Glasgow College UESTC

Exam paper

Electronic Systems Design (UESTC3003)

Date: Feb 26th 2023
Time: 14:30-16:30PM

Attempt all PARTS. Total 100 marks

Start each answer on a new answer sheet for each of the questions in this exam. Show all work on the answer sheet.

Make sure that your University of Glasgow and UESTC Student Identification Numbers are on all answer sheets.

An electronic calculator may be used provided that it does not allow text storage or display, or graphical display.

All graphs should be clearly labelled and sufficiently large so that all elements are easy to read.

The numbers in square brackets in the right-hand margin indicate the marks allotted to the part of the question against which the mark is shown. These marks are for guidance only.

PHYSICAL CONSTANTS Boltzmann Constant, $k_B = 1.38 \times 10^{-23}$ J.K^{-1}

Q1 A kettle manufacturing company has approached you to measure the leakage resistance of their products. You must design a test setup as shown in **Figure Q1**. Their kettle's power plug is attached to the instrument with the 'Earth' pin connected to test terminal 'B', and the 'live' power conductor connected to terminal 'A'. Terminal 'A' is connected to a high voltage, low current voltage generator.

The circuit shown will produce an output signal of -1.0V at 'V_{out}' for an input current into terminal 'B' of 1uA equivalent to a leakage resistance (*Rx*) of 100V / 1uA = 100MΩ.

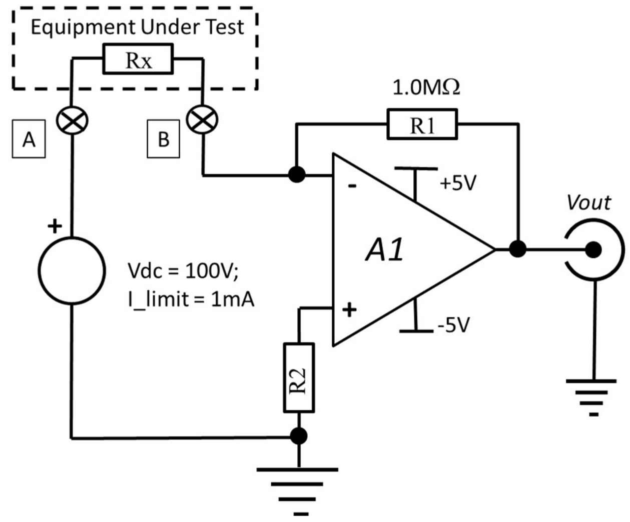

Figure Q1

(a) Assuming there is no equipment connected to the terminals 'A' and 'B' (i.e. the terminals are open circuit), re-draw the circuit showing all sources of DC error. [5]

(b) Derive an expression for the maximum total DC error, as an error current referred to the input. Include the effects of bias and offset currents, and the amplifier input offset voltage. Clearly state any assumptions you make. [8]

(c) If the terminals 'A' and 'B' are open circuit, state the value of *R2* required to minimise the total error of the circuit and explain your reasoning with reference to the expression in part (b). [6]

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(d) The opamp *A1* is one of the three listed in **Table Q1**. Write down a Figure of Merit (FoM) expression for *A1* and prepare a table showing the FoM for each amplifier. Hence choose the best amplifier for this leakage measurement application. [6]

Opamp	Offset Voltage, μV	Bias current, pA	Offset current, pA
Amplifier 1	150	7000	6000
Amplifier 2	60	2800	2800
Amplifier 3	500	40	20

Table Q1

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Q2 All automobiles have seat belts and consequent reminders to wear a seatbelt. These reminders appear as belt lights in the car's dashboard. These lights appear when there's pressure detected on the car seat and the seat belt is not locked. The output from the lock is simple 'on' and 'off' signal, however, the seat pressure sensors are to be designed in a way that they do not provide false information to the control unit. To avoid false readings, there are a series of pressure sensors installed under the car seat. A diagram of the seat belt reminder system is shown in **Figure Q2a.**

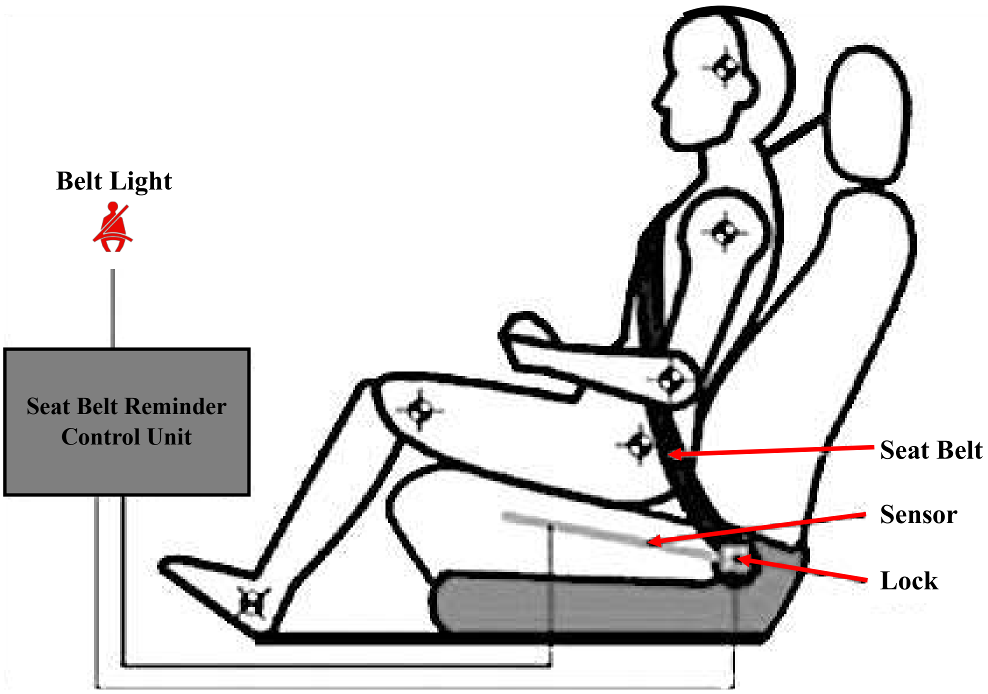

Figure Q2a

To optimise the efficiency of the seat belt sensors, it is important that the weights detected by the sensors are accurate and so a high quality, high accuracy amplifier is to be used to amplify the signals received from the sensor circuits before they are processed in the control unit. The other sensors and amplifier circuits are identical. **Figure Q2b** shows one of the amplifier circuits used with the pressure sensor.

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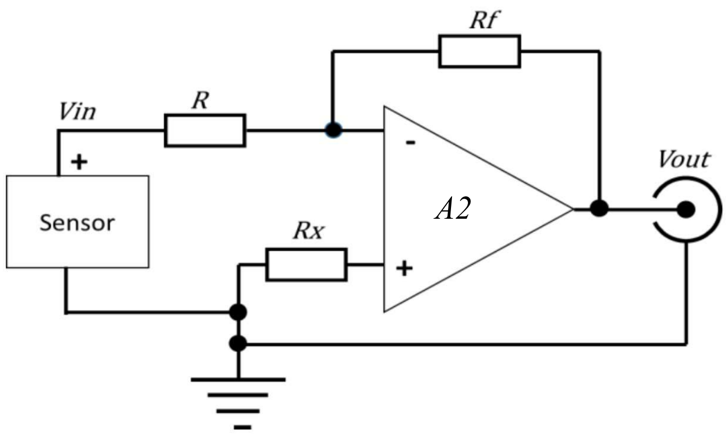

Figure Q2b

(a) Redraw the circuit in **Figure Q2b** showing all sources of DC error due to the OpAmp, *A2*. [5]

(b) Hence, derive an expression for the total DC error as a voltage referred to the output. Include the effects of both the bias and offset currents, and offset voltage. Clearly state any assumptions you make. [8]

(c) Using the expression you derived in (b), and resistor values $R = 25\text{k}\Omega$ and $Rf = 750\text{K}\ \Omega$, choose a value for Rx which minimises the error voltage appearing at the output. [5]

(d) Define a figure of merit (FoM) for the circuit shown in **Figure Q2b**. If the circuit is required to have an error at *Vout* of less than 18.0 mV, use your FoM calculation to calculate the error at *Vout* for all 3 amplifiers. Hence, select the most suitable opamp for *A2* from **Table Q2** and justify your choice. [7]

Opamp	Offset Voltage (µV)	Bias current (pA)	Offset current (pA)	Price (RMB)
Amplifier A	440	7,000	7,500	10
Amplifier B	500	65,000	6,000	15
Amplifier C	100	85,000	20,000	12

Table Q2

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Q3 (a) Including the circuit fragment shown in **Figure Q3a**, draw the diagram of an instrumentation amplifier with three op-amps. [3]

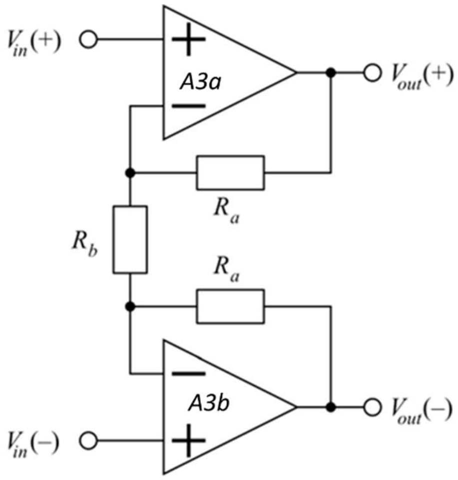

Figure Q3a

(b) Considering the circuit segment shown in **Figure Q3a** derive expressions for the differential and common mode gain. [6]

(c) You are asked to design an analogue front end for an ECG. **Figure Q3c** shows the signal inputs into the front end from high impedance ECG electrodes. The analogue front end for an ECG measurement outputs to an ADC with a 5 Volt dynamic range. **Note:** The electrode offset is a DC offset.

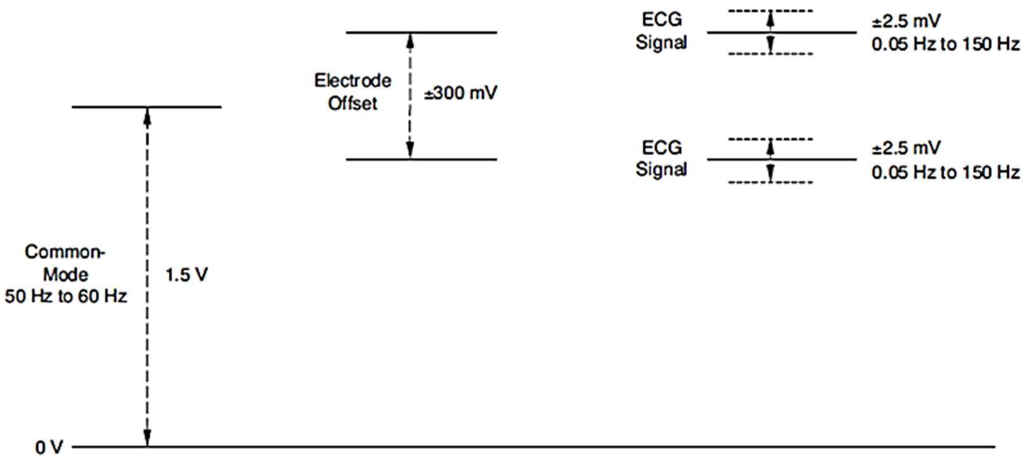

Figure Q3c

i. Draw a block diagram of your proposed analogue front end for a single pair of electrodes. Your block diagram should include appropriate

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amplifiers and filters. You must clearly show what type of filter, or filters, would be used. [5]

ii. Fully explain your block diagram. In your explanation you must refer to **Figure Q3c** to justify your choice of amplifier, the gain required and the types of filter used. You must include all relevant frequencies in the description of the filter elements. [11]

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Q4 In modern audio equipment, Digital-to-Analog Converters (DACs) are responsible for converting the digital information into analog waveforms which can be connected to amplifiers used to drive loudspeakers or headphones. **Figure Q4a** shows the circuit schematic for a high-quality studio headphone amplifier used to monitor the studio's output quality.

From a noise analysis perspective, the DAC can be modeled as a noiseless, variable DC voltage source (V_{dac}) whose value depends on the digital code value driving a series output resistor (R_{dac}). This signal is passed to the headphones by an operational amplifier (A1) powered from a ±15 V power supply. The operational amplifier is capable of driving the 32 Ω headphone load to within 100 mV of the power supply rails. The gain of the headphone amplifier circuit is set by the feedback resistors, *R1* and *R2*.

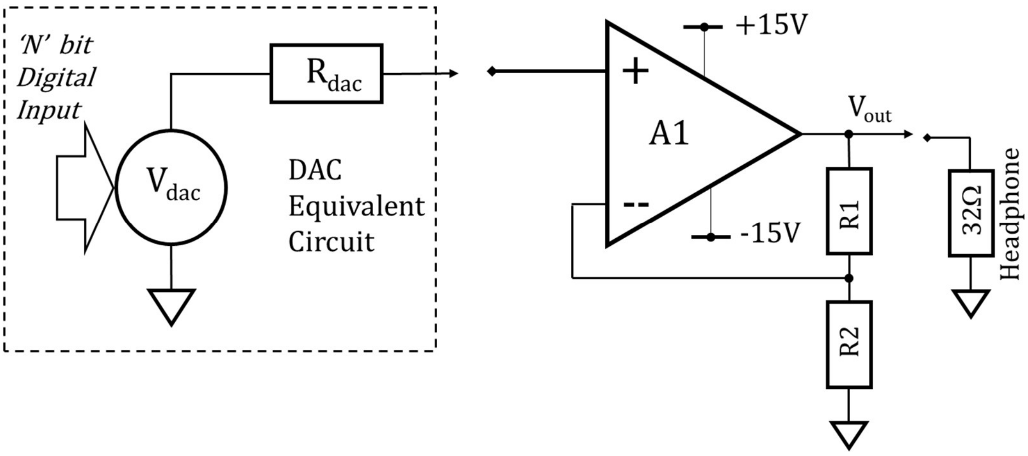

Figure Q4a: Studio Headphone Amplifier Schematic

(a) Using the above information assuming a value of R_{dac} of 10k Ω and an ambient temperature of 27 °C, calculate the Power Spectrum Density (PSD) of the DAC output and hence the equivalent input noise over an audio bandwidth of 100 Hz to 20 kHz. Show your calculations and any assumptions you make. [5]

(b) Including the noise equivalent resistance of the DAC, re-draw the circuit diagram in **Figure Q4a** showing and identifying all sources of noise appearing at *Vout*. [5]

(c) Hence derive an expression for the voltage noise power spectral density present at the output (V_{out}) of the amplifier at a room temperature of 27 °C. Clearly identify each source of noise in your calculations and state any assumptions you make. [6]

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(d) The following two sub question parts relate to Figure Q4b:-

i. **Figure Q4b** shows the relationship of equivalent input noise versus the source resistance for a typical amplifier. Please state what each of the lines (A, B, C) represent and comment on how they are derived. Also, explain the significance of point 'D', how it may be simply calculated, and hence used in the design of low noise amplifiers. [5]

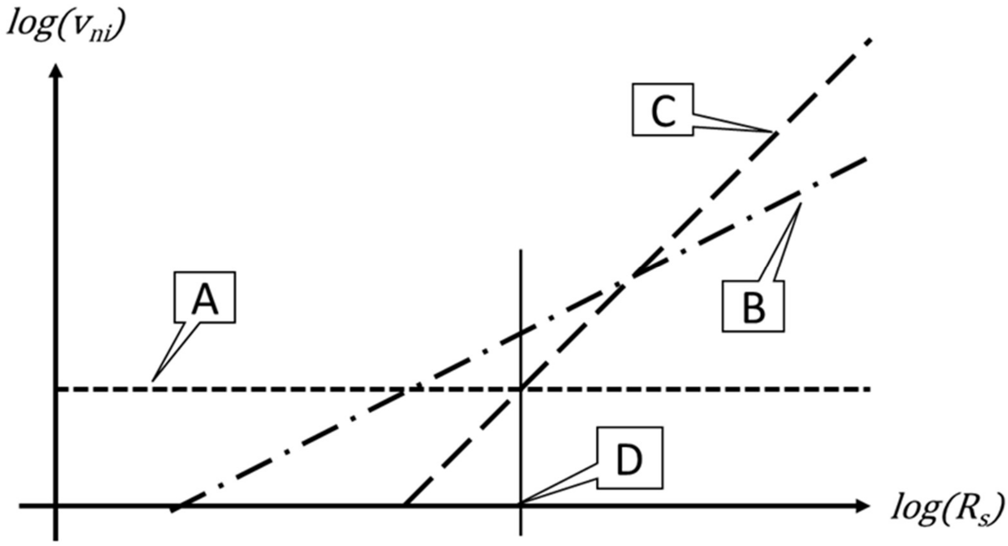

Figure Q4b: Graph showing effect of source resistance (R_s) on equivalent input noise (v_{ni})

ii. The operational amplifier 'A1' is one of the three shown in **Table Q4**:

OpAmp	v_n **(nV /√Hz)**	i_n **(fA/√Hz)**
Amplifier 1	3.8	1800
Amplifier 2	4.7	460
Amplifier 3	7.0	25

Table Q4

If the source resistance (R_{dac}) for this circuit is 10,000Ω and the parallel combination of $R1||R2$ is less than 50 Ω, draw a table comparing the performance of each amplifier and identify which would be most suitable for this application. Explain the reason for your choice. [4]

End of question paper