ECEG 350 Electronics I Fall 2024

Homework Assignment #4 – due via Moodle at 11:59 pm on Friday, Sept. 27, 2024

***Instructions, notes, and hints*:**

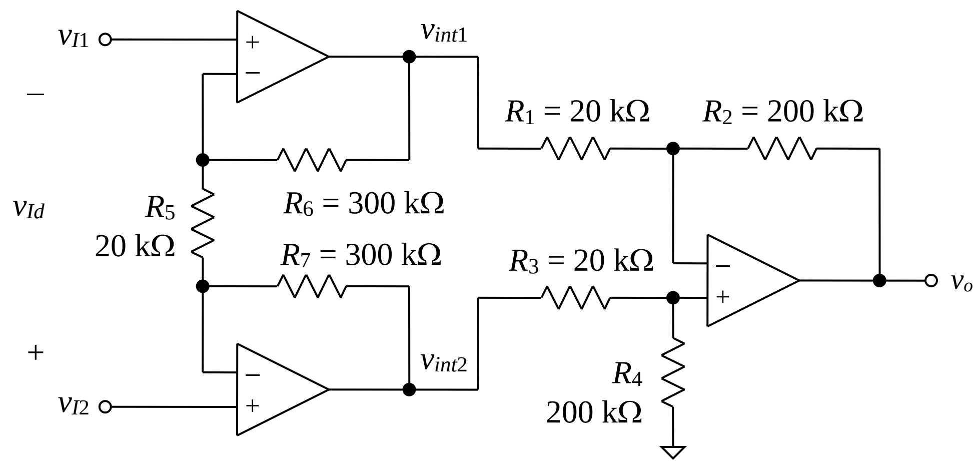
You may make reasonable assumptions and approximations in order to compensate for missing information, if any. Provide the details of all solutions, including important intermediate steps. You will not receive credit if you do not show your work.

The first few problems will be graded and the rest will not be graded. Only the graded problems must be submitted by the deadline above. Do not submit the ungraded problems.

***Graded Problems*:**

1. The resistors in the instrumentation amplifier shown below are labeled with their nominal values. A sinusoidal differential-mode voltage with the waveform given by the expression below is applied across the input terminals of the amplifier (between nodes v_{I1} and v_{I2}). The common-mode voltage gain of the second stage is 0.028 V/V. Find the resulting peak-to-peak differential intermediate voltage $v_{int2} - v_{int1}$ and the peak-to-peak differential output voltage v_{od}. The power supply voltages are ±15 V but are not shown in the diagram to improve clarity.

$$v_{Id}(t) = 0.44\cos(2{,}200\pi t - 50°)\ \text{mV}$$



2. Referring to the instrumentation amplifier considered in the previous problem, suppose that nearby building wiring causes a common-mode periodic signal with a peak-to-peak voltage of 120 mVpp and a frequency of 60 Hz to appear at the two inputs v_{I1} and v_{I2}. All resistor values are the same as in the previous problem. The common-mode gain of the second stage is also the same. Ignoring the differential-mode input voltage, find the peak-to-peak common-mode node voltages at the v_{int1}, v_{int2}, and v_o nodes.

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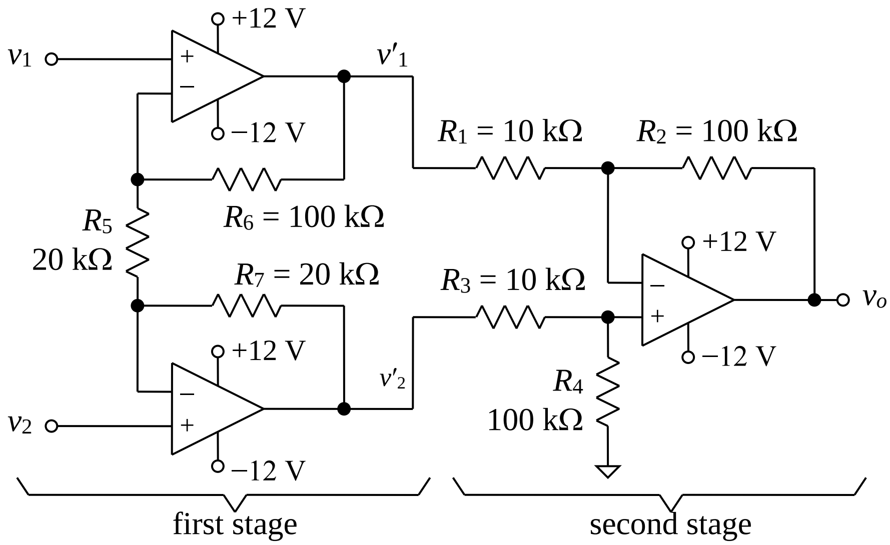
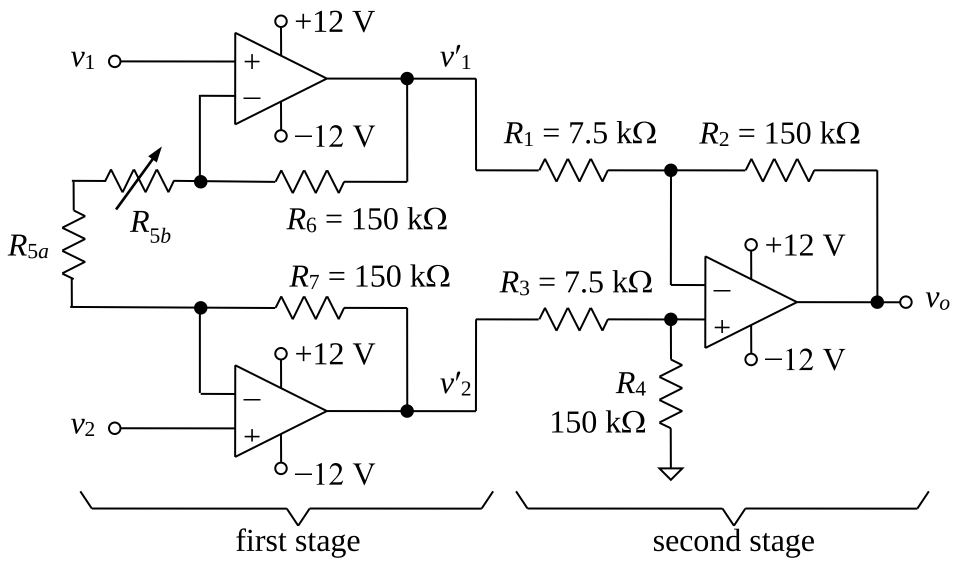
3. The instrumentation amplifier shown below was accidentally assembled with the wrong value for resistor R_7; its value should have been 100 kΩ. All resistors have 5% tolerance; the values shown are the nominal ones. If the common-mode gain A_{cm2} of the second stage is 0.0044 V/V, find the differential-mode and common-mode gains of the full amplifier to reasonably good approximations (accurate to ±5% or so). Also find the CMRR expressed in decibels.



4. The instrumentation amplifier depicted below uses 1% tolerance resistors in the first stage and 0.1% tolerance resistors in the second stage. The circuit is unusual in that resistor R_5 has been split into a fixed portion R_{5a} and a variable portion R_{5b}. The variable resistor can have a minimum value of zero and a maximum value $R_{5b\max}$. Find the required values for R_{5a} and $R_{5b\max}$ so that the overall nominal differential-mode gain varies from 40 to 100 V/V. Also find the lowest possible overall CMRR value (expressed in dB) obtained as R_{5b} is varied over its full range of values. That is, find the worst-case CMRR obtained over the full range of differential-mode gains from A_d = 40 to 100 V/V.



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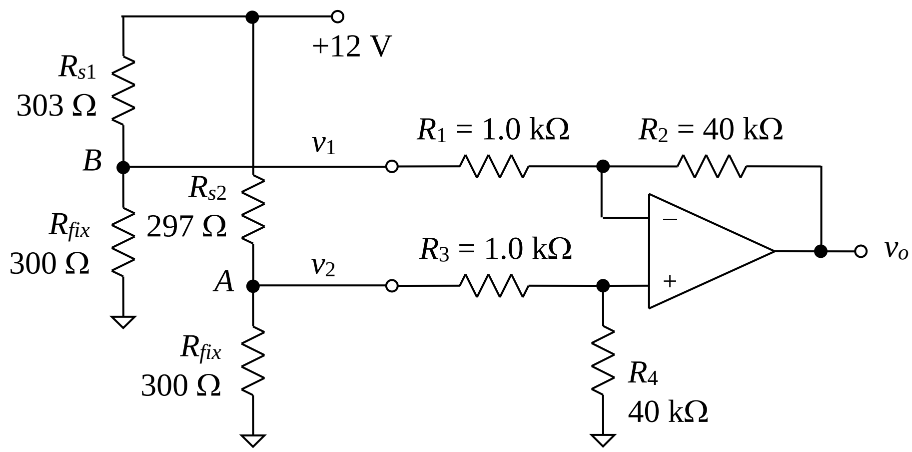
***Ungraded Problems*:**

The following problems will not be graded. They are intended to serve as practice problems and examples. The solutions to these problems will be posted along with those to the graded ones.

1. The diff amp circuit shown below is meant to scale up the differential voltage produced by a pair of strain gauges arranged in a Wheatstone bridge. Each strain gauge resistance R_{s1} and R_{s2} has a nominal value of 300 Ω at the neutral position. The gauge factor is 2.0, which means that the fractional resistance change $\Delta R/R_{nom}$ from nominal is twice that of the strain (e.g., 0.1% strain yields $\Delta R/R_{nom} = 0.002$). The two strain gauges are mounted so that when one gauge's resistance increases in value, the other's resistance decreases. The other two resistors (labeled R_{fix}) are fixed and have the indicated values to a very high precision. At a strain of 0.5%, the differential voltage $v_2 - v_1$ would be equal to 60 mV if an infinite resistance were connected across the bridge (i.e., between the nodes *A* and *B*). The diff amp is designed to amplify the bridge voltage by a factor of 40. Thus, for a bridge voltage of 60 mV, the diff amp output voltage should be 2.4 V. Using the differential input resistance of the diff amp, estimate the output voltage actually obtained at a strain of 0.5%, and compare it to the ideal value of 2.4 V. The power supply voltages for the op-amp are ±12 V (not shown for clarity). *Hint*: Replace the Wheatstone circuit with a floating Thévenin equivalent circuit connected between nodes *A* and *B*.



2. Suppose that the resistors in the diff amp and Wheatstone bridge in the previous problem have values that are exactly as labeled. Use the superposition principle to find the actual output voltage. That is, find the output voltage due to the +12 V source, R_{fix}, and R_{s1} connected to node *B* and the output voltage due to the +12 V source, R_{fix}, and R_{s2} connected to node *A*, and then add them together. The value found in this problem and the one from the previous problem do not exactly match, but they are close.

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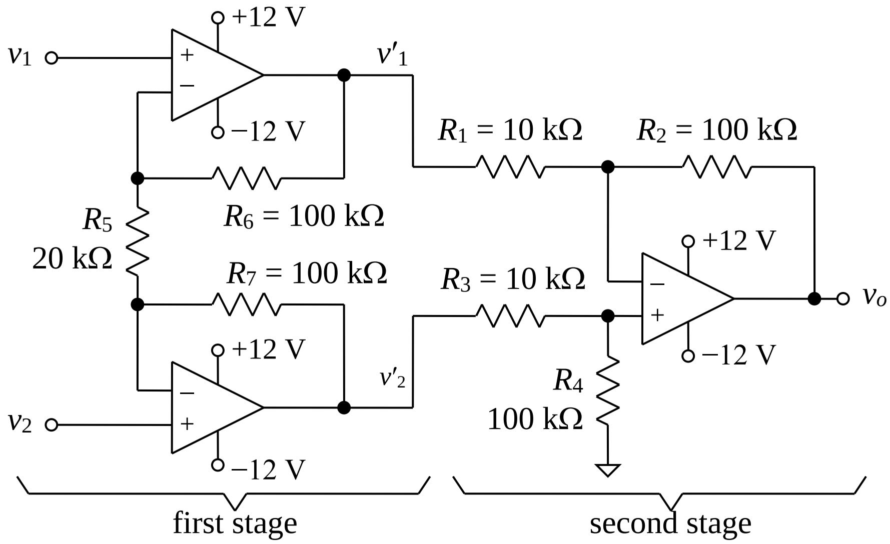
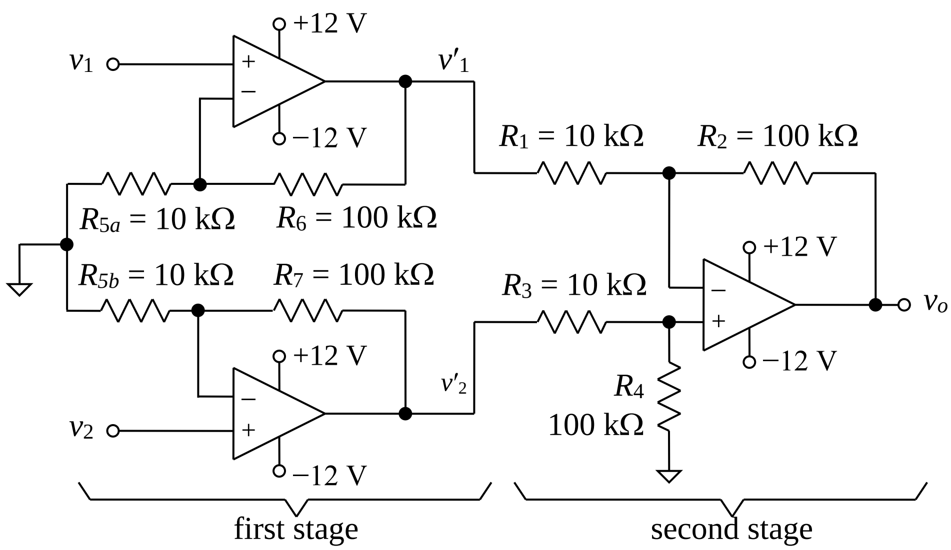
3. The instrumentation amplifier shown below is to be assembled using 5% tolerance resistors in the first stage, but the second stage will incorporate resistors manufactured using a precision laser cutting method. The resistor values shown are the nominal values. Find the resistor tolerance in the second stage required to guarantee that the overall CMRR will be at least 120 dB.



4. Now suppose that resistor R_5 in the previous problem is split into two resistors of equal value (i.e., each is 10 kΩ) and a connection to ground is added to the node between them. The new circuit would have the form shown below. Find the constraint on the resistor tolerances in the second stage that would be necessary to again achieve a CMRR of at least 120 dB. The first-stage resistors would still have 5% tolerances. Compare this answer to the one for the previous problem.



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5. As in one of the graded problems, the amplifier shown below was assembled with the wrong value for resistor R_7. Note that the diagram does not depict a true instrumentation amplifier because resistor R_5 has been split into two 10 kΩ resistors and a connection to ground has been added between them. The common-mode gain A_{cm2} of the second stage is still 0.0044 V/V. Find reasonably good approximations of the differential-mode and common-mode gains of the full amplifier. This problem is somewhat challenging. You need to understand clearly how the differential-mode and common-mode gains are defined. You also need to be careful how you calculate the output voltage for the two types of input signals.