CID No: ________________________

IMPERIAL COLLEGE LONDON

Design Engineering MEng EXAMINATIONS 2020

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

DE 2.3 – Electronics 2

28 April 2020: 10.00 to 11.30 (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 approximately how the examiners intend to distribute the marks for this paper.

This is a CLOSED BOOK Examination.

1. A signal $x(t)$ can be modelled mathematically as:

$$x(t) = w(t) + y(t)$$

where

$$w(t) = -\mathrm{j}\left(e^{+0.628jt} - e^{-0.628jt}\right)$$

$$y(t) = 0.5u(t-10) - 0.5$$

(i) Sketch the amplitude spectrum $|W(j\omega)|$ of the signal $w(t)$.

[4]

(ii) Sketch the waveforms of $y(t) = 0.5u(t-10) - 0.5$.

[4]

(iii) Hence or otherwise, sketch the signal $x(t)$ for $0 \leq t \leq 15$.

[6]

2. The motor used for the mini-Segway project has a 13-poles magnet sensed by two Hall effect sensors, and a gearbox with a step-down ratio of 1:30. The wheel attached to the motor has a diameter of 6.8cm.

The following code segment was used to measure the speed of the motor using interrupts.

```
import micropython
micropython.alloc_emergency_exception_buf(100)
from pyb import ExtInt

A_speed = 0
A_count = 0

def isr_motorA(dummy):
    global A_count
    A_count += 1

def isr_speed_timer(dummy):
    global A_count
    global A_speed
    A_speed = A_count
    A_count = 0

motorA_int = ExtInt ('Y4', ExtInt.IRQ_RISING, Pin.PULL_NONE,isr_motorA)

speed_timer = pyb.Timer(4, freq=10)
speed_timer.callback(isr_speed_timer)
```

(i) Explain why using interrupts is better than using polling in detecting the speed of the motor.

[4]

(ii) Briefly explain the purpose of each line in this MicroPython code segment and how this code measures the speed of the motor.

[6]

(iii) Write one line of Python code that calculates the speed of travel of the wheel in cm/sec. You may assume that the wheel is mounted on a vehicle travelling on a flat surface in a straight line.

[4]

3. It is known that a second-order system has a transfer function H(s) of the general form:

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

where $K =$ dc gain
$\omega_0 =$ natural frequency
$\zeta =$ damping factor

A 2nd order mechanical system has an input-output relationship that obeys the following 2nd order differential equation:

$$2\frac{d^2y(t)}{dt^2} + 2\frac{dy(t)}{dt} + 80y(t) = 40x(t)$$

(i) Derive, with justifications, the transfer function H(s) of the system.

[4]

(ii) Derive the DC gain, natural frequency and damping factor of the system H(s). State any assumptions used.

[4]

(iii) What is the gain of the system if the input to the system x(t) is a sinusoid at a frequency of 0.1Hz?

[4]

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

$$y[n] = 0.93\,x[n] - 0.93\,x[n-1] + 0.86\,y[n-1]$$

(i) Given that $x[n]$ is a unit step signal, list the values of $x[n]$ for n = -1, 0, 1, .., 9.

[4]

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

[4]

(iii) Assuming that $y[-1] = 0$, calculate and sketch the step response of the system for the first ten terms.

[4]

(iv) Hence or otherwise, explain, with justification, the type of filtering the system is performing.

[4]

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

[4]

5. Your group is designing a device to discover which type of flowers honeybees prefer by sensing the sound they make. It is known that a honeybee, while hovering to collect honey, has a fundamental wingbeat frequency of 235 ± 15Hz. it also produces detectable vibration up to the fifth harmonic of the wingbeat frequency and, for each increasing harmonic component, the power decreases by a factor of 9 (i.e. the 1st harmonic has one ninth the power of the fundamental; the 2nd harmonic has one ninth of the power of the 1st harmonic etc.).

An A-to-D converter (ADC) is used to convert the sound signal for processing with a microprocessor. Your device is required to detect the presence of a honeybee using a microphone, assuming the honeybee makes a sound that constitutes at least 10% of the full dynamic range of the captured sound signal.

(i) A member of your team suggests that a sampling frequency of 2.5kHz should be used. Explain your opinion on this suggestion and justify your answer.

[5]

(ii) Your team sampled the microphone signal directly after amplification at 2.5kHz. A nearby burglar alarm makes an ear-piercing tone of 1.5kHz. What is the impact of this alarm signal on your captured digital signals in your device? What improvements can you make to your design to mitigate the spurious signal from the alarm?

[5]

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

[5]

(iv) Your team has decided to use Fourier analysis to detect the presence or absence of honeybees. You are responsible to come up with the recognition algorithm. Explain briefly how you would approach this problem.

[5]

6. (a) With the help of an example explain the difference between a closed-loop and an open-loop control system. What are the advantages of closed-loop control systems over an open-loop control system?

[4]

(b) A lighting system is controlled using pulse-width modulation with a duty cycle of x(t) (in percent). The brightness of the light y(t) is measured in lumen, and the transfer function G(s) of the lighting system is given by:

$$G(s) = \frac{K_L}{0.1s + 1}$$

where K_L is a constant with a value of 1 if the system is ideal. However, manufacturing processes cause this value to vary by ±20%.

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

[4]

(ii) Sketch the response of the open-loop system if x(t) is a step function $50\ u(t)$. What is the time constant of the system?

[4]

(iii) Figure Q6 shows a proportional closed-loop control system to control the lighting system described above. The proportional gain K_P is 10. Estimate the maximum and minimum value of the output intensity if x(t) is 50.

[4]

(iv) Derive the closed-loop transfer function of the feedback system. Hence state the time constant of the feedback system.

[4]

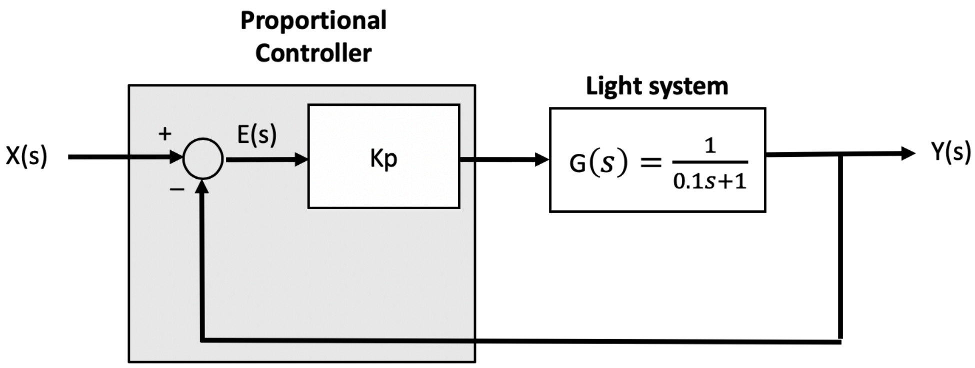

Figure Q6

[END OF PAPER]