Experiment Report: Study of Basic OPAMP Configurations and Simple Mathematical Operations

Abhijnan Saraswat Gogoi
Roll no.: 2411072
PHY241 Course

7th, October 2025

Abstract

An inverting and non-inverting amplifier circuits were made using Operational Amplifiers (OPAMP) with some input and feedback resistance values. The input voltage supplied was direct current. The gain of the amplifier circuits were obtained from observations which were consistent with the theory predicted values $-R_f/R_i$ for inverting amplifier and $1 + R_f/R_i$ for non-inverting amplifier. Also, at high input voltage, the output voltage did not show much deviations showing the saturation of the output voltage. Voltage adder and voltage difference circuits were also configured using the OPAMP to perform addition, subtraction and mean averaging. The results of the mathematical operations showed consistency with theory, thereby demonstrating the usefulness of OPAMPs to perform mathematical operations.

1 Objectives

- Study of the inverting amplifier configuration and to find its gain.
- Study of the non-inverting amplifier configuration and to find its gain.
- Study simple mathematical operation and design an averaging amplifier.

2 Theory and Working Formula

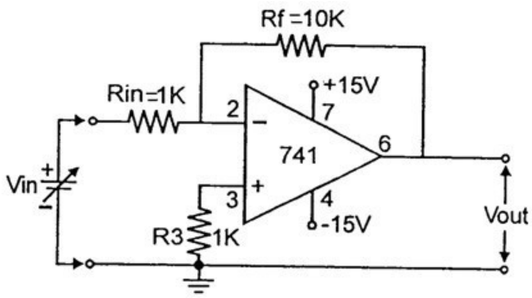
An operational amplifier (OPAMP) is a voltage-controlled 5 terminal amplification device with very high gain. Sometimes, the gain can be of the order of 10^8. It is an active element, i.e. it is connected to a power supply. The input voltage is given in two terminals which are known as the non-inverting (V_+) and inverting (V_-) input signal. The difference $V_i = V_+ - V_-$ is amplified to give the output signal V_o. For this reason, OPAMPs are also known as 'difference amplifiers'.

An OPAMP can be in open-loop configuration or in closed-loop configuration. The open-loop configuration is defined as an OPAMP circuit in which there is no circuit loop that connects the output of the OPAMP to its input. If such a loop exists, it is called a closed-loop configuration. The gain of OPAMP in the open-loop configuration is known as the open-loop gain A_o:

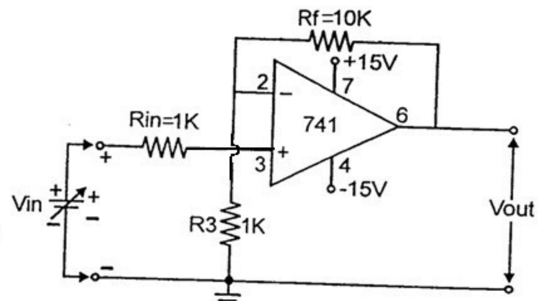
$$A_o = \frac{V_o}{V_i} \text{ (in open-loop configuration)} \tag{1}$$

The open-loop gain decreases linearly with the increase in frequency of the input signal V_i. The plot of the open-loop gain versus the frequency of the differential input signal V_i is the open-loop frequency response curve throughout which the product of the gain and frequency remains constant, known as the 'gain-bandwidth-product' (GBP).

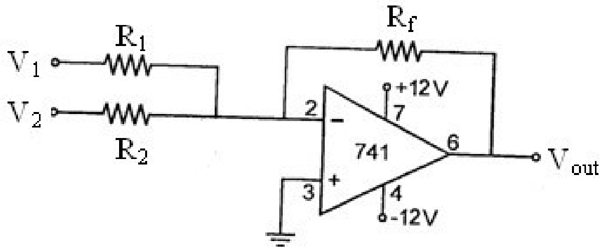
Ideally, an OPAMP has a very high input impedance (which ensures that the OPAMP does not demand power from the input signal) and zero output impedance (ensuring that the output signal does not depend on the load resistance). Also, the bandwidth of an ideal OPAMP is infinite, i.e. it can amplify signal of any given frequency and the offset-voltage is zero (the output signal is zero in the absence of an input signal). The bandwidth is defined as the region in the open-loop frequency response curve where the gain of the OPAMP is greater than $\frac{1}{\sqrt{2}}$ or greater than -3dB (where 0dB is taken as the maximum



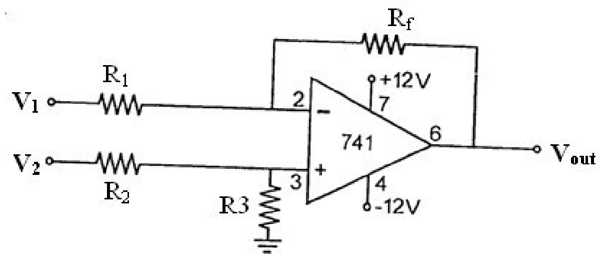
(a) Inverting amplifier



(b) Non-inverting amplifier



(c) Summing amplifier



(d) Difference amplifier

Figure 1: Circuit diagrams

gain).

In practice, OPAMPs do not behave in ideal ways and are designed to approximate these ideal conditions as closely as possible. The high input impedance and low output impedance make OPAMPs incredibly useful in a wide variety of analog signal processing tasks, including amplification, filtering, and signal mixing. Furthermore, their inherent high gain (often on the order of 100,000 or more in open-loop conditions) makes them ideal for applications where small differences in input voltage need to be amplified into much larger output voltages. OPAMPs can be used in countless configurations, such as inverting amplifiers, non-inverting amplifiers, integrators, and differentiators.

The circuit diagram for an inverting amplifier using OPAMP is given in figure 1a. The given circuit is a closed-loop circuit with a gain given by:

$$A = -\frac{R_f}{R_i} \tag{2}$$

where the negative sign is because the current is fed into the inverting input terminal and has a phase difference of 180° with the output signal. The gain of the circuit can be controlled with precision with the resistance values R_i and R_f. However, the maximum possible gain for the OPAMP circuit is the open-loop gain A_o which is ideally taken to be infinite. The resistance R_+ is added as a protection to the OPAMP in case a high current passes through the non-inverting input terminal of the OPAMP.

The circuit diagram for a non-inverting amplifier using OPAMP is given in figure 1b. As with the inverting amplifier circuit, the gain of the circuit can be controlled by varying the resistances R_f and R with the gain given by:

$$A = 1 + \frac{R_f}{R} \tag{3}$$

The circuit diagram of a voltage adder circuit using OPAMP is given in figure 1c. This circuit is used to obtain the sum of the given input voltages as the output voltage. The output voltage for the voltage adder circuit is given by:

$$V_{\text{out}} = -\frac{R_f}{R_i}(V_1 + V_2) \tag{4}$$

If we take $R_f = R_i$, we get the output voltage to be the arithmetic sum of the input voltages. We can also obtain the mean average of the input voltages if we take $R_f = 0.5R_i$.

The difference of voltages can also be obtained using the configuration of the OPAMP given in figure 1d, known as a difference amplifier. The output voltage is given by:

$$V_{\text{out}} = \left(\frac{R_1 + R_f}{R_2 + R_3}\right)\left(\frac{R_3}{R_1}\right)V_2 - \left(\frac{R_f}{R_1}\right)V_1 \tag{5}$$

For $R_1 = R_2 = R_3 = R_f$, we get $V_{\text{out}} = V_2 - V_1$ giving us the difference of the input voltages.

3 Materials Required

(i) OPAMP 741 chip, (ii) resistors, (iii) oscilloscope, (iv) DC voltage source, (v) bread board.

4 Observations

OPAMP IC Code: UA741CP

Table 1: Inverting and non-inverting amplifier data

$$-\frac{R_f}{R_i} = -\frac{9.89\Omega}{0.977\Omega} = -10.12$$

Sl. No.	Input	Output (V)	Gain (V_o/V_i)	Average Gain *
1	207.4 mV	-2.083	-10.04	
2	413.4 mV	-4.192	-10.14	
3	0.587 V	-5.95	-10.14	
4	0.805 V	-8.18	-10.16	-10.24
5	1.003 V	-10.18	-10.15	
6	1.196 V	-12.14	-10.15	
7	1.402 V	-13.16	-9.38	
8	1.685 V	-13.17	-7.82	
–	–	–	–	–
–	–	–	–	–

* Average gain for first 6 observations

(a) Inverting Amplifier

$$1 + \frac{R_f}{R_i} = 1 + \frac{9.89\Omega}{0.977\Omega} = 11.12$$

Sl. No.	Input	Output (V)	Gain (V_o/V_i)	Average Gain **
1	153.6 mV	1.695	11.04	
2	269.8 mV	2.981	11.05	
3	429.1 mV	4.74	11.05	
4	572.2 mV	6.33	11.06	11.08
5	0.784 V	8.70	11.10	
6	0.916 V	10.17	11.10	
7	1.072 V	11.90	11.10	
8	1.186 V	13.16	11.10	
9	1.454 V	14.52	9.98	
10	1.646 V	14.52	8.82	

** Average gain for first 8 observations

(b) Non-inverting Amplifier

Table 2: Simple Mathematical Operations using OPAMP

$R_1 = R_2 = R_f = 10\text{k}\Omega \pm 5\%$

Sl. No.	V_1 (V)	V_2 (V)	V_{out} (V)	$V_1 + V_2$ (V)
1	0	4.407	-4.46	4.407
2	2.489	4.407	-6.97	6.896
3	6.86	4.407	-11.39	11.26
4	6.86	5.199	-12.19	12.06
5	2.091	5.199	-8.36	7.290
6	0.820	5.199	-7.08	6.019

(a) Summing Amplifier

$R_1 = R_2 = R_3 = R_f = 10\text{k}\Omega \pm 5\%$

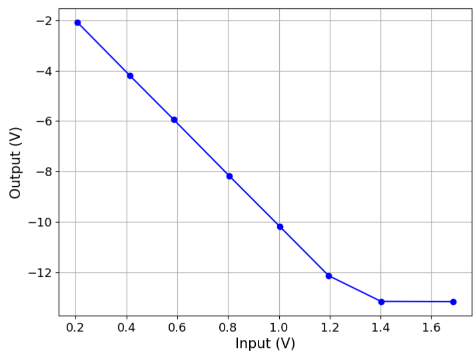
Sl. No.	V_1 (V)	V_2 (V)	V_{out} (V)	$V_2 - V_1$ (V)
1	0.46	4.40	3.93	3.94
2	1.526	4.40	2.867	2.874
3	4.49	4.40	-0.128	-0.09
4	4.49	4.542	0.005	0.05
5	4.49	5.630	1.095	1.14
6	8.92	5.630	-3.369	-3.29

(b) Difference Amplifier

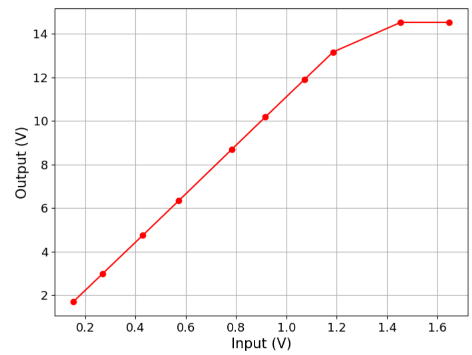
$R_1 = R_2 = 1\text{k}\Omega$, $R_f = 420\Omega \pm 5\%$

Sl. No.	V_1 (V)	V_2 (V)	V_{out} (V)	$(V_1 + V_2)/2$ (V)
1	0	4.404	-2.077	2.202
2	2.002	4.404	-3.019	3.203
3	6.88	5.054	-5.61	5.96
4	14.18	5.054	-9.07	9.62
5	0.257	5.054	-2.500	2.655
6	3.808	6.16	-4.69	4.98

(c) Mean Averaging using OPAMP



(a) Inverting amplifier



(b) Non-inverting amplifier

Figure 2: Transfer characteristics of the inverting and non-inverting amplifier.

5 Results

The inverting amplifier circuit was constructed with $R_f = 9.89\,\Omega$ and $R_i = 0.977\,\Omega$, giving a theoretical gain of -10.12. The average gain in the first six measurements was -10.24, closely matching the expected value. Only the first six measurements are considered for the average as the last two are in the saturation region (see figure 2a).

The non-inverting amplifier used the same resistor values, yielding a theoretical gain of 11.12. The measured average gain over the first eight data points was 11.08, again very close to the theoretical prediction. The last two data points are in the saturation region (see figure 2b), hence neglected while calculating average gain.

So, the experimental gain of the amplifier circuits:

$$\text{Inverting amplifier gain} = -10.24$$
$$\text{Non-inverting amplifier gain} = 11.08$$

The summing amplifier correctly produced output voltages approximately equal to the negative of the sum of the input voltages, consistent with the design where $R_f = R_1 = R_2 = 10\text{k}\Omega \pm 5\%$.

The difference amplifier, configured with all resistors equal to $10\text{k}\Omega \pm 5\%$, produced output voltages that matched the expected result of $V_{\text{out}} = V_2 - V_1$ with high accuracy, showing a maximum deviation of less than 0.1 V in most cases.

The mean averaging amplifier was designed with $R_1 = R_2 = 1\text{k}\Omega \pm 5\%$ and $R_f = 420\text{k}\Omega \pm 5\% \approx 0.5R_i$, and the output voltages were approximately equal to the negative of the mean of the input voltages. The results were consistent with the expected mathematical operation.

6 Discussion

It can be seen that both the inverting and non-inverting amplifier configurations showed gains in agreement with theoretical predictions. Small deviations in gain at higher input voltages (as observed in later entries) can be due to the saturation of the output at higher input voltage as seen in figures 2a and 2b.

In the summing amplifier, the output values were very close to the negative sum of the inputs, which is in agreement with the theory. Slight discrepancies are likely due to resistor tolerances.

The difference amplifier's output closely matched the expected difference $V_2 - V_1$. Minor mismatches suggest either resistor tolerances or slight input offset voltages in the OPAMP.

In the mean averaging amplifier, the output was approximately equal to the negative of the arithmetic mean of V_1 and V_2, confirming the correct design. However, some deviation was observed, likely due to the fact that R_f is taken as $420\Omega \pm 5\%$ which is slightly off the ideal value $R_i/2 = 500\Omega$.

7 Conclusion

The inverting and non-inverting amplifier circuits were successfully built using OPAMP. Also, it is successfully demonstrated that OPAMP can be configured to perform simple mathematical operations like addition, subtraction and mean average up to reasonable accuracy.

8 Precautions

1. The pins of the OPAMP must be identified correctly and connected in the circuit accordingly.

2. Add appropriate resistance to the input terminals of the OPAMP to avoid any high current passing through it causing damage to the IC.

3. Ensure the resistors, IC and all the components are connected properly in the breadboard with a common ground.