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Report 3

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Abstract

An operational amplifier (Op-Amp) is a fundamental building block in analog electronics due to its high gain and versatility. In this experiment, the IC 741 Op-Amp is studied in different configurations including inverting amplifier, non-inverting amplifier, adder, and subtractor. The relationship between input and output voltages is analyzed theoretically and verified experimentally. The experiment demonstrates that the Op-Amp can perform both amplification and basic mathematical operations with high accuracy under proper biasing and feedback conditions.

Contents

1 Introduction

An operational amplifier is a DC-coupled high-gain differential amplifier having two input terminals (inverting and non-inverting) and one output terminal. It amplifies the difference between the input voltages.

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

where A is the open-loop gain, typically of the order 10^5 or higher. Due to this large gain, even a small difference between the input terminals produces a significant output voltage.

In practical applications, the Op-Amp is used with negative feedback which reduces the effective gain but improves linearity, bandwidth, and stability. Under negative feedback, the Op-Amp operates in a linear region where:

$$V^+ \approx V^-$$

This condition is called the *virtual short*. Additionally, due to very high input impedance:

$$I^+ \approx I^- \approx 0$$

1.1 Aim

To study the working and characteristics of the IC 741 Op-Amp and verify its applications as:

1. Inverting amplifier
2. Non-inverting amplifier
3. Adder (summing amplifier)
4. Subtractor (differential amplifier)

1.2 Components and Instruments

The following components are used:

1. Power supply, 2 Nos : ± 15 V , $0 \sim +5$ V (use pot for variable voltage from fixed if not available)
2. $R_f = 2.2\ \text{K}\Omega,\ 10\ \text{K}\Omega,\ 22\ \text{K}\Omega$, one each 3 Nos
3. $R_i = 1.0\ \text{K}\Omega$, 4 Nos
4. 1.0 kΩ Potentio-meter, 1.0 W, 2 Nos
5. OPAMP LM741 = 1 No
6. Breadboard = 1 No
7. Two DT-830D multi-meters for voltage measurements.
8. single strand wires = 6 - 8 Nos.

2 Theory

2.1 Circuit Notation

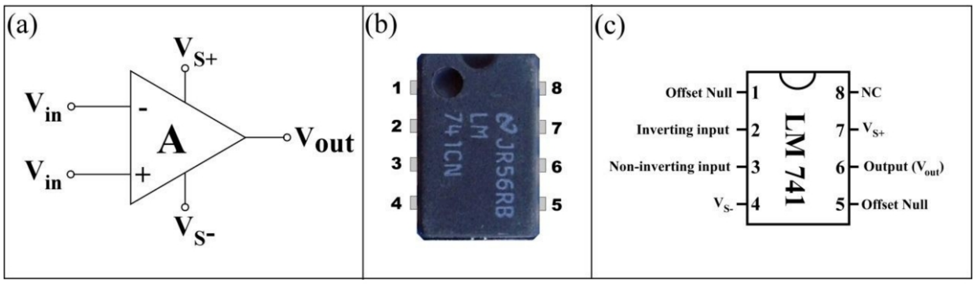

Figure 1: (a) Symbolic representation of OPAMP (b) Real 8-pin OPAMP showing how to count pin numbers (c) Detail pin-out configuration of LM 741 OPAMP.

2.2 Construction

An Op-Amp consists of multiple internal stages:

1. **Input stage:** A differential amplifier that amplifies the difference between input signals.
2. **Intermediate stage:** Provides high voltage gain.
3. **Output stage:** A push-pull amplifier that delivers output with low impedance.

All stages are directly coupled, allowing the amplification of both DC and AC signals without coupling capacitors.

2.3 Working Principle

The Op-Amp operates by amplifying the difference between two input voltages. When negative feedback is applied, the output adjusts such that the difference between inputs becomes nearly zero. Applying Kirchhoff's Current Law (KCL) and using the assumptions:

$$V^+ = V^- \quad \text{and} \quad I_{in} = 0$$

the circuit equations can be derived for different configurations.

2.4 Properties

1. Infinite open-loop gain (ideal)
2. Infinite input impedance (no current drawn)
3. Zero output impedance
4. Infinite bandwidth (ideal case)
5. High common-mode rejection ratio (CMRR)

3 Applications

3.1 Op-Amp as Inverting Amplifier

In this configuration, the input is applied to the inverting terminal through resistor R_i and feedback is provided through R_f.

Using KCL at the inverting node:

$$\frac{V_{in} - V^-}{R_i} = \frac{V^- - V_{out}}{R_f}$$

Since $V^- \approx 0$:

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

Thus,

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

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

The negative sign indicates phase inversion.

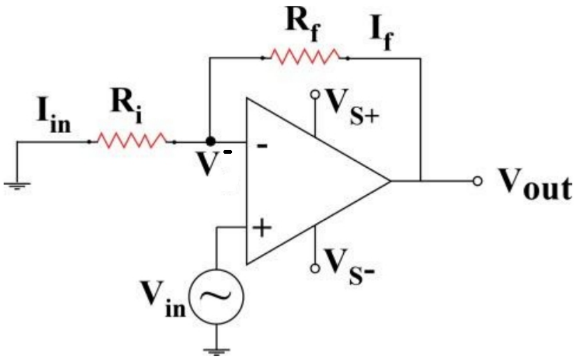

Figure 2: Op-Amp as Inverting Amplifier

3.2 Op-Amp as Non-Inverting Amplifier

The input is applied to the non-inverting terminal, and feedback is connected to the inverting terminal.
Using voltage division:

$$V^- = \frac{R_i}{R_i + R_f} V_{out}$$

Since $V^+ = V^-$:

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

Thus,

$$V_{out} = \left(1 + \frac{R_f}{R_i}\right) V_{in}$$

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

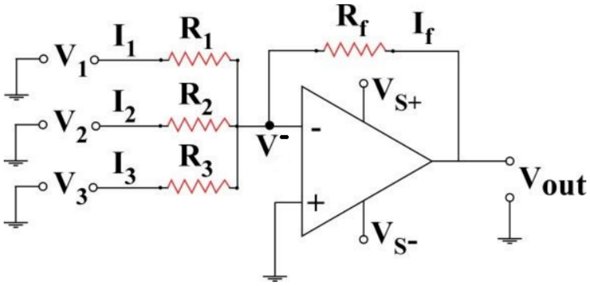

Figure 3: Op-Amp as Non-Inverting Amplifier

3.3 Op-Amp as an Adder

Multiple input voltages are applied through resistors to the inverting terminal.
Applying KCL:

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

Thus,

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

For equal resistors:

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

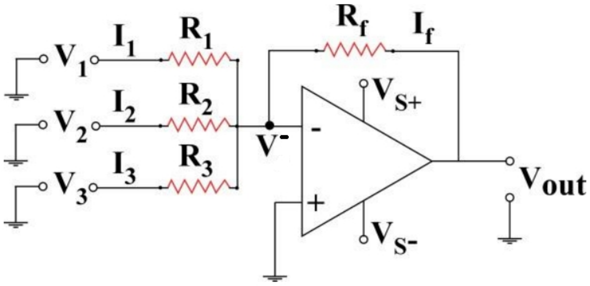

Figure 4: Op-Amp as an adder

3.4 Op-Amp as an Subtractor

In this configuration, the Op-Amp amplifies the difference between two input signals.
Using superposition:

$$V_{out} = \frac{R_f}{R_1}(V_2 - V_1)$$

For equal resistors:

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

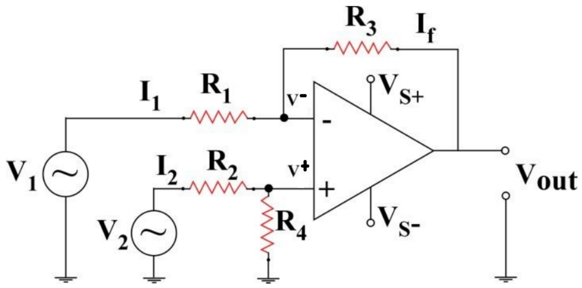

Figure 5: Op-Amp as a subtractor

4 Observation Table

Biasing voltage $V_{S\pm} = \pm 15$ V is applied to Op-Amp in all the following configurations.

4.1 Op-Amp as Inverting Amplifier

Case I: R_f =2.2 kΩ, R_i = 1.0 kΩ

S.N.	V_{in} (V)	V_{out} (V)	Measured Gain (V_{out}/V_{in})
1	1.52	3.37	2.22
2	2.01	4.42	2.20
3	2.77	6.13	2.21
4	3.83	8.45	2.21
5	4.67	10.31	2.21

Theoretical gain (R_f/R_i) is 2.20 and avergae measured gain is 2.21

Case II: R_f =10 kΩ, R_i = 2.2 kΩ

S.N.	V_{in} (V)	V_{out} (V)	Measured Gain (V_{out}/V_{in})
1	0.82	3.75	4.57
2	1.03	4.73	4.59
3	1.31	6.01	4.59
4	1.67	7.64	4.57
5	1.89	8.61	4.56

Theoretical gain (R_f/R_i) is 4.55 and avergae measured gain is 4.58

Case III: R_f =10 kΩ, R_i = 1.0 kΩ

S.N.	V_{in} (V)	V_{out} (V)	Measured Gain (V_{out}/V_{in})
1	0.13	1.34	10.31
2	0.24	2.45	10.21
3	0.42	4.27	10.17
4	0.64	6.49	10.15
5	0.81	8.24	10.17

Theoretical gain (R_f/R_i) is 10.00 and avergae measured gain is 10.20

Case IV: R_f =22 kΩ, R_i = 1.0 kΩ

S.N.	V_{in} (V)	V_{out} (V)	Measured Gain (V_o/V_i)
1	0.05	1.11	22.20
2	0.13	2.88	22.15
3	0.21	4.66	22.19
4	0.34	7.53	22.15
5	0.47	10.44	22.21

Theoretical gain (R_f/R_i) is 22.00 and avergae measured gain is 22.18

4.2 Op-Amp as Non-Inverting Amplifier

Case I: R_f =2.2 kΩ, R_i = 1.0 kΩ

S.N.	V_{in} (V)	V_{out} (V)	Measured Gain (V_{out}/V_{in})
1	1.61	5.17	3.21
2	2.22	7.14	3.22
3	2.65	8.52	3.22
4	3.91	12.53	3.20
5	4.54	14.61	3.22

Theoretical gain ($1+\frac{R_f}{R_i}$) is 3.20 and avergae measured gain is 3.21

Case II: R_f =10 kΩ, R_i = 2.2 kΩ

S.N.	V_{in} (V)	V_{out} (V)	Measured Gain (V_{out}/V_{in})
1	0.75	4.18	5.57
2	1.11	6.19	5.58
3	1.43	7.97	5.57
4	1.87	10.41	5.57
5	2.23	12.47	5.59

Theoretical gain ($1+\frac{R_f}{R_i}$) is 5.55 and avergae measured gain is 5.58

Case III: R_f =10 kΩ, R_i = 1.0 kΩ

S.N.	V_{in} (V)	V_{out} (V)	Measured Gain (V_{out}/V_{in})
1	0.11	1.24	11.27
2	0.26	2.89	11.12
3	0.41	4.59	11.20
4	0.67	7.48	11.16
5	0.84	9.42	11.21

Theoretical gain ($1+\frac{R_f}{R_i}$) is 11.00 and avergae measured gain is 11.19

Case IV: R_f =22 kΩ, R_i = 1.0 kΩ

S.N.	V_{in} (V)	V_{out} (V)	Measured Gain (V_o/V_i)
1	0.07	1.62	23.14
2	0.11	2.55	23.18
3	0.24	5.55	23.13
4	0.32	7.42	23.19
5	0.45	10.42	23.16

Theoretical gain $(1+\frac{R_f}{R_i})$ is 23.00 and avergae measured gain is 23.16

4.3 Op-Amp as an Adder

We have used $R_f = R_1 = R_2 = R_3 = 1$ kΩ

S.N.	V_1 (V)	V_2 (V)	V_3 (V)	Measured V_{out} (V)	Theoretical V_{out} (V)= $(V_1 + V_2 + V_3)$
1	0.12	3.15	5.21	8.43	8.48
2	0.16	3.16	5.30	8.56	8.62
3	0.25	3.10	5.35	8.61	8.70
4	0.29	3.19	5.27	8.63	8.75
5	0.37	3.14	5.33	8.75	8.84
6	0.46	3.22	5.41	8.98	9.09
7	0.61	3.33	5.39	9.24	9.33
8	0.73	3.27	5.32	9.21	9.32
9	0.77	3.23	5.41	9.30	9.41
10	0.92	3.41	5.24	9.46	9.57

4.4 Op-Amp as a Subtractor

We have used $R_1 = R_2 = R_3 = R_4 = 1$ kΩ.

S.N.	V_1 (V)	V_2 (V)	V_{out} (V)	Theoretical V_{out} (V) = $(V_2 - V_1)$
1	1.13	4.24	3.07	3.11
2	1.24	4.20	2.92	2.96
3	1.41	4.29	2.86	2.88
4	1.63	4.33	2.63	2.70
5	1.81	4.41	2.57	2.60
6	2.02	4.44	2.37	2.42
7	2.17	4.39	2.15	2.22
8	2.33	4.47	2.09	2.14
9	2.46	4.55	2.05	2.09
10	2.62	4.50	1.83	1.88

5 Sources of Error

5.1 Systematic Errors

1. **Instrumental Errors:**
    - Calibration errors in the digital multimeter (DMM) may lead to consistently incorrect voltage readings.
    - Limited resolution of measuring instruments introduces small but consistent deviations.
2. **Op-Amp Non-Idealities:**
    - Finite open-loop gain of the IC 741 instead of ideal infinite gain.
    - Non-zero input bias current and offset voltage.
    - Finite bandwidth and slew rate limitations affecting accuracy.
3. **Resistor Tolerance:**
    - Practical resistors have tolerance (typically ±1% or ±5%), causing deviation from theoretical gain.
4. **Power Supply Variations:**
    - Fluctuations in the $\pm 15\,V$ supply may affect output voltage stability.
5. **Loading Effects:**
    - Finite input and output impedance of the Op-Amp affects ideal assumptions.

5.2 Random Errors

1. **Noise:**
    - Electrical noise from surroundings and power supply fluctuations.
2. **Thermal Effects:**
    - Temperature variations affecting resistor values and Op-Amp characteristics.
3. **Human Errors:**
    - Errors in reading the multimeter display.
    - Slight variations while adjusting the potentiometer for input voltage.
4. **Contact and Connection Issues:**
    - Loose connections or poor contacts in the breadboard leading to fluctuating readings.

6 Results

The experimental results obtained for different configurations of the IC 741 Op-Amp closely match the theoretical predictions.

1. In the **inverting amplifier**, the measured gain was found to be approximately equal to $-\frac{R_f}{R_i}$.
2. In the **non-inverting amplifier**, the measured gain closely followed the theoretical value $1 + \frac{R_f}{R_i}$.
3. The **adder circuit** successfully produced an output proportional to the sum of input voltages.
4. The **subtractor circuit** accurately generated the difference between the input signals.

Minor deviations between theoretical and experimental values were observed, which can be attributed to non-ideal characteristics and experimental errors.

7 Conclusion

The experiment successfully demonstrated the working and applications of the IC 741 Operational Amplifier in various configurations. The following conclusions can be drawn:

- The Op-Amp operates effectively as an inverting and non-inverting amplifier with predictable gain determined by external resistors.
- Negative feedback plays a crucial role in stabilizing gain and improving linearity.
- The Op-Amp can perform basic mathematical operations such as addition and subtraction with good accuracy.
- The small discrepancies between theoretical and experimental values confirm the presence of practical limitations such as finite gain, resistor tolerances, and noise.

Overall, the IC 741 Op-Amp proves to be a reliable and versatile component in analog circuit design.

References

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