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.

Prob. 2.125: Assume that the op-amp’s power supplies can accommodate a 20-V peak-to-peak output voltage.

Assignment:

Probs. 2.122 and 2.125 in the textbook, plus the following additional problems:

1. The instrumentation amplifier circuit shown below will be assembled using 5% tolerance resistors in the first stage. The resistors in both stages are to have the indicated nominal values. The second stage will incorporate resistors manufactured using a precision laser cutting method. What constraint on the resistor tolerance is required to guarantee that the CMRR will be at least 120 dB?

2. If resistor $R_5$ in the previous problem were divided into two resistors of equal value and a ground connection were placed between them (so that the circuit had the form shown in Fig. 2.20a of the textbook), what would be the new constraint on the resistor tolerances in the second stage to achieve a CMRR of at least 120 dB? The resistors in the first stage would still have a tolerance of 5%.

(continued on next page)
3. The op-amps in the instrumentation amplifier shown below have input bias currents with the indicated values. Neglecting the input offset voltages of each op-amp, what value would the output voltage $v_o$ have if $v_1 = v_2 = 0$? Find a symbolic expression for $v_o$ first and then substitute the input bias current values. Comment on the circuit’s effectiveness (or lack thereof) at minimizing the effects of input bias currents. *Hint: Apply superposition.*

![Instrumentation Amplifier Circuit](image)

$I_{B11} = 100 \text{ nA}$
$I_{B21} = 110 \text{ nA}$
$I_{B12} = 80 \text{ nA}$
$I_{B22} = 70 \text{ nA}$
$I_{B13} = 90 \text{ nA}$
$I_{B23} = 70 \text{ nA}$

4. Neglecting the effects of the input offset voltages and input bias currents on the instrumentation amplifier circuit from the previous problem, what is the maximum common-mode input voltage amplitude $v_{icm}$ that can be applied without causing any of the op-amps to saturate at either the positive or negative power supply voltage?

5. The circuit shown below is the first stage of an instrumentation amplifier. The resistors are small enough so that the effects of the input bias currents on output voltages $v'_1$ and $v'_2$ are negligible; however, the effects of the two input offset voltages $V_{OS1}$ and $V_{OS2}$ (modeled as shown) might not be. Find the effect of both input offset voltages together on the value of output voltage $v'_1$. Repeat for output voltage $v'_2$. That is, find $v'_1$ and $v'_2$ as functions of only $V_{OS1}$ and $V_{OS2}$ (not of the common and differential-mode inputs). Find symbolic expressions for $v'_1$ and $v'_2$ first and then substitute the values of $V_{OS1}$ and $V_{OS2}$ to find their numerical values of $v'_1$ and $v'_2$.

![Instrumentation Amplifier Circuit (Continued)](image)
6. Find the voltages \( v \) and \( v_o \) in the circuit shown below. Carefully consider the output voltage limits. You should find that \( v \neq 0 \) in this case. You may assume that the op-amp is otherwise ideal.