# INTERFACING FOR MECHATRONIC SYSTEMS
22WSC355

Semester 2 2023 In-Person Exam paper

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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.

<u>Help during the exam</u>

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.

You may use a calculator for this exam. 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).

# INTERFACING FOR MECHATRONIC SYSTEMS

(22WSC355)

Semester 2 2023 | 2 Hours

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Answer **ALL FOUR** questions.

All questions carry equal marks.

Any University-approved calculator is permitted.

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

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**1.** Answer the following short questions

a) Explain the difference between 'natural binary' and 'binary coded decimal' numerical representations, and give a practical example of how each might be used in microcontroller interfacing applications. [5 marks]

b) Describe how quantisation noise occurs. Use a graph(s) to explain your answer [5 marks]

c) Twisted-pair and co-axial cables use different methods for noise rejection. Draw a schematic of each, label the components and explain the theory of operation. [5 marks]

d) Give the chain of conversions from mass to voltage when using a strain gauge load cell to lift a load. Give the constants and conversion factors at each step. [5 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 components and principle of operation. [5 marks]

**2.** A pneumatic valve within an accurate pressure regulation system is controlled by an electromagnetic arrangement where the electromotive force holds the valve open against a compressed spring to allow gas flow through the orifice, as shown in Figure Q2

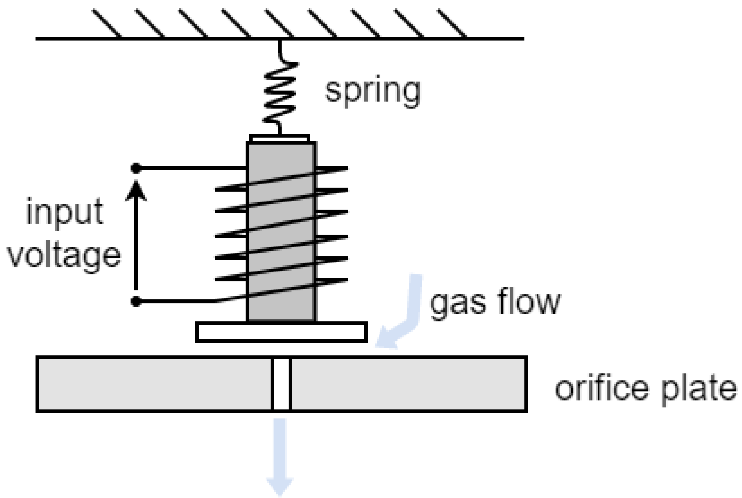


Figure Q2

It is necessary to design drive electronics to provide current through the electromagnet's coil in response to a PWM signal from a microcontroller.

By analysis of the mass, spring and damping within the system, the time constant of the mechanical system can be shown to be $\tau_m = 0.13\ s$, and the time constant of the electrical system is $\tau_e = 6 \times 10^{-4} s$. The electromagnet has a maximum voltage of 12 V and a coil resistance of $3\Omega$. It has a linear electromagnetic constant of $B_{em} = 2\ N/A$, where:

$$F_e = I_c B_{em}$$

Where $I_c$ is the current through the coil and $F_e$ is the electromagnetic force. The maximum electromagnetic force is to be $5N$.

a) Draw a block diagram representing the stages of transduction required to effectively manipulate the end effector. Ensure all block gains and signal maxima are labelled. Make necessary assumptions where appropriate. [4 Marks]

b) Identify a suitable PWM frequency for this application. Explain your design choice. [6 Marks]

c) Calculate the slowest fundamental clock speed required to deliver a 10 bit resolution PWM pulse width [2 Marks]

d) Design an active filter for the early stages of the signal chain. Include in your answer the chosen component values and the specifications of any filter chosen [8 Marks]

e) Discuss the advantages and disadvantages of driving this system using a switching approach instead of an analogue drive system. Include in your answer suggested mitigation methods for any problems encountered. [5 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 ±0.50 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 ±10 V. The active filter circuit has a low-frequency gain of 10 V/V and the ADC has a fundamental resolution of 12 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 | $98dB\ SNR$ (IC internal noise only) |
| PCB interconnect | $0.08\ mV_{rms}$ |
| ADC Thermal noise | 82dB SNR |

If the required effective number of bits (ENOB) in measurement is to be 8 bits:

i. Calculate the approximate allowable total signal noise at as an 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.** The following questions relate to the capacitive fluid-level sensor shown in Figure Q4.

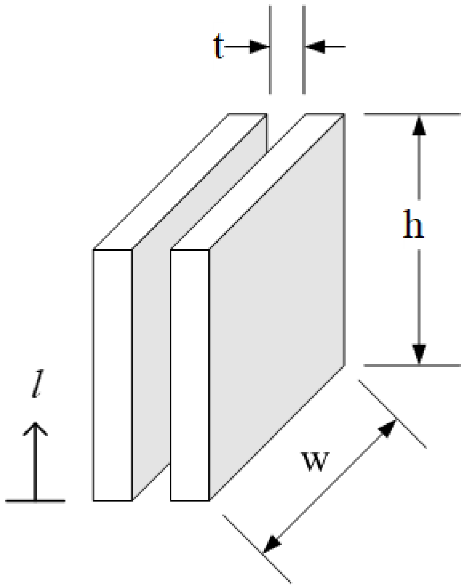


*Figure Q4 Capacitive level sensor*

a) A capacitive sensor is used to determine the level of a fluid, $l$, as shown in Figure Q4. Describe its theory of operation. [4 Marks]

b) Write the equation for the capacitance of the plates with air as the dielectric. [3 Marks]

c) Derive the equation for the capacitance of the plates as a function of $l$, the liquid level. [5 Marks]

d) How would this change in capacitance be measured in practice? Sketch a circuit that would allow this measurement to be made. [7 Marks]

e) Explain what practical considerations may need to be considered if a similar sensor were used to determine the fuel quantity in an aircraft. [6 Marks]

**P. D. Hubbard**
**T. Harrison**

## 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

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

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

**Heat transfer**

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

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

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

($\sigma$ is the Stefan-Boltzmann constant: $5.67\times10^{-8}$W·m$^{-2}$·K$^{-4}$)

## 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 | |