Department of Electronic & Telecommunication Engineering,
University of Moratuwa, Sri Lanka.

Analog Computer

Group Members:

220145U	P.D.Dodampegama
220072R	B.M.N.S.Basnayake
220268A	A.J.M.K.K.B.Jayasundara
220721H	R.D.P.H.Wijesinghe

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EN 2091 Laboratory Practice and Projects

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Abstract
Our 'Analog Computer' project explores the application of operational amplifiers in performing fundamental analog computations, which can be very beneficial in analog signal processing. Within 1Hz to 10kHz frequency range, it executes addition, subtraction and multiplication operations with high accuracy. It has a dual-channel input interface for each operation with control mechanisms for easily adjustable gain and is powered by a stable and clean power supply system which acts as a separate module.

Contents

1 Introduction and Functionality

Our project, "Analog Computer" aims to demonstrate the functionality of op-amp circuits in performing fundamental analog computations such as addition, subtraction, and multiplication. Additionally, we have implemented integration and differentiation as extra features.

1.1 Requirements

- Required operations
  - Addition
  - Subtraction
  - Multiplication
- Frequency Range - 1 Hz to 10 kHz
- Inputs - Dual-channel input interfaces for each operation
- Control Interface - Control Mechanisms for adjusting gain, biasing and operation mode
- Power Supply - Stable and clean power supply system

2 System Architecture

2.1 Adder

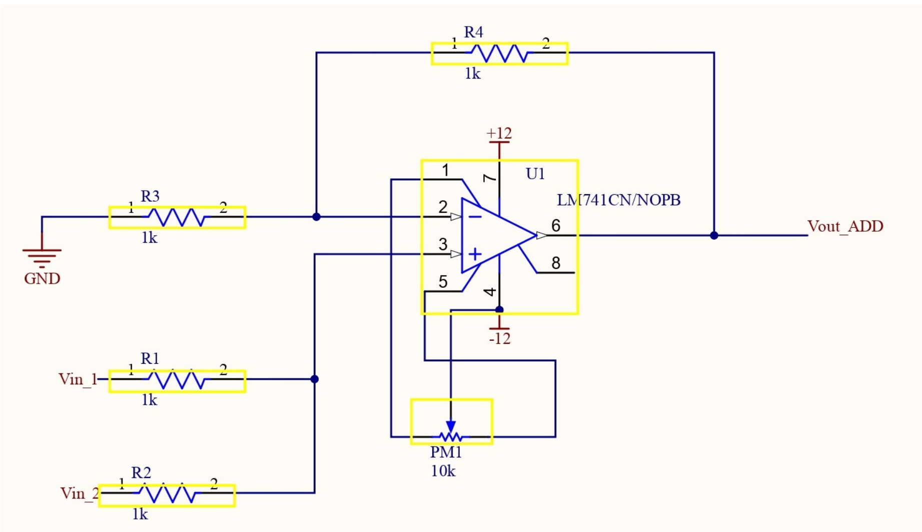


Figure 1: Adder Circuit

We implemented a non-inverting adder circuit which sums two input voltages applied to the non-inverting terminal of an op-amp. Each input voltage is applied through a resistor and a feedback resistor connects the output to the inverting terminal to stabilize the gain.
The output voltage is given by

$$V_{out} = \left(1 + \frac{R_4}{R_3}\right) \cdot V_+$$

By the superposition theorem,

$$V_+ = \left(\frac{R_2}{R_1 + R_2}\right) \cdot V_1 + \left(\frac{R_1}{R_1 + R_2}\right) \cdot V_2$$

$$V_{out} = \left(1 + \frac{R_4}{R_3}\right) \cdot \left(\frac{R_2 \cdot V_1 + R_1 \cdot V_2}{R_1 + R_2}\right)$$

when $R_3 = R_4$ and $R_1 = R_2$,

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

2.2 Subtractor

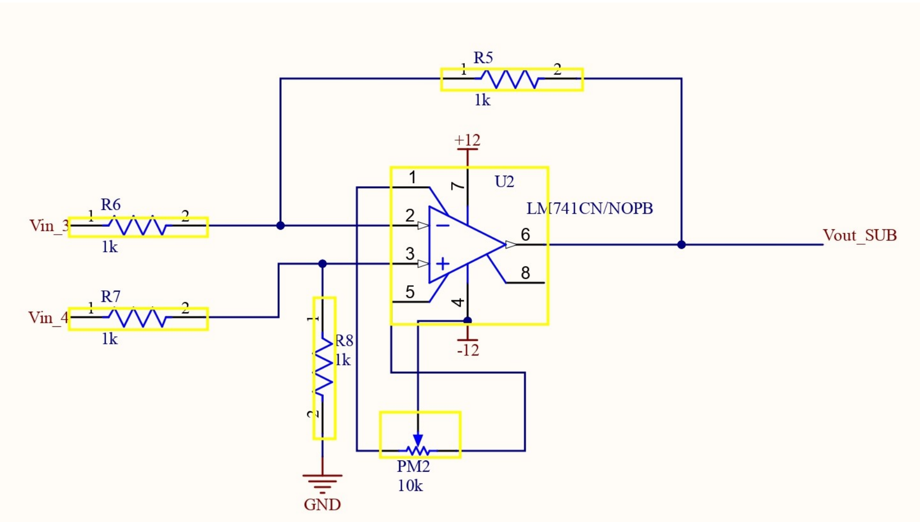


Figure 2: Subtractor Circuit

This is an inverting op-amp configuration that outputs the difference between two input voltages. When $R_6 = R_7$ and $R_5 = R_8$, the output voltage is

$$V_{out} = -\frac{R_5}{R_6}(V_4 - V_3)$$

when $R_5 = R_6$,

$$V_{out} = V_3 - V_4$$

2.3 Multiplier

We used a Gilbert cell[3] with adjustable gain for inputs and output since the circuit works best for small-amplitude signals. The circuit diagram is given below.

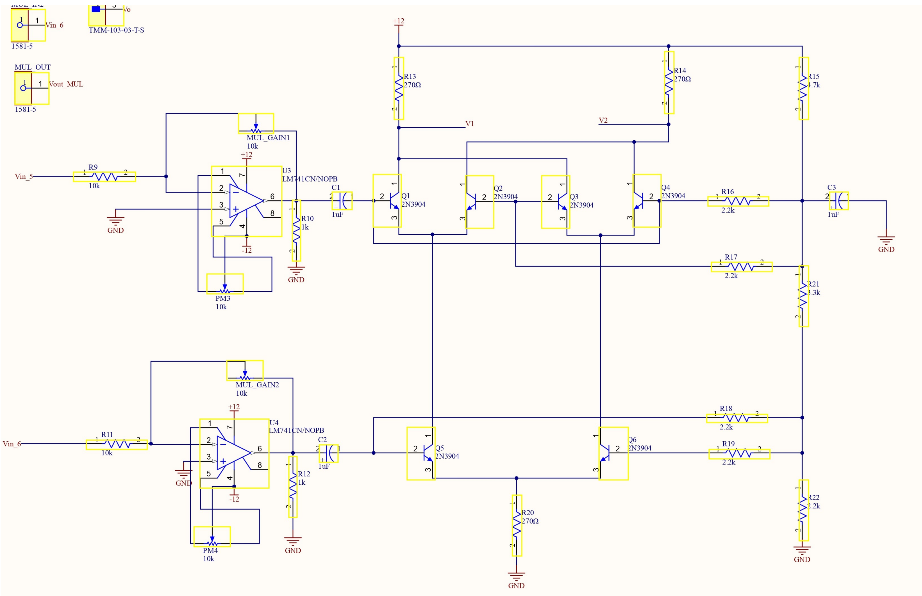


Figure 3: Multiplier Circuit

The differential output voltage is given by:

$$V_0 = k \cdot V_{i1} \cdot V_{i2} = V_{R1} - V_{R2}$$

where I_1 and I_2 are the tail currents of the differential amplifiers at the top.

1. If $I_1 = I_2$, then $V_{R1} = V_{R2}$, and therefore $V_0 = 0$ (regardless of V_{i1}).
2. If $I_1 \neq I_2$, then $V_0 = k_1 \cdot V_{i1}$, where k_1 is proportional to $(I_1 - I_2)$.

Since I_1 and I_2 are supplied by the differential amplifier at the bottom which is biased by V_{i2}, we have:

$$k_1 = k_2 \cdot (I_1 - I_2) = k_2 \cdot k_3 \cdot V_{i2}$$

Therefore, the output voltage V_0 is given by:

$$V_0 = k \cdot V_{i1} \cdot V_{i2}$$

2.4 Differentiator

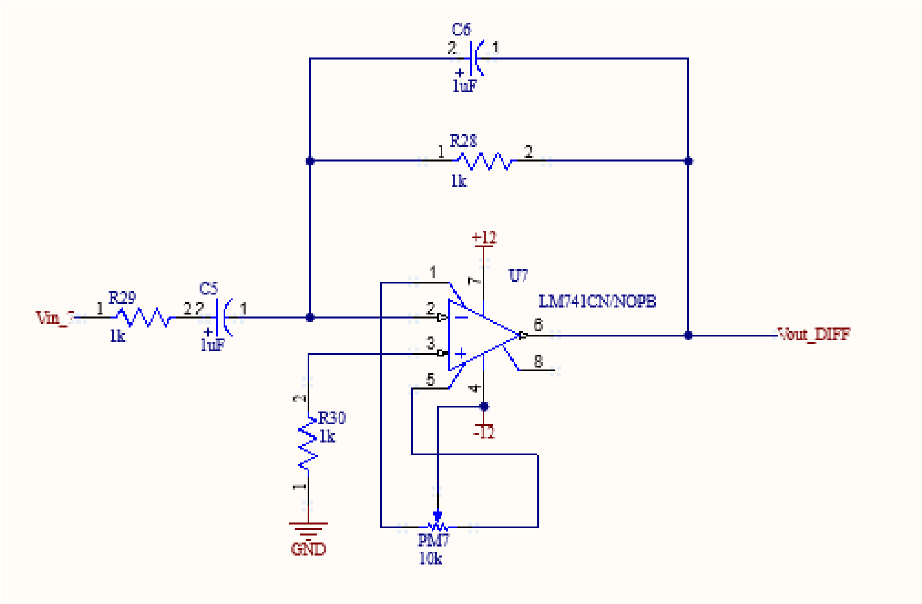


Figure 4: Differentiator Circuit

2.5 Integrator

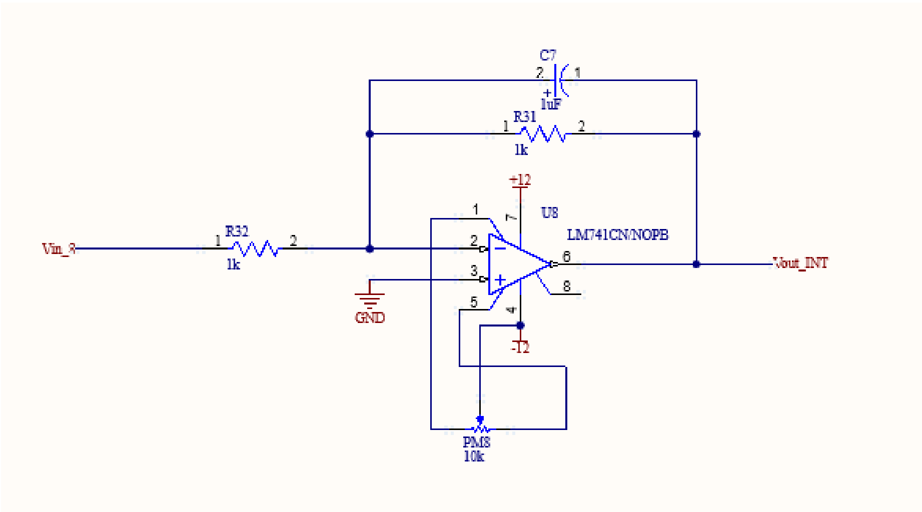


Figure 5: Integrator Circuit

2.6 Gain-controlling circuit

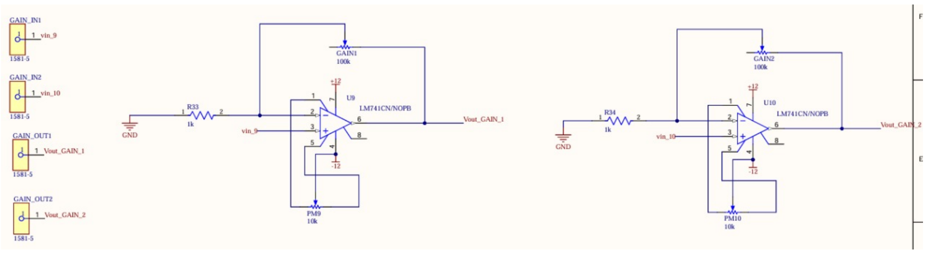


Figure 6: Gain Control Circuit

2.7 Power Supply System

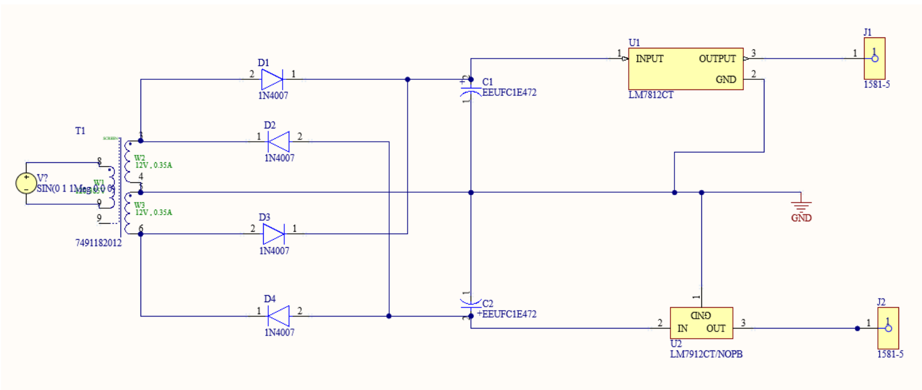


Figure 7: Power Supply Circuit

To power the analog computer, we designed a dual power supply system capable of providing regulated outputs of +12V and -12V. The power supply system uses a standard domestic power source of 230V, 50Hz. This AC input is stepped down using a 500mA 12V*2 center tapped transformer. The stepped-down voltage is rectified using four 1N4007 diodes. This pulsating DC voltage is then smoothed using two 4700 μF electrolytic capacitors to minimize the ripple, one for each polarity. Finally, the smoothed DC voltages are regulated to precise +12V and -12V outputs using LM7812 and LM7912 voltage regulators, respectively.

3 Component Selection

LM741 Op-Amp[2]:

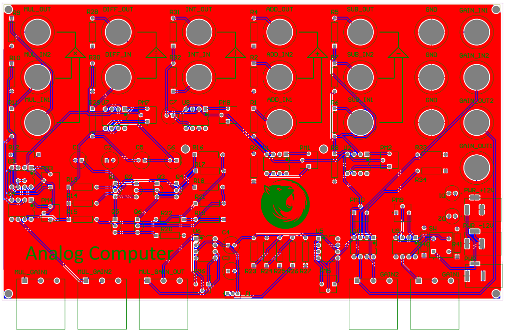
- **W**idely available and affordable.
- **I**deal for basic operations like addition, subtraction, differentiation and integration.
- **B**andwidth ($\sim$ 1 MHz) is sufficient for 1 kHz to 10 kHz signals.
- **S**table and easy to implement without complex compensation.

2N3904 Transistor[1]:

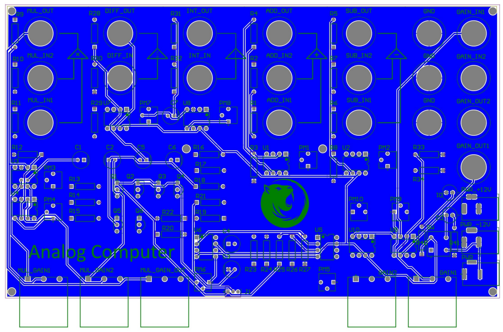
- **C**ommonly available, low-cost NPN transistors.
- **T**ransition frequency of $\sim$ 300 MHz easily handles 1 kHz to 10 kHz operations.
- **S**uitable for various analog applications, including the Gilbert cell multiplier.
- **M**inimizes heat dissipation, ideal for compact analog circuits.

4 PCB Design

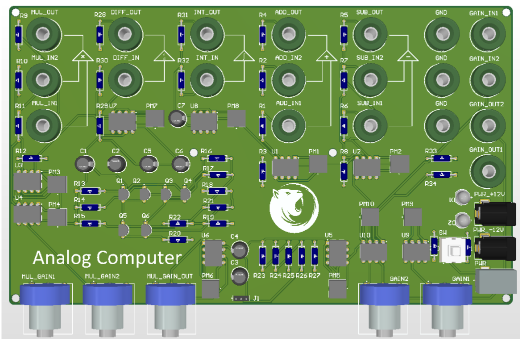
After achieving desired results from our breadboard implementations we designed our PCB through Altium Designer.



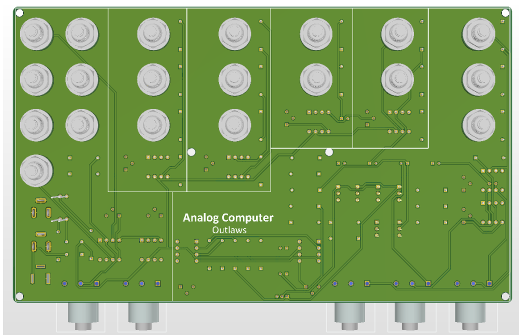
(a) 2D view of Top Layer



(b) 2D view of Bottom Layer



(c) Top View



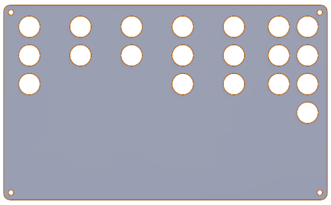
(d) Bottom View

Figure 8: PCB Layouts and Circuits

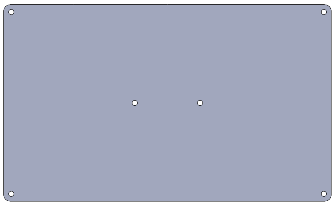
We integrated the adder, subtractor, multiplier, differentiator, integrator, and gain control circuits into a single two-layer PCB, while designing the power supply system as a separate module.

5 Enclosure Design

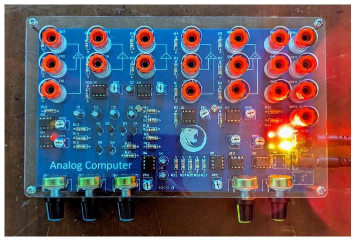
The enclosure consists of two laser-cut perspex layers that securely hold the PCB in place using spacers. The perspex layers include cutouts to allow access to connectors. The enclosure was designed with Solidworks.



(a) 2D view of Top Layer



(b) 2D view of Bottom Layer



(c) Analog Computer

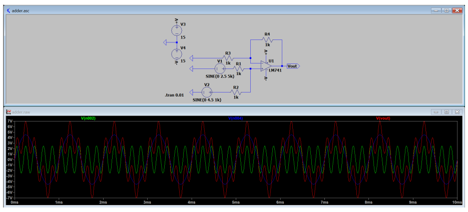
Figure 9: Enclosure Design

6 Software Simulation and Hardware Testing

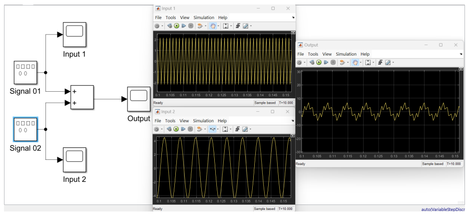
6.1 Software Simulations

LTspice was used for simulating all the circuits before breadboard implementations and Simulink was used to verify the results of each operation.

6.1.1 Adder

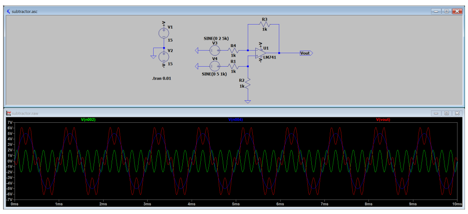


(a) Adder Simulation

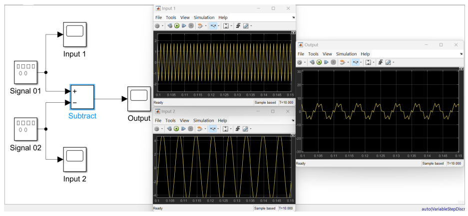


(b) Verification of results by Simulink

6.1.2 Subtractor

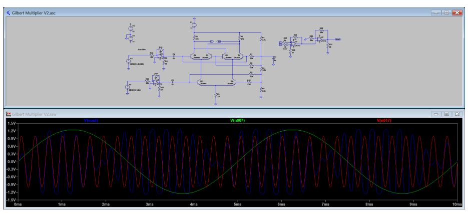


(a) Subtractor Simulation

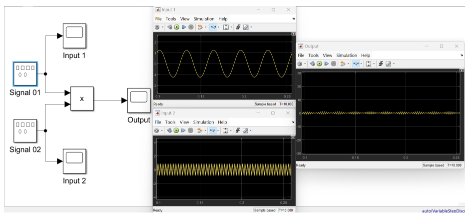


(b) Verification of results by Simulink

6.1.3 Multiplier



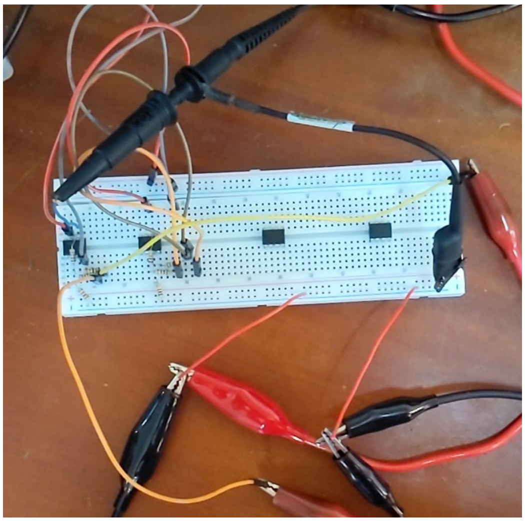
(a) Multiplier Simulation



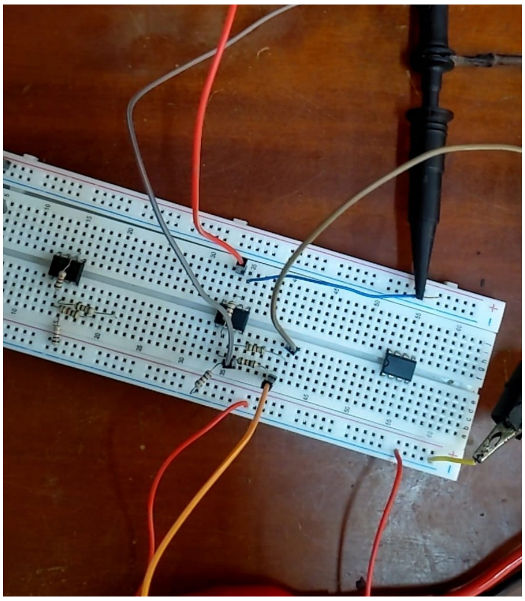
(b) Verification of results by Simulink

6.2 Hardware Testing

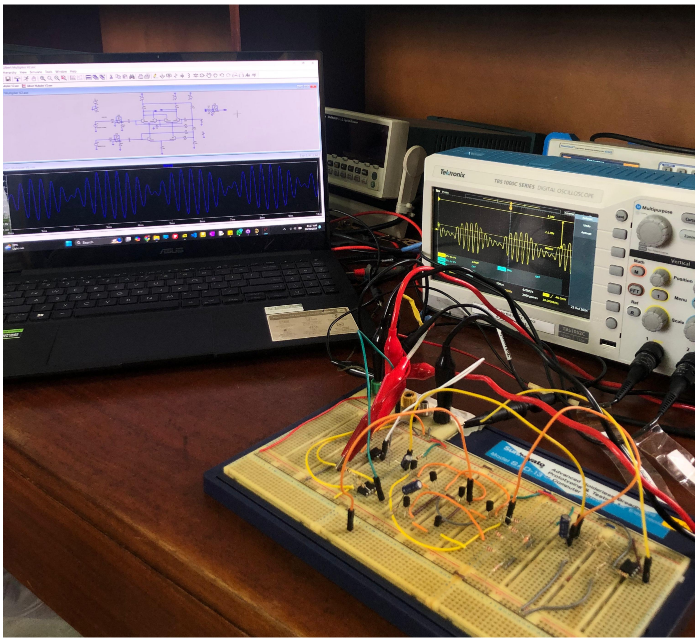
6.2.1 Breadboard Implementation



(a) Adder



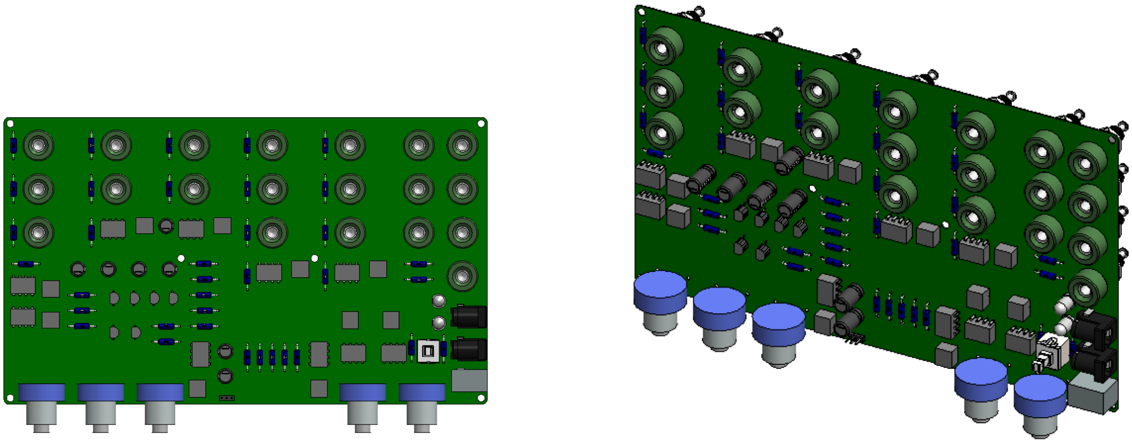
(b) Subtractor



(c) Multiplier

Figure 13: Breadboard Implementations

6.2.2 Final PCB Implementation



(a) Top View (b) Trimetric View

Figure 14: 3D view of the final PCB Implementation

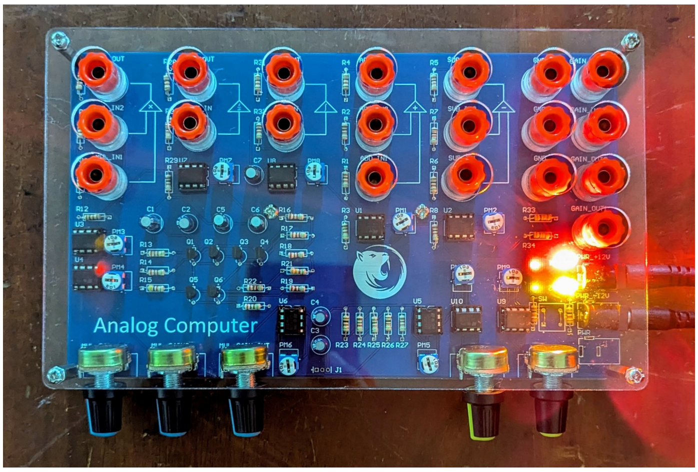


Figure 15: Final PCB Implementation with the enclosure

7 Conclusion & Future Works

In conclusion, our "Analog Computer" project has successfully demonstrated the functionality of op-amp circuits in performing fundamental analog computations such as addition, subtraction and multiplication. After thorough hardware testing and verifying we can be sure that it provides accurate results within 1Hz to 10kHz.

In the future there is the possibility of improvement in the frequency range of the Analog Computer. Some work could also be done to improve the results of the additional operations we have implemented such as differentiation and integration. Additionally, the development of a more precise gain control system capable of finer adjustments would make a significant change.

8 Contribution of Group Members

Index Number	Team Member	Contribution
220145U	Dodampegama P.D.	PCB designing, Simulation, Breadboard Implementations
220072R	Basnayake B.M.N.S.	PCB designing, Components assembly, Breadboard Implementations
220268A	Jayasundara A.J.M.K.K.B.	Enclosure designing, Power supply, Simulation, Breadboard Implementations
220721H	Wijesinghe R.D.P.H.	PCB designing, Power supply, Breadboard Implementations

Acknowledgment

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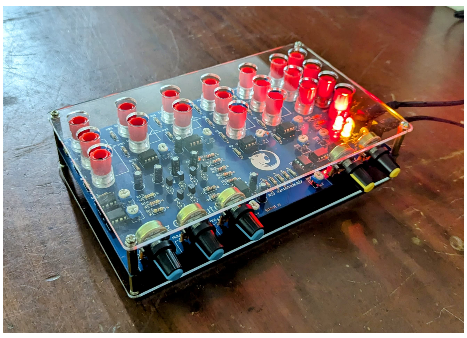
References

[1] On Semiconductor. 2n3904 npn transistor datasheet. https://www.alldatasheet.com/view.jsp?Searchword=2n3904%20datasheet&gad_source=1&gclid=Cj0KCQiAsaS7BhDPARIsAAX5cSBr_QDG_IuKcr_FYYGot05GOw-xljkVX90OYapayCIwYCgZToVktsMaAizQEALw_wcB.

[2] Texas Instruments. Lm741 operational amplifier datasheet. https://www.alldatasheet.com/view.jsp?Searchword=Lm741%20datasheet&gad_source=1&gclid=Cj0KCQiAsaS7BhDPARIsAAX5cSBejcw-ksCzR91hTNy2i4vRN04vMAFpG-cE_6bDbxhJQrwCvGBqlU8aAjI2EALw_wcB.

[3] YouTube. Basics of the gilbert cell — analog multiplier — mixer — modulator. https://youtu.be/7nmmb0pqTU0?si=n-Pz-5JIU4PpdGRa.

Appendix



(a) Analog Computer

(b) Power Supply