



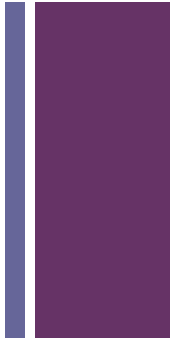
# Battery Pack and Backup Design for Wireless Infrastructure

Group #5

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# Introduction



- Sponsored by Open Technology Institute (OTI).
- Need a way to charge devices in developing countries where there is poor access to stable power.
- Primarily will be used to charge wireless routers to facilitate the development of communication networks in countries.

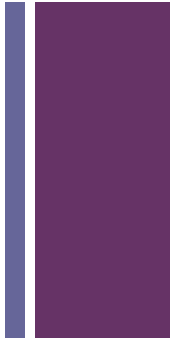


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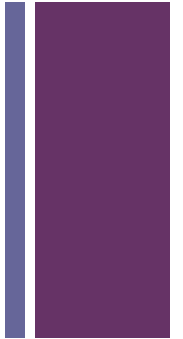
# Overview



- Introduction
- Objectives
- Design
  - Wall Power
  - Solar Power
  - Power Switch
  - Lead Acid Charger
  - Lithium Ion Charger
- Testing
  - Power Outputs
  - Lead Acid Charger Voltage and Current
  - Lithium Ion Voltage and Current
- Successes and Challenges
- Additional Testing
- Future Improvements
- References



# Objectives



- To provide a robust and stable battery charger and backup design.
- Product must also utilize natural solar power for charging, and outlet power.
- It will also be composed to commonly available parts, available almost everywhere.
- The circuit must also charge two types, lead acid and lithium ion batteries.



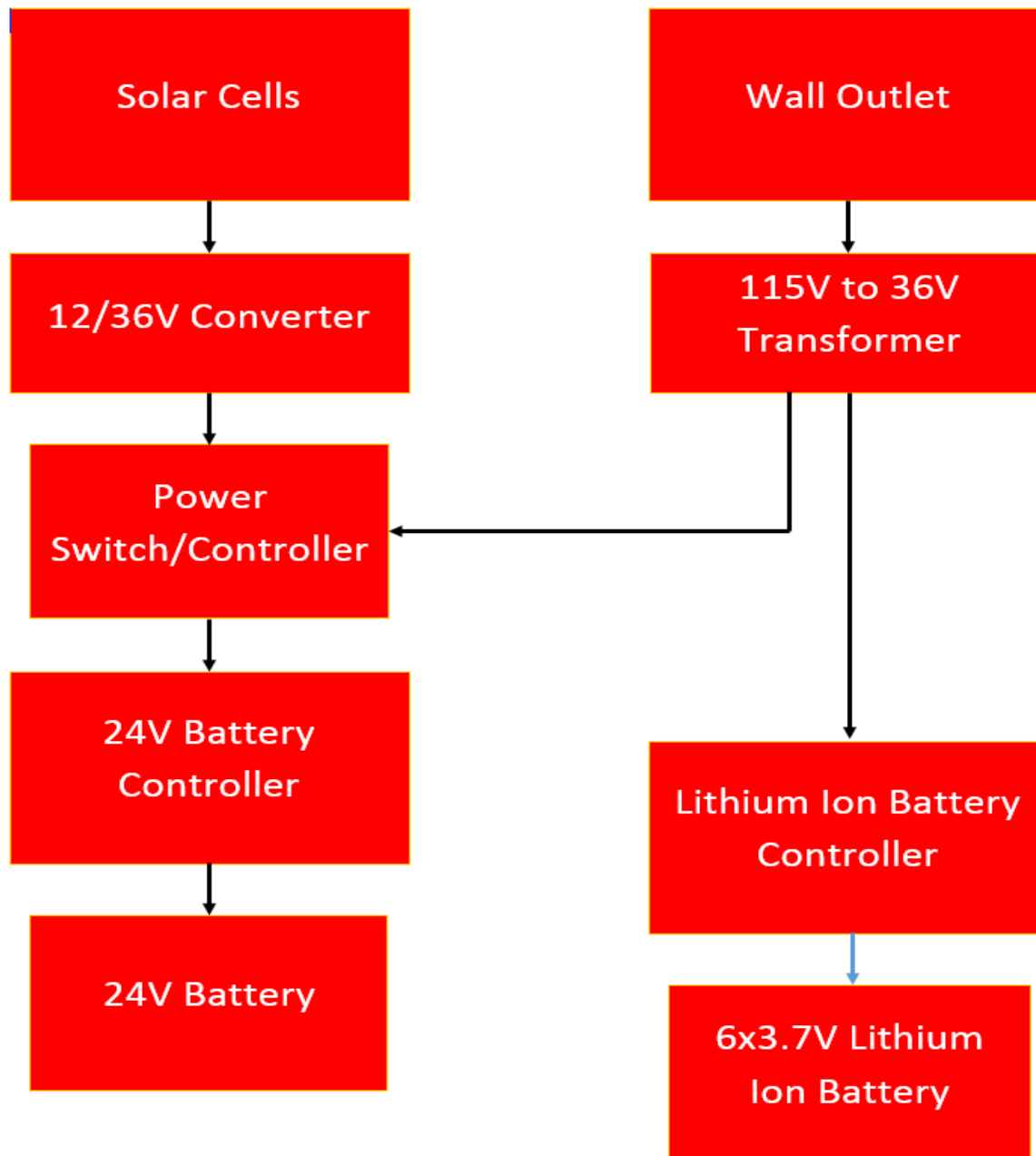
# + Battery Information

| State of Charge | Sealed or Flooded Lead Acid |
|-----------------|-----------------------------|
| 100%            | 12.70+                      |
| 75%             | 12.40                       |
| 50%             | 12.20                       |
| 25%             | 12.00                       |
| 0%              | 11.80                       |

- Lead Acid Batteries charge state can be determined by the voltage level of the battery.
- The charge current is ideally around 20% of the battery capacity or lower.
- When full lead acid batteries must have a float charge.
- Lead acid batteries also have a danger of overcharging.
- Lithium Ion Batteries are very sensitive to current, thus must be charged through a dedicated IC.

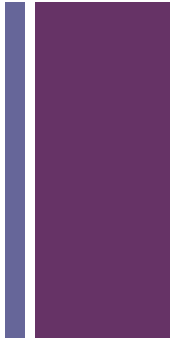


# Block Diagram





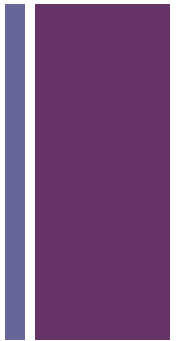
# Original Design



- Two power inputs, wall and solar.
- The Lead Acid Charger will be powered by both.
- The Lithium Ion Charger will only be powered by the wall.
- The Lead Acid Charger will be purposed to charge 30 – 100Ah batteries in dual configurations.
- The Lithium Ion Charger will charge multiple batteries in series ideally 6 to 7.



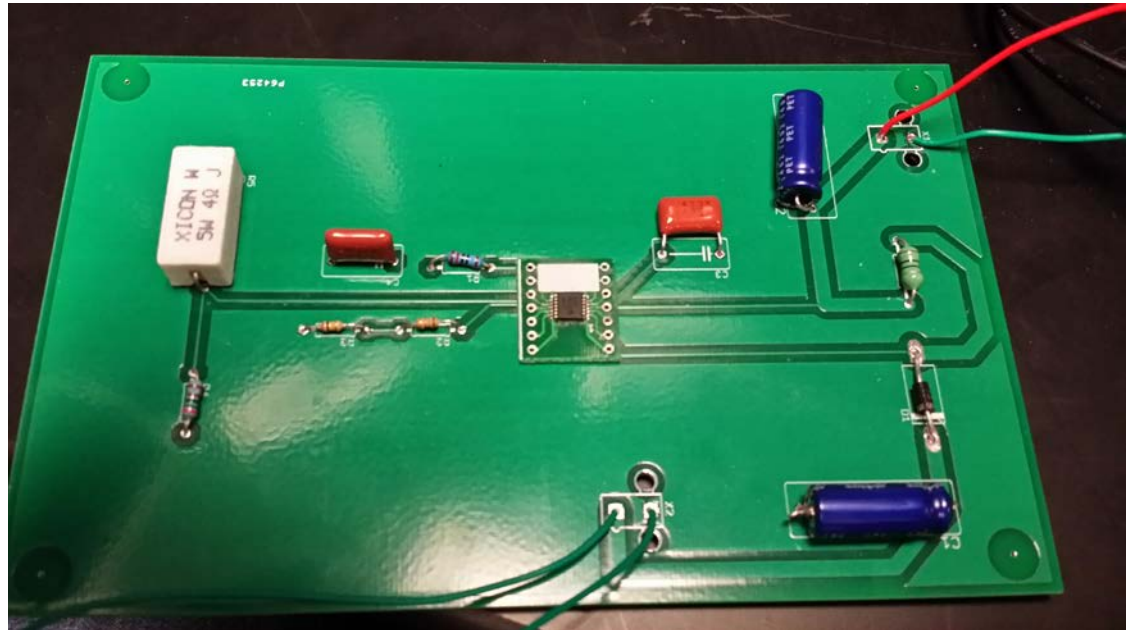
# Solar Boost Converter Requirements and Verification



| System Requirements and Verifications                                          |                                                                                     |
|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Requirement                                                                    | Verification                                                                        |
| <b>Output voltage must be 35V DC, with an output current under load of 4A.</b> | Utilize a multi-meter to measure both current and voltage of the output under load. |

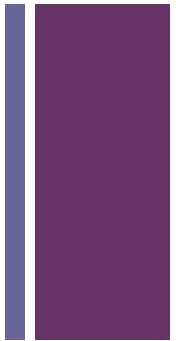


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# Solar Boost Converter Parameter Calculations



- Must output 4A at 35V

$$V_{ref} = 1.229V$$

- Calculate  $R_{SH}$  and  $R_{SL}$

$$V_{out} = V_{ref} \left( 1 + \frac{R7}{R6} \right)$$

$$V_{out} = 1.229 \left( 1 + \frac{120.5}{4.5} \right) = 35V$$

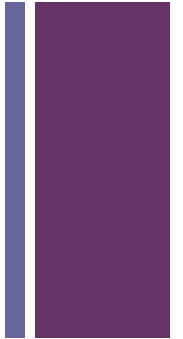
$$I_{total} = \frac{150}{35} = 4.28A$$

$$I_{loss} = \frac{35}{R_{total}} = 0.28A$$

$$I_{out} = I_{total} - I_{losses} = 4A$$



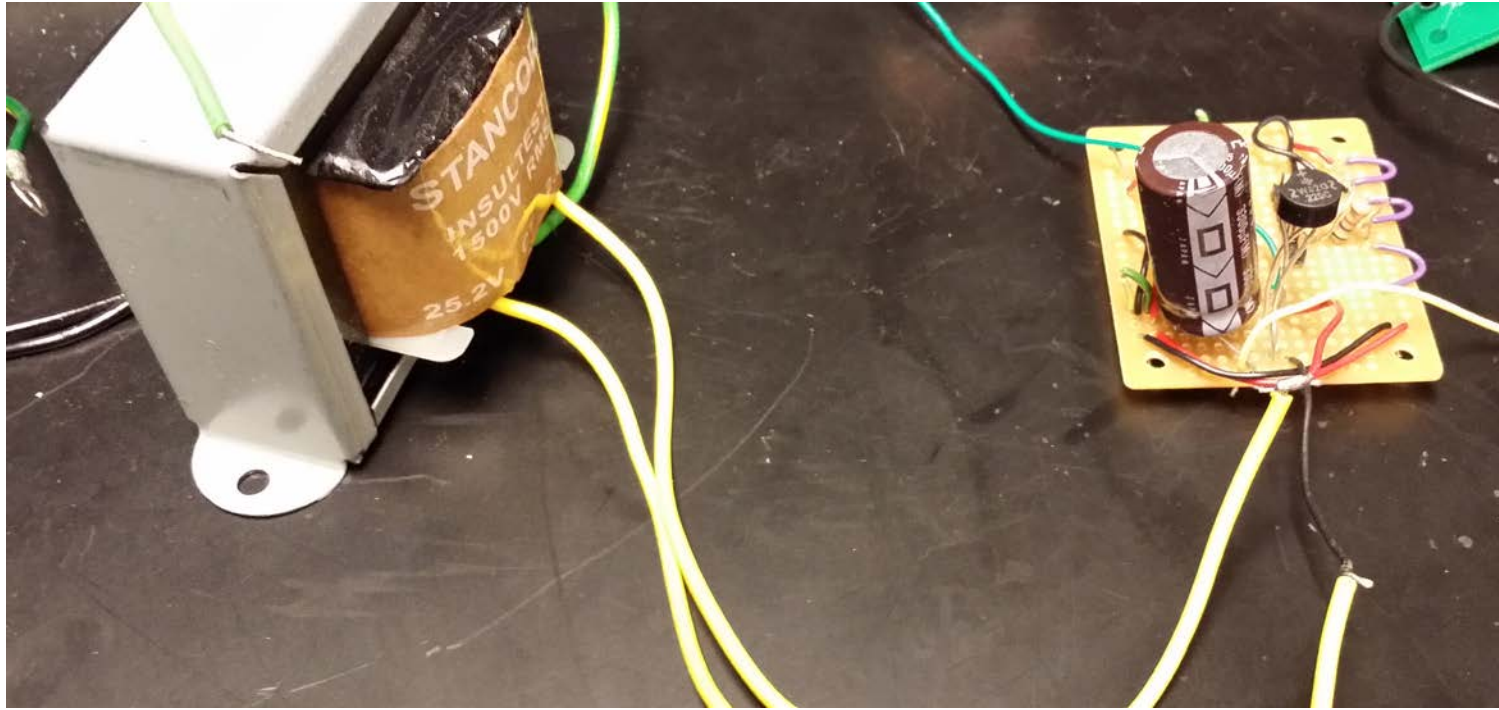
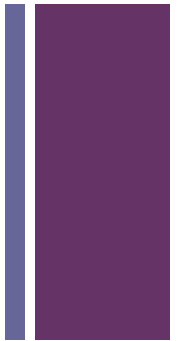
# Wall Power Requirements and Verification



| System Requirements and Verifications                                                         |                                                 |
|-----------------------------------------------------------------------------------------------|-------------------------------------------------|
| Requirement                                                                                   | Verification                                    |
| <b>Output 25V AC through the transformer</b>                                                  | Verify through a voltage probe.                 |
| <b>After rectified and filtered, output must be at least 35V DC, with a 2.3V peak to peak</b> | Measure output voltage through an oscilloscope. |



# + Wall Power Calculations



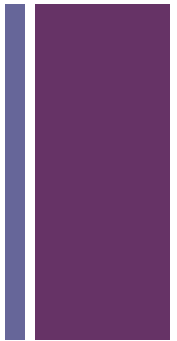
$$R = \frac{35}{6}$$

$$V_{ripple} = \frac{I_{load}}{f * R * C}$$

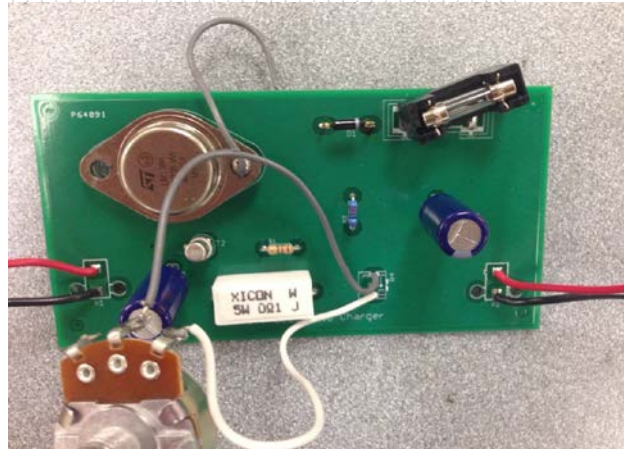
$$V_{ripple} = \frac{6}{200 * 5.83 * 2200 * 10^{-6}} = 2.33V$$



# 24V Lead-Acid Design



| System Requirements and Verifications                                                                                      |                                                                                                                                                  |
|----------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| Requirement                                                                                                                | Verification                                                                                                                                     |
| <b>Charger outputs 1A charging current to the battery module while voltage across the battery terminals is below 28.8V</b> | Input power is simulated using a DC Voltage source. Charging current is monitored using and ammeter on the positive lead of an uncharged battery |
| <b>Output current drops to less than 0.3A trickle charge current for battery terminal voltage above 28.8V</b>              | Input power is simulated using a DC Voltage source. Charging current is monitored using an ammeter on the positive lead of a charged battery     |
| <b>Battery terminal voltage will never exceeded 30V to prevent gassing.</b>                                                | Voltage will be monitored during full battery conditions while charging for 10 hours                                                             |
| <b>Charging current will never exceed 3A</b>                                                                               | Monitor using ammeter during charging                                                                                                            |





# 24V Calculations and Parts

$$I_{\text{charging}} = \text{Capacity}/5$$

$$V_{\text{cell}} = V_{\text{battery}}/\text{Number of Cells}$$

$$V_{24V} = V_{\text{cell}} * 12$$

$$V_{\text{cell}} = 2.033V$$

$$V_{24V} = 2.033V * 12 = 24.4V$$

$$T_{\text{min}} = 30AH/6A = 5 \text{ Hours}$$

$$T_{\text{max}} = 100/6A = 16.67 \text{ Hours}$$

| charge | 12-V battery | 24-V bank |
|--------|--------------|-----------|
| 100%   | 12.73        | 25.46     |
| 90%    | 12.62        | 25.24     |
| 80%    | 12.50        | 25.00     |
| 70%    | 12.37        | 24.74     |
| 60%    | 12.24        | 24.48     |
| 50%    | 12.10        | 24.20     |
| 40%    | 11.96        | 23.92     |
| 30%    | 11.81        | 23.62     |
| 20%    | 11.66        | 23.32     |
| 10%    | 11.51        | 23.02     |



Parts Costs

| Part              | Retail Cost (\$) | Actual Cost (\$) |
|-------------------|------------------|------------------|
| Diode             | \$0.15           | 0.60             |
| IC-LM138          | \$7.87           | Free             |
| 2000uF Capacitor  | \$1.29           | 2.58             |
| BC547C            | \$0.04           | 0.04             |
| 100Ω Resistor     | \$0.02           | Free             |
| 0.1Ω 5W Resistor  | \$0.48           | Free             |
| 220Ω Resistor     | \$0.04           | Free             |
| 10K Potentiometer | \$1.45           | 1.45             |
| Power Diode       | \$0.94           | Free             |
| 8A Fuse           | \$1.14           | 1.14             |
| <b>Total</b>      | <b>\$13.42</b>   | <b>5.81</b>      |

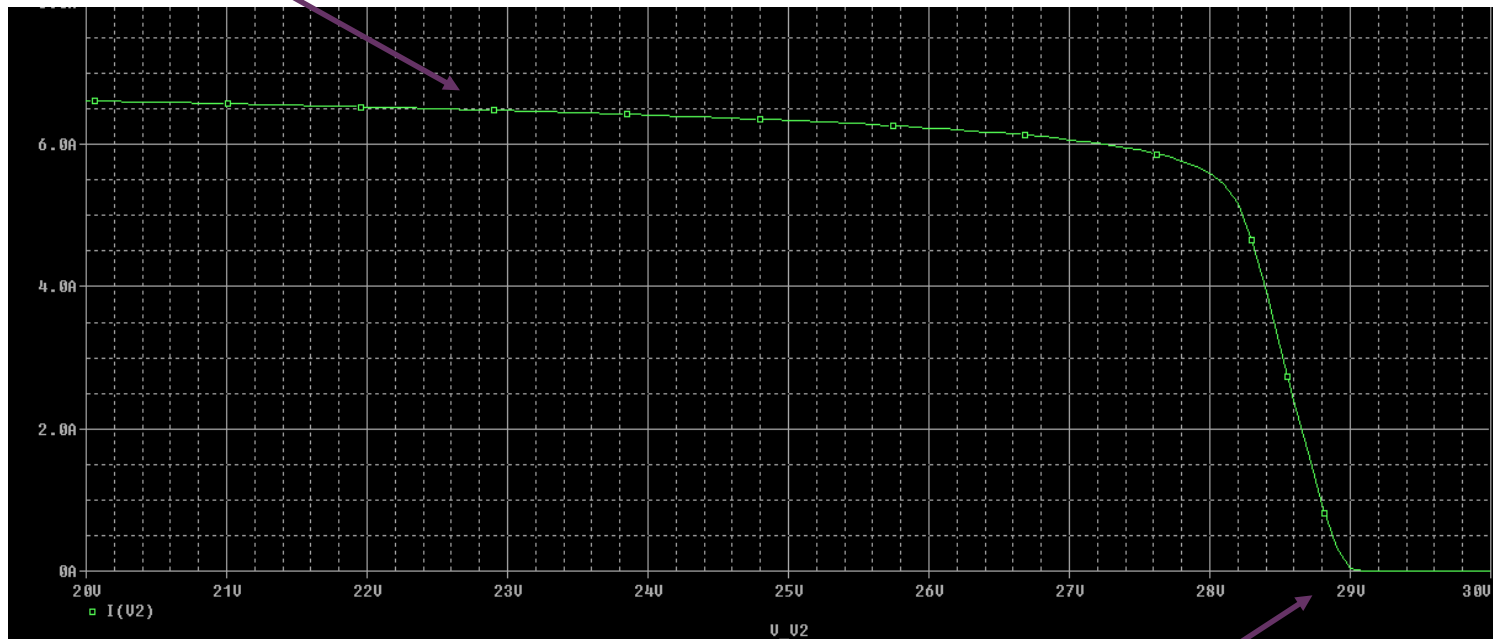


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# 24V Lead-Acid Simulations

Constant charging current of close to 6A for a 30Ah battery

Charging Current



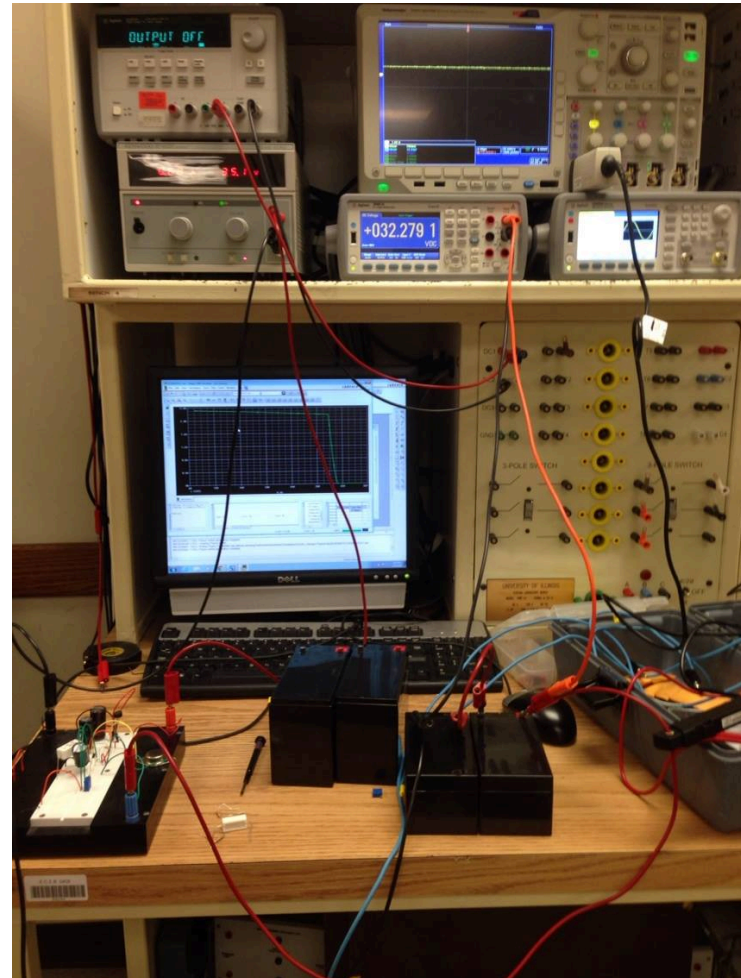
Battery Voltage

Boost Voltage of 28.8V



# 24V Build and Functional Testing

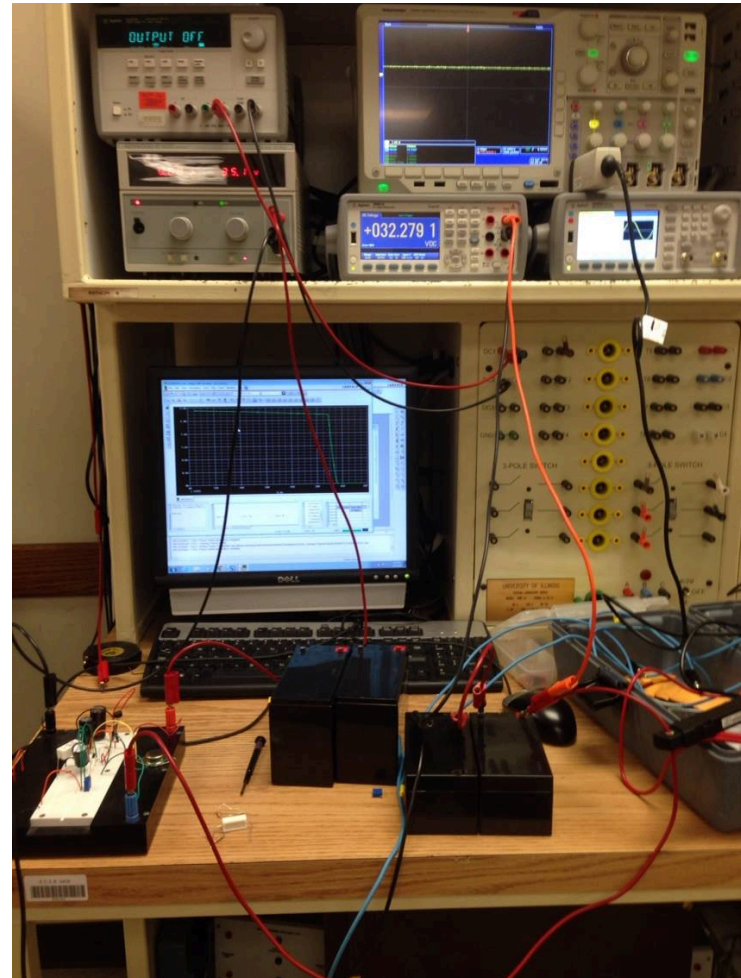
- Empty Battery Test
  - Original Battery Voltage – 23.8V corresponding to 40% full
  - 1.25A – 0s
  - .870A – 1m
  - .860A – 2m
  - .868A – 3m
  - .873A – 4m
  - .841A – 5m
  - Final Stabilized Battery Voltage – 24.2V





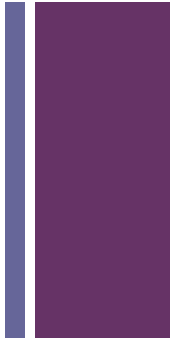
# 24V Build and Functional Testing

- Full Battery Test
  - Original Battery Voltage – 25.4V corresponding to 95% full
  - .240A – 0s
  - .163A – 1m
  - .146A – 2m
  - .116A – 3m
  - .106A – 4m
  - 99mA – 5m
  - Final Stabilized Battery Voltage – 25.45V





# Li-Ion Design



- Sponsor's Requirement

Battery Voltage between 12 - 24 V

Battery Capacity between 1200mAh – 6600mAh

- Safety Concerns

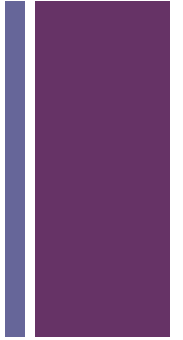
- Desired charging voltage and current

$$3.7 * 5 = 18.5 \text{ V}$$

$$0.5\text{C} = 3 \text{ A}$$



# Preliminary Li-Ion Charge Controller

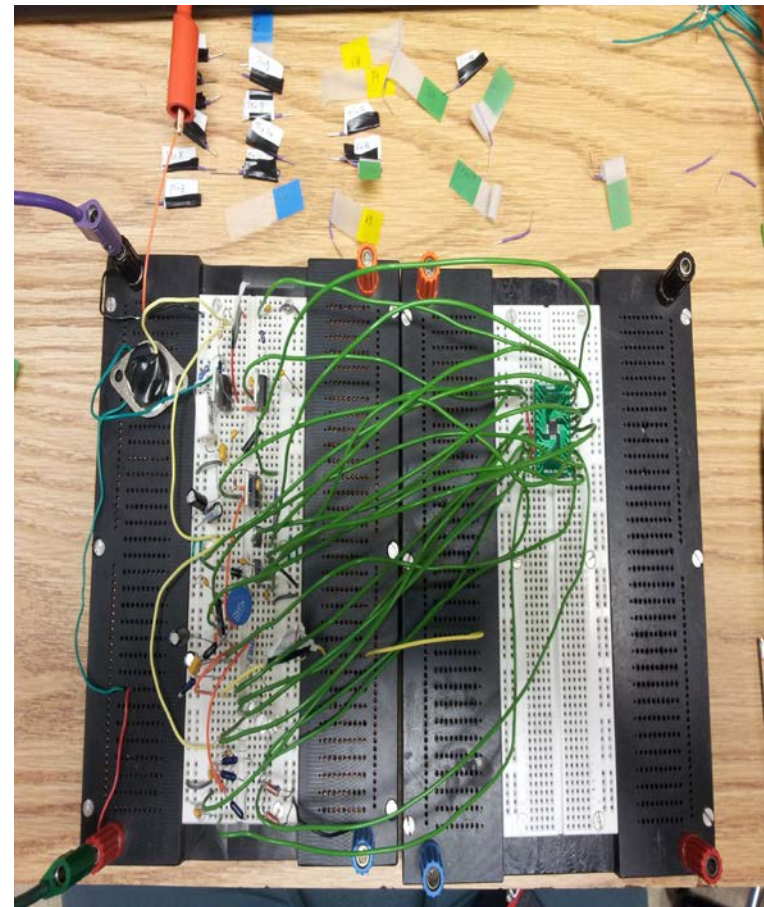
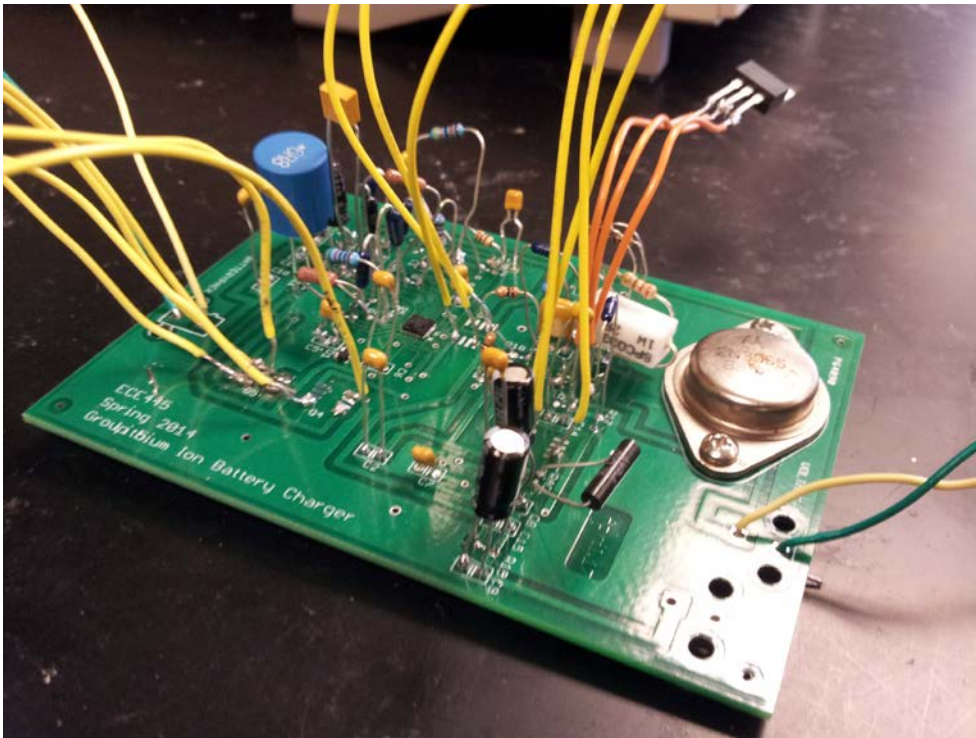


- TI Charging Chip
- Support Features include:
  - High voltage
  - 0.5% Voltage and 3% Current Regulation Accuracy
  - Safety Protection :
    - Battery Overvoltage Protection
    - Battery Detection
    - Safety Timer
    - Battery Short Protection



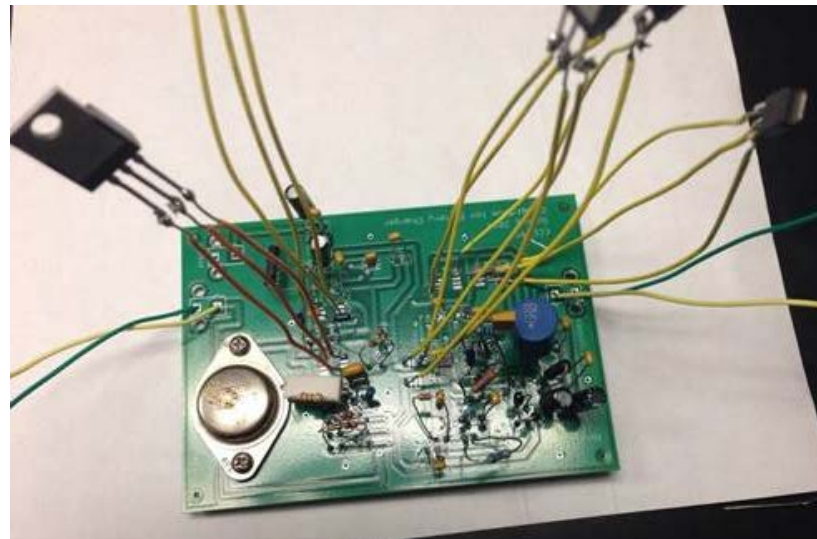
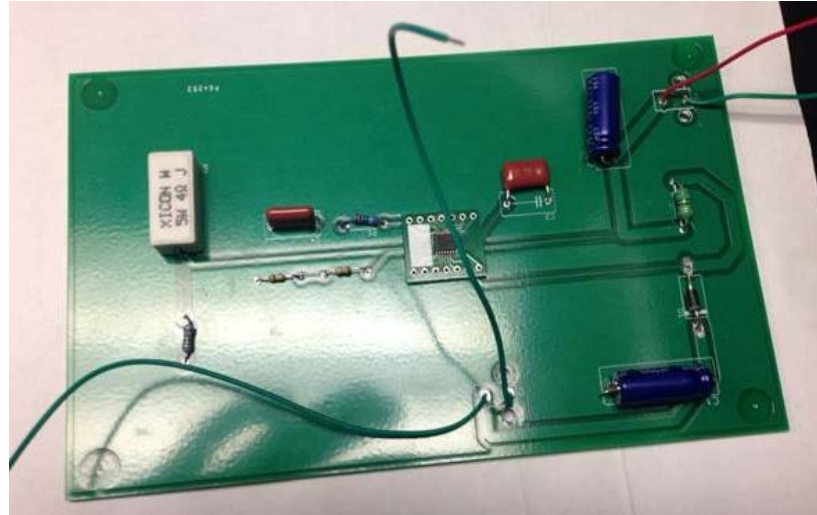
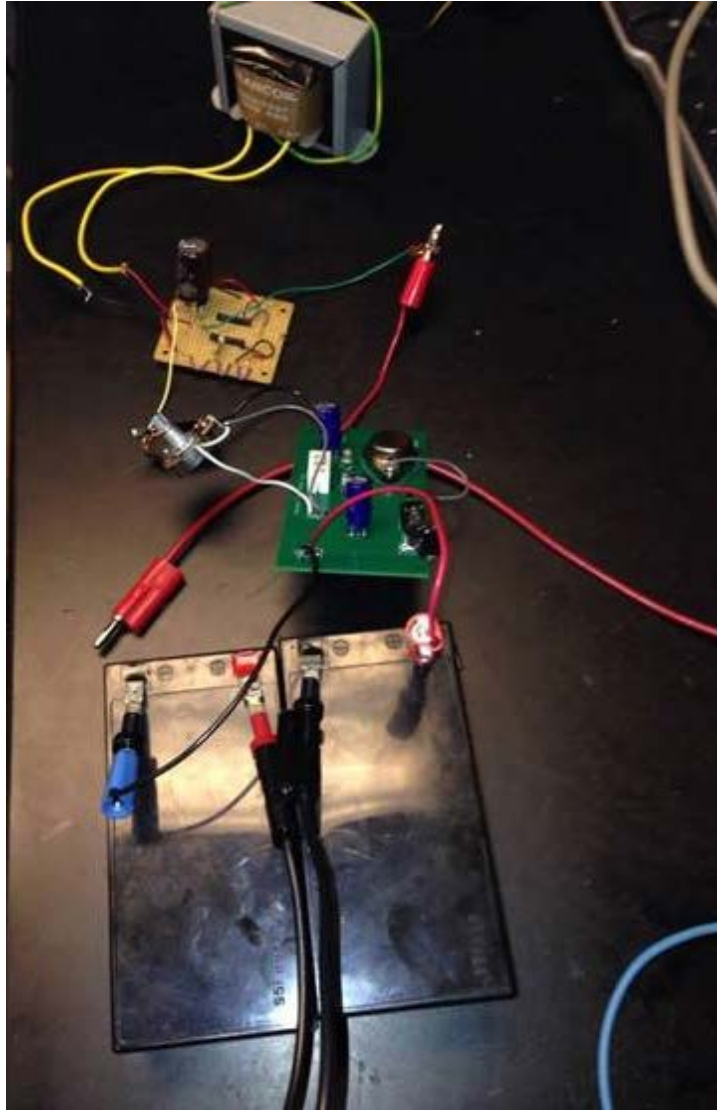
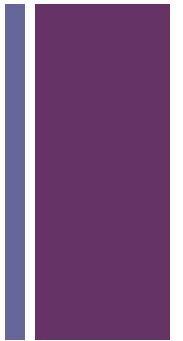
# Li-Ion Build and Functional Testing

- Bread Board and PCB
- Testing : Without a battery



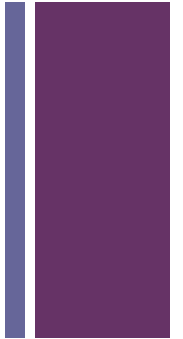


# + Final Circuitry





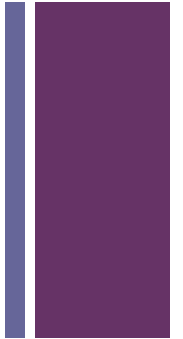
# Successes



- Lead-Acid charger can be powered in multiple ways.
- Lead-Acid charging current is regulated by voltage.
- Charging current drops to .25A for fully charged batteries.
- Applying the correct voltage through the Lithium Ion Charger



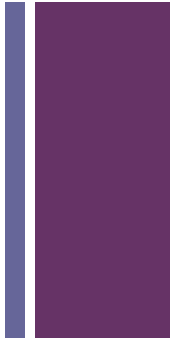
# Challenges



- Overheating and burnt out TPS53340 and LM138K
- Charging Voltage Adjustment
- Precision Resistors
- Smaller Capacity Batteries
- Boost Converter Parameters
- Lithium Ion Chip Parameters



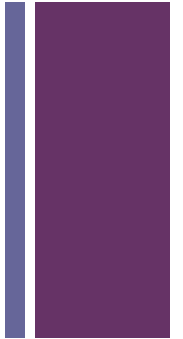
# Failed Verifications + Reasons



- Boost Converter
  - Parameter selection for the TPS55340 Chip
- 24V Lead Acid Battery
  - LM138K Failure
  - Power Losses
- Lithium Ion Battery
  - Difficulty in charging and testing Lithium Ion Batteries



# Future Work/Recommendations

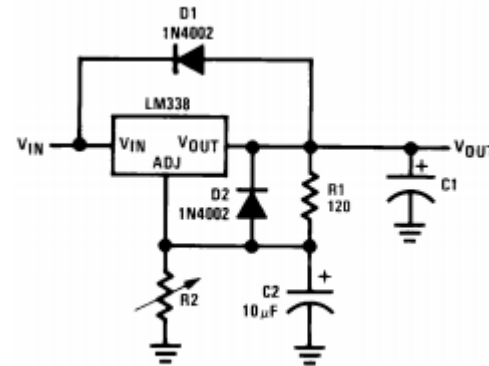
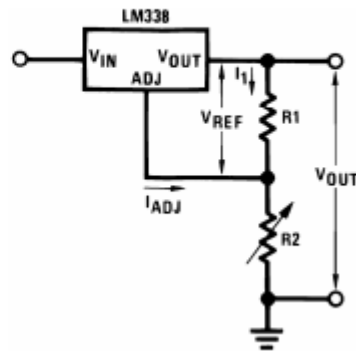


- A kill switch for the main power supply.
- A “smart” power switch for measuring and automatic switching
- Protective circuitry elements for voltage regulator
- Overheating considerations
- Potential multiple battery applications



# Future Work/Recommendations for the Lead Acid Charger

$$V_{OUT} = V_{REF} \left( 1 + \frac{R2}{R1} \right) + I_{ADJ}R2.$$

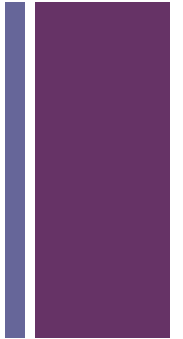


| Symbol           | Parameter                     | Conditions                                                                                    | LM138 |       |      | Units |
|------------------|-------------------------------|-----------------------------------------------------------------------------------------------|-------|-------|------|-------|
|                  |                               |                                                                                               | Min   | Typ   | Max  |       |
| $V_{REF}$        | Reference Voltage             | $3V \leq (V_{IN} - V_{OUT}) \leq 35V$ ,<br>$10\text{ mA} \leq I_{OUT} \leq 5A$ , $P \leq 50W$ | 1.19  | 1.24  | 1.29 | V     |
| $V_{RLINE}$      | Line Regulation               | $3V \leq (V_{IN} - V_{OUT}) \leq 35V$ <sup>(2)</sup>                                          |       | 0.005 | 0.01 | %/V   |
| $V_{RLOAD}$      | Load Regulation               | $10\text{ mA} \leq I_{OUT} \leq 5A$ <sup>(2)</sup>                                            |       | 0.02  | 0.04 | %/V   |
|                  |                               |                                                                                               |       | 0.1   | 0.3  | %     |
|                  |                               |                                                                                               |       | 0.3   | 0.6  | %     |
|                  | Thermal Regulation            | 20 ms Pulse                                                                                   |       | 0.002 | 0.01 | %/W   |
| $I_{ADJ}$        | Adjustment Pin Current        |                                                                                               |       | 45    | 100  | μA    |
| $\Delta I_{ADJ}$ | Adjustment Pin Current Change | $10\text{ mA} \leq I_{OUT} \leq 5A$ ,<br>$3V \leq (V_{IN} - V_{OUT}) \leq 35V$                |       | 0.2   | 5    | μA    |
| $\Delta V_{RT}$  | Temperature Stability         | $T_{MIN} \leq T_J \leq T_{MAX}$                                                               |       | 1     |      | %     |
| $I_{LOAD(Min)}$  | Minimum Load Current          | $V_{IN} - V_{OUT} = 35V$                                                                      |       | 3.5   | 5    | mA    |
| $I_{CL}$         | Current Limit                 | $V_{IN} - V_{OUT} \leq 10V$                                                                   |       |       |      |       |
|                  |                               | DC                                                                                            | 5     | 8     |      | A     |
|                  |                               | 0.5 ms Peak                                                                                   | 7     | 12    |      | A     |
|                  |                               | $V_{IN} - V_{OUT} = 30V$                                                                      |       | 1     | 1    | A     |

Current Limits within our parameters



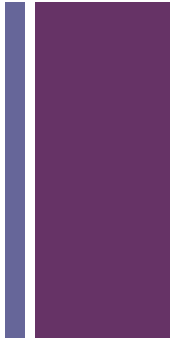
# + Ethical Considerations



- This device could have public health consequences if it should fail, so the utmost importance is on safety.
- We must ensure that our charge controllers meet standards and we have realistic expectations.
- We must make sure safety is our top priority due to the high currents and voltages inherent to the charge controller
- We hope to educate our sponsor on the design and application of our charge controller
- We have referred to Professor P. Krein for his expertise on battery charging circuits



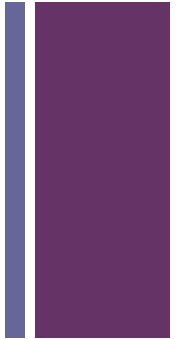
# Conclusion



- Functional power supply for temporary communications systems
- Easily portable devices
- Cheaply built using widely available parts
- Easily repairable
- Fits sponsors needs



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We also thank Professor P. Krein for his time and input for helping our design.