

UNIVERSITY OF IDAHO

Switching LiPo Battery Charger

Design Report

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Executive Summary

The University of Idaho marching band requires a Lithium battery charging system capable of charging 200 batteries in a week with minimal user interface. Because of this need the Switching LiPo Battery charging system was developed.

Features

- Modularity
 - Allows users to create a charging system custom to their needs
- Switching capability
 - Allows charging with minimal user interface
- Fault detection
 - Detects faults in the charging process and shuts down. This allows for safe charging of batteries.
- Cost effective
 - Does the job of ten individual battery chargers

Background

If you've gone to see a game, I'm sure you've seen the University of Idaho's marching band put on their show with lights flashing to the beat of music and the band marching with their flash and flair. As is true with any show, the marching band is always pushing to make the show bigger and better. Their next great idea comes in the form of goofy glasses. Each band member will be wearing sun glasses with LED lights that will add the next level of flash to the show.

In order to add the glasses to the show the marching band has a need to power these glasses. This power comes in the form of a 12.6 volt 800mA/hour lithium polymer battery. With 200 batteries to charge every week, charging the batteries one at a time would take a large commitment from volunteers and several battery chargers to complete the job.

This is why Dr. Rinker has asked our team to develop a battery charging system that will reduce the interaction needed to charge the batteries and still perform the task in a timely manner.

Problem Definition

Marketing specifications:

- 200 batteries need to be charged per week.
- Should be user friendly and require minimum amount of interfacing during or after charging.
- The device should be scalable so that the prototype could be multiplied or added to charge more batteries in future iterations i.e. a modular system.
- The charging status should be indicated to the user.

Engineering Specifications:

- Since 200 batteries need to be charged per business week, a battery matrix system (charging multiple batteries or charging in sequence through a single board) needs to be formulated. Charging circuit for parallel (simultaneously) or series (charging 1 battery then switching to the next in series) needs to be devised.
- For minimum interfacing, a control system needs to be integrated within the design that controls the voltage and current flow to the batteries. Possible microcontroller programming required.
- The rows and column number of the battery matrix will decide the number of batteries to be charged, parallel or serial charging and the amount of interfacing required. The number of batteries being charged per 2 hrs. (Approx. charging rate for a single battery) or over a course of a day or a week needs to be analyzed to allow the client minimum interfacing but good results.

Design Specifications:

- A battery matrix of 10 X 1 was decided. The design will charge one battery at a time and switch to the next one in the column as soon as the microcontroller senses a voltage

change. Hence the design will charge 10 batteries in roughly 20 hours and 40 batteries in the same time if 4 modules of the design are used and connected in parallel to a power supply. Thus, it will charge 200 batteries/business weeks. This matrix was selected since it will require minimum interfacing from the user as 40 batteries have to be connected once and removed by the end of the day rather than charging 10 batteries in parallel, that will require plugging the batteries in and out after every 2 hours. The single evaluation board circuit (single IC) will be used to charge and will switch to the next battery in the column through a switching circuit consisting of an electro mechanical relay controlled by a microcontroller.

- Adriano Uno was selected because of its small size and a list of important functions (required for the project) that it could implement.
- For charging 200 batteries per week, four of the PCB boards (10 X 1 matrix per board) connected in parallel to a power supply can be used. The whole modular system will charge 40 batteries per day hence 200 batteries per week. A single PCB board will be designed and made while the modular system is left for future senior design teams to finish.

Design Constraints:

- The charger needs to be powered by a 120 volt 15 amp power source
 - Wall socket
- The charger needs to be cost effective
 - Approximately 300 dollars

Project Plan

Team Responsibilities	Deadline
• Initial Client meeting	Jan 26, 2014
• Develop Attributes List	Jan 27, 2014
• Develop Objectives List	Feb 4, 2014
• Client Q/A	Feb 25, 2014
• Research <ul style="list-style-type: none"> ○ Types of Charging ○ Types of Balancing 	Feb 26, 2014 Feb 26, 2014
• Consultant Meeting	March 6, 2014
• Concept Design	March 27, 2014
• Product Research and Selection	April 10, 2014
• Order and test Products	April 25, 2014
• Final Design	Sep 18, 2014
• Product development	Dec 19, 2014

Individual Responsibilities	Deadline
<ul style="list-style-type: none"> • Ryler Adams: <ul style="list-style-type: none"> ○ Product Testing and Refinement 	Dec 1, 2014
<ul style="list-style-type: none"> • Pankaj Dhyani <ul style="list-style-type: none"> ○ PCB Design, Circuit Configuration and Wiki Manager 	Dec 19, 2014
<ul style="list-style-type: none"> • Abe Martinez <ul style="list-style-type: none"> ○ Microcontroller development and programming, Circuit Configuration and Wiki Manager 	Dec 5, 2014

Concepts Considered

Concept 1:

- Single charging station utilizing multiple charging circuits in parallel that would charge one battery each.
 - Would charge 10 batteries in two hours.
 - Still requires user to swop out batteries every few hours
 - Requires a minimum of 120 Watts.

Concept 2:

- Single charging station utilizing multiple charging circuits in parallel that would switch in batteries one at a time to be charged. Switches would be controlled by a microcontroller.
 - Would charge 10 batteries in two hours
 - Would automatically switch to next set of batteries charging 200 batteries in 40 hours.
 - Requires minimal user interaction
 - Has complicated circuitry
 - Requires a minimum of 120 Watts

Concept 3:

- An expandable charging station utilizing single charging modules in parallel. Each module would be a standalone unit that would switch in batteries one at a time to be charged. Switches would be controlled by a microcontroller.
 - One module would charge 10 batteries in 20 hours
 - Expandability allows charging unit to grow as demand grows
 - Four modules will charge 200 batteries in five days
 - Requires minimal user interaction
 - Has simplified circuitry
 - Requires a minimum of 12 Watts per module

Charging IC options

- MAX1641
- MAX1701
- BQ24115
- BQ24105
- Criteria
 - Must be able to charge a three cell LiPo Battery
 - 12V-12.6V, 1A-2A, Constant current constant voltage charging (switch mode).
 - Must have an available evaluation board to test
 - Must have fault detection capabilities
 - Detect faults on batteries such as over heating or over charging.
 - Must have available indications of battery status
 - Indicates when battery is charged, when a battery is connected, and when charge is in progress.

Microcontroller options

- Teensy 3.1
- Arduino Uno Revision 3
- Arduino Micro

Relay options

- Nmos, pmos
- Solid state
- Electro mechanical
- Criteria
 - Must be able to be controlled by the microcontroller
 - Must electrically isolate each battery
 - Requires minimal auxiliary circuitry to operate

Concept Selection

Concept three is an iteration of concept one and two. It provides the most flexibility while meeting the clients' needs. While the battery matrix was originally part of concept 2, Dr. Santora suggested that we invert our matrix and create a standalone module that would allow for expandability. This expandability would allow the client to purchase individual units based on his current needs. The modular design will also reduce the initial cost for the client. The decision matrix for this concept can be seen in table 1.

Table 1 Concept Matrix

	Concept 1	Concept 2	Concept 3	points
Charges 200 batteries in a week	no	yes	yes	Yes=1
minimal user interface	no	yes	yes	No=0
Simple Circuit	no	no	yes	
Expandability	no	no	yes	
Low Power Requirements	no	no	yes	
Point Total	0	2	5	

Table 2 IC Matrix

	MAX1641	MAX1701	BQ24115	BQ24105	points
Charges LiPo Batteries	yes	yes	yes	yes	Yes=1
Charges 3 Cells	yes	yes	yes	yes	No=0
Has EVM Available	no	no	yes	yes	
Cell Balancing	no	no	no	no	
Switch Mode	yes	yes	yes	yes	
Battery Status	yes	yes	yes	yes	
Error Detection	yes	yes	yes	yes	
Microcontroller compatibility	yes	no	yes	no	
Point Total	6	5	7	6	

Table 3 Switch Matrix

	Nmos/Pmos	Solid State	Electro Mechanical	points
Can isolate 15W	yes	yes	yes	Yes=1
Microcontroller controlled	yes	yes	yes	No=0
Minimal Auxiliary Circuitry	no	yes	no	
Point Total	2	3	2	

System Architecture

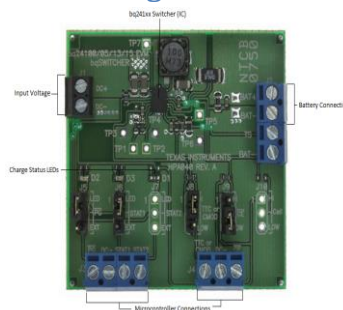
The Switching LiPo Battery Charger is a standalone module that can charge 10 batteries in twenty hours. Essentially it will charge one battery at a time, when a battery is fully charged the charging IC will detect

this and notify the microcontroller. The microcontroller will then switch out this battery and switch in the next battery in line and repeat the process until all the batteries have been charged. Using this system allows for a simplistic design that meets the clients need of charging 200 LiPo batteries in a week with minimal user interaction. By simplifying the design, the possibility for design flaws is reduced and also allows the charging system to be developed in sections that can be debugged individually and then combined into a single product. The charging system consists of 3 major components:

Charging circuit

- The major component of the charging circuit is the BQ24105 charging integrated circuit (IC) developed by Texas Instrument.
 - The Charging IC is a standalone switch mode charger that can charge up to three cells (12.6V) with a maximum current of two amps.
 - The IC has two indicators, stat 1 and stat 2 (pins 2 and 19 respectively), that are utilized by the microcontroller for switching purposes.
 - Pull up resistors and an inverter have been added between stat 1 and stat two to provide the required high low indication for the microcontroller to read. The inverter electrically isolates the node from the microcontroller which allows the microcontroller to read the status at the node without affecting the circuit.
 - The charging current is set by resistors attached to pins Iset 1 and Iset 2 (pins 8 and 9 respectively), this controls the rate at which the batteries are charged as well as several fault detection functions.
 - The charging voltage is set by pin FB (pin 13); this sets the maximum voltage of the batteries.
 - The charging IC also provides protection against overcharging and will reject charging damaged batteries. Thermal protection is also available, but was not utilized as this issue has been addressed in the charging rate.

Figure 1

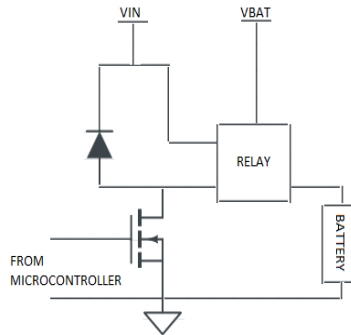


Switching circuit

- The major component of the switching circuit is the electro mechanical relay DS1E-M-DC12V developed by Panasonic.
 - The electromechanical relay provides electrical isolation for the batteries allowing one battery to be charged at a time.

- The relay is coupled with nmos transistor which allows the microcontroller to control the relay by providing gate voltage to the transistor. A simple one line cans be seen in figure 2

Figure 2



Microcontroller

- The major component used for sensing and automating the charging circuit and the switching circuit is the Arduino Uno Revision 3 microcontroller.
 - The programming language used to program the Arduino is a friendly c-based language that makes code implementation simple.
 - The microcontroller senses the stat1 and stat2 pin on the bq24105 IC. Stat1 and stat2 are digital pins, so either a high potential or a low potential will be read from these pins. If stat1 is low then this signifies that the battery needs to be charge and is charging. If stat2 is low then this signifies that the battery is done charging. The microcontroller senses/reads the pins and manipulates the data in loops to iterate through each battery. The code is structured in the event of missing batteries or the removal of a battery.

Code Implementation

- `/*`
- `Circuit and Relay Interface`
- `The following program interfaces the bq24105 Eval. Board circuit topology`
- `and interfaces mechanical relays.`
- `*/`
- `// give pins a name:`
- `// Array can be easily modified to accommodate for more/less batteries`
- `int relayPins[] = { 2, 3, 4 };`
- `int relayCount = 3;`
- `// digital input pins that use external pull-up resistors`

```

▪ int status_1 = 8;
▪ int status_2 = 12;
▪
▪
▪ // the setup routine runs once when you press reset:
▪ void setup() {
▪
▪ // initialize serial communication at 9600 bits per second:
▪ Serial.begin(9600);
▪
▪ // initialize the pins.
▪ // use a for loop to initialize each pin as an output to the mechanical relays:
▪ for (int thisRelay = 0; thisRelay < relayCount; thisRelay++) {
▪   pinMode(thisRelay, OUTPUT);
▪ }
▪ pinMode(status_1, INPUT);
▪ pinMode(status_2, INPUT);
▪ }
▪
▪ // the loop routine runs over and over again forever:
▪ void loop() {
▪
▪ // initialize the mechanical relays to be closed
▪ // loop from the lowest mechanical relay to the highest:
▪ for (int thisRelay = 2; thisRelay < relayCount; thisRelay++) {
▪   digitalWrite(relayPins[thisRelay], LOW);
▪ }
▪ // start switching process
▪ // loop from the lowest mechanical relay to the highest:
▪ for (int thisRelay = 0; thisRelay < relayCount; thisRelay++) {
▪
▪ // turn on the first switch
▪ digitalWrite(relayPins[thisRelay], HIGH);
▪
▪ // delay for read stability
▪ delay(5000);
▪
▪ // print out to serial monitor for error checking
▪ Serial.print( "stat1: " );
▪ Serial.print( digitalRead(status_1) );
▪ Serial.print( " stat2: " );
▪ Serial.println( digitalRead(status_2) );

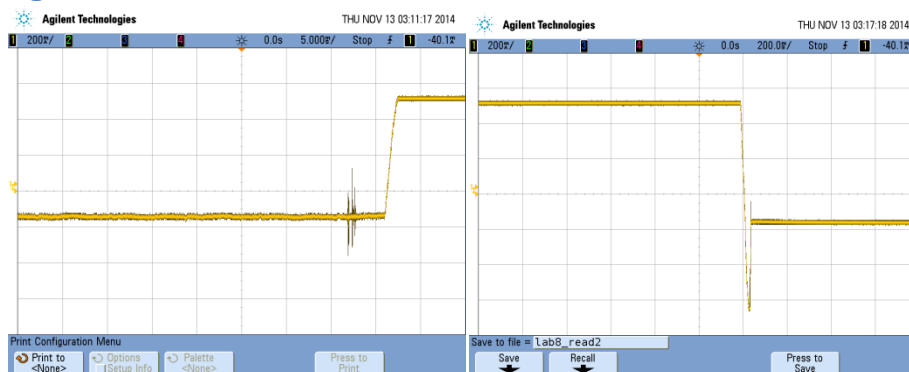
```

-
- // delay for more read stability
- delay(1000);
-
- // read the charging status pins of the microcontroller
- while ((digitalRead(status_1) == HIGH) && (digitalRead(status_2) == LOW) {
-
- // turn/leave switch on if charge is needed
- digitalWrite(relayPins[thisRelay], HIGH);
-
- }
-
- // turn/leave switch off if no charge is needed
- digitalWrite(relayPins[thisRelay], LOW);
-
- }
- }

Table 4 Electrical Characteristics

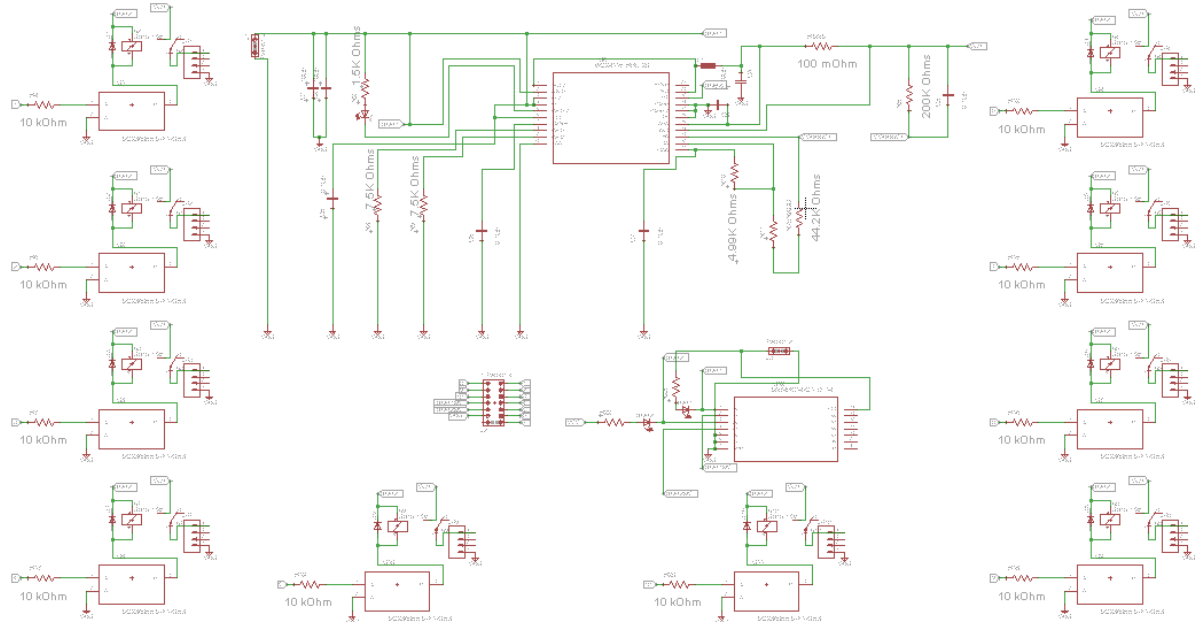
	Min	Set	Max	Tested	
Vbat	9V	12V	12.6V	11.98V	R5 = 220k ohm, R7 = 47k ohm
Charging Current	1A	1A	2A	.98A	Rset1 = 10k ohm, Rset2 = 5k ohm
Vin Charging Circuit	11.8V	12.5V	16V	12.5V	
Switching circuit gate voltage	2.3V	3V	5V	2.9V	
Vin microcontroller		5V		5V	
Relay Load			60W	11.74W	
Relay Coil Voltage	5V	12V		12.5V	
Charge time	15 min		2 hours	45 min	Initial charge on battery was 11V

Figure 3 Test Results for Switch Mode

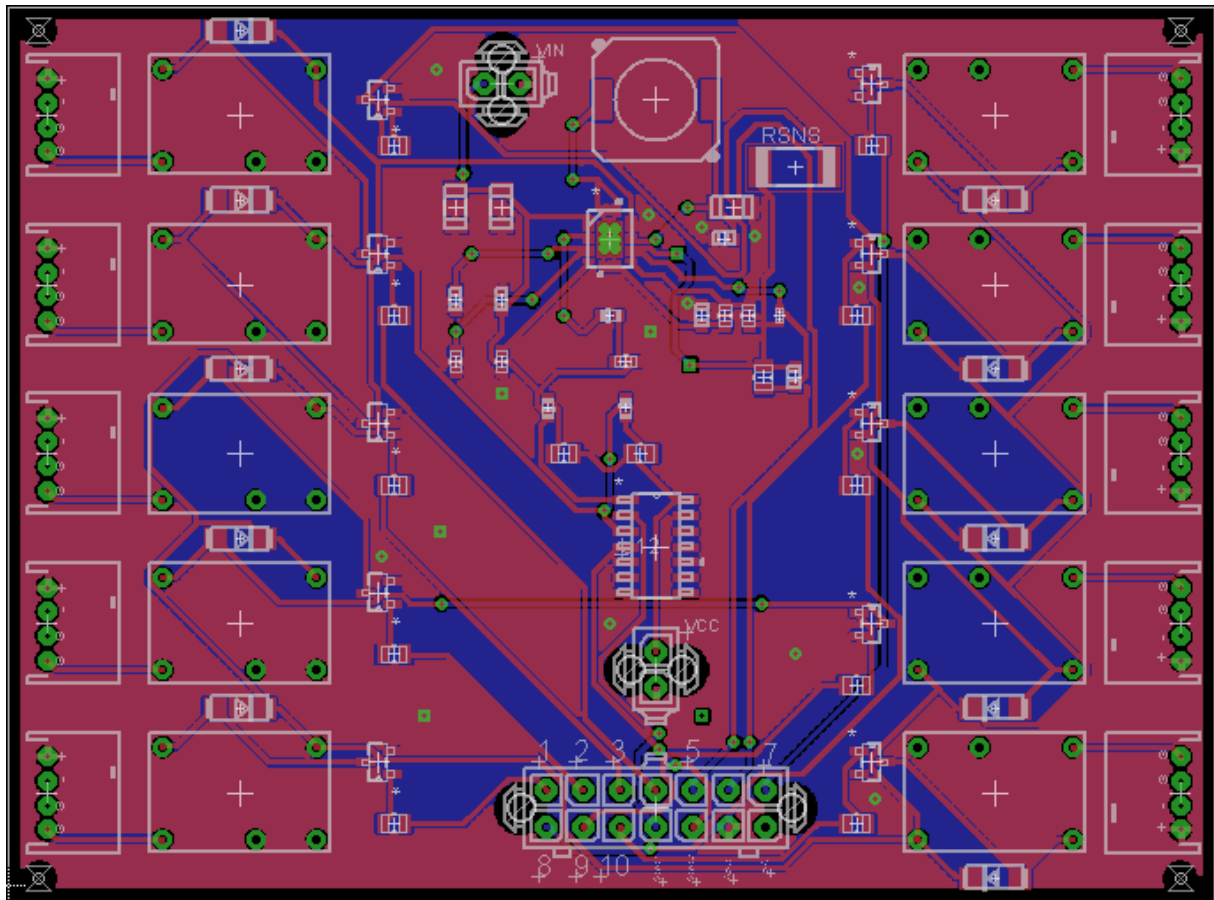


PCB Design

Schematic:



Layout:



Future Work

Possible future iterations:

- Develop modular enclosure to house individual modules
 - Would include power supply
 - Latching mechanism
 - Cabling system
- Streamline circuit and pcb design
 - Create on board power supply for microcontroller
 - Create external connection ports compatible with enclosure
 - Design pcb latching mechanism compatible with enclosure
 - Improve charging system design

Appendices

Vendor Data Sheets

TI IC Data Sheet

<http://www.ti.com/lit/gpn/bq24105>

TI EVM Data Sheet

<http://www.ti.com/lit/pdf/slou200>

Panasonic Relay Data Sheet

<http://www.farnell.com/datasheets/1682777.pdf>

Arduino Uno Data sheet

<http://arduino.cc/en/Main/ArduinoBoardUno>