2CJ4 – Lab 1 – Set 1 – Operational Amplifiers

Thursday, January 30th, 2025

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Introduction:

This lab is all about understanding how to use operational amplifiers (op-amps) and how they work by analyze an inverting amplifier. In this lab we observe how the op-amp operates in its linear region, where the output follows the expected gain, and in saturation, where the output clips at the power supply limits. We utilize out AD3's to gather experimental data to compare against theoretical calculations.

This lab is very important as op-amps are electronic components used in signal amplification, filtering, and math operations. Op-amps have many real world applications in things such as audio systems, sensor circuits, and much more.

Operational principle of the experimental circuit:

As previously mentioned, this lab uses an inverting amplifier, meaning the circuit produces an output voltage that which is opposite to the phase of the input voltage. It uses negative feedback through R2 to stabilize the gain, which is given by Vo/Vi, or -R2/R1.

Ideal op-amps have infinite gain, so the inverting inputs voltage is equal to the non-inverting input, which is connected to ground. The input current flows through R1, then through R2 to the output, which produces an amplified and inverted voltage. If the output is greater than the supply limits, the op amp saturates, clipping the output at the max or min voltage.

Measurement Results:

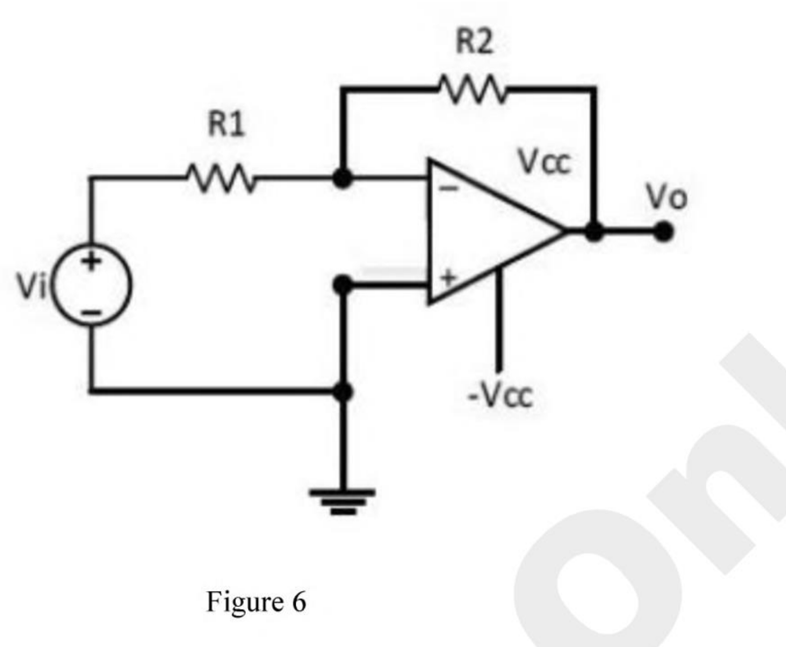

Figure 6

Given the circuit in Figure 6 with R_1 = 1OkΩ, R_2 = 47kΩ, $+V_{cc}$ 5 and $-V_{cc}$ = - 5 V, express the gain $A = \frac{V_0}{V_i}$ as a function of R_1 and R_2 and determine the linear active region and saturation region.

$V+ = V- = 0$

$I+ = I- = 0$

$\underline{KCL\ at\ V_o}$:

$$\frac{0 - V_i}{R_1} + \frac{0 - V_o}{R_2} = 0$$

$$\frac{V_o}{R_2} = \frac{-V_i}{R_1}$$

<u>Gain:</u>

$$A = \frac{V_0}{V_i} = -\frac{R_2}{R_1} = -\frac{47k\Omega}{10k\Omega} = -4.7$$

<u>Linear active region:</u>

$$-V_{cc} < V_o < +V_{cc}$$

$$-V_{cc} < A * V_i < +V_{cc}$$

$$\frac{-V_{cc}}{A} < V_i < +\frac{V_{cc}}{A}$$

$$\frac{-50}{47} < V_i < +\frac{50}{47}$$

Therefore, the linear active region is when $\frac{-50}{47} < V_i < \frac{50}{47}$. The saturation region is anything outside of this region, so when $V_i \le \frac{-50}{47}$ $(V_o = -5V)$ or $V_i \ge \frac{50}{47}$ $(V_o = 5V)$.

i. **Build the circuit with the values given and with V_i being a 1 kHz square wave with amplitudes of 200 mV, 2V, and 5V and an offset of 0V, where you should only observe the peak-to-peak magnitude. Plot V_i and V_o using the oscilloscope tool on the Analog Discovery 2 in the linear active region and saturation region.**

200mV:

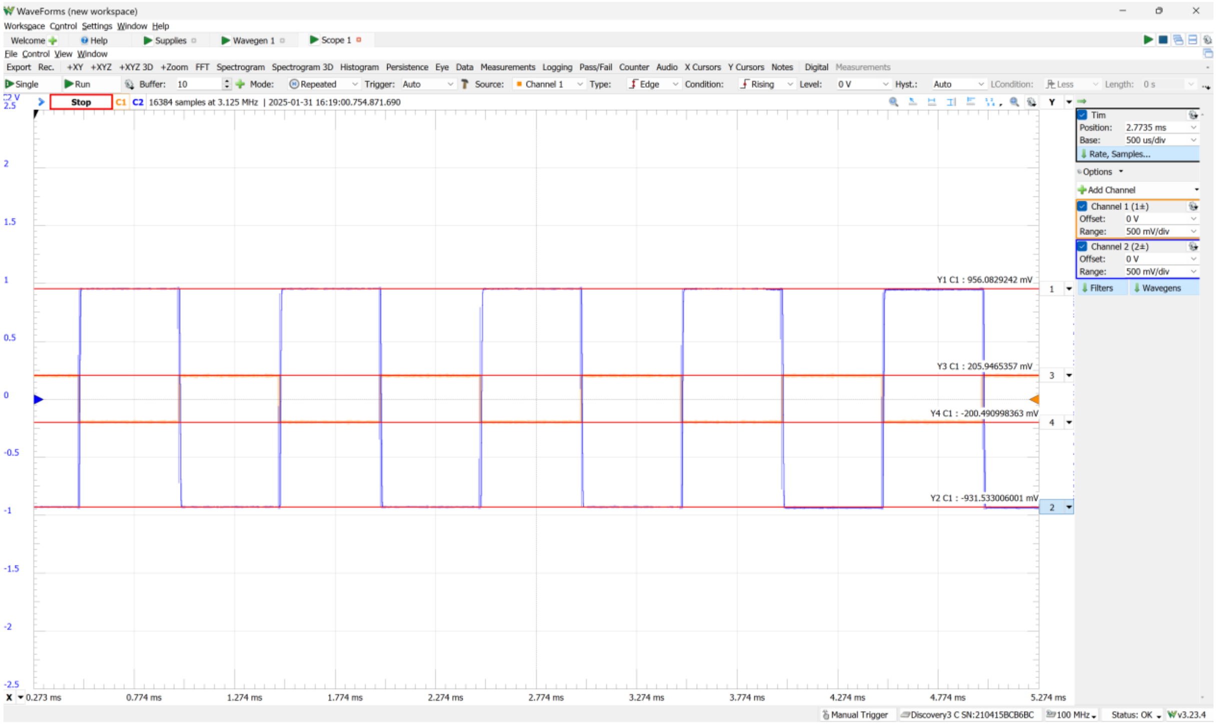

Figure 1: Vi and Vo with 200mV amplitude - With cursors

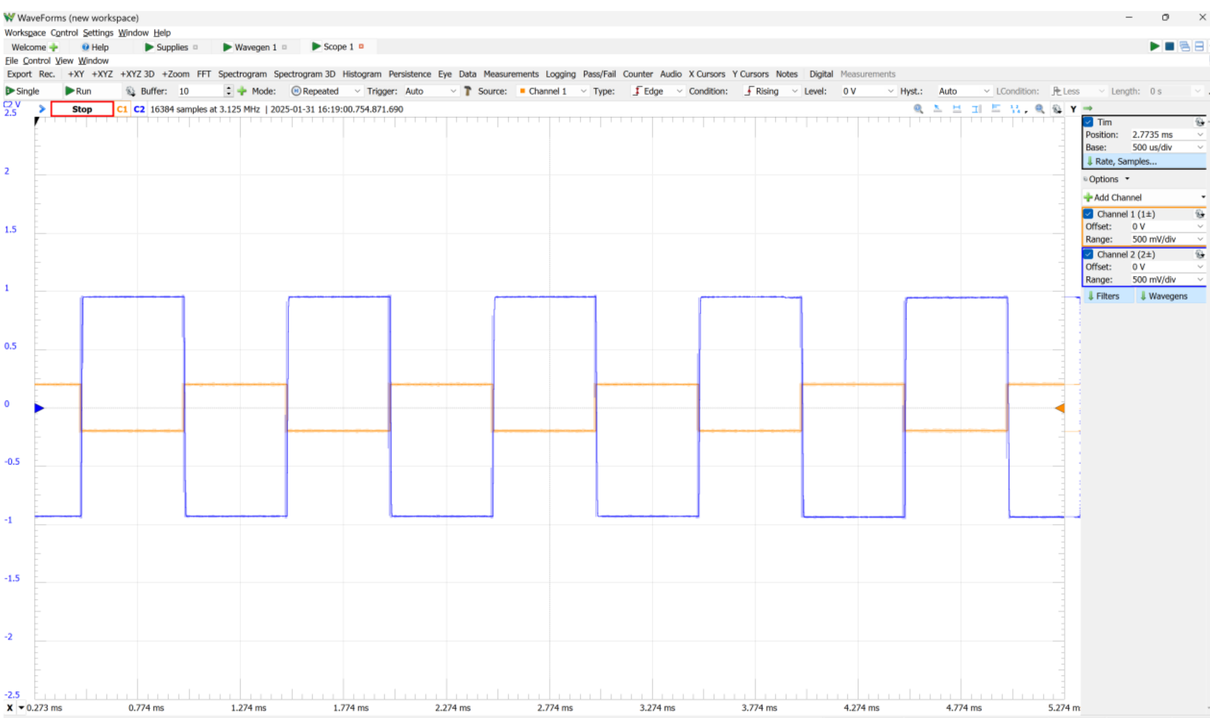

Figure 2: Vi and Vo with 200mV amplitude - No cursors

2V:

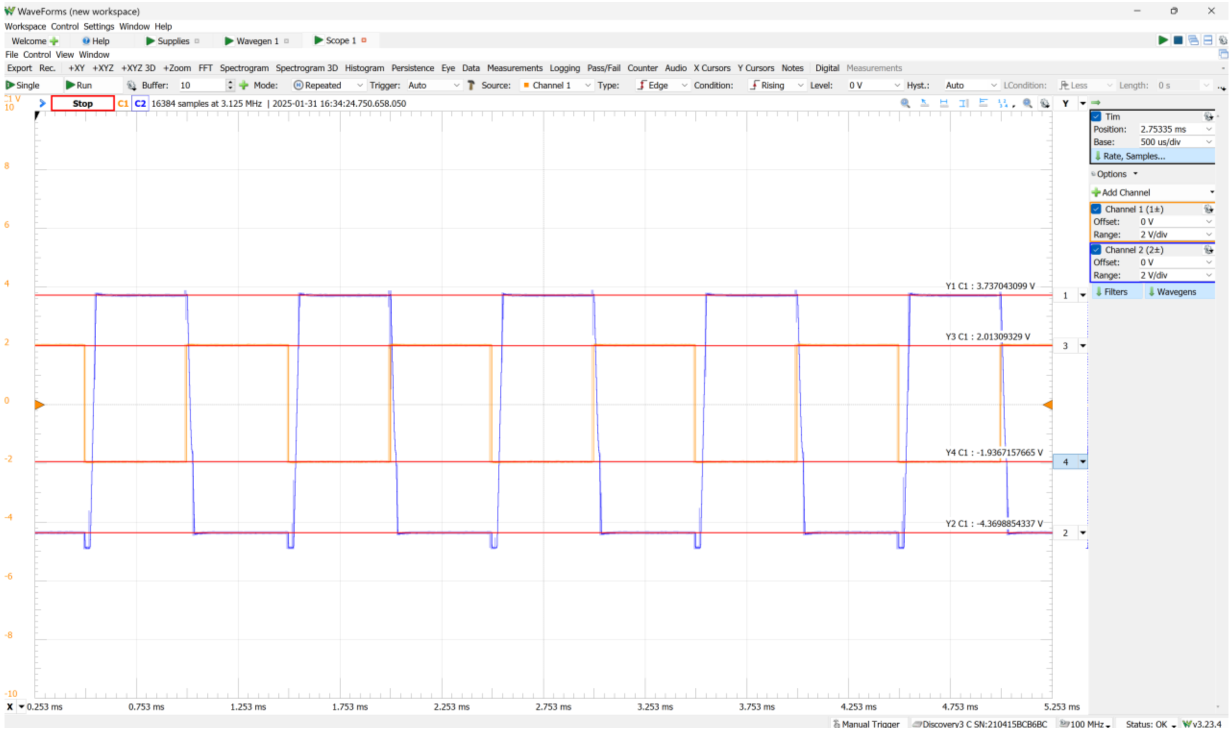

Figure 3: Vi and Vo with 2V amplitude - With cursors

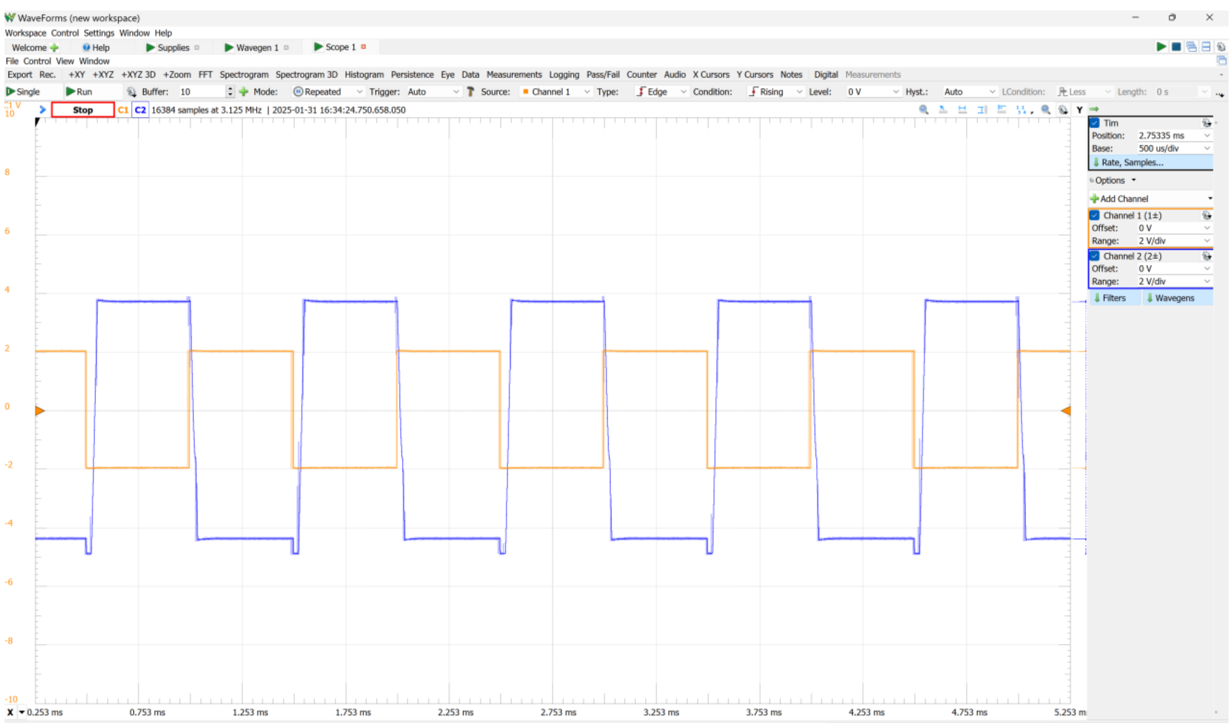

Figure 4: Vi and Vo with 2V amplitude - No cursors

5V:

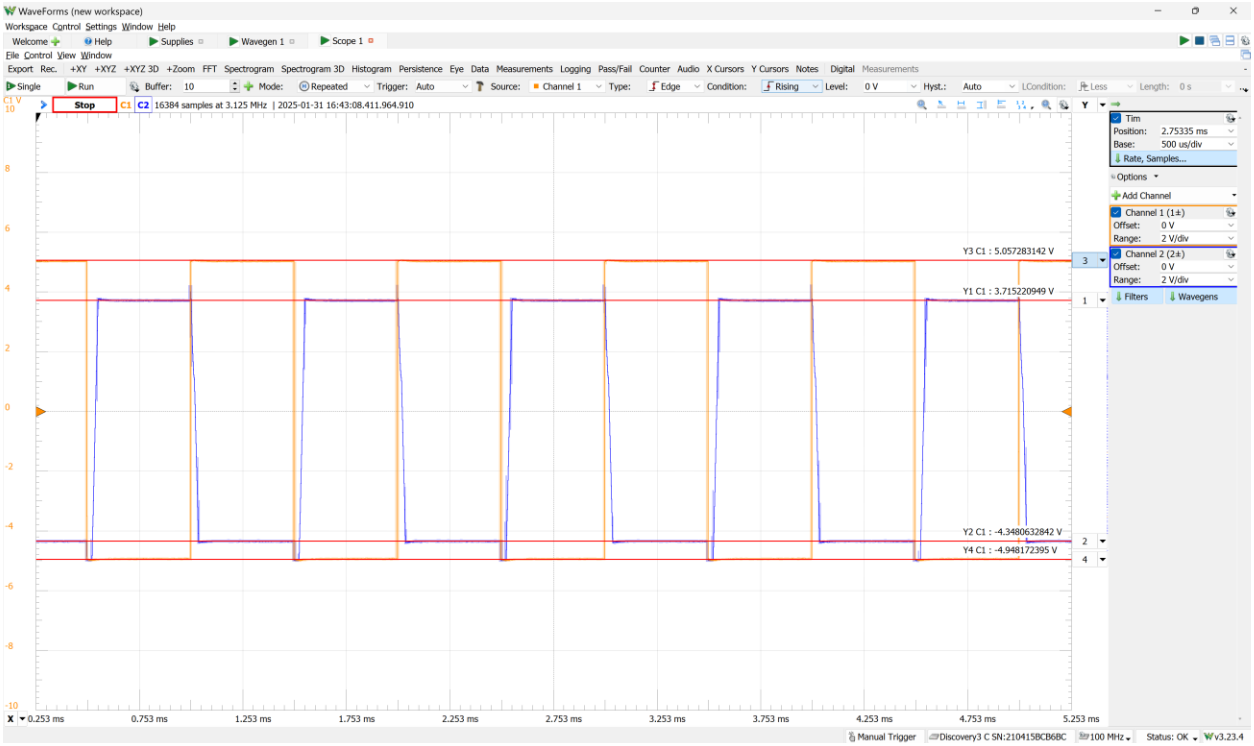

Figure 5: Vi and Vo with 5V amplitude - With cursors

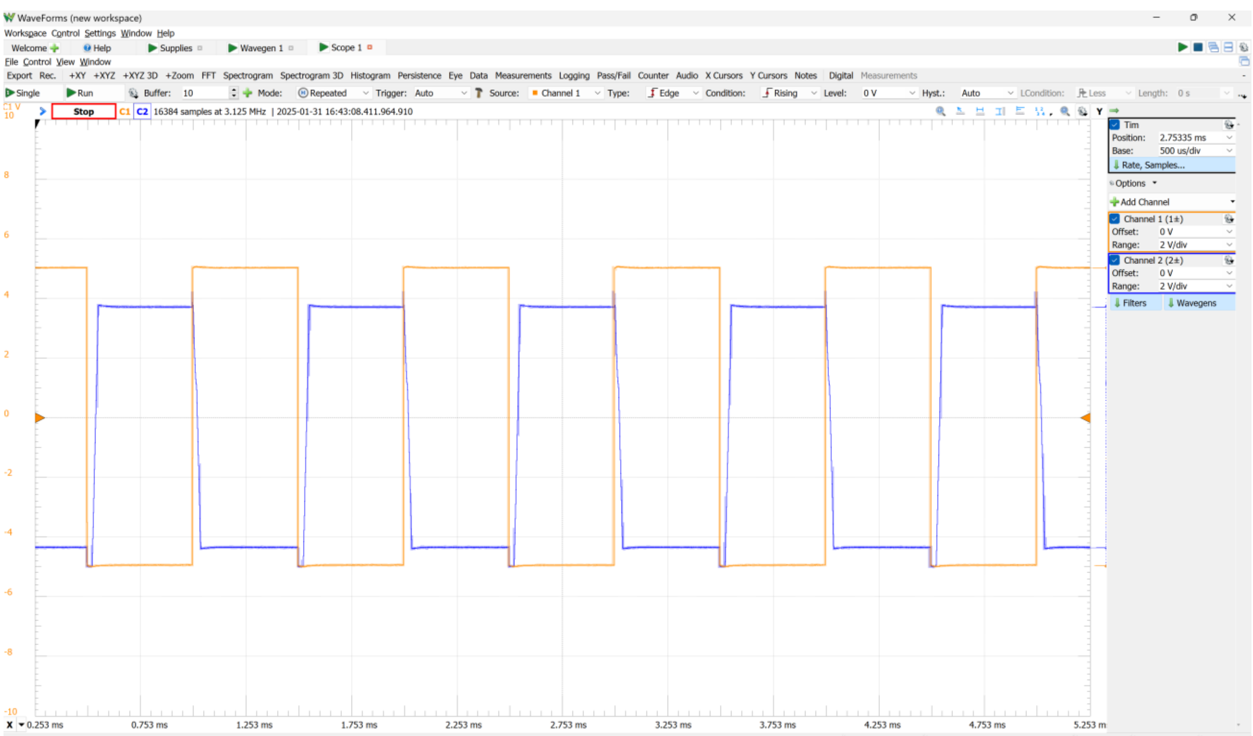

Figure 6: Vi and Vo with 5V amplitude - No cursors

ii. **Using the circuit from part i, estimate the gain using the Analog Discovery 2. Compare your analytical results with your experimental measures.**

<u>200mv:</u>

Theoretical: $A_V = 4.7$

Experimental: $A_V = \frac{V_o}{V_i} = \frac{0.945+0.934}{0.206+0.198} = 4.65$

<u>2V:</u>

Theoretical (accounting for saturation): $A_V = \frac{5}{2} = 2.5$

Experimental: $A_V = \frac{V_o}{V_i} = \frac{3.74+4.37}{2.01+1.94} = 2.05$

<u>5V:</u>

Theoretical (accounting for saturation): $A_V = \frac{5}{5} = 1$

Experimental: $A_V = \frac{V_o}{V_i} = \frac{3.72+4.35}{5.06+4.95} = 0.806$

The experimental and theoretical values for gain slightly differ. The experimental values are close to the theoretical values but are slightly smaller for all the tested amplitudes. This is likely due to slight imperfections in the resistors or the fact we are using a non-ideal operational amplifier.

iii. **Repeat parts i-ii for the following values: $+V_{cc} = 2.5V$, $-V_{cc} = -2.5V$. Does the gain change? Explain.**

200mV:

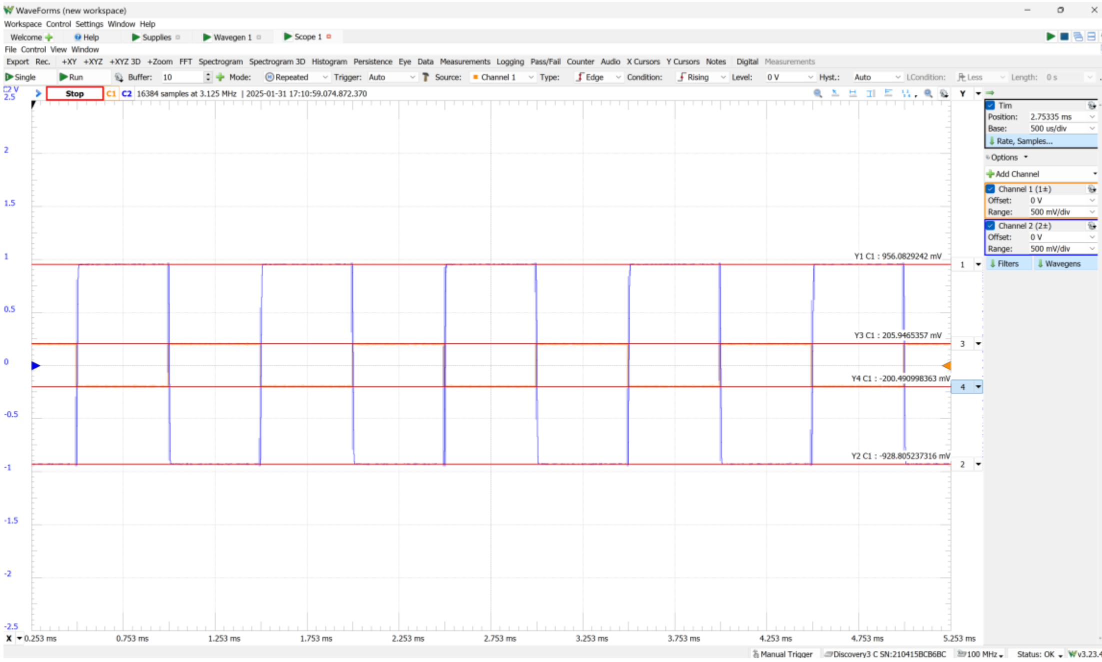

Figure 7: Vi and Vo with 200mV amplitude - With cursors (2.5Vcc)

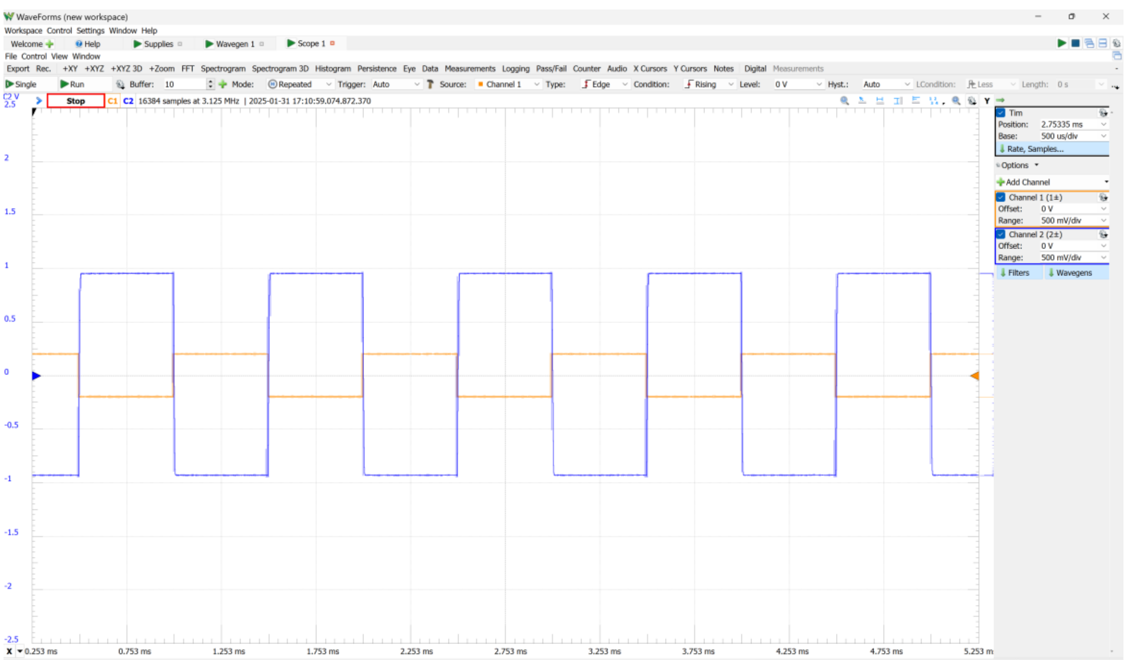

Figure 8: Vi and Vo with 200mV amplitude - No cursors (2.5Vcc)

Theoretical: $A_V = 4.7$

Experimental: $A_V = \frac{V_o}{V_i} = \frac{0.956+0.923}{0.206+0.200} = 4.63$

2V:

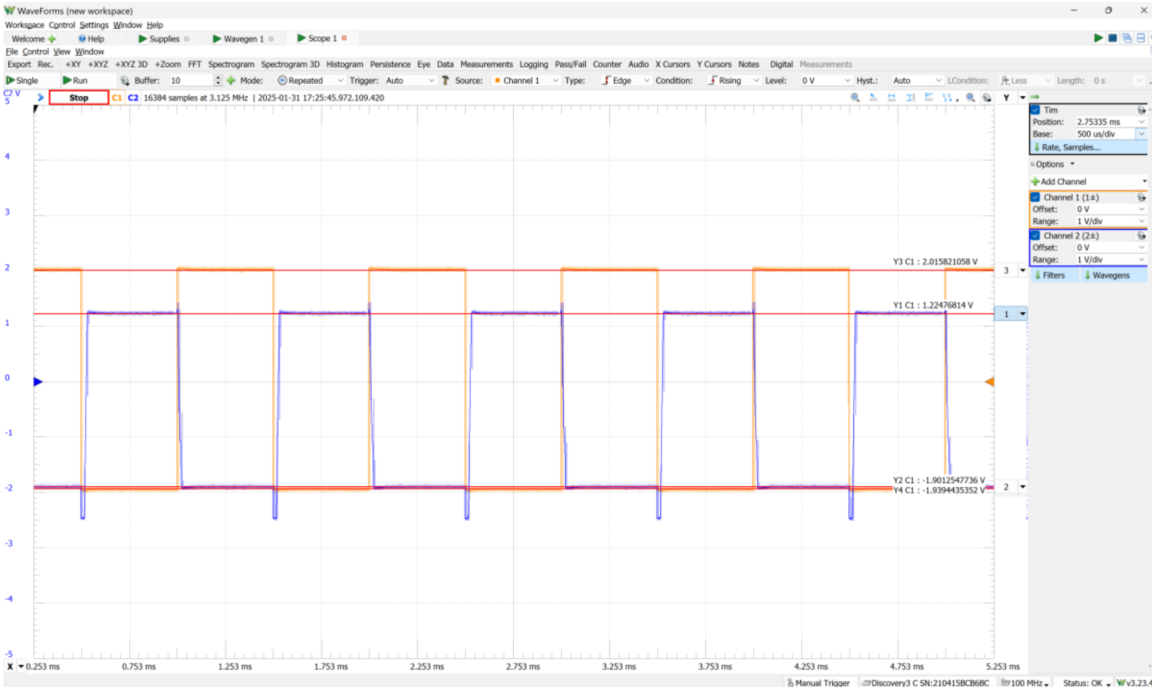

Figure 9: Vi and Vo with 2V amplitude - With cursors (2.5Vcc)

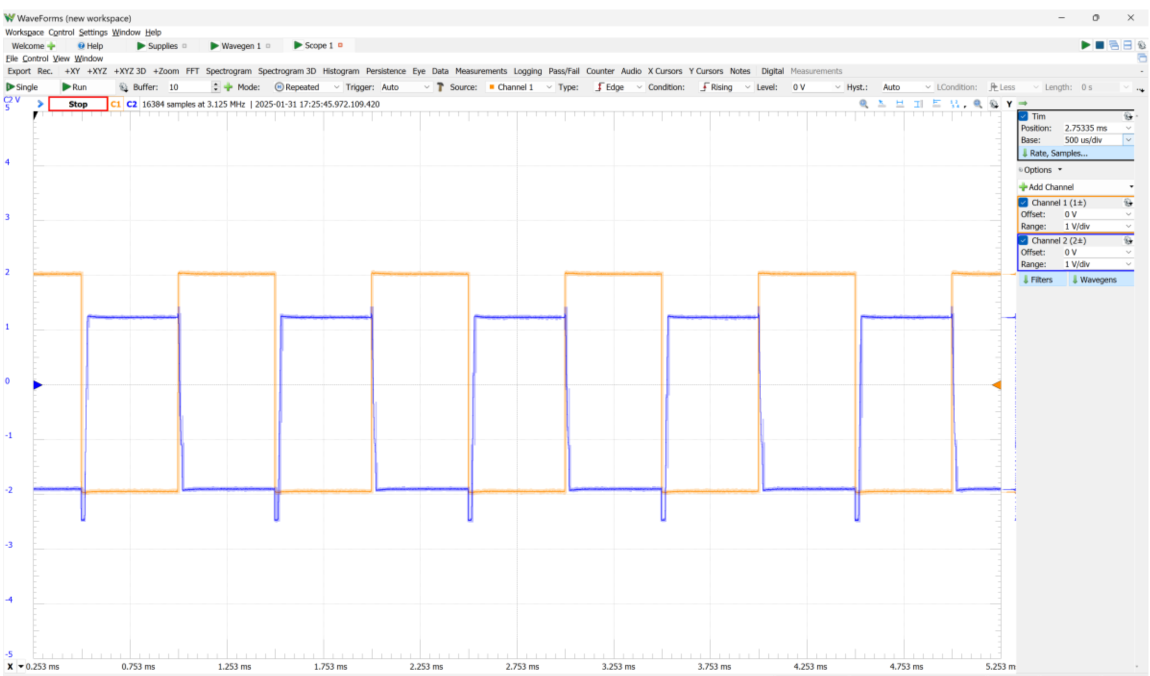

Figure 10: Vi and Vo with 2V amplitude - No cursors (2.5Vcc)

Theoretical (accounting for saturation): $A_V = \frac{2.5}{2} = 1.25$

Experimental: $A_V = \frac{V_o}{V_i} = \frac{1.22+1.90}{2.02+1.94} = 0.788$

5V:

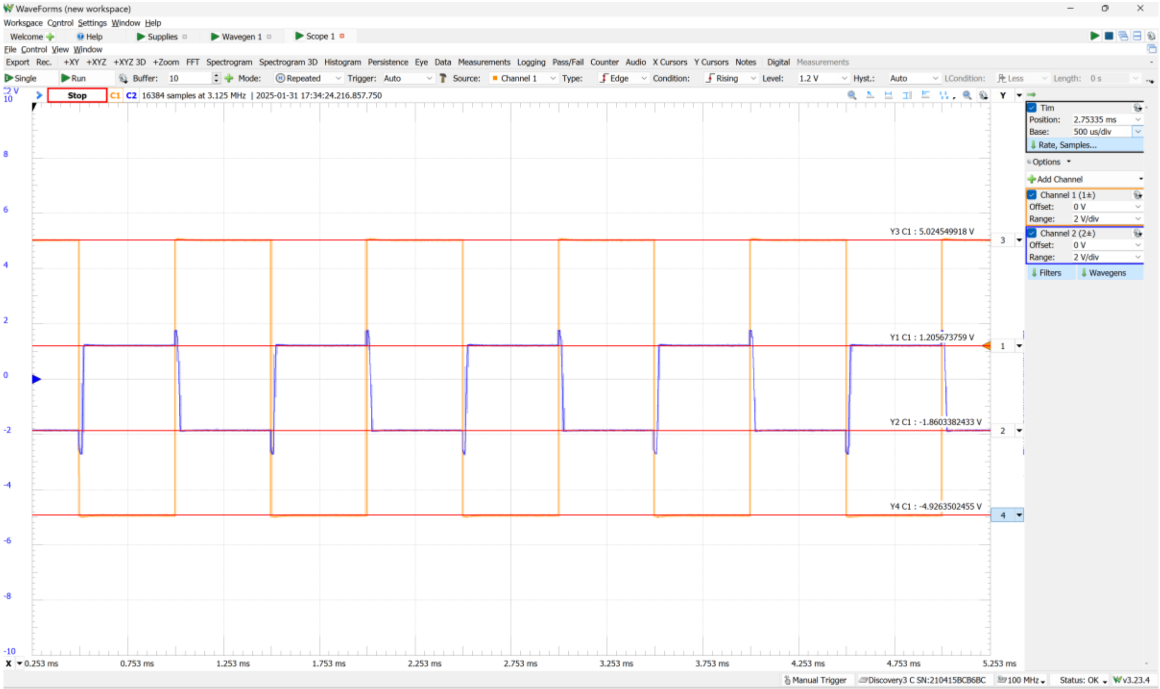

Figure 11: Vi and Vo with 5V amplitude - With cursors (2.5Vcc)

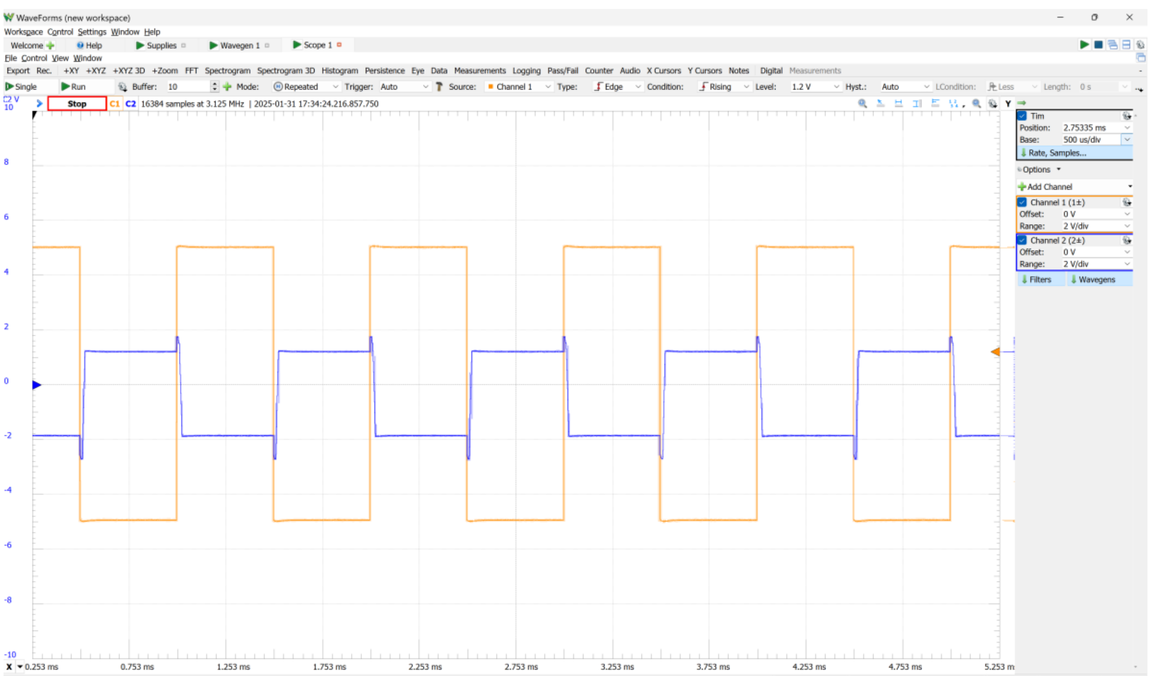

Figure 12: Vi and Vo with 5V amplitude - No cursors (2.5Vcc)

Theoretical (accounting for saturation): $A_V = \frac{2.5}{5} = 0.5$

Experimental: $A_V = \frac{V_o}{V_i} = \frac{1.21+1.86}{5.02+4.93} = 0.309$

Once again, the experimental values for gain are comparable to the theoretical values but are all slightly smaller (same as in parts i and ii). Making $+V_{cc} = 2.5V, -V_{cc} = -2.5V$ affected the gain by making the linear region smaller. Therefore, V_i has a smaller range that can produce the full increase of V_o.

Discussion:

This experiment focused on understanding how Op-Amps work, specifically in its linear region. Our goal was to compare the theoretical gain with the actual gain measured in the lab and observe the Op-Amp's behavior when it reaches saturation.

Our results show that the experimental values obtained were consistent and comparable to our calculated theoretical values. Small differences between these values were most likely caused by component tolerances and measurement errors. In addition, these results support the practical behavior of op-amps in both the linear and saturation region. As predicted by theory, in the linear region, the output voltage followed the input voltage. In the saturation region, the output voltage clipped at the max voltage.

The lab went smoothly, but one challenge we faced was accurately measuring the input and output voltages, especially when the Op-Amp entered saturation. Capturing these generated waveforms required constant adjustment of the oscilloscope setting. For example, if the settings were off, the waveforms would appear distorted or even incomplete, making it difficult to analyze the data.