

DESIGN, IMPLEMENTATION AND PERFORMANCE EVALUATION OF AN LM741 OPERATIONAL AMPLIFIER TRAINER

*Odo, K.O.¹, Ajayi, E.A.², Yerima, O.³ and Onyenagbagha, N.C.⁴

^{1,2,3}Department of Electrical and Electronic Engineering, Michael Okpara University of Agriculture, Umudike, Abia State.

⁴Department of Electrical and Electronic Engineering, Federal Polytechnic Kaltungo, Gombe State.

*Corresponding Author: odo.kingsley@mouau.edu.ng

ABSTRACT

The teaching of analog electronics often suffers from limited hands-on exposure and inadequate instructional tools, which can hinder students' understanding of fundamental operational amplifier concepts. The design, implementation and performance evaluation of an LM741 operational amplifier-based training module intended for use in Electronics Engineering laboratory of the department of Electrical and Electronic Engineering, Michael Okpara University of Agriculture, Umudike is presented in this study. The trainer consists of a user-friendly interface for circuit implementation, a power supply, and various essential components such as resistors, capacitors, and LM741 op-amps. The developed trainer integrated multiple configurable circuits, including inverting and non-inverting amplifiers, voltage followers, and summing amplifiers allowing users to conveniently explore a wide range of operational amplifier applications on a single platform. The system was designed using standard analog circuit principles and implemented with readily available, low-cost components to ensure affordability and ease of replication. Proteus and Matlab software were used to design and simulate the op-amp trainer. Performance evaluation was conducted through a combination of theoretical and experimental values, focusing on key parameters such as output voltage, linearity, and signal fidelity. The results demonstrated that the trainer reliably reproduces theoretical expectations, with minimal deviation between calculated and measured outputs. Furthermore, the developed system provided a practical, cost-effective solution for bridging the gap between theoretical instruction and real-world application in analog electronics education. This work contributed to engineering education by offering an accessible and scalable training tool suitable for undergraduate laboratories and technical training institutions.

Keywords: Integrated circuit, Operational amplifier, inverter amplifier, non-inverter amplifier, summing amplifier.

1.0 INTRODUCTION

The operational amplifiers 741 also known as LM741 are fundamental components in electronic circuits, known for their versatility in analog signal processing. They have numerous applications in various fields, including audio amplification, signal conditioning, instrumentation amplifiers, voltage amplification, current-to-voltage conversion, active filters, integrators/differentiators and comparators, (Allen and Holberg, 2015, Sedra and Smith, 2015, Horowitz and Hill, 2015, Jung, 2017). Among these devices, the LM741 Operational Amplifier continues to occupy a prominent role in engineering education due to its simplicity, robustness, and well-documented characteristics. Despite the availability of more advanced modern op-amps, the LM741 is still extensively employed in academic environments as a pedagogical tool for introducing core analog circuit

concepts (ICDrex, 2025). The ideal op-amp characteristics have infinite input impedance, infinite open-loop gain, zero output impedance, infinite bandwidth and zero input offset voltage while real op-amps don't achieve these ideals; they come close, allowing for highly predictable behavior, (Sedra and Smith, 2015). Op-amps can be configured in various ways such as inverting and non-inverting configurations, depending on the arrangement of input and feedback elements, (Horowitz and Hill, 2015). In negative feedback configurations, op-amps maintain virtual short circuits between their inverting and non-inverting terminals, ensuring that the voltage difference between them is virtually zero, (Razavi, 2016). The entire operational amplifier is the heart of any analog circuit; based on its design and functionalities the performance of entire circuit can be judged. It is a basic building block of analog and mixed signal circuits. Earlier, op amps were general purpose like IC 741 with compromise on the parameters such as output swing, power dissipation by contrast, now it's possible to design op amp for specific need application, (Patnaik *et al*, 2020, Jin and He 2020, Sharvani *et al*, 2022). Operational amplifier began in the days of vacuum tubes and analog computers. They consisted of relatively complex differential amplifiers with feedback. The circuit was constructed such that characteristics of the overall amplifier were determined by the type and amount of feedback. Thus, the complex differential amplifier itself had become a building block that could function in different operations by altering the feedback. Some of the operation that was used includes adding, multiplying, and logarithmic operations, (Terrell, 1996). The operational amplifier is the most important building block for the design of analog circuits. Good Knowledge of the Op-Amp characteristics and application is essential for a successful analog Engineer. Operational Amplifier trainer is designed to simplify the designing of digital and analogue circuits. It contains most of the necessary test equipment needed to build and test the circuits, (Manuel, 2008). An operational amplifier (op-amp) has many applications in analog electronic systems. It is normally connected to a circuit with external circuit elements (resistors and capacitors) that determine its operation, (Ribbens, 2017). There are rules guiding the analysis and design of op-amp circuits. They include the virtual short circuit concept and the assumption of zero input current into the op-amp's input terminals, (Gray *et al*, 2015). Students often have difficulties in understanding fundamental concepts of introductory electronics and operational amplifiers (op-amps) most especially during practical sessions because they tend to address electronic circuit problems in a rather local and sequential way with no reference to the appropriate principles, rules and methods. However, students are expected to have a better understanding of how electronic circuits are analyzed and designed, (Nikolaos and Gerasimos, 2017). The significance of practical training linking theoretical studies with practice made Nina *et al*, (2006) to design a setup of hands-on training for students, and as a result, more students felt a more complete understanding of the topic.

Despite these advantages, there remains a shortage of standardized, low-cost, and modular training systems specifically designed for operational amplifier education. Many existing laboratory setups are either too complex, expensive, or lack flexibility, making them unsuitable for widespread adoption in resource-constrained environments (Jibunor *et al.*, 2025). This gap underscores the need for the development of dedicated training modules that are affordable, user-friendly, and capable of supporting multiple op-amp configurations within a single platform. In response to these challenges, this study presents the design, implementation, and performance evaluation of an LM741 operational amplifier trainer. The proposed system is intended to provide an interactive and modular platform for exploring key op-amp configurations, including amplifiers and signal processing circuits. By integrating both theoretical analysis and experimental validation, the trainer aims to enhance practical learning, improve student engagement, and support effective teaching of analog electronics. Additionally, performance evaluation of the developed system ensures that it meets expected operational characteristics, thereby validating its suitability as an educational tool. This work

contributes to engineering education by offering a cost-effective and scalable solution that bridges the gap between theory and practice in analog electronics instruction, particularly in environments where access to advanced laboratory infrastructure is limited.

2.0 MATERIALS AND METHOD

The materials needed in this study are resistors (10K, 9.1K and 100K), capacitors, voltage regulator, operational amplifier (LM741), Diodes, LEDs, Terminal Blocks, Transformers, Voltmeters, Potentiometers, Matlab software and Proteus software.

2.1 Method

The LM741 op-amp is a general-purpose operational amplifier used in analogue circuit design. The method used in designing the circuit include understanding the LM741 Op-amp's pin configuration, choosing the circuit configuration (inverting amplifier, non-inverting amplifier and summing up amplifier), selecting components values, selecting appropriate power supply for the op-amp, simulating and testing using Proteus simulation software.

2.1.1 The system block diagram

The block diagram of the study is shown in Figure 1

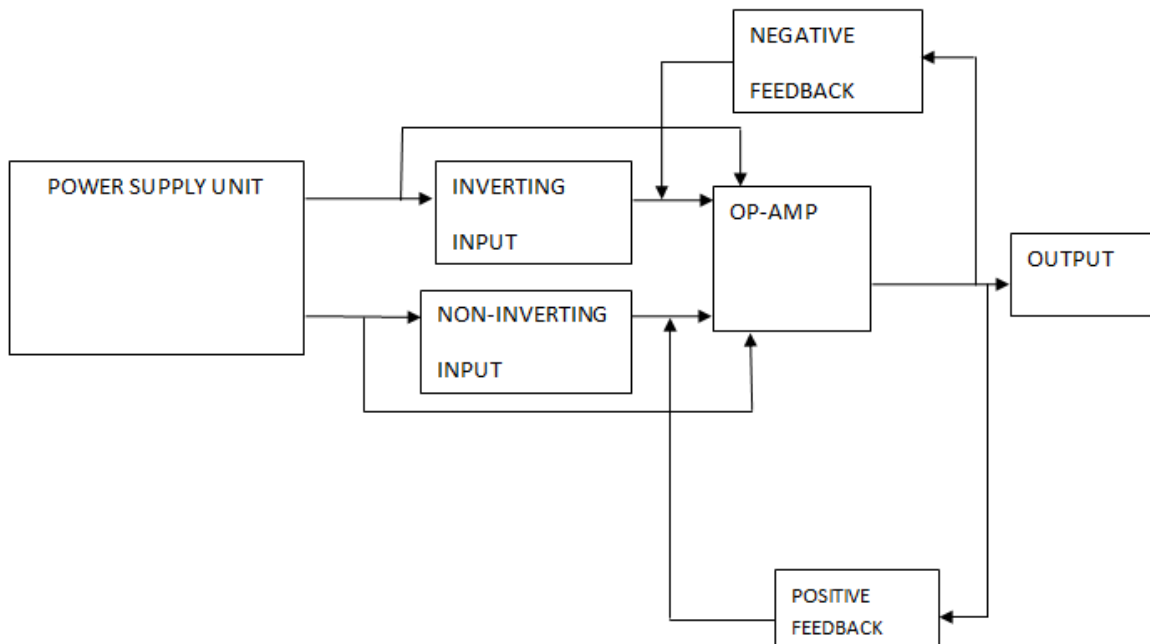


Figure 1: Block diagram of the study

2.1.2 Power Supply Unit

The power supply units consist of a full wave rectifier, capacitors, resistors and voltage regulators for regulating the output voltage. This unit performs the function of converting AC voltage to DC voltage which is needed to supply power to the entire circuit as all the component work on direct current.

The objective is to build a dual supply that generates regulated +5V and -5V from 220VAC mains. Such power supply is a very common requirement in all those circuits that use Op-amps.

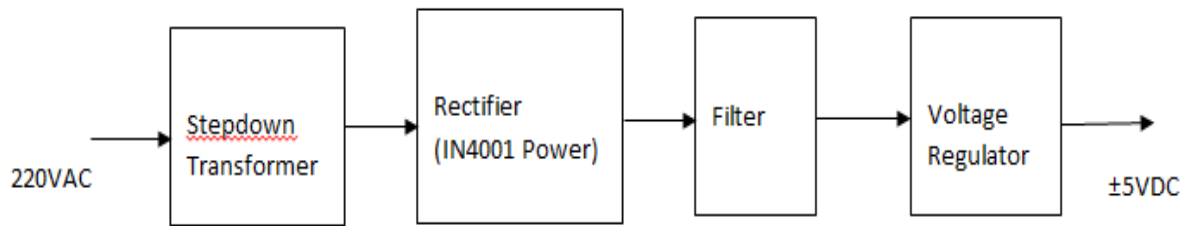


Figure 2: Block diagram of power system unit

a. Step-Down Transformer

This is 220/240V center-tapped step-down transformer. The work of this transformer is to convert 220V AC supply from the mains to 12-0-12VAC. The 12-0-12VAC is fed to the full wave rectifier circuit, taking the 0V at the center as the ground.

b. Full Wave Rectifier Circuit

The output from the secondary of the step-down transformer is set into the rectifier circuit for rectification. In this rectifier circuit, only two diodes are used in which one is made to conduct in the positive half cycle while the second diode conducts in the negative half cycle. The output voltage from the rectifier circuit is a pulsating DC voltage. This voltage is fed to the filter circuit for smoothing out the ripples in the voltage.

c. Filter Circuit

Filter circuit consist of electrolytic capacitor that is connected in parallel with the rectifier circuit. The work of the filter circuit is to smoothen the ripple content of the rectifier output voltage so a purely DC voltage can be obtained.

d. Voltage Regulator Circuit

The voltage regulator circuit consists of two voltage regulator ICs 7805 and 7905. The ICs 7805 and 7905 supply constant +5V and -5V respectively to pins 7 and 4 of the Op-amp respectively. The purpose of using these ICs is to get a regulated constant voltage even when is increased in the supply voltage or when there is fluctuation in the supply voltage.

2.1.3 Power Supply Calculation

1) 7805 IC rating

Input voltage range 7V to 35V

Current Rating $I_c = 1A$

Output Voltage rating $V_{max} = 5.2V, V_{min} = 4.8V$

Since the transformer is 12-0-12V center-tapped with current rating of 500mA, the secondary peak voltage is going to be $12\sqrt{2} = 16.97V$

2) Capacitors

Ripple factor is given by

$$Y = \frac{I}{(4\sqrt{3}FRC)} \tag{1}$$

where F = Frequency of AC supply (50Hz), R = Resistance Calculated

$$\text{But, } R = \frac{V}{I_c} \tag{2}$$

$$V = 12\sqrt{2} = 16.97V$$

$$R = 16.97/500 \times 10^{-3} = 33.94\Omega. \text{ Standard } 33\Omega \text{ was chosen.}$$

C = Filtering capacitance

$$Y = \frac{V_{ac-rms}}{V_{dc}} \tag{3}$$

$$V_{ac-rms} = \frac{V}{2\sqrt{3}} = \frac{12}{2\sqrt{3}} = 3.46V$$

$$V_{dc} = V_{max} - V_{min} \tag{4}$$

$$V_{dc} = 5.2 - 4.8 = 0.4V$$

Therefore,

$$Y = \frac{3.46}{0.4} = 8.65$$

Filter capacitor can be obtained thus;

$$C = \frac{1}{Y \times 4\sqrt{3}FR} \tag{5}$$

$$C = \frac{1}{8.65 \times 4\sqrt{3} \times 50 \times 33} = 1.01 \times 10^{-5} F$$

Therefore, 10 μF standard was chosen as the filtering capacitor

Also, 0.01μF capacitor was used at the output side of the 7805 to prevent transient change in voltage due to change in load.

2.1.4 System Design

The inverting op-amp trainer was designed and simulated using Proteus software as shown in figure 3.

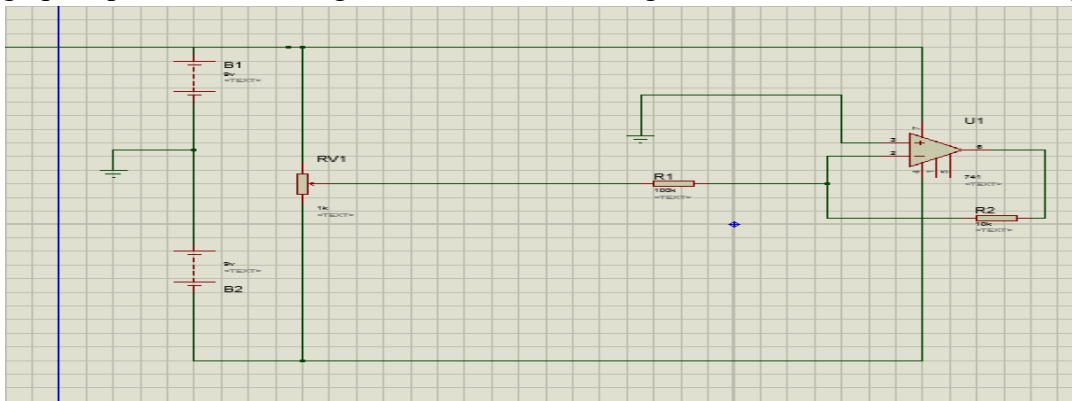


Figure 3: System design of inverting Op-amp

The output voltage of an inverting op-amp is given as;

$$V_{out} = -\frac{R_f}{R_{in}} \times V_{in} \tag{6}$$

The inverting op-amp trainer was designed and simulated using Proteus software as shown in figure 4.

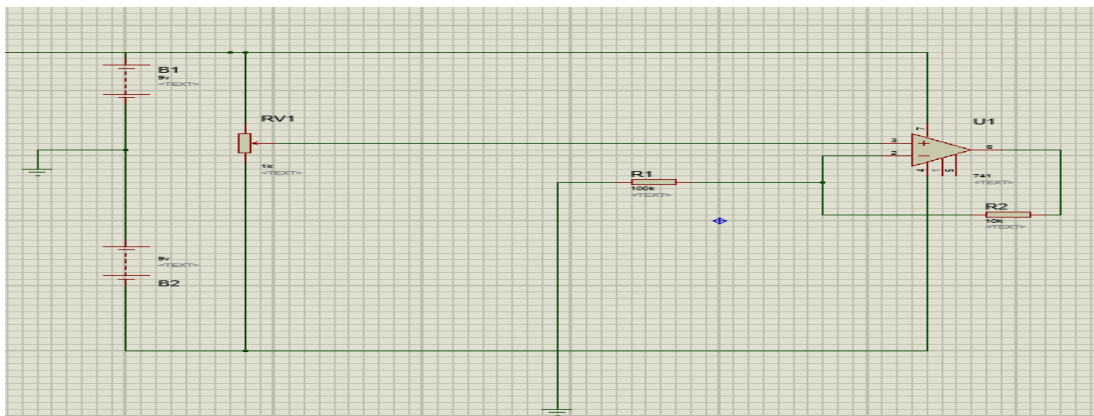


Figure 4: System design of non-inverting Op-amp

The output voltage of a non-inverting op-amp is given as;

$$V_{out} = \frac{R_{in} + R_f}{R_{in}} \quad (7)$$

The summing op-amp trainer was designed and simulated using Proteus software as shown in figure 5.

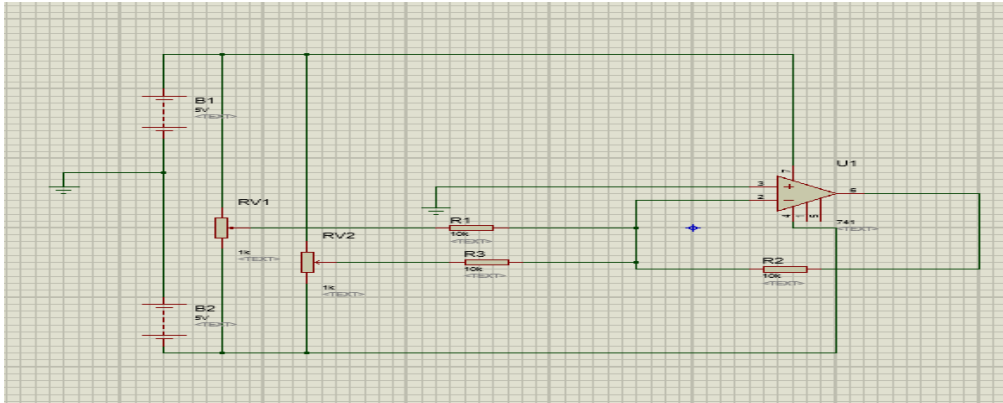


Figure 5: System design of summing Op-amp.

$$V_{out} = -R_f \left[\frac{V_1}{R_1} + \frac{V_2}{R_2} \right] \quad (8)$$

If $R_1 = R_2 = R_f$

$$\text{Then } V_{out} = -(V_1 + V_2) \quad (9)$$

The complete circuit of LM741 op-amp trainer is shown in figure 6



Figure 6: The complete LM741 operational amplifier trainer

3.0 RESULTS AND DISCUSSION

The results of various experiments conducted on the op-amp trainer are discussed and compared with the results obtained theoretically.

3.1 Theoretical and practical results of op-amp inverting and non-inverting trainer

Table1: Theoretical and practical results of an inverting op-amp trainer

Input Voltage (Volts)	Rf (KΩ)	Rin (KΩ)	Vout – Inverting (Theoretical values in Volts)	Vout – Inverting (Practical values in Volts)
1.0	10	100	-0.100	-0.0982
1.5	10	110	-0.136	-0.1470
2.0	10	120	-0.167	-0.1756
3.0	10	130	-0.231	-0.2358
4.0	10	140	-0.286	-0.3096
5.0	10	150	-0.333	-0.3560

Table 1 presents theoretical and practical results for an inverting operational amplifier trainer. It includes input voltage values, feedback and input resistance values and corresponding theoretical and practical output voltages. It is observed that as the input voltage increases, the output voltage also increases in magnitude. The negative output voltage confirmed the inverting nature of the op-amp trainer.

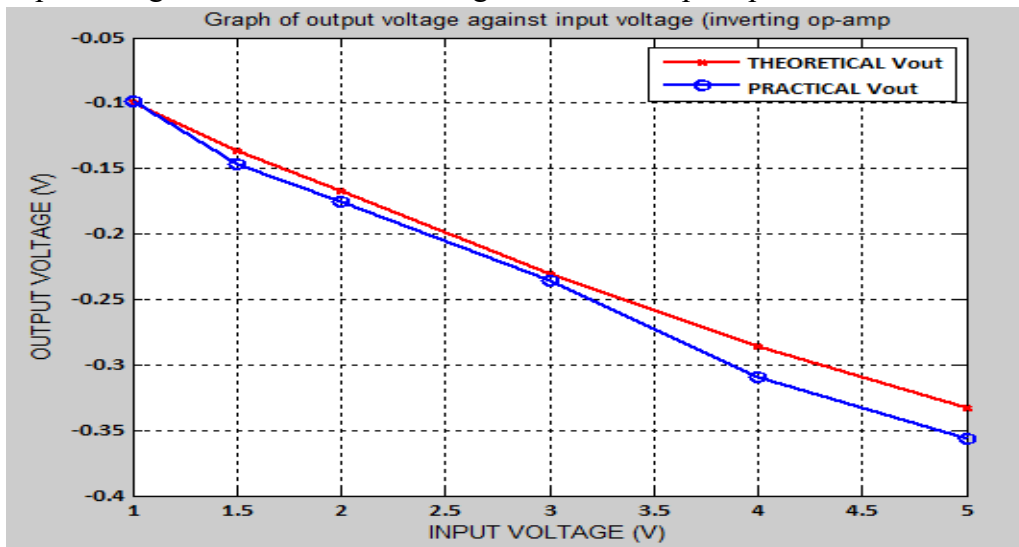


Figure 7: Graph of output voltage against input voltages of the theoretical and practical values of an inverting Op-amp

Figure 7 shows the graph of output voltage against input voltage of the theoretical and practical values of an inverting op-amp trainer. It is seen that the practical values of output voltage are higher than the theoretical values of the output voltage. The negative values of the output voltage indicate that the inverting op-amp trainer is inverted in magnitude and in phase with the input voltage. Also, both theoretical and practical output voltages follow a nearly linear trend, which confirms that the op-amp is behaving as expected according to the inverting formula in equation 6. The practical values slightly deviated from the theoretical values especially at higher input voltages due to real world factors such as components tolerances, op-amp non-

idealities and measurement errors. The significance of this result is that the experimental data aligns well with theoretical expectations confirming the correctness of the op-amp trainer.

Table 2: Theoretical and practical results of non- inverting op-amp trainer

Input Voltage (Volts)	Rf (KΩ)	Rin (KΩ)	Vout – Non Inverting (Theoretical values in Volts)	Vout – Non Inverting (Practical values in Volts)
1.0	10	100	11	11.982
1.5	10	110	12	12.970
2.0	10	120	13	13.956
3.0	10	130	14	14.928
4.0	10	140	15	15.960
5.0	10	150	16	16.950

Table 2 presents the theoretical and practical results of a non-inverting operational amplifier trainer. It is seen that output voltage increases proportionally with the input voltage. This table demonstrates the working of a non-inverting and how real-world results compare to theoretical calculations.

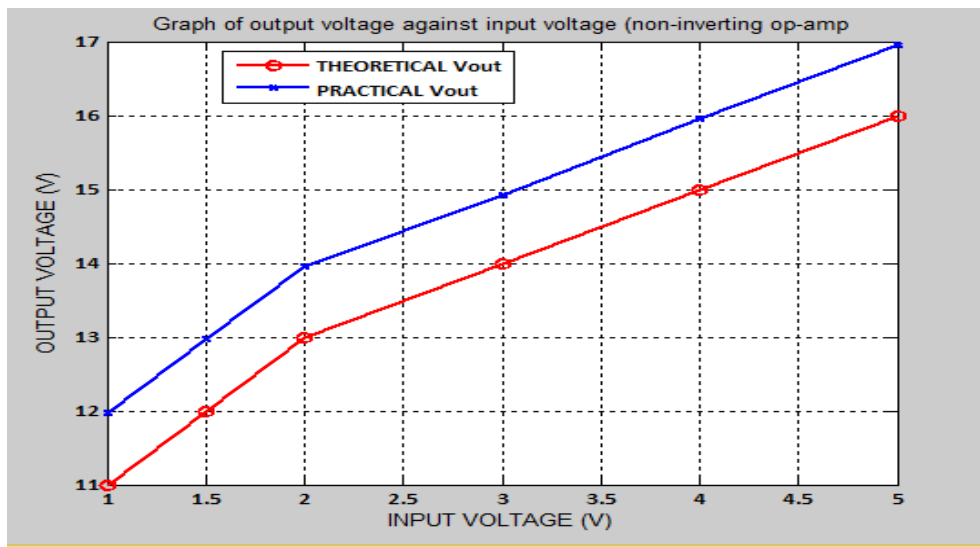


Figure 8: Graph of output voltage against input voltages of the theoretical and practical values of non-inverting op-amp.

Figure 8 shows the graph of output voltage against input voltage of the theoretical and practical values of non-inverting op-amp trainer. It is seen that the practical values of output voltage are slightly higher than the theoretical values of the output voltage due to real-world circuit imperfections such as component tolerances, power supply variations and op-amp limitations. The positive values of the output voltage imply that the non-inverting op-amp trainer is in phase with the input voltage. This result obtained is significant in understanding the limitations of op-amps in practical applications and emphasizes why circuit designers must account for real-world constraints when designing amplifiers for signal processing, measurement and control systems.

The result of the theoretical and practical values of summing op-amp is shown in Table 3

V1(volts)	0	0.5	1	2.5	3.5	4.5	5.5	6.5	7.5
V2(volts)	0	-1	-2	-4.5	-0.5	-1	-1.5	-2	-2.5
Vout(theory in volts)	0	0.5	1	2	-3	-3.5	-4	-4.5	-5
Vout(practical in volts)	0	0.58	1.67	2.53	-3.42	-3.82	-4.42	-4.87	-5.46

Table 3 presents the theoretical and practical output values of a summing operational amplifier circuit based on different input voltages. The practical output values are close to the theoretical values but show small deviations. These deviations arise due to real-world factors such as op-amp imperfections, power supply limitations, components tolerances and measurement inaccuracies.

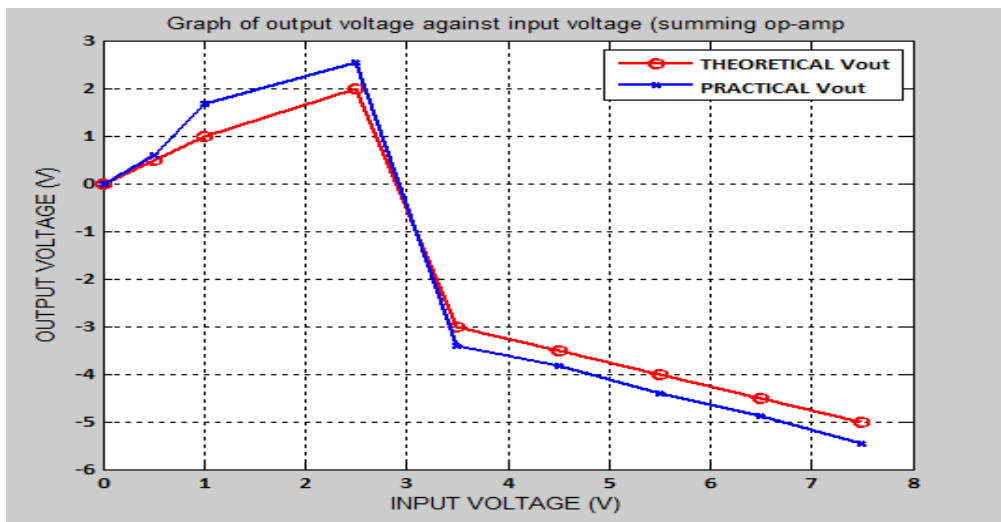


Figure 9: Graph of output voltage against input voltages of the theoretical and practical values of summing Op-amp

Figure 9 shows the graph of output voltage against input voltage of the theoretical and practical values of a summing op-amp trainer. It is seen that the practical values of output voltage are greater than, less than and almost the same as the theoretical values of the output voltage at some points on the graph. For example, at lower input voltages (0V to approximately 3V), both curves match well but as input voltage increases, deviations become more noticeable. It is an indication that the op-amp trainer designed will function maximally while performing experiment with it. The result validates the operation of a summing amplifier, showing that while practical results closely match theoretical expectations, minor discrepancies exist due to real-world non-idealities in electronic components.

4.0 CONCLUSION

This study developed and evaluated an **LM741 Operational Amplifier trainer** to improve practical learning in analog electronics at Michael Okpara University of Agriculture, Umudike. The system addresses the gap between theory and practice by providing a compact, modular platform for hands-on experimentation with key op-amp configurations such as inverting, non-inverting, voltage follower, and summing amplifiers.

The trainer was designed for simplicity, affordability, and flexibility using readily available components, and its implementation produced a functional and user-friendly system. Performance evaluation showed strong agreement between theoretical and experimental results, with minor deviations attributed to component tolerances and inherent non-idealities, which also served as valuable learning experiences.

Overall, the trainer enhances student engagement, supports active learning, and reduces laboratory cost and setup complexity. It offers a practical, low-cost, and scalable solution for analog electronics education, with potential for further improvement through digital integration and expanded functionality.

REFERENCES

- Allen, P. E., & Holberg, D. R. (2015). *CMOS analog circuit design* (3rd ed.). Oxford University Press.
- Gray, P. R., Hurst, P. J., Lewis, S. H., & Meyer, R. G. (2015). *Analysis and design of analog integrated circuits* (5th ed.). Wiley.
- Horowitz, P., & Hill, W. (2015). *The art of electronics* (3rd ed.). Cambridge University Press.
- ICDrex. (2025). *Practical guide to the LM741 operational amplifier: Principles, design, and applications*. ICDrex.
- Jibunor, J. E., Olayinka, A. S., & Igbape, O. R. (2025). Design and development of an LM741 instrumentation module for enhancing the teaching of basic analog circuit principles in physics and electrical engineering. *International Journal of Research and Scientific Innovation*.
- Jin, X., & He, J. (2020). Design and analysis of two-stage CMOS operational amplifier for fluorescence signal processing. In *Proceedings of the 2020 7th International Conference on Information Science and Control Engineering (ICISCE)* (pp. 2345–2348). <https://doi.org/10.1109/ICISCE51195.2020.00508>
- Jung, W. G. (2017). *Op-amp applications handbook* (2nd ed.). Newnes.
- Manuel, T. (2008). *INEL 5205 instrumentation: Basic op-amp circuits*. University of Puerto Rico, Mayagüez, Department of Electrical and Computer Engineering.
- Nikolaos, F. V., & Gerasimos, P. (2017). Operational amplifiers teaching and students' understanding. In *Proceedings of the 2017 IEEE Global Engineering Education Conference (EDUCON)* (pp. 1–6). <https://doi.org/10.1109/EDUCON.2017.7942865>
- Nina, K., Sari, L. Y., & Jouni, H. (2006). *The significance of practical training in linking theoretical studies with practice*. Springer.
- Patnaik, A., Panigrahy, R. K., Patjoshi, S., & Rout, S. (2020). Design and implementation of optimized parameter based operational amplifier for high speed analog signal processing. In *Proceedings of the 2020 IEEE International*

Symposium on Sustainable Energy, Signal Processing and Cyber Security (iSSSC) (pp. 1–6).
<https://doi.org/10.1109/iSSSC50941.2020.9358837>

Razavi, B. (2016). *Fundamentals of microelectronics* (2nd ed.). Wiley.

Ribbens, W. B. (2017). Understanding automotive electronics. In *Understanding automotive electronics: An engineering perspective* (8th ed., pp. 23–88). Butterworth-Heinemann. <https://doi.org/10.1016/B978-0-12-810434-7.00002-8>

Sedra, A. S., & Smith, K. C. (2015). *Microelectronic circuits* (7th ed.). Oxford University Press.

Sharvani, V., Mahesh, M., & Pankaj, R. (2022). Design and implementation of 45nm operational amplifier. *International Journal for Research Trends and Innovation*, 7(9), 452–458.

Terrell, D. L. (1996). Basic concepts of the integrated operational amplifier. In *Op amps: Design, application and troubleshooting* (2nd ed., pp. 1–35). Butterworth-Heinemann. <https://doi.org/10.1016/B978-075069702-6/50002-0>