Department of Electronic and Telecommunication Engineering

University of Moratuwa, Sri Lanka

EN2091 -Laboratory Practices II

LEAD ACID BATTERY CHARGER

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Group members

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Abstract

This report provides a concise overview of the methodology employed for the design of a 12V Lead acid battery charger, featuring a maximum charging current of 1A. The charging process is accomplished through the utilization of a 230V AC input voltage source and the application of Pulse Width Modulation (PWM) techniques. Various essential components such as resistors, capacitors, inductors, and operational amplifiers (OPAMPs) are strategically integrated into functional blocks, collectively forming the intricate circuitry. The design process extensively relies on Ltspice software for circuit part design and simulation visualization. Additionally, Solidworks software is employed for the meticulous design of the enclosure, while Altium software is utilized for the detailed Printed Circuit Board (PCB) design.

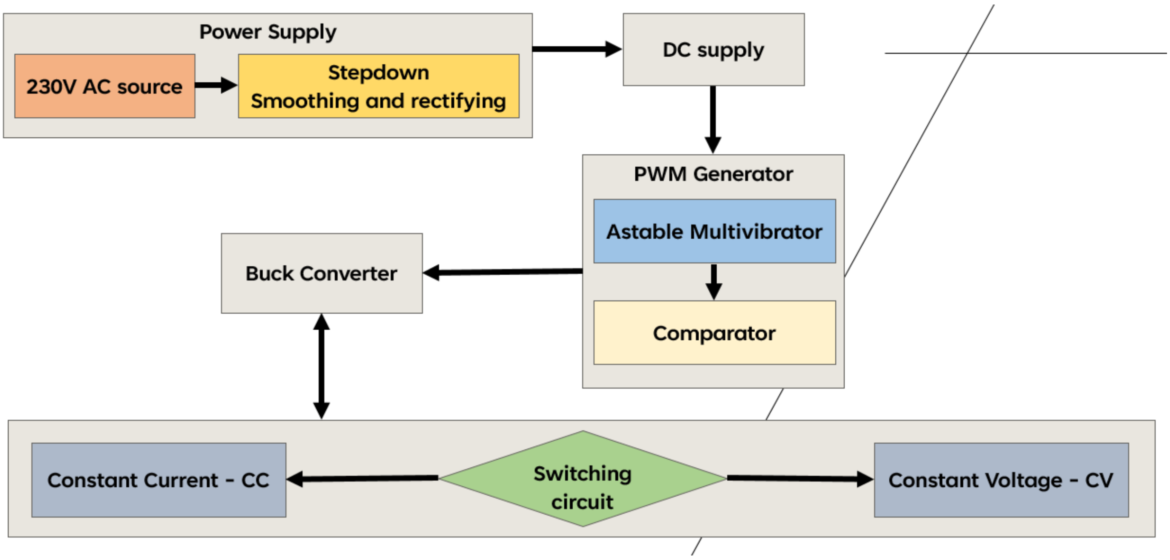
CONTENT

1 Introduction and functionality.

Lead acid battery

A lead-acid battery is a type of rechargeable battery that utilizes a chemical reaction between lead dioxide (PbO2) and lead (Pb) in an electrolyte solution of sulfuric acid (H2SO4) to generate electrical energy. These batteries are widely used for various applications due to their reliability, relatively low cost, and well-established technology. These are consist of two electrodes as positive electrode and negative electrode. During charging those plates are charged by the external source. 2.2V is the nominal voltage of a single cell and it will change around 1.8V-2.3V during operating.[1]

2 Functional Block diagram.



The Lead-acid battery charger seamlessly interfaces with a 230V AC source, necessitating a preliminary step-down to the required voltage level. Subsequently, rectification and smoothing procedures are executed through apt circuits. This intricate process demands both a 15V DC dual supply voltage and a 20V DC voltage to energize the PWM generator and Buck converter, respectively.

Our design is grounded in the P control method, whereby the 20V DC voltage is governed by a PWM signal. The dynamic adjustment of the PWM signal's duty cycle is autonomously regulated based on feedback mechanisms. In the constant current mode, a sense resistor detects the current flowing through the Buck converter. This current is then scrutinized against a reference value (1A), with any disparity serving as feedback to dynamically alter the duty cycle of the PWM signal.

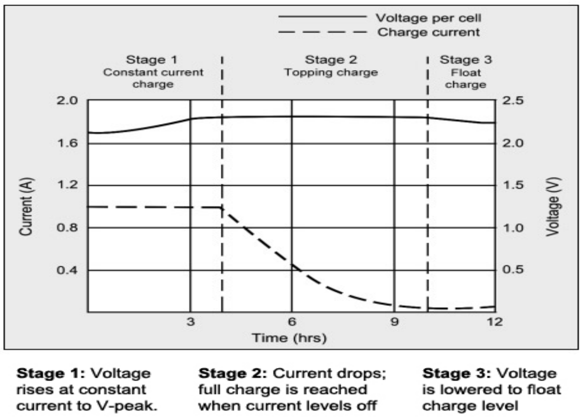
Transitioning into the constant voltage mode, the battery voltage is measured through a resistor divider. The voltage error between the output of this divider and a predefined reference value is channeled into the PWM generator circuit as feedback. This informs the system to adapt the duty cycle of the PWM signal accordingly.

Throughout the battery-charging process, the voltage between the battery terminals undergoes continuous monitoring. If this voltage surpasses the threshold of 13.4V, the charging method seamlessly transitions from Constant Current (CC) to Constant Voltage (CV), ensuring optimal and controlled charging conditions.[2]

Charging methodology.

The charging profile of a battery is unique, tailored to sustain the battery's well-being, revitalize its charging capacity, and uphold its level without succumbing to self-discharge. This unique profile demands strict adherence for optimal performance. In the case of lead-acid batteries, three fundamental methodologies are employed to achieve these objectives.

1. Constant current mode
2. Constant voltage mode
3. Floating charging mode



First the battery charge by the constant current. It will consume approximately half the charging time and battery get charged up to 70%. After reaching the set voltage of 13.4V, voltage will get constant while current start decreasing. Ultimately, the floating charging mode is initiated when the current level dwindles to zero, effectively compensating for self-discharging losses. This is crucial for sustaining the battery at full charge. Failure to do so may result in the battery losing its ability to maintain a full charge, primarily due to sulfation.

3 Pulse Width Modulated signal generation (PWM)

Here we have created a PWM signal generator circuit where we can adjust the pulse width (Duty cycle) using a external voltage level as the feedback and this circuit includes 2 main parts to achieve this task.

They are as below,

1. Astable Multi-Vibrator

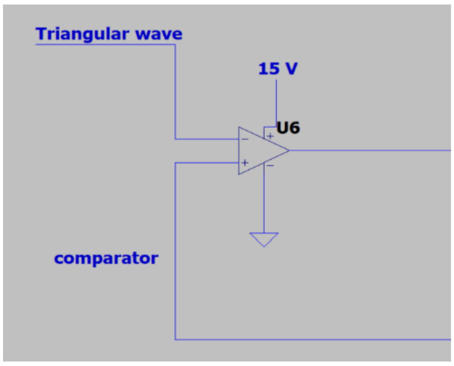
2. Comparator.

3.1 Astable Multi-Vibrator

We have used NE555 IC in astable mode to generate the required triangle wave form to compare it with the voltage levels given by control current and voltage circuits. The main components that we have to choose is the R1,R2 and C2 values because the waveform is generated by charging and discharging the C2 capacitor if we put low resistor values for R1 and R2 we will get saturated triangle waveform that is similar to a square pulse. We have choosen R1=4.7K and R2=10K and C2=220Pf and according to the equation of the NE555 astable mode we can get a frequancy of Hz . This waveform is obtained by the positive terminal of the C2 capasitor.

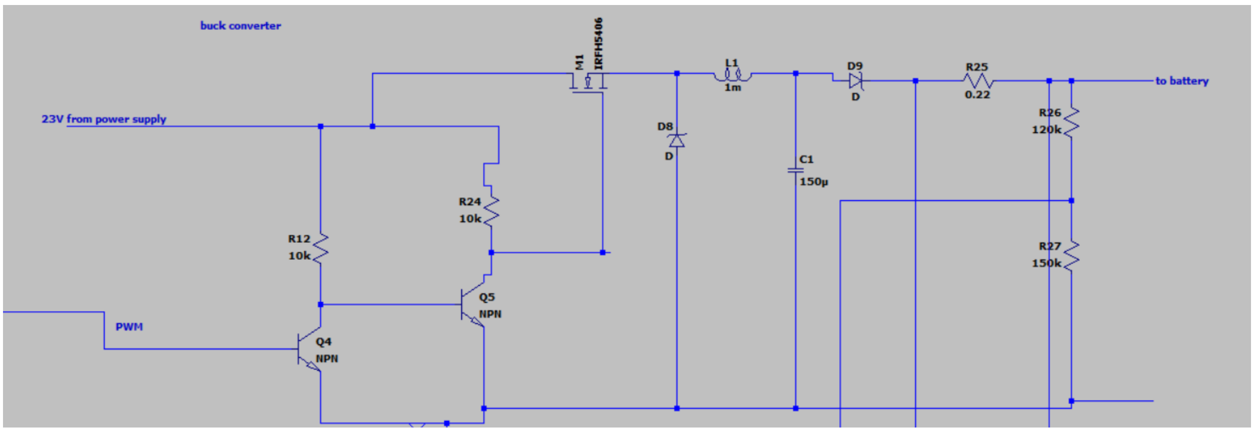
3.2 Comparator

In this comparator non-inverting terminal of the opamp is connected to the CC, CV feedback error correction voltages through a Switching circuit and inverting terminal is connected to the positive side of C2 Capacitor which gives the Integrator (Triangle Wave). If the error voltage is higher than the Triangle wave, comparator Opamp will output 0V and otherwise +15V. So the duty cycle of the output PWM is controlled by the error voltages. [3]



4 Buck Converter

Buck converter is a circuit which can reduce the input voltage using PWM. It converts the input PWM signal and makes a pulse that it’s width changes by the PWM width to get the required output voltage. Initially input voltage is given to a Drain of a N channel mosfet. The gate of the mosfet is controlled by the PWM signal that we input. After that the source of the mosfet will produce a High current 23V PWM pulse which is used to charge the battery as intended. Before that, PWM pulse will be filtered by a LC low pass filter and DC component of the PWM is extracted for charging the battery. We give 15V or 0V from the comparator opamp and it will make T1 cut off or saturated when T1 is saturated T2 becomes cutt off and the mosfet gate receives 20V. When the T1 becomes cutt off then T2 becomes saturated and gate of the mosfet receives 23V. So we have used 2 transistors to overcome the inverting effect and amplify the pwm signal to use it to drive the gate.



5 Feedback Control (P control)

In this curicuit the controlling the duty cycle is is done by using feedbacks. To give the feed backs we have used differential amplifiers and comparators.

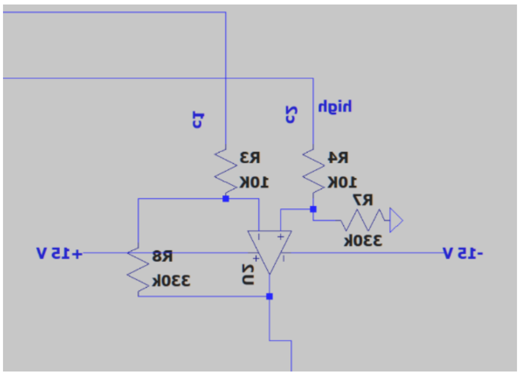
5.1 Constant Current Control

We need to give a constant current less than 1A to charge the battery correctly. To measure the current going into the battery we have connected a 0.77Ω 10W sense resistor in series with the LC filter. Since as that resistor is 0.77Ω voltage across the resistor is always equal to .

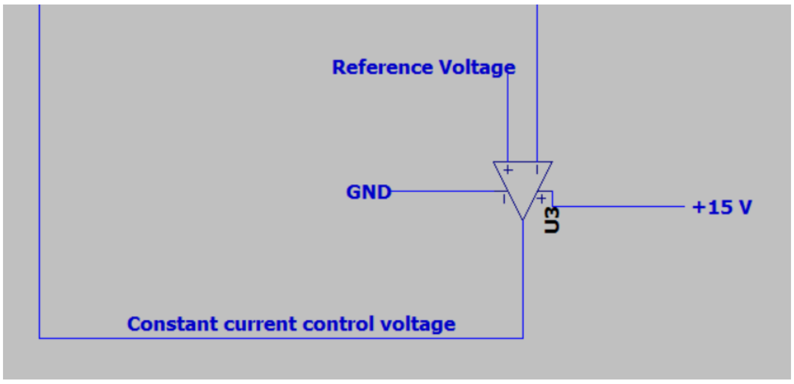
$\Delta V = \Delta I \times 0.77$

This voltage difference is fed to the differential amplifier. Output of the differential amplifier is given by following equation.

$Vout1 = (330k\Omega / 10k\Omega)\ \Delta V = 33\ \Delta V$



The output of the differential amplifier is given to the inverting terminal of a comparator and it will be compared with the reference value that we gave to it and if the current is high error voltage will be 0V and the gate of the mosfet will close and the current through the battery will drop and if the current ids low comparator will give 15V and the gate of the mosfet will open and increase the current that flows through the battery.

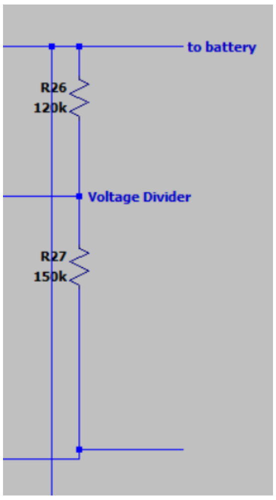


Reference voltage is the voltage that we get from the differential amplifier when the desired current is flowing to the battery. If we want 1A we should give 33×0.77 V to the reference.

5.2 Constant Voltage Control

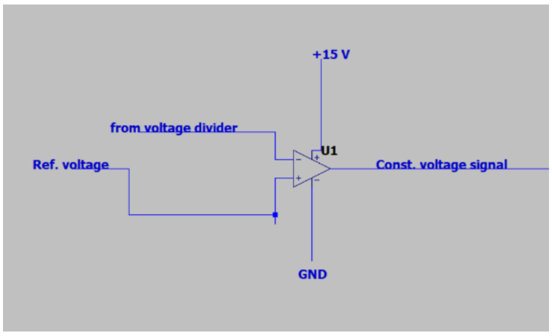
This is done by a simple curcuit . Constant voltage control is used to keep the battery voltage below 13.4V. Once the battery reaches that voltage the current will reduce and voltage is maintained belowin 13.4V so that battery can be left connected to charger till we use it. We have used a voltage divider to get the reference voltage value which indicates the battery voltage proportionaly.

V IN = R1/(R1+R2)· V battery



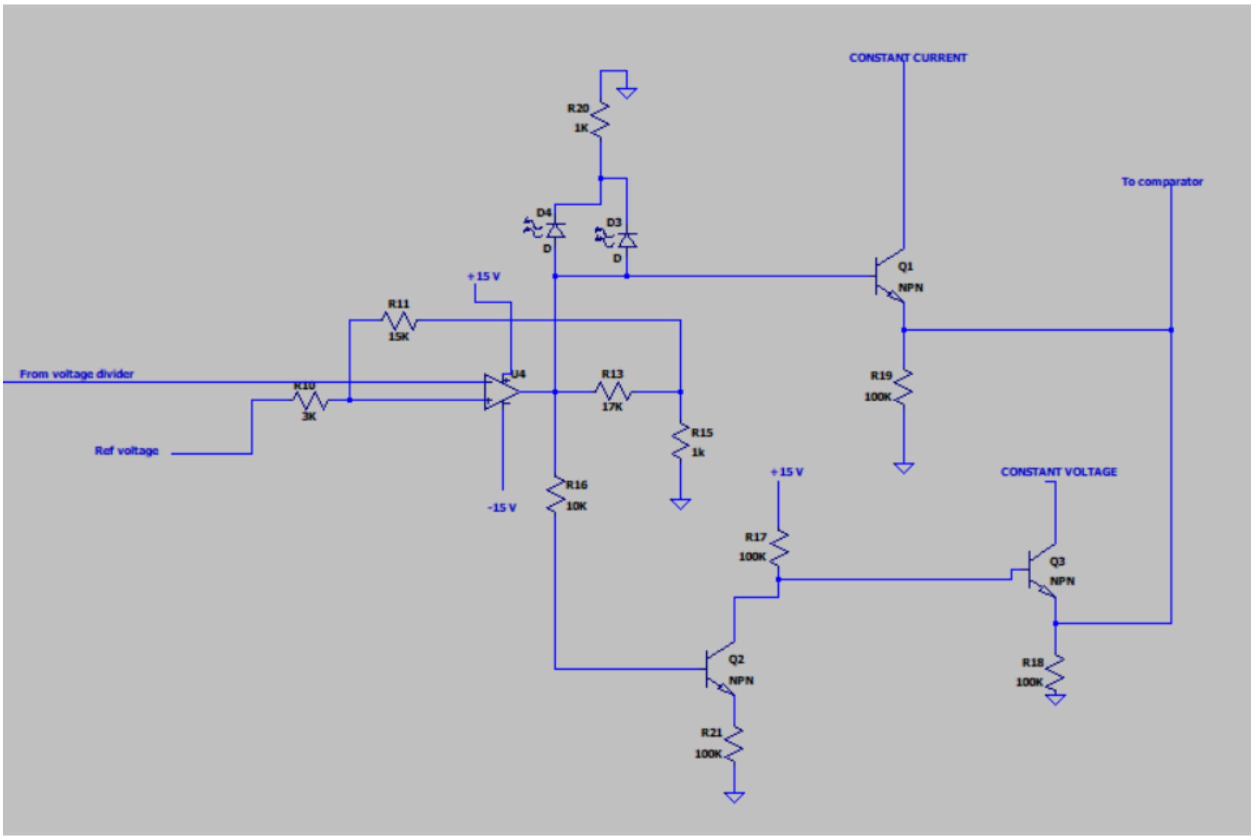
Resisters have been selected in high values to minimize the current flow through this voltage divider and get accurate reference value of the voltage of the battery.

Then we feed this voltage to a inverting pin of the comparator and we give a reference voltage to the non inverting pin of the comparator.When the voltage of the battry gets low than the reference comparator output will be 15V and it will get feeded to the gate of the mosftet and the gate will open and voltage will increase When the voltage of the battry gets higher than the reference comparator output will be 0V and it will get feeded to the gate of the mosftet and the gate will close and voltage will drop.



6 Switching from CC to CV

This is done by a smitt trigger the resistor values have been chosen to change the output voltage of the opamp in V and it can have a range of V So even the voltage of the battery gets dropped after going to the constsnt voltage mode it won't get switched back to constant current mode. We have used transistors as swiches these transistors goes to cutt of mode to saturated mode and vice versa when switching the output voltage is when the bttery is charging in constsnt current mode and it get to when in the constsnt voltage mode so we can use that voltage to directly bias the transisor that switches constsnt current signal. We use a inverting transistor to invert the output voltage and then give that inverted voltage to bias the transistor that switches constsnt voltage. We use this method to keep one mode on all the time so when the output of the opamp is high constsnt current mode constsnt current is getting passed throuhh its switching transisor as its in saturated regoin while constsnt voltage signal is getting blocked as its in cuttoff region. This happen in the opposite diretion in the constsnt voltage mode.



7 Power supply circuit

We need to get +15V and -15V dual power supply to power up the Opamp ICs and another 23V High current supply to give to buck conveter to charge the battery . We have added center tap transformer to to step down 230Ac. The secondary outputs are connected to a Diode full wave rectifier and positive and negative voltage regulators. 24V secondary outputs are connected to 2 diodes and a Large smoothing capacitor to reduce the ripple and voltage drop when drawing high amount of current.

8 Components Selection and Calculations

8.1 PWM generation.

The formular given below gives the output frequency of the NE555 IC in stable mode.

$Fc = 1.44/ [(R1+ 2R2)C1]$

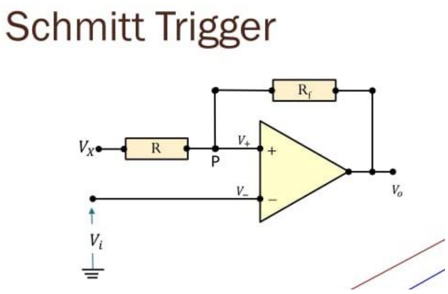
We have chosen R1 as 4.7 kΩ and R2 as 10 kΩ. Also, C1 is a 220 pF capacitor. So, the theoretical frequency of our astable multi- vibrator is around 261 kHz.

8.2 Opamp selection

We used opamps mainly as comparators and differential amplifiers. For comparating purposes we used LM393 comparator opamp as this opamp have a very low input bias current of 25nA , input offset current of 5nA and input offset voltage of 2mV. Also it has a very low response time of 1.5 µs .[4] For differential amplifier and Schmitt trigger we have used TL084 opamp , because it has very low input bias and offset current, high input impedence, internal frequency compensation and it has slew rate of 16V/µs and the main advantage of this opamp is that it can have +15, -15 dual input voltage. Also, it has a CMRR of 86dB. [5]

8.3 Switching.

For the switching process, we have used Schmitt trigger circuit. In the Schmitt trigger circuit, the upper and lower threshold value are calculated as below.



$V_{LTH} = [R_f/(R+R_f)]V_x - [R/(R+R_f)]V_s$

$V_{UTH} = [R_f/(R+R_f)]V_x + [R/(R+R_f)]V_s$

So, we have chosen R= 2 kΩ and R_f = 10kΩ. We have put potentiometers to get the correct value for V_x from 15V and V_s from the output voltage of the Opamp in Schmitt trigger configuration.

8.4 Buck Converter.

A buck converter is a type of DC-DC power converter that steps down a higher voltage to a lower one, efficiently regulating and delivering a stable output voltage for electronic devices. The buck converter, plays a pivotal role in sustaining the current or voltage of the battery at prescribed levels. All elements within the buck converter circuit must possess the capability to manage elevated currents and voltages effectively.

8.5 MOSFET Selection and Supply circuit

In our buck converter, the IRFZ44N N-Channel MOSFET was employed. It boasts a continuous drain current (ID) of 49A, featuring an exceptionally low drain-to-source resistance (RDS) of 17.5mΩ. Additionally, it is well-suited for applications that require high frequency switching as it have rise and fall times of nano seconds range.

We opted for 1N5821 rectifier diodes to convert the 18V AC root mean square (rms) output from the transformer's 18V secondary. These diodes boast a continuous current capacity of approximately 3A.

Smoothing capacitor value can be calculated using following equation,

$$C = (I_{Load}) / [2 \times f \times V(p-p)]$$

Here V(p−p) is the ripple output voltage after the process of smoothing.

In order to achieve a higher current output, we decided to enhance the capacitance of the smoothing capacitor. As a solution, we employed a parallel configuration of two 2200µF 63V capacitors to serve as the smoothing capacitors.

8.6 Inductor Selection

The control of the output supplied to the load relies significantly on the duty cycle of the PWM signal. The inductor assumes a crucial function in furnishing consistent current to the load during the switching of the PWM signal. The inductance value is contingent upon the anticipated ripple current, ensuring the device operates as intended, and is influenced by the duty cycle. The buck converter exhibits variation in inductor current within one of the recognized conduction modes.

The value of the inductor will depend on the following parameters.

1. Output voltage
2. Duty cycle
3. Max input voltage
4. Max ripple current
5. Frequency

First, we have to calculate the maximum duty cycle of the buck converter.

Maximum duty cycle (D) = (Vout(max))/ Vin · η

Where η represents the efficiency of the buck converter. For our calculations, we have considered a presumed efficiency of 90%, an input voltage (Vin) of 23V, and a maximum output voltage (Vout(max)) set at 15V.

So, the maximum duty cycle is,

D = 15V/ (25V × 0.9)= 66.7%

The current flowing through the inductor undergoes oscillations around the established steady-state current, resulting in a discernible ripple in the inductor current. In our design, we have made the assumption that the inductor ripple current hovers at approximately 30% of the maximum current, set at 1A.

Inductor ripple current = ΔIL = 0.3A

When selecting the inductor, it is imperative to opt for a high-power variant capable of accommodating currents of 1A or beyond.

Required inductance for the buck converter is given by,

inductance (L) = [Vout × (Vin − Vout)]/ [ΔIL × fs × Vin]

where fs = Switching frequency.

From the equation,

L = [15V × (25V − 15V)]/ [0.03A × 250kHz × 25V] = 0.8mH

So, We have made our own inductor by wrapping a 0.7 mm wire around a ferrite core.

Its Q factor is 7.29

8.7 Capacitor Selection.

The output capacitor in a buck converter serves the purpose of regulating the output. It charges during high PWM periods and discharges during low PWM periods. In instances of low PWM, the output capacitor safeguards against excessive drops in regulation. Therefore, it is essential for the output capacitance to be sufficiently high to uphold the desired ripple voltage. The determination of output capacitance is contingent upon various parameters such as,

1. Ripple output voltage
2. Switch frequency
3. Inductor ripple current

Equation which is used to calculate the required value of the capacitance is,

ΔV_{out} = Desired output voltage ripple

This ripple voltage is approximately0. 3V.

$C_{out}(min) = \Delta I_L/(8 \times f_s \times \Delta V_{out})$

From the equation we get, $C_{out}(min) = 0.3A/(8 \times 250kHz \times 0.3V) = 500\mu F$

So, according to the equation we have added a 220 µF 50V capacitor for the buck converter.

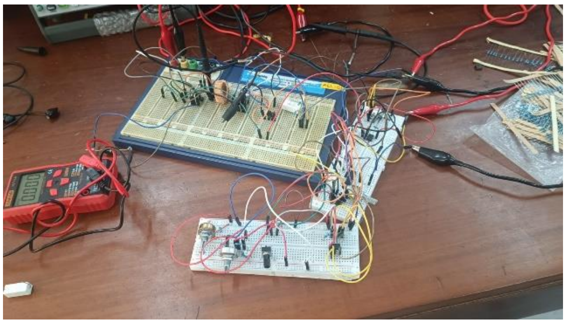
8.8 Diode Selection and Current Sense resistor.

As the current courses through the inductor, the capacitor undergoes charging, accumulating and storing energy. During intervals when there is no current flow through the inductor, a diode establishes a pathway for the charge stored in the capacitor to flow into the output, thereby enhancing the efficiency of the buck converter. However, it is crucial for this diode to function effectively at high frequencies and exhibit minimal voltage drop. Opting for Schottky diodes is advantageous due to their low voltage drop and support for rapid switching. In our buck converter, a 1N5817 Schottky diode with a 1A average forward current was employed. The use of Schottky diodes not only ensures low voltage drop but also minimizes power dissipation.[6]

The current sensing resistor employed in the buck converter has a resistance of 1Ω, and consequently, it experiences heating that may alter its resistance. To mitigate this effect, a 5W cement-type resistor was chosen to enhance stability and minimize the likelihood of resistance changes.

9 Testing and Simulation

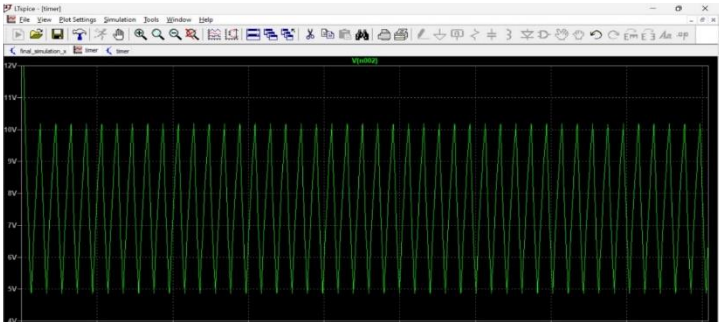
To facilitate simulation, we utilized the LTspice software due to its advantageous features that enable more convenient visualization of voltage and current waveforms. Prior to the PCB design phase, we conducted testing on our circuits through Breadboard implementation.



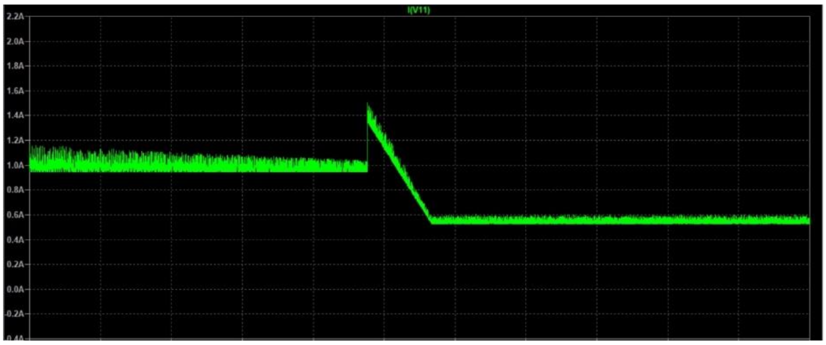
9.1 Simulation results

These are the output waveforms by simulation through LTspice software.

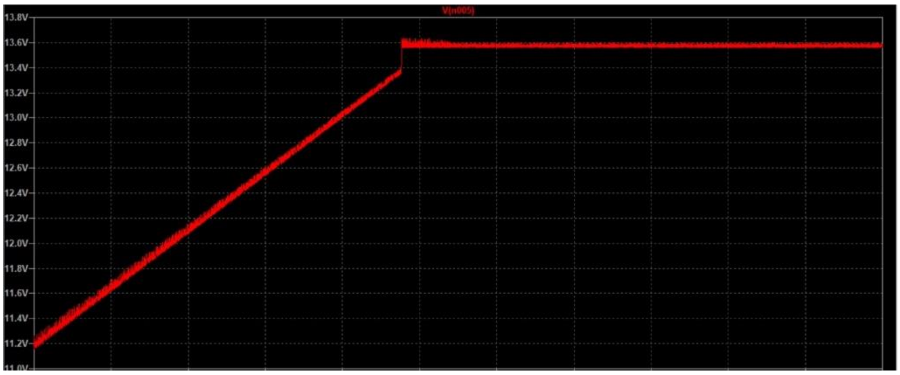
1. Triangular wave in astable multi vibrator



2. Current level goes into the battery

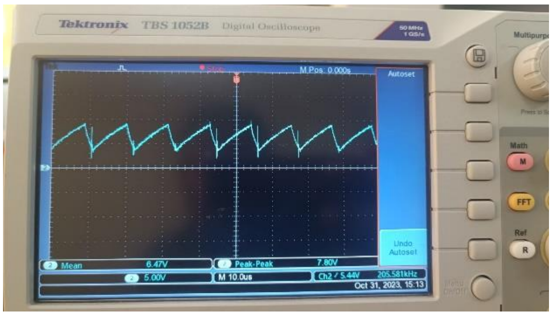


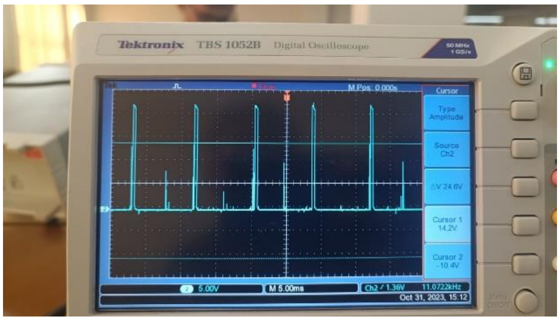
3. Output Voltage level



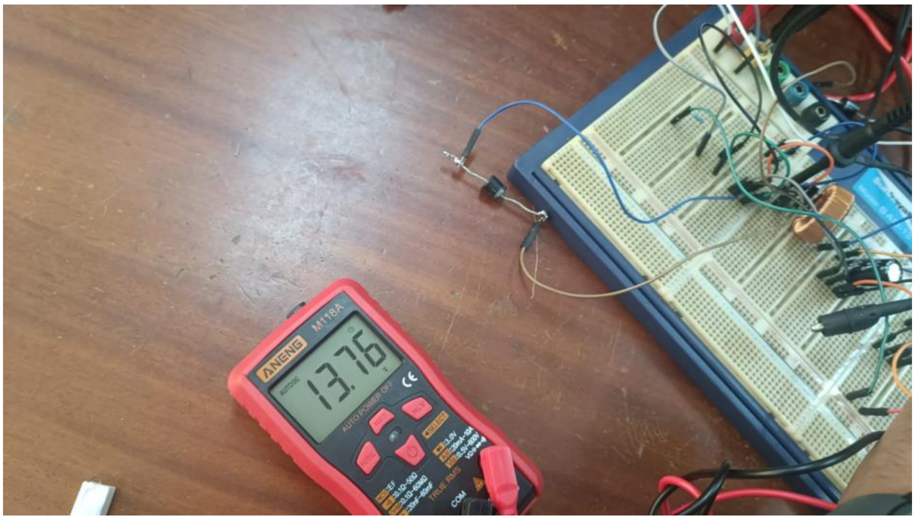
9.2testing results of the circuit.

Triangular wave from astable multi vibrator. PWM signal





We have got the desired 13.7 V constant output voltage as we desired.



10 PCB design

We designed PCBs for our project using the ALTIUM Designer software and printed through JLCPCB. We designed 3 PCBs for Power Supply circuit, PWM and Buck Convertor circuit, and Switching, Constant current and Constant Voltage circuit separately as a measure of . We made double Layer PCBs and their dimensions are,

Power Supply circuit – 8.0 x 6.9 (cm)

PWM and Buck Convertor circuit – 12.8 x 4.6 (cm)

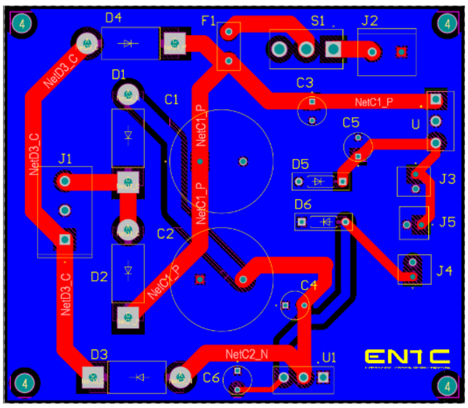
Switching, Constant current and Constant Voltage circuit – 8.9 x 5.1 (cm)

Traces of the power lines are 2.8mm width while all the other traces are 0.5mm and 1mm widths.

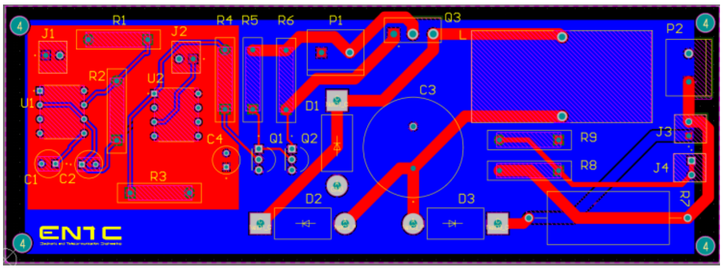
Drill hole sizes in the PCB are 0.8mm and 1.4mm.

We placed the components in such a way that space utilization is optimized, routing is perfectly arranged as well as thermal heating issues are overcome.

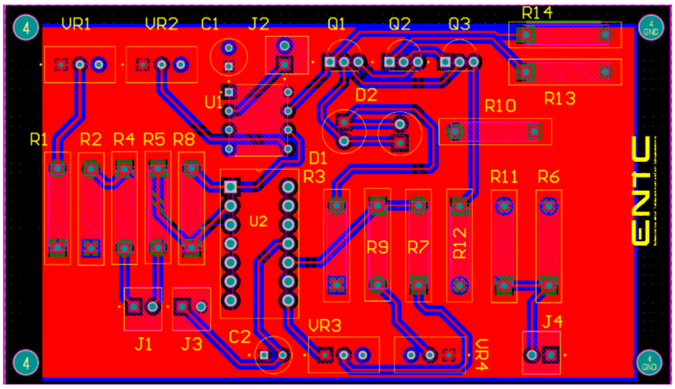
- Power Supply circuit



- PWM and Buck Convertor circuit



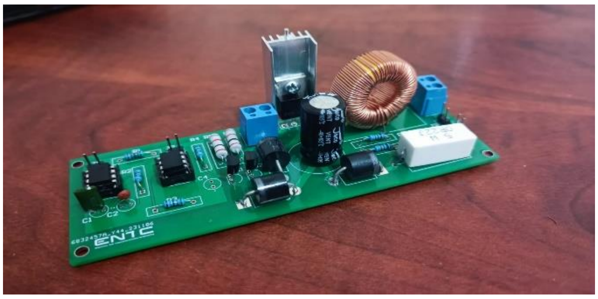
- Switching, Constant current and Constant Voltage circuit



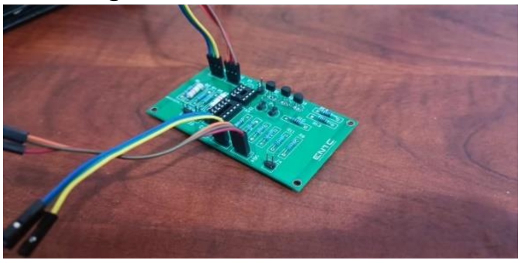
These are the soldered PCB

Main power supply circuit

Timer and Buck Converter



Switching circuit

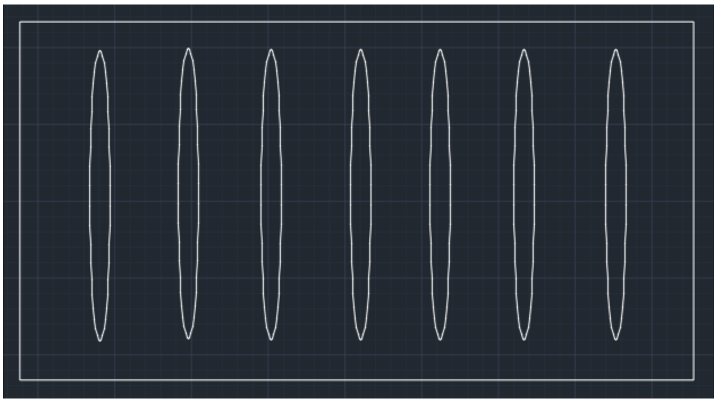


11 Enclosure Design

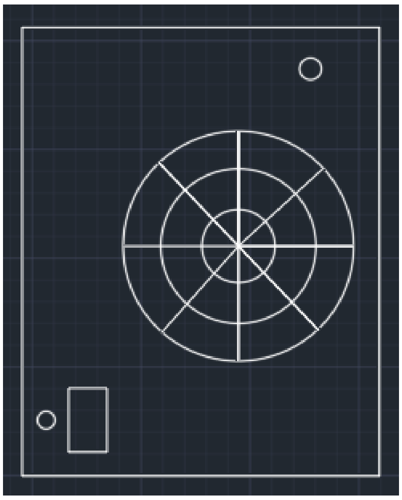
The enclosure for the Lead-Acid battery charger is a simple hollow cuboidal structure designed using SOLIDWORKS designing software. With calculations done, initial sketches were drawn using the online version of AutoCAD software as follows.

The outer dimension of the enclosure is 24.3cm X 14.2cm X 16.2cm, while a thickness of 3mm was also kept for the box.

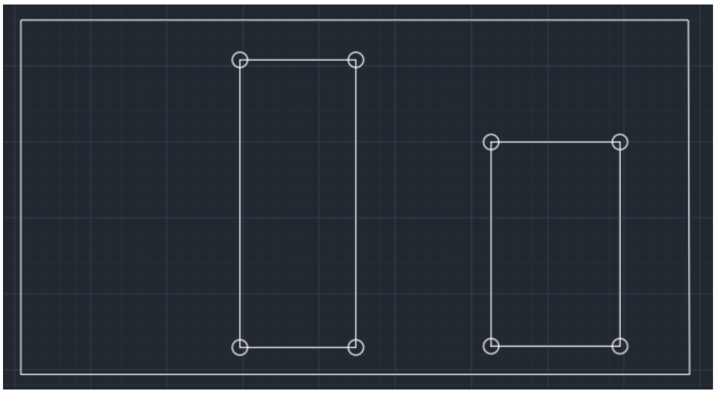
Vent part – backside



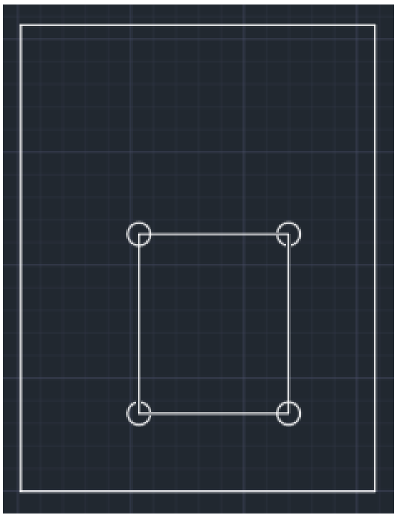
Fan and switch side



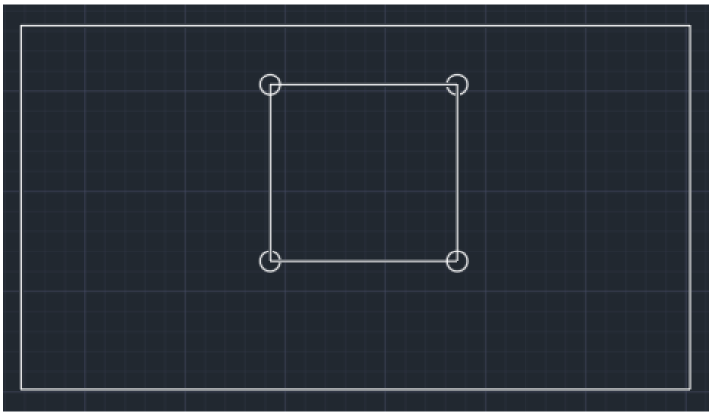
PCB side- front side



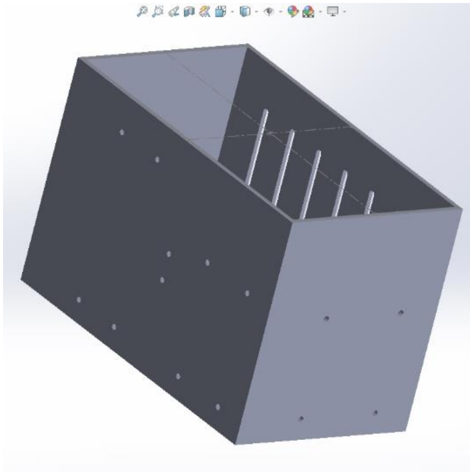
Power supply side

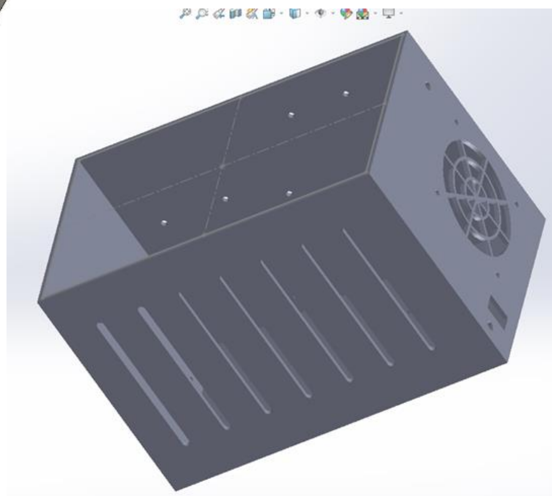


Bottom part



Then the final design was done by the SOLIDWORKS design software, with the correct measurements calculated. For the ventilation, holes and extra vent parts have been added to the enclosure. For considering the safety of the other components and PCBs, the center tapped transformer is placed on the bottom side of the enclosure.





12 Conclusion and Future works

This project fulfills the requirements. We have successfully overcome the constraint of the low switching frequency in the buck converter using the NE555 timer IC . We have added a cooling fan for the enclosure to dissipate the heat power generated by the mosfets and voltage regulators. The main drawback is that the inability to adjust the charging current or switching voltage. It would have been beneficial to incorporate a display for real-time monitoring of the charging current and battery voltage. Without such a feature, external measurement tools like a multimeter are required to assess these parameters.

Future works.

1. Adding a display to show output current level and output voltage level.
2. Implementing a cutoff circuit with timer.

13 Task allocation

ANJULA M.K. – 210368V	DOCUMENTATION, CIRCUIT DESIGN, SOLDERING AND TESTING OF THE CIRCUIT
MEEMANAGE N.A. – 210385U	CIRCUIT DESIGN, COMPONENT SELECTION AND TESTING
PERERA L.C.S. – 210463H	PCB DESIGN, CIRCUIT DESIGN AND TESTING OF THE CIRCUIT
UDUWAKA S.S. – 210663V	ENCLOSURE DESIGN, DOCUMENTATION, SOLDERING

Bibilography

[1]"Lead Acid Battery - an overview | ScienceDirect Topics," *Sciencedirect.com*, 2010.

https://www.sciencedirect.com/topics/engineering/lead-acid-battery

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