ECE 477 Final Report – Spring 2009
Team 13 – Moto-eV

Team Members:

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CRITERION	SCORE	MPY	PTS
Technical content	0 1 2 3 4 5 6 7 8 9 10	3	
Design documentation	0 1 2 3 4 5 6 7 8 9 10	3	
Technical writing style	0 1 2 3 4 5 6 7 8 9 10	2	
Contributions	0 1 2 3 4 5 6 7 8 9 10	1	
Editing	0 1 2 3 4 5 6 7 8 9 10	1	
		TOTAL	

Comments:

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Abstract

The Moto-eV concept is a full scale electric motorcycle. The electric modifications will be retrofitted into a 1986 Honda VF500F chassis. The combustion engine and transmission will be replaced with an electric motor and a fixed gear final drive. The Moto-eV is engineered to be a commuting vehicle which provides a more environmentally friendly alternative to inner city driving.

1.0 Project Overview and Block Diagram

The idea for the Moto-eV stemmed strongly from the groups mutual interest in electric motors. All group members have taken ECE 321 and are all interested in using an electric motor to provide some sort of personal transportation. Mike currently owns and rides a Honda VFR motorcycle and proposed the idea of designing an electric motorcycle. The bike is powered by either a PM brushed DC being supplied with between 48 volts. All of the hardware is fitted into a 1986 Honda VF500F chassis and relevant user information is displayed through a LCD via serial interface. The motorcycle is designed for short commutes to and from work or school. Cruising speed is 35 miles per hour with effective range of 20 miles.

Mike's focus was on choosing and integrating the hardware peripherals as well as using his ee423 knowledge to assist Loren with motor control. He also has extensive knowledge of the mechanical workings of motorcycles therefore he also was the lead mechanic in disassembly and maintenance. Loren targeted motor control with hardware and in software as well as designing the layout for the PCB. Arin undertook the responsibility lead programmer; however every member of the team will contribute in this area. Janell took charge of packaging all of our components into the motorcycle frame. The entire team will be committed to the testing and debugging as well as the final paint job.

Table 1.1: Initial Cost Estimate

Part	Quantity	Price	Cost
PM Brushed DC Motor	1	$500	$500
12V SLA Batteries	4-6	$100	$600
VF500F Chassis	1	$100	$100
Metal and Fasteners	N/A	$150	$150
Sprockets	2	$75	$150
LCD Screen	1	$75	$75
Tilt Sensor	1	$15	$15
		TOTAL	$1,590

Figure 1.1: Block Diagram

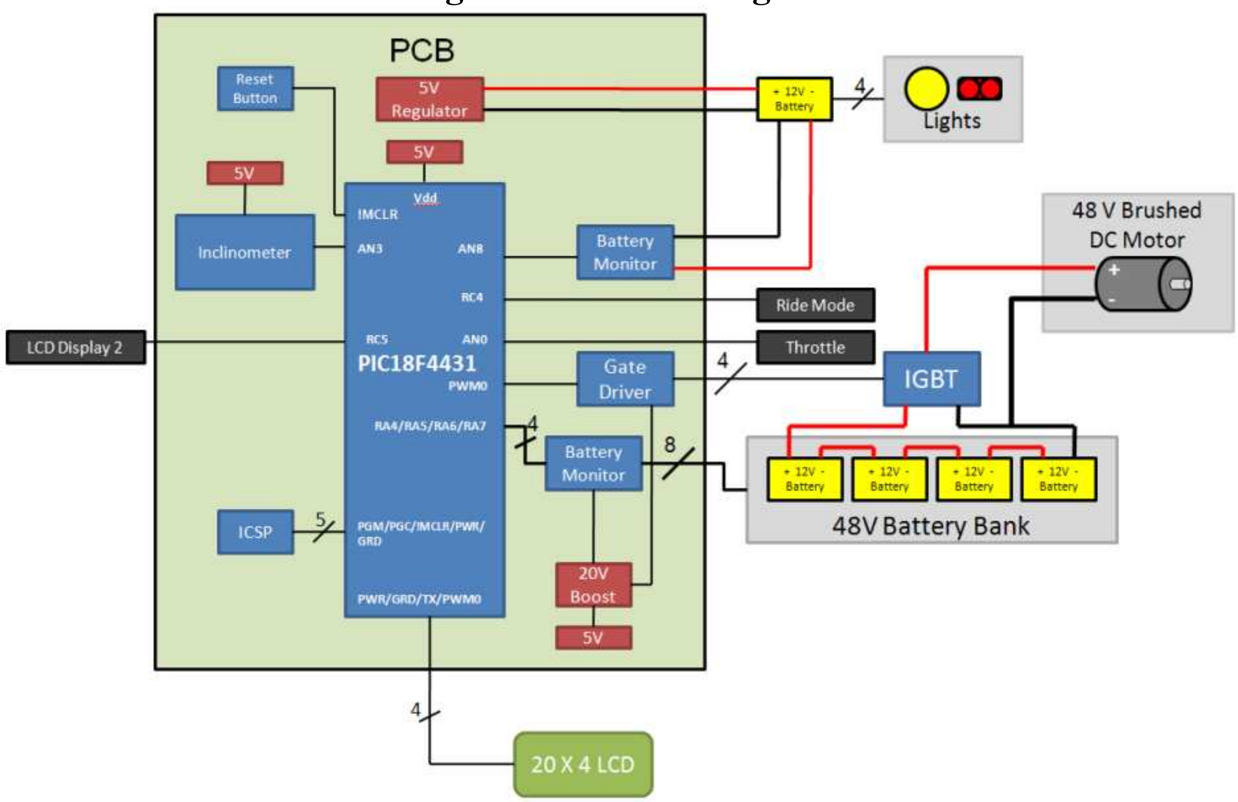


Table 1.2: Division of Labor

Design Component Homework		***Professional Component Homework***	
4-Packaging Design and Specs	Janell	3-Design Constraint Analysis/Parts List	Mike
5-Hardware Narrative and Prelim Schematic	Mike	10-Patent Liability Analysis	Arin
6-PCB Narrative and Prelim Layout	Loren	11-Reliability and Safety Analysis	Loren
9-Software Design Narrative	Arin	12-Social/Political/Environmental Analysis	Janell

2.0 Team Success Criteria and Fulfillment

1. An ability to control an electric motor from throttle input.
2. An ability to monitor battery levels and shut down at a specified level of charge.
3. An ability to provide user selectable ride modes.
4. An ability to use a tilt sensor to monitor lean angles.
5. An ability to display pertinent data to rider using a LCD.

All of the Project-Specific Success Criteria (PSSC) were fulfilled, with some being more difficult than others. PSSC-5 was the first to be completed. This proved useful because it provided a means to debug all other issues with software by displaying values and registers to the LCD.

PSSC-4 was the next to be checked off the list. This was the next logical step because the inclinometer chip was already on the PCB and its values could be displayed onto the LCD to ensure proper depiction of lean angle.

PSSC-1 was then completed. This was a large milestone in the project and allowed the team its first chance to take the motorcycle out for a ride. In the end, voltage control via PWM was utilized for this PSSC. This was the most difficult PSSC to complete due to our lack of experience in implementing a real world drive system and issues with our current monitoring circuit. Multiple iterations of the final drive system where designed and tested before the final 2 quadrant drive with bootstrap circuit was implemented.

PSSC-2 was the second to last to be completed. The ability to display values to the LCD made this PSSC rather easy. The most difficult part of this PSSC was tuning in each individual differential amplifier to display the correct voltage to the LCD.

The final PSSC to be completed was PSSC-3. This dampens the throttle input and limits the maximum speed of the bike to allow for a novice rider to feel comfortable and safe while riding.

3.0 Constraint Analysis and Component Selection

3.1 Introduction

The Moto-eV concept is a full scale electric motorcycle. The Moto-eV is engineered to be a commuting vehicle and thus will be equipped for a modest range of 25 miles with a top speed around 35 mph. The main design constraints stem from the size and weight of the 1986 Honda VF500F chassis. The combustion engine and transmission will be replaced with a brushed PM DC motor and a fixed gear final drive.

3.2 Design Constraint Analysis

Given the target consumer of the Moto-eV is the short distance commuter, the main constraints are focused on obtaining a certain top speed and run time. This will require a balance of power and weight in the batteries and the motor. Also an adequately powerful motor and a sufficient number of batteries, each with an ample amount of stored energy will be required. All of this hardware will have to be light to reach the target performance. Interfacing with such large power components will be extremely challenging. Some parts will be required to handle extremely large amounts of current while maintaining long term reliability.

Interfacing with the rider via an LCD screen, throttle control, & brake control is also very important. The Moto-eV must be safe for anyone with a moderate background of motorcycle experience to pick up and ride. Battery level, bike side-to-side lean angle, and ride mode and throttle data will need to be displayed for the rider to monitor the bikes conditions.

3.2.1 Computation Requirements

The primary purpose for the microcontroller will be motor control. This will be implemented through current control. By monitoring and controlling the current feed it is easy to prevent the motor from attempting to draw excessive amounts of current. This protects the batteries, the switching circuit, the associated linkages, and the motor itself. The motor control algorithm will monitor the requested throttle input and the real time current draw. This data will be run through the software, which then will subsequently cycle two discrete digital output pins that drive the two quadrant chopper. By applying this method of control, the system will operate within current limits imposed by the batteries, IGBT, and motor specifications. This project requires a very fast ATD sampling frequency to monitor the current draw across the shunt resistor. The current algorithm will require very accurate monitoring of the current draw at a high frequency. This is due to the speed at which the current will be increasing during times of high load torques and low speeds.

As a backup method of motor control a voltage control method could be implemented. It is important to make a microcontroller selection where this control option will be available in the future. This contingency plan requires a high speed 10-bit PWM output, which will be considered during microprocessor selection. Other uses of the microcontroller will be to monitor & display lean angles, battery level, ride mode, and throttle levels.

3.2.2 Interface Requirements

Starting with the main motor control function the microcontroller will have to have PWM functionality to implement voltage control. The motor driving signal will be optically isolated and will connect to the switching circuitry through a gate driver. A serial communication interface will be needed to communicate with the Crystalfontz LCD. Finally, it is important to have a reasonable number (excess of 6) of general digital I/O pins to control things such as the ride mode and LCD backlight.

Input number one will be from the current monitoring circuitry. This ATD input is essential for the motor control algorithm. Two additional ATD inputs will be used for the 0-5kΩ potentiometer throttle and the tilt sensor intended to monitor lean angles. Battery monitoring circuitry will interface via an ATD input. Ride mode selection, LCD display page selection, and LCD backlight control will each use digital input pins.

3.2.3 On-Chip Peripheral Requirements

The input – output (I/O) requirements in the previous section dictate the use of a micro with at least five 10-bit analog to digital (ATD) inputs, three digital inputs, one channel of 10-bit PWM, and SCI/UART functionality. Additional general I/O pins will be required for the possibility of future peripherals.

3.2.4 Off-Chip Peripheral Requirements

The off chip peripherals that are interfaced with the microprocessor are the built in serial communication chip on the LCD, the single axis inclinometer chip, and the gate driver chip.

3.2.5 Power Constraints

The Moto-eV is powered from around 72Ah of battery power. Despite this large well of energy, the drive circuitry must remain efficient in order to leave as much power as possible available to the motor. A 5V supply voltage will provide an ample ATD resolution while not consuming too much power. The abilities of the switching circuit will be dictated by the motor's power requirements. A robust switching circuit using an insulated gate bipolar transistor (IGBT) is required for this application. To dissipate the heat generated from switching, a long heatsink and fan is mounted below the IGBT [30]. The switching circuit and batteries will need to be able to supply short burst of high currents up to 200 amps (with capacitor assistance). The batteries also must provide at least 48V of power, while being rechargeable, light, and compact.

3.2.6 Packaging Constraints

The main packaging constraints were the size of the motorcycle frame. There is plenty of room inside the tank for the large circuit board, switching circuitry, LCD, and associated hardware. However, the batteries and motor are more restricted. The motor can only be mounted directly in front of the swing-arm, and it should not have a depth that is wider than the bike's frame. The batteries are mounted inside of a "battery cage". This cage is mounted in front of the motor and behind the front wheel in whatever space is left inside the frame once the motor is mounted. The cage is also removable in order to allow access to the individual batteries. The dimensions of the batteries are compact, while still providing a respectable amount of power.

3.2.7 Cost Constraints

Cost constraints are $305 per team member, for a total of $1,219.58 dollars. This is out of pocket money and does not consider any donations made. The team acquired a LCD module from Crystalfontz, a potentiometer throttle from Magura, 12V sealed lead acid batteries from

NPC Robotics, connectors from Molex, and fuses, fuse block, and master switch from Blue Sea. The cost to the team was $100 for the rolling chassis and $350 for the motor, plus additional hardware costs.

3.3 Component Selection Rationale

Chassis

The donor chassis being used for this project is a 1986 Honda VF500F. This was chosen for its small size, frame design, cost, and ease of acquisition. The chassis was purchased for $100 and required little maintenance to get it rolling. This is a double cradle frame, which will be advantageous when mounting the motor and batteries. The negatives of this frame are its weight and size. The frame is made of steel instead of the lighter alternative of aluminum, and since the original motor was a 500cc v-four, the space that remained to install the batteries after placing the motor was limited.

Microcontroller

When researching the different appropriate microcontrollers available for this project it was clear from the beginning that the PIC line was more appropriate than the offerings from Freescale. Below is an outline of the two PIC micros that the team was deciding between.

Table 3.1: Microcontrollers Under Consideration

Features	PIC18F4431 [2]	dsPIC30F3011 [3]
Peak Operating Frequency	40 MHz (10MIPS)	30 MIPS
Program Memory (Bytes)	16384	24000
I/O Ports	five 8-bit bidirectional ports	20 pins
Capture/Compare PWM modules	2	4
PWM	8 channels 14-bit resolution Complement mode	6 channels 14-bit resolution Complement mode
Quadrature Encoder Interface	YES	YES
ATD	10-bit High Speed (200ksps) 9 input channels 2 comparators for 2 cannel simultaneous reads	10-bit High Speed (1Msps) 9 channels 4 S/H inputs for simultaneous reads
Serial Communication	Synchronous Serial Port (SSP) EUSART RS-232	SPI I2C UART
Operating Voltage (V)	5.0	5.0
Instruction Set Size	75	83
Pin Count	40	40/44
Internal Oscillator	YES	YES

These two chips are very similar and both would have most likely met the project needs. When deciding which chip to choose, the exact frequency at which the current needed to be monitored was not known. This frequency would have been dependent on the motor, and the team needed to get more concrete data on the motor. However, it was unlikely that a sampling frequency greater than 200ksps was going to be required. Therefore, the team decided to use the PIC18F4431. This processor offered all of the peripherals required and also provided enough extra pins for any design expansions that took place.

Inclinometer

The first contender in the inclinometer selection was the Rieker H4 [4]. This inclinometer is designed for rugged applications on cranes, agricultural equipment, and other industrial applications. It offers a range of +/-70 degrees and outputs an analog voltage of 0-5V. The only drawback was the cost, which is unknown, but anticipated to be in excess of $100.

The other sensor option was the VTI single axis SCA61T-FA1H1G (digikey part #551-1005-1-ND) [5]. This small surface mount device has a measuring range of +/-90 degrees and includes internal temperature measurements and compensations. It operates on 5V and outputs data via an analog signal from 0-5V or SPI. Another plus to this option was that they only cost around $40. This was the team's best option given the constraints of operating voltage, cost, and output options.

Batteries

There were several design constraints associated with the batteries, but the most important was obviously voltage level. The motor must operate between 48V and 72V. To obtain this level, the team used four 12V SLA batteries in series. It was possible to implement more, but due to budgetary reasons it was not considered. The second constraint on the batteries was the amount of energy they can store. With a motor that is capable of drawing over 200A in bursts, the team needed plenty of battery capacity. This capacity was a compromise with the third constraint, which was physical size. The frame had limited space, and measured only 13" wide. Also, the batteries needed to be maintenance free, rechargeable, light, and most importantly cheap.

The website batteryspace.com offered the team a discount, and their LA-12V26Ah model is particularly appealing. The main motivation to use this particular model is its price point. There are other more expensive models which would offer a greater riding range, but they are out of reach due to the team's budget. At $50 dollars apiece the LA model offers a nice balance. The 26Ah capacity will give a total 104Ah of power. This is obviously a compromise on range, but should offer an increase in performance. Each battery weighs 19.4lb., which will give a total battery weight of a mere 77.6lbs. Their 4.92" x 6.54" x 6.89" form factor is extremely small, and will offer a large variety of mounting options in the bike's frame. These batteries are sealed lead acid and are not necessarily the ideal choice for this application. There are several other battery chemistries which would offer better power to weight ratios. However no technologies can beat the price of SLA batteries, despite their high weight [6].

The team also considered using 4 Panasonic LC-X1228P SLA batteries [7]. Each battery can provide 28Ah and weighs 24.34lbs, for a total of 112Ah of power weighing 97lbs. These batteries have a nice small size at 6.49" x 4.92" x 7.07" which would have been easy to mount in the bike's frame. The cost of these batteries was also very competitive at a mere $45 a piece, ringing in at a total of $180. These batteries were less expensive, offered a slightly higher capacity, but each weighed 4.94lbs more than the LA-12V26Ah. The extra 19.76lbs would have been worth the higher quality brand name Panasonic batteries and the extra 8Ah of capacity.

Ultimately cost won out over the other criteria of weight and capacity. NPC Robotics sponsored the team with four 12V sealed lead acid batteries with a 350A max current draw (for 10 seconds), 100A continuous current draw, and 18Ah of battery life. The dimensions of the batteries are 8" x 6.5" x 3.5" and weighed in at 18.8 pounds each.

Motor

Originally this project was going to implement a brushless DC motor [8]. These motors would be the best for this project because they offer high efficiency and zero maintenance. Due to complexity of control, limited available motor options, and cost, the team has decided to use a brushed PM DC motor. The rest of the system is designed around the motor choice so the only motor constraints are efficiency, weight, operating voltage, and cost.

The best motor for this project is the Lynch/Lemco LEM-200-D127 [9]. This brilliant motor can operate between 48 and 72 volts. It offers a rated power of 12.56kW (16.84 electric hp at 72V) and a rated continuous current pull of 200A. At 48V the motor should output 8.55kW (11.46 electric hp) continuously and 33.3 N*m of torque. These motors can also achieve an amazing peak efficiency of 90%. Another benefit to this motor is its weight of only 25lbs. Compared to a series wound brushed DC motor the team was considering, this is about twice the power at half the weight. The one major downside to using a Lemco, is its very high cost. These advanced motors cost over $900 shipped to the US. This price is after a discount offered to the team by the company owner, as well as the exchange rate (motors are made in the UK). Unfortunately this motor will be out of reach due to the extremely high price.

Another motor that was considered was the Advanced DC A89-4001 series wound brushed DC motor. The team was offered a used one for $350 plus shipping. This motor has a continuous output of 6hp and a peak of 27hp. A downside is that it weighs 50lbs, which is twice that of the Lemco. This weight also corresponds to size, with the A89 being over 10.4" long compared to the Lemco's depth of 170.2mm (6.7"). It was important to try to keep the weight of each component to a minimum. Once everything is in the chassis the weight of the bike will directly correspond to performance and range. Another downfall of this motor was the lack of support. It was difficult to find much information on this motor or any previous examples of electric vehicle implementation. Seeing as how the motor was used, the team also didn't know the condition of the brushes or any of the other mechanics. Yet another pitfall for the A89 is its lack of efficiency. The Lemco is the leader in efficiency as far as brushed DC motors go.

In the end the motor choice was the Mars ME0709 PM brushed DC motor [10]. This motor weighs in at 36lbs and a cost of $500. While the motor is twice the depth of the Lemco and heavier, due to its lower price it is the winner. It can operate between 48V and 72V, with a continuous current draw of 114A. The motor provides approximately 7.03kW of continuous power at 72V. Running at 48V this number will be slightly reduced, but is still more than enough to power a motorcycle.

LCD

The team used a Crystalfontz CFA634-YFB-KS [11]. This is a 20x4 positive screen that has a backlight and a serial interface. The team chose this character based display for its ease of implementation. A graphical display was an option but due to the scope of the project, it was decided to be too ambitious. This character display offers the screen real estate required for all of the information the rider will need, and will be very simple to interface with. A large design constraint was for the LCD to have a positive display so that the rider would be able to view it in direct sunlight.

Switching Technology

Darlington BJT, Power MOSFET, IGBT, & MCT were all different technologies available for switching the motor. The team decided to use an IGBT module based on its low gate current and low collector-emitter resistance. A separate IGBT module is beneficial in this application due to the power which it must switch and the temperatures that the transistors will reach during peak operation. The module architecture being used prevents excessively large PCB traces, and in the event that it is destroyed, it will not destroy any PCB boards. When switching 80V or less, 75% to 80% of the time power MOSFET's are used. However the high current and the time constraints of this application dictate the use of a sealed module and IGBT technology.

Fairchild had graciously decided to sponsor the team by providing the half bridge as well as the optical isolator/gate driver chip. The FMG2G150US60E IGBT half bridge can handle up to 600V and 150A continuous across the collector and emitter [12]. This worked perfectly for the power needs of the Mars motor.

3.4 Summary

The Moto-eV project uses a 1986 Honda VF500F chassis, powered by a Mars Brushed PM DC motor. This motor works well for this project due to its weight and power output. The motor runs off of 48V provided from four 12V SLA batteries in series. While these batteries are heavier than alternate options, they offer the best price to performance, weight, & capacity ratio. System control is implemented with a PIC18F4431. This micro provides the necessary high speed ATD, PWM, and general I/O pins. A current control algorithm is used to switch an external IGBT module which in turn will power the motor. Relevant user information is provided on a character based 20x4 Crystalfontz LCD. This screen is easily interfaced with using serial communication and offers the screen real estate required for the data. This data consists of battery charge, current draw, throttle demand, & lean angle values. The lean angle will be provided by a VTI SCA61T single axis inclinometer, a small surface mount chips which provides +/-90 degrees range of measurement.

4.0 Patent Liability Analysis

4.1 Introduction

The Moto-eV is an electric motorcycle which is powered by sealed lead acid batteries and a DC brushed permanent magnet motor. The motorcycle is designed primarily for city driving and will serve as a stylish alternative for gas combustion vehicles. The motorcycle will offer a number of features aside from being a transportation vehicle: an inclinometer will measure the lean angle of the rider; a Ride Mode option which will set a maximum speed so that licensing and age restrictions will not apply to the bike in certain states; and an LCD panel will display the amount of battery power left to power the bike, the tilt angle of the user, the throttle demand, and the current ride mode.

Moto-eV seems like an ideal candidate for patent infringement, since the motorcycle has been in existence for so long, and patented extensively. When researching motorcycle, scooter, and bicycle devices to search for any potential infringements, the existing patents must be analyzed with respect to the main components and functions of our project. Since the Moto-eV uses batteries to power a DC motor, and it is digitally controlled using a microcontroller and software, there could be enough differences to show that the Moto-eV has a substantially different function and performs in a substantially different way, in order to avoid any potential liabilities.

4.2 Results of Patent and Product Search

Initially, research regarding patent infringement was done with respect to the functions and methods of Moto-eV as a whole; the function being a mid range transportation device and the method being a motorcycle driven by an electric motor which is powered by batteries. A general view will be considered with respect to the motorcycle patent, the electric bicycle patent, and the electric scooter patent. Then a motor control method comparison was made with respect to the electric motor controller patent and the microprocessor motor controller having discreet processing patent.

Motorcycle – Filing date: July 25, 1986

According to claim 1 of the motorcycle patent, a motorcycle is a device having a fairing and a radiator. It must have a longitudinal body with a head pipe mounted to the front of the bike extending back towards the bike. The radiator must be placed ahead of the head pipe, mounted such that it is perpendicular to the longitudinal axis of the bike. Claim 2 then continues to elaborate on how the instrument cluster is to be mounted above the radiator at an upward angle toward the rider, and that a headlight is mounted on the front of the bike between the instrument cluster and the radiator. The lighting, instrument cluster, and radiator are all to be covered by a fairing.

The key claims for infringement would be based on the longitudinal shape and arrangement of the instrument panels and headlights. Although, much of the motorcycle patent was based around the arrangement of the radiator on the chassis, showing promise of substantial differences in the way Moto-eV performs with respect to a motorcycle. Since the DC brushed motor used to propel Moto-eV does not need to be water cooled, it will not require a radiator.

The other key points in the motorcycle patent were found in claim 3. These points revolved around the use of fairing to enclose and protect the devices on the motorcycle. But, the details of the fairing design are based around the radiator placement on the chassis in coordination with the instrument cluster and headlights. Once again, the lack of a radiator has shown substantial differences between the patented motorcycle and the Moto-eV.

Electric Scooter – Filing date: January 31, 1996

Claim 1 of the electric scooter patent explains that an electric scooter is an electrically powered device that has a front and rear wheel connected by a tube like structure. The connector between the front and rear wheel must also lie below the center of the wheels, parallel to the ground, providing the place where the rider is to stand. The electric motor is mounted on the rear wheel of the scooter which is powered by batteries mounted below the chassis of the scooter. The primary purpose of the device is for powered travelling over the ground. Claim 2 simply continued to dive into greater details about the same categories.

The motive for patent infringement would be the use of batteries mounted on the chassis to power the electric motor and propel the device via the rear wheel. The Moto-eV is extremely similar in that perspective, since there are batteries mounted within the chassis and the motorcycle is indirectly propelled forward by the rear wheel.

Electric Bicycle – Filling date: March 26, 1998

According to claim 1 of the electric bicycle patent, an electric bicycle is technically a bicycle frame with a high performance lightweight engine mounted onto it. The front wheel contains the steering mechanism and the rear wheel must have a hub to accommodate multiple gears. The motor is to be powered in conjunction with a variable V-belt drive, capable of managing a centrifugal slip clutch so that the bicycle can utilize multiple gears. The front wheel also contains a regenerative system to charge the battery during use of the bicycle. Claim 2 pertains to the final primary function of the patented electric bicycle. It is a mechanically actuated power control switch to provide a motor starter power level, along with two other power levels during use of the bike.

Electric Motor Controller – Filing date: November 11, 1986

Claim 1 states that the electric motor controller patent applies to a system that has a current controlled motor. The speed of the motor is controlled with the use of an error signal, which is based on the difference between the current speed of the motor and a preselected desired motor speed. One set of terminals are to be connected parallel to the input terminals to the controller and another set are connected in series to the input terminals to the controller. By using a pulse train at a frequency much higher than the mechanical resonant frequency, the error signal modulates the speed of the motor by changing the duty cycle of the pulse train. This seems to be extremely similar to the use of a PWM system to set the motor output to specifically preset duty cycles.

Microprocessor Motor Controller Having Discreet Processing – Filing date: Jan 30, 1990

This patent is worded in a manner that makes it sound like it is used for large scale, multiple device motor control mechanisms. According to claim 1, the motor control is accomplished using a microprocessor that uses its outputs to signal outputting power and uses its inputs to read a variety of sensors providing feedback information to help control the motor apparatus. The second main point in this patent essentially summarizes the principle of an interrupt service routine. There are different motor control tasks accomplished at different frequencies based on timers which define intervals in the microprocessor. The remainder of the patent goes into great detail about the types of sensors being used for determining EMF, calculating speeds and managing communication devices.

4.3 Analysis of Patent Liability

Motorcycle Patent

The motorcycle patent is a highly mechanical system, distinguished by its design around the radiator. By introducing the presence of a microcontroller and controls that are digitally analyzed using software, the substantial differences between Moto-eV and the patented motorcycle seem great enough to avoid literal infringement with the help of a good lawyer. The fact that Moto-eV is meant for smaller distances and lower speeds than that which a fuel combustion engine is capable of, could help to push the substantially different methods and functions of Moto-eV with respect to the doctrine of equivalents.

Electric Scooter

Factors supporting the substantially different methods and functions of Moto-eV from an electric scooter would be based on the type of travelling and way that travelling is performed. For example, a scooter could be used for inner city travelling, but could it be used to travel to work from home, or any other particularly long distances? Since Moto-eV has a sitting user position, a 48 volt power source, and most probably a higher top speed, it would be suitable for purposes beyond the scope of the electric scooter. The fact that the motor is not literally attached to the rear wheel could also be twisted by the lawyer to show that it functions substantially differently from the motor mounted onto the rear wheel of an electric scooter. Some licensing may be necessary to legally manage production of the Moto-eV prototype even after considering any substantial differences with the point of view of the doctrine of equivalents, but literal infringement should not be an issue.

Electric Bicycle

Most of the defining characteristics of the electric bicycle patent do not interfere with the key aspects of Moto-eV. The part of the electric bicycle that would give the most incentive to file a case of patent infringement would be the power control system. The system on the electric bicycle is controlled using a mechanically actuated switch, though, which is substantially different than having a digitally controlled power switch. Most other aspects of the bike can be dodged easily enough, since Moto-eV will be a single gear motorcycle with no regenerative battery charging system, removing any conflicts with a clutch based motor drive or battery charging methods.

Electric Motor Controller

This patent will fortunately play no role in patent infringement since it was filed over twenty years ago.

Microprocessor Motor Controller Having Discreet Processing

This patent is worded in a manner that makes it sound like it is used for large scale, multiple device motor control mechanisms. The motor control is accomplished using a microprocessor that uses its outputs to signal outputting power and uses its inputs to read a variety of sensors providing feedback information to help control the motor apparatus. The second main point in this patent essentially summarizes the principle of an interrupt service routine. There are different motor control tasks accomplished at different frequencies based on timers which define intervals in the microprocessor. The remainder of the patent goes into great detail about the types of sensors being used for determining EMF, calculating speeds and managing communication devices.

There are a number of similarities between the function and way that Moto-eV accomplishes motor control and the way the Microprocessor Motor Controller Having Discreet Processing does things. The use of different intervals of time to accomplish tasks at different intervals would probably be extrapolated for the purpose of maintaining a sense of priority, although it wasn't specifically documented in that fashion. The wording was quite ingenious in this patent, because it essentially makes any motor controller that uses interrupt service routines viable for infringement. This is a definitive candidate for patent infringement under the doctrine of equivalents for having substantially the same function in a substantially same method.

4.4 Action Recommended

For the first three of the previously mentioned patents, there does not seem to be any highly intimidating potential for infringement. The motorcycle and electric bicycle patents both used exclusively mechanical systems. This is a huge factor of persuasion under the doctrine of equivalents in support of Moto-eV. When comparing the capabilities and functions of a digital system to those of a mechanical system, vast differences can be found in how Moto-eV functions and what its purposes are. The main gist of the substantially different functions lies in the exclusive purpose of travelling moderate distances, like the kind of travelling that takes place regularly in high traffic, metropolis areas. It would be unlikely that the motorcycle or electric scooter could find the legal prowess to show that Moto-eV is guilty of patent infringement. The electric bicycle is more similar to Moto-eV in its purpose than the motorcycle or scooter, but once again the mechanical systems of the clutch and gear switching components have caused great differences between Moto-eV and the electric bicycle.

Thus, the action recommended would be to highly emphasize the differences between mechanical systems in the current patents and the digital systems being implemented in Moto-eV. In the case that patent infringement does become a real issue and digital systems are not capable of showing their substantial differences in how the devices work. The functions of Moto-eV should be brought up to explain that the purpose of Moto-eV may overlap with that of a motorcycle, scooter, or bicycle, but mostly entertains its own category of city travelling at moderate distances. Ultimately, all is in vain though. The Microprocessor Motor Control Having Discreet Processing would definitely be a case of patent infringement under the doctrine of equivalents. Since Moto-eV doesn't have the financial prowess to manage licensing the patent, the only option would be to not produce the motorcycle until the patent were to expire.

4.5 Summary

In summary, the patents that most closely resemble the functions and methods of Moto-eV are the motorcycle, electric scooter, and electric bicycle; and the patents that resemble the motor control mechanism is the Electric Motor Controller and Microprocessor Motor Control Having Discreet Processing. After reviewing the patents of those devices, the Microprocessor Motor Control Having Discreet Processing would be a definitive issue with regards to patent infringement under the doctrine of equivalents. Licensing would be the only possible option as this point, but due to financial constraints, the only viable option is to wait for the expiration of the patent at hand.

5.0 Reliability and Safety Analysis

5.1 Introduction

The Moto-eV is designed to be an inexpensive and environmentally friendly form of transport for individuals living in condensed urban areas. It can transport the rider a distance of up to 20 miles at 35 MPH on a single charge an can be recharged in under 6 hours. The Moto-eV will function just as any other motorcycle will, with the expectation that it is fixed gear and fully electrical. The main safety concern for this project is protecting the wellbeing of the rider and the motor control system by avoiding injury and damage from falling over. The Moto-eV can only go so far in protecting the rider from danger; ultimately it is still the rider's responsibility to be a safe and smart driver. A safety feature that has been implemented on the bike is a mechanical kill switch. This physically breaks the circuit that sends power to the motor in case there is a failure with any part of the motor control circuitry and the motor ramps up without any user input. With this implemented, if the user does lose control over the motor speed he can simply turn a key and shut down the motor.

To be a successful and commercial product, the Moto-eV also needs to be reliable. The schematic has been broken down into five functional blocks, and components from each will be analyzed individually. A few of the most critical components that will be represented in this report include the LT 1529 Linear Voltage Regulators [34], the PIC18F4331 microcontroller [2], the CM300DY-24H IGBT [30], and the LM2733 Boost converter [35]. The failure rate and mean time to failure (MTTF) are included in the tables below for each of the previously mentioned components.

5.2 Reliability Analysis

The components mentioned above have a high risk associated with them if they fail. They have been analyzed for reliability and the results can be seen in the tables below. The LDO, boost, IGBT's are the components in with the highest probability of failure due to over-heating. If the LDO failed it would cause the entire system to stop working. A failure in the boost converter would simply cause the battery monitor to fail. A failure of the IGBT's can in the best scenario, simply open circuit and shut down the motor. Although it could also short and cause the motor to ramp up out of control and risk causing serious injury to the rider. The microcontroller is also highly critical because it is what reads the user inputs and system feedback and determines how to drive the motor. If this component fails, then the entire system cannot operate.

The tables that follow are a compilation of the necessary variables and calculations to determine the number of failures per 10^6 hours and mean time to failure (MTTF) for each of the previously mentioned components. Referring to the model found on page 25 of the Military Handbook: Reliability Prediction of Electronic Equipment [36]: $\lambda_P = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ and $\text{Mean Time To Failure (MTTF)} = (\lambda_P)^{-1}$ for microcircuits and microprocessors. Therefore, these can be used to calculator the failures/10^6 hours and MTTF for the microprocessor, LDO, and boost converter. In these equations, λ_P is the number of failures per 10^6 hours, C_1 is the die complexity, π_T is the junction temperature coefficient, C_2 is the package failure rate, π_E is the environmental constant, π_Q is the quality factor, and π_L is the learning factor associated with how long the particular component has been manufactured.

Certain assumptions have been made in order to complete the following analysis. Such as all components are operating at their respective maximum temperatures. Also, the system will be ground mobile with commercially manufactured parts and has been in production for over two years. The tables below are used to derive the failure rates and MTTF using these assumptions and information taken from the component datasheets.

Table 5.1: LT 1529 Linear Voltage Regulator

Parameter	Description	Value	Comments
C_1	Die Complexity	.02	Linear, MOS 101-300 transistors
π_T	Temperature Factor	58	Linear MOS, Max Temp of 125° C
C_2	Package Failure Rate	.0016	4 pins, Nonhermetic DIP
π_E	Environmental Factor	4	Ground Mobile
π_Q	Quality Factor	10	Commercial
π_L	Learning Factor	1	In Production for over 2 years
λ_P	Failures/10^6 hours	11.664	
MTTF	**85,733.88 hours = 9.787 years**		

Table 5.2: PIC18F4331

Parameter	Description	Value	Comments
C_1	Die Complexity	.28	16 bit, CMOS
π_T	Temperature Factor	3.1	CMOS, Max Temp of 125° C
C_2	Package Failure Rate	.019	40 pins, Nonhermetic DIP
π_E	Environmental Factor	4	Ground Mobile
π_Q	Quality Factor	10	Commercial
π_L	Learning Factor	1	In Production for over 2 years
λ_P	Failures/10^6 hours	9.44	
MTTF		**105932.20 hours = 12.093 years**	

Table 5.3: LM2733 Boost

Parameter	Description	Value	Comments
C_1	Die Complexity	.02	Linear MOS 101-300 transistors
π_T	Temperature Factor	58	Linear MOS, Max Temp of 125° C
C_2	Package Failure Rate	.0016	4 pin Nonhermetic SMT
π_E	Environmental Factor	4	Ground Mobile
π_Q	Quality Factor	10	Commercial
π_L	Learning Factor	1	In Production for over 2 years
λ_P	Failures/10^6 hours	11.64	
MTTF		**85733.88 hours = 9.787 years**	

Referring to the model found on page 58 of the Military Handbook: $\lambda_P = \lambda_B \pi_T \pi_A \pi_M \pi_Q \pi_E$ and $\mathrm{MTTF} = (\lambda_P)^{-1}$ for high power, high frequency bipolar transistors. In these equations, λ_P is the number of failures/10^6 hours, λ_B is the base failure rate, π_T is the temperature factor, π_A is application factor, π_M is the matching network factor, π_Q is the quality factor, and π_E is the environmental factor.

Certain assumptions have been made in order to complete the following analysis. The IGBT will be operating at its maximum temperatures. Its duty cycle will be greater than 30%, it has a JANTX quality factor with a no matching network and is ground mobile. The table below is used to derive the failure rate and MTTF using these assumptions and information taken from the IGBT datasheet.

Table 5.4: CM300DY-24H IGBT

Parameter	Description	Value	Comments
λ_B	Base Failure Rate	2.12	Power output of 750W
π_T	Temperature Factor	2.4	$V_S=V_{CE}/BV_{CES}$; V_{CE}=48V BV_{CES}=1200V
π_A	Application Factor	2.2	Duty Cycle > 30%
π_M	Matching Network Factor	4	None
π_Q	Quality Factor	1	JANTX
π_E	Environmental Factor	10	Ground Mobile
λ_P	Failures/10^6 hours	447.744	
MTTF		**2233.42 hours = .255 years**	

These results and calculations are derived for the worst case scenario for each component. To get these results, π_T is assumed to be at the maximum operating temperature before the component burns up and no longer works. That is why the MTTF is relatively low. If we used a more conservative temperature value to calculate MTTF for the LDO and boost converter such as 35° C ($\pi_T = 0.23$), the MTTF would increase to nearly 250 years for both chips and 230 years for the microprocessor. Along with the assumption of maximum operating temperature, I assumed a 300 amp current draw on the IGBT. If more reasonable values were chosen such as a temperature and current draw such as 100° C ($\pi_T = 0.38$) and 50 amps respectively; the MTTF would increase to 94 years.

By using values for π_T and λ_B that are in a more reasonable range, the MTTF for these critical components drastically increases. Based on the operation at lower temperatures, the reliability of each of the critical components is acceptable.

5.3 Failure Mode, Effects, and Criticality Analysis (FMECA)

The schematic can be broken down into five major functional blocks. Appendix A contains the schematics of each functional block while Appendix B contains the FMECA Worksheet which provides information about the different failure modes, causes, effects, and criticality for each of the functional block. The functional blocks are organized in the following manner:

A. Microcontroller

B. Sensors

C. Power

D. Motor Control

E. User Interface

Each failure is assigned a failure criticality level corresponding to its severity. The following table explains how the levels are broken down.

Table 2.1: Criticality levels

Criticality	Failure effect	Maximum Probability
High	Failure that causes system instability	$\lambda_p \geq 10^{-6}$
	Possible damage to user and/or system	
Medium	Requires replacement of minor component	$10^{-6} < \lambda_p < 10^{-9}$
	Causes undesirable behavior	
Low	LCD malfunction, incorrect battery level	$\lambda_p \leq 10^{-9}$
	No damage to device	

5.4 Summary

The components that were analyzed are very important because failures in those particular functional blocks have high criticality. MTTF is a good estimate of the lifetime of these components and by operating them in a reasonable range they should be more than sufficient for use in the Moto-eV. With regards to the FMEC analysis, the most critical failures occur in Sections D & E which contain the motor control and user interface. Failure in any of these two regions can cause damage to the device or the user. Precautions have been taken to prevent such accidents but unforeseen complications can arise during operation that will have to be corrected before the Moto-eV is ready for commercial production. Overall, Moto-eV is a safe and reliable product.

6.0 Ethical and Environmental Impact Analysis

6.1 Introduction

The Moto-eV is a full scale electric motorcycle. The Moto-eV is engineered to be a commuting vehicle and thus will be equipped for a modest range of 25 miles with a top speed around 40 mph. The bike will be powered by a bank of four 12V SLA batteries connected in series to provide 48V to the motor. The microcontroller will run off of a single, sealed, 12V lantern battery mounted inside the tank.

Just like any other product that is going to be marketed, there are ethical and environmental issues that need to be taken into consideration prior the release of the product. As a mode of transportation, the main ethical concern would be the safety of the rider. Therefore, where to place warning labels and the testing of the product in many situations was taken into consideration. In terms of environmental issues, topics to consider are pollution and waste that may take place during the three phases of the product's life: manufacturing, normal use, and recycling/disposal.

6.2 Ethical Impact Analysis

Since there are many ethical considerations that needed to be taken into account prior to the production of the Moto-eV the Institute of Electrical and Electronics Engineers (IEEE) Code of Ethics [18] was used as a reference. The rider's safety is at utmost importance since the Moto-eV will be considered a motor vehicle to be used on public streets, roads, and highways. Thus, it is required to abide by the Federal Motor Vehicle Safety Standards (FMVSS) [19]. The bike will need to be tested for different temperature ranges to ensure that all parts are able to withstand the low and high temperatures that the bike may encounter. Then if there is a temperature range in which the bike does not function well, the appropriate advisories can be placed in the user manual. The bike is also not water proof, therefore, it will be advised to not use the bike when it is raining or snowing. The bike should also be tested on pavement, gravel, dirt, grass, and any other possible terrains the driver may encounter. It is considered a road ready motorcycle, though, and the rider will be advised to not drive the bike on rough terrains.

In that case that it is necessary to take the Moto-eV off-road, the manual will instruct one to proceed with extreme caution.

With safety being the main concern there will be labels added on specific components of the bike, to indicate a possible danger. The most significant source of danger is the battery cage, especially since the batteries will be in series with the capability of supplying 48 volts. Therefore a label would be placed on the battery cage indicating the danger that could occur if one somehow managed to get short circuited. The battery cage would also include a picture that represents an electrical hazard and a page number for the manual in order to explain the potential danger in greater detail. Even though the tank should not be taken off, another warning label would be placed on the electronic mounting plate that is located under the tank which holds the PCB, shunt resistor, and IGBT. The warnings would show a picture to represent that some parts may be hot to the touch and represents the possibility of electrical hazard. There is also a cord attached to the battery charger so that the bike can be plugged into a wall outlet, which will need warning to indicate electrical hazard possibilities. The warning would also include a page number reference to the manual to explain the potential danger in greater detail.

Another ethical consideration is how reliable the battery monitoring system is. If for some reason the display was indicating a battery is charged at a higher value than it actually is, and a user gets stuck somewhere because of this, there would be a problem. Therefore numerous tests would be preformed to ensure data values are accurate at all times of the battery charge cycle to maintain accuracy with time.

The user manual will be the main source of communication between the manufacturer and the customers. This will provide the user with crucial information for their safety, service information, how to drive the Moto-eV, and troubleshooting information on any type of problem that may arise. Due to that fact that Moto-eV is a street legal motorcycle, it would require a license to drive, which would also be clearly stated in the manual. The manual will discuss the possible driving environments and how the motorcycle will react in all of the situations tested above and advise against driving on certain terrains and in specific weather conditions. The manual will also specify how many riders are permitted at one time with respect to weight limit. It would also advise wearing proper motorcycle gear which includes a helmet, riding jacket, and riding pants. The warning labels will be explained in more details. With the Moto-eV displaying the lean angle this leads to possible desire for competition in achieving a greater lean angle, therefore the manual will indicate that the lean angle measurement is for safety and feedback purposes and not to be used as a means of competition. Lastly, the manual will provide contact information for Moto-eV retailers, maintenance, and information for disposal/recycling.

For additional safety, there is a kill switch that will complete cut the power to the motor. In the case of a defect or accident resulting in the gate drive getting stuck, the motor can be disconnected from the power source to maintain control.

6.3 Environmental Impact Analysis

Besides just ethical concerns, environmental impact also must be taken into consideration. This can take place in any of the three stages of the life of the product: manufacturing, normal use, and disposal/recycling. The main concern during the manufacturing stage is the pollution that occurs during the fabrication of the printed circuit board (PCB), from the chemicals and natural resources that are needed in the fabrication process. Therefore all the chemicals and materials must be separated and taken care of respectively. With this taken into consideration, Moto-eV would look into the production and waste procedures to determine a producer.

Use of the Moto-eV is more environmentally safe than most other motorcycles, due to the fact that the Moto-eV does not have harmful emissions. The batteries could become an issue if they were to become damaged, for instance, if the bike was in a collision. Thus, sealed lead acid batteries were selected to prevent of any chemicals from leaking into the environment. Also during normal production tires will need to be changed periodically and the old ones will need to be discarded. In order to be more environmentally safe the manually will provide information for the recycling of the tires. [20]

At the end of the product's life the product should be taken apart so that different components can be disposed of or recycled as needed. The batteries should be brought to any automotive store so that they can be recycled; this information will be in the manual. As for the PCB and LCD there will be information in the manual so that they can be sent back to the company where the material will be disposed of properly. For the rest of the frame, it could be recycled either in pieces or as a whole. [21] For the disposal of the tires, users will be advised to find proper recycling facilites.

6.4 Summary

The ethical and environmental impact of the Moto-eV has been carefully considered. The main ethical concern is the safety of the rider, therefore, many test will be implemented prior to the production of the bike. Also, there will be warnings located on the bike with more information on what the labels mean and how to ride the motorcycle located in the manual. With respect to the environmental impact, the major concern was the PCB, LCD, and the proper disposal of the batteries.

7.0 Packaging Design Considerations

7.1 Introduction

As an electric motorcycle the Moto-eV requires that batteries and motor must fit within the frame of the motorcycle. The chassis that is used for this product is a 1986 Honda VF500F. The main constraint is that the motor must be mounted directly in front of the swingarm. The PCB, switching circuitry, LCD, and associated hardware fit underneath the existing tank.

7.2 Commercial Product Packaging

With the current energy crisis people are doing anything to try and limit the amount of gas being used. Consequently, the demand for electric vehicles has increase. Some commercial products that are similar to the Moto-eV are Enertia, Zero X as well as a few others, but they tend to be more along the lines of a dirt bike or scooter. However, Honda and Yamaha are both planning on coming out with an electric motorcycles within the next two years. Therefore, the packaging methods of the products currently in the market were taken into consideration when coming up with the packaging for the Moto-eV.

7.2.1 Product #1

The Enertia Electric Motorcycle (EEM) is a new product that is just coming into market and being sold for $11,995 and weighs 280 pounds. The EEM can travel 35 miles per charge with a top speed of 50 mph and a recharge time of 3 hours. As for general dimensions the length of the EEM is 80” with a body width of 12.5” and 19.5” from peg to peg. The wheelbase will be 55 inches, while the seat height is 33 inches.

Figure 1

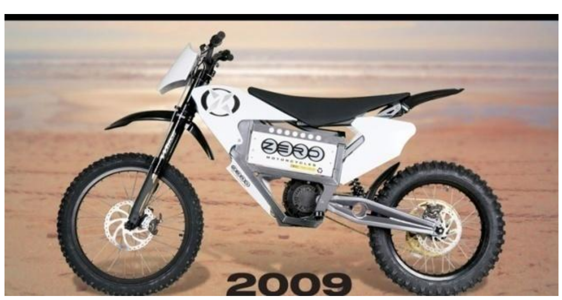
The motor is located on the chassis such that the output shaft delivers power directly through the chain to the back wheel. Using a direct drive maximizes efficiency. This is also the plan for the motor of the Moto-eV .

Figure 2

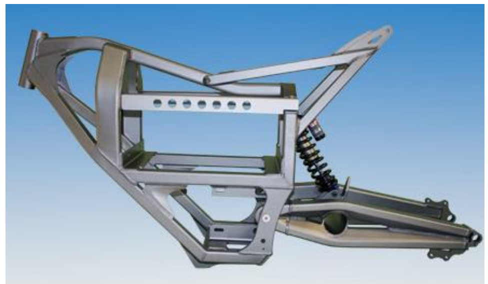
The chassis of the EEM is eng ply hold the motor and batteries. Therefore, the frame is a "H" beam that holds three batteries on top and three on bottom with the motor located at the bottom of the frame. The chassis weighs in at a total of 16 pounds. The batteries packaging is ideal with this chassis, but the Moto-eV chassis is different and the battery layout may not be the most space efficient or even possible depending on where the motor will have to be located in order to be in front of the swing-arm.

7.2.2 Product #2

Another electric motorcycle that is currently in the market is the Zero X. The Zero is claiming to be the fastest, cleanest, and lightest electric motorcycle. The Zero X is currently being sold for $7,450 and used for both off road and street purposes. The frame weighs 18 pounds, and the Zero X weighs in at only 140 pounds total. The Zero X is powered by a lithium-ion power pack that can be recharged in 2 hours. The bike can travel up to 40 miles in one charge with a top speed being 55 mph. Like the EEM the motor power is directly applied from the chain to the back wheel for efficiency. The wheelbase will be 55.75 inches, while the seat height is 35.5 inches.



With the lithium-ion power pack the frame is more compact that the Moto-eV layout. This allows for a much smaller and light weight bike, but also strays away from a motorcycle and towards a dirt bike.



7.3 Project Packaging Specifications

Packaging of the Moto-eV revolves around the 1986 Honda VF500F chassis. The motor is placed in the frame directly in front of the swingarm. The battery pack is placed directly in front of the motor. The battery pack consist of four 12 V batteries in a cage that uses the existing frame mounts.

The old tank was cut open and used for as a protective shell for the electronics. The PCB board, which is estimated to be 72mm by 83mm, and IGBT, 93mm by 35mm by 30mm, is placed underneath the tank. The micro battery is mounted right next to the rear shock where the stock motorcycle originally mounted its 12V battery. The LCD is mounted on the top of the tank. The rider merely needs to look directly down to view critical data.

7.4 PCB Footprint Layout

The microcontroller, a PIC18F4431 is used in a 40 pin DIP package. The inclinometer SCA61T chip is 10.48mm by 11.31mm. While the driver, an IR2184 chip, is 9.9mm by 10.30mm. This leads to a PCB board that is approximately 72mm by 83mm.

7.5 Summary

The Moto-eV's main packaging constraints come from the fact we are using a prebuilt chassis. Every component must fit within this existing frame. The main constraints are the location of the motor and batteries. After looking at other commercial products packaging, the initial plan of mounting the motor right in front of the singarm was confirmed. The battery pack was designed to fit within the frame and we are utilizing the old tank to protect our sensitive electronics.

8.0 Schematic Design Considerations

8.1 Introduction

The Moto-eV concept is a full scale electric motorcycle. The Moto-eV is engineered to be a commuting vehicle and thus will be equipped for a modest range of 25 miles with a top speed around 35 mph. The design requires precise sensor input to the microcontroller as well as medium to high frequency switching motor drive output. We are using seven analog inputs to the microcontroller and this data cannot be corrupted from the noise generated by the switching circuitry and the motor.

8.2 Theory of Operation

Microcontroller

The PIC18F4431 microcontroller interfaces with all of the major components on the bike [2]. The main function of this component is to collect relevant sensor and user input data, then process this data to modify the motor control and user display. The microcontroller will capture inputs from the throttle, an inclinometer, and a battery monitoring circuit. The throttle information is used for motor control, while the battery monitoring and inclinometer will be used for the user display.

Power Supply

The Moto-eV will have two completely separate power systems. The main 12V system will run off of a single, sealed, 12V battery mounted inside the tank. The components on the pcb that will run at the full 12V are the gate driver, the heatsink fan, and the differential amplifiers. The gate driver will take the logic level 0 to 5V from the micro and then optically isolate and amplify that signal. The 12V micro battery will be stepped down to 5V through a linear regulator to power the other circuitry on the pcb [34]. While a linear regulator is not the most efficient means of converting a DC signal to a lower DC signal, this method was chosen for its simplicity. When compared to the power being used by the rest of the system in the bike, the small amount of power lost in this component is of little concern. This 5V will power the microcontroller, LCD, inclinometer, & system lighting.

The other power system used inside the bike will be completely dedicated to the motors. A bank of four 12V SLA batteries connected in series will be used to provide 48V to the motor. This system will need to be separate from the microcontroller 12V system, but issues will arise from having two supplies and two separate grounds. This issue was solved by using a common chassis ground. It is necessary to isolate the micro system because of the huge amounts of power the motor requires. The motor can pull 114A continuously and peak draw can exceed 300A. We used 4 gauge wire to connect the batteries, IGBT, & motor. This large diameter wire is necessary to handle the large amount of current our drive system uses.

Sensors & Inputs

A single axis inclinometer is used to monitor bike lean angles [25]. This chip is oriented on the pcb (at a slight anlge to the horizon, with pin one facing the front left of the bike) such that it will record side-to-side changes in angle. The inclinometer has an internal temperature sensor and it adjust its output in real time using the collected temperature data. This is very beneficial because inclinometers are in general very sensitive to temperature fluctuations. This sensor will interface to the micro via an ATD pin and then calculations in software provide accurate angle measurements.

Micro battery monitoring is implemented using a simple voltage divider connected directly to the battery and input through an ATD pin. It will be important to use very high value resistors as to not draw too much current away from powering the motor. While there are more elegant and efficient means of implementing a charge monitoring circuit, this alternative provides the simplest solution. Also since the micro battery is of the lead acid chemistry, the battery level drop off should be quite linear. This linearity provides an accurate measurement using a voltage divider. However the main 48V battery bank is monitored by differential amplifiers. Each of the four 12V SLA batteries is read and displayed via the LCD. This gives the user early warning if one of the batteries is starting to go bad.

The main motor control input is the throttle. The team has obtained sponsorship of a 0-5k potentiometer throttle from Magura. This is a complete unit which can mount directly in place of a normal mechanical motorcycle throttle. It will interface with the micro controller via an ATD pin. 100% open throttle will correspond to about 0Ω of resistance. This input will then be directly related to current. The torque equation for a Brushed PM DC motor is $T_e=k_v i_a$. This means that the electromagnetic torque produced by the motor is directly related to the armature current by a motor constant k_v. This is the advantage of implementing current control, and this was how the throttle data would have been interpreted in software. However due to time constraints and other project issues a more simple voltage control scheme was used via PWM.

Motor Controller

The motor will be controlled using a PWM signal from the micro. The original plan of current control was abandoned due to time constraints. However if it were to be implemented in the future a pin will be toggled on and off based on the control algorithm. The frequency of this signal is not a discrete number, but will vary depending on the load torque and throttle input. Based on the throttle input, the necessary current can be calculated. This requested current would be given a certain hysteresis. The actual current will then alternated in between the top and bottom hysteresis. It is anticipated that the motor will switch between 4kHz and 10kHz. However using a simple PWM signal ignores the current the motor is pulling and simply alters the applied voltage. The signal is then be fed to an optical isolator and gate driver [26]. This chip will protect the micro, while amplifying the control signal to 12V, the level required by the IGBT module [30]. Originally the team anticipated using a full bridge (4 switches) to control the motor, but a motorcycle does not need to run in reverse. Next a half bridge was considered (2 switches), but this was decided against because regenerative braking will not be implemented. A single switch will lower cost and still provide ample performance. Half bridge IGBT modules rated at 300A are used due to their cost and because they are much more common than single switches. However only the top switch is controlled, while the bottom switch is grounded.

LCD

To interface with the rider a large 20x4 backlit LCD is being used [31]. This provides data such as battery level, lean angle, and throttle position. The LCD interfaces with the microcontroller through a USART connection. The LCD module has built in serial communication chips, so it was relatively simple to interface with using the built in USART functions.

8.3 Hardware Design Narrative

Once it was clear what sort of pin each part of the circuit needed, the microcontroller pins were all chosen based upon their physical location. Due to noise, it was attempted to keep all of the analog inputs far away from the high frequency switching ports.

The ATD module is used extensively for reading all of the system's sensors and inputs. The 0-5kΩ potentiometer throttle is monitored through input on pin RA0. The inclinometer outputs 0-5V based on angle levels and interfaces through RA3. The micro battery monitoring voltage divider inputs on RA8. This circuit was designed to output 4.36V given a full 12V of battery charge. The resistor values were chosen using commonly available parts as well as allowing for some headroom for slightly higher than 12V battery levels. The 4 individual 12 SLA batteries input on pins RA5, RE0, RE1, and RE2. The current monitoring circuit would of interfaced through RA4.

The PWM module is used for our main motor drive. The motor is driven at a frequency of 7.8kHz. This frequency is audible, but when riding the bike there are several, more prevalent, noises.

Several general I/O pins are used as well. A LCD display selector switch and a ride mode selector are interfaced via RC4 and RD3 respectively. The motor control signal will output on pin RB1. This pin was carefully selected to be both a digital I/O and a PWM capable pin. This leaves the team with a contingency plan of running the motor via PWM should the current control scheme fail. Where in the end, we did abandon current control and implement a voltage control. Lastly pin TX will be used to output LCD data.

Table 8.1: Pinout and Signal Table

Signal	Pin Title	Pin Number
Reset	!MCLR	1
Throttle In	AN0	2
Shunt	AN2	4
Inclinometer In	AN3	5
Battery 1,2,3,4 & micro-batt	AN4, AN5, AN6, AN7, AN8	6,7,8,9,10
Ride Mode Select In	RC4	23
Power +5V	Vdd	11
GND	Vss	12
LCD Data Out	TX	25
Motor Control Out	RB1/PWM1	34
ICSP Programming Entry Pin	PGM	38
In-Circuit Debugger & ICSP Programming Clock Pin	PGC	39
In-Circuit Debugger & ICSP Programming Data Pin	PGD	40

8.4 Summary

The Moto-eV circuitry has been carefully designed to provide the sensitivity required for the analog inputs while simultaneously providing high frequency (high noise) motor drive signals. The two power supplies are designed to provide ample current for the motors as well as the controlling circuitry. These power supplies are regulated to stable voltage supplies. The microcontroller's analog inputs are filtered and amplified where necessary, while the motor control output is optically isolated and amplified via a gate driver. The end result is a noise resistant circuit which performs to the team's performance expectations.

9.0 PCB Layout Design Considerations

9.1 Introduction

The Moto-eV is designed to be an inner city commuter vehicle with a range of 25 miles and a top speed of around 35 to 40 mph. The three major components of the design are the motor, drive circuitry and the brain board. All of these must be designed to mesh with each other in order to create a reliable working product. The brain board will accept user inputs in the form of a throttle and other various switches and output to the rider via a Crystalfontz LCD screen [31]. The brain board also sets the parameters of the drive circuitry which in turn apply the proper voltage and current to the motor.

9.2 PCB Layout Design Considerations – Overall

The Moto-eV PCB has a number of design considerations. The PCB is partitioned into four quadrants, all contained on one board. These quadrants are power regulation, analog I/O, digital I/O, and gate drive. This is mainly to isolate any sensitive signals from noisy high frequency/high current signals.

First, the board requires a 12V input which will be passed through the LT1529 voltage regulator which supplies 5V to most of the PCB components [34]. The reason such a high supply voltage was chosen is because the gate driver requires a 12V source and this way we will not need two separate batteries to operate the PCB. A 48V source will also be attached to the PCB from our battery bank in order to monitor the charge level on the batteries. The 48V pack, the “dirty supply” and the 12V rail, aka the “clean supply” share a common ground.

The second area is where the analog I/O is placed. This accommodates the throttle input, shunt resistor input, inclinometer, and amplifier. Noise on either the throttle or the shunt resistor lines can severely impact the performance of the bike. These inputs are also located close to the micro to avoid long traces that can lead to parasitic inductances. A standard 12 mils trace is used for this section. Special care must be taken in the placement of the inclinometer due to it only being a single axis, and that axis must be perpendicular to the angle of incline [25].

Thirdly, the digital I/O is isolated to again avoid noise on the signal. This is not nearly as important as the analog I/O because we can accommodate a larger variation in the digital signal and no key control or device monitoring will be conducted on these lines.

Finally the gate driver is as far as possible from the analog I/O. This is due to the high current draw and fast switching frequency that the gate driver must achieve [26]. These are the main factors that contribute to EMI and because of this a ground pour underneath the IC would be favorable. The trace leading to the output header is approximately 50 mils to accommodate the current draw which is expected to be in the 300mA range.

There is plenty of mounting space for the board so size is not really an issue. An initial estimates of 6x6 (inches) was chosen, and the final board dimensions measured in at 5.735" x 4.975". This provides us with enough space to isolate our sensitive components and to keep our trace lengths short enough to avoid parasitic inductances.

9.3 PCB Layout Design Considerations – Microcontroller

The microcontroller is a PIC18F4431 and we have chosen a DIP package due to its simple installation and port pin arrangement [2]. The micro is placed vertically in the middle of the board to allow easy access to the port pins from each IC. The port pins for each device were chosen to help facilitate the partitioning of the board into its four quadrants. The microcontroller itself will not source much current so a 50 mil trace is more than adaquate. The power and ground traces run up the side of the micro and branch out to supply power to the micro and individual IC's. Several bypass capacitors are placed underneath the micro to facilitate any instantaneous power needs. No external oscillator is needed with this microcontroller since we are not doing anything that requires very precise timing. The internal clock will be more than accurate.

9.4 PCB Layout Design Considerations - Power Supply

The 12V source is sent through the LT1529 to produce the 5V rail. The maximum current draw will be 2 Amps therefore the power and ground traces are 100 mils. The current is largely dependent on how bright our LCD backlight is. The LCD backlight at full brightness, will pull 380 mA. The 5V rail also supplies the LM2733 which boosts the voltage to 20V. This is only to power the differential amplifiers and will not draw much current. The power traces from the LM2733 will are 30 mils. Bulk capacitors are placed close to where the sources enter the board and decoupling capacitors are placed under the all of the IC's.

9.5 Summary

In conclusion, the PCB is partitioned into four quadrants with the microcontroller at the origin. This is done to isolate sensitive signals from noisy ones and to keep all trace lengths to the micro down to a minimum. This also reduces EMI and parasitic inductances that can cause significant degradation in the SNR. Large traces are used for the power and ground due to the large current draw from the gate driver and LCD backlight. Careful planning of part placement and port usage makes the PCB layout process run much smoother and take considerably less time.

10.0 Software Design Considerations

10.1 Introduction

The Moto-eV concept is a full scale electric motorcycle. The Moto-eV motorcycle is engineered to be a commuting vehicle and thus will be equipped for a modest range of 25 miles with a top speed around 40 mph. The motorcycle will house a MARS ME0709 brushed permanent magnet DC motor, which will be powered by four, twelve volt, sealed lead acid batteries. The main software considerations involve powering the motor, with respect to the feedback received from the peripherals on the bike, to ensure that everything is working reliably and safely.

The peripherals on our bike are easier to summarize when looking at their real time priority levels: The most important component will be the shunt resistor circuit to determine the current draw of the motor; closely following is the throttle input; then come the inclinometer circuit, battery level monitoring circuits, brake lights, and LCD display preference inputs; the least important real time component is the ride mode input.

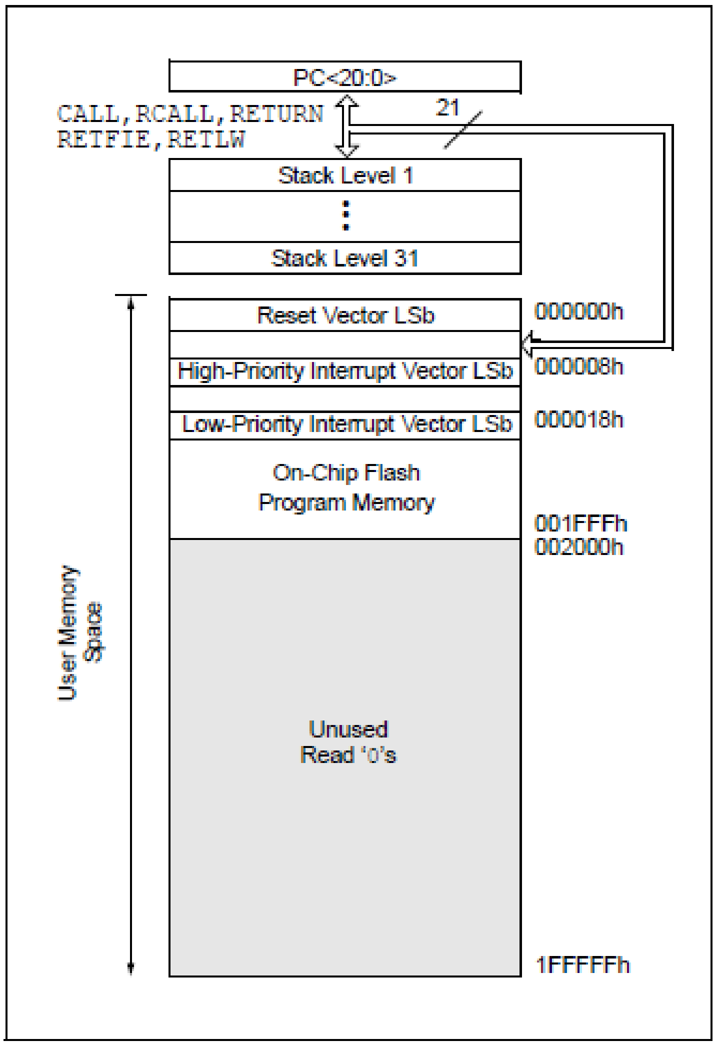
The main control of the motorcycle will come from the user turning the throttle and expecting the motor to respond accordingly. The current draw and throttle input also happen to have the most volatility over time. Thus, the main purpose of the microprocessor's software will be to process a motor control algorithm based on these two components. The inclinometer, battery monitors, brake lights, and lcd monitor will also be varying with time, but more predictably and with less of an impact on the control of the bike. They will be incorporated into the software when reaching extreme levels. When the batteries are becoming too drained or the motorcycle is at an excessively acute angle, the motor control algorithm may be affected. The ride mode can only be selected when the bike is at a stall, and will have priority only when the bike shows no speed.

10.2 Software Design Considerations

Memory Mapping

The microprocessor chosen for our project is the Microchip PIC18F4331. It has a 21 bit program counter which addresses the 2 mega bytes of program memory available, along with 8 kilo bytes of flash memory capable of storing up to 4,096 single word instructions. The user space memory (program memory) starts with the RESET at 000 000h memory address. Then, the high priority interrupt and low priority interrupt vectors are located at 000 008h and 000 018h respectively. The addresses from 000 019h to 001 FFFh are allocated for on-chip flash. Lastly, the addresses from 002 000h to 1FF FFFh are categorized as Unused Read 0's. Above all the program memory is the 32 bit stack memory. As shown in the figure below, the memory location for the 31 word deep stack is located in the 32 bytes before the 000 0000h RESET location.

Figure 10.1: Memory Map on PIC18F4431



For programming the microprocessor, Microchips, MPLAB C18 compiler will be used in conjunction with the ICD2 programmer and development kit. One of the great benefits of using this development kit is how the application code is optimally organized when the code is built on

MPLAB. Thus, the locations for static data, variables, stack, and code are automatically placed in their respective memory locations by the compiler. All of the start-up code and initializations are also taken care of by the compiler software.

Peripherals

The peripherals of the PIC18F4331 that will be used for monitoring and controlling the motorcycle are the analog to digital conversion (ADC) module, the timer module, capture compare (CPP) module, serial communication interface (SCI), and the pulse width modulation (PWM) module.

Majority of the monitoring process will be done using the ADC module. The PIC18F4331 has 9 A/D input channels, and can perform conversions at up to 200 kilo samples per second, which is a high speed rate that is perfect for our motor control application. The ADC result is a 10 bit value, with 8 bits stored in the low result register (ADRESL) and the other 4 bits stored in the lower nibble of the high result register (ADRESH). The ADC will be interrupt driven through an interrupt service routine (ISR). Each time an interrupt takes place, the ADC inputs for the throttle and current sensing shunt resistor will be read, and every 10 times an interrupt takes place the less volatile ADC inputs will be read. The throttle and shunt inputs will also be averaged using an array 5 index deep, since these values will be quite staggered. A conditional loop with a counter will be used to check when 10 timer interrupts have taken place to allow the reading of the low priority devices. At that point, the counter will be reset back to the starting counter value and repeated. The components which will involve ADC are the throttle, current sensing shunt resistor circuit, inclinometer, and battery monitoring circuits.

The CPP module will tentatively be used for getting the motor speed from an optical sensor watching the front sprocket. The front sprocket will be painted black and white to correspond to high and low states digitally. The speed of the switching will be used to determine the speed at which the motor is rotating.

The timer module will be used for the interrupt service routine. The timer 1 interrupt will be used to read the input values for the ADC every time the interrupt flag is set. Timer 1 is set as a 16-bit timer, which will run at 8 MHz, speed of the internal oscillator on the microchip. This was accomplished easily using the <timers.h> header file included with the MPLAB C18 compiler.

The SCI module will be used to communicate with the LCD and the development kit during debugging protocol. The <usart.h> header file was used with the C18 compiler in order to initialize the processor to output the data to the LCD screen with just one data pin connecting the output (TX) pin to the data input pin of the display. It also included a useful display functions so that the use of excessively large header files like <stdio.h> could be avoided.

The PWM will be used for controlling the power level of the motor. This is done using the PWM1 output pin in coordination with the throttle input from the ADC. The PTPERL and PTPERH register make up the PWM period settings. These settings along with the clock speed and timer prescaler will determine the frequency of the PWM. Timer 2 is preconfigured to have its prescaler apply to the PWM frequency, when the PWM signal is enabled. The input throttle value is then scaled to such that the duty cycle resolution is less than the period of the PWM. A 20 kHz PWM frequency was chosen such that the motor spins as a frequency outside of the human hearing spectrum.

Debugging

For debugging our processor, the ICD2 development kit is once again showing its value. The PIC18F4331 will connect to the development kit serially and will be extremely easy to debug and manipulate using the MPLAB software, which is conveniently installed on a laptop to be flexible with the motorcycle. It can also be powered from the USB port of the computer, eliminating the need for an external power source.

Application Organization

The software was originally planned to be organized using a hybrid polling system. The rationale behind this approach was based around setting different flags for different interrupts based on the priority level of the interrupts. The PIC18F4331 has the feature of setting certain interrupts as high priority and other interrupts as low priority. If a high priority interrupt takes place, it will override any operations taking place at the time, even if the processor is in the middle of processing a low priority interrupt. The use of multiple interrupts priorities and multiples timers eventually became more of a hassle and confusion, than being useful. Thus, a single priority, single timer interrupt scheme was reverted to. This system will set priority levels for certain inputs and processes simply by using a counter to allow elements with less real time needs to be processed and read only in multiples of the higher priority processes.

The single timer interrupt service routine will call functions for the ADC and increment counters. The rest of the grunt work takes place in the main loop. In the main loop majority of the code are simply initializations with regards to settings certain pins and ports as outputs or inputs and setting prescaler, postscaler, and configuration bits for the more complex operations like the PWM, ADC, and SCI modules.

The rationale for this new system of organization was based on its simplicity. It became apparent that the needs of Moto-eV with respect to the capabilities of the PIC18F4331 micro were nothing too extravagant. Reading sensor inputs, configuring their values quickly, and then updating the LCD display output and motor power output are the operations of the microprocessor in a nutshell. So, a simple, single ISR polling loop should do the job effectively and accurately.

10.3 Software Design Narrative

The software design builds off an interrupt service routine, powered by the timer module. The timer sets an interrupt at a 1:1 ratio to the clock speed of the internal oscillator (8 MHz). The main loop will consist primarily of initializations for all the different peripheral modules. The functions and loops outside of the main loop are the adc_loop(), tim_ISR(), lcd_disp(), and motor(). These functions will be called by the timer interrupts.

There are an extensive number of initializations in the main loop: First, the oscillator clock speed is set to 8 MHz by configuring the OSCCON register. Next, the port status bits are initialized by setting the TRIS and PORT registers. This defines which pins are used as an input and which pins are used as an output according to their function. Then, the timer1 and timer2 initializations are taken care of. The timer 1 initialization is set for the main ISR and the timer 2 initialization is set for configuring the PWM frequency. After that, the ADC conversions settings are initialized to set the ADC clock speed, acquisition time, analog input channels and reference voltages (+5 and 0). Then, the USART registers are set for communicating with the LCD display. This involves setting the transmission for 8-bit resolution, a 9600 baud rate, Asynchronous mode, and enabling the communication. Finally, the PWM is configuring by manipulation a large number of registers and bits. It is set up to function in free running mode, independent output for PWM1, and to have a PWM timer base such that our PWM frequency optimizes output power, while minimizing the noise from the motor.

Beside the initialization, the main loop with have a while (1) loop nested in it, that has been used to debug by testing basic led toggles thus far. When the software is completely cleaned up and finalized, the while loop in main may end up being a blank polling loop.

For the functions outside of the main loop, the adc_loop() is probably the most intense and important. In this function will be called every time a timer interrupt takes place. In the function, first the input channel is designated then a while loop suspends until the conversion is completed. When the conversion is completed, the input value is saved to a value in an array which is then averaged. This ensures that stray spikes in the current or throttle input don't result in the motor randomly kicking forward or losing power. The throttle and shunt will be read every time adc_loop () is called, but inside the function there will be an if loop with a counter which will decrement from ten to zero. Every time zero is reached, the battery meters and inclinometer will be read and the counter will be reset. This will keep the priority of the throttle and current readings above the rest of the inputs, while using only one timer interrupt.

The tim_ISR () function is extremely simple. It only calls the adc_loop () function and clears the timer 1 interrupt flag. The lcd_disp () fuction uses the putrsUSART (), putsUSUART (), and sprintf () commands that come in the <usart.h> header file, in order to display characters on the crystal fontz LCD display which will be mounted on the motorcycle. It has been used for debugging purposes thus far. For the final display, it will display the battery charge level for each battery as a percentage (4 12 Volt 18 Amp-hour sealed lead acid batteries to power the motor and one 12 Volt sealed lead acid 7.5 Amp-hour battery to power the PIC18F4331), the tilt angle from the inclinometer, the ride mode, and possibly a range value associated with the battery charge remaining.

The final function, motor (), will contain the commands associated with powering the motor via the PWM. It is where the duty cycle is scaled to relate to the PWM timer scaling. This function also has some bit shifting that needs to take place to use the specific 12 bits that are allocated for the duty cycle high and low registers (PDCOH and PDCOL).

All of these functions are written into the same file instead of using separate files and calling them into the main file. Including a significant amount of commented lines and test code included at this point, the complete code is still less than 400 lines. It would seem a bit over the top to split this software into multiple files.

10.4 Summary

The software involved to control and power Moto-eV is fairly straight forward and simple. The majority of the control is accomplished by the ADC module, which is driven by an ISR using a built in timer that is driven by the internal oscillator in the PIC18F4331. The values read from the ADC will be averaged and used directly when displayed as feedback information, or used indirectly with the PWM module to control the power output from the motor by adjusting the duty cycle of the PWM output.

11.0 Version 2 Changes

The main issues that version 1 of the Moto-eV had is not being able to coast and lack of current monitoring. The combined motor control knowledge of the group was all centered around commanding a certain speed of the motor. This however does not permit the motor to coast when zero speed is commanded, In fact it causes severe engine breaking that if not done properly could lock up the rear tire and cause damage to the motor. A new control circuit can be utilized in order to allow coasting without sacrificing performance.

Version one utilized a shunt resistor to monitor the current in the armature windings. This is not used in the final product due to noise on the monitoring lines and issues with the differential amplifier. Version 2 will utilize LEM current monitors which create a closed loop around the armature wire and produce a voltage relative to the magnetic field created when current passes through the armature. This is far more accurate and more widely used in industry.

The second iteration of the bike will also utilize current control. This is the industry standard for motor control and allows for more precise control over the torque and current draw of the motor. This was not possible to implement in the first iteration because our current monitoring was not accurate enough. Utilizing the LEM units, an accurate current can be measured and current control can be implemented.

It was decided that version one would use a single two quadrant chopper IGBT module. These were purchased used due to their high price and simplicity of integration. The next iteration will use discrete IGBT's. This is much more cost efficient and allows for adjustable current handling and easy replacement of broken parts. This would be harder to interface with but the benefits outweigh the costs.

12.0 Summary and Conclusions

This semester proved to be extremely challenging, yet at the same time very rewarding. This was the largest project that the team has undertaken from start to finish. Many of the requirements of this project were new to the team including, ordering parts, designing a pcb layout, and contacting companies for sponsorship. By the end of the semester we had demonstrated all five of our PSSCs and had an end product that is actually usable. While the semester has ended, the Moto-eV is in its infancy of development. The team learned a great deal about teamwork, problem solving, meeting deadlines, motor control and of course embedded programming.

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[37] Appendix A: Individual Contributions

A.1 Contributions of : Janell Neikamp

The first four weeks of the project most of my time was dedicated mostly to the selection of our components. With space and financing being large factors in the selection process, we needed to be sure that the motor and batteries would fit within the chassis and be within our price range. I also helped with the selection of the microprocessor and IGBT that we ended up finding on ebay. I also help with determining our individual Project-Specific Success Criteria.

Once the components were selected I worked on the packaging design. First I looked up other electric motor cycles such at the Enertia Electric Motorcycle (EEM) and Zero X in order to compare possible packaging. These were not to relevant do to the fact that they were designing chassis for the bike and the Zero X had a special patent pending battery supply. So Mike and I came up with the current packaging with motor being place right in front of the swing arm, while the batteries are right in front of that within the chassis. In order to be space efficient I helped cut the out the bottom of tank and scrubbed at the inside to get ride of all the build up that had taken place over the years. Then I help cut the top off where the filler cap had been in order to put the LCD display there.

Once the packaging was planned out and the machine shop was working on the battery cage and electronic mounting plates, I started working with the coding a bit. First I worked on interrupts that were triggered by the timer overflows and AD conversions to toggles the systems based on user inputs. Then I started working on using the high and low priority interrupts so that the high priority interrupt was triggered by the pushbuttons that would switch the direction in which the LEDs were being light up. While the low priority interrupt was triggered by the potentiometer, which switched the speed of the lights being lit up.

Then I worked on wiring the bike and adding the batteries in series. Once we had the bike working I helped trouble shoot the GPIO, which was causing the microprocessor to reset itself do to the noise, therefore added capacitors and resistors to the circuit. I worked on adding the heat sink and fan under the electronic mounting plate.

A.2 Contributions of : Arin Chakraverty

For the first two weeks my contribution to the team was the development of the team webpage. I developed the main layout of the website by configuring the theme, buttons, and header links. I also set up all the individual notebooks for the rest of the team to just start updating them. During the second week I finalized a working format for the website, although it could still use some style point.

The third week consisted almost entirely of the component search process. I didn't understand a lot of the motor control mechanism and components involved, so I let Loren and Mike take the lead for that. I would still help in anyway I could though, by looking up products and components and learning about the datasheets and systems to try and get lower prices that met our requirements. I then devoted my time to setting up a complete schedule with all of the group members to help arrange meeting times.

In the next few weeks my major contribution consisted of making the CAD models of the chassis and the mounting scenario. I had experience from my summer internship last year using AutoCAD 2008 in 2D. So, it was quite a bit of hard work and self teaching to extrapolate my computer graphic skills into creating a 3D model for this project.

Week 6 was when I started looking at the coding scenario in greater detail. I read so many manuals and user guides over the course of the semester that it is quite ridiculous. I read the MPLAB C18 Compiler Guide, MPLAB User Guide, MPLAB C18 Getting Started document, almost all of the PIC18F4431 datasheet, and the C18 libraries document. At first it seemed to be pointless, but as I started coding and learned how to code using the MPLAB compiler I noticed that my readings played a huge role in understanding how to configure the C code used to program the PIC microprocessor.

Weeks 6 – 8 were spent doing examples on the development kit to understand the inner workings of the MPLAB compiler. I installed the IDE onto my personal laptop and did a lot of work to understand how to set up the interrupt service routine and timer interrupts to run the code for our microprocessor. Then, I put my time into trying to figure out how to read inputs from the ATD inputs. This gave me quite a bit of trouble and it took some time to get it all working properly. I used to the adc.h header file but then learned from the microchip forums that the adc.h file doesn't properly apply for the PIC18F4431.

By the time week 11 and 12 rolled around, I was getting a great grip on the code and had the main structure for motor control software written up. It was composed of the timer being run off the internal oscillator to drive high and low priority interrupt routine, where everything was being tested and confirmed using the development kit and flashing its LEDS. It was also around this time that the software design and patent liabilities homework assignments started to consume much of my tie.

The end of the semester consisted of Mike, Loren, and I working hard on the software aspects of the project. I was the expert when it came to setting up the timers and their scalars; configuring the PWM frequency and scaling the duty cycle respectively; and then finally setting up the ATD input channels appropriately. I give props to Mike and Loren to jumping into the software side of things at this point, because it was all we had left to work on.

Some troubles surfaced as we worked on the motorcycle and got it working during the last couple weeks. It seems to have been working fine, and then certain diodes, chips, and the IGBT were getting burned out for unknown reasons. After using up the last replacements and backups, we just had to call the project where it was. It was successful from a grading aspect. The last push and effort were with respect to finishing up the paperwork and presentations for finals week, for which I did a great deal of editing and writing

A.3 Contributions of : Mike Stuckenschneider

My first contribution to the project was finding our chassis. I spent quite a bit of time of Christmas break scouring Craigslist and ebay, looking for a rolling chassis. Once I found a suitable donor, I stripped it down, cleaned it up, replaced the steering stem bearings, and reassembled it. Over the break I also spent a significant amount of time looking for potential sponsors. I emailed over 15 companies looking for various parts which could be donated or discounted. These requests were met with various amounts of success.

Once the semester officially started I continued the search for parts. I picked out most of the hardware we used and obtained a good deal of sponsorship. For example our throttle, LCD, 48V power switch, two fuses, a master fuse mount, and a fuse block were all 100% donated to the project through my inquiries. I also was able to obtain a $150 discount on our Mars brushed DC motor. A lot of my time was spent picking out the pcb hardware as well.

Towards the end of the semester Loren and I obtained a 100 dollar donation for new tires from a complete stranger.

Loren and I had several meetings with professor Wasynczuk. We discussed our motor drive circuitry. We discussed using the IGBT modules that we had already purchased and the need for a bootstrap. The bootstrap circuitry drives the upper gate. We used the lower switch's diode as the freewheeling diode for the motor.

The next portion of the semester, I was dedicated to designing the motor mount, battery cage, and electronics plate. I used paper models of the motor and batteries to design cardboard models for the battery cage, motor mount, and electronics plate. These items took a lot of refining due to the tight tolerances I had to work with. The motor mount was also extremely critical because it needed to be positioned precisely and be extremely robust. I used Google SketchUp for all of my 3D models. Some time was also spent cutting out the bottom of the tank and cleaning it out. Along with this mechanical work I researched the drive system. I picked out the front and rear sprocket sizes and got them ordered. I used calculations to predict our final top speed. The size of the chain was also important because I wanted it to be easy to replace with a standard 530 size motorcycle chain. I picked ANSI 50 roller chain for this exact reason.

After finally getting the mechanical stuff sorted out with the machine shop I lent a little bit of assistance to Loren with the pcb design. I really would just review his layouts and help him with hardware questions if he had them. Through the pcb process him and I modified the schematic as well. This was especially true after our design review when we added our battery monitoring differential amplifiers. I picked out the parts and then Loren added them to the layout.

Spring break passed and our pcb came in. I spent the next two weeks populating and debugging all of our hardware. We had some power supply issues with our 20V rail, Loren and I couldn't get our boost to work. We replaced the part and still could not seem to get it functioning. After Loren and I breadboarded the circuit and used a desk power supply to run it, we discovered that the issue lay with our 5V regulator. After we reviewed and modified our 5V LDO circuit the boost worked perfectly. Another issue was with the differential amplifier footprints. I installed surfboards for each differential amplifier. Loren and I then finished installing all of the connectors and components.

I took some time to test a couple of the different gate drivers that I picked out. Theoretically the IR2184 was superior to the IR2302. I set up a test bench and used high power 3.2 ohm resistors as my test load. I played around with different gate resistances and obtained several plots from the scope, which I posted to the webpage. This analysis helped me to decide which gate driver to use in our final implementation.

After it was determined that the hardware was pretty much finished, I started on software. Unfortunately we got a late start on the software so I started from scratch. I read through the user manual and tutorials. My first piece of software was simply getting the micro initialized correctly and having the ATD working. After I got the ATD working I then started on the LCD software. I researched the built in USART functions and eventually go the LCD to display correctly. Arin and I wrote a current control algorithm but unfortunately it fried our gate driver. We decided that it was too late in the semester to play around with current control, so we moved to a simpler voltage control scheme. I wrote the first PWM code, but it was changed for the final code to run at a different frequency. I wrote a few different averaging routines, but the one that I decided to implement in the final software uses a weighted average. I also wrote the software to modify the ride mode and select between the two LCD displays.

During the time I was writing software I was also wiring up the bike. Loren and I came into lab and worked on the wiring harness. I wired up the rear brake lights to be activated by both the front and rear brakes. I also wired up the three switches that are mounted to the front dashboard, the headlight, the tachometer, the fuse block, the throttle, the IGBT, the ignition key, the chargers, and micro-battery. Loren tacked the battery monitors, the micro battery charger, and the main power connection to the pcb.

Loren and I spent a few days down at the shop painting the bike's bodywork. This wasn't necessary for graduation, but I feel like presentation is important. Loren and I primed the tank, and painted the front cowl, rear cowl, front fender, side piece, battery cage, and the tank. After everything had been installed in the chassis we ran the bike around for some testing. Loren blew out the IGBT, gate driver, & bootstrap circuitry. He and I spent a long night in lab reworking how we drive our motor. The new circuitry allowed the motorcycle to coast, instead of shorting the motor upon deceleration. The only problem we encountered was that the bootstrap capacitors were depleting during long durations of coasting. Unfortunately I blew our last IGBT and gate driver before we could fix this issue. Luckily we were able to shoot our PSSC video before hand. Loren, my friend Mike, and I spent a lot of time shooting and editing the video. We started with over 10 minutes of film and edited it down to the final 2 minute run time.

A.4 Contributions of : Loren Garby

My fist contribution to the project involved contacting companies asking for sponsorship for the project. Among the companies that I contacted were Alcoa, National Power Chair (NPC), Elemental Design, and Optima. I also searched for used chassis' on eBay and Craiglist. I was able to secure 400 dollars in batteries from NPC Robotics and was offered a discount at Elemental Designs but to save on shipping we wound up purchasing our wire from another supplier in which we were already purchasing other components.

I then turned my attention to picking out our major components that we needed to be decided on for our design constraint analysis. I researched microprocessors that were designed for motor control and found two PIC's that would meet our needs. I then researched what type of chip we would need for our lean angle measurement. I originally looked at tilt sensors but soon discovered that these act more as a switch once a certain angle of incline is achieved. I then found inclinometers which output a certain voltage based on the angle of inclination. This matched perfectly with what we wanted for our bike. I then found a large discrete shunt resistor that matched our power needs and had a low enough resistance. Then I researched IGBT's and tried to find a high enough current rating that wasn't too expensive. We decided that an IGBT module would be the best option for us due to the easy integration. If we didn't find a module to use we would need multiple discrete IGBT's in parallel on a PCB and we would have to worry about creating PCB traces large enough to handle 300+ amps.

Mike designed most of the schematic but towards the end I helped with which pins should go to which connector. After our first formal design review I designed the circuit for the differential amplifiers for our battery monitoring as well as the 20V boost circuit. Throughout the semester up to this point, Mike and I spent a considerable amount of time discussing with ourselves and professor Wasynczuk the different methods of motor control and how to implement them. Soon after the schematic was finalize I turned my attention to the PCB Layout. I looked over the footprint book that we have in lab and learned the notation that OrCad uses for their footprints. I then created the netlist for our schematic and imported it into Layout. After it was all said and done I made six iterations to the layout, created 16 custom footprints and spent a total of 40 hours. During that time I made numerous changes to the schematic so to avoid adding vias and to allow wires to run straight into their respective connectors.

Over spring break I spent approximately 16 hours working on fiber glassing the tank and fitting the LCD. I documented this expensively in my notebook but since this was more done for aesthetic reasons I will not go into depth in this paper.

After spring break Mike and I spent two weeks populating our PCB. Most of this time was spent troubleshooting why our 20V boost converter was not working. Our 5v LDO worked right away but when we added the boost converter neither worked. It turned out that the problem was with our LDO after all. We used a sensing circuit that was in the application notes which would not work for our purposes. We removed two resistors from our circuit and both power rails worked perfectly. The only other problem we had with the population was with the differential amplifier footprints. The datasheet did not have technical drawings of the differential amplifiers and I did not realize that SOIC packages were of universal size and lead space.

After the PCB was populated I started working on integrating everything onto the bike. I trimmed the electronics plate to fit better into the frame and drilled all of the mounting and through holes for the wires. I also made multiple trips to ACE Hardware with the group to pick out hardware that we needed to mount our components to the frame and electronics plate. Mike and I then painted the tank, faring, and battery cage. I also cut all of our 4awg wires to length and attached the terminals and heat shrink. Mike and I then ran the entire wiring harness and hooked up the four 12V batteries with their chargers and monitoring wires.

After all of the hardware was completed I started working on the code. I created the inclinometer lookup table and wrote the code to read the ADC pin and output the correct angle. I also wrote the battery monitoring code and spent a lot of time with Arin trying to figure out our ADC initialization issue.

Once all the code and hardware was done Mike and I spent a considerable amount of time debugging our motor control circuit and figured out why our GPIO pins were messing with our control algorithm.

Appendix B: Packaging

Figure B.1: Battery Cage (1)

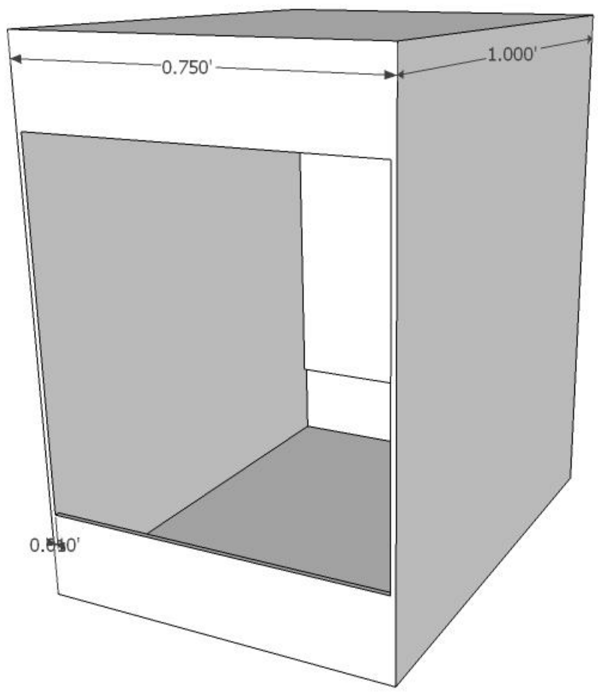


Figure B.2: Battery Cage (2)

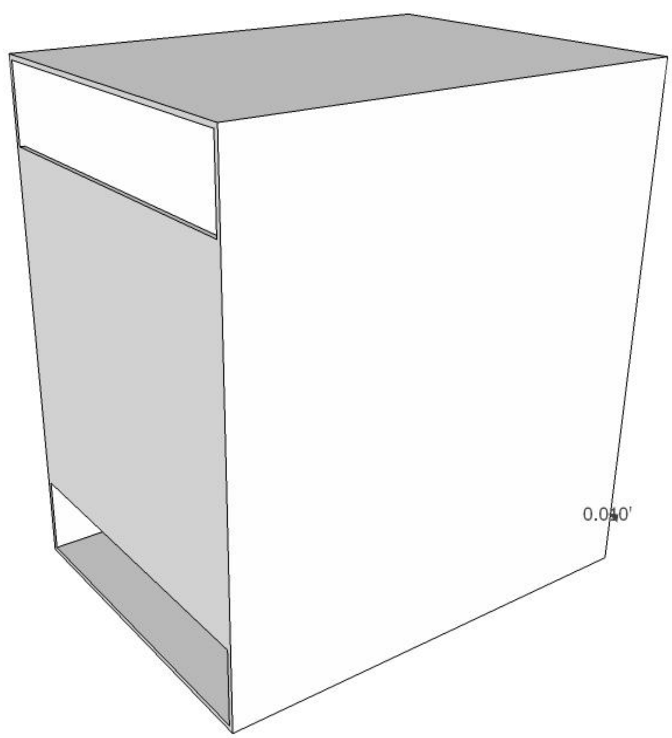


Figure B.3: Battery and Motor Placement (Front)

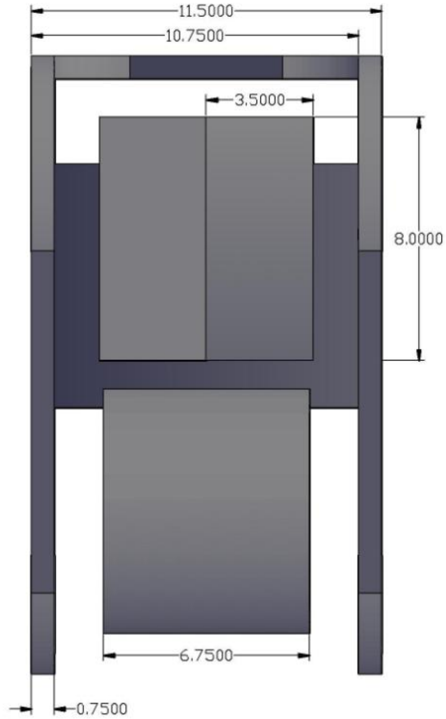


Figure B.4: Battery and Motor Placement (Side)

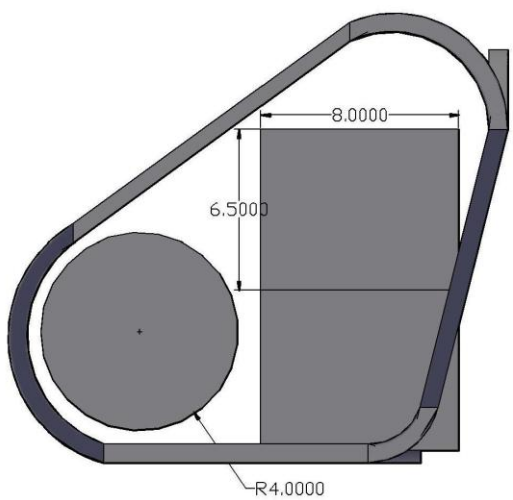


Figure B.5: Battery and Motor Placement (Isotropic)

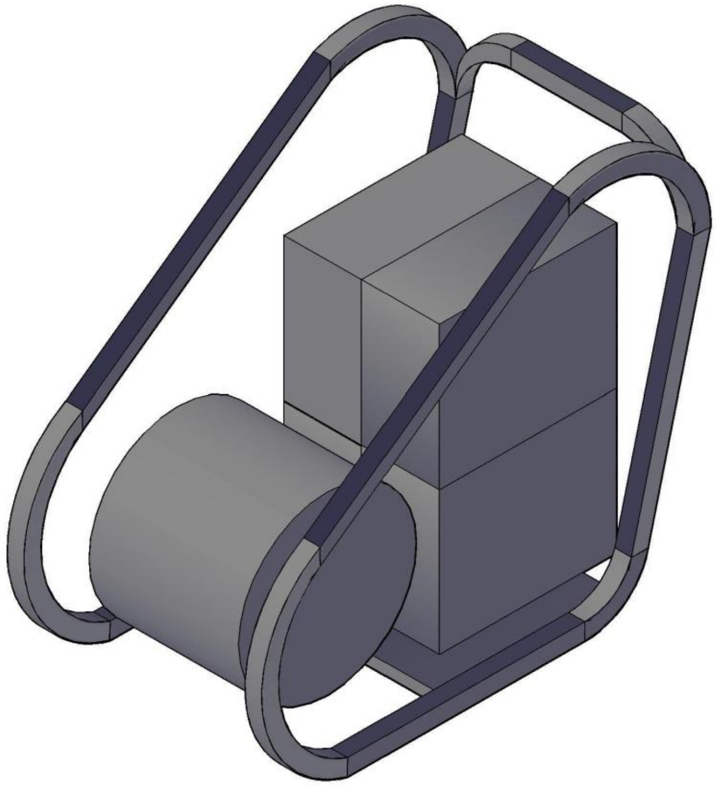


Figure B.6: Electronics Plate

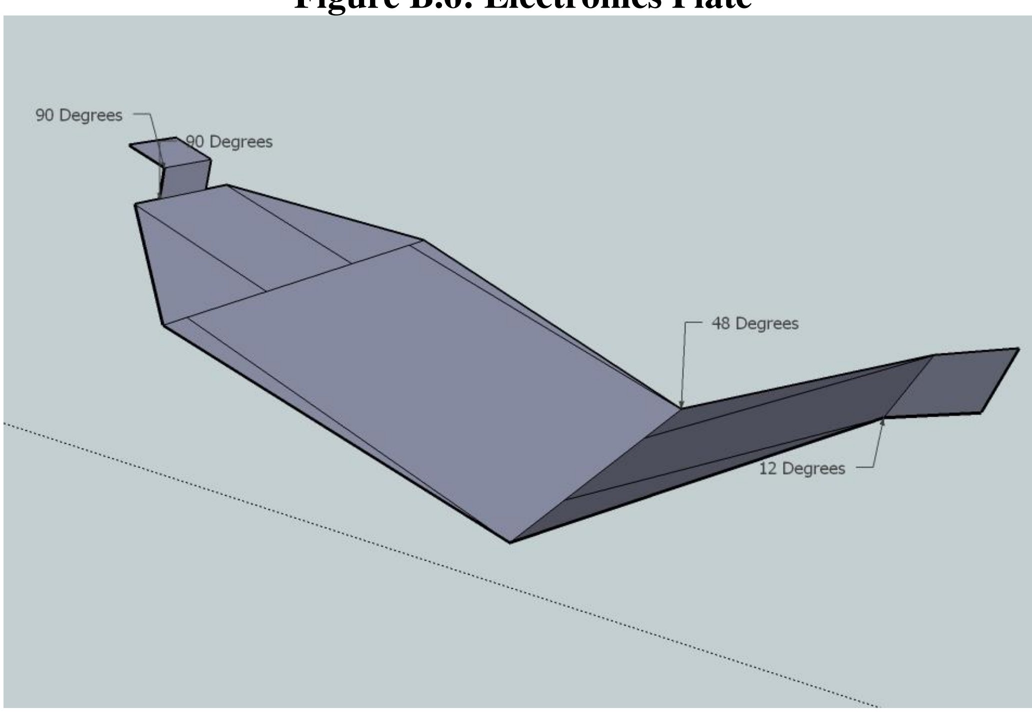


Figure B.7: Motor Mount (1)

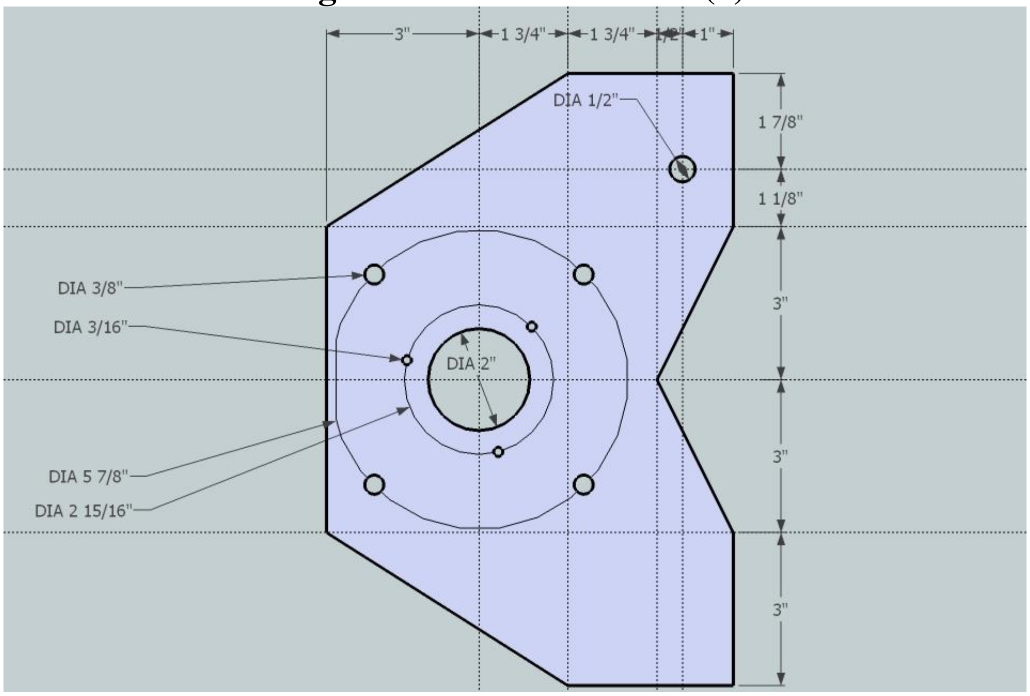


Figure B.8: Motor Mount (2)

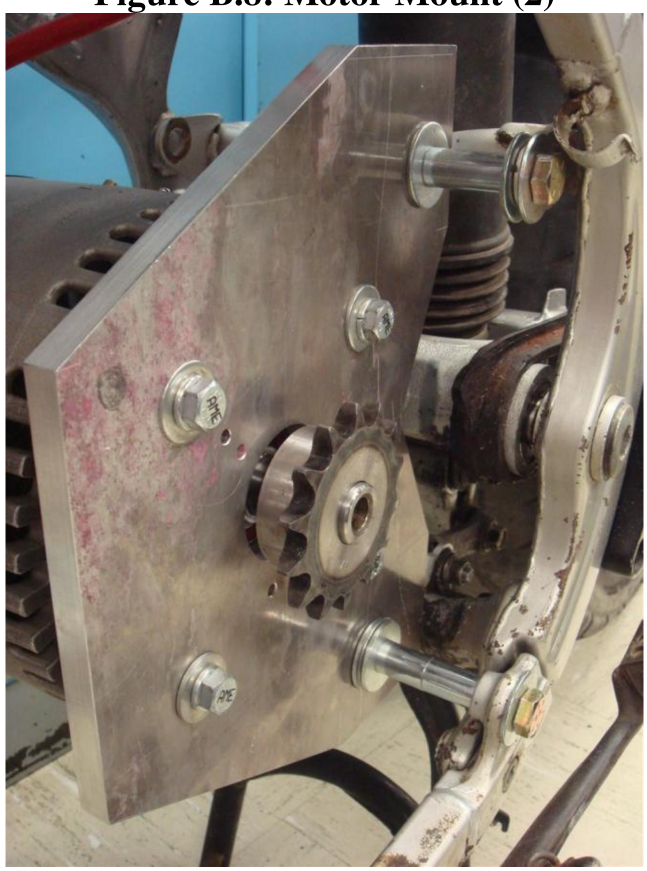


Figure B.9: Dash

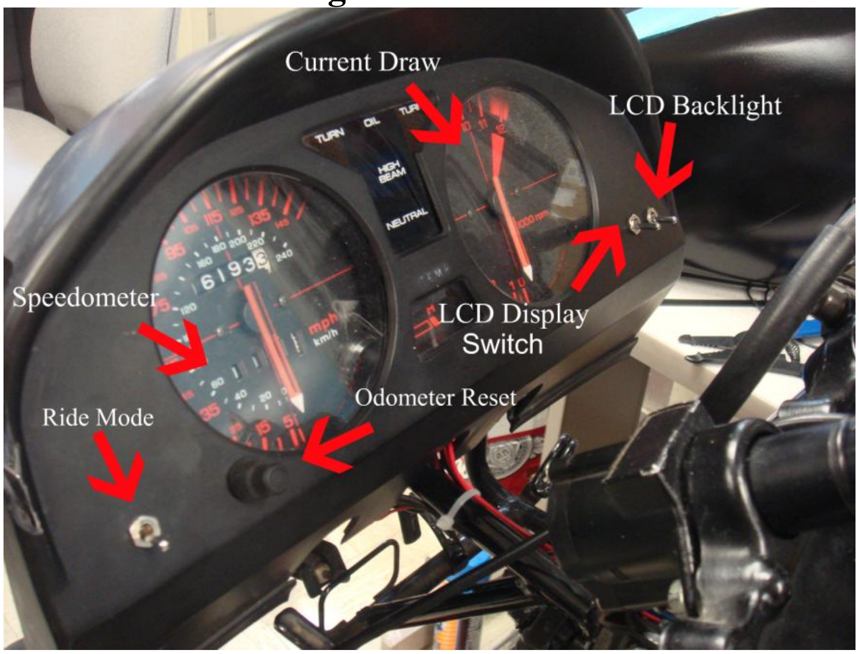
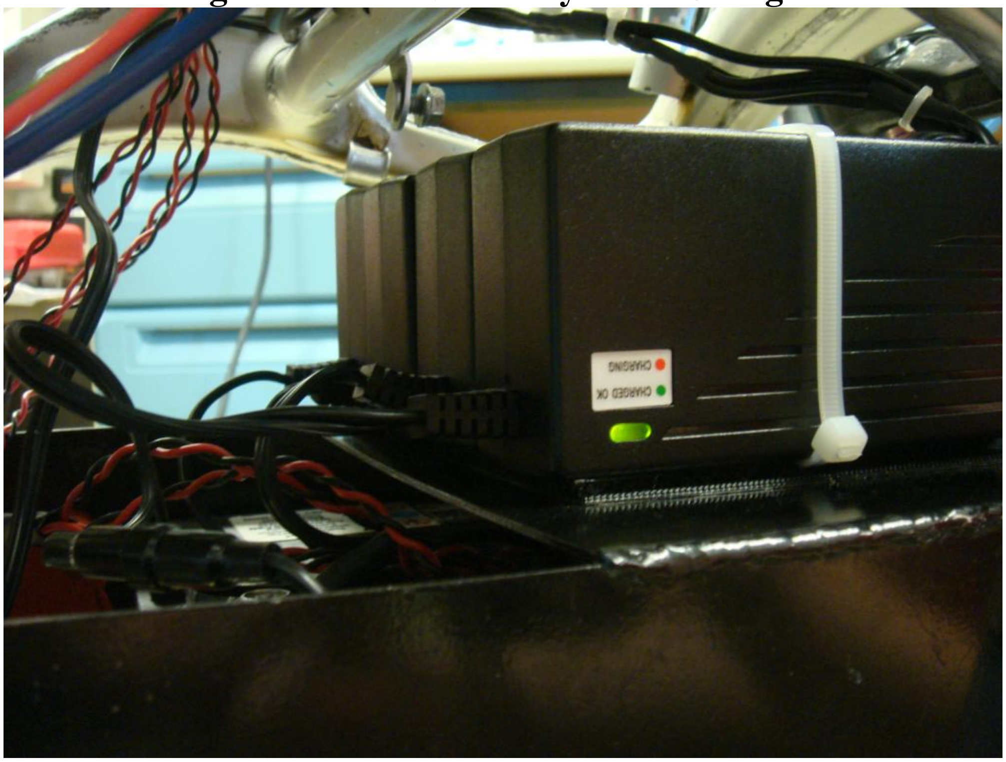


Figure B.10: LCD Mounted in Tank

Figure B.11: 48V Battery Bank Chargers



Appendix C: Schematic

Appendix A: Schematic Functional Blocks

Figure C.1 -- Schematic Page 1

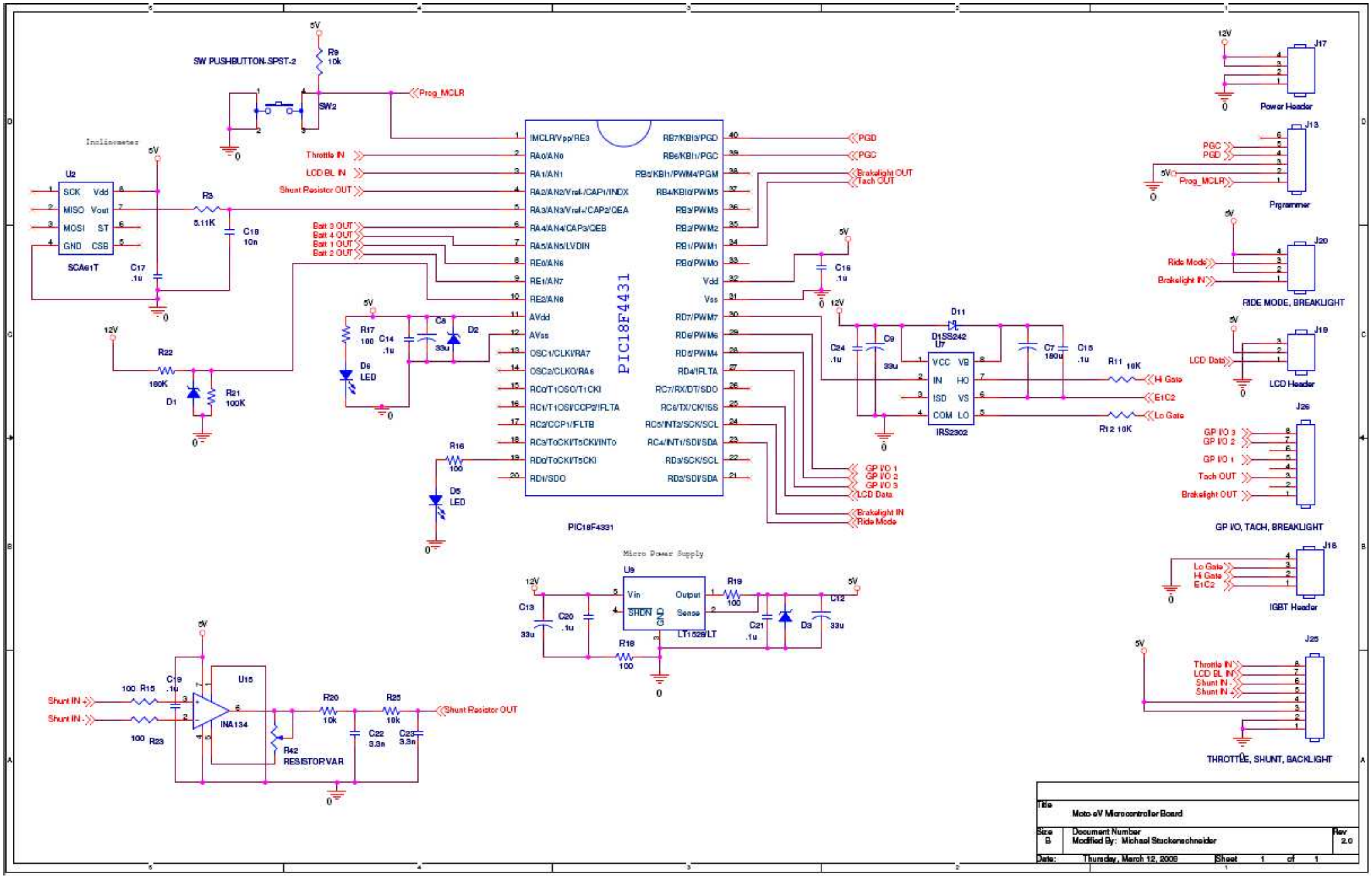


Figure C.2 – Schematic Page 2

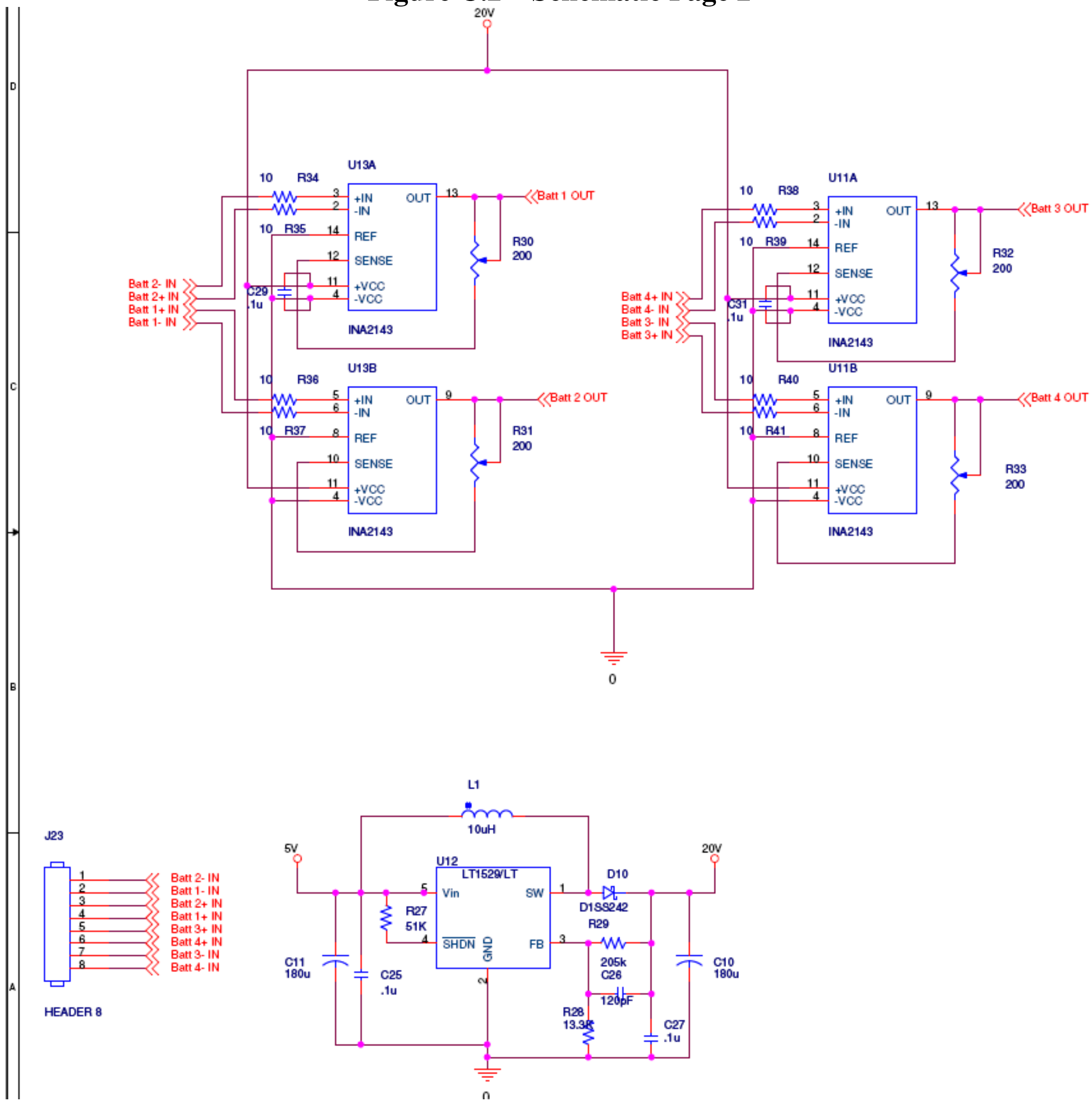


Figure C.3 – Microcontroller (Functional Block A)

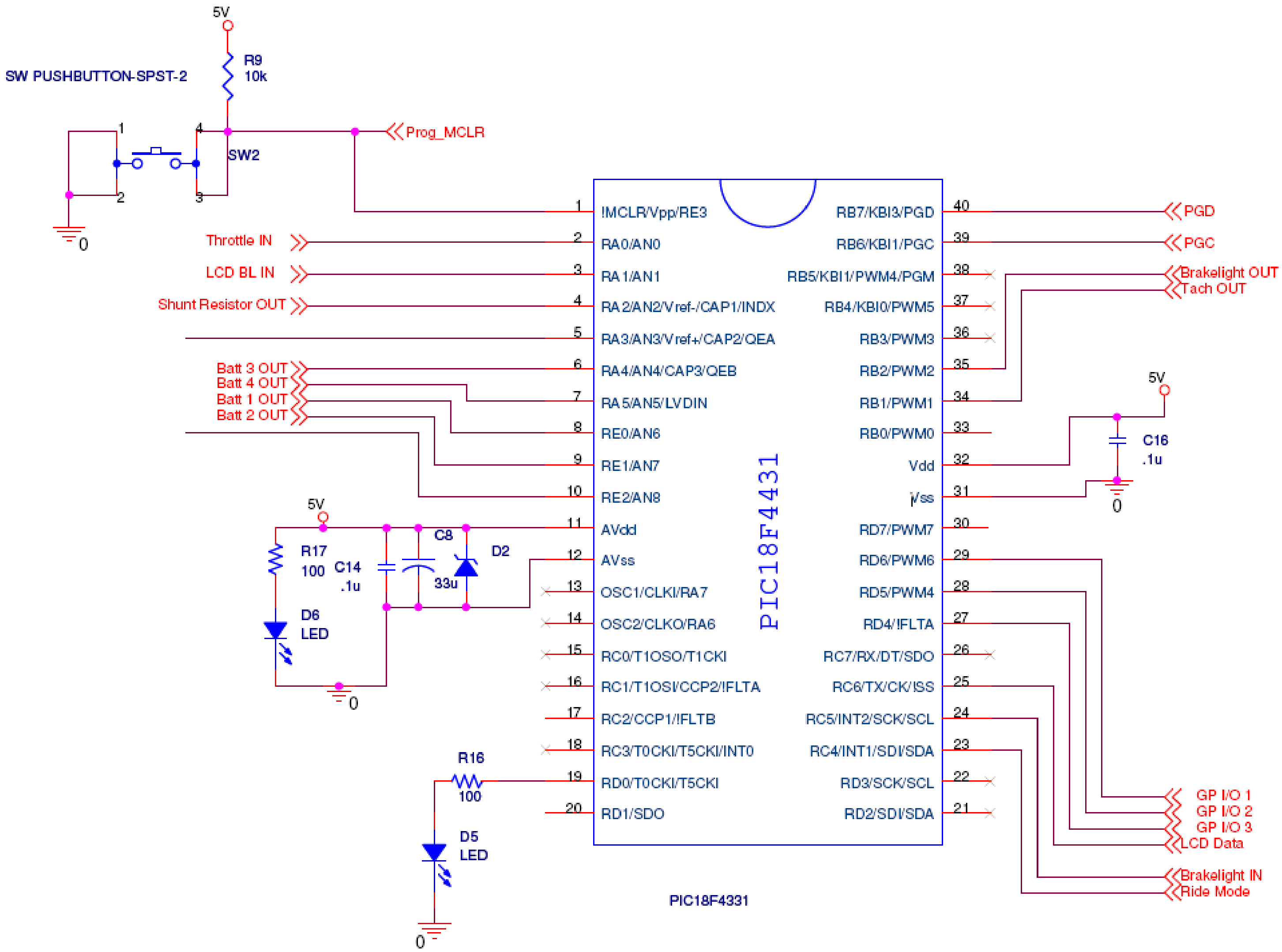


Figure C.4.1 – Sensors (Functional Block B)

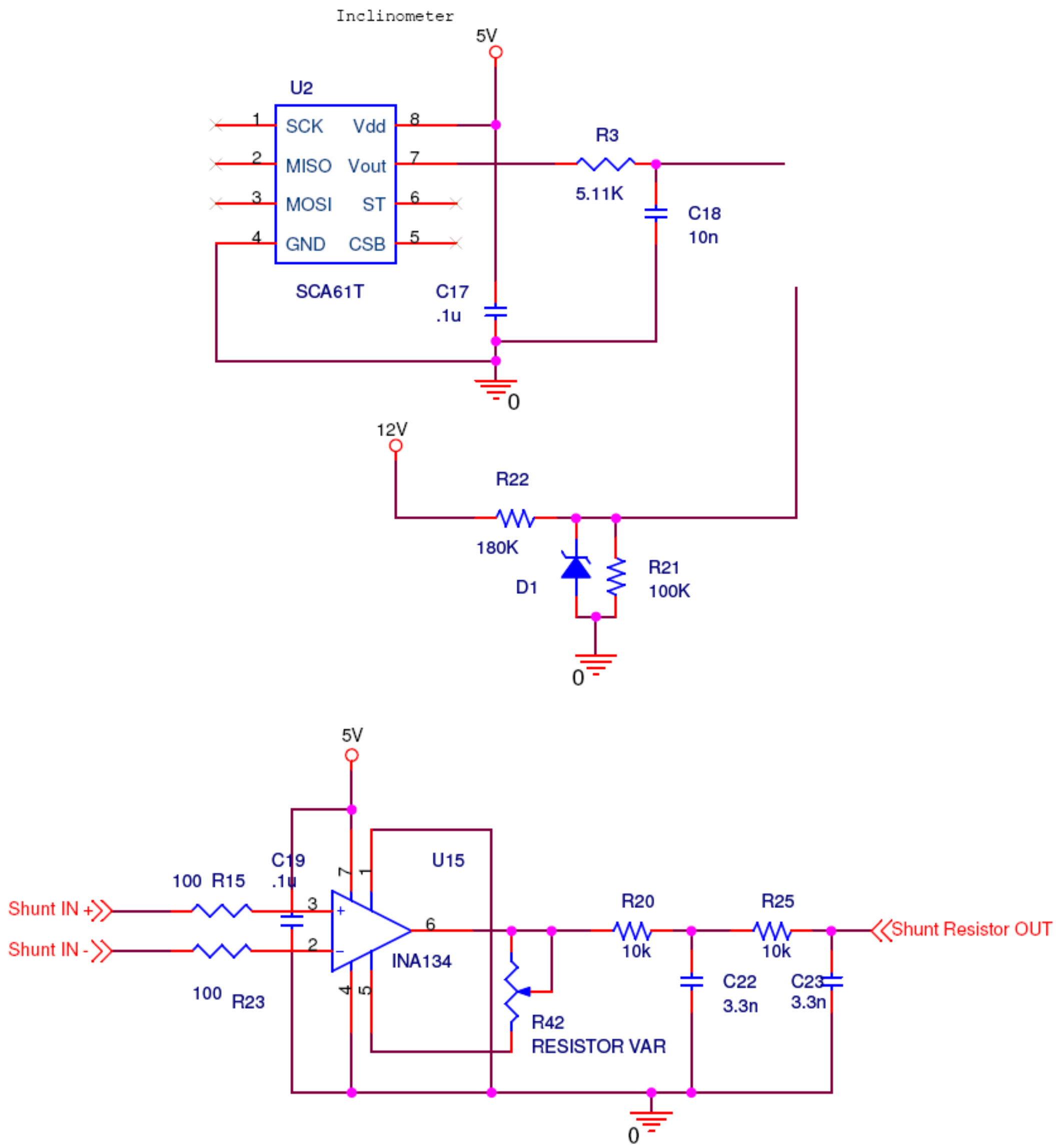


Figure C.4.2 – Sensors (Functional Block B)

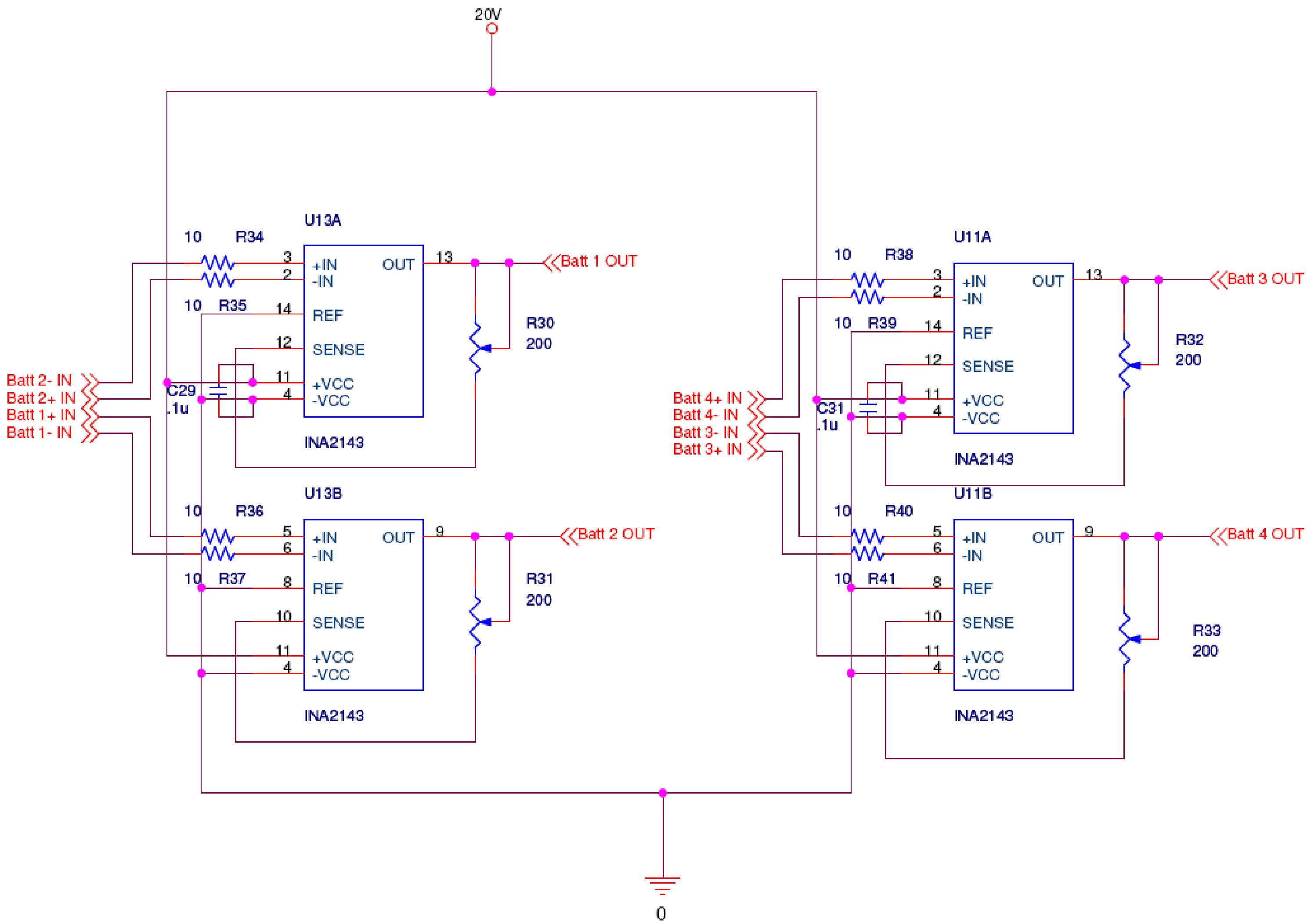
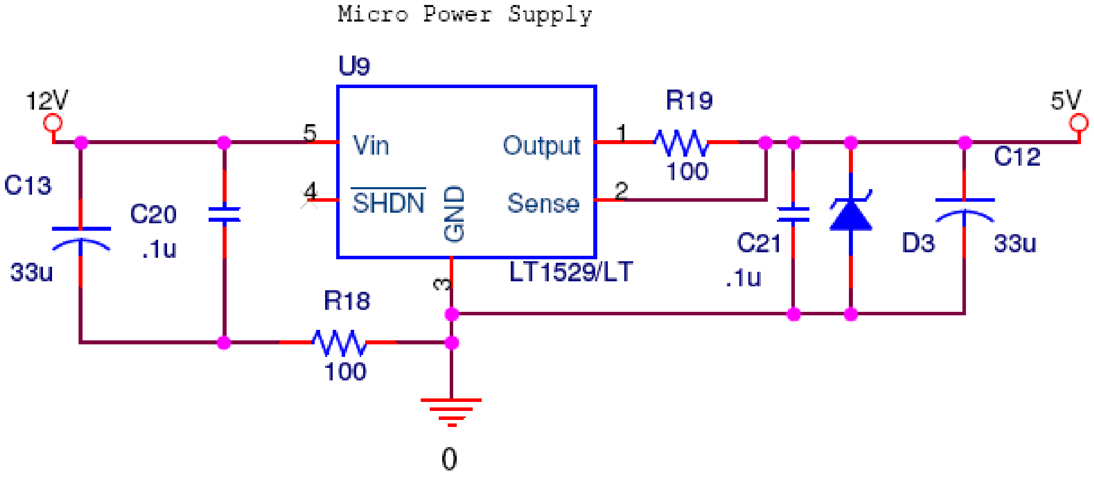


Figure C.5 – Power (Functional Block C)



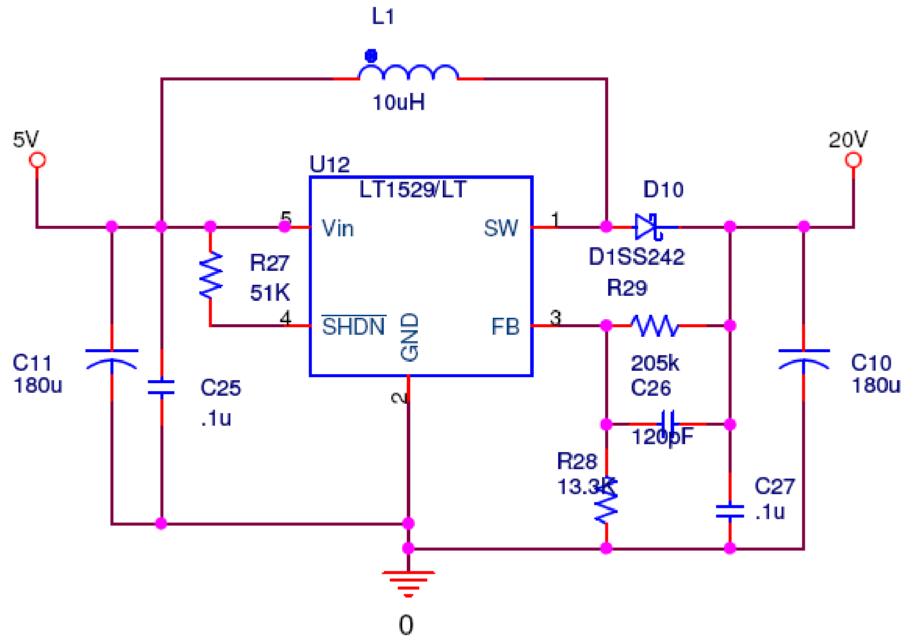


Figure C.6 – Motor control (Functional Block D)

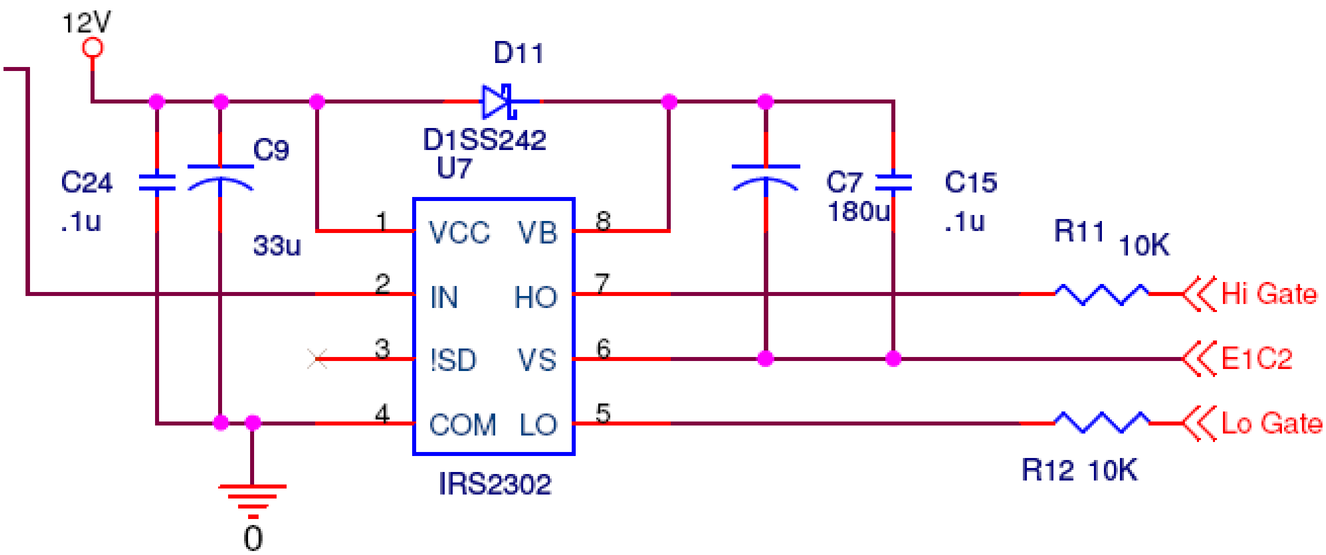
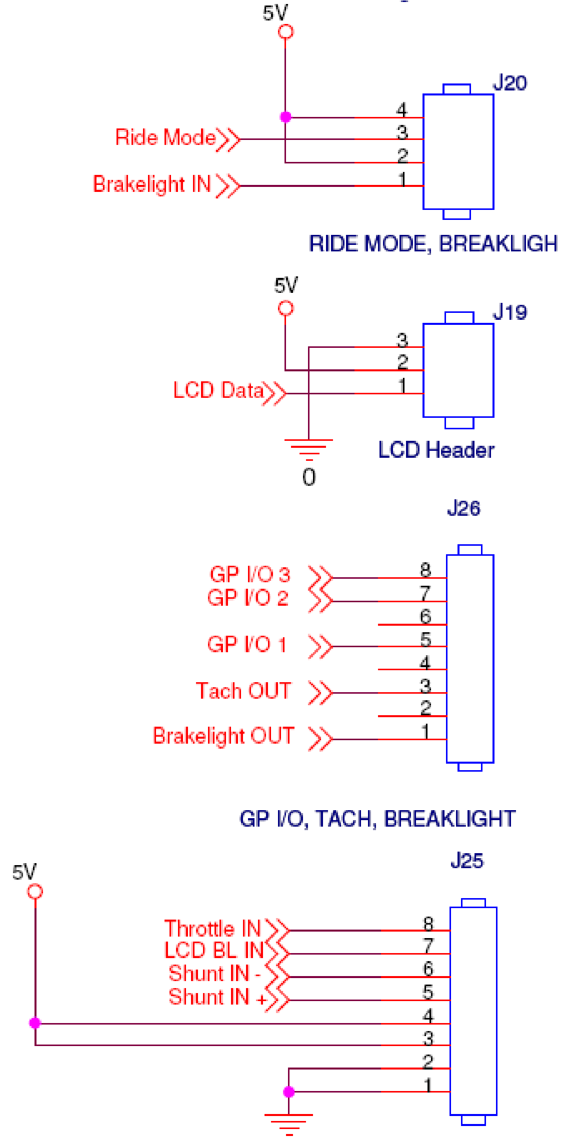


Figure C.7 – User Interface (Functional Block E)



Appendix D: PCB Layout Top and Bottom Copper

Figure D.1: PCB Top Copper with Silkscreen

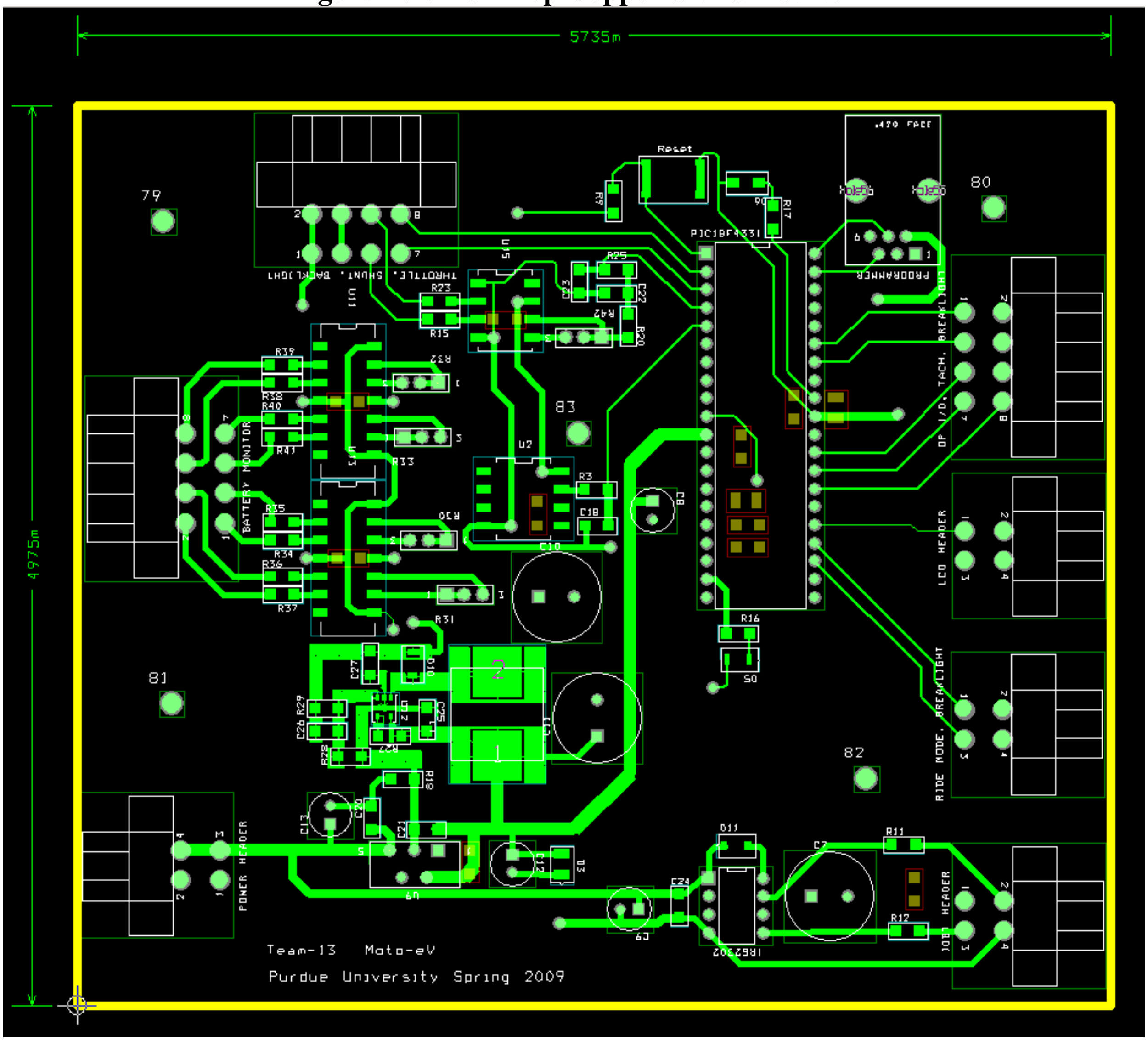
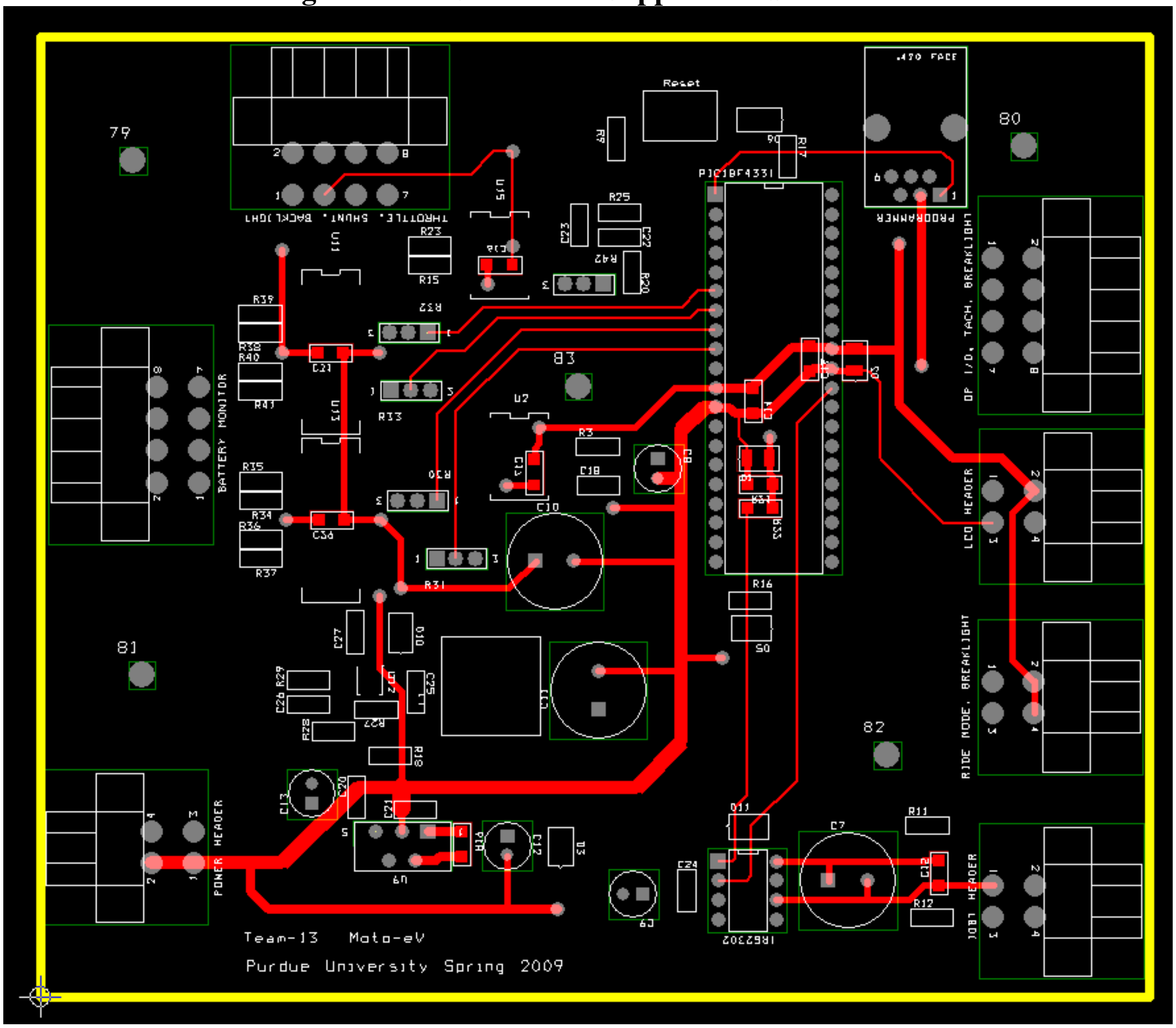


Figure D.2: PCB Bottom Copper with Silkscreen



Appendix E: Parts List Spreadsheet

Vendor	*Manufacturer*	*Part No.*	*Description*	*Unit Cost*	Qty	*Total Cost*
	Honda VF500F Chassis	VF500F	Honda VF500F Chassis	100.00	1	100.00
Mars Electric LCC	Mars Electric LCC	ME0709	48-72V Brushed PM DC Motor	350.00	1	350.00
Magura	Magura	THR35	0-5kΩ Potentiometer Throttle	0.00	1	0.00
Surplus Center	Grizzly	1-2124-12-D	12 Tooth Front Sprocket	5.00	1	7.53
Surplus Center	Grizzly	1-2124-13-D	13 Tooth Front Sprocket	5.00	1	7.53
Surplus Center	Grizzly	1-2124-14-D	14 Tooth Front Sprocket	6.00	1	9.04
Sprocket Specialist	Sprocket Specialist	424-66	66 Tooth Rear Sprocket	102.04	1	102.04
Tractor Supply Co.	Tractor Supply Co.	1150060	50 Roller Chain 10 ft.	27.02	1	27.02
Tractor Supply Co.	Tractor Supply Co.	1151066	50 CLN 4PK Connecting Link	3.99	1	3.99
Batteryspace			Battery Chargers	133.00	1	133.00
NPC	SVR		SVR18 12V 22Ah SLA Batteries	0.00	4	0.00
Microchip	Microchip	PIC18F4331	PIC18F4331	4.99	3	25.23
Ebay	Powerex		IGBT CM300DY-24H	25.00	2	62.41
Crystalfontz	Crystalfontz	CFA-634-YFB-KS	Serial 20x4 LED Backlit LCD	11.00	1	11.00
Digi-Key	Ohmite	TGHGCR0020FE	0.002 Ohm Shunt Resistor	26.31	1	26.31
Digi-Key	International Rectifier	IRS2117PBF	IC DRIVER MOSFET/IGBT	3.08	3	9.24
Digi-Key	Murata Electronics North America	490-2976	Trimpot 20K	1.23	1	1.23
Digi-Key	National Semiconductor	LM392N	IC Op Amp Volt Comparator	1.80	2	3.60
Digi-Key	Linear Technology	LT1529CT	Voltage Regulator	6.75	1	6.75
Digi-Key	VTI Technologies	SCA61T	Single Axis +/-90 Inclinometer	49.16	1	49.16
Digi-Key	National Semiconductor	LM2733XMFCT	Boost Converter	3	1	3.00
Digi-Key	Texas Instruments	INA143UA	Differential Amplifiers	2.36	2	4.72
Digi-Key	Texas Instruments	INA2143UA	Differential Amplifiers	3.83	3	11.49
Digi-Key	Micro Commercial Co	MBR0530TPMSCT	Schottky Diode	0.44	2	0.88
Digi-Key	Stackpole Electronics Inc	RMCF1/85.11KFRCT	5.11k Resistor	0.18	2	0.36

Digi-Key	Diodes Inc	DFLZ5V1DICT	5.1V Zener Diode	0.44	10	4.40
Digi-Key	Panasonic	PCC2239CT	.1uF Ceramic Capacitor	0.47	1	0.47
Digi-Key	Nichicon	493-1672	180uF Electrolytic Capacitor	0.52	3	1.56
Digi-Key	Sumida America Components	308-1436-1	10uH Inductor	2.02	1	2.02
Digi-Key	Lumex Opto/Components Inc	67-1357-1	Green Pwr LED	0.16	1	0.16
Digi-Key	Panasonic	P11525CT	Blue General LED	0.65	1	0.65
Digi-Key	International Rectifier	IR2302PBF	Gate Driver	3.00	2	6.00
Digi-Key	Tyco	A9440	DIP Socket (micro)	2.64	1	2.64
			Body Filler & Hardner	17.32	1	17.32
			Fiberglass Kit	29.62	1	29.62
			Self Etching Primer	6.46	1	6.46
			Fasteners	5.97	1	5.97
			Sand Paper	17.35	1	17.35
			Degreaser	12.00	1	12.00
			New Steering Head Bearings	38.00	1	38.00
			Wiring & Main Fuse	48.95	1	48.95
			Total			1149.10

Appendix F: Software Listing

```
/*       Moto-eV 2009
         Completed: April 28, 2009

         Software wriiten by:
         Arin Chakraverty
         Mike Stuckenschneider
         Loren Garby
*/

#include <p18f4431.h>
#include <delays.h>
#include <timers.h>
#include <adc.h>
#include <usart.h>
#include <stdio.h>
#include <stdlib.h>
#include <pwm.h>


#define SINGLE_OUT     0b00000000 /* single output */
#define PWM_MODE_1     0b00001100 /* PxA,PxC active high, PxB,PxD active high */

// FUNCTION INTIALIZATION=========================================================================

void tim_ISR (void);                  // Interrupt service routine
void adc_high (void);                          // High priority ADC
void adc_low (void);                  // Low priority ADC
void lcd_disp1(void);                 // LCD display page 1
void lcd_disp2 (void);                // LCD display page 2
void LCD_init (void);                 // LCD initialization
int batt_avg (unsigned int[], unsigned float);
void motor (void);
void coast (void);

// VARIABLE DECLARATIONS==========================================================================

unsigned int prev_lcd_state=0;

// THROTTLE VARIABLES
unsigned int throttle[6]={0,0,0,0,0,0};
unsigned int throttle_read=0;
unsigned int throttle_avg_prev=0;
unsigned int throttle_avg=0;
```

```
unsigned int sum_throttle=0;
int i=0;
unsigned int duty_cycle;
unsigned int dutyH;
unsigned int dutyL;
unsigned float throttle_disp;


// SHUNT VARIABLES
unsigned int shunt_read=0;
unsigned int shunt_avg=0;
unsigned int shunt_disp = 0;
unsigned int sum_shunt=0;

// INCLINOMETER VARIABLES

unsigned int inclin_read=0;
unsigned int inclin_avg=0;
unsigned int inclin_val=0;

rom unsigned int inclin_angle[87]={0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,
27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,
62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,84,90,90,90};
rom unsigned  int inclin_volt_neg[87]={102,103,104,105,106,108,109,110,111,113,114,116,118,120,122,124,126,
129,131,134,137,140,143,146,149,153,156,160,163,167,171,175,179,183,188,192,196,201,206,211,215,220,225,231,
236,241,246,252,258,263,269,275,281,286,292,298,305,311,317,323,330,336,343,349,356,362,369,376,383,389,396,
403,410,417,424,431,438,445,452,459,466,473,480,487,495,502,509};
rom unsigned int inclin_volt_pos[86]={516,523,530,538,545,552,559,566,573,580,587,594,601,608,615,622,629,
636,642,649,656,663,669,676,682,689,695,702,708,714,720,727,733,739,744,750,756,762,767,773,779,784,789,794,
800,805,810,814,819,824,829,833,837,842,846,850,854,858,862,865,869,872,876,879,882,885,888,891,894,896,899,
901,903,905,907,909,911,913,914,915,917,918,919,920,921};

// BATTERY VARIABLES

unsigned int batt1_read=0;
unsigned int batt2_read=0;
unsigned int batt3_read=0;
unsigned int batt4_read=0;
unsigned int batt_micro_read=0;

unsigned int batt1_avg=0;
unsigned int batt2_avg=0;
unsigned int batt3_avg=0;
unsigned int batt4_avg=0;
unsigned int batt_micro_avg=0;
```

```
unsigned int batt_micro_disp = 0;
unsigned int batt1_disp = 0;
unsigned int batt2_disp = 0;
unsigned int batt3_disp = 0;
unsigned int batt4_disp = 0;

unsigned float batt_read=0;
unsigned float sum_batt=0;
unsigned float batt_average=0;


// DISPLAY VARIABLES
char buf[6]={0,0,0,0,0,0};

// TIMER VARIABLES
int tim_cnt=13;


// PRAGMA CONFIGURATIONS============================================

#pragma config OSC=IRCIO             // internal oscillator
#pragma config WDTEN = OFF           // turn off watchdog timer
#pragma config PWRTEN = OFF          // turns off the power up timer
#pragma config BOREN = OFF           // turns off the brown out reset
#pragma config LVP = OFF             // turn off Low voltage programming


//=====================INTERRUPT VECTOR=========================
/*****************************************************************
         This is the function that specifies where the interrupt vector
         is, and which memory address in the code to proceed to when an
         interrupt takes place
*****************************************************************/

#pragma code low_vector = 0x08
void low_ISR (void)
{
         _asm GOTO tim_ISR _endasm
}
#pragma code

//=====================INTERRUPT ROUTINE========================
/*****************************************************************
         This is the function that takes place every time an interrupt
         occurs (at the clock speed of 8Mhz). In this interrupt service
         routine the adc() function is called and the motor() function
```

```
        is called. These functions are described in greater detail in
        their respective function headers.
*******************************************************************/

#pragma interruptlow tim_ISR
void tim_ISR (void)
{
        adc_high();
        motor();

        INTCONbits.TMR0IF = 0;      // CLEAR TIMER INTERRUPT FLAG

}


//=====================HIGH PRIORITY ADC=======================
/******************************************************************
        This is where the high priority analog to digital inputs are
        read. The high priority interrupts were chosen according to
        the importance of their real-time value. To know that the micro
        battery and throttle input are accurate values are accomplished
        in this routine.

        This function is called whenever a timer interrupt takes
        place.
*******************************************************************/

void adc_high (void)
{

// Throttle========================================================

                ADCON0bits.ACMOD1 = 0;              // GROUP A
                ADCON0bits.ACMOD0 = 0;
                ADCHSbits.GASEL1=0;                          // AN0
                ADCHSbits.GASEL0=0;


                ADCON0bits.GO = 1;
                while (ADCON0bits.GO);
                throttle_read = ReadADC();
                throttle_avg = ((4*throttle_read)+(6*throttle_avg))/10;

                if (PORTCbits.RC4 == 1)
                {
                        throttle_avg = throttle_avg/2;
```

```
                    }

// Micro Battery==========================================================

                    ADCON0bits.ACMOD1 = 0;                // GROUP A
                    ADCON0bits.ACMOD0 = 0;
                    ADCHSbits.GASEL1=1;                            // AN8
                    ADCHSbits.GASEL0=0;

                    ADCON0bits.GO = 1;
                    while (ADCON0bits.GO);
                    batt_micro_read = ReadADC();
                    batt_micro_avg = (((9*batt_micro_avg)+batt_micro_read)/10);
                    batt_micro_disp = batt_micro_avg * 1.453;

}

//=========================LOW PRIORITY ADC==========================
/******************************************************************
          This is where the low priority analog to digital inputs are
          read. The low priority interrupts were all of the batteries
          aside from the microprocessor battery. They are still being
          updated quickly and accurately, but simply not as often as the
          throttle and microprocessor battery.

          This function is called in the while(1) loop, nested in the
          main loop. Thus, it is called once per iteration of the main
          polling loop.
******************************************************************/
void adc_low (void)
{

// Battery 1 ===========================================================

                    ADCON0bits.ACMOD1 = 1;                // GROUP C
                    ADCON0bits.ACMOD0 = 0;
                    ADCHSbits.GCSEL1=0;                            // AN6
                    ADCHSbits.GCSEL0=1;

                    ADCON0bits.GO = 1;
                    while (ADCON0bits.GO);

                    batt1_read = ReadADC();

                    batt1_avg = (((9*batt1_avg)+batt1_read)/10);
```

```
                //batt1_avg = batt_avg(batt1, batt1_div);
                batt1_disp = batt1_avg*1.557;                      // display scaling

// Battery 2 ============================================================

                ADCON0bits.ACMOD1 = 0;                // GROUP A
                ADCON0bits.ACMOD0 = 0;
                ADCHSbits.GASEL1=0;                            // AN4
                ADCHSbits.GASEL0=1;

                ADCON0bits.GO = 1;
                while (ADCON0bits.GO);

                batt2_read = ReadADC();

                batt2_avg = (((9*batt2_avg)+batt2_read)/10);
                //batt2_avg = batt_avg(batt2, batt2_div);
                batt2_disp = batt2_avg*1.367;                      // display scaling

// Battery 3 ============================================================

                ADCON0bits.ACMOD1 = 0;                // GROUP B
                ADCON0bits.ACMOD0 = 1;
                ADCHSbits.GBSEL1=0;                            // AN5
                ADCHSbits.GBSEL0=1;

                ADCON0bits.GO = 1;
                while (ADCON0bits.GO);

                batt3_read = ReadADC();

                batt3_avg = (((9*batt3_avg)+batt3_read)/10);
                //batt3_avg = batt_avg(batt3, batt3_div);
                batt3_disp = batt3_avg*1.371;

// Battery 4 ============================================================

                ADCON0bits.ACMOD1 = 1;                // GROUP D
                ADCON0bits.ACMOD0 = 1;
                ADCHSbits.GDSEL1=0;                            // AN7
                ADCHSbits.GDSEL0=1;

                ADCON0bits.GO = 1;
                while (ADCON0bits.GO);

                batt4_read = ReadADC();
```

```
                    batt4_avg = (((9*batt4_avg)+batt4_read)/10);
                    //batt4_avg = batt_avg(batt4, batt4_div);
                    batt4_disp = batt4_avg*1.612;                            // display scaling

}


//============================COASTING==============================
/*******************************************************************
          This function lets the motor slowly decrease in a coasting
          fashion. It is solving the problem of the motor doing the
          equivalent of an engine break, when the throttle was
          released.
*******************************************************************/
void coast (void)
{

          if(throttle_avg_prev > throttle_avg)
          {
                    PORTDbits.RD1 = 0;
                    PORTDbits.RD0 = 1;
          }
          else
          {
                    PORTDbits.RD1 = 1;
                    PORTDbits.RD0 = 0;
          }
}


//========================LCD INITIALIZE=========================
/*******************************************************************
          This is where the LCD is initialized. It hides the LCD
          cursor and clears the display.

          This function is called before LCD display pages are
          switched and in the main initialization loop before any
          display appear.
*******************************************************************/

void LCD_init (void)
{
          putrsUSART("\004");                    //Hide LCD Cursor
          putrsUSART("\f");           //Clear Display
}
```

```
//========================LCD DISPLAY========================
/*****************************************************************
         This is where the second page of the LCD display is
         configured. It displays the battery charge status of the
         four 12V batteries that power the motor.

         This function is called in the while(1) loop nested in the
         main pooling loop. Thus, it is called once per main loop
         iteration.
*****************************************************************/


void lcd_disp1 (void)
{

         putrsUSART("\001\004");
         Delay100TCYx(0);

         putrsUSART("Batt 1: ");
    sprintf(buf, "%2d.%-1dV\r\n", batt1_disp/100, (batt1_disp%100)/10);
    putsUSART(buf);
         Delay10TCYx(0);

         putrsUSART("Batt 2: ");
    sprintf(buf, "%2d.%-1dV\r\n", batt2_disp/100, (batt2_disp%100)/10);
    putsUSART(buf);
    Delay10TCYx(0);

         putrsUSART("Batt 3: ");
         sprintf(buf, "%2d.%-1dV\r\n", batt3_disp/100, (batt3_disp%100)/10);
         putsUSART(buf);
    Delay10TCYx(0);

         putrsUSART("Batt 4: ");
         sprintf(buf, "%2d.%-1dV", batt4_disp/100, (batt4_disp%100)/10);
         Delay10TCYx(0);
    putsUSART(buf);

}
// ======================================================================

void lcd_disp2 (void)
```

```
{
         putrsUSART("\001\004");
         Delay10TCYx(0);

// INCLINOMETER

         putrsUSART("Lean Angle: ");
         sprintf(buf, "%-2u", inclin_val);
    putsUSART(buf);
         Delay10TCYx(0);
         putrsUSART("\036\001\200");
         Delay10TCYx(0);
         putrsUSART("\r\n");

// MICRO BATTERY

         putrsUSART("Micro Batt: ");
         sprintf(buf, "%2d.%-1dV\r\n", batt_micro_disp/100, (batt_micro_disp%100)/10);
         putsUSART(buf);
    Delay10TCYx(0);

// THROTTLE

         putrsUSART("Throttle: ");
         Delay10TCYx(0);
    sprintf(buf, "%-3u", (throttle_avg/102)*10);
    putsUSART(buf);

}


//==========================MOTOR CONTROL==========================
/*****************************************************************
         This is where the motor output is configured. It works by
         reading the input from the throttle and then transposing it
         into a duty cycle which then determines the PWM output to
         the motor.
*****************************************************************/

void motor (void)
{
         duty_cycle = (throttle_avg/0x0F) << 4;                  // DELAY FOR 17.6 KHZ PWM FREQUENCY  /0x25

         dutyH = (duty_cycle >> 8) & 0x00FF;
         dutyL = duty_cycle & 0x00FF;
```

```
        PDC0H = dutyH;
        PDC0L = dutyL;
}

//===========================MAIN LOOP===========================
/*****************************************************************
        This is the main pooling loop of the code. It is where all
        the initializations are made with respect to the oscillator
        speed for the internal clock, the input and output status
        of the port pins, the timer intializations and their
        scalings, the initializations of the ATD pins and how they
        are sampled and referenced, EUSART initializations for the
        LCD display output settings, and finally the PWM settings
        for the control of the motor output and to set the PWM
        frequency to maximize motor output and minimize the noise
        produced by the motor.

        The nested while(1) loop in the main function includes the
        inclinometer readings and algorithm to display the degrees
        appropriately. It also has a lcd display monitoring set up
        to check which lcd display page should be output.

*****************************************************************/

void main (void)
{

// INTERNAL OSCILLATOR PRESCALAR================================================

        OSCCONbits.IRCF2 = 1;
        OSCCONbits.IRCF1 = 1;                //8MHz
        OSCCONbits.IRCF0 = 1;

// IRCF2:IRCF0
// 111 = 8 MHz
// 110 = 4 MHz
// 101 = 2 MHz
// 100 = 1 MHz
// 011 = 500 kHz
// 010 = 250 kHz
// 001 = 125 kHz
// 000 = 31 kHz

// PORT STATUS==================================================================

        TRISA = 0xFF;                                        // Port A set as input
```

```
        TRISEbits.TRISE0 = 1;                          // Port E0 set as input     - AN6
        TRISEbits.TRISE1 = 1;                          // Port E1 set as input - AN7
        TRISEbits.TRISE2 = 1;                          // Port E2 set as input - AN8

        TRISCbits.TRISC5 = 1;                          // LCD Display toggle input
        TRISCbits.TRISC4 = 1;                          // Ride Mode toggle input

        TRISBbits.TRISB1 = 0;
        TRISBbits.TRISB2 = 0;
        TRISDbits.TRISD0 = 0;
        TRISDbits.TRISD1 = 0;                          //Output for coast feature
        TRISDbits.TRISD2 = 0;
        TRISDbits.TRISD3 = 0;
        TRISDbits.TRISD4 = 1;
        TRISDbits.TRISD5 = 1;
        TRISDbits.TRISD6 = 0;
        TRISDbits.TRISD7 = 0;

        PORTBbits.RB1 = 1;
        PORTDbits.RD1 = 1;                             //Gate Driver Initially Enabled
// TIMER INTERRUPT INTIALIZATIONS===============================================

        OpenTimer0 (TIMER_INT_ON & T0_16BIT & T0_SOURCE_INT & T0_PS_1_1);
        OpenTimer2 (TIMER_INT_OFF & T2_PS_1_1 & T2_POST_1_1);                                       // SET PWM
PRESCALAR TO 1:1

        INTCONbits.GIE = 1;
        INTCONbits.TMR0IF = 0;

// ANALOG TO DIGITAL CONVERSION INTIALIZATION=====================================

// OLD CONFIGURATION

    ADCON0bits.ACSCH = 0;               //Single Channel Mode
        ADCON0bits.ACONV = 0;                                   // Single shot mode
    ADCON0bits.ADON = 1;               //Turns on AD
    ADCON1bits.VCFG1 = 0;               //References are +5V & 0V
    ADCON1bits.VCFG0 = 0;
    ADCON1bits.FIFOEN = 0;               //FIFO disabled
    ADCON2bits.ADFM = 1;               //Right justified results
    ADCON2bits.ACQT3 = 0;
    ADCON2bits.ACQT2 = 0;
    ADCON2bits.ACQT1 = 1;               //4 TAD acquisition time select
    ADCON2bits.ACQT0 = 0;

    ADCON2bits.ADCS2 = 0;
```

```
    ADCON2bits.ADCS1 = 1;                //AD Clk = Fosc/32
    ADCON2bits.ADCS0 = 0;

         ANSEL0 = 0b11111111;                                          // set all inputs as analog inputs
         ANSEL1bits.ANS8 = 1;


//EUSART INITIALIZATION=================================================================

         TXSTAbits.TX9 = 0;          //Enables 8-bit transmission
         TXSTAbits.TXEN = 1;                  //Tansmit enabled
         TXSTAbits.SYNC = 0;                  //Asynchronous mode
         TXSTAbits.BRGH = 0;                  //High speed baud rate disabled

         RCSTAbits.SPEN = 1;                  //Serial port enabled (RX & TX pins as serial port pins)
         RCSTAbits.CREN = 0;                  //Disables receiver

         BAUDCTLbits.BRG16 = 0;      //8-bit baud rate generator
         SPBRGH = 0x00;                       //Sets high baud rate byte to zero
         SPBRG = 0x0C;                        //sets baud rate to 9600


// PWM INITIALIZATION===================================================================

         PTCON0bits.PTOPS3 = 0;                                        // 1-1 POST SCALAR
         PTCON0bits.PTOPS2 = 0;
         PTCON0bits.PTOPS1 = 0;
         PTCON0bits.PTOPS0 = 0;

         PTCON0bits.PTCKPS1 = 0;                                       // TIME BASE INTPUT CLOCK 1/:1
         PTCON0bits.PTCKPS0 = 0;

         PTCON0bits.PTMOD1 = 0;                                        //TIME BASE IS FREE RUNNING MODE
         PTCON0bits.PTMOD0 = 0;

         PTCON1bits.PTEN = 1;                                          //PWM TIME BASE IS ON

         PWMCON0bits.PWMEN2 = 0;                                       // ENABLE PWM 0, 1, 2, and 3
         PWMCON0bits.PWMEN1 = 1;
         PWMCON0bits.PWMEN0 = 1;

         PWMCON0bits.PMOD0 = 0;                                        // INDEPENDENT MODE FOR PWM0 AND PWM1
         PWMCON0bits.PMOD1 = 0;                                        // INDEPENDENT MODE FOR PWM2 AND PWM3
```

```
        PTPERL = 0x1F;                                              // PWM PERIOD VALUE TO SET PWM FREQUENCY TO 1
kHz
        PTPERH = 0x01;

        LCD_init();                                                 // INITIALIZE LCD DISPLAY


//WHILE LOOP========================================================================

        while (1)
        {


/*************************************
=============INCLINOMETER============
*************************************/

                ADCON0bits.ACMOD1 = 1;              // GROUP D
                ADCON0bits.ACMOD0 = 1;
                ADCHSbits.GDSEL1=0;                         // AN3
                ADCHSbits.GDSEL0=0;

                ADCON0bits.GO = 1;
                while (ADCON0bits.GO);

                inclin_read = ReadADC();
                inclin_avg = ((0.9*inclin_avg)+(0.1*inclin_read));


// INCLINOMETER CONFIGURATIONS

                if(inclin_avg <= 523 && inclin_avg >= 495)
                {
                        inclin_val=0;
                }
                else if(inclin_avg < 495)
                {
                        for(i=1;i<=87;i++)
                        {
                                if(inclin_avg <= inclin_volt_neg[i])
                                {
                                        inclin_val=inclin_angle[87-i];
                                        i=87;
                                }
                        }
                }
```

```
                else
                {
                        for(i=1;i<=87;i++)
                        {
                                if(inclin_avg <= inclin_volt_pos[i])
                                {
                                        inclin_val=inclin_angle[i];
                                        i=97;
                                }
                        }
                }


                adc_low();

// =============================================================
// LCD DISPLAY SELECT ==========================================

                if (PORTCbits.RC5 == 0)
                {
                        if(prev_lcd_state == 1)
                        {
                                prev_lcd_state = 0;
                                putrsUSART("\f");
                        Delay10TCYx(0);
                        }
                        else
                        {
                                lcd_disp1();
                        }
                }
                else
                {
                        if(prev_lcd_state == 0)
                        {
                                prev_lcd_state = 1;
                                putrsUSART("\f");
                        Delay10TCYx(0);
                        }
                        else
                        {
                                lcd_disp2();
                        }
                }
        }
}
```

Appendix G: FMECA Worksheet

Table G.1: Microcontroller

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remark
A1	VCC shorted to ground	Bypass Capacitor Shorts	No Power to Microprocessor	DMM	Medium	Causes entire system to shutdown
A2	Micro remains in reset	Reset switch shorts closed	Microprocessor fails to execute program	DMM	Medium	User input will be non-existent

Table G.2: Sensors

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remark
B1	No power to inclinometer	Bypass Capacitor Shorts	No lean angle displayed on LCD	DMM	Medium	
B2	No power to Battery Diff-Amps	Bypass Capacitor shorts	No battery level displayed on LCD	DMM	Medium	User will not know how much charge is left
B3	No Power to shunt Diff-Amp	Bypass Capacitor shorts	Micro reads current as zero and applies full power to motor	DMM	High	Can cause serious damage to critical components and the rider

Table G.3: Power						
Failure No.	**Failure Mode**	**Possible Causes**	**Failure Effects**	**Method of Detection**	**Criticality**	**Remark**
C1	System Performance seems erratic	Bypass Capacitor fails	Introduces noise into the system which causes output voltage to vary	Observation while riding	Medium	Can cause unpredictable ride performance
C2	Battery level seems erratic	Boost feedback resistor fails causing unreliable output voltage	LCD displays false battery levels	Observation	Low	Boost reads unpredictable feedback voltage, tries to correct output voltage
C3	Battery level seems erratic	Output capacitor fails	Micro reads current as zero and applies full power to motor	Observation	Low	20V output switches over too large a range that diff-amps fail to function properly

Table G.4: Motor Control						
Failure No.	**Failure Mode**	**Possible Causes**	**Failure Effects**	**Method of Detection**	**Criticality**	**Remark**
D1	Cannot control motor	Gate driver may have burned up	Motor stops operating	Observation	Medium	Would cause motor to coast to a stop
D2	High side gate not switching	Bootstrap capacitor/diode failure	Motor stops operating	Oscilloscope	Medium	Causes motor windings to be shorted
D3	No power to gate driver	Bypass capacitor shorts	Motor stops operating	DMM	Medium	
D4*	High side IGBT switch stuck closed	Excessive current draw	Motor speeds up out of control	DMM	High	Can cause serious injury to rider

Table G.5: User Interface						
Failure No.	**Failure Mode**	**Possible Causes**	**Failure Effects**	**Method of Detection**	**Criticality**	**Remark**
E1	Motor seams unresponsive	Throttle ATD not functioning	No motor response from user input	Observation	High	Can occur while at speed with unpredictable results
E2	No output/ Junk to LCD	Buffer overrun, dead TX pin	Pertinent data cannot be sent to the user	Observation	Medium	Can cause user to over discharge batteries
E3	Break light I/O pin	Dead I/O pin	Causes brake lights no to function	Observation	High	Causes bike to not be street legal and increases risk of accident