ECEN 325 Lab 3: Operational Amplifiers – Part I

Objectives

The purpose of the laboratory is to study the properties of the fundamental amplifier building blocks using commercially available Operational Amplifiers (opamps). Inverting and non-inverting amplifiers will be investigated.

Introduction

Practical devices are non-ideal. You can find information about their specifications and performance measures from the manufacture's data sheet. It is an important skill for an engineer to obtain relevant analytical data from data sheets, which are generally arranged in three main sections:

- ***General Description*** section, which summarizes the important properties of a device, pin-out diagram and equivalent circuit diagrams.
- ***Maximum Ratings*** section, which defines the safe limits of device operation.
- ***Electrical Characteristics*** section, which gives information about the ranges of performance for most of the important device parameters. This section usually includes graphical and tabular presentations. The graphs often repeat the data from the tables but give more detailed information. Sometimes the vendors provide test circuits.

Some specifications listed as typical are not verified by tests by the manufacturer. Only minimum and maximum specifications are binding. In this lab some specifications of the Opamp will be measured. Before that, please be sure to consult the manufacturer's data sheets first.

Opamp Parameters

The opamp is one of the most widely used devices in electronic instrumentation and analog integrated circuit design. There are many parameters to be considered for a simple opamp. In this lab, only a few parameters are briefly discussed and studied. The information about the parameters below can be found in the data sheet.

Power Supplies: The most frequently used supplies are: ±15 V, ±12 V, ±10 V and ±5 V. In all our labs we will use ±5 V supplies for all opamp circuits. Never exceed the specified power supply limit.

Input Resistance and Output Resistance: The input resistance looking into the two input terminals of the opamp is ideally infinite. For a real 741 Opamp, it is about 2 MΩ. The finite input resistance of the opamp must be taken into account, but it is especially critical if the impedances of the components attached to the opamp inputs are comparable with its input impedance. The output resistance on the other hand is ideally zero. For a real 741 opamp, it is about 75 Ω. The finite output resistance of the opamp must be taken into account in analysis and design of networks if it is comparable with the resistance of components directly connected to the output of the opamp.

Output Offset Voltage and Input Offset Voltage: When the opamp input signal is zero, the output should be zero. However, in practice, this is not the case. For a real 741, the output voltage is typically around 2 mV when the inputs are connected to the analog ground. This offset is called the output offset voltage, which is divided by the open-loop gain of opamp to get the equivalent input offset voltage.

Input Offset Current: The ideal opamp has an infinite input resistance and draws no current from the inputs. In the real 741, each input draws a small amount of DC current because of the finite input resistance. The difference between the current drawn into the positive and negative input terminal is called the input offset current.

Open Loop Voltage Gain: The open loop voltage gain is the opamp's gain when an input signal is applied and feedback is not used. The gain is ideally infinite, but in a real case it is finite. For the 741, the DC gain is around 200,000 V/V (around 106 dB). The gain also depends on frequency and other parameters.

Gain-Bandwidth Product: The open loop gain of the opamp decreases as the frequency increases, so the opamp is less efficient at high frequencies. However, the product of open loop DC gain and the -3 dB frequency (bandwidth) is a constant. This is defined as the Gain-Bandwidth product (GBW). For a real 741, GBW is about 1.2 MHz.

Slew Rate: An ideal opamp is able to follow the input signal no matter how quickly the input changes. In a real 741, the output rise and fall transients cannot exceed a maximum slope. The maximum rate of change of the output voltage as a function of time is called the slew rate. Applying signals with transients that exceed this limit results in distorted output signals. The slew rate can be measured by applying a large square waveform at the input. The frequency of the input signal should be increased until the output becomes a triangular waveform. The slope of the triangular waveform is the slew rate.

Handling Opamps: Picking up an IC package by your hand could destroy the circuit inside due to the static voltage discharge. Always wear a ground-strap so that static voltage does not accumulate.

Calculations

1. Read the data sheet for the UA741 opamp and write down the typical values of the following parameters:
   - Supply Voltage
   - Input Offset Voltage
   - Voltage Gain
   - Power Consumption
   - Output Resistance
   - Bandwidth
   - Input Resistance
   - Input Offset Current
   - Slew Rate
2. Derive the voltage gains $\frac{V_{o1}}{V_i}$, $\frac{V_{o2}}{V_i}$, and $\frac{V_{o3}}{V_i}$ for the circuits in Fig. 1, assume the opamps are ideal.

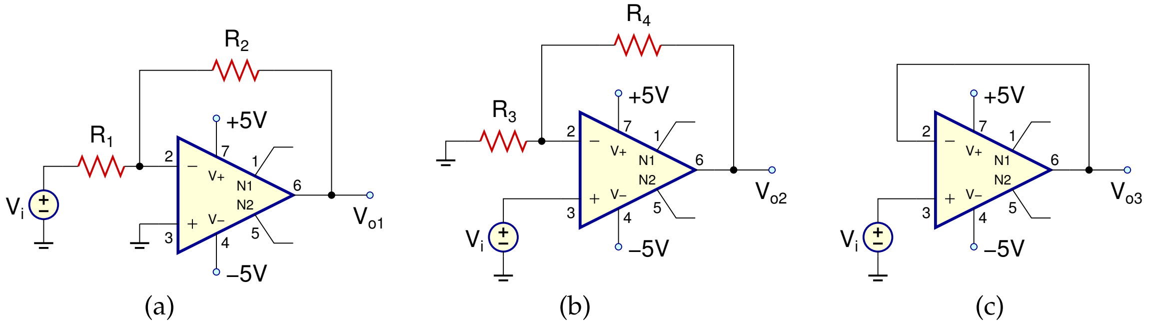

Figure 1: Opamp configurations (a) Inverting amplifier (b) Non-inverting amplifier (c) Voltage follower

3. If $R_1 = R_3 = 10k\Omega$, find R_2 and R_4 such that $\frac{V_{o1}}{V_i} = -3$ and $\frac{V_{o2}}{V_i} = 6$.

Simulations

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

Draw the schematics for the circuits in Fig. 1 with the calculated component values using the UA741 opamp model. Perform the following simulations for each circuit:

1. Obtain the magnitude and phase **Bode plots** of the transfer function using **AC simulation**, and measure the gain at 1kHz.
2. Apply the input $V_i(t) = 0.2\sin(2\pi 1000t)$ and obtain the **time-domain waveforms** for the input and the output voltages using **transient simulation**. Measure the magnitude of the input and the output voltages, and find the resulting gain.
3. Sweep the amplitude of the 1kHz sine wave input from 0 to 5V using **transient simulation** with **parameter sweep**. Determine the maximum value of the input amplitude $V_{i,max}$ before clipping occurs at the output.
4. Apply the input $V_i(t) = V_{i,max}\sin(2\pi 1000t)$ and perform **Fourier simulation** to measure the **total harmonic distortion (THD)** on the output waveform.

Measurements

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

Input Offset Current Measurement

1. Build the circuit in Fig. 2 and measure the voltages across the two $100k\Omega$ resistors (after measuring one, switch the two resistors and make the second voltage measurement on the same resistor, but on the other terminal).

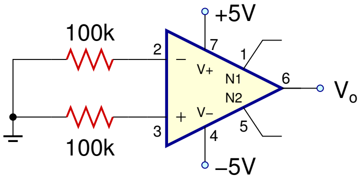

Figure 2: Offset Current Measurement Configuration

2. Use Ohm's law to calculate the DC input currents. The difference between the current into positive and negative input terminals is the input offset current.

DC Offset Voltage Measurement

1. Build the circuit in Fig. 3 with the calculated values of R_3 and R_4. Measure the value of V_o, which is the output offset voltage.

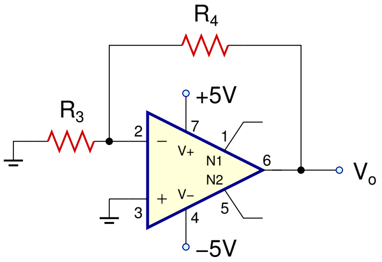

Figure 3: Offset Voltage Measurement Configuration

2. Calculate the input offset voltage of the opamp by dividing the output offset voltage by the gain.

3. To minimize the offset voltage, connect a 100 $k\Omega$ potentiometer (pot) between pins 1 and 5 as shown in Fig. 4. Be sure to connect the center tap of the pot to the -5 V supply. Use the pot to zero the opamp's output. This is how the opamp's offset voltage is compensated.

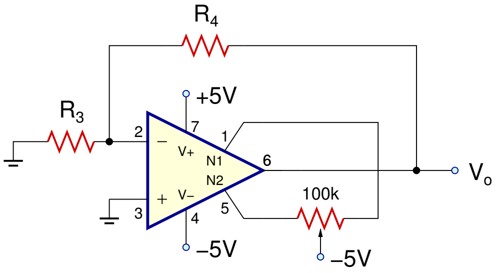

Figure 4: Compensation of offset voltage

Inverting and Non-inverting Configurations

Build the circuits in Fig. 1 with the simulated component values. Perform the following measurements for each circuit:

1. Obtain the magnitude and phase **Bode plots** of the transfer function using the **network** analyzer, and measure the gain at 1kHz.
2. Apply the input $V_i(t) = 0.2\sin(2\pi 1000t)$ and obtain the **time-domain waveforms** for the input and the output voltages using the **scope**. Measure the magnitudes of the input and the output voltages, and find the resulting gain.
3. Starting with 0.2V at 1kHz, increase the input sine wave amplitude by small increments and measure the maximum value of the input amplitude $V_{i,max}$ before clipping occurs at the output.
4. Apply the input $V_i(t) = V_{i,max}\sin(2\pi 1000t)$ and measure the **total harmonic distortion (THD)** on the output voltage using the **spectrum** analyzer.

Report

1. Tabulate all of the Opamp parameters measured in the lab. Look up the same parameters on the data sheet for the 741 Opamp. Calculate and list the differences between your measurement and specified values given by the manufacturer.
2. Include all measurement plots.
3. Prepare a table showing calculated, simulated and measured results.
4. 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 inverting amplifier in Fig. 1(a) and the non-inverting amplifier in Fig. 1(b):
   - Show the frequency response using the **network** analyzer.
4. For the buffer in Fig. 1(c):
   - Show the frequency response using the **network** analyzer.
   - Measure the time-domain output voltage for 0.2V 1kHz sine wave input using the **scope**.
   - Measure the THD at the output voltage at 1kHz just before clipping (when $V_{i,max}$ is applied) using the **spectrum** analyzer.
5. For the offset voltage measurement circuit in Fig. 3:
   - Measure the input offset voltage.
   - Compensate the offset by adding the potentiometer to the same circuit.