International University

School of Electrical Engineering

Principle of EE1 Laboratory

EE052IU

Lab 4

Operational Amplifiers

Submitted by

Student A	Student B
Full name: Nguyễn Đình Ngọc Huy	Full name: Trần Thuận Thành
Student number: EEEEIU22020	Student number: EEEEIU22069

Date Submitted:	[13/12/2023]
Date Performed:	[7/12/2023]
Lab Section:	[4]
Course Instructor:	[M.Eng Nguyen Minh Thien]

GRADING GUIDELINE FOR LAB REPORT

Number	Content		Score	Comment
1	**Format (max 9%)**			
	- Font type	Yes No		
	- Font size	Yes No		
	- Lab title	Yes No		
	- Page number	Yes No		
	- Table of contents	Yes No		
	- Header/Footer	Yes No		
	- List of figures (if exists)	Yes No		
	- List of tables (if exists)	Yes No		
	- Lab report structure	Yes No		
2	**English Grammar and Spelling (max 6%)**			
	- Grammar	Yes No		
	- Spelling	Yes No		
3	**Data and Result Analysis (max 85%)**			
Total Score				

Signature:

Date:

Table of Contents

List of Figures

List of Tables

Nomenclature

V_{DD} = DC Voltage Source

V_{dd} = AC Volatge Source

I_{ref} = Reference Current

Etc.

Theoretical Background

1. Op-Amp Terminal Characteristics

The Fig. 1 illustrates a 741 Op-Amp. It has two input terminals where the input voltage Vi is measured. These terminals are known as inverting (Vn) and non-inverting (Vp), leading to Vi=(Vp-Vn). The output, Vo, is measured against the ground. Extra terminals like V+ or +Vcc, V- or -Vcc, serve purposes like bias and offset.

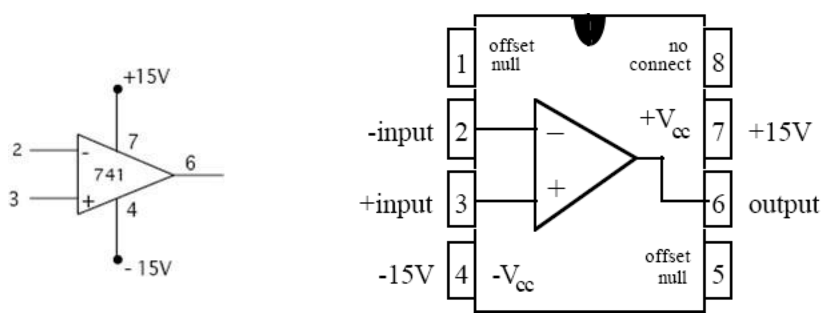

Fig.1. Pinout for the 741 Op-Amps

The operational amplifier's realistic model, as per your textbook and depicted with equivalent symbols, includes distinct input and output sections. The input features an input resistance Ri across the inverting and noninverting terminals. The output involves a voltage-dependent voltage source (with voltage AvVi) in line with an output resistance Ro. It's important to note that the dependent source's proportionality relation is the sole link between the input and output.

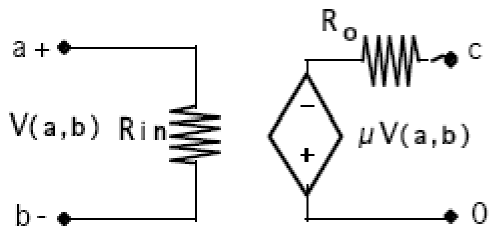

Fig. 2. An Op-am equivalent circuit.

a. **Input Voltage V_i:** $V(a,b)=V_i=(V_p-V_n)$

b. **Output Voltage V_o:** This is proportional to the input as long as it's smaller than in absolute terms of the DC bias voltages V+ and V-.

.

c. **Input Resistance R** : This resistance sits between the inverting and noninverting terminals with Vi across it. It's determined by dividing the input voltage Vi by the current entering Vp or leaving Vn.

d. **Open Loop Voltage Gain μ or A_v :** This gain is the proportionality constant in the dependent source equation where V = AvVi (or V=μV(a,b)).

e. **Output Resistance Ro:** This resistance is in series with the dependent source. If Ro isn't zero, the voltage across a load RL isn't all of V = AvVi and can be calculated by examining the voltage divider between Ro and RL.

2. Linear Operation and Saturation

Op-Amps have two regions of operation: linear and saturation. In the linear region, the voltage transfer characteristic, i.e. the mathematical relationship between the input and output voltages, is linear. This holds true when the output voltage lies in the range $V^- \leq V_o \leq V^+$

From the earlier definition of voltage gain, which is Vo = AvVi, it can be inferred that this range aligns with input voltages within a certain range. $\frac{V^-}{A_v} \leq V_i \leq \frac{V^+}{A_v}$

In this range, the output voltage is directly proportional to the input voltage, by the factor A_v.

If the input voltages fall outside this range, the Op Amp is said to be in the saturation region. In this region, its output is limited by the DC bias voltages. Specifically, the output voltage is limited to V- when Vi<V-/Av and to V+ when Vi>V+/Av. This essentially means that the output cannot exceed these voltage limits, regardless of the input.

3. Ideal Op-Amp

a. **R_i = ∞**:Based on the above definition of input resistance, an infinite input resistance implies that no current flows into or out of the input terminals of the op-amp. This simplification makes the analysis of op-amp circuits much easier.

b. **R_o = 0:** When the output resistance is zero, the entire dependent source voltage is present across the load resistance or is inputted into another device. This implies that there is no voltage drop across the op-amp output due to its output resistance, which is another useful simplification for circuit analysis.

c. **μ =Av = ∞**: : With infinite voltage gain, if the output voltage isn't saturated, the input will approach zero (Vi $\approx$ 0), assuming negative feedback exists. This creates a virtual short circuit between input terminals, simplifying calculations. If one terminal is grounded, both are at zero voltage, creating a virtual ground.

4. The Inverting Amplifier

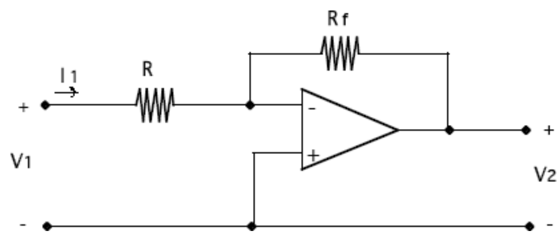

Fig. 3. An inverting amplifier

Circuit analysis of the inverting amplifier in Fig. 3 yields the equation,

$$V_2 = K\ V_1 = (-R_f/R)V_1 \quad (1)$$

Thus, the theoretical gain K of the whole stage (that is, the entire Op-Amp circuit of Fig 3.) is given by

$$K = V_2/V_1 = (-R_f/R).$$

5. The Non-Inverting Amplifier

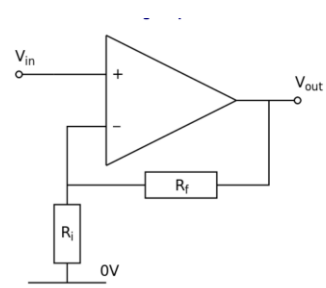

Fig. 4. A non-inverting amplifier.

Circuit analysis of the non-inverting amplifier shown in Fig. 4 yields the equation,

$$V_2 = (1+R_f/R)V_1 \quad (2)$$

Thus, the theoretical gain K of the whole stage is given by

$$K = V_2/V_1 = (1 + R_f/R).$$

6. Oscilloscope

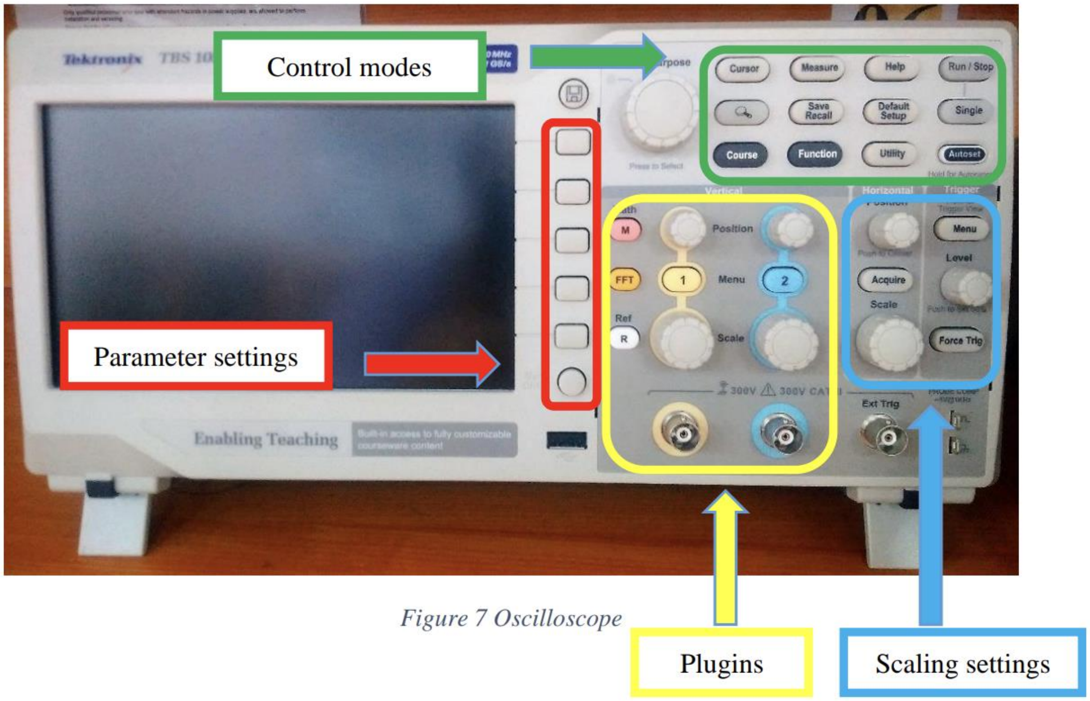

Fig. 5. Digital Oscilloscope

In this lab section, Mr.Thien, taught us a method to use the functions of this powerful machine, which will accompany EE's students for further lab.

An oscilloscope is an essential tool in electronics, primarily used to graphically display how signal voltages change over time. It allows users to measure voltage (both peak-to-peak and RMS), determine the frequency of oscillating signals, and compare the phase and delay between two signals. Additionally, it can measure the duration of pulses in digital systems and analyze signal integrity by detecting abnormalities such as noise, jitter, and other distortions. Proper use of an oscilloscope requires an understanding of voltage and time scales, trigger types, and other pertinent settings.

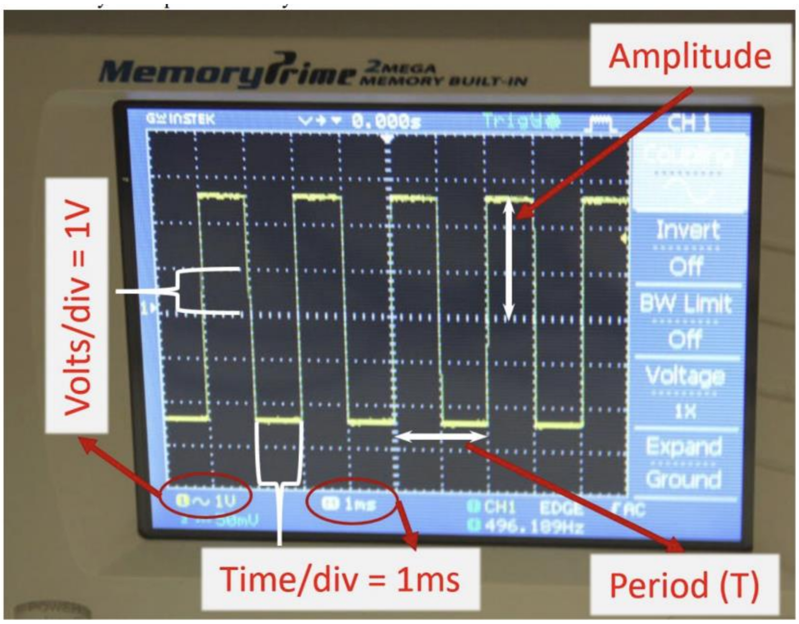

Fig. 6. Scaling on Oscilloscope

During the lab session, it's important to keep in mind several key points: verifying the functionality of the probe, configuring the scale for simplified readings of amplitude and period, as well as adjusting the cursor. Remember to engage the 10X mode on the probe and reaffirm its activation on the display.

Experimental Procedure And Results:

SET UP

Adjust the Function Generator:

Figure 7. Function Generator

Step 1: Connect the wire to the channel input (CHA/ CHB) and the other head to the lead (+) **RED** and the (-) **BLACK** of the circuit.

Step 2: Set up the Frequency to 1000 Hz, the Amplitude to 2V (peak-to-peak) and the Sine's waveform.

Step 3: Turn on the Output Trigger **GREEN** to begin generating

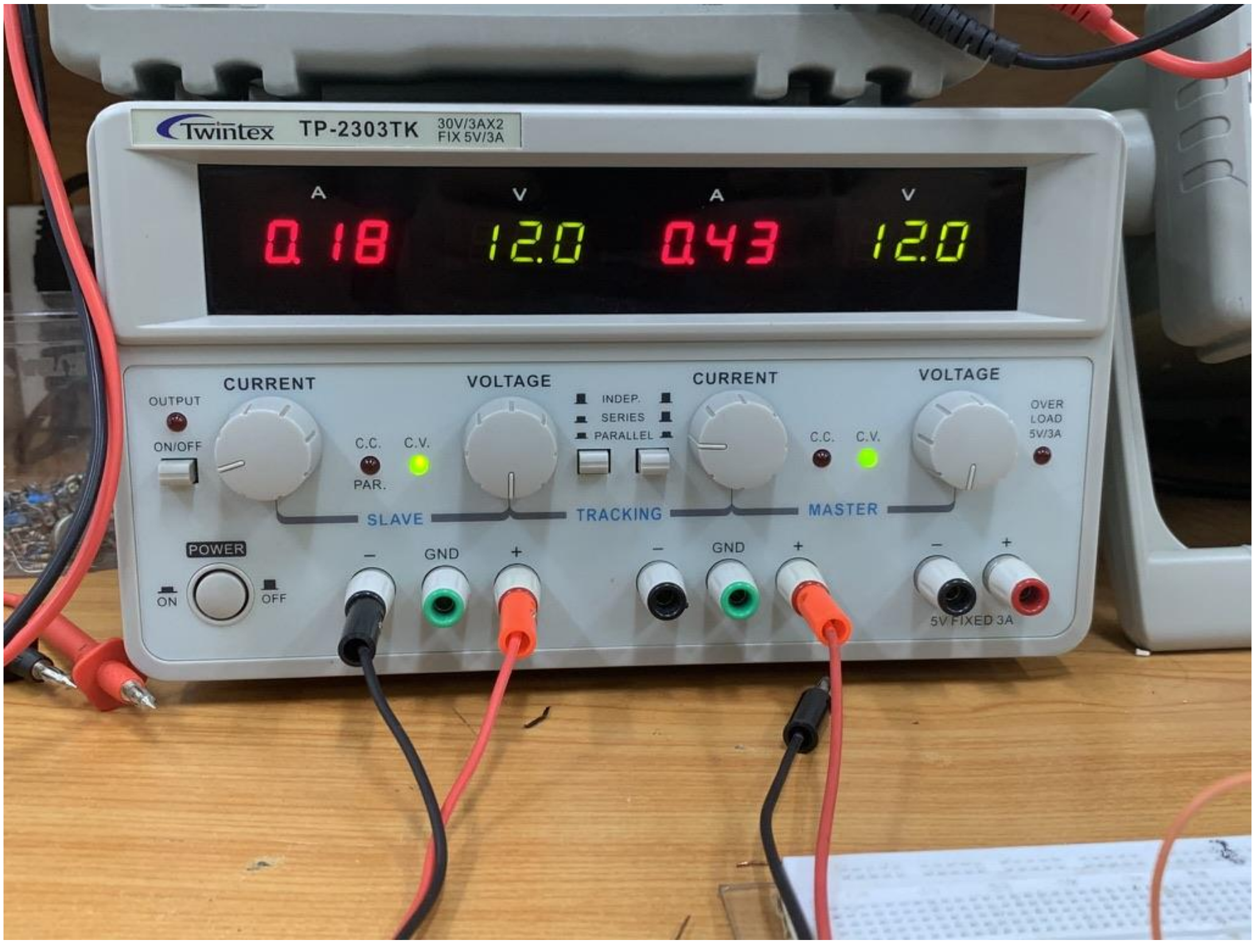

Figure 8. Dual-Channel Power Supply

Step 1: Connect two output channels to the OpAmp: The first (+) input **RED** to the port (4) to and the GND, the other (+) **RED** connect to the port (7) and the GND.

Step 2: Set up the Current to 5V and Voltage to 12V for both channels.

Step 3: Press the button "serries" and plug out one cable to make it become ground, so we have 2 output with -12V and +12V to supplied for op-amp.

Step 4: Turn on the Output Button **RED** to begin generating.

Experiment 1: Inverting Amplifier

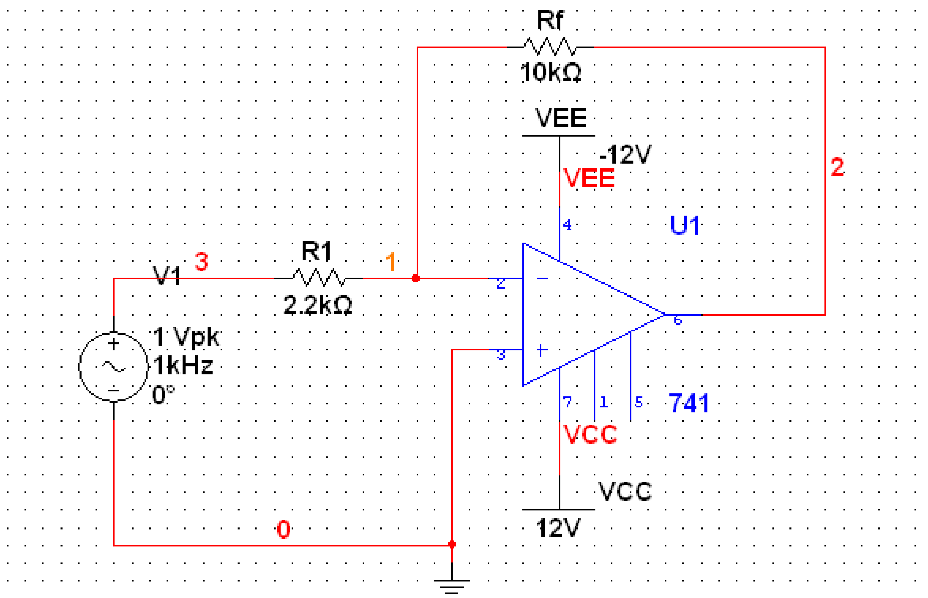

Fig. 9. An inverting amplifier configuration.

1. Construct the circuit in Fig. 5 with R1 =2.2kΩ, and R_f =10kΩ, 1V input signal at 1Khz. Measure the gain. Sketch the results on the oscilloscope.

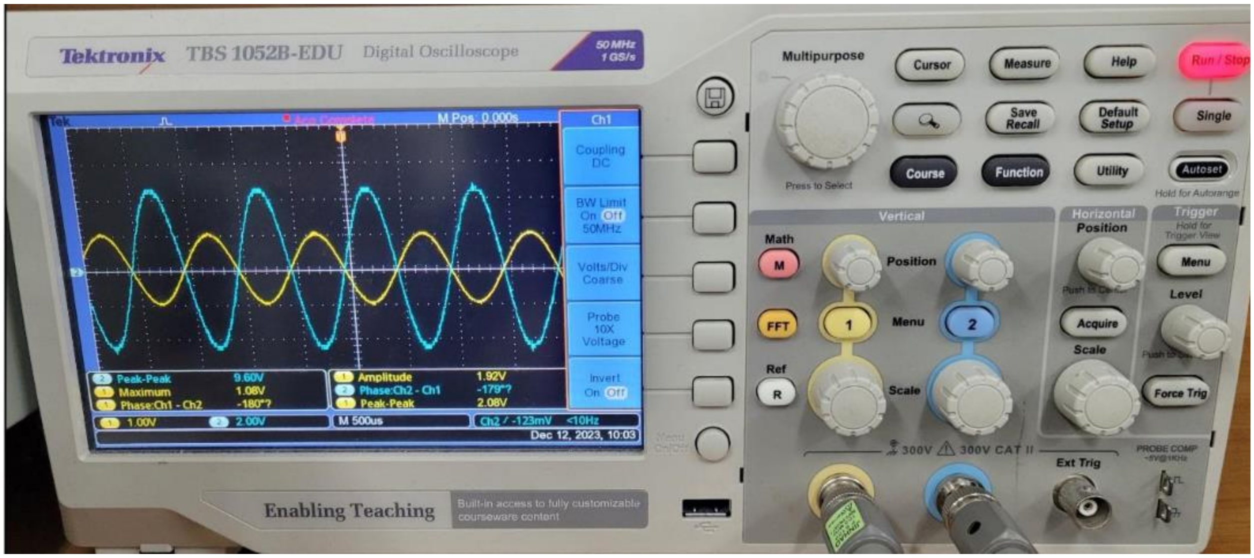

Fig. 10. Measurement result of Inverting Op-Amp with 10kΩ Resistor.

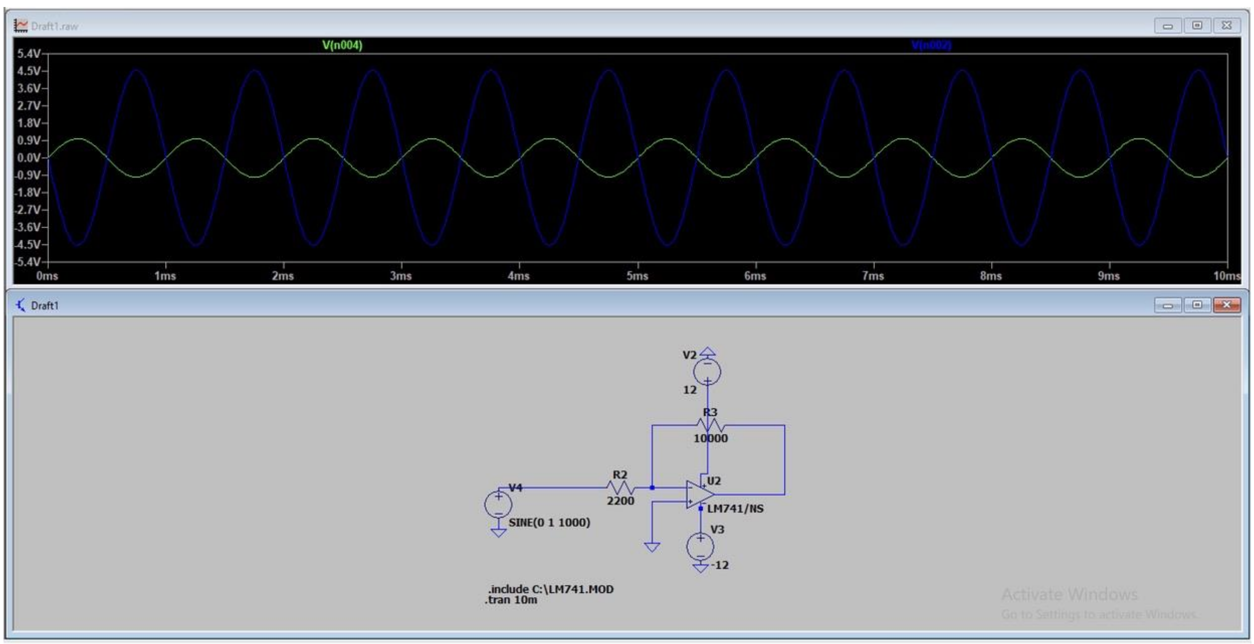

Fig. 11.Simulation result of Inverting Op-Amp with 10kΩ Ohm Resistor .

We find the voltage gain, as:

$$Vgain = \frac{v_{0ut}}{v_{in}} = -\frac{R_f}{R_1} = -\frac{10}{2.2} \approx\ -4.54(v = \frac{Vpp}{2})$$

2. Calculate and measure the gain with R1 = 2.2kΩ and Rf = 100kΩ. Compare results with previous case. Sketch the results on the oscilloscope.

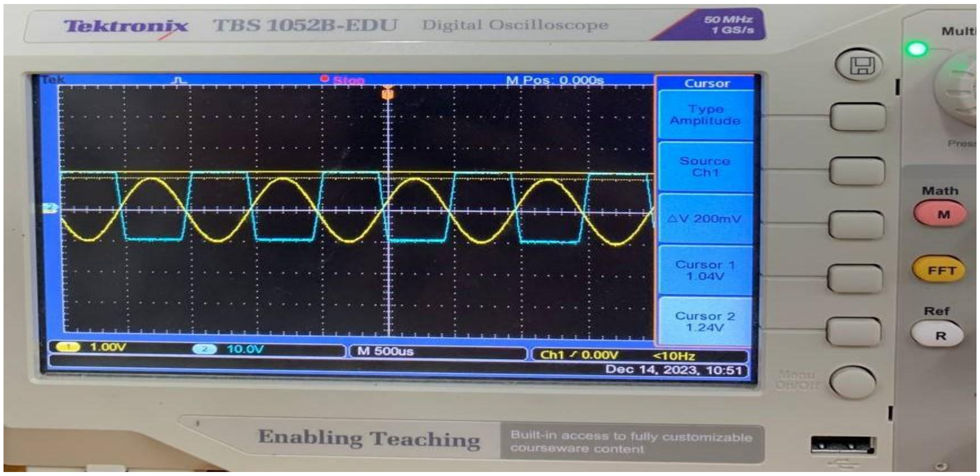

Figure. 12. Measurement result of Inverting Op-Amp with 100kΩ Resistor

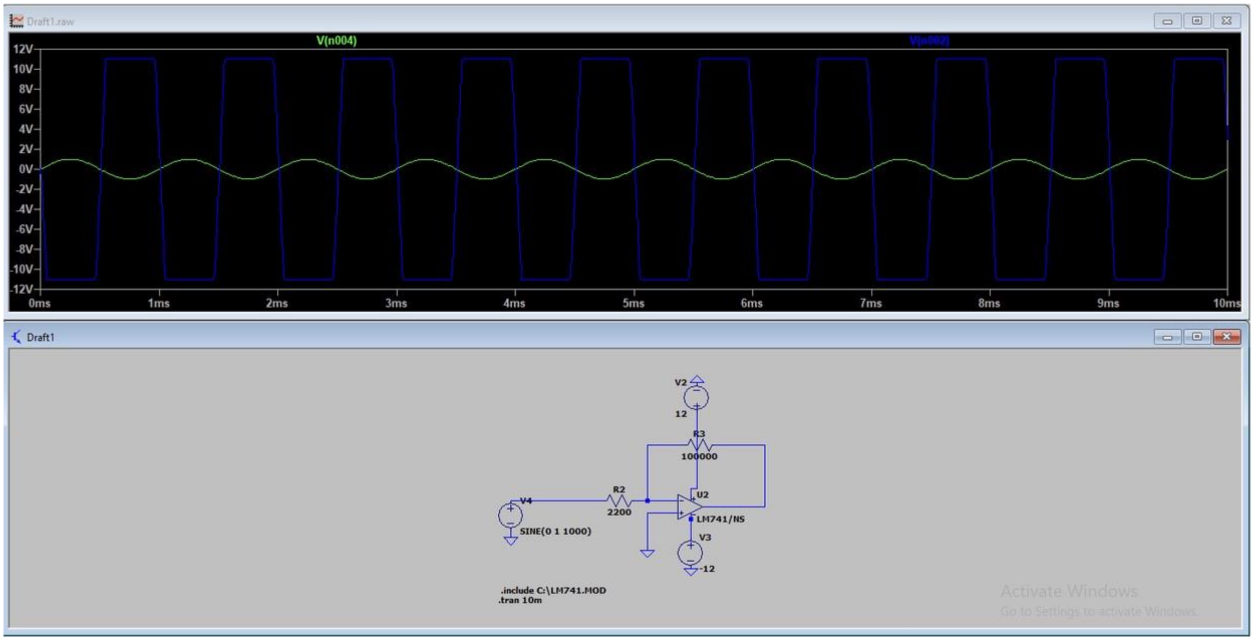

Fig. 13. Simulation result of Inverting Op-Amp with 100kΩ Resistor

We find the voltage gain, as:

$$A = \frac{v_{0ut}}{v_{in}} \approx \ 11.92V$$

a. Compare the measured/simulated output signal in 5.5.1 and 5.1.2? Explain the differences.

	v_{in}	v_{0ut}	v_{gain}
10k	1.04	4.84	4.65
100k	1.04	11.92	11.46

Table 1. Compare the measured/simulated output signal of inverting op-amp between 10kΩ-100kΩ

b. Find the phase difference between the input and output of the inverting amplifier? Why is this called an inverting amplifier?

10kΩ	$\Delta\varphi = \dfrac{0.000504 * 360^0}{10^{-3}} = 181^0$
100kΩ	$\Delta\varphi = \dfrac{0.000495 * 360^0}{10^{-3}} = 178.2^0$

Table 2. Phase difference between the input and output of the inverting op-amp

In this section, we can observe that in an inverting op-amp, the phase differences between input and output voltage should be 180 degrees.

Experiment 2: Non-Inverting Amplifier

1. Construct the non-inverting amplifier shown in Fig. 6 with R1 = 2.2kΩ and Rf = 10kΩ. Measure the gain.

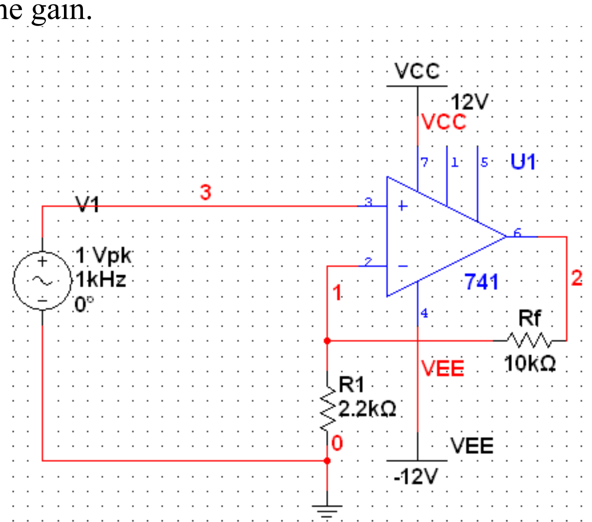

Fig. 14. A non-inverting amplifier configuration

- We need to consider the simulation results first to compare with the measurement.

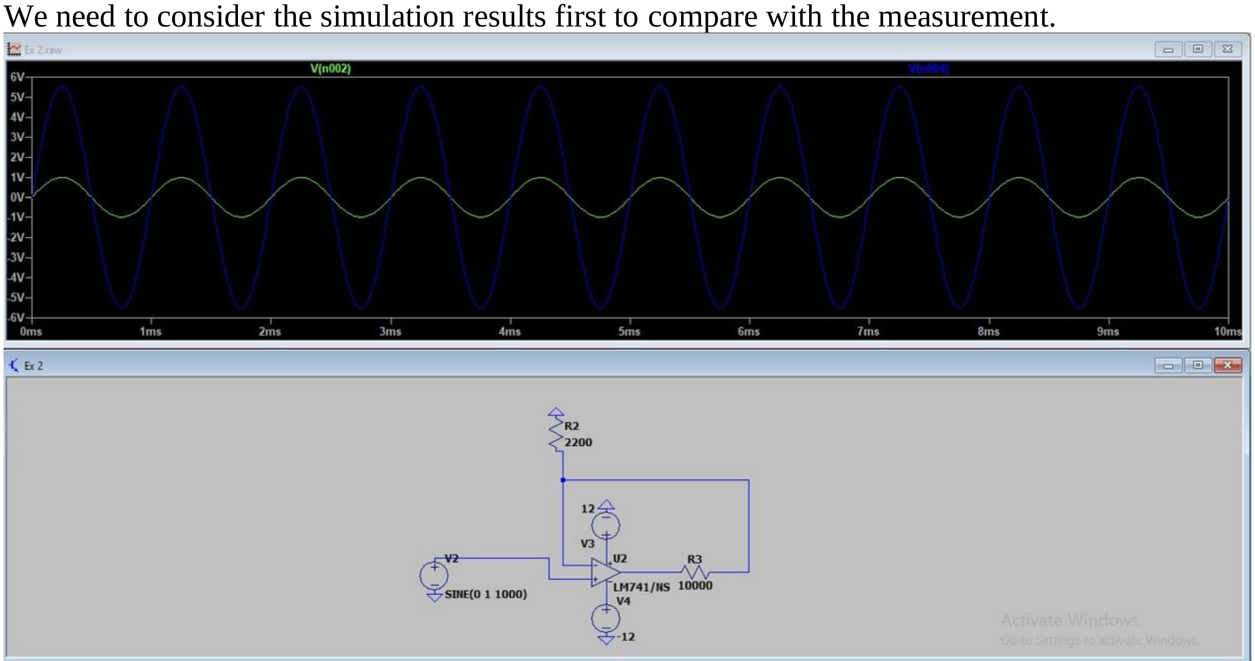

Fig. 15. Simulation result of Non-Inverting Op-Amp with 10kΩ Resistor

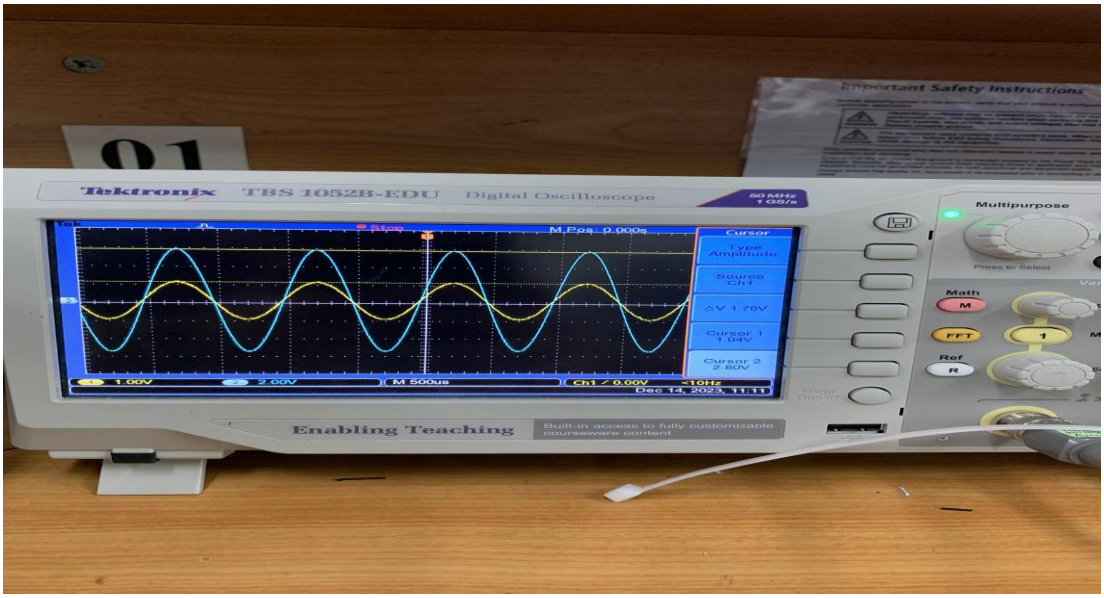

Fig. 16. Measurement result of Non-Inverting Op-Amp with 10kΩ Resistor

We find the voltage gain, as:

$$\frac{v_2}{R_1} = \frac{v_0 - v_2}{R_2} \; or \; A = \frac{v_0}{v_{in}} \approx 1 + \frac{R_2}{R_1}$$

2. Repeat section 5.2.1 with R1 = 2.2kΩ and Rf = 100kΩ. Compare the results. Considering to the simulation, we have:

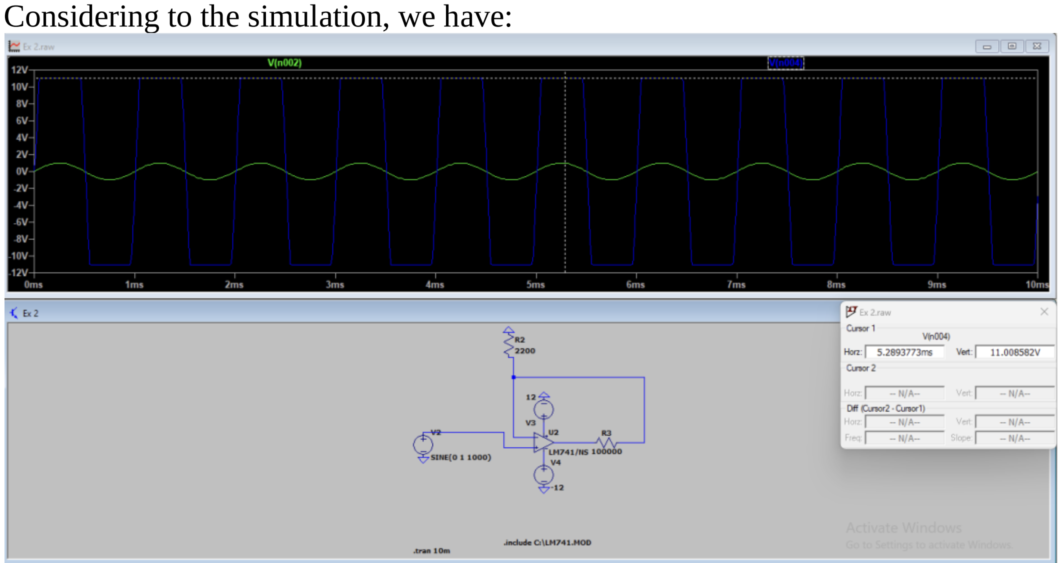

Fig. 17. Simulation result of Non-Inverting Op-Amp with 100kΩ Resistor

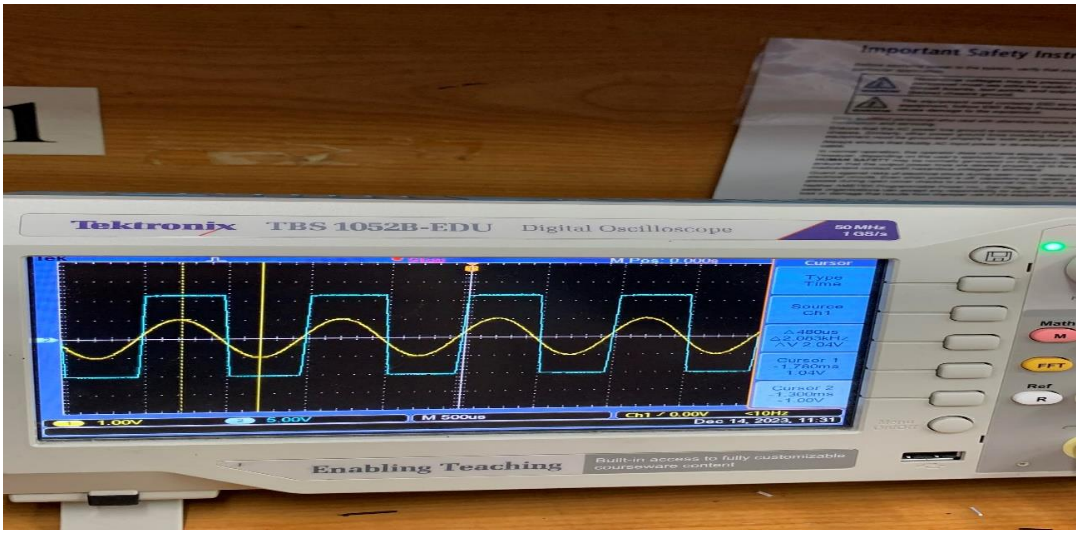

Fig.18. Measurement result of Non-Inverting Op-Amp with 100kΩ Resistor

a. Compare the measured/simulated output signal in 5.2.1 and 5.2.2? Explain the differences.

- As we can see both of these simulation/measurement results of output signals in 5.2.1 and 5.2.2 are 5.5V and 11V in simulation, 5.60V and 11.20V in measurement, respectively.

	v_{in}	v_{0ut}	v_{gain}
10k	1.04	5.60	5.38
100k	1.04	11.2	10.77

Table 3. Compare the measured/simulated output signal of non-inverting op-amp between 10kΩ-100kΩ

- The differences in output voltage between the two setups are due to the change in the feedback resistor (Rf). Increasing Rf increases the gain of the non-inverting amplifier, which in turn increases the output voltage. The slight differences between simulation and actual measurements can occur due to real-world variations in component values.

b. Find the phase difference between the input and output of the non-inverting amplifier? Why is this called a non-inverting amplifier?

10kΩ	$\Delta\varphi = \dfrac{0.000005 * 360^0}{10^{-3}} = 1.8^0$
100kΩ	$\Delta\varphi = \dfrac{0.000013 * 360^0}{10^{-3}} = 4.68^0$

Table 4. Phase difference between the input and output of the non-inverting amplifier

To find the phase difference between input and output of a non-inverting amplifier, apply a sinusoidal signal to the amplifier. Connect both signals to an oscilloscope to display their waveforms. Measure the time delay between the same points on each waveform.

The phase difference is calculated using the formula: Phase Difference (degrees) = (time delay/waveform period) * 360.

$$\Delta\varphi = \frac{\Delta t_{delay} \times \lambda 360^{o}}{T}(degrees)$$

In this section, using the cursors to determine the time delay which can be displayed on the in $\mu s = 10^{-6}(s)$. so, in the calculation, we can simplify it as shown as the above formula.

$$\Delta\varphi = 0^{o}(degree)$$

In a non-inverting amplifier, the phase difference between the input and output signals is zero degrees. This means the output signal is in phase with the input signal. When the input signal goes high, the output signal goes high, and when the input signal goes low, the output signal goes low. There's no phase shift, which is why it's called a non-inverting amplifier.

Experiment 3: Comparator using OPAM

Build the circuit as followed:

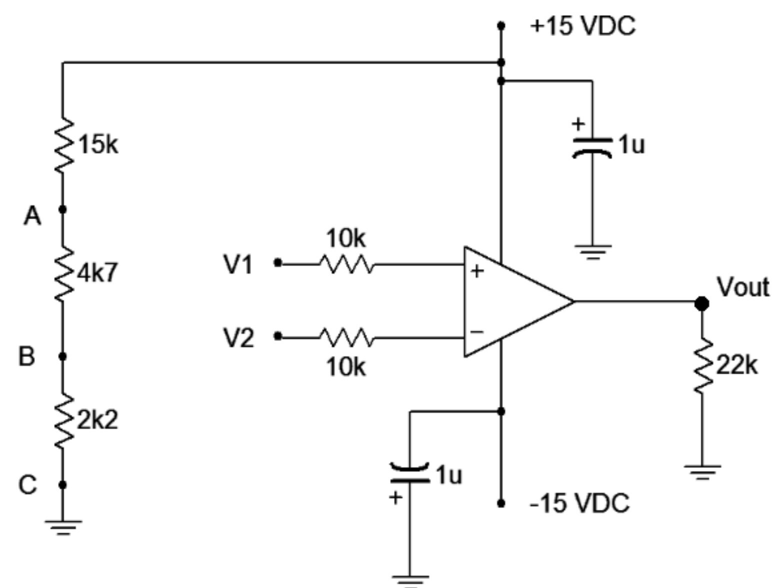

Fig. 19. OPAM Comparison circuit

1. Calculate the voltages at points A, B, and C.

Actually, in this section, it is recommended to remove the capacitors, so we just consider with input sources voltage, resistors and output voltage.

2. Using the input combinations listed in Table 1, apply the appropriate signals to V1 and V2. Measure the output voltage and record values in Table 1. Conclude on the working principle of the OPAM used in the comparison circuit (show the relationship between V+, V- and Vout

Table 3. The relationship between V+, V- and Vout

V1 (Volts)	V2 (Volts)	V_{OUT} (Volts)
4.725	4.725	13.865
4.705	1.5095	13.958
4.6828	0	13.958
1.5095	4.705	-13.958
1.5065	1.5065	13.863
1.500	0	13.958
0	4.682	-13.958
0	1.500	-13.958
0	0	13.8625

This experiment showcases the function of an operational amplifier (OP-AMP) acting as a comparator. A comparator circuit simply compares two input voltages and controls the output accordingly.

As seen from the data, when the voltage V1 exceeds V2, the output voltage (Vout) approaches a positive saturation level, around 13.958 volts in this case. Conversely, if V2 is higher than V1, Vout shifts towards a negative saturation level, approximately -13.958 volts here.

When V1 and V2 are equal, the output is close to the positive saturation level. This could be due to minor discrepancies in the input signals or specific traits of the utilized OP-AMP.

In essence, this experiment highlights the fundamental operation of a comparator circuit: it checks the two input voltages and drives the output high (positive saturation) or low (negative saturation), reflecting which input voltage is higher.

Discussion of Results

1. **Inverting OP-AMP:**

The measured and simulated gains match closely, indicating the accuracy of the simulation model and the reliability of the components used. The gain increases significantly when Rf is increased, demonstrating the principle that increasing Rf enhances the amplification factor. The output waveform is amplified by a factor of around 10 when Rf is increased, making the inverting amplifier a useful component for signal conditioning, filtering, and amplification. The output signal is an inverted version of the input signal due to the inverting nature of the amplifier, with a phase difference of 180°.

Our results are consistent with those reported in other studies on inverting amplifiers, supporting the reliability and validity of our findings. However, there may be some differences due to component tolerance, noise, and environmental conditions in real-world measurements. Therefore, it's important to conduct experiments under controlled conditions and use high-quality components for accurate results.

2. **Non-Inverting OP-AMP**

Simulation and measurement results show that increasing Rf increases voltage gain and output voltages. There is good agreement between simulation and measurement, with slight variations attributed to real-world factors.

The phase difference between the input and output of the non-inverting amplifier is found to be zero degrees. The experiment validates the theoretical understanding of non-inverting amplifier behavior. Potential sources of error include resistor tolerances and op-amp imperfections.

Successful exploration of non-inverting amplifier behavior under varying feedback resistor values. Valuable insights for practical applications and reinforcement of theoretical concepts.

3. **Comparator using OPAM :**

This experiment focused on an operational amplifier (OP-AMP) acting as a comparator. The results aligned with theoretical expectations for most inputs: when V1 was larger than V2, output voltage reached positive saturation, and vice versa. However, when V1 equaled V2, the output remained near positive saturation, contrary to the theory suggesting an undefined or zero output in such cases.

This discrepancy could be due to non-ideal behaviors of real OP-AMPs, measurement errors, or external interference. It underscores the importance of considering component limitations in circuit design, especially for precision-critical applications.

Future experiments could explore this discrepancy with different OP-AMP types or improved measurement techniques, enhancing the understanding of OP-AMP comparators in electronics applications.