

Laboratory 2.4 – The Instrumentation Amplifier

(Note: the section and page references here do not directly point to the correct page of your text as they reference an earlier edition text)

What is an Instrumentation Amplifier?

This is a very useful, three OpAmp design that has a differential pair of inputs with:

- A high input impedance (The two non-inverting OpAmps have a high input impedance)
- Good and stable differential gain (The output due to the difference between the two inputs)
- A very high Common Mode Rejection ratio (CMRR)
 - The CMRR is the ratio in dB between the differential gain (the second stage OpAmp does the differencing) and:
 - The common mode gain (the output due to the sum of the two inputs divided by 2)
 - The common Mode signal is usually an external disturbance that is undesirable signal.
- Low distortion, due to the use of feedback

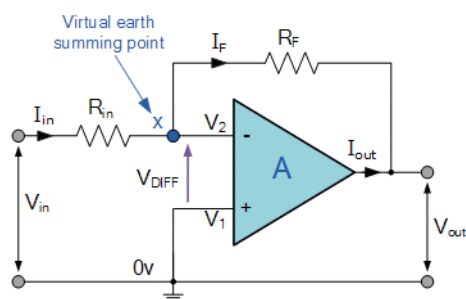
You are asked to choose some resistor values to set the gains of the circuit and the differential gain. The remote member of the team will simulate the circuit while the “hands-on” member builds and tests the circuit. Make sure to measure the actual resistor values used so the performance of simulated circuit and the circuit as built can be compared.

Download the specification sheet for the 741 OpAmp to see both the pinout diagram (remember to power all three OpAmps with +15 and – 15 volts on the correct pins) and its expected performance (gain, input/output impedances, and offset voltages/currents).

Make a point of also unbalancing the circuit a bit (as mentioned in the last paragraph of the Lab) to see the effect on the Common Mode Rejection Ratio (CMRR). Measuring the CMRR is easily done in your simulation, if time allows, also try measuring the CMRR in your circuit as built.

Your full Lab report should be uploaded to Blackboard by the next lab session. Do not fall behind as it becomes difficult to catch up later in the semester and I will be penalizing teams that submit reports late. These labs are a good opportunity to learn so do not be afraid to experiment with your circuit. ASK QUESTIONS! As they arise via Quip. You can direct questions to @jdenenberg or better @everyone to get responses from your instructor, your TA, or others in your cohort of 16 students in our lab course.

How Do I Calculate OpAmp Gain? (You did this in EE213!)



Let us look at an “inverting operational amplifier”

(Not the ones in the first stage of the Instrumentation Amplifier)

There are basic rules for an OpAmp:

- The input impedance is very high.
- The output impedance is very low.
- The gain is ridiculously high

Since the gain is so high, the voltages V_1 and V_2 **must be virtually identical** since a small difference would cause the output to go to one of the power rails (they are not shown here, but the OpAmp chip requires +V and -V supplies). Since V_1 (the positive input) is grounded, V_2 becomes a “virtual ground” (due to feedback) as denoted.

Now just write a “Node Equation” at node x:

$$I_{in} = I_f \text{ or } V_{in}/R_{in} = -V_{out}/R_f \text{ or}$$

$$\text{Gain} = V_{out}/V_{in} = -R_f/R_{in}$$

I never memorize equations. I just remember the basics and easily re-derive the needed equation since I cannot rely on my memory to get everything right. It is easy to forget the assumptions that were made to derive the equations in your Text, so using equations often results in wrong answers.

I expect to see a derivation of the gain equation for each of the two OpAmp configurations in your Instrumentation Amplifier Laboratory Report.

LAB 2.4

Instrumentation Amplifier

[See Section 2.4.2, p. 76 of Sedra/Smith]

OBJECTIVES:

To study an instrumentation amplifier circuit by:

- Completing the analysis of the circuit and selecting resistors that satisfy design specifications.
- Simulating the circuit to compare the results with the paper analysis.
- Implementing the circuit in an experimental setting, taking measurements, and comparing its performance with theoretical and simulated results.

MATERIALS:

- Laboratory setup, including breadboard
- Three 741-type operational amplifiers
- Several wires and resistors of varying sizes

PART 1: DESIGN AND ANALYSIS

Consider the circuit shown in Figure L2.4:

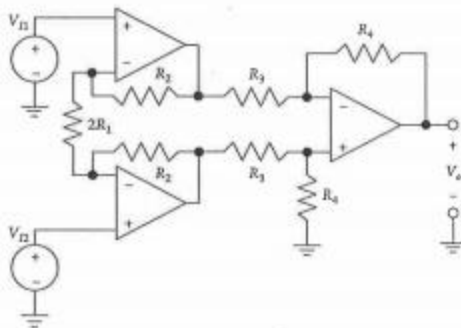


FIGURE L2.4:
Instrumentation amplifier.
Based on Fig. 2.20(c),
p. 77 S&S.

Note that the $2 \cdot R_1$ resistor is just two R_1 resistors in series, each acts as the input resistor for its respective OpAmp and the point in the middle is another "Virtual Ground" that shifts along with the Common Mode Signal as it equals the average of the two inputs to the Instrumentation Amplifier. Actually, grounding this center point causes the input OpAmps to saturate if there is a significant Common Mode signal.

Design the circuit in Figure L2.4 such that $A_d = 110$ V/V. Select resistor values such that the first stage provides a gain of 11 V/V (magnitude) and $R_1 = 1$ k Ω and the second stage provides a gain of -10 V/V. Use supplies of $V_+ = +V_{CC} = 15$ V.

Hand calculations

- Sketch the circuit in your lab book, clearly labeling the op-amp terminals.
- What values of R_1 , R_2 , R_3 , and R_4 do you need to use to meet the gain and input resistance specifications? Is the problem completely specified?

Simulation

- Use a 50-mV_{pk-pk} 1-kHz input sine wave applied to v_{I1} and another 50-mV_{pk-pk} 1-kHz input sine wave applied to v_{I2} that is 180° out of phase with v_{I1} . In your simulation, assume your input voltage sources have an output resistance of 50 Ω . What are V_{Id} and V_{Icm} ? What are V_{Od} and V_{Ocm} ?
- Plot the input and output waveforms for all simulations.
- For all simulations, report the DC voltage at the inverting terminal and output of each op-amp.
- What are the simulated values of differential and common-mode gain?

PART 2: PROTOTYPING AND MEASUREMENT

- Assemble the circuit onto a breadboard. Do not include the 50- Ω output resistance of your signal sources.
- While leaving v_{I2} grounded, provide a DC input to v_{I1} in increments of 0.01 V, from -0.1 V to $+0.1$ V. Record the values of v_O and plot your results.
- While leaving v_{I1} grounded, provide a DC input to v_{I2} in increments of 0.01 V, from -0.1 V to $+0.1$ V. Record the values of v_O and plot your results.
- Using a function generator, provide a 1-kHz 50-mV_{pk-pk} sine wave to input v_{I1} and ground input v_{I2} . Using an oscilloscope, capture the output voltage waveform.
- Using a function generator, provide a 1-kHz 50-mV_{pk-pk} sine wave to input v_{I2} and ground input v_{I1} . Using an oscilloscope, capture the output voltage waveform.
- Using a digital multimeter, measure all resistors to three significant digits.

PART 3: POST-MEASUREMENT EXERCISE

- Calculate the values of A_d and A_{cm} obtained in your measurement. What is the common-mode rejection ratio (CMRR) of the circuit? Express the CMRR in units of decibels. Explain any discrepancies between the experiments, simulations, and hand analysis.

LAB 2.4 INSTRUMENTATION AMPLIFIER

- Recalculate the theoretical gains of the circuit, using the measured resistor values. Are the recalculated values closer to your measured gains?

PART 4 [OPTIONAL]: EXTRA EXPLORATION

- In your measurement setup, replace R_4 with a resistor that is 10% smaller in value and remeasure A_d and A_{cm} . How do their values change? What do you conclude?