Sub-Group: A-7
Experiment 3: Study of Operational Amplifier

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1 Aim

To study operational amplifier (Op-Amp) as inverting and non-inverting amplifier and its application as adder and subtractor.

2 Theory

Operational amplifier also called op-amp, is a DC-coupled high-gain electronic voltage amplifier with differential inputs and a single output. In ideal case, the input impedence is kept at infinity and the output impedence is zero. In real case, the input imdepedence can not be at infinite, but it is quite high, and the output impedence is very close to zero. A simple representation for op-amp is shown below,

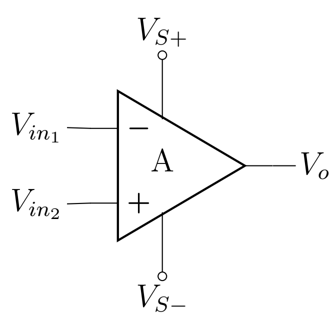

Figure 1: Representation of op-amp

In this picture, V_{in_1} is inverting input voltage, V_{in_2} is non-inverting voltage, V_o is output voltage, V_{S+} is positive power supply and V_{S-} is negative power supply. Actual operation amplifiers also has other terminals the helps in biasing the op-amp. When input voltage difference is zero, output voltage should be zero. Biasing means changing the bias voltage so that this happens. Pin configuration of an op-amp are,

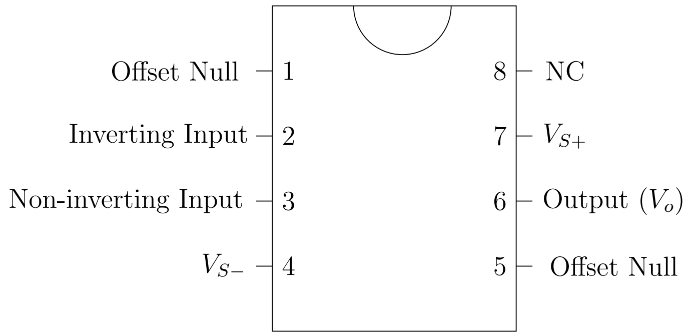

Figure 2: Pin configuration of op-amp

Even though the amplification for an op-amp is infinite, the output voltage is limited by the supply voltage V_{S+} and V_{S-}. Some important and useful op-amp circuits are shown below.

2.1 Inverting Op-Amp

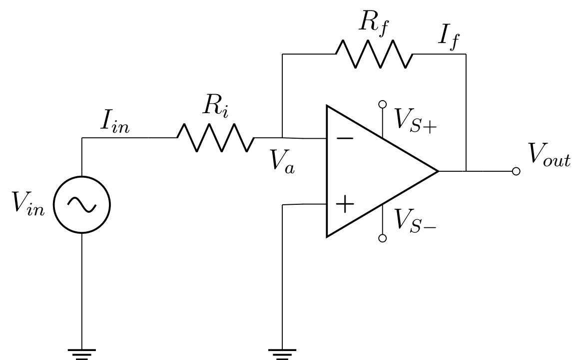

Figure 3: Inverting Op-amp

An operational amplifier can be operated as an inverting amplifier as shown in the figure. Biasing supply to op-amp, $V_{S\pm} = \pm 15$ V must be applied. As the op-amp has very high impdedence, we can write the equation as,

$$\frac{V_{in} - v_a}{R_i} = \frac{V_a - V_{out}}{R_f}.$$

And V_a is the virtual ground, so $V_a = 0$, so the voltage gain in inverting op-amp is,

$$A = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_i}.$$

2.2 Non-inverting Op-Amp

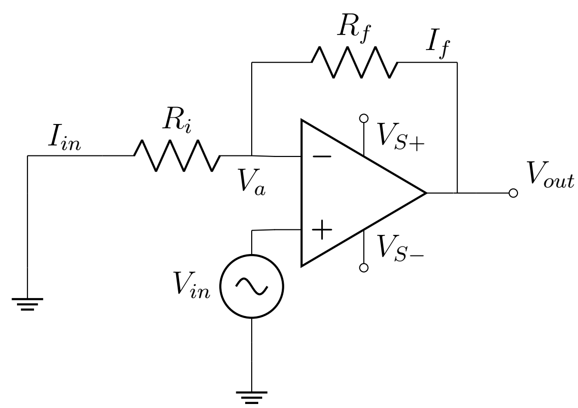

Figure 4: Non-inverting Op-Amp

An operational amplifier can be operated as a non-inverting amplifier as shown in the figure. From the circuit diagram, we can write that

$$\frac{0 - V_a}{R_i} = \frac{V_a - V_{out}}{R_f}.$$

As, $V_a = V_{in}$ the gain for this circuit is,

$$A = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_i}.$$

2.3 Adder Circuit

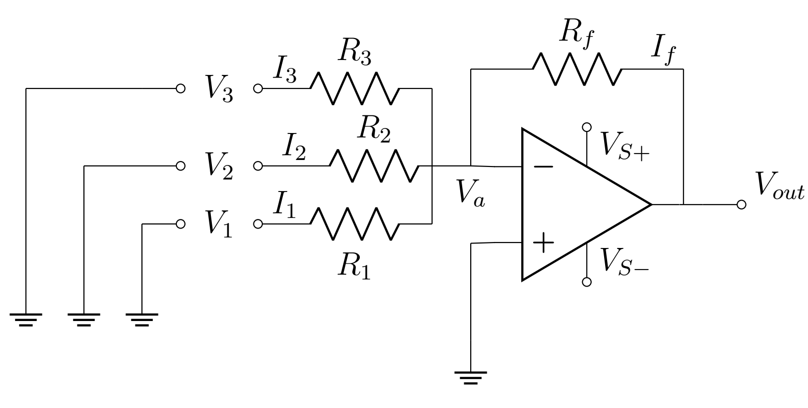

Figure 5: Adder Circuit

In the above configuration, the operation amplifier acts as an adder circuit. The output is proportional to the sum of all input voltages V_1, V_2, V_3. From the circuit diagram, we can write,

$$\frac{V_3 - V_a}{R_3} + \frac{V_2 - V_a}{R_2} + \frac{V_1 - V_a}{R_1} = \frac{V_a - V_{out}}{R_f}.$$

From virtual ground, $V_a = 0$, so

$$\frac{V_3}{R_3} + \frac{V_2}{R_2} + \frac{V_1}{R_1} = -\frac{V_{out}}{R_f}.$$

If the resistances $R_1 = R_2 = R_3 = R_f$, the output voltage is

$$V_{out} = -(V_1 + V_2 + V_3).$$

2.4 Subtractor Circuit

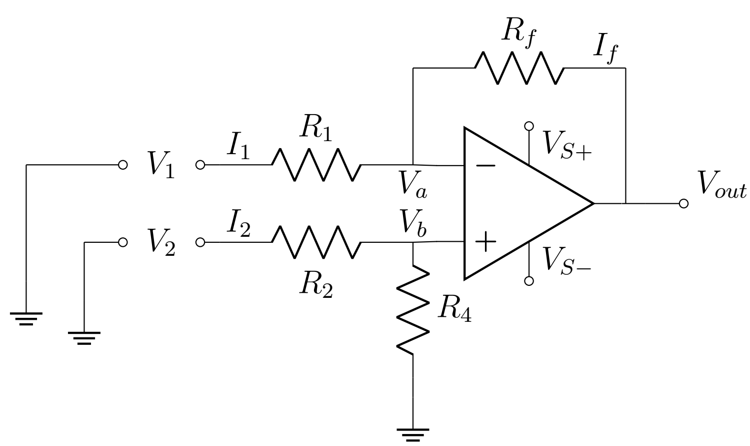

Figure 6: Subtractor Circuit

In the above configuration, op-amp circuit acts as a subtractor circuit. It subtracts one signal from the other signals.

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

$$\frac{V_2 - V_b}{R_2} = \frac{V_b}{R_4}.$$

From virtual ground, $V_a = V_b$, so from these two equations we get,

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

When the resistances $R_1 = R_2 = R_3 = R_4$, then the output voltage is

$$V_{out} = (V_2 - V_1).$$

3 Data and Calculation

In this experiment, we set up circuits for op-amp configurations given above, and for each of the configuration we tabulated the data found. We have used the LM741 op-amp.

3.1 Inverting Op-Amp

We set up the circuit by taking different values of R_f, and different values of R_i. We changed the input voltage V_{in}, and for each input voltage, we tabulated the data in the following tables.

3.1.1 $\mathbf{R_i = 1\,k\Omega}$ and $\mathbf{R_f = 2.2\,k\Omega}$

V_{in}(Volt)	V_{out}(Volt)	Gain	Average
0	0.02		
0.5	1.22	2.44	
1	2.35	2.35	
1.5	3.39	2.26	
2	4.56	2.28	
2.5	5.64	2.256	2.2773
3	6.77	2.2567	
3.5	7.85	2.2428	
4	8.97	2.2425	
4.5	10.02	2.2267	
5	11.09	2.218	

We see the average gain is 2,28. Theoretically the gain is $R_f/R_i = 2.2$.

3.1.2 $\mathbf{R_i = 1\,k\Omega}$ and $\mathbf{R_f = 10\,k\Omega}$

V_{in}(Volt)	V_{out}(Volt)	Gain	Average
0	0.12		
0.2	2.26	11.3	
0.4	4.56	11.4	
0.6	6.91	11.5167	10.8373
0.8	8.91	11.1375	
1	10.52	10.52	
1.2	12.67	10.5583	
1.4	13.2	9.4286	

The average value of the gain is 10.84, theoretically the value of gain is $R_f/R_i = 10$.

3.1.3 $R_i = 10\,k\Omega$ and $R_f = 22\,k\Omega$

V_{in}(Volt)	V_{out}(Volt)	Gain	Average
0	0.02		2.3079
0.5	1.32	2.64	
1	2.38	2.38	
1.5	3.53	2.3533	
2	4.54	2.27	
2.5	5.67	2.268	
3	6.89	2.2967	
3.5	7.9	2.2571	
4	9	2.25	
4.5	10.13	2.2511	
5	11.22	2.244	
5.5	12.52	2.2763	
6	13.25	2.2083	

The average value of the gain in this configuration is 2.31 and the theoretical value of gain is $R_f/R_i = 2.2$.

3.1.4 $R_i = 2.2\,k\Omega$ and $R_f = 10\,k\Omega$

V_{in}(Volt)	V_{out}(Volt)	Gain	Average
0	0.05		4.8453
0.2	1.07	5.35	
0.4	2.24	5.6	
0.6	2.92	4.8667	
0.8	3.99	4.9875	
1	4.7	4.7	
1.2	5.9	4.9167	
1.4	6.76	4.8286	
1.6	7.46	4.6625	
1.8	8.61	4.7833	
2	9.45	4.725	
2.2	10.47	4.7591	
2.4	11.21	4.6709	
2.6	12.37	4.7577	
2.8	13.07	4.6679	
3	13.21	4.4033	

Average value of gain in this configuration is 4.84 and theoretical value of gain is $R_f/R_i = 10/2.2 = 4.54$.

3.2 Non-Inverting Circuit

3.2.1 $\mathbf{R_i = 2.2\,k\Omega}$ and $\mathbf{R_f = 10\,k\Omega}$

V_{in}(Volt)	V_{out}(Volt)	Gain	Average
0	0.07		6.0397
0.2	1.74	8.7	
0.4	2.6	6.5	
0.6	3.51	5.85	
0.8	4.75	5.9375	
1	5.71	5.71	
1.2	6.93	5.775	
1.4	7.96	5.6857	
1.6	9.07	5.6687	
1.8	10.46	5.8111	
2	11.68	5.84	
2.2	12.68	5.7636	
2.4	13.85	5.7708	
2.6	14.31	5.5038	

The average value of gain in this configuration 6.04. But for small value of the voltage is very higher than expected (possibly an error). Calculating the average without taking the first value, we get 5.76. The expected value of the gain is $1 + R_f/R_i = 5.54$.

3.2.2 $\mathbf{R_i = 1\,k\Omega}$ and $\mathbf{R_f = 2.2\,k\Omega}$

V_{in}(Volt)	V_{out}(Volt)	Gain	Average
0	0.05		3.3234
0.5	1.91	3.82	
1	3.31	3.31	
1.5	4.92	3.28	
2	6.57	3.285	
2.5	8.24	3.296	
3	9.73	3.2433	
3.5	11.51	3.2886	
4	12.93	3.2325	
4.5	14.2	3.1556	

Average gain in this configuration is 3.32. The expected value of the gain is $1+R_f/R_i = 3.2$.

3.2.3 $\mathbf{R_i = 10\,k\Omega}$ and $\mathbf{R_f = 22\,k\Omega}$

V_{in}(Volt)	V_{out}(Volt)	Gain	Average
0	0.05		3.3902
0.5	1.84	3.68	
1	3.55	3.55	
1.5	5.15	3.4333	
2	6.76	3.38	
2.5	8.39	3.356	
3	10.07	3.3567	
3.5	11.55	3.3	
4	13.06	3.265	
4.5	14.36	3.1911	

The average value of the gain in this configuration is 3.39 and the theoretical value of the gain is $1 + R_f/R_i = 3.2$.

3.3 Adder Circuit

V_1(Volt)	V_2(Volt)	V_3(Volt)	V_{out}(Volt)	V_1+ V_2+ V_3(Volt)
0	0	0.01	0.02	0.01
1	1.06	1.07	3.18	3.13
1	0.68	1.08	2.79	2.76
1.5	1.01	1.28	3.83	3.79
1.5	0.85	0.85	3.25	3.2
2	1.12	1.33	4.47	4.45
2	2.09	1.12	5.22	5.21
2.5	1.52	1.66	5.66	5.68
3.1	1.72	2.57	7.33	7.39
3.1	2.68	2.57	8.28	8.35
3.5	2.91	2.91	9.21	9.32
4	2.96	3.22	9.96	10.18
4.5	3.36	2.37	10.01	10.23
4.5	4.35	2.9	11.44	11.75
5	2.55	2.53	9.88	10.08

From this table, we can see that the output voltage that we got is very close to the sum of input voltages. So, op-amp circuit behaves as an adder circuit.

3.4 Subtractor Circuit

V_1(Volt)	V_2(Volt)	V_{out}(Volt)	V_2-V_1(Volt)
1	0.79	0.29	-0.21
2	1.45	0.54	-0.55
2.5	2.52	0.06	0.02
2.5	1.82	0.65	-0.68
4.3	2.91	1.39	-1.39
5	3.37	1.6	-1.63
5.5	4.29	1.15	-1.21
6	4.32	1.58	-1.68
6.5	4.38	2.02	-2.12
7	4.64	2.21	-2.36
7.5	5.23	2.06	-2.27
8	5.52	2.18	-2.48
8.5	6.62	1.54	-1.88
9	7.32	1.48	-1.68
9.5	7.67	1.56	-1.83
10	8.19	1.64	1.81

From the above table we see that the output voltage is almost same as the difference between the two input voltages. So, this op-amp circuits behaves as a subtractor circuit.

4 Sources of Error

1. In any configurations, when different voltages had to be measured we used different voltmeters, but they have different internal resistance. This can cause deviation in the result. This can explain the slight deviation that we see in case of adder and subtractor circuit.

2. The internal resistance of the multimeter can induce some error in the measurement of output voltage. This can explain the slightly different gain values obtained in our experiment.

5 Discussion and Conclusion

In this experiment, we used LM741 IC to study the properties of op-amp as an inverting and non-inverting amplifier. For each of these configurations we have also calculated the gain and compared them with the theoretical value of the gain. We also studied the use of op-amp in making a adder and subtractor circuit and again for these configurations verified their output voltages with the expected value.