ECEN 325 Lab 4: Operational Amplifiers – Part II

Objectives

The purpose of the lab is to study some of the advanced opamp configurations commonly found in practical applications. The circuits studied will include the summing amplifier, the differential amplifier and the instrumentation amplifier.

Introduction

Summing Amplifier

An inverting amplifier can be modified to accommodate multiple input signals as shown in Fig. 1. Since the circuit is linear, the output voltage can easily be found by applying the superposition principle: the output voltage is a weighted sum of the two input signals. The weighting factor is determined by applying one of the input signals while the other is grounded and analyzing the resulting circuit. Since the circuit is linear, the analysis is repeated for the other input, and the final result is the addition of both signals. The advantage of this approach is that we can easily recognize the effect of each signal on the circuit's performance, and the overall output can be obtained in most of the cases by inspection. For the circuit in Fig. 1, the output voltage can be found as

$$V_o = -\left(\frac{R_3}{R_1}V_{i1} + \frac{R_3}{R_2}V_{i2}\right) \tag{1}$$

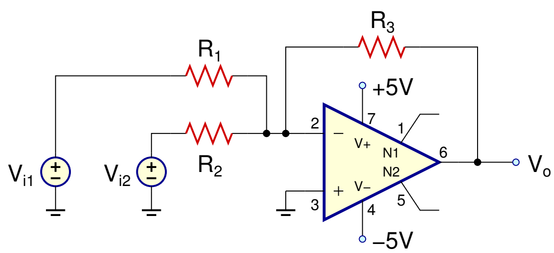

Figure 1: Summing amplifier circuit

The summing amplifier can be extended to have any number of input signals. Consider a two-bit digital signal applied to the inputs of the circuit in Fig. 1, resulting in an analog voltage at the output that is determined by the binary input. A more general configuration based on this circuit can be used to build digital-to-analog converters (DAC).

Differential Amplifier

The differential amplifier is designed to amplify the difference of the two inputs. The simplest configuration is shown in Fig. 2. If the resistor values are chosen such that $R_2/R_1 = R_4/R_3$, then the output of the amplifier is given by:

$$V_o = \frac{R_2}{R_1}(V_{i2} - V_{i1}) \tag{2}$$

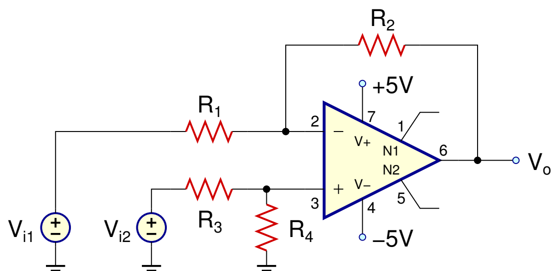

Figure 2: Differential amplifier circuit

This expression shows that the circuit amplifies the difference between the two input signals $V_{i2} - V_{i1}$ and rejects the common mode input signals ($V_o = 0$ if $V_{i1} = V_{i2}$). Therefore, the differential amplifier can be used in a very noisy environment to reject common noise that appears at both inputs. When the same signal is applied to both inputs, the voltage gain is defined as common-mode gain (A_{CM}), which is zero for an ideal differential amplifier. The common-mode rejection ratio is defined as,

$$CMRR = \frac{A_{DM} \text{ (Differential-mode gain)}}{A_{CM} \text{ (Common-mode gain)}} \tag{3}$$

Substituting $A_{CM} = 0$ to the above expression, $CMRR$ for an ideal differential amplifier becomes infinite. In practice, resistors have a tolerance of typically 5%, and the common-mode gain will not be zero, resulting in finite $CMRR$.

Instrumentation Amplifier

The instrumentation amplifier is a differential amplifier that has high input impedance and the capability of gain adjustment through the variation of a single resistor. A typical instrumentation amplifier is shown in Fig. 3.

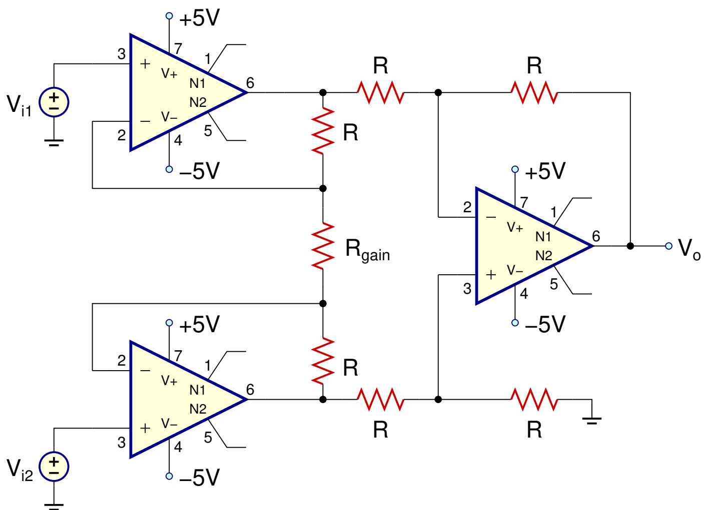

Figure 3: Typical instrumentation amplifier circuit

The voltage drop across R_{gain} is equal equal to the voltage difference of the two input signals. Therefore, the current through R_{gain} caused by the voltage drop must flow through the two R resistors above and below R_{gain}. The output voltage can be calculated as

$$V_o = \left(1 + \frac{2R}{R_{gain}}\right)(V_{i2} - V_{i1}) \tag{4}$$

Though this configuration looks cumbersome to build a differential amplifier, the circuit has several properties that make it very attractive. It presents high input impedance at both terminals because the inputs connect into non-inverting terminals. Also a single resistor R_{gain} can be used to adjust the voltage gain.

Calculations

1. For the summing amplifier in Fig. 1, find R_1 and R_2 to have $V_o = -(V_{i1} + 2V_{i2})$, if $R_3 = 15k\Omega$.

2. For the differential amplifier in Fig. 2, find R_1 to have $V_o = V_{i2} - V_{i1}$, if $R_2 = R_3 = R_4 = 10k\Omega$.

3. For the instrumentation amplifier in Fig. 3, find R to have $V_o = 3(V_{i2} - V_{i1})$, if $R_{gain} = 1k\Omega$.

4. For each circuit, find V_o if $V_{i1} = 0.2\sin(2\pi 1000t)$ and $V_{i2} = 0.3V$.

Simulations

For all simulations, provide screenshots showing the schematics and the plots with the simulated values properly labeled.

1. Draw the schematics for the circuits in Figs. 1, 2, and 3 with the calculated component values using the UA741 opamp model.
2. Apply the inputs $V_{i1} = 0.2\sin(2\pi 1000t)$ and $V_{i2} = 0.3V$, and obtain the **time-domain waveforms** for the input and output voltages using **transient simulation**. Confirm that the circuits operate as designed.

Measurements

For all measurements, provide screenshots showing the plots with the measured values properly labeled.

Summing Amplifier

1. Build the circuit in Fig. 1 with the simulated component values.
2. Apply the inputs $V_{i1} = 0.2\sin(2\pi 1000t)$ and $V_{i2} = 0.3V$, and obtain the **time-domain waveforms** for the input and the output voltages using the **scope** to confirm that the circuit is a summing amplifier.
3. Raise the DC input voltage V_{i2} until clipping at the output is observed.

Differential Amplifier

1. Build the circuit in Fig. 2 with the simulated component values.
2. Apply the inputs $V_{i1} = 0.2\sin(2\pi 1000t)$ and $V_{i2} = 0.3V$, and obtain the **time-domain waveforms** for the input and the output voltages using the **scope** to confirm that the circuit is a differential amplifier.
3. Apply $V_{i1} = 0.2\sin(2\pi 1000t)$ and connect V_{i2} to ground. Measure $A_{DM} = V_o/V_i$.
4. Apply $V_{i1} = V_{i2} = 0.2\sin(2\pi 1000t)$. Measure $A_{CM} = V_o/V_i$.
5. Calculate the common-mode rejection ratio (CMRR).

Instrumentation Amplifier

1. Build the circuit in Fig. 3 with the simulated component values.
2. Apply the inputs $V_{i1} = 0.2\sin(2\pi 1000t)$ and $V_{i2} = 0.3V$, and obtain the **time-domain waveforms** for the input and the output voltages using the **scope** to confirm that the circuit is a instrumentation amplifier.

Report

1. Include all measurement plots.
2. Prepare a table showing calculated, simulated and measured results.
3. Compare the results and comment on the differences.

Demonstration

1. Calculations and simulations must be submitted on Canvas as a single pdf file **before** the lab session. All simulation plots must include a timestamp.
2. Your name and UIN must be written on the side of your breadboard.

3. For the differential amplifier in Fig. 2:

- Show the time-domain waveforms with $V_{i1} = 0.2\sin(2\pi 1000t)$ and $V_{i2} = 0.3V$.
- Measure A_{dm} with $V_{i1} = 0.2\sin(2\pi 1000t)$ and $V_{i2} = 0$.
- Measure A_{cm} with $V_{i1} = V_{i2} = 0.2\sin(2\pi 1000t)$.
- Calculate CMRR

4. For the instrumentation amplifier in Fig. 3:

- Show the time-domain waveforms with $V_{i1} = 0.2\sin(2\pi 1000t)$ and $V_{i2} = 0.3V$.