School of Computing & Engineering

(Engineering and Technology)

University of
HUDDERSFIELD

NME3523

Signal Analysis & Processing

Date: May 2013

Time allowed: 3 hours

Instructions to Candidates:

This is an unseen examination.

Candidates should answer 4 out of 6 questions. All questions are marked out of *25*.

Materials provided: Table of transforms.

Materials allowed: None

A scientific calculator may be used in this exam.

Unannotated paper versions of general bi-lingual dictionaries only may be used by overseas students whose first language is not English. Subject-specific bi-lingual dictionaries are not permitted.

Access to any other materials is not permitted.

Turn Over

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Question 1

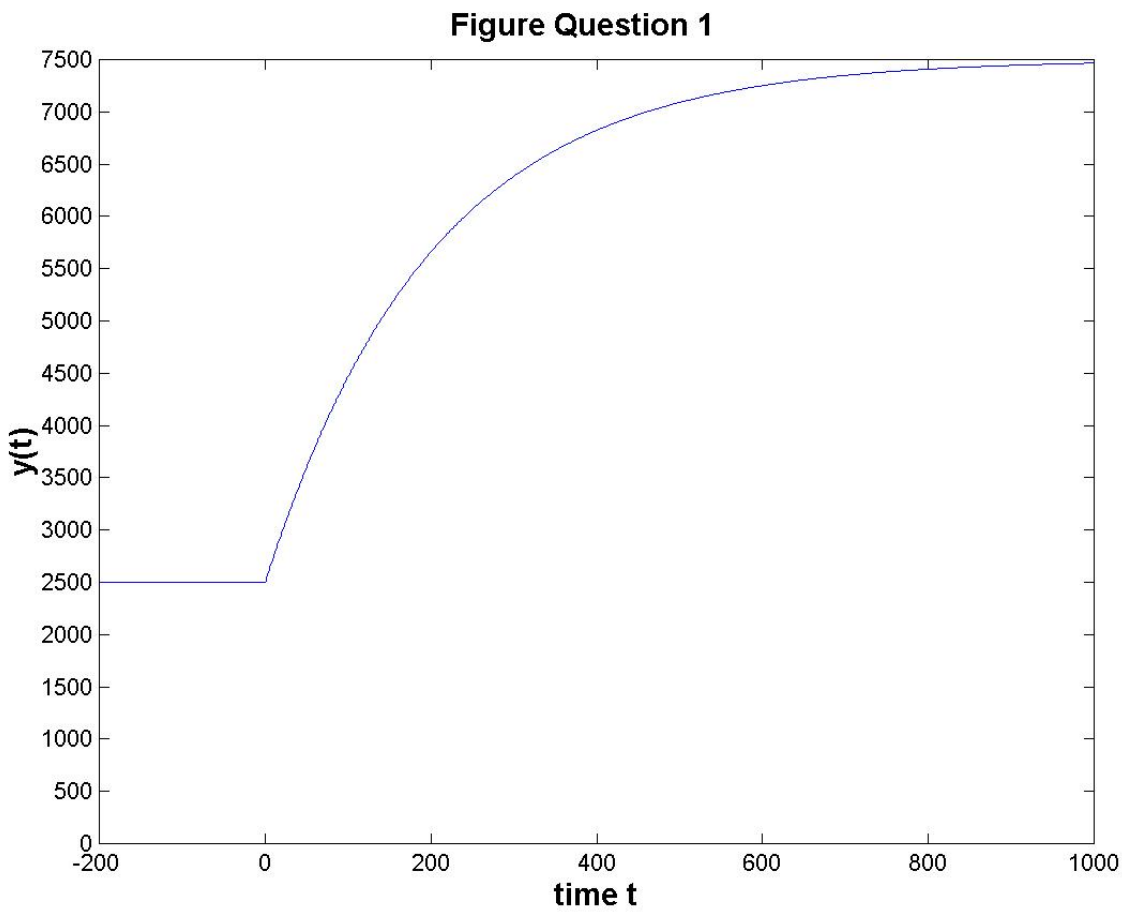
A system is defined by the differential equation $\frac{dy(t)}{dt}+(a-b)y(t)=(a+2b)x(t)$ where $y(t)$ is the output and $x(t)$ is the input. For time t < 0 the system is in steady state with the input equal to 5,000. At t = 0, the input undergoes a step change **to** 15,000. The variation of $y(t)$ with time is shown in 'Figure Question 1'.

What are the values of constants a and b?

[16 marks]

Suppose the input is now varied sinuosoidally with a maximum value of 12,000 and a minimum value of 8,000 at a frequency of 5×10^{-3} radians per second. When all transients have died away what are the maximum and minimum values of the output $y(t)$?

[9 marks]



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Question 2

(i) A car has mass of 2000kg, the overall stiffness of the springs K is 30,000kgs^{-2} and the overall damping factor f of the shock absorbers is 3000kgs^{-1}. The distance of the lowest point of the body of the car from the ground when the car is empty is 0.2m. Four people with a combined mass of 360kg get into the car simultaneously and the car drops to a maximum distance below its initial position ('first overshoot'), rebounds ('first undershoot') and then oscillates before stabilising. At the 'first undershoot' it is noted that the car body is 0.0796m below its initial position. [The acceleration of gravity g = 9.81ms^{-2}].

What is the damping ratio for the car (including passengers)?
[3 marks]

What is the final distance of the car body from the ground when the car has stopped oscillating?
[3 marks]

What is the closest the car body comes to the ground?
[10 marks]

(ii) A system has the transfer function $H(s) = \dfrac{1}{Ms^2 + fs + K}$ where M, f and K are all positive numbers. The system undergoes <u>sinusoidal excitation</u> with angular frequency ω. Show that as $\omega \to \infty$ the system gain G in dB can be approximated by $G = -20\log_{10} M - 40\log_{10} \omega$.

Find an expression for the system gain in dB as $\omega \to 0$.
[9 marks]

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Question 3

(i) A flow meter used for measuring the axial flow velocity of solids particles in a two-component slurry flow consists of an upstream conductance sensor S1 and a downstream conductance sensor S2. The axial separation of S1 and S2 is 50cm. Samples of the output voltages (in mV) from S1 and S2 are taken every 0.2 seconds as shown in 'TABLE QUESTION 3' below. Calculate and plot the cross correlation function for the sampled outputs from S1 and S2. Use this cross correlation function to determine the mean axial flow velocity of the solids particles in the slurry.

[16 marks]

Time (seconds)	Output from S1 (mV)	Output from S2 (mV)
0	2	5
0.2	-9	4
0.4	-22	-7
0.6	-1	6
0.8	-10	6
1.0	6	-1
1.2	5	9
1.4	17	-11
1.6	6	-19
1.8	-6	3
2.0	4	-5
2.2	-10	1
2.4	0	6
2.6	0	18
2.8	0	1
3.0	-3	-10
3.2	11	9
3.4	-19	-11
3.6	4	2
3.8	9	0

TABLE QUESTION 3

(ii) It is required to produce a random signal x containing 512 evenly spaced points in the time interval 0 to 1 seconds. It is also required to produce a second random signal y which is identical to x but delayed by $\frac{20}{512}$ seconds. It is then required to cross correlate the signals x and y using the MATLAB 'xcorr' function. Write an 'm' file which will perform the above functions and which will also enable the signals x, y and the resultant cross correlation function to be plotted.

[9 marks]

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Question 4

The filter circuit shown in 'Figure Question 4' consists of two stages separated by a voltage follower. Stage 1 has transfer function $G(s)$ and Stage 2 has transfer function $H(s)$. The overall transfer function relating *Vout(t)* to *Vin(t)* is $P(s)$ where $P(s) = \dfrac{100s}{s^2 + 105s + 500}$.

Find expressions for $G(s)$ and $H(s)$.

Give the time constants associated with $G(s)$ and $H(s)$ and use these to make an approximate sketch of the gain Bode plot for $P(s)$, showing all relevant -3dB frequencies (in rads^{-1}).

[10 marks]

Calculate the exact gain M of $P(s)$ to three decimal places for an angular frequency ω equal to 20rads^{-1} (where M is NOT expressed in dB). Demonstrate that $M \to 0$ as $\omega \to 0$ and as $\omega \to \infty$.

[12 marks]

What is the purpose of the voltage follower?

[3 marks]

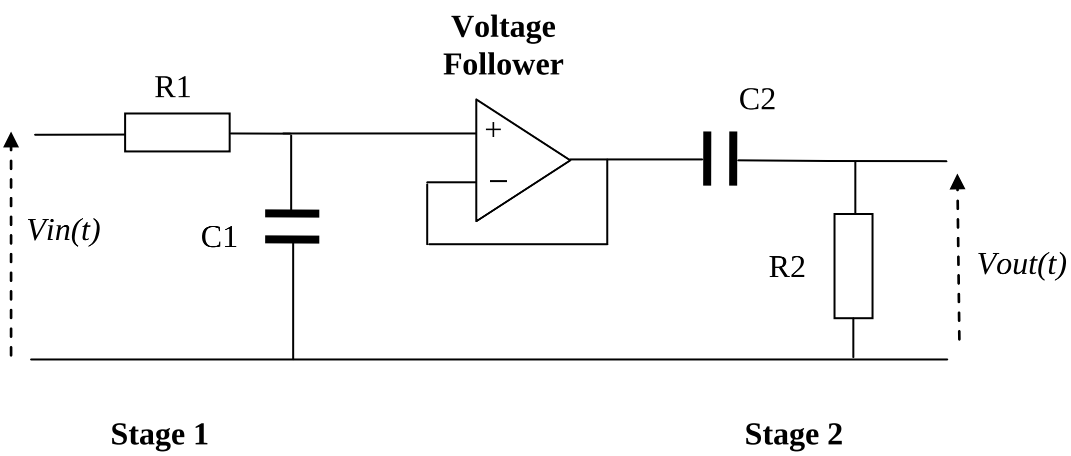

Figure Question 4

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Question 5

A high pass digital filter is represented by the expression $y(n) = 0.5\{x(n) - x(n-1)\}$.
Derive an expression the gain of this filter in terms of ωT.
Using this expression, plot a graph of gain versus ωT for the filter and use this graph to explain why any low frequency components to be attenuated and any high frequency components to be passed must all lie below the Nyquist frequency.
[16 marks]

If a sampled cosine wave of with a frequency of one eighth of the sampling frequency is applied to this high pass filter what is the phase angle, in degrees, between the output cosine wave and the input cosine wave?
Does the output cosine wave lead or lag the input cosine wave?
[9 marks]

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Question 6

(i) How would you obtain the modulus and phase of the Fourier Transform of a sampled, random signal using the Trapezium Rule of numerical integration? Describe the stages involved and show what equations you would use at each stage. [Note: you should also show how you can ensure that the phase angle Φ of the Fourier Transform always lies in the range $-\pi \leq \Phi \leq \pi$].

[15 marks]

(ii) How would you obtain the frequency response (in the form of Bode plots) of an open loop system using pulse testing?

[10 marks]

[**Note:** $X(f) = \int_{t=-\infty}^{t=\infty} x(t)\, e^{-(2\pi\ j\, f\, t)}\, dt$]

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	$f(t)$	$F(s)$	$f(k)$	$F(z)$
1	Unit impulse	1	$\delta(k)$	1
2	Unit step	$\frac{1}{s}$	$u(k)$	$\frac{z}{z-1}$
3	Unit ramp t	$\frac{1}{s^2}$	kT	$\frac{Tz}{(z-1)^2}$
4	t^2	$\frac{2}{s^3}$	$(kT)^2$	$\frac{T^2z(z+1)}{(z-1)^3}$
5	t^3	$\frac{6}{s^4}$	$(kT)^3$	$\frac{T^3z(z^2+4z+1)}{(z-1)^4}$
6	e^{-at}	$\frac{1}{s+a}$	$(e^{-aT})^k$	$\frac{z}{z-e^{-aT}}$
7	$1-e^{-at}$	$\frac{a}{s(s+a)}$	$1-(e^{-aT})^k$	$\frac{z(1-e^{-aT})}{(z-1)(z-e^{-aT})}$
8	$t\,e^{-at}$	$\frac{1}{(s+a)^2}$	$kT(e^{-aT})^k$	$\frac{Tz\,e^{-aT}}{(z-e^{-aT})^2}$
9	$(1-at)\,e^{-at}$	$\frac{s}{(s+a)^2}$	$(1-akT)(e^{-aT})^k$	$\frac{z[z-e^{-aT}(1+aT)]}{(z-e^{-aT})^2}$
10	$e^{-at}-e^{-bt}$	$\frac{b-a}{(s+a)(s+b)}$	$(e^{-aT})^k-(e^{-bT})^k$	$\frac{z(e^{-aT}-e^{-bT})}{(z-e^{-aT})(z-e^{-bT})}$
11	Item 6 with $e^{-aT}=c$		c^k	$\frac{z}{z-c}$
12	Item 8 with $e^{-aT}=c$		kTc^k	$\frac{kTz}{(z-c)^2}$
13	$\sin\omega t$	$\frac{\omega}{s^2+\omega^2}$	$\sin k\omega T$	$\frac{z\sin\omega T}{z^2-2z\cos\omega T+1}$
14	$\cos\omega t$	$\frac{s}{s^2+\omega^2}$	$\cos k\omega T$	$\frac{z(z-\cos\omega T)}{z^2-2z\cos\omega T+1}$
15	$e^{-at}\sin\omega t$	$\frac{\omega}{(s+a)^2+\omega^2}$	$(e^{-aT})^k\sin k\omega T$	$\frac{z\,e^{-aT}\sin\omega T}{z^2-2z\,e^{-aT}\cos\omega T+e^{-2aT}}$
16	$e^{-at}\cos\omega t$	$\frac{s+a}{(s+a)^2+\omega^2}$	$(e^{-aT})^k\sin k\omega T$	$\frac{z(z-e^{-aT}\cos\omega T)}{z^2-2z\,e^{-aT}\cos\omega T+e^{-2aT}}$
17	$\sinh\omega t$	$\frac{\omega}{s^2-\omega^2}$	$\sinh k\omega T$	$\frac{z\sinh\omega T}{z^2-2z\cosh\omega T+1}$
18	$\cosh\omega t$	$\frac{s}{s^2-\omega^2}$	$\cosh k\omega T$	$\frac{z(z-\cosh\omega T)}{z^2-2z\cosh\omega T+1}$

Note: T is the sampling period.

End of Exam Paper

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