Adaptive Battery Charging Unit

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Introduction

- Constant Current (CC) contributes to the bulk of battery charging while Constant Voltage (CV) contributes to just a small portion of the end
  - CC charging close to 100% State of Charge (SoC) will quickly overcharge the battery, causing the battery to smoke/catch on fire (https://youtu.be/YuKF8XfCVKQ?t=132)
- Adaptive charging unit required to safely charge a battery
  - Overcharging batteries causes accelerated interior material degradation over time
- Careless charging will damage a battery or destroy it (like in video)
- Need a to find a solution for highly controlled charging to prevent damage

Project Description

Goal: Adaptively charge an 18650 Li-Ion battery

- Correctly use constant current (CC) and constant voltage (CV) to deliver power to the battery
- Display the battery's State of Charge (SoC) as it is charging
- Safely protect battery from overcharging
- Complete an overall user-friendly and easy plug-and-play charging device

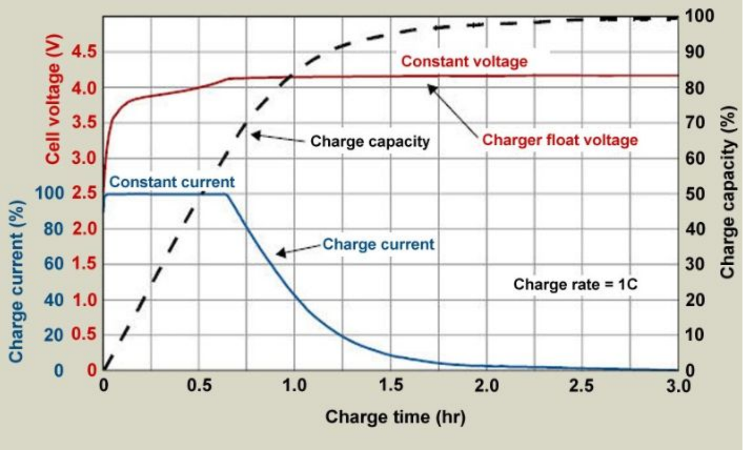

Figure 1: Example CCCV charging characteristics
Dashed line represents the battery's SoC, blue curve is the current used to charge the battery over time, and the red curve is the voltage charging over time.

https://batteryuniversity.com/learn/article/charging_lithium_ion_batteries

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Feasibility Study

- Executive Summary
  - Charge ICR 18650 Lithium Ion batteries
  - Charge in 3-4 hours using CC/CV method
- Technological Considerations
  - Charging profile does not display charging voltage as two microcontrollers would have to be used due to ATMega 1284 architecture since we did not have time to implement UART
- Existing Marketplace
  - Battery chargers are readily available on the market
- Marketing Strategy
  - Keep development cost as low as possible
  - Unique features such as charging profile and LED indicator
  - Ability to adjust charging voltage/current

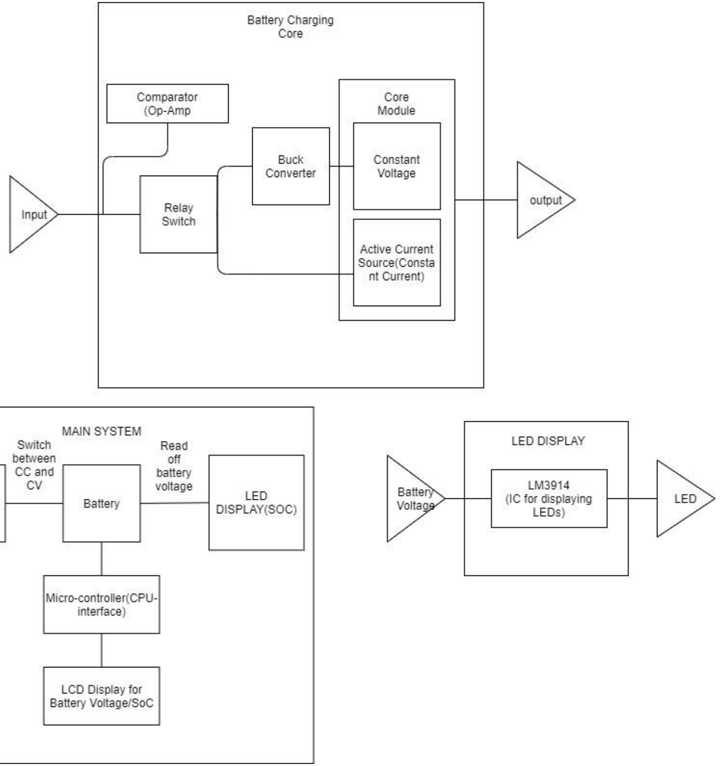
Design Specifications

- Charging unit charges at normal (1.3 A CC) rate
  - Charging time: 3-4 hours
- Charging unit adapts charging time and phase depending on its current SoC
- Charging unit charges battery until 100% SoC is achieved
- Buck converter supplies 4.2 ± 0.03 V
- ATMega1284 Microcontroller is used
  - Analog to Digital Conversion (ADC) reads battery voltage
  - Controls a relay which switches between CC and CV phases
  - Controls a digital potentiometer in CC circuit to regulate charging current
- Battery profile displays battery voltage, and battery SoC
- LED indicator displays SoC in form of 10 LEDs

Budget

Part	Seller	Amount	Price
LM2678T-ADJ/NOPB	Texas Instruments	2	16.21
Resistor Kit (500)	Sparkfun	1	7.95
GL5E Relay	Sparkfun	2	3.9
18650 Li-Ion Battery	Sparkfun	7	41.65
Battery Holder	Sparkfun	2	2
IFRZ44N NMOS	Amazon	20	10
PMOS	Sparkfun	5	9.27
TIP-31C BJT	Amazon	2	6.2
Super Capacitor	Sparkfun	2	9.9
LM3914 LED Display Driver	Amazon	5	9.99
MCP4131	Amazon	2	11.5
Boost Converter	Amazon	5	9.99
Knob Potentiometer Pack	Amazon	1	6.99
10k Ohm Potentiometers	Amazon	10	5.99
Power Inductors	Amazon	20	9.99

System Block Diagram



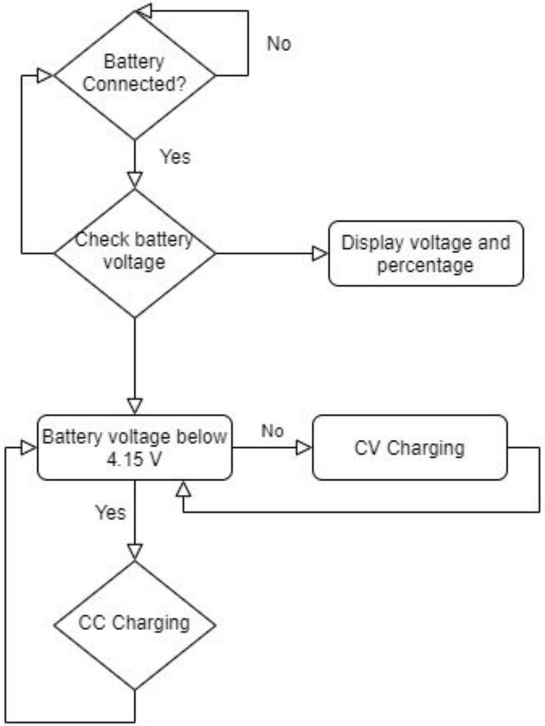
Technical Challenges

- LCD screen was not displaying any information
  - Solution: went through LCD library code to replace corresponding pin values
- Testing analog to digital conversion (ADC)
  - Did not work to turn on LEDs when input voltage was above/below 2.5 V
  - Solution: debugged with LCD
- Unsolved: could not use ADC values to control relay with MCU
  - Workaround: used comparator
- LED Indicator would not turn on LEDs on LED bus
  - Solution: flipped orientation of LED bus because diodes were in reverse polarity

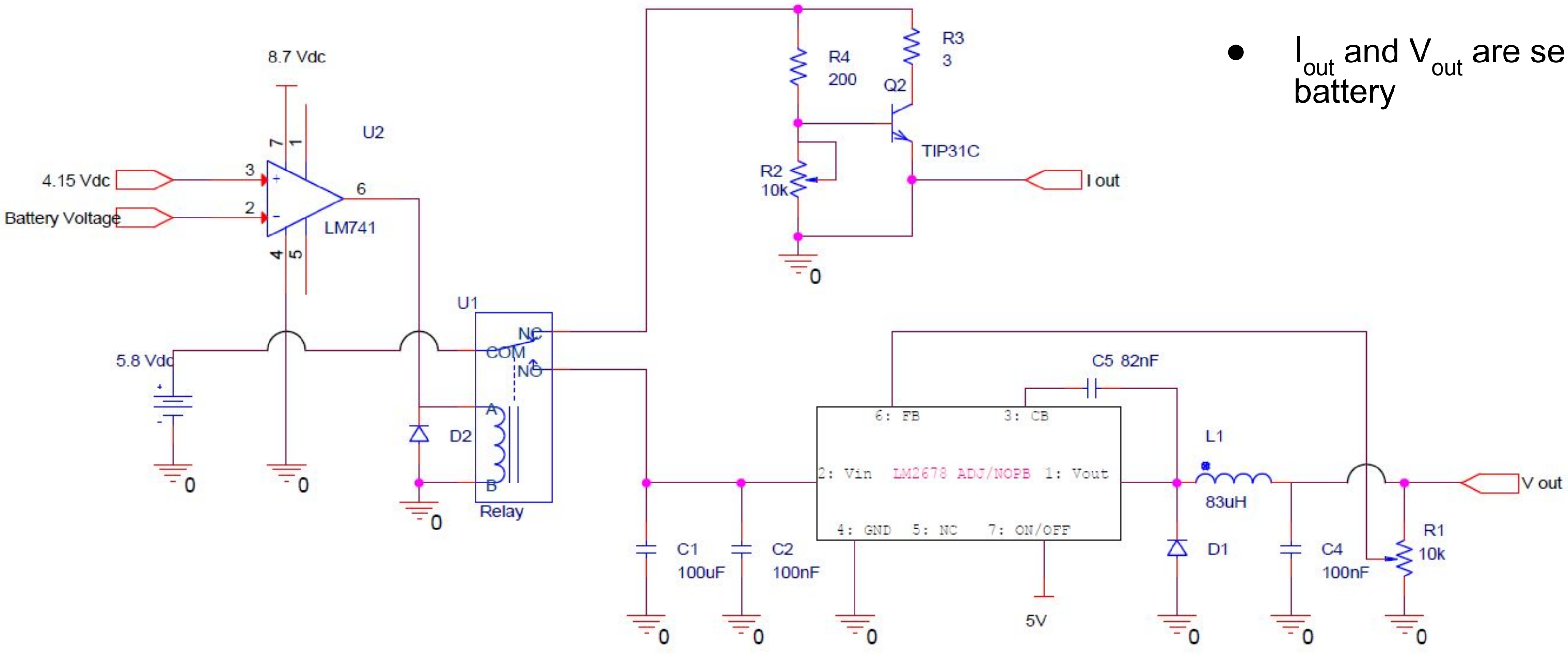
Implementation

Schematics, Operation, Pictures

Flowchart

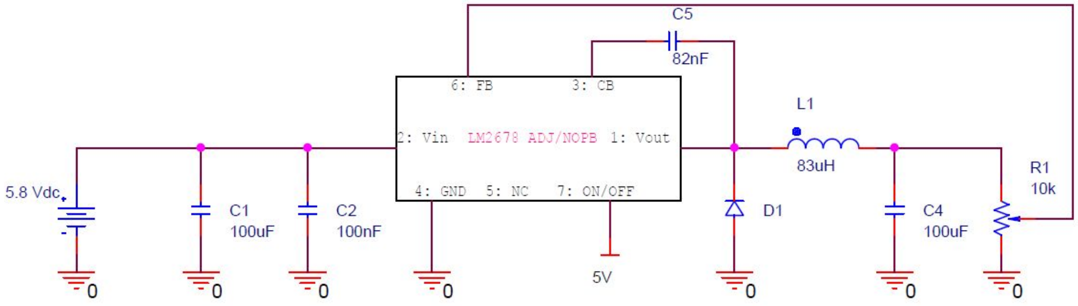

Battery Connected?
No
Yes
Check battery voltage
Display voltage and percentage
Battery voltage below 4.15 V
No
CV Charging
Yes
CC Charging

Total Input Circuit



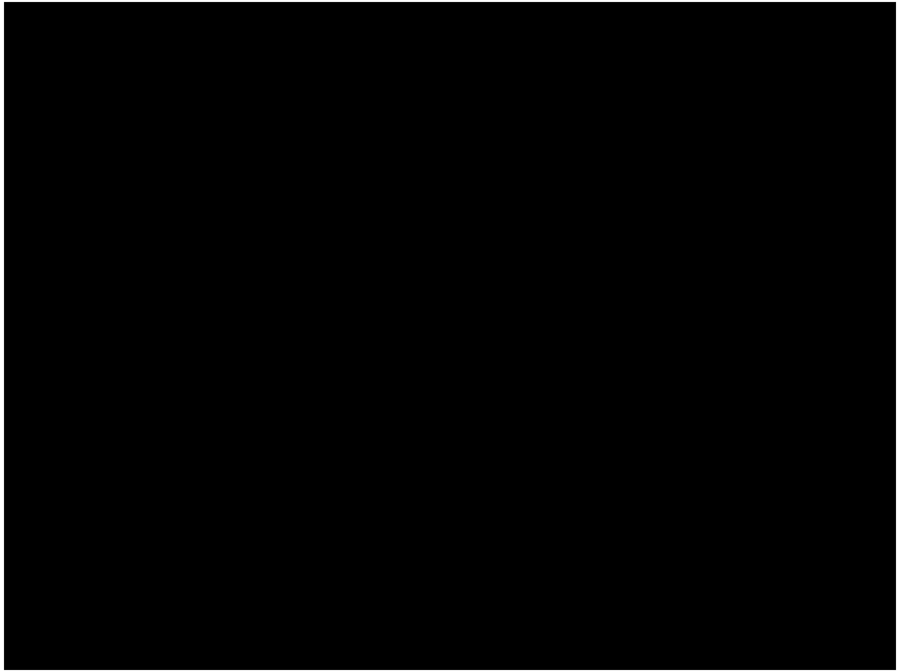
- I_{out} and V_{out} are sent to the battery

Buck Converter: Constant Voltage



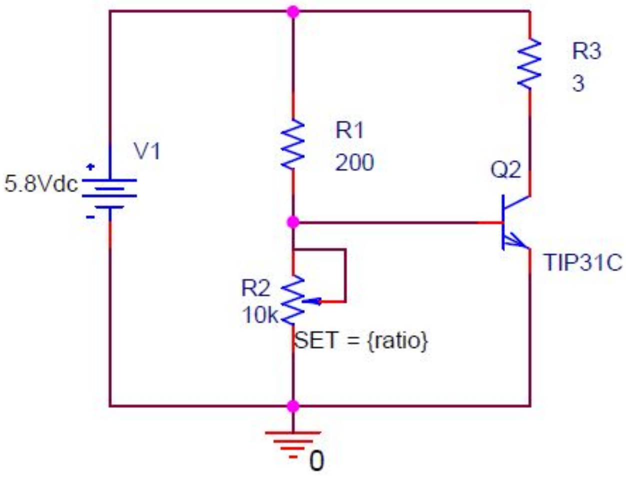
- Buck converter is required for a step down DC-DC voltage conversion
  - Stable voltage is needed for CV charging phase
- Input: 5.8VDC
- Output: 4.2VDC
- Works as CV phase in charging
- Efficiently steps down voltage
- Output can be adjusted by turning R1

Buck Converter operation



- Adjusting PWM percentage increases/decreases the output voltage
- Voltage feedback to pin 6
- R1 acts as voltage divider
- Output adjusted by IC adjusting PWM to keep feedback voltage 1.25V
    - Feedback required to keep system stable
- This design has 96% efficiency
- We need to adjust the voltage level to fine tune the voltage charging the battery and voltage fed to the CC stage

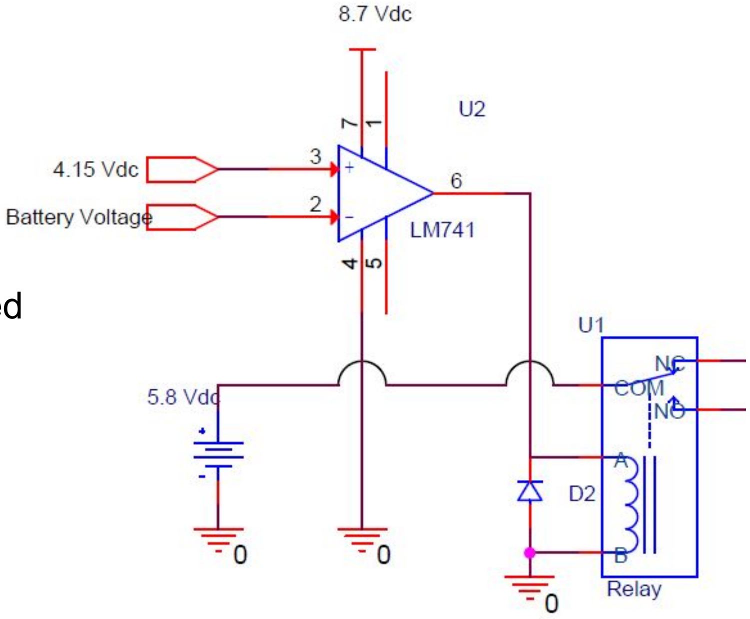
BJT Constant Current Source



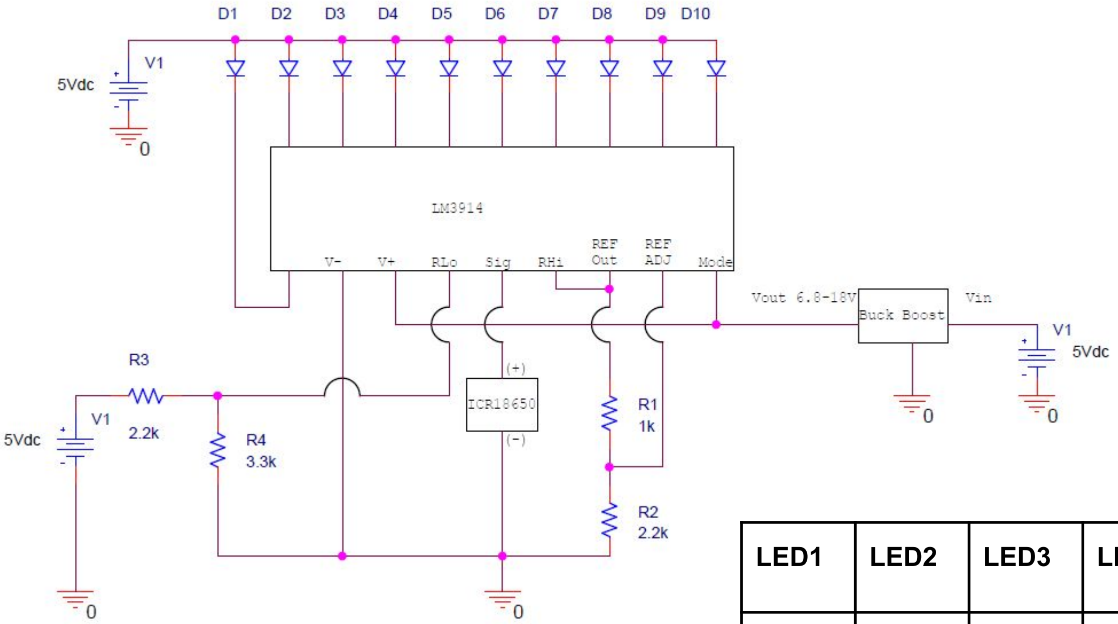
- This circuit acts as the source for the CC charging phase
- Output current is at the collector terminal
- Load in this circuit is the resistor R3
- Acts as a CC source due to BJT operation
  - Current at collector and emitter are dependent on the base current and the β value of the transistor
  - Varying R2 changes the current more than the variation of input voltage

Relay Operation

- Relay switches between CC and CV by using a comparator to detect when the battery voltage reaches around 4.15 V
    - When battery voltage is under 4.15 V, 0 V is applied to the relay coil and relay stays on NC terminal
    - When battery voltage reaches 4.15 V, 8.7 V is applied to the relay coil and relay switches to NO terminal
- D2 is a flyback diode which is placed parallel with an inductor to eliminate flyback when supply current is suddenly removed
    - Power in an inductor does not drop instantaneously after power supply is cut



LED Indicator



- SoC indicator for the battery during the charging process
- LEDs turn on from left to right for voltage values between 3 - 4.2 V
- LEDs corresponding SoC percentage can be seen in the table below
  - The percentages were calculated based on the battery discharge curve
- Boost converter is needed to supply 8 V to select "bar graph" mode

LED1	LED2	LED3	LED4	LED5	LED6	LED7	LED8	LED9	LED10
3.098V	3.221V	3.333V	3.452V	3.571V	3.685V	3.805V	3.927V	4.043V	4.167V
0.2%	1.2%	2.2%	4.6%	15%	24%	57.5%	74.3%	85.6%	98.1%

Design Considerations

- Constraints
  - Relay, TIP-31C, IRFZ44N Transistors chosen because they are made for high power applications
  - ATMega 1284 sampling rate 125 kHz
- Industry standards
  - Standard charging current: 1.3 A
  - Fast/maximum charging current at 25°C: 2.6 A
  - Constant voltage charging voltage: 4.2 ± 0.03 V
  - Standard charge time (CC + CV): 3 - 4 hours

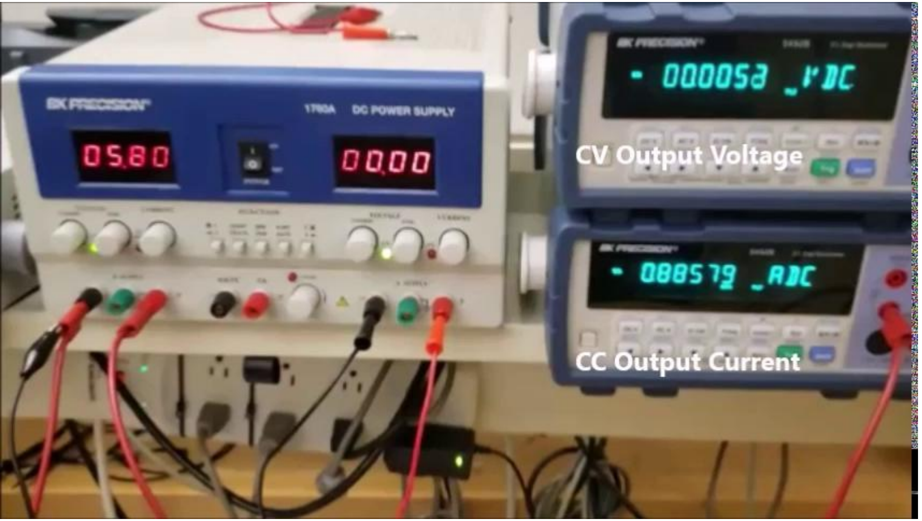
Results and Summary

Test Report

- Buck Converter: output must be 4.2 ± 0.03 V
  - Tested with 5.8 V input: observed output 4.20 ± 0.001 V
- CC Circuit: output must be between 0.5 A and 1.3 A
  - Tested with 5.8 V input: observed output 0.86 A
- LCD Screen: must display battery voltage with maximum 10% error margin
  - Tested with varying power supply voltage: displays battery voltage within 5% of the actual reading
- Relay: switch from NC terminal to NO terminal when battery voltage ≥ 4.15 V
  - Relay switches correctly when ≥ 4.15 V is applied

Videos

CC/CV Switching



https://www.youtube.com/watch?v=faIGTjM3U6M&feature=youtu.be

Summary

- Used knowledge of EE 1A, 100A/B, 123, 133
- Learned a few basics of power electronics
- A few features did not work out and were omitted
- Overall the core concepts of our project functions as intended

Acknowledgements

- Dr. Roman Chomko
  - Design ideas
  - EE 123 notes
- Dr. Hossny El-Sherief
  - Documentation