MQP FJL-CHRG

Sealed Lead Acid Battery Smart Charger

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This project report is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed herein are those of the authors and do not necessarily reflect the positions or opinions Worcester Polytechnic Institute.

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1.0 Introduction

1.1 Introduction

Sealed Lead Acid (SLA) batteries have a variety of uses, from powering wheelchairs and golf carts, to supporting solar panels, starting automobiles, and emergency power supplies. For SLA batteries, the internal chemistry allows for 2 volts per cell of electrical potential storage when fully charged. The most common SLA battery contains 6 cells, thus described as a 12V battery[1]. When properly maintained SLA batteries can provide consistent outputs for 300-500 cycles. The difficulty occurs in maintaining the batteries, as SLA batteries typically self-discharge (not connected to any load) at a rate of 3% per month[2]. Due to this, the batteries require periodic maintenance charging to keep the charge at or near full.

There are two main types of chargers for SLA batteries currently on the market. The first type of charger is the single-unit charger. These single unit chargers cost around $20-$50 and can charge a single battery quickly. The other type of charger is a multi-unit charger. They are more expensive than single chargers and usually cost around $60-$100 per charging output. This can drive the cost of a multi-unit charger up significantly. How these cost estimates are obtained is explained in detail in section 2.4.

Our goal was to create a multi-charger using a single charging circuit, with an algorithm to analyze multiple battery levels, that charges multiple batteries and provides a maintenance charge. This type of system would provide a much lower cost solution for charging multiple batteries compared to buying multiple single unit chargers, or expensive multi-unit chargers.

1.2 Project Statement

The goal of this project was to design and prototype a SLA battery charger for use with multiple connected batteries, while maintaining a lower price per output than current multiple output chargers in the SLA battery market. To achieve this goal, the following objectives were identified:

- Research Sealed Lead Acid Battery Characteristics
- Design a Sealed Lead Acid Charging Device Utilizing a Single Charge Controller with Multiple Outputs
- Verify System Functionality Through Extensive Laboratory Integration and Operational Testing
- Prototype the Device as A Marketable Product

These objectives will be fully discussed in section 3.

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[1] BU-403: Charging Lead Acid, April 4th, 2017, <http://batteryuniversity.com/learn/article/charging_the_lead_acid_battery>.

[2] SEALED LEAD ACID BATTERY QUESTIONS, 2016, <https://www.atbatt.com/sealed-lead-acid-batteries/faq>.

1.3 Summary

To summarize, our project will create a product that is a less expensive, more effective charging solution for SLA batteries. By utilizing a single charging circuit, we can be more cost efficient while providing a quality charge for the batteries. The objectives for our project are laid out to accomplish our goals of a finished project.

2.0 Background

2.1 Introduction

The problem wanted to explore is how to charge multiple SLA batteries with a single charging circuit. Single chargers are available, but only charge one battery at a time, while gang-chargers are also available, but are expensive due to multiple charging circuits for the multiple batteries being charged. Our idea was to create a multi-charger utilizing a single charging circuit to charge multiple SLA batteries smartly, completely, and correctly insure full charge and no damage. SLA batteries also slowly lose charge over time, so they need to have a maintenance charge, where they get topped off at a certain interval of time. Storing batteries at a full charge increases the life and value of the battery.

In this section, we review topics that are important to understanding our system design and reasoning behind this project. Topics include SLA batteries, SLA charging methods and charger modes, and market research.

2.2 Sealed Lead Acid Batteries

SLA batteries are dependable, are inexpensive on a cost-per-watt basis and can be used in a variety of applications. There are three types: starters, deep-cycle, and stationary. Starter batteries are designed to provide a high current over a short period of time to start a device, such as a car, and then is charged by the alternator, which also powers the electrical system of the car after the battery starts the car. A starter battery is built with multiple thin lead plates, as shown in Figure 2.1. The thinness of the plates increases surface area inside the battery, increasing the area available for high current discharges. However, starter batteries can not be fully discharged and should be limited to no more than about 30% depth of discharge, or the number of cycles they have left will be significantly decreased.

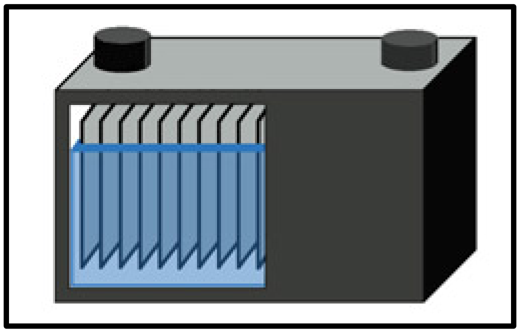


Figure 2.1. Inside of starter battery, (batteryuniversity.com)

A deep-cycle battery is designed for continuous power delivery, and a higher charge-discharge cycle count. They are designed to provide a steady amount of current over a long period of time. These batteries are used in devices needing a higher energy capacity and constant current delivery over a longer period of time and to a deeper level of discharge. They are designed with fewer, but thicker plates, as shown in Figure 2.2. These plates allow the battery to deep-cycle repeatedly with a steady supply of current.

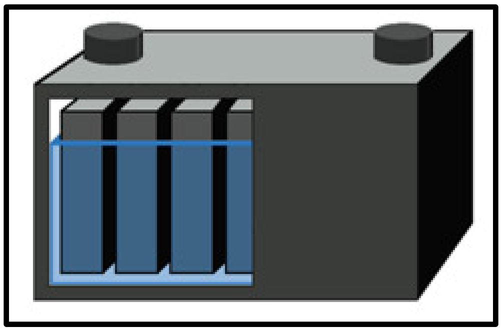
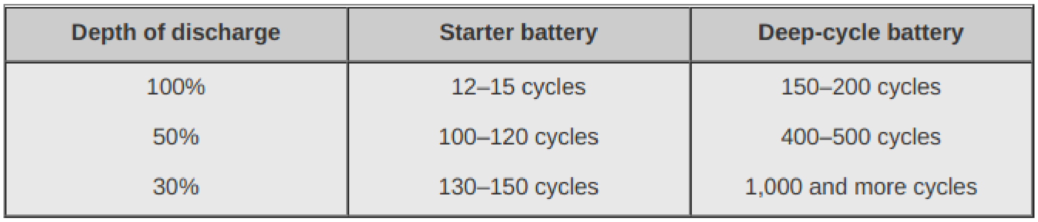


Figure 2.2. Inside of deep-cycle battery, (batteryuniversity.com)

The last type of battery is the Valve-Regulated Lead Acid battery, or the VRLA. These batteries require minimal maintenance and are therefore good for emergency power. These batteries build up gas when they are recharged and release the gas through their valves when needed.

All SLA batteries require desulfating on the plates and all have a limited number of discharge-charge cycles they can provide before they lose capacity. As shown in Figure 2.3, based on the depth of discharge, and the type of battery, the lifetime of the battery can be estimated.

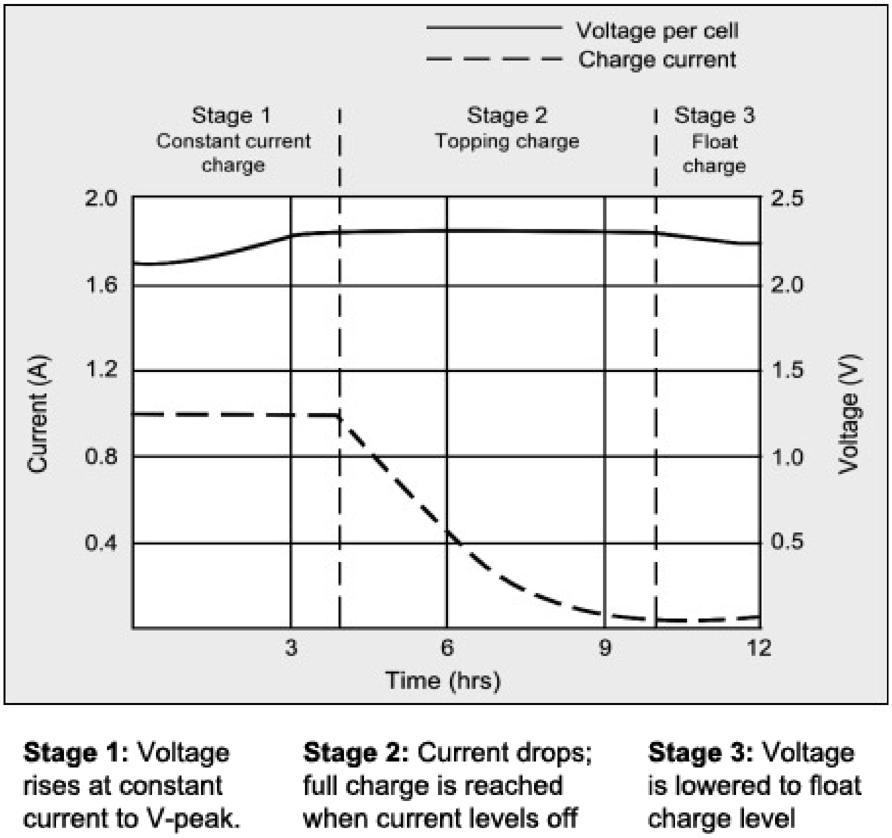


Depth of discharge	Starter battery	Deep-cycle battery
100%	12–15 cycles	150–200 cycles
50%	100–120 cycles	400–500 cycles
30%	130–150 cycles	1,000 and more cycles

Figure 2.3. Lifetimes of SLA battery depending on depth of discharge, batteryuniversity.com

2.3 SLA Charging

Figure 2.4 shows the current and voltage values for each of the three charging stages for the charging cycle of an SLA battery. The first stage is called the Constant-Current charge, where as the name suggests, a constant current is supplied to the battery. This stage takes up the bulk of the charging, as it charges to about 70% and take around 5-8 hours, depending on the depth of discharge of the battery. The next stage is called the Topping current. This stage slowly decreases the current over the time interval, while slightly increasing the voltage, to give the battery a full charge. This takes about 7-10 hours and is designed to provide saturation to avoid sulfation. The last stage is called a Float charge. This is a maintenance charge, as SLA batteries tend to self-discharge over time they need to have a trickle charge to counter self-discharge losses.



Stage 1: Voltage rises at constant current to V-peak.

Stage 2: Current drops; full charge is reached when current levels off

Stage 3: Voltage is lowered to float charge level

Figure 2.4. Voltage and Current Levels per charge stage, batteryuniversity.com

2.4 SLA Chargers

There are two main types of SLA battery chargers, single-unit chargers and multi-bank chargers. Each of these charger types fulfil their purposes, but have unique limitations. Single-unit chargers, shown in figures 2.5-2. 8, are ideal for rapid charging of batteries and are inexpensive, typically $20-$50; however, for consumers with multiple batteries, single unit chargers require switching the wires between batteries.

12 Volt Smart Battery Chargers: 4 Amps and Under [top]

Tenergy 12v-24v 500 mA NiMH/NiCd Battery Pack Charger T-01027
~~$24.00~~ ***$21.95***

Universal 12v 500 mAh Lead Acid Battery Smart Charger UPG12
$14.00

NOCO Genius 6v 12v 750 mA Wicked Smart Battery Charger G-750
~~$37.95~~ ***$29.95***

Battery Tender Junior 12V 750 mA 3 Stage Smart Charger - BTjr12v021-0123
~~$39.00~~ ***$23.95***

OptiMATE Lithium 4s 12v 0.8 Amp 8-Step Smart Charger
~~$64.90~~ ***$58.41***

CTEK 12v US 0.8 Amp Smart Charger - CTEK-56-865
~~$62.99~~ ***$59.99***

Battery Tender 12v 800 mA Waterproof Marine Smart Charger BTW022-0150
~~$42.00~~ ***$33.95***

Japlar Schauer 12v 1 Amp Automatic Smart Charger CM1A
~~$35.00~~ ***$27.95***

Japlar Schauer 12v 1/4/6 Amp Automatic Smart Charger CM6A
~~$62.00~~ ***$48.95***

NOCO Genius 6v 12v 1100 mA Wicked Smart Battery Charger G-1100
~~$49.95~~ ***$39.95***

Soniel 12v 1 Amp Constant Current Smart Charger SON1202cc
$34.00

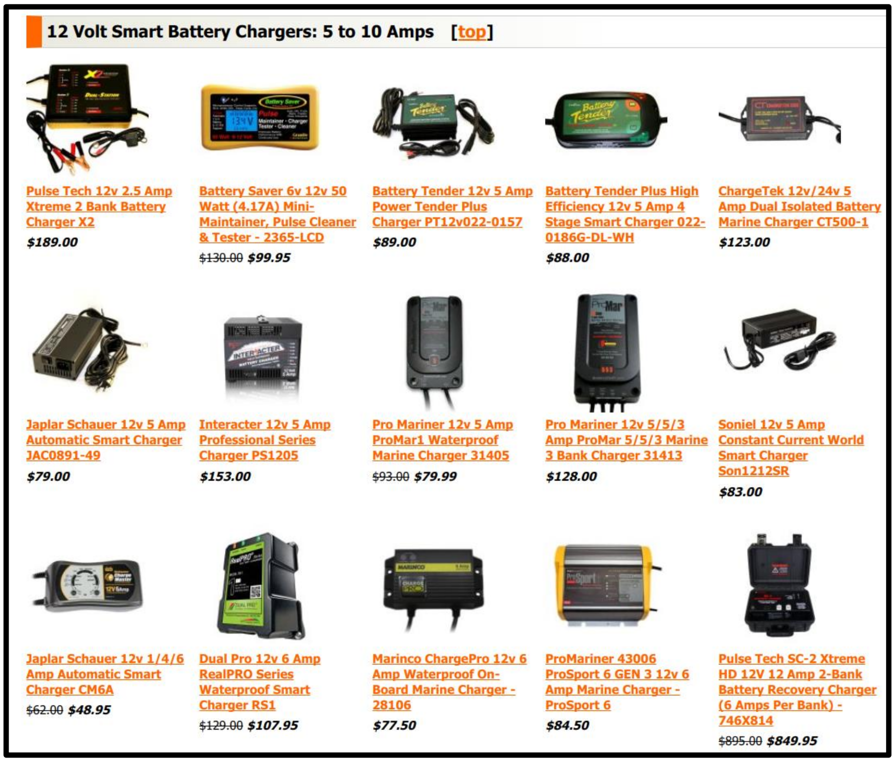
Battery Tender Plus - 12v 1.25 Amp 4 Stage Smart Charger (BT-021-0128)
~~$53.00~~ ***$44.95***

Battery Saver 6v 12v 12 Watt (1.25A) Mini-Maintainer, Pulse Cleaner & Tester - 1200-LCD
~~$70.00~~ ***$59.95***

Battery Tender Plus High Efficiency 12v 1.25 Amp 4 Stage Smart Charger BT-022-0185G-DL-WH
~~$70.00~~ ***$46.95***

Battery Tender 12v 1.25 Amp 4 Bank International Charger BT4b022-0148
~~$209.00~~ ***$191.00***

Figure 2.5: ≤ 4A Single Battery Chargers, (www.batterystuff.com)



12 Volt Smart Battery Chargers: 5 to 10 Amps [top]

Pulse Tech 12v 2.5 Amp Xtreme 2 Bank Battery Charger X2
$189.00

Battery Saver 6v 12v 50 Watt (4.17A) Mini-Maintainer, Pulse Cleaner & Tester - 2365-LCD
~~$130.00~~ ***$99.95***

Battery Tender 12v 5 Amp Power Tender Plus Charger PT12v022-0157
$89.00

Battery Tender Plus High Efficiency 12v 5 Amp 4 Stage Smart Charger 022-0186G-DL-WH
$88.00

ChargeTek 12v/24v 5 Amp Dual Isolated Battery Marine Charger CT500-1
$123.00

Japlar Schauer 12v 5 Amp Automatic Smart Charger JAC0891-49
$79.00

Interacter 12v 5 Amp Professional Series Charger PS1205
$153.00

Pro Mariner 12v 5 Amp ProMar1 Waterproof Marine Charger 31405
~~$93.00~~ ***$79.99***

Pro Mariner 12v 5/5/3 Amp ProMar 5/5/3 Marine 3 Bank Charger 31413
$128.00

Soniel 12v 5 Amp Constant Current World Smart Charger Son1212SR
$83.00

Japlar Schauer 12v 1/4/6 Amp Automatic Smart Charger CM6A
~~$62.00~~ ***$48.95***

Dual Pro 12v 6 Amp RealPRO Series Waterproof Smart Charger RS1
~~$129.00~~ ***$107.95***

Marinco ChargePro 12v 6 Amp Waterproof On-Board Marine Charger - 28106
$77.50

ProMariner 43006 ProSport 6 GEN 3 12v 6 Amp Marine Charger - ProSport 6
$84.50

Pulse Tech SC-2 Xtreme HD 12V 12 Amp 2-Bank Battery Recovery Charger (6 Amps Per Bank) - 746X814
~~$895.00~~ ***$849.95***

Figure 2.6: 5-10A Single Battery Chargers, (www.batterystuff.com)

12 Volt Smart Battery Chargers: 11 to 20 Amps [top]

IOTA 12v 15 Amp Charger Converter Power Supply w/Integrated IQ4 Sensor
$154.00

Japlar Schauer 12v 12 Amp Automatic Smart Charger JAC0891-41
$98.00

Pro Mariner 43012 ProSport 12 GEN 3 12v/24v 12 Amp Pro Sport 12 Marine 2 Bank Charger - ProSport 12
~~$149.00~~ *$125.95*

ProMariner ProTournament 360 Elite Quad 12v 24v 36v 48v 36 Amp 4 Bank Charger - ProMariner-52038
~~$599.00~~ *$359.95*

Pulse Tech SC-2 Xtreme HD 12V 12 Amp 2-Bank Battery Recovery Charger (6 Amps Per Bank) - 746X814
~~$895.00~~ *$849.95*

ProMariner 52032 12v 24v 36 Amp ProTournament 2 Bank 360 Elite Charger
~~$399.00~~ *$319.95*

Samlex 12v 15 Amp 3 Bank Automatic Smart Charger SEC-1215UL
~~$169.70~~ *$144.00*

Dual Pro 12v 15 Amp Professional Series Waterproof Marine On-Board Charger - PS1
~~$249.00~~ *$215.95*

Pulse Tech 12v 16 Amp World Battery Charger & Restorer XCR-20
~~$739.00~~ *$681.00*

Battery Tender 12v 20 Amp High Frequency Smart Charger BTHF12-20
~~$499.95~~ *$365.00*

ChargeTek 12v 20 Amp Waterproof On-Board Smart Charger RTIC-1120
~~$255.00~~ *$245.00*

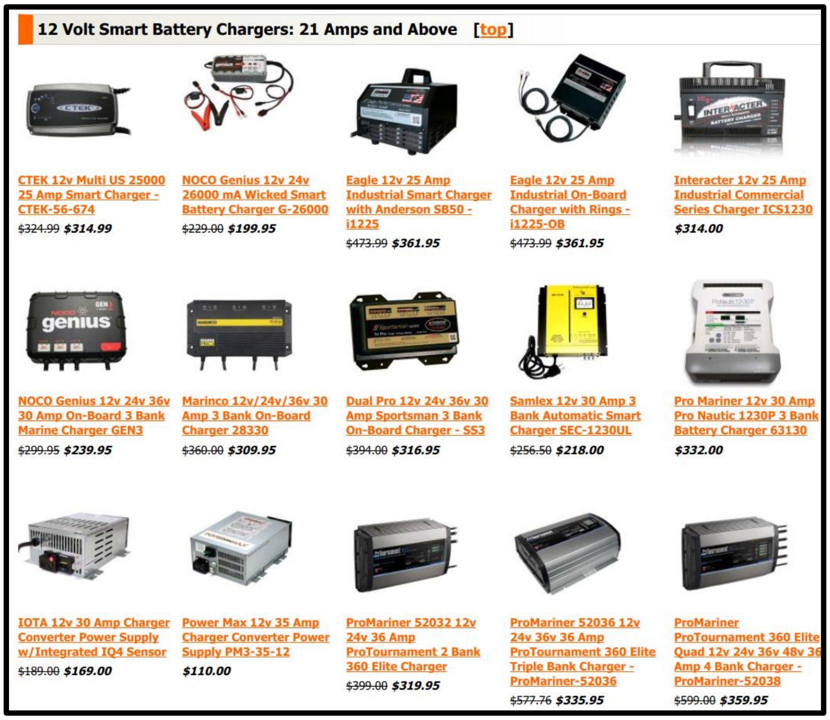
ChargeTek 12v 20 Amp On-Board Marine 2 Bank Boat Charger TPro-220
$299.00

NOCO Genius 12v 24v 20 Amp On-Board 2 Bank Marine Charger GEN2
~~$199.95~~ *$159.95*

Marinco 12v/24v 20 Amp 2 Bank On-Board Charger 28220
~~$360.00~~ *$181.95*

ProMariner 43020 ProSport 20 GEN 3 12v/24v 20 Amp Marine 2 Bank Charger - ProSport 20
$159.00

Figure 2.7: 11-20A Single Battery Chargers, (www.batterystuff.com)



12 Volt Smart Battery Chargers: 21 Amps and Above [top]

CTEK 12v Multi US 25000 25 Amp Smart Charger - CTEK-56-674
~~$324.99~~ *$314.99*

NOCO Genius 12v 24v 26000 mA Wicked Smart Battery Charger G-26000
~~$229.00~~ *$199.95*

Eagle 12v 25 Amp Industrial Smart Charger with Anderson SB50 - i1225
~~$473.99~~ *$361.95*

Eagle 12v 25 Amp Industrial On-Board Charger with Rings - i1225-OB
~~$473.99~~ *$361.95*

Interacter 12v 25 Amp Industrial Commercial Series Charger ICS1230
$314.00

NOCO Genius 12v 24v 36v 30 Amp On-Board 3 Bank Marine Charger GEN3
~~$299.95~~ *$239.95*

Marinco 12v/24v/36v 30 Amp 3 Bank On-Board Charger 28330
~~$360.00~~ *$309.95*

Dual Pro 12v 24v 36v 30 Amp Sportsman 3 Bank On-Board Charger - SS3
~~$394.00~~ *$316.95*

Samlex 12v 30 Amp 3 Bank Automatic Smart Charger SEC-1230UL
~~$256.50~~ *$218.00*

Pro Mariner 12v 30 Amp Pro Nautic 1230P 3 Bank Battery Charger 63130
$332.00

IOTA 12v 30 Amp Charger Converter Power Supply w/Integrated IQ4 Sensor
~~$189.00~~ *$169.00*

Power Max 12v 35 Amp Charger Converter Power Supply PM3-35-12
$110.00

ProMariner 52032 12v 24v 36 Amp ProTournament 2 Bank 360 Elite Charger
~~$399.00~~ *$319.95*

ProMariner 52036 12v 24v 36v 36 Amp ProTournament 360 Elite Triple Bank Charger - ProMariner-52036
~~$577.76~~ *$335.95*

ProMariner ProTournament 360 Elite Quad 12v 24v 36v 48v 36 Amp 4 Bank Charger - ProMariner-52038
~~$599.00~~ *$359.95*

Figure 2.8: ≥ 10A Single Battery Chargers, (www.batterystuff.com)

From an analysis of one hundred chargers from four different companies, the following chart was created (Figure 2.9). The orange line represents the average from the chargers. The trendline from Figure 2.9 shows the average cost for a single-unit charger is around $20 per amp of current.

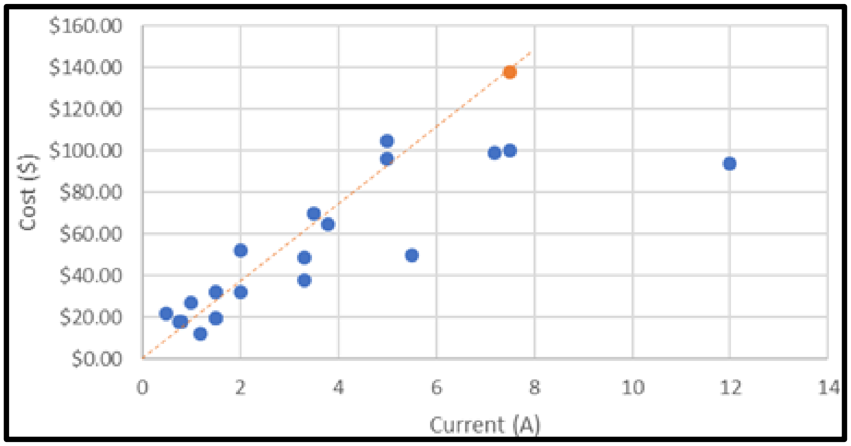
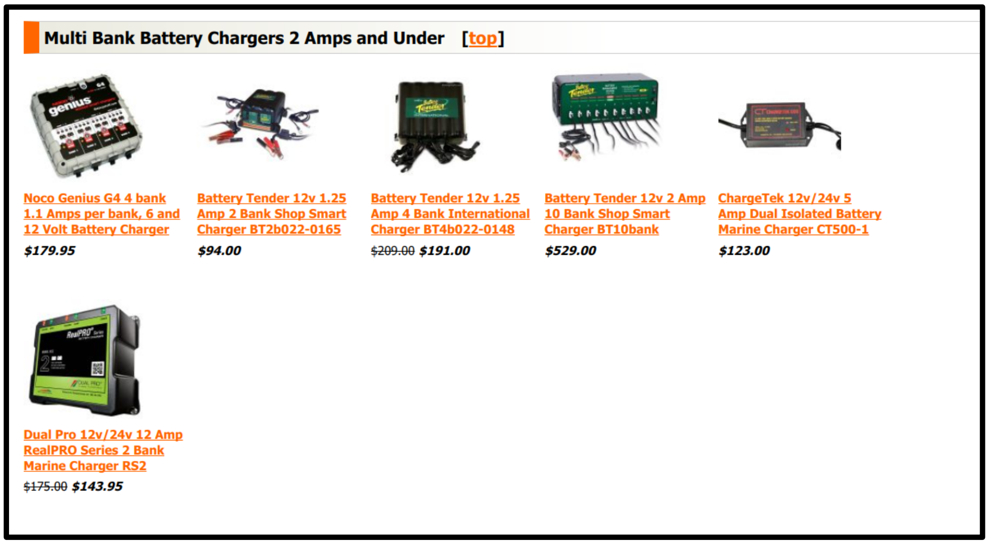


Figure 2.9: Cost v Current for Single-Unit Charger

Multi-bank SLA battery chargers are used by consumers with multiple batteries and who want to charge their batteries simultaneously. These chargers typically contain 4-24 outputs and can individually charge as many batteries as outputs, but for each output, the charger bank must have a dedicated circuit to control the charging. Each dedicated circuit requires its own current to charge a battery. Due to Kirchhoff's current law, the delivered current from the battery is obtained from the same input current, so if a multi-charger is charging 2 batteries at 10A each, the total input current needed is 20A. Most single unit chargers don't even need 20A input, as the most single-unit chargers we saw needed less than 8A. We can see the range of prices in Figures 2.10-2.13.



Multi Bank Battery Chargers 2 Amps and Under [top]

Noco Genius G4 4 bank 1.1 Amps per bank, 6 and 12 Volt Battery Charger
$179.95

Battery Tender 12v 1.25 Amp 2 Bank Shop Smart Charger BT2b022-0165
$94.00

Battery Tender 12v 1.25 Amp 4 Bank International Charger BT4b022-0148
~~$209.00~~ ***$191.00***

Battery Tender 12v 2 Amp 10 Bank Shop Smart Charger BT10bank
$529.00

ChargeTek 12v/24v 5 Amp Dual Isolated Battery Marine Charger CT500-1
$123.00

Dual Pro 12v/24v 12 Amp RealPRO Series 2 Bank Marine Charger RS2
~~$175.00~~ ***$143.95***

Figure 2.10: ≤2A Multi-Battery Chargers, (www.batterystuff.com)


Multi Bank Battery Chargers 3-6 Amps [top]

Pulse Tech 12v 2.5 Amp Xtreme 2 Bank Battery Charger X2
$189.00

Pro Mariner 12v 5/5/3 Amp ProMar 5/5/3 Marine 3 Bank Charger 31413
$128.00

Auto Meter 12v 5 Amp/Bank 6 Station Shop Smart Charger BusPro-600s
$829.95

Pulse Tech SC-2 Xtreme HD 12V 12 Amp 2-Bank Battery Recovery Charger (6 Amps Per Bank) - 746X814
~~$895.00~~ *$849.95*

Dual Pro 12v 24v 36v 18 Amp RealPRO Series 3-Bank Marine Charger RS3
~~$234.00~~ *$191.95*

Dual Pro 12v/24v 12 Amp RealPRO Series 2 Bank Marine Charger RS2
~~$175.00~~ *$143.95*

NOCO Genius 12v 24v 8 Amp Marine On-Board Battery Charger Gen 2 Mini - GENM2
~~$125.95~~ *$99.95*

ProMariner 43008 ProSport 8 GEN 3 12v/24v 8 Amp Marine 2 Bank Charger - ProSport 8
~~$129.00~~ *$109.95*

Pro Mariner 43012 ProSport 12 GEN 3 12v/24v 12 Amp Pro Sport 12 Marine 2 Bank Charger - ProSport 12
~~$149.00~~ *$125.95*

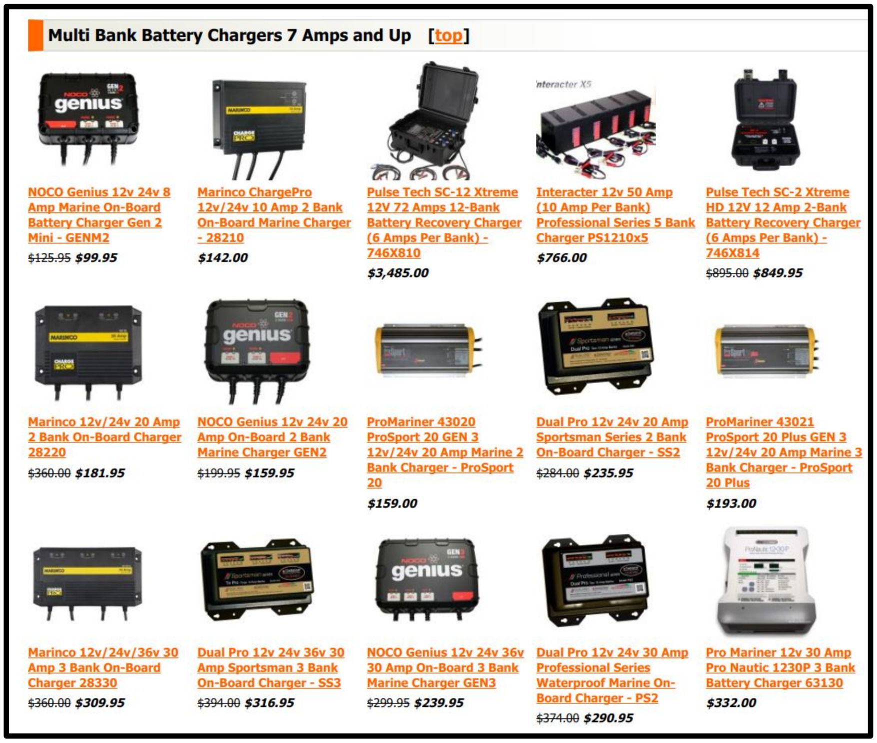
Marinco ChargePro 12v/24v 10 Amp 2 Bank On-Board Marine Charger - 28210
$142.00

Pulse Tech SC-6 Xtreme HD 12V 36 Amp 6 Bank Battery Recovery Charger (6 Amps Per Bank) - 746X816
~~$1,975.00~~ *$1,895.00*

Pulse Tech SC-12 Xtreme 12V 72 Amps 12-Bank Battery Recovery Charger (6 Amps Per Bank) - 746X810
$3,485.00

ProMariner ProTournament 360 Elite Quad 12v 24v 36v 48v 36 Amp 4 Bank Charger - ProMariner-52038
~~$599.00~~ *$359.95*

Figure 2.11: 3-6A Multi-Battery Chargers, (www.batterystuff.com)


Multi Bank Battery Chargers 7 Amps and Up [top]

NOCO Genius 12v 24v 8 Amp Marine On-Board Battery Charger Gen 2 Mini - GENM2
~~$125.95~~ *$99.95*

Marinco ChargePro 12v/24v 10 Amp 2 Bank On-Board Marine Charger - 28210
$142.00

Pulse Tech SC-12 Xtreme 12V 72 Amps 12-Bank Battery Recovery Charger (6 Amps Per Bank) - 746X810
$3,485.00

Interacter 12v 50 Amp (10 Amp Per Bank) Professional Series 5 Bank Charger PS1210x5
$766.00

Pulse Tech SC-2 Xtreme HD 12V 12 Amp 2-Bank Battery Recovery Charger (6 Amps Per Bank) - 746X814
~~$895.00~~ *$849.95*

Marinco 12v/24v 20 Amp 2 Bank On-Board Charger 28220
~~$360.00~~ *$181.95*

NOCO Genius 12v 24v 20 Amp On-Board 2 Bank Marine Charger GEN2
~~$199.95~~ *$159.95*

ProMariner 43020 ProSport 20 GEN 3 12v/24v 20 Amp Marine 2 Bank Charger - ProSport 20
$159.00

Dual Pro 12v 24v 20 Amp Sportsman Series 2 Bank On-Board Charger - SS2
~~$284.00~~ *$235.95*

ProMariner 43021 ProSport 20 Plus GEN 3 12v/24v 20 Amp Marine 3 Bank Charger - ProSport 20 Plus
$193.00

Marinco 12v/24v/36v 30 Amp 3 Bank On-Board Charger 28330
~~$360.00~~ *$309.95*

Dual Pro 12v 24v 36v 30 Amp Sportsman 3 Bank On-Board Charger - SS3
~~$394.00~~ *$316.95*

NOCO Genius 12v 24v 36v 30 Amp On-Board 3 Bank Marine Charger GEN3
~~$299.95~~ *$239.95*

Dual Pro 12v 24v 30 Amp Professional Series Waterproof Marine On-Board Charger - PS2
~~$374.00~~ *$290.95*

Pro Mariner 12v 30 Amp Pro Nautic 1230P 3 Bank Battery Charger 63130
$332.00

Figure 2.12: ≥7A Multi-Battery Chargers, (www.batterystuff.com)

Pro Mariner 24v 30 Amp Pro Nautic 2430P 3 Bank Battery Charger 63180
$559.00

Pulse Tech SC-6 Xtreme HD 12V 36 Amp 6 Bank Battery Recovery Charger (6 Amps Per Bank) - 746X816
~~$1,975.00~~ **$1,895.00**

Eagle 24v 48v 40 Amp 2 Bank Industrial On-Board Smart Charger - i2440OB
~~$899.99~~ **$775.00**

Eagle 36v 72v 40 Amp 2 Bank Industrial On-Board Smart Charger - i3640OB
~~$993.99~~ **$757.50**

ProMariner 52032 12v 24v 36 Amp ProTournament 2 Bank 360 Elite Charger
~~$399.00~~ **$319.95**

ProMariner 52036 12v 24v 36v 36 Amp ProTournament 360 Elite Triple Bank Charger - ProMariner-52036
~~$577.76~~ **$335.95**

ProMariner ProTournament 360 Elite Quad 12v 24v 36v 48v 36 Amp 4 Bank Charger - ProMariner-52038
~~$599.00~~ **$359.95**

NOCO Genius 12v 24v 36v 48v 40 Amp On-Board 4 Bank Charger GEN4
~~$375.95~~ **$299.95**

Dual Pro 12v 24v 36v 48v 40 Amp Sportsman 4 Bank Marine Charger - SS4
~~$529.00~~ **$414.95**

Dual Pro 12v 24v 36v 45 Amp Professional Series Waterproof Marine On-Board Charger - PS3
~~$499.00~~ **$401.95**

Eagle 24v 48v 50 Amp 2 Bank Industrial On-Board Smart Charger - i2450OB
~~$994.99~~ **$852.50**

Pro Mariner 12v 60 Amp Pro Nautic 1260P 3 Bank Battery Charger 63160
~~$541.00~~ **$517.95**

Dual Pro 12v 24v 36v 48v 60 Amp Professional Series Marine On-Board Charger - PS4
~~$624.00~~ **$490.95**

Pro Mariner 12v 50 Amp Pro Nautic 1250P 3 Bank Battery Charger - ProNautic 1250P-63150
$415.00

Samlex 12v 80 Amp 2 Bank Automatic Smart Charger - SEC-1280UL
~~$628.00~~ **$534.00**

Figure 2.13: ≥7A Multi-Battery Chargers, (www.batterystuff.com)

Repeating the analysis from the single-unit chargers, the cost v. total current relationship was similar for the multi-bank chargers, Figure 2.14, as the average cost was $20 per Amp.

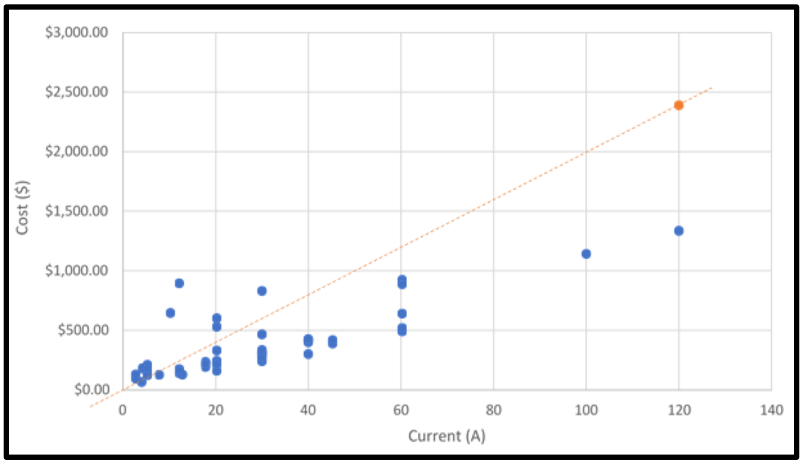


Figure 2.14: Cost v Current for Multi-Bank Charger

In addition to increased current and power, the multi-bank chargers had the unique property of multiple outputs. At average, this rate is approximately $100 per output, but there is a standard deviation of $48. This trend is shown in Figure 2.15.

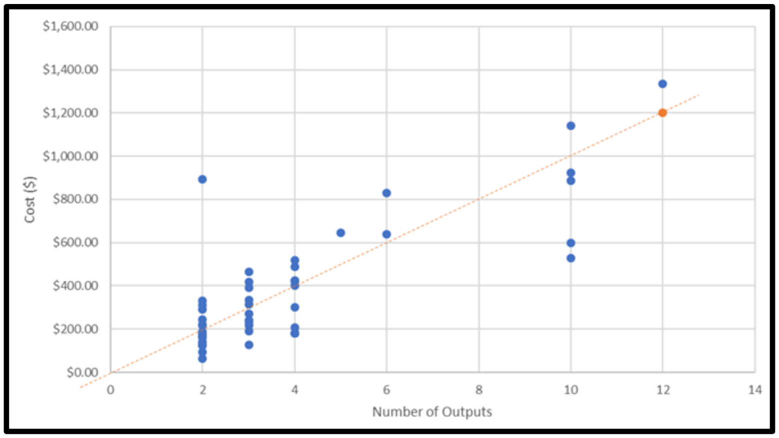


Figure 2.15: Cost v Outputs for Multi Bank

2.5 Summary

General research about SLA batteries was conducted, allowing us to develop a sense of how SLA batteries differ from standard lithium-ion batteries, how they need to be charged, and different types. Some market research was also conducted, and we were able to determine a price point for our final product, were we to sell a prototype. Given that the current market has multi-bank chargers for $100 per output and single chargers for $20 per amp of current, the suggested retail price for the prototype would be $125.

3.0 Problem Statement

3.1 Introduction

This section presents our detailed project statement, our project goals, and specific objectives we wanted to accomplish related to our project.

3.2 Project Statement

The purpose of this project was to use electrical and system engineering skills and concepts to design and build a multiple output sealed lead acid battery charger. This charger would use a single SLA charging circuit to be able to charge 4-8 sealed lead acid batteries. First, it would verify the charge in each battery, then use a three-step charge to completely and correctly charge the batteries, and finally would check each battery over a certain time interval and provide a maintenance charge to top-off each battery.

3.3 Goals, Objectives, Tasks

- Research Sealed Lead Acid Battery Characteristics
- Design a Sealed Lead Acid Charging Device Utilizing a Single Charge Controller with Multiple Outputs
- Verify System Functionality Through Extensive Laboratory Integration and Operational Testing
- Prototype the Device as A Marketable Product

3.4 Research Sealed Lead Acid Battery Characteristics

We needed to learn as much about how sealed lead acid batteries function. We wanted to assemble information on how the different types of SLA batteries are built, the multiple charging steps, and market research of products already available to get an idea of what we could price our project at and any features that we could include.

3.5 Design a Sealed Lead-Acid Charging Device Utilizing a Single Charge Controller with Multiple Outputs

To design a charge controller, we needed to plan and test multiple circuits. They are the charge controller, the switching circuit, and the buck converter. The charge controller is a circuit that takes an input current, A microcontroller would control which battery was charged by controlling the switching circuit and the charge controller.

These circuits would be assembled in the lab, verified through multiple tests, then assembled into onto a final printed circuit board (PCB) for a completed prototype.

3.6 Verify System Functionality Through Extensive Laboratory Integration and Operational Testing

3.7 Summary

This chapter introduced our problem we wanted to address. It also discusses our solution to said problem and goes into detail about the goals we wanted to accomplish for a successful project.

4.0 Design

4.1 Introduction

This section describes the progression of the design process. It starts with the high-level design and encompasses the reasons why different components were selected.

4.2 High Level Design

At the high level, the design contains only four parts: power connection, battery charge logic, battery select logic, and power steering and interface (Figure 4.1). The power connection component contains the conversion from the 120V AC to DC power for the battery charging as well as providing a lower voltage supply for the logic controls. Battery charge logic and battery select logic are similar but are distinctly different specialized systems. In the original designs, these were combined under one heading, however, the logic blocks vary enough to be considered as distinct blocks.

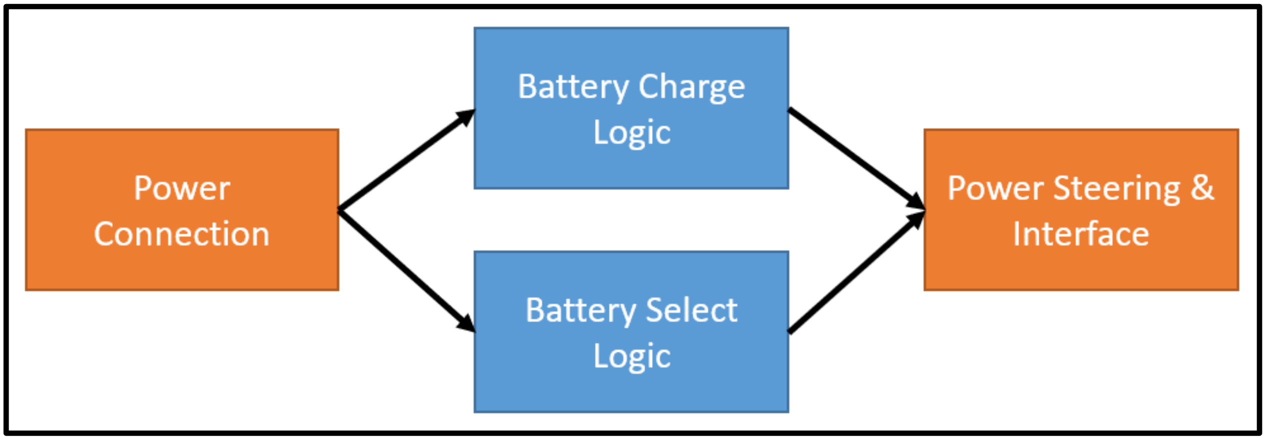


Figure 4.1: High Level Design Diagram

4.3 Detail Design

Elaborating upon the basic block design, specific components were arranged in a functional block diagram (Figure 4.2). In this design, the Microcontroller (MCU) is performing the role of the battery select logic while the SLA chip is handling the battery charge logic.

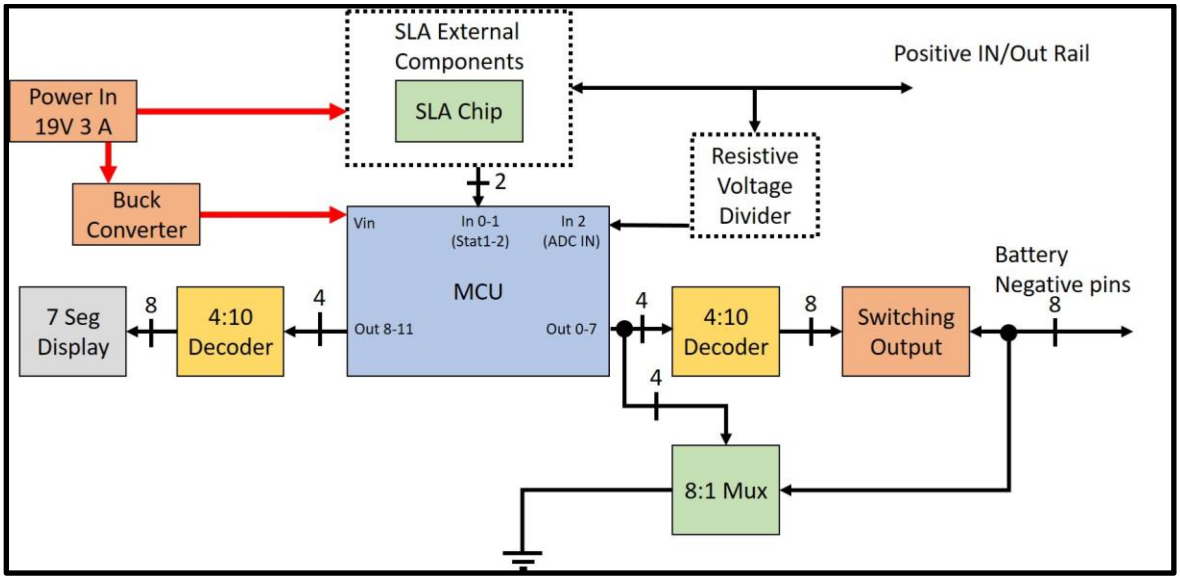


Figure 4.2: Functional Block Diagram, Initial Design

The preliminary design was intended for use with a 12 Input/Output Microcontroller. Due to the limited In/Out pins, this design utilized decoders to emulate 8 binary bits. The benefit of this design was the simplicity for control and reading the battery voltages, as shown in Figure 4.3. The downside of this design was that for the switching output, we decided to use MOSFETs. To operate as close to an ideal switch as possible, the MOSFETs required the voltage on the gate to be greater than the voltage on the drain. With the switch on the positive side of the batteries, the drain would have a voltage up to 15V. Since the logic board can only output 5V, an alternative approach was suggested.

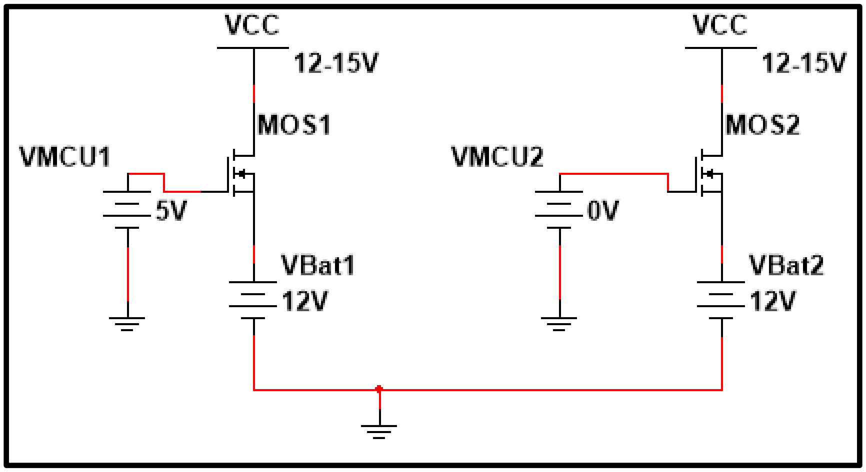


Figure 4.3: Switching Circuit, MOSFET High-Side Switch, Design 1

The second design was similar to the first, but with the switching output on the negative side of the batteries. Additionally, this design was optimized for a microcontroller with more Inputs/Outputs without a decoder for the switching output. See Figure 4.4 for the new switching circuit.

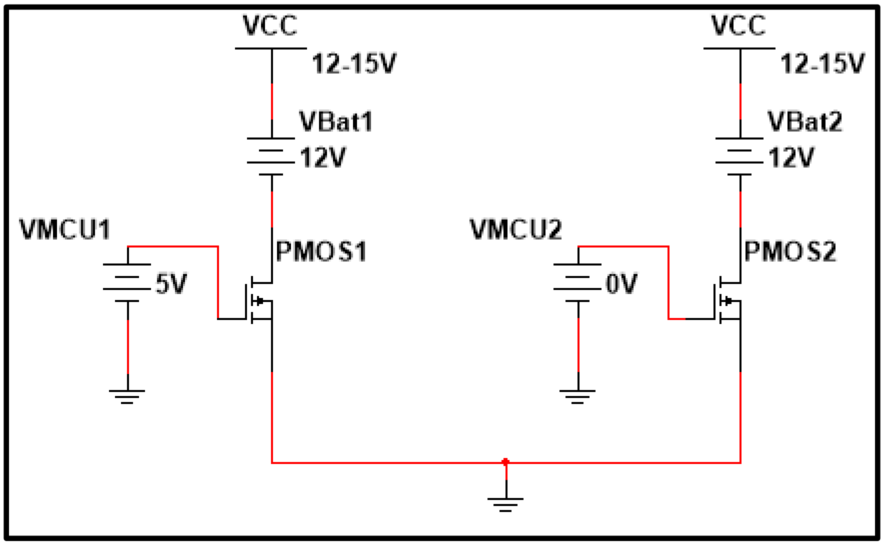


Figure 4.4: Switching Circuit, MOSFET Low-Side Switch, Design 2

The third design, Figure 4.5, is a combination of the first two ideas: a microcontroller with input/output pins, positive side switching with different MOSFETs. The 7-segment display is added to display relevant information during operations, while the 8:1 multiplexer is added to decrease the required number of outputs from the MCU.

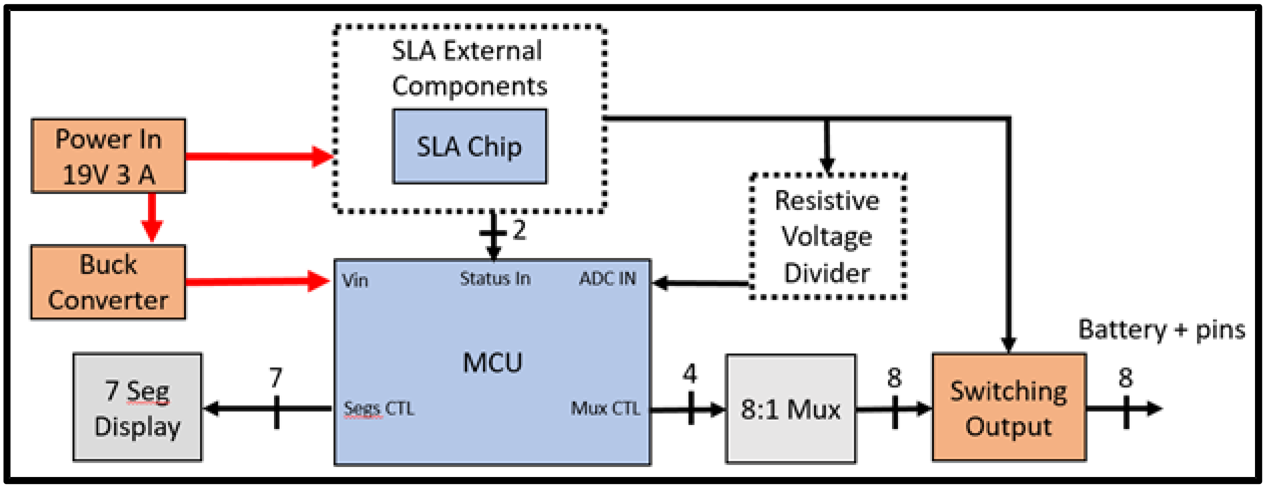


Figure 4.5: Functional Block Diagram, Third Design

Our fourth and final design for our project was created due to the fact MOSFETs could not be used in our design due to the differences between the gate and source voltages. The final design, see Figure 4.6, contained two changes from our third design. The first was a reduction to 4 outputs, and second was a new design for our switching circuit, which used solid state optically switched relays, see Figure 4.7.

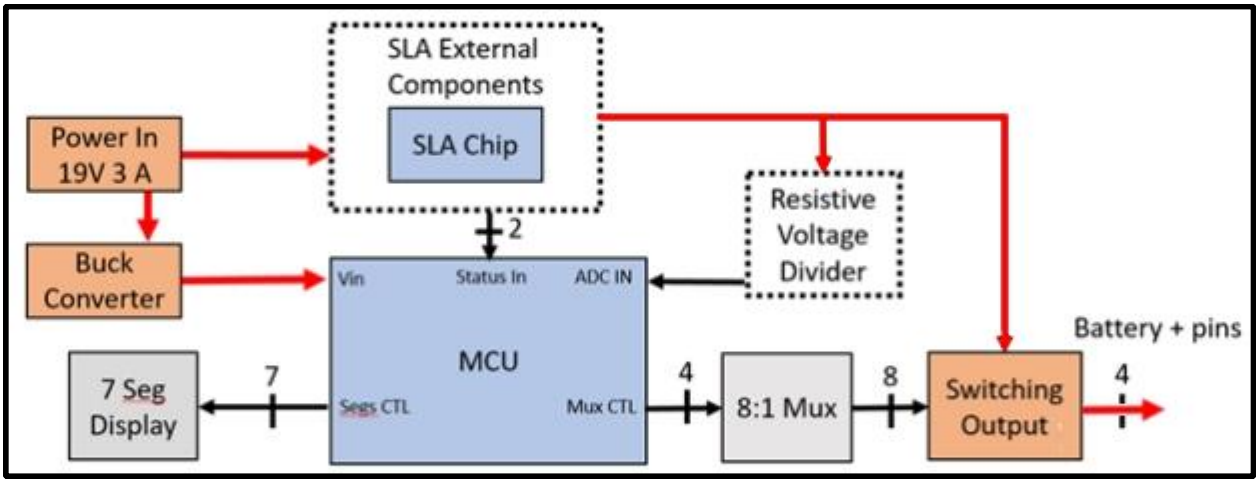


Figure 4.6: Final Block Diagram

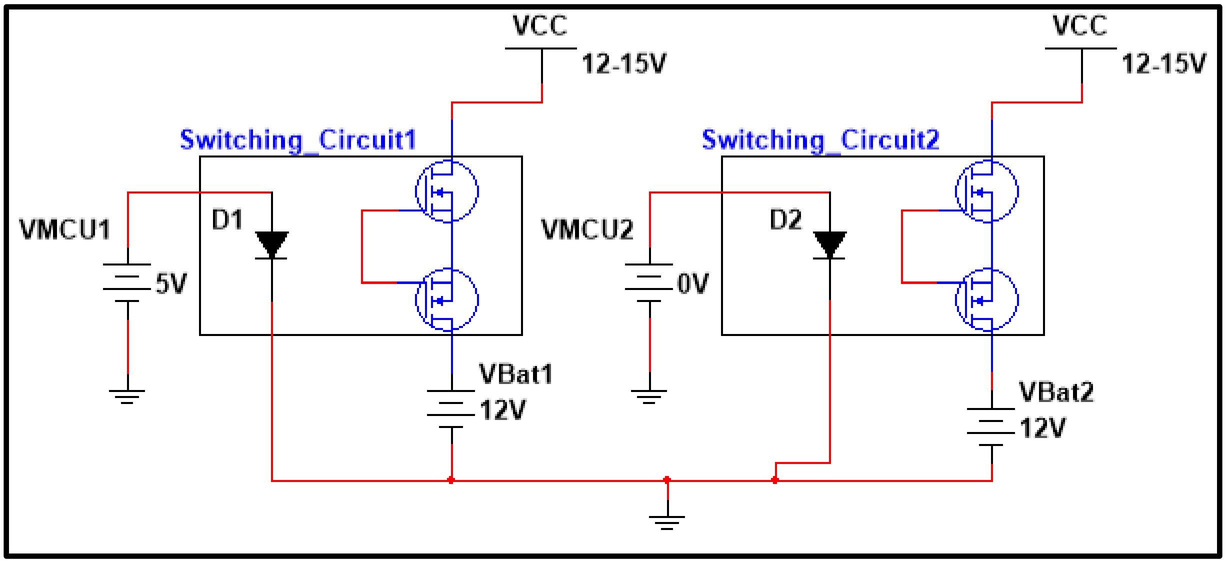


Figure 4.7: Switching Circuit Design

4.4 Component Selection

All product specifications can be found in the Appendix.

4.4.1 Power in Conversion (Buck Converter)

Microcontrollers need a specific voltage to operate, usually 5 volts. Our power in provides 19V, as seen in Figure 4.5, which is too high for the microcontroller. A step-down circuit was needed to convert the 19 volt input to a 5 volt output for safe operation of the microcontroller. Figure 4.8 shows the buck converter utilized in our circuit. It can take the input of 19 volts and be adjusted to deliver 5 volts with 1 amp to the microcontroller via USB.

Figure 4.8: Icstation Buck Converter with USB Output

4.4.2 SLA Charge Control

To control the charging of the SLA batteries, an integrated charge control chip was selected for ease of use. The selected chip is the BQ24450 manufactured by Texas Instruments. This charge control chip uses a multistage algorithm designed for optimized charging while preserving the quality of SLA batteries. In the simplified schematic, Figure 4.9, there are 7 resistors, 1 transistor, 1 diode, and 1 capacitor, external to the charge control chip. These external components are used to set the charging characteristics for the chip. Using external components instead of internal allowed this chip to be integrated into different charger designs as needed.

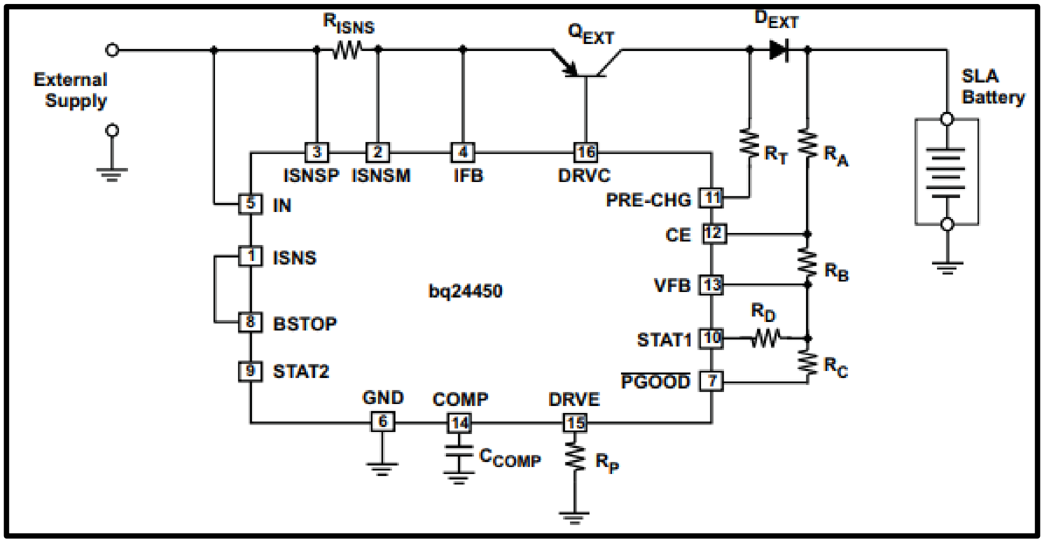


Figure 4.9: Simplified Schematic of BQ24450 SLA Charge Control Chip

To determine the values for the external components for the following calculations were performed. Most of the equations and setup were included in the datasheet for the BQ24450, with the remaining formulae deducted from circuit analysis.

Vin	19.2V		
Final Discharge Voltage	1.75V per cell	10.5V	V TH
Float Voltage	2.30V per cell	13.8V	V Float
Voltage in Boost Mode	2.45V per cell	14.7V	V Boost
Charge Rate	0.05C to .3C	1000mA	I MAX-CHG
V Bat(min)	8V		
Trickle Charge Rate	10mA		

Table 4.1: Calculated Values for SLA Charge Control Chip

In addition to the calculated values, the external pass transistor, Qext and the protection diode, Dext, were also selected. For the Qext, the BD242 PNP power transistor meets all required electrical specifications. For the diode, the RL201-TP power rectifier diode is an easily accessible diode capable of rectifying up to 50V at 2A. Both the transistor and diode were chosen for electrical characteristics and for being available in very high quantities on a component distributor website.

4.4.3 Microcontroller

For the logic control of the design, a microcontroller (MCU) was determined to be ideal due to the full system being contained on one chip. For the testing phase, a development board was used to interface with the MCU chip for ease in programming. The minimum requirements for the MCU was an 8-bit Analog to Digital Converter (ADC) and 12 In/Out pins. Two different MCU development boards were analyzed for ease of use. The first had a 10-bit ADC and 12 In/Out pins, while the second had a 12-bit ADC and 40 In/Out pins. The board with more pins and ports was chosen due to ease of use and the possibility of future expansion. The chosen development board is the MSP-EXP430F5529LP, Figure 4.10. This MCU and development board allows for simplification and the potential for further expansion.

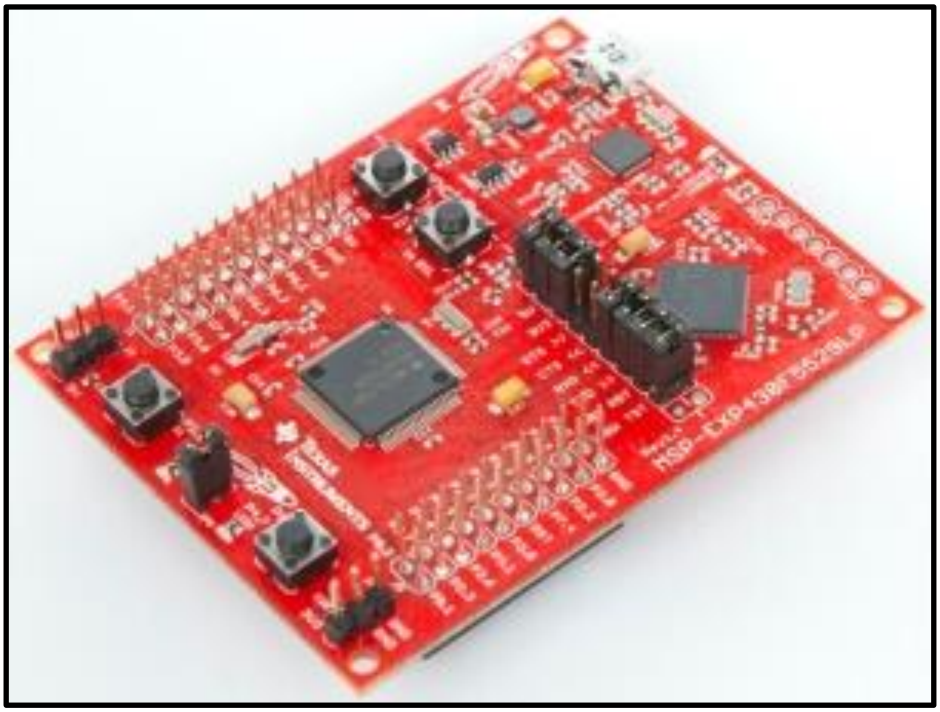


Figure 4.10: MSP-EXP430F5529LP Development Board

4.4.4 Switching Output

To control what battery gets charged, we needed to implement a way to isolate each battery from the charging circuit. For this need, we elected to use solid state relays, see Figure 4.11, to isolate the batteries from the rail. To analyze the amount of charge on each battery, or to allow a current to charge a battery, first the microcontroller would send a voltage signal to the anode of the infrared diode in the solid-state relay we wanted to turn on. This allowed the infrared diode inside to emit photons, which turned the high performance MOSFET on, and let the load current reach the battery to charge or to analyze the current charge level.

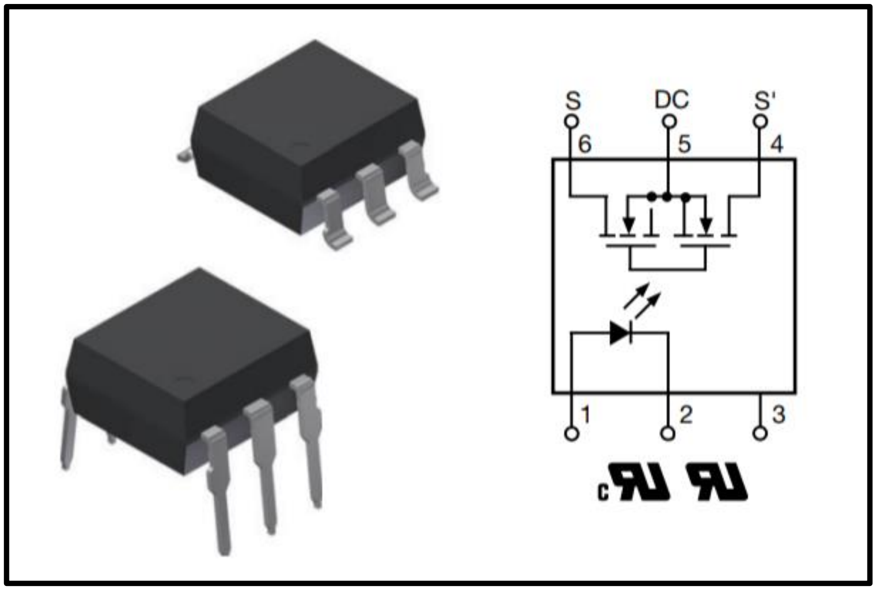


Figure 4.11: Solid State Relay Optically Switched Relay

4.5 Detailed Designs

4.5.1 Charge Control Circuit Design

For the charge control circuit, we designed a circuit to combine the components to control the switching and created the schematic in figure 4.12. On the top is the original reference provided in the schematics and on the bottom was the first attempt interpretation with properly arranged pinouts.

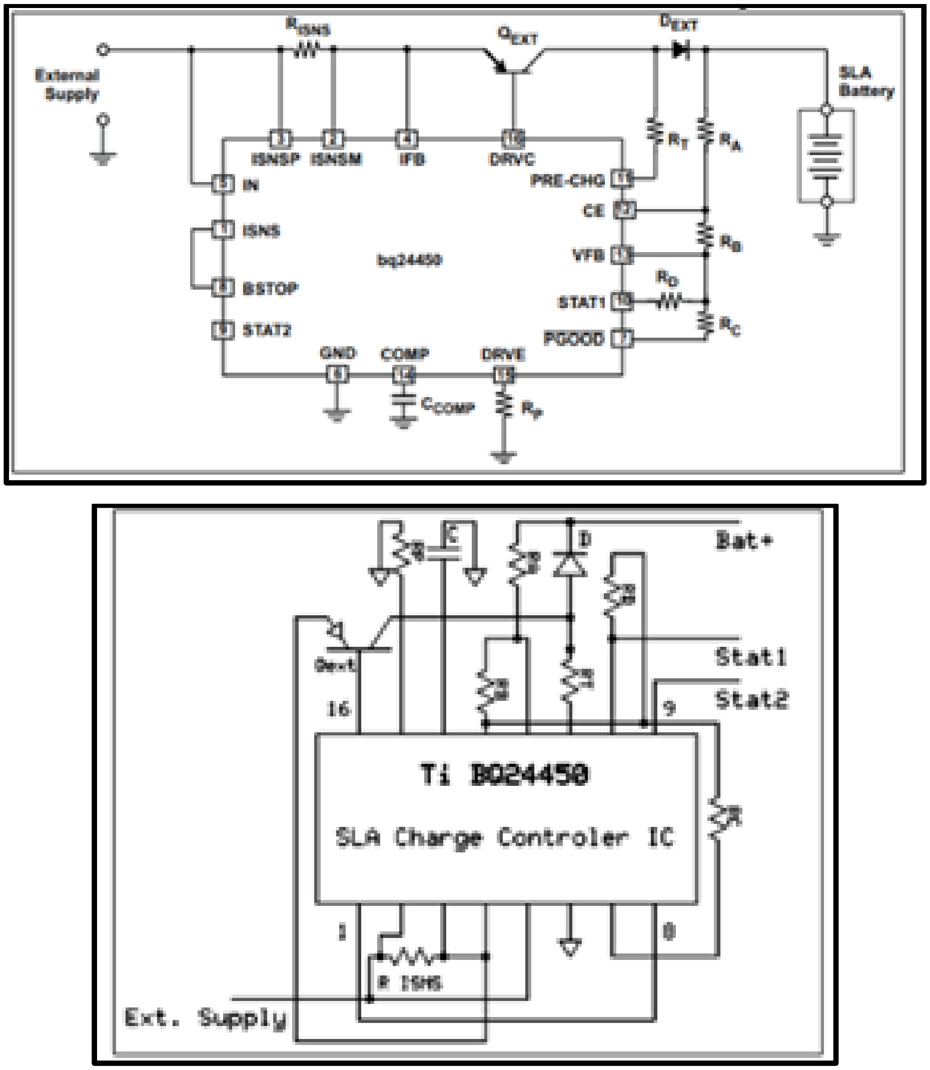


Figure 4.12: SLA Charge Control Circuit

4.5.2 Full Circuit Design

Building from the schematic for the charge control, a full circuit schematic was created (Figure 4.13).

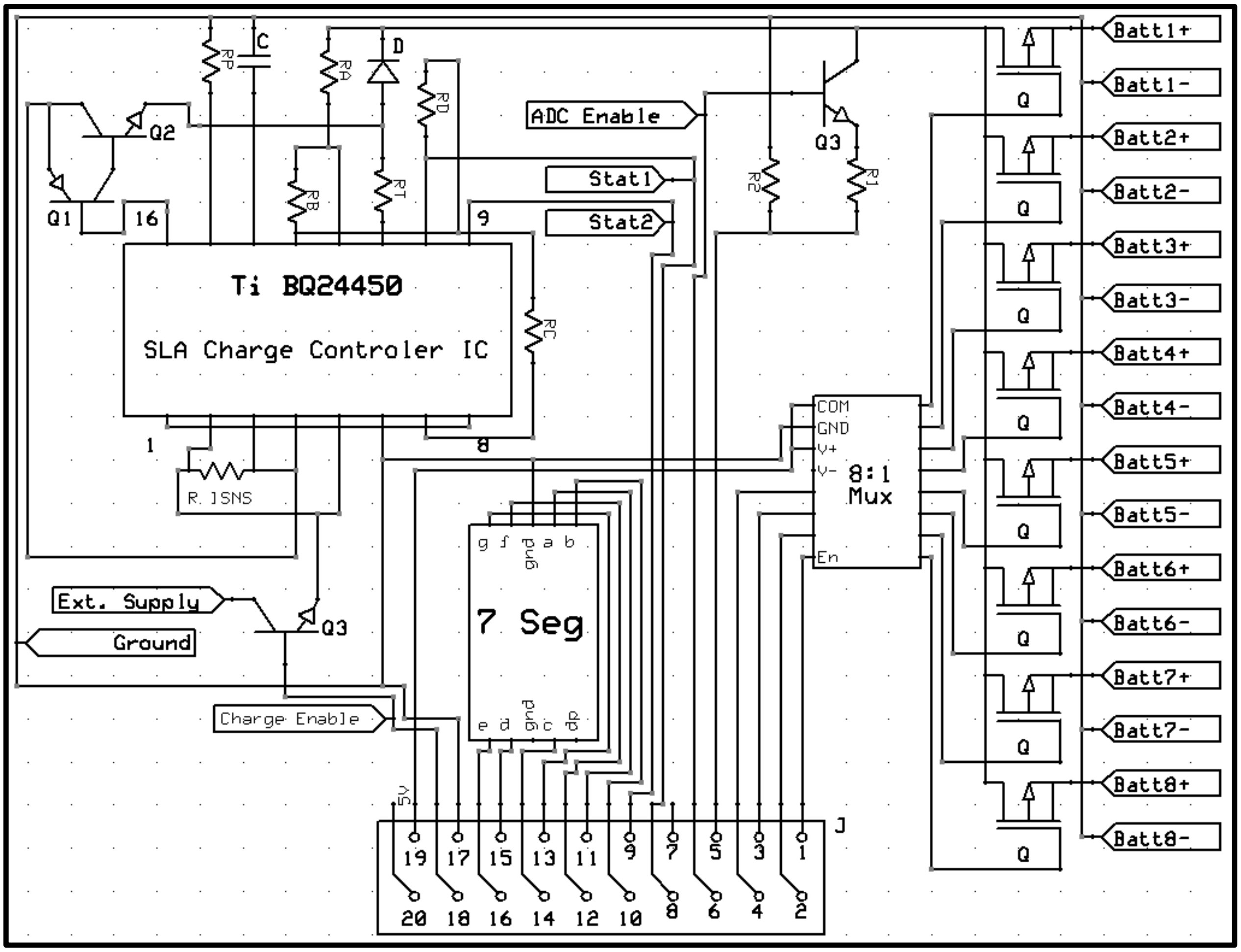


Figure 4.13: Initial Design Schematic

Due to some required modifications, this schematic was updated as shown in figure 4.14. The modifications include a slight change to the charge control circuit to increase efficiency and replacing the 8 nmos chips with 4 solid state relays. The reasoning for these changes is described in further detail in chapter 5.

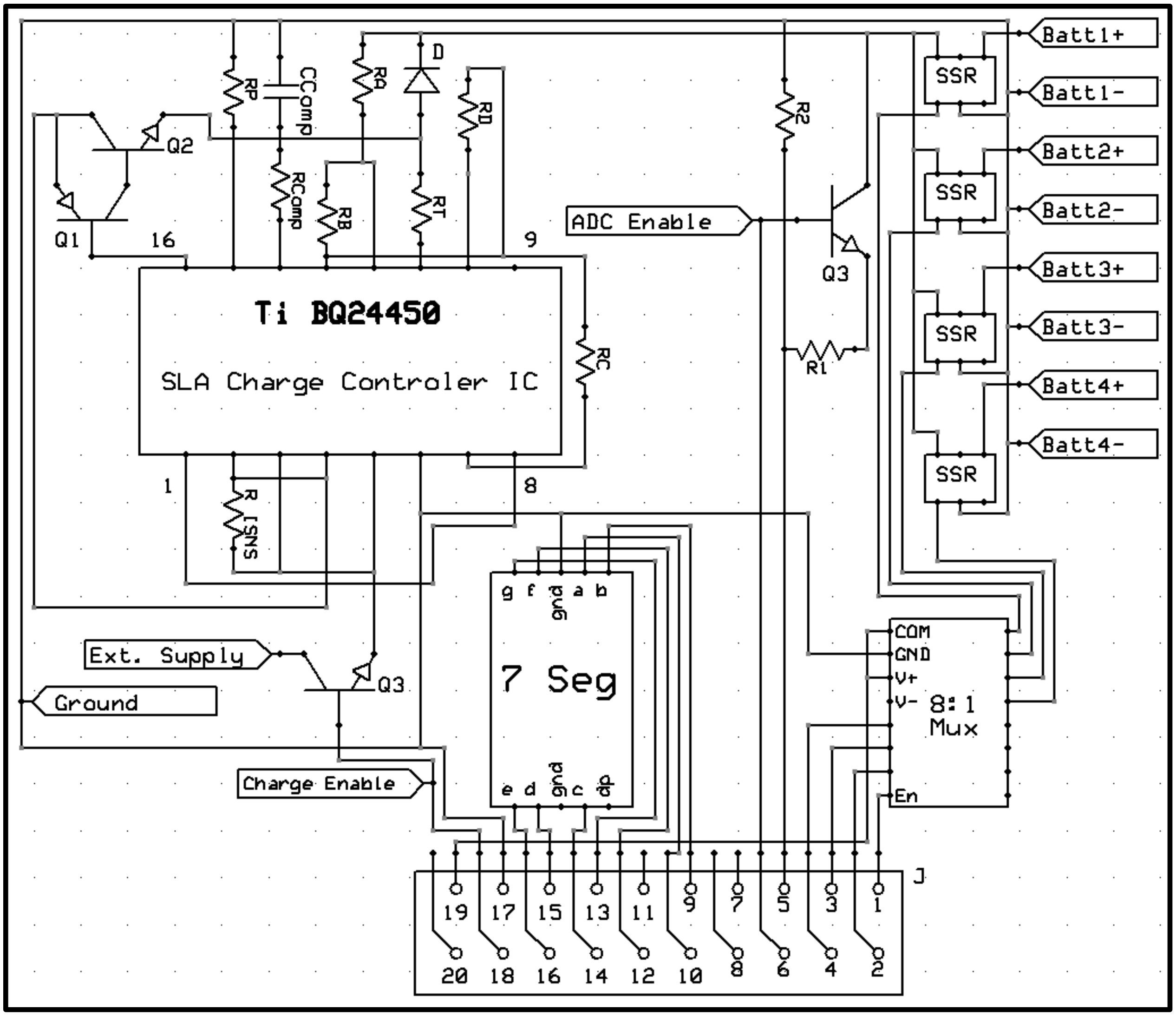


Figure 4.14: Final Design Schematic

4.5.4 PCB Design

From the schematic, a PCB design was constructed. The design was constructed with 3.8” x 2.5” dimensions using the ExpressPCB software[3]. The design consists of dual copper layers with red being the top layer and green being the bottom layer (Figure 4.15). Component placements and through-layer pads are also shown to assist with understanding of components.

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[3] https://www.expresspcb.com/

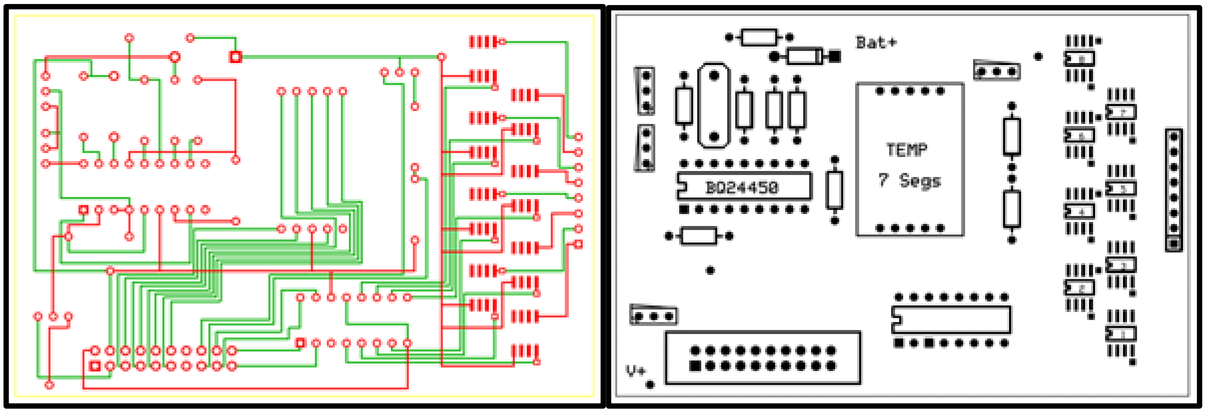

Figure 4.15: Initial PCB Design Copper Layer (left) & Screen-print with Through-pads (right)

PCB designs were assessed by a PCB manufacturing professional before ordering. Additional advice from our advisor was to increase the size of power leads and create screw holes for ease of mounting. The second design, figure 4.16, were modified to take the input into consideration and then submitted for manufacturing to ExpressPCB[4].

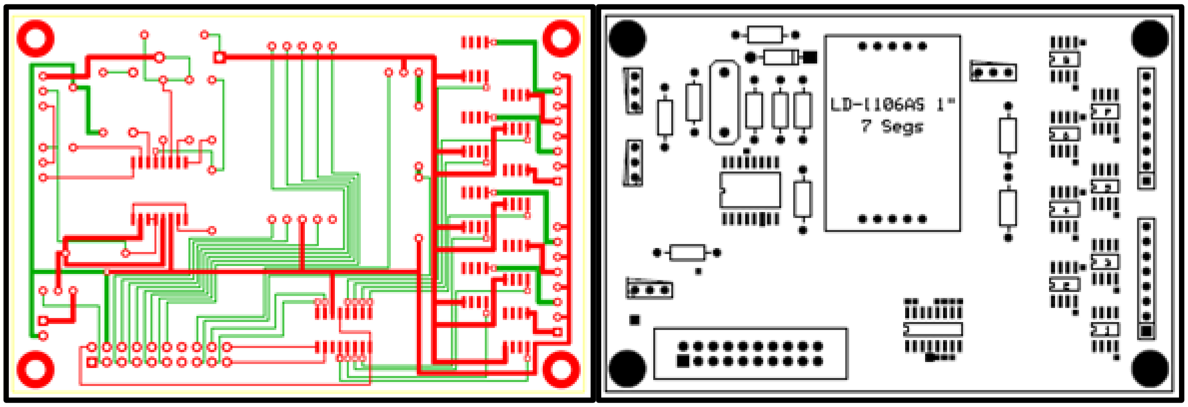

Figure 4.16: Second PCB Design Copper Layer (left) & Screen-print with Through-pads (right)

During testing, documented in Chapter 5, it was determined that some parts were incompatible, and the PCB design was imperfect. Additional changes include larger through holes, reducing the outputs from 8 to 4, and changing some of the components from top mount to through hole (Figure 4.17).

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[4] https://www.expresspcb.com/

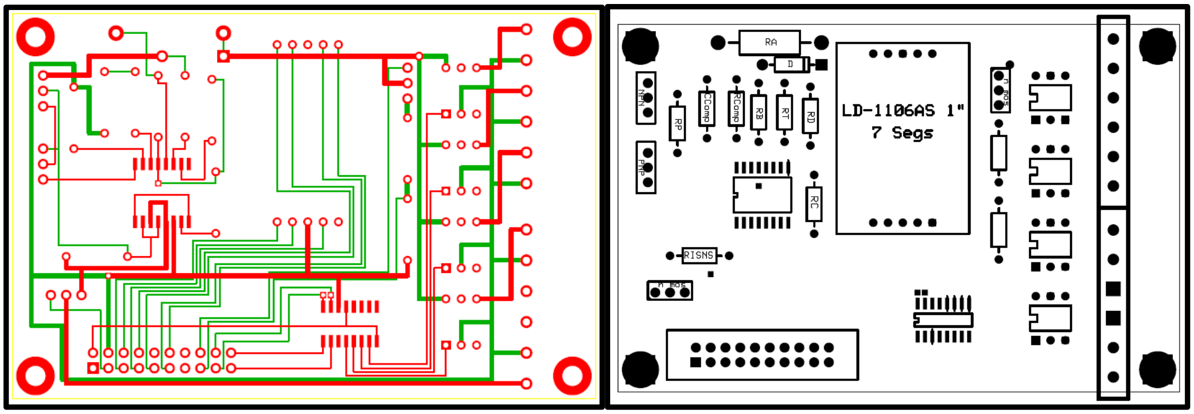

Figure 4.17: Second PCB Design Copper Layer (left) & Screen-print with Through-pads (right)

4.6 Summary

The market for SLA battery chargers is large, but does not include an inexpensive charger that can charge multiple batteries over a longer period of time compared to multi-chargers currently available. Our project investigates filling the hole in the market and cater to the need for a multiple battery, long term charger that can provide a trickle charge to keep the battery fully charged in storage. Our design is less expensive than chargers currently on the market, and can be tested easily.

5.0 Design Testing

5.1 Introduction

Before a successful project could have been achieved, comprehensive testing must have been completed first. To achieve this need for comprehensive testing, the full system was blocked out into separate sections, having both a known input and a desirable output. We then created a detailed test plan before any physical testing in order to understand what inputs were available, what outputs were expected, and other successful test criteria. Different plans were created for both hardware and software, with the hardware plans being measurable, while the software plans are more of a flow chart. After block testing met the success criteria, integration testing, where we tested multiple blocks together, was completed. Integration testing was required to guarantee that the blocks of our system would work together.

5.2 Test Plans

This section details the test plans for each separate block of this project. In this section are the test plans for the buck converter, the SLA charge controller, the optocoupler switch circuit, and the microcontroller.

5.2.1 Buck Converter

For the buck converter, the input was known to be 19 Volts with a max current of 3.42 Amperes. This input was to be taken from the laptop charger we obtained to turn AC voltage into a usable DC voltage.

5.2.2 SLA Charge Controller

- Connect to power supply providing 5-20V and measure open load voltages.
    - Voltage at Batt+ should be no less than 90% of input voltage
- Connect battery and measure STAT1, STAT2 and Bat+, VFB, RISNS voltages and determine the mode:
    - Bulk: STAT1 on, STAT2 off, when VFB < 2.185V
    - Boost: STAT1 on, STAT2 on, when Voltage over RISNS > 25mV and VFB > 2.185V
    - Float: STAT1 off, STAT2 off, when Voltage over RISNS < 25mV
    - Bat+ voltage and current will be plotted on a time axis and compared to the theoretical plots.

5.2.3 Output Control

For the solid-state relays, we needed to test at what voltage the infrared diode turned on, and if turned on, a load voltage would be supplied to a lesser voltage source, which would be an SLA battery in the final design. Also, we needed to test that the voltage did not get applied to the load when the infrared diode was turned off, or no voltage was being applied.

5.2.4 Microcontroller

The selected microcontroller, Texas Instrument's MSP430F5529, is contained on a Launchpad circuit board as shown in figure 5.1, thus testing is focused primarily on the software.

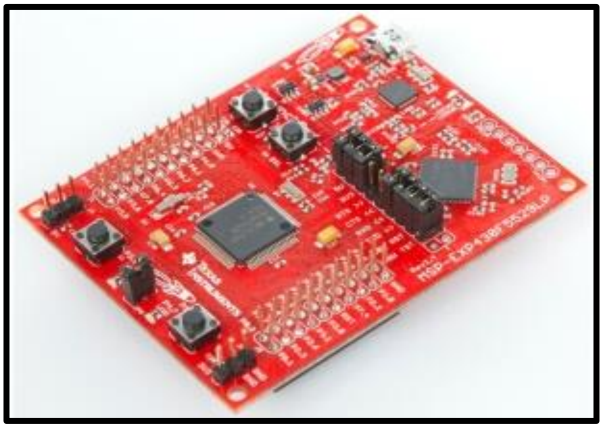

Figure 5.1: MSP430F5529LP Launchpad Test Board

The purpose of the microcontroller is to connect the components together and perform the task of determining which battery is connected. The simplified Software logic flow is shown in figure 5.2 with the complete code in appendix C. The system works by functioning in an executive loop and charging the batteries sequentially.

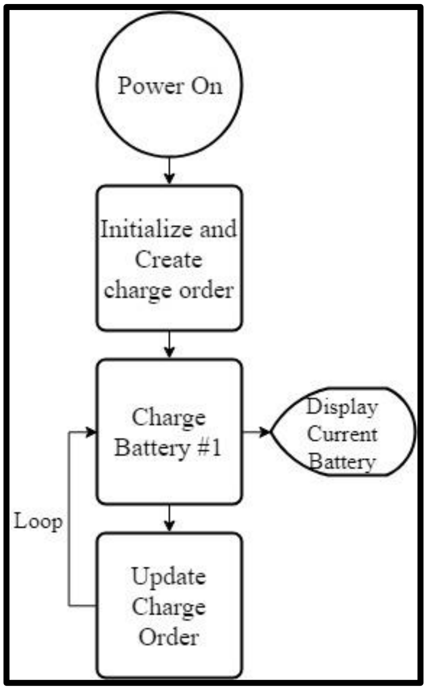

Figure 5.2: Simplified Software Logic Flow

The success criteria for the microcontroller are:

- Function with 5V input
- Switch into low power mode and wake after the programmed time period
- Control 3 sets of outputs simultaneously
  - Charging Enable (highest priority)
  - Battery Select (high priority)
  - 7 Segment Display (low priority)
- Read the voltages through the ADC and make comparisons to determine a charge order

5.3 Block Testing

In this section are images and further explanations for the block testing for the buck converter and SLA charge controller.

5.3.1 Buck Converter

For the buck converter test, we know we had an input of 19.2V with a max of 2A into the converter. The input was taken from the Laboratory DC Power Supply. The underside of the board was used to test the output, as it was easier to touch the probes to the pins, as seen in figure 5.3.

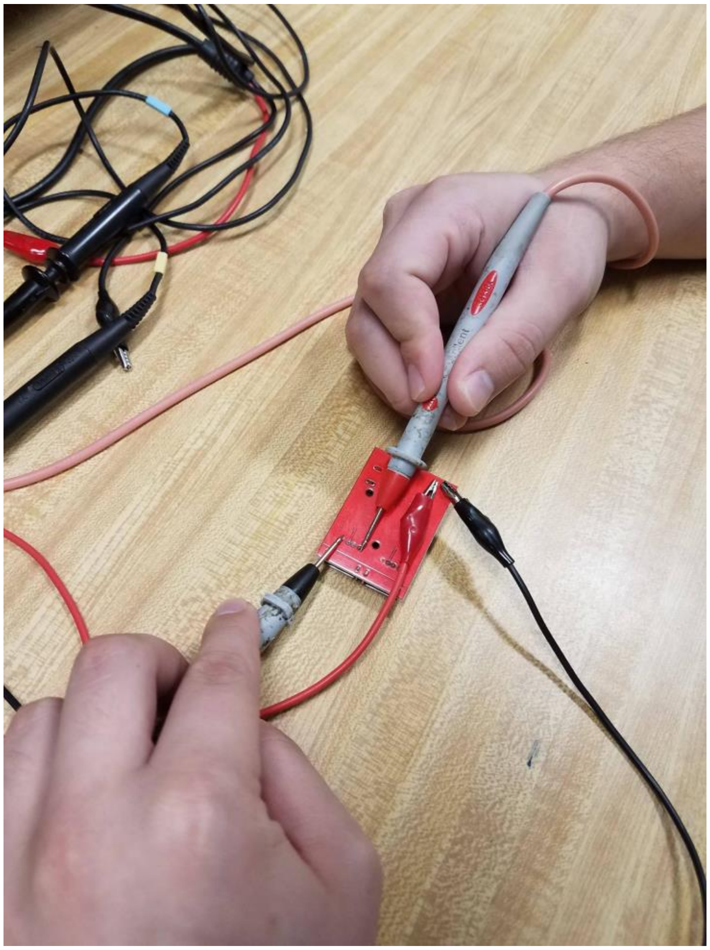

Figure 5.3: Testing Buck Converter

5.3.2 SLA Charge Controller

To test the SLA charge controller, the top-mount style SOIC was soldered to a through-hole adaptor to enable breadboard interfacing. The necessary components were assembled on the breadboard and tested with and without a battery (Figure 5.4).

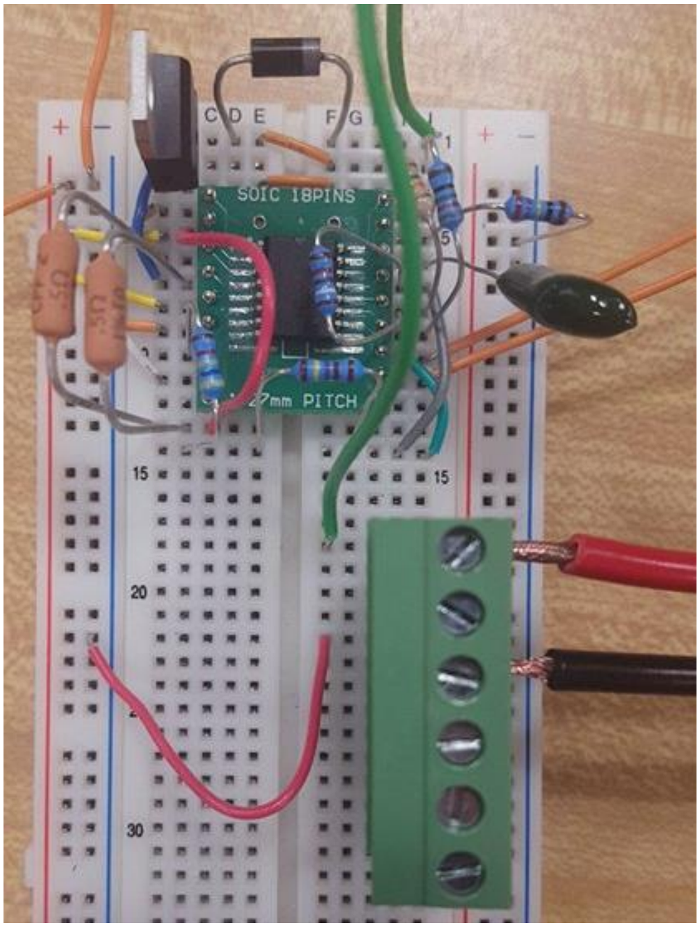

Figure 5.4: Initial Testing SLA Charge Control Circuit

5.4 Block Testing Results

In this section are the results of the block testing for the buck converter, SLA charge controller, optocoupler switch circuit, and microcontroller.

5.4.1 Buck Converter

The output of the buck converter was confirmed to be 5V, which was needed to power the microcontroller, as shown in the next Figure 5.5.

Figure 5.5: 5 Volts Out with 19.2 Volts In, Variable Current

5.4.2 SLA Charge Controller

During the first tests for the SLA charge controller, a few issues were found.

- Both batteries we have were nearly fully charged (around 13V) making it impossible to test all modes of operations
- When batteries are not connected, Rp, the resistor to the ground dissipates all the provided voltage.
- Current is being limited through the power transistor

To remedy these problems, the circuit was reassessed, and it was determined that the common emitter PNP style drive circuit, utilizing Qext and Rp, was the primary problem. Due to the large voltage and current required to charge batteries, an external quasi-Darlington was required instead (Figure 5.6).

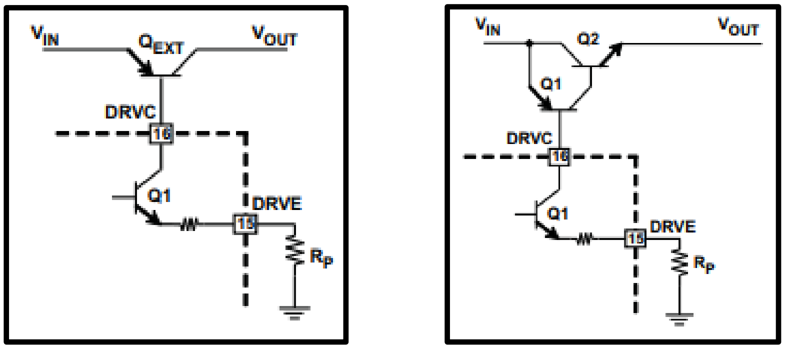

Figure 5.6: Drive Circuits: (Left) Common Emitter PNP, (Right) External Quasi-Darlington

This change in drive control required the recalculation of all resistors in the circuit. The updated values were simulated and tested on breadboard (Figure 5.7). The orange wires on the left are the positive power in, the yellow wires are the status pins, and the green wire is the output provided to batteries. This circuit was tested with both available batteries and successfully showed two modes of charging each with none of the previous problems occurring.

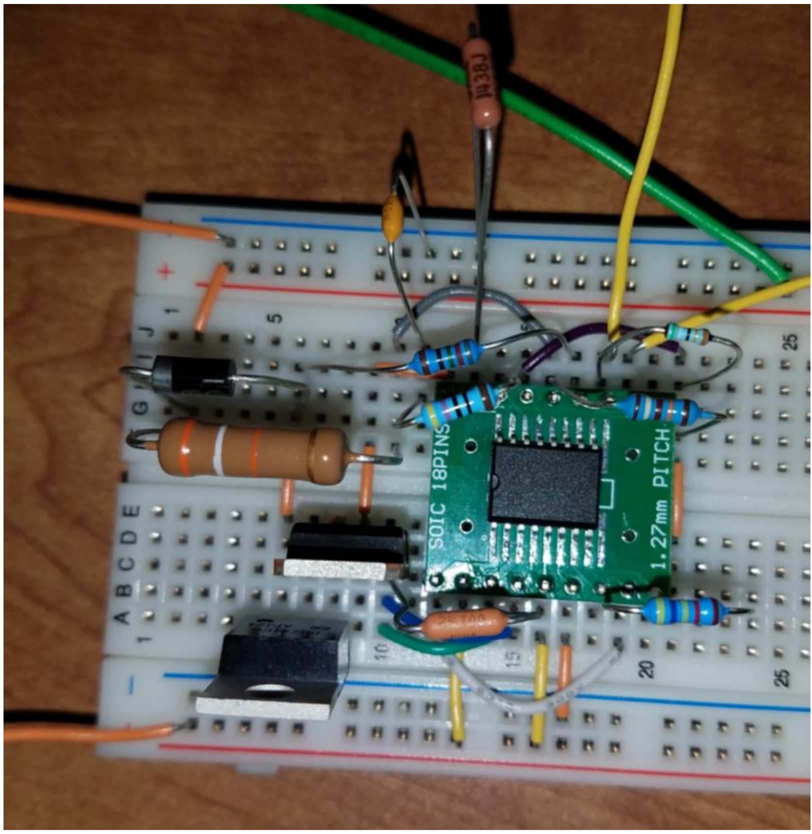

Figure 5.7: Updated SLA Charge Control Breadboard Testing

5.4.4 Microcontroller

For the microcontroller, two software versions were created. The first was the smart battery switching software described above, while the second was a simple version that switches the batteries in numerical order without ordering based on the voltages. This second software is the final version on the prototype.

5.4.5 Switching Output - Solid State Relay

For the solid-state relays, they were wired as described in the data sheets and connected to power supplies. The power supply on the control inputs was varied from 0-5V and the cutoff to trigger the output was measured.

5.5 Integration Testing

After we designed and obtained the printed circuit board, we conducted integration testing. For integration testing, our team added one component to the printed circuit board, then conducted a simple test to check for functionality. If that test was successful, another component would be added, then both blocks were checked for functionality. Then another component was added, and checked for functionality. This was continued until the system was completed and the printed circuit board was built.

If a test failed, we were able to see what block was not functioning correctly, and the component was then verified to work correctly. If the component was faulty, we selected a replacement and the replacement was tested in the faulty components place. This was continued until the block was functional.

5.5.1 Seven Segment Display Test

The first test we conducted was the seven-segment display. To verify the seven-segment display worked, we set up a code to test each segment one at a time, then a designed a new code to display numbers through the seven-segment display.

We noticed that the display was not correctly illuminating the necessary segments and spent a full day of work trying to fix the issue in software, only to find that the seven-segment display used had an extra ground line than was specified in the data sheet. In the initially tested PCB, this extra line was wired to the MSP430 header. It took an extended amount of time to determine what the problem was. The solution was to not wire that pin to the MSP430 header on the final PCB design.

5.5.2 Integrate Buck Converter into System

The next step we took was to power the MSP430 using the buck converter. This was important as the buck converter was designed to power the system. There was no failure when testing with the buck converter as input to the system.

5.5.3 Integrate Multiplexer into System

Adding the multiplexer, we used a timer program on the MCU to cycle through the various multiplexer inputs. The outputs of the multiplexer were measured to ensure proper function.

5.5.4 Integrate Output Control into System

This is the stage where we encountered the most difficulty. Although a single mosfet test passed, when connecting to the multiplexer used to interpret the control signal from the microcontroller, we found that the multiplexer was active high style. As p-channel mosfets are active low, this would cause all of our mosfets except one to be on, instead of the intended one at a time on. As a result, we had to reevaluate and find a different part. What we settled on was a special type of LED driver, also known as a solid-state relay. This device allows for low voltage AC or DC signals to switch a high voltage power line. Testing this new part on its own in AC mode with the secondary input grounded successfully allowed for bidirectional power transmission on the two-load input/output pins. The turn on voltage was measured at 1.3V for the solid-state relay.

5.5.5 Full System Test

With the solid-state relays working, the full circuit was ready to be tested (figure 5.8). Using a time of 10 seconds per battery, 2 batteries were tested simultaneously. Both batteries were in the boost phase of charging and thus, the maximum current of 1.5A was drawn. This large current resulted in the quasi-Darlington arrangement of drive transistors to get hot, however everything operated within expected margins.

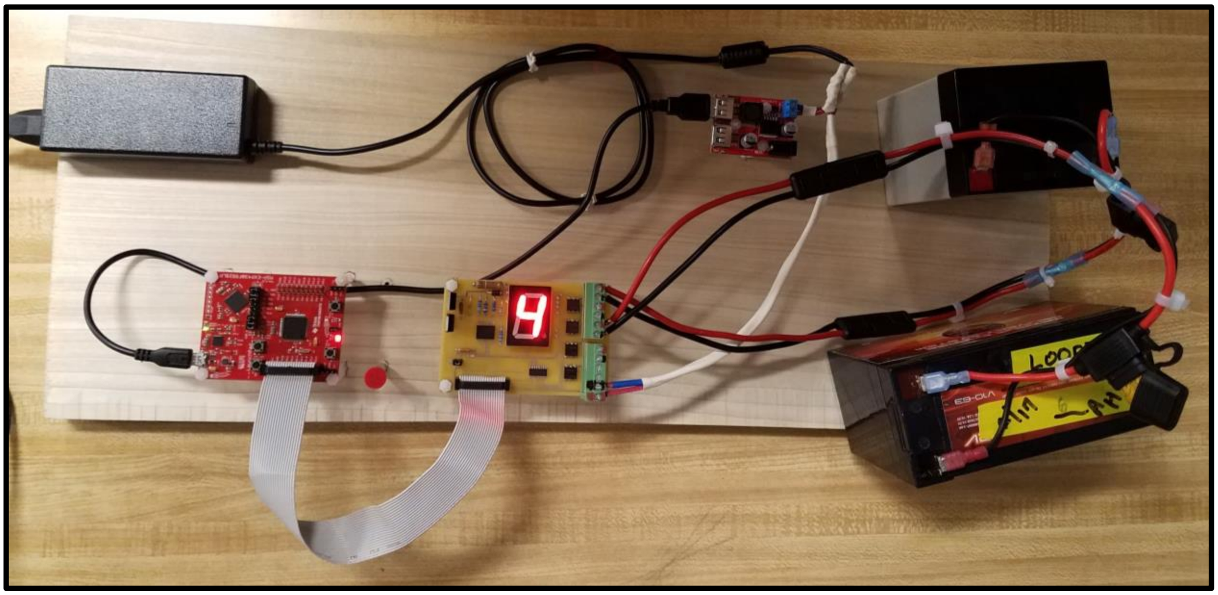

Figure 5.8: Final Prototype Testing

5.6 Summary

In this section, the test plans and results were compiled. Testing went through many iterations to ensure each component would function as intended; however, there were many failures and setbacks once additional components were combined. At the end, there was a working prototype, although the prototype differed vastly from the original vision.

6.0 Discussion, Summary and Conclusions

6.1 Introduction

This section of the report examines what we learned through the project, the marketability of a finalized product, and recommendations for future work should this prototype be enhanced.

6.2 Discussion of Results – What was Learned?

The completion of this project resulted in a sealed lead acid battery charger that utilized a single charge control chip, and had the ability to fully charge up to 4 SLA batteries over the course of a few days. After the batteries were fully charged, the charger would provide a maintenance charge to each battery, which improved the amount of times a battery could be cycled, which in turn improved the lifetime of the batteries.

Our team also learned a few lessons about the engineering process. They were using group members specializations effectively, adjusting to mistakes quickly and appropriately, designing printed circuit boards, creating a professional report with detailed steps on our prototype, and working as a team to accomplish our design project.

6.3 Marketability

The cost of our prototype components added up $37. Our mounting solution added $10 more for a total cost of $47.

6.4 Recommendations for Future Work

We decided there are four main improvements that could be made if this prototype was finalized as a marketable product.

The first recommendation could be adding additional outputs. Our prototype had 4 outputs from the switching circuit, which only allowed for 4 batteries to be charged on the charger. Our multiplexer that adjusted the battery charge control signal from the MSP had and output of 8, meaning that the PCB could be redesigned for the ability to charge up to batteries.

Another recommendation would be to enable active power switching. This means that our SLA charge circuit would analyze the voltage level of each battery before charging began. This would allow the MSP to control which battery gets charged first, based on voltage levels and user inputs.

A third recommendation could be improving the enclosure. Our prototype is mounted on a large wooden plank. This allowed the prototype's components to be easily visible for presentation purposes. However, a finalized product would have a professionally designed case, be as compact as possible, and still allow ease of use for the customer.

Lastly, another recommendation would be to integrate the microcontroller onto the PCB. This would allow size to decrease from the final product, which could save money on an enclosure.

7.0 References

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Appendices

Appendix A: Data Sheets

Icstation Buck Converter

1. Name: Double USB 3A output Step-Down Power Supply Module
2. Input: 6V-40V (DC5.5 / 2.1 jack, terminals)

3. Output: 5V / 3A (MAX) (with Apple identification resistor)

4. Efficiency: 92% (MAX)

5. Switching Frequency: 150KHZ

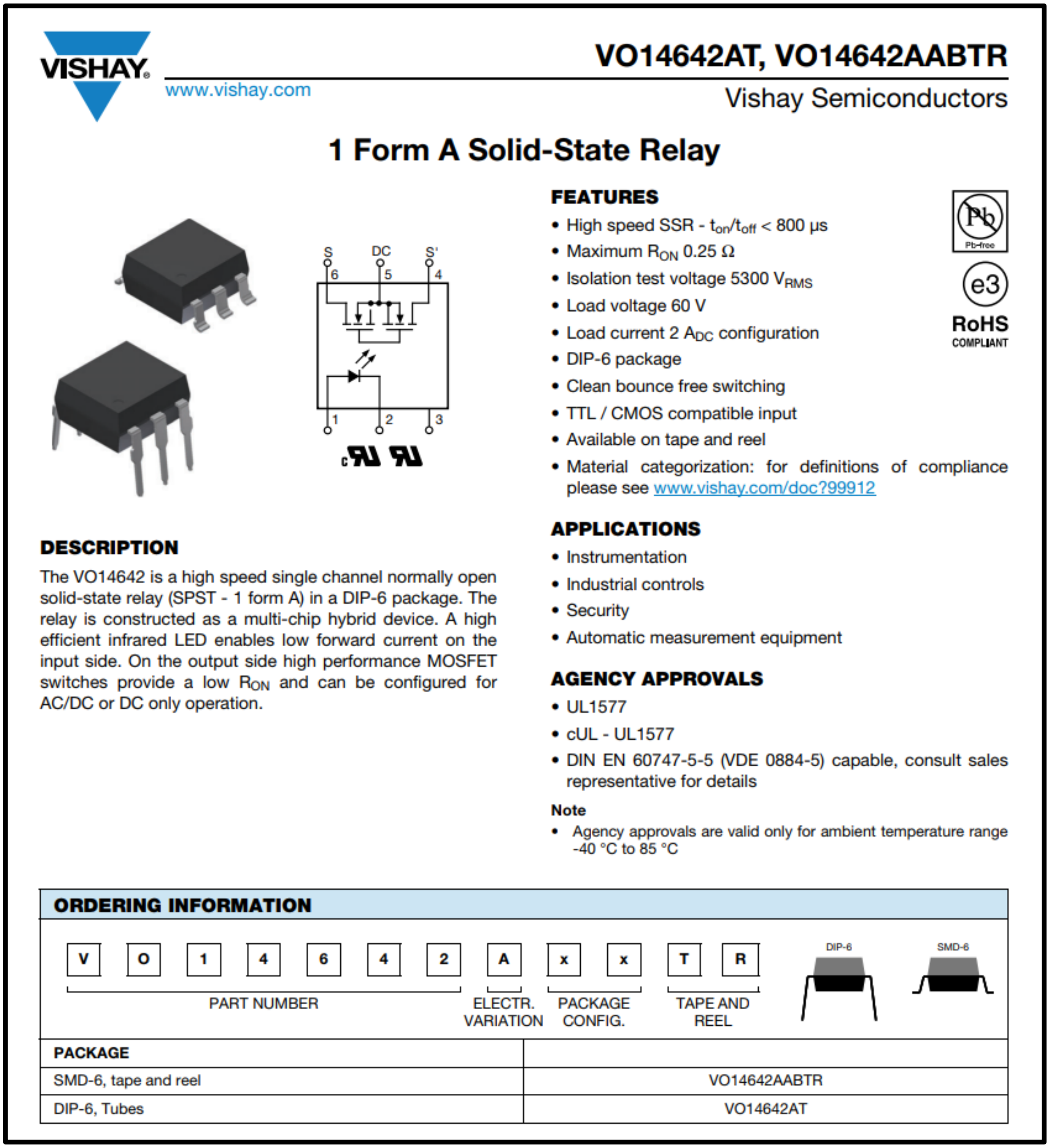
6. Operating Temperature: -40 ℃~ + 85 ℃

7. Size: 50mm*35mm*12mm(L*W*H)

8. Load Capacity: Maximum output 3A (can with two mobile phones at the same time)

http://www.icstation.com/double-step-down-module-buck-converter-power-supply-module-voltage-regulator-solar-charger-p-8663.html

Solid State Relays



VO14642AT, VO14642AABTR

www.vishay.com

Vishay Semiconductors

1 Form A Solid-State Relay

FEATURES

- High speed SSR - $t_{on}/t_{off} < 800$ μs
- Maximum R_{ON} 0.25 Ω
- Isolation test voltage 5300 V_{RMS}
- Load voltage 60 V
- Load current 2 A_{DC} configuration
- DIP-6 package
- Clean bounce free switching
- TTL / CMOS compatible input
- Available on tape and reel
- Material categorization: for definitions of compliance please see www.vishay.com/doc?99912

DESCRIPTION

The VO14642 is a high speed single channel normally open solid-state relay (SPST - 1 form A) in a DIP-6 package. The relay is constructed as a multi-chip hybrid device. A high efficient infrared LED enables low forward current on the input side. On the output side high performance MOSFET switches provide a low R_{ON} and can be configured for AC/DC or DC only operation.

APPLICATIONS

- Instrumentation
- Industrial controls
- Security
- Automatic measurement equipment

AGENCY APPROVALS

- UL1577
- cUL - UL1577
- DIN EN 60747-5-5 (VDE 0884-5) capable, consult sales representative for details

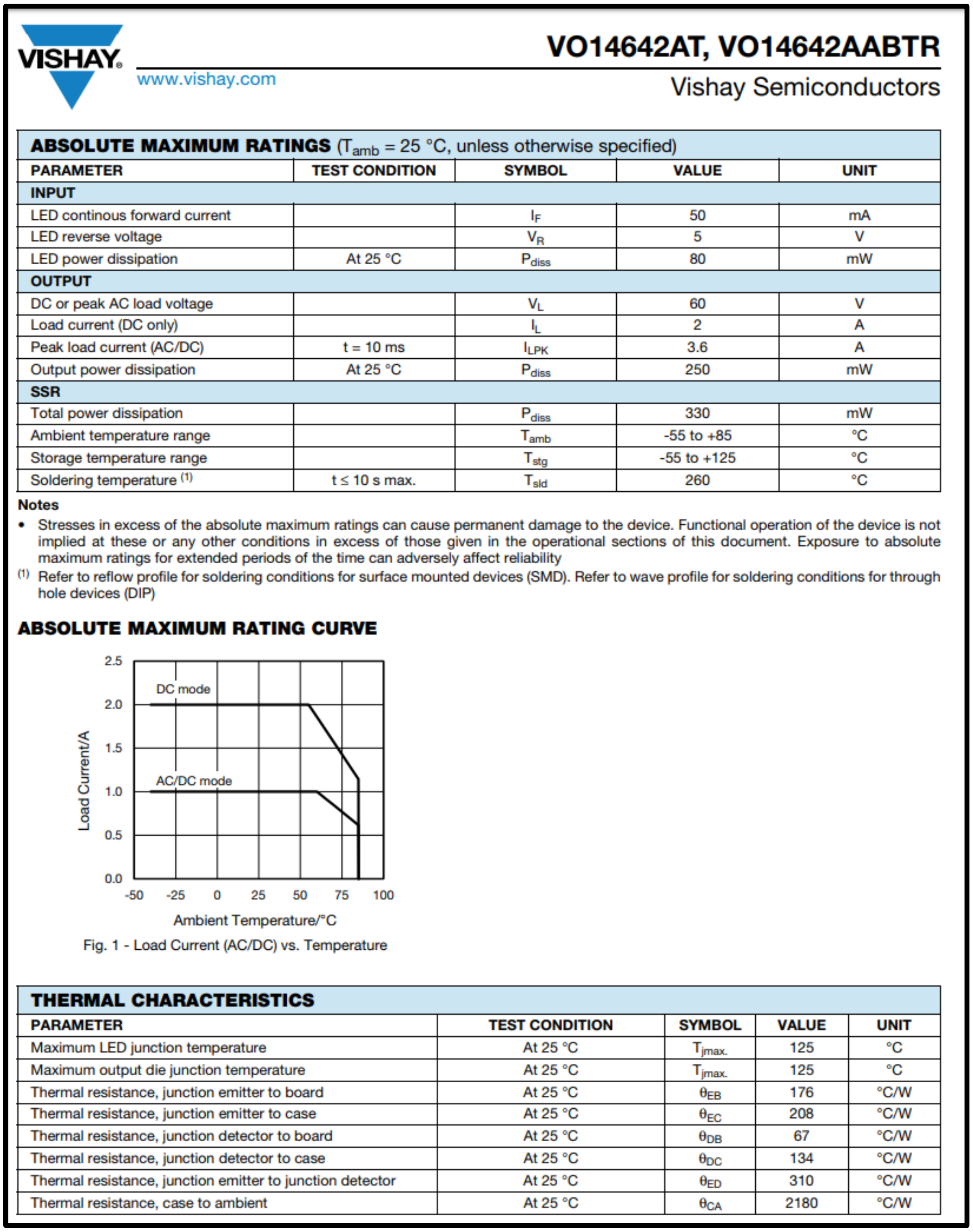
Note

- Agency approvals are valid only for ambient temperature range -40 °C to 85 °C

ORDERING INFORMATION

V	O	1	4	6	4	2	A	x	x	T	R
PART NUMBER							ELECTR. VARIATION	PACKAGE CONFIG.		TAPE AND REEL	

PACKAGE	
SMD-6, tape and reel	VO14642AABTR
DIP-6, Tubes	VO14642AT



VISHAY.

www.vishay.com

VO14642AT, VO14642AABTR

Vishay Semiconductors

ABSOLUTE MAXIMUM RATINGS (T_{amb} = 25 °C, unless otherwise specified)				
PARAMETER	**TEST CONDITION**	**SYMBOL**	**VALUE**	**UNIT**
INPUT				
LED continous forward current		I_F	50	mA
LED reverse voltage		V_R	5	V
LED power dissipation	At 25 °C	P_{diss}	80	mW
OUTPUT				
DC or peak AC load voltage		V_L	60	V
Load current (DC only)		I_L	2	A
Peak load current (AC/DC)	t = 10 ms	I_{LPK}	3.6	A
Output power dissipation	At 25 °C	P_{diss}	250	mW
SSR				
Total power dissipation		P_{diss}	330	mW
Ambient temperature range		T_{amb}	-55 to +85	°C
Storage temperature range		T_{stg}	-55 to +125	°C
Soldering temperature (1)	t ≤ 10 s max.	T_{sld}	260	°C

Notes

- Stresses in excess of the absolute maximum ratings can cause permanent damage to the device. Functional operation of the device is not implied at these or any other conditions in excess of those given in the operational sections of this document. Exposure to absolute maximum ratings for extended periods of the time can adversely affect reliability

(1) Refer to reflow profile for soldering conditions for surface mounted devices (SMD). Refer to wave profile for soldering conditions for through hole devices (DIP)

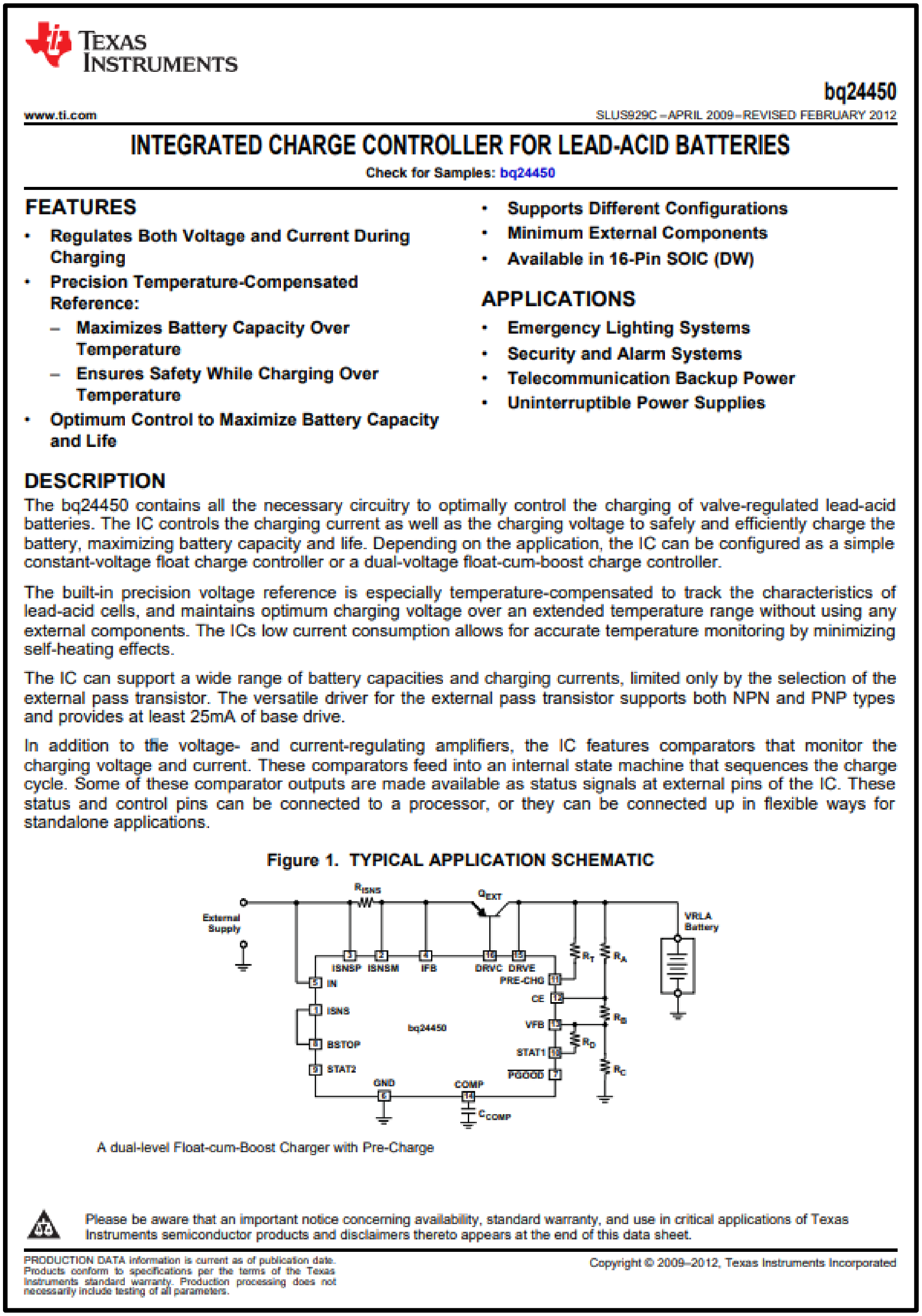
ABSOLUTE MAXIMUM RATING CURVE

Fig. 1 - Load Current (AC/DC) vs. Temperature

THERMAL CHARACTERISTICS				
PARAMETER	**TEST CONDITION**	**SYMBOL**	**VALUE**	**UNIT**
Maximum LED junction temperature	At 25 °C	$T_{jmax.}$	125	°C
Maximum output die junction temperature	At 25 °C	$T_{jmax.}$	125	°C
Thermal resistance, junction emitter to board	At 25 °C	θ_{EB}	176	°C/W
Thermal resistance, junction emitter to case	At 25 °C	θ_{EC}	208	°C/W
Thermal resistance, junction detector to board	At 25 °C	θ_{DB}	67	°C/W
Thermal resistance, junction detector to case	At 25 °C	θ_{DC}	134	°C/W
Thermal resistance, junction emitter to junction detector	At 25 °C	θ_{ED}	310	°C/W
Thermal resistance, case to ambient	At 25 °C	θ_{CA}	2180	°C/W

Link: https://www.mouser.com/datasheet/2/427/vo14642a-279692.pdf

SLA Charge Control Circuit



TEXAS INSTRUMENTS

bq24450

www.ti.com

SLUS929C – APRIL 2009 – REVISED FEBRUARY 2012

INTEGRATED CHARGE CONTROLLER FOR LEAD-ACID BATTERIES

Check for Samples: bq24450

FEATURES

- Regulates Both Voltage and Current During Charging
- Precision Temperature-Compensated Reference:
  - Maximizes Battery Capacity Over Temperature
  - Ensures Safety While Charging Over Temperature
- Optimum Control to Maximize Battery Capacity and Life
- Supports Different Configurations
- Minimum External Components
- Available in 16-Pin SOIC (DW)

APPLICATIONS

- Emergency Lighting Systems
- Security and Alarm Systems
- Telecommunication Backup Power
- Uninterruptible Power Supplies

DESCRIPTION

The bq24450 contains all the necessary circuitry to optimally control the charging of valve-regulated lead-acid batteries. The IC controls the charging current as well as the charging voltage to safely and efficiently charge the battery, maximizing battery capacity and life. Depending on the application, the IC can be configured as a simple constant-voltage float charge controller or a dual-voltage float-cum-boost charge controller.

The built-in precision voltage reference is especially temperature-compensated to track the characteristics of lead-acid cells, and maintains optimum charging voltage over an extended temperature range without using any external components. The ICs low current consumption allows for accurate temperature monitoring by minimizing self-heating effects.

The IC can support a wide range of battery capacities and charging currents, limited only by the selection of the external pass transistor. The versatile driver for the external pass transistor supports both NPN and PNP types and provides at least 25mA of base drive.

In addition to the voltage- and current-regulating amplifiers, the IC features comparators that monitor the charging voltage and current. These comparators feed into an internal state machine that sequences the charge cycle. Some of these comparator outputs are made available as status signals at external pins of the IC. These status and control pins can be connected to a processor, or they can be connected up in flexible ways for standalone applications.

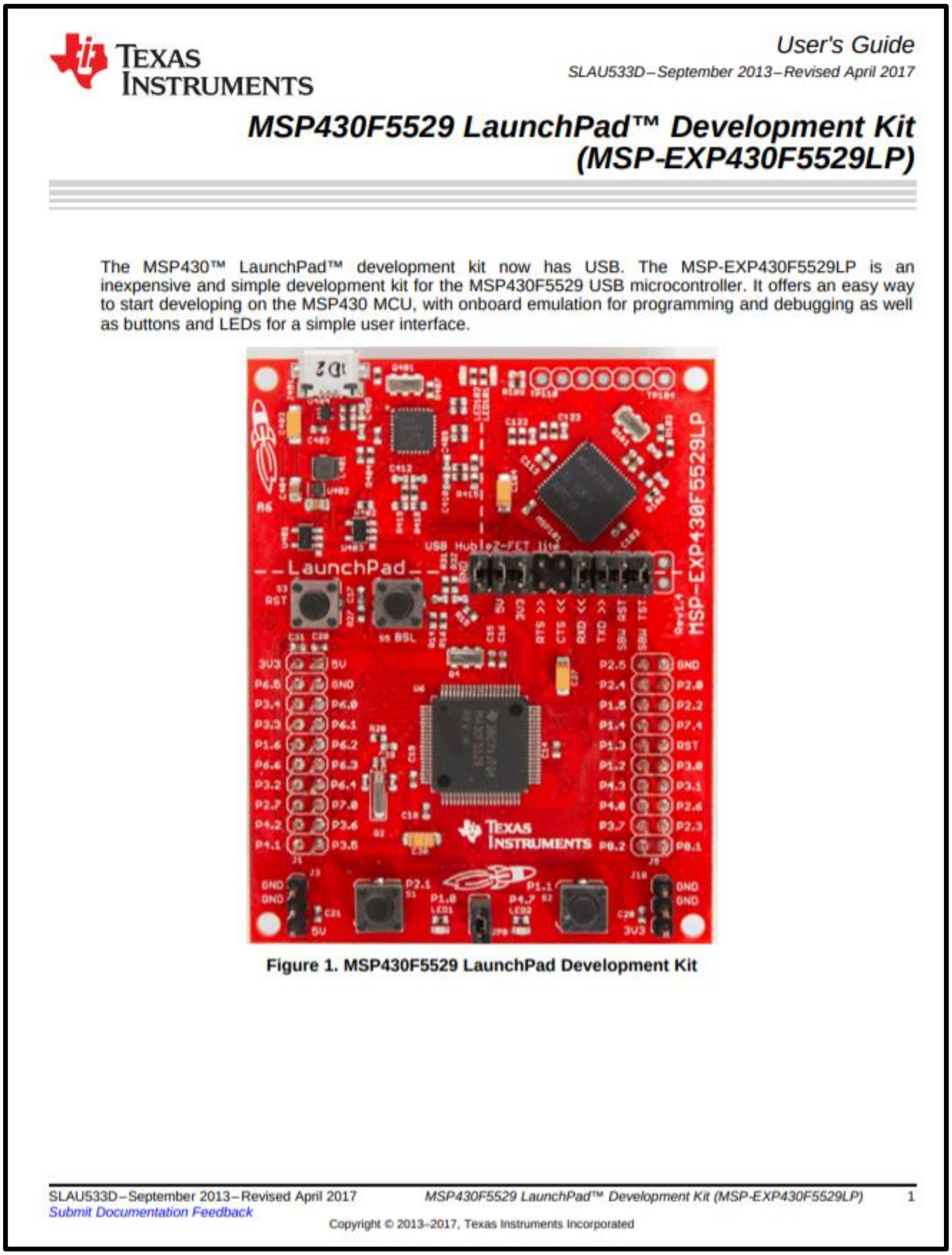
Figure 1. TYPICAL APPLICATION SCHEMATIC

A dual-level Float-cum-Boost Charger with Pre-Charge

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

Link: http://www.ti.com/lit/ds/symlink/bq24450.pdf

MSP430



TEXAS INSTRUMENTS

User's Guide

SLAU533D–September 2013–Revised April 2017

MSP430F5529 LaunchPad™ Development Kit (MSP-EXP430F5529LP)

The MSP430™ LaunchPad™ development kit now has USB. The MSP-EXP430F5529LP is an inexpensive and simple development kit for the MSP430F5529 USB microcontroller. It offers an easy way to start developing on the MSP430 MCU, with onboard emulation for programming and debugging as well as buttons and LEDs for a simple user interface.

Figure 1. MSP430F5529 LaunchPad Development Kit

SLAU533D–September 2013–Revised April 2017 *MSP430F5529 LaunchPad™ Development Kit (MSP-EXP430F5529LP)* 1

Submit Documentation Feedback

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Link: http://www.ti.com/lit/ug/slau533d/slau533d.pdf

Appendix B: MOSFET Switching Circuit

This section of the Appendix is information on the MOSFETs that were tested and documented. They were not used in the final design of our prototype.

To control which battery is charged or checked for voltage levels, we used P-Channel MOSFETs in enhancement mode (Figure 4.8). The charge controller was connected to the source of 8 P-Channel MOSFETs. The drain of each MOSFET was connected to a terminal going to the positive lead of an SLA battery, and the negative lead of the SLA battery was connected to ground. The gate of each MOSFET was connected to a multiplexer, or mux. This mux took a voltage signal from the microcontroller and sent the voltage signal to a MOSFET the microcontroller determined by controlling the mux. The MOSFETs we used have a gate to source voltage of +/-20V, meaning from the SLA charge controller, we could charge a battery at our calculated Vin value of 19V while the battery being charged had a minimum value of 8V. The difference is a maximum of 11V, a little over half of our maximum ratings for the MOSFETs. When powered off, a MOSFET prevents the component on the drain side from being seen by the charge controller, as it acts as an extremely high resistor.

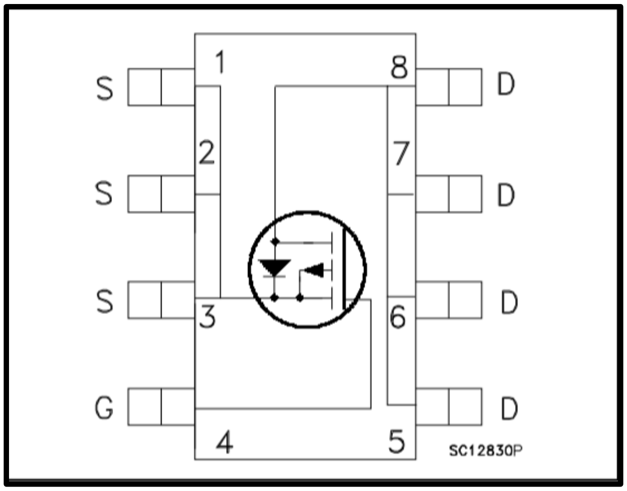

Figure 4.8. P-Channel Enhancement MOSFET

At the beginning of the project, our team decided to use N-Channel Enhancement Mode MOSFETs at the negative side of the SLA batteries, and connect the positive side of the SLA batteries directly to the SLA charge controller. This idea was scrapped as the batteries not being charged could affect the battery being charged through the connected positive rail from the SLA charge controller.

To control which battery gets charged, we designed a switching circuit made up of mosfets. Depending on what battery we wanted to charge, the MCU would send a voltage to the gate of a mosfet. That mosfet would “turn on,” which allowed a current to go from the source to the drain, then to the positive lead of an SLA battery we wanted to charge. This switching circuit allowed us to charge a specific battery, while having multiple batteries connected at once.

For the mosfets, there were a few major characteristics we needed to verify through multiple tests. At first, we planned on using N-Channel Enhancement Mode mosfets at the negative terminal to control which battery gets charged. We conducted successful tests which verified key factors, such as an "on" resistance of 24 Ohms, the ability to handle a drain current of 1 Amps, Gate Voltage of around 4 Volts, a small drain to source voltage when "on," and a high drain to source voltage when "off."

For the P-Channel mosfets, our tests were similar to the N-Channel. We wanted to verify what gate voltage would "turn on" the mosfet, what the "on" and "off" drain to source voltages was, what the "on" resistance was, and if it handled the amperage needed to charge our batteries.

The MOSFET tests proved to be successful. With the gate voltage at 0V, and the circuit setup as seen in the test plan section in figure 6.10, the drain to source voltage was equal to the input voltage, with a miniscule voltage across the 5 resistors, as shown in figure 6.11. This shows that a battery would not be charged with the MOSFET off, as the voltage across the MOSFET would be equal to the input, and no a tiny amount would be registered across the battery.

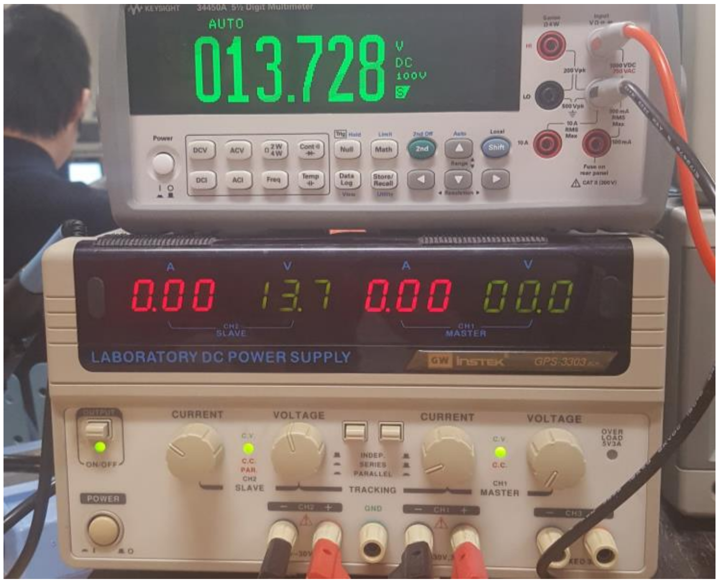

Figure 6.10: Voltage Across MOSFET, Gate Voltage Equal to 0V

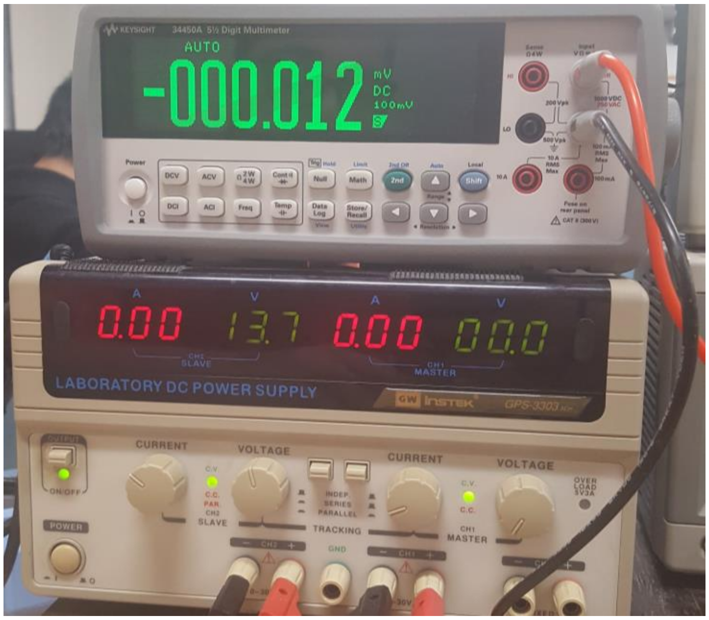

Figure 6.11: Voltage Across Load Resistor, Gate Voltage Equal to 0V

When the gate voltage was equal to 4V, and the same circuit was tested, the voltage from drain to source on the MOSFET was less than 50mV, and the voltage across the resistors was 13.7V. This proves the test a success, as the voltage across the test resistors was almost equal to the input, meaning the battery would be able to be charged, and the MOSFET drain to source voltage was negligible (Figures 6.12-6.13).

Figure 6.12: Voltage Across MOSFET, Gate Voltage Equal to 4.0

Figure 6.13: Voltage Across Load Resistors, Gate Voltage Equal to 4V

For the MOSFET testing, an adapter board was used with the MOSFET chip, as the pins were small, meaning it would have been quite difficult to test without the adapter board. The addition of the adapter board meant we could test the MOSFET on a breadboard.

We tested the MOSFET using five 3 Ohm, 5-Watt resistors in series. This created an equivalent resistance value of 15 Ohms and dividing the voltage between the 5 resistors equally. These resistors were needed as the MOSFET's are rated for power applications. The Mosfets, as well as the batteries we want to charge, need around 1 Amp, at a maximum of 13.6 Volts. To test for these conditions, we needed low resistance values, as well as resistors that could tolerate a high-power dissipation (Figure 6.6).

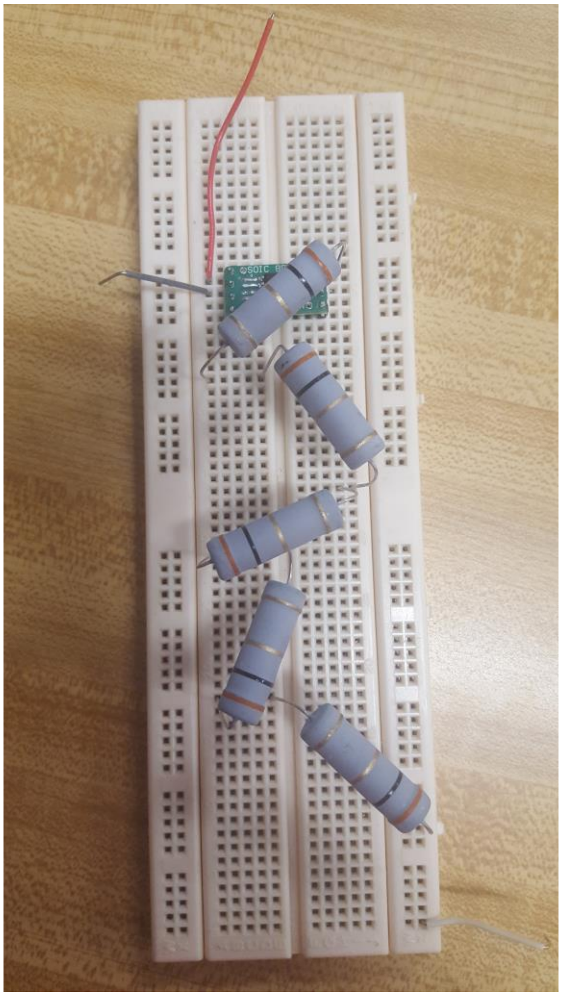

Figure 6.6: Testing MOSFET with Load Resistor

Appendix C: Code

```
#include <msp430.h>
#include <msp430f5529.h>
#include <math.h>
#include <msp430.h>

const int timescale = 900; //seconds per battery (Default 900s = 15min)

//variables
volatile int count;


int savedInput;
```

```
const int lpLed1 = BIT0;  //lpLED1 on P1.0
const int lpLed2 = BIT7;  //lpLED2 on P4.7

const int a = BIT6;       //Segment A on P6.6
const int b = BIT3;       //Segment B on P6.3
const int c = BIT3;       //Segment C on P3.3
const int d = BIT0;       //Segment D on P6.0
const int e = BIT4;       //Segment E on P3.4
const int f = BIT6;       //Segment F on P1.6
const int g = BIT1;       //Segment G on P6.1

const int mosEn = BIT1;   //mosEN on P4.1
const int mos0 = BIT5;    //mos0 on p3.5
const int mos1 = BIT2;    //mos1 on p4.2
const int mos2 = BIT6;    //mos2 on p3.6

const int chrgEn = BIT5;  //chrgEn on P6.5 (not used)

//function declarations
int hex2seg(int input);
int mosCtl(int input);

int main(void)
{
        WDTCTL = WDTPW | WDTHOLD;     // stop watchdog timer
        // P1.0 LP led1, P1.6 Segs(f),
   P1DIR |= BIT0 + BIT6;
   // P4.7 LP led2, P4.1 mosEN, P4.2 mos1,
   P4DIR |= BIT7 + BIT1 + BIT2;
   //P3.3 Segs(c), P3.4 Segs(e), P3.5 mos0, P3.6 mos2,
   P3DIR |= BIT3 + BIT4 + BIT5 + BIT6;
   //P6.0 Segs(d), P6.1 Segs(g), P6.3 Segs(b), P6.6 Segs(a), P6.5 chrgEn,
   P6DIR |= BIT0 + BIT1 + BIT3 + BIT5 + BIT6;
   //6.2 is additional ground

   TA1CCTL0 = CCIE;                          // CCR0 interrupt enabled
   TA1CCR0 = 0xFFFF; // half second
   TA1CTL = TASSEL_2 + MC_2 + ID_3 + TACLR;        // SMCLK, contmode, clear TAR
   __bis_SR_register(GIE);
   __no_operation();                         // For debugger

   P1OUT &= ~(g + lpLed1);
   P3OUT &= ~(c + e);
   P6OUT &= ~(a + b + d + f + chrgEn);  //Makes sure all segments are off

   P4OUT &= ~(mosEn + lpLed2); //turn off multiplexor


   while(1){
      hex2seg(count / timescale);
      mosCtl(count / timescale);
```

```
        }
}

#if defined(__TI_COMPILER_VERSION__) || defined(__IAR_SYSTEMS_ICC__)
#pragma vector=TIMER1_A0_VECTOR
__interrupt void TIMER1_A0_ISR(void)
#elif defined(__GNUC__)
void __attribute__ ((interrupt(TIMER1_A0_VECTOR))) TIMER1_A0_ISR (void)
#else
#error Compiler not supported!
#endif
{
  count += 0x01;
  if (count == 10*timescale){ // 5*2* timescale (5 sections with half second ticks)
    P4OUT ^= lpLed2; // Toggle P1.0 (to see when count resets)
    count = 0;     // reset to 0 at 11 (one blank tick)
  }
  P1OUT ^= lpLed1;  // Toggle P1.0 (to see the .5 sec tick)
}


//7Seg Decoder Function
//takes hex input and outputs 7 seg with active high
int hex2seg(int input){
  int out = 0x00;
  P1OUT &= ~(f);
  P3OUT &= ~(c + e);
  P6OUT &= ~(a + b + d + g);  //Makes sure all segments are off

  //template for switch case
  //P1OUT |= f;
  //P3OUT |= c + e;
  //P6OUT |= a + b + d + g;

  switch (input){
    case 0x00:
      P1OUT |= f;
      P3OUT |= c + e;
      P6OUT |= a + b + d;
      out = 0x3F;
      break;
    case 0x01:
      P3OUT |= c;
      P6OUT |= b;
      out = 0x06;
      break;
    case 0x02:
      P3OUT |= e;
      P6OUT |= a + b + d + g;
      out = 0x5B;
      break;
```

```
        case 0x03:
            P3OUT |= c;
            P6OUT |= a + b + d + g;
            out = 0x4F;
            break;
        case 0x04:
            P1OUT |= f;
            P3OUT |= c;
            P6OUT |= b + g;
            out = 0x66;
            break;
        case 0x05:
            P1OUT |= f;
            P3OUT |= c;
            P6OUT |= a + d + g;
            out = 0x6D;
            break;
        case 0x06:
            P1OUT |= f;
            P3OUT |= c + e;
            P6OUT |= a + d + g;
            out = 0x7D;
            break;
        case 0x07:
            P3OUT |= c;
            P6OUT |= a + b;
            out = 0x07;
            break;
        case 0x08:
            P1OUT |= f;
            P3OUT |= c + e;
            P6OUT |= a + b + d + g;
            out = 0x7F;
            break;
        case 0x09:
            P1OUT |= f;
            P3OUT |= c;
            P6OUT |= a + b + d + g;
            out = 0x67;
            break;
        default:
            P1OUT &= ~(f);
            P3OUT &= ~(c+e);
            P6OUT &= ~(a + b + d + g);  //Makes sure all segments are off
            out = 0x00;
            break;
    }
    return out;
}
```

```
int mosCtl(int input){
    int out = input;
    /*
     P4OUT |= mosEn + mos1;
     P3OUT |= mos0 + mos2;
    */
    if (savedInput != input){
        savedInput = input;
        P4OUT &= ~(mosEn + mos1);
        P3OUT &= ~(mos0 + mos2);
        switch (input){
            case 0x00:
                P4OUT &= ~(mosEn + mos1);
                P3OUT &= ~(mos0 + mos2);
                break;
            case 0x01:
                P4OUT |= mosEn;
                break;
            case 0x02:
                P4OUT |= mosEn;
                P3OUT |= mos0;
                break;
            case 0x03:
                P4OUT |= mosEn + mos1;
                break;
            case 0x04:
                P4OUT |= mosEn + mos1;
                P3OUT |= mos0;
                break;
            case 0x05:
                P4OUT |= mosEn;
                P3OUT |= mos2;
                break;
            case 0x06:
                P4OUT |= mosEn;
                P3OUT |= mos0 + mos2;
                break;
            case 0x07:
                P4OUT |= mosEn + mos1;
                P3OUT |= mos2;
                break;
            case 0x08:
                P4OUT |= mosEn + mos1;
                P3OUT |= mos0 + mos2;
                break;
            default:
                P1OUT &= ~(f);
                P3OUT &= ~(c+e);
                P6OUT &= ~(a + b + d + g);  //Makes sure all segments are off
                out = 0x00;
                break;
```

```
        }
    }
    return out;
}
```