[ENG02]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG (HONS) BIOMEDICAL ENGINEERING

SEMESTER 2 EXAMINATIONS 2022/23

MEDICAL INSTRUMENTATION & CONTROL

MODULE NO: BME5002

Date: Tuesday 9th May 2023 **Time: 2:00pm – 4:30pm**

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 following the questions.

Question 1.

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

$$\frac{900}{s^2 + 40s + 900}$$

(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:

$$\frac{800}{s^2 + 60s + 800}$$

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

School of Engineering
BEng (Hons) Biomedical Engineering
Semester 2 Examinations 2022-2023
Medical Instrumentation and Control
Module No. BME5002

Question 2

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

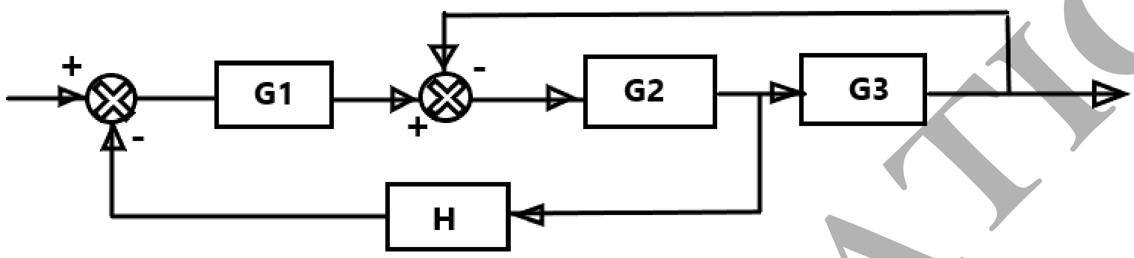

Figure 2a

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.

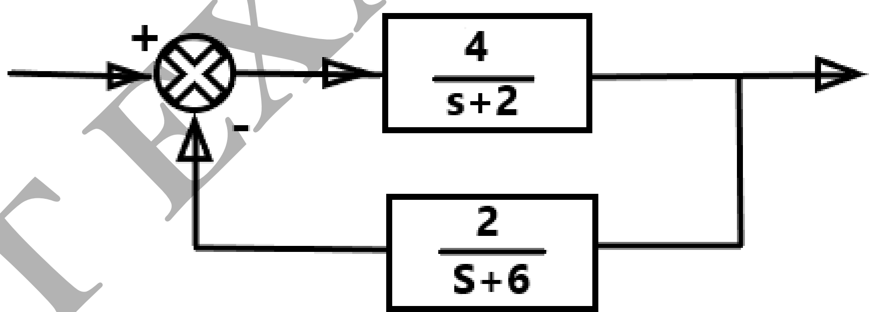

Figure 2b

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

[10 marks]

Total 25 marks

Question 3

Consider the control system shown in figure 3

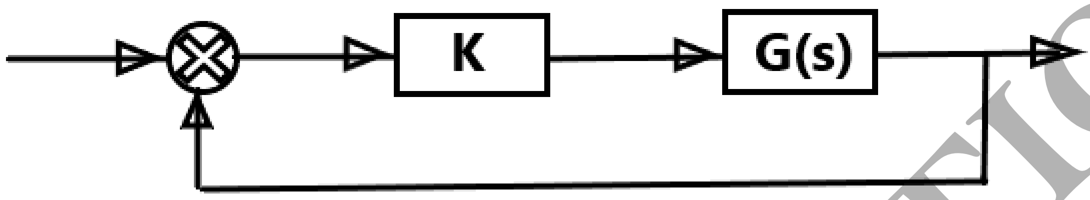

Figure 3

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

$$G(s) = \frac{3}{s^2 + 10s + 12}$$

and the system uses unity negative feedback. We wish to design the controller so that the overshoot does not exceed 10% and the steady state error for a unit step input does not exceed 0.2.

(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 0.2. [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 10%. [3 marks]

(vii) Find the range of values for *K* for which the overshoot does not exceed 10%. [4 marks]

Total 25 marks

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Question 4

(a) For the medical signal processing circuit shown in **Figure 4**, derive an equation for Vo, if the applied signal is; $Vs = 10mV \sin(1000t)$.
[8 Marks]

(b) Sketch the input and output waveforms; indicating the period/amplitude with appropriate values.
[6 Marks]

(c) If the calculated value for the output signal is; $Vo = -2mV$, calculate the positive value time (t) to achieve this.
[4 Marks]

(d) Describe a medical application for the circuit shown in **Figure 4.** [7 Marks]

Useful formulae $y = sinax, \frac{dy}{dx} = a\ cosax$

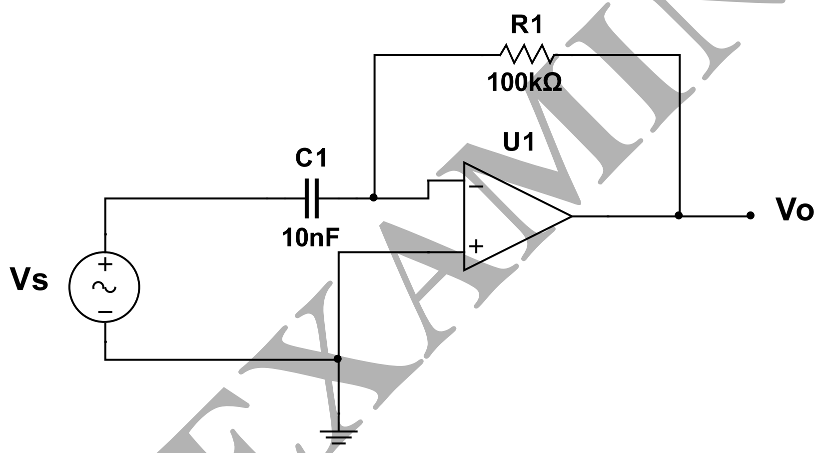


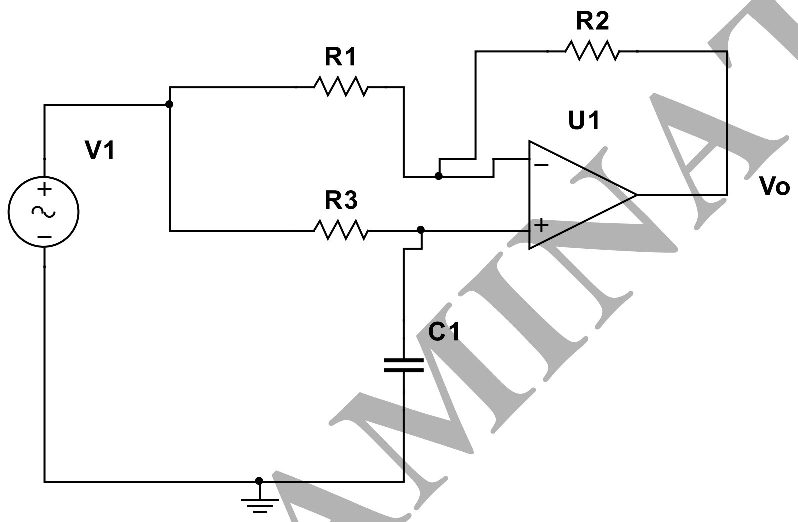
Figure 4

Total 25 marks

Question 5

A signal conditioning circuit is shown for a monitor in **Figure 5.**

(a) Derive the Laplace transfer equation for **Figure 5.** [8 marks]
(b) Sketch the pole-zero map. [5 marks]
(c) Draw the Bode plots. [10 marks]
(d) State the application for the circuit shown in **Figure 5.** [2 marks]



All the resistors are 1kΩ and the capacitor is 1nF

Figure 5

Total 25 marks

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Question 6

(a) Name five measurands used in Biomedical Instrumentation. [5 marks]

(b) Describe the following terms:

(i) Reference value.
(ii) Resolution.
(iii) Precision.
(iv) Accuracy.
(v) Repeatability.

[10 marks]

(c) An instrument amplifier is shown in **Figure 6**, calculate the output voltage and what is the purpose of the second amplifier U2 shown. [10 marks]

If V1= 100mV and V2 = 200mV

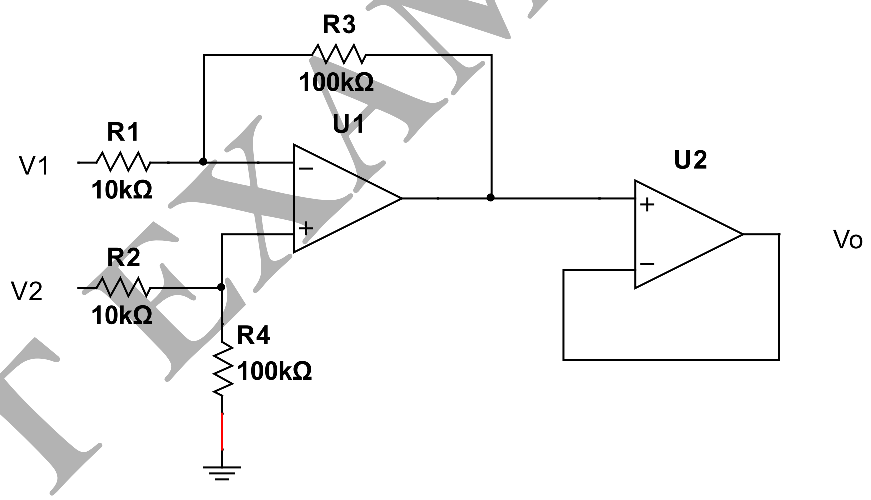

Figure 6

Total 25 marks

END OF QUESTIONS

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School of Engineering
BEng (Hons) Biomedical Engineering
Semester 2 Examinations 2022-2023
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:

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

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

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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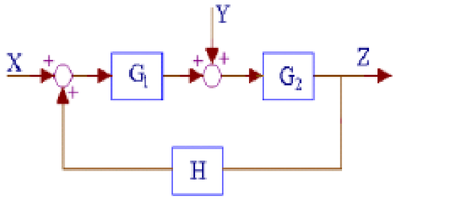
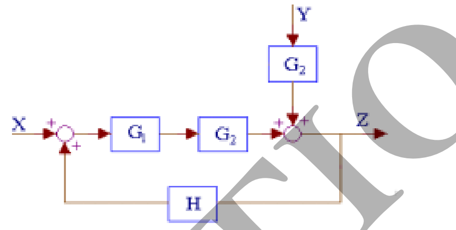
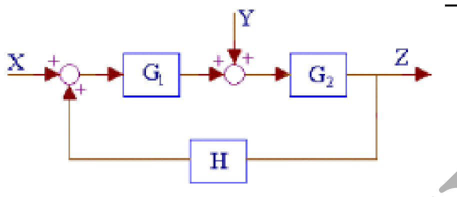
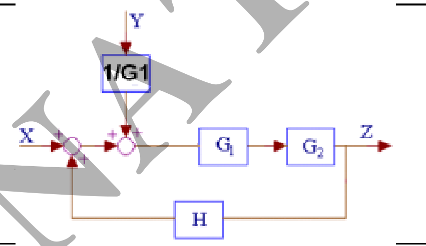
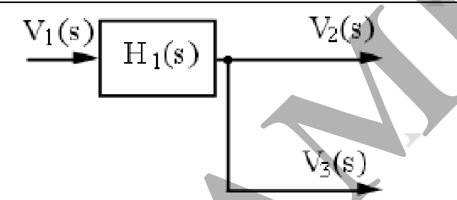
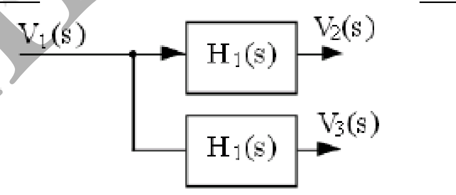
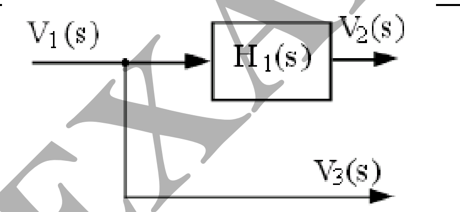
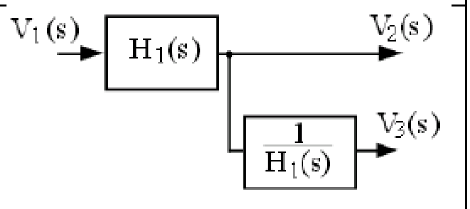
Block diagrams

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

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