**Multi-Disciplinary Senior Design Conference**
**Kate Gleason College of Engineering**
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**Project Number: P12402**

# CHARGING DOCK AND POWER CONTROL

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## ABSTRACT

The aim of the charging dock & power control (CDPC) project is to design, build, and test and deliver a charging station that controls the charging of portable power sources. The portable power supply can be a battery pack or battery packs that ultimately powers the Land Vehicle for Education (LVE, R12005). The circuit board is integrated with the portable power supply, and is required to interface both mechanically and electrically with the charging dock as well as the LVE. The charging dock will receive power from other sustainable energy sources such as the Wind Energy Collection to Energy Bank (WECEB) project, and/or a standard AC outlet.

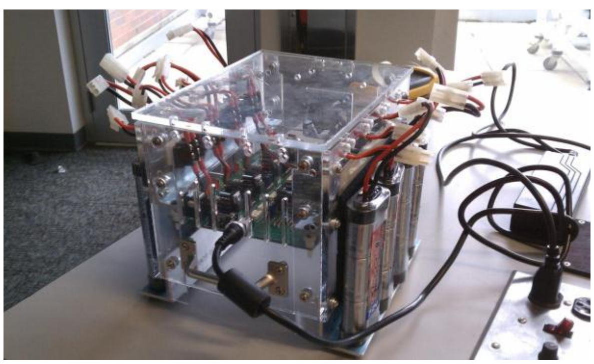

*Figure 1 - Working Final Product*

## NOMENCLATURE

*T – Temperature*
*θ – Thermal Resistance*
$P_d$ *– Power Dissipated*
Ω - *Ohm. Unit of electrical resistance.*
*V - Volt. Unit of electrical potential.*
*mA - 1/1000 of an amp. Unit of electrical current.*
*Subscripts*
*J – Junction*
*A – Ambient*
*C – Case*
*JA – Junction to ambient*
*JC – Junction to case*
*HS – Heat sink*

## BACKGROUND

The mission of the Sustainable Energy Systems for Education (SESE) family of projects is to design, develop, build, test, and deliver interchangeable sustainable energy technological solutions for use by future senior design teams and undergraduate engineering class projects in the KGCOE, beginning fall semester 2013.
The SESE projects should demonstrate the core functions of sustainable systems. All work produced should be in an open source / open architecture format, encouraging use of the technologies by others.

## PROCESS

Students will carry the dock and its corresponding weatherproof enclosure to the windmill location, depending on where it is on that given day. Students will also need to bring the charge-depleted LVE batteries so that they may be charged and used in the LVE. The user will connect the wire from the windmill's battery storage to the charging dock and flip the switch from the 'Off' to 'On' position to start the charging process. The user will then, according to the user manual, connect each battery to its respective terminal on the dock and attach the battery to the side of the dock for placement. The user will be educated on the current status of batteries and charging levels according to the LED lights on the outside of the dock. Interpretation of the LED lights can be found in the user manual.

***Electrical Process***

The dock will either convert or regulate the received power depending on which energy source is the current provider. The dock will accommodate up to eight LVE batteries. They will be charged indoors or outdoors, based on the source of power.

There are generally three different modes of charging a battery; trickle charge, fast charge, and rapid charge. Trickle charging takes a very long time to charge a battery but batteries charged this way have the longest lifetime. Fast chargers charge the batteries faster but batteries charged this way have a shorter lifetime. Rapid chargers charge the batteries very fast but batteries charged this way have the shortest lifetime. Smart chargers use a combination of these charging methods to produce the quickest charging times that are least damaging to the battery. They start out charging the battery with a fast or a rapid charging method and then when the battery reaches a certain threshold switch to the trickle charging method. The battery to be charged is a 7.2V, 3000mAH capacity, Nickel-Metal Hydride (NiMH) battery. A typical rapid charge rate for a battery with that capacity is to charge the battery with 1500mA for about two hours. The rapid charge charging current is 600mA for 8 hours. The trickle charge charging current is 300mA for 12h. The goal was to create a charger that could charge a battery within 8 hours. A smart charger could do this efficiently. The charging circuit was found in the data sheet of a voltage regulator, LT1086 as seen in Appendix D. Equations for the forward current $I_f$ and the change in forward current verse the battery voltage are given in equations 1 and 2.

$$I_f = \frac{V_{bat} - 1.25(1+\frac{R2}{R1})}{-R_S(1+\frac{R2}{R1})} \qquad (1)$$

$$\frac{dI_f}{dV_{bat}} = \frac{-1}{R_S(1+\frac{R2}{R1})} \qquad (2)$$

When the battery is fully discharged (5V) the desired forward current is 750mA so the battery is charging using fast charging. When the battery is nearly fully charged (8.2V) the desired forward current is 300mA so the battery is charging using trickle charging. The resistor values are solved to be $R_S$=0.75Ω, R1=100Ω, and R2=750Ω. Once the battery is fully charged the battery should stop charging. Ancillary devices had to be added around the charger circuit in order for this to happen.

A relay was added in front of the regulator to open and close to turn off the circuit depending on the battery voltage. A microcontroller is used to control the relay. The microcontroller reads the battery voltage and opens the relay when the battery is charged. The microcontroller also is used operate a display to let the user know if the battery is charging, full, or broken. The chosen display is a very simple LED scheme. A green LED flashes if the battery is charging. If the battery is fully charged the green LED stays on. If no battery is attached a red LED turns on. If the battery is not functional both the green and red LED turn on. Resistor values were calculated to change the current powering the diode. A reset switch and a 3.6V regulator had to be added to power and reset the microcontroller as well. After various thermal calculations it was determined that a fan had be added to cool down the regulators. Diodes were added to negate the effect of arcing from the relay closing. The microcontroller analog to digital converter (ADC) input pin could only accept voltage levels from 0-3.6V. The battery voltage could be at most 8.7V. A voltage divider into a unity gain op amp had to be added in order for the microcontroller to be able to read this voltage. The voltage is divided by three to assure the voltage on that input will never exceed 3.6V. The microcontroller could not supply enough voltage or current to the coil of the relay to close it. Another op amp had to be added to boost the voltage and current of this signal to be able to control the relay. Finally, capacitors were added to minimize the noise between the power line and ground plane. This charging schematic was duplicated eight times in order to independently charge eight separate batteries.

A single battery charging circuit was tested for functionality on a breadboard. Once functionality was proven a printed circuit board was laid out. Before the actual layout was done, a PCB vendor was chosen. One vendor that was recommended was ExpressPCB. The major drawback from this vendor was the pricing quote that was being provided from them. Based on the board specifications, the total cost would have been $260.00, a little over half of the budget for the entire project. New vendors were researched and based on board specifications along with budget constraints, Advanced PCB was chosen. The quote received was of $33 per board plus shipping. There was a minimum of two boards per order but because the board was for a school project, the minimum board count required was only one. The total cost of the board came out to be $55.00.

When creating the board layout, one channel was laid out first in order to find the best possible way of organizing components. Each component was laid down and rearranged several times in order to find the layout that required the minimum area on the board. Once a suitable arrangement was found, traces were drawn connecting components. The top copper layer was chosen to be the power plane due to the high amperage being supplied. Using a trace for 8 Amps would have been wasteful due to the trace being extremely thick. Using the whole top copper layer as the power plane rendered running traces to each channel unnecessary. The bottom copper layer was used as a ground plane. This was done to reduce noise in the circuit as there would be eight microcontrollers, one in each channel. There were moments when traces could not be made without crossing other traces on the top layer, in this case, the use of thru holes and the bottom copper layer was used. When a trace could not cross another trace, a thru hole was used to connect the top and bottom layers.

### *Initial EE Concept to Final Design*

Initially, the idea was to create a smart charging circuit. This circuit topology would allow the batteries to charge very quickly and then have a shut off relay that would stop the batteries from being over charged and getting damaged. The final circuit would become a mix between a dumb and smart charging circuit. While a dumb charging circuit just keeps pumping current into the battery, the hybrid charger uses a relay so that battery overcharging can be avoided. The charging times are not that fast, but the charging times are still within the needs of the customer. For the battery charging circuit, the LT1086 voltage regulator would became the center of the design. The data sheet for the LT1086 provided an example of a battery charging circuit. Accompanied with that circuit came a set of equations that could be used to determine resistor values based on required current at different levels of battery charging. Based upon the customer needs for acceptable charging times, levels of current could be chosen to meet these needs. The design will start charging the batteries with a current of .75 amperes and later when the battery is mostly charged, have a charging current of .3 amperes. The current decreases linearly between those two end points. After using standard resistor values, these values were slightly different than ideal, yet still were acceptable. At first the application of the equations provided for the regulator was unclear; many sets of calculations were made and the circuit was built using the resulting calculations.

A relay must be added in front of the regulator to open and close to turn off the circuit depending on the battery voltage. A microcontroller is used to control this function. The microcontroller reads the battery voltage and opens the relay when the battery is charged – it must also operate a display to let the user know if the battery is charging, full, or broken. The chosen display is a very simple LED scheme; a green LED flashes if the battery is charging and if the battery is fully charged, the green LED stays on. If no battery is connected, a red LED is displayed. If the battery is not functional both the green and red LED both are displayed. Resistor values were calculated to change the current powering the diode. A reset switch and a 3.6V regulator had to be added to power and reset the microcontroller. After analyzing the thermal calculations (in a later section), it was determined that a fan must be added to cool down the regulators. Diodes were added to negate the effect of arcing from the relay closing. The microcontroller analog to digital converter (ADC) input pin could only accept voltage levels from 0-3.6V. The battery voltage could be at most 8.7V. A voltage divider into a unity gain op amp had to be added in order for the microcontroller to be able to read this voltage. The voltage is divided by three to assure the voltage on that input will never exceed 3.6V. The microcontroller could not supply enough voltage or current to the coil of the relay to close it. Another op amp had to be added to boost the voltage and current of this signal to be able to control the relay. Finally, capacitors were added to minimize the noise between the power line and ground plane.

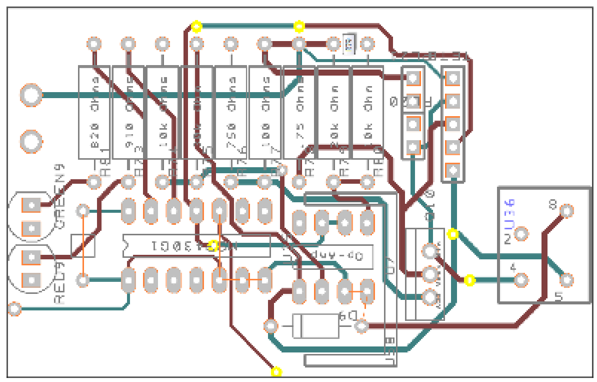

*Figure 2 - Single Channel Layout*

### *PCB Development*

To ensure proper fit and function of the PCB inside of the enclosure, the PCB was modeled in SolidWorks including all of the components. This model is imperative to outline mechanical interfaces between the enclosure and various electrical connections. Another importance of creating the model is to detect any interference between mechanical and electrical components and correct them prior to actual assembly. The bare 5 x 7 inch board was initially modeled and the layout file was then imported and laid over top of it to maintain accurate component placement. From the model, various drawings were created to outline critical dimensions such as mounting hole locations, overall thickness with components and any physical wire or component connections. The main interfaces between the PCB and the enclosure included LED connections, battery connections, incoming power and the power supply to a fan. Figure 3 shows the 3D model of the completed PCB.

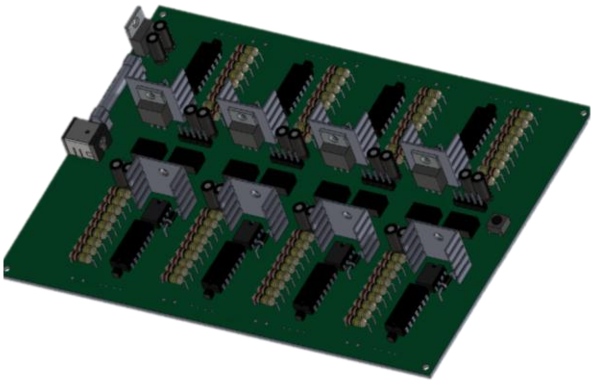

*Figure 3 - 3D PCB Model*

***Thermal Analysis***

Many of the electrical components have operating characteristics highly dependent on their operating temperatures. To ensure safe and reliable operation of all components, a pre-constructed thermal analysis was performed. Fortunately, there was only one component that dissipated a significant amount of power, that being the linear regulators. The PCB contains a total of eight linear regulators, dissipating a maximum power of four watts each. The regulators have maximum junction temperatures that must not be exceeded and nearby electrical components also need to operate under certain maximum ambient temperatures. Not only are the regulator junction temperatures important, but also the outer case temperature that affects the other components is similarly important. Design specifications required for proper calculation are power dissipation, maximum junction temperatures, junction-to-ambient thermal resistance, junction-to-case thermal resistance, contact resistance and the thermal resistance of a heat sink (if necessary). The design uses LT1086 regulators with the TO-220 package and the maximum ambient temperature is assumed to be 32 degrees Celsius. For the regulators, there are two separate junctions that must be analyzed: the control section and the power transistor. Both must be below their respective maximum values. The following specifications were taken from the LT1086 data sheet:

*Maximum Allowable Junction Temperature*

Control Section: 125 °C

Power Transistor: 150 °C

*Thermal Resistance*

$\theta_{JA}$ = 50 °C/W (without heat sink)

$\theta_{JC}$ = 1.5 °C/W (Control Section)

$\theta_{JC}$ = 4.0 °C/W (Power Transistor)

A junction-to-ambient resistance was calculated to determine if a cooling device was necessary. The following equation was used to compute the junction temperatures:

$$T_j = T_a + P_d * \theta_{JA} \quad (1)$$

Substituting into the above equation:

$$T_j = 32 + 4 * 50 = 232\ °C$$

The junction temperature was found to be far above both of the maximum allowable junction temperatures and therefore a cooling device was required. Post examination of the variety of available heat sinks, it was determined that ones with a low enough thermal resistance was too large and would require a major change to the already established PCB layout. The solutions was a combination of a smaller heat sinks as well as the inclusion of a fan that would provide sufficient cooling without making any major design changes. The selected fan provides an airflow of 400 LFM and the selected heat sink has a thermal resistance of 7.5 °C/W with an airflow of 400 LFM. The contact resistance between the regulator case and the heat sink was assumed to be 0.2 °C/W. The new junction temperature calculation is shown below.

$$T_j = T_a + P_d * (\theta_{JC} + \theta_{contact} + \theta_{HS}) \quad (2)$$

$$T_j = 32 + 4 * (1.5 + 0.2 + 7.5) = 68.6\ °C$$

(Control section)

$$T_j = 32 + 4 * (4.0 + 0.2 + 7.5) = 78.8\ °C$$

(Power transistor)

These junction temperatures are both well below the maximum allowable. Next, case temperatures must be tested to ensure that the temperature inside will not exceed 70 °C, such that the regulators do not adversely affect other electrical components.

$$T_C = T_j - P_d * \theta_{JC} \quad (3)$$

$$T_C = 68.6 - 4 * 1.5 = 62.6\ °C \text{ (Control Section)}$$

$$T_C = 78.8 - 4 * 4.0 = 62.8\ °C \text{ (Power Transistor)}$$

From the above calculations, the heat sink and fan combination provides sufficient cooling to ensure reliable and safe operation of the regulators as well as surrounding electrical components. With user safety being a large concern, warning signs have been included to alert users aware when contents inside the enclosure exceed a certain threshold temperature. The above calculation is practical; however, it is more of an approximation. Since there will be more than one regulator on the PCB and only one fan pushing air from one side to another, the ambient temperature for the regulators on one side of the PCB may potentially be higher. They may also not receive the total airflow due to blocking interference from other components. To solve this more complex calculation would require a software package such as Floworks, to calculate and analyze the airflow over the entire PCB. This type of analysis is beyond the scope of this project and therefore, the above calculation is sufficient.

***Initial Charging Dock Design***

A structure was necessary to support and protect the printed circuit board as well as the batteries during charging. An enclosure was designed to perform these functions while minimizing the size and weight of the unit. The initial design had various housing configurations; materials required were generated in a brainstorming activity and the decision to use Lexan for the structure was made due to its robustness, durability, and lightweight structure and relatively low cost. The driving force behind the design was the battery size and the goal of charging ten batteries at once. The initial concept was compact and functional with sliding drawers that pulled out to support the batteries. However, it quickly became apparent that the design was too complex, lacked long-term battery storage, was overly robust and was not easily transportable. For these reasons, the external housing was redesigned to address these issues.

***Final Charging Dock Design***

Manufacturing the prototype using Lexan material proved to be difficult because toxic emissions given off from the plastic during laser cutting, the preferred manufacturing method for cutting out the housing pieces. Alternative options for manufacturing included a milling machine to create each part, or water jet cutting. Laser cutting was the simplest and most cost effective solution, and thus was the method selected for use. Since Lexan was not suitable for this process, ¼" thick acrylic was substituted as a viable and safer replacement. The material was initially cut into smaller pieces to fit into the laser cutter with an allowable one inch of excess material on each side, which would later be discarded.

3D modeled parts were transformed into 2D drawing files (DWG) and imported into Draftsight, a software package designed by the company that created SolidWorks. In Draftsight, lines from the internal features are green, and the edges blue. This was required so that the laser would cut the internal features prior to cutting the borders to prevent alignment error. The ¼" thick acrylic required multiple passes to prevent the material from melting and warping. The laser's algorithm generator was used to determine the order of cutting parts to minimize time in use, as well as costs for production.

The charging dock was constructed and assembled per the SolidWorks model. The acrylic sides and corner brackets were assembled initially without the aluminum brackets. During assembly, it was discovered that the solid model of the parts and the actual product were not exact, and some interferences became apparent. Different screws were used to solve initial issues, however further issues surfaced and required redesign and reselection of hardware. When assembling the original hardware, alignment became difficult and select mounting through holes were changed to slots on successive iterations to eliminate interferences. To make lid alignment simpler, the initial design of two hinges was replaced with one, and the type of hinge was changed to allow proper lid closure. Placements of holes on acrylic tiles were moved to account for these changes and then were again cut for the final product.

## PROOF OF CONCEPT

This testing was completed without use of a microcontroller and relay. A battery was charged from 7.2V to 8V in the time span of two hours. The results can be found in Electrical Test 1 in the appendix. The temperature of the linear regulator was very hot and some thermal analysis needed to be done to determine if additional cooling is needed. Once a single channel was tested and functionality was verified the PCB was ordered. A single channel was populated with the relay and microcontroller. A heat sink was added to the regulator. The regulator still got very hot. The fan was then added to blow on the regulator. The regulator's temperature decreased significantly. It was also noted that the reset switch was designed incorrectly. This could easily be fixed on the board by cutting a single trace, tying one side of the switch to ground, and add in a 10k ohm pull up resistor to the other side of the reset switch. The results can be found in Electrical Test 2 in the appendix. After the single channel worked and the reset switch was fixed the full PCB was populated. Full functionality results can be found in Electrical Test 3 in the appendix. It was discovered that the reset switch does not reset microcontrollers that are charging batteries. Also it was found that arcing from relay opening on occasion reset the microcontrollers. These problems still need to be fixed. Another unforeseen problem was discovered. When a battery is charging and the power is removed from the charging dock the battery back feeds the VDD line. This keeps the microcontroller powered. The microcontroller reads the voltage of the battery and keeps the relay open. This causes the battery to discharge. This is a major problem in the charging dock. If the dock does not receive power the batteries can discharge instead of charging. This problem is fixed by altering the microcontroller code. If the battery voltage decreases then the relay closes.

## RESULTS AND DISCUSSION

### Electrical Testing

Refer to Appendices A-C for detailed electrical test systems and settings.

The P12402 charging dock passed all tests within these three appendices.

### Mechanical Testing

#### *Drop Testing*

It was previously mentioned the main function of the dock housing is to protect and support the PCB. With normal handling and use of the charging dock, there is a possibility that a user may drop the device during transportation. For this reason, testing was completed to ensure the dock enclosure was robust enough to withstand such an impact. The assembled dock was dropped three separate times from a height of three feet, in order to simulate potential occurrences during handling (the dock was dropped on its bottom, on its side and was pushed off a table where it tumbled). After each drop, the housing and PCB were inspected for any physical damage and the device was then tested to ensure proper function and charging capabilities. The charging dock suffered no efficiency or function loss due to the prescribed testing.

#### *Weatherproof Testing*

The charging dock was originally designed to use power from an alternative energy source (external windmill) to charge the required number of batteries. Therefore, the dock must be able to operate in and withstand the grueling elements of the Rochester, NY environment. To meet this requirement, a weatherproof enclosure was purchased and modified to contain and protect the entire charging doc. The primary functional requirement of the weatherproof enclosure is to restrict any water intrusion that could potentially harm electrical components. To test this, a paper towel was placed inside the weatherproof enclosure, the lid was sealed and the enclosure was showered with water for two minutes. The paper towel was then inspected for any water spots.

The second part of the weatherproofing was to ensuring the dock can hold up to frigid temperatures. To simulate this effect, the enclosure was placed inside of a freezer for twelve hours and was then immediately inspected for any cracking.

The weatherproof enclosure passed all testing procedures; no water was able to enter the unit from the water test, as the paper towel collected no precipitants, and it also passed the freeze test as no cracking occurred.

#### *Thermal Testing*

To ensure that the thermal calculations are accurate and internal temperatures will remain at adequate levels, temperature testing was conducted. Temperatures of the regulator cases were monitored during a typical charging scenario and the maximum temperature was recorded. Ideally, this temperature would remain below 50°C throughout testing, but below 70°C is considered acceptable. The internal air temperature of the dock was also monitored to test the circulation system by placing thermal couples at the inner top four corners of the charging dock. These temperatures must remain below 70°C to ensure that other electrical components are not adversely affected by the increase in ambient temperature due to the dissipated power. During testing, the maximum regulator case temperature observed was 54°C and the maximum dock internal temperature was 33°C, only ten degrees above ambient temperature. These results proved the dock passed thermal testing and all components will remain in safe in typical operating conditions.

#### *Size and Weight Testing*

The final testing procedure was a check of the size and weight measurements versus the engineering metrics set forth in the beginning of the project. To test this, a tape measure was used to determine the outer dock dimensions (length x width x height). Next, a scale was used to measure the weight of the unit without any batteries being connected to the charging dock. The results of these tests can be found in Table 1.

Table 1: Size and Weight Results

| | Length (cm) | Width (cm) | Height (cm) | Weight (kg) |
|---|---|---|---|---|
| Satisfactory | 23 | 23 | 10 | < 1.4 |
| Ideal | 15 | 15 | 7.5 | < 0.7 |
| Tested | 21.4 | 19.1 | 16.2 | 1.8 |

The dock failed both tests because the weight and height of the device had exceeded the engineering metrics, derived from the customer requirements. This failure was a direct result of the battery length. In the design, the batteries stand up along side of the dock, which was required to be tall enough to support them. This accounted for the additional height of the dock and the associated excess material resulted in the increased weight. A future redesign of this dock height could be created that passes both specifications and would still be able to support the batteries. One positive from the larger dock design was an increased ability for air to move around the unit and the PCB, allowing greater cooling and added user safety. Potentially due to the added user safety, a reworking of the customer needs and engineering metrics may be negotiated to find a good middle ground between size and safety.

## CONCLUSIONS AND RECOMMENDATIONS

Initially many vendors were considered, but almost all parts were available from Digi-Key. An additional advantage to getting most parts from the same vendor was reduced shipping costs. They also have a very good search function to help find parts that meet all desired specs of the device being designed and also magnificent customer service. Due to all of these reasons, Digi-Key became the primary supplier of parts.

Over the duration of the course, many changes were made to the design. In a preliminary design, surface-mount parts used however, in the end through-hole parts were found to be more suitable for the project. This actually caused an error leading to purchasing of a wrong part because one part was incorrectly updated on the bill of materials. The part was able to be exchanged so it really wasn't too much of a hassle. This could have potentially been a much costlier mistake if many of the parts had longer lead times; fortunately all of the parts used in this design had very short lead times.

If this project were to be done again a single microcontroller would be used instead of eight separate ones. This would reduce board space and price. Not much else could be done to improve the electrical design of the charging dock.

***Lessons Learned***

- Always make sure someone is checking the mechanical drawings for accuracy.
- Double check any calculations before designing around them.
- Order parts early and expect complications with shipments and incorrect parts.
- Ensure everyone is using a common naming scheme for drawings, components, etc.
- Use revision control and make sure everyone is using the correct revision of the drawings.
- How to lay out a PCB.
- How to coordinate with other members of different engineering areas in order to reach a given goal, i.e. EE's working with ME's.
- Being able to working with deadlines.
- Linear regulators can be back fed. When designing a circuit, make sure your power line is kept separate from other possible power supplies.
- Probes should not be used to test pins on chips. There should be test pins so nothing gets accidently shorted.
- Electrical schematics are hard to make and maintain.
- Before ordering material, figure out how it is going to be cut, and figure out if the material being ordered can be cut that way safely.
- Take account of all material available before ordering to prevent ordering something not useful.
- Before having material cut, have in hand all parts to be assembled with material, check alignment and fastener interferences.
- Have multiple engineers check drawings, do not trust creator to make perfect drawings the first time.
- Have multiple people check everything before submission and cutting, fresh eyes often see the things missed by the people who have spent tens of hours staring at one thing.
- Consult other faculty earlier on in the project, since we had very little experience with the topic, additional starting ideas would have been nice.
- Have guides more thoroughly look at circuit layout for potential problems, since bad things happened (like back feeding the regulator) that could have easily been fixed but we were unaware of such potential problems.
- Creating drawings were very difficult from an EE perspective, since we have 0 experiences with standards that they need to comply by. So a lesson from faculty on how to create proper drawings would be cool.
- Make sure proper tools are available to you before creating drawings and schematics. RIT really doesn't supply all the best stuff.
- Have more people (including teammates) actually check over all documentation including BOM so that errors don't occur when ordering the wrong part or wrong amounts, which happened like 2 or 3 times.


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*Rob Kraynik*
*Mark Smith*
*Mechanical Engineering Department*

## APPENDICES

*Appendix A – Electrical Testing 1*

| | | | |
|---|---|---|---|
| **Using microcontroller battery charging program and backup AC supply** | | | |
| ***Materials needed: Ammeter*** | | from left to right | |
| Program all 8 microcontrollers and insert them into all channel slots | x | tp1 | battery voltage |
| Plug in power supply to AC outlet and connect barrell connector to the input of the Charging dock | x | tp2 | input to voltage regulator |
| Wait 16 seconds and verify all 8 red LEDs turn on | x | tp3 | output of regulator |
| Plug discharged battery into chanel 1 | x | tp4 | voltage divider opamp output |
| wait 16 seconds and verify red LED 1 turn off and green LED 1 starts blinking | x | tp5 | voltage into relay |
| Plug discharged battery into chanel 2 | x | | |
| wait 16 seconds and verify red LED 2 turn off and green LED 2 starts blinking | x | | |
| Plug discharged battery into chanel 3 | x | | |
| wait 16 seconds and verify red LED 3 turn off and green LED 3 starts blinking | x | | |
| Plug discharged battery into chanel 4 | x | | |
| wait 16 seconds and verify red LED 4 turn off and green LED 4 starts blinking | x | | |
| Plug discharged battery into chanel 5 | x | | |
| wait 16 seconds and verify red LED 5 turn off and green LED 5 starts blinking | x | | |
| Plug discharged battery into chanel 6 | x | | |
| wait 16 seconds and verify red LED 6 turn off and green LED 6 starts blinking | x | | |
| Plug discharged battery into chanel 7 | x | | |
| wait 16 seconds and verify red LED 7 turn off and green LED 7 starts blinking | x | | |
| Plug discharged battery into chanel 8 | x | | |
| wait 16 seconds and verify red LED 8 turn off and green LED 8 starts blinking | x | | |
| measure current going into battery 1, verify current going into battery is between 0.3 and 0.7 A | x | | |
| measure current going into battery 2, verify current going into battery is between 0.3 and 0.7 A | x | | |
| measure current going into battery 3, verify current going into battery is between 0.3 and 0.7 A | x | | |
| measure current going into battery 4, verify current going into battery is between 0.3 and 0.7 A | x | | |
| measure current going into battery 5, verify current going into battery is between 0.3 and 0.7 A | x | | |
| measure current going into battery 6, verify current going into battery is between 0.3 and 0.7 A | x | | |
| measure current going into battery 7, verify current going into battery is between 0.3 and 0.7 A | x | | |
| measure current going into battery 8, verify current going into battery is between 0.3 and 0.7 A | x | | |
| Unplug battery in channel 1 | x | | |
| wait 16 seconds and verify green LED1 stops blinking and red LED1 goes solid | x | | |
| Unplug battery in channel 2 | x | | |
| wait 16 seconds and verify green LED2 stops blinking and red LED2 goes solid | x | | |
| Unplug battery in channel 3 | x | | |
| wait 16 seconds and verify green LED3 stops blinking and red LED3 goes solid | x | | |
| Unplug battery in channel 4 | x | | |
| wait 16 seconds and verify green LED4 stops blinking and red LED4 goes solid | x | | |
| Unplug battery in channel 5 | x | | |
| wait 16 seconds and verify green LED5 stops blinking and red LED5 goes solid | x | | |
| Unplug battery in channel 6 | x | | |
| wait 16 seconds and verify green LED6 stops blinking and red LED6 goes solid | x | | |
| Unplug battery in channel 7 | x | | |
| wait 16 seconds and verify green LED7 stops blinking and red LED7 goes solid | x | | |
| Unplug battery in channel 8 | x | | |
| wait 16 seconds and verify green LED8 stops blinking and red LED8 goes solid | x | | |
| Unplug barrell connector from the input of the Charging dock and unplug power supply to AC outlet | x | | |

## Using microcontroller test program and backup AC supply

***Materials needed: Voltmeter***

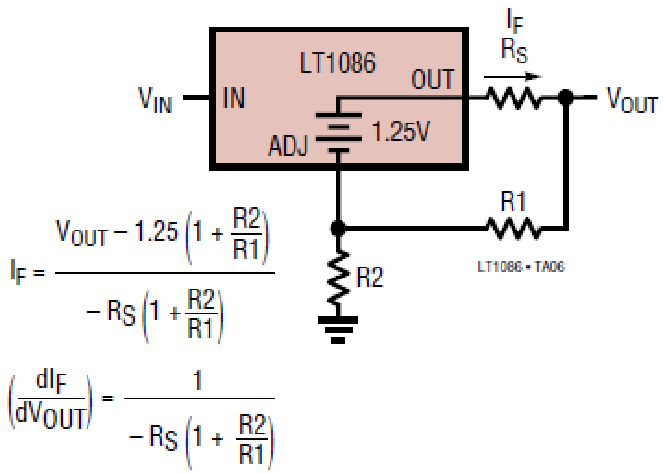
Put test program on  8 microcontroller and insert them into all channel slots
Plug in power supply to AC outlet and connect barrell connector to the input of the Charging dock
Test channel 1, confirming red and green leds blink every 1 second
Voltage of pin 7 of microcontroller should go from 0-3.6V every second
Voltage of test pin 2, goes from 0-12V
check to make sure reset button stops voltage strobing
Test channel 2, confirming red and green leds blink every 1 second
Voltage of pin 7 of microcontroller should go from 0-3.6V every second
Voltage of test pin 2, goes from 0-12V
check to make sure reset button stops voltage strobing
Test channel 3, confirming red and green leds blink every 1 second
Voltage of pin 7 of microcontroller should go from 0-3.6V every second
Voltage of test pin 2, goes from 0-12V
check to make sure reset button stops voltage strobing
Test channel 4, confirming red and green leds blink every 1 second
Voltage of pin 7 of microcontroller should go from 0-3.6V every second
Voltage of test pin 2, goes from 0-12V
check to make sure reset button stops voltage strobing
Test channel 5, confirming red and green leds blink every 1 second
Voltage of pin 7 of microcontroller should go from 0-3.6V every second
Voltage of test pin 2, goes from 0-12V
check to make sure reset button stops voltage strobing
Test channel 6, confirming red and green leds blink every 1 second
Voltage of pin 7 of microcontroller should go from 0-3.6V every second
Voltage of test pin 2, goes from 0-12V
check to make sure reset button stops voltage strobing
Test channel 7, confirming red and green leds blink every 1 second
Voltage of pin 7 of microcontroller should go from 0-3.6V every second
Voltage of test pin 2, goes from 0-12V
check to make sure reset button stops voltage strobing
Test channel 8, confirming red and green leds blink every 1 second
Voltage of pin 7 of microcontroller should go from 0-3.6V every second
Voltage of test pin 2, goes from 0-12V
check to make sure reset button stops voltage strobing

**Using microcontroller battery charging program and 12401 Battery**

***Materials needed: 12401 Battery, ammeter***

Program all 8 microcontrollers and insert them into all channel slots
Plug in power supply to AC outlet and connect barrell connector
Wait 16 seconds and verify all 8 red LEDs turn on
Plug discharged battery into chanel 1
wait 16 seconds and verify red LED 1 turn off and green LED 1 starts blinking
Plug discharged battery into chanel 2
wait 16 seconds and verify red LED 2 turn off and green LED 2 starts blinking
Plug discharged battery into chanel 3
wait 16 seconds and verify red LED 3 turn off and green LED 3 starts blinking
Plug discharged battery into chanel 4
wait 16 seconds and verify red LED 4 turn off and green LED 4 starts blinking
Plug discharged battery into chanel 5
wait 16 seconds and verify red LED 5 turn off and green LED 5 starts blinking
Plug discharged battery into chanel 6
wait 16 seconds and verify red LED 6 turn off and green LED 6 starts blinking
Plug discharged battery into chanel 7
wait 16 seconds and verify red LED 7 turn off and green LED 7 starts blinking
Plug discharged battery into chanel 8
wait 16 seconds and verify red LED 8 turn off and green LED 8 starts blinking
measure current going into battery 1, verify current going into battery is between 0.3 and 0.7 A
measure current going into battery 2, verify current going into battery is between 0.3 and 0.7 A
measure current going into battery 3, verify current going into battery is between 0.3 and 0.7 A
measure current going into battery 4, verify current going into battery is between 0.3 and 0.7 A
measure current going into battery 5, verify current going into battery is between 0.3 and 0.7 A
measure current going into battery 6, verify current going into battery is between 0.3 and 0.7 A
measure current going into battery 7, verify current going into battery is between 0.3 and 0.7 A
measure current going into battery 8, verify current going into battery is between 0.3 and 0.7 A
Unplug battery in channel 1
wait 16 seconds and verify green LED1 stops blinking and red LED1 goes solid
Unplug battery in channel 2
wait 16 seconds and verify green LED2 stops blinking and red LED2 goes solid
Unplug battery in channel 3
wait 16 seconds and verify green LED3 stops blinking and red LED3 goes solid
Unplug battery in channel 4
wait 16 seconds and verify green LED4 stops blinking and red LED4 goes solid
Unplug battery in channel 5
wait 16 seconds and verify green LED5 stops blinking and red LED5 goes solid
Unplug battery in channel 6
wait 16 seconds and verify green LED6 stops blinking and red LED6 goes solid
Unplug battery in channel 7
wait 16 seconds and verify green LED7 stops blinking and red LED7 goes solid
Unplug battery in channel 8
wait 16 seconds and verify green LED8 stops blinking and red LED8 goes solid
Unplug barrell connector from the input of the Charging dock

**Battery Charger**




$$I_F = \frac{V_{OUT} - 1.25\left(1 + \frac{R2}{R1}\right)}{-R_S\left(1 + \frac{R2}{R1}\right)}$$

$$\left(\frac{dI_F}{dV_{OUT}}\right) = \frac{1}{-R_S\left(1 + \frac{R2}{R1}\right)}$$