Faculty of Engineering and Technology

Electrical and Computer Engineering Department

CIRCUITS AND ELECTRONICS LABORATORY– ENEE2103

Experiment No. 10 Report

The Operational Amplifier

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Abstract

This experiment aims to study the application of the op amp circuits such as adding, Voltage follower, Comparator, and Comparator with Hysteresis (Schmitt Trigger). As well investigate these circuits properties, measure characteristics like voltage gain using an oscilloscope, a digital voltmeter (DVM), and a DC power source in the laboratory.

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Theory

1.Adding application:

Op-amp can be utilized to sum the input voltage of two or more sources into a single output voltage. Figure 1 is a circuit chart delineating the application of an op-amp as adder or summing amplifier.

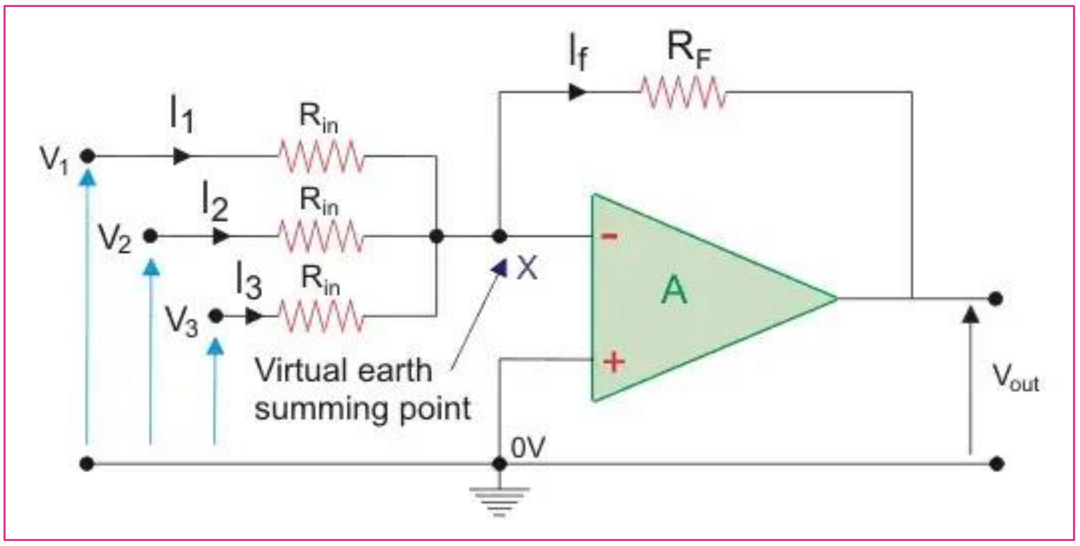


Figure 1 Adder op-amp

The input voltages are connected to the inverting terminal of the op-amp. The non-inverting terminal is connected to the ground. The output voltage is proportional to the entirety of the input voltages (Vout) is the sum of the input voltages, V1, V2, V3. [1] (7:45PM, 5/4/2024)

$If = I1 + I2 + I3 = -[(\frac{V1}{Rin}) + (\frac{V2}{Rin}) + (\frac{V3}{Rin})$

Inverting Equation: Vout = $-\frac{Rf}{Rin} \times Vin$

So Vout = $-[(\frac{Rf}{Rin}) V1 + (\frac{Rf}{Rin}) V2 + (\frac{Rf}{Rin}) V3]$ in this case

Vout = $-[(\frac{Rf}{Rin}) V1 + (\frac{Rf}{Rin}) V2 + \ldots + (\frac{Rf}{Rin}) Vn]$ for n input voltages.

As the circuit can be modified to put more input voltages and follow the equation to get the desired output voltage.

2.Voltage Follower Application:

A voltage follower, also known as a noninverting buffer, other common names for the voltage follower are isolation amplifier, and unity-gain amplifier the output signal equal in amplitude to the input signal, Hence, the name of the follower that the output voltage directly follows the input voltage.

It operates with unity gain that is achieved through negative feedback. Without this feedback, the operational amplifier would display a high output voltage for any small input changes due to its high gain. [2]

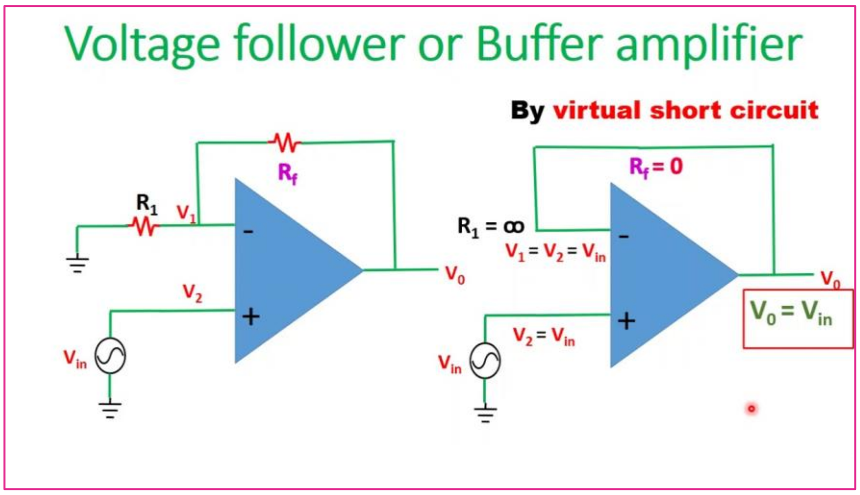


Figure 2 Voltage follower [3]

Since the op-amp is ideal, negative feedback (V−) reduces change by adjusting the output voltage (Vo), to matches the voltage at the noninverting input terminal (V+ = Vi), So V− = V+ = Vi = Vo.

3.Voltage Comparator Application

The op-amp comparator compares two analog voltage levels or with a reference voltage and produces an output signal based on this comparison, specifying which input is larger. Unlike op-amps comparators operate with positive feedback or open-loop gain A_O so its output voltage is given by the expression: $V_{OUT} = A_O (V+ – V-)$ where V+ and V- correlate to the voltages at the non-inverting and the inverting terminals respectively.

This setup allows the comparator to switch between saturated states, either to its positive or negative supply(reference), due to its high open-loop gain. Meanwhile with reference when V_{IN} is less than the DC voltage level at V_{REF}, ($V_{IN} < V_{REF}$), the output will be LOW and at the negative supply voltage, -Vcc resulting in a negative saturation of the output.

If the V_{IN} is increased above V_{REF}, the output rapidly switches to HIGH and reaches positive saturation. When the V_{IN} is slightly lower than V_{REF} again, the output switches back to negative saturation.

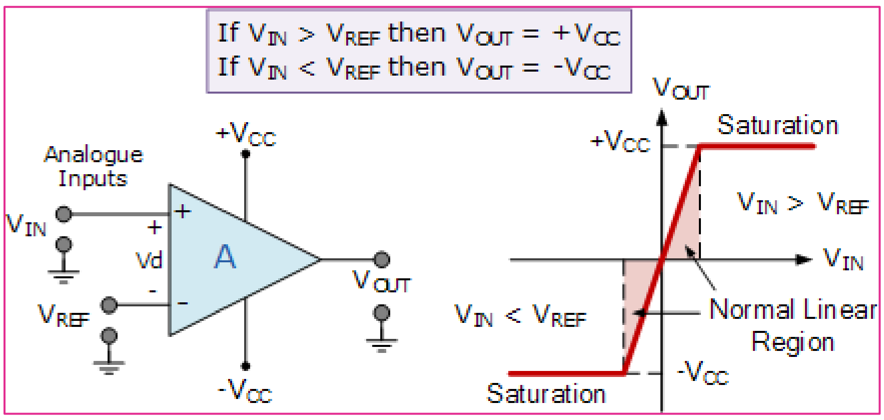


Figure 3 Op-Amp comparator

In theory the comparators reference voltage can be set to be anywhere between 0v and the supply voltage but there are practical limitations on the actual voltage range depending on the op-amp comparator being device used. [4]

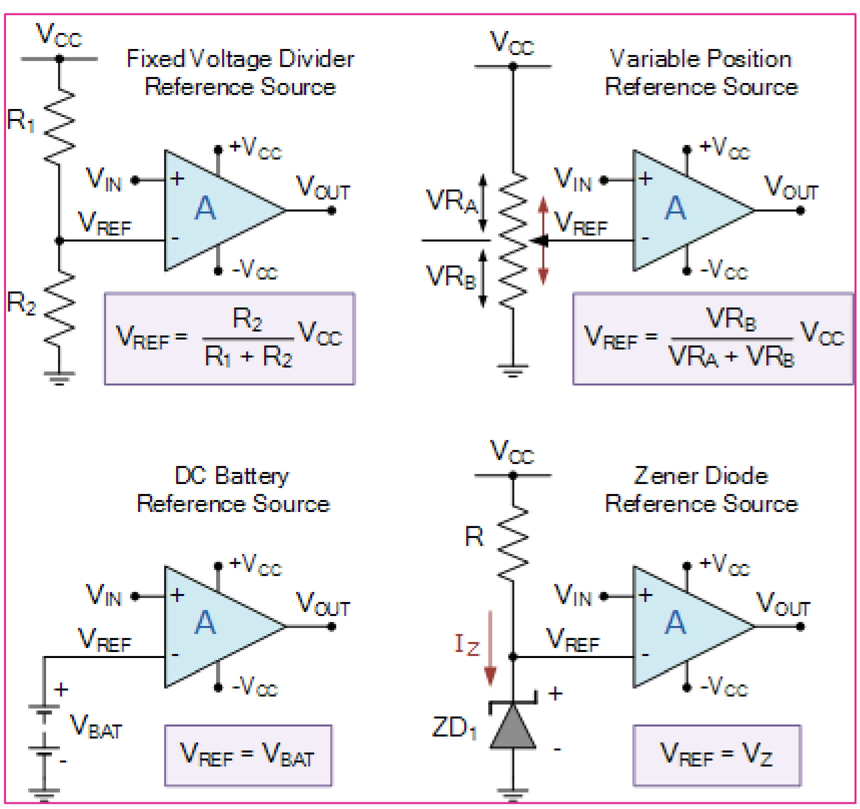


Figure 4 Op-Amp comparator with reference

4. Comparator with Hysteresis (Schmitt Trigger)

in an Inverting Schmitt Trigger, the input is applied to the inverting terminal of the Op-Amp. In this mode, the output produced is of opposite polarity. This output is applied to non-inverting terminal to ensure positive feedback.

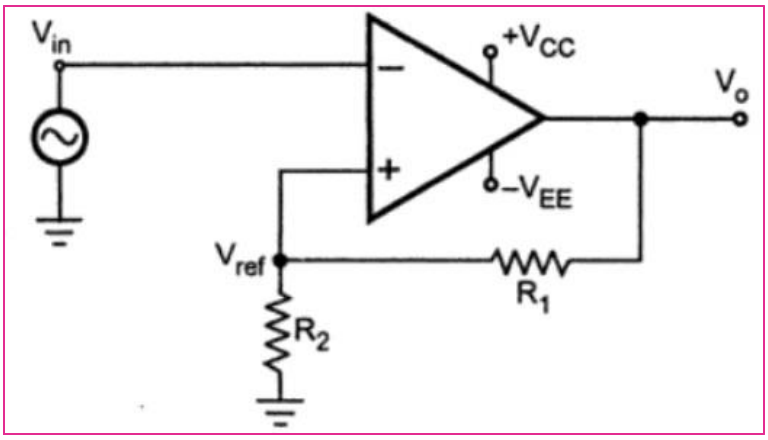


Figure 5 Schmitt Trigger

When V_{IN} is slightly greater than V_{REF}, the output becomes $-V_{SAT}$ and if V_{IN} is slightly less that $-V_{REF}$ (more negative than $-V_{REF}$), then output becomes V_{SAT}. Hence, the output voltage V_O is either at V_{SAT} or $-V_{SAT}$ and the input voltage at which these state changes occur can be controlled using R_1 and R_2.

The values of V_{REF} and $-V_{REF}$ can be formulated as follows:

$$V_{REF} = \frac{(VO \times R2)}{(R1 + R2)}$$

But $V_O = V_{SAT}$. Hence,

$$V_{REF} = \frac{(V_{SAT} \times R2)}{(R1 + R2)}$$

$$-V_{REF} = \frac{(VO \times R2)}{(R1 + R2)}$$

But $V+= -V_{SAT}$. Hence,

$$-V_{REF} = \frac{(V_{SAT} \times R2)}{(R1 + R2)}$$

The reference voltages V_{REF} and $-V_{REF}$ are called Upper Threshold Voltage V_{UT} and Lower Threshold Voltage V_{LT}. The following image shows the output voltage versus input voltage graph. It is also known as the Transfer Characteristic of Schmitt Trigger.[5]

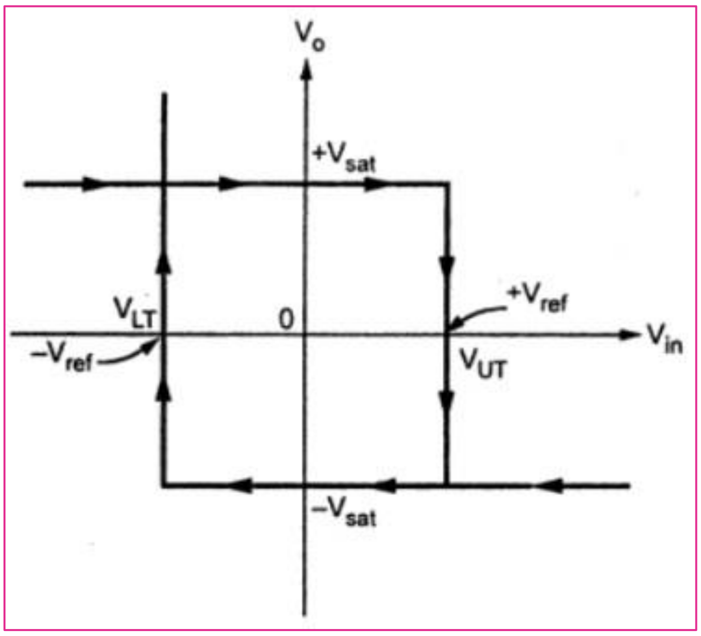


Figure 6 Transfer Characteristic of Schmitt Trigger

or as a pure sinusoidal input signal, the output of an Inverting Schmitt Trigger Circuit.

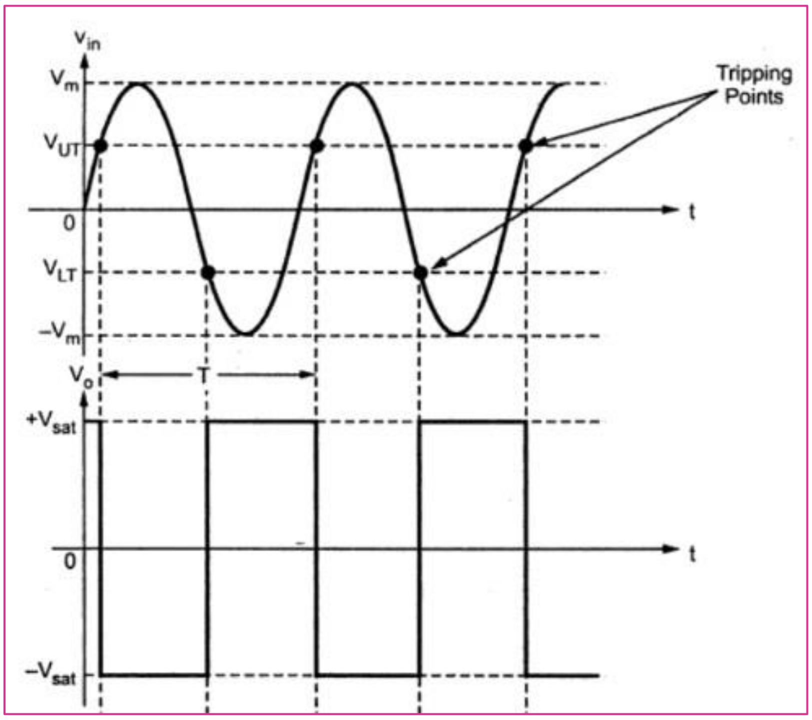


Figure 7 Transfer Characteristic of Schmitt Trigger with a sinusoidal input

5. Electronic components:

5.1: Oscilloscope:

Oscilloscope is the device used to measure time response in the circuits, it will display the output of the circuit as a graph of either voltage or current depending on the inputs connect to its channels.[11]

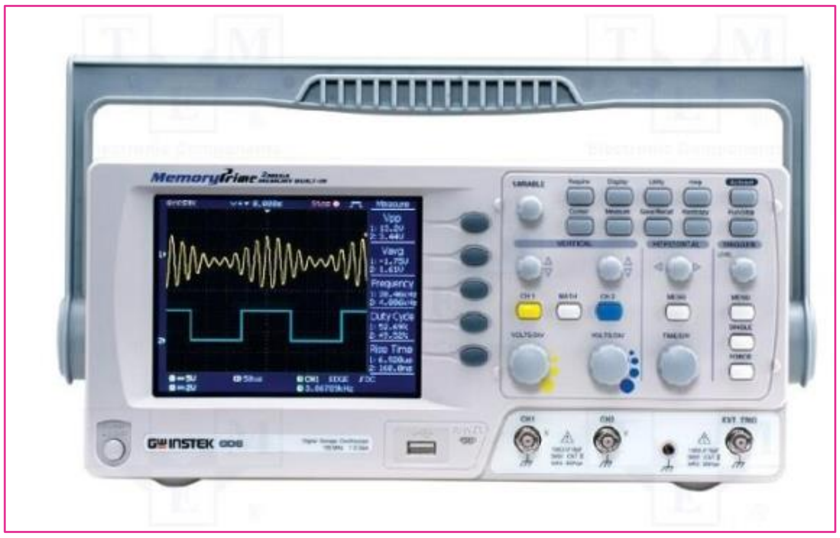


Figure 8 Oscilloscope

5.2: DVM Digital Volt Meter:

DMV is used to measure the voltage at which various appliances, the readings that a digital voltmeter offers are more accurate and fast as compared to analog meters. They are stable and hence, more reliable than earlier systems. They can measure both AC and DC voltage systems.[12]

Figure 9 Digital Volt Meter

Procedure and Data analysis

1. Adding Application:

After the circuit in figure 10 has been connected, as V1 is controlled and adjusted by the potentiometer and V2 from DC source on trainer.

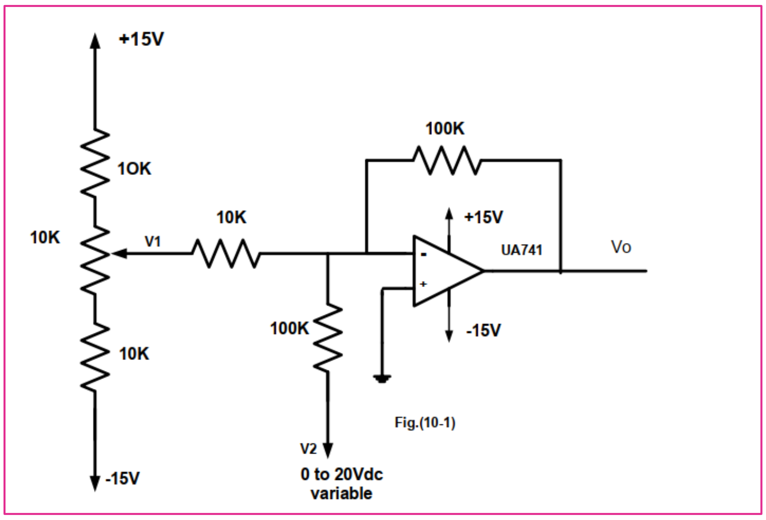


Figure 10 Adding Application circuit

V0 values has been measured as the following:

Table 1 Measured Data of V1, V2, V0

Input voltage		Output voltage	
V1	V2	V0	Calculated voltage
0.5	2	-7.147	-7
0.3	4	-7.028	-7
-0.9	2	7.002	7
-1.5	6	9	9

1.1: Calculating V_0:

To calculate V0

$$Vo = -\left(\frac{R_F}{R_1} V_1 + \frac{R_F}{R_2} V_2\right)$$

$$-\left(\frac{100k}{10k} V_1 + \frac{100k}{100k} V_2\right)$$

$$Vo = -(10\,V_1 + V_2)$$

It has been n noticed how the values of V0 measured and calculated are almost identical with a small difference between them.

2. Voltage Follower Application

The circuit in figure 11 has been connected, and Vo has been connected to the oscilloscope.

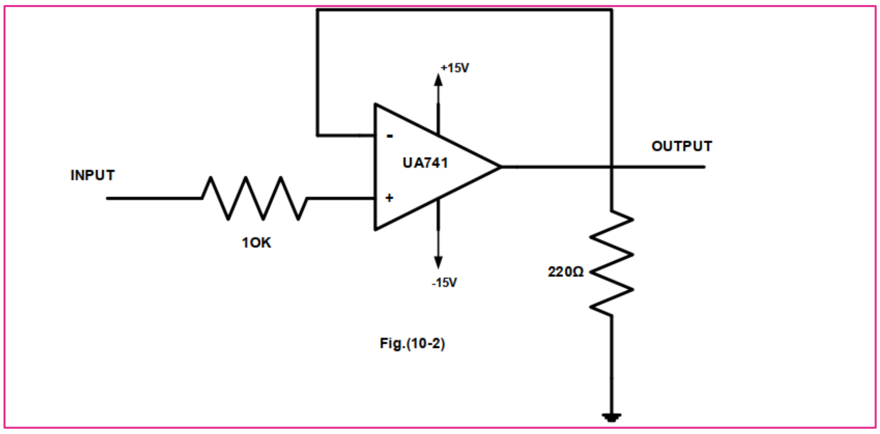


Figure 11 Voltage follower application circuit

Measurements of Vo for a dc input Vi by changing the connection from the DC trainer.

Table 2 Voltage Follower voltage output

Vi [DC, V]	**1**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**12**	**14**	**15**
Vo R_L=220Ω	1.055	3.089	4.067	4.538	4.521	4.507	4.501	4.493	4.488	4.483	4.479
Vo R_L=1kΩ	1.002	3.057	4.012	5	6.003	7.083	8.090	10.064	12.040	12.282	12.274

Questions Answers:

1. Both circuits provide isolation between the input and output signals. The emitter follower or common collector circuit provides an ideal buffer amplifier, and the op-amp acts as a voltage follower, producing an output voltage that closely tracks the input voltage. And both circuits have high input impedance and low output impedance.

2. Its used as a buffer in electronic logic circuits, isolation of input and output circuits, bridge circuits through a transducer, sample and hold circuits and in active filters. [6]

3.A. For 220Ohm:
Vo = Vi from 0 to around 4.5 until it reached the saturation mode
Vo=Vmax = 4.538 for [4.5-15]
3.B. For 1kOhm:
Vo = Vi from 0 to around 12.2 until it reached the saturation mode
Vo=Vmax = 12.282 for [12.2 -15]

An ideal op amp has no limits. Real ones do Because it's not possible to drive an output beyond the power supply rails due to Kirchhoff Voltage Law (KVL). the sum of the voltages in any circuit loop must sum to zero and the power supply is algebraically "negative" and resistor, have positive voltage drops so the latter can never exceed the former.[7]

4.A. $I_{Max} = V_{Max} / 220$
$= 4.5380 / 220 = 20.6272mA$
4.B. $I_{Max} = V_{Max} / 1000$
$= 12.282 / 1000 = 12.282mA$

3. Comparator Application

The circuit in figure 12 has been connected, and Vo has been connected to the oscilloscope. DC reference has been changed in small steps from 0 to -1.5 and -1.5 As the following:

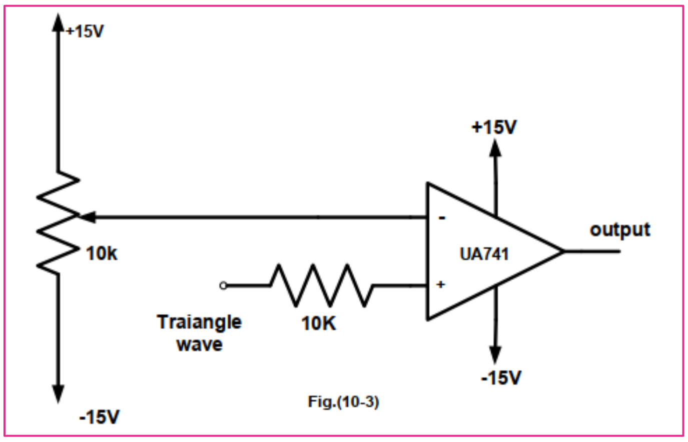


Figure 12 Comparator Application circuit

3.1 When V_{DC} = 0 Volt.

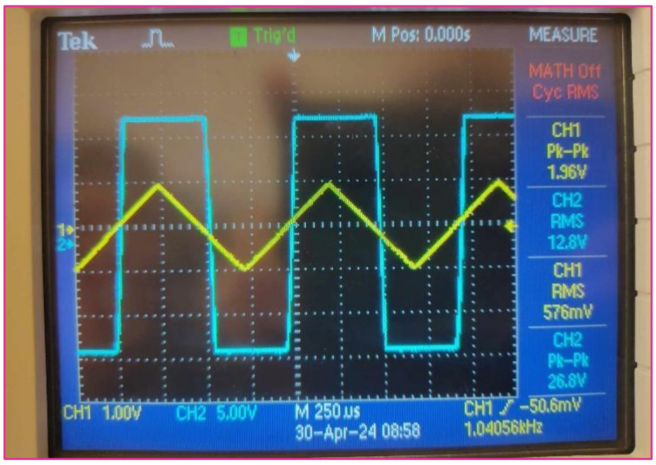


Figure 13 Comparator circuit output when V_{DC} = 0Volt

From figure 13: When V_{AC} >0 then V_{OUT} = Vsat and when V_{AC} < 0 the output = -Vsat, as the input reference (V_{DC}) is 0v, So the value of the output voltage is totally dependent on the supply voltage.

3.2 When V_{DC} = -1.5 Volt.

Figure 14 Comparator circuit output when V_{DC} = -1.5Volt

From figure14: V_{OUT} = +Vsat as +Vsat = 200mV as the input (V_{DC}) is -1.5v, as $V_{AC} > V_{DC}$.

3.3 When V_{DC} = 1.5 Volt.

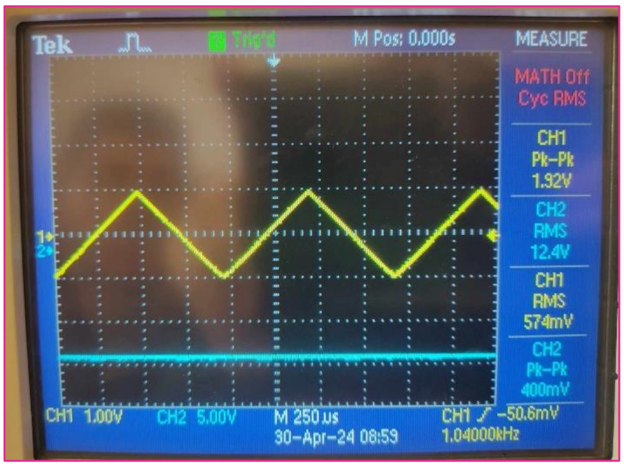


Figure 15 Comparator circuit output when V_{DC} = 1.5Volt

From figure 15: V_{OUT} = -Vsat as -Vsat = 200mV as the input (V_{DC}) is +1.5v, as $V_{AC} < V_{DC}$.

Questions Answers:

1.A. As has been seen through output pictures, when triangle input (V_{AC}) > 0, V_{OUT} will equal to Vsat and when V_{AC} less than 0 the output = -Vsat, as the input reference (V_{DC}) is 0v, So the value of the output voltage is only dependent on the supply voltage, V_{OUT} equal to zero when $V_{AC} = V_{DC}$.

The output shift to -Vsat = 200mV when the input reference (V_{DC}) is +1.5v because V_{AC} is less than input reference.

The output shift to +Vsat = 200mV when the input reference (V_{DC}) is -1.5v because V_{AC} is more than input reference.

1.B. Comparator used as Threshold detector, zero crossing detector, Schmitt trigger and Relaxation oscillator. [8]

2. The comparator can only provide +Vsat or - Vsat, whereas the diff amplifier can provide the difference of two voltages, therefore they do not share the same output, as example:

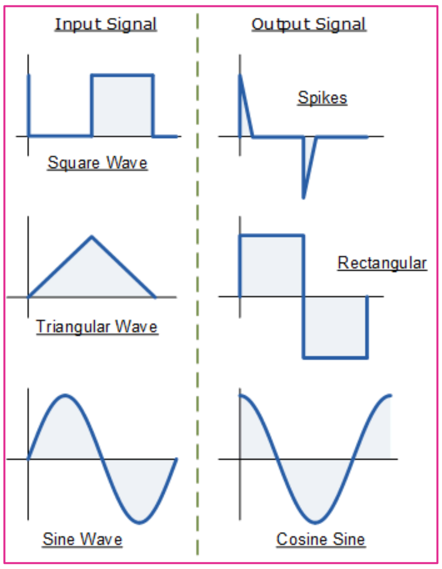


Figure 17 Differentiator op amp [9]

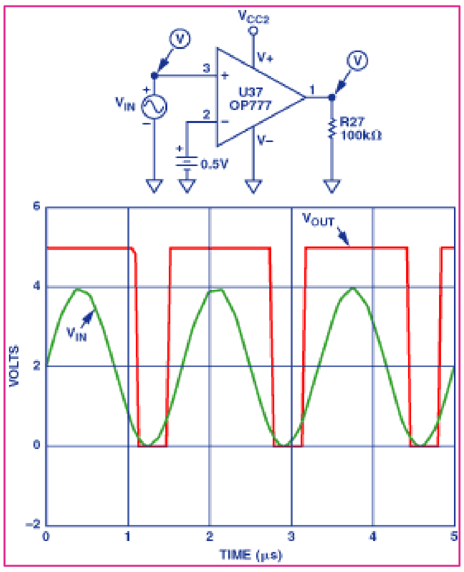


Figure 16 Comparator Op amp [10]

4. Comparator with Hysteresis (Schmitt Trigger):

The circuit in figure 18 has been connected, vi is sat to be sinusoidal wave of frequency 1kHz and $15V_{P-P}$, Vo has been connected to the oscilloscope.

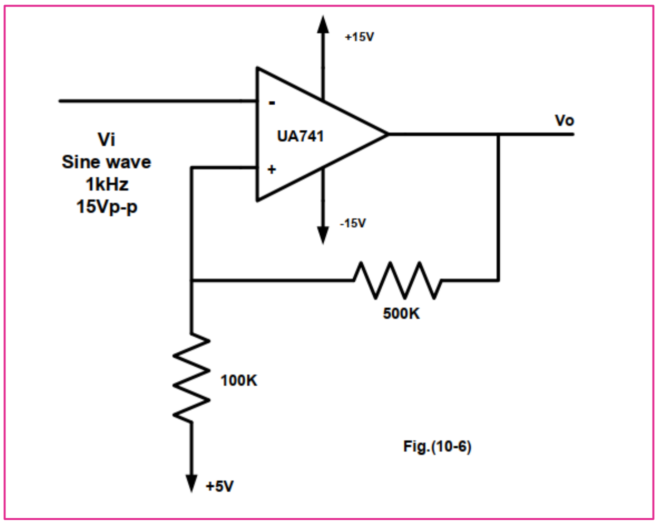


Figure 18 Schmitt trigger circuit

Which has given the following output:

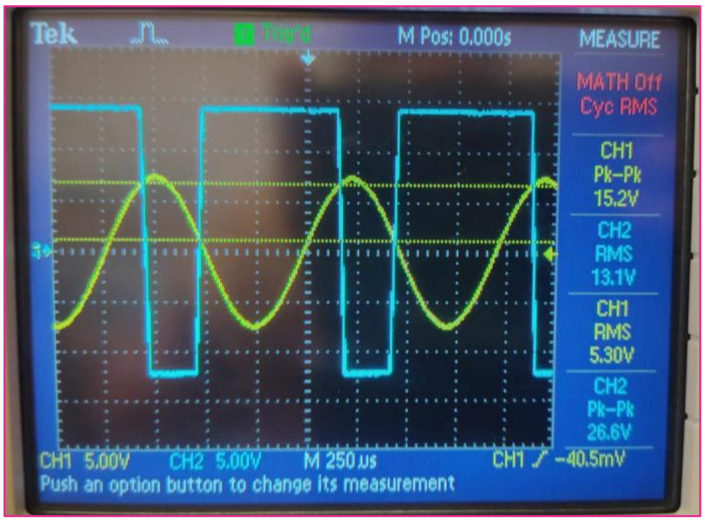


Figure 19 Schmitt trigger circuit simulation

For measurement, the curser has been used:

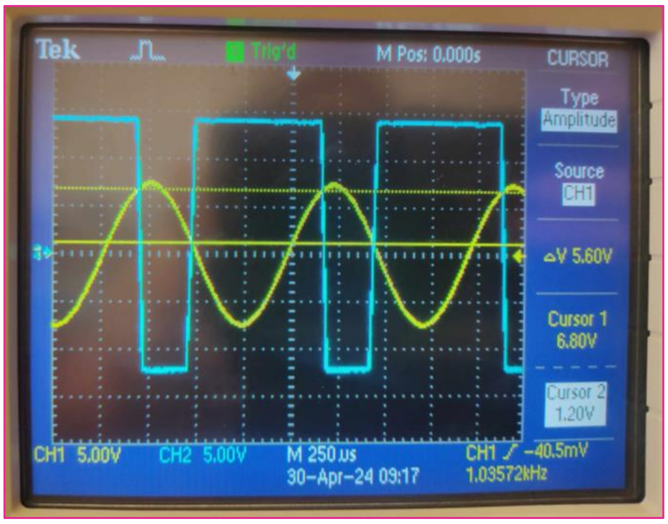


Figure 20 Schmitt trigger circuit simulation with measurement

From figure 20, V_{UT} As Voltage of Upper threshold, V_{LT} As Voltage of Lower threshold

V_{UT} = 6.8 Volt.
V_{LT} = 1.2 Volt

Then the Hysteresis voltage can be given as:

$$V_H = V_{UT} - V_{LT} = 6.8 - 1.2 = 5.6$$

$V_{UT} = \left(\frac{R_1}{R_1+R_2} V_{sat} + \frac{R_2}{R_1+R_2}(5)\right)$ $\left(\frac{100k}{600k} 13 + \frac{500k}{600k} 5\right)$ $= 6.333$
$V_{LT} = -\left(\frac{R_1}{R_1+R_2} V_{sat}\right) + \frac{R_2}{R_1+R_2}(5)$ $-\left(\frac{100k}{600k} 13\right) + \frac{500k}{600k} 5$ $= 2$

Then the Hysteresis voltage can be given as:

$$V_H = V_{UT} - V_{LT} = 6.3333 - 2 = 4.333$$

It has been noticed that the values are similar and close, yet there's a difference that's firstly due to Vin was close to 15, but it has been put to 15.2V, Leading the values to the Schmitt trigger to varies, as well as other errors in op-amp possibly or in the wires' impedance connection.

Conclusion

In summary, the experiment shows the applications and the benefits of using feedback in electronic circuits. Through the use of different configurations such as inverting and noninverting adder amplifier, voltage follower, comparator and comparator with hysteresis (Schmitt trigger). The experiment also concluded that buffer feedback is a powerful circuit element that can be used to improve signal integrity, reduce noise and distortion, and provide stable gain in electronic systems

References

[1] https://www.electrical4u.com/applications-of-op-amp/ [7:45 PM, 4 May 2024]

[2] https://www.allaboutcircuits.com/video-tutorials/op-amp-applications-voltage-follower/ [8:45 PM, 4 May 2024]

[3] https://www.youtube.com/watch?v=gtJPeh3HvHU [9:30 PM, 4 May 2024]

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

[5] https://www.electronicshub.org/schmitt-trigger-basics/ [11:10 PM, 4 May 2024]

[6]https://www.tutorialspoint.com/voltage-follower-using-operational-amplifier-definition-circuit-diagram-working-and-applications [10:20 AM, 5 May 2024]

[7] https://www.quora.com/Why-does-the-output-of-the-op-amp-reach-a-limit-and-saturate-regardless-of-the-gain [12:15 AM, 5 May 2024]

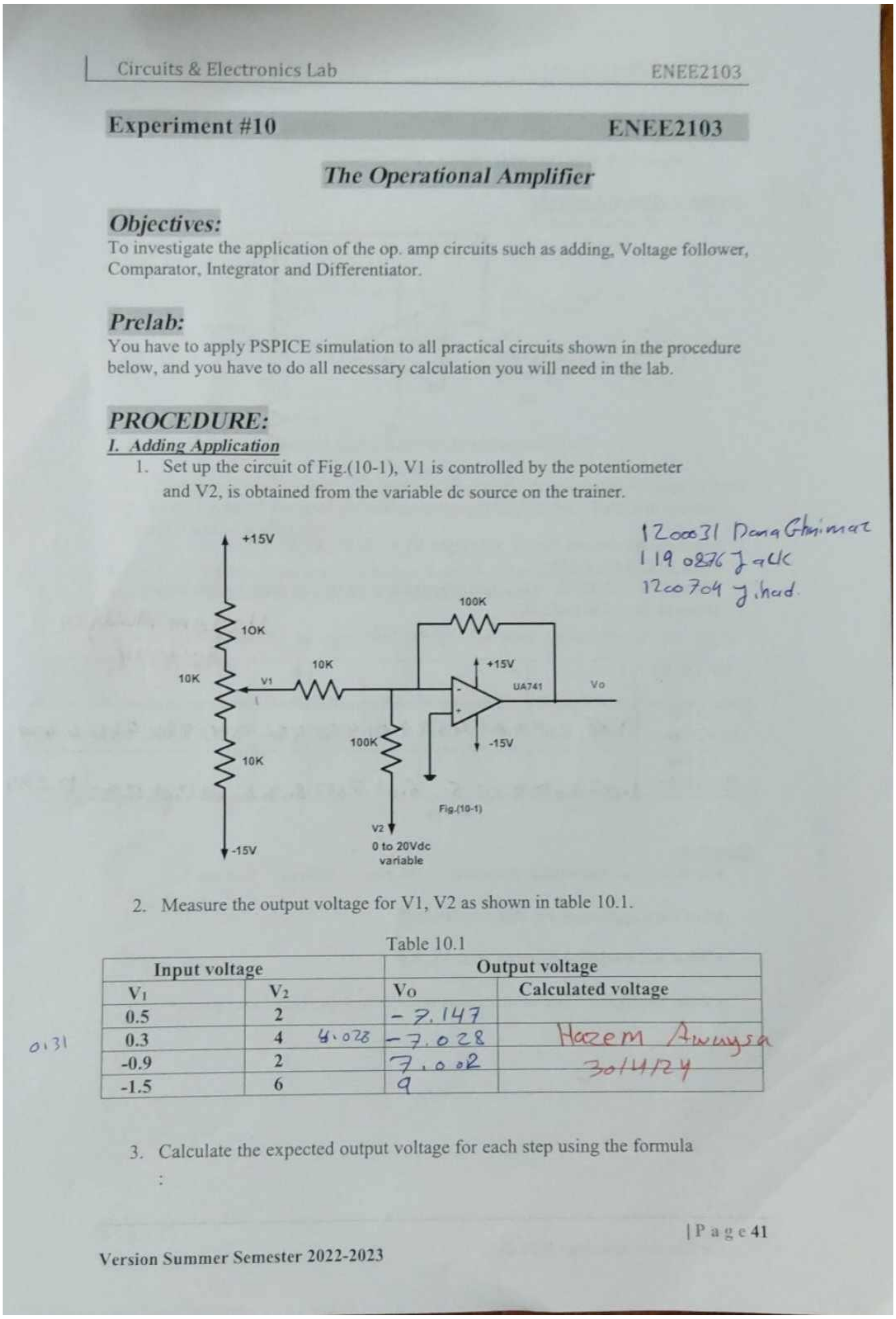
[8] https://en.wikipedia.org/wiki/Comparator_applications [12:50 AM, 5 May 2024]

[9] https://www.electronics-tutorials.ws/opamp/opamp_7.html [1:20 PM, 5 May 2024]

[10] https://www.analog.com/en/resources/analog-dialogue/articles/amplifiers-as-comparators.html [1:20 PM, 5 May 2024]

Appendix

1. Lab paper table of adder



Circuits & Electronics Lab ENEE2103

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.

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1190876 Jack
1200704 Jihad

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	-7.147	
0.3 (0.31)	4 (4.028)	-7.028	Hazem Awwysa
-0.9	2	7.002	30/4/24
-1.5	6	9	

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

:

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Figure 21 Lab paper 1 adder table

2. Lab paper follower table

$$V_0 = XV_1 + YV_2$$

where X, Y is the resistors ratios.

II. ***Voltage Follower Application***

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

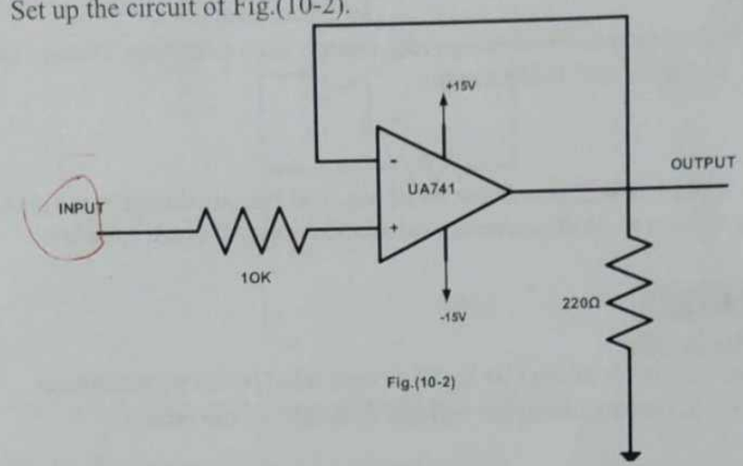

Fig.(10-2)

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.

Hazem Awaysa
30/4/24

Table 10.2

Vi [DC,V]	1	3	4	5	6	7	8	10	12	14	15
Vo For RL=220ohm	1.055	3.089	4.067	4.538	4.521	4.567	4.501	4.493	4.488	4.483	4.479
Vo For RL=1kohm	1.062	3.057	4.012	5 4.999	6.003	7.083	8.090	10.069	12.06	12.282	12.274

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?

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Figure 22 Lab paper 2 Follower table