Faculty of Engineering & Technology

Department of Electrical & Computer Engineering

ENEE2103-CIRCUITS AND ELECTRONICS LABORATORY

Report#3

Experiment#10: The Operational Amplifier

Prepared by:

Hala Mohammed 1210312

Partners: Hamza Barhosh - 1210920 Ahmad Saqer - 1210085

Instructor: Dr. Mohammad Jehad Al Ju'Beh

Teaching Assistant: Eng. Rafah Rahhal

Section: 3

Date:17-8-2024

Abstract

This experiment explores the functionality of operational amplifier (op-amp) circuits in adders, voltage followers, and comparators, among other configurations. Comparators function as switches, comparing input signals to a reference; adders combine several inputs to produce a linear output; and voltage followers function as buffers, maintaining the input signal while producing a high output. The experiment also studies the behavior of a hysteretic comparator using an oscilloscope and a Schmitt trigger circuit. Utilizing potentiometers, DC sources, resistors, amplifiers, function generators, and other tools, the experiment seeks to investigate and characterize these circuits in electronic systems.

Table of Contents

Abstract .... *I*

List of figures .... *III*

List of tables .... *IV*

Theory *1*

Operational Amplifier: **1**
Adding Application **1**
Voltage Follower Application **2**
Comparator Application **2**
Comparators with Hysteresis (Schmitt Trigger): **3**

Procedure *5*

1. Adding Application **5**
2. Voltage Follower Application : **6**
3. Comparator Application **7**
4.Comparator with Hysteresis (Schmitt Trigger) **10**

Conclusion *11*

References *12*

Appendix *13*

List of figures

Figure 1 :Circuit diagram symbol for a representative op amp.[1] 1
Figure 2 :Adding circuit[2] 2
Figure 3 :Comparator circuit[4] 3
Figure 4 :Comparator with Hysteresis (Schimitt Trigger) digram[5] 4
Figure 5 :Schmitt Trigger characteristics[6] 4
Figure 6 :Circuit for Adding Application 5
Figure 7 :Voltage Follower Application Circuit 6
Figure 8 :Comparator Application circuit 7
Figure 9 :Comparator when Vdc=0 8
Figure 10 :Comparator when Vdc=+1.5 8
Figure 11 :Comparator when Vdc=- 1.5 9
Figure 12 :Hysteresis circuit 10
Figure 13 :I/O voltage in Hysteresis circuit 10

List of tables

Table 1 :Adding Application Result 5
Table 2 :Voltage Follower Application 6

Theory

Operational Amplifier:

An operational amplifier, often known as an op amp or opamp, is a DC-coupled electrical voltage amplifier that has a very high gain, a differential input, and a (mostly) single-ended output. Its original application in carrying out mathematical calculations on analog computers gave rise to its moniker. [1]

The parameters of an operational amplifier circuit, such as its gain, input and output impedance, bandwidth, and functionality, can be controlled by external components through the use of negative feedback. The characteristics of the op amp itself are not heavily dependent on temperature coefficients or technical tolerance. Because of its adaptability, the op amp is a widely used component in analog circuits.[1]

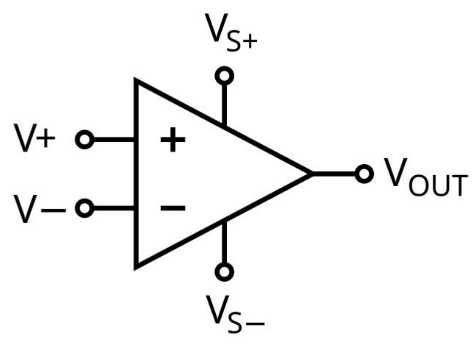

Figure 1:Circuit diagram symbol for a representative op amp.[1]

Adding Application

A circuit that adds input voltages using an op amp is called an adding application. Depending on how the op amp is configured, the output voltage may match or differ from the input voltages. Depending on the resistors, the output voltage may also have distinct gains for every input channel.[2]

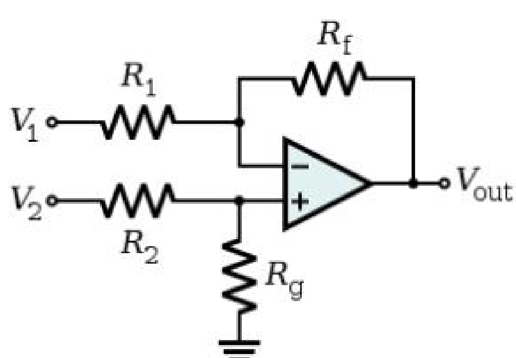

Figure 2:Adding circuit[2]

A circuit for an inverting summing amplifier is shown in Figure 2. The total of the negative input voltages is the output voltage. This equation provides the output voltage:

$$Vout = -\ Rf\sum_{i=1}^{n}\frac{Vi}{Ri}$$

Voltage Follower Application

A voltage follower is an op-amp circuit intended to provide a voltage gain of one. It is sometimes referred to as a buffer amplifier or unity-gain amplifier. This indicates that the output voltage and input voltage are exactly same. In essence, the signal is not impacted while the input and output are isolated. [3]

Because of the virtual short principle, which maintains the same voltage at the inverting and non-inverting terminals, the output voltage in a voltage follower circuit reflects the input voltage. The following equation can be used to express this relationship:

$$V-=V+=Vi=Vo$$

Voltage followers are widely utilized in a variety of applications, such as active filters, bridge circuits with transducers, sample and hold circuits, logic circuit buffers, and signal isolation and buffering.[3]

Comparator Application

In order to compare voltages, an op-amp comparator is essential. It determines which of two analog voltages is larger by comparing them or by using a predefined reference value, VREF.[4]

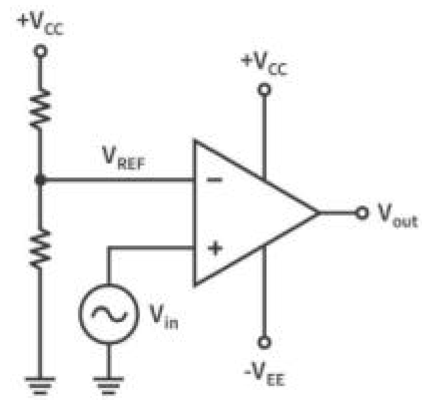

Figure 3:Comparator circuit[4]

The op-amp in the standard circuit (Figure 3) compares the input voltage (VIN) to a DC reference that is constant (VREF). The output decreases to a point where it approaches the negativity bottom when VIN is smaller than VREF. The output rapidly rises to a high value when VIN exceeds VREF. This op-amp comparator also functions as a threshold detector. Should VIN marginally fall below

$$V_o = \begin{cases} V_{sat+}, & if\ V_+ > V_- \\ V_{sat-}, & if\ V_+ < V_- \end{cases}$$

VREF, the cycle is repeated when the output returns to low. The op-amp comparator's ability to detect and react to changes in voltage relationships makes it valuable in electrical applications.[4]

Comparators with Hysteresis (Schmitt Trigger):

In op-amp designs, for example, hysteresis is just a positive feedback loop that provides predefined comparator threshold levels. Hysteresis is also called a Schmitt trigger. Figure below illustrates an op amp hysteresis circuit. This op-amp is configured as an inverting comparator, which becomes a positive feedback network when Vin is connected to the V– inverting input and the V+ (positive terminal) connects to the middle of the voltage divider (R2 and R3). The voltage V+ now represents the comparator higher threshold and lower threshold set by R2, R3 and R2, respectively.[5]

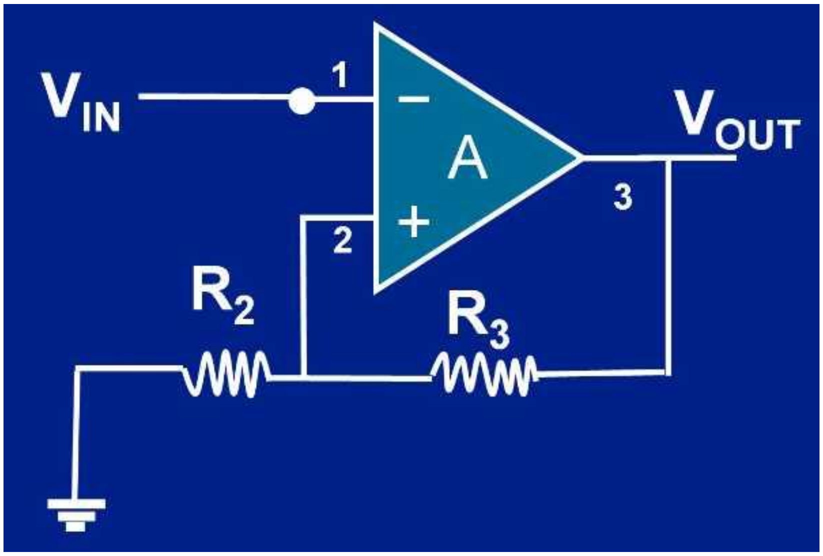

Figure 4:Comparator with Hysteresis (Schimitt Trigger) digram[5]

Feedback is added in Schmitt Trigger circuits to make the transfer characteristics exhibit hysteresis. The working of this circuit is basically a positive feedback comparator. For an increasing input voltage, the output voltage reaches negative saturation at a threshold value known as the upper threshold point. As shown in Figure 5, the output would not oscillate around Vr but instead remain stable in the presence of noise if the voltage difference between the UTP and LTP is greater than the noise. [6]

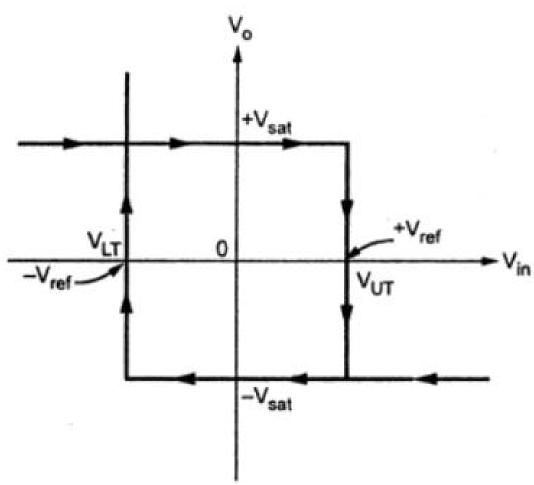

Figure 5:Schmitt Trigger characteristics[6]

Procedure

1. Adding Application

we set up the circuit below

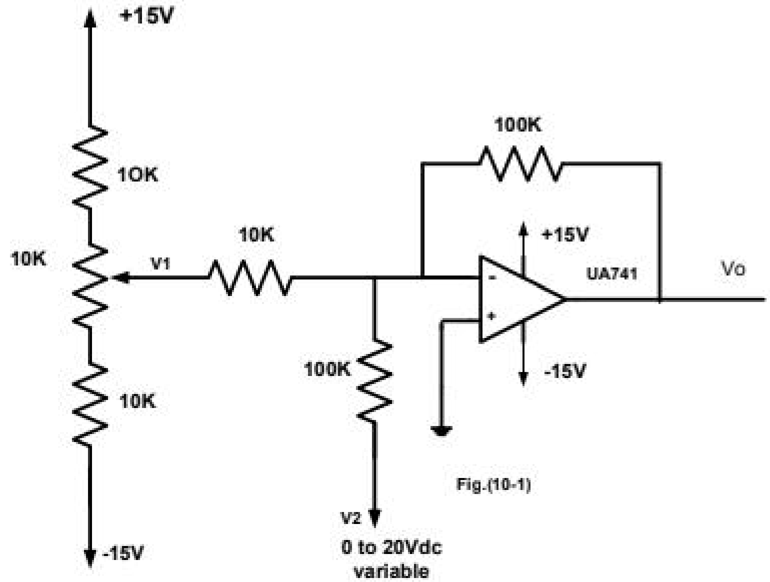

Figure 6:Circuit for Adding Application

The results obtained were gathered in table, after which Vo was calculated.

Input Voltage		Output Voltage	
V1	**V2**	**Vo**	**Calculated Voltage**
0.5	**2**	-7.0	-7
0.3	**4**	-7.35	-7
-0.9	**2**	6.86	7
-1.5	**6**	9.12	9

Table 1:Adding Application Result

The Output Voltage was Calculated as folllowing:

$$\text{Vo} =- (\frac{0.5}{10\text{K}} + \frac{2}{100\text{K}}) * 100\text{K} = -7\text{v}$$

The rest of the values were calculated in the same way.

Theoretically expected values of the output voltage were very close to the output, as can be seen in Table 1:. Application Result Adding. For example, with V1 = 0.5V and V2 = 2V, Vo measured was -7.0V against the calculated value of -7V. Also when V1 = -0.9V and V2 = 2V, Vo = 6.86V measured was very close to the calculated 7V. In this case, the output voltage will be calculated on a uniform basis for all conditions of input, hence yielding accurate and reliable results.

2. Voltage Follower Application :

we set up the circuit below

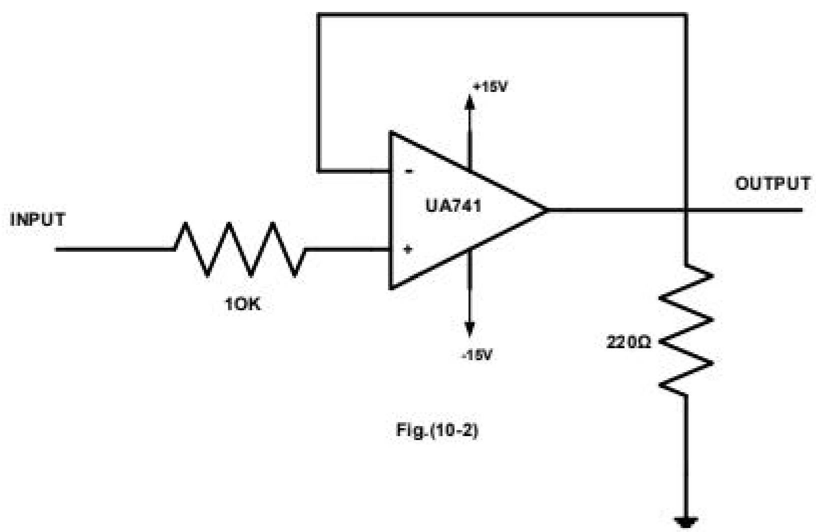

Figure 7:Voltage Follower Application Circuit

Vi was applied using a VDC source, and the output recorded with different input values, using an RL value of 220Ω and 1KΩ.

Vi[Dc,V]	**1**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**12**	**14**	**15**
Vo For RL=220ohm	1.003	3.015	4.069	4.5	4.5	4.44	4.44	4.43	4.43	4.42	4.42
Vo For RL=1Kohm	1.022	3.01	3.99	5.06	6	7.08	7.98	9.95	12.11	12.87	12.87

Table 2:Voltage Follower Application

- This circuit behaves like a voltage buffer and does not provide any voltage gain, unlike the Emitter Follower circuit.
- In general, the relationship that relates the input to the output is simply: Vo = Vi if Vi < Vsat, or Vo = Vsat if Vi ≥ Vsat.
- This puts the maximum possible current, Imax, through the circuit at 20.09mA for a resistor of 220Ω, calculated by 4.42V / 220Ω. In the case of a 1kΩ resistor, Imax is 12.87mA, calculated as 12.87V / 1000Ω.

3. Comparator Application

we set up the circuit below

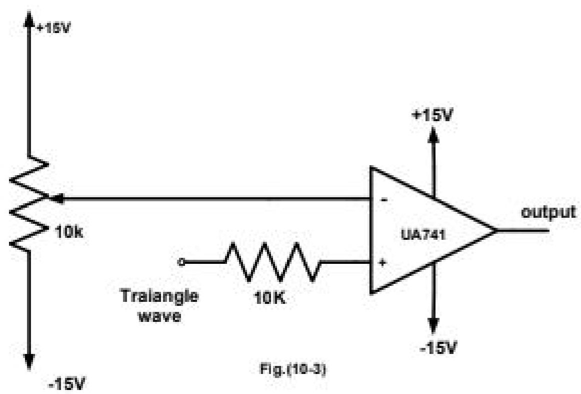

Figure 8:Comparator Application circuit

The DC reference voltage was incremented through a small range from -1.5 to +1.5 to obtain excess +Vsat, –Vsat, and the square wave outputs.

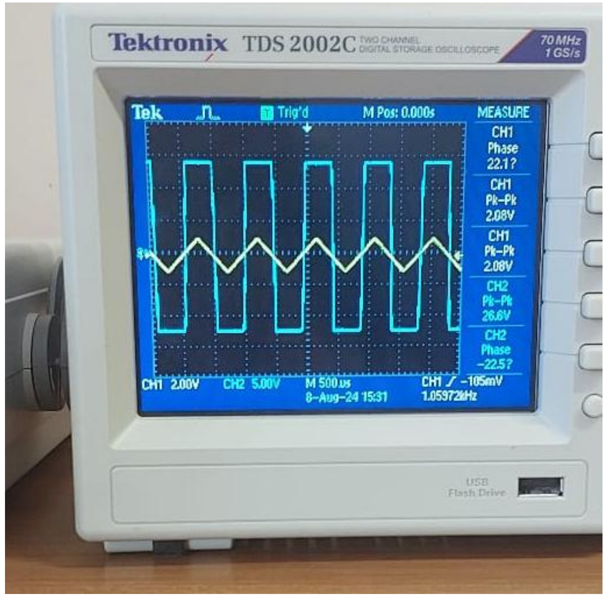

Figure 9:Comparator when Vdc=0

Thus, as given in the above fig, if V1>V2, you get +Vsat = 15V at the output, while if V1<V2, you get -Vsat = -15V at the output.

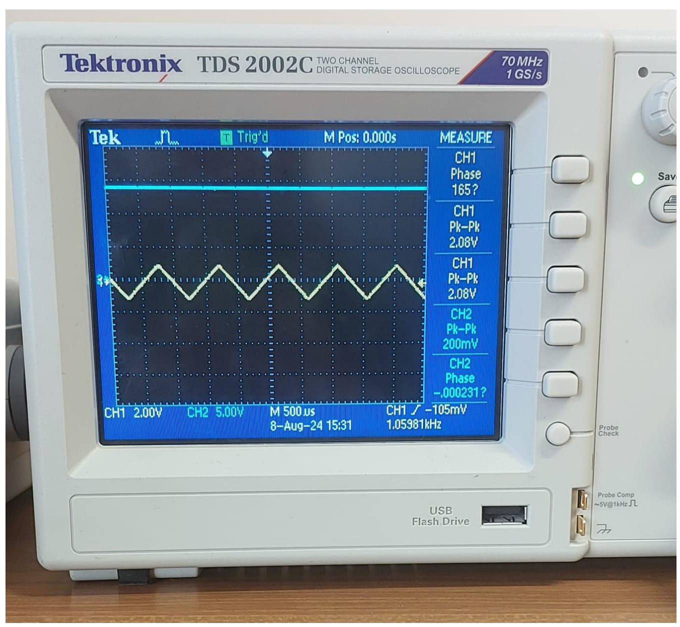

Figure 10:Comparator when Vdc=+1.5

As the above figure shows, when V1 is adjusted to 1.5v and V2 a triangle wave with an amplitude of 1v, V1 always stays greater than V2.

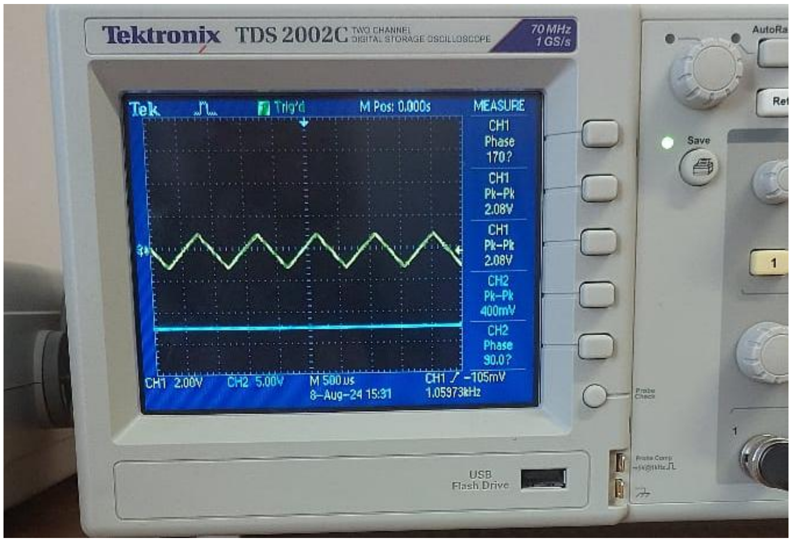

Figure 11:Comparator when Vdc=- 1.5

As shown by the figure above, setting V1 to –1.5V and V2 as a triangle waveform of amplitude 1V will show that V2 is always greater than V1.

- Vsat = -1.590

+ Vsat = -1.590

Square Wave = 0.014

- If Vac is greater than Vdc, Vo is +Vsat. If Vac is less than Vdc, then Vo is –Vsat. If Vac equals Vdc, then Vo is 0.
- The key distinction between this circuit and a differential amplifier is that a comparator can only drive its output to either +Vsat or -Vsat, while a differential amplifier actually produces the difference of two voltages.

4.Comparator with Hysteresis (Schmitt Trigger)

we set up the circuit below

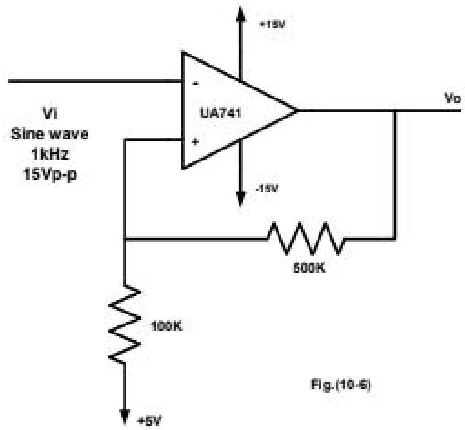

Figure 12:Hysteresis circuit

We set up the function generator to generate a triangular waveform of 1kHz frequency, and amplitude of 15Vp-p. And considered the output signal.

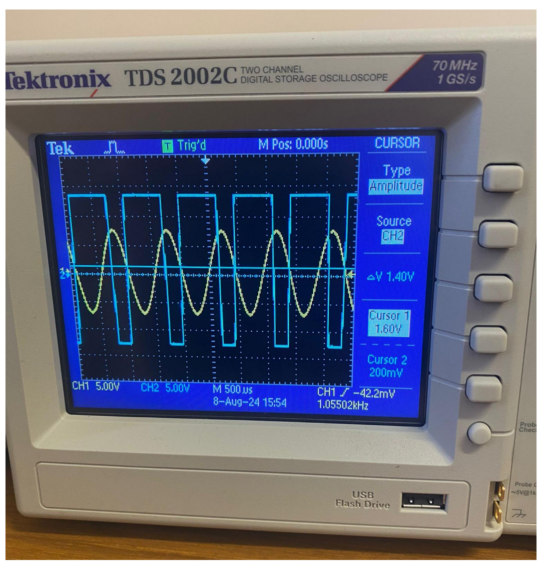

Figure 13:I/O voltage in Hysteresis circuit

- The theoretical value of High, developed by Equation for $\mathrm{Vhigh} = 5 + \frac{100k}{600k} * 15 = 7.5v$, and the theoretical value developed with Equation for $\mathrm{Vlower} = 5 - \frac{100k}{600k} * 15 = 2.5v$.

Conclusion

This lab evaluated the designs of op-amps, such as adding amplifiers, voltage followers, and comparators, to show how feedback enhances an electronic circuit. We saw that, in addition to ensuring stable performance and reducing noise, feedback actually improves the quality of signals. In this process, we learned how to select the most appropriate configuration of op-amps for a given application by considering output voltages. We also determined the differences between Schmitt Triggers and standard comparators and checked their behaviors under realistic conditions.

References

[1] https://en.wikipedia.org/wiki/Operational_amplifier

[Accessed 13/8/2024 ,9:30PM]

[2] https://www.electronics-tutorials.ws/opamp/opamp_4.html
[Accessed 13/8/2024 ,9:46PM]

[3] https://www.electricity-magnetism.org/voltage-followers/
[Accessed 13/8/2024 ,10:06PM]

[4] https://www.electronics-tutorials.ws/opamp/op-amp-comparator.html
[Accessed 13/8/2024 ,10:17PM]

[5] https://developerhelp.microchip.com/xwiki/bin/view/products/amplifiers-linear/operational-amplifier-ics/introduction/comparators-with-hysteresis-schmitt-trigger/
[Accessed 13/8/2024 ,10:22PM]

[6] http://ee.cet.ac.in/downloads/Notes/ECLab/11Comparator%20and%20Schmitt%20Trigger.pdf
[Accessed 13/8/2024 ,10:45PM]

Appendix

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

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.

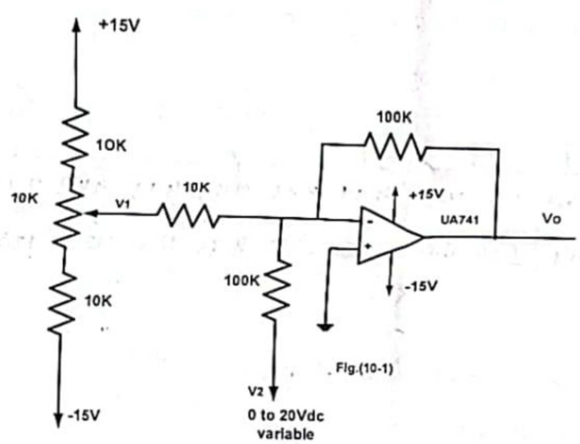

Fig.(10-1)

8/8
11:00

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

Table 10.1

Input voltage		Output voltage	
V_1	V_2	Vo	Calculated voltage
0.5	2	-7.0 V	
0.3	4	-7.35 V	
-0.9	2	6.86 V	
-1.5	6	9.12 V	

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

$$V_O = XV_1 + YV_2$$

where X, Y is the resistors ratios.

II. ***Voltage Follower Application***

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

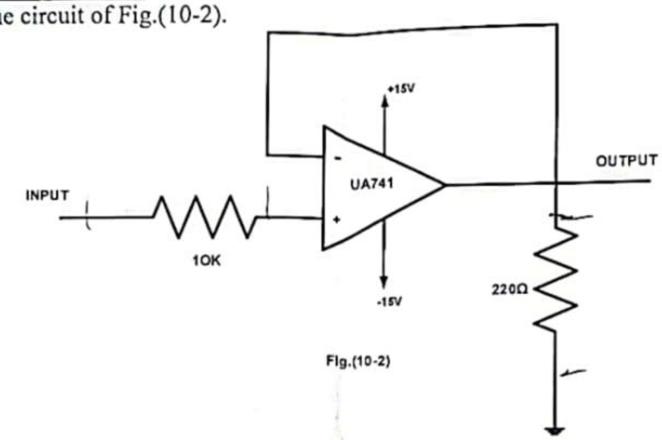

Fig.(10-2)

5. Measure and records Vo for a dc input Vi = (1V,2V,3V,4V,5V,6V, 7V,8,10,12,14 and 15).
6. 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	3	4	5	6	7	8	10	12	14	15
Vo For RL=220ohm	1.003	3.015	4.069	4.5	4.5	4.44	4.44	4.43	4.43	4.42	4.42
Vo For RL=1kohm	1.622	3.01	3.99	5.06	6.0	7.68	7.98	9.95	12.11	12.87	12.87

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?

III. *Comparator Application*

1. Set up the circuit of Fig.(10-3).

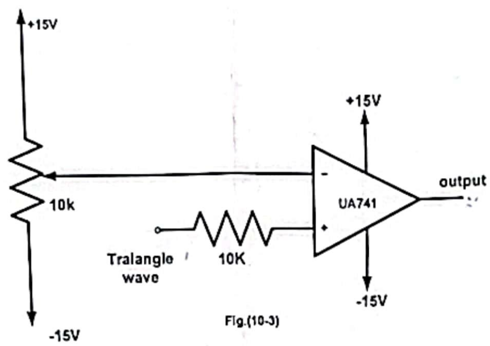

Fig.(10-3)

2. Use 1 kHz triangular input signal from the function generator.

3. Set the triangle input signal to 2 Vp-p and change the **dc reference voltage** in small steps from **-1.5 to +1.5** so that you obtain an output of positive +Vsat then negative -Vsat and a square wave output.

4. For each of these cases draw the output voltage and record the value of the dc reference voltage and **take a picture of the scope screen.**

Question:

- What happens to the amplifier output?. For what application is this circuit used?
- Is there any similarity between this circuit and the diff amplifier, what is the shape of the output?

-Vsat = -1.590
+Vsat = -1.590
squre vave = 0.614

IV. *Comparator with Hysteresis (Schmitt Trigger):*

1. Connect the **Schmitt trigger** circuit shown in Fig.(10-6).

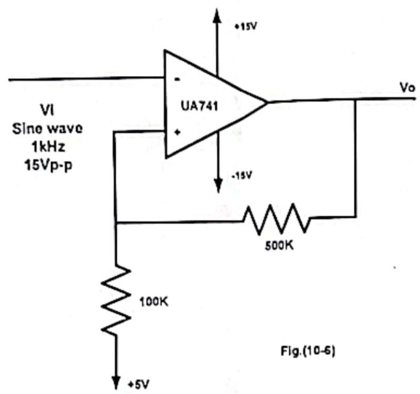

Fig.(10-6)

2. Put Vi(t) = 15Vp-p sine wave of frequency 1 kHz.
3. Sketch the output voltage with respect to Vi(t).
4. Indicate the levels of Vi(t) where Vo(t) changes its level.
5. Calculate the theoretical lower and upper trigger levels for the circuit above and compare them with those of measured values.

Vlow