IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2016

EEE/EIE PART III/IV: MEng, BEng and ACGI

**BIOMEDICAL ELECTRONICS**

Corrected copy

Tuesday, 6 December 9:00 am

Time allowed: 3:00 hours

Correction @ 10:15 am
Q 3.

**There are FIVE questions on this paper.**

**Answer 4 out of 5 questions**

*All questions carry equal marks.*

**Any special instructions for invigilators and information for candidates are on page 1.**

Examiners responsible
First Marker(s) : T. Constandinou
Second Marker(s) : P. Georgiou

1. This question relates to the design of a multichannel instrument for measuring bio-potentials from neurons in the brain.

   a) Figure 1.1 shows an AC coupled bio-potential amplifier connected to a set of electrodes for measuring neural activity from the brain. It is required that this amplifier can be connected to more than one set of electrodes, therefore two 16X1 analogue multiplexers are connected to points A and B shown in Figure 1.1 to interface to 16 pairs of electrodes. The electrodes used have a capacitance $C_E$=10μF and $V_{sig}$ and $V_{os}$ denote the measured bio-potential and common mode offset.

      i. Give one advantage and one disadvantage of using AC rather than DC coupled bio-potential amplifiers for this application. [2]

      ii. Derive the input voltage to the amplifier $V_{in}$, and show that it is high pass function stating the equation of the cut off frequency stating any assumptions made. To aid your calculations you may use just one branch of the differential input for your analysis. [3]

      iii. $C_1$ is chosen to be 10pF. Calculate a suitable value for $R_1$ to give you a high pass cut off at 50 Hz. [1]

      iv. Every time the multiplexer is connected a 1V transient spike appears at points A and B. Calculate the time taken for one complete scan of 16 electrodes assuming the multiplexer can switch to the next electrode with the spike reaches a voltage of 368mV and using this value calculate the frame rate of the system. [4]

   b) The Bio-potential amplifier in Figure 1.1 is used as part of a monitoring system to detect the action potential signal shown in Figure 1.2. between one pair of electrodes.

      The gain of the bio-potential amplifier is set to A=100. The output of the Bio-potential amplifier is band-pass filtered between 0.3KHz and 5KHz with a 20dB/decade high-pass followed 40dB/decade low-pass filter. A final gain stage is added to maximize the dynamic range between +3V to -3V.

      i. Sketch the complete schematic of this monitoring system, calculating suitable resistor values for your filters. You may assume all capacitors are, C=100pF for your filters. [6]

      ii. Choose suitable gains and calculate resistor values to ensure that the action potential shown in Figure 1.1 utilises the maximum dynamic range of the measurement system. [4]

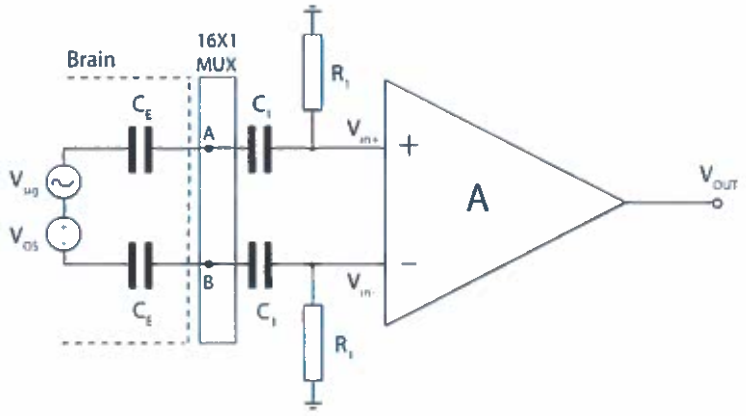
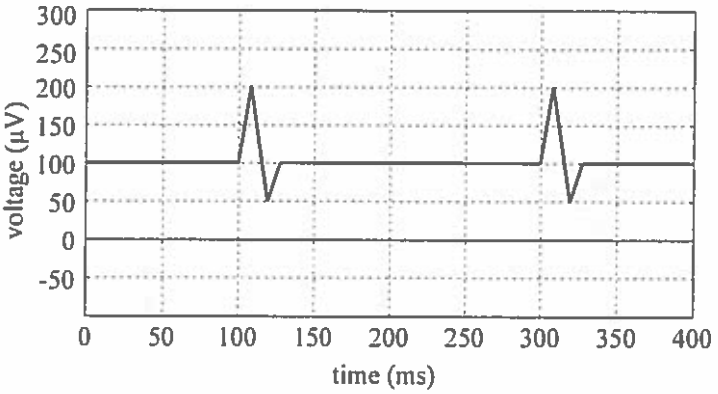



Figure 1.1


300
250
200
150
100
50
0
-50
voltage (μV)
0
50
100
150
200
250
300
350
400
time (ms)
Figure 1.2

2. This question relates to electrical stimulation.

An asymmetric biphasic current waveform that is generated by an electrical stimulation circuit is shown in Figure 2.1.

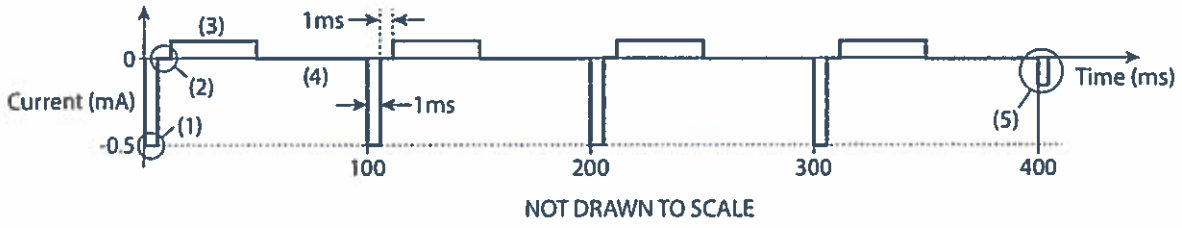



Figure 2.1

a) Name titles for phases (1), (2), (3), (4), and (5) as annotated in Figure 2.1, and briefly describe the purpose of each.

[10]

b) State one advantage and one disadvantage of using an asymmetric waveform instead of a symmetric waveform.

[2]

c) Given a 5kΩ electrode impedance, estimate the voltage headroom that is needed to generate the stimulus waveform shown in Figure 2.1. State any assumptions made.

[2]

d) If four stimulation channels are to be interleaved such that each channel delivers a stimulus at 10Hz, calculate the durations of phases (3) and (4), in addition to the amplitude of phase (3).

[4]

e) Briefly describe how the magnitude of phase (5) is determined.

[2]

For someone with diabetes

@ 10.15

3. Figure 3.1 shows a smart contact-lens system for non-invasive measurement of tear glucose. The glucose concentration in the tear fluid is within 0.1-0.6mM for a healthy person and may go up to 1mM in patients with diabetes. The Glucose sensor comprises a working electrode (WE) with an area of $1mm^2$, a reference electrode (RE) (area:$0.3mm^2$) and a counter electrode (CE) (area:$2mm^2$). The sensor readout IC receives AC power from the antenna and sends the measured data back to the transmitter. The instrumentation operates on a single supply with a VDD of 1.8V.

The working electrode is coated with glucose oxidase to give a peak current to glucose at $V_{Cell}$=0.7 V according to the following reaction:

$$\text{Glucose}+O_2 \xrightarrow{\textit{Glucose Oxidase}} \text{gluconic acid}+ H_2O_2$$

$$H_2O_2+O_2 \xrightarrow{V=0.7V} 2H^++2e^-$$

a) Calculate the peak redox current for the reaction above using the Randels Equation below. You may assume the number of electrons $n$ is solely given by the oxidation of $H_2O_2$ , the scan rate is 1V/sec and the diffusion coefficient $D=4.38X10^{-8}\ m^2/s$:

$$i_p = 2.69x10^5 \cdot n^{3/2} \cdot A \cdot D^{1/2} \cdot C \cdot v^{1/2}$$

[2]

b) Design a potentiostat and trans-impedance amplifier (TIA) with opamps and resistors to apply the cell voltage, measure the sensor current and maximize the output swing. Annotate the schematic.

[4]

c) Describe two alternative circuits to measure the sensor current, and state one advantage for each with respect to TIA in part c. Which one is most suitable for the contact-lens and why?

[3]

d) Common mode sensor interference and current drift limits the performance of bio-sensing systems. Propose one method that can help to compensate these effects and redesign the circuit in part b and one of the circuits in part c to implement this method.

[5]

e) Draw the block level diagram of the sensor readout IC to interface the sensor electrodes and the antenna and list the function of each block.

[6]

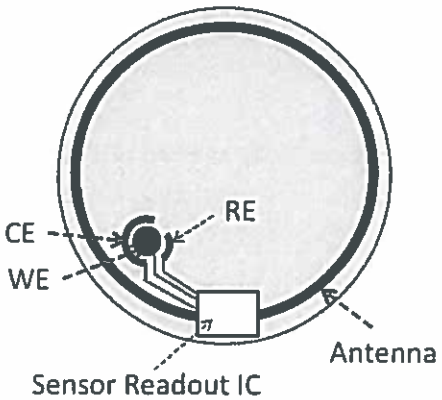



Figure 3.1

4. This question concerns the powering of implanted medical device and their power management.

a) An implantable sub-retinal prosthesis consumes an average power of 500μW (excluding stimulation power). Given the following parameters determine what capacity of implantable battery would be required in order to operate the device. State any assumptions that are made. [10]

| | |
|---|---|
| Array size: | 32 x 32 |
| Electrode impedance: | 100kΩ |
| Stimulation type: | Current-mode (symmetric biphasic pulses) |
| Average stimulus magnitude: | 50nC |
| Stimulation rate (per channel): | 25Hz |

b) Thermoelectric generators (TEGs) are a possible alternative source of electrical power to batteries.

i) Draw a cross section through a TEG, labelling the important parts, and explain how the device generates electrical power.

[4]

ii) It is proposed to attach a boost power converter to a TEG that will be used to power a body worn heart rate monitor. Other than stepping up the TEG's voltage, what other important role should this converter perform and why?

[3]

c) Inductive power transfer between coils coupled with poor coupling factor, $k<0.1$, provide a difficult challenge for the drive electronics. Explain why, and what solutions are employed.

[3]

5. Sequencing the human genome requires the identification of 3.2 billion bases of DNA which can be implemented using the process of pyrosequencing.

   a) Explain what DNA is and describe one of its physical properties that allow detection of single bases for DNA sequencing.

   [4]

   b) Explain the process of pyrosequencing, including a diagram showing the sequence of DNA bases with the signals generated for detection.

   [4]

   c) Name one sensor which is suitable for detecting DNA bases, drawing the structure of the device and listing the equations determining its operation.

   [4]

   d) Draw a block level circuit schematic to show how the sensor named in part c can be connected when scaled to millions of sensors.

   [5]

   e) Explain why using this sensor has significantly reduced the cost of DNA sequencing.

   [3]