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IMPERIAL COLLEGE LONDON

Design Engineering MEng EXAMINATIONS 2024

For Internal Students of the Imperial College of Science, Technology and Medicine
This paper is also taken for the relevant examination for the Associateship or Diploma

DESE50002 – Electronics 2

Date: 1 May 2024 (one hour thirty minutes)

This paper contains SIX questions.
Attempt ALL questions.

The numbers of marks shown by each question are for your guidance only; they indicate how the examiners intend to distribute the marks for this paper.

This is a CLOSED BOOK Examination.

1. a) (i) Sketch in the answer book the signal $x_0(t) = u(t) - u(t-2)$.

[2]

(ii) Sketch in the answer book the signal $x_1(t) = t \times [u(t) - u(t-2)]$.

[4]

(iii) State the equation that describes the signal $y(t)$ shown in ***Figure Q1***.

[6]

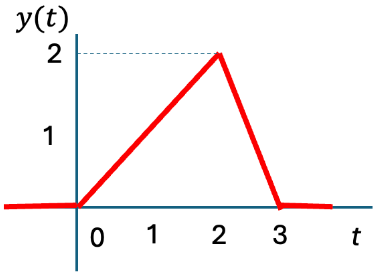

Figure Q1

b) A signal $x(t)$ is mathematically modelled by the following equation where $\delta(t)$ is the unit impulse function. Sketch in your answer book the signal $x(t)$.

$$x(t) = 5\,\delta(t+2) + 2\delta(t-2) - 5\delta(t-1) + \delta(t)$$

[3]

2. A signal $y(t)$ is mathematically modelled by the following equation:

$$y(t) = 2.0 \times \cos\left(628.32t + \frac{\pi}{2}\right) + 1.0$$

a) Rewrite $y(t)$ in exponential form.

[3]

b) The signal is sampled at a sampling frequency of 400 Hz. What are the amplitude values of $y[n]$ for $n = 0$ to 5?

[4]

c) Write in the answer book the equation that models the discrete signal $y[n]$ at the sampling frequency of 400 Hz.

[4]

d) A rectangular window is applied to the signal $y[n]$ to form a new signal $w[n]$ such that:

$$w[n] = \begin{cases} y[n] & \text{for } 0 \leq n \leq 5 \\ 0 & \text{otherwise} \end{cases}.$$

Write in the answer book the equation that describes the windowed signal $w[n]$.

[4]

3. ***Figure Q3a*** shows an electronic circuit that produces an output $y(t)$ from two input signals $x_1(t)$ and $x_2(t)$, where $x_1(t) = 1 + \sin(2\pi f_1 t)$ and $x_2(t) = \sin(2\pi f_2 t)$. Furthermore, it is known that $f_1 \ll f_2$.

(a) Assume that the electronic circuit is a summing amplifier that adds the two input signals to produce the output. Sketch in the answer book the two-sided exponential Fourier spectrum of the output signal $y_1(t)$. That is:

$$y_1(t) = x_1(t) + x_2(t).$$

[4]

(b) Assume that the electronic circuit is a multiplier that multiplies the two input signals to produce the output. Sketch in the answer book the two-sided exponential Fourier spectrum of the output signal $y_2(t)$. That is:

$$y_2(t) = x_1(t) \times x_2(t).$$

(Hint: Multiplication in the time domain is convolution in the frequency domain.)

[6]

(c) The input signal $x_1(t)$ to the multiplier is replaced with a signal source whose spectral profile $Y_1(f)$ is as shown in ***Figure Q3b***, where the maximum frequency component of the signal is f_m. The other input $x_2(t)$ remains unchanged.

Sketch in the answer book the two-sided exponential Fourier spectrum of the output signal $y_2(t)$.

[6]

(d) The output signal $y_2(t)$ from part (c) is to be sampled into discrete signals at a sample frequency f_{samp}.

Assume that f_m= 4kHz and f_2 = 20kHz, what is the minimum value of f_{samp} to ensure that no aliasing occurs? Briefly justify your answer.

[4]

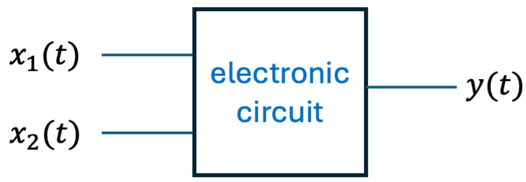

Figure Q3a

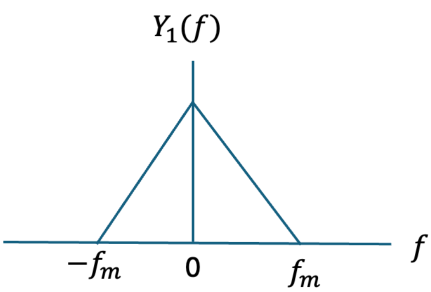

Figure Q3b

4. The denominator of the transfer function of a simple second-order system is given by:

$$D(s) = s^2 + 2\zeta\omega_0 s + \omega_0{}^2 \ .$$

A simplified one-dimensional model of an automobile suspension system is shown in ***Figure Q4***. The input is the displacement $x(t)$ of the road surface from a reference ground elevation. The output is the distance $y(t)$ of the car body from the same ground reference. M is the mass of the vehicle, K is the spring constant and B is the damper constant.

If the differential equation relating the output $y(t)$ to the input $x(t)$ is given by:

$$Ky(t) + B\frac{dy(t)}{dt} + M\frac{d^2y(t)}{d^2t} = Kx(t) + B\frac{dx(t)}{dt}$$

a) Derive the transfer function $H(s) = Y(s)/X(s)$.

[10]

b) What is the system's DC gain?

[2]

c) What is the natural frequency of the system?

[4]

d) What is the damping ratio of the system?

[4]

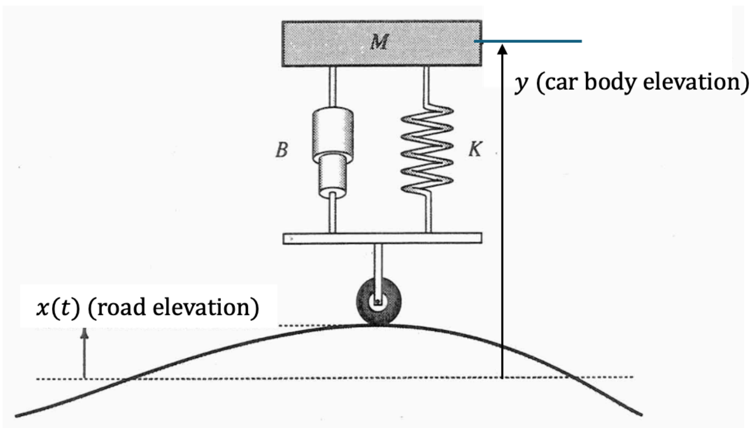

Figure Q4

5. A digital filter has an impulse response $h[m]$ as shown in ***Figure Q5a***.

a) What is the transfer function $H[z]$ of this filter?

[3]

b) A signal $x[n]$ shown in ***Figure Q5b*** is applied to the input of the filter. Write down the difference equation which relates the output signal $y[n]$ of the filter to its input $x[n]$.

[4]

c) Derive the output $y[n]$ for $0 \leq n \leq 7$.

[8]

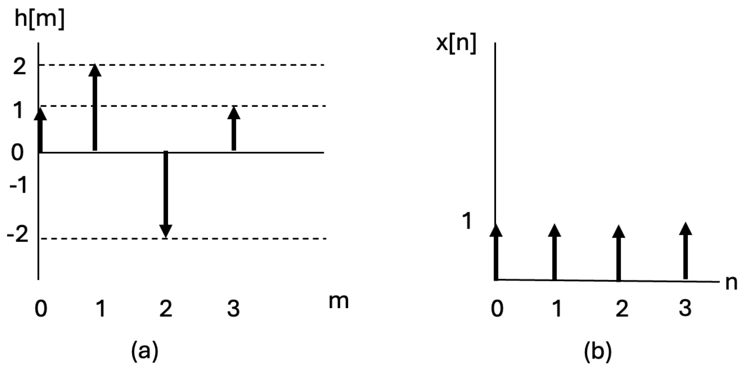

Figure Q5

6. ***Figure Q6*** shows an open-loop process with transfer function:

$$H(s) = \frac{1}{s^2 + 5s + 6}.$$

(a) Sketch in the answer book a diagram showing the system in a feedback control loop by adding a proportional-only controller to the system with a proportional gain of 5.

[5]

(b) Derive the closed-loop transfer function with input $R(s)$ and output $Y(s)$.

[5]

(c) Explain how the controller design can be improved. State the benefit and drawbacks that such modifications may bring to the system's dynamic and static behaviour.

[5]

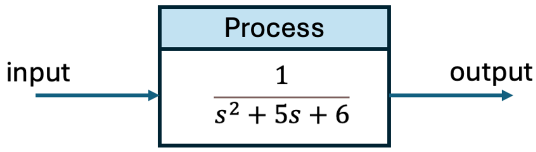

Figure Q6

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