GLASGOW COLLEGE UESTC

Exam paper

Electronic Systems Design (UESTC3003)

Date: 21st Dec 2023
Time: 14:30-16:30

Attempt all PARTS. Total 100 marks

Use one answer sheet for each of the questions in this exam.
You must show all work on the answer sheet to obtain full marks.

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

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

All graphs must 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.

Boltzmann constant (k_B) = 1.38×10^{-23} J K^{-1}

Continued overleaf

Q1

(a) Considering an op-amp, define what is meant by input offset voltage (V_{os}) and explain what causes it. [2]

(b) *Figure Q1a* shows an integrating amplifier with zero input. Derive an expression for the output voltage, V_o, and explain the effect that V_{os} will have on its operation. [3]

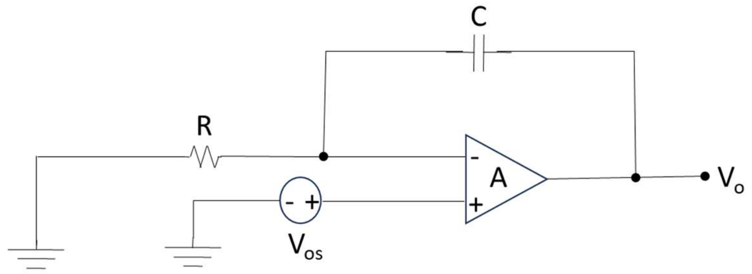

Figure Q1a

(c) *Figure Q1b* shows an Op-amp with a bias current compensating resistor (R_p).

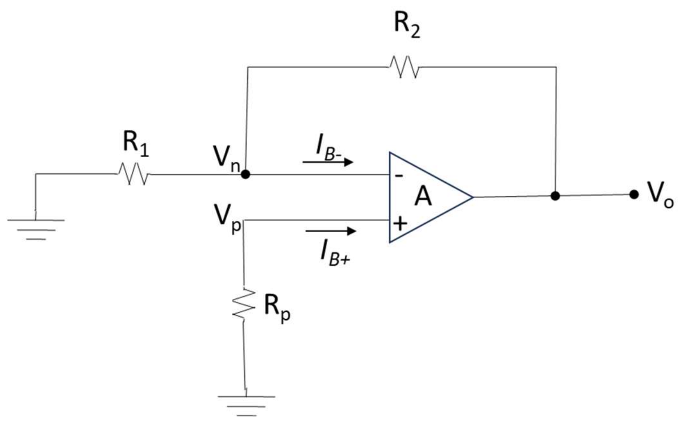

Figure Q1b

(i) Derive an expression for V_o to quantify the effect of bias currents I_{B+} and I_{B-}. [3]

(ii) Explain how you would choose a value for R_p to reduce the output error due to the bias currents, I_{B+} and I_{B-}. [3]

(d) Referring to an op-amp define what is meant by common-mode rejection ratio (CMRR) and explain the effect a finite CMRR would have on high-precision applications. [4]

Continued overleaf

(e) Consider the inverting amplifier shown in *Figure Q1c*. Initially R_1=10 kΩ, R_2=1 MΩ and R3 is a short circuit (0 Ω).

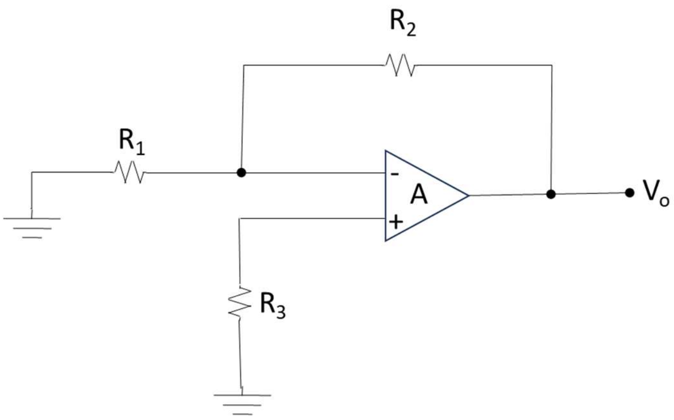

Figure Q1c

(i) If the op-amp has an input bias current of 100 nA and an input offset current of 10 nA, calculate the output voltage. [2]

(ii) Evaluate the required value of R3 to cancel the effect of bias current at the output. [2]

(ii) Calculate the new value of Vo. [2]

(f) Explain the need for decoupling capacitors and the importance of their placement. [4]

Continued overleaf

Q2 A differential input (subtracting) amplifier is shown in *Figure Q2*.

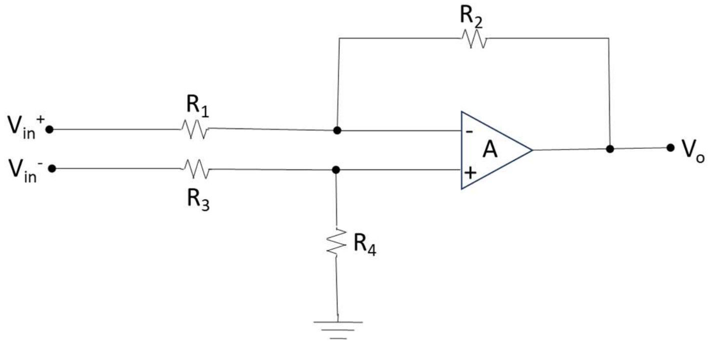

Figure Q2

(a) If all the resistors are equal state the voltage gain and give an expression for V_{out}, neglecting any sources of error. [2]

(b) Redraw *Figure Q2* showing of all the sources of DC error. [2]

(c) Derive an expression for the total DC error as a voltage referred to the output (RTO). You can assume that impedances are matched and that all the resistors are the same and equal 10kΩ. [8]

(d) Describe what is meant by Figure of Merit (FoM) and write an expression for it using your solution to Part (c). [3]

(e) *Table Q2* shows op-amps that are available for A1. Calculate the FoM for each op-amp and choose an appropriate device. In your answer you must explain your decision. There should be a table and a graph (Cost versus FoM) to support your analysis. [10]

Table Q2

Op-amp	Offset voltage (μV) (max)	Offset current (pA) (max)	Price per unit (RMB)
OP07	150	6000	3.6
OP277	50	2800	15.3
OP97	75	150	22
OP1097	50	250	29.1
LT1050	5	125	36.5

Continued overleaf

Q3 (a) Two possible configurations of differential amplifier are shown in *Figures Q3a* and *Q3b*. Explain why it would be preferable to implement the configuration shown in *Figure Q3b* as a general-purpose instrumentation amplifier. [7]

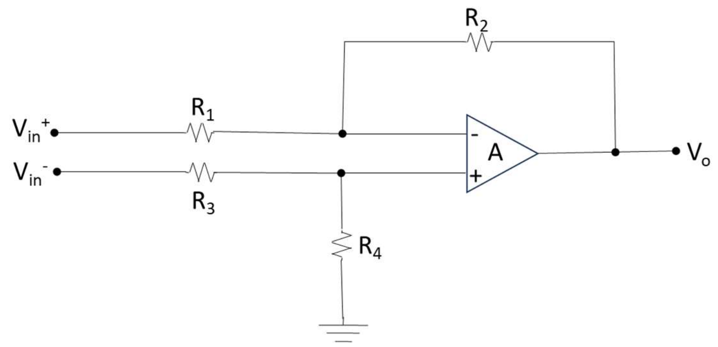

Figure Q3a

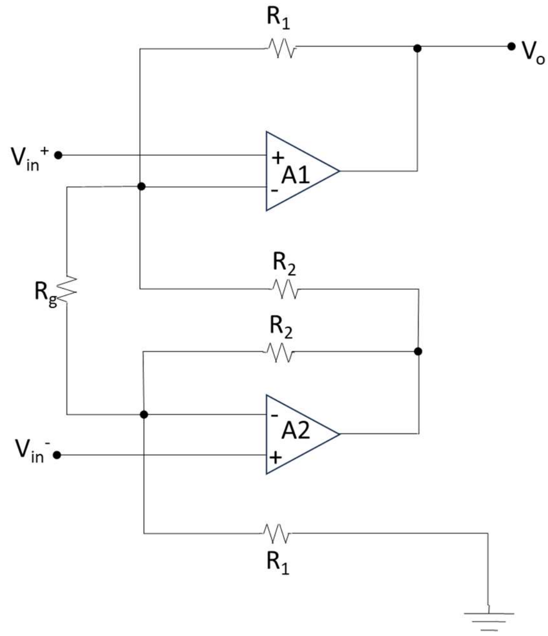

Figure Q3b

Continued overleaf

(b) While an instrumentation amplifier can be implemented using the configuration shown in *Figure Q3b* it is more common to use three operational amplifiers.

(i) Draw the circuit diagram of a three op-amp instrumentation amplifier, clearly labelling each component. [3]

(ii) Explain the operation of the circuit you have drawn for Part b(i) and derive an expression for the differential gain. [9]

(c) A twisted pair cable is used to carry two inputs to an instrumentation amplifier. Discuss why this is good practice and how it reduces the filtering requirement in the electronic system. [6]

Continued overleaf

Q4 (a) Summarize possible strategies for improving the Signal to Noise ratio (SNR) when using operational amplifiers. [8]

(b) Explain what is meant by white Noise Equivalent Bandwidth (NEB). [5]

(c) An inverting amplifier is shown in *Figure Q4a*. The data sheet for the op-amp gives the value of Gain Bandwidth (GBW) as 5.2 MHz and a voltage spectral density of white noise of $e_{nw} = 16nV/\sqrt{Hz}$.

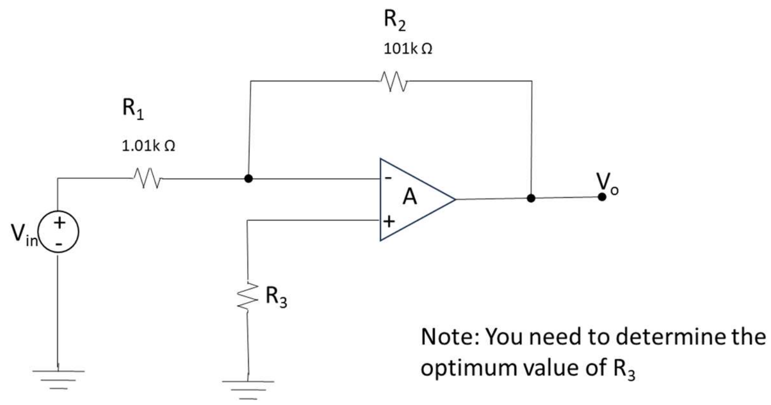

Figure Q4a

(i) Calculate the white noise equivalent bandwidth (NEB) and the thermal noise contribution from each resistor at 25ºC. State any assumptions used in your calculations. [7]

(ii) Determine the output SNR for an output voltage of 4V peak-to-peak given that the op-amp current noise is negligible. [5]

End of question paper