CID No: ________________________

IMPERIAL COLLEGE LONDON

Design Engineering MEng EXAMINATIONS 2019

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

Engineering Analysis EA 2.3 – Electronics 2

30th April 2019: 10.00 to 11.30 (one hour thirty minutes)

This paper contains EIGHT 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:

$$x(t) = \left[2.5 + 1.5\cos(31.42t + \tfrac{\pi}{4})\right] + 0.5\,\delta(t-1)$$

(i) Sketch the waveforms $1.5\cos(31.42t + \frac{\pi}{4})$ and $0.5\,\delta(t-1)$ for $0 \leq t \leq 0.2$. Hence sketch the signal $x(t)$ for $0 \leq t \leq 0.2$.

[8]

(ii) Rewrite $x(t)$ in exponential form where appropriate. (There is no need to simplify the equation.)

[4]

(iii) Sketch the amplitude spectrum $|X(j\omega)|$ of the signal x(t).

[4]

2. You are designing a bat detector by directly sampling the echolocation signal emitted by bats. Bats emit ultrasound in the frequency range of 12 kHz to 160 kHz, which is detected by an ultrasound transducer that produces an AC signal in the range of ±10 mV with a 2.5V offset. However, your detector is designed to work up to only 100 kHz since any signal above this frequency is rapidly absorbed in air. Your detector will first directly convert the raw bat signal from analogue to digital form using an A-to-D converter (ADC) with an accuracy of ±0.1%. The ADC operates in the voltage range of 0 to 5V.

(i) What sampling frequency would you choose for the ADC? Justify your answer.

[3]

(ii) What circuit would you need to connect to the ultrasound detector *before* the ADC? Why?

[3]

(iii) What is the resolution of the ADC required in terms of number of bits? What is its resolution in volts?

[3]

(iv) The detector "converts" the digital bat signal from the ultrasound range of 12 kHz to 160 kHz to the audible frequency range. Describe briefly a method or approach for your instrument that will map the bat's ultrasound to the audible range of 120 Hz to 15 kHz.

[6]

3. In the Dancing Segway team project, you used the following code segments to implement an interrupt service routine.

```
# Interrupt Service Routine
def isr_sampling (dummy):   # interrupt happens at 8kHz rate
    global  ptr             # pointer to buffer
    global  buffer_full     # buffer status indicator

    s_buf[ptr] = mic.read() # s_buf[] stores samples - pre-allocated
    ptr = ptr + 1
    if (ptr == 200):
        ptr = 0
        buffer_full = True

#  Create timer interrupt  - one every 125 usec
sampling_timer = pyb.Timer (7, freq = 8000)
sampling_timer.callback(isr_sampling)
```

(i) Explain why interrupt is necessary in this application.

[4]

(ii) Briefly explain the purpose of each line in this MicroPython code segment

[8]

4. A system H consists of two sub-systems A and B connected in series. System A is a first-order system, while system B is a second-order system. The combined transfer function H(s) is given by the equation:

$$H(s) = \frac{1}{0.01s + 1} \times \frac{100}{s^2 + s + 50}$$

(i) Deduce the transfer functions of A and B separately?

[2]

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

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

where $K =$ dc gain

$\omega_0 =$ natural frequency

$\zeta =$ damping factor

Derive the DC gain, nature frequency and damping factor of the system H. State any assumption used.

[4]

(iii) What is the over gain of the system at a frequency of 0.32Hz?

[4]

5. The transfer function H(s) of a system is given by the following equation:

$$H(s) = \frac{Y(s)}{X(s)} = \frac{200 + s}{200 + 10s + s^2}$$

(i) What is the order of this system?

[2]

(ii) Given that y(t) and x(t) are inverse Laplace transform of Y(s) and X(s), write down the differential equation that relates y(t) and x(t) in the time domain.

[5]

6. A 5-tap moving average 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:

$$y[n] = \frac{1}{5}(x[n] + x[n-1] + x[n-2] + x[n-3] + x[n-4])$$

(i) If Y(z) and X(z) are the z-transform of the discrete signals y[n] and x[n] respectively, derive the transfer function Y(z)/X(z].

[4]

(ii) Sketch, not necessary to scale, the frequency response you expect of such a filter.

[4]

(iii) Given that the sampling frequency of the system is 10 kHz, explain with justifications what you expect this filter will do to a signal at 1 Hz and at 4.5 kHz.

[4]

7. A discrete-time filter is characterised by the z-domain transfer function:

$$H(z) = \frac{Y(z)}{X(z)} = \frac{1}{1 - 0.2z^{-1}}$$

where X(z) and Y(z) are the z transforms of the input x[n] and output y[n] respectively.

(i) Derive the difference equation relating x[n] to y[n].

[5]

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

[5]

(iii) Assuming that the input is causal and that y[n] = 0 for all n < 0, derive the first 6 samples of the system's impulse response.

[5]

8. Figure Q8 shows a simple proportional feedback system to control the motor speed y(t) in response to the set-point r(t) in the s-domain. The motor has a system transfer function given by:

$$P(s) = \frac{20}{0.2s + 1}$$

The controller has a constant gain, i.e. $C(s) = K_p$.

(i) Derive the close-loop transform function of the system Y(s)/R(s).

[5]

(ii) Modify the system block diagram in Figure Q8 to include an integral term in the controller and derive the close-loop transform function of the feedback system with this addition.

[5]

(iii) What is the impact of including an integral term in the controller on the dynamic behaviour of this feedback system?

[4]

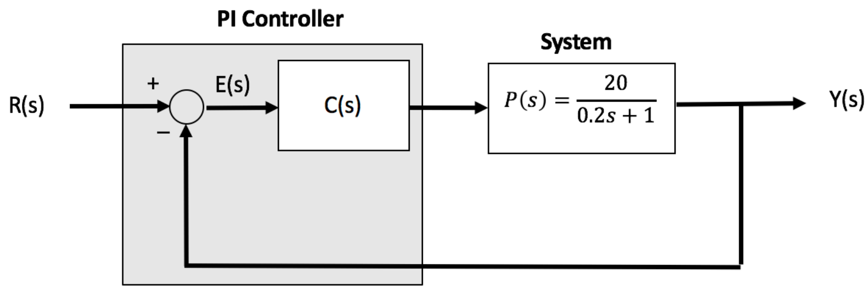

Figure Q8

[END OF PAPER]