Department of Electronic & Telecommunication Engineering
University of Moratuwa

EN2091 - Laboratory Practice and Projects

Analog Computer

Group 212

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Abstract
The "Analog Computer" project focuses on the use of operational amplifier (op-amp) circuits to perform fundamental analog computations such as addition, subtraction, and multiplication. The primary objective of this project is to demonstrate the capability of analog signal processing by emphasizing the design and implementation of dedicated circuits for each operation. Key specifications include a frequency range of 1 Hz to 10 kHz, dual-channel input interfaces, user-friendly control mechanisms enabling adjustments of gain, biasing, and operation mode. The ultimate goal is to achieve a high level of accuracy and precision in the computed results.

Contents

1 Introduction and Functionality

1.1 Objective

The project aims to design and implement accurate operational amplifier circuits for analog computations, highlighting their importance in modern signal manipulation.

1. Bandwidth: 1 Hz - 10 kHz

2. Minimum op amps: 3

3. Operating voltage: ¡ 9V

4. Input: 18 Vp-p (MAX)

5. Adjustable gain and DC shifting

These parameters to be determined for the specifications sheet for the product

1. Open Circuit Gain

2. Closed Loop Gain

3. Bandwidth

4. Input Offset Current

6. CMRR

2 Methodology

2.1 Adder and Subtractor

In Figure 1, We have shown here the circuit Diagram of Addition circuit Follow shows the application of kirchoff's laws, considering OpAmps as ideal. For the subtractor circuit in figure 2, We used same adder circuit with inverting OpAmp circuit to provide negative input of given signal.

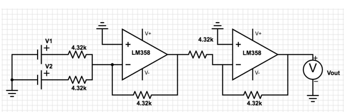


Figure 1: Adder Circuit

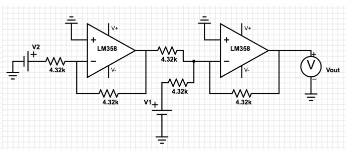


Figure 2: Subtractor Circuit

$$
\begin{aligned}
I_1 &= \frac{v_1}{R} \\
I_2 &= \frac{v_2}{R} \\
I &= I_1 + I_2 = -\frac{v_0}{R} = \frac{v_1}{R} + \frac{v_2}{R} \\
v_0 &= -(v_1 + v_2) \\
I &= -\frac{v_{\text{out}}}{R} = \frac{v_0}{R} = -(v_1 + v_2) \\
v_{\text{out}} &= v_1 + v_2
\end{aligned}
$$

$$
\begin{aligned}
I_1 &= \frac{v_1}{R} \\
I_2 &= \frac{v_2}{R} = \frac{-v_0}{R} \quad \Rightarrow \quad v_2 = -v_0 \\
I &= I_1 + I_2 = -\frac{v_{\text{out}}}{R} = \frac{v_1}{R} + \frac{v_0}{R} = \frac{v_1}{R} - \frac{v_2}{R} \\
v_{\text{out}} &= v_2 - v_1
\end{aligned}
$$

2.2 Multiplier Circuit

Derivation: The given expression for v_0 of multiplier circuit is as follows:

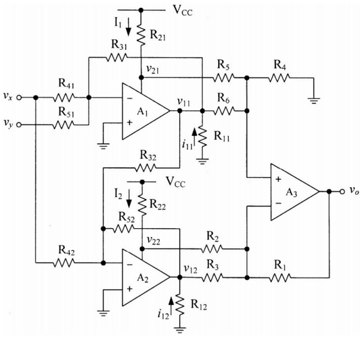


Figure 3: Multiplier Circuit

$\mathrm{v}_0 = -R_f R_s \frac{2R_c}{2R_q} I_s v_x v_y$
$v_y = -k_m v_x v_y$
$Rp = R_3 = R_6, \quad R_f = R_1 = R_4, \quad R_q = R_2 = R_6,$
$R_c = R_{11} = R_{12}, \quad R_s = R_{21} = R_{22},$
$I_s =$ Class AB bias current of op amp
Substituting $\mathrm{R}_f = 100\mathrm{k}, \quad R_q = 100\mathrm{k}, \quad R_c = 5\mathrm{k},$
$R_s = 2\mathrm{k}, \quad I_s = 145\mathrm{A},$
$k_m = 0.275$

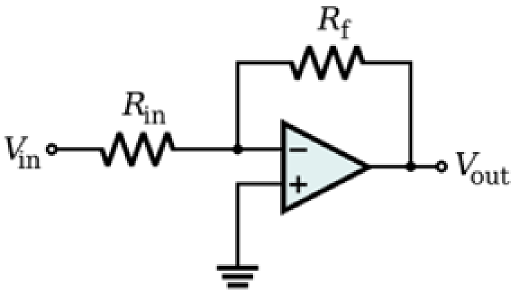


Figure 4: Inverting Circuit

To amplify and invert the output signal, an inverting amplifier configuration is used.

$$v_{\text{in}} = v_0$$
$$v_{\text{out}} = -R_f R v_0 = k_m R_f R v_x v_y$$

To ensure that the factor $k_m R_f R$ equals 1, the values are chosen.
Therefore:

$$v_{\text{out}} = v_x v_y$$

Mathematical Basis for the Multiplier Circuit: The multiplier circuit employs two adder circuits to process the input signals. The first adder combines the two input signals (v_x+v_y). Simultaneously, the second adder combines one input signal with its inverted form, resulting in (v_x-v_y). The outputs of the two adder circuits are then squared individually, leading to $(v_x+v_y)^2$ and $(v_x-v_y)^2$. These squared outputs are processed through a differential amplifier to produce the final output:

$$(v_x+v_y)^2 - (v_x-v_y)^2 = 4v_x v_y$$

2.3 Gain-controlling Circuit:

An inverting amplifier configuration is employed to control the gain of each circuit. A resistor (Rf) is connected between the output and the inverting input of the op-amp. The input signal is applied to the inverting input through another resistor (Rin).

By changing the values of the feedback resistor or the input resistor, the gain of the amplifier can be adjusted.

2.4 Bias-controlling Circuit:

Potential divider circuit using resistors is used to create the desired DC voltage level at the input terminals.

3 Component Selection

3.1 Initial calculations

To select a suitable OpAmp calculated Slew Rate that we required for our design.

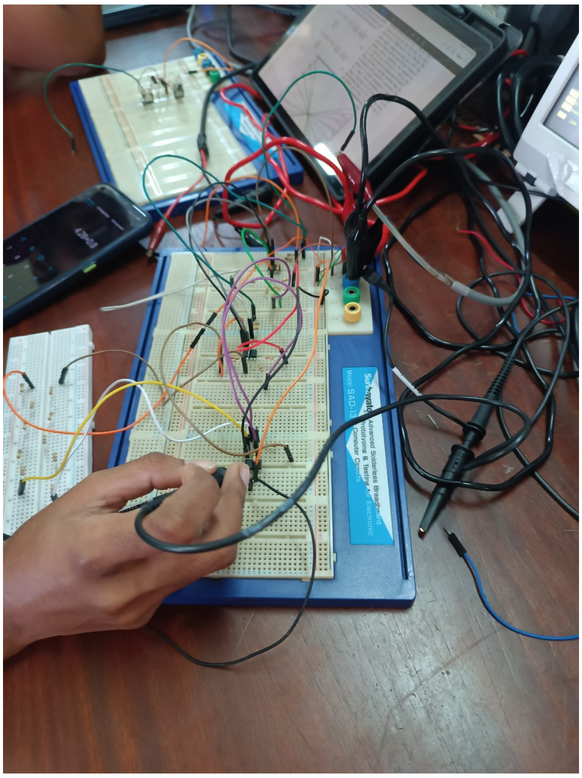
$$|2fA_vV_m| < S$$

$$S_{\text{min}} = \left|2\pi \times 10^4 \times 9\right| = 0.5652\,\text{V/s}$$

3.2 Unity gain bandwidth

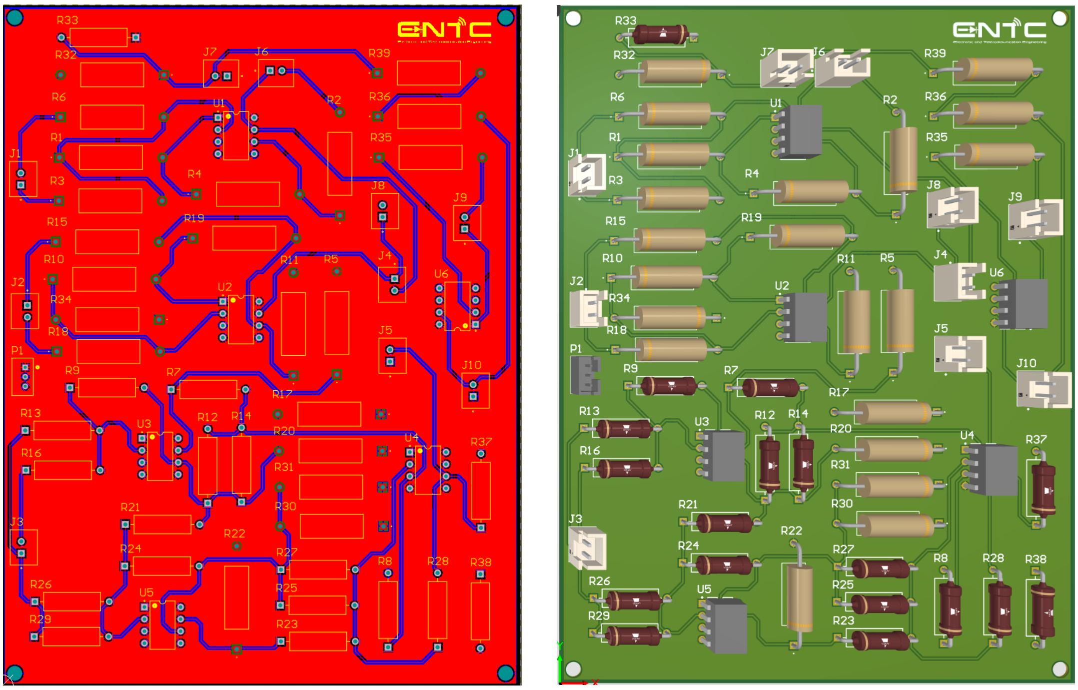
The graphs in the data sheets of both TL072 and UA741 shows that the unity gain bandwidth of op amps are are satisfying gain and maximum frequency of 10kHz multipication

3.3 BreadBoard Implementation



4 PCB Design

Figure shows the breadboard implementation of circuits for testing purposes. After obtaining better results we designed the PCB using Altium Software.



(a) 2D view of Main PCB

(b) 3D view of Main PCB

4.1 Main PCB

We have designed PCB such that separate Circuits been implemented for three operations. We have provided the option of DC shifting and adjustable gain using potentiometers as variable resistors.

4.2 Power Regulating PCB

A 19.5V dc power adapter is employed to provide power to the circuit. To ensure that the circuit receives a stable power supply a voltage splitter circuit is utilized with a LM358 op amp. P channel and N channel mosfets are used to amplify the output current of the op amp. The six diodes in the circuit are connected to bias the two mosfets. To regulate the output voltages of splitter circuit LM7809 and LM7909 voltage regulator circuits are combined later.

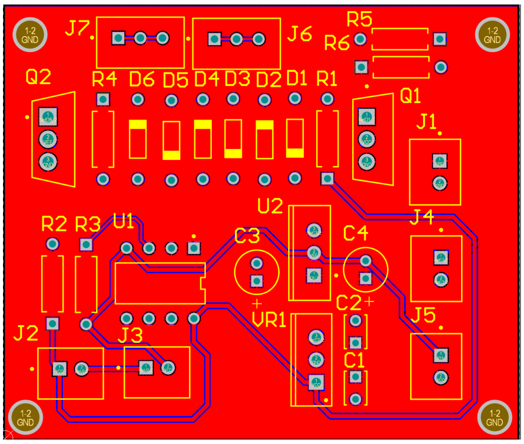


Figure 6: 2D view of Power PCB

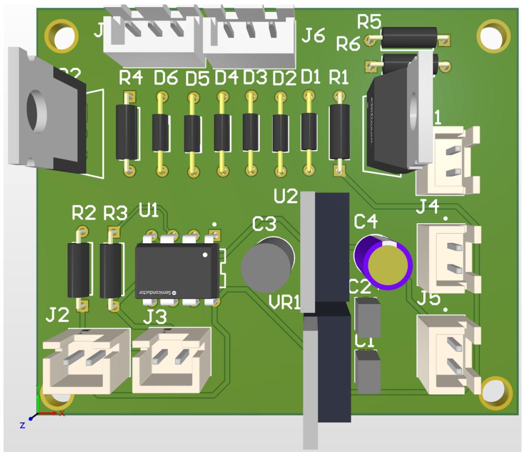
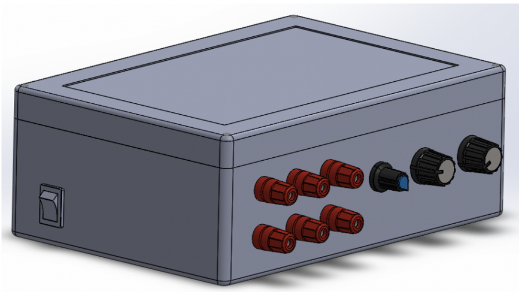
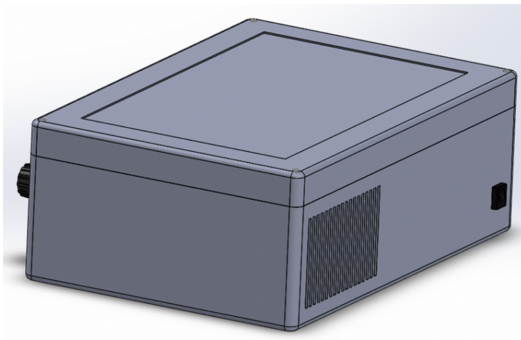


Figure 7: 3D view of Power PCB

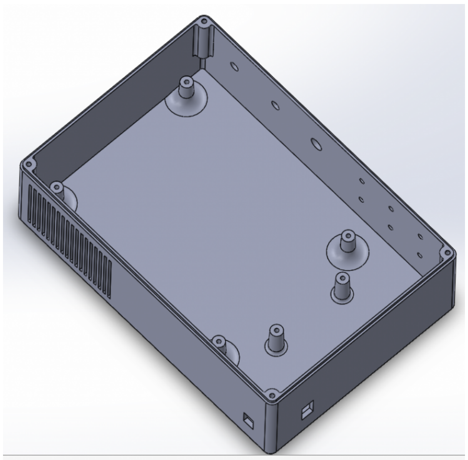
5 Enclosure Design



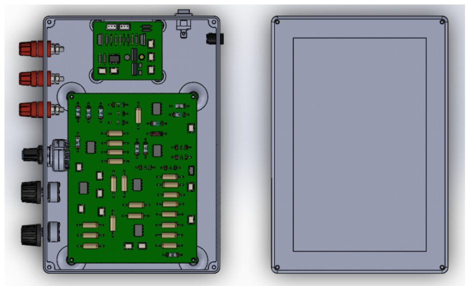
(a) Front view of Enclosure



(b) Rare view of Enclosure



(a) Inside view



(b) Inside view with PCB

6 Software Simulation and Hardware Testing

6.1 Simulation

Multisim was used to simulate each circuit including the adder, subtractor, multiplier and the power supply. Since we obtained the expected results through the simulations, we proceeded with the designed circuits.

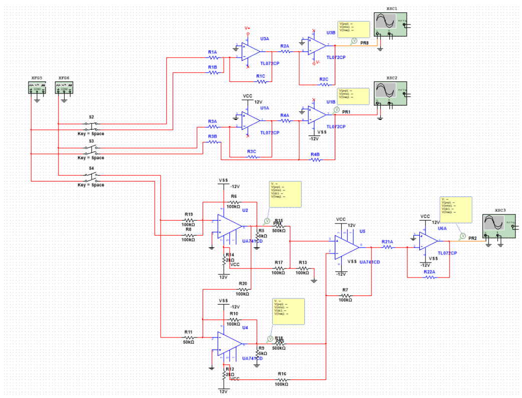


Figure 10: Multisim Schematic Diagram

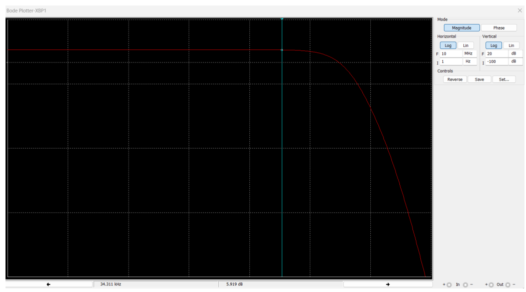


Figure 11: Bode Plot

6.1.1 Bandwidth

The bode plotter tool which is available in Multisim was used to test the usable bandwidth of the circuits. The figures 11 above show that the cut off frequencies of all the circuits are above 10kHz.

6.1.2 Output Waveforms

The oscilloscope tool in Multisim was used to capture the output waveforms resulting from the processing of input signals. We successfully obtained the expected values and shapes for each output signal.

6.2 Hardware Testing

In the hardware testing phase of the project, various input waveforms, including sine waves and square waves, were employed to rigorously evaluate the performance of each circuit within the specified frequency range of 1 Hz to 10 kHz. The circuits were tested for their ability to handle different types of signals, and the obtained outputs for each circuit were observed to align consistently with the theoretical expectations, affirming the reliability and effectiveness of the circuits in practical analog computations.

7 Conclusion & Future Works

In conclusion, the "Analog Computer" project successfully demonstrated the functionality of operational amplifier (op-amp) circuits in performing fundamental analog computations such as addition, subtraction, and multiplication. Through comprehensive hardware testing, we confirmed the circuits' robustness in handling diverse input waveforms, including sine waves and square waves, within the specified frequency range of 1 Hz to 10 kHz

For future works, potential enhancements could focus on refining the user-friendly control interface to provide even more precise adjustments for gain, biasing, and operation modes. Additionally, further optimizations in the circuit design could be explored to minimize signal distortion and noise, enhancing overall accuracy and precision. The integration of additional features or functionalities to expand the capabilities of analog computer may also be considered.

8 Contribution of Group Members

AMARATHUNGA D.N.	Power supply PCB designing, Testing, Circuit designing, Report writing
KURUPPU M.P	Assembling components, Testing, Circuit designing, Report writing
PASIRA I.P.M.	Main PCB designing, Testing, Circuit designing, Report writing
PEIRIS D.L.C.J.	Enclosure Designing, Testing, Circuit designing, Report writing

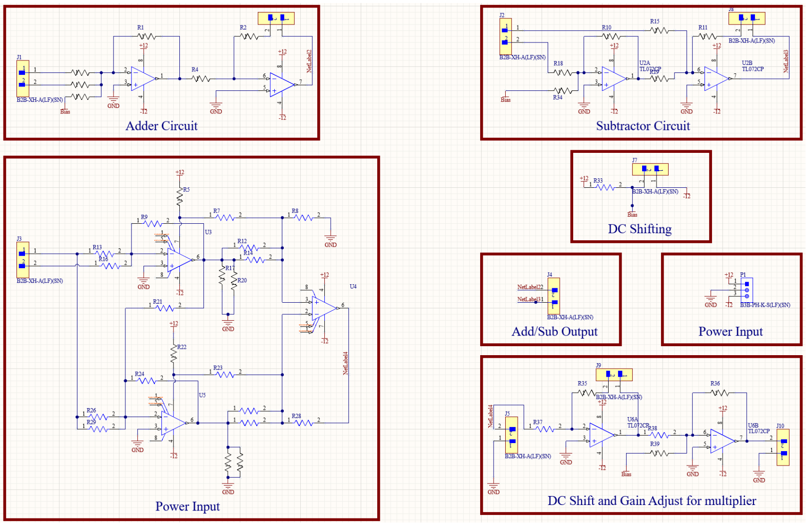
Acknowledgment

We would like to express our gratitude to Dr. Perera M.T.U.S.K. Sampath first, as he helped us with this project. He provided us with the project's original concept and assisted us in continuing. We also extend our thanks to Drs. Jayathu Samarawickrama and Chamira U.S. Edussooriya, as they provided a very clear explanation of the theory behind some circuits that we couldn't figure out. We successfully completed this project with the aid of the modules we studied in the third semester. Additionally, we are grateful to Dinuka Ayya and Saliya Ayya for their unwavering guidance throughout the process. Finally, we extend our appreciation to the non-academic staff members, as they have supported us at various stages and in various ways.

9 References

1. Research Papers https://docplayer.net/117392287-Analog-calculator-spring-2018.html
2. Multiplier Research Paper https://nopr.niscpr.res.in/bitstream/123456789/6896/1/IJPAP
3. TL072 Datasheet https://www.alldatasheet.com/view$_{d}atasheet.jsp?Searchword = TL072$
4. UA741 Datasheet https://www.alldatasheet.com/view$_{d}atasheet.jsp?Searchword = UA741$
5. LM358 Datasheet https://www.alldatasheet.com/view$_{d}atasheet.jsp?Searchword = LM358$

Appendices



Appendix B- Addition Operation Testing

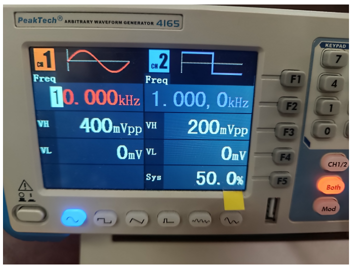


Figure 12: Signal Generator Input

Figure 13: Output of Analog Computer

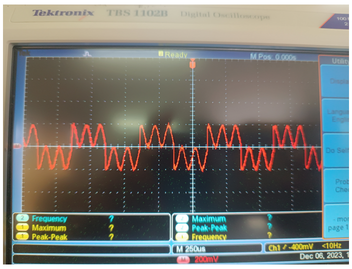


Figure 14: Oscilloscope's Math function Output

Appendix C- Multiplying Operation Testing

Figure 15: Signal Generator Input

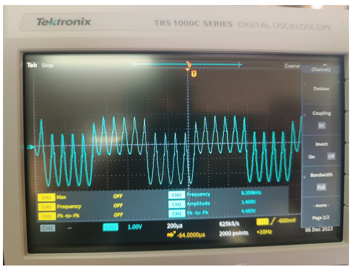


Figure 16: Output of Analog Computer

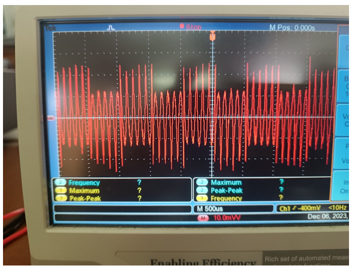
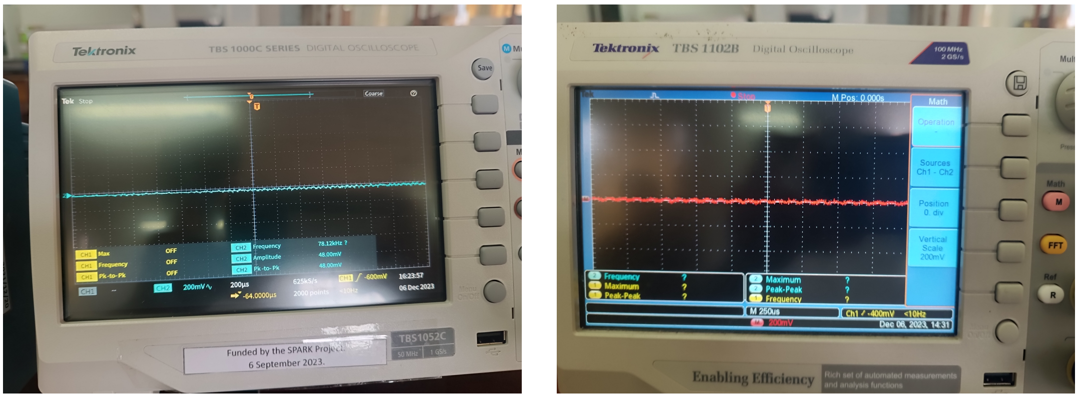


Figure 17: Oscilloscope's Math function Output

Appendix D- Subtraction Operation Testing



(a) Output of Analog Computer (b) Oscilloscope's Math function Output

Figure 18: Subtraction operation when same signals given

Figure 19: Caption for your signal image.