PH3204: Electronics Laboratory

Experiment 03: Study of Operational Amplifier (OpAmp) as inverting and non-inverting amplifier and its applications as adder and subtractor

Ronit Bhuyan (22MS025)

Sub-Group B01

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Contents

1 Theory

1.1 Operational Amplifier (OpAmp)

An Operational Amplifier or OpAmp is a differential amplifier that has a very high voltage gain, high input impedance and low output impedance. The OpAmp ha two inputs namely a non-inverting input(V_+) and an inverting input(V_-). The OpAmp amplifies the difference between the two inputs. The output voltage (V_{out}) is given by

$$V_{out} = A_0(V_+ - V_-)$$

where A_0 is the open loop gain of the amplifier. The OpAmp is usually operated with a negative feedback. The OpAmp used in this experiment is the LM741 OpAmp. The pin configuration of the LM741 OpAmp and its circuit diagram is shown in the figure below.

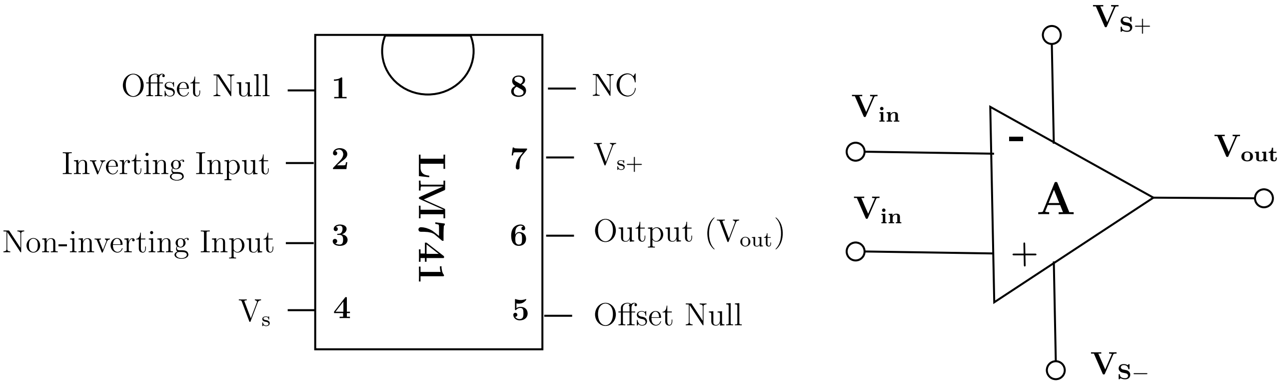

Figure 1: Pin configuration of LM741 OPAMP (left) and its circuit symbol (right)

The OpAmp can be used in various configurations such as inverting amplifier, non-inverting amplifier, adder, subtractor,differentiator, integrator etc. In this experiment, we will study the OpAmp as an inverting amplifier, non-inverting amplifier, adder and subtractor.

1.2 Inverting Amplifier

The OpAmp can be used as an inverting amplifier by connecting it as per the following circuit diagram.

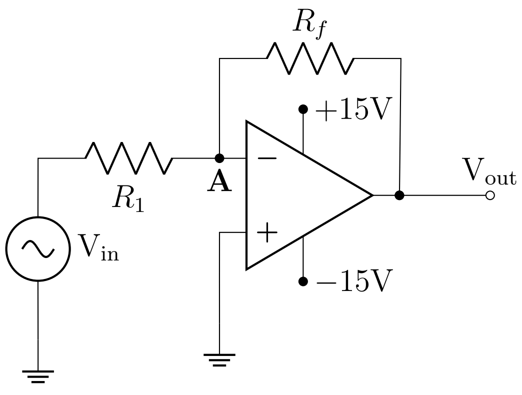

Figure 2: Circuit diagram of OpAmp as an Inverting Amplifier

At the point **A**, the voltgae is 0 due to virtual ground. Theus, by applying Kirchoff's current law at the point **A**, we get

$$\frac{V_{in} - 0}{R_1} = \frac{0 - V_{out}}{R_f} \implies V_{out} = -\frac{R_f}{R_1} V_{in}$$

Hence, the amplification A_0 in the case of inverting amplifier is given by

$$\boxed{A_0 = -\frac{R_f}{R_1}} \tag{1}$$

1.3 Non-Inverting Amplifier

The circuit diagram of an OpAmp as a non-inverting amplifier is shown below.

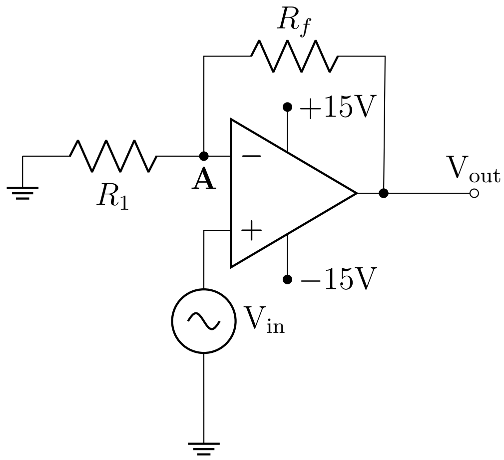

Figure 3: Circuit diagram of OpAmp as a Non-Inverting Amplifier

At point **A**, the potential is V_{in}. Thus, by applying Kirchoff's current law at point **A**, we get

$$\frac{V_{in} - V_{out}}{R_1} = \frac{V_{out} - 0}{R_f} \implies V_{out} = \left(1 + \frac{R_f}{R_1}\right) V_{in}$$

Hence, the amplification A_0 in the case of non-inverting amplifier is given by

$$\boxed{A_0 = 1 + \frac{R_f}{R_1}} \tag{2}$$

1.4 Adder

The OpAmp can be used as an adder by connecting it as per the following circuit diagram.

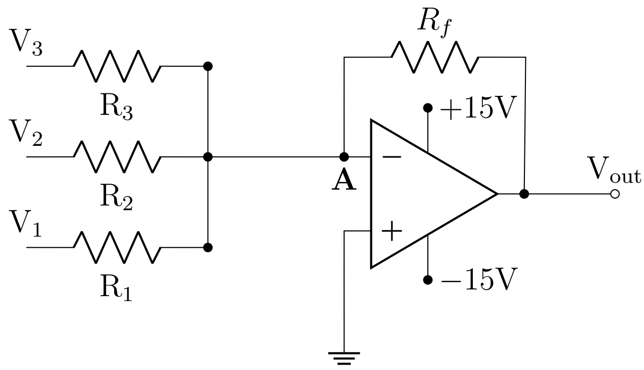

Figure 4: Circuit diagram of OpAmp as an Adder

Similar to the case of the inverting and non-inverting amplifiers, the potential at the point **A** is 0. Thus, by applying Kirchoff's current law at point **A**, we get

$$\frac{0-V_1}{R_1}+\frac{0-V_2}{R_2}+\frac{0-V_3}{R_3}=\frac{V_{out}}{R_f}$$
$$\implies V_{out}=-\left(\frac{R_f}{R_1}V_1+\frac{R_f}{R_2}V_2+\frac{R_f}{R_3}V_3\right)$$

In the special case when $R_1 = R_2 = R_3 = R_f = R$, the output voltage is given by

$$\boxed{V_{out}=-(V_1+V_2+V_3)} \tag{3}$$

Thus, the OpAmp acts as an adder in this case by addiing the input voltages.

1.5 Subtractor

The circuit diagram for OpAmp as a subtractor is shown below.

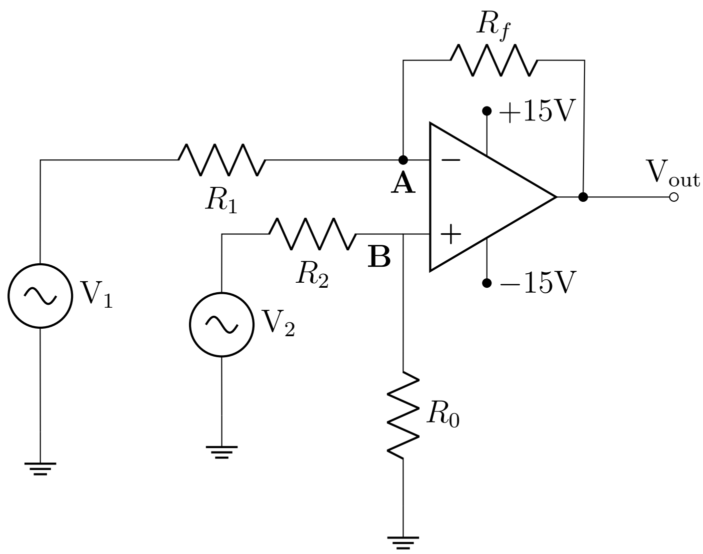

Figure 5: Circuit diagram of OpAmp as a Subtractor

Again, by applying the concept of virtual ground, we know that the potntial at point **A** and at the point **B** is the same. Let the potential at point **A** and **B** be V. Thus, by applying Kirchoff's current law at point A, we get

$$\frac{V - V_1}{R_1} = \frac{V_{out} - V}{R_f}$$

Similarly, by applying Kirchoff's current law at point B, we get

$$\frac{V - V_2}{R_2} = \frac{-V}{R_0}$$

Solving for V_{out}, we get

$$V_{out} = \frac{R_f}{R_1}\left(\frac{V_2 R_0}{R_0 + R_2} - V_1\right) + \frac{V_2 R_0}{R_0 + R_2}$$

In the special case when $R_1 = R_2 = R_f = R_0 = R$, the output voltage is given by

$$\boxed{V_{out} = V_2 - V_1} \tag{4}$$

Thus, the OpAmp acts as a subtractor in this case by subtracting the input voltages.

2 Data and Analysis

Inverting Amplifier

Here, we present the data collected for the inverting amplifier for various combinations of R_i and R_f. The data is presented below in Table 1.

V_{in}	V_{out}	Amplification(A_0)
1.00	-2.20	-2.20
2.00	-4.38	-2.19
3.00	-6.57	-2.19
4.00	-8.75	-2.19
5.00	-10.93	-2.19
Average A_0 = -2.19		
Theoretical Value = -2.18		

(a) $R_i = 996\Omega, R_f = 2170\Omega$

V_{in}	V_{out}	Amplification(A_0)
0.02	-0.18	-9.00
0.20	-2.03	-10.15
0.40	-4.04	-10.10
0.60	-6.01	-10.02
0.79	-7.95	-10.06
Average A_0 = -9.87		
Theoretical Value = -9.89		

(b) $R_i = 996\Omega, R_f = 9850\Omega$

V_{in}	V_{out}	Amplification(A_0)
0.50	-2.30	-4.60
1.00	-4.59	-4.59
1.50	-6.85	-4.57
2.00	-9.16	-4.58
2.50	-11.44	-4.58
Average A_0 = 4.58		
Theoretical Value = -4.56		

(c) $R_i = 2160\Omega, R_f = 9850\Omega$

V_{in}	V_{out}	Amplification(A_0)
2.00	-0.90	-0.45
4.00	-1.80	-0.45
6.00	-2.71	-0.45
8.00	-3.62	-0.45
10.00	-4.53	-0.45
Average A_0 = -0.45		
Theoretical Value = -0.45		

(d) $R_i = 21800\Omega, R_f = 9850\Omega$

Table 1: Data for Inverting Amplifier for various combinations of R_i and R_f

Non-Inverting Amplifier

Here, we present the data collected for the inverting amplifier for various combinations of R_i and R_f. The data is presented below in Table 2.

V_{in}	V_{out}	Amplification(A_0)
1.00	3.20	3.20
1.50	4.77	3.18
2.00	6.35	3.18
3.00	9.54	3.18
4.00	12.69	3.17
Average $A_0 = 3.18$		
Theoretical Value = 3.15		

(a) $R_i = 1006\Omega, R_f = 2160\Omega$

V_{in}	V_{out}	Amplification(A_0)
1.00	2.02	2.02
2.00	4.04	2.02
3.00	6.07	2.02
4.00	8.10	2.03
5.00	10.10	2.02
Average $A_0 = 2.02$		
Theoretical Value = 2.00		

(b) $R_i = 985\Omega, R_f = 983\Omega$

V_{in}	V_{out}	Amplification(A_0)
1.00	1.12	1.12
3.00	3.33	1.11
5.00	5.54	1.11
7.00	7.75	1.11
9.00	9.96	1.11
Average $A_0 = 1.11$		
Theoretical Value = 1.01		

(c) $R_i = 21800\Omega, R_f = 2170\Omega$

V_{in}	V_{out}	Amplification(A_0)
0.50	2.84	5.68
1.00	5.60	5.60
1.50	8.38	5.59
2.00	11.18	5.59
2.50	13.97	5.59
Average $A_0 = 5.61$		
Theoretical Value = 5.53		

(d) $R_i = 2170\Omega, R_f = 9850\Omega$

Table 2: Data for Non-Inverting Amplifier for various combinations of R_i and R_f

Adder

In this section, we present the data collected for the OpAmp as an adder for various combinations of R_i and R_f. The data is presented below in Table 3.

V_1	V_2	V_3	V_{out}(Experimental)	V_{out}(Theoretical)
0.72	1.02	1.45	3.15	3.19
1.44	1.73	2.92	6.01	6.09
1.27	1.99	2.04	5.23	5.30
1.52	1.31	2.16	4.92	4.99
1.40	1.40	2.81	5.55	5.61
1.78	1.67	3.01	6.34	6.46
0.41	0.45	0.82	1.66	1.68
0.52	0.74	1.05	2.26	2.31
1.65	2.75	3.31	7.52	7.71
1.11	1.85	2.23	5.03	5.19

Table 3: OpAmp as an Adder

Subtractor

Finally, we have tabulated the data collected for the OpAmp as a subtractor for various combinations of R_i and R_f. The data is presented below in Table 4.

V_1	V_2	V_{out}(Experimental)	V_{out}(Theoretical)
3.60	4.80	1.14	1.20
2.55	3.18	0.60	0.63
0.82	3.55	2.68	2.73
5.18	6.93	1.65	1.75
6.67	8.91	2.12	2.24
0.46	0.61	0.15	0.15
1.93	2.58	0.63	0.65
3.61	4.85	1.19	1.24
4.57	5.55	0.95	0.98
9.02	12.03	2.85	3.01

Table 4: OpAmp as a Subtractor

3 Results and Discussion

In this experiment, we have studied the use of an OpAmp as an amplifier (non-inverting and inverting) , adder and a subtractor. In case of the inverting and non-inverting amplifier, we experimented with the values of R_i and R_f and calculated the amplification factor A_0, which matched pretty well to the the theoretical value calculated using the equation 1 and 2.
Similarly, for the adder and subtractor, we experimented with the values of R_i and R_f and calculated the output voltage V_{out}, which accurately matched to the the theoretical value calculated using the equation 3 and 4.

4 Sources of Error

- There can be errors while measuring the resistance values of the resistors used in the circuit due to the internal resistances of the given multimeters. This can potentially lead to errors in the calculation of the amplification factor.
- Similarly, the may also be erros in the calculated values of the output voltage due to the internal resistance of the used multimeters.