ELECENG 2CJ4

Lab 1 Report

Basic Properties of Op-Amp Circuits

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1. Introduction

An Operational Amplifier (Op-amp) is a three-terminal (two inputs and one output) voltage amplifying device. Due to their high versatility and efficiency, they have become fundamental components in modern electronic circuits, important enough to be considered one of their building blocks.

It is reasonable to seek to understand before putting it into practice. With the aim of understanding the operational amplifier, a series of experiments were carried out, and the results were documented. This report summarises the findings from these experiments, focusing on analyses of the basic properties of the operational amplifier, understanding its behaviours, performing gain calculations, and discovering the limitations observed under different conditions.

2. Operational Principle of the experiment

Theoretical calculation of Gain:

Using the following ideal op-amp assumptions:

a. $i_+ = i_- = 0$
b. $v_+ = v_-$

Since v_+ is connected directly to the ground: $v_+ = v_- = 0$

Applying KCL at V_- node:

$$\frac{v_- - v_i}{R_1} + \frac{v_- - v_o}{R_2} = 0$$

$$\frac{0 - v_i}{R_1} + \frac{0 - v_o}{R_2} = 0$$

$$\left(\frac{-v_i}{R_1} + \frac{-v_o}{R_2} = 0\right) \times R_1 R_2$$

$$-R_2 v_i - R_1 v_o = 0$$

$$-R_2 v_i = R_1 v_o$$

$$\frac{v_o}{v_i} = -\frac{R_2}{R_1}$$

$$\therefore \boldsymbol{Gain} = -\frac{\mathbf{47k}}{\mathbf{10k}} = \mathbf{-4.7}$$

The gain is negative because the op-amp is configured as an inverting amplifier.

Linear Active and Saturation Region:

The input voltage range (for the linear active region) is given by:

$$V_{EE} < V_o < V_{cc}$$

$$V_{EE} < A_o(V_+ - V_-) < V_{cc}$$

$$\frac{V_{EE}}{A_o} < V_+ - V_- < \frac{V_{cc}}{A_o}$$

$$\frac{-5}{-4.7} < V_+ - V_- < \frac{+5}{-4.7}$$

$$1.064 > V_{in} > -1.064$$

If $V_{in} < 1.064$ then $V_o = -5\ V$ and if $V_{in} > -1.064$ then $V_o = 5\ V$ (saturation region).

3. Measurement results

i. Graphs for $V_{cc} = 5V, V_{EE} = -5V$

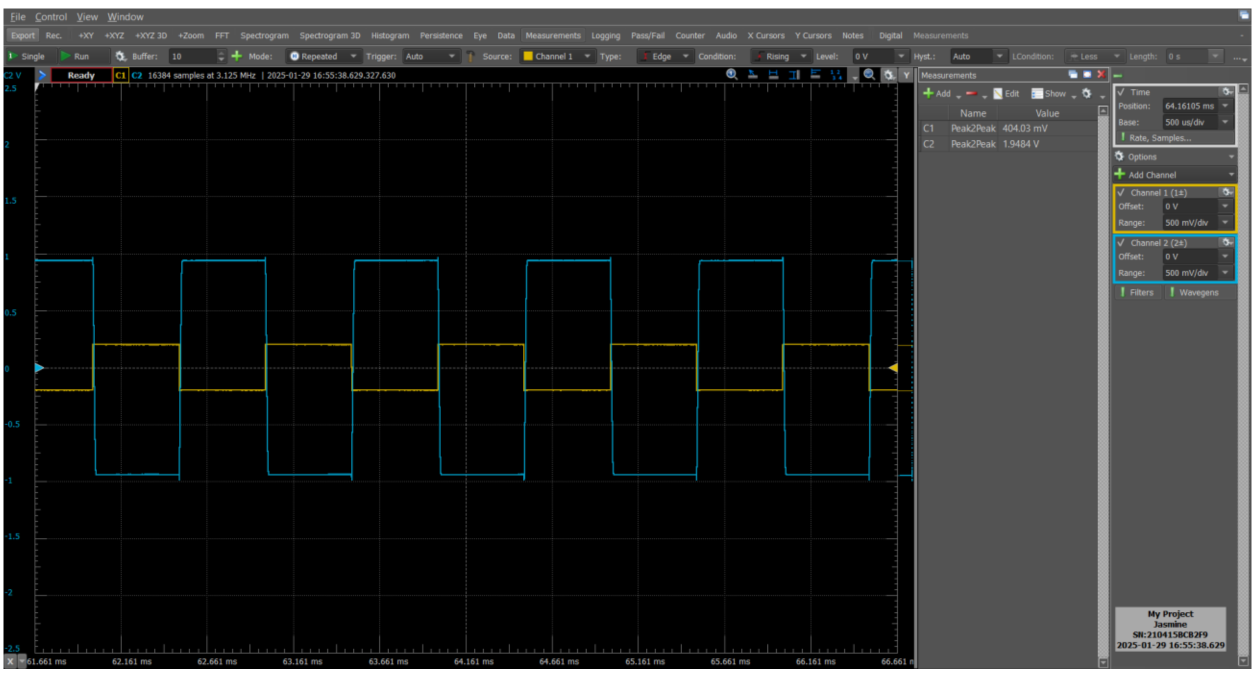

Figure 1. Vi = 200 mV

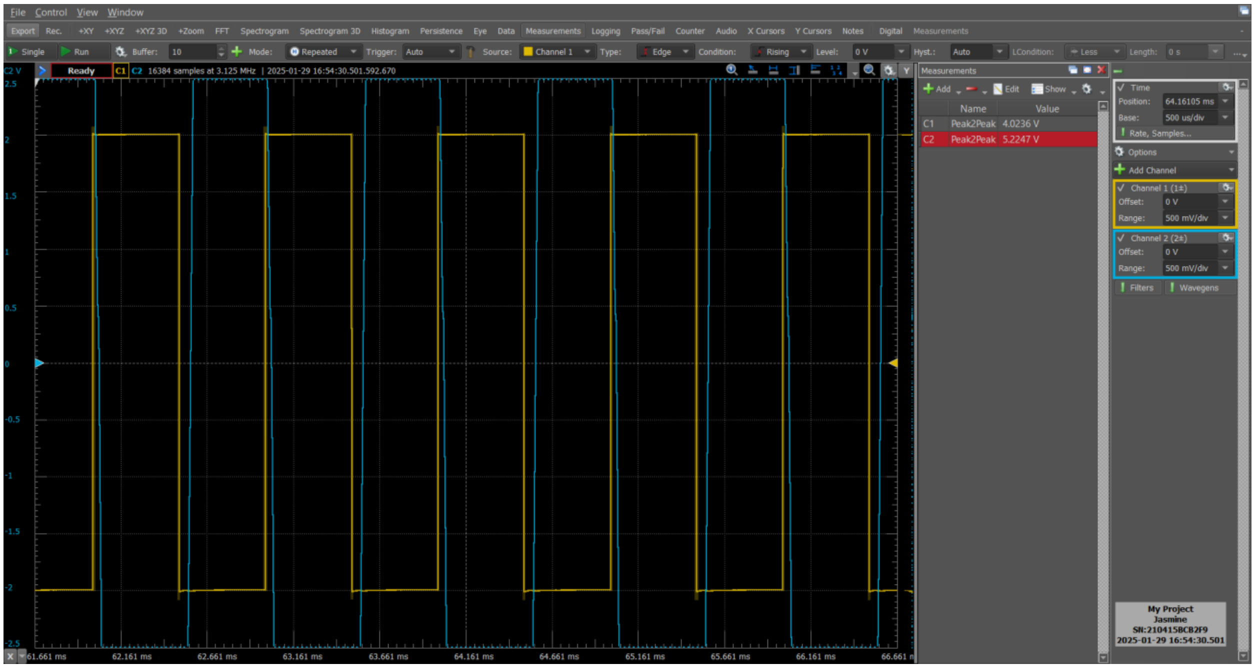

Figure 2. Vi = 2 V

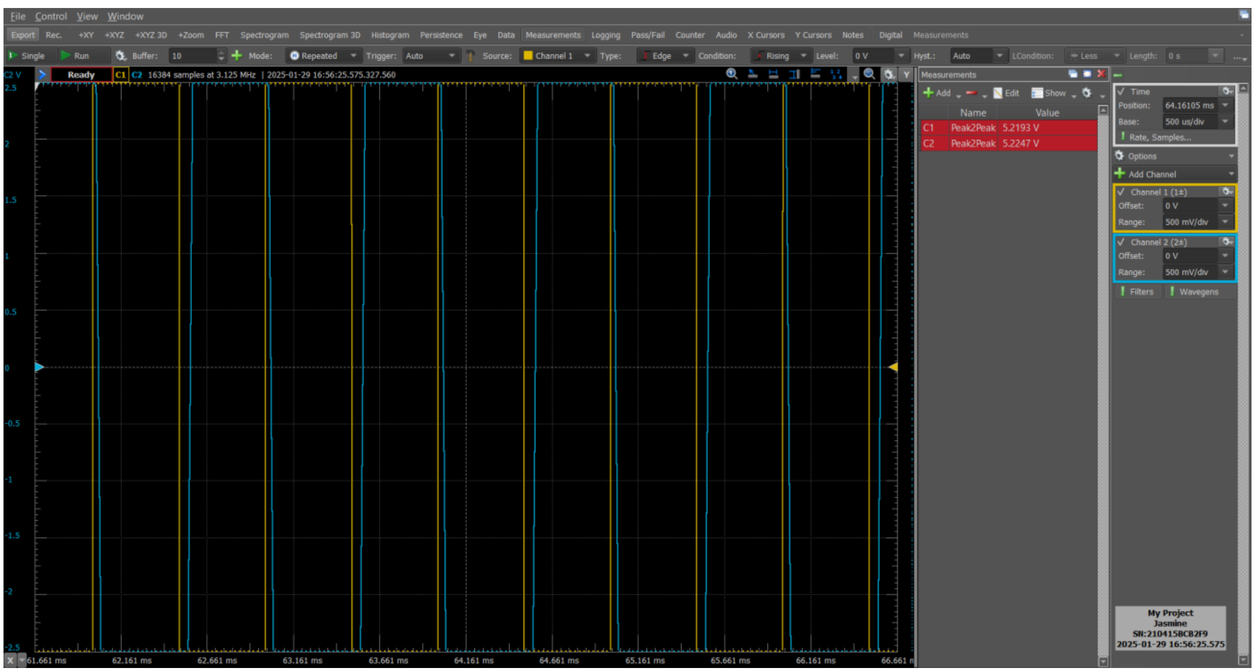

Figure 3. Vi = 5 V

Graphs for $V_{cc} = 2.5V, V_{EE} = -2.5V$

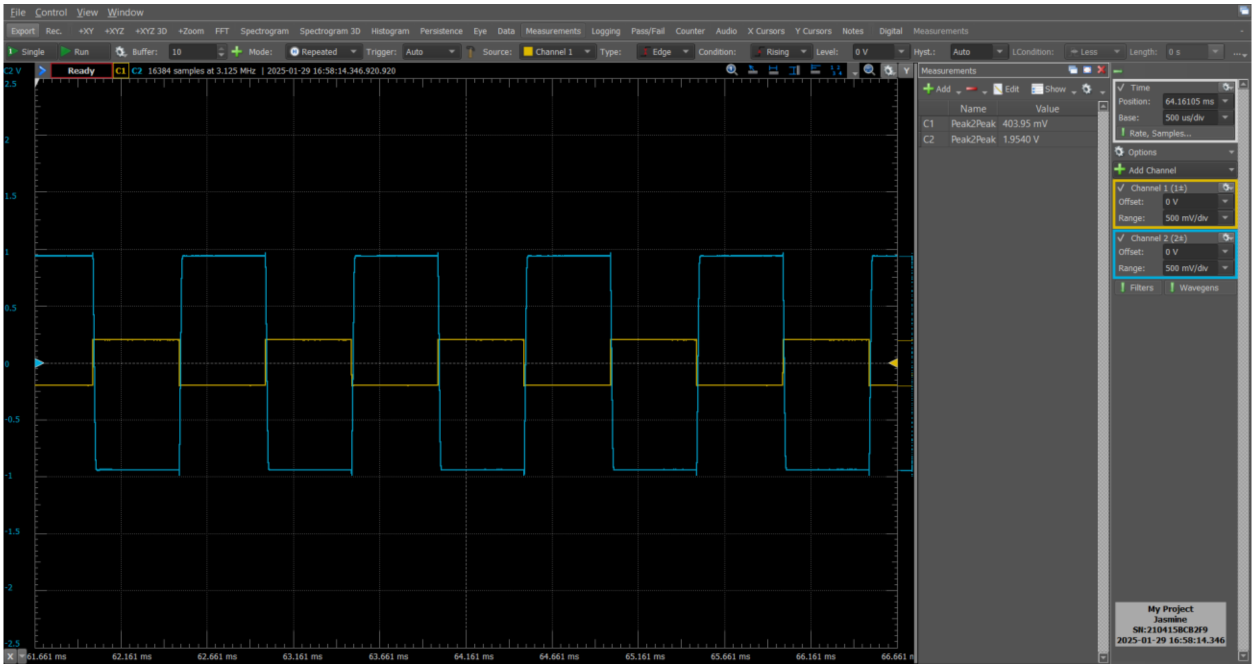

Figure 4. Vi = 200 mV

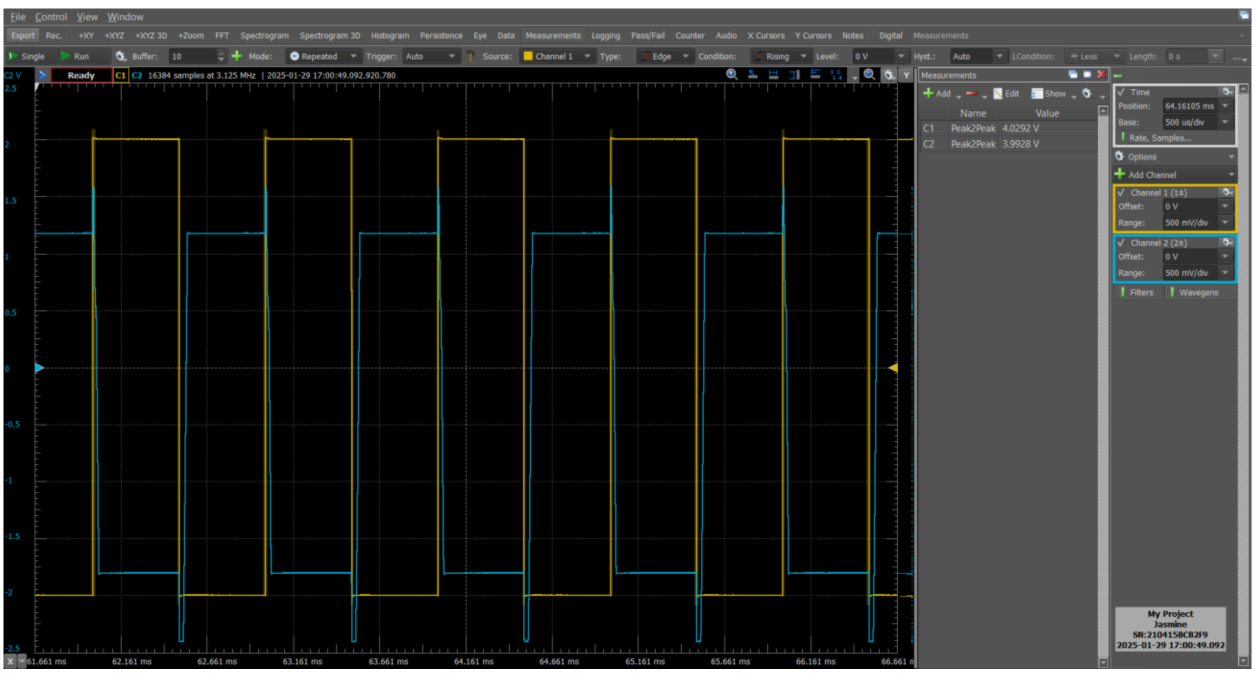

Figure 5. Vi = 2 V

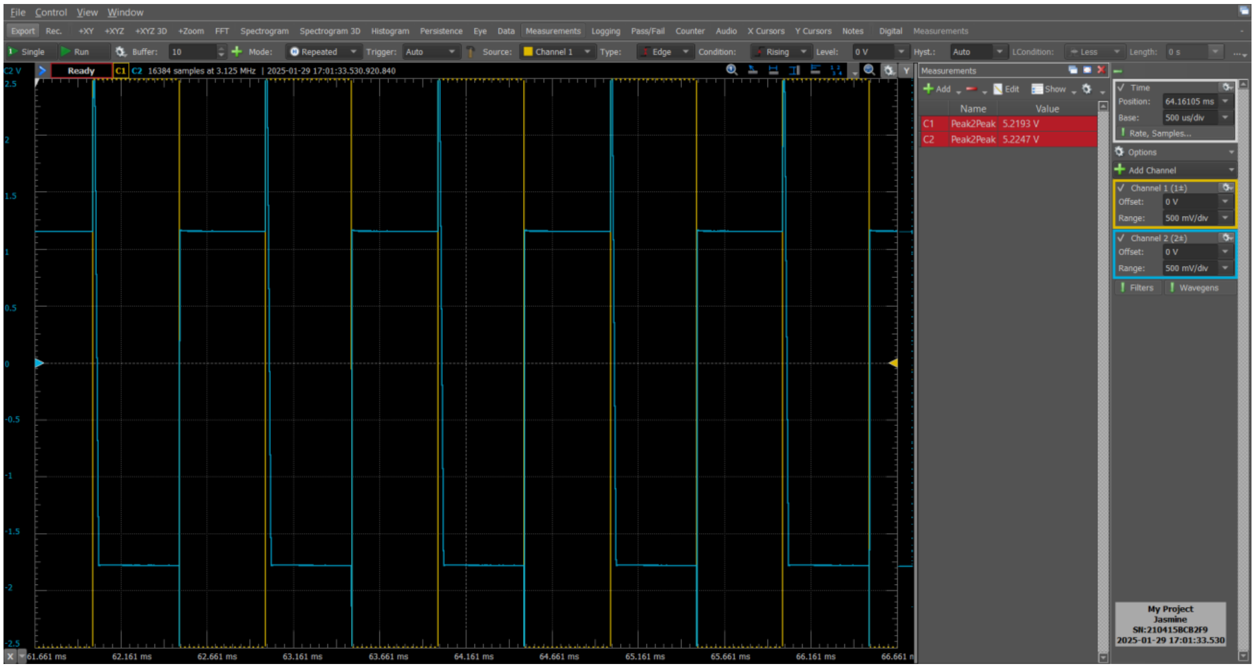

Figure 6. Vi = 5 V

i. Experimental Gain Calculation for $V_{cc} = 5V, V_{EE} = -5V$

$$Gain_{200mV} = \frac{V_o}{V_i} = \frac{1.9548\ V}{403.63\ mV} = 4.843$$

$$Gain_{2V} = \frac{V_o}{V_i} = \frac{5.2247\ V}{4.0154\ V} = 1.3012$$

$$Gain_{5V} = \frac{V_o}{V_i} = \frac{5.2247\ V}{5.2193\ V} = 1.001$$

Our theoretical results yielded a gain of 4.7. However, our experimental results show that as the input voltage increased, the output voltage reached a saturation value of 5.2247. This reduced the output-to-input ratio, thereby decreasing the gain.

ii. Experimental Gain Calculation for $V_{cc} = 2.5V, V_{EE} = -2.5V$

$$Gain_{200mV} = \frac{V_o}{V_i} = \frac{1.8994\ V}{403.79\ mV} = 4.6906$$

$$Gain_{2V} = \frac{V_o}{V_i} = \frac{3.9848\ V}{4.0175\ V} = 0.9919$$

$$Gain_{5V} = \frac{V_o}{V_i} = \frac{4.9321\ V}{5.2193\ V} = 0.9450$$

When the voltage supplies are reduced from ± 5V to ± 2.5V, the gain slightly decreases. This occurs because the lower supply voltages cause the output voltage to reach saturation earlier (at ± 2.5V instead of ± 5V). As a result, the output-to-input ratio decreases, leading to a further reduction in gain.

4. Discussion

After performing the experiments and documenting their results, it was found that the experimental results obtained strongly aligned with the expectations derived from theoretical knowledge.

The circuit had its operational amplifier inverted; as such, it was expected the amplified output signal to be negative relative to the original signal. This prediction was confirmed as the output signal was out of phase relative to the original by 180 degrees, aligning with earlier expectations.

In the experiments with a supply voltage of ±5V, the output signal showed an expected gain that aligned with theoretical expectations, and it reached saturation at the expected moments.

While the results closely matched expectations, they also had minor deviations as it was a real-world non-ideal component, unlike results in theoretical calculations.

An important observation was the effect of the supply voltage on the operational amplifier's performance. As the supply voltage was reduced from ± 5V to ± 2.5V, the gain decreased slightly, mainly due to the output signals reaching saturation earlier. It aligns with theoretical knowledge as the operational amplifier operates within a linear region where the output signal is bounded by the supply voltages, limiting amplification. The gains would have aligned better and remained at a roughly constant value if the input signals contained only values five times below the supply voltages, as the output signal will be expected to always stay within the linear region.

The experiment results highlight the limitations of operational amplifiers in practical settings and demonstrate their non-ideal behaviours. However, it also reinforces the understanding of the fundamental properties of op-amp circuits and their significance in electronics.