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Analog Voltmeter

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Abstract

This report provides an overview of the design process for an analog voltmeter aimed at measuring voltage levels in electronic circuits. The voltmeter is designed to operate within 3 ranges; 0-2.5V, 0-5V and 0-10V, offering reliable voltage readings for various applications. The methodology involves the utilization of analog components such as resistors, capacitors, and operational amplifiers (OPAMPs) to construct different functional blocks within the voltmeter circuit.

The core design incorporates precision analog components to ensure accurate voltage measurements. NI Multisim 14.2 software is employed for circuit design and simulation, allowing for thorough testing and optimization of individual components. Additionally, SolidWorks software is utilized for the creation of a robust and aesthetically pleasing enclosure to house the analog voltmeter, ensuring durability and user-friendly design.

Furthermore, Altium software is employed for the printed circuit board (PCB) design, enabling the efficient layout of components for optimal performance. The project aims to provide a cost-effective and reliable analog voltmeter solution for electronic enthusiasts and professionals, with an emphasis on precision, durability, and ease of use.

Contents

1. Introduction and Functionality

Introduction:

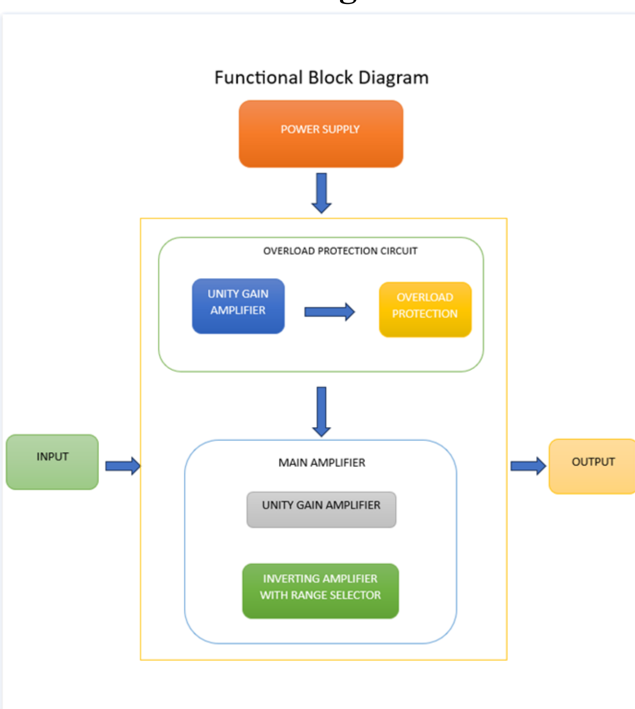
This analog voltmeter project aims to address the common issue of voltage drop and circuit loading encountered in conventional voltmeters. The primary objective is to design a high-precision voltmeter that provides accurate voltage measurements while imposing minimal impact on the circuit under test. Unlike traditional voltmeters that often draw current from the circuit, leading to voltage inaccuracies, our project incorporates operational amplifiers (Op-Amps) to achieve high input impedance and effectively isolate the voltmeter circuit from the measured circuit.

Functionality:

The key functionality of our analog voltmeter project focuses on achieving high input impedance to minimize the impact on the measured circuit. Traditional voltmeters often introduce voltage inaccuracies by drawing current from the circuit under test. To overcome this, Op-Amps are strategically used to create a buffer, ensuring the voltmeter draws minimal current and maintains a high input impedance. This design choice guarantees accurate and reliable voltage readings, making the voltmeter suitable for applications requiring precision without compromising the integrity of the measured circuit.

2. System Architecture

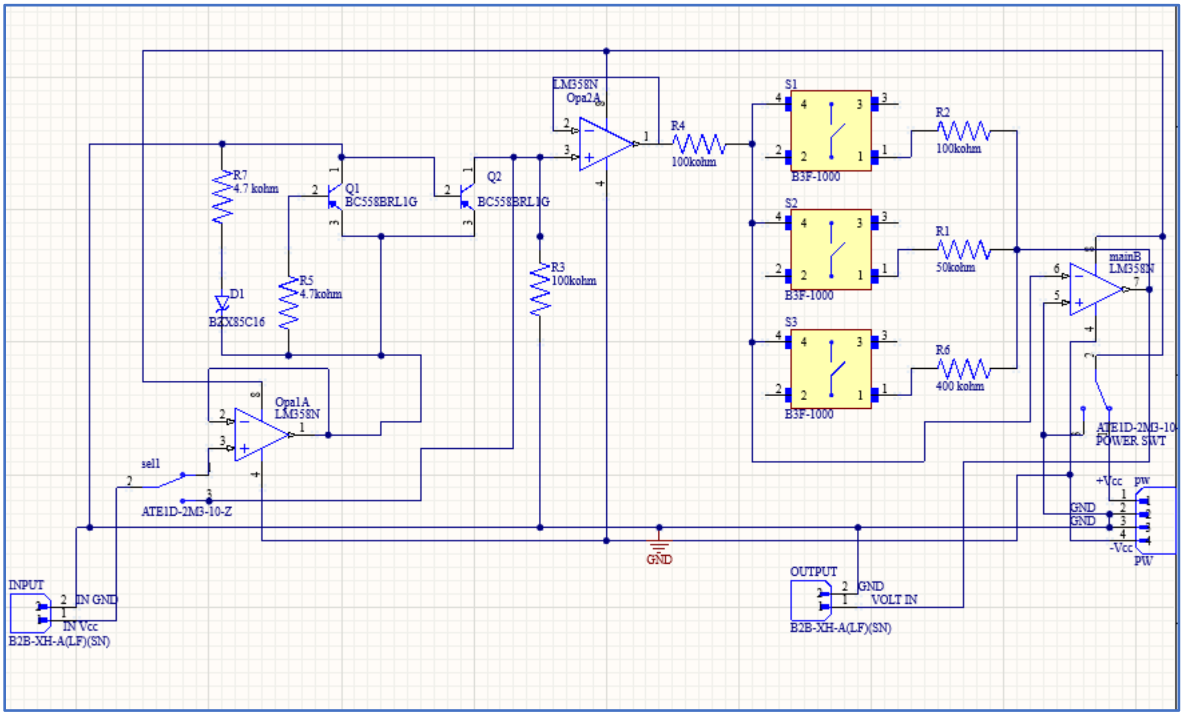
Functional Block Diagram



The system comprises four main blocks: input, output, power supply, and amplifier. Input is facilitated through two probes, and the customized voltmeter panel serves as the output.

There are few power supply options are available, including using a 230V to 24V power adapter, direct power connection, utilizing a dual channel 12V power supply, or employing a 24V power supply designed in-house.

The amplifier block consists of two main parts: the main amplifier and the overload protection circuit. The main amplifier features an inverting amplifier with three ranges and a range selector.

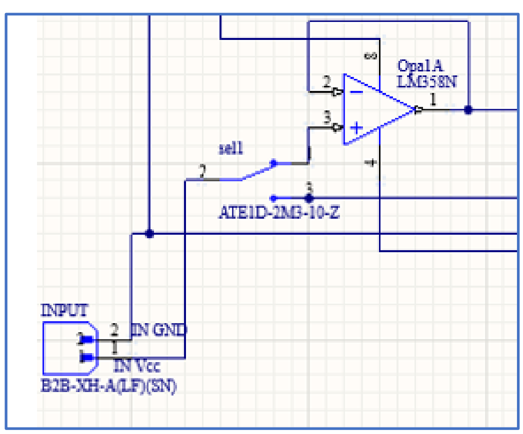


Schematic Diagram

Maintaining a high Input Impedance

At the initiation of our probe, we integrated a unity gain amplifier circuit utilizing the LM358 operational amplifier. This strategic incorporation serves the purpose of isolating the circuit from the voltmeter, thereby maintaining an exceptionally high input impedance. The utilization of the LM358 op-amp is particularly advantageous, as it draws a negligible current from the circuit.

The unity gain amplifier, inherent in the LM358 op-amp, ensures that the output voltage mirrors the input voltage, allowing us to safely channel the voltage into our circuit. This design choice mitigates the risk of voltage drop associated with the internal resistance of the voltmeter. By virtue of this configuration, our system adeptly prevents any compromise in voltage integrity, facilitating accurate and reliable measurements without distortion.



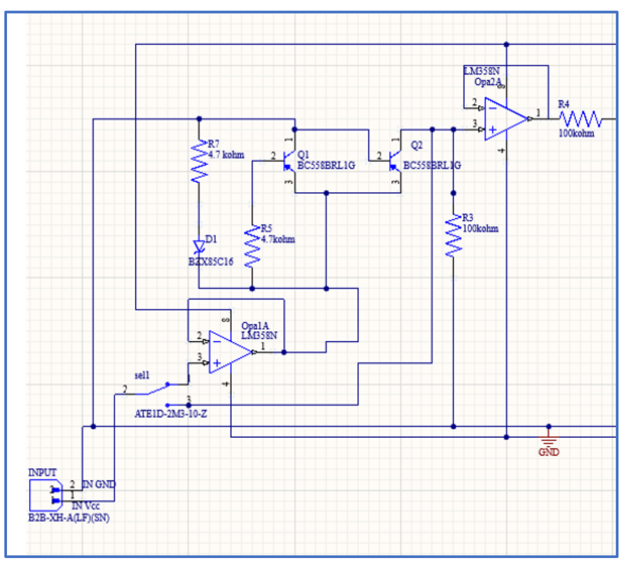
Overload Protection Mechanism

To safeguard our voltmeter from potential mishaps caused by inadvertent overload scenarios, we've implemented an effective overload protection system. This system is comprised of two BC558 PNP transistors and a 16-volt Zener diode carefully chosen to align with the specific requirements of our setup.

The selection of a 16-volt Zener diode is deliberate, considering the input voltages of 12V. It ensures that the Zener voltage is above 12V, safeguarding against potential harm to the voltmeter needle, while not exceeding 20V to maintain optimal functionality within safe limits (keeping in mind that the LM358 op-amp can handle up to 36V).

In operation, when the voltage is below the preset level, the base terminal of Q2 is high, causing it to turn off. With Q2 in the off state, the base terminal of Q1 is low, allowing current to flow through it. However, when the voltage surpasses the predetermined value, the Zener diode begins conducting, connecting the base of Q2 to ground and activating Q2. As a result, the base terminal of Q1 becomes high, causing Q1 to turn on and behave as an open switch. This, in turn, prevents the flow of current through Q1, effectively protecting the load from excessive voltage and ensuring the safety of the voltmeter in overload situations.

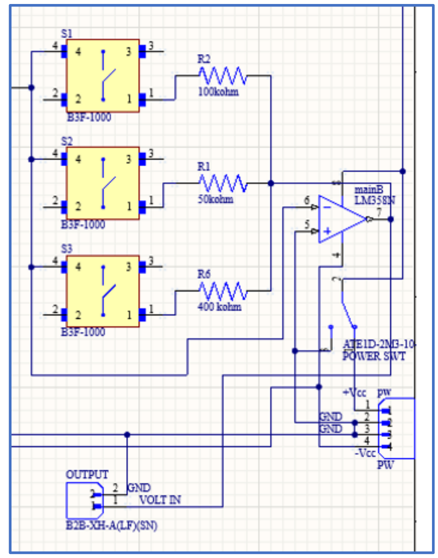
Inserted between the overload protection circuit and the three-range amplification system, a crucial unity gain amplifier serves to isolate these two sections. This isolation prevents current draw from the load, averting any potential voltage drop issues. The unity gain amplifier acts as a buffer, ensuring stable voltage levels and safeguarding the accuracy of voltage measurements throughout the entire system.



Overload Protection Circuit

Measurement Range

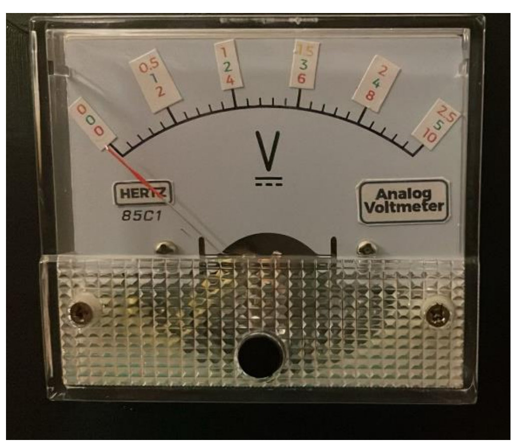
The voltmeter has been primarily designed to measure across three distinct ranges: 0-2.5V, 0-5V, and 0-10V. This design enables the measurement of minimum voltages of 100mV, 200mV, and 400mV, respectively. To achieve these varying ranges, three different resistors are employed in conjunction with three inverting op-amp mechanisms. Additionally, the user is provided with the flexibility to select the desired range through the incorporation of three push buttons.



Analog Display Customization

In our design, we have implemented a customized analog display featuring an analog needle equipped with a pointer, specifically tailored for the measurement of voltages across three distinct ranges. Each range on the analog display is meticulously divided into five segments, providing clear and precise readings.

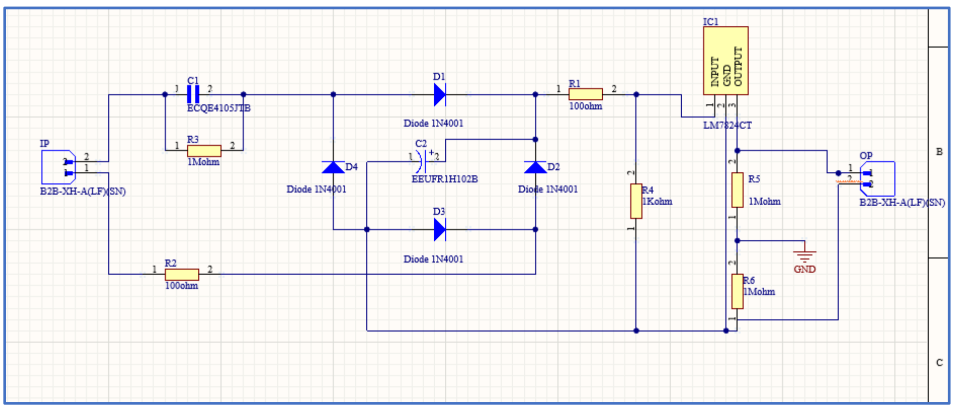
To ensure accuracy and adaptability, an in-built screw mechanism has been incorporated, allowing for the calibration of the needle based on initial conditions. This feature ensures that the analog needle aligns accurately with the voltage scale, guaranteeing reliable and calibrated voltage measurements across the selected ranges.



Power Supply

To ensure reliable and stable operation of the meter, a dedicated power supply circuit has been developed. This circuit transforms the incoming 230V AC voltage into a consistent +12V and -12V DC supply for all three operational amplifiers. The design incorporates a bridge with four IN4001 diodes, a 24V voltage regulator, as well as capacitors and resistors to optimize performance.

Additionally, flexibility has been integrated into the power options for the voltmeter. It can be powered externally using a wall power adapter with a 230V AC to 24V DC output. Moreover, for laboratory applications, the voltmeter can be powered by a dual channel 12V power supply. The latter option features four connector ports to facilitate easy and convenient connection of probes to the power supply. This dual-powered approach enhances the adaptability and versatility of the voltmeter in different usage scenarios.



Power Supply Circuit Schematic

3. Component Selection

1. Overload Protection
   - BC558B Transistor – Used to cutoff the input volage when input voltage become higher than 13V to protect the main amplifier circuit. It has high cutoff voltage and low saturation current.
   - LM358P – Used this op-amp to isolate the main circuit from input and overload protection circuit.
   - 16V Zener diode - We use 16V Zener diode to set the threshold through the transistors. So, we can cut the voltages higher than the 13V and protect the main op-amp and the voltmeter panel.

2. Main Amplifying Circuit
   - LM358P – Used as the non-inverting amplifier to amply the input voltages according to the dc voltage.
   - 100Kohm,50Kohm and 200Kohm - These resistors are used for range selection. When we measure the 10V range. We selected 50Kohm for 5V range and we used 200Kohm range for 2.5V range.
   - Voltmeter Panel – We use voltmeter panel to indicate what is the value of measuring voltage.

3. Power Supply Circuit
   1. IN4001 Diodes – To rectify the input AC voltage and get the DC output voltage.
   2. 2W, 400v 1uf capacitor – To reduce the voltage 230V rms to 34V rms. Also, we use 2W capacitors because the high current can be gone through the circuit and prevent the components from high current.
   3. 2W, 50V 1000uf capacitor - To reduce the ripple voltage of the DC output.
   4. LM7824 Voltage Regulator – Regulate the voltage to the 24V DC output.
   5. 2W, 1Mohm – Prevent the diode, voltage regulator and other connected components from surge current.

Calculations

Amplifier gain

0-10V Range

$V_o = V_{in} (R_f/R)$

$A = R_f/R$

$= 50kohm/100kohm$

$= 0.5$

0-5V Range

$A = R_f/R$

$= 100Kohm/100Kohm$

$= 1$

0-2.5V Range

$A = R_f/R$

$= 200Kohm/100Kohm$

$= 2$

Input impedance of the main op-amp amplifier – 100Kohm

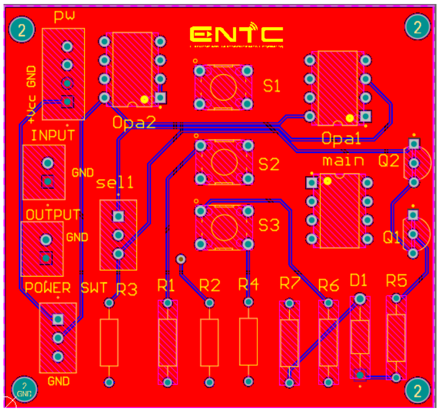
Output impedance of the main op-amp – 50Kohm

Threshold Voltage of overload protection – 13V

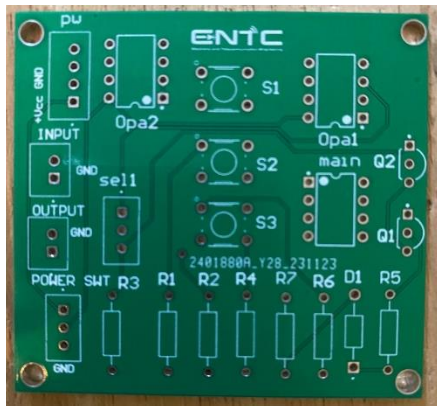
4. PCB Design

For the analog voltmeter, we designed a compact 54 x 58mm printed circuit board (PCB) using Altium. The PCB, a two-layered structure, was manufactured in China and subsequently shipped to our location.

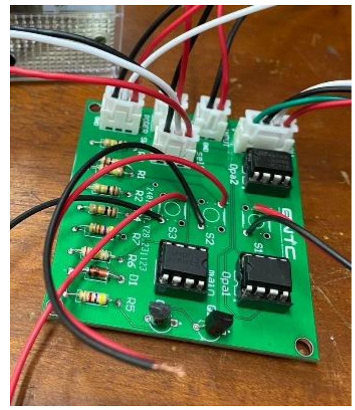
Traces of the lines are 0.254mm width. The drill hole size in the PCB is 3mm. We placed the components in such a way to overcome the complexity in the routing and thermal heating issues.



PCB Design



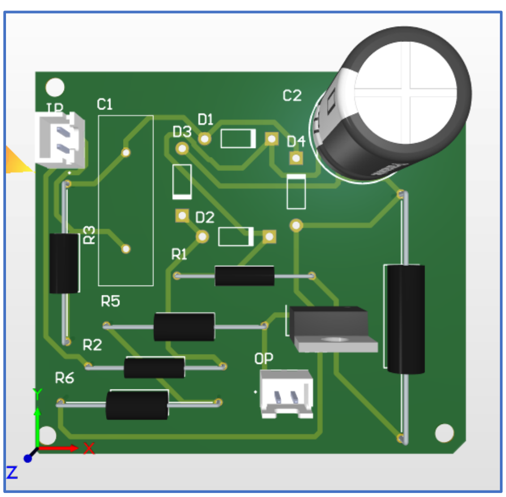
PCB



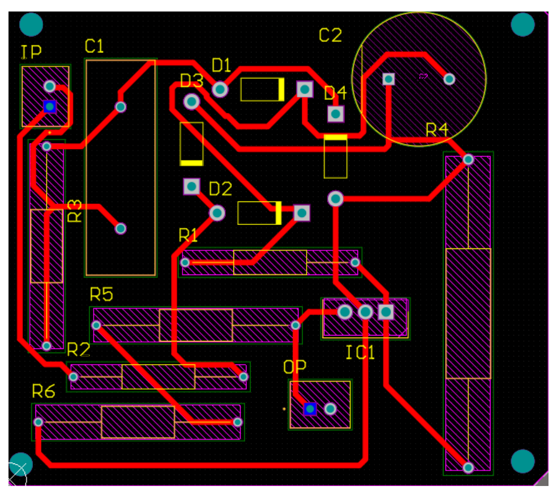
Soldered PCB

We also designed a separate power supply to power up the circuit. For it, we designed a compact 60 x 65mm printed circuit board (PCB) using Altium. The PCB, a single-layered structure.

Traces of the lines are 1.2mm width. The drill hole size in the PCB is 3mm. We placed the components in such a way to overcome the complexity in the routing and thermal heating issues.



Power supply PCB 3D view



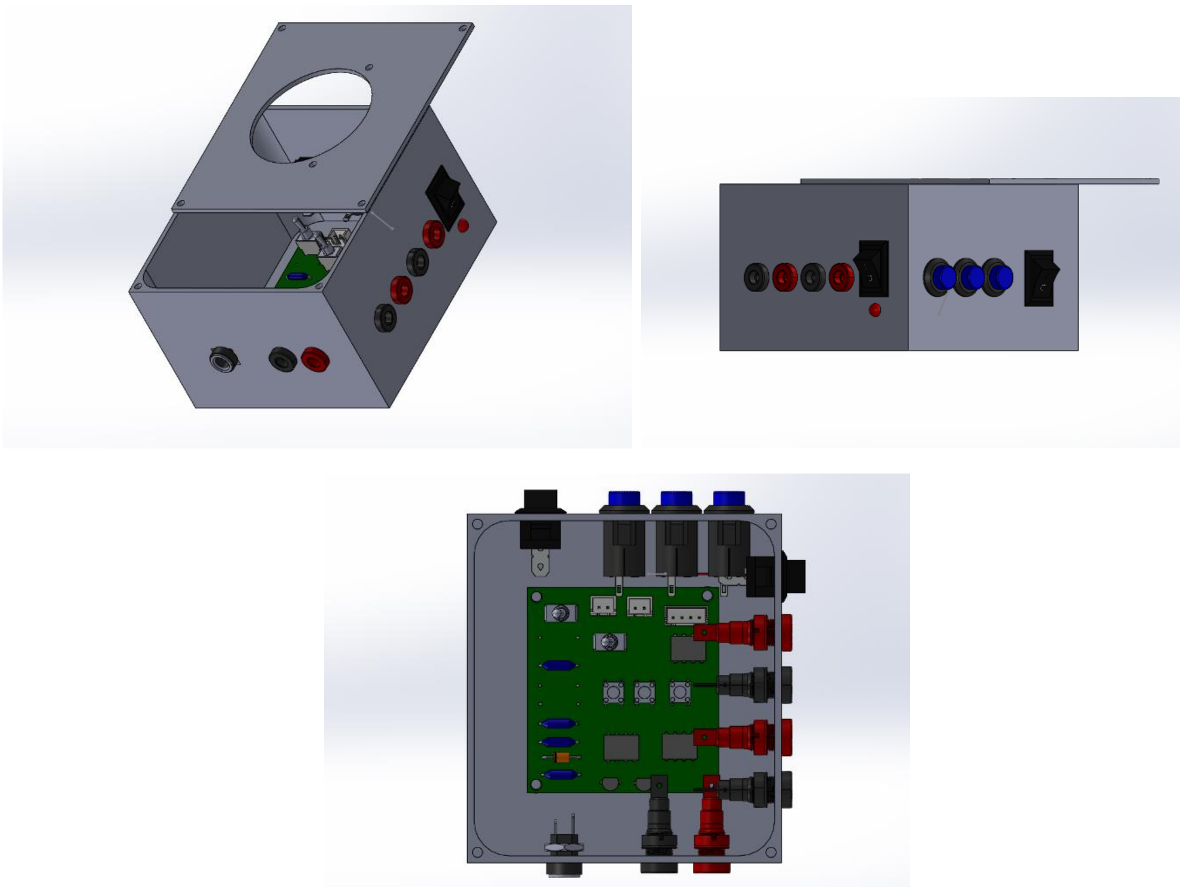
Power Supply PCB Design

PCB Design Files – https://dms.uom.lk/s/xP8RYKjXwsNPgjf

5. Enclosure Design

We have designed an enclosure using SolidWorks. The enclosure measures 10cm x 9cm and is designed to be user-friendly. During the design process, we paid special attention to the power supply. The enclosure has 4 banana connectors to connect to the laboratory power supply and a barrel jack connector to connect to the 24V power supply. The user can use either one of them.

We have also used two banana connectors to connect the two probes. Additionally, you have added a power switch and a separate switch to enable overload protection. The enclosure has 3 push buttons for range selection.

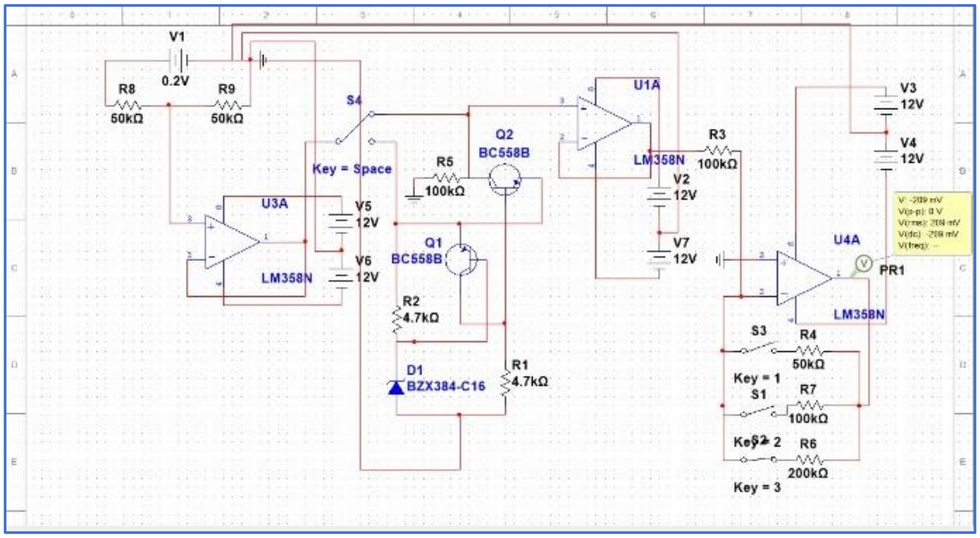


Enclosure Design

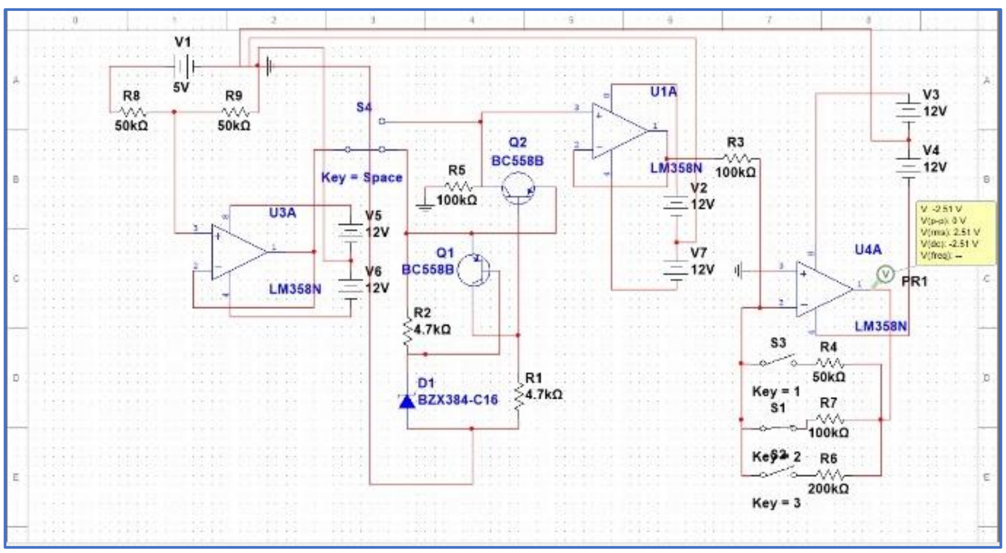
Enclosure Design Files - https://dms.uom.lk/s/JL3cXNGJY5aBqZH

6. Software Simulation and Hardware Testing

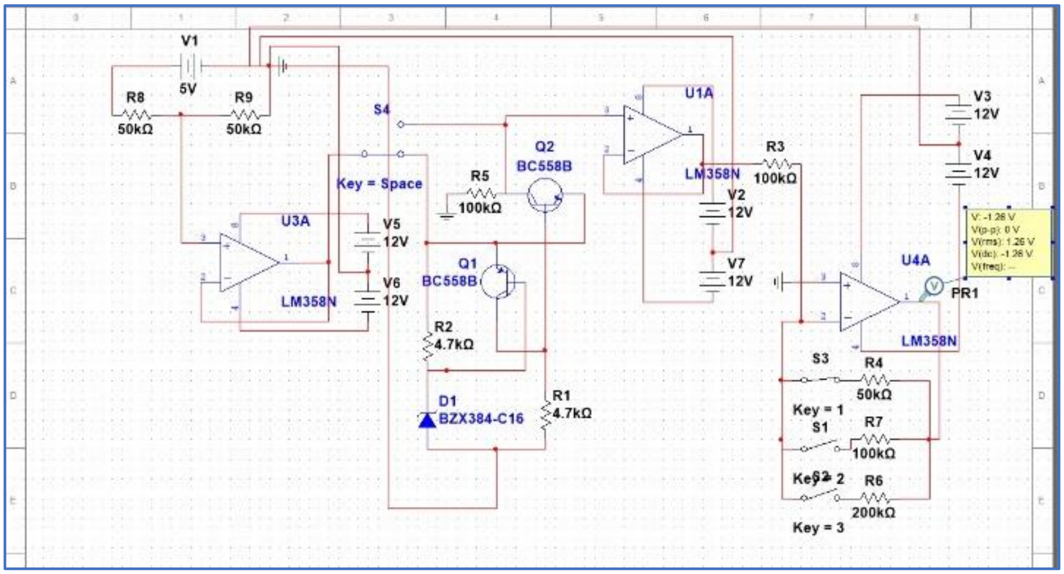
We used Multisim software to simulate the circuit that we created. It gave the voltage outputs very accurately and we confirmed that the selected components are suitable for the implementation.



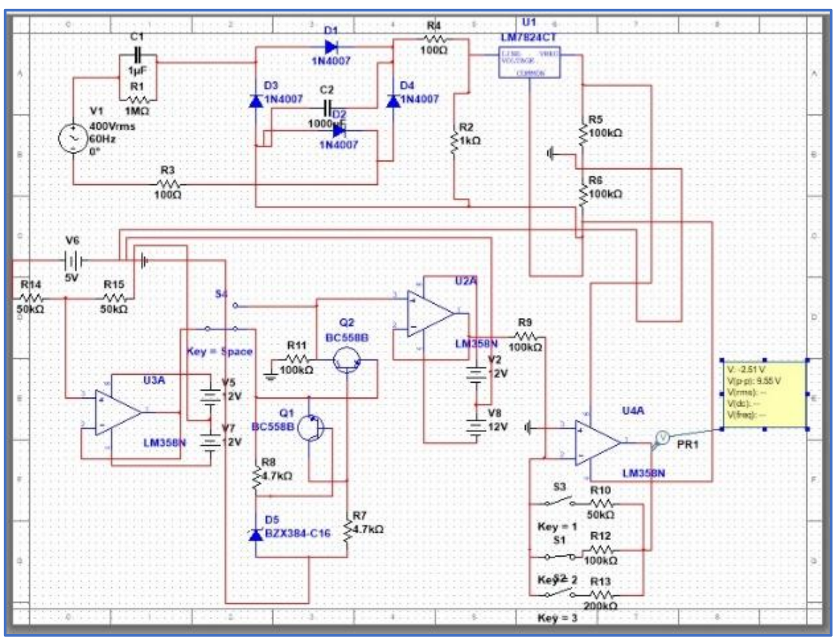
Voltmeter simulation which measures 100mV (Output = around 200mV in 0-2.5V range means 100mV correctly displayed at the panel meter)



Voltmeter simulation which measures 2.5V (Output = 2.51 V in 0 - 5V range means 2.5V correctly displayed at the panel meter)

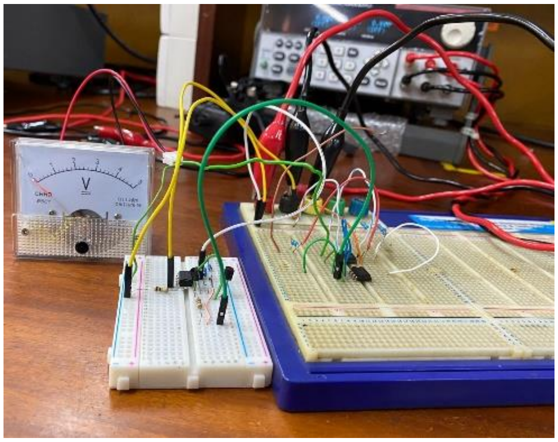


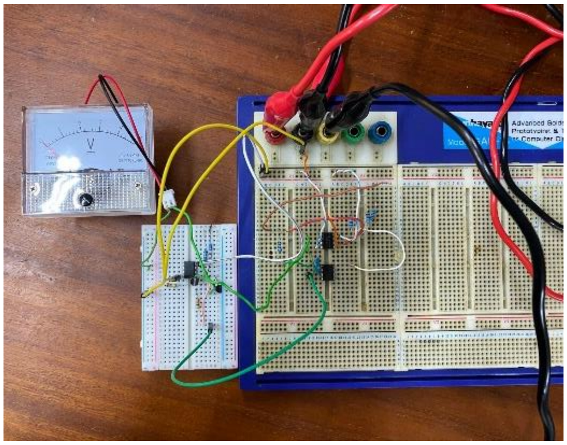
Voltmeter simulation which measures 2.5V (Output = 1.26 V in 0 - 10V range means 2.5V correctly displayed at the panel meter)



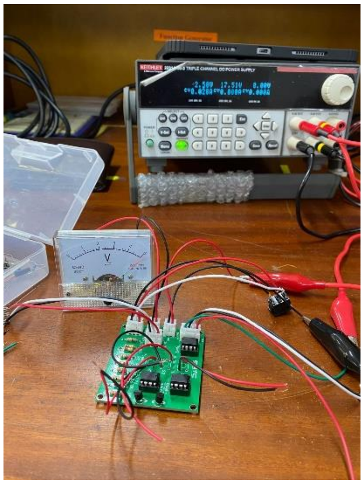
Simulation of the power supply attached to the voltmeter circuit which correctly outputs the input voltage in the 0-5V range.

First, we implemented the circuit on the bread board and calibrated the components until getting successful results. Then we designed the PCB and did a PCB testing using the multimeter by checking the output voltage. Finally, we have attached every component to our enclosure and did a testing and got successful results.





Breadboard Implementation



PCB Testing

7. Conclusion and Future Works

Results

0-10V Range

Voltage	Reading	Error
0	0	0%
2	1.95	2.5%
4	3.9	2.5%
6	5.9	1.67%
8	7.8	2.5%
10	9.85	1.5%

0-5V Range

Voltage	Reading	Error
0	0	0%
1	1	0%
2	1.98	1%
3	2.95	1.67%
4	3.95	1.25%
5	5	0%

0-2.5V Range

Voltage	Reading	Error
0	0	0%
0.5	0.5	0%
1	0.99	1%
1.5	1.5	0%
2	2.01	0.5%
2.5	2.5	0%

Future Developments

1. PCB Implementation for the Optimized Power Supply

- Finalize the in-house power supply for the voltmeter by developing a printed circuit board (PCB) for the designed power supply to enhance reliability and streamline the manufacturing process.

2. Boost Converter Integration

- Implement a boost converter to elevate the DC voltage, enabling the use of rechargeable batteries. This enhancement promotes increased mobility and compactness of the voltmeter.

3. Improved Measurement Parameters

- Enhance the voltmeter's functionality by lowering the minimum voltage measurement to 50mV.

- Achieve a tolerance level of +/-0.5% to ensure precision and accuracy in voltage readings.

4. Implementing a Static calibration mechanism

- Utilizing potentiometers as feedback resistors and varying the potentiometers' resistance until the correct gain is achieved. This process will enhance the accuracy of the voltmeter under different conditions.

Conclusion and Discussion

This project fulfills almost all the requirements, but there are some constraints we couldn't overcome. The main problem we faced was providing power to the op-amps. After some research, we were able to find a solution and design our own power supply, which can directly plug into the wall and the voltmeter. However, we couldn't print the PCB, so we had to use a dual-channel power supply in the laboratory.

Another drawback of our design is that when we turn on the overload protection circuit, we can't measure voltages below 500mV. Therefore, we have to use a separate switch to turn ON/OFF the overload protection circuit when measuring 100mV. To overcome this issue, we would need to change the transistors, but we couldn't find another model that fulfills our needs.

Despite these challenges, as we were able to achieve the required accuracy of +/-1% and a minimum measurement of 100mV, overall, we have designed a successful project for an analog voltmeter with high impedance.

8. Bill of Materials

Component	Quantity	Price
LM358B IC	8	80.00
BC558B	3	30.00
Resisters (100Kohm, 50Kohm, 200Kohm, 4.7Kohm) 0.25W	12	20.00
16V Zener Diode 1W	2	10.00
Analog Voltmeter panel	1	550.00
Mount Wire clips (two way and four way)	10	180.00
8 pin IC base	4	20.00
Banana Socket	6	180.00
Multimeter probes	2	225.00
Push buttons	3	105.00
PCB Printing	5	6000.00
Enclosure Printing 3D	1	4800.00

9. Contribution of Group Members

210583B	Sehara G.M.M.	- Enclosure Design and Assembling
210293K	Kodikara U.S.S.	- Circuit Building, Breadboard Implementation
210451U	Pathirana R.P.S.	- PCB Design and Testing
210200C	Gunawardhana E.R.N.H.	- Power Management, Soldering

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