IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2015 16

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

BIOMEDICAL ELECTRONICS

Corrected copy

Tuesday, 8 December 9:00 am

Time allowed: 3:00 hours

Before start of exam - 5(e) typo $R = 10k\Omega$

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) : P. Georgiou
Second Marker(s) : T. Constandinou

1. This question relates to the design of an instrument for measuring bio-potentials.

a) Explain how an action potential is generated referring to the ionic flow of sodium and potassium ions. You are required to sketch the waveform of an action potential and annotate each phase, explaining the mechanism contributing to these. [4]

b) Table 1.1 lists five commonly observed bio-potentials and their amplitude and frequency characteristics. A doctor requires an instrumentation system to record activity from the quadriceps muscles to aid rehabilitation during stair climbing. A schematic of a suitable instrumentation system is shown in Figure 1.1 to measure the signal in Figure 1.2. The gains of the first and second instrumentation amplifiers are 10 and 50 respectively and the system runs off a +/-3V supply.

(i) Design a suitable band pass filter (B.P.F in Figure 1.1) to extract the signals of interest. You may assume a 40dB/decade roll off for the low-pass and 20dB/decade roll off for the high pass sections. State equations for cut off frequencies and select suitable resistors. You may assume you have 10nF capacitors to your disposal. Show all circuit schematics and annotate component values. [4]

When the doctor conducts the stair climbing experiment he notices significant interference on the EMG signal, as shown in Figure 1.2, of a periodic nature.

ii) Why will this be a problem for the instrumentation system shown in Figure 1.2?

In order to extract the measured EMG signal shown in Figure 1.3, a potential solution is to use feedback on the instrumentation amplifier. [2]

iii) Explain why and show that the feedback arrangement using an integrator with $\tau = RC$ and a gain stage of $-\frac{1}{B}$ around IA2 is a suitable solution to filter out this unwanted periodic signal. [5]

iv) Choose suitable values for B, R to filter out the unwanted signal shown in Figure 1.2, assuming C=10nF. [2]

v) Calculate values for resistors R1 and R2 to maximize the dynamic range for the detected signal shown in Figure 1.2.

[3]

Table 1.1

Signal	Frequency range (Hz)	Amplitude range (mV)
ECG	0.1 - 300	0.05 - 3
EEG	0.5 - 40	0.001 - 1
EMG	20 - 2000	0.001 - 100
Neural Spikes	300 - 5000	0.001- 0.5
Local Field Potentials	10 - 200	0.001 - 5

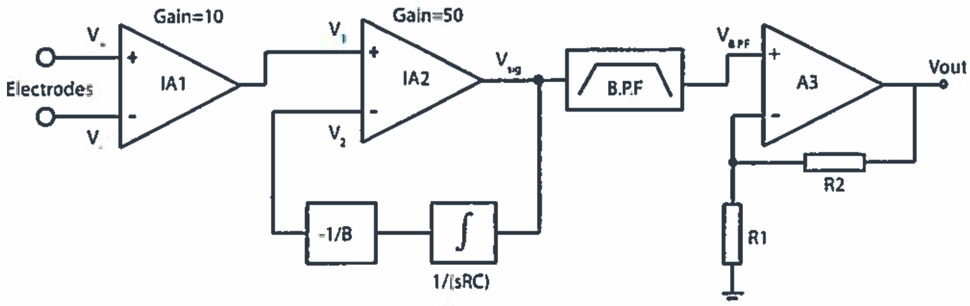

Figure 1.1

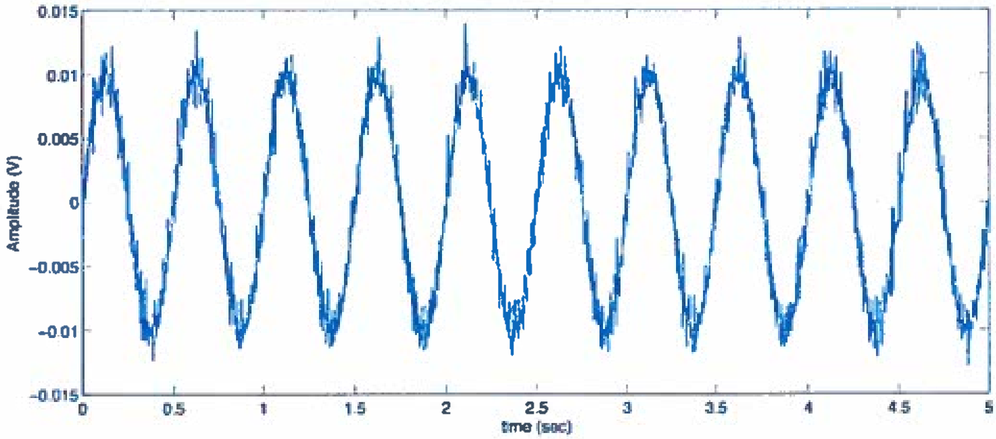

Figure 1.2, EMG signal with motion artifact

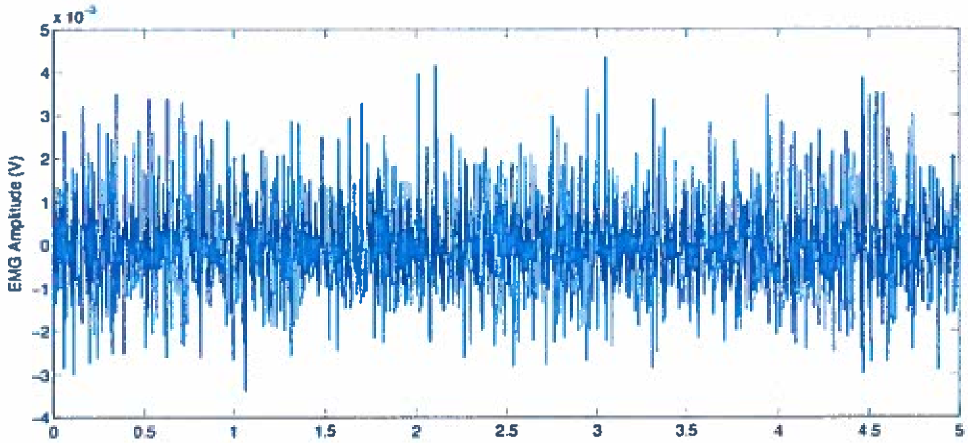

Figure 1.3, Extracted EMG signal

2. This question relates to electrical stimulation.

a) Briefly describe *current-*, *voltage-*, and *charge-mode* stimulus generation for electrical stimulation. [4]

b) Compare the relative merits and drawbacks between these methods with respect to power efficiency, voltage compliance, safety and circuit complexity. [4]

c) Select and justify which of the 3 methods would be most suitable for the following applications: [6]

(i) A wearable functional electrical stimulation (FES) system

(ii) An implantable cardiac defibrillator

(iii) An implantable cochlear prosthesis

(iv) An implantable deep brain stimulation (DBS) system

d) A 32-channel current-mode cortical stimulator achieves a 2% charge imbalance during continuous operation. Describe the suitability of the following charge balancing solutions: [6]

(i) Capacitive coupled electrodes

(ii) Implementing a shorting phase

(iii) Active charge balancing (metering with compensation)

3. This question relates to the design of chemical sensor instrumentation.

a) State one desirable and one undesirable characteristic for chemical sensors. [2]

b) The potentiostat system shown in Figure 3.1 is used to drive a three-electrode amperometric glucose sensor to form part of a Glucometer for treatment of diabetes.

i) Explain what is the role of the potentiostat and the function of the reference and counter electrodes. [3]

The sensor shall be used to measure a physiological glucose range of 0-20mM. The output current of the sensor maps to the range of IF = 0 - 400nA. The peak redox current is given by the following equation for a scan rate of 1V/s:

$$i_p = 2.69 \times 10^5 n^{3/2} A D^{1/2} C$$

where n=2 are the number of electrons given by the redox reaction and the diffusion coefficient $D=4.38X10^{-8}\ m^2/s$.

ii) Calculate a suitable area A, for the Working Electrode that will map the required concentration to the required current range. [2]

ii) The system shown in Figure 3.1 operates off a dual supply with VDD=5V and VSS=-5V. The transimpedance amplifier is clocked at a frequency f=10KHz. Calculate a value for the capacitor C_M which ensures the maximum utilization of dynamic range at 20mM of glucose. [3]

iv) Sketch a block level diagram of a glucometer using this system that could be used to measure blood glucose in diabetes. [5]

c) The sensor shown in Figure 3.2 is an Ion-Sensitive Field Effect Transistor.
Sketch the schematic of a circuit used to instrument to this sensor and describe its operation using transistor equations to show dependence on pH. [5]

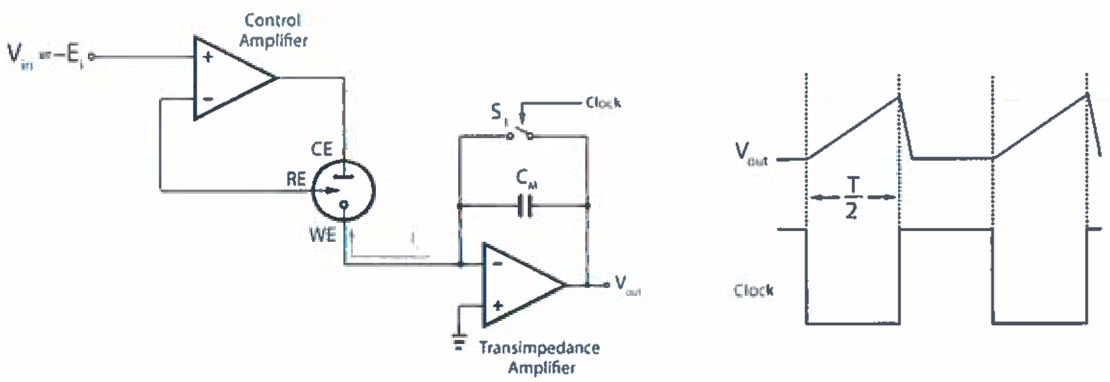

Figure 3.1

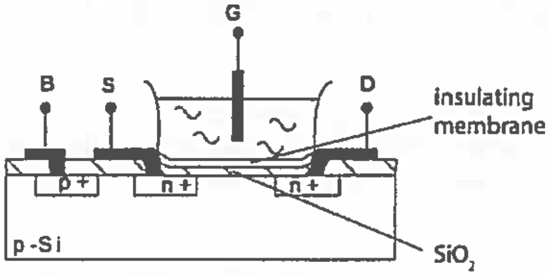

Figure 3.2

4. This question concerns inductive power transfer (IPT) systems for body worn and implanted medical electronics.

a) Safety of IPT systems in medical applications is paramount:

i) Name two adverse effects that can be observed on the human body if subjected to excessive electric or magnetic fields.

[2]

ii) Discuss which organisations are responsible for setting electric and magnetic field strength safety limits and how the limits would be used to determine if an IPT transmitter is safe for use in human proximity.

[5]

iii) An IPT transmitter system is certified safe for human exposure. Why would the system need to be recertified if powering a medical implant? Is the system more of less likely to meet the human exposure limits for a person with the receiver implanted, or for a person without the implant?

[3]

b) This question relates to power management of an implantable cochlear prosthesis.

The device consumes an average power of 200μW (excluding stimulation power). Given the following parameters, determine what capacity of implantable battery would be required in order to operate the device for a week. State any assumptions that are made. [10]

Number of electrodes:	25
Electrode impedance:	15kΩ
Stimulation type:	Current-mode (symmetric biphasic pulses)
Average stimulus magnitude:	100nC
Stimulation rate (per channel):	500 cycles/s

5. This question relates to electrical stimulation and the design of an implantable neural prosthesis.

A blind cockroach needs to avoid light areas and find dark places to survive.

a) Make a block diagram of an "eye prosthesis" which would solve the task of informing the cockroach about the ambient light level by stimulating its optic nerve. Clearly label each block and very briefly explain the role of each of them. [6]

b) Only one platinum electrode is used for the optic nerve stimulation. The stimulation is created using a current source producing I_{max}=10mA. Design and draw the current stimulus waveform if the stimulation frequency is f=10Hz and minimum interphase delay is t_i=2ms. Assume biphasic, symmetric stimulation pulses. The threshold for stimulus is Q_{th}=50nC for the stimulus pulse durations between 3ms and 200ms. Clearly mark on the diagram all elements of your stimulation waveform and explain their role. [5]

c) It is needed to encode three different stimulation levels: the threshold stimulus, 2x and 4x the threshold stimulus. Show the stimulus waveform for the last two. [3]

d) The maximum allowable charge density for a Pt electrode is q_m=150mC/cm^2. Calculate the minimum diameter of the electrode (D) if only the surface of the tip of the electrode is exposed and the maximum stimulus produces 4xQ_{th}. [2]

e) If the electrode-tissue impedance is R=10kΩ calculate the average power dissipation at the load impedance for all three stimulation levels. [4]