[ENG70]

UNIVERSITY OF GREATER MANCHESTER

SCHOOL OF ENGINEERING

BENG (HONS) BIOMEDICAL ENGINEERING

SEMESTER 2 EXAMINATIONS 2024/25

MEDICAL INSTRUMENTATION & CONTROL

MODULE NO: BME5002

Date: Tuesday 13 May 2025 **Time: 10:00 – 12:00**

INSTRUCTIONS TO CANDIDATES:

There are six questions.

Answer any four (4) questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Electronic calculators may be used provided that data and program storage memory is cleared prior to the examination.

CANDIDATES REQUIRE:

A formula sheet is included.

Question 1.

(a) A second order system has the following transfer function:

$$\frac{250}{s^2 + 35s + 250}$$

State, with reasons, whether the system is *underdamped* or *overdamped*.

[2 marks]

Find the response of the system to a unit step input.

[8 marks]

(b) A second order system has the following transfer function:

$$\frac{450}{s^2 + 25s + 225}$$

(i) Find the natural frequency ω_n, the damping ratio ζ and the damped frequency ω_d. **[6 marks]**

(ii) Calculate the peak time and the rise time for the system **[6 marks]**

(iii) Calculate the percentage overshoot for the system to two significant figures. **[3 marks]**

Question 2

(a) Consider the system block diagram shown in Figure 2a.

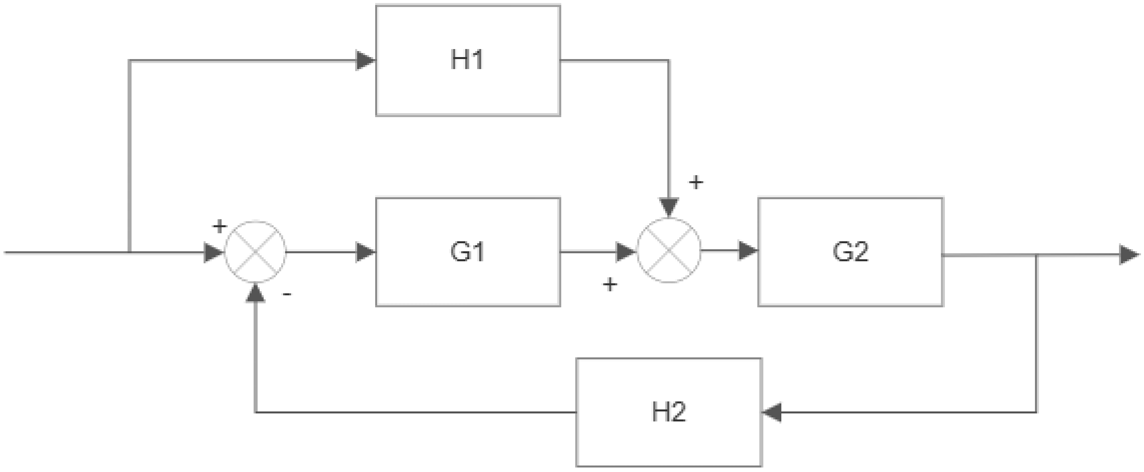

Figure 2a

By applying the rules for block reduction, find the transfer function to represent this system as a single block.

[15 marks]

(b) Consider the system block diagram shown in Figure 2b.

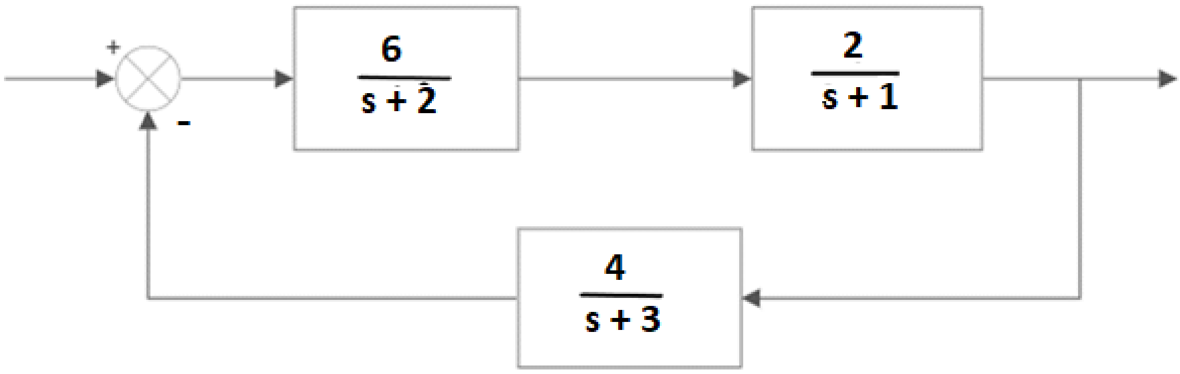

Figure 2b

Calculate and simplify the closed loop transfer function for the system.

State, with reasons, whether or not the system is stable.

[10 marks]

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Question 3

Consider the control system shown in figure 3

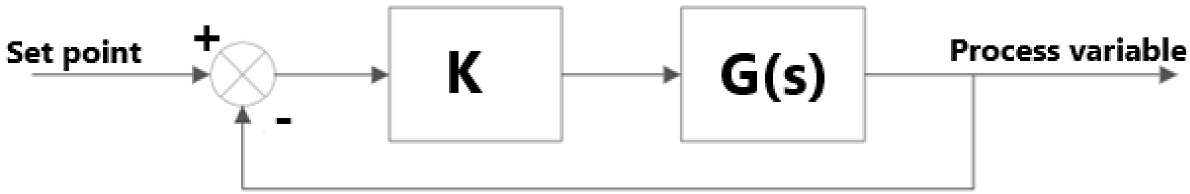

Figure 3

The controller *K* is a proportional controller, the plant is

$$G(s) = \frac{4}{s^2 + 16s + 20}$$

and the system uses unity negative feedback. We wish to design the controller so that the overshoot does not exceed 15% and the steady state error for a unit step input does not exceed 0.1.

(i) Write down the *open loop* transfer function of the system. **[2 marks]**

(ii) Find an expression for the steady state error for unit step input in terms of *K*. **[4 marks]**

(iii) Find the range of values for *K* for which the steady state error does not exceed 0.1. **[4 marks]**

(iv) Find the *closed* loop transfer function of the system. **[3 marks]**

(v) Find expressions for the natural frequency and the damping ratio in terms of *K*. **[5 marks]**

(vi) Find the value of the damping ratio that gives an overshoot of 15%. **[3 marks]**

(vii) Find the range of values for *K* for which the overshoot does not exceed 15%. **[4 marks]**

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Question 4

a) Figure Q4 shows equivalent circuit of a biopotential electrode. A pair of these electrodes are tested in a beaker of physiological saline solution. The test consists of measuring the magnitude of the impedance between the electrodes as a function of frequency via low-level sinusoidal excitation so that the impedances are not affected by the current crossing the electrode–electrolyte interface. The impedance of the saline solution is small enough to be neglected. Sketch a Bode plot (log of impedance magnitude versus log of frequency) of the impedance between the electrodes over a frequency range of 1 to 100,000 Hz. **[10 marks]**

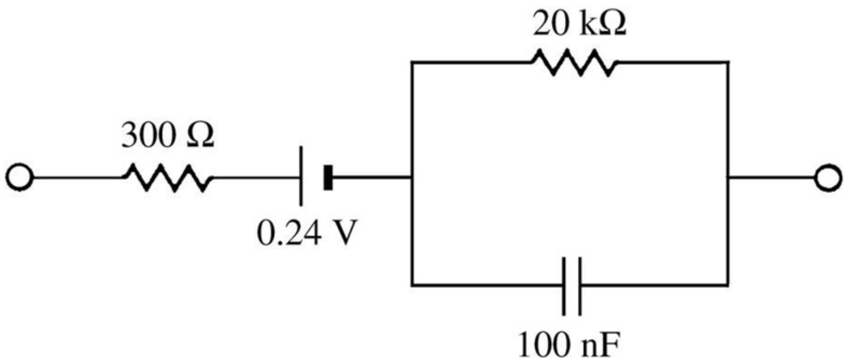

Figure Q4.

b) Clinical diagnoses depend on the accurate and efficient design of biomedical instrumentation. As a biomedical engineer you are tasked to graphically represent the clinical diagnoses process to help improve the differential diagnosis process. Assume the patient coming into the clinic is complaining about abnormal breathing.

[8 marks]

Please turn the question continues…

c) Sensors are an essential part of all biomedical instrumentation systems. Classify the sensors into three different types based on their working principle. Give three examples of each type of sensors.

[7 marks]

Total 25 marks

Question 5

a) A piezoelectric sensor has a capacitance C=50 picofarad (pF). Sensor leakage resistance is 20 gigaohm ($G\Omega$). The amplifier input impedance is 5 megohms ($M\Omega$) and later changes to 500 megohms ($M\Omega$). Calculate the lower corner frequency for both values of input impedance.

[8 marks]

b) As a biomedical engineer you are tasked to design a temperature sensor. It is essential as a design engineer to make sure your instrument is accurate and precise. Assume you calibrate your device by taking 10 consecutive readings. How would you graphically display the accuracy and precision in this case?

[10 marks]

c) Medical instruments after a period of usage need to be calibrated. Assume you were given the task to calibrate a thermometer. Design a calibration mechanism in this case while keeping in mind that the hysteresis loop, one-point and two-point calibration examples discussed in the lecture.

[7marks]

Total 25 marks

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Question 6

a) Most sensors used in biomedical instruments are analogue in nature. The use of analogue signals is prone to noise in the system which eventually leads to system error. Identify and graphically explain the techniques you would employ to reduce noise in the systems. **[8 marks]**

b) Explain the role that the plasma membrane plays in the cellular organisation. How can we represent the permeability of the plasma membrane mathematically? Is the plasma membrane thickness inversely or directly proportional to the permeability?

[8 marks]

c) You have been given the task of developing a capacitive sensor. The 2 cm^2 capacitance sensor has a resistance R of 200 megaohms (MΩ). Calculate 'x', the plate spacing required to pass sound frequencies above 10 Hz.

[9 marks]

Total 25 marks

END OF QUESTIONS

A FORMULA SHEET APPEARS OVER THE PAGE

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School of Engineering
BEng (Hons) Biomedical Engineering
Semester 2 Examinations 2024-2025
Medical Instrumentation and Control
Module No. BME5002

FORMULA SHEET

$C = \frac{1}{2\pi f R}$ $\qquad f = \frac{1}{2\pi RC}$

where R is resistance, f is frequency and C is the capacitance.

Parameters of second order systems

Relation between ω_n, ω_d and ζ:

$$\omega_d = \sqrt{1-\zeta^2}\,\omega_n \qquad \omega_n = \frac{1}{\sqrt{1-\zeta^2}}\omega_d \qquad \zeta = \sqrt{1-\left(\frac{\omega_d}{\omega_n}\right)^2}$$

Relation between damping ratio and percentage overshoot:

$$overshoot = 100exp\left(-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}\right) \qquad \zeta = \sqrt{\frac{(\ln A)^2}{\pi^2+(\ln A)^2}}$$

Rise time, peak time, and 5% and 2% settling times:

$t_{rise} = \frac{\pi-\phi}{\omega_d}$ where $\phi = \cos^{-1}(\zeta)$ $\qquad t_{peak} = \frac{\pi}{\omega_d}$

$t_{settle,5\%} \approx \frac{3}{\zeta\omega_n}$ $\qquad t_{settle,2\%} \approx \frac{4}{\zeta\omega_n}$

Table of Laplace Transforms

$\boldsymbol{f(t)}$	$\boldsymbol{F(s) = \int_0^\infty f(t)e^{-st}dt}$
1	$\frac{1}{s}$
t	$\frac{1}{s^2}$
e^{-at}	$\frac{1}{s+a}$
$\sin\omega t$	$\frac{\omega}{s^2+\omega^2}$
$\cos\omega t$	$\frac{s}{s^2+\omega^2}$
$e^{-at}f(t)$	$F(s+a)$
$f'(t)$	$sF(s)-f(0)$

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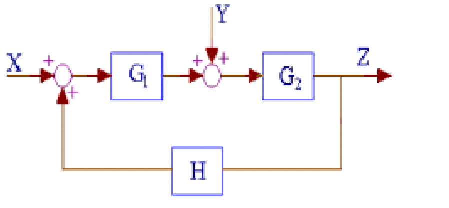
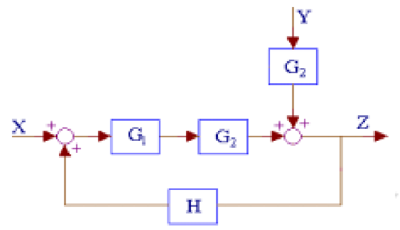
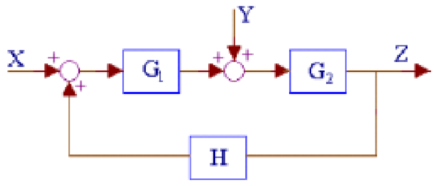
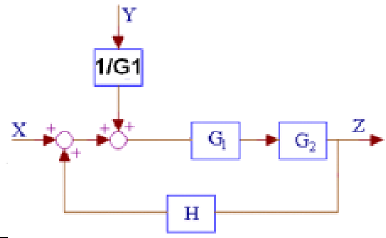
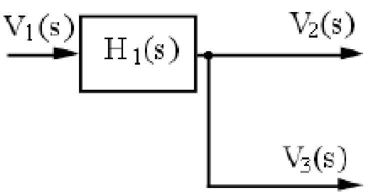
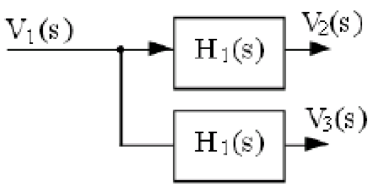
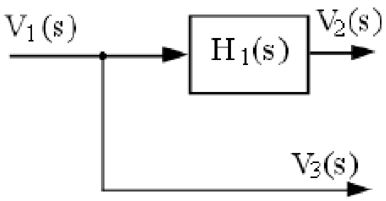
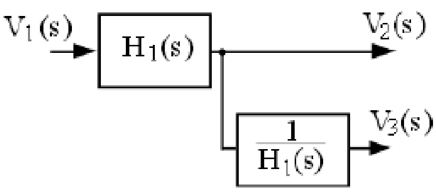
Block diagrams

Rule	Original Diagram	Equivalent Diagram
1. Moving a summing point beyond a block		
2. Moving a summing point in front a block		
3. Moving a takeoff point to front of a block		
4. Moving a takeoff point to beyond a block		

Blocks with feedback

$G(s)$ is forward path, $H(s)$ is feedback path.

Negative feedback: $\frac{G(s)}{1+G(s)H(s)}$

Positive feedback: $\frac{G(s)}{1-G(s)H(s)}$

Steady state error Unit step $\left[\frac{1}{1+G(s)}\right]_{s=0}$ Unit ramp $\left[\frac{1}{sG(s)}\right]_{s=0}$

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