[ENG20]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG (HONS) BIOMEDICAL ENGINEERING

SEMESTER 2 EXAMINATIONS 2023/24

MEDICAL INSTRUMENTATION & CONTROL

MODULE NO: BME5002

Date: Tuesday 14th May 2024 **Time: 2:00pm – 4:30pm**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer any FOUR 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 following the questions.

Question 1.

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

$$\frac{800}{s^2 + 30s + 400}$$

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. (3 marks)

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

$$\frac{400}{s^2 + 40s + 800}$$

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)

Total 25 marks

Please turn the page…

School of Engineering
BEng (Hons) Biomedical Engineering
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Medical Instrumentation and Control
Module No. BME5002

Question 2

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

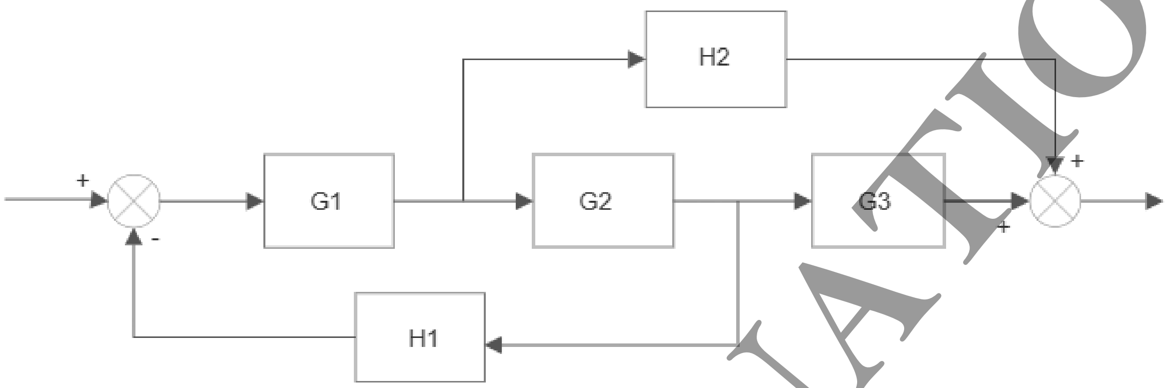

Figure 2a

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.

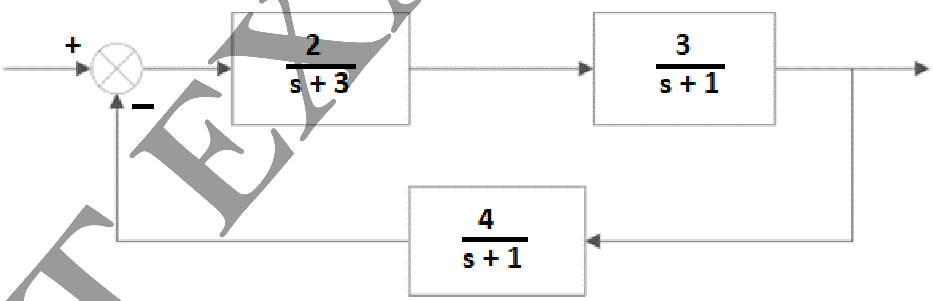

Figure 2b

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

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

[10 marks]

Total 25 marks

Please turn the page…

Question 3

Consider the control system shown in figure 3:

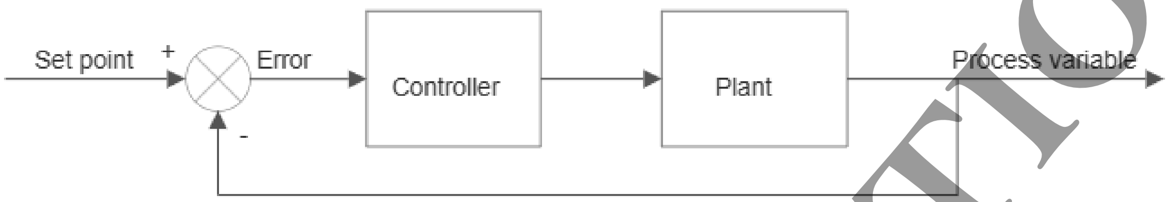

Figure 3

The controller is an integral controller, and the plant is

$$G(s) = \frac{4}{s+6}$$

and the system uses unity negative feedback. We wish to design the controller so that the overshoot does not exceed 5% and the steady state error for a unit ramp input does not exceed 0.5.

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

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

c) Find the range of values for *K* for which the steady state error does not exceed 0.5. [3 marks]

d) Find the *closed* loop transfer function of the system. [4 marks]

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

f) Find the value of the damping ratio that gives an overshoot of 5%. [3 marks]

g) Find the range of values for *K* for which the overshoot does not exceed 5%. [4 marks]

Total 25 marks

Please turn the page…

Question 4

a) Define resting potential and action potential. [4 marks]

b) Depolarization and repolarization of cells play an important role in controlling the action potential of the cell. Define *depolarization* and *repolarization*. Draw a graphical waveform that shows the *depolarization* and *repolarization* of the action potential of a cell. [6 marks]

c) Transducers are an essential part of all biomedical instrumentation systems. Classify the transducers into three different types based on their working principle. [5 marks]

d) A piezoelectric sensor has a capacitance C=500 picofarad (pF). Sensor leakage resistance is 10 gigaohm (GΩ). The amplifier input impedance is 5 megohms (MΩ) and later changes to 500 megohms (MΩ). Calculate the lower corner frequency for both values of input impedance. [10 marks]

Total 25 marks

Please turn the page

Question 5

a) Feedback components in biomedical measurement systems are essential for signal correction and comparison. Design a generalized measurement system using a block diagram for a glucometer that is to be used in a clinical environment. [10 marks]

b) Medical instruments after a period of usage need to be calibrated. Assume you were given the task to calibrate a blood pressure monitor. Design a calibration mechanism in this case while keeping in mind that the one-point and two-point calibration examples discussed in the lecture. [8 marks]

c) Define biopotential amplifiers. Give one example of biomedical instruments based on biopotential amplifiers discussed during the lectures. [7 marks]

Total 25 marks

Please turn the page

Question 6

a) An electrocardiogram (ECG) is normally used to record electrical signals in the heart. In a 12-lead ECG system, how many leads/electrodes are placed on the chest, and how many leads/electrodes are placed on the limb? How would you graphically represent the two lead vectors a1 and a2 with respect to cardiac vector M in an ECG measurement? [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? [10 marks]

c) Discuss in detail a generalized biomedical instrumentation system with the help of an appropriate diagram. [7 marks]

Total 25 marks

END OF QUESTIONS

A FORMULA SHEET APPEARS OVER THE PAGE

Please turn the page…

School of Engineering
BEng (Hons) Biomedical Engineering
Semester 2 Examinations 2023-2024
Medical Instrumentation and Control
Module No. BME5002

FORMULA SHEET

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

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

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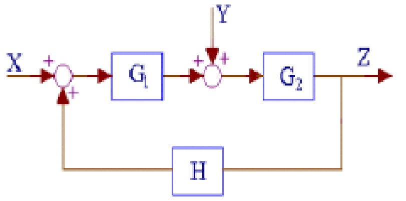
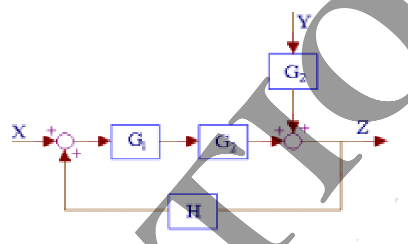
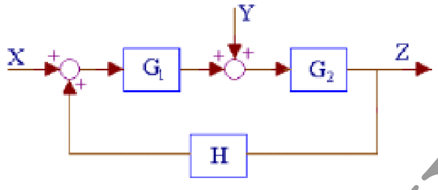
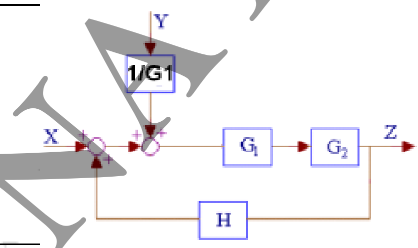
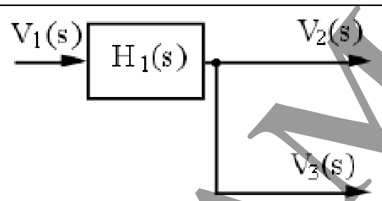
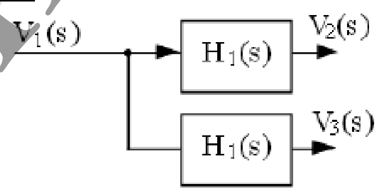
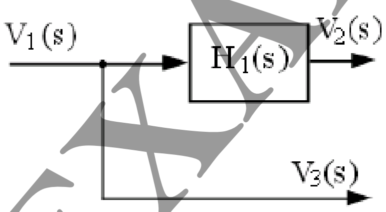
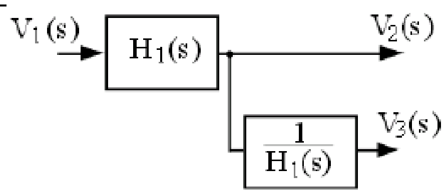
Block diagrams

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

Corner frequency = $f_c = \frac{1}{2\pi Rc}$

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