UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG (HONS) IN BIOMEDICAL ENGINEERING

SEMESTER ONE EXAMINATION 2018/2019

ADVANCED BIOMECHATRONIC SYSTEMS

MODULE NO: BME6003

Date: Friday 18 January 2019 **Time: 10.00 am-12.00 noon**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions. You are required to answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

CANDIDATES REQUIRE:

Property tables provided
Formula Sheet (attached)
Take density of water as 1000 kg/m^3

Q1

(a) The following experimental data presented in Table Q1(a) were recorded by using a sinusoidal signal as the input and monitoring the steady-state output to determine the Gain and the Phase shift between the output and input.

Table Q1 (a) Input (Volts peak-peak) = 6 (V)

Frequency (Hz)	Output (Volts peak-peak)	Phase Shift (Degree)
0.2	0.4	86
0.6	1.2	78
1.2	1.5	58
2.4	1.9	46
3.6	3.8	32
4.8	4.6	24
6	5.8	12

Analyse these data from the table and answer:

i) How to determine the Gain. **[2 marks]**

ii) What the meaning of Phase shift is. **[2 marks]**

iii) What kind of system it is. **[2 marks]**

(b) Explain, helped by sketches, what frequency response is and why it is useful for biomechatronic systems control.

[6 marks]

(c) Figure Q1(c) (on the following page) shows a Bode plot.

i) Estimate the gain margin and the phase margin.

[4 marks]

ii) Explain the functions of gain margin and phase margin in systems control.

[4 marks]

iii) Comment on the system's stability performance.

[2 marks]

iv) Explain the system's Peak Resonance M_p and Bandwidth.

[3 marks]

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Q1 continued…..

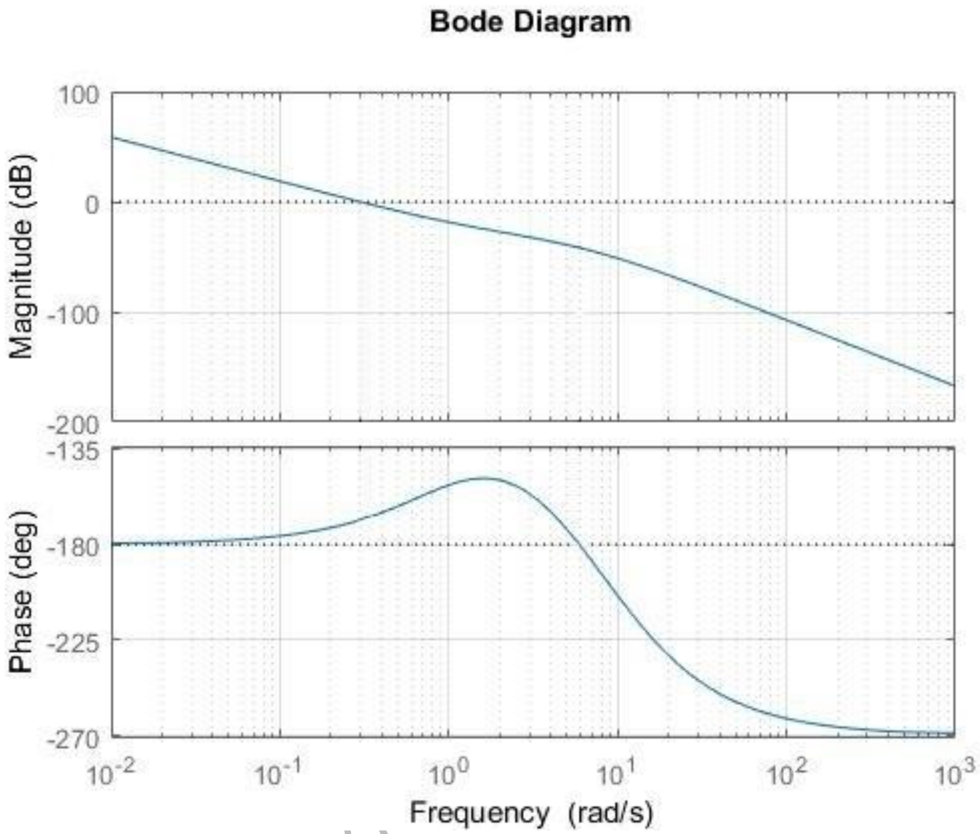

Figure Q1 (c) A Bode Plot

[Total 25 marks]

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Q2

A simplified model of a prosthesis arm system is shown in Figure Q2. The control system for the prosthesis limb dynamics is given by:

$$G_p(s) = \frac{8}{(2s+4)(s+2)}$$

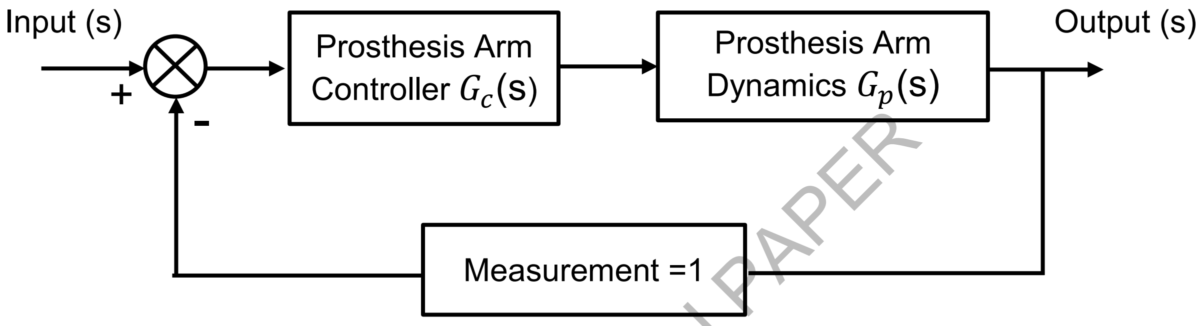

Figure Q2 A Prosthesis Arm

The system responses for a unit step input are required as:

- The maximum overshoot is less than 12%
- The rise time is less than 0.4 seconds
- The steady-state error is 0

(a) If Gc (s) is a PID controller with Kp = 2, Ki = 5 and Kd = 3, find the range of the gain Kp making the system to be an underdamped system for unit step input. examine the actual system's percent overshoot, rise time and steady-state error under the PID controller and check whether the design criteria have been achieved or not.

[14 marks]

(b) Describe, helped by sketches, how the error item is handled by proportional, integral and derivative controller.

[8 marks]

(c) If the design criteria haven't been achieved by using the PID controller provided above, explain the procedure to modify the PID controller.

[3 marks]

[Total 25 marks]

Q3

(a) Using block diagrams, briefly explain an analogue closed loop control system and a digital closed loop control system. Assume that input, output and sensor signals for both control systems are all analogue signals.

[6 marks]

(b) Explain what is meant by a zero-order hold (ZOH) system.

[4 marks]

(c) A controller has an 12 bit Analogue to Digital Converter with the signal range between 0 Volt to +12 Volt:

(i) What is the resolution of the AD converter?

[2 marks]

(ii) What integer number represented a value of +6 Volts?

[2 marks]

(iii) What voltage does the integer 3072 represent?

[2 marks]

(iv) What voltage does 010011100101 represent?

[2 marks]

(d) A controller of biomechatronic system consists of a Digital to Analogue Converter with zero order element in series with the processing centre which has a transfer function

$$G_p(s) = \frac{6}{s(s+6)}$$

Find the sampled-data transfer function, G (z) for the digital control system. The sampling time, T, is 1 seconds.

[7 marks]
[Total 25 marks]

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Q4

(a)A typical op-amp has an open loop gain graph shown in Figure Q4 (a), derive a transfer function which predicts the open loop gain/frequency response.

[5 marks]

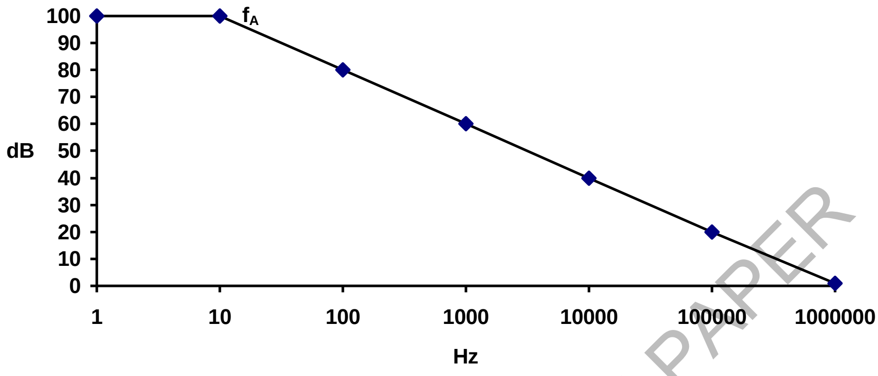

Figure Q4 (a)

(b)If a non-inverting amplifier configuration has a closed loop gain of eleven, sketch a suitable circuit and calculate the bandwidth and input/output resistance of the non-inverting amplifier using the transfer function from part (a), if Rin is 100kΩ and Rout is 100Ω.

[10 marks]

(c)A low pass first order filter is connected to the input of the amplifier (in part b), sketch the frequency/phase plots of the modified circuit, if the low pass filter uses a resistor of 100kΩ and a capacitor of 100nF.

[10 marks]
[Total 25 marks]

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Q5

(a)When describing an OP-Amp, what is meant by the terms; common - mode rejection ratio, slew rate and transition frequency.

[6 marks]

(b)For the circuit shown in Figure Q5 (b) calculate the output voltage.

[10 marks]

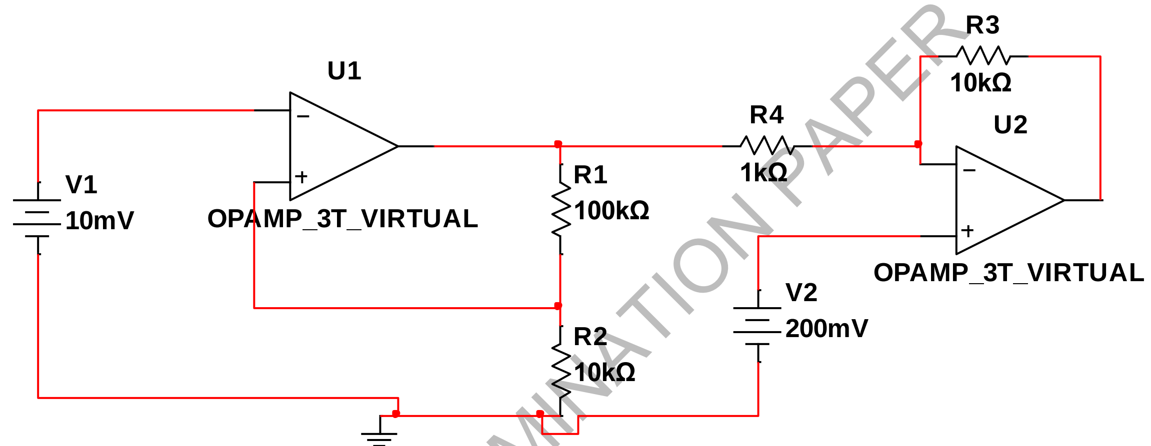

Figure Q5 (b)

(c)A low pass active filter is shown in Figure Q5 (c), derive the transfer function and calculate the closed loop gain and corner frequency.

[9 marks]

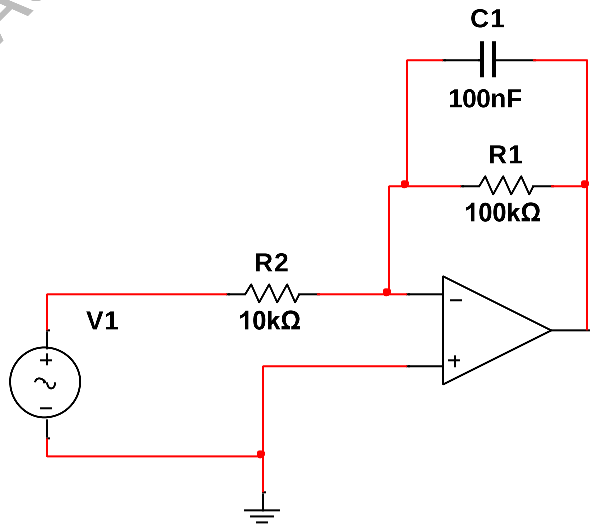

Figure Q5 (c)

[Total 25 marks]

Q6

a) A Biomedical system has the following closed loop transfer function; sketch the magnitude and phase plots and the final closed loop plot.

[10 marks]

$$T_{(s)} = \frac{10(0.5s+1)}{(0.2+1)}$$

b) Describe what is meant by gain and phase margins.

[2 marks]

c) A low pass filter is shown in Figure Q4, derive the transfer function and sketch magnitude and phase.

[6 marks]

d) By deriving the transfer function for the circuit shown in Figure Q6 (d) and converting to the s-domain, sketch the pole zero diagram and indicate on the diagram all relevant points.

[7 marks]

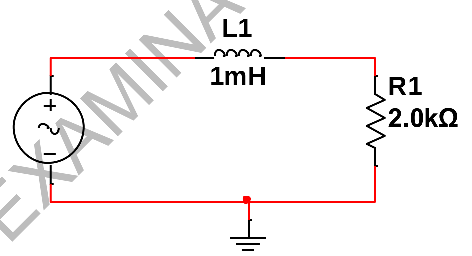

Figure Q6 (d)

[Total 25 marks]

END OF QUESTIONS

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Formula Sheets

Blocks with feedback loop

$$\mathrm{G(s)} = \frac{\mathrm{G_o(s)}}{1 + \mathrm{G_o(s)H(s)}} \quad \text{(for a negative feedback)}$$

$$\mathrm{G(s)} = \frac{\mathrm{G_o(s)}}{1 - \mathrm{G_o(s)H(s)}} \quad \text{(for a negative feedback)}$$

Steady-State Errors

$$e_{ss} = \lim_{s\to 0}[s(1 - G_o(s))\theta_i(s)] \quad \text{(for an open − loop system)}$$

$$e_{ss} = \lim_{s\to 0}\left[s\frac{1}{1 + G_o(s)}\theta_i(s)\right] \quad \text{(for the closed − loop system with a unity feedback)}$$

$$e_{ss} = \lim_{s\to 0}\left[s\frac{1}{1 + \frac{G_1(s)}{1 + G_1(s)[H(s) - 1]}}\theta_i(s)\right] \quad \text{(if the feedback H(s)} \neq 1\text{)}$$

$$e_{ss} = \lim_{s\to 0}\left[-s\frac{G_2(s)}{1 + G_2(G_1(s) + 1)}\theta_d(s)\right] \quad \text{(if the system subjects to a disturbance input)}$$

First order Systems

$$\mathrm{G(s)} = \frac{\theta_o}{\theta_i} = \frac{G_{ss}(s)}{\tau s + 1}$$

$$\tau\left(\frac{d\theta_o}{dt}\right) + \theta_o = G_{ss}\theta_i$$

$$\theta_o = G_{ss}\left(1 - e^{-t/\tau}\right) \quad \text{(for a unit step input)}$$

$$\theta_o = AG_{ss}\left(1 - e^{-t/\tau}\right) \quad \text{(for a step input with size A)}$$

$$\theta_o = G_{ss}\left(\frac{1}{\tau}\right)e^{-(t/\tau)} \quad \text{(for an impulse input)}$$

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Second- order Systems

$$\frac{d^2\theta_o}{dt^2} + 2\zeta\omega_n \frac{d\theta_o}{dt} + \omega_n^2\theta_o = b_o\omega_n^2\theta_i$$

$$G(s) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{b_o\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$\omega_d t_r = 1/2\pi$ $\qquad$ $\omega_d t_p = \pi$

p.o.= $\exp\left(\frac{-\zeta\pi}{\sqrt{(1-\zeta^2)}}\right) \times 100\%$

$t_s = \frac{4}{\zeta\omega_n}$ $\qquad$ $\omega_d = \omega_n\sqrt{(1-\zeta^2)}$

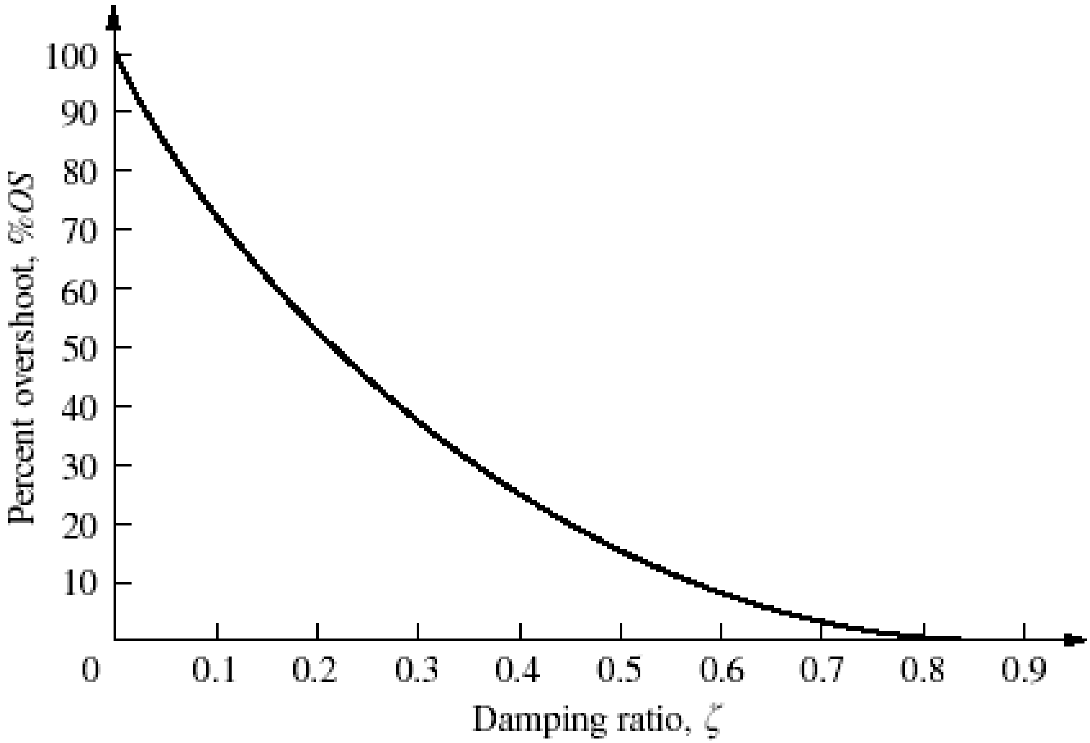

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Table 4.1 Laplace transforms

Laplace transform	*Time function*	*Description of time function*
1		A unit impulse
$\frac{1}{s}$		A unit step function
$\frac{e^{-sT}}{s}$		A delayed unit step function
$\frac{1-e^{-sT}}{s}$		A rectangular pulse of duration T
$\frac{1}{s^2}$	t	A unit slope ramp function
$\frac{1}{s^3}$	$\frac{t^2}{2}$	
$\frac{1}{s+a}$	e^{-at}	Exponential decay
$\frac{1}{(s+a)^2}$	$t e^{-at}$	
$\frac{2}{(s+a)^3}$	$t^2 e^{-at}$	
$\frac{a}{s(s+a)}$	$1-e^{-at}$	Exponential growth
$\frac{a}{s^2(s+a)}$	$t-\frac{(1-e^{-at})}{a}$	
$\frac{a^2}{s(s+a)^2}$	$1-e^{-at}-ate^{-at}$	
$\frac{s}{(s+a)^2}$	$(1-at)e^{-at}$	
$\frac{1}{(s+a)(s+b)}$	$\frac{e^{-at}-e^{-bt}}{b-a}$	
$\frac{ab}{s(s+a)(s+b)}$	$1-\frac{b}{b-a}e^{-at}+\frac{a}{b-a}e^{-bt}$	
$\frac{1}{(s+a)(s+b)(s+c)}$	$\frac{e^{-at}}{(b-a)(c-a)}+\frac{e^{-bt}}{(c-a)(a-b)}+\frac{e^{-ct}}{(a-c)(b-c)}$	
$\frac{\omega}{s^2+\omega^2}$	$\sin \omega t$	Sine wave
$\frac{s}{s^2+\omega^2}$	$\cos \omega t$	Cosine wave
$\frac{\omega}{(s+a)^2+\omega^2}$	$e^{-at}\sin \omega t$	Damped sine wave
$\frac{s+a}{(s+a)^2+\omega^2}$	$e^{-at}\cos \omega t$	Damped cosine wave
$\frac{\omega^2}{s(s^2+\omega^2)}$	$1-\cos \omega t$	
$\frac{\omega^2}{s^2+2\zeta\omega s+\omega^2}$	$\frac{\omega}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t]$	
$\frac{\omega^2}{s(s^2+2\zeta\omega s+\omega^2)}$ with $\zeta < 1$	$1-\frac{1}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t+\phi]$ with $\zeta = \cos\phi$	

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Table 15.1 *z*-transforms

Sampled f(t), sampling period T	*F(z)*
Unit impulse, $\delta(t)$	1
Unit impulse delayed by kT	z^{-k}
Unit step, $u(t)$	$\frac{z}{z-1}$
Unit step delayed by kT	$\frac{z}{z^k(z-1)}$
Unit ramp, t	$\frac{Tz}{(z-1)^2}$
t^2	$\frac{T^2z(z+1)}{(z-1)^3}$
e^{-at}	$\frac{z}{z-e^{-aT}}$
$1-e^{-at}$	$\frac{z(1-e^{-aT})}{(z-1)(z-e^{-aT})}$
$t\,e^{-at}$	$\frac{Tz\,e^{-aT}}{(z-e^{-aT})^2}$
$e^{-at}-e^{-bt}$	$\frac{(e^{-aT}-e^{-bT})z}{(z-e^{-aT})(z-e^{-bT})}$
$\sin \omega t$	$\frac{z\sin\omega T}{z^2-2z\cos\omega T+1}$
$\cos \omega t$	$\frac{z(z-\cos\omega T)}{z^2-2z\cos\omega T+1}$
$e^{-at}\sin\omega t$	$\frac{z\,e^{-aT}\sin\omega T}{z^2-2z\,e^{-aT}\cos\omega T+e^{-2}}$
$e^{-at}\cos\omega t$	$\frac{z(z-e^{-aT}\cos\omega T)}{z^2-2z\,e^{-aT}\cos\omega T+e^{-2}}$

Table 15.2 *z*-transforms

$f[k]$	$f[0], f[1], f[2], f[3], \ldots$	$F(z)$
$1u[k]$	$1, 1, 1, 1, \ldots$	$\frac{z}{z-1}$
a^k	$a^0, a^1, a^2, a^3, \ldots$	$\frac{z}{z-a}$
k	$0, 1, 2, 3, \ldots$	$\frac{z}{(z-1)^2}$
ka^k	$0, a^1, 2a^2, 3a^3, \ldots$	$\frac{az}{(z-a)^2}$
ka^{k-1}	$0, a^0, 2a^1, 3a^2, \ldots$	$\frac{z^2}{(z-a)^2}$
e^{-ak}	$e^0, e^{-a}, e^{-2a}, e^{-3a}, \ldots$	$\frac{z}{z-e^{-a}}$

END OF FORMULAE SHEETS