8) muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]*

**Instructions :** Answer **ALL FIVE (5)** questions.

*[**Arahan** : Jawab **LIMA (5)** soalan]*

Appendix: Student's t-Distribution (Values of $t_{\alpha, v}$)

1. [a] What is meant by loading error? Give ONE (1) example of situations that can give rise to loading error. Is loading error a systematic (bias) or random (precision) error?

**(25 marks)**

[b] Based on the quote "response is a measure of a system's fidelity to purpose",

(i) give definition to the term 'fidelity', hence list down all response characteristics that can be used to measure the 'system's fidelity'.

(ii) give ideal conditions of each response characteristics as listed in (i).

**(35 marks)**

[c] An engineer is investigating heating effect on a new type of lubricant at 120°C. To maintain the temperature, constant heat is supplied, and the temperature of the lubricant is checked using a thermometer every 60 seconds. The thermometer is assumed to be approximating a first-order system with a known time constant of 25 seconds. The room temperature is controlled to be 30°C during the investigation.

(i) Sketch the time response of the thermometer when it is immersed to the lubricant, from 30°C to 120 °C. Indicate $t = \tau$ and its corresponding temperature.

(ii) Determine whether the response of the thermometer is suitable for the task if the error of temperature measurement should be less than 0.5°C.

(Note: The process completion $P$, at time, $t$, approximating a first order system is given as $P = P_\infty + [P_A - P_\infty]e^{-t/\tau}$ where $P_\infty$ is process completion at time, $t = \infty$, $P_A$ is the process completion at time, $t = 0$ and $\tau$ is the time constant.

**(40 marks)**

2. [a] Briefly describe the relationship of 'uncertainty interval' and 'level of confidence' in the context of measurement uncertainty. Hence, justify the significance of uncertainty analysis in a measurement system.

**(20 marks)**

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[b] A technician measures the resistance of 12 resistors using a multimeter and records the readings as shown:

| | | |
|---|---|---|
| 15.8 Ω | 14.6 Ω | 14.7 Ω |
| 15.7 Ω | 14.8 Ω | 14.8 Ω |
| 14.3 Ω | 15.2 Ω | 15.3 Ω |
| 15.8 Ω | 15.0 Ω | 15.7 Ω |

(i) Calculate the uncertainties for the true mean of the resistance value, utilizing 95% and 99% confidence intervals for the true mean.

(ii) Based on calculation above, does the uncertainty increase or decrease when the confidence level increases? Does the accuracy improve with a larger confident interval? Explain your answer.

**(40 marks)**

[c] The determination of the density of a cylindrical metal ingot is crucial for the purpose of quality control in a factory. With existing measuring equipment in the laboratory, the mass m, can be determined to within 0.1 kg; the length L, can be determined to within 0.01 cm and the diameter D, to within 0.005 cm. in addition, equipment for each variable has a known calibration uncertainty of 1% of its reading.

Given the nominal values of m = 4.5 kg, L = 8 cm, and D = 4 cm,

(i) estimate the total uncertainty in mass (m), length (L), and diameter (D) individually.

(ii) Subsequently, calculate the propagation of uncertainty in determining the density of the metal ingot.

**(40 marks)**

3. [a] State THREE (3) classifications of sensor with TWO (2) examples of each classification.

**(30 marks)**

[b] Explain the working principle for the listed sensors below. Suggest ONE (1) application that is suitable for each sensor.

(i) Thermocouple
(ii) Strain gage

**(40 marks)**

[c] Consider a capacitive displacement transducer having a diameter of 0.05 m. Assume that the following relationship governs the capacitive displacement transducer in Figure 3:

$$C = \frac{0.225A}{d}$$

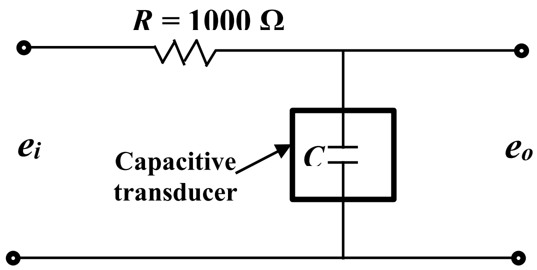


Figure 3

where

$C$ = capacitance (F),
$A$ = cross-sectional area of transducer tip ($m^2$),
$d$ = air-gap distance (m)

The excitation frequency is 100 Hz. Determine the change in $e_o$ when air gap changes from 0.001 m to 0.002 m.

**(30 marks)**

4. [a] List TWO (2) advantages of utilizing decibels (dB) in amplification calculations.

**(20 marks)**

[b] Explain the theory of the following types of filters with the help of a sketch of the RC circuit:

(i) Low-pass filters
(ii) High-pass filters

**(30 marks)**

[c] Figure 4 shows a circuit diagram of a differential amplifier. Derive an expression for the output voltage $e_o$ in terms of the input voltages $e_i$, where resistance $R_1 = R_2$ and $R_3 = R_4$.

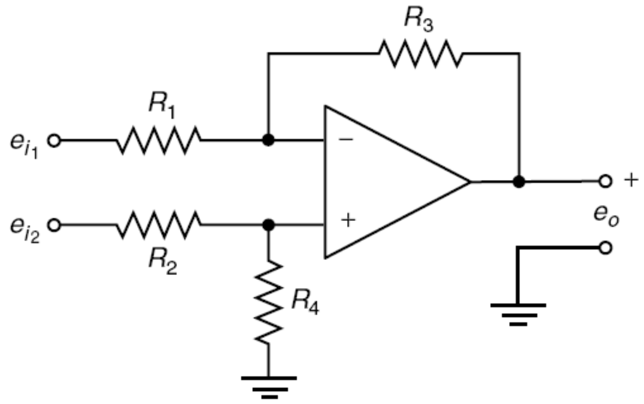


Figure 4

**(25 marks)**

[d] A transducer measures a sinusoidal signal with an amplitude of ± 5V and a frequency up to 10 Hz. Superimposed on this signal is 60 Hz noise with an amplitude of 0.1 V. It is desired to attenuate the 60 Hz signal to less 10% of its value using Butterworth filter. Select a filter order to perform this task if the corner frequency is 10 Hz. The gain for low pass Butterworth filters with frequency *f* and order *n* is given by

$$G = \frac{1}{\sqrt{1 + \left(\frac{f}{f_c}\right)^{2n}}}$$

**(25 marks)**

5. [a] Figure 5[a] and Table 5 show a logic circuit and its incomplete truth table. Complete the truth table and show which input will cause a low output.

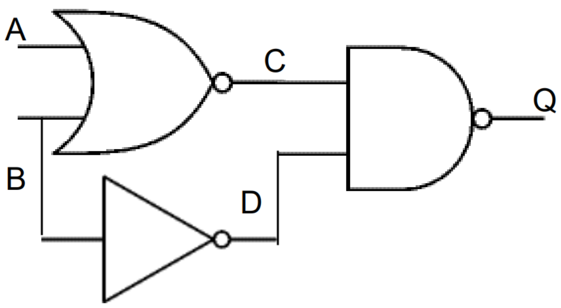


Figure 5[a]

**(20 marks)**

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Table 5

| A | B | C | D | Q |
|---|---|---|---|---|
| | 0 | | | |
| | 1 | | | |
| | 0 | | | |
| | 1 | | | |

[b] Figure 5[b] shows a simple 8 bit digital-to-analog converter (DAC) is required to give an output voltage in the range of 0 to 3.3 V, corresponding to input signal 00000000 to 11111111.

(i) Assuming $V_{REF}$ = -15 V, R= 820 Ω, calculate the value of $R_F$ required.
(ii) Determine the output voltage corresponding to an input signal of 11001001.

**(60 marks)**

[c] An analog-to-digital converter (ADC) has an input range of 0 to 5 V and incorporates an 8-bit encoder.

(i) Determine the voltage resolution per-bit and quantization uncertainty
(ii) Briefly explain how the bit size of the ADC affects the system performance.

**(20 marks)**

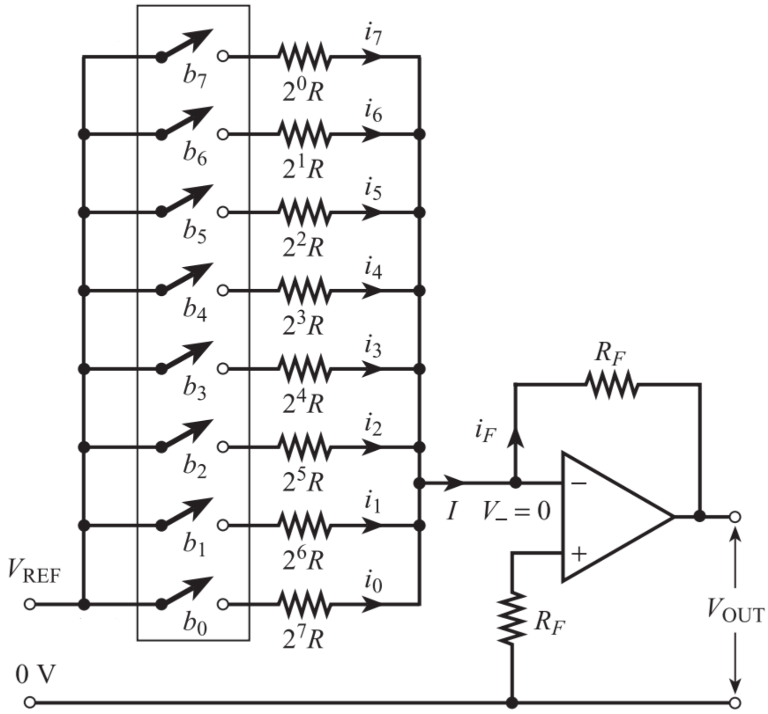

Figure 5[b]

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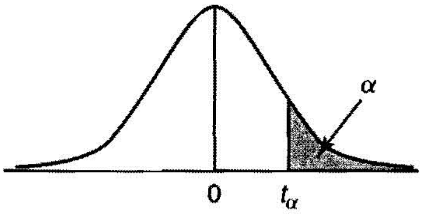
**Appendix A**

Student's $t$-Distribution (Values of $t_{\alpha,\nu}$)




| $\nu$ | $t_{0.10,\nu}$ | $t_{0.05,\nu}$ | $t_{0.025,\nu}$ | $t_{0.01,\nu}$ | $t_{0.005,\nu}$ | $\nu$ |
|---|---|---|---|---|---|---|
| 1 | 3.078 | 6.314 | 12.706 | 31.821 | 63.657 | 1 |
| 2 | 1.886 | 2.920 | 4.303 | 6.965 | 9.925 | 2 |
| 3 | 1.638 | 2.353 | 3.182 | 4.541 | 5.841 | 3 |
| 4 | 1.533 | 2.132 | 2.776 | 3.747 | 4.604 | 4 |
| 5 | 1.476 | 2.015 | 2.571 | 3.365 | 4.032 | 5 |
| 6 | 1.440 | 1.943 | 2.447 | 3.143 | 3.707 | 6 |
| 7 | 1.415 | 1.895 | 2.365 | 2.998 | 3.499 | 7 |
| 8 | 1.397 | 1.860 | 2.306 | 2.896 | 3.355 | 8 |
| 9 | 1.383 | 1.833 | 2.262 | 2.821 | 3.250 | 9 |
| 10 | 1.372 | 1.812 | 2.228 | 2.764 | 3.169 | 10 |
| 11 | 1.363 | 1.796 | 2.201 | 2.718 | 3.106 | 11 |
| 12 | 1.356 | 1.782 | 2.179 | 2.681 | 3.055 | 12 |
| 13 | 1.350 | 1.771 | 2.160 | 2.650 | 3.012 | 13 |
| 14 | 1.345 | 1.761 | 2.145 | 2.624 | 2.977 | 14 |
| 15 | 1.341 | 1.753 | 2.131 | 2.602 | 2.947 | 15 |
| 16 | 1.337 | 1.746 | 2.120 | 2.583 | 2.921 | 16 |
| 17 | 1.333 | 1.740 | 2.110 | 2.567 | 2.898 | 17 |
| 18 | 1.330 | 1.734 | 2.101 | 2.552 | 2.878 | 18 |
| 19 | 1.328 | 1.729 | 2.093 | 2.539 | 2.861 | 19 |
| 20 | 1.325 | 1.725 | 2.086 | 2.528 | 2.845 | 20 |
| 21 | 1.323 | 1.721 | 2.080 | 2.518 | 2.831 | 21 |
| 22 | 1.321 | 1.717 | 2.074 | 2.508 | 2.819 | 22 |
| 23 | 1.319 | 1.714 | 2.069 | 2.500 | 2.807 | 23 |
| 24 | 1.318 | 1.711 | 2.064 | 2.492 | 2.797 | 24 |
| 25 | 1.316 | 1.798 | 2.060 | 2.485 | 2.787 | 25 |
| 26 | 1.315 | 1.706 | 2.056 | 2.479 | 2.779 | 26 |
| 27 | 1.314 | 1.703 | 2.052 | 2.473 | 2.771 | 27 |
| 28 | 1.313 | 1.701 | 2.048 | 2.467 | 2.763 | 28 |
| 29 | 1.311 | 1.699 | 2.045 | 2.462 | 2.756 | 29 |
| $\infty$ | 1.282 | 1.645 | 1.960 | 2.326 | 2.576 | $\infty$ |