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IMPERIAL COLLEGE LONDON

Design Engineering MEng EXAMINATIONS 2025

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: 29 April 2025 (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 $x_0(t) = 3u(t-1) - u(t-4)$.

[2]

(ii) Sketch in the answer book the signal $x_1(t) = -(t-4) \times [u(t-1) - u(t-4)]$.

[4]

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

[6]

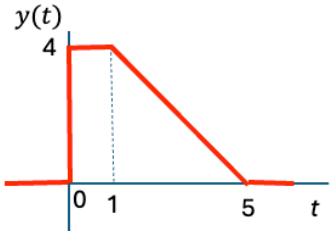

Figure Q1

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 $x(t)$.

$$x(t) = 3\,\delta(t+1) - \delta(t) + 3\delta(t+2)$$

[3]

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

$$y(t) = \frac{1}{j}\left(e^{j(125.7t)} - e^{-j(125.7t)}\right) + 2.0$$

a) Rewrite $y(t)$ in terms of a sine function.

[3]

b) The signal is sampled at a sampling frequency of 160 Hz. It is known that the first sample y[0] = 2.0 and the second sample y[1] = 3.414. What are the values of $y[n]$ for $n = 2$, 3, 4 and 5?

[4]

c) Write in the answer book the mathematical equation that models the discrete signal $y[n]$.

[4]

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

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

Write in the answer book the equation that describes the windowed signal $z[n]$ in terms of $\delta[n]$.

[4]

3. You are required to design a device that detects sound made by blue whales in some part of the North Atlantic Ocean. It is known that blue whales produce sound in the frequency range of 10 to 40 Hz. An A-to-D converter (ADC) is used to convert the sound signal for processing with a microprocessor such that it can pick up whale sounds with loudness between 30 and 100 decibels (dB).

    (i) Someone suggests that a sampling frequency of 200 Hz should be used. Explain your opinion on this suggestion and justify your answer.

    [4]

    (ii) If the microphone signal is sampled at 200 samples per second and the sound of a blue whale is detected, sketch the one-sided amplitude spectrum (i.e. only positive frequencies) of the **sampled signal** between 0 Hz and 250 Hz. State any assumptions used.

    [6]

    (iii) If the microphone amplifier has an automatic gain control that always adjusts the signal voltage to a full voltage range corresponding to 100 decibels, estimate the resolution of the ADC required in terms of number of bits? State any assumptions used and justify your answer.

    [5]

    (iv) Someone switches on an underwater beacon which emits two tones at 120 Hz and 150 Hz respectively. If no anti-aliasing filter is used, what **aliased frequency** components will be produced?

    [5]

4. A second-order LTI system has a transfer function H(s) of the general form:

$$H(s) = \frac{b_0}{s^2 + a_1 s + a_0} = K \frac{{\omega_0}^2}{s^2 + 2\zeta\omega_0 s + {\omega_0}^2}$$

where K = dc gain
ω_0 = natural frequency
ζ = damping ratio

Figure Q4 shows the small signal frequency response of a particular second-order system, with input $x(t)$ and output $y(t)$, measured at some input operating voltage x_0. It is also known that ζ = 0.1.

a) Assuming that this system is linear, derive the transfer function $H(s) = \frac{Y(s)}{X(s)}$ of the system based on information given.

[10]

b) Write down the differential equation that relates the output $y(t)$ to the input $x(t)$.

[4]

c) It was later discovered that the system input-output DC characteristic is nonlinear. The output y is a function of x according to the equation: $y = x^{2.5}$. What is the value of the input operating voltage x_0 around which the small signal frequency response was measured?

[6]

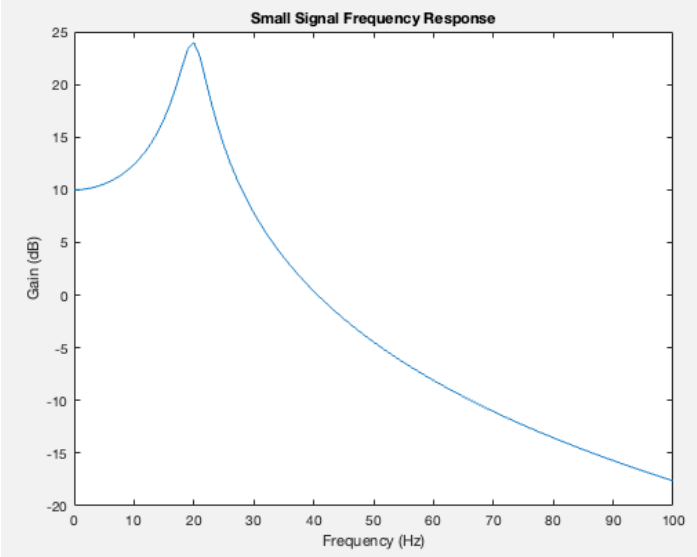

Figure Q4

5. A digital filter has discrete input signal $x[n]$ and output signal $y[n]$, and the system is causal. The filter has a difference equation given by:

$$y[n] = 0.6\,x[n] + 0.4\,y[n-1]$$

a) Given that $x[n]$ is a unit step signal and that $y[-1] = 0$, list the values of $x[n]$ and $y[n]$ for n = -1, 0, 1, .. , 6.

[5]

b) Explain, with justification, the type of filtering the system is performing.

[2]

c) Derive the transfer function $H[z]$, of this system in the z-transform domain.

[4]

d) Draw a diagram showing how this filter can be implemented using multipliers, adders and delay modules.

[4]

6. A DC motor system is controlled using pulse-width modulation with a duty cycle of $x(t)$, which has a range of 0 to 1. The speed of the motor $y(t)$ is measured in revolutions per second (rps), and the transfer function $G(s) = \frac{Y(s)}{X(s)}$ of the motor is given by:

$$G(s) = \frac{K_L}{0.05s + 1}$$

where K_L is a constant with a value of 4 if the system is ideal. However, manufacturing processes cause this value to vary by ±20%.

(i) If the motor is controlled directly as an open-loop system with $x(t)$ set to 0.5 (i.e. 50% duty cycle), calculate the maximum and minimum steady-state speed of the motor.

[4]

(ii) Sketch the response of the open-loop system if x(t) is a step function $u(t)$. What is the time constant of the system?

[5]

(iii) *Figure Q6* shows a proportional closed-loop control system to control the motor described above. The proportional gain K_P is 10. Derive the closed-loop transfer function of this feedback system.

[6]

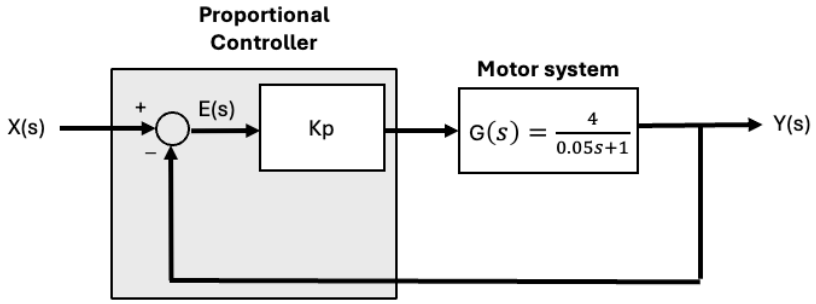

Figure Q6

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