Study of Operational Amplifiers (OPAMP)

PH3204 - Electronics Laboratory

Debayan Sarkar
22MS002
Group B-10

March 18, 2025

1 Aim

In this experiment we will study OPAMPs (Operational Amplifiers), mainly their application in circuits as inverting and non-inverting amplifiers. We will also, see their application as voltage adders, and subtractors.

2 Theory

Opamps have a very high gain, and they work on the principle of virtual ground. Below is the symbol for an Opamp.

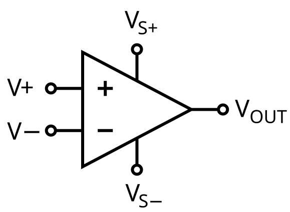

Figure 1: An operational amplifier (Souce: The Internet)

As we can see in the given figure above, an opamp has an inverting input, and a non-inverting input. The gain of the amplifier is given by

$$A = \frac{V_{out}}{V_+ - V_-}$$

Generally A is extremely large, however an OPAMP cannot produce arbitrarily high voltages. The maximum voltage it can produce is decided the power supply connected to it, which is denoted by $V_{S\pm}$. In this experiment and in most cases in general, we have chosen $V_S = 15V$. So, the output of the OPAMP saturates at V_S, and hence, it does not follow the linear gain relation we have mentioned above.
Also, out opAmp of choice in this experiment is the LM741 Operational amplifier. The pinouts of this IC have been given below.

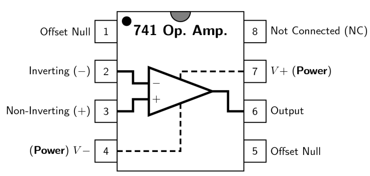

Figure 2: LM741 pinouts (Souce: The Internet)

2.1 Inverting Amplifier

In this configuration, the output of the OPAMP is of the opposite sign of the input voltage. The circuit diagram of this configuration is given below.

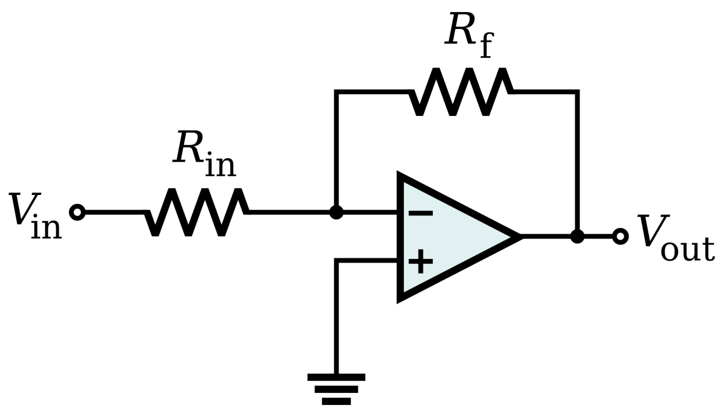

Figure 3: An op amp connected in the inverting amplifier configuration (Source: Internet)

In this case, the gain of the amplifier is decided by the two resistors, and is given by the formula

$$A = -\frac{R_f}{R_i}$$

The minus sign here is where the "inverting" nature arises, since the input is connected to the inverting input terminal of the OPAMP.

2.2 Non Inverting Amplifier

In this configuration, the output of the OPAMP is of the same sign of the input voltage. The circuit diagram of this configuration is given below.

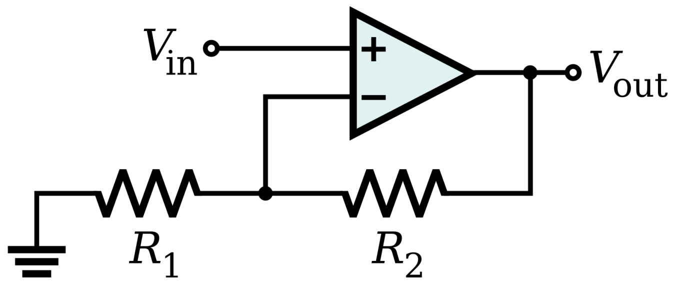

Figure 4: An op amp connected in the non-inverting amplifier configuration (Source: Internet)

In this case, the gain of the amplifier is decided by the two resistors, and is given by the formula

$$A = 1 + \frac{R_2}{R_1}$$

Again, it's non-inverting because this time, the input signal is being fed into the non-inverting terminal of the OPAMP.

2.3 Voltage Adder

In this configuration, the output of the OPAMP is given by a weighted sum of the input voltages, with a minus sign, because it's being sent through the inverting terminal of the OPAMP. The circuit diagram for this configuration is given below.

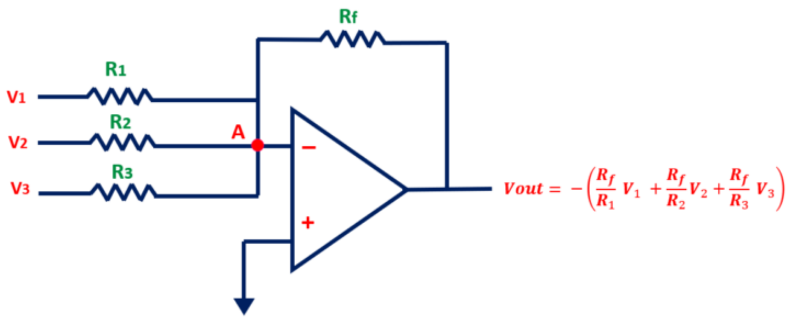

Figure 5: An op amp connected in the voltage adder configuration (Source: Internet)

In this configuration, the output of the OPAMP is given by,

$$V_o = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

2.4 Voltage Subtractor

In this configuration, the output of the OPAMP is given by a weighted difference of the input voltages, with a minus sign, because it's being sent through the inverting terminal of the OPAMP. The circuit diagram for this configuration is given below.

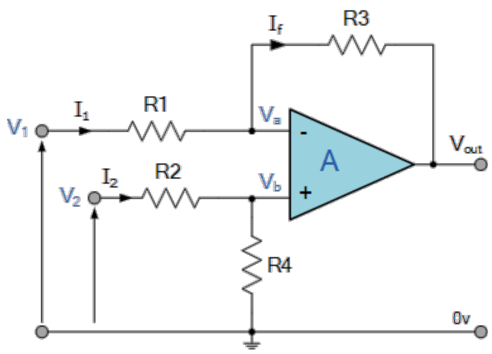

Figure 6: An op amp connected in the voltage subtractor configuration (Source: Internet)

In this configuration, the output of the OPAMP is given by,

$$V_o = -R_f\left(\frac{V_1}{R_1} - \frac{V_2}{R_2}\right)$$

3 Data and Analysis

The data tables for this experiment have been provided in the supplementary section.

3.1 Inverting Amplifier

The experiment was carried out by varrying the input voltage for fixed values of R_f and R_i. The data was taken in 5 such configurations. The average gains and the corresponsing standard deviations have been tabulated below.

-R_f/R_i	A(Theo.)	Average	Std. Dev
-9.8/1	-9.8	-9.791919192	0.001583593511
-9.8/2.16	-4.537037037	-4.548838384	0.0005091215182
-21.7/9.8	-2.214285714	-2.212244898	0.0005997501041
-2.16/1	-2.16	-2.1625	0.000075
-3.16/1	-3.16	-3.175036014	0.0001273865128

Table 1: Average Gain and Standard Deviation

3.2 Non-Inverting Amplifier

The experiment was carried out by varrying the input voltage for fixed values of R_f and R_i. The data was taken in 5 such configurations. The average gains and the corresponsing standard deviations have been tabulated below.

1 + R_f/R_i	A(Theo.)	Average	Std. Dev.
1+2.16/1	3.16	3.155	0.0005
1+9.08/1	10.08	10.89469388	0.00819092045
1+21.7/9.8	3.214285714	3.2025	0.000475
1+9.8/2.16	5.537037037	5.526338384	0.0009750306091
1+3.16	4.16	4.206927438	0.003361377727

Table 2: Average Gain and Standard Deviation

3.3 Voltage Adder

A plot of the collected data with a linear fit has been shown below.

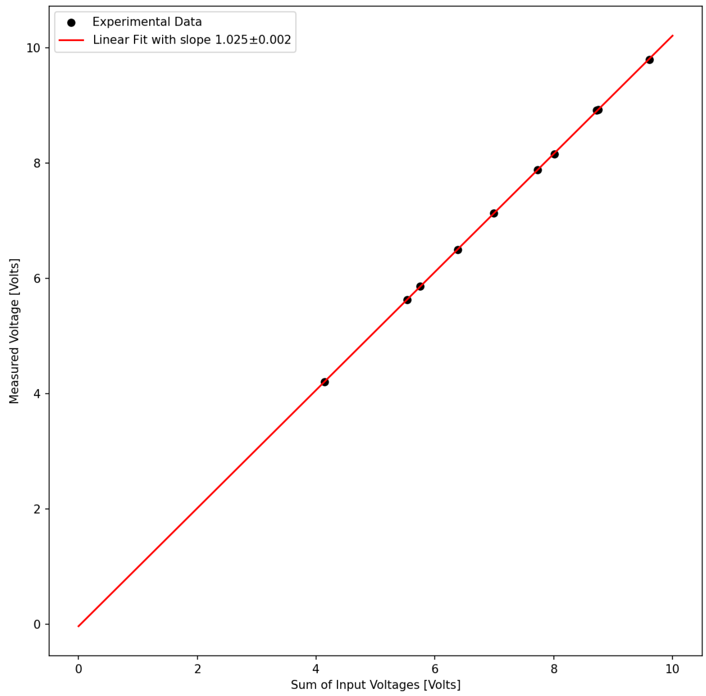

Figure 7: Plot of the Sum of Input Voltages provided and the Measured Output Voltage

The slope of the linear fit was obtained to be 1.025 ± 0.002 which is pretty close to our expected value of 1.

3.4 Voltage Subtractor

A plot of the collected data with a linear fit has been shown below.

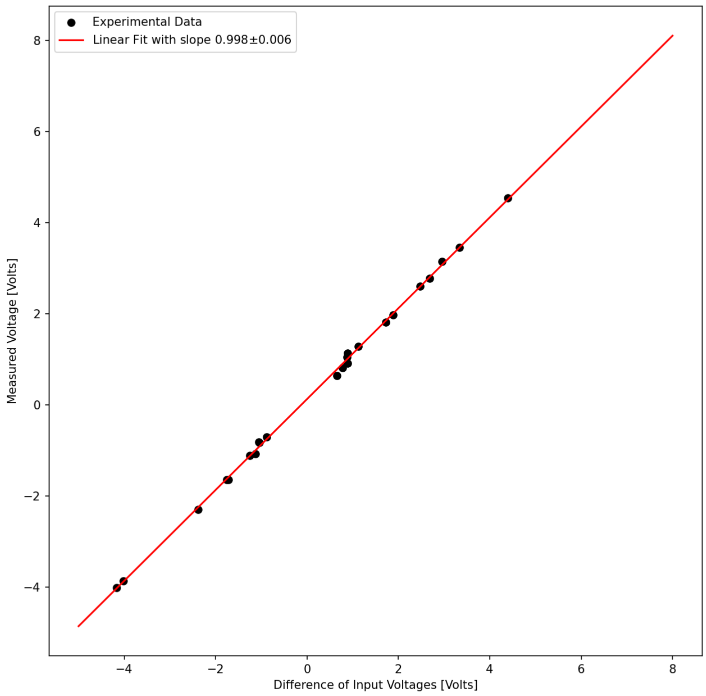

Figure 8: Plot of the Difference of Input Voltages provided and the Measured Output Voltage

The slope of the linear fit was obtained to be 0.998 ± 0.006 which again, is pretty close to our expected value of 1.

4 Sources Of Error

1. Thermal fluctuations in the OPAMP might lead to deviations in the output gain of the amplifier.
2. The tolerences of the resistance values of the given resistors also lead to some error in the measured theoretical gains.

5 Conclusion

In this experiment we studied the applications of the given OPAMP in various different configurations, and the results agree quite well with the theoretical predictions.

6 Supplementary

-R_f/R_i	A(Theo.)	Vi(V)	Vo(V)	A(Expt)
-9.8/1	-9.8	-0.5	4.9	-9.8
-9.8/1	-9.8	-0.99	9.67	-9.767676768
-9.8/1	-9.8	0.5	-4.91	-9.82
-9.8/1	-9.8	1	-9.78	-9.78
-9.8/2.16	-4.537037037	1	-4.56	-4.56
-9.8/2.16	-4.537037037	0.5	-2.28	-4.56
-9.8/2.16	-4.537037037	-0.99	4.49	-4.535353535
-9.8/2.16	-4.537037037	-0.5	2.27	-4.54
-21.7/9.8	-2.214285714	-0.49	1.09	-2.224489796
-21.7/9.8	-2.214285714	-1	2.2	-2.2
-21.7/9.8	-2.214285714	0.49	-1.09	-2.224489796
-21.7/9.8	-2.214285714	1	-2.2	-2.2
-2.16/1	-2.16	1	-2.16	-2.16
-2.16/1	-2.16	0.5	-1.08	-2.16
-2.16/1	-2.16	-1	2.17	-2.17
-2.16/1	-2.16	-0.5	1.08	-2.16
-3.16/1	-3.16	-1	3.17	-3.17
-3.16/1	-3.16	0.51	-1.62	-3.176470588
-3.16/1	-3.16	1	-3.17	-3.17
-3.16/1	-3.16	-0.49	1.56	-3.183673469

Table 3: Inverting Amplifier

1 + R_f/R_i	A(Theo.)	Vi(V)	Vo(V)	A(Expt)
1+2.16/1	3.16	1	3.17	3.17
1+2.16/1	3.16	0.5	1.58	3.16
1+2.16/1	3.16	-1	-3.15	3.15
1+2.16/1	3.16	-0.5	-1.57	3.14
1+9.08/1	10.08	-0.49	-5.36	10.93877551
1+9.08/1	10.08	-1	-10.82	10.82
1+9.08/1	10.08	0.5	5.46	10.92
1+9.08/1	10.08	1	10.9	10.9
1+21.7/9.8	3.214285714	1	3.2	3.2
1+21.7/9.8	3.214285714	0.5	1.61	3.22
1+21.7/9.8	3.214285714	-1	-3.19	3.19
1+21.7/9.8	3.214285714	-0.5	-1.6	3.2
1+9.8/2.16	5.537037037	-0.5	-2.75	5.5
1+9.8/2.16	5.537037037	-0.99	-5.48	5.535353535
1+9.8/2.16	5.537037037	0.5	2.77	5.54
1+9.8/2.16	5.537037037	1	5.53	5.53
1+3.16	4.16	0.99	4.2	4.242424242
1+3.16	4.16	0.5	2.11	4.22
1+3.16	4.16	-0.99	-4.16	4.202020202
1+3.16	4.16	-0.49	-2.04	4.163265306

Table 4: Non-Inverting Amplifier

SL no.	V1(V)	V2(V)	V3(V)	Column 1	Vo(meas)	Vo(Theo)
1	4.93	2.01	1.07	8.16	-8.16	8.01
2	5.91	2.42	1.28	9.8	-9.8	9.61
3	2.4	1.18	0.56	4.2	-4.2	4.14
4	3.94	1.58	0.86	6.5	-6.5	6.38
5	4	1.83	1.16	7.13	-7.13	6.99
6	3.28	1.45	0.8	5.63	-5.63	5.53
7	3.34	1.64	0.77	5.86	-5.86	5.75
8	5.12	2.57	1.06	8.93	-8.93	8.75
9	4.49	2.2	1.04	7.88	-7.88	7.73
10	5.7	2.13	0.89	8.92	-8.92	8.72

Table 5: Voltage Adder

SL. no.	V1(V)	V2(V)	Vo(Meas)	Vo(Theo)
1	0.15	1.04	0.91	0.89
2	0.26	1.04	0.82	0.78
3	0.39	1.04	0.64	0.65
4	1.12	3	1.97	1.88
5	1.39	3.11	1.81	1.72
6	1.59	4.07	2.6	2.48
7	0.86	3.55	2.78	2.69
8	3.02	5.98	3.15	2.96
9	1.41	5.8	4.54	4.39
10	1.08	4.42	3.46	3.34
11	5.31	6.2	1.14	0.89
12	3.69	4.56	1.05	0.87
13	3.34	4.46	1.29	1.12
14	4.13	3.25	-0.71	-0.88
15	4.85	3.81	-0.83	-1.04
16	5.79	4.73	-0.82	-1.06
17	3.36	1.6	-1.64	-1.76
18	3.5	2.25	-1.11	-1.25
19	5.32	1.15	-4.01	-4.17
20	5.13	1.11	-3.87	-4.02
21	3.05	0.66	-2.3	-2.39
22	2.19	0.47	-1.65	-1.72
23	1.43	0.3	-1.07	-1.13

Table 6: Voltage Subtractor