BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 316 (January 2024)

Power Electronics Laboratory

Battery Charge Controller with Auto Cutoff System

Section: A1 Group: 03

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1 Abstract

The "Battery Charge Controller using Buck Converter with Auto Cutoff Feature" project presents the planning, creation, and use of a cutting-edge battery charging system that maximizes charging efficiency while maintaining security and effectiveness. Our project's main goal is to improve conventional battery chargers' drawbacks by adding an automated cut-off function. This project's main goals are to reduce the risk of overcharging, increase battery longevity, and improve battery charging efficiency.

2 Introduction

An auto cutoff charging system is a crucial safety and performance feature in modern rechargeable battery systems, especially for high-energy-density batteries. The main function of an auto cutoff system is to prevent overcharging by automatically stopping the charging process once the battery reaches a certain voltage threshold. This is essential for ensuring the safety, longevity, and efficiency of the battery and the device using it.

The most important aspect of an auto cutoff system is its ability to prevent overcharging. Overcharging occurs when a battery is charged beyond its recommended voltage level. Overcharging can cause the battery's internal structure to degrade, leading to reduced capacity and shorter battery life. Overcharged batteries can become hot, potentially causing thermal runaway, which could lead to fire or explosion in extreme cases. Overcharging also increases the risk of leakage, swelling (nowadays known as *spicy pillows* in popular internet culture), or fire, making it a significant safety concern.

Auto cutoff charging systems not only prevent damage but also enhance the long-term health and efficiency of the battery. Batteries perform best within a certain voltage range. An auto cutoff system ensures that the battery is never overcharged, helping to maintain an *optimal charge cycle*. This increases the number of charge-discharge cycles a battery can undergo before its performance significantly degrades. By cutting off the charge at the right moment, the system minimizes the potential heat buildup during charging. Excessive heat can lead to faster wear and loss of capacity in batteries. In recent times, this aspect has become so important that even mobile phone vendors are now compromising on battery safety over how long it it should last on one charge. They use fuzzy logic algorithms to assess the situation and keep the battery from charging to full capacity. They are even giving the users the options to set the maximum charging limit to an arbitrary value like 80%.

The portable tech industry moving to *multiple cell* battery packs ($2S, 3S$ and such) lends the auto cutoff system even more relevance. When charging these multi-cell packs, each cell needs to be charged to the same voltage level for balanced performance and safety. Using an auto cutoff system can ensure the flexibility of using different combinations of cells all while ensuring each cell charges upto their individual set levels.

3 Design

3.1 Problem Formulation

3.1.1 Identification of Scope

This project is about designing and creating an advanced battery charger with an auto cut-off feature. The goal is to make a charger that works efficiently with modern battery-powered devices while being safe and easy to use. The auto cut-off feature will stop charging when the battery is full, preventing overcharging and extending the battery's life.

The project will explore current battery charging technologies to find the best ways to create a system with variable DC output and compatibility with different types and sizes of batteries. It will involve choosing the right components, building a strong design, and testing the system to ensure it works well.

In the end, this project aims to improve battery charging technology and provide useful knowledge for practical applications in different industries. The auto cut-off charger will be a reliable and efficient solution for today's battery charging needs. The results of the project will help improve battery charging technology and offer important insights into how this type of charger can be used effectively across various industries and situations.

3.1.2 Formulation of Problem

The project tackles the problem of designing and implementing an innovative battery charging system that offers variable DC output and includes an automatic cut-off feature. The fundamental difficulty revolves around the requirement for an efficient and versatile battery charger that can cater to a wide range of battery types, sizes, and applications while assuring optimal charging, safety, and battery health preservation. Aspects that we need to consider while designing the project are:

- **Efficiency**: Ensuring that the system maximizes energy transfer efficiency. High efficiency is especially important for reducing power consumption, lowering heat generation, and improving charging times.
- **Adaptability**: A charger must be capable of adjusting its output to accommodate different battery types, sizes, and applications. Different battery chemistries have varying charging requirements. A charger that can adjust its output voltage and current will offer broader compatibility.
- **Safety**: Robust safety mechanisms is critical for protecting both the charger and the battery from potential hazards, such as overcharging, overheating, and short circuits.
- **Battery Health**: Concentrating on adding features that stop overcharging or charging at the wrong voltages in order to extend the life of rechargeable batteries.

- **User Convenience**: Designing a user-friendly interface and control system that delivers real- time information, allowing users to monitor and control the charging process effectively.

3.1.3 Analysis

Designing a battery charger with an auto cutoff system that balances efficiency, adaptability, safety, battery health, and user convenience presents a complex challenge. The charger must efficiently transfer energy while minimizing heat and power loss, adapting to a wide range of battery chemistries and capacities, from lithium-ion to lead-acid. It must incorporate robust safety features to prevent overcharging, overheating, and short circuits, while also safeguarding long-term battery health by avoiding conditions that could degrade performance or lifespan. Additionally, the system must be user-friendly, providing real-time feedback and offering intuitive control over charging processes. Achieving these objectives requires a careful integration of advanced power management technologies, intelligent charging algorithms, and safety mechanisms, all while ensuring the charger remains compatible with a broad range of devices and easy to use for both novice and experienced users.

3.2 Design Method

Here in this project at first we used a transformer to take power from 220 V source and convert it to 12 V. We know our input source voltage is always sinusoidal wave in our households. So, the peak input voltage here is

$$V_{\text{peak, 1}} = 220\sqrt{2} \approx 311\,\text{V}$$

The output voltage from the transformer needs to be 12 V RMS, which means a peak voltage of

$$V_{\text{peak, 2}} = 12\sqrt{2} \approx 17\,\text{V}$$

Then we used a full wave bridge rectifier to convert this voltage to DC and used a capacitor in the end of the full wave bridge rectifier so that all the ripples in the DC are mitigated. But we can't give this output directly to charge a battery because if we give too much greater voltage to charge a battery than it's rated voltage then the battery's health will be reduced. Here we are using a LIPO battery of 12 V which will be charged.

From the datasheet of the Battery we found that the charging optimum voltage of the LIPO is almost 12.6 V. So from this output of the capacitor we used a buck converter to convert the voltage of almost 17 V to almost 12.6 V. Then this voltage is divided using a potentiometer and a resistor and the divided voltage is sent to a MOSFET's gate. We know if this voltage is greater than 4.2 V, the MOSFET will turn on. The same output voltage of the buck converter is then sent to the energizing coil of a relay and also in the input of the relay. The relay can only be energized if the MOSFET becomes on. The normally closed point of the relay is directly connected to a power diode and the Cathode of the power diode is directly connected to the battery's positive part and the negative part of the battery is connected to the ground. Also a green LED is connected in parallel with the power diode and the battery which is connected to the ground through a resistor. This green LED indicates that the battery is now charging.

This battery's voltage is actually used as a feedback to the output of the buck converter. When this battery's voltage increases the voltage which is divided using the pot also increases and as a result when the input voltage to the gate of the MOSFET crosses 4.2 V and the relay energizes as the relays other side is connected to the ground through MOSFET's drain and source parts being connected together. As soon as the relay energizes the relays input gets connected to the normally open part of the relay and as a result the input gets connected to a red LED which is connected to the ground through a resistor. And this red LED indicates that the battery is charged to our desired voltage and is now in cutoff mode as the battery is fully charged.

When the buck converter's output voltage is divided using a $10\,\mathrm{k}\Omega$ resistor and a $10\,\mathrm{k}\Omega$ potentiometer,

$$\text{Gate voltage to the MOSFET} = \frac{R_{\text{pot}}}{20} \times \text{output of buck converter} \qquad (1)$$

where R_{pot} is the resistance of the pot in kilo ohms.

Moreover, output voltage of the buck converter is equal to the feedback voltage coming from the battery's voltage added to the voltage drop in the power diode (approximately 0.7 V). A capacitor is also used in parallel with the gate of the MOSFET to reduce the ripples of the voltages further and obtain almost a pure DC voltage.

3.3 Circuit Diagram

Following is the circuit diagram without the buck converter.

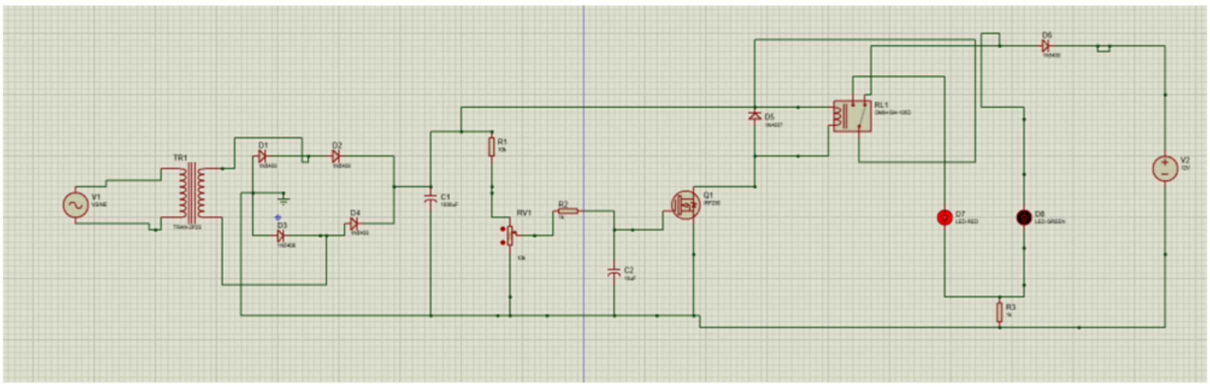

Figure 1: Circuit diagram without buck converter

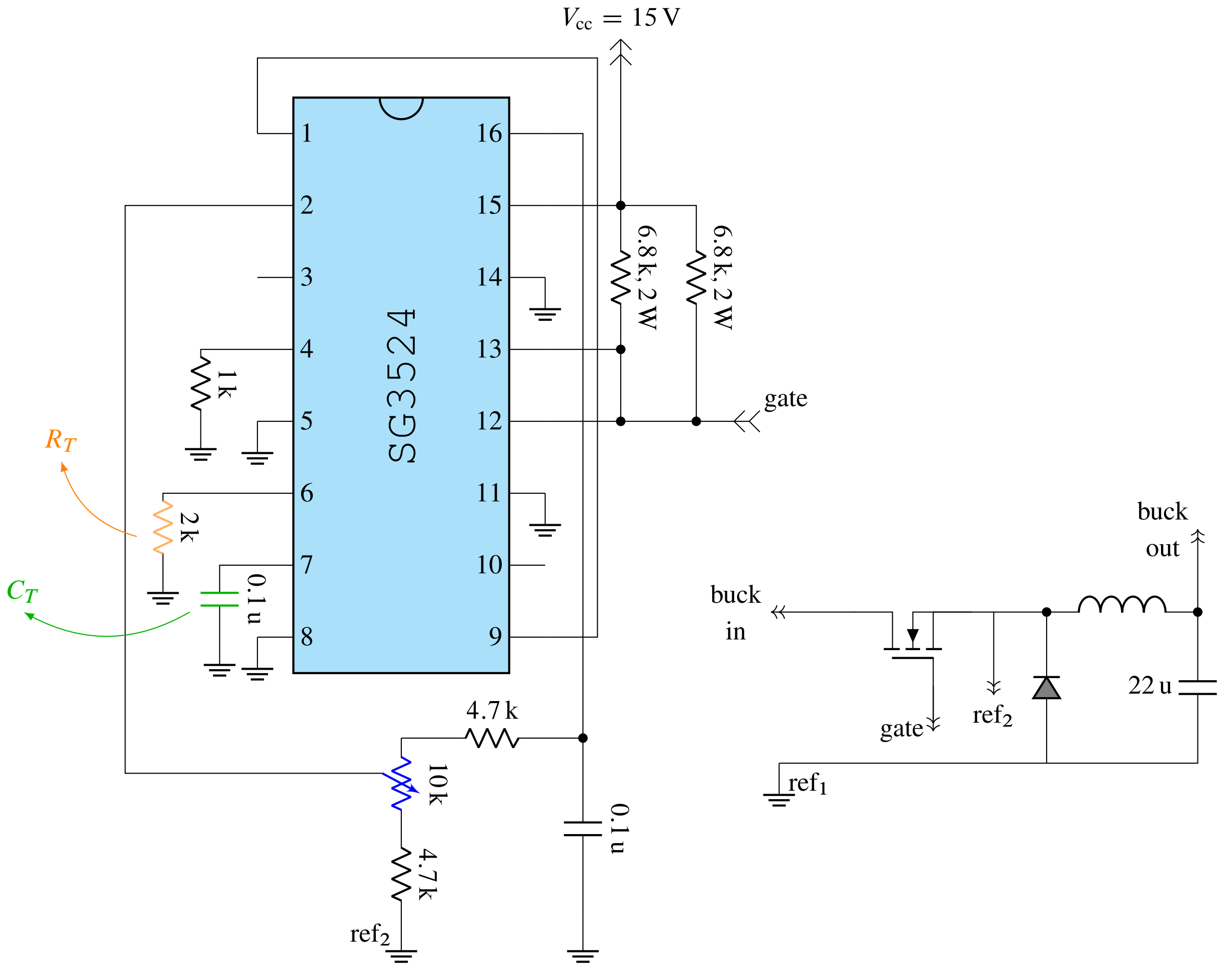

Figure 2: Buck converter circuit diagram

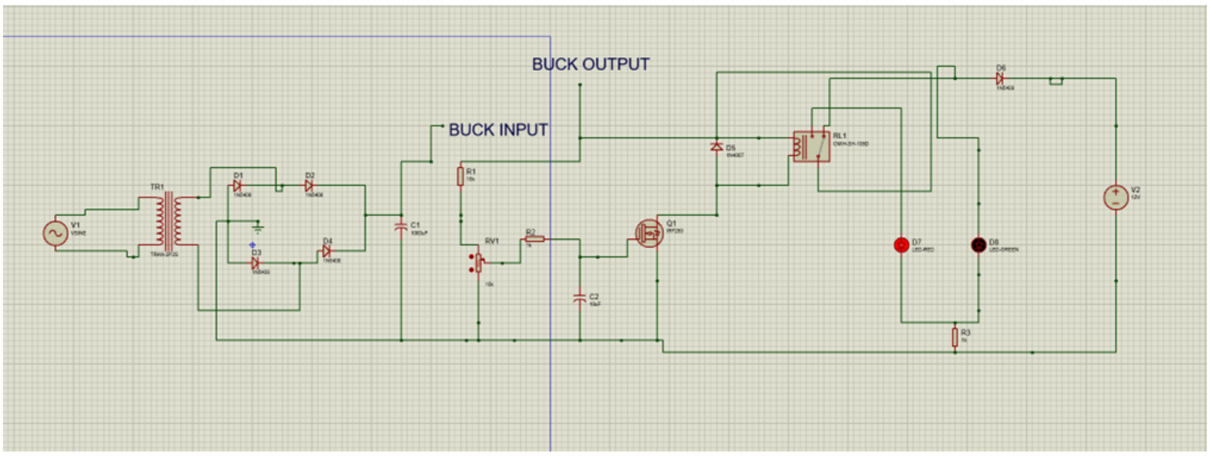

Figure 3: Circuit diagram with buck converter

3.4 Simulation Model

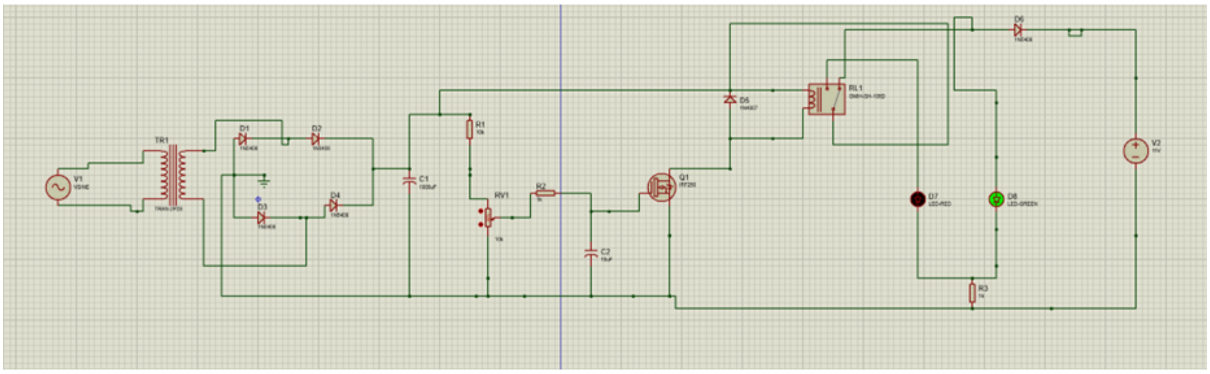

Figure 4: Green LED indicates that the battery is charging

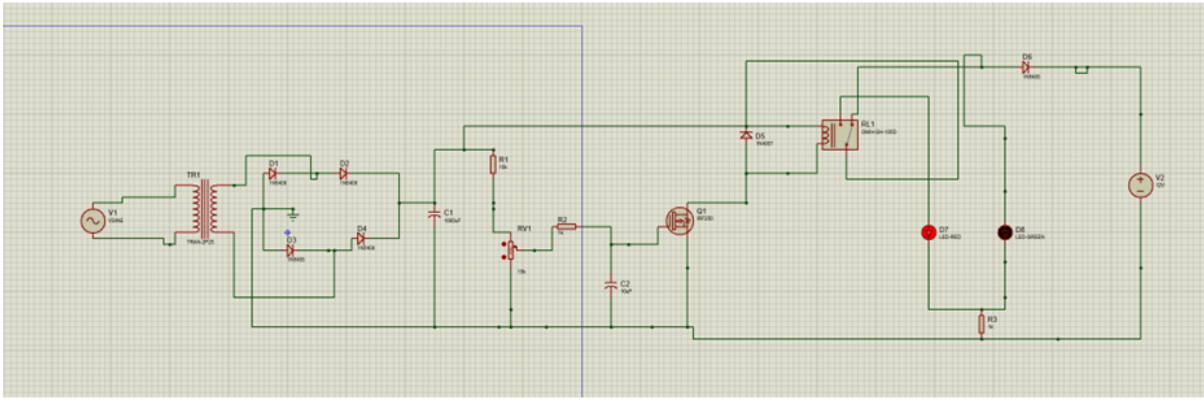

Figure 5: Red LED indicates cutoff situation

4 Implementation

4.1 Description

Although we initially built the project on a breadboard, we decided to opt for a printed circuit board (PCB) at the end. Using a PCB over a breadboard offers distinct advantages. A PCB allows for a compact design, enabling all components to be placed on a single board in a structured manner. Once soldered onto a PCB, components are securely fixed in place, which increases the overall durability of the circuit. Unlike a breadboard where components might loosen over time or due to dropping or transporting, a PCB provides mechanical stability. This further offers better consistency, ridding us of the phenomenon "*it's only on the demonstration day that the project stops working*".

The buck converter and the actual charging module were built on separate boards. While combining them on a single board might seem like a good way to reduce complexity and cost, separating them can offer some desirable advantages. The two circuits have different requirements in terms of power handling and component selection. By keeping the charger and the converter separate, each design remains simpler and more modular, we could focus on fine tuning the converter for better efficiency while separately fine-tuning the charging circuit to perform it's cutoff duty. Moreover, this allows for better thermal management, as the buck is connected directly to the high voltage output from the rectifier and dissipates a lot of heat. The actual charger module is thermally less demanding. This way, the heat generated by the buck converter doesn't affect the performance of the charger circuit. While our components are far from being this much sensitive, it's a good safety measure to take.

For implementing the PCB design, here is the schematic layout for the battery charger circuit:

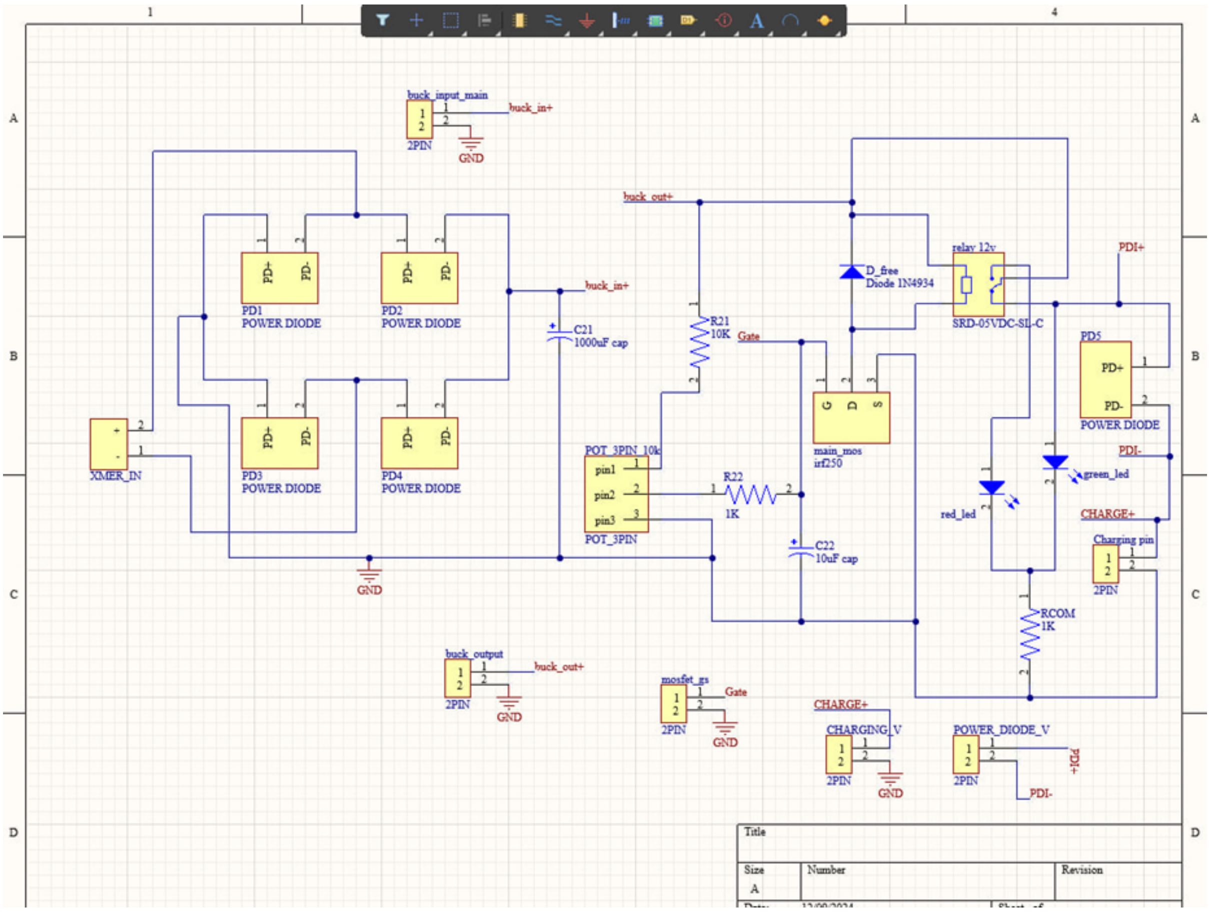

Figure 6: Charger circuit layout

After the voltage from the transformer is rectified, it is transferred to the buck converter. The output voltage from the buck converter is again returned to this circuit. Its PCB layout:

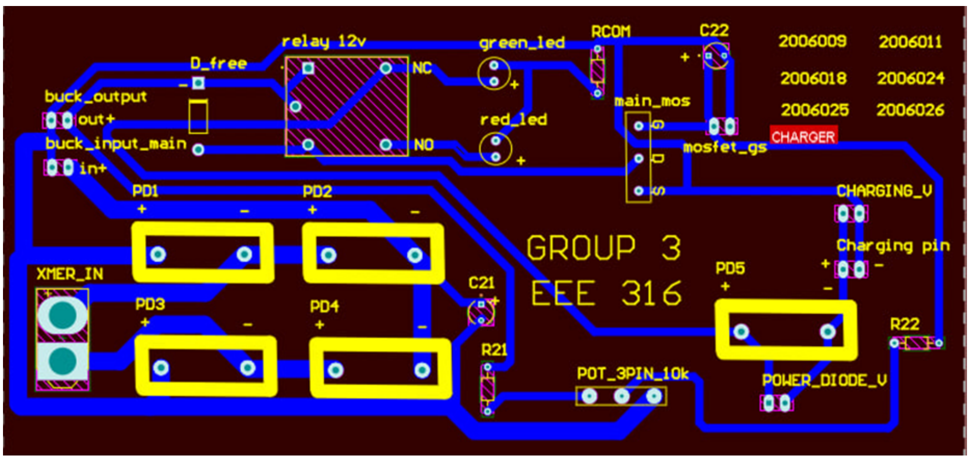

Figure 7: PCB layout for charger circuit

We used the software Altium designer for PCB designing. XT60 connectors were used for power input from the transformer. We placed some male header pins on the PCB to check the voltage across certain nodes using multimeter. The output voltage is also transferred to the lipo battery via the male header pin.

For the buck converter that we constructed separately, here is the schematic layout:

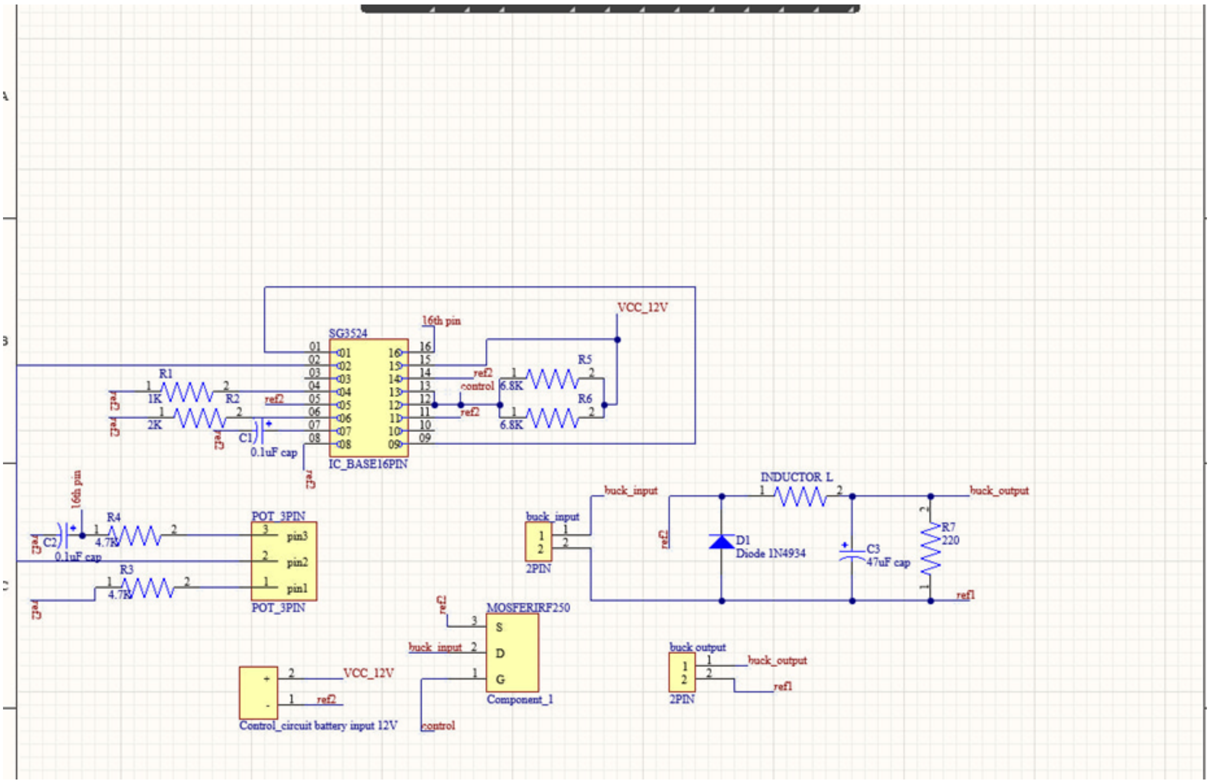

Figure 8: Schematic layout for buck converter

The PCB layout for said converter is the following:

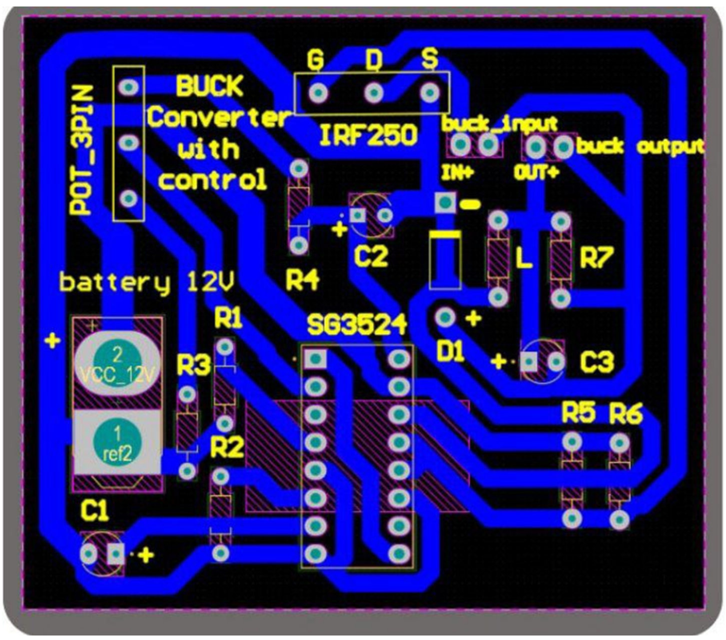

Figure 9: PCB layout for buck converter

In the buck converter circuit we also used XT60 connector as well to get voltage input from the battery to power up the IC.

The following figures show the resultant PCB boards after printing and soldering:

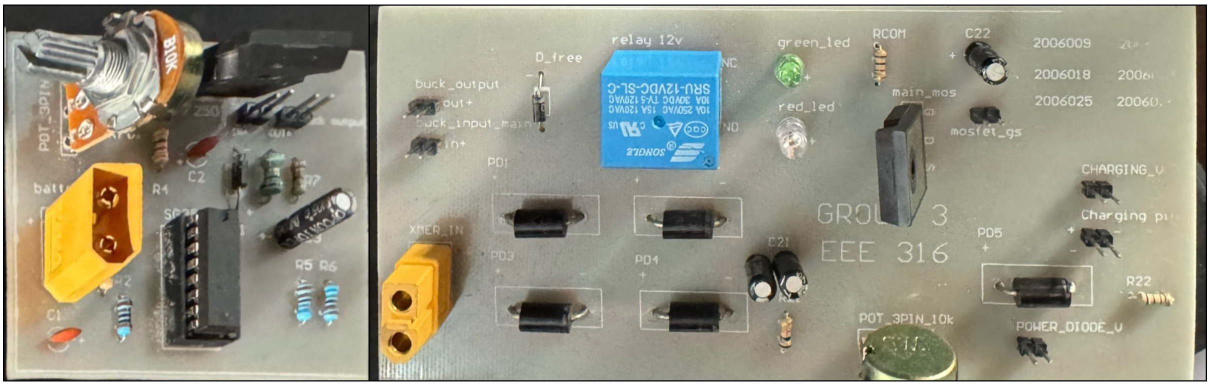

Figure 10: PCBs for (left) buck converter and (right) charger

4.2 Experiment and Data Collection

Here in the PCB board the green LED is showing battery is charging and the pot is set like so that the battery cut off happens in 11.67 V.

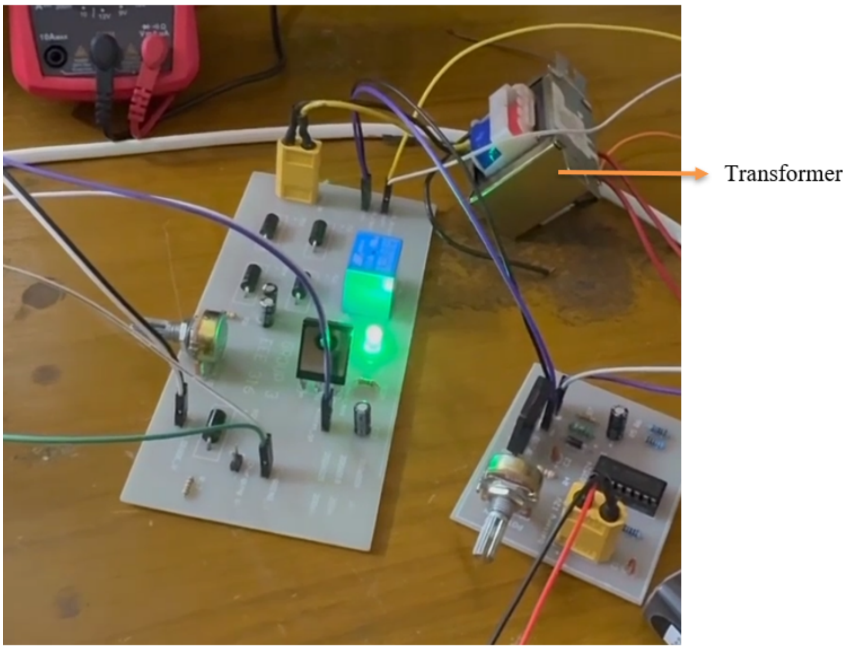

Figure 11: Setup while charging

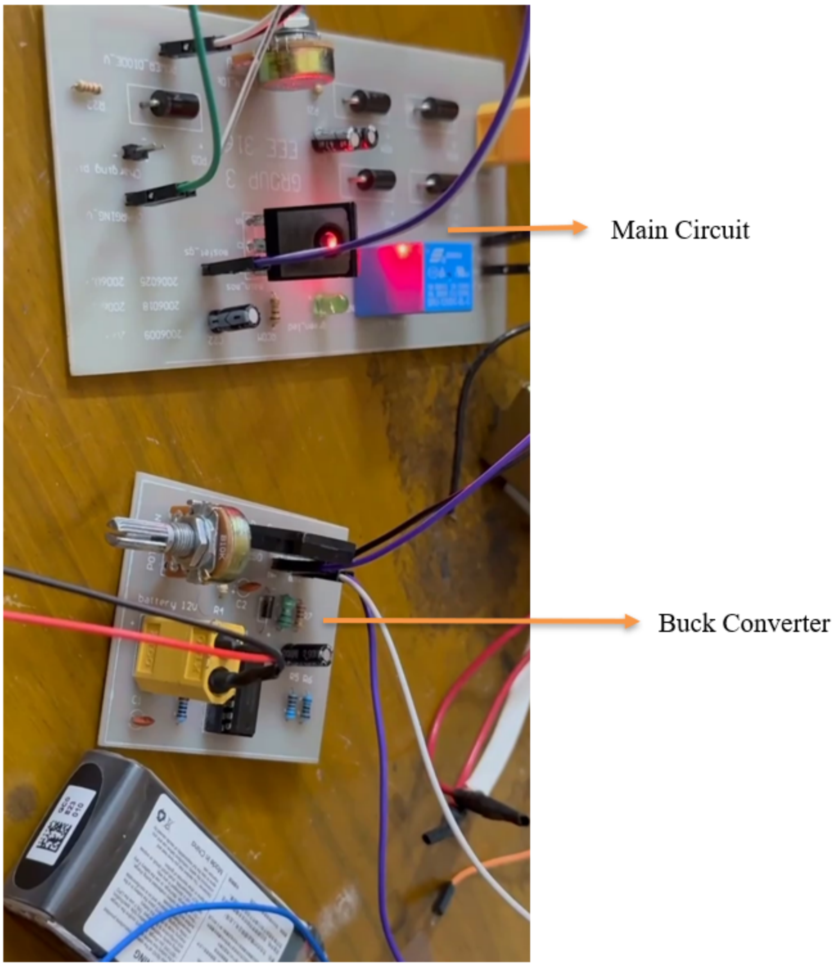

Figure 12: Charging cutoff achieved

Figure 13: Cutoff voltage

4.3 Data Analysis

For the charging to be cut off at a battery voltage of $11.65\,\text{V}$, the pot resistance can be determined using Eq. (1):

$$4.2 = \frac{R_{\text{pot}}}{20} \times (11.65 + 0.7) \implies R_{\text{pot}} = 6.8\,\text{k}\Omega$$

Measuring the resistance of the potentiometer using a multimeter in resistance mode, we get the current value as $6.9\,\text{kV}$. The percent error is then

$$\%\text{Error} = \frac{6.9 - 6.8}{6.8} \times 100\% = 1.45\%$$

The error in the cutoff voltage can also be found as

$$\%\text{Error (cutoff voltage)} = \frac{11.67 - 11.65}{11.67} \times 100\% = 0.17\%$$

5 Design Analysis and Evaluation

5.1 Novelty

The adjustablility of both the charging voltage and cutoff voltage is the key novelty factor in out project. Usual charging solutions are fixed for certain devices or at best, a range of devices. However, our solution promises to be much more versatile when it comes to the application - ensuring enhanced flexibility and user customization. Common, off the shelf chargers have a predetermined output voltage level according to the charging profile of the battery it's made to work with. Our solution ups the game in two ways. Firstly. the variable voltage level makes it suitable for different sorts of batteries. Secondly, even for the same battery, the optimal charging voltage usually varies with age, wear and tear. As a battery ages, it may require lower voltages to preserve its lifespan. And the converter knob provides the solution.

The variable cutoff level is another novel aspect. The user can simply set the cutoff level as per their use case scenario and application. For example, when the user is not using the battery frequently or shelving it up, they might want to keep the battery moderately charged, but at other times, the batteries might need charging to full or near full capacity. The flexibility to tune it to circumstances make the battery charger ideal for all situations.

5.2 Design Considerations

5.2.1 Considerations to public health and safety

The development and deployment of a battery charger, especially one with adjustable charging and cutoff voltage controls, involves several significant public health and safety considerations.

LiPo batteries, while being widely used in consumer electronics, drones, electric vehicles, and other high-performance applications, come with a set of risks, particularly related to overcharging, thermal runaway, and improper handling. It's not very rarely that we hear about mobile phone batteries exploding. Even as recently as December 2024, we have heard of death from such hazards in our country. Therefore, ensuring the safety of both the charger design and its users is paramount.

The most prominent safety concern with LiPo batteries is the risk of overcharging. LiPo batteries are highly sensitive to charging voltages. Overcharging can lead to thermal runaway, a condition in which the battery generates excessive heat, potentially resulting in a fire or explosion. This risk is particularly severe if the charger lacks appropriate voltage regulation or cutoff protection. And this is the very problem that our project seeks to solve.

LiPo batteries are prone to fire hazards if mishandled. They contain highly flammable electrolytes, and if damaged (e.g., by puncture or mishandling) or exposed to short-circuit conditions, they can catch fire or even explode. The charger itself also poses a potential risk, especially if the DC-DC buck converter or other components malfunction or become faulty, causing a short circuit. The PCB design minimizes movable parts to ensure better safety in this regard.

While the adjustable charging voltage and cutoff voltage features offer greater flexibility, they also introduce user safety risks. Inexperienced or careless users may inadvertently adjust the voltage to unsafe levels, leading to improper charging profiles, overcharging, or even damage to the battery. If the user sets the charging voltage too high or the cutoff voltage too low, it could result in reduced battery lifespan, safety hazards, or device failure. It is easy to see a child or someone inexperienced mishandling the module and increasing the buck converter output to unsafe levels, causing potentially deadly hazards.

Given that the charger operates with high voltages (depending on the input power supply) and potentially large currents during charging, there is a risk of electrical shock or electrical fires if the charger is improperly connected and/or used. This is especially true when dealing with unprotected connections or exposed wires.

We can offer up several safety measures that can be further implemented to reduce the associated risks discussed above:

- **Thermal Management**: Temperature sensors can be integrated into the charging circuit to monitor the battery's temperature during charging. If the temperature exceeds a safe threshold, the charging process should be automatically terminated or throttled back to prevent overheating.

- **Overcurrent Protection**: Adding an overcurrent protection circuit to prevent excessive current from flowing into the battery. This feature protects both the battery and the charger components from overheating or damaging high current conditions.

- **Short Circuit Detection**: The charger should be equipped with short-circuit protection to detect and isolate the circuit in case of a short. This can prevent battery damage, potential fires, and reduce the risk of electrocution or harm to users.

- **Fire Resistant Materials**: To prevent direct exposure to potential fires, the charger could be housed in a fire-resistant or flame-retardant enclosure. While this does provide an additional layer of safety, this also adds excess cost and might make for a financial barrier.
- **Visual Feedback for Tuning**: In its current state, all the tuning tasks (voltage level and cutoff level) are carried out manually. A visual display or indicator LEDs showing the current voltage and cutoff settings would help users stay informed of their adjustments.
- **Voltage Adjustment Locks**: To prevent users from accidentally setting unsafe voltage levels, the charging circuit could include mechanical voltage adjustment locks to restrict the adjustment range to safe operating limits while still offering some flexibility within those bounds.

5.2.2 Considerations to environment

Important environmental considerations that must be addressed throughout the product's life cycle — from *design and manufacturing* to *usage and end-of-life disposal*. In order to achieve our goals for sustainable practices, we must ensure minimal ecological footprint of our product.

Since out charger includes a DC-DC converter, which can contribute to unnecessary energy consumption. It needs ensuring that the configurations used are suitable with each other and together, provides a reasonably efficient system.

Use of sustainable materials is another thing that should be considered. Electric circuit components have significant environmental consequences depending on how they are sourced and manufactured.

The above considerations apply mostly to mass manufacturing of the product and depends almost entirely on the manufacturer. We had little choice in answering those questions. However, something we could actively consider is the repairability and recyclability of the product. We made the design as modular as possible to allow for easy troubleshooting and repairability by the user. As such, small malfunctions will not put the module beyond repair and force the user to buy a completely new unit. This also makes sure that the components from units beyond usage can be salvaged and reused.

Further than this, we can only formulate a set of instructions (advices would be a more suitable word perhaps) to be followed for production. These will include energy efficient components, ethical sourcing, minimizing resource use, local sourcing, waste reduction during manufacturing, recycling programs, minimalist packaging, proving clear instructions and proper disassembling tools and so on.

5.3 Investigations

5.3.1 Experimental Design

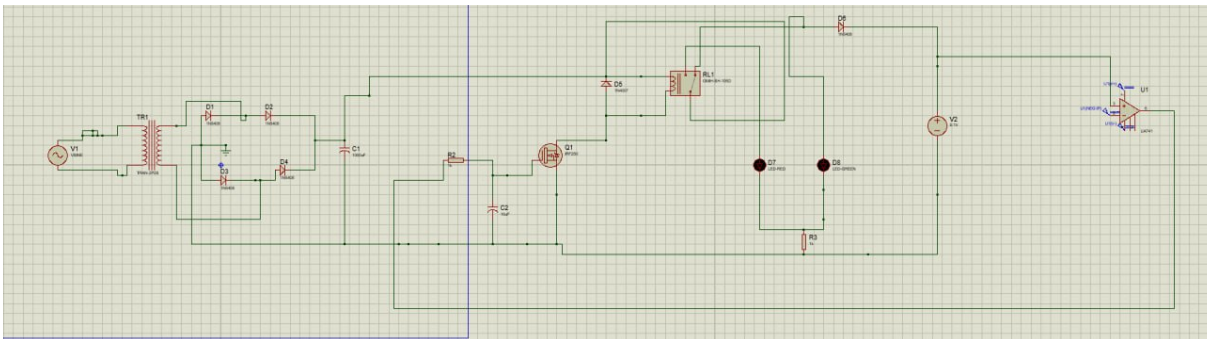

Figure 14: Initial design

In the first phase of the design process, we considered the above circuit, which uses an op amp configuration to drive the MOSFET gate. The optimization serves several purposes: it's decidedly simpler, more cost effective (resistors are extremely cheap compared to op amps), lower power consumption, as the op amp is an active circuit element and requires its own V_{cc}. Moreover, the resistor configuration provides better stability against natural factors, and better precision and reliability.

5.4 Limitations of Tools

The components used in the project are rather basic. Nonetheless, there are several inherent limitations in the selected tools that can affect both performance and design flexibility. These limitations should be considered during development to optimize the overall system design and ensure safety and functionality.

To step down the rectified voltage, we use a DC-DC buck converter. The converter circuit comes with its own limitations. These type of converters have different efficiency characteristics under varying load. Moreover, high-frequency switching introduces voltage ripple. This potentially affects sensitive components in the charger circuit or the battery itself. While we used capacitors to mitigate this issue, these came at a trade-offs in terms of component size and cost.

Potentiometers are used to control both the charging voltage (via the buck converter) and the cutoff voltage in the charger module. However, potentiometers, while cost-effective and simple to implement, have limitations. Pots are not inherently precise devices and may lead to inaccurate voltage settings, especially if the user adjusts them frequently. Small changes in resistance can lead to larger variations in output voltage, making it difficult to fine-tune charging parameters consistently. Also, potentiometers can degrade due to mechanical wear, which can lead to inconsistent performance. This can be problematic in designs requiring precise and reliable voltage control over long periods.

MOSFETs are used for switching and controlling the flow of current in the charging circuit. While MOSFETs are fast and efficient, they can overheat, potentially leading to failure or reduced performance. The same applied to the transformer used. Similarly, like MOSFETs, diodes can also generate heat under high-current conditions. Improper heat dissipation can lead to diode failure or reduced lifespan.

5.5 Impact Assessment

5.5.1 Assessment of Health and Safety Issues

The automatic cutoff battery charger for LiPo batteries project significantly influences user health and safety by mitigating critical dangers linked to charging high-energy batteries. Lithium Polymer batteries, although efficient, are susceptible to risks such as overcharging, thermal runaway, and overheating, which may result in fires or explosions. The charger substantially mitigates these dangers by integrating auto cutoff mechanisms to avoid overcharging. The charger incorporates appropriate design elements and safety features to reduce potential hazards, hence providing a safer experience for users using LiPo batteries.

Moreover, the project's focus on instructional materials and explicit user manuals intends to make sure that the users understand the appropriate usage, storage, and disposal of LiPo batteries. By incorporating these precautions into both the charger and the corresponding battery management system, the project not only protects users from immediate hazards but also promotes long-term safety protocols. The auto cutoff battery charger thus plays a role to create a safer environment for users while improving the reliability and longevity of LiPo batteries, which are increasingly utilized in consumer gadgets.

5.6 Sustainability and Environmental Impact Evaluation

Our project has some important sustainability and environmental considerations, both in terms of the materials used and the long-term impact on waste management. At its core, the key feature of the project is sustainability. Thus, sustainability and reducing environmental effects of consumer electronics are at the heart of the project.

Overcharging is a common cause of premature battery failure, leading to reduced capacity and shortened lifespan. By ensuring that the battery is charged to its optimal voltage and automatically stopping the charge once it's full, the charger prevents the damage associated with overcharging, thereby helping to preserve battery health and extend its operational life. This directly reduces the need for frequent battery replacements, which in turn minimizes the waste generated from disposed batteries. Moreover, by extending the lifetime of each LiPo battery, the project helps reduce the overall demand for new batteries, contributing to less resource extraction and production waste.

In essence, by promoting proper charging practices and reducing premature battery wear, the auto cutoff charger helps reduce the environmental footprint associated with battery disposal and replacement. This sustainable approach not only minimizes the waste generated from the batteries themselves but also supports a longer, more efficient use of resources throughout the battery's lifecycle.

6 Reflection on Individual and Teamwork

6.1 Individual Contributions of Each Member

ID	Contributions in Project
2006009	Circuit and PCB design
2006011	Circuit Simulation and build up
2006018	Breadboard Implementation and PCB Testing
2006024	Breadboard Implementation and PCB Testing
2006025	Circuit Simulation and build up
2006026	Circuit design and soldering

Table 1: Individual contributions of team members

6.2 Mode of Teamwork

Teamwork is an essential aspect of any successful project. However, teamwork can only be effective if it is done in an efficient manner. One key factor in efficient teamwork is clear communication. Team members must be able to effectively communicate with one another in order to share ideas, provide feedback, and coordinate their efforts. Without clear communication, team members may work at cross purposes and/or duplicate efforts.

Throughout the entire duration of the project, we had in place a well-defined structure and process of teamwork. A well-defined structure helps to prevent confusion, duplication of efforts, and conflicts over roles and responsibilities.

We established clear procedures, timelines, and milestones so that we could stay organized, focused, and on track. We emphasized that each member understood their roles and responsibilities, as well as how their work fit into the overall project. This outlook worked very well as we more or less all of the goals and deadlines we set as a project team.

As the design of the circuit is quite modular, we could organize ourselves so that different subgroups could work over each portion of the project. We also conducted online and offline meeting to ensure that each subgroup understood the others' work and how it related to their portion.

6.3 Log Book of Project Implementation

Notable Achievements	Date
Simulation without buck converter	27/10/24
Full Circuit Simulation	30/10/24
Breadboard Implementation	01/11/24
Constructing buck converter on board	02/11/24
Laboratory test of the breadboard circuit	17/11/24
PCB design	23/11/24
PCB Implementation	28/11/24
PCB testing and debugging	06/12/24

Table 2: Milestones

7 Communication

7.1 Executive Summary

We are excited to announce the launch of our innovative Auto Cutoff LiPo Battery Charger, designed to safely and efficiently charge lithium polymer (LiPo) batteries used in everything from drones to consumer electronics. This charger features an automatic cutoff mechanism, ensuring the battery stops charging once it's fully charged, preventing overcharging and increasing battery life. By preventing heat buildup and optimizing charging conditions, our charger extends battery lifespan, reducing the need for frequent replacements and minimizing electronic waste. Simple to use, with adjustable voltage and cutoff settings, it offers both safety and sustainability for users. With this cutting-edge technology, we are setting a new standard in battery care, promoting safer, longer-lasting, and environmentally friendly charging solutions.

7.2 User Manual

The auto cut-off battery charger is designed to provide safe and efficient charging for modern battery-powered devices. It features an adjustable voltage cut-off mechanism, allowing users to set the charger to stop charging at any voltage above 8.4 volts. To configure the desired cut-off voltage, a dummy load or test setup must be connected to the output, simulating the target voltage. By rotating the potentiometer knob, adjust the system until the MOSFET gate voltage reads exactly 4.2 volts at the specified output voltage. Once calibrated, the charger will automatically disconnect the power supply when the battery reaches the set voltage, preventing overcharging and ensuring a longer battery lifespan. This system is compatible with various battery types and capacities, making it versatile for different applications, including consumer electronics, renewable energy systems, and industrial machinery. Built with a robust design, the charger prioritizes safety, reliability, and adaptability. Users must ensure proper calibration by setting the desired cut-off voltage accurately and checking all connections before use. The charger should not be exposed to extreme temperatures or moisture and must be maintained regularly for optimal performance. If troubleshooting is needed, ensure the calibration process was completed correctly and the potentiometer is adjusted accurately.

8 Project Management and Cost Analysis

8.1 Cost of Components

Component	Per Unit Cost	Quantity	Cost
10 k, 1 k Resistors	0.2/=	200	40/=
10 k Pot	15/=	2	30/=
10 uF Capacitor	5/=	2	10/=
N-mos (`IRF250`)	150/=	2	300/=
Diode (`1N4007`)	1/=	5	5/=
12 V Relay	35/=	1	35/=
Diode (`1N5408`)	100/=	4	400/=
Battery (`18650`)	25/=	1	25/=
4S Case	60/=	1	60/=
100 mAh 3S	1400/=	1	1400/=
PWM IC (`SG3524`)	60/=	1	60/=
XT60 Connector	60/=	4	240/=
PCB	550/=	2	1100/=
	Total		**3705/=**

Table 3: Component costs

9 Future Work

The project offers some exciting prospects when it comes to making further improvements to the current unit. Below are only some of the possibilities:

- **Thermal Protection**: Adding a temperature sensor can prevent overheating by monitoring the battery's temperature during charging. If the temperature exceeds a safe limit, the charger can automatically cut off or reduce the charging current to prevent damage.
- **Overcurrent Protection**: Add overcurrent protection mechanisms to safeguard against excessive current flow, which can cause overheating and potential battery failure.
- **Audible Alerts**: Currently, there is an LED system to indicate full charge. We can easily extend it to use a bell or any other audible alerts, which is more effective than a visual one.
- **Adaptive Charging**: If a software based control system can be implemented, then we can use algorithms that adapt the charging profile based on battery state, health, and environmental conditions. This can extend battery life and improve performance..

- **User Interface**: For now, all the tunings and such are completely manual. But we can implement a robust user interface that, at least in part, automates/semi-automates things. Such as a display to indicate the current cutoff level.

- **Renewable Energy Integration**: Allow charging from solar power. This can make the charger more eco-friendly and versatile for off-grid applications.

- **Further Charging Methods**: Different charging methods such as pulse charging or desulfation charging can be implemented for further generalization.

10 References

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