California Polytechnic State University, San Luis Obispo

Rapid Battery Exchange (RBX) Charger Interface

Electrical Engineering Department

Adam Morris
6/10/2014

Table of Contents

List of Figures

List of Tables

Acknowledgements

My whole life I have been acquiring and building upon the necessary skills that have allowed me to contribute effectively to the large, multidisciplinary project that is the Rapid Battery Exchange. I owe many thanks to the people who have guided me along the way. In particular, I would like to thank:

- everyone who has ever given me a meal.
- everyone who has ever taught me anything.
- my parents for not stifling my insatiable desire to tinker and create.
- my childhood neighbor George Keeling who gave me full access to his tools when I was a kid and exposed me to the idea that with enough time and patience a person can make some pretty interesting and functional stuff out of scrap and derelict parts.
- Katie Driskell for all of the unwavering support that she provided me throughout my pursuit of a bachelor’s degree.
- Professor Art MacCarley for his technical guidance and for fully embodying the “learn by doing” philosophy that I so thoroughly enjoy.

Abstract

As fossil fuel prices steadily rise and concerns associated with burning the fuels increase, electric vehicle sales continue to grow. According to the U.S. Department of Energy, EV sales “tripled from about 17,000 in 2011 to about 52,000 in 2012” [1]. In order to meet consumer transportation expectations—molded by fuel-powered vehicles—electric cars must have the ability to “refuel” quickly. Rapidly charging an EV’s traction battery poses one solution but doing so requires large power levels “five times as much as the average office consumes,” [2] making rapid charging less than ideal for the masses. Alternatively, swapping an EV’s depleted battery with a charged one eliminates the vehicle’s charging downtime and allows the battery pack to charge at an optimal rate while out of the vehicle.

Introduction

People have been driving cars for over a hundred years and over those years certain expectations have evolved, most notably the virtual unlimited range of a fuel-powered vehicle. As long as one travels near fuel station infrastructure, and maintains the mechanical integrity of the vehicle, a fuel-powered vehicle can travel indefinitely. With the re-emergence of electric vehicles on the personal transportation market, charging solutions for the electric vehicle traction batteries, that enable an EV to also travel indefinitely, need exploring. One solution lies in exchanging the EV's depleted battery with a charged one, thus allowing the EV to continue traveling while the depleted battery charges elsewhere.

To address the solution of electric vehicle battery swapping, Cal Poly's Electric Vehicle Engineering Club (EVEC) has taken on the challenge of creating a proof of concept Rapid Battery Exchange (RBX) system. The RBX exchanges the traction battery in a modified 1991 GMC electric G-Van. Work completed up to the beginning of this project included most of the exchange apparatus and automation, but interfacing of charging equipment with an extracted battery remained untouched.

The Van's original design included a permanent traction battery. Charging the battery required parking and plugging the van into one of two specially designed chargers [3]. One charger uses 120 Vac supply and the other uses 240 Vac. With the RBX system making the van's depleted battery packs removable, the original chargers needed an interface allowing them to charge a pack once extracted from the van. This report presents the design and build of the RBX's charger interface.

Requirements and Specifications

A successful RBX system exchanges an electric vehicle's depleted traction battery with a charged one. Upon a completed exchange, charging of the depleted battery begins, readying it for the next exchange.

This report focuses on the design and build of one sub-module of the whole RBX system: the electrical interface between a stand-alone battery charger and the RBX system. In order to consider the RBX charger interface a success, it must meet the following criteria:

- Stop battery charging before carrying out a battery exchange
- Supply power to the charger during times of standby (no exchange in process)
- Supply battery-charging power to one of two possible charging stations with one charger
- Allow for the use of either the 120 Vac or 240 Vac supplied charger
- Facilitate the use of several different types of chargers; this keeps from constraining the RBX to a specific battery type
- Integrate into the RBX's existing automation sequence
- Operate safely

Table 1 describes all of the specifications and requirements taken into account in order to meet the above criteria while designing and building the RBX charger interface.

Table 1: RBX requirements and specifications

Marketing Requirements	Engineering Specifications	Justification
1	Electrically disconnect the battery pack from the charger before the battery pack moves	• Prevents potential arcing between the battery pack and charging station contacts
1	Keep the charger disconnected from both charging stations during a battery pack exchange	• Prevents potential arcing between the battery pack and charging station contacts • Prevents the possibility of having charging voltage at open charging station terminals
1, 2	All of the charger's electrical supply components rated for no less than single phase 240 V_{ac}, 50 A_{ac}	• The larger Electro Networks charger requires single phase 240 V_{ac}, 42 A_{ac} supply
1	Over current protect the charger's electrical supply at 50 A_{ac}	• Prevents injury and damage in the event of an electrical short on the charger's AC supply

Marketing Requirements	Engineering Specifications	Justification
1, 2	All of the charger's DC output circuit components rated for no less than 252 V_{dc}, 40 A_{dc}	• The larger Electro Networks charger nominally outputs 216 V_{dc}, 36 A_{dc} • Some 12 V battery chargers charge 12 V batteries at up to 14 V; with 18 batteries in series in a pack, 18*14 V=252 V_{dc}
1	Over current protect the charger 's battery charging output at 40 A_{dc}	• Prevents injury and damage in the event of an electrical short on the charger's DC output circuit
3	Manually resettable over current protection	• Prevents the need to have consumable fuses on hand
2	Make all terminations for conductors supplying more than 5V within an NEC approved junction box or similar housing	• Prevents exposure to dangerous voltage levels
3	Mount all non-weather proof components in a weather proof enclosure	• The RBX system may be employed outside and exposed to the elements
4, 5	The charger's DC output circuit provides an electrical path to one of two possible charging stations depending on 5 V_{dc}, 10 mA_{dc} microcontroller logic signals	• The RBX ramp's microcontroller has I/O pins rated at 0-5V_{dc}, with a maximum output signal current of 20 mA_{dc}
4, 5	Microcontroller sense a battery pack as soon as the system moves it under one of the two charging stations	• One battery charger provides charging power to two different charging stations; the microcontroller needs to know the battery location on the ramp in order to send the appropriate logic signals to line up the DC charging circuit correctly
5	All components interfacing with microcontroller logic have an R_{in} of no less than 500Ω	• The microcontroller's I/O pins have a maximum rating of 5 V_{dc} and 20 mA_{dc}, the charger interface requires 5 V_{dc} and 10 mA_{dc} max to function R_{in}=5V/10mA=500Ω
5	Switch the charger's AC electrical supply with a Metasol MC-50a contactor	• This device previously existed in the EVEC's parts inventory. Since devices of this size cost $65.00 or more, the charger interface design was constrained by the use of the Metasol
6	Connect the charger's electrical supply via a grounded plug rated at: • 240 V_{ac}, 50 A_{ac} if using the large charger • 120 V_{AC} 20 A_{AC} if using the small charger	• Connecting the charger with a plug makes swapping the charger out simpler. This facilitates the option of using a different type of batteries, which may need a different type of charger without having to change the charger interface
6	Electrically connect the charger's DC output to the charger interface using a Chloride 7 pin connector	• Connecting the charger with a plug makes swapping the charger out simpler. This facilitates the option of using a different type of batteries, which may need a different type of charger • The current chargers are equipped with this plug

Marketing Requirements	Engineering Specifications	Justification
7	Plug the available AC electrical supply (120 or 240 V_{ac}) directly into the ramp. This passes through the AC over current protection, and energizes the appropriate plug depending on the charger in use	• With 240 V_{ac} available, use the large charger • With only 120 V_{AC} available, use the small charger

Marketing Requirements

1. Operates Safely
2. Meets National Electric Code (NEC)
3. Robust
4. One charger supplies charging power to two charging stations
5. Interfaces with the existing RBX ramp
6. Does not require a specific battery or charger type
7. Flexible electrical supply supports chargers that require either 120 V_{ac} or 240 V_{ac}

Functional Decomposition

Figure 1 shows a level 0 block diagram for the RBX charger interface. The diagram includes all system inputs and outputs.

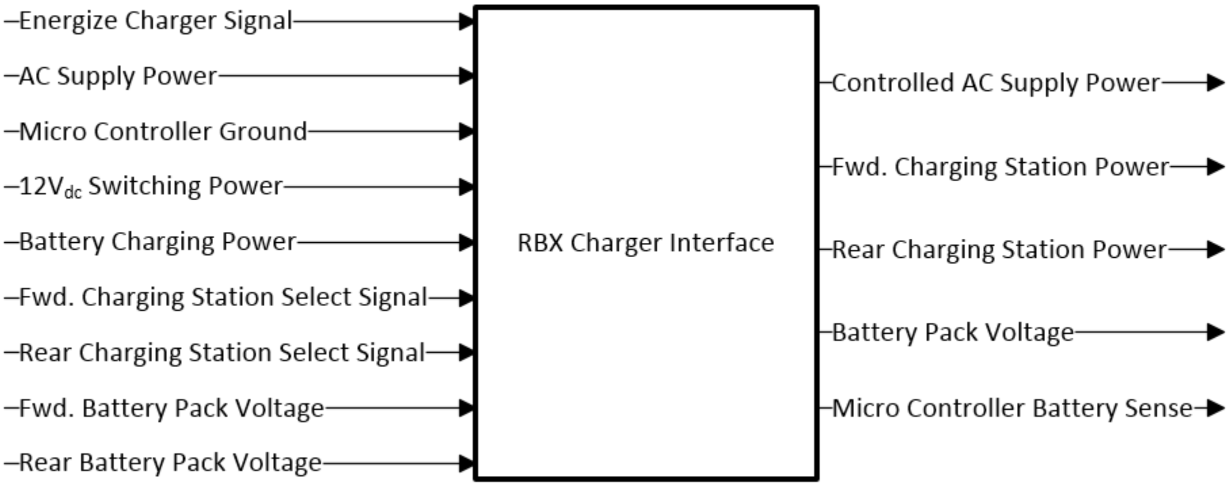


Figure 1: RBX Charger Interface level 0 block diagram

Table 2 contains descriptions of the level 0 inputs, outputs, and the overall functionality of the system.

Table 2: Level 0 functional requirements

Inputs	• **Energize Charger Signal**: Signal form micro controller that controls supply power to the charger • **AC Supply Power**: Battery charger AC supply power (120 V_{AC} or 240 V_{AC} depending on the charger in use). Note: controlling the supply power controls the on/off state of the charger • **Micro Controller Ground**: Provides complete path for micro controller signals and the 12 V_{dc} switching power • **12V_{dc} Switching Power**: Used to amplify control signals from the micro controller in order to energize relay coils • **Battery Charging Power**: Battery charging DC created by a stand-alone charger and distributed to the appropriate charging station by the charger interface • **Fwd. Charging Station Select Signal**: Signal form micro controller that controls sending charging power to the forward charging station • **Rear Charging Station Select Signal**: Signal form micro controller that controls sending charging power to the rear charging station • **Fwd**. **Battery Pack Voltage:** Voltage of battery pack at forward charging station • **Rear Battery Pack Voltage**: Voltage of battery pack at rear charging station
Outputs	• **Controlled AC Supply Power**: Battery charger AC supply power (controlled on and off by the micro controller via the Energize Charger Signal) • **Fwd. Charging Station Power**: Battery charging DC directed to the forward charging station • **Rear Charging Station Power**: Battery charging DC directed to the rear charging station • **Battery Pack Voltage**: Battery pack voltage sent to the stand alone charger so it can control the charging schedule • **Micro Controller Battery Sense**: Allows micro controller to sense the presence of a battery
Functionality	The RBX Charger interface • Controls the AC supply power to the charger • Directs the DC charging power to either the forward or the rear charging station depending on where a battery pack is located at the time • Sends battery pack voltage to the charger so it can control the charging schedule • Allows micro controller to sense the presence of a battery

Figure 2 shows the level 1 block diagram for the RBX charger interface. This diagram breaks the level 0 diagram into the next hierarchical level of functional subsystems.

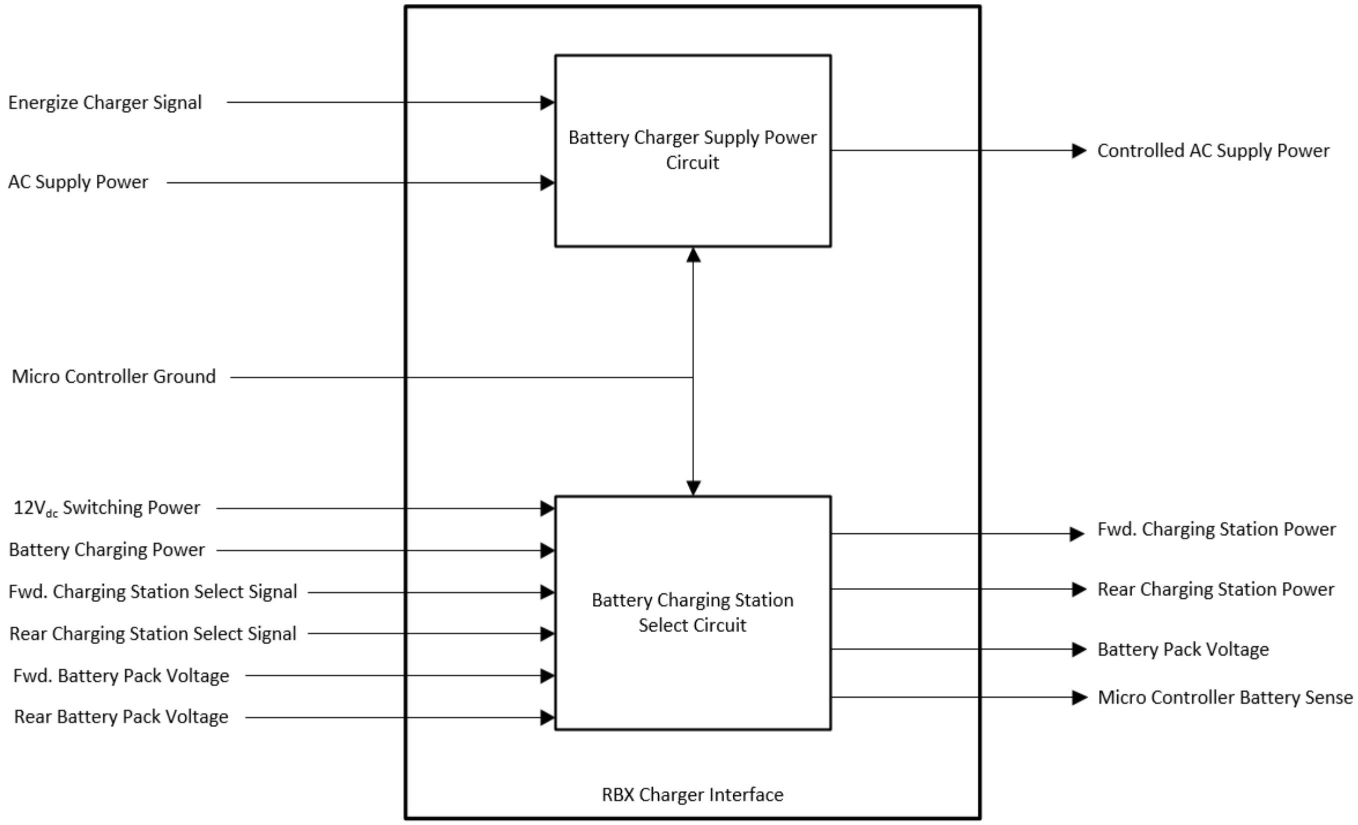


Figure 2: RBX Charger Interface level 1 block diagram

Table 3 contains descriptions of the level 1 module inputs, outputs, and the overall functionalities.

Table 3: Level 1 functional requirements

Subsystem	Inputs	Outputs	Functionality
Battery Charger Supply Power Circuit	• **Energize Charger Signal**: Signal form micro controller that controls supply power to the charger • **AC Supply Power**: Battery charger AC supply power (120 V_{AC} or 240 V_{AC} depending on the charger in use). Note: controlling the supply power controls the on/off state of the charger • **Micro Controller Ground**: Provides complete path for micro controller signals	• **Controlled AC supply-power**: the ramp's microcontroller controls the charger's on/off state by controlling the charger's supply power	Controls the AC supply power to the charger
Battery Charging Station Select Circuit	• **12V_{dc} Switching Power**: Used to amplify control signals from the micro controller in order to energize relay coils • **Micro Controller Ground**: Provides complete path for micro controller signals and the 12 V_{dc} switching power • **Battery Charging Power**: Battery charging DC created by a stand-alone charger and distributed to the appropriate charging station by the charger interface • **Fwd. Charging Station Select Signal**: Signal form micro controller that controls sending charging power to the forward charging station • **Rear Charging Station Select Signal**: Signal form micro controller that controls sending charging power to the rear charging station • **Fwd. Battery Pack Voltage:** Voltage of battery pack at forward charging station • **Rear Battery Pack Voltage**: Voltage of battery pack at rear charging station	• **Fwd. Charging Station Power**: Battery charging power directed to the forward charging station • **Rear Charging Station Power**: Battery charging power directed to the rear charging station • **Battery pack voltage**: Battery pack voltage sent to the stand alone charger so it can control the charging schedule • **Micro Controller Battery Sense**: Allows micro controller to sense the presence of a battery	• Directs the DC charging power to either the forward or the rear charging station • Sends battery pack voltage back to the charger so it can control the charging schedule • Allows micro controller to sense the presence of a battery

Subsystem Development and Design

This section describes the design of the two subsystems that make up the charger interface—the Battery Charger Supply Power Circuit, and the Battery Charging Station Select Circuit.

Battery Charger Supply Power Circuit

The Battery Charger Supply Power Circuit allows the RBX system to control the standalone battery charger's supply power thus enabling it to turn the charger off before moving a battery pack (for instance during an exchange) and back on after an exchange.

The design of the Battery Charger Supply Power subsystem was constrained by three major elements, it had to:

- facilitate the use of either a 120 V_{ac} or 240 V_{ac} supplied charger
- make use of a Metasol MC-50a contactor as it was appropriately sized and already in the EVEC's parts inventory
- interface with the existing RBX system control which is carried out with 5 V_{dc}, 20 mA_{max} micro controller signals

The coil on the Metasol MC-50a contactor requires 120 V_{ac}. A BTA140 triac was selected to switch the coil circuit and an MOC3022 optoisolator triac driver was selected to interface between the triac and the micro controller as seen in figure 3.

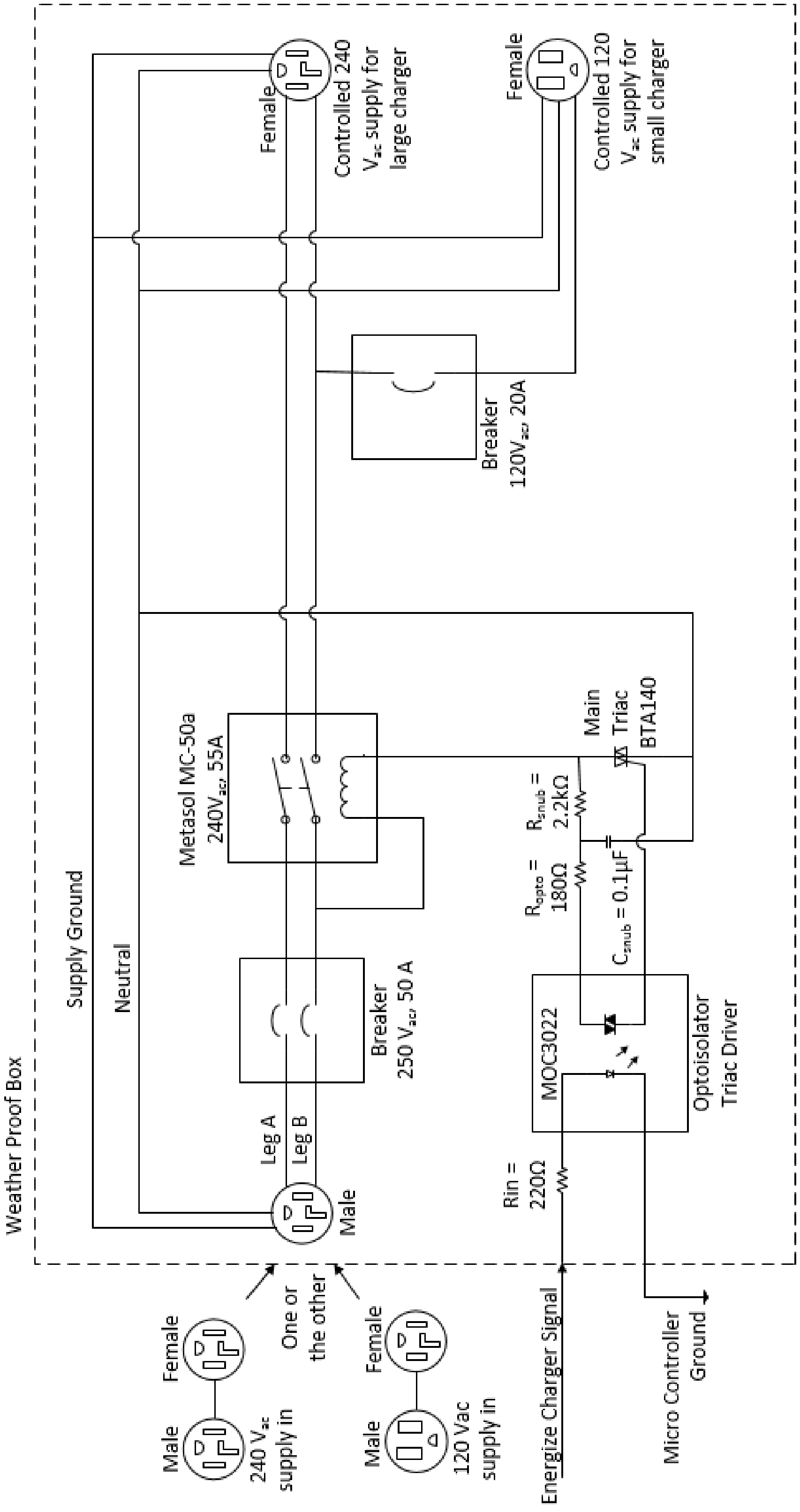


Figure 3: Battery Charger Supply Power Circuit

The main triac and the internal triac of the optoisolator are both susceptible to unintentionally turning on if their conduction terminals are exposed to a critical change in voltage per time $\left(\frac{dv}{dt}\right)$ as noted in their respective data sheets[4],[5]. Coupling the triacs to an inductive load (like the coil of the Metasol contactor) requires a snubber circuit to keep the rate of voltage rise at the triac terminals upon coil de-energization below the critical $\frac{dv}{dt}$.

Calculations sizing the snubber circuit were initially made using the typical triac gate trigger current (I_{GT}) of 6 mA as given in the data sheet [4] and the circuit was breadboarded for testing. The triac circuit fully energized the Metasol contactor when first constructed. The following morning, when the ambient temperature was lower, the circuit failed to fully energize the Metasol. When the ON signal was delivered to the triac circuit the Metasol rapidly engaged and disengaged, emitting a loud “buzzing” sound.

The triac’s data sheet revealed that as temperature decreases, minimum required I_{GT} increases. Not providing the necessary I_{GT} prevented the triac from fully turning on which in turn prevented the Metasol from fully turning on. Having too low of an I_{GT} was further confirmed in the following two ways: First, after the ambient temperature had risen, R_{snub} was increased to 10 kΩ (nearly twice the original resistance); this caused the expected failure-to-energize . Second, the original R_{snub} was inserted back into the circuit and the whole circuit was placed in a refrigerator overnight. The circuit was immediately given an ON signal after removal from the refrigerator the next day. Again, as expected, the Metasol failed to energize.

The following calculations show the resizing of snubber circuit components which allow a larger I_{GT} thus allowing the circuit to function properly in lower temperatures (tested down to ~35° F).

Size R_{opto} to limit the peak capacitor discharge current into the MOC3022 triac driver.

$$R_{opto} = \frac{V_{Csnub\ pk}}{I_{driver\ out\ max}} = \frac{170V}{1A} = 170\Omega$$

Use standard 5% resistor value of 180Ω.

To size R_{snub} and C_{snub} we assume the triac turns off very quickly and that the voltage over the driver and C_{snub} spikes to approximately $V_{Csnub\ pk}$ in τ seconds, i.e. $\frac{dv_{csnub}}{dt} = \frac{V_{Csnub\ pk}}{\tau} = \frac{170V}{(R_{snub})(C_{snub})}$. The critical $\frac{dv}{dt}$ that turns the driver on unintentionally $0.8\frac{V}{\mu s}$ (figure 4 Triac Driver Application Note [6]). Setting the two together and solving for $(R_{snub})(C_{snub})$ we get:

$$0.8\frac{V}{\mu s} \geq \frac{170V}{(R_{snub})(C_{snub})} \quad \rightarrow \quad (R_{snub})(C_{snub}) = \tau \geq \frac{170V}{0.8\frac{V}{\mu s}} = 212.5\mu s$$

Now, taking into consideration triac gate trigger current, $I_{GT} = 15mA$, to ensure that the triac fully turns on, and selecting to turn the triac on at 40V, we find the largest usable R_{snub} (Note that triac turn on at 40V was arbitrarily suggested by the application note [6]).

$$\left(\mathrm{R_{opto}} + \mathrm{R_{snub}}\right) = \frac{\mathrm{V_{triac\ trig}}}{\mathrm{I_{GT}}} = \frac{40\mathrm{V}}{15\mathrm{mA}} \quad \rightarrow \quad \mathrm{R2} = \frac{40\mathrm{V}}{15\mathrm{mA}} - 170\Omega \approx 2.2\mathrm{k}\Omega$$

Use standard 5% resistor value of 2.2kΩ.

With R_{snub} sized we size C_{snub}:

$$\mathrm{C_{snub\ min}} = \frac{\tau}{\mathrm{R_{snub}}} = \frac{212.5\mu\mathrm{s}}{2.2\mathrm{k}\Omega} = 96.6\mathrm{nF}$$

Setting $\mathrm{C_{snub}} = 0.1\mathrm{uF}$ sufficiently meets $\tau \geq 212.5\mu\mathrm{s}$

In the steps above the snubber circuit for the triac-driver was designed. The triac being driven has a critical $\frac{\mathrm{dv}}{\mathrm{dt}}$ of $300\,\frac{\mathrm{V}}{\mu\mathrm{s}}$. This tolerance is much looser than the tolerance of the triac-driver, therefore the snubber circuit designed for the triac-driver sufficiently “snubs” the triac as well.

The triac-driver’s data sheet indicates that it is guaranteed to trigger when the LED receives between 10mA and 60mA [triac-driver data sheet citation number] with a voltage drop of 1.5V over the LED. Designing for 15mA LED trigger current, and using a driver trigger signal voltage $\mathrm{V_{driver\ trig}} = 5\mathrm{V}$ nominal we can size the triac-driver’s input resistor:

$$\mathrm{R_{in}} = \frac{\mathrm{V_{driver\ trig}} - \mathrm{V_{LED}}}{\mathrm{I_{LED}}} = \frac{5\mathrm{V} - 1.5\mathrm{V}}{15\mathrm{mA}} \approx 233.3\Omega$$

Use standard 1% resistor value of 220Ω.

Battery Charging Station Select Circuit

The Battery Charging Station Select Circuit allows the RBX system to sense whether or not there is a battery under a given charger and allows for the proper electrical line-up when charging a battery; sending charging power only to the station that has a battery present.

Three major elements constrained the design of the Battery Charging Station Select subsystem:

- interface with the existing RBX system control which is carried out with 5 V_{dc}, 20 mA_{max} micro controller signals
- sense whether or not a battery is present under a given charging station
- distribute battery charging power to only one of two charging stations at a time

Figure 4 shows the Battery Charging Station Select Circuit schematic.

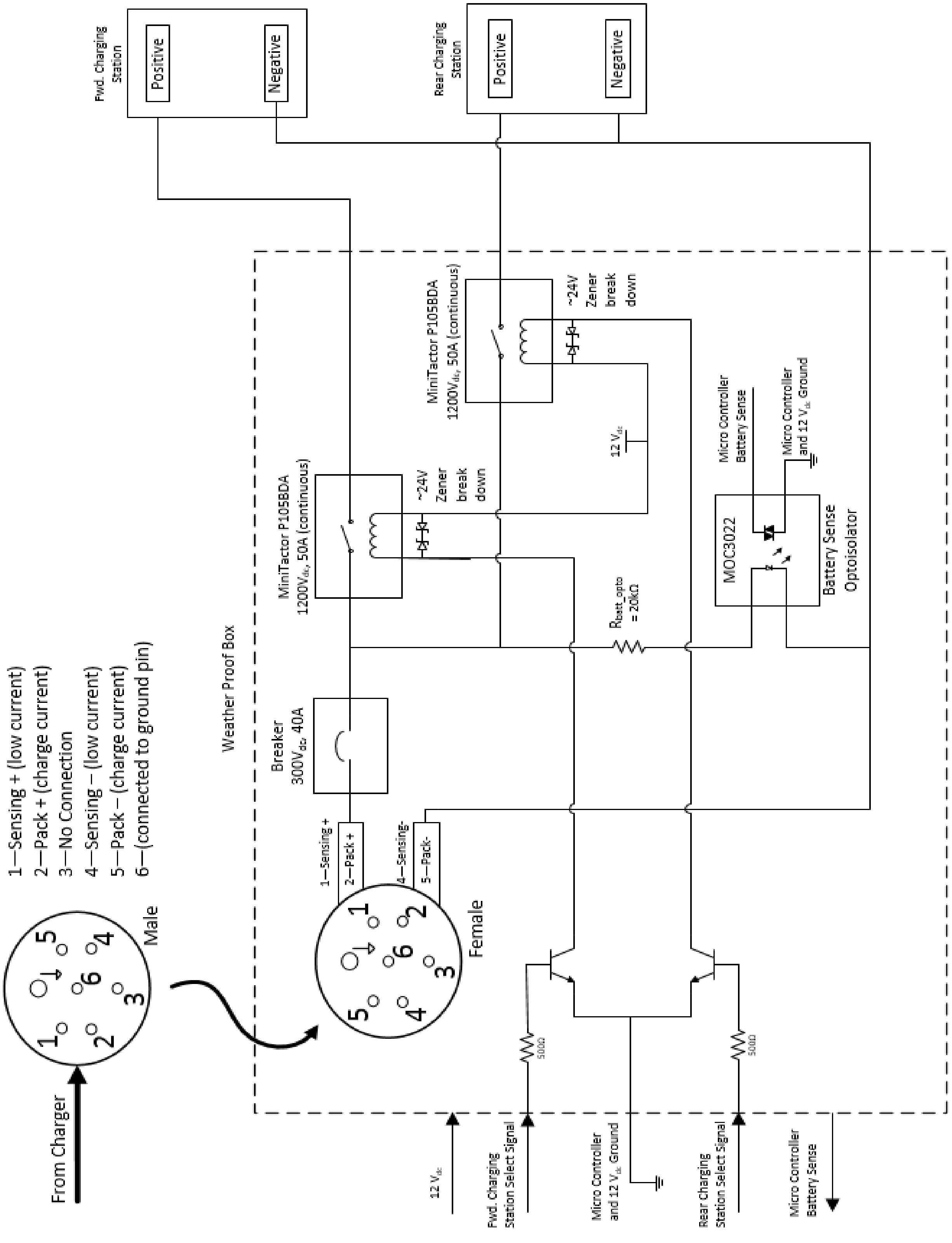


Figure 4: Battery Charging Station Select Circuit

Initially the battery pack was going to relay its position to the ramp micro controller; the charger interface was not responsible for sensing the battery. Unfortunately, when the system made electrical connection between the battery pack to the RBX system for charging, the battery pack's micro controller had intermittent problems with resetting. We deduced that the problem was caused by floating grounds. When the electrical connection was made and ground potentials on the battery pack and the RBX system equalized, the battery pack's micro controller ground changed potential which evoked the micro controller to reset.

One proposed solution to the floating ground problem was to power the battery packs micro controller with an isolated DC-DC converter. This would provide and isolated ground to the micro controller which should prevent reset during ground equalization. Unfortunately, this solution required more time for development and implementation than was available.

It was decided to use the charger interface to sense a battery. This implementation was first carried out with a voltage divider between the output terminals of the battery pack: pack + and pack –. The full battery voltage was proportionally reduced down to levels that the RBX's micro controller could handle (5 V_{dc} maximum) and sent to the RBX micro controller's analog to digital converter. Unfortunately, electrically coupling the battery to the RBX at different times for sensing induced the same floating ground problem that was seen with the battery pack micro controller, but this time with the RBX's micro controller.

The final iteration of battery pack position sensing replaced the sensing voltage divider with an optoisolator as seen in figure 4. The optoisolator allows sensing of the batteries presence while keeping the battery's ground and the RBX system's ground separate. When a cart is in position under a charging station, the appropriate miniTactor is energized (either forward or rear). If a battery is not present, the optoisolator's LED is not energized and the RBX micro controller battery sense pin does not get a path to ground which keeps it from "seeing" a battery. If a battery is present, the optoisolator's LED is energized and the RBX micro controller battery sense pin gets a path to ground which is interpreted by the micro controller as a battery being present.

The GIGAVAC miniTactor data sheet recommended 24 V_{dc} external coil suppression [7] and GIGAVAC's coil suppression application note recommended the "use of a zener-zener or diode-zener combination with the zener voltage at 2 times, or more, of the coil source voltage" [8]. The zener diodes seen in figure 4, in parallel with the miniTactor's coils, have a reverse break down of 24 V and a forward voltage drop of ~1.2 V. They prevent voltage spikes in the coil circuit upon coil de-energization by clamping the coil voltages to approximately 25.2 V.

The battery sense optoisolator's LED drops approximately 1.5 V when on. To size R_{batt_opto} I calculated for $i_{optp\_LED} \approx 10mA$ with the nominal pack voltage of 216 V_{dc} therefore:

$$R_{batt\_optp} = \frac{V_{batt} - V_{opto\_LED}}{i_{opto\_LED}} = \frac{216V - 1.5V}{10mA} = 21.45k\Omega$$

Use standard 5% resistor value of 20kΩ.

Note that delivering the roughly 10 mA of current from the battery pack requires that R_{batt_opto} has the capability to deal with the amount of power dissipated in it. Furthermore, calculations must consider that each battery in the battery pack may have a maximum voltage of 14 V_{dc}. Thus, the total battery pack may have a maximum voltage of $14\frac{V_{dc}}{battery} x\ 18batteries = 252V_{dc}$

Resistor power calculations are as follows:

$$P_{R\_batt\_opto} = \frac{\left(V_{R\_batt\_opto}\right)^2}{R_{batt\_opto}} = \frac{\left(V_{batt\_max} - V_{opto_{LED}}\right)^2}{R_{batt\_opto}} = \frac{(252V - 1.5V)^2}{20k\Omega} \approx 3.14W$$

In order to meet the above required power specification two 10kΩ, 2W resistors in series were used to make up R_{opto_LED}. Doing so lets each resistor dissipate ~1.57W of power.

Charger Interface Construction

After designing the charger interface circuits seen in figures 3 and 4 I laid out the control circuit components using PCB Artist (figure 5).

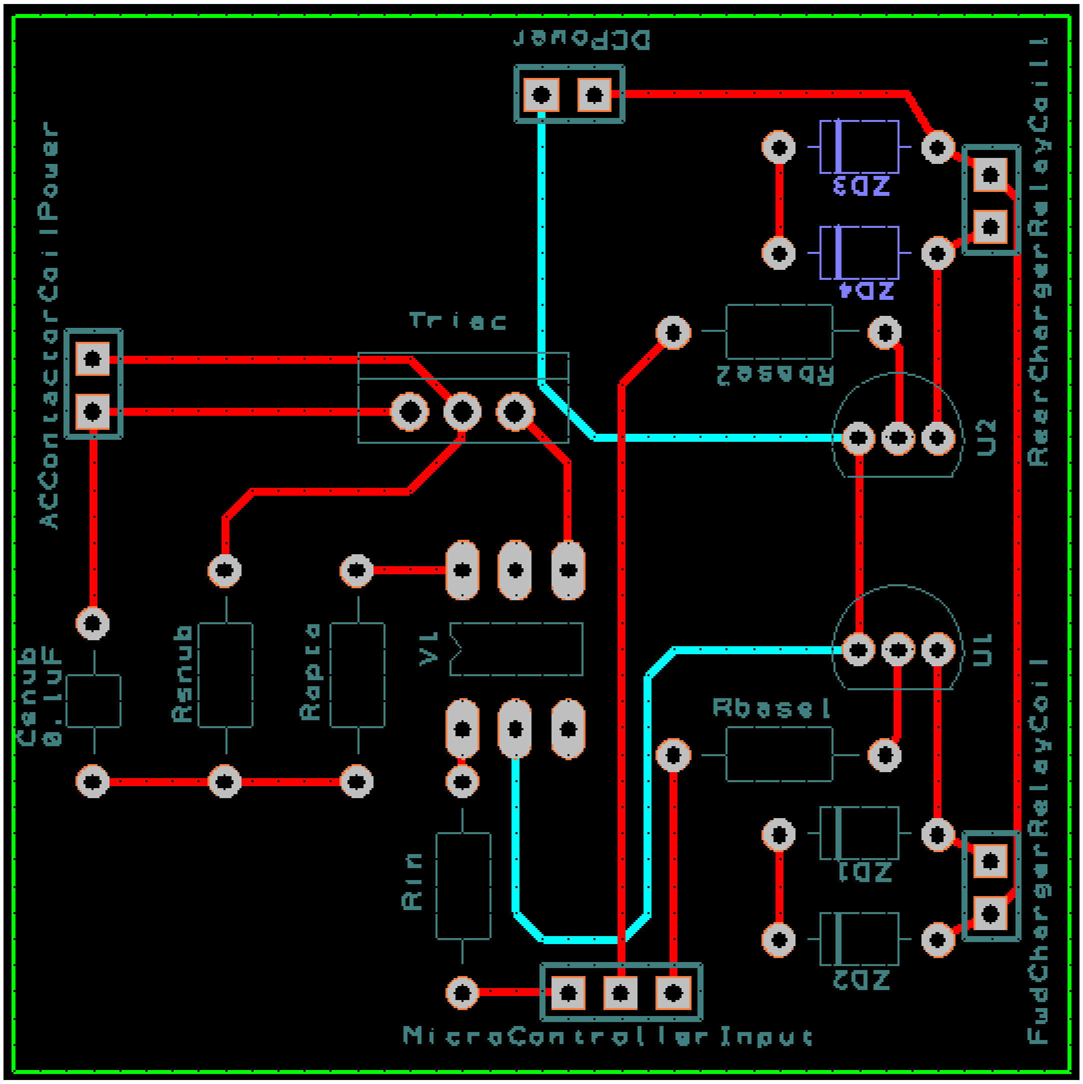


Figure 5: Charger Interface Control Circuit PCB Layout

Note that the battery sensing components R_{sense_opto} and Battery Sense Optoisolator are not included on the PCB layout seen in figure 5 as they were added during the testing and integration phase.

After creating the PCB layout the control circuits were made on the proto-board seen in figure 6.

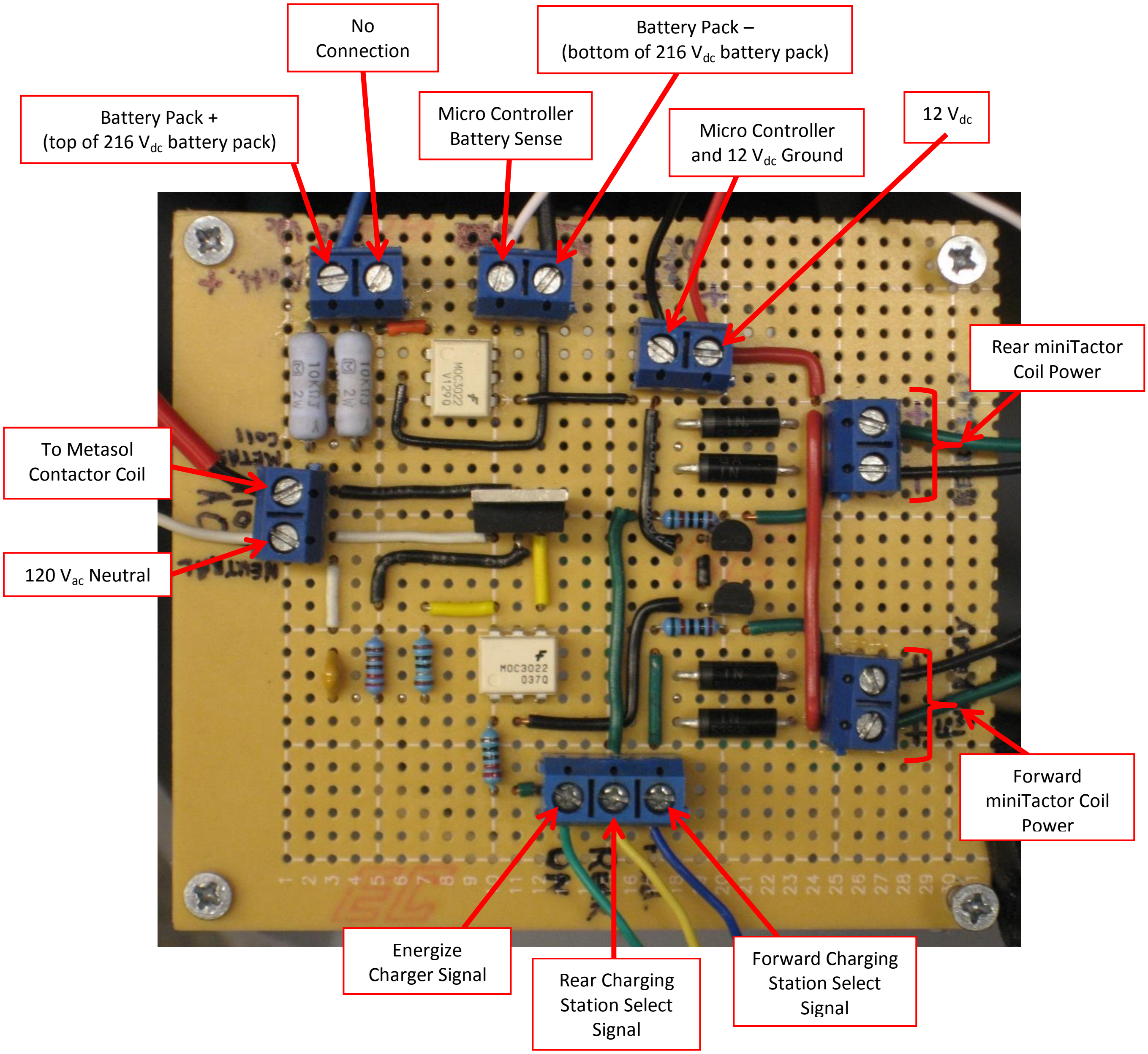
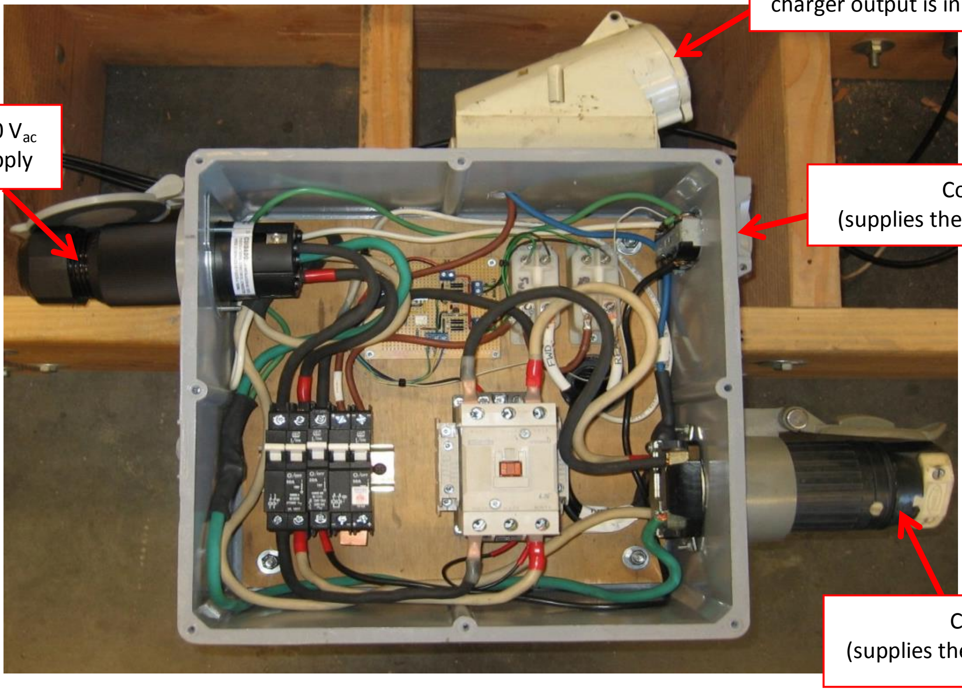


Figure 6: Charger Interface Control Circuits Proto-board

Note that the battery sensing components R_{sense_opto} and Battery Sense Optoisolator that were not included in the PCB layout (figure 5) are included on the proto-board seen in figure 6.

After completing the charger interface control circuits proto-board I tested it with all of the interface components together. This testing is covered in the Integration and Test Results section. Upon successful completion of bench testing, all of the charger interface components where mounted in a 12” x 12” x 6” enclosure seen in figure 7.



216 V_{dc} Battery Charging Power (Stand-alone charger output is input to the RBX system here)

120 or 240 V_{ac} Mains Supply

Controlled 120 V_{ac} (supplies the large stand-alone charger)

Controlled 240 V_{ac} (supplies the large stand-alone charger)

Figure 7: Charger Interface Enclosure

Spring Provides Down Force

Pivot Point

Battery Pack Terminal Contact

Figure 8: Charger Interface Contact

Once the interface components were mounted in the enclosure, I constructed four of the copper contacts seen in figure 8. They serve as the electrical connections between the RBX system and the battery pack for charging.

The eyebolt in the contact provides a pivot point; this coupled with the down force provided by the spring ensures a good electrical connection between the RBX system and the battery pack terminals.

After making the contacts, I built a structure that holds the contactors in place both charging stations (figure 9). Then, the contacts were wired to the charger interface and the RBX system micro controller inputs were wired up.

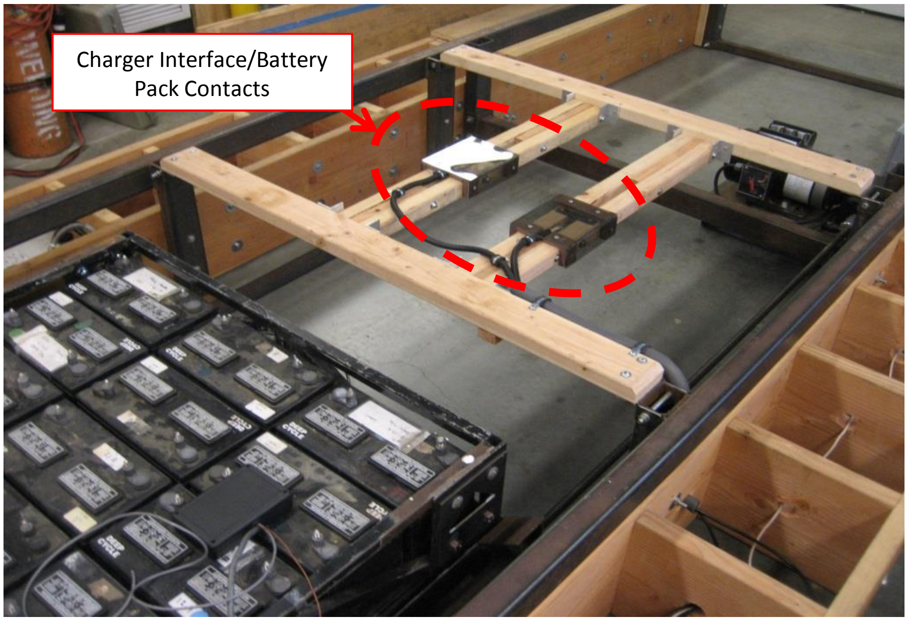


Figure 9: Rear Charging Station

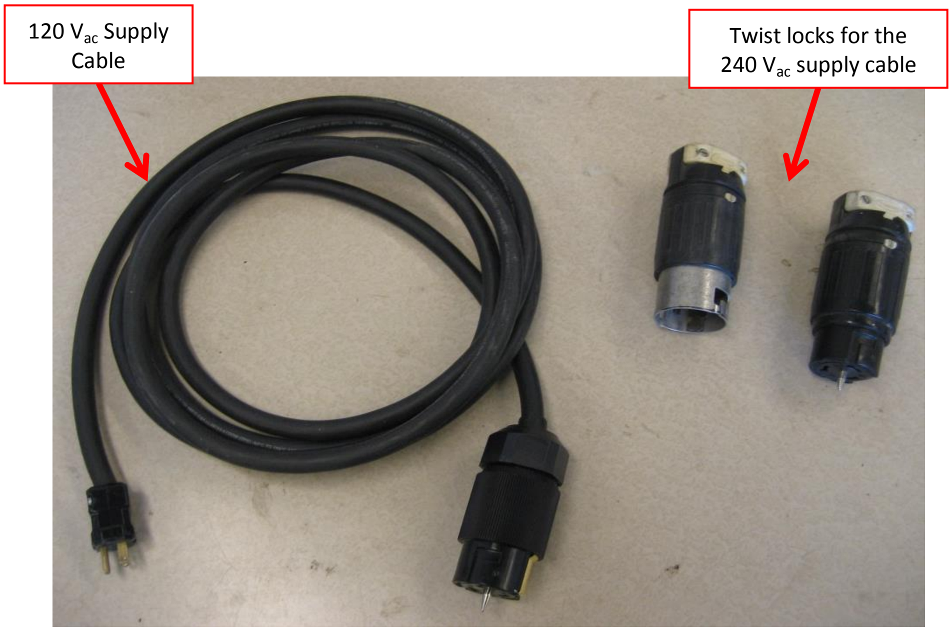


Figure 10: 120 V_{ac} mains supply cable

Lastly, I made a cable that provides 120 V_{ac} to the charger interface from mains power (figure 10). On the mains side is a standard 120V grounded plug which provides one hot leg, neutral, and ground. The interface side is terminated with a 125/250V, 50A twist lock connector. This cable is intended for use only with the small charger. I refrained from making the 240 V_{ac} supply cable for use with the large charger because I could not justify the added expense of the required 6 AWG cable (needed for the larger charger current requirement) since there is not 240 V supply currently available in the Advanced Technology Lab where the RBX system is set up. However, the EVEC has the appropriate twist lock connectors (figure 10) to make the cable if the RBX is ever set up in a place with 240 V_{ac} supply.

Integration and Full Component Test Results

This section describes the tests implemented to verify the expected operation of the charger interface. Note that the tests that led to design revisions are detailed where they apply in the Subsystem and Design section.

After receiving all of the charger interface components and prototyping the interface control circuits, the charger interface was bench tested with manually applied 5 V_{dc} inputs. Figure 11 shows the bench test setup.

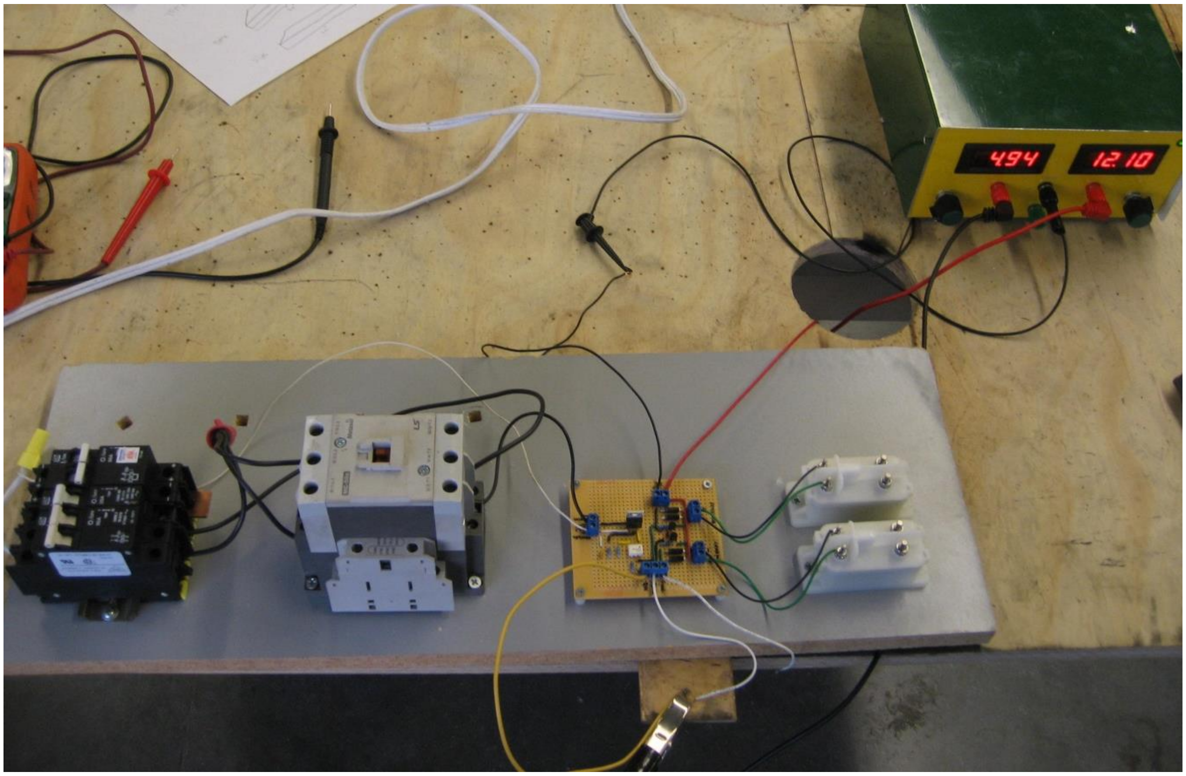


Figure 11: Charger Interface Bench Test

Table 4 outlines the bench tests.

Table 4: Charger Interface Bench Tests

Test Purpose	Test Implementation	Pass or Fail
Ensure that the Energize Charger Signal works	Supply 5 V_{dc} to the energize charger signal input node on the charger interface control proto board and ensure that the Metsol contactor energizes.	Pass
Ensure that the Fwd. Charging Station Select Signal works	Supply 5 V_{dc} to the fwd. charging station select signal input node on the charger interface control proto board and ensure that the forward station miniTactor energizes.	Pass
Ensure that the Rear Charging Station Select Signal works	Supply 5 V_{dc} to the rear charging station select signal input node on the charger interface control proto board and ensure that the rear station miniTactor energizes.	Pass

After bench testing, the charger interface was mounted and wired to the RBX system. Then it was tested for proper operation with manually applied 5 V_{dc} inputs. Table 5 outlines the manual interface tests. Note that all inputs were applied at the RBX system micro controller's DB-25 connector, this verified proper wiring.

Table 5: Manual Charger Interface Integration tests

Test Purpose	Test Implementation	Pass or Fail	Notes
Ensure 12 V_{dc} and GND at correct pins in the Charger Interface enclosure	Connect 12 V_{dc} and GND (DB-25 pins 9 and 5 respectively) and measure between the appropriate nodes on the charger interface control proto board.	Pass	
Ensure that the Energize Charger Signal works	Supply 120 V_{ac} to the interface enclosure. Apply 5 V_{dc} to energize charger signal wire (DB-25 pin 23) and ensure that the Metasol contactor energizes. Measure the current into DB-25 pin 23 and ensure it is less than the micro controller I/O pin maximum output current of 20 mA	Pass	$I_{pin23} = 7.5$ mA
Ensure that the Fwd. Charging Station Select Signal works	Supply 12 V_{dc} to the interface enclosure. Apply 5 V_{dc} to the fwd. charging station select signal wire (DB-25 pin 15) and ensure that the forward station miniTactor energizes, confirm that the rear station miniTactor remains un-energized.	Pass	$I_{pin15} = 8.3$ mA
Ensure that the Rear Charging Station Select Signal works	Supply 12 V_{dc} to the interface enclosure. Apply 5 V_{dc} to the rear charging station select signal wire (DB-25 pin 17) and ensure that the fwd. station miniTactor remains un-energized.	Pass	$I_{pin} = 8.3$ mA
Ensure the forward charging lineup functions properly for extended periods of time	Energize the Metasol contactor. Energize the forward station select miniTactor. Leave energized for one hour and periodically monitor for abnormalities.	Pass	
Ensure the rear charging lineup functions properly for extended periods of time	Energize the Metasol contactor. Energize the rear station select miniTactor. Leave energized for one hour and periodically monitor for abnormalities.	Pass	

After manually testing the charger interface and its wiring, it was operationally tested while under the control of the RBX automation. A person was stationed at the emergency stop button for all tests until the system was deemed fully functional. Table 6 outlines the operational tests.

Table 6: Charger Interface Automation Control Tests

Test Purpose	Test Implementation	Pass or Fail
RBX initializes properly with a battery pack in the forward cart	1. Start with battery packs in both carts 2. Place the forward cart pack in to auto contactor control mode 3. Have the rear battery pack contactor in manual off so it cannot be sensed 4. Energize the RBX ramp micro controller 5. Ensure that the charger interface's Metasol contactor is off while the carts move and the battery location is being determined by the ramp 6. Ensure the initialization sequence ends with the forward cart under the forward charging station 7. Ensure that after the initialization sequence, the charger interface's Metasol energizes, current is being delivered to the forward battery pack, and no voltage is present on the rear charging station contacts	Pass
RBX initializes properly with a battery pack in the rear	1. Start with battery packs in both carts 2. Place the rear cart pack in to auto contactor control mode 3. Have the forward battery pack contactor in manual off so it cannot be sensed 4. Energize the RBX ramp micro controller 5. Ensure that the charger interface's Metasol contactor is off while the carts move and the battery location is being determined by the ramp 6. Ensure the initialization sequence ends with the rear cart under the rear charging station 7. Ensure that after the initialization sequence, the charger interface's Metasol energizes, the charger energizes, current is being delivered to the rear battery pack, and no voltage is present on the forward charging station contacts	Pass

Test Purpose	Test Implementation	Pass or Fail
RBX delivers error when no batteries are present during initialization	1. Start with battery packs in both carts 2. Place both battery pack contactors in manual off so they cannot be sensed 3. Energize the RBX ramp micro controller 4. Ensure that the charger interface's Metasol contactor is off while the carts move and the battery location is being determined by the ramp 5. Ensure that after the initialization sequence: • the charger interface's Metasol does not energize thus keeping the charger off • no voltage is present on the empty charging station contacts • the error LED on the ramp indicator box flashes Short, Short, Long, Long, indicating that no batteries were detected	Pass
RBX delivers error when two batteries are present during initialization	1. Start with battery packs in both carts 2. Place both battery pack contactors in auto contactor control mode so they can both be sensed 3. Energize the RBX ramp micro controller 4. Ensure that the charger interface's Metasol contactor is off while the carts move and the battery location is being determined by the ramp 5. Ensure that after the initialization sequence: • the charger interface's Metasol does not energize thus keeping the charger off • no voltage is present on the empty charging station contacts • the error LED on the ramp indicator box flashes Short, Short, Long, Short, indicating that two batteries were detected	Pass
RBX manipulates the charger interface correctly during a battery exchange when the battery on the ramp starts in the forward station	1. Start with one battery in the van and one battery under the forward charging station in the ramp, already initialized. 2. Ensure current is being delivered to the battery on the ramp until an exchange is initiated 3. Once an exchange is initiated ensure: • that the charging interface's Metasol contactor is de-energized, thus de-energizing the battery charger • the charging station select miniTactors are de-energized 4. Upon completion of a successful exchange ensure: • that the charging interface's Metasol contactor is re-energized, thus turning the battery charger back on • current is being delivered to the battery on the ramp now in the rear charging station • no voltage is present on the forward charging station contacts	Pass

Test Purpose	Test Implementation	Pass or Fail
RBX manipulates the charger interface correctly during a battery exchange when the battery on the ramp starts in the rear station	1. Start with one battery in the van and one battery under the rear charging station in the ramp, already initialized. 2. Ensure current is being delivered to the battery on the ramp until an exchange is initiated 3. Once an exchange is initiated ensure: • that the charging interface's Metasol contactor is de-energized, thus de-energizing the battery charger • the charging station select miniTactors are de-energized 4. Upon completion of a successful exchange ensure: • that the charging interface's Metasol contactor is re-energized, thus turning the battery charger back on • current is being delivered to the battery on the ramp now in the forward charging station • no voltage is present on the rear charging station contacts	Pass

Conclusion

In this project I set out to interface an existing stand-alone electric vehicle battery charger with the Electric Vehicle Engineering Club's Rapid Battery Exchange system. The interface needed to be safe, functionally reliable, rated to electrically support the larger of the two chargers available. And, the internals of the charger needed to be non-specific to the chargers it was designed for. This allows for changing battery and charger technology as long as the new charger has equal or lower electrical requirements as the large charger does.

In my estimation I have succeeded. The charger interface reliably delivers battery charging power to the appropriate charging station at the appropriate times, and shuts down in the event of an error. For instance, when no batteries are detected on the ramp.

The path to the current, functioning, charger interface was not a direct, unimpeded one. As with all projects endeavored upon by people with limited experience in the given field, implementation often took two to three times longer than was expected. Contributing to the miss estimation of required time is the reality that many things do not work out the way they do on paper (usually due to the paper lacking the complete picture). In the case of this project, two major items that were not considered on paper during the design phase were Triac gates requiring higher current in lower temperatures, and voltage differences in separate, relative grounds coming together, initiating micro controller resets.

Appendix A: References

[1] Energy.gov. (2013, Jul. 19). Energy Department Releases Updated eGallon Prices as Electric Vehicle Sales Double [Online]. Available: http://energy.gov/articles/energy-department-releases-updated-egallon-prices-electric-vehicle-sales-double, [Nov. 9, 2013].

[2] Peter Fairley (2007, Nov. 1) Electric-Car Maker Touts 10-Minute Fill-up [Online]. Available: http://www.nxp.com/documents/application_note/APPCHP6.pdfhttp://spectrum.ieee.org/green-tech/advanced-cars/electriccar-maker-touts-10minute-fillup, [Dec. 1, 2013].

[3] Bruce D. Braga (1992, Dec.) Electric G-Van Demonstration and Commercial Assessment Project (Final Report) [Online]. Available: http://www.osti.gov/scitech/servlets/purl/10130809, [Dec. 1, 2013].

[4] NXP Semiconductors. (2003) BTA140 series Triacs data sheet [Online]. Available: http://www.nxp.com/documents/data_sheet/BTA140_SERIES.pdf, [Nov. 10, 2013].

[5] Motorola (1995) Optoisolators Triac Driver Output data sheet [Online]. Available: http://pdf.datasheetcatalog.com/datasheet/motorola/MOC3021.pdf, [Nov. 10, 2013].

[6] Motorola (1995) Applications of the MOC3011 Triac Driver, AN780A [Online]. Available: ftp://www.elex.camosun.bc.ca/browningi/ELEX242/2011/Modules/Module13PowerDevicesTriggered/Reference/MOC311TRIAC.pdf, [Nov. 10, 2013].

[7] GIGAVAC. (2003) miniTACTOR P105 data sheet [Online]. Available: http://www.gigavac.com/pdf/ds/pp/p105.pdf, [Nov. 10, 2013].

[8] GIGAVAC. (2003) Contactor Coil Suppression Application Note 1 [Online]. Available: http://www.gigavac.com/apps/coil-supression.html, [Nov. 10, 2013].

[9] Johnson Controls Battery Group Inc. (2012) Lead/acid Battery, Wet, filled with acid, MSDS [Online] Available: http://corporate.interstatebatteries.com/msds/msds_wetcell_us_and_canada_11-28-12.pdf, [Dec. 3, 2013].

Appendix B: Parts List and Costs

Table 7 summarizes the parts used in the charger interface and their cost.

Table 7: Parts List and Costs

Item	Quantity	Quantity Unit	Price Per Unit	Part Total	Notes
P105 Contactor, 12V, NO, 50 Amp “miniTactor”	2	ea.	$34.00	$68.00	
Metasol MC-50a contactor	1	ea.	$150.00	$150.00	Already in EVEC parts inventory
BTA140 Triac	1	ea.	$1.50	$1.50	Already in EVEC parts inventory
Optoisolator MOC3022	1	ea.	$2.00	$4.00	Already in EVEC parts inventory
Capacitors	1	ea.	$0.50	$0.50	Already in EVEC parts inventory
Resistors	7	ea.	$0.50	$3.50	Already in EVEC parts inventory
Switching Transistors	2	ea.	$0.50	$1.00	Already in EVEC parts inventory
8 AWG Stranded Wire	40	ft.	$0.57	$22.80	
8 AWG Ring Terminals	25	pack	$8.25	$8.25	
12 AWG Stranded 3 Conductor wire	12	ft.	$1.18	$14.16	Already in EVEC parts inventory
Signal Wire	20	ft.	$0.15	$3.00	Already in EVEC parts inventory
12” x 12” x 6” Plastic Component Enclosure	1	ea.	$33.60	$33.60	
120 V_{ac} Grounded Plug	1	ea.	$6.00	$6.00	Already in EVEC parts inventory
120 V_{ac} Electrical Receptacle	1	ea.	$5.00	$5.00	Already in EVEC parts inventory
50 Amp Power Inlet	1	ea.	$59.99	$59.99	
Twist Lock Connector, 50A, 125/250V	1	ea.	$44.99	$44.99	
Zener Diodes	4	ea.	$2.12	$2.12	
MidNite Solar MNEAC50-2P, Two Pole 120/240V_{ac}, 50A Breaker	1	ea.	$26.31	$26.31	
MidNite Solar MNEAC20, Single Pole 120V_{ac}, 20A Breaker	1	ea.	$12.96	$12.96	
Midnite Solar MNEPV50-300, Single Pole 50-300V_{dc}, 50A Breaker	1	ea.	$26.90	$26.90	
Twist Lock receptacle, 50A, 125/250V	1	ea.	$40.00	$40.00	Already in EVEC parts inventory

Total Parts Cost $534.58

Note: Many items for the charger interface already existed in EVEC’s parts inventory making the total expenditure for the project $305.92.

Appendix C: Schedule - Time Estimates

The following three Gantt charts show the projected and actual time spent on different aspects of the charger interface.

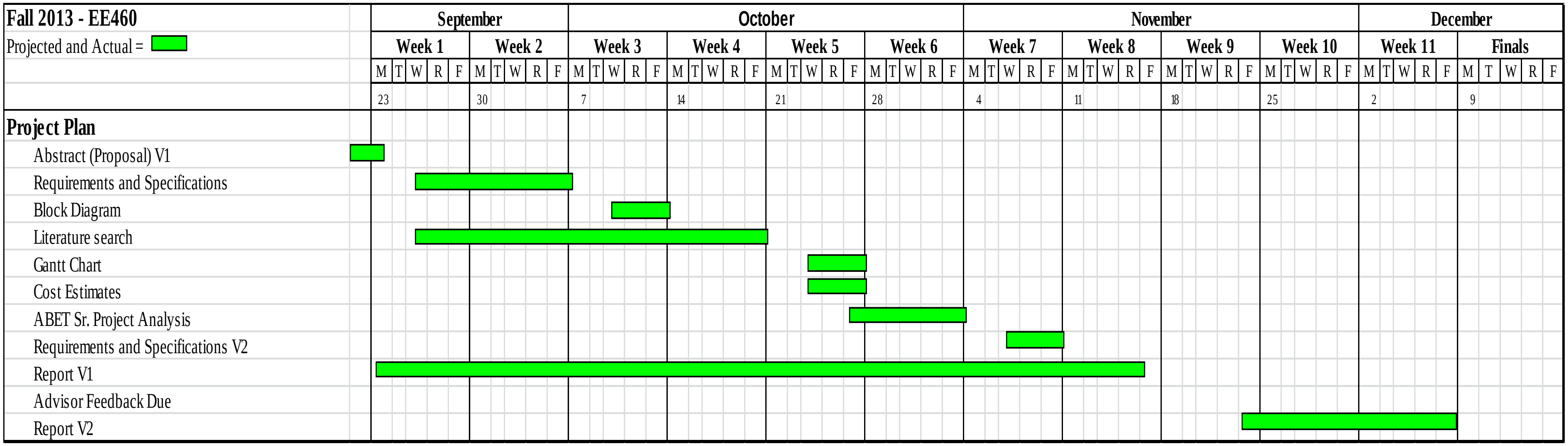


Figure 12: Fall 2013-EE460 Schedule

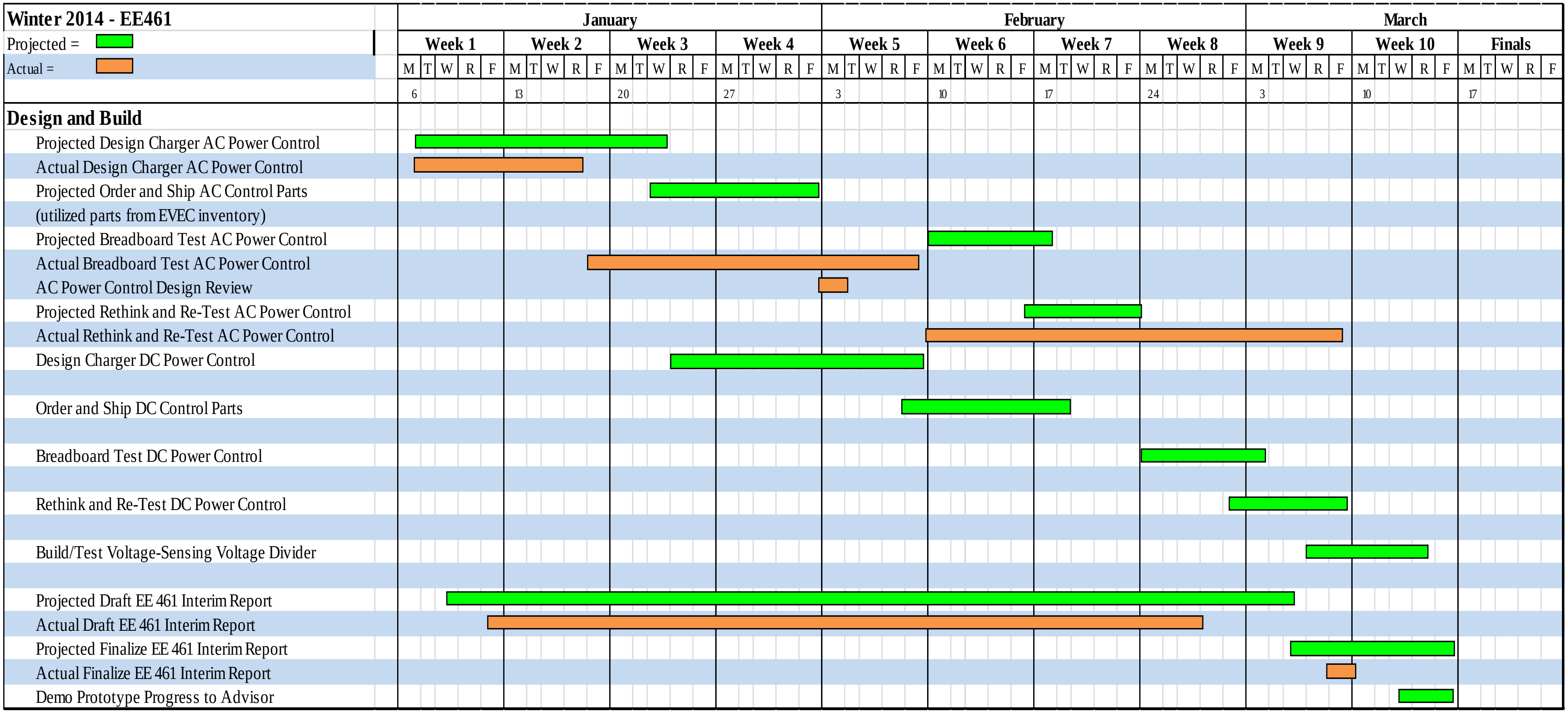
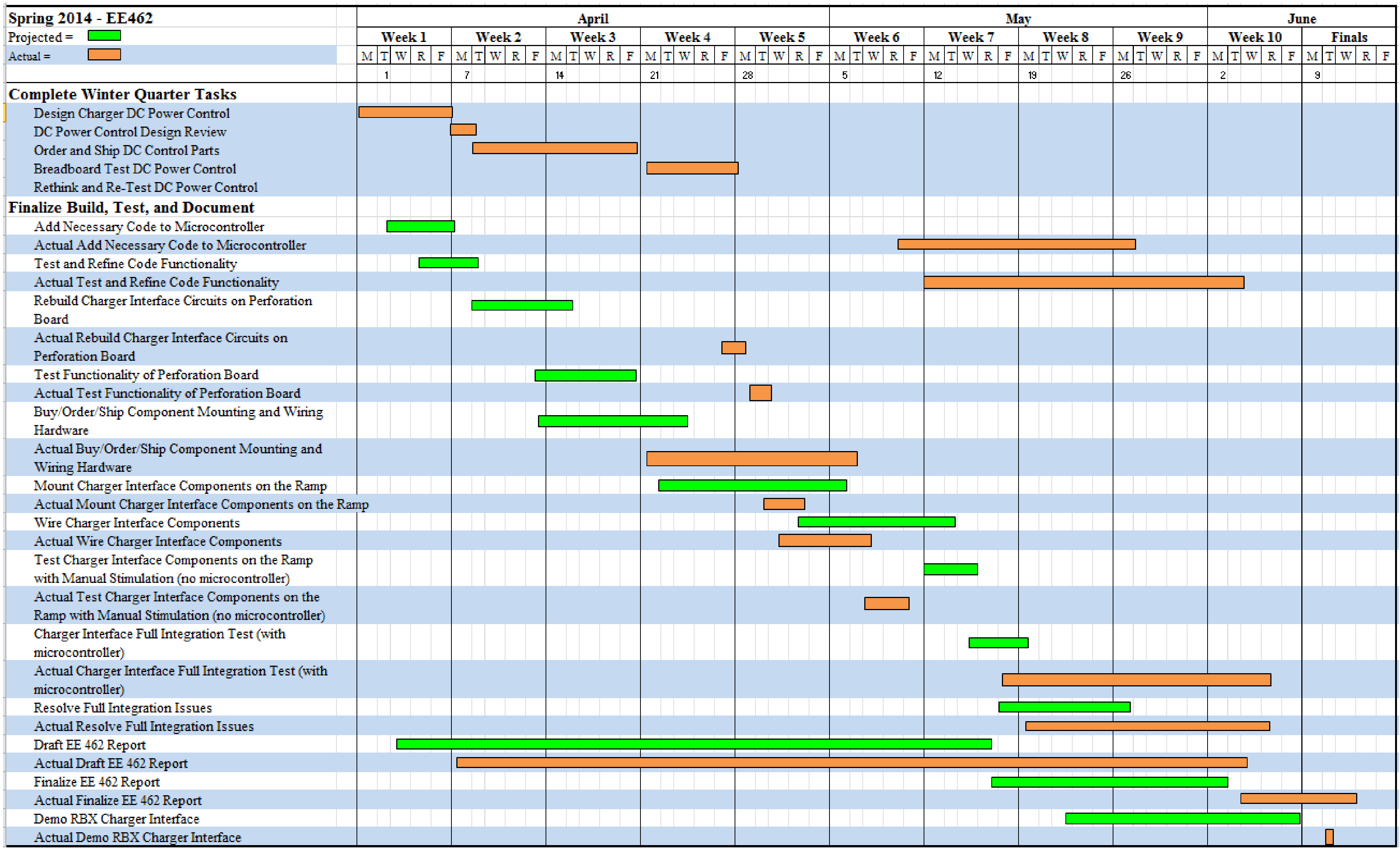


Figure 13: Winter 2014-EE461 Schedule



Spring 2014 - EE462

Projected = 🟩

Actual = 🟧

Complete Winter Quarter Tasks
- Design Charger DC Power Control
- DC Power Control Design Review
- Order and Ship DC Control Parts
- Breadboard Test DC Power Control
- Rethink and Re-Test DC Power Control

Finalize Build, Test, and Document
- Add Necessary Code to Microcontroller
- Actual Add Necessary Code to Microcontroller
- Test and Refine Code Functionality
- Actual Test and Refine Code Functionality
- Rebuild Charger Interface Circuits on Perforation Board
- Actual Rebuild Charger Interface Circuits on Perforation Board
- Test Functionality of Perforation Board
- Actual Test Functionality of Perforation Board
- Buy/Order/Ship Component Mounting and Wiring Hardware
- Actual Buy/Order/Ship Component Mounting and Wiring Hardware
- Mount Charger Interface Components on the Ramp
- Actual Mount Charger Interface Components on the Ramp
- Wire Charger Interface Components
- Actual Wire Charger Interface Components
- Test Charger Interface Components on the Ramp with Manual Stimulation (no microcontroller)
- Actual Test Charger Interface Components on the Ramp with Manual Stimulation (no microcontroller)
- Charger Interface Full Integration Test (with microcontroller)
- Actual Charger Interface Full Integration Test (with microcontroller)
- Resolve Full Integration Issues
- Actual Resolve Full Integration Issues
- Draft EE 462 Report
- Actual Draft EE 462 Report
- Finalize EE 462 Report
- Actual Finalize EE 462 Report
- Demo RBX Charger Interface
- Actual Demo RBX Charger Interface

Figure 14: Spring 2014-EE462 Schedule

Appendix D: Wiring and Pinout

Figure 15 is the wiring and pinout diagram for the signal wires connecting the RBX's micro controller to the charger interface.

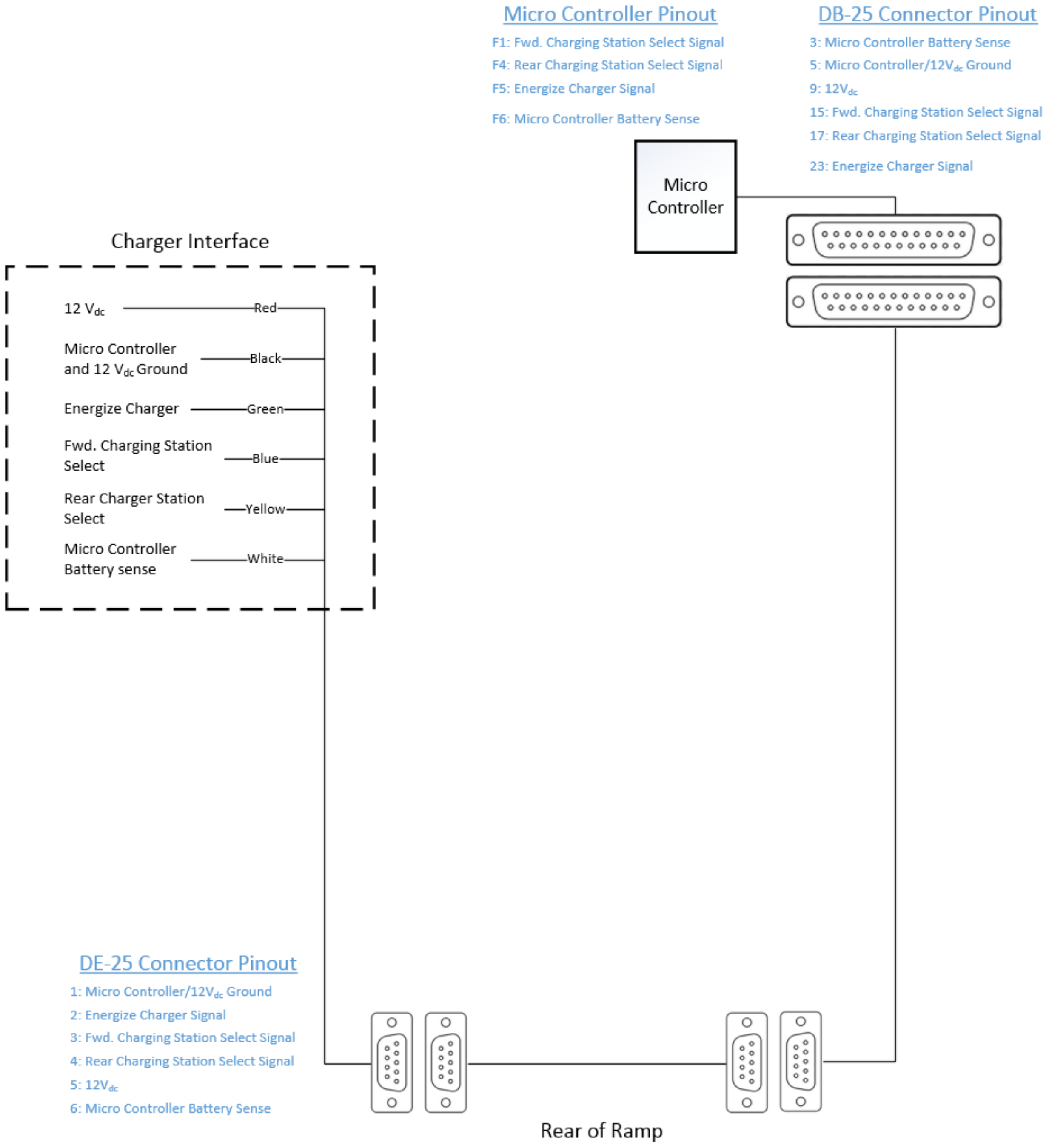


Figure 15: Charger Interface to Ramp Wiring and Pinout

Appendix E: Senior Project Analysis

Student's Name: Adam Morris ______________________________

Advisor's Name: Art MacCarley _____________________________ Date: ____________

1. **Summary of Functional Requirements**

The Rapid Battery Exchange (RBX) Charger Interface provides an electrical interface between a 216V battery-pack charger and two battery-pack charging stations. The RBX system consists of an electric van with an extractable traction battery, and a ramp apparatus that facilitates battery removal. Once extracted from the van, a battery moves to one of two similar charging stations on the ramp. Then, after the exchange sequence fully completes, the RBX's micro controller communicates with the charger interface, allowing power-on of the charger and prompting an electrical connection between the charger and the appropriate battery charging station.

The charger interface receives $5V_{dc}$, $20mA_{max}$ control signals from the RBX's micro controller. With these signals, the charger interface controls the battery charger's on/off status by controlling its AC electrical supply and it controls which charging station the charger's battery-charging-DC-output electrically couples to. Appropriately sized components in the charger interface handle the chargers maximum specifications of:

- AC Input: $240V_{AC}$, $42A_{AC}$
- DC Output: $216V_{DC}$, $36A_{DC}$

Quick electrical disconnects (electrical "plugs") provide the connections between the charger and the charger interface. This allows for a simple transition to a different charger in the event that the electric van is upgraded to a different battery type and requires a different charger.

2. **Primary Constraints**

Cal Poly's Electric Vehicle Engineering Club has iteratively worked on the RBX over several years now. The work already completed on the RBX system constrains the design of the charger interface. Constraints included:

- Controlling the charger interface with the RBX's ATmega32u4 microcontroller, the microcontroller provides signals of $5V_{dc}$, $20mA_{max}$
- Writing the necessary new code to implement the charger interface control in C and adding it to the RBX microcontroller's existing code
- Using the existing $5V_{dc}$, $12V_{dc}$, and $120V_{ac}$ on the RBX as necessary for controlling and/or powering the charger interface components

- Using a Metasol MC-50a contactor to switch the charger's AC input. The contactor's coil requires $120V_{ac}$ for control. This device previously existed in the EVEC's parts inventory and building a circuit to convert the microcontroller's $5V_{dc}$ control signals to the necessary $120V_{ac}$ costing approximately $10 appealed to the club more than sourcing a new contactor costing $65 or more.

Challenges associated with the project:

- Finding relays that drew small coil currents (< 500mA) but had the current carrying capacity necessary for the DC side of the charger.
- Adding the new code needed for the charger interface to the RBX microcontroller's existing code. Success required several iterative code changes followed by tests on a simulation platform (an array of LEDs and buttons) to ensure that the code functioned as expected.
- Another senior project team was working on a subsystem of the RBX at the same time as me. They were working on battery pack safety and sensing. We had to continuously collaborate and keep each other posted on the status of our respective projects in order to effectively coordinate times for work and tests that could and did conflict with the other group. Furthermore, integration of our individual projects took several iterations before they worked well together.

3. **Economic**

Potential economic impacts of the Charger Interface:

Human Capital:

The RBX system does away with electric vehicle downtime associated with charging an electric vehicle's battery. So, creating a functional electric vehicle battery exchange and charging system may facilitate a shift in the type of energy storage behind human transportation, without requiring a shift in human transportation behavior.

Financial Capital – Monetary instruments:

Although electric vehicles will not serve as full replacements to fuel-powered vehicles, they will grow as viable alternatives for transportation. As systems like the rapid battery exchange eliminate the down time of an EV associated with charging, electric vehicles will appeal to more customers accustomed to, and who rely on, the uninhibited readiness of fuel- powered vehicles. Since EVs currently hold a small market share of cars on the road, and their viability as alternatives to fuel- powered vehicles continues to increase, electric vehicles could prove profitable to investors.

Manufactured or Real Capital – Made by people and their tools:

The functionality of the RBX defines its real value—having the ability to support a transportation infrastructure that developed societies depend on. Aside from that, the RBX has value in the recyclability of its materials, most notably copper and steel.

Natural Capital – The Earth's resources and bio-capacity:

Manufacture of a marketable RBX system requires resources including

- concrete for a permanent, weather resistant ramp apparatus
- steel for structural members and fasteners
- copper for conductors
- silicon for integrated circuits
- plastics for component enclosures and encasement of various components (e.g. integrated circuits)
- substances associated with electric vehicle batteries including lead, sulfuric acid, lithium, nickel, and cadmium, depending on the battery technology used

The values of the above resources will increase due to increased demand.

Original estimated cost of component parts:

Table 8:RBX charger interface cost estimate

Item	Description	Quantity	Quantity Unit	Price Per Unit	Part Total
DC Relay		2	ea.	$40.00	$80.00
AC Relay		1	ea.	$150.00	$150.00
Triac		1	ea.	$1.00	$1.00
Capacitors		5	ea.	$0.50	$2.50
Resistors		10	ea.	$0.35	$3.50
Switching Transistors		4	ea.	$0.50	$2.00
Power Wire		40	ft.	$1.50	$60.00
Signal Wire		100	ft.	$0.10	$10.00
Large Component Enclosure		1	ea.	$15.00	$15.00
Junction Boxes		4	ea.	$3.00	$12.00
240 Vac Electrical Plug (male end)		1	ea.	$25.00	$25.00
240 Vac Electrical Plug (female end)		1	ea.	$25.00	$25.00
120 Vac Electrical Plug (male end)		1	ea.	$3.00	$3.00
120 Vac Electrical Plug (female end)		1	ea.	$3.00	$3.00
40 Amp DC Circuit Breaker		1	ea.	$30.00	$30.00
50 Amp AC Circuit Breaker		1	ea.	$30.00	$30.00
Prototype Labor		1200	hr.	$17.00	$20,400.00

Expected Sub-Total	$20,852.00
Expected Total Using Cost Model	$21,199.53

Bill of materials for the RBX Charger Interface, and final costs:

Item	Quantity	Quantity Unit	Price Per Unit	Part Total	Notes
P105 Contactor, 12V, NO, 50 Amp “miniTactor”	2	ea.	$34.00	$68.00	
Metasol MC-50a contactor	1	ea.	$150.00	$150.00	Already in EVEC parts inventory
BTA140 Triac	1	ea.	$1.50	$1.50	Already in EVEC parts inventory
Optoisolator MOC3022	1	ea.	$2.00	$4.00	Already in EVEC parts inventory
Capacitors	1	ea.	$0.50	$0.50	Already in EVEC

Item	Quantity	Quantity Unit	Price Per Unit	Part Total	Notes
					parts inventory
Resistors	7	ea.	$0.50	$3.50	Already in EVEC parts inventory
Switching Transistors	2	ea.	$0.50	$1.00	Already in EVEC parts inventory
8 AWG Stranded Wire	40	ft.	$0.57	$22.80	
8 AWG Ring Terminals	25	pack	$8.25	$8.25	
12 AWG Stranded 3 Conductor wire	12	ft.	$1.18	$14.16	Already in EVEC parts inventory
Signal Wire	20	ft.	$0.15	$3.00	Already in EVEC parts inventory
12” x 12” x 6” Plastic Component Enclosure	1	ea.	$33.60	$33.60	
120 V_{ac} Grounded Plug	1	ea.	$6.00	$6.00	Already in EVEC parts inventory
120 V_{ac} Electrical Receptacle	1	ea.	$5.00	$5.00	Already in EVEC parts inventory
50 Amp Power Inlet	1	ea.	$59.99	$59.99	
Twist Lock Connector, 50A, 125/250V	1	ea.	$44.99	$44.99	
Zener Diodes	4	ea.	$2.12	$2.12	
MidNite Solar MNEAC50-2P, Two Pole 120/240V_{ac}, 50A Breaker	1	ea.	$26.31	$26.31	
MidNite Solar MNEAC20, Single Pole 120V_{ac}, 20A Breaker	1	ea.	$12.96	$12.96	
Midnite Solar MNEPV50-300, Single Pole 50-300V_{dc}, 50A Breaker	1	ea.	$26.90	$26.90	
Twist Lock receptacle, 50A, 125/250V	1	ea.	$40.00	$40.00	Already in EVEC parts inventory

Total Parts Cost	$534.58

Note: Many items for the charger interface already existed in the Electric Vehicle Engineering Club’s parts inventory making the total expenditure (note including my time) for the project $305.92.

Additional equipment costs:

A PC with the capability of editing and compiling C code for the ATmega32u4 micro controller, along with standard electrical test bench equipment including:

- multimeter
- oscilloscope

- DC power supply
- function generator

This report does not include the costs of the above equipment because California Polytechnic State University, San Luis Obispo provides access for to them all students.

How much does the project earn? Who profits?

The RBX is a proof of concept project. Upon successful completion the Electric Vehicle Engineering Club may profit in the form donations provided to improve the system.

Timing:

When do products emerge?

The RBX charger interface was complete and operational June 2014.

How long do products exist and what maintenance or operation costs exist?

The changer interface includes relays and contactors that employ electrically controlled mechanical switching. The relays have an expected life of 1 million switches. On average, each relay costs approximately $75.00 to replace.

What happens after the project ends?

After the RBX charger interface project ends, the Electric Vehicle Club will focus on fine tuning other aspects of the RBX system.

4. **If manufactured on a commercial basis:**

Estimated number of devices sold per year:

As the viability of rapid battery exchange and electric vehicles becomes accepted, consumer demand could drive the number of RBX systems sold per year to the hundreds of thousands until an infrastructure resembling that of gas stations is established. As rapid battery exchange approaches the point of new-construction-saturation, the number of devices sold per year would slow to tens of thousands.

Estimated manufacturing cost for each device:

Each complete RBX system should cost approximately $10,000. The charger interface, a subsystem of the RBX and the focus of this project, should cost approximately $300.

Estimated purchase price for each device:

Purchase of a complete RBX system should cost approximately $15,000.

Estimated profit per year:

100,000 [per year] x $15,000.00 [each] = 1.5 billion [per year gross]

1.5 billion [per year gross] – 100,000 [per year for manufacturing] x $10,000 [each] = $500 million per year profit.

Estimated cost for user to operate device, per year:

Assumptions

- $0.12 per kWh
- 60 kWh electric vehicle battery
- Use 75% of battery everyday on average

60 kWh x 0.75 per day = 45 kWh per day. Therefore $0.12 per kWh x 45 kWh = $5.40 per day or $1,971 per year to charge. Plus $100 per year maintenance. = $2,071 per year.

5. **Environmental**

Mining for raw components to create the following used in the RBX system will impact the environment.

- concrete for a permanent, weather resistant ramp apparatus
- steel for structural members and fasteners
- copper for conductors
- silicon for integrated circuits
- plastics for component enclosures and encasement of various components (i.e. integrated circuits)

- substances associated with electric vehicle batteries including lead, sulfuric acid, lithium, nickel, and cadmium, depending on the battery technology used

Manufacturing of the RBX takes energy which has the potential to create emissions unless the energy derives from wind, hydro, solar or the like.

Also, without a robust reclamation and recycling system in place, use of electric vehicles could produce dangerous waste, most notably from the battery, and prove hazardous to the environment and its inhabitants.

Although the rapid battery exchange supports electric vehicles, which create no emissions on board, we cannot dismiss where the battery charging electricity comes from. Currently, generation of much of the world's electricity consumes natural gas or coal. Creating a larger demand for electricity to charge large batteries could create an increase in emissions from natural gas and coal powered power-plants.

Natural resources by this project:

Making and employing the RBX depends on an electrical source (batteries do not charge without electricity). If the electricity derives from a petroleum source, using the RBX to support electric vehicles only shifts the emissions from several individual cars to the power plant that generates the electricity. But, even if emissions are only being shifted, extracting energy from petroleum products at centralized locations like power plants may be better from an emissions standpoint than extracting at several decentralized locations as in cars. Large plants have more of an opportunity to work in their peak efficiency zone, where cars operate their engines over a wide range, not always inside peak efficiencies.

Natural resources and ecosystem services improved by this project:

The RBX system, coupled with increasing generation of renewable energies, has the potential to improve air quality and reduce dependence on fossil fuels.

The impact of this project on other species:

The RBX supports an infrastructure of electric vehicles. Fuel-powered vehicles kill animals including but not limited to opossums, snakes, frogs, armadillos, skunks, raccoons, squirrels, deer, moose, elk, cats, and dogs, humans, crabs, and grasshoppers. Driving electric vehicles will not offset these kills.

6. **Manufacturability**

Potential issues and challenges associated with manufacturing:

Manufacturing the RBX charger interface requires people and or automated technologies with the ability to:

- follow a wiring schematic for laying out components in the correct place
- solder components to printed circuit boards and terminals to wires
- crimp various terminals for various connectors
- use hand tools including screw drivers and nut drivers to securely mount components
- use heat shrink and a heat gun to insulate exposed conductors near terminals.

Most of the charger interface components are mounted in one 12”x 12” x 6” enclosure making it an ideal candidate for assembly line type manufacturing.

7. **Sustainability**

Potential issues and challenges associated with maintaining the completed system:

The RBX has a physical footprint as big as a full sized passenger van. The cheapest employment of the system entails setting it up outside. This exposes the RBX and all of its components to the elements. To prevent deterioration, all electrical components need enclosing in weatherproof cabinets/boxes and all structural members need painting.

Impacts on the sustainable use of resources by this project:

Materials mentioned in section 5 of this appendix make up the RBX and its subsystems. The acquisition of the material components requires recycling from other sources or mining. As the use of raw materials like copper increases the demand for more of it increases, thus increasing its mining.

Upgrades that would improve the design of the project:

Currently, plywood makes up the RBX’s super structure—the “ramp.” Constructing the ramp out of concrete or a like material would make the RBX more robust and easier to maintain outdoors. With respect to the charger interface, redesigning the ramp in such a way to need only one charging station would do away with one set of contactors and nearly 1/3 of its conductors. Doing so would save copper.

Potential issues and challenges associated with upgrading the design:

Constructing the ramp out of concrete would make it more expensive and more permanent.

Removing one of the charging stations in order to simplify the charger interface requires a complete mechanical redesign of the ramp apparatus. A mechanical redesign of the ramp would require new control.

8. **Ethical**

Ethical implications of the project in the Utilitarianism Ethical Framework:

Electric vehicles provide an alternative mode of transportation from standard fuel-powered vehicles, and any use of EVs reduces the use of the other. Since electric vehicles have the potential of harnessing renewable energy, using EVs potentially reduces fossil fuel emissions. Reducing fossil fuel emissions is generally accepted as a necessary step to preserving life as we know it on earth. Supporting electric vehicles, as the RBX does, works toward preserving a healthy planet. This brings the greatest good to the greatest number of people—those who use vehicles and those who do not.

Ethical implications of the project in the framework of the IEEE code of ethics (the numbers refer to the IEEE's code numbers):

1. The acquisition of the necessary resources including copper for conductors and plastics for packaging may endanger the environment. Furthermore, batteries pose hazards to people and the environment if not disposed of properly. However, in the long run, supporting a technology that does not rely solely on fossil fuels for energy supports the health and welfare of the public.
3. Honesty and realism dictate the following statement: the RBX supports an electric car infrastructure which will weigh heavily on the environment as long as production of the supporting electricity creates emissions.
6. The RBX charger interface solves the problem of charging an electric vehicle's traction battery after its removal from the vehicle by utilizing the existing battery charger. I do not hold the qualifications necessary to design an appropriate and safe battery charger. I did however have enough time to understand the requirements of, and build, the interface.

9. **Health and Safety**

Health and safety concerns include:

- battery compounds (acids and heavy metals)

  According to a Material safety Data Sheet produced by Johnson Controls Battery Group Inc., contact with battery electrolyte causes burns to the eyes and skin. And, absorption of lead may cause poisoning and reproductive effects [9].

- heavy battery packs

  The battery packs designed for and used with RBX weigh in excess of 800 pounds. Installing and removing the battery pack requires powerful machinery, obstructing any of the moving machinery could cause severe injury or death.

- high voltage

  The battery packs designed for and used with RBX have a nominal voltage of 216 V_{dc}, furthermore the battery charger requires either 120 or 240 V_{ac}. Such voltages could cause severe injuries, burns, or death. De-energize all high voltage circuits before accessing circuit enclosures. If the nature of access requires energized circuits (i.e. troubleshooting by qualified personnel), follow proper electrical safety precautions including: removing all metallic jewelry and accessories, do not work alone, wear electrical safety gloves, wear eye protection, create a “rubber room” with insulation mats, and work with only one hand.

10. **Social and Political**

Social and political issues associated with design, manufacture, and use of this project:

- Batteries are resource heavy and dangerous if not disposed of properly.
- Driving an electric car only shifts pollution from a tailpipe to a power plant unless the electricity derives from a renewable source.
- Increase use of electric vehicles put more strain the ageing electrical grid.

Who the project impacts:

The RBX supports electric vehicles and their viability as an alternative to fuel-powered vehicles. Electric vehicles produce no local emissions, thus not polluting their immediate surroundings. This positively affects the respiratory health of all people living near vehicle transportation infrastructure. Also, anyone involved in the manufacturing of the RBX, including those affected by resource acquisition, will be impacted by the manufacture and use of the RBX.

How the project benefits the stakeholders:

Use of RBX systems will make driving electric vehicles more viable. This will stimulate growth in electric vehicle design, manufacturing, and power grid upgrades, which will in turn create jobs.

It will also stimulate continued research in battery technologies, benefiting all facets of alternative energy which rely on energy storage.

Potential access inequities created by the project:

The projected cost of an RBX will prohibit personal ownership. RBX systems will likely be available to the public through small business franchises, similar to gas stations. Any inequalities of availability and benefit will be akin to those associated with gas stations.

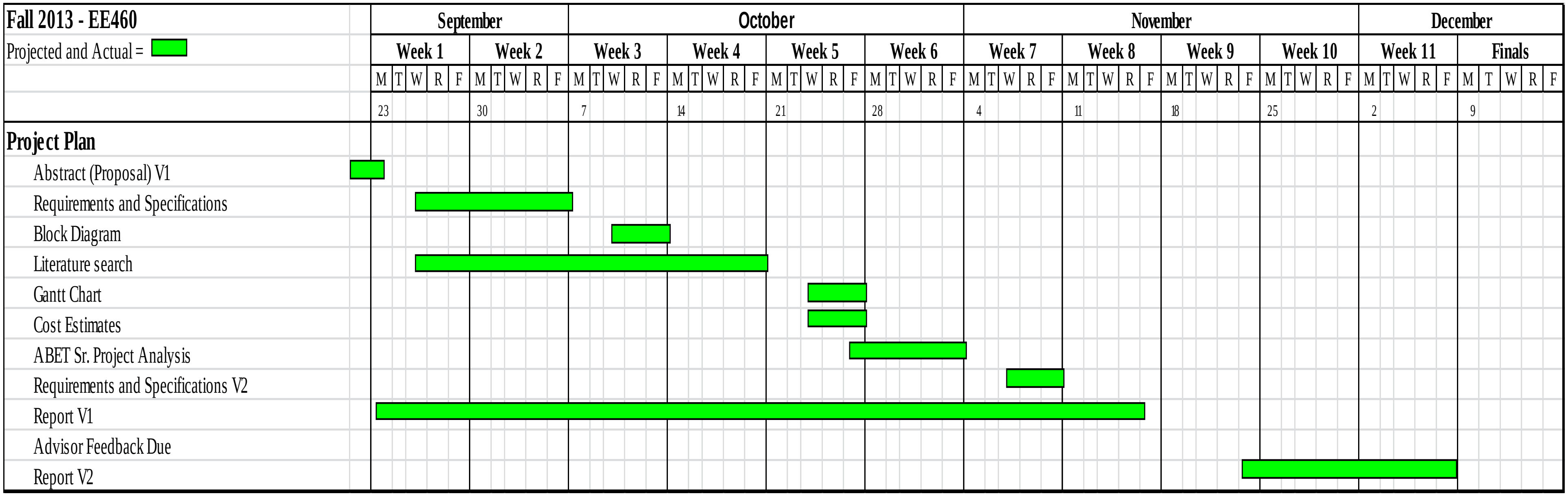
The availability of RBX systems will be consumer driven. More demand will result in more units installed. Metropolitan areas will see the largest demand, thus RBX infrastructure will develop more rapidly in those areas.

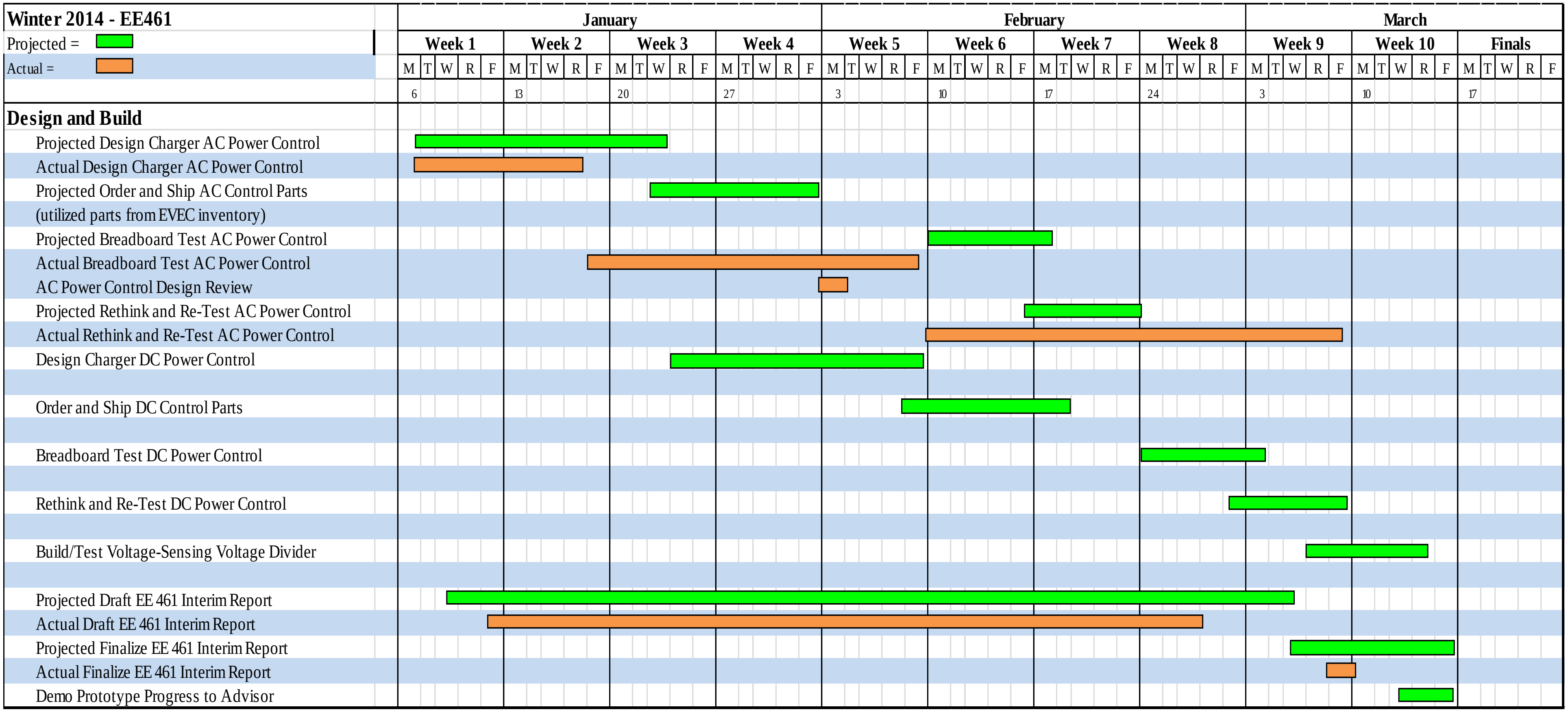
11. **Development**

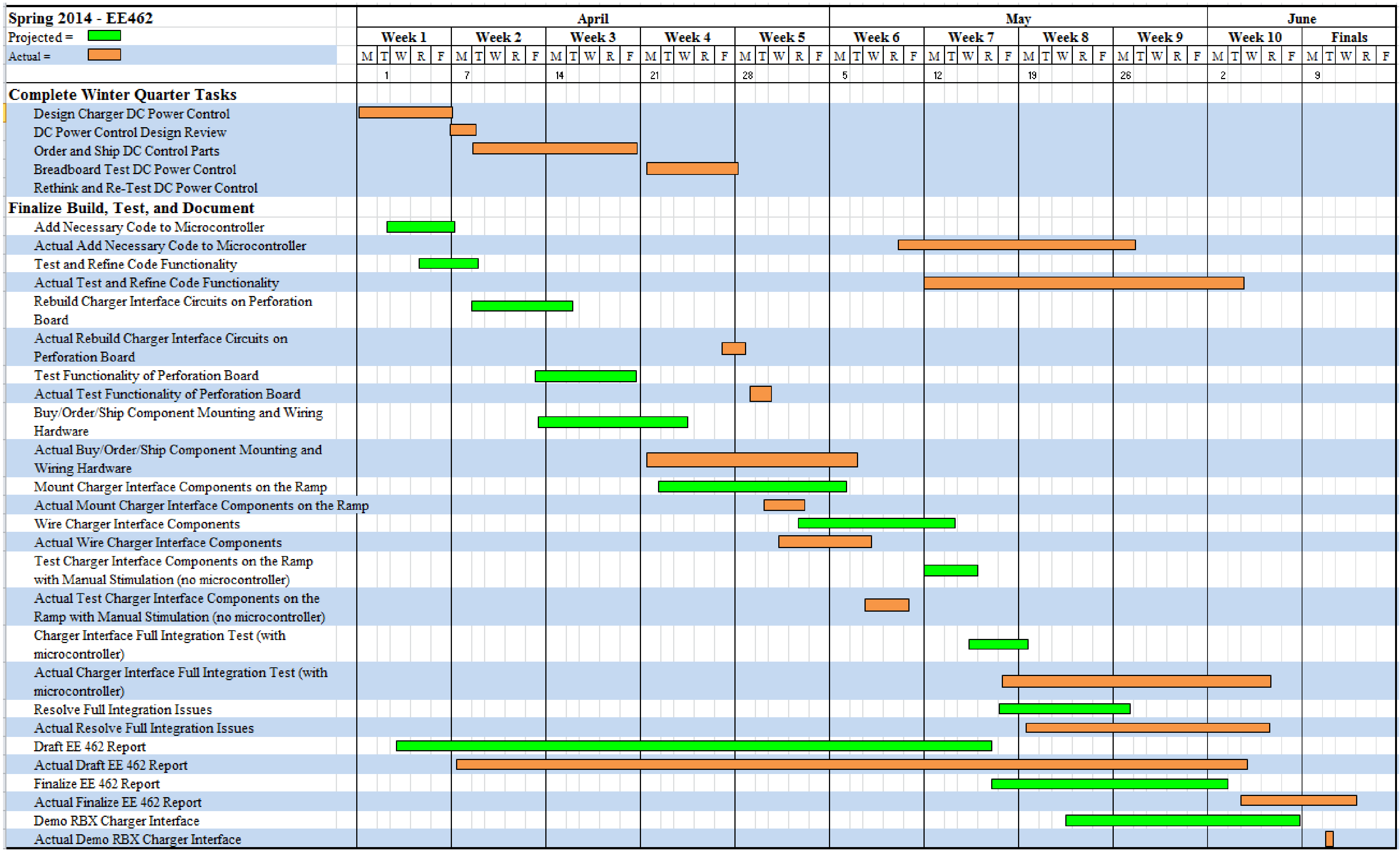
New tools and techniques, used for development of the project:

- I learned how to run a Monte Carlo sensitivity analysis in LTspice. This allowed me to observe the effects of a circuit output based on an element, or elements, that may vary due to tolerance, temperature, or some other changing parameter.
- I learned how to model relays and contactors in LTspice.
- I learned how to utilize an optocoupler and a TRIAC to build an isolated DC controlled AC switch.

12. Estimated and Actual Development Time




Winter 2014 - EE461
Projected = 🟩
Actual = 🟧
January
February
March
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Finals
M T W R F
6
13
20
27
3
10
17
24
3
10
17
Design and Build
Projected Design Charger AC Power Control
Actual Design Charger AC Power Control
Projected Order and Ship AC Control Parts
(utilized parts from EVEC inventory)
Projected Breadboard Test AC Power Control
Actual Breadboard Test AC Power Control
AC Power Control Design Review
Projected Rethink and Re-Test AC Power Control
Actual Rethink and Re-Test AC Power Control
Design Charger DC Power Control
Order and Ship DC Control Parts
Breadboard Test DC Power Control
Rethink and Re-Test DC Power Control
Build/Test Voltage-Sensing Voltage Divider
Projected Draft EE 461 Interim Report
Actual Draft EE 461 Interim Report
Projected Finalize EE 461 Interim Report
Actual Finalize EE 461 Interim Report
Demo Prototype Progress to Advisor


Spring 2014 - EE462
Projected = 🟩
Actual = 🟧
April
May
June
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Finals
M T W R F
1
7
14
21
28
5
12
19
26
2
9
Complete Winter Quarter Tasks
Design Charger DC Power Control
DC Power Control Design Review
Order and Ship DC Control Parts
Breadboard Test DC Power Control
Rethink and Re-Test DC Power Control
Finalize Build, Test, and Document
Add Necessary Code to Microcontroller
Actual Add Necessary Code to Microcontroller
Test and Refine Code Functionality
Actual Test and Refine Code Functionality
Rebuild Charger Interface Circuits on Perforation Board
Actual Rebuild Charger Interface Circuits on Perforation Board
Test Functionality of Perforation Board
Actual Test Functionality of Perforation Board
Buy/Order/Ship Component Mounting and Wiring Hardware
Actual Buy/Order/Ship Component Mounting and Wiring Hardware
Mount Charger Interface Components on the Ramp
Actual Mount Charger Interface Components on the Ramp
Wire Charger Interface Components
Actual Wire Charger Interface Components
Test Charger Interface Components on the Ramp with Manual Stimulation (no microcontroller)
Actual Test Charger Interface Components on the Ramp with Manual Stimulation (no microcontroller)
Charger Interface Full Integration Test (with microcontroller)
Actual Charger Interface Full Integration Test (with microcontroller)
Resolve Full Integration Issues
Actual Resolve Full Integration Issues
Draft EE 462 Report
Actual Draft EE 462 Report
Finalize EE 462 Report
Actual Finalize EE 462 Report
Demo RBX Charger Interface
Actual Demo RBX Charger Interface

13. **References**

[1] Energy.gov. (2013, Jul. 19). Energy Department Releases Updated eGallon Prices as Electric Vehicle Sales Double [Online]. Available: http://energy.gov/articles/energy-department-releases-updated-egallon-prices-electric-vehicle-sales-double, [Nov. 9, 2013].

[2] Peter Fairley (2007, Nov. 1) Electric-Car Maker Touts 10-Minute Fill-up [Online]. Available: http://www.nxp.com/documents/application_note/APPCHP6.pdfhttp://spectrum.ieee.org/green-tech/advanced-cars/electriccar-maker-touts-10minute-fillup, [Dec. 1, 2013].

[3] Bruce D. Braga (1992, Dec.) Electric G-Van Demonstration and Commercial Assessment Project (Final Report) [Online]. Available: http://www.osti.gov/scitech/servlets/purl/10130809, [Dec. 1, 2013].

[4] NXP Semiconductors. (2003) BTA140 series Triacs data sheet [Online]. Available: http://www.nxp.com/documents/data_sheet/BTA140_SERIES.pdf, [Nov. 10, 2013].

[5] Motorola (1995) Optoisolators Triac Driver Output data sheet [Online]. Available: http://pdf.datasheetcatalog.com/datasheet/motorola/MOC3021.pdf, [Nov. 10, 2013].

[6] Motorola (1995) Applications of the MOC3011 Triac Driver, AN780A [Online]. Available: ftp://www.elex.camosun.bc.ca/browningi/ELEX242/2011/Modules/Module13PowerDevicesTriggered/Reference/MOC311TRIAC.pdf, [Nov. 10, 2013].

[7] GIGAVAC. (2003) miniTACTOR P105 data sheet [Online]. Available: http://www.gigavac.com/pdf/ds/pp/p105.pdf, [Nov. 10, 2013].

[8] GIGAVAC. (2003) Contactor Coil Suppression Application Note 1 [Online]. Available: http://www.gigavac.com/apps/coil-supression.html, [Nov. 10, 2013].

[9] Johnson Controls Battery Group Inc. (2012) Lead/acid Battery, Wet, filled with acid, MSDS [Online] Available: http://corporate.interstatebatteries.com/msds/msds_wetcell_us_and_canada_11-28-12.pdf, [Dec. 3, 2013].