# PH3204: Electronics Laboratory

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

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# 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

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

where $A$ 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.

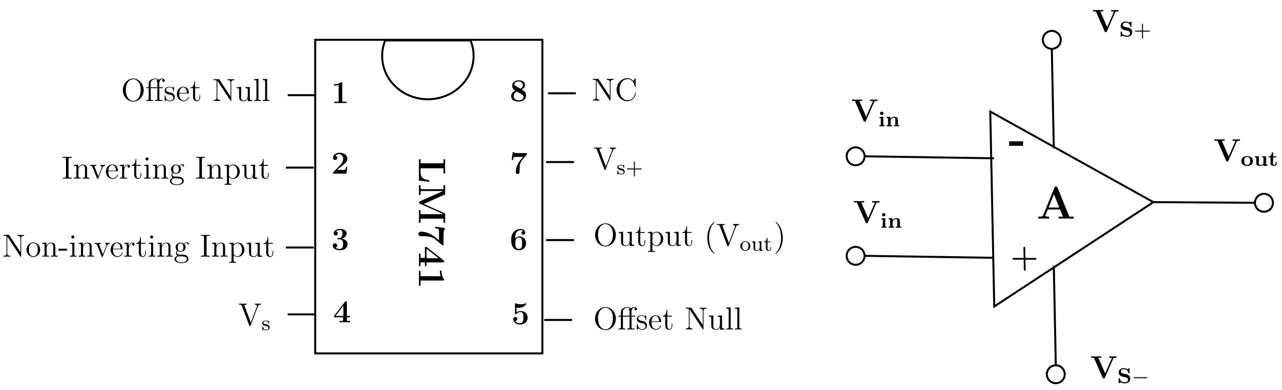


Figure 1: Pin configuration of LM741 OPAMP (left) and its circuit symbol (right)

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.

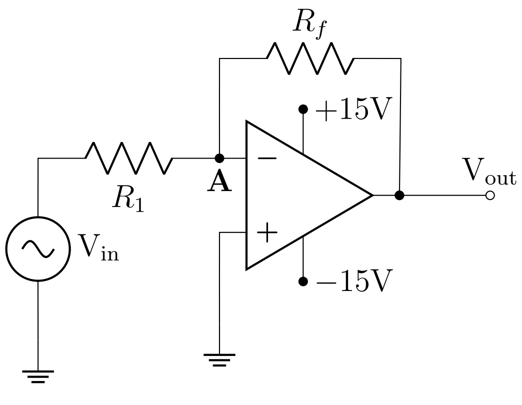


Figure 2: Circuit diagram of OpAmp as an Inverting Amplifier

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 in the case of inverting amplifier is given by

$$\boxed{A = -\frac{R_f}{R_1}}$$

## 1.3 Non-Inverting Amplifier

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

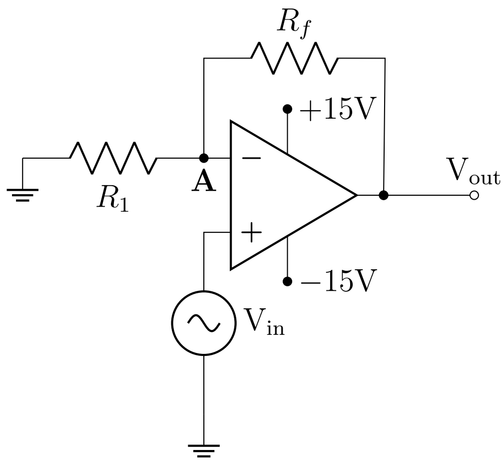


Figure 3: Circuit diagram of OpAmp as a Non-Inverting Amplifier

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 in the case of non-inverting amplifier is given by

$$\boxed{A = 1 + \frac{R_f}{R_1}}$$

## 1.4 Adder

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

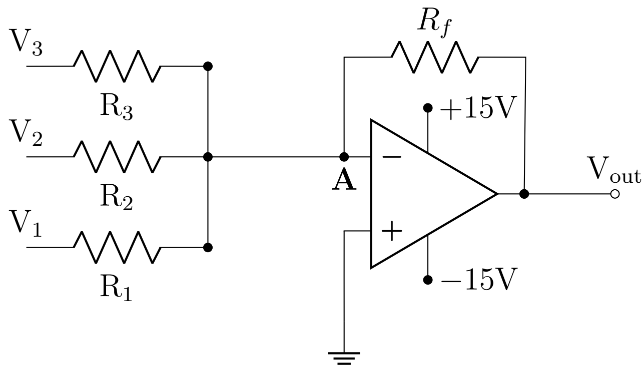


Figure 4: Circuit diagram of OpAmp as an Adder

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

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

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

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

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.

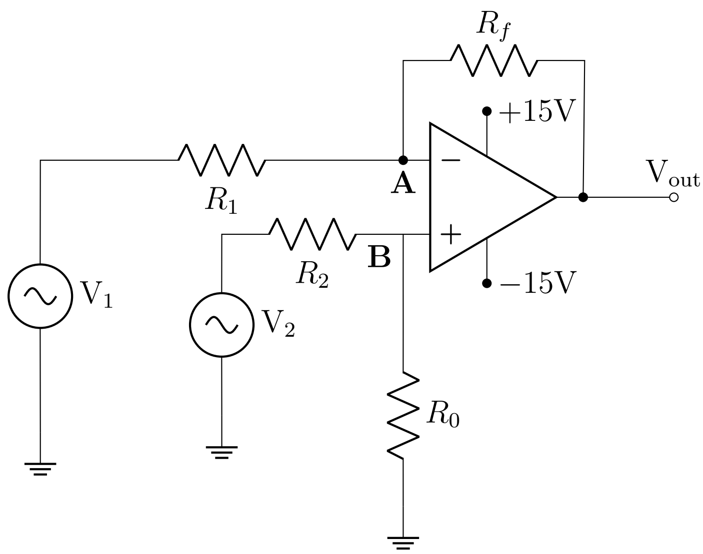


Figure 5: Circuit diagram of OpAmp as a Subtractor

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

$$V_{out} = V_2 - V_1$$

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

# 2 Data and Analysis

## Inverting Amplifier

| $V_{in}$ | $V_{out}$ | A |
|---|---|---|
| 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 = -2.19 | | |

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

| $V_{in}$ | $V_{out}$ | A |
|---|---|---|
| 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 | | -9.87 |

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

| $V_{in}$ | $V_{out}$ | A |
|---|---|---|
| 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: $A = -4.58$ | | |

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

| $V_{in}$ | $V_{out}$ | A |
|---|---|---|
| 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: $A = -0.45$ | | |

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

Table 1: Data for Inverting Amplifier

## Non-Inverting Amplifier

| $V_{in}$ | $V_{out}$ | A |
|---|---|---|
| 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 = 3.18 | | |

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

| $V_{in}$ | $V_{out}$ | A |
|---|---|---|
| 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 = 2.02 | | |

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

| $V_{in}$ | $V_{out}$ | A |
|---|---|---|
| 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 = 1.11 | | |

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

| $V_{in}$ | $V_{out}$ | A |
|---|---|---|
| 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 = 5.61 | | |

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

Table 2: Data for Amplifier Gain for Non-Inverting Amplifier

## Adder

| $V_1$ | $V_2$ | $V_3$ | $V_{out}$ | $V_{\text{Theoretical}}$ |
|---|---|---|---|---|
| 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

| $V_1$ | $V_2$ | $V_{out}$ | $V_{\text{Theoretical}}$ |
|---|---|---|---|
| 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

## 4 Sources of Error