Lab 6: Instrumentation Amplifiers

Physics 327

Spring 2025

Goals

Build and examine more complex multi-component circuits, constructing a single–op amp difference amplifier and three–op amp instrumentation amplifier. **Note:** This is a two-week lab.

Pre-Laboratory Exercises

To prepare for this laboratory:

1. Read about the instrumentation amplifier in Chapter 32.
2. Construct the circuit shown in Figure 2 in a SPICE simulation program. In `LTspice`, you can use the **OP07** operational amplifier. Perform the linearity measurement described in Part B.

Introduction

The instrumentation amplifier is a widely used device in the kinds of instrumentation electronics that perform measurements in physics experiments. This circuit was discussed in class, and further details can be found in Chapter 32 of the textbook.

This will be the first circuit you are building with multiple IC components, so be sure to lay out your breadboard neatly and perform basic debugging, to ensure your circuit works as expected. It is recommended to build and test each part/component of the circuit individually, and only combine them once they are known to be working correctly. It may also be helpful to use a color coding scheme with wiring. Always double-check your wiring before powering on the 741, and switch off or disconnect the power before making any changes.

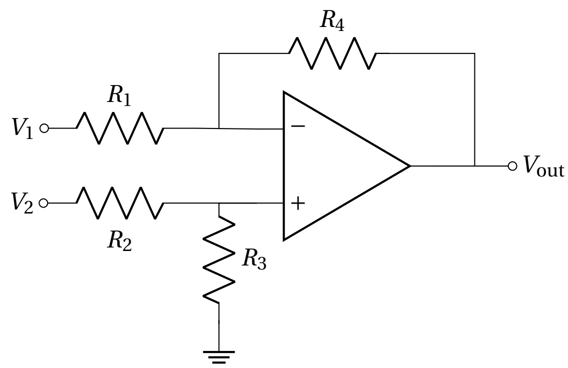
A Difference Amplifier

Part 1 The Amplifier Circuit

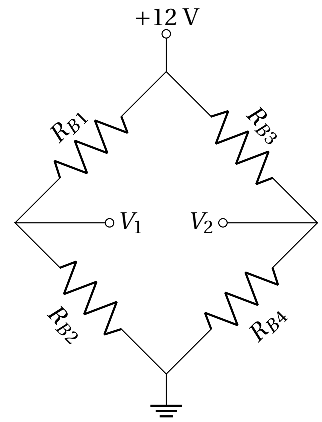
First, build the difference amplifier circuit shown in Figure 1a, according to the pinout in datasheet (also in the Lab 5 manual). Use $R_1 = R_2 = 10$ kΩ, and choose $R_3 = R_4$ to achieve a voltage gain of about 10. Perform the offset nulling procedure as you did in Lab 5, minimizing V_{out} when the inputs are grounded. Test your circuit (gain and inversion) by measuring the output with a known input. Describe the input and output in your report.

Part 2 Bridge

Set up the bridge circuit shown in Figure 1b. This device outputs the difference between two voltage dividers, and is thus sensitive to resistance changes in one of the branches. Begin with $R_{B1} = R_{B2} = R_{B3} = 3$ kΩ, and R_{B4} a 10 kΩ potentiometer in series with a 1 kΩ resistor. Power on the +12 V supply and, using a DC voltmeter, adjust the potentiometer such that $V_1 - V_2 = 0$ V.



(a) Difference amplifier schematic.



(b) Bridge circuit schematic.

Figure 1: Schematics for Part A.

Connect the V_1 and V_2 output terminals of the bridge to the corresponding inputs of the difference amplifier. Power on the circuit and record the value of V_{out} (if it is nonzero when both inputs are grounded, this offset must be subtracted from the subsequent measurements). Adjust the potentiometer to vary $V_1 - V_2$ and measure V_{out} as a function of this difference. Take measurements for about six voltages between −0.8 to +0.8 V.

Question 1: Describe the dependence of the output on the input. Is it linear?

Part 3 Voltage Divider

Next, disconnect the bridge circuit from the difference amplifier. Construct a voltage divider network to provide voltages from −0.8 to +0.8 V. Connect V_2 to ground and V_1 to the voltage divider. Take measurements at six input voltages in this range with the voltage divider input, and compare your results to the case with the bridge.

Question 2: Describe the linearity of the output and compare it with the case using the bridge.

B Instrumentation Amplifier

The instrumentation amplifier, shown in Figure 2, is widely used in analog design, especially in devices used for making measurements such as in physics experiments. This amplifier combines multiple op amps to create a differential input device with high input impedance on both inputs and low output impedance, along with low offsets and minimal sensitivity to common-mode signals (i.e. appearing on both inputs).

The amplifier shown in Figure 2 has a voltage gain of

$$G = \frac{V_{\text{out}}}{V_1 - V_2} = -k(1 + 2a),$$

with the first stage having a gain of $(1 + 2a)$ and the second stage k. Set up the circuit with a total gain around −10, with $a = 5$ and $k = 1$. Ground both inputs and check the DC offset. If non-zero, use a potentiometer on one op amp to perform an offset null, adjusting until V_{out} is as close as possible to zero.

Input a low-frequency (a few kHz) sine wave input to V_1, with V_2 grounded. Measure the linearity (gain as a function of input voltage) and the frequency dependence from about 1 kHZ to 1 MHz. Create a plot of your results.

Question 3: Describe the linearity of the output and compare to your results from Part A.

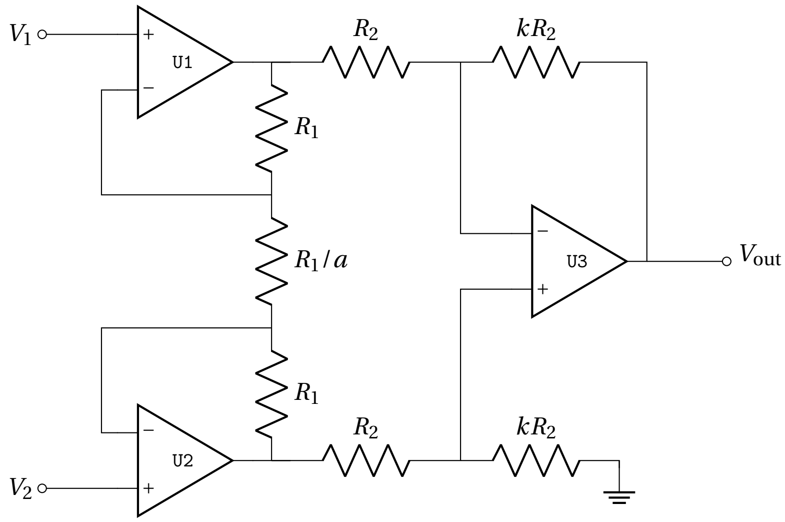


Figure 2: Instrumentation amplifier schematic.

C Temperature Measurement

Finally, you will use an instrumentation amplifier together with a *thermistor* in a bridge configuration to create a device to measure temperature. A thermistor is a resistor with a highly temperature-dependent resistance.

Use a multimeter to measure the resistance of a thermistor at room temperature, and at 0°C by placing the thermistor in ice water (be careful not to let the water short out the wires). Using your measurements, determine the parameters R_0 and α for the *thermistor formula* which gives the approximate thermistor resistance:

$$R_{th} = R_0 \exp(-\alpha T_C)$$

where T_C is the temperature in degrees Celsius.

Next, connect your instrumentation amplifier to a bridge circuit (as in Part B) with $R_{B1} = R_{B3} = 470\ \text{k}\ \Omega$. For R_{B4}, use a parallel combination of a 470 kΩ resistor and the thermistor. Choose the value of R_{B2} such that the bridge outputs zero at about room temperature; this will be around 270 kΩ. Note this in your report.

While holding the thermistor in your hand, measure V_{out}. First, assume that the output is linear (proportional to temperature), compute the measured *temperature* in degrees C.

> **Question 4:** What is the measured temperature under this assumption, and how well does it agree with the "normal" human body temperature value of about 37°C?

Finally, use the thermistor formula (R_{th} for a given T_C) together with the instrumentation amplifier gain and bridge formula (a difference of voltage dividers giving the bridge V_{out} for a given R_{B4}) to estimate the temperature.

> **Question 5:** What is this temperature, and how well does it agree with the "normal" value?