Experiment

Study of basic OP-AMP operations, mathematical operations and applications

Objectives

1. Study of inverting and non-inverting amplifier configurations and finding their gain.
2. Study simple mathematical operations - Summing and difference amplifiers
3. Applications of OP-AMP - Comparator and Schmitt trigger

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1 Study of inverting and non-inverting amplifier configurations and finding their gain

1.1 Circuit components/equipment

1. OPAMP 741 chip
2. Resistors
3. Oscilloscope
4. DC voltage source
5. Breadboard.

1.2 Theory

Operational amplifiers can be connected using external resistors or capacitors in a number of different ways to form basic "Building Block" circuits such as, Inverting, Non-Inverting, Voltage Follower, Summing, Differential, Integrator and Differentiator type amplifiers. There are a very large number of operational amplifier IC's available to suit every possible application. The most commonly available and used of all operational amplifiers is the industry standard 741 type IC.

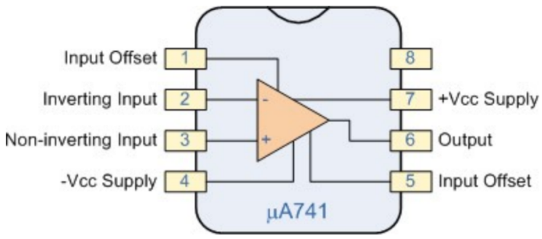

Figure 1: Schematic of an OP-AMP.

Inverting amplifier

In inverting amplifier circuit, the operational amplifier is connected with feedback to produce a closed loop operation. There are two very important rules to remember about inverting amplifiers: "no current flows into the input terminal" and that '$V_1 = V_2$'. This is because the junction of the input and feedback signal (X) is at the same potential as the positive (+) input which is at zero volts or ground then, the junction is a "Virtual Earth". Because of this virtual earth node, the input resistance of the amplifier is equal to the value of the input resistor, R. Then by using these two rules one can find the equation for calculating the gain of an inverting amplifier, using first principles. Current (I) flows through the resistor network as shown.

$$I_{\text{in}} = \frac{V_{\text{in}}}{R_{\text{in}}} = -\frac{V_{\text{out}}}{R_F}$$

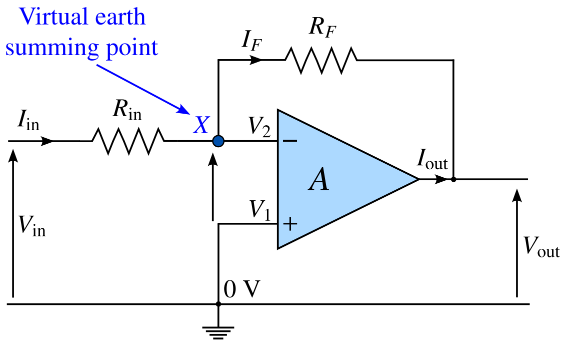

Figure 2: Typical circuit diagram of an OP-AMP.

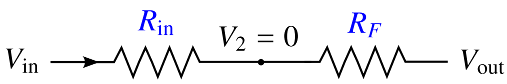

Figure 3: Voltage divider circuit.

The negative sign in the equation indicates an inversion of the output signal with respect to the input as it is 180° out of phase. This is due to the feedback being negative in value. Then, the Closed-Loop Voltage Gain of an Inverting Amplifier is given as

$$\text{Gain} = \frac{V_{out}}{V_{in}} = -\frac{R_F}{R_{in}}$$

Non-inverting amplifier

The second basic configuration of an operational amplifier circuit is that of a non-inverting amplifier. In this configuration, the input voltage signal, (V) is applied directly to the non-inverting (+) input terminal which means that the output gain of the amplifier becomes "positive" in value in contrast to the "inverting amplifier" circuit whose output gain is negative in value. Feedback control of the non-inverting amplifier is achieved by applying a small part of the output voltage signal back to the inverting (−) input terminal via a $R_F - R_2$ voltage divider network, again producing negative feedback. This produces a non-inverting amplifier circuit with very good stability, a very high input impedance, R approaching infinity (as no current flows into the positive input terminal) and a low output impedance, R_{out} as shown below.

Since no current flows into the input of the amplifier, $V_1 = V_{in}$. In other words, the junction is a "virtual earth" summing point. Because of this virtual earth node, the resistors R_F and R_2 form a simple voltage divider network across the amplifier and the voltage gain of the circuit is determined by the ratios of R_2 and R_F as shown below.

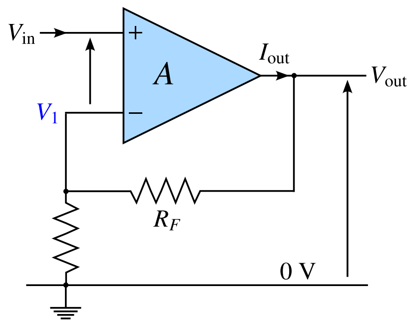

Figure 4: A typical non-inverting amplifier circuit.

Equivalent voltage divider network

Then using the formula to calculate the output voltage of a potential divider network, we can calculate the output voltage gain of the Non-Inverting Amplifier as:

$$V_{out} = V_{in}\left(1 + \frac{R_F}{R_2}\right)$$
$$\text{Gain} = \frac{V_{out}}{V_{in}} = 1 + \frac{R_F}{R_2}.$$

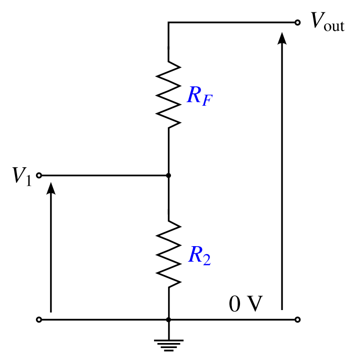

Figure 5: Voltage divider circuit (Non-inverting).

1.3 Circuit diagram

The circuit diagrams for inverting and non-inverting amplifiers are shown in figure 6 and figure 7 respectively.

1.4 Procedure

1.4.1 Inverting amplifier

1. Configure the circuit as shown in the circuit diagram. Connect pins 7 and 4 of the IC to the ±15 V output terminals of the DC power supply. Connect the

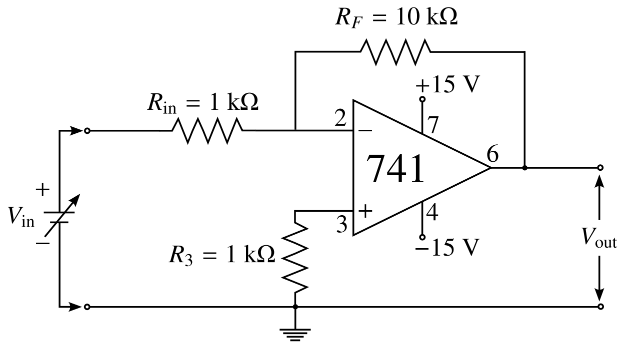

Figure 6: Inverting amplifier circuit.

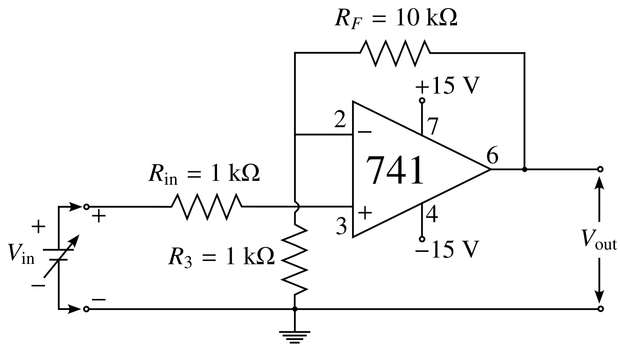

Figure 7: Non-inverting amplifier circuit.

0 V terminal to the ground. Choose $R_{in} = 1$ kΩ and $R_F = 10$ kΩ. Measure the resistance values with a multimeter and calculate gain, $-R_F/R_{in}$. Connect a resistor $R_3(R_{in} \vee R_F \approx R_{in})$ as shown in the circuit diagram to minimize offset due to input bias current.

2. Connect one of the output terminals of the DC power supply (0 - 30V) at the inverting input (pin no. 2).

3. Switch on the power supply and apply different voltages in the range 0 - 1.5 V in steps of 0.2 V at the inverting terminal. Measure this input using a digital multi-meter.

4. Measure the corresponding output voltages with the multimeter and calculate gain V_{out}/V_{in}. Note the sign of the output voltage.

5. Now, replace R_F by 50 kΩ. Measure the resistance value with the multimeter and calculate gain, $-R_F/R_{in}$.

6. Apply different voltages in the range 0 - 0.5 V in steps of 0.1 V at the inverting terminal. Measure this input using a digital multimeter.

7. Measure the corresponding output voltages with the multimeter and calculate gain V_{out}/V_{in}.

8. Plot graphs for V_{in} vs. V_{in} for both the values of R_F.

9. You may also use a function generator to give a sinusoidal input and notice the output waveform using an oscilloscope.

1.4.2 Non-inverting amplifier

1. Configure the circuit as shown in the circuit diagram with $R_{in} = 1$ kΩ and $R_F = 10$ kΩ. Using the measured value of resistance calculate gain, $1 + (R_F/R_{in})$.
2. Connect one of the output terminals of the DC power supply (0 - 30V) at the non-inverting input (pin no. 3).
3. Repeat steps 3. onwards of procedure of the inverting amplifier with inputs applied at the non-inverting terminal.

1.5 Observations

Table 1: Inverting amplifier

Obs. No.	Input (V)	$-R_F/R_{in} =$			$-R_F/R_{in} =$		
		Output (V)	Gain = V_{out}/V	Average	Output (V)	Gain = V_{out}/V	Average
1	0.2						
2	0.4						
...	...						

Table 2: Non-inverting amplifier

Obs. No.	Input (V)	$1 + R_F/R_{in} =$			$1 + R_F/R_{in} =$		
		Output (V)	Gain = V_{out}/V	Average	Output (V)	Gain = V_{out}/V	Average
1	0.2						
2	0.4						
...	...						

1.6 Results

2 Study simple mathematical operations - Summing and difference amplifiers

2.1 Theory

Summing amplifier

The summing amplifier is a very flexible circuit based upon the standard inverting operational amplifier configuration. We saw previously that the inverting amplifier has a single input signal applied to the inverting input terminal. If we add another input resistor equal in value to the original input resistor, R_{in} we end up with another operational amplifier circuit called a "summing amplifier", "summing inverter" or even a "voltage adder" circuit as shown below

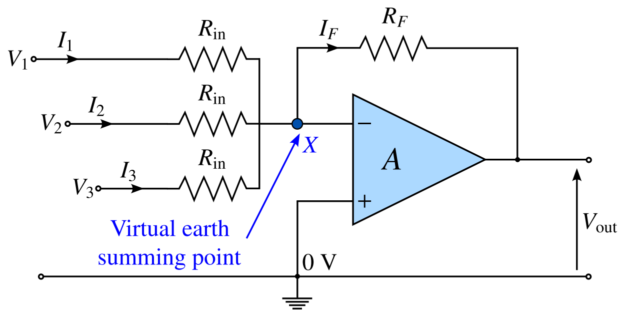

Figure 8: Typical summing amplifier circuit.

The output voltage, (V_{out}) now becomes proportional to the sum of the input voltages, V_1, V_2, V_3 etc. Then we can modify the original equation for the inverting amplifier to take account of these new inputs thus:

$$I_F = I_1 + I_2 + I_3 = -\left(\frac{V_1 + V_2 + V_3}{R_{\text{in}}}\right) = \frac{V_{\text{out}}}{R_F}$$

$$V_{\text{out}} = -\frac{R_F}{R_{\text{in}}}(V_1 + V_2 + V_3)$$

The summing amplifier is a very flexible circuit indeed, enabling us to effectively "add" or "sum" together several individual input signals. If the input resistors are all equal a unity gain inverting adder can be made. However, if the input resistors are of different values a "scaling summing amplifier" is produced which gives a weighted sum of the input signals.

Difference amplifier

Up to now we have used only one input to connect to the amplifier, using either the "inverting" or the "non-inverting" input terminal to amplify a single input signal with the other input being connected to ground. But we can also connect signals to both of the inputs at the same time producing another common type of operational amplifier circuit called a differential amplifier. The resultant output voltage will be proportional to the "difference" between the two input signals, V_1 and V_2. This type of circuit can also be used as a subtractor.

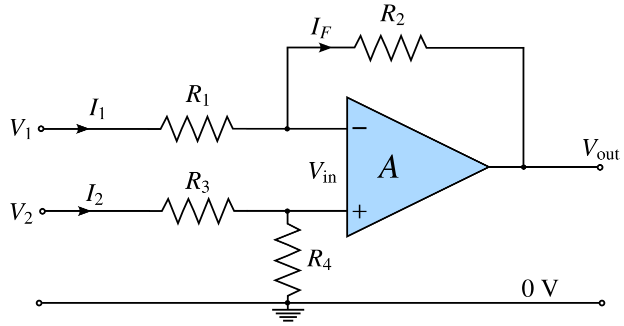

Figure 9: Typical difference amplifier circuit.

The transfer function for a differential amplifier circuit is given as:

$$V_{\text{out}} = -\frac{R_2}{R_1}V_1 + \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right)V_2.$$

When $R_1 = R_3$ and $R_2 = R_4$, the transfer function formula can be modified to the following:

$$V_{\text{out}} = -\frac{R_2}{R_1}(V_2 - V_1).$$

If all the resistors are of the same ohmic value, the circuit will become a unity gain differential amplifier and the gain of the amplifier will be 1 or unity.

2.2 Circuit diagram

The circuit diagrams for summing and difference amplifiers are shown in figure 10 and figure 11 respectively.

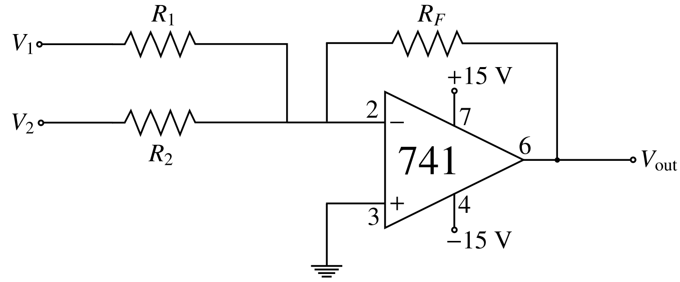

Figure 10: Summing amplifier circuit.

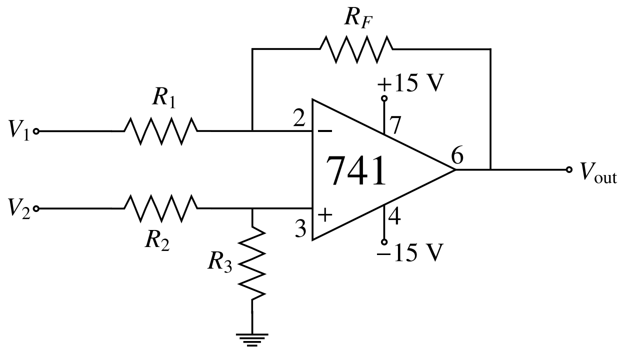

Figure 11: Difference amplifier circuit.

2.3 Procedure

2.3.1 Summing amplifier

1. Assemble the circuit as shown in circuit diagram choosing $R_1, R_2, R_F = 10$ kΩ each. Use 0 to ±15 V terminal output to provide supply to the IC.

2. Using 0 to 30 V and 5 V terminals of the power supply, apply two inputs at the inverting terminal. Measure each input with multimeter.

3. Measure the output with multimeter for at least five input combinations.

4. Compare the output with the sum of the two inputs.

2.3.2 Difference amplifier

1. Assemble the circuit as shown in circuit diagram choosing $R_1, R_2, R_F = 10$ kΩ each. Use 0 to ±15 V terminal output to provide supply to the IC.

2. Using 0 - 30 V and 5 V terminals of the power supply, apply two inputs at the inverting terminal. Measure each input with multi-meter.

3. Measure the output with multi-meter for at least five input combinations.

4. Compare the output with the sum of the two inputs.

2.4 Observations

2.5 Results

Table 3: Summing amplifier

Obs. No.	V_1 (V)	V_2 (V)	V_{out} (V)	$V_1 + V_2$ (V)
1				
...				
5				

Table 4: Difference amplifier

Obs. No.	V_1 (V)	V_2 (V)	V_{out} (V)	$V_1 - V_2$ (V)
1				
...				
5				

3 Applications of OP-AMP - Comparator and Schmitt trigger

3.1 Components/Equipment

1. OPAMP (IC-741) chip,
2. A DC power supply,
3. A digital multimeter (DMM),
4. A digital storage oscilloscope (DSO),
5. Connecting wires,
6. Breadboard

3.2 Theory

3.2.1 Comparator

When the feedback signal (voltage) is applied to the inverting (−) input of the op- amp then the feedback is negative. Negative feedback tends to reduce the difference between the voltages at the inverting and non-inverting terminals and make linear circuits. Without negative feedback the op-amp output is highly sensitive to the input, which can be used to design switching or nonlinear circuits. The voltage comparator is a device which uses no feedback; then saturation is the desired result.

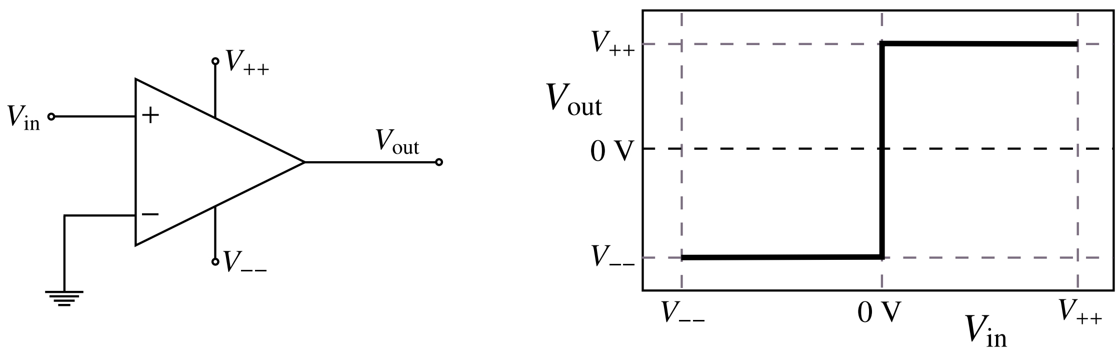

Figure 12: OP-AMP as a ground level comparator.

In this circuit, we want a simple yes-no answer to be signified by either positive saturation or negative saturation of the output. In the circuit diagram shown for figure 12,

1. if $V_{in} > 0$, $V_{out} \approx V_{++}$
2. if $V_{in} < 0$, $V_{out} \approx V_{--}$

The output is no longer linearly related to the input. It's more like a digital signal, high or low depending on how V_{in} compares to ground (0 V). Needless to mention that, if V_{in} is applied at the inverting terminal with respect to a grounded non-inverting terminal, the output will switch to low when $V_{in} > 0$.

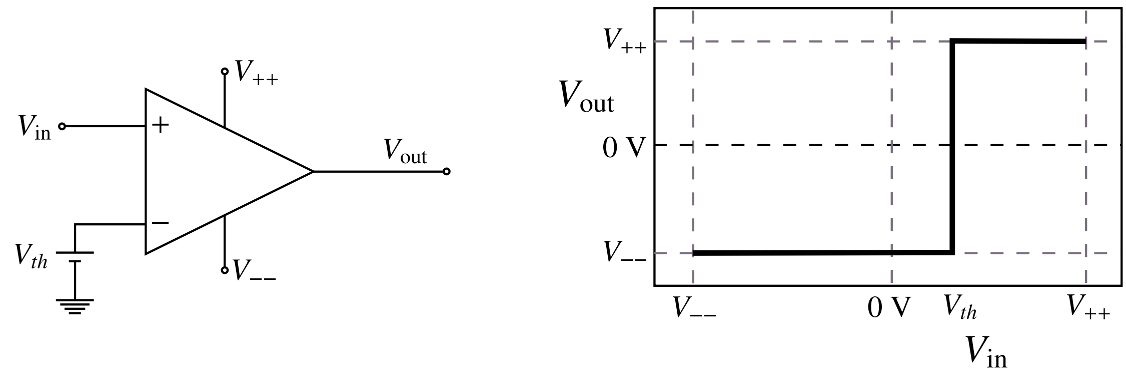

Figure 13: OP-AMP as a threshold comparator.

Figure 13 shows a small modification, allowing the circuit to switch its output when V_{in} crosses a certain preset voltage level, often called the threshold voltage, V_{th}.

Typical applications of this circuit are crossover detectors, analog to digital converters or counting applications where one wants to count pulses that exceed a certain voltage level.

3.2.2 Schmitt trigger

The Schmitt trigger is a variation of the simple comparator which has hysteresis, that is, it has a toggle action. It uses positive feedback. When the output is high, positive feedback makes the switching level higher than it is when the output is low. A little positive feedback makes a comparator with better noise immunity.

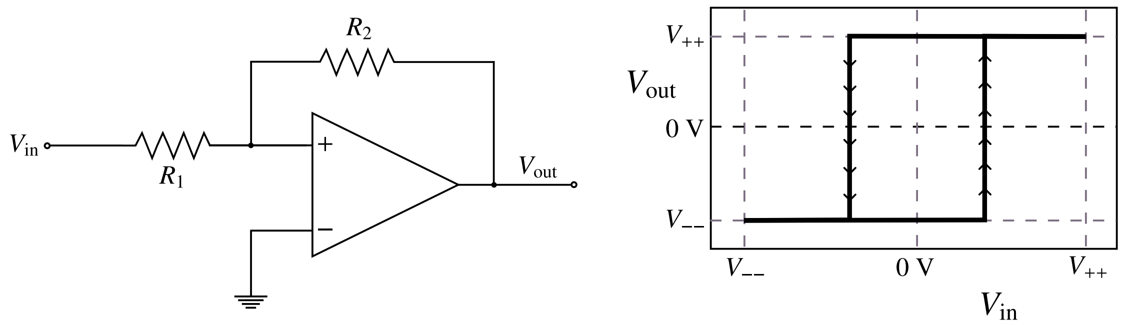

Figure 14: OP-AMP as a Schmitt trigger.

Now, to understand what causes the hysteresis let's analyze the circuit diagram given below, using the same rules as in the previous section for the comparator. The key in understanding this circuit will again be in calculating the voltages that cause its output to switch. If V_+ and V_- are the actual voltages at the non-inverting and inverting terminals of the OPAMP, then the output will be the following, considering that $V_- = 0$:

1. if $V_+ > 0$, $V_{\text{out}} \approx V_{++}$
2. if $V_+ < 0$, $V_{\text{out}} \approx V_{--}$

Since V_{out} changes its state whenever V_+ crosses 0 V, we need to find what value of V_{in} results in $V_+ = 0$. The two values of V_{in} for which the output switches are called the trip points. V_+ acts as a voltage divider formed by R_1 and R_2 between V_{in} and V_{out}. Thus, the trip points of a noninverting Schmitt trigger are:

1. $V_{\text{in}} = -V_{\text{out}}(R_1/R_2) =$ (Lower trip point, LTP)
2. $V_{\text{in}} = +V_{\text{out}}(R_1/R_2) =$ (Upper trip point, LTP).

Choosing suitable ratios of R_1 to R_2, enough hysteresis can be created in order to prevent unwanted noise triggers.

3.3 Circuit diagram

Refer to diagrams in the theory section.

3.4 Procedure

3.4.1 Comparator

1. Construct the comparator circuit on the breadboard as shown in the circuit diagram. Take care to give proper connections at the desired pins of the IC.

2. Use terminal C of the DC power supply (denoted by V_+ and V_- knobs) to provide power supply to IC. Connect the 0 V terminal to ground.

3. Connect terminal *A* of the DC power supply (0 - 30 V) at the input. Use terminal *B* (5 V) to provide threshold voltage V_{th} for circuit shown in figure 13.

4. Vary the input from a negative value to a positive value through 0.

5. Using the DMM, measure and tabulate V_{in} and V_{out}. You can also look at the output using a DSO by coupling the output to it in DC mode.

6. Make a plot of V_{out} vs. V_{in} for each circuit. Estimate V_{th} from graph for figure 13 and compare with the V_{th} value applied. You can repeat the same procedure for different values of threshold.

7. Repeat the entire procedure described above with input at the inverting terminal and the non-inverting terminal being grounded w/o and with the threshold voltage connected to it.

3.4.2 Schmitt trigger

1. Construct the Schmitt trigger circuit on the breadboard as shown in the circuit diagram.

2. Connect the DC power supply at the input. Vary the input from a negative value to a positive value through 0.

3. Using the DMM, measure and tabulate V_{in} and V_{out}.

4. Make a plot of V_{out} vs. V_{in}. Estimate the trip points from the graph and compare with the computed value, i.e., $V_{in} = \pm V_{out}(R_1/R_2)$.

5. You can also look at the output using a DSO by coupling the output to it in DC mode.

3.5 Observations

Table 5: Ground level comparator

Obs. No.	V_{in} (V)	V_{out} (V)
1		
...		
...		

Table 6: Threshold comparator

Obs. No.	V_{in} (V)	V_{out} (V)
1		
...		
...		

Table 7: Schmitt trigger

Obs. No.	V_{in} (V)	V_{out} (V)
1		
...		
...		

3.6 Results

Discuss the graphs you obtain and the switching action of the Schmitt trigger.