EN2090

Laboratory Practice II

Project Report

LEAD ACID BATTERY CHARGER

Group 14

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Contents

1 Introduction

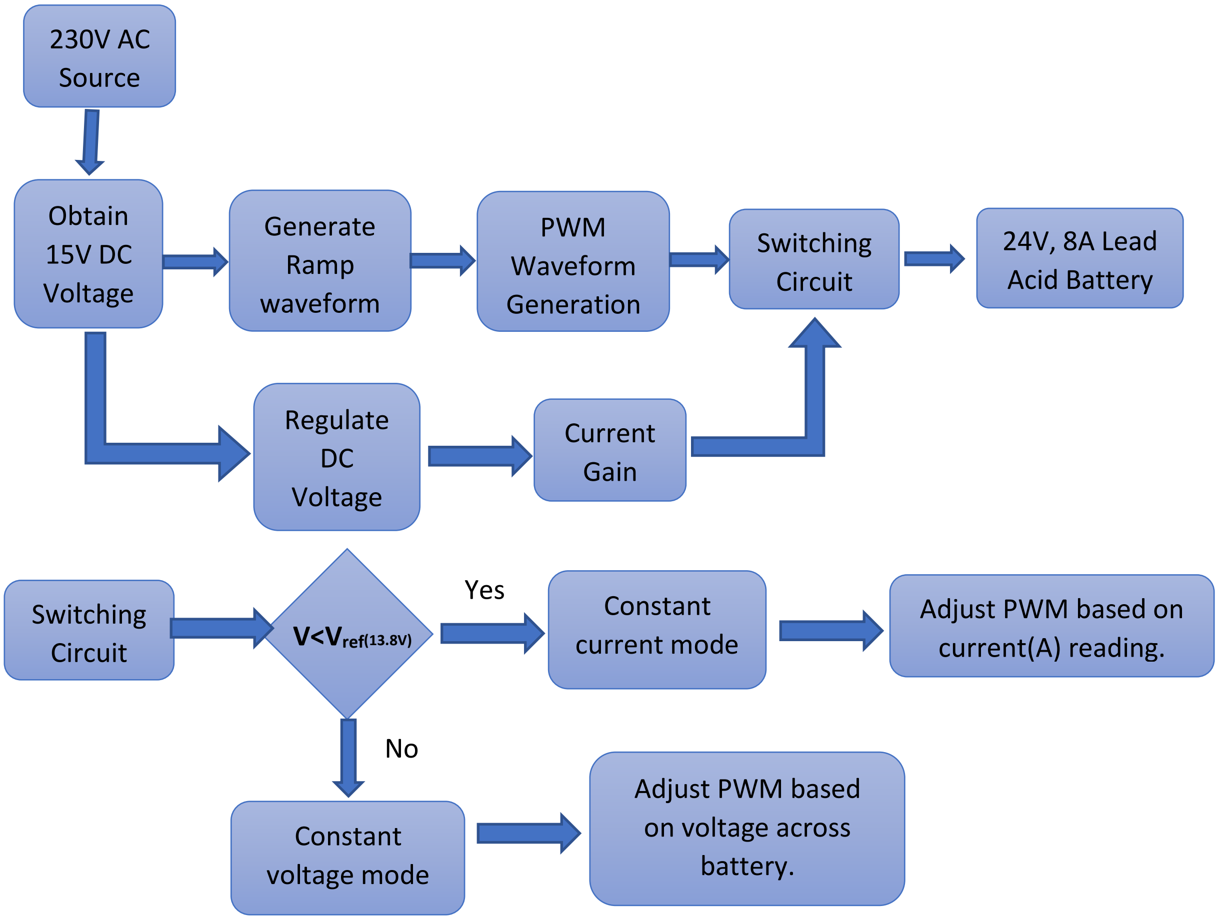
Lead acid batteries were invented in 1859 and it was the first rechargeable battery. As the name suggests it contains lead and acid where lead is added with antimony, calcium, tin, and selenium to increase the strength of lead. Starter batteries and recycle batteries are the major type of lead-acid batteries. There are various types of charging methods to charge this lead acid battery. Here, we are using the constant current battery charging method, which can be automatically switched to the constant voltage method when the battery reaches a specific voltage.

Here as per the requirements, we are using 1A as the constant current limit and then when the battery voltage reaches 13.8 V it'll automatically switch to constant voltage form. By this method, we can protect the battery from overcharging, and it'll increase the lifetime of the battery. We implement the PWM technique to charge the battery.

As we were instructed to use a 230V power supply we developed an AC to DC converter which can produce a 15V DC to recharge the battery. Typically, a voltage above 12V is applied as the input used because it forces the charging reaction at a higher rate. Charging at the minimum voltage usually takes a long time. So here we select 15 V to charge the 12V lead acid battery.

2 Methodology

2.1 Block diagram



2.2 Circuit design

Before building the circuits physically, we develop the online simulation using multisim and proteus software. Physically due to component limitations, we made some changes in the ICs and the values of active components.

2.2.1 PWM Generation with Smooth Circuit

Pulse Width Modulation (PWM) is mostly used in control circuits which is also a digital signal. This PWM has major two parameters. They are the duty cycle of PWM and frequency of PWM. According to our project, we need the PWM that should have a variable duty cycle and more than 50 kHz frequency that we can control to achieve this project work.

According to our circuit, we use TI084 IC to generate a triangular waveform using its three Operational amplifiers after this IC convert triangular wave to the PWM signal. In this circuit, we have controlled the output frequency of the PWM signal by a voltage feedback mechanism. After generating the PWM signal we use a simple buck converter. We used LC low pass filter for this purpose. Our buck converter has an inductor (200mH), capacitor (10μF), and an NPN transistor (BC108BP). We connected the PWM input to the transistor base terminal. After the LC filter smooths that voltage level to get DC smoothing voltage

2.2.1.1 Calculations

The frequency had been calculated using the following formula

$$F = \frac{R4}{4R2 * R3 * C2} = \frac{3 \times 10^3}{4 \times 1 \times 10^3 \times 1 \times 10^3 \times 10 \times 10^{-9}} = 75\ KHz$$

The upper threshold and lower threshold voltages of the triangular wave form are decided by the below equation

$$V_{uth} = \frac{V_{cc}}{2}\left(\frac{R4 + R3}{R4}\right) = \frac{15}{2}\left(\frac{3 \times 10^3 + 1 \times 10^3}{3 \times 10^3}\right) = 5V$$

$$V_{lth} = \frac{V_{cc}}{2}\left(\frac{R4 - R3}{R4}\right) = \frac{15}{2}\left(\frac{3 \times 10^3 - 1 \times 10^3}{3 \times 10^3}\right) = 10V$$

when the voltage is equal to 5V the PWM wave form will be in 0 % duty cycle and at 10V the PWM wave will be in 100% duty cycle. The feedback output must be in between 5 to 10 V to control the PWM duty cycle.

$$Slew\ rate = 2\pi f V = 7.06V/\mu s$$

As per the availability we use TL 084N opamp for the PWM(slew rate 20V/μs)

For smoothing circuit inductor and the capacitor values are selected based on the below equation.

$$L = \frac{D\ \times (V_{IN} - V_{out})}{\Delta I_L\ \times f} = \frac{2/3\ \times (20 - 15)}{1.5 \times 0.2\ \times 75 \times 10^3} = 200mH$$

$$C = \frac{\Delta I_L}{8\ \times f\ \times\ \Delta V_{OUT}} = \frac{1.5 \times 0.2}{8\ \times 75 \times 10^3 \times\ 50mV} = 10\mu F$$

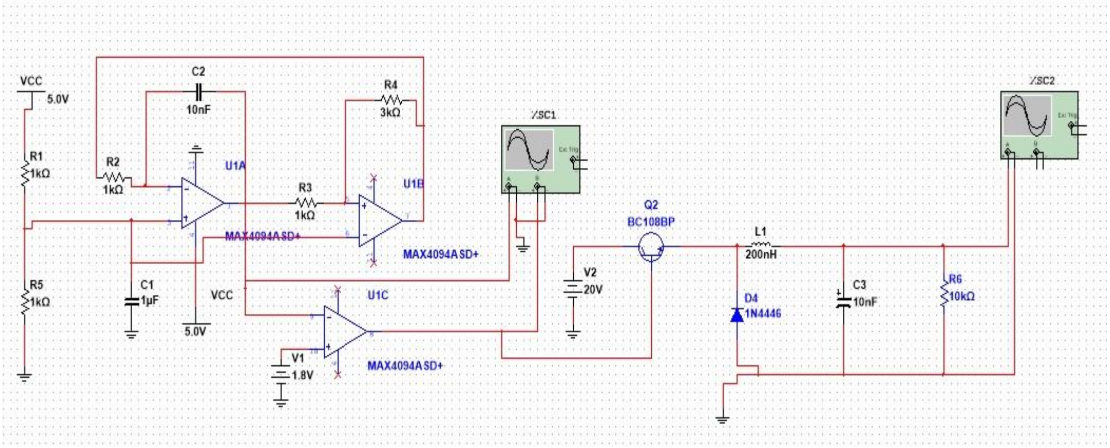
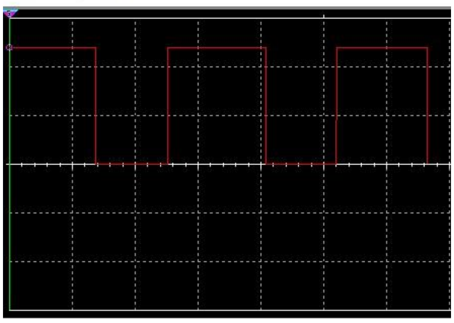
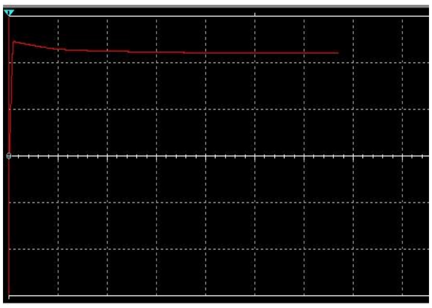


Figure 2.1: Multisim simulation of PWM and smoothing part

Oscilloscope-XSC1



Oscilloscope-XSC2



2.2.2 *Constant Current Control*

We must provide our battery charging for 1 A constant current. We divide three ways for this purpose. They are low side current sensing, differential amplifier, and integrator for measuring current, measuring error, and controlling PWM. To accomplish this, we are considering using a PID like the approach that first measures the current, and then by the error value, we will manipulate the PWM.

2.2.2.1 Measuring the current

We chose low-side current measurement for a cost-effective solution and easy implementation. We avoid other high current sensing methods for it use high voltage and the shunt resistor must choose correct values otherwise that will damage. This low-side current sensing has an operational amplifier in a non-inverting configuration.

$$V_{OUT(Current\ Measuring)} = I_{LOAD} \times R_{SHUNT} \times Gain = 1A \times 0.1m\Omega \times (\ 1 + \frac{3300}{220}\ ) = 1.6V$$

2.2.2.2 Error Measuring

A differential amplifier is used to measure error. Stationary voltage previously calculated should be applied since it corresponds to 1 A.

$$V_{OUT(Error)} = \frac{R_2}{R_1}\left(V_{OUT(Current\ Measuring)} - 1.6V\right) = \frac{1}{4.7}\left(V_{OUT(Current\ Measuring)} - 1.6V\right)$$

2.2.2.3 Controlling PWM

After taking the error value we will apply this to an integrator circuit for Adjusting PWM signals. Integrator is used because the manipulation of PWM needs to be done due to accumulation of error rather than just by current instantaneous error.

$$V_{OUT(PWM\ control)} = -\int_0^t \frac{V_{IN}}{RC}dt = -\int_0^t \frac{V_{IN}}{7.5 \times 10^3 \times 1 \times 10^{-6}}dt$$

If 1A > I_{LOAD} then V_{out} maintains increasing until the correct voltage is wanted for the PWM duty cycle.

If 1A < I_{LOAD} then V_{out} maintains decreasing until the correct voltage is wanted for the PWM duty cycle.

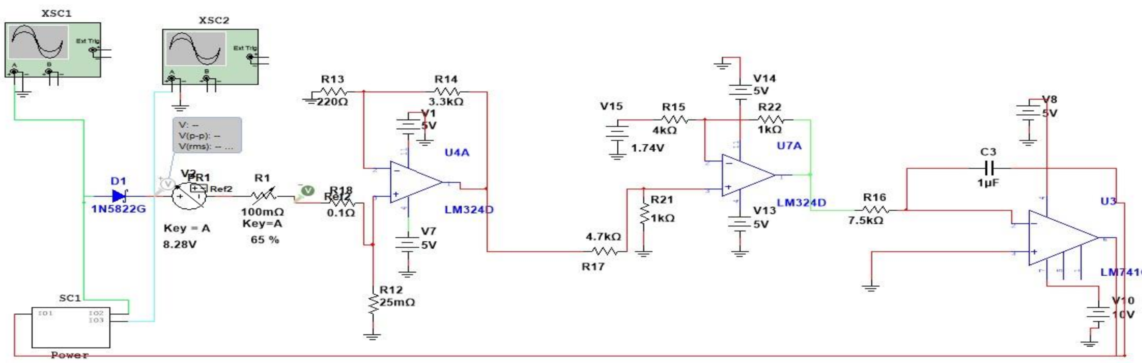
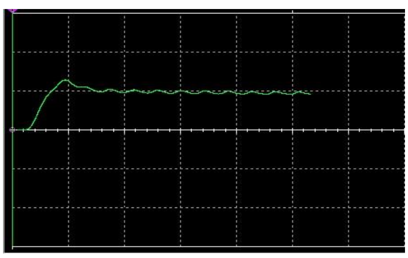
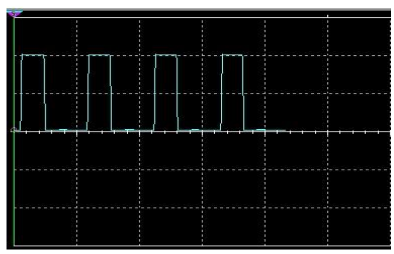


Figure 2.2:Constant Current Circuit





2.2.3 *Constant Voltage Control*

We must be kept under 13.8V constant voltage for our battery charging. Here also, we divide three ways for this purpose. They are differential amplifiers for measuring voltage, measuring error, and integrators for controlling PWM. To accomplish this, we are considering the same above approach that first measures the voltage, and then by the error value, we will manipulate the PWM.

2.2.3.1 Voltage Measuring

A differential amplifier is used by stepping down voltage by 0.1 times for voltage measuring across the battery terminals.

$$V_{OUT(Voltage\ Measuring)} = \frac{R_2}{R_1}(V_+ - V_-) = \frac{1}{10}(Battery\ Voltage)$$

For the voltage of 13.8V $V_{OUT} = 0.1 \times 13.8V = 1.38$V

2.2.3.2 Error Measuring

A differential amplifier is used to measure error. The stationary voltage previously calculated should be applied since it corresponds to 13.8V.

$$V_{OUT(Error)} = \frac{R_2}{R_1}(V_{IN} - 1.7V) = \frac{10}{1}\left(V_{battery} - 1.38V\right)$$

2.2.3.3 Controlling PWM

After taking the error value we will apply this to an integrator circuit for Adjusting PWM signals. Integrator is used because of the manipulation of the PWM signal.

$$V_{OUT(PWM\ Control)} = -\int_0^t \frac{V_{IN}}{RC}\,dt = -\int_0^t \frac{V_{IN}}{7.5 \times 10^3 \times 1 \times 10^{-6}}\,dt$$

If 13.8V > $V_{Battery}$ then V_{out} maintains increasing until the correct voltage is wanted for the PWM duty cycle.

If 13.8V < $V_{Battery}$ then V_{out} maintains decreasing until the correct voltage is wanted for the PWM duty cycle.

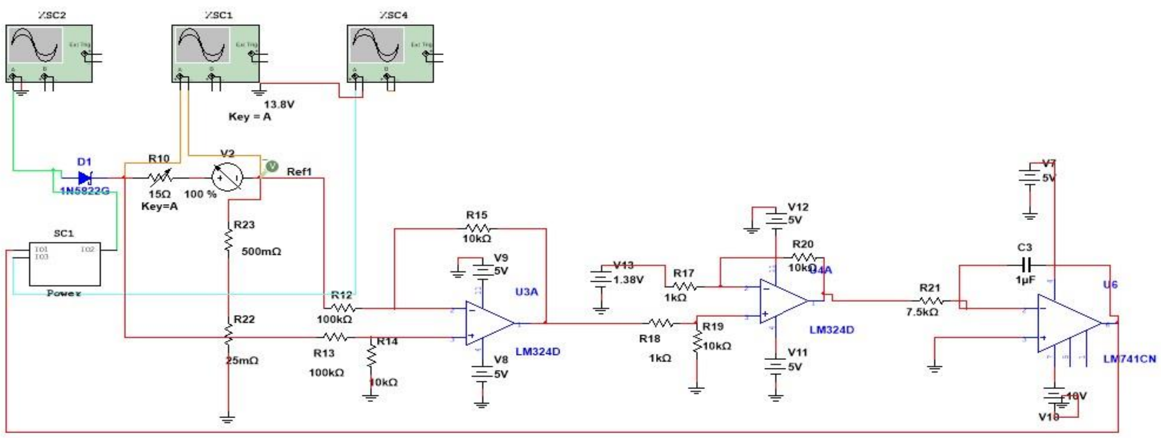
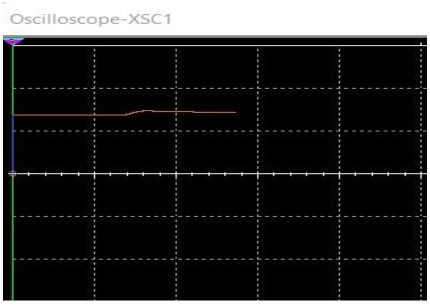
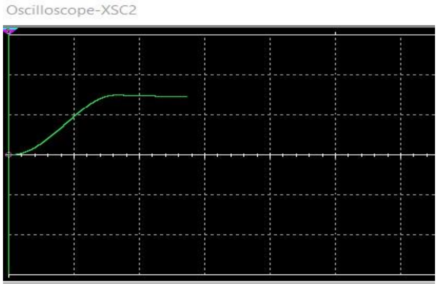
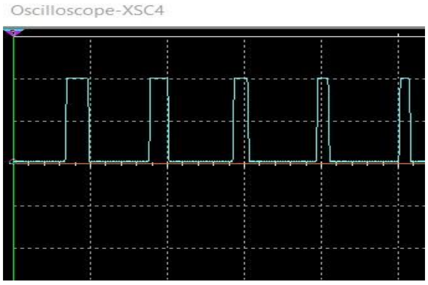


Figure 2.3:Constant Voltage Circuit







2.2.4 *Switching Between Constant Current and Constant Voltage Stage.*

We use a 5V relay to change the battery connection between constant current and constant voltage source. At the beginning of the relay input, we use a comparator circuit because it gives the correct required voltage for relay functionalities. After relay connection, we use operational amplifiers to give the battery the correct current or voltage for the requirement of battery conditions.

Output from the constant voltage source battery voltage measurement will be input here and the respective battery voltage will be compared with the reference voltage 1.37V(output from the battery voltage measurement is 1/10 of battery voltage). If the battery voltage is below 13.7V comparator will produce 0V and the relay will remain at a constant current mode connection. If the battery voltage increases above 13.7V then the comparator will produce 5V and the relay will be switched to constant voltage mode.

As the output from the PWM controller is between -2.5V and 2.5V, we have added a 7.5V offset voltage to maintain the feedback voltage between 5V to 10V.

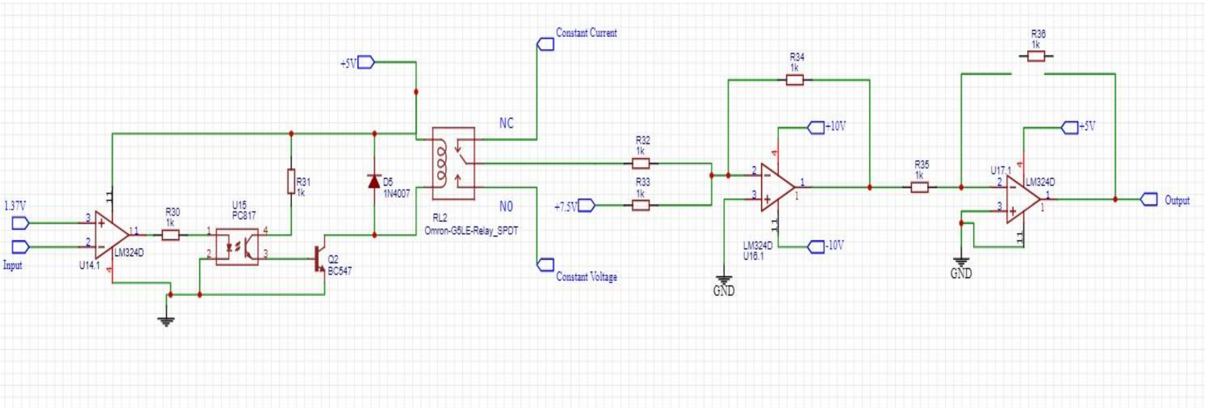
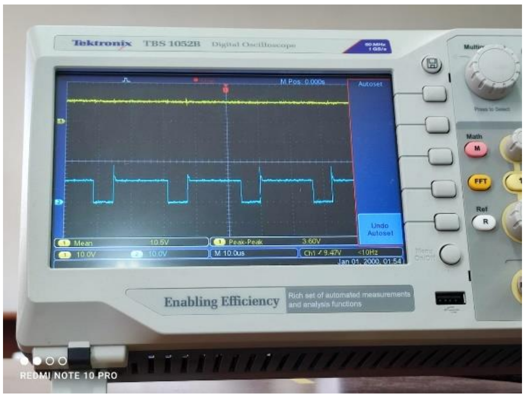


Figure 2.4:Switching Circuit

3 Results

In our circuit, we reach the PWM frequency up to 75KHz and the duty cycle also be change automatically regarding the feedback from each stage. On the smoothing part, it reduces the triple voltage and filters the noise properly. Our constant current and the constant voltage parts also worked properly but the last time there was an issue with the error accumulator, we couldn’t be able to demonstrate the outcome of our project properly. But any way part by part we build all the circuits successfully and properly demonstrate them.



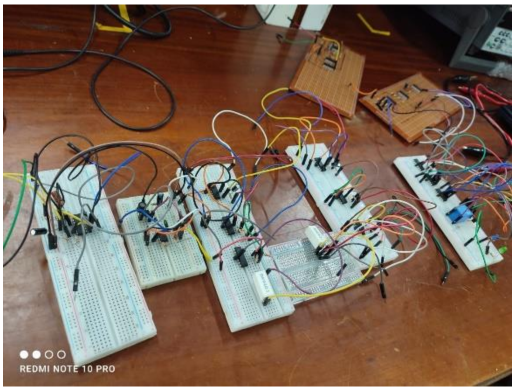


Figure 3.1: Physically building circuits

Figure 3.2:PWM and smoothing the output

3.1 PCB Designing

We designed two-layer PCBs for our product. First, we designed separate PCBs for different parts of our circuit design. We use ECADA software to design the PCB. Separate PCB schematic diagrams are attached in the appendix.

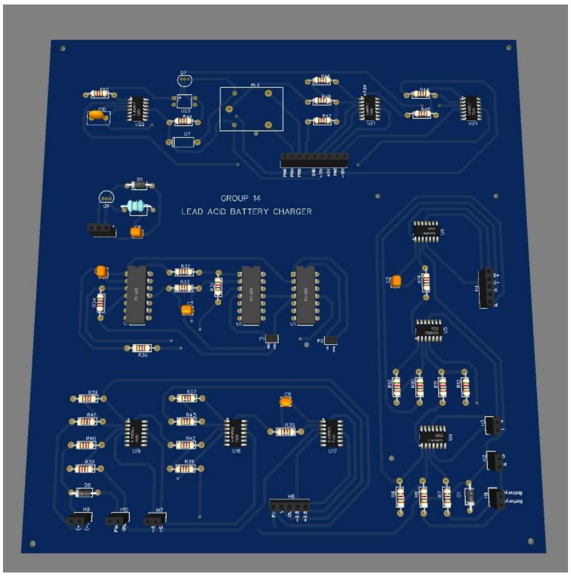


Figure 3.3: PCB top view

3.2 The Enclosure

The enclosure of the product is made of 200mm in length, 200mm in width, and 70mm in height and it is planned to be made in plastic with 2mm thickness.

To show the state of charging (constant-current and constant-voltage), it has two indicator LEDs.

And the power on/off switch is to control the overall functioning of the charger.

The enclosure has holes to increase airflow to avoid overheating inside the charger. The charger is to be powered by a 230V AC supply, so there is a power cord attached to it to power it directly.

The input for the charger is the main power supply (230V 50Hz AC). It has internal AC to DC converter to get the required power. This battery charger can deliver around 1A current in the constant current charging state. This charger is developed to be in an optimized state which supports both reduced charging time and increased protection in maintaining the good health of the battery.

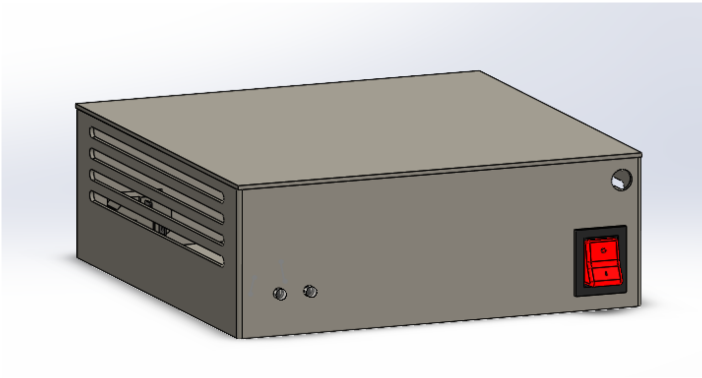


Figure 3.4:Enclosure

4 Conclusion

The objective of this project is to build a basic lead acid battery charger using the constant current charging approach with the implementation of the PWM technique and Feedback mechanism to control the duty cycle of PWM. Here as per the requirement, we must maintain a 1A constant current at the beginning and after the battery reaches a predefined voltage of 13.8 V, it has to be in a constant voltage stage. The PWM frequency must keep over 50KHz and the duty cycle must be changed automatically regarding the current and voltage across the battery.

We achieved all the specifications in the online simulation and due to some practical difficulties, we couldn't be able to implement our whole circuit physically. We demonstrate each part using our breadboard and dot board circuits and develop a proper PCB using ECADA and Enclosure using SolidWorks. Through this project we learnt a lot about battery chargers and the practical implementation of analog electronics. Even though at the beginning we faced a lot of struggles to implement the project, in the end, we overcome everything as a team and give our best solution for the project.

5 References

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6 Contributions from each member

LOSHANAN M.	**Enclosure design, build constant voltage part physically**
LUXSHAN S.	**Build online simulation, physically build the switching part**
MATHOTAARACHCHI M.M.	**PCB design, dot board soldering, build constant current path physically**
MOKEESHAN V.	**Did all the Calculations, Designed all the circuit diagrams, and build PWM and smoothing part physically.**

7 Appendix

7.1 PCB design

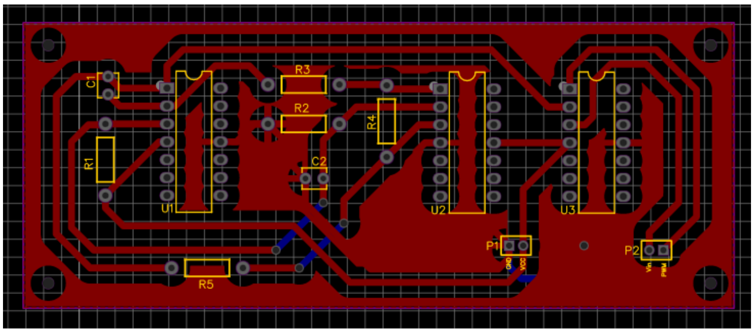

Figure 7.1:PWM Generator Circuit

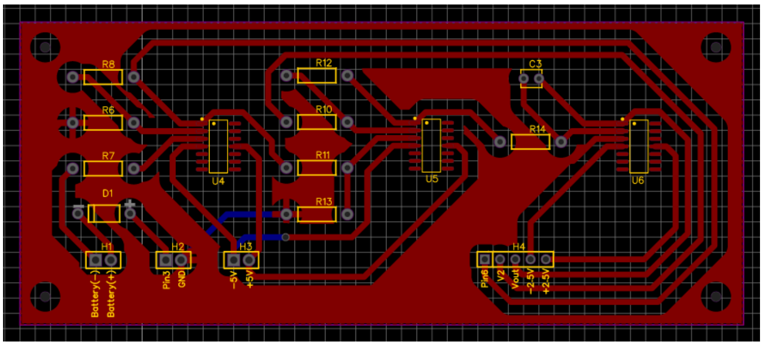

Figure 7.2:Constant Current Circuit

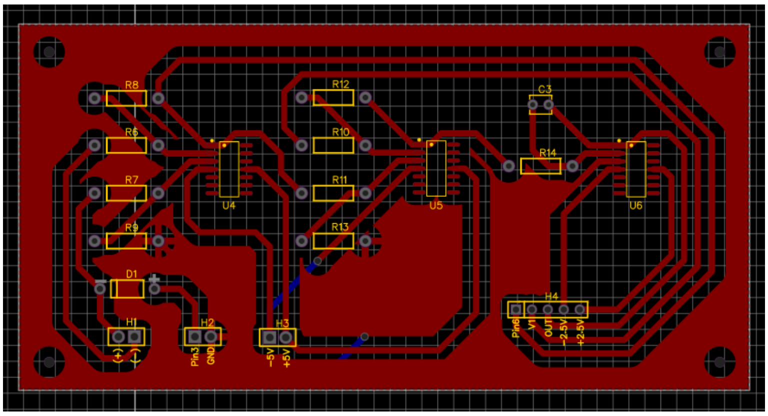

Figure 7.3:Constant Voltage Circuit

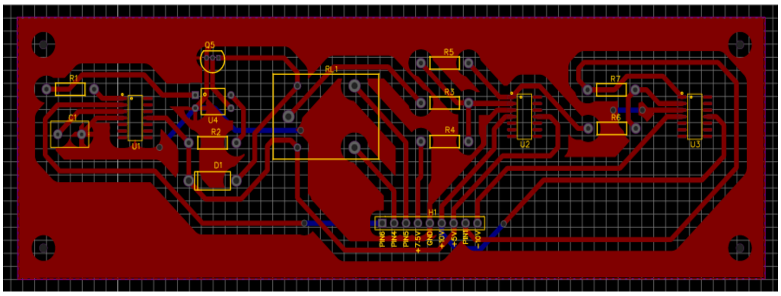

Figure 7.4:Switching Circuit

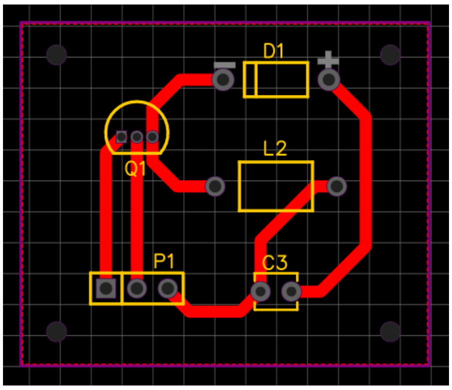

Figure 7.5:Smoothing Circuit

7.2 Enclosure

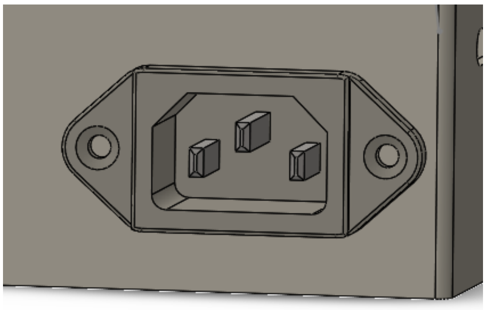

Figure 7.6:Enclosure power