INTERFACING FOR MECHATRONIC SYSTEMS
(24WSC353)

Semester 1 2024 — In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

Answer **ALL FOUR** questions.

All questions carry equal marks.

Use a **SEPARATE** answer book for **EACH** question.

Use of a calculator is permitted - It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are not allowed).

A range of formulae and tables likely to be of benefit in the solution of these questions is provided at the rear of the paper.

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1. Answer the following questions:

a) Explain the difference between 'binary' and 'hexadecimal' numerical representations, and explain why hexadecimal numbers are more commonly used compare to binary. [4 marks]

b) Explain what is aliasing in electronics and give three practical solutions to reduce noise when sampling. [6 marks]

c) Give the chain of conversions from fluid volume to voltage when using a capacitive sensor to measure fluid volume in a tank. Give the constants and conversion factors at each step. [4 Marks]

d) These questions relate to strain gauges and their operation:

i. Describe a strain gauge and its theory of operation. [3 marks]

ii. One of several variants of a piece of circuitry is often used in tandem with a strain gauge. Draw a circuit diagram of any one of the variants. [3 marks]

e) Name two methods of measuring the velocity of a flow <u>not</u> constrained in a pipe. A sketch/diagram should be used to show the components and principle of operation. [5 marks]

2. The following question relates to the design of Analogue to Digital Conversion technologies.

a) Draw the circuit schematic and explain the principle of operation of an 'integrator' type ADC. [8 Marks]

b) Draw the circuit schematic and explain the principle of operation of a parallel ADC converter. [8 Marks]

c) Briefly compare the two methods presented in parts a) and b). Your answer should refer to appropriate characteristics for assessing ADC technologies. [5 Marks]

d) Considering an application such as position measurement, briefly discuss the pros and cons of using an analogue signal chain compared to a pulse-based technology. [4 Marks]

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3. The following question relates to the design of Analogue to Digital Conversion (ADC) technologies and the following conceptual signal chain for an analogue position sensor.

The sensor outputs a signal between ±0.40 V for the anticipated range of operation. This is passed through an active low-pass filter based on an OpAmp design then input into an ADC. The supply range for the OpAmp is ±12 V and the input range for the ADC is ±10V. The OpAmp has a low-frequency gain of 6 V/V and the ADC has a fundamental resolution of 10 bits. Assume all noise outside of the required operating frequencies are filtered out.

a) The ADC to be used in the scenario is a successive approximation register (SAR) type device.

Describe the principles of operation of a SAR ADC. Draw a fundamental circuit diagram to aid your explanation. [9 marks]

b) The components of the signal chain have the following properties that have been obtained from the respective datasheets or directly measured.

COMPONENT	NOISE SPECIFICATION
Cable	$0.015\ mV_{rms}$
Amplifier	$110dB\ SNR$ (IC internal noise only)
PCB interconnect	$0.08\ mV_{rms}$
ADC Thermal noise	90dB SNR

If the required effective number of bits (ENOB) in measurement is to be 6 bits:

i. Calculate the approximate allowable total signal noise as RMS voltage. [4 Marks]

ii. Calculate the total noise contribution of all components in the signal chain described [8 Marks]

iii. Calculate the minimum SNR in dB allowable in the sensor specification to meet the required ENOB in measurements [4 marks]

4. A thermocouple measures the ambient temperature near a transistor's heat sink to be 21°C:

a) Describe the theory of operation of a thermocouple and give examples of common materials used to make them. [2 marks]

b) What is the cold/reference junction, and why is it required when measuring temperatures with a thermocouple? [2 marks]

c) Using thermal resistances, draw a simple diagram showing how heat flows from the transistor junction to the case, then to the heatsink and finally to ambient. [3 marks]

d) The transistor is constantly dissipating 20W due to internal losses. Given the thermal resistances in the table below, what is the junction temperature?

Thermal Resistance of:	**Value (°C/W)**
Junction to case	1.5
Case to heatsink	0.2
Heatsink to ambient	4

[4 marks]

e) How might the thermal resistance from the heatsink to ambient be reduced? [2 marks]

f) Using your temperature for the heatsink from d), above, how much power is being dissipated by radiation from the heatsink?
Assume:
- the emissivity of the heatsink is 0.9
- the area of the heatsink is $1cm^2$
- the Stefan-Boltzmann constant is 5.670367×10^{-8} $W\cdot m^{-2}\cdot K^{-4}$ [10 marks]

g) Re-draw your diagram from c) to include this power dissipation path [2 marks]

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USEFUL FORMULAE

$$ENOB \approx \frac{SNR_{dB} - 1.76 + 20\,log\left(\frac{Signal\ Amplitue\ (V)}{ADC\ Input\ Range\ (V)}\right)}{6.02}$$

For sinusoidal:

$$SNR_{dB} \approx 1.76 + 6.02n$$

For linear input

$$SNR_{dB} = 20\log_{10}(Q\sqrt{3})$$

$$SNR_{dB} \approx 6n + 4$$

Heat transfer

$$Q_r = \epsilon\sigma AT^4$$

$$Q_{conv} = h_c A\Delta T$$

$$Q_{cond} = -\frac{KA\Delta T}{x}$$

(σ is the Stefan-Boltzmann constant: 5.67×10^{-8}W·m^{-2}·K^{-4})

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PREFERRED COMPONENT VALUES

Resistors:

1K	10K	100K	1M
1K2	12K	120K	1M2
1K5	15K	150K	1M5
1K8	18K	180K	1M8
2K2	22K	220K	2M2
2K7	27K	270K	2M7
3K3	33K	330K	3M3
3K9	39K	390K	3M9
4K3	43K	430K	4M3
4K7	47K	470K	4M7
5K1	51K	510K	5M1
5K6	56K	560K	5M6
6K8	68K	680K	6M8
7K5	75K	750K	7M5
8K2	82K	820K	8M2
9K1	91K	910K	9M1

Capacitors:

10pF	100pF	1000pF	.010uF	.10uF	1.0uF	10uF
12pF	120pF	1200pF	.012uF	.12uF	1.2uF	
15pF	150pF	1500pF	.015uF	.15uF	1.5uF	
18pF	180pF	1800pF	.018uF	.18uF	1.8uF	
22pF	220pF	2200pF	.022uF	.22uF	2.2uF	22uF
27pF	270pF	2700pF	.027uF	.27uF	2.7uF	
33pF	330pF	3300pF	.033uF	.33uF	3.3uF	33uF
39pF	390pF	3900pF	.039uF	.39uF	3.9uF	
47pF	470pF	4700pF	.047uF	.47uF	4.7uF	47uF
56pF	560pF	5600pF	.056uF	.56uF	5.6uF	
68pF	680pF	6800pF	.068uF	.68uF	6.8uF	
82pF	820pF	8200pF	.082uF	.82uF	8.2uF	