BIRZEIT UNIVERSITY

Faculty of Engineering and Technology

Electrical and Computer Engineering Department

ENEE2103

Circuits and Electronics Lab

Experiment No.10

The Operational Amplifier

Report No.6

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Abstract

The aim of this experiment is to examine the application of the operational amplifier circuits such as adding application, voltage follower, and comparator application. In addition, to determine the integrator and differentiator, and active clipping circuits. And finally, to compare the measured values and figures to the theoretical ones.

The method used in this experiment is that all the specified circuits were connected to the board using the elements operational amplifier, a potentiometer to adjust the voltage value, resistors, capacitors, zinor diode, diodes. In addition, the Function Generator was used to generate different types of electrical waveforms over specified frequencies values, DC voltage to provide a fixed voltage, the Oscilloscope was used to test and display the signals, and the Digital Multimeter (DMM) was used to measure the voltage and the current.

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1. Theory

1.1 Operational Amplifier:

The operational amplifier, or op-amp for short, is fundamentally a voltage amplifying device designed to be used with external feedback components such as resistors and capacitors between its output and input terminals.

The op-amp is basically a three terminal device which contains two high impedance inputs. One of the inputs is called the **Inverting Input**, marked with the negative sign. The other input is called the **Non-inverting Input**, marked with a positive sign. While the third terminal represents the operational amplifiers output port which is the difference between the signals being applied to its two individual inputs.

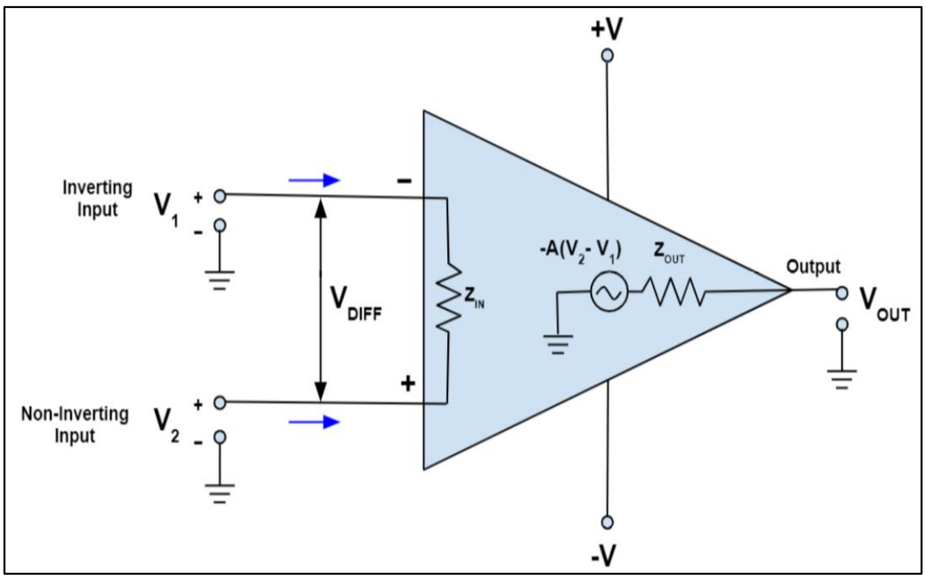

Figure 1. Operational Amplifier Schematic

The op-amps are widely used in many analog and power applications such as voltage buffers, creating analog filters, and threshold detectors. The benefits of using an op amp are that they are generally widely understood, well-documented and supported, and are fairly easy to use and implement.

1.2 Operational Amplifier Circuits:

There are many types of the operational amplifier circuits that are represented as the following:

1.2.1 The Summing Amplifier:

It also called as "**summing inverter**" or even a "**voltage adder**". The summing amplifier is a type of op-amp circuit configuration that is used to combine the voltages present on inputs into single output voltage. So, the summing op-amp circuit will amplify each individual voltage and produce an output voltage signal to the algebraic sum of the individual input voltages as shown in the following:

$$V_{out} = -(\frac{R_f}{R1} * V1 + \frac{R_f}{R2} * V2 + \frac{R_f}{R3} * V3 + \cdots)$$

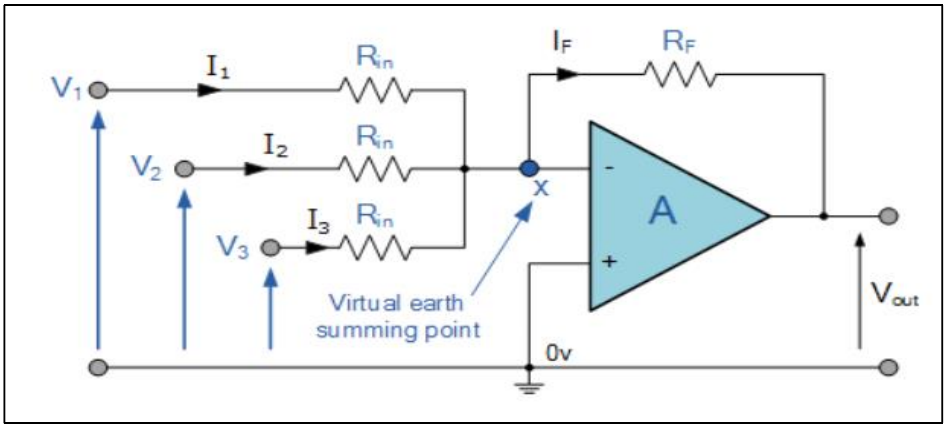

Figure 2. Summing Amplifier Circuit

1.2.2 Voltage Follower Amplifier:

A voltage follower which is also known as a "**buffer amplifier"**, or "**unity-gain amplifier**" is an op-amp circuit whose output voltage is equal to the input voltage (it follows the input voltage). In other word, the output a voltage follower op-amp does not amplify the input signal and has a voltage gain of 1.

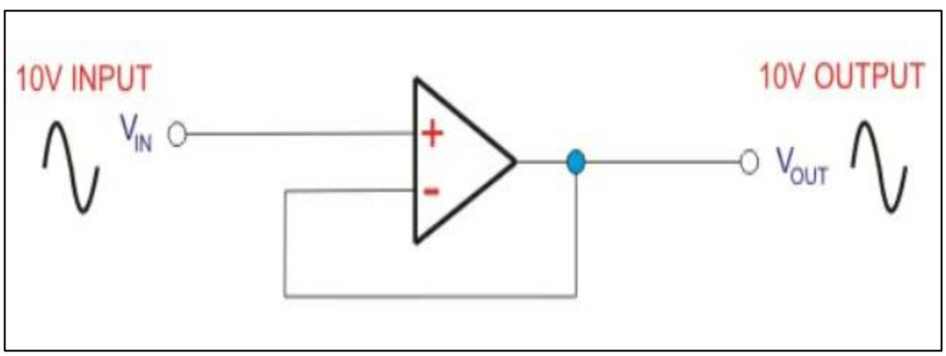

Figure 3. Voltage Follower Circuit

1.2.3 The Comparator Amplifier:

The op-amp comparator compares one analogue voltage level with another analogue voltage level. In other words, the op-amp voltage comparator compares the magnitudes of two voltage inputs and determines which is the larger of the two.

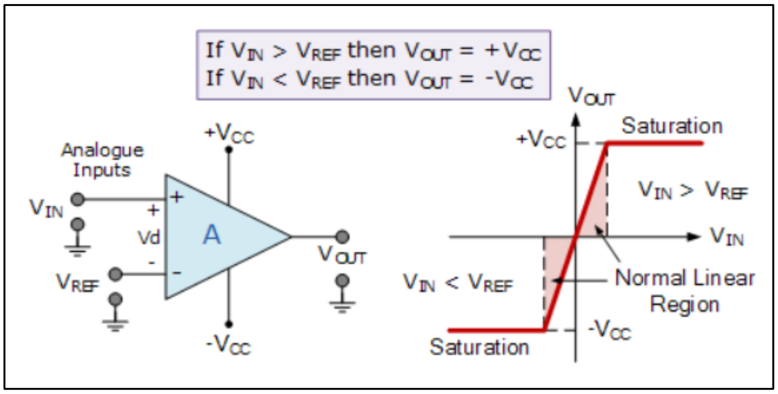

Figure 4. Comparator Circuit

If the input voltage (VIN) is less than the DC voltage level at Vref, the output will be low and the negative supply voltage (**-vcc**) which is the negative saturation, while if the input voltage (VIN) was increased, so that the value is greater than the reference voltage Vref, then the output supply will be switched to high (**+vcc**) which is the positive saturation.

1.2.4 Integrator Amplifier:

The op-amp Integrator circuit is an operational amplifier circuit that performs the mathematical operation of Integration which causes the output to respond to changes in the input voltage over time as the op-amp integrator produces an output voltage which is proportional to the integral of the input voltage. Since the capacitor will be connected between the op-amp's inverting input and the output, the voltage potential voltage, Vc developed across the capacitor slowly increases causing the charging current to decrease as the impedance of the capacitor increases.

$$V_{out} = -\frac{R}{C}\int_0^t V_{in}\,dt$$

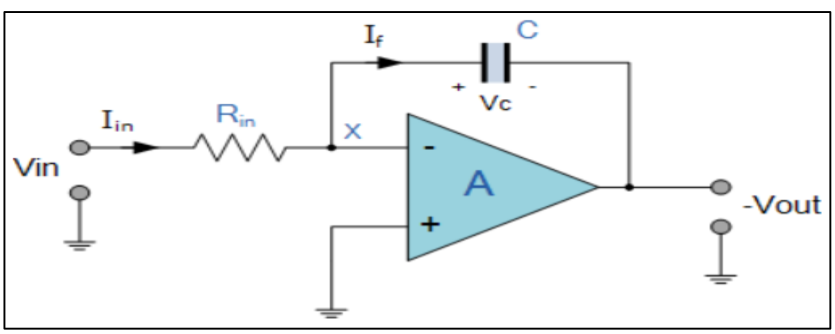

Figure 5. Integrator Circuit

1.2.5 The Differentiator Amplifier:

The differentiator op-amp circuit performs the mathematical operation of Differentiation that is it produces a voltage output which is directly proportional to the input voltage's rate-of-change with respect to time. In other words, the faster or larger the change to the input voltage signal, the greater the input current, the greater will be the output voltage change in response.

The input signal to the differentiator is applied to the capacitor, and it only allows AC type input voltage changes to pass through and whose frequency is dependent on the rate of change of the input signal. So, the output voltage can be calculated as the following:

$$V_{out} = -R * C * \frac{d\,Vin}{dt}$$

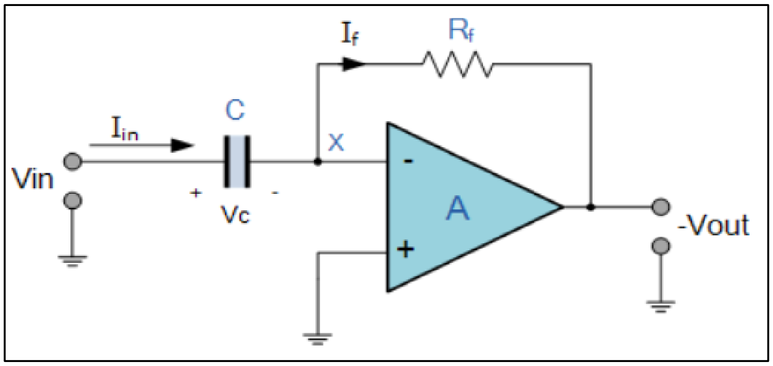

Figure 6. Differentiator Circuit

1.2.6 Active Clipping Amplifier:

A clipping circuit consists of linear elements like resistors and non-linear elements like diodes or transistors, but it does not contain energy-storage elements like capacitors. In op-amp clipper circuits a rectifier diode may be used to clip off a certain portion of the input signal to obtain a desired output waveform. The diode works as an ideal diode (switch) because when on, the voltage drop across the diode is divided by the open loop gain of the op-amp. When off (reverse biased) the diode is an open circuit.

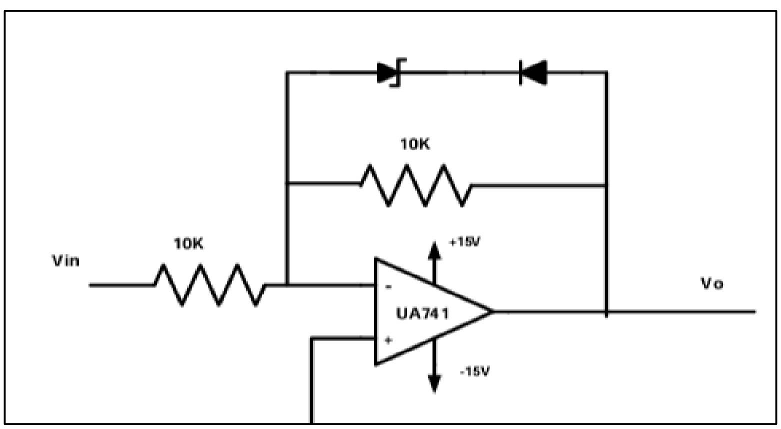

Figure 7. Active Clipping Circuit

1.2.7 Comparator with Hysteresis (Schmitt Trigger):

The hysteresis comparator is operated by applying a positive feedback to the comparator. This forms a Schmitt trigger circuit. Note that, if an operational amplifier is driven to saturation as a closed-loop circuit (i.e., with hysteresis thanks to a feedback loop), then the output can also saturate and provides the same function as a comparator. A comparator cannot be operated as a hysteresis comparator when a negative feedback is applied.

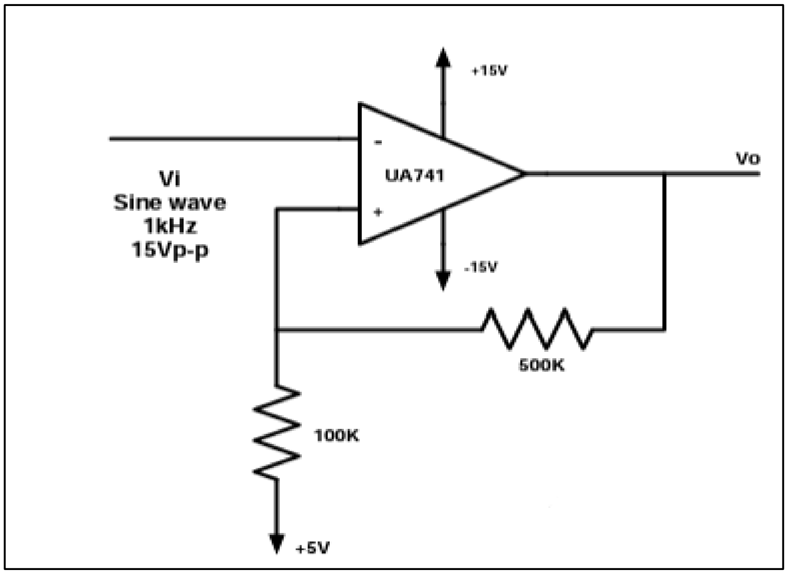

Figure 8. Hysteresis Comparator Circuit

2. Procedure and Data Analysis

2.1 Adding Application:

The objective of this part is to find the output voltage of the operational amplifier in the adding or summing amplifier circuit.

- **Experimental Results:**

  First of all, the adding amplifier circuit which contained several resisters and an operational amplifier was connected in the board, and the first voltage (V1) was controlled by the potentiometer and the second voltage (V2) is obtained from the variable DC voltage as the following figure:

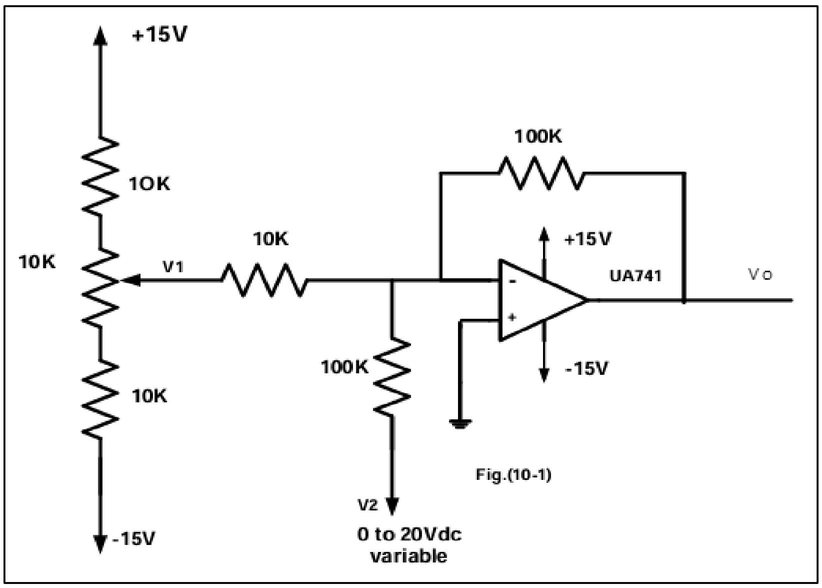

Figure 9. Adding Application Circuit

And the output voltage of the operational amplifier was measured in different values of both voltages V1 and V2.

Figure 10. Output voltage when V1=0.3 and V2=4

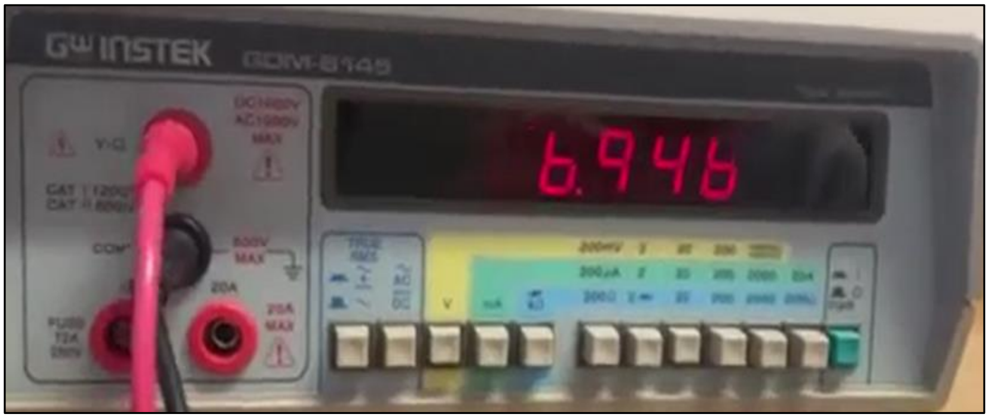

Figure 11. Output voltage when V1=-0.9 and V2=2

Table 1. Mesured output voltages

Input Voltage		Output Voltage	
V1	**V2**	**Vo**	**Calculated Voltage**
0.5	**2**	-6.700	-7
0.1	**6**	-7.230	-7
0.3	**4**	-6.536	-7
-0.9	**2**	6.916	7
-1.1	**4**	6.726	7
-1.5	**6**	8.810	9

To find the expression of output voltage:

$$\boldsymbol{Vo = -\left(\frac{V1}{R1} + \frac{V2}{R2}\right) \times R_{feedback}}$$

→ By entering the Rf into the brackets:

$$\boldsymbol{Vo = -\left(\frac{V1 * R_{feedback}}{R1} + \frac{V2 * R_{feedback}}{R2}\right)}$$

$$\boldsymbol{Vo = -\frac{V1 * R_{feedback}}{R1} - \frac{V2 * R_{feedback}}{R2}}$$

So, the $\boldsymbol{X} = \frac{-R_{feedback}}{R1} = \frac{-100K}{10K} = -10$ and $\boldsymbol{Y} = \frac{-R_{feedback}}{R2} = \frac{-100K}{100K} = -1$

Finally, the expression relating Vo to V1 and V2 is:

$$\boldsymbol{Vo = -10V1 - V2}$$

- **Theoretical Results:**

  The theoretical results can be calculated by using the previous formula:

$$Vo = -\left(\frac{V1}{R1} + \frac{V2}{R2}\right) \times R_{feedback} = -10V1 - V2$$

1. **V1=0.5 and V2=2:**
   Vout = -10(0.5) – 2 → **-7 Volt.**

2. **V1=0.1 and V2=6:**
   Vout = -10(0.1) – 6 → **-7 Volt.**

3. **V1=0.3 and V2=4:**
   Vout = -10(0.3) – 4 → **-7 Volt.**

4. **V1=-0.9 and V2=2:**
   Vout = -10(-0.9) – 2 → **7 Volt.**

5. **V1=-1.1 and V2=4:**
   Vout = -10(-1.1) – 4 → **7 Volt.**

6. **V1=-1.5 and V2=6:**
   Vout = -10(-1.5) – 6 → **9Volt.**

From the experimental and theoretical results, it is noticed that the values were too close to other, which means that the measured values are correct.

2.2 Voltage Follower Application:

The object of this part is to find the output voltage when the input is an AC voltage source, and variable DC voltage.

- **Experimental Results:**

  First of all, the circuit with two different resisters, and an operational amplifier was connected as the following figure (Figure 12), and voltage generator was used to generate an input voltage with 2 Vp-p and frequency 100 Hz:

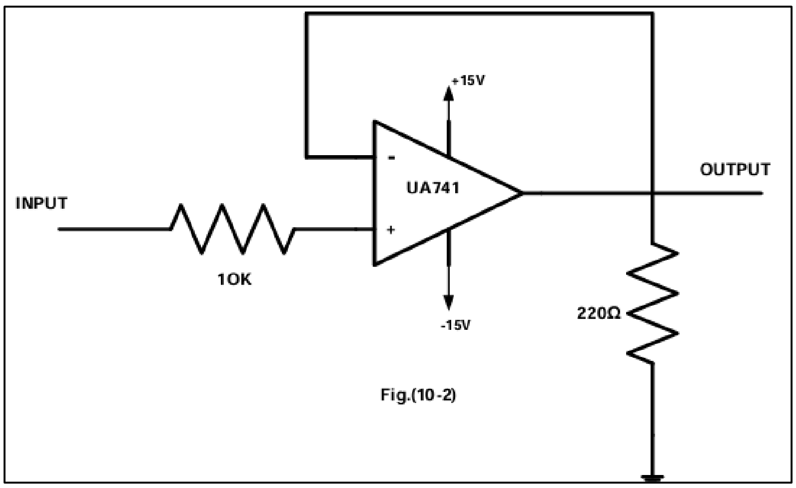

Figure 12. Voltage follower Application

And the output voltage of the operational amplifier was measured as the following:

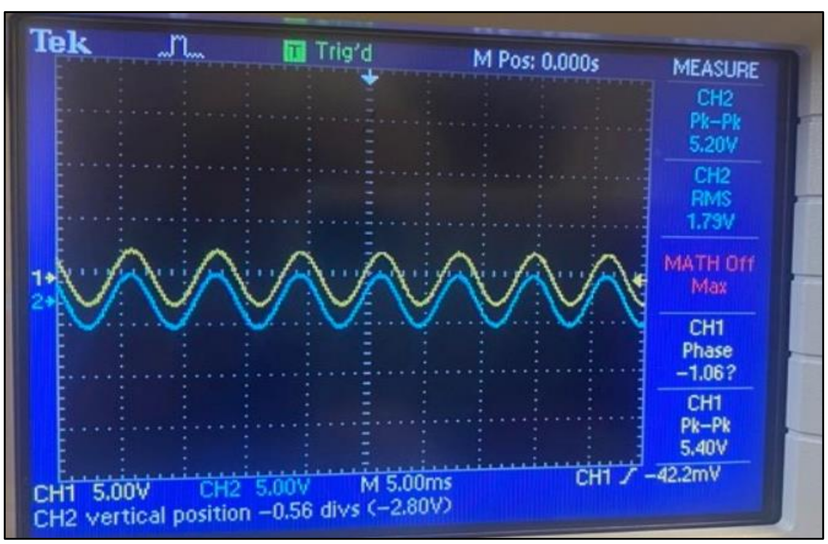

Figure 13. Output voltage when the input voltage is AC

While when the input is DC voltage which provide fixed values of voltages, and the resister is equals to 220 ohm, then the output voltage will be measured and recorded for many values of the input voltages(1V,2V,3V,4V,5V,6V, 7V,8,10,12,14 and 15). Then the same steps was repeated when the resister was replaced by 1 Kohm.

Table 2. The output voltage of voltage follower application

DC (V)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**12**	**14**	**15**
R=220	1.006	2.107	3.046	4.048	4.68	4.658	4.625	4.608	4.598	4.587	5.87	4.57
R=1K	-0.34	-1.17	-3.05	-3.93	-5.08	-6.08	-6.96	-8.13	-10.08	-12	-12.8	-12.8

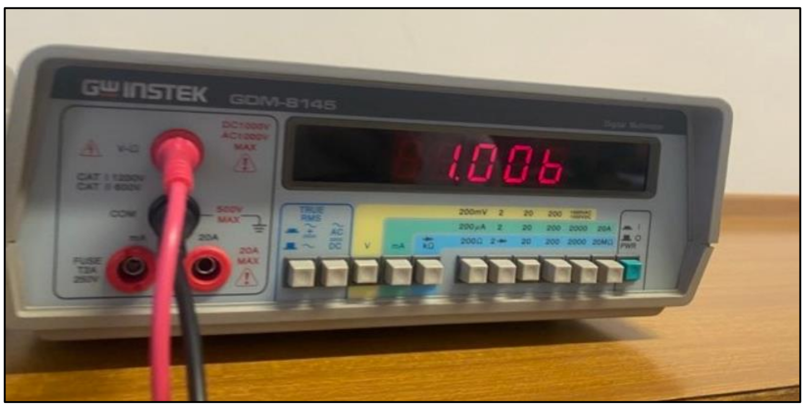

Figure 14. The output voltage when R=220 and Vi=1

Figure 15. The output voltage when R=1k and Vi=14

- **Theoretical Results:**

  Since the circuit is voltage follower, theoretically the output voltage will be the same as the input one. From the measured values and results, it is noticed that the values were too close which means that they are true.

- **Questions:**

1. **Is this circuit has similar properties as the emitter follower. Explain?**

   No, the voltage follower uses an op-amp to set the voltage on the output to be the same as the voltage on the input. It does however have limited drive capability. An emitter follower on the other hand drives or sources current to the output so that said output is a base emitter voltage different from the base voltage.

2. **For what applications is this circuit used?**

   The voltage follower circuit can be used as a buffer because it draws very little current due to the high input impedance of the amplifier, thus eliminating loading effects while still maintaining the same voltage at the output.

3. **What is the relation between your Vi, Vo?**

   The output voltage is the same as the input voltage with gain equals 1.

4. **What the approximate value of maximum output current of the op-amp?**

   The approximation value of the output current is **40mA** when R= 220 ohm, and **no current (zero value)** when the when the resister changed to 1Kohm.

2.3 Comparator Application:

The aim of this part is to find the output voltage of the operational amplifier, and obtain when the output voltage turns to the positive saturation, negative saturation or the square wave.

- **Experimental Results:**

  As the previous circuits, the comparator circuit that consists of a resistor, operational amplifier and the potentiometer was connected in the board. In addition, the function generator was set with 1 KHz frequency and input triangular waveform with 2 Vp-p. The DC refrence voltage was changed in small steps from **-1.5** to **1.5** as shown in the following figure:

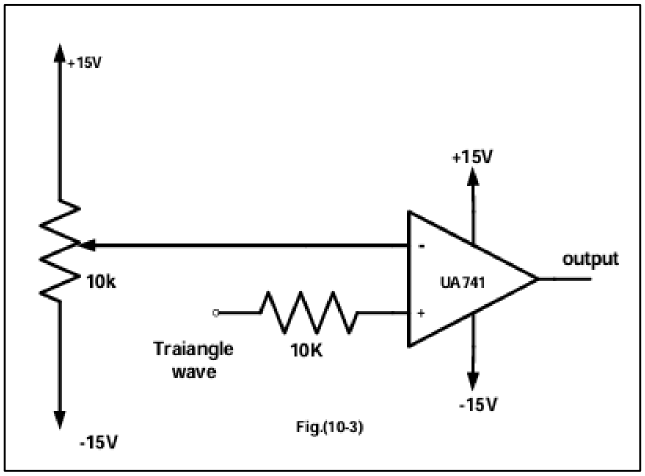

Figure 16. Comparator Application Circuit

The plots of the output voltage of the op-amp were taken as the following:

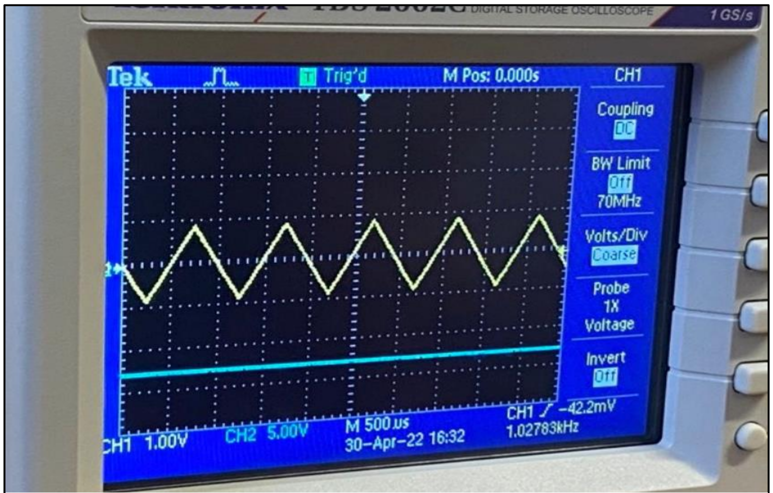

Figure 17. The output voltage when DC reference is greater than the AC input voltage

Figure 18. The output voltage when the DC reference is less than the AC input voltage

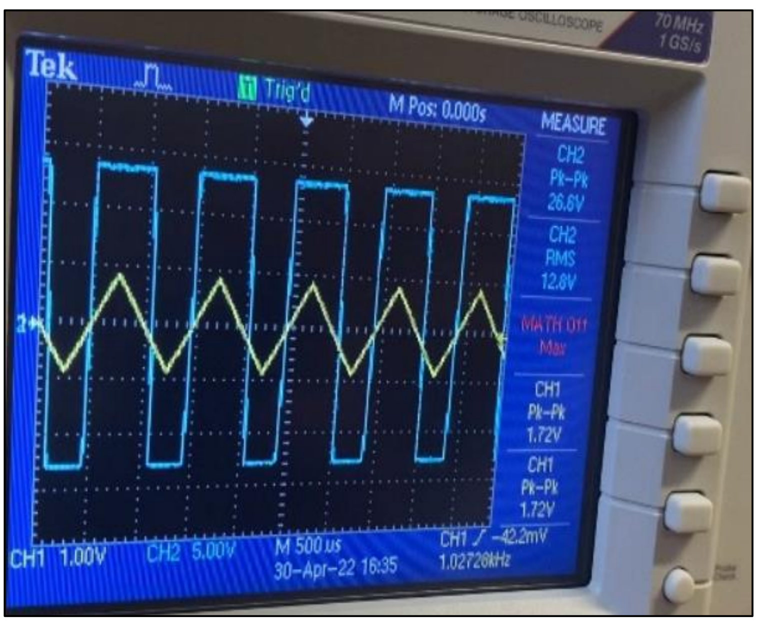

Figure 19. The output voltage when the DC reference is almost zero

- **Theoretical Results:**

In this comparator circuit, when the input DC voltage is less than the analog input voltage, the output voltage will be in the positive saturation mode (+vcc). On the contrary, when the DC voltage is greater than the analog input voltage, then the output voltage will be in the negative saturation mode. Finally, when the input DC voltage source is around the zero, the output voltage will be as square wave signal as shown in the following figures:

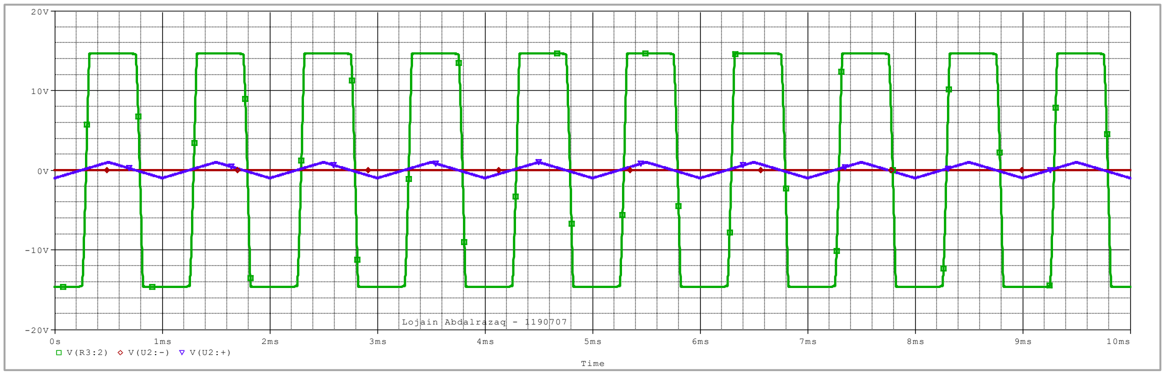

Figure 22. The output voltage when the DC voltage is equal to zero

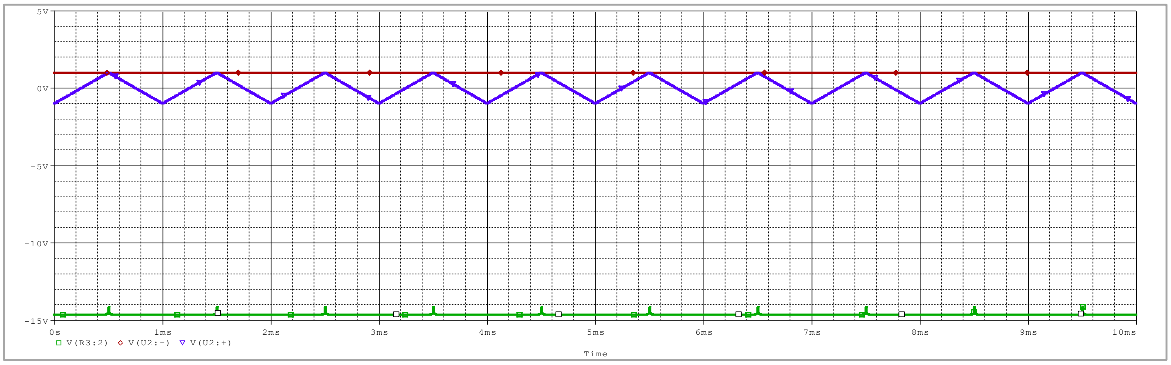

Figure 21. The output voltage when the DC voltage is greater than the input AC voltage

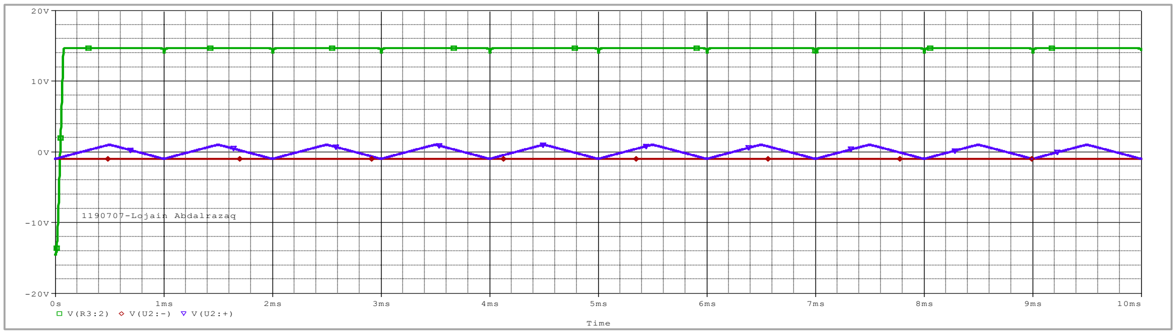

Figure 20. The output voltage when the DC voltage is less than the input AC voltage

It is noticed that the measured values output voltage is equals to the theoretical ones, which means they are true.

- **Questions:**

1. **What happens to the amplifier output?. For what application is this circuit used?**

   The op-amp comparator compares one analogue voltage level with another DC voltage level. In other words, the op-amp voltage comparator compares the magnitudes of two voltage inputs and determines which is the larger of the two. If the input voltage (VIN) is less than the DC voltage level at Vref, the output will be low and the negative supply voltage (**-vcc**) which is the **negative saturation**, while if the input voltage (VIN) was increased, so that the value is greater than the reference voltage Vref, then the output supply will be switched to high (**+vcc**) which is the **positive saturation**. And finally, if the input DC voltage is around the zero value, then the output voltage will as a **square wave.**

2. **Is there any similarity between this circuit and the diff amplifier?**

   Yes, when the DC voltage source is equal to zero, the output voltage will be as a square wave which is the same output of the diff amplifier.

2.4 Integrator and Differentiator:

This part contains two types of amplifier, the integrator and differentiator operational amplifiers.

2.4.1 Integrator Application:

The objective of this part is to find the output voltage when the circuit is an integrator and compare the measured values and figures to the theoretical ones.

- **Experimental Results:**

  The integrator circuit was connected in the board, three capacitors were connected in parallel between the op-amp's inverting input and the output, and the function generator was set with 30 Hz and 2 Vp-p. The input voltage signal was repeated for all types of signals, **sin wave, triangular, and sawtooth**.

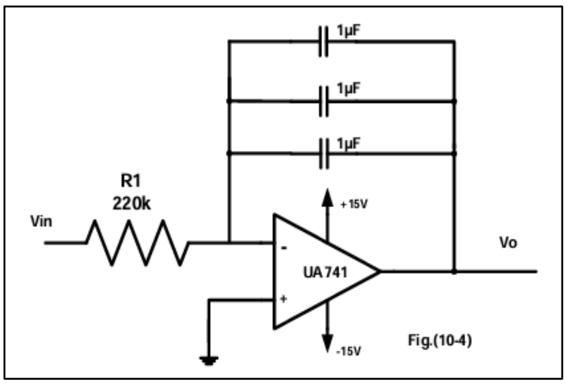

Figure 23. Integrator Application

The output voltage of the circuit is as the following:

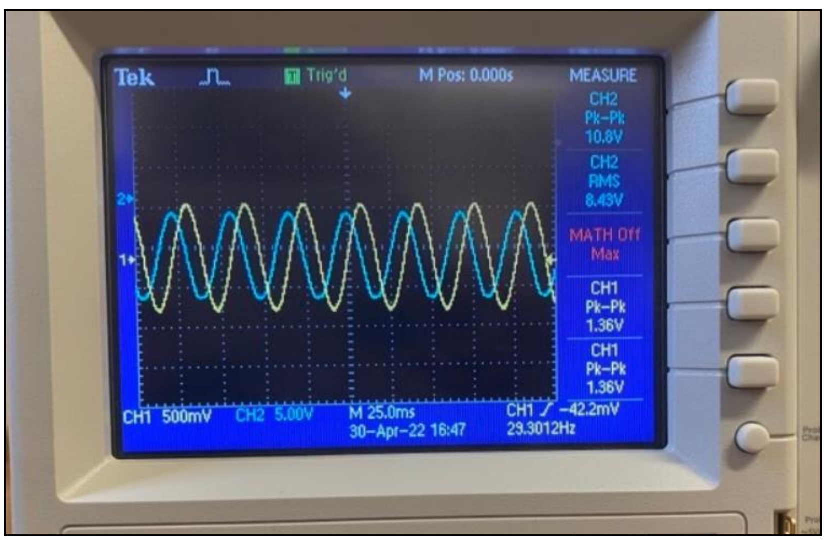

Figure 24. The output voltage when the input signal is sine wave

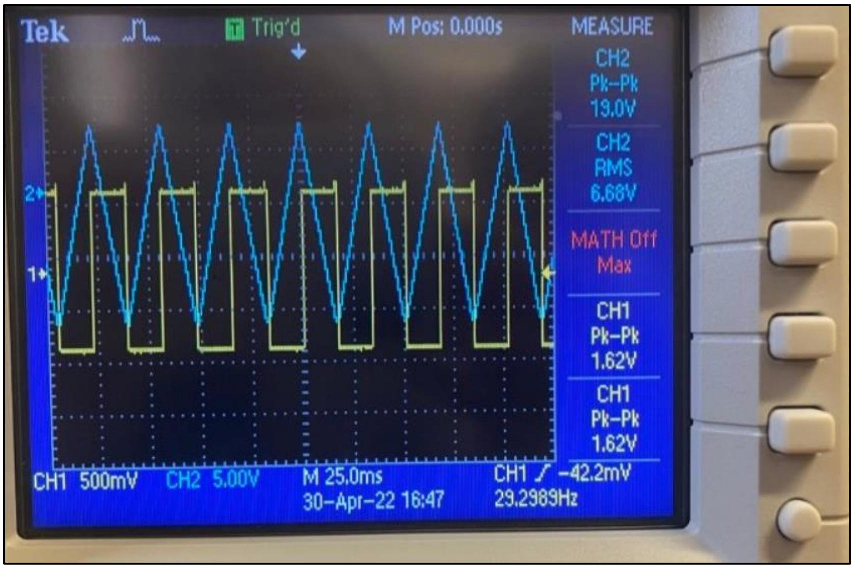

Figure 25. The output voltage when the input signal is square wave

Note: We have forgotten to take a photo of the output voltage when the input voltage is sawtooth wave.

- **Theoretical Results:**

In the integrator circuit the output voltage equals the proportional to the integral of the input voltage as the shown in the following equation:

$$V_{out} = -\frac{R}{C}\int_0^t V_{in}\,dt$$

As a result, when the input voltage is sin wave, the output voltage will be the **cosine waveform** as shown in the following figure:

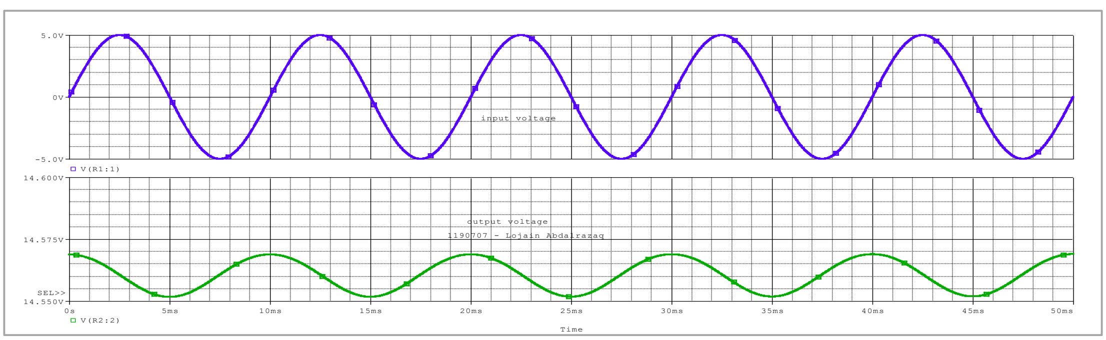

Figure 26. The output voltage when the input is sine wave

And the same thing with other input signal types. So the measured output voltages are so close to the theoretical results, so they are true.

2.4.2 Differentiator Application:

The objective of this part is to find the output voltage when the circuit is differentiator and compare the measured values and figures to the theoretical ones.

- **Experimental Results:**

  The circuit was connected to the board, which contained a 50Kohm resister connected between the op-amp's inverting input and the output, and the function generator was set also with 30 Hz and 2 Vp-p. The input voltage signal was repeated for all types of signals, **sin wave, triangular, and sawtooth**.

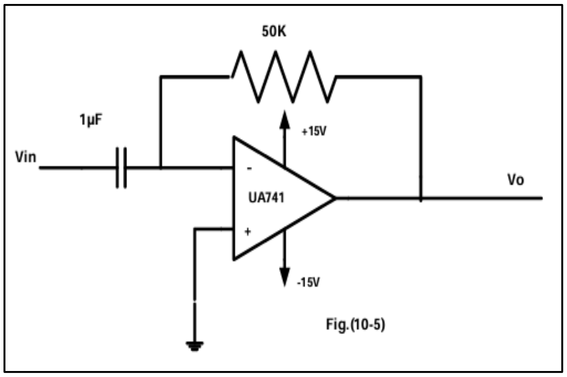

Figure 27. Differentiator Application

The output voltage of the operational amplifier was measured as the following:

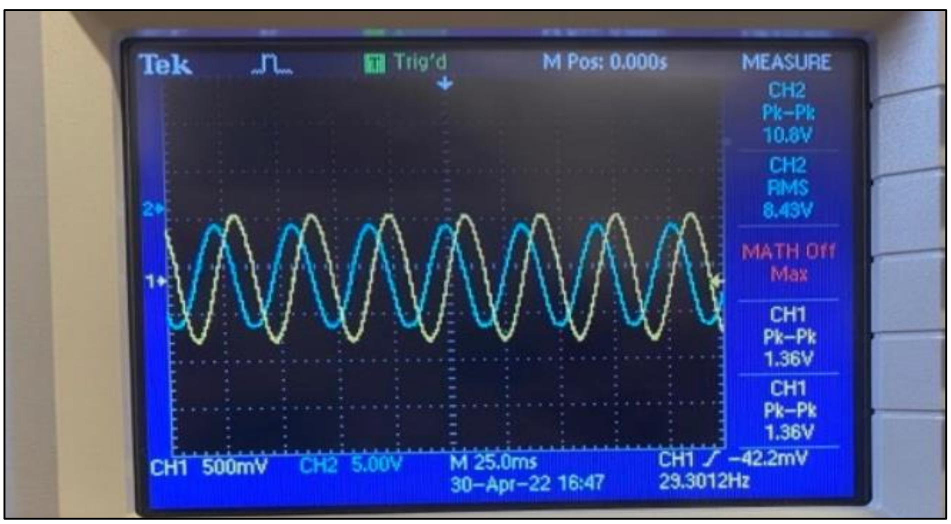

Figure 28. The output voltage when the input signal is sine wave

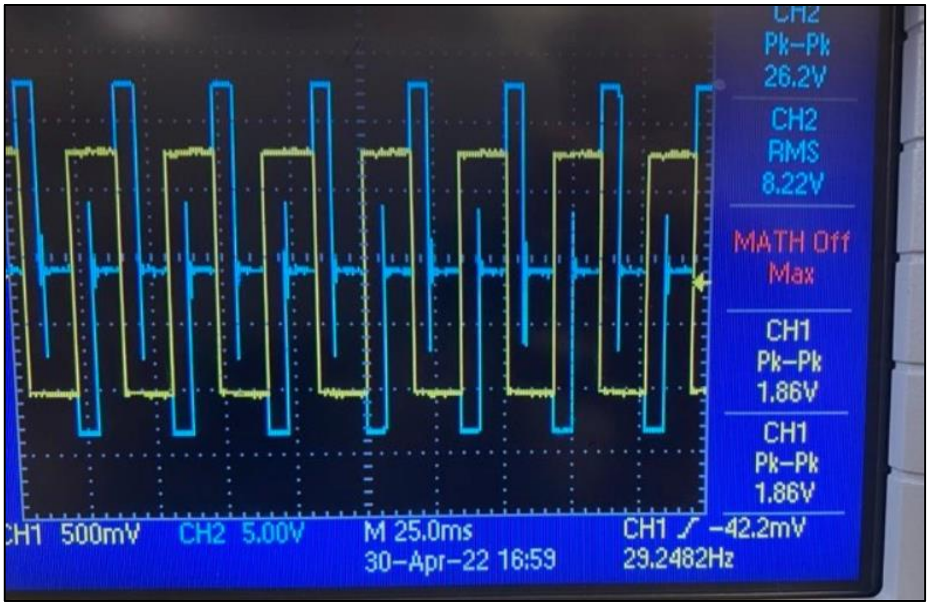

Figure 29. The output voltage when the input signal is square wave

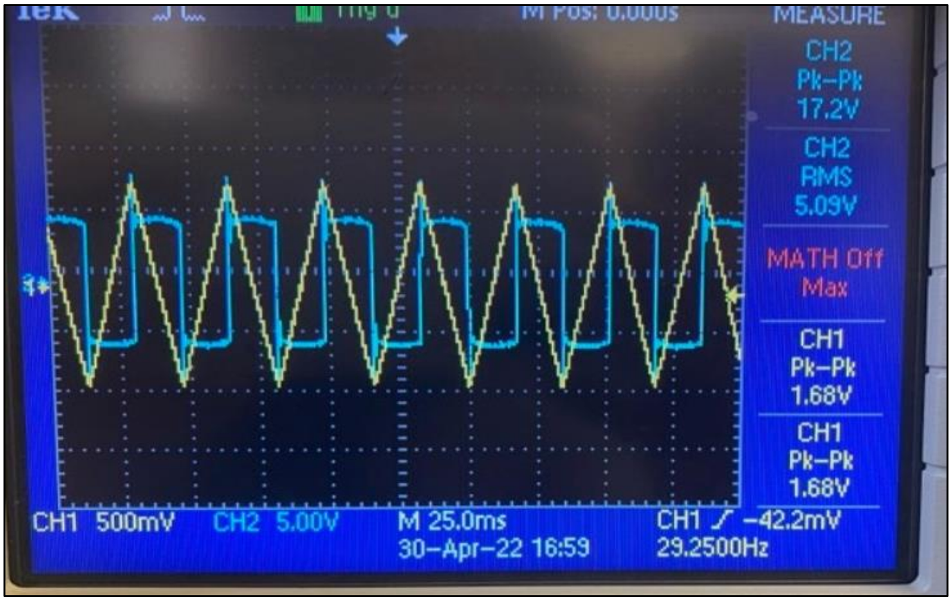

Figure 30. The output voltage when the input signal is triangular wave

Note: We have forgotten to take a photo of the output voltage when the input voltage is sawtooth wave.

- **Theoretical Results:**

As mentioned before, the operational amplifier performs the mathematical operation of Differentiation that is it produces a voltage output which is directly proportional to the input voltage's rate-of-change with respect to time according to the following equation:

$$V_{out} = -R * C * \frac{d\,Vin}{dt}$$

As a result, when the input voltage is sine wave, the output voltage will be as the following figure:

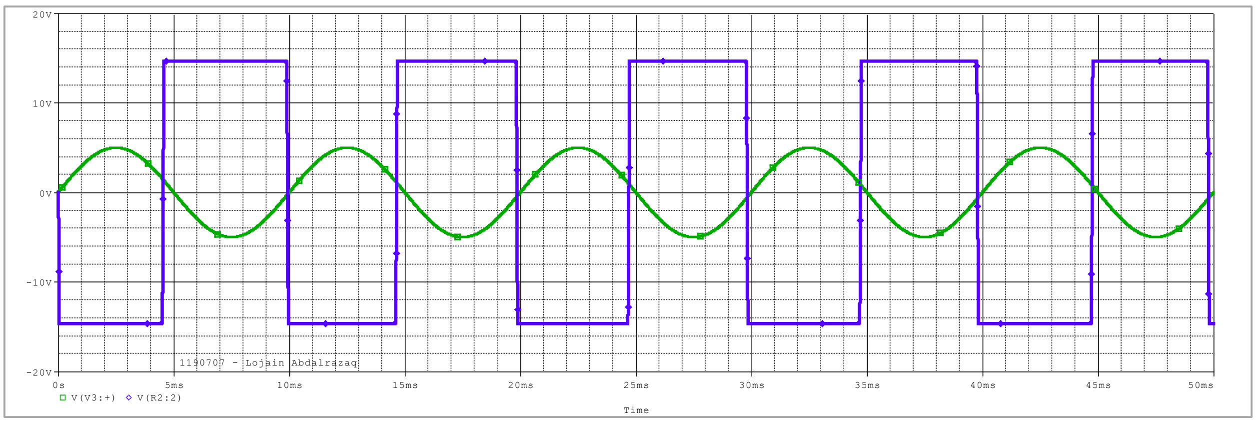

Figure 31. The output voltage when the input signal is sine wave

So, it is noticed that the measured results when the input voltage is sine wave is not the same as the theoretical ones, which means there is a mistake.

2.5 Comparator with Hysteresis (Schmitt Trigger):

The objective in this part of the experiment is to find the output voltage in the Schmitt trigger circuit.

- **Experimental Results:**

  Firstly, the Schmitt trigger circuit was connected, it contained a positive feedback with 500 Kohm resister, and the voltage generator was set to 1 KHz and 15 Vp-p.

  The output voltage of the circuit is as the following:

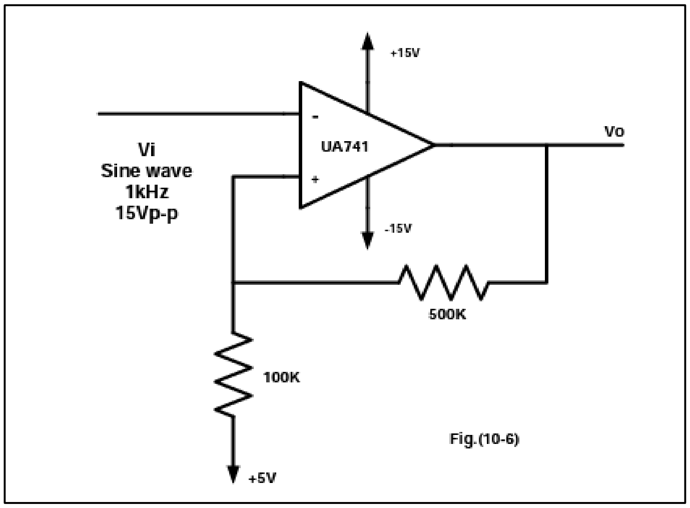

Figure 32. Comparator with Hysteresis

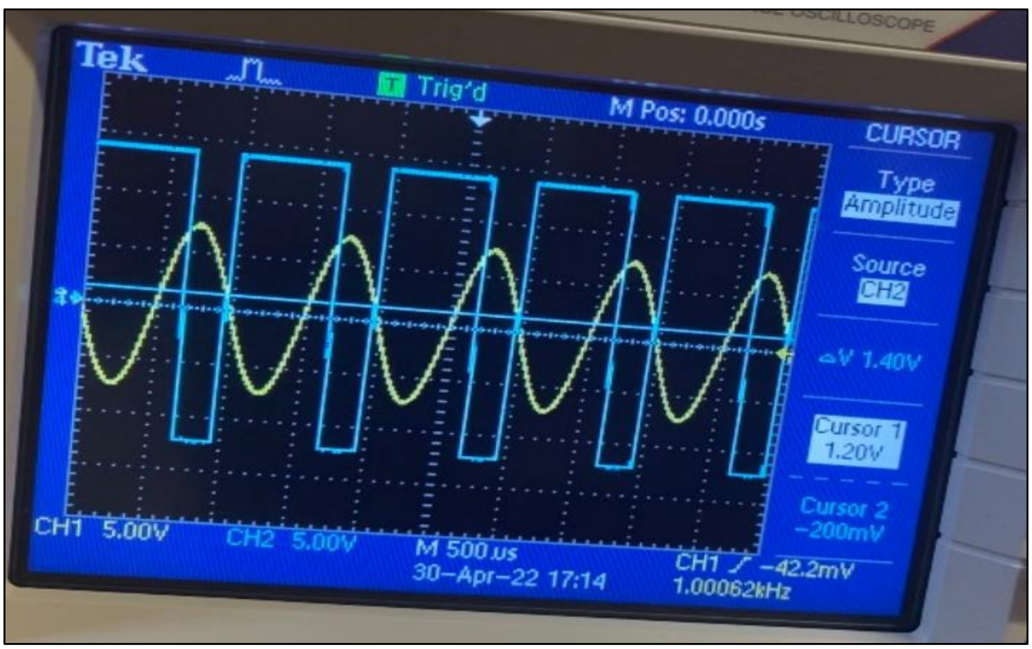

Figure 33. The output voltage of the Schmitt Trigger circuit

- **Theoretical Results:**

$+V_{sat} = 15 - 2 = +13\ V$

$-V_{sat} = -15 + 2 = -13\ V$

$By\ putting\ V_o = +13\ V$

$Vd > 0\ , V_+ - V_- > 0\ which\ means\ that\ V_+ > V_-$

$V_- = V_{in}$

$By\ using\ voltage\ devider\ rule$:

$$V_+ = \left(\frac{100K}{100K + 500K}\right) * 13 + \left(\frac{500K}{500K + 100K}\right) * 5 = 6.33\ Volt$$

$so\ Vi\ is\ less\ than\ V_+, V_{out} = +13\ V$

$And\ when\ Vi\ is\ greater\ than\ 6.33\ V, then\ it\ will\ be\ put\ V_{out} = -13\ V$

$By\ putting\ V_o = -13\ V$

$Vd < 0\ , V_+ - V_- < 0\ which\ means\ that\ V_+ < V_-$

$$V_+ = \left(\frac{100K}{100K + 500K}\right) * -13 + \left(\frac{500K}{500K + 100K}\right) * 5 = 2\ Volt$$

$And\ when\ Vi\ is\ greater\ than\ 2\ V, then\ it\ will\ be\ put\ V_{out} = -13\ V$

$By\ putting\ V_o = +13\ V$

And finally finding the Hysteresis using the difference between both voltages as the following:

$$\boldsymbol{Hysteresis = 6.334 - 2 = 4.334}$$

$\boldsymbol{To\ compare\ the\ mesured\ values\ to\ theoritical\ ones, it\ is\ noticed\ that\ the\ results\ are\ so\ close\ to\ each\ other, so\ that\ the\ upper\ triggered\ is\ 6.3\ Volt\ while\ the\ lower\ is\ 1.4\ Volt.}$

2.6 Active Clipping Circuit:

- **Experimental Results:**

The circuit of clipping was connected, it contained two resistors, op-amp, diode ,and zinor diode. The function generator was set to 1KHz frequency.

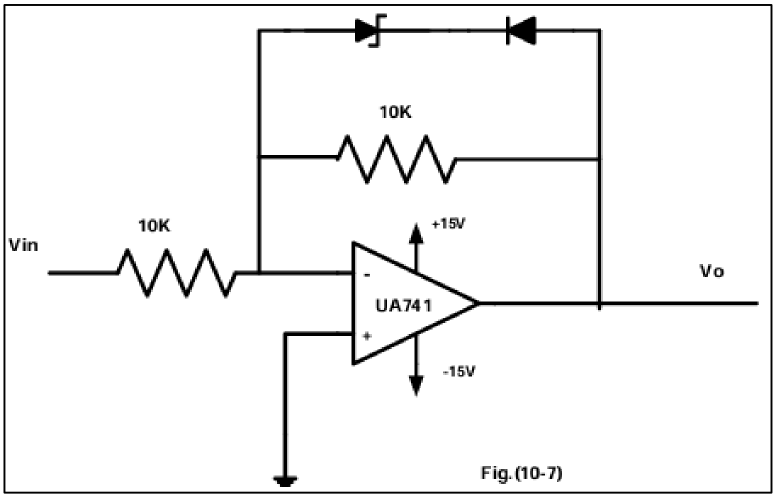

Figure 34. Active Clipping circuit

And the output voltage is measured as the following:

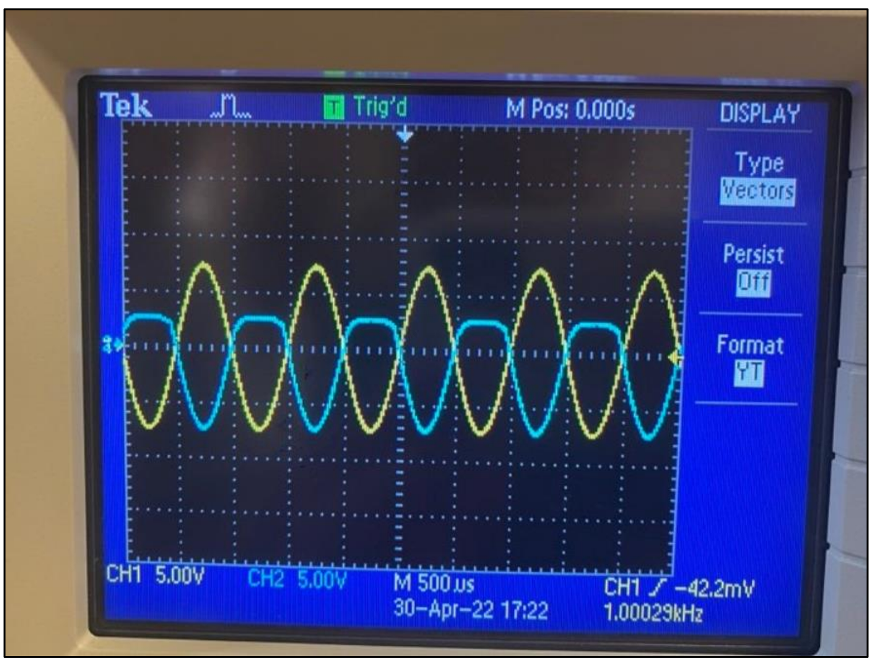

Figure 35. The output voltage of the clipping circuit

Note: We have forgotten to reverse both diode connections.

- **Theoretical Results:**

  In this circuit, the operational amplifier clipper circuits which contain a rectifier diode which is used to clip off a certain portion of the input signal to obtain a desired output waveform. From the measured results, it is noticed that the output voltage represented the input signal but with a cut of small portion from it which means that the result is **true**.

3. Conclusion

The experiment has covered many concepts applications for the operational amplifier circuits such as adding application, voltage follower, and comparator application. In addition, the integrator and differentiator, and active clipping circuits.

The measured results for each circuit were compared to the theoretical ones and most of them were the same as the theoretical ones which meant that the work and connection were **correct**. While, in the Differentiator Application circuit, the output voltage **was not** the same as the theoretical one.

4. References

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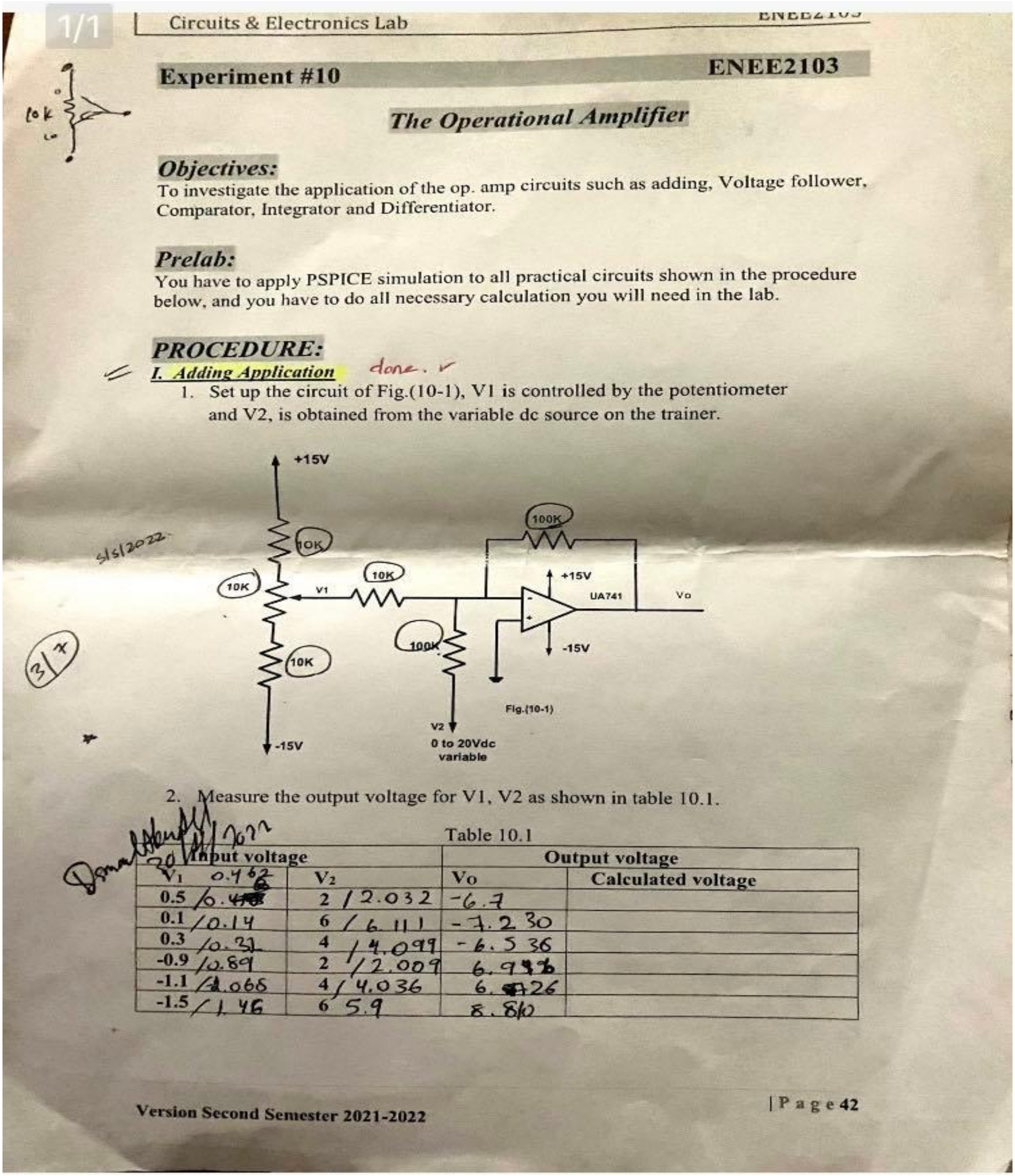
5. Appendixes



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Experiment #10 **ENEE2103**

The Operational Amplifier

Objectives:
To investigate the application of the op. amp circuits such as adding, Voltage follower, Comparator, Integrator and Differentiator.

Prelab:
You have to apply PSPICE simulation to all practical circuits shown in the procedure below, and you have to do all necessary calculation you will need in the lab.

PROCEDURE:

I. Adding Application done. ✓

1. Set up the circuit of Fig.(10-1), V1 is controlled by the potentiometer and V2, is obtained from the variable dc source on the trainer.

Fig.(10-1)

2. Measure the output voltage for V1, V2 as shown in table 10.1.

Table 10.1

Input voltage		Output voltage	
V_1 0.462	V_2	Vo	Calculated voltage
0.5 / 0.4[illegible]	2 / 2.032	-6.7	
0.1 / 0.14	6 / 6.111	-7.230	
0.3 / 0.32	4 / 4.099	-6.536	
-0.9 / 0.89	2 / 2.009	6.9[illegible]	
-1.1 / 1.066	4 / 4.036	6.[illegible]26	
-1.5 / 1.46	6 5.9	8.810	

3. Calculate the expected output voltage for each step using the formula :

yes, it is noticed, yellow -> input clone.

$$V_o = XV_1 + YV_2$$

where X, Y is the resistors ratios.

II. Voltage Follower Application

1. Set up the circuit of Fig.(10-2).

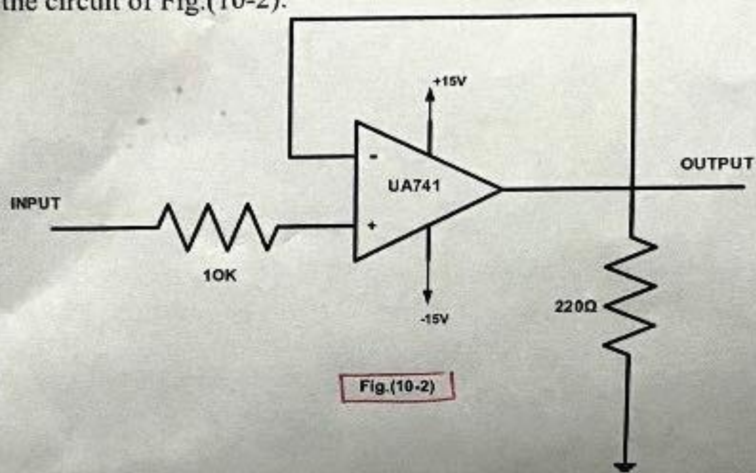

Fig.(10-2)

Done !!

2. Draw the output Vo(t) for Vi(t) is 2V p-p sinusoidal with 100Hz
3. Measure and records Vo for a dc input Vi = (1V,2V,3V,4V,5V,6V, 7V,8,10,12,14 and 15).
4. Change RL (220Ω) to 1KΩ , then measure and record Vo for the same values above as shown in table 10.2.

Table 10.2

Vi [DC,V]	1 1.002	2 2.206	3 3.041	4 4.063	5 5.01	6 6.031	7 7.154	8 8.146	10 10.09	12 12.4	14 13.97	15 15.2
Vo For RL=220ohm	1.0069	2.107	3.046	4.048	4.68	4.658	4.625	4.608	4.598	4.587	5.878	4.570
Vo For RL=1kohm	-0.342	-1.175	-3.053	-3.934	-5.028	-6.085	-6.966	-8.13	-10.08	-12.063	-12.835	-12.636

Question

- Is this circuit has similar properties as the emitter follower. Explain ?
- For what applications is this circuit used?
- What is the relation between your Vi, Vo?
- What the approximate value of maximum output current of the op-amp?