HYBRID'S ANGELS

Low-Level Design

Hybrid Electric Motorcycle

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This document details the preliminary low-level design for the Hybrid's Angels Senior Design Project. It will address design requirements, low-level design decisions, and questions that still need be answered.

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1 INTRODUCTION

From August 2007 to May 2008, a group of senior electrical engineering majors at the University of Notre Dame began construction on a series hybrid electric motorcycle. Over the course of the year, they successfully converted a 1983 Yamaha Seca into a battery powered vehicle; however, they were unable to meet the ambitious goal of mechanical power system hybridization. In this proposal, Hybrid's Angels will delineate a plan to realize this goal in addition to fixing and enhancing current issues with the motorcycle's current design.

2 PROBLEM STATEMENT AND PROPOSED SOLUTION

2.1 PROBLEM STATEMENT

The phrase "going green" has gained widespread popularity in recent years. As uncertainty mounts about the effects of carbon emissions on the earth's future, increased pressure is falling upon individuals around the world to reduce their carbon footprints. This can be accomplished in a wide variety of ways from an increased devotion to recycling to simply turning off a light when not in use. Energy conservation and decreased emissions are more important now than ever because evidence of the negative effect of the world's hitherto wasteful nature is finally beginning to manifest itself. One of the major sources of this waste is a product that has become fundamental to Americans' daily activities – the automobile. Automobiles have been a staple of transportation for decades, and the carbon dioxide and carbon monoxide that they billow through their exhausts is a colossal part of the problem. A great deal of stress has been placed upon auto manufacturers to trim their vehicles' emissions, and thus far the most popular response has been the introduction of the hybrid vehicle. Although certainly not the solution to all of the energy ills, hybrid technology will act as a critical transition technology until cleaner, more efficient sources are implemented.

2.2 PROPOSED SOLUTION

While hybrid vehicles are not completely independent of fossil fuels, they are much more "green" than gasoline powered engines. The electricity used to power the batteries in a hybrid is likely to come from a power plant that burns fossil fuels, but even that situation is much more efficient and environmentally friendly than the combustion engine of a car. In addition, a hybrid vehicle will not produce any emissions while running off the batteries. So why not just build an electric vehicle? Range and charging time of current electric automobile technology cannot compete with traditional gasoline powered engines used in most cars. A hybrid is therefore the best solution because it is a compromise between current gasoline powered automobiles and the emission-free vehicles of the future.

Last year, a group of senior electrical engineering majors, the Lightning Riders, built a prototype electric motorcycle. For this group's project, they will modify and improve the electric motorcycle built by the Lightning Riders by turning it into a hybrid motorcycle.

3 SYSTEM DESCRIPTION AND BLOCK DIAGRAM

3.1 SYSTEM DESCRIPTION

Hybrid's Angels' hybrid motorcycle will utilize a series hybrid configuration. This configuration begins with power from a standard 120VAC wall outlet being sent into a specially designed circuit. This circuit will be created to convert the AC waveform into a DC signal of approximately 90V. This 90V of direct current will be used to charge the 72V stack of batteries. When the batteries are fully charged, the group will take the wall input plug and insert it into the generator.

The generator produces the same waveform as the wall output but it is mobile because it runs off of gasoline power. Therefore, we can use the same charging circuit to charge the batteries while the motorcycle is running. The generator will be electric start, meaning that we will be able to control its operation with a microcontroller.

In operational mode, the batteries will be used to power two things. First and foremost, the 72V battery stack will drive the analog motor controller. This motor controller drives the electric motor, which in turn rotates the wheel via a gear shaft. It is operated by the bike's throttle. This entire system was put in place by the Lightning Riders and will not be our biggest concern. Since the original design suffered a slight flaw when the electronic circuitry was being powered by two batteries in the stack, the group will need to explore a more efficient way to power these onboard electronics, which include the microcontroller, LED display, sensors, and other necessary onboard electronic components.

Of more interest to the group will be the electronic system. There will be a system of sensors placed all over the bike – temperature on the batteries, current from the batteries, and voltage remaining on the batteries. All of these data will be fed into the microcontroller. Based on these data, the control module will make real-time decisions about ways to increase the bike's energy efficiency. A monitoring module will also receive the data from the sensors, but its primary focus is to store that data for future analysis.

3.2 BLOCK DIAGRAM

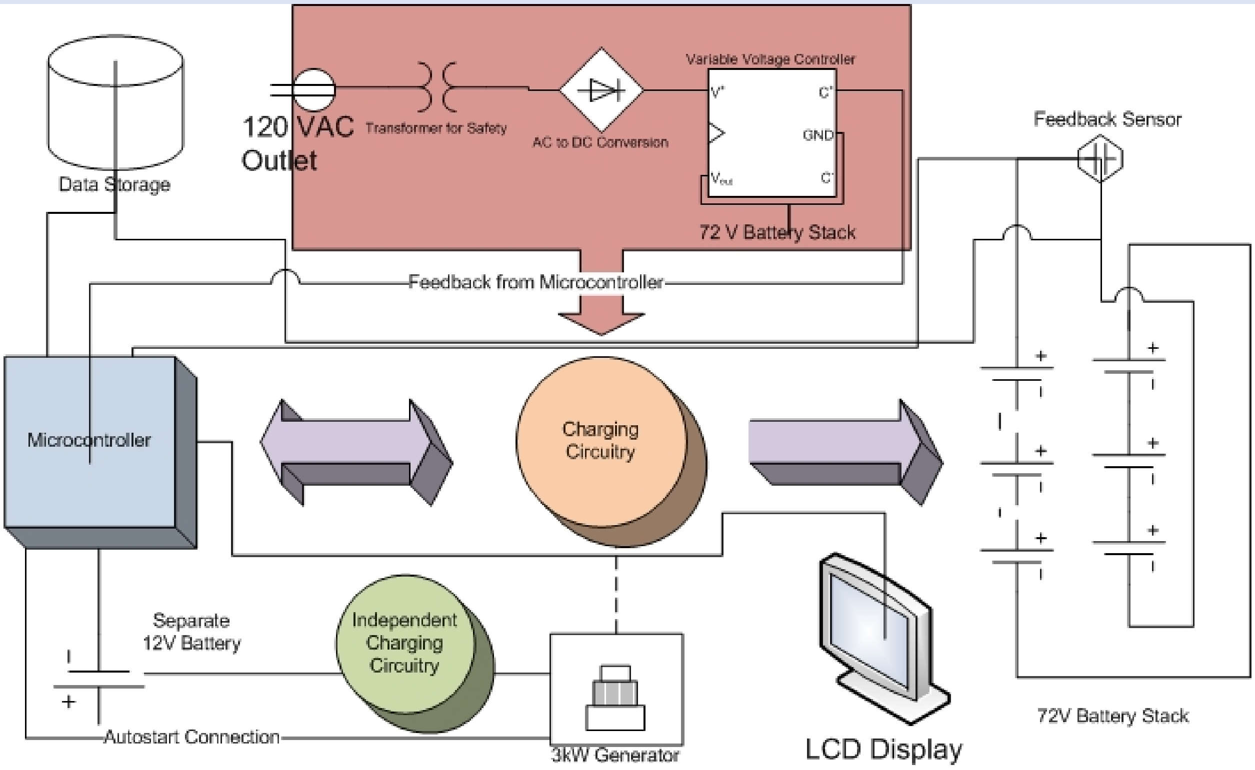


Figure 3.2a: Block Diagram Design

4 SYSTEM REQUIREMENTS

4.1 OVERALL SYSTEM

Hybrid's Angels' overarching goal will be to make a working hybrid motorcycle. Still, the group intends to fix and improve some of the features, which were implemented to varying degrees of success in the Lightning Riders' model. In May, Hybrid's Angels expect to demonstrate a fully functional hybrid motorcycle with top speeds of at least 50 miles per hour and a range of at least 20 miles before refueling and/or recharging.

4.2 SUBSYSTEM REQUIREMENTS

4.2.1 GENERATOR

The generator will have to be gas-powered and mobile. Hybrid's Angels have decided to use a single generator mounted on the back rather than the dual-generator saddle-bag configuration, so size and balance are of the utmost importance. In addition, the group wants to use an electric start generator; this is so that the microcontroller can send a signal to start the gas engine inside. Finally, it has to output 120VAC, and the group will have to be able to draw a continuous 20 amps in order to charge the batteries to the ideal specifications.

4.2.2 CHARGING CIRCUITRY

Ultimately, the overlying goal in the creation of the charging circuitry will be to develop a system that charges the 72V battery stack as quickly as possible while maintaining an appropriate level of safety. Appropriate measures should be considered not only to protect the user but also the integrity of the batteries. As a goal of this project is to show that a series hybrid system is ready, viable solution, the charging circuitry must interface with a common electrical socket (120 VAC, 60 Hz). In order to enhance the charging speed, this circuitry will be duplicated in order to draw as much power as possible without tripping a standard household breaker.

From the outlet, a mechanism, such as a fuse and or transformer, must be present so as to prevent the high voltage AC signal from destroying the circuitry. This circuitry will then require conversion circuitry to transform the AC signal to a stable DC one which can ultimately be used to charge the 72V battery stack. It would be nice if the group could only output one DC voltage as this would greatly simplify the process; however, the group will have to design a circuit that can output variable levels of voltage and current to the battery stack. The group's desire to create a quick and efficient charge necessitates this more complicated requirement. As a result, it will be imperative to have a way to receive feedback from the battery stack and make a decision based on the temperature, voltage, and or current in the battery. Thus, the charging circuitry will require a way to interface with the microcontroller, which will be reading the appropriate sensors at a given interval, in order to make the correct decisions in a timely manner.

Charging the 72V battery stack is not the only on board device that the group must power. Hybrid's Angels will need to also power onboard electronic circuitry on the motorcycle—LED display, microcontroller, etc. As last year's group experienced some issues with the battery system being heavily taxed by the onboard electronics, it will be worthwhile to discuss adding a separate battery instead of drawing the power from the 72V stack, which serves as the primary source of energy to the motorcycle's motor.

4.2.3 CONTROL SYSTEM

For this project, the control system will be the brains behind the operation. It will be extremely important to write robust, functional code as the microcontroller will have to shoulder many important tasks without user intervention. First, it should be able to process the incoming data from various onboard sensors, which include temperature sensors, voltage sensors, and current sensors. Based on the information that is read into the system, this design must give feedback to the appropriately adjust the DC voltage and or current into the 72V battery stack so that the batteries will charge efficiently. Part of the analysis process will also be auto-starting the generator when the batteries are at a level that does not allow for efficient operation. Besides making decisions, it must inform the user of the state of the vehicle via the LED display. Of course, this design must not only be able to make real time decisions and display them but it also must be able to output formatted data and save it to an external storage for later analysis and use.

4.2.4 MONITORING SYSTEM

4.2.4.1 DATA COLLECTION SUBSYSTEM

The finished product will have a number of sensors at key locations to measure critical data points such as voltages and currents. Some of these are vital for successful real-time operation while others are of more interest in on a historical basis. The data collection subsystem will contain appropriate hardware and software to periodically sample the data from the onboard sensors and record it in an onboard storage device for future retrieval. Both the hardware and software have specific requirements in this subsystem:

Hardware – it must be capable of capturing both analog and digital signals; many of the sensors generate an analog signal between 0 and 5 volts. In addition, it must sample all data inputs quickly to maintain a high sampling rate while not tying up the system resources for extended periods of time. In the same way, the storage scheme must be simple and swift to execute, once again to avoid tying up the system processor during real-time operation. Finally, the subsystem storage capacity needs to be of sufficient size to hold data from a reasonable length ride.

Software – while important, data collection must be a secondary concern to safe and efficient real-time operation. The data collection routines should seamlessly integrate with the critical software functions and should not significantly affect the overall system speed. Wherever possible the system should use standard communication protocols that are easy to understand and debug, such as SPI. Finally, the storage scheme should use the available storage space efficiently while avoiding an extremely complicated methodology.

4.2.4.2 ANALYSIS SUBSYSTEM

Data is not much use until it is transformed into useful information, which is accomplished in the analysis subsystem. Data is transferred from the onboard storage system to a PC where statistical and graphical analysis can take place. There are both hardware and software components to this subsystem:

Hardware – primary component is the physical data link between the microcontroller and the PC. Ideally this will be a wireless data link but a hardware backup will be in place to ensure a reliable connection. The data link will be based on the standard RS-232 protocol

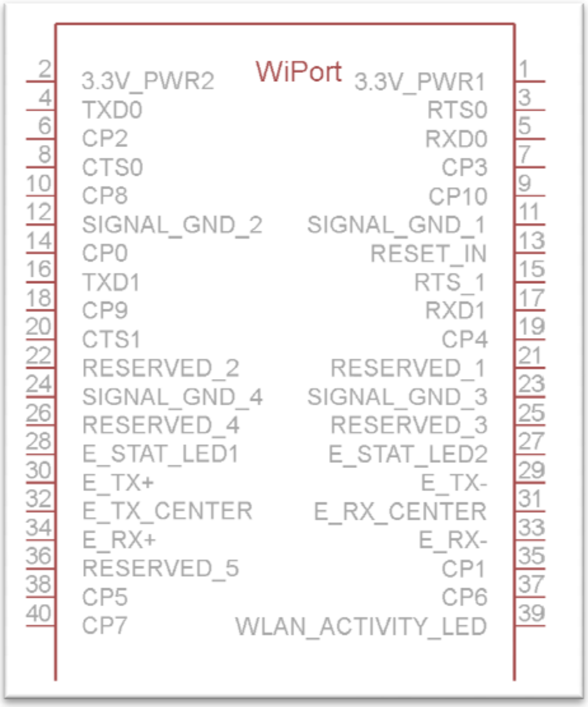
Software – there are two software components to this subsystem. First, on the microcontroller end the software must interface with the storage system and retrieve all the data in an organized fashion and send it through the data link. In addition, the microcontroller software must communicate back and forth with the PC based software to reliably transfer the data. On the PC side the software must capture the incoming data, store it in more permanent hard drive based storage (database) and enable the user to perform statistical and graphical analysis.

4.3 FUTURE ENHANCEMENT REQUIREMENTS

Although of minor importance, the Hybrid's Angels would like to additionally implement a few features to either enhance the safety or mission of the hybrid motorcycle. First and foremost, the group would like to implement a functional headlight, which the user could turn on or off from the control console. To make the design fully street legal, it will also be necessary to install front brakes, a taillight, brake lights, mirrors, and a horn. These devices will require a neat, orderly connection and wiring scheme. Another additional feature would be to digitize the motorcycle's speedometer instead of the analog sensor that is currently present. In order to further enhance the operation safety, the Lightning Riders indicated that it may be useful to create a physical disconnect on the battery stack, allowing for safer maintenance.

In the spirit of energy economy, the group would also like to implement an alternative energy source to power one of the electronic components. Preliminary thoughts on such an implementation would include utilizing solar technology or better harnessing the energy from the existing regenerative braking system. Incorporating an alternative source will be no small challenge; it will require a proper design to achieve the necessary ratings to power the given electronic device as well as a storage scheme when peak conditions are not present.

Last year, team member Steve Govea received a wireless module that simulates an RS232 connection with a computer. Since this part is already present, he intends to implement this part when the group designs its board for the project. Although a nice feature, this part is certainly redundant as the group will already be able to program and download information from the system via a USB to serial converter, which is described below.



5 LOW-LEVEL DESIGN

5.1 GENERATOR

5.1.1 GENERATOR DIAGRAM

The following diagram depicts the generator subsystem:

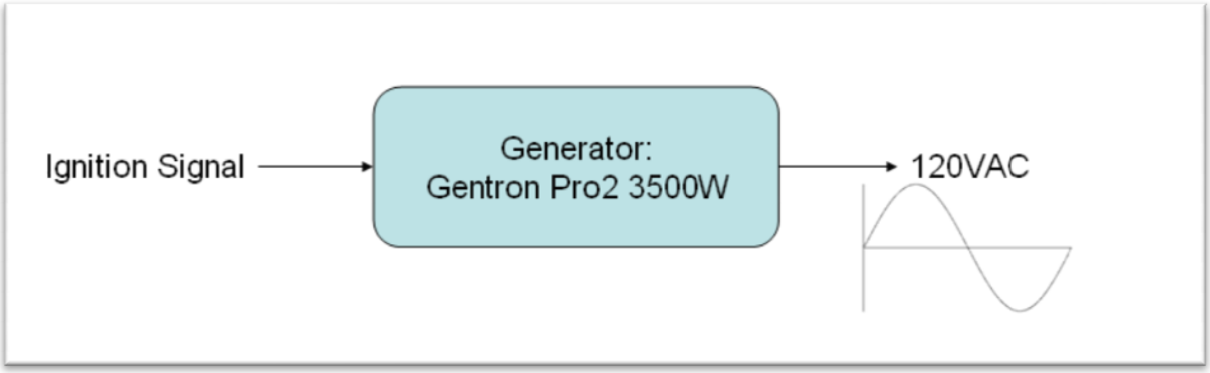


Figure 1: Generator Start Diagram

The generator subsystem is comprised of one input and one output. When the battery voltage is running low, the microcontroller will send a signal to the generator's electric-start to ignite the engine and begin creating power. This power will be the 120VAC output from the generator. The interface between microcontroller and electric-start cannot be determined at this time because it depends on the generator's construction; however, the group believes that the start button will involve contact between two metal leaves. If this is the case, an enhancement-type MOSFET between the leaves and the microcontroller could simply send a voltage to activate the gate when ignition is desired.

5.1.2 GENERATOR SUBSYSTEM MOUNTING

Without having the generator at the group's disposal, it will be very difficult to construct a safe, sturdy mounting design for the generator. Nevertheless, based on mock-ups and studies of the motorcycle, the group believes that they will leave the generator in the metal housing in which it comes, allowing metal to more easily be welded to the frame. In order to secure the generator tightly to the body of the motorcycle, holes will be cut through the seat so that the support bars can reach through. Although the vehicle will no longer be able to support a second passenger, the benefits afforded by increased range and mobility are much more desirable.

5.1.3 GENERATOR TESTING PLAN

Testing of this subsystem will be rather trivial. Initially, the group will fill the generator with fuel and then press the electric start button to verify that it is working. It would be worthwhile to use a voltmeter to confirm that the generator is outputting the expected $120V_{RMS}$. Next, an electric-start to microcontroller interface will be constructed to ensure that a voltage pulse from the microcontroller turns on the generator.

5.2 CHARGING CIRCUITRY

5.2.1 CHARGING CIRCUIT DIAGRAM

This diagram demonstrates the role of the charging circuit:

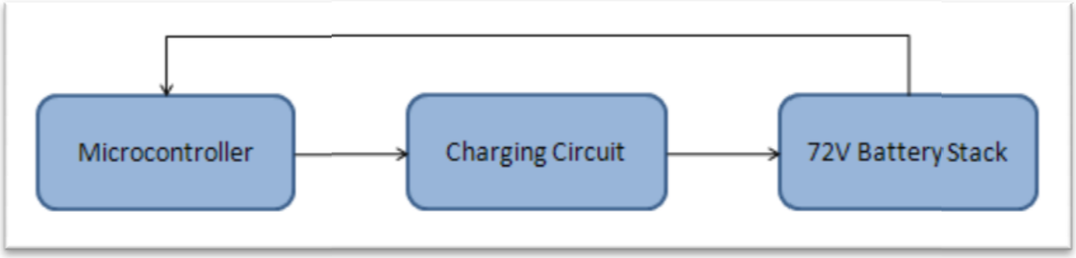


Figure 2: Integration of Charging Circuit in System

The charging circuit itself is manipulated by the microcontroller. The microcontroller will receive real-time data about remaining voltage on the battery stack and continuously adjust the charging circuit to output a voltage that is slightly higher. The batteries charge more quickly when the charging voltage is only a little higher than remaining charge, so this approach will maximize efficiency.

The next diagram represents the composition of the charging circuit itself:

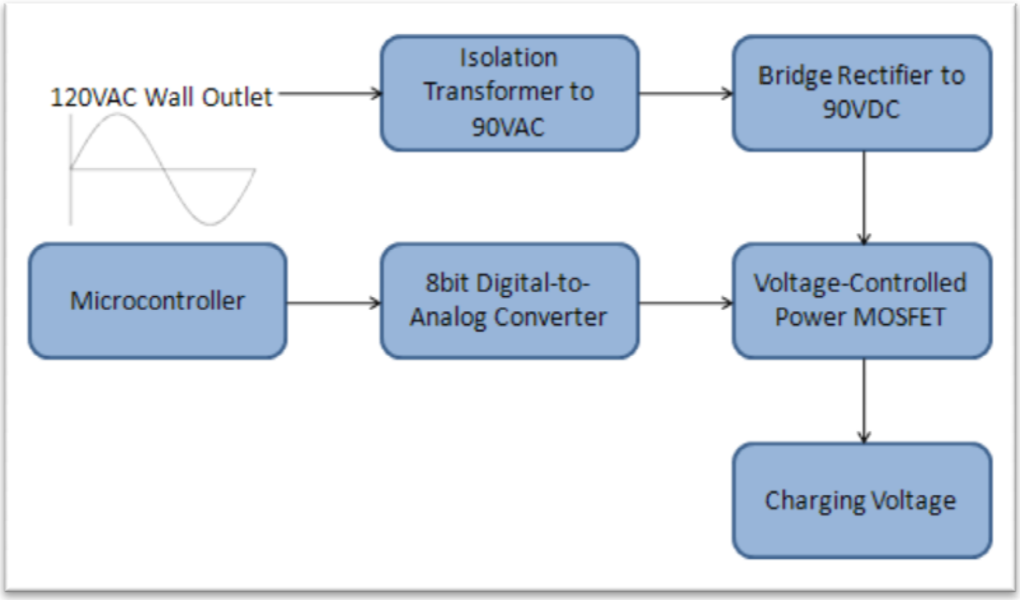


Figure 3: Charging Circuit Composition

The circuit begins with a 120VAC 60Hz signal. An isolation transformer will be used to step this voltage down to 90VPP at which point a full-bridge rectifier will convert the alternating current to direct current. In the meantime, eight output ports from the microcontroller will be dedicated to controlling the amount of voltage that is applied to the batteries. These eight bits will be fed into a digital-to-analog converter to create a variable analog signal; then, this signal will be applied to the gate of a Power MOSFET to adjust the amount of voltage that the batteries receive.

5.2.2 CHARGING CIRCUIT SCHEMATIC

PSPICE was used to design and model our intended circuit. The results are shown here.

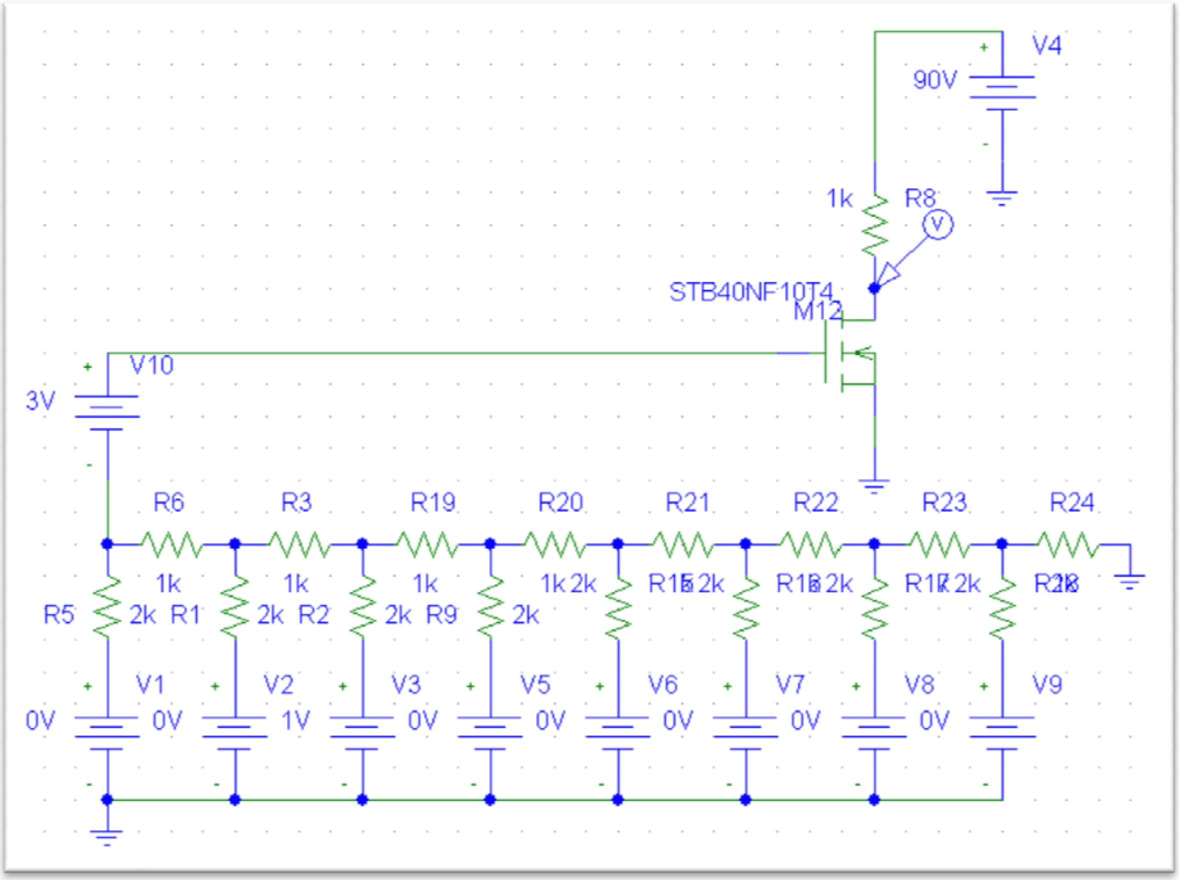


Figure 4: Charging Circuit Schematic

Hybrid's Angels intend to first use voltage regulators to convert the 5V outputs from the microcontroller to 1V outputs. These eight outputs will be fed into an R-2R digital-to-analog converter (DAC) network to create a variable signal between 0V and 1V, symbolized above by the eight sources in the bottom of the schematic. A voltage converter will be used to create a 3V source that the group can place in series with the DAC. Using the manufacturer's PSPICE model of their Power MOSFET, Hybrid's Angels simulated this converter and found that they had the most control over the circuit's output voltage when the gate voltage was between 3V and 3.4V. Using this approach gave a high degree of precision in creating voltages between 3V and 4V. The output voltage of the circuit is at the node on the MOSFET's source.

In order to test the accuracy of the design, the group calculated the voltages that are theoretically possible in the desired range of 3.0V to 3.4V. The following equation was used to determine the accuracy of the R-2R DAC:

$$V_{CNTRL} = V_{REF} \text{ x DECIMAL VAL} / 2^N$$

While this accuracy seems very excessive, PSPICE simulations highly suggested that the group will need a similar level of precision in order to control the MOSFET. In addition, once the range is narrowed down through testing, the group will likely be able to tie some of the pins used for the eight bit control to either VDD (1V) or GND given that they will not be changing in the desired range.

Value:		**V_{REF}:**	**N(# of bits):**	**V_{CNTRL}:**	**V_{OUT} (with 3V addition):**
Binary:	**Decimal:**				
11010	26	1	8	0.101563	3.1015625
11011	27	1	8	0.105469	3.10546875
11100	28	1	8	0.109375	3.109375
11101	29	1	8	0.113281	3.11328125
11110	30	1	8	0.117188	3.1171875
11111	31	1	8	0.121094	3.12109375
100000	32	1	8	0.125	3.125
100001	33	1	8	0.128906	3.12890625
100010	34	1	8	0.132813	3.1328125
100011	35	1	8	0.136719	3.13671875
100100	36	1	8	0.140625	3.140625
100101	37	1	8	0.144531	3.14453125
100110	38	1	8	0.148438	3.1484375
100111	39	1	8	0.152344	3.15234375
101000	40	1	8	0.15625	3.15625
101001	41	1	8	0.160156	3.16015625
101010	42	1	8	0.164063	3.1640625
101011	43	1	8	0.167969	3.16796875
101100	44	1	8	0.171875	3.171875
101101	45	1	8	0.175781	3.17578125
101110	46	1	8	0.179688	3.1796875
101111	47	1	8	0.183594	3.18359375
110000	48	1	8	0.1875	3.1875
110001	49	1	8	0.191406	3.19140625
110010	50	1	8	0.195313	3.1953125
110011	51	1	8	0.199219	3.19921875
110100	52	1	8	0.203125	3.203125
110101	53	1	8	0.207031	3.20703125

Value:		V_{REF}:	N(# of bits):	V_{CNTRL}:	V_{OUT} (with 3V addition):
Binary:	**Decimal:**				
110110	54	1	8	0.210938	3.2109375
110111	55	1	8	0.214844	3.21484375
111000	56	1	8	0.21875	3.21875
111001	57	1	8	0.222656	3.22265625
111010	58	1	8	0.226563	3.2265625
111011	59	1	8	0.230469	3.23046875
111100	60	1	8	0.234375	3.234375
111101	61	1	8	0.238281	3.23828125
111110	62	1	8	0.242188	3.2421875
111111	63	1	8	0.246094	3.24609375
1000000	64	1	8	0.25	3.25
1000001	65	1	8	0.253906	3.25390625
1000010	66	1	8	0.257813	3.2578125
1000011	67	1	8	0.261719	3.26171875
1000100	68	1	8	0.265625	3.265625
1000101	69	1	8	0.269531	3.26953125
1000110	70	1	8	0.273438	3.2734375
1000111	71	1	8	0.277344	3.27734375
1001000	72	1	8	0.28125	3.28125
1001001	73	1	8	0.285156	3.28515625
1001010	74	1	8	0.289063	3.2890625
1001011	75	1	8	0.292969	3.29296875
1001100	76	1	8	0.296875	3.296875
1001101	77	1	8	0.300781	3.30078125

Figure 5: R-2R DAC Output Table

5.2.3 CHARGIN CIRCUIT SOFTWARE

The following is a general outline of the software module that will be used to control the power delivered to the batteries during charging operation:

Routine for Adjusting Charging Circuit

```
start routine
read voltage on battery stack
if voltage < 82V
  mode = constant current mode
elseif 82<battery voltage<90
  mode = constant voltage mode
else
  cut power to battery
end

if mode = constant current mode
```

```
  sense current fed to batteries
  adjust voltage to deliver 15-20A to the batteries
elseif mode = constant voltage
  sense battery voltage
  set battery-charging voltage to 82-90V
  sense current delivered to batteries
end

interrupts if currents are ever over 20A or voltage is ever over 90V

end routine
```

5.2.4 CHARGING CIRCUITRY TESTING PLAN

Testing the charging circuitry will take place as the circuitry is built. First, the group will connect the isolation transformer to a wall outlet and test its output with an oscilloscope. Hopefully, it will read 90VPP at 60Hz. Then, the full-bridge rectifier will be inserted, and an oscilloscope will again be used to verify an output of 90VDC.

Once the group has shown that the setup produces a steady 90V DC output, they will begin building the rest of the circuit. First, they will wire up the R-2R DAC and voltage regulators and test a variety of output combinations from the microcontroller. Then, the outputs of this sub-circuit can be tested very easily with a digital multimeter. Lastly, the Power MOSFET can be installed so one may verify that the circuit can dynamically adjust the 90VDC to appropriate levels with the oscilloscope.

5.3 CONTROL SYSTEM

5.3.1 CONTROL SYSTEM SCHEMATICS

5.3.1.1 POWER SUPPLY SCHEMATIC

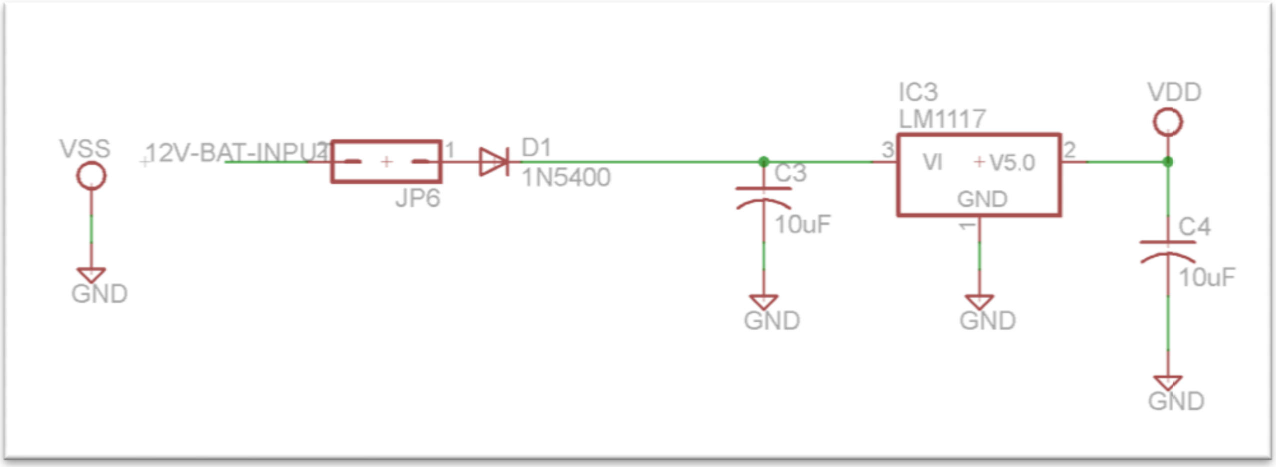


Figure 6: Power Supply Schematic

5.3.1.2 MICROCONTROLLER SCHEMATIC

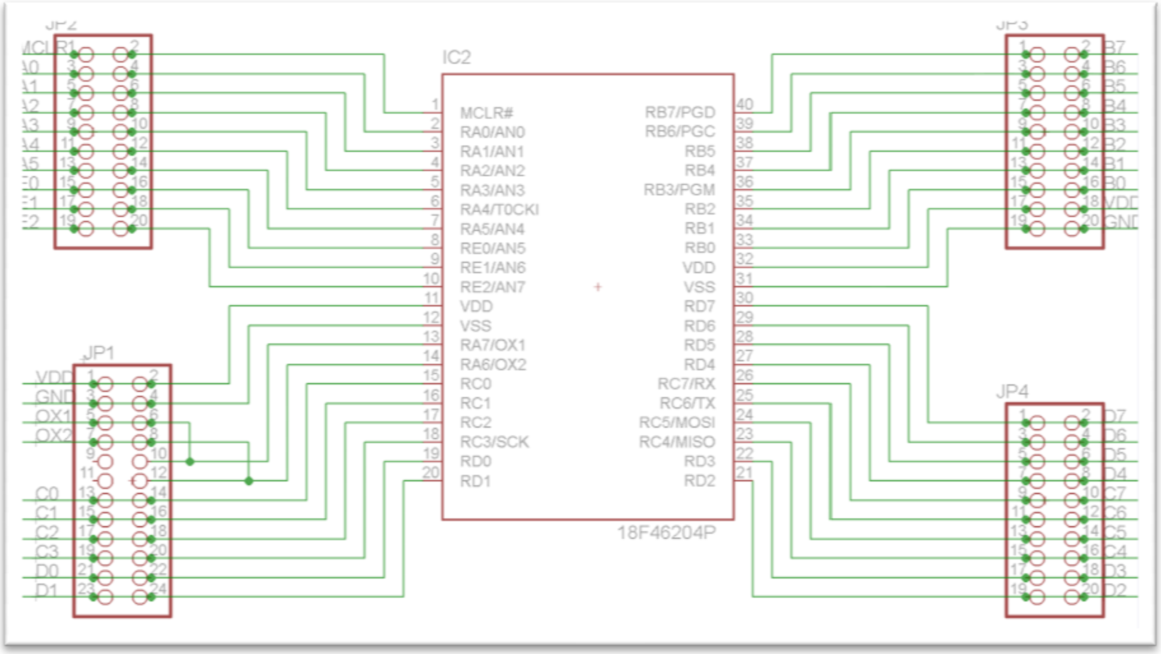


Figure 7: Microcontroller Schematic

5.3.1.3 USB TO SERIAL CONVERTER SCHEMATIC

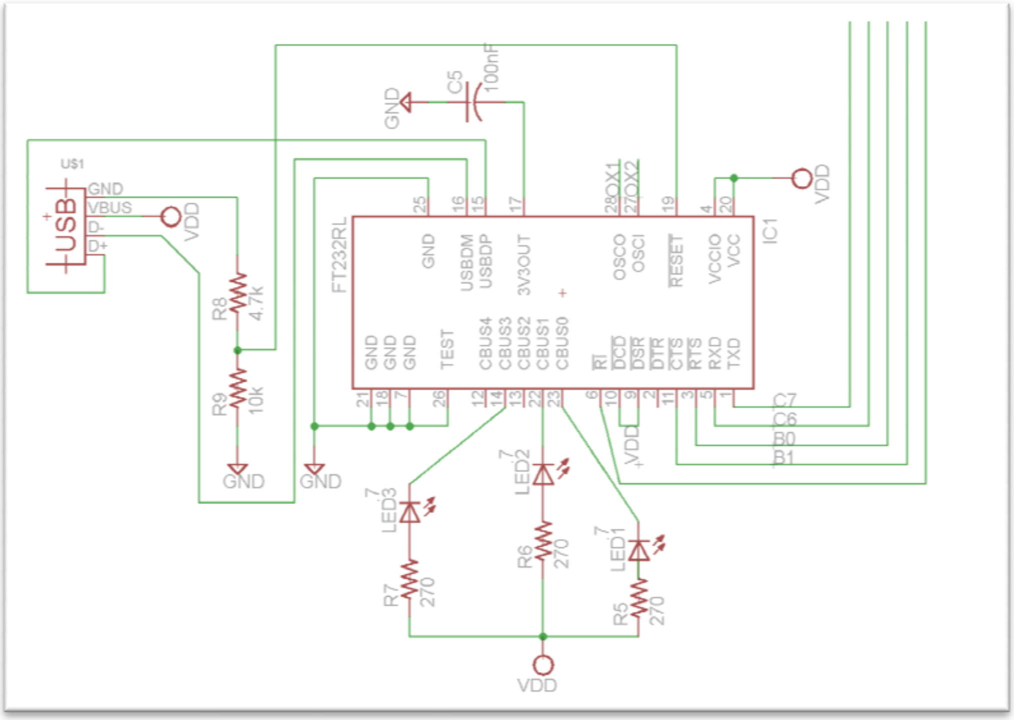


Figure 8: USB to Serial Converter Schematic

5.3.1.4 SENSOR CIRCUITRY SCHEMATIC

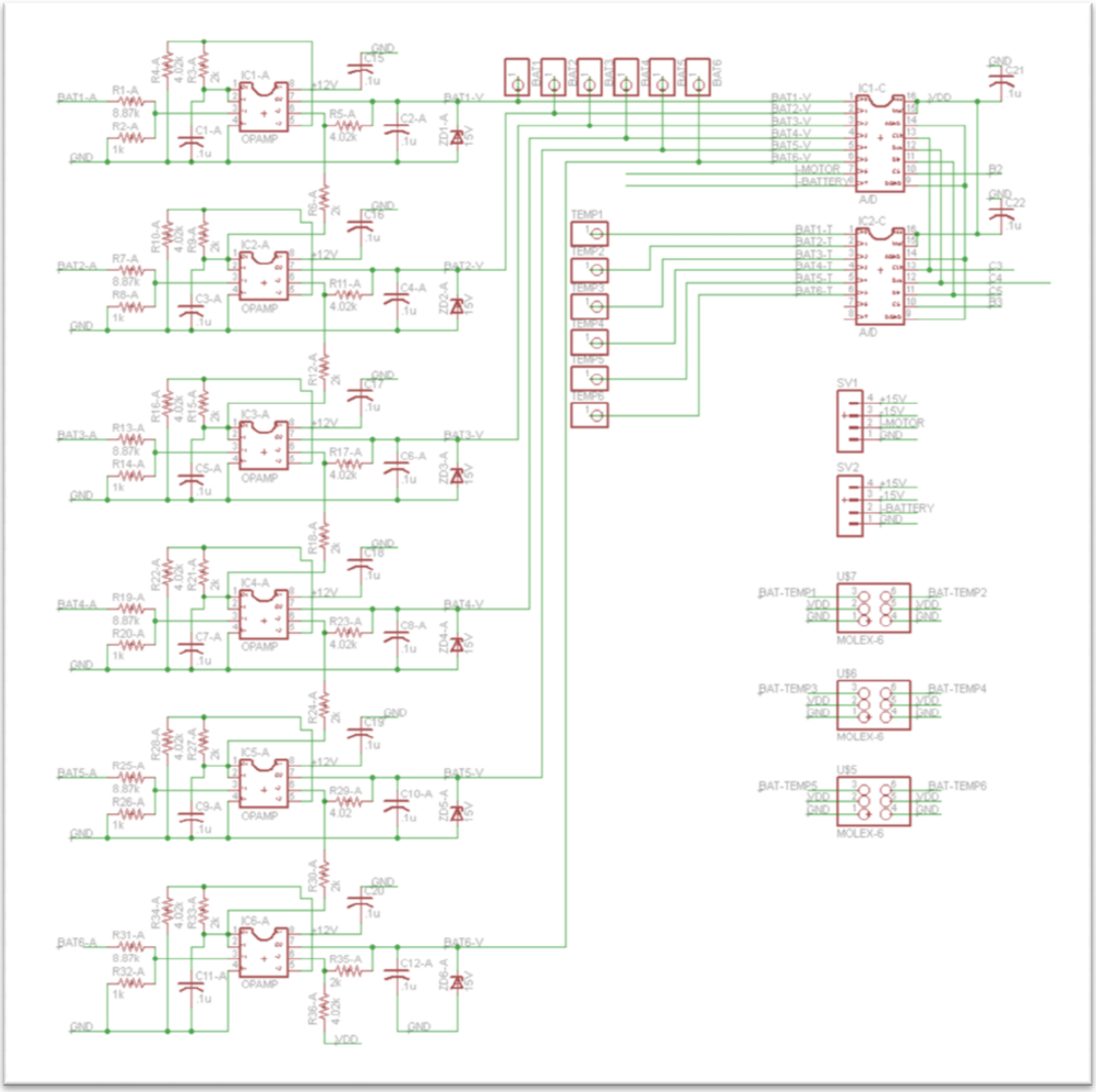


Figure 9: Sensor Circuitry Schematic

5.3.1.5 LCD DISPLAY CONNECTION SCHEMATIC

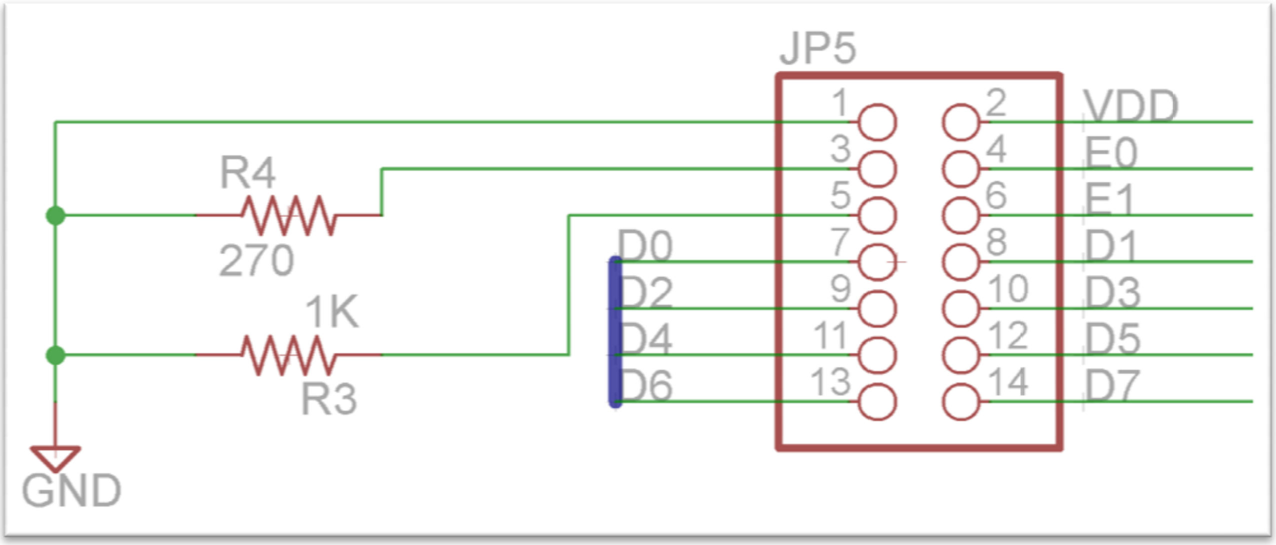


Figure 10: LCD Display Connection Schematic

5.3.2 CONTROL SYSTEM DESCRIPTION

5.3.2.1 POWER SUPPLY

In the previous configuration, the Lightning Riders tapped two batteries in the 72V stack to power the control system circuitry. Naturally, this voltage was stepped down from 24V to more useable levels, such as 12V, 10V, 5V, and 3.3V. As a result, last year's group perceived some irregularities on the overall voltage stack as a result of this technique. Because the current charging circuitry is no longer functional, it would be a hefty task to reconstruct the previous group's circuitry to test the validity of their theory. For better or worse, the group must accept this evaluation as it is. In this light, the Hybrid's Angels have been searching for an alternative technique to power the control circuitry.

At the present stage, the group has opted to purchase a separate 12V battery to power the control circuitry. Because the group will be using their own circuitry design, it was deemed that measuring the power consumed by the Lightning Riders' system would not give an accurate picture regarding the power needs for the circuitry that will be built. First of all, there are various components, which have been included in the schematic, that are not present on the board. Although technically in another subsystem, the charging circuitry would also not be drawing power due to its currently inoperable state. In addition, the LCD display is not functioning on the bike at this moment. In the end, to measure the power consumed by the onboard electronics would have forced the present group to reconstruct the previous design without necessarily providing an accurate insight into the power demands of the overall system.

This area will be one that the group continues to monitor throughout the project. If it is later deemed that the onboard electronics will not require a separate power supply, the group will adjust accordingly.

As can be seen below, the cost of a 12V battery including charging circuitry is rather minor. Ultimately, the group has opted for excess in this prototype just to be safe.

Voltage (V):	Amp-Hours:	Price ($):	Charger:
12	1.2	16.95	Smart Charger (1.0 A) - $15.95

All components in the control system will not be powered at 12V. In fact, most components, such as the microcontroller, the analog to digital converters, and USB to serial converter, will require a 5V input. This voltage will be generated by utilizing the LM1117-5.0 voltage regulator. This device will produce the necessary output to power these devices. Although most devices need 5V to operate, six components will require 12V. These components are the LM392 Comparator/Operational Amplifier chips used to measure the voltage on each of the batteries.

5.3.2.2 MICROCONTROLLER

For this project, space is certainly not a concern, at least not as it has to do with the onboard electronic circuitry. Thus, the group decided to stick with the seeming EE 41430 standard, 18F4620P microcontroller from MicroChip. This microcontroller will provide the group with sufficient speed and port availability to accomplish the goals of this project. Data storage for this device will not be an issue as the group will include a MicroSD chip on the order of a couple gigabytes. Admittedly, the decision to utilize this microcontroller was aided by the presence of eight of these chips left over from the year before.

Selection of the microcontroller is just one portion of the decision making process for the control system. In addition, the group needed to allocate ports on the microcontroller. At this point, this decision making process was performed by meeting functionality and availability. For instance, certain ports on the device are utilized for Serial Peripheral Interface (SPI) communication; whereas others are strictly reserved for VDD or GND. Listed in the table below is a summary of the allocation of microcontroller ports. Please note that these port assignments might ultimately change when it comes time to design the board as location will become a determining factor in the decision making process.

µcontroller pin:	Other End:	Description:
MCLR	Reset Button	Input
A0	#RI	Ring Indicator on USB to Serial
A1	Chip select	Data Storage Chip Select
A2	MOSFET 1	MOSFET Switch
A3	MOSFET 2	MOSFET Switch
A4	MOSFET 3	MOSFET Switch
A5	MOSFET 4	MOSFET Switch
E0	Main LED display	Output
E1	Main LED display	Output

µcontroller pin:	Other End:	Description:
E2		
Vdd	5V	
GND	0V	
OX1/A7	Oscillator/timer	I/O
OX2/A6	Oscillator/timer	I/O
C0	MOSFET	POWER MOSFET
C1		
C2		
C3	SPI CLK	Data storage SPI clock
D0	Main LED display	Output
D1	Main LED display	Output
B7		
B6		
B5		
B4		
B3	Chip select	A/D 2 Chip Select
B2	Chip select	A/D 1 Chip Select
B1	CTS	Control Signals
B0	RTS	Control Signals
Vdd	5V	
GND	0V	
D7	Main LED display	Output
D6	Main LED display	Output
D5	Main LED display	Output
D4	Main LED display	Output
C7	TXD	Serial Output
C6	RXD	Serial Input
C5	Data Input	Data Input (A/D, Storage Card)
C4	Data Output	Data Output (A/D, Storage Card)
D3	Main LED display	Output
D2	Main LED display	Output

In this project, the microcontroller will play a key role in running the entire system. From reading important data values to making decisions for the system, the microcontroller will be at the heart of this project. To make sure that the microcontroller knows what to do in a given situation, it is of paramount importance to have intelligent, yet robust code to allow the system to function as quickly, efficiently, safely, and effectively as possible.

In the subsequent pages, pseudo-code is given as intelligibly as possible at this time. Whenever the bike is appropriately powered, this code will run on the microcontroller to check the status of the system. Checking the system includes constantly ensuring that voltages, currents, and temperatures remain at proper levels on each of the motorcycle's subsystems. If these values fall outside the specified constraints, the microcontroller is instructed to take action until the system properly stabilizes. High priority interrupts will be written to control the power to the generator and enter an "emergency off" stage via dashboard switches. Of course, the microcontroller will further be responsible for storing important system variables and providing system information to the LCD screen via low priority interrupts.

Pseudo-code:

```
Reset all variables and change the status of the generator in memory to "OFF".

Check the status of the generator switch.

    • If it is in the ON position
        o Alert the user and ask him to turn the switch off
    • If it is in the OFF position
        o Do nothing

While (running) loop {

Check voltage on batteries by reading the values in from the analog to digital converter and adjusting the values accordingly. In other words, take the value of 0V to 2.5V from the analog to digital converter and translate it into a proportional value from 0V to 12V.

    • If the voltage on any battery is less than 3V,
        o If the generator is OFF,
            ▪ Turn the generator ON
            ▪ Change the status of the generator in memory
            ▪ Alert the user via the LCD screen that the generator has been turned on
        o Else if the generator is ON,
            ▪ Do nothing
    • Else if the voltage on any of the batteries is between 3 and 5V.
        o If the generator is OFF,
            ▪ Alert the user via the LCD screen of the low battery power and suggest they turn on the generator
        o Else if the generator is ON,
            ▪ Do nothing
    • Else (voltage is above 5V)
        o Do nothing
```

Check Temperature on Batteries by reading the values output by the digital to analog converter. Once again, these values will have to be appropriately translated into a temperature based on the voltage present.

- If the temperature on one of the batteries is above 30°C,
    - Display the temperature and the battery number to the user on the LCD screen
    - If the batteries are in the process of charging,
        - Step down the current going to the batteries.
    - Else
        - Do nothing
- If the temperature on the batteries is at a normal level ,
    - Calculate the average temperature of the batteries.
    - Display it on the LCD screen.

}

Record DataLow Priority Interrupt********

Every minute, trigger the interrupt

Store in memory

    Temperature of each battery

    Voltage of each battery

****

Update LCD ScreenLow Priority Interrupt***

Every tenth of a second, trigger the interrupt

Update the screen

    Average temperature

    Voltage left on batteries in user-friendly manner

    Status of generator

****

Generator SwitchHigh Priority Interrupt***

(The generator will start off when the bike turns on, and we will ask the user to turn the generator switch to the OFF position)

Trigger the interrupt when the switch changes positions

- If the switch is turned ON
    - Start the generator
    - Change the status of the generator in memory to ON
- If the switch is turned OFF
    - Turn off the generator
    - Change the status of the generator in memory to OFF

****

EMOHigh Priority Interrupt***

Trigger the interrupt when the EMO switch turns off.

Turn off the generator

If it is charging, cut power input to the batteries

Cut power to the control circuit

****

5.3.2.3 USB TO SERIAL CONVERTER

A USB to serial converter, the FT232RL from FTDI chip, is included in the group's design of the control system circuitry. This device will provide a valuable interface to not only program the microcontroller but also download data from the device. Although one of the future enhancements, staunchly proposed by team member Stephen Govea, will be to install a wireless interface to download data, and even program the microcontroller, the USB to serial converter will provide a simple, yet powerful way to interact with the microcontroller in case the wireless connection does not come to fruition.

5.3.2.4 VOLTAGE SENSOR CIRCUITRY

Measuring the voltage on each of the batteries in the 72V stack is of obvious importance for the charging circuitry react properly to the change in state of the batteries. Thus, the voltage on each of the batteries, as well as the entire stack, must readily be available to both protect and enhance the charging circuitry as much as possible. To accomplish this objective, the group decided to utilize the method that the Lightning Riders used last year with some minor alterations to correct perceived problems with the design.

Ultimately, this design will render a voltage between 0V and approximately 2.5V corresponding to the charge level on the specific battery. This method will provide a voltage, which can safely be translated to the microcontroller via the analog to digital converter circuitry described below. Then, the microcontroller can work backwards to determine the true voltage on each of the batteries in the stack. With this information, the microcontroller will be able to inform the user of the charge state as well as make the necessary alterations to the voltage level (and current level) being output by the charging circuitry.

Naturally, calibration will be an important element in this process; however, due to the proportionality of the constructed system, this calibration should be easily tested and accomplished. Such a process will be generally outlined in the "Control System Testing Plan" below.

Each battery's high voltage terminal is fed into the control system circuitry and stepped down to approximately one tenth of its initial value. This voltage is fed into a comparator, whereby it is compared with its previous value, allowing it to be amplified to that voltage at any given time. This voltage is once again stepped down to roughly two thirds of its value and fed into an operational amplifier. Configuring the operational amplifier in a non-inverting configuration allows for the voltage to be solved as a value between 0V and 2.5V.

Additional features of the voltage sensor circuitry include decoupling capacitors to better stabilize the important voltages that are fed into the operational amplifiers as well as a Zener diode to help protect the system from short circuits.

5.3.2.5 TEMPERATURE SENSOR CIRCUITRY

Temperature sensor circuitry will be implemented in the same fashion as the Lightning Riders began to do. At present, the motorcycle has temperature sensors mounted on five of the six batteries. As with the voltage sensors, these devices will have to be calibrated accordingly, and this process will be outlined in a subsequent section.

As five of the six sensors are already mounted, the group will naturally stick with the same technology chosen by last year's group, the LM35DT. This sensor will continued to be constructed in the basic configuration outlined in the manufacturer's data sheet and shown below. This configuration will allow for temperatures to be measured from 2°C to 150°C. This range should be more than sufficient for the temperatures that will likely occur in the battery.

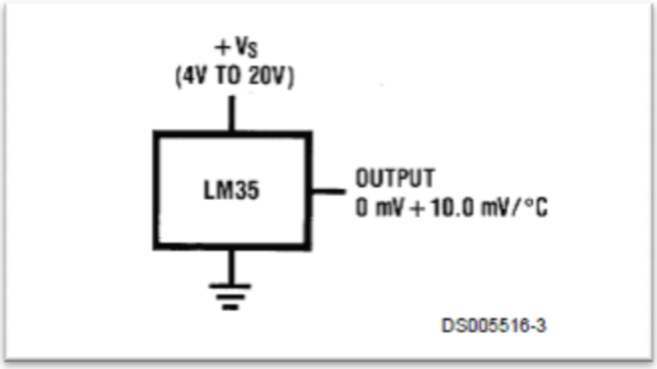
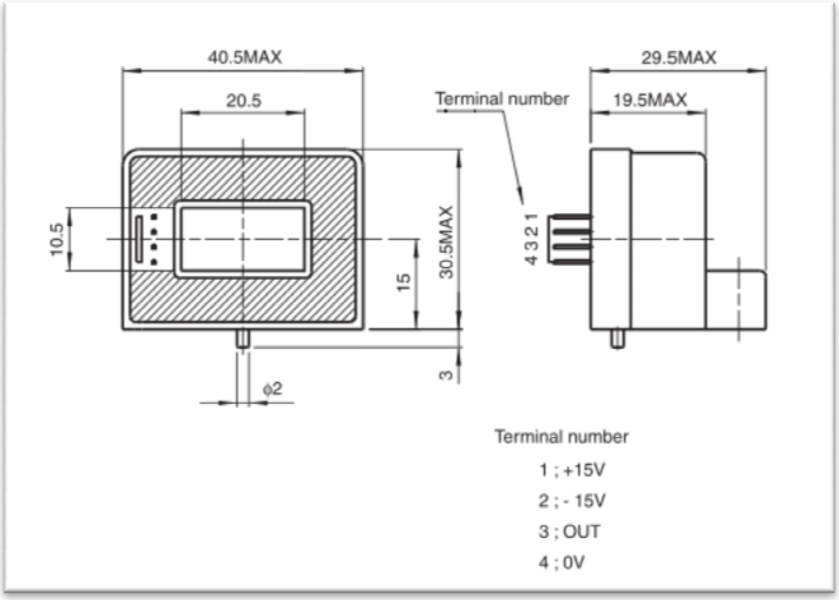


Figure 11: Temperature Sensor Configuration

It can also be seen in the diagram above that the output voltage is proportional to 10mV per degree Centigrade. This output voltage will be fed into an analog to digital converter, which will pass the voltage on to the microcontroller. At this point, the microcontroller can both inform the user of the temperature on the batteries as well as make decisions to remedy a high temperature if necessary.

5.3.2.6 CURRENT SENSOR CIRCUITRY

In order to calculate the power consumption of the system and safely charge the batteries, current sensors need to be installed on the bike. Hybrid's Angles plan to install the two, hall-effect current sensors, Tamura L03S300D15, that the Lightening Riders purchased last year. These sensors are rated for 300A with an accuracy of ±3A. One current sensor will be located between the batteries and the motor in order to measure the current drawn to power the bike. The other current sensor will be located between the charging circuitry and the batteries. This sensor will provide useful information to the microcontroller, enabling it to regulate the current flow into the battery pack.



Terminal number
1 ; +15V
2 ; - 15V
3 ; OUT
4 ; 0V

Figure 12: Current Sensor Layout

Since these devices are hall-effect current sensors, they do not need to be electrically connected to the wires they are monitoring. Rather, the wire will slip through the hole in the center of the sensor so that the sensor does not interfere with the current it is measuring. There are four terminals on each current sensor that must be connected to the control circuitry. They require +15V and -15V supply voltages as well as a ground terminal. The remaining pin will output a DC voltage around 4V to the microcontroller corresponding to the current it is measuring.

As soon as the group found that this device required both +15V and -15V, they realized that this posed a substantial engineering challenge. Although using a separate battery source, this source only produces 12V to power the board; whereas, this device essentially needs 30V. Since the battery that powers the electronics will not suffice, the group will naturally turn to drawing power from the 72V stack and using two voltage regulators to achieve +15V and -15V.

According to the specifications of the selected voltage regulator, LM3480-15, the regulator will need at least 17V to produce the necessary output. At first glance, one would think that the group could connect the two voltage regulators in parallel, with one connected to a voltage inverter chip (so that -15V could also be achieved), across two of the six batteries in the voltage stack. Unfortunately, this method will only help so long as the voltage on the two batteries remains above 8.5V on each battery. Seeing as the current sensors are very important for the operation of the charging circuitry, this method would be unacceptable as the current sensors would not function when the batteries had less than two-thirds charge. At the same time, the current sensors cannot take an input greater than 35V, which would not allow for three batteries to be connected in series—albeit the same problem would eventually arise with this configuration.

To solve this problem, the group will need a very creative solution, and the Hybrid's Angels believe that they have just this solution. To begin, the voltage regulators will be connected in parallel across two batteries in the voltage stack. One of these voltage regulators will be attached to an inverter chip to produce the necessary -15V for the current sensor. As the voltage on these batteries decreases to roughly two thirds of its initial value, or approximately the minimum voltage needed by the regulator, the devices will switch so that the regulators (and inverter chip) will be connected across a third battery. Thus, approximately 24V will be input into the terminals of the voltage regulator from three batteries in the stack. Naturally, this method will allow it to output the necessary voltage to the current sensor. Still, this configuration of three batteries will lead to the same problem at the previous one. Take for example when the voltage across the three batteries falls to half its maximal charge, or again approximately the minimum voltage needed by the regulator. Once again, the group plans to connect the fourth battery across the terminals of the voltage regulator, theoretically producing a voltage of 24V. This process would continue until it was necessary to connect all of the batteries in the stack. At this point, the system has already been programmed to turn the generator on automatically to charge the batteries since they are critically low. Therefore, the current sensors would work for all voltages in which the motorcycle would possibly be running at.

Although theoretically a creative solution, this method still needs to be implemented for the process to work properly. To achieve this goal, the group would essentially be using MOSFETs that would act as switches to connect an additional battery to power the voltage regulator as needed. Since the microcontroller already possesses the voltage information on each of the batteries, the microcontroller will need to give a signal to the gate of the MOSFET to turn it on and to connect the batteries at the appropriate time so that the minimum voltage on the regulator is always achieved.

In addition, the group will use operational amplifiers to function as high impedance devices so that this portion of the circuit does not require an inordinate amount of current as the sensors need only roughly 12mA to run properly. Below is a rough design of how the group envisions the circuit working.

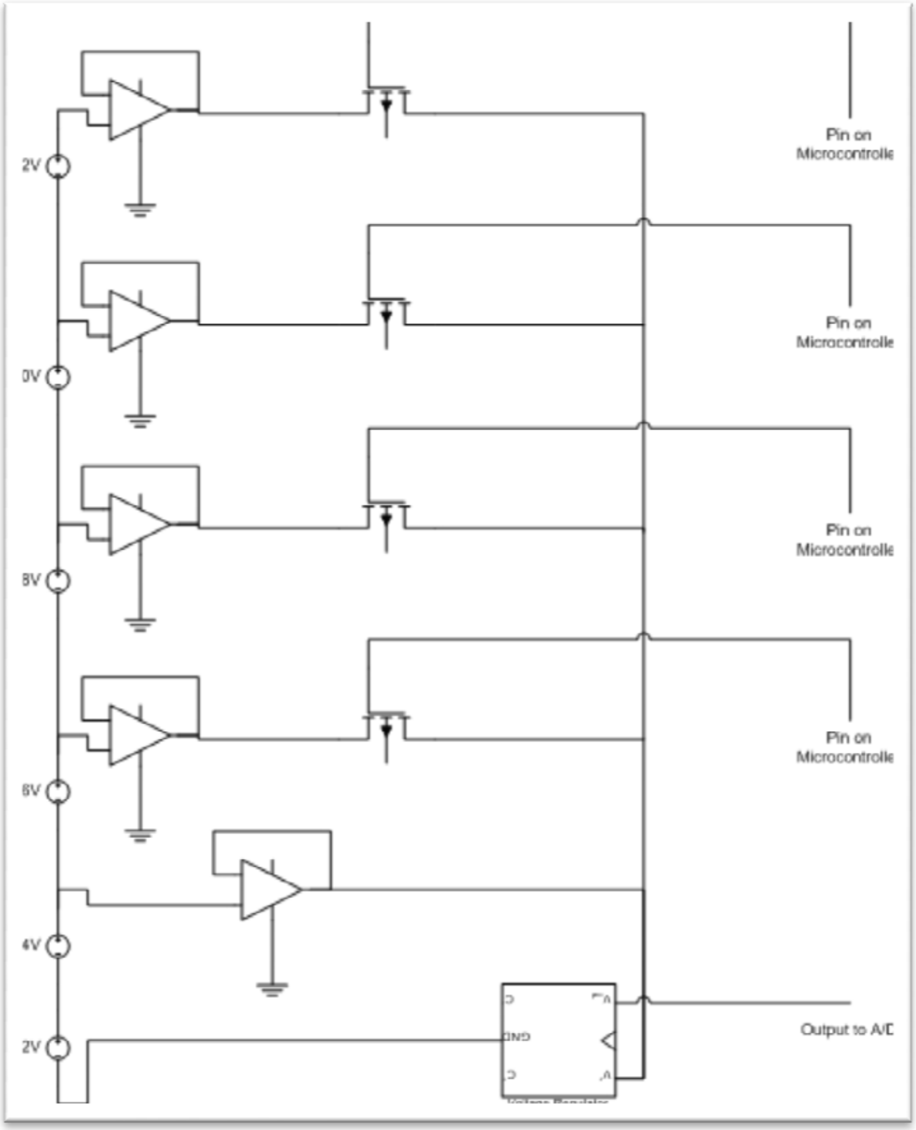


Figure 13: Voltage Regulator Powering Schematic

5.3.2.7 ANALOG TO DIGITAL CONVERSION OF SIGNALS

Proper analog to digital conversion will be essential for the microcontroller to properly receive feedback regarding currents, voltages, and temperatures that various components of the system may be expecting. Once again, the group will utilize the analog to digital converters purchased by the Lightning Riders.

These analog to digital converters, which are part number MCP3208, have eight channels which interface with the microcontroller via SPI. Basically, the microcontroller will select one of the eight channels on the analog to digital converter and the device will output the voltage on that channel in binary. This output value will be based on the following digital output code:

$$\text{Digital Output Code} = \frac{4096 \times V_{IN}}{V_{REF}}$$

Where:

V_{IN} = analog input voltage

V_{REF} = reference voltage

Figure 14: Digital Output Code for Analog to Digital Converter

Since the reference voltage is 5V, a temperature sensor outputting a voltage of 0.5V would likely send the following binary values to the microcontroller: 110011010, corresponding to 410. This value would allow the microcontroller to know that the temperature sensor is measuring a temperature of 50^{o}C.

Obviously, each analog to digital converter will require its own distinct chip select port on the microcontroller. By periodically cycling through all of the channels, the microcontroller will be able to read critical information from the system's sensors and process decisions accordingly.

To increase the accuracy of the device, a decoupling capacitor is included on the reference voltage. This decoupling capacitor will stabilize the reference voltage lending to better accuracy in the overall system.

5.3.2.8 LCD USER INTERFACE

The LCD user interface plays a very important role in the control system, as it is the means by which the microcontroller can communicate intelligibly with the rider of the motorcycle. It will be the source of important information on the cycle such as warnings, critical errors, and general information. In a noncritical state, the LCD should display information regarding the state of charge on the batteries as well as the expected distance that this charge will provide the rider. This screen should also display information regarding the status of the generator as well as any other important notices the user should be aware of. Upon flipping a switch, the LCD display should switch to display information regarding the temperature on the batteries as well as the power being drawn from the motor, the batteries, and the generator.

5.3.3 CONTROL SYSTEM TESTING PLAN

5.3.3.1 MICROCONTROLLER

The microcontroller will first be tested by applying power to the control board. The supply voltages and ground contacts will then be tested through the use of a digital multimeter. When these contacts are proven functional, the microcontroller will be programmed through the USB to serial converter.

The output pins will be tested by setting them all to ground and then to 5V. The voltages of the output pins will be read at each setting through the use of a voltmeter. Testing the input pins requires slightly more complex code. The microcontroller will be programmed to output a high signal when any of the input pins receives a high signal. This output pin will be monitored while 5V is applied to each input pin, one by one, to verify their functionality.

5.3.3.2 USB TO SERIAL CONVERTER

To test the USB to serial converter, the group will program the microcontroller using the USB port. If the programming process is successful, then the converter is functional. If the programming process does not work, then the logic analyzer will be used to troubleshoot the system.

5.3.3.3 VOLTAGE SENSORS

The voltage sensors can be tested by applying a known voltage across the terminals of the sensor and measuring the sensor's output voltage. A multimeter will be used to measure the voltages at different nodes along the resistive network if any problems occur. The output voltage and the known input voltage then can be used to calibrate the voltage sensors.

5.3.3.4 TEMPERATURE SENSORS

In order to test the temperature sensors, a previously calibrated thermometer will be held next to the temperature sensors on the batteries. First, the output of temperature sensor will be calibrated at room temperature by comparing it to a thermometer. Once this calibration has been achieved, the temperature sensor will be tested during the charging process. Upon these two calibrations, the temperature sensor should be sufficiently accurate.

5.3.3.5 CURRENT SENSORS

In order to test the current sensors, a digital multimeter will be used to verify the current in a test wire. The wire will then be threaded through the center of a current sensor with the proper supply voltages. The output voltage will then be monitored and the current sensor can be calibrated accordingly.

5.3.3.6 ANALOG TO DIGITAL CONVERSIONS

To test the analog to digital converter, an analog signal will be applied to the input and the logic analyzer will be used to measure the output signal. As the analog input is changed, the digital output should change as well. This device will also be tested in reverse. A digital signal will be applied to the input and the analog output will be verified using an oscilloscope.

5.3.3.7 LCD INTERFACE

To test the LCD screen the microcontroller will be programmed to output a script to the screen. Thanks to the supplies left by the Lightning Riders, the group has two LCD screens that can be used to test this process. If neither screen displays the script, then the logic analyzer will be used to test the signals of the LCD pins on the control board.

5.4 MONITORING SYSTEM

5.4.1 DATA COLLECTION

This subsystem enables two key functional tasks: real-time and historical analysis of critical variables. Applicable sensor outputs need to be captured in order to make accurate real-time decisions and to allow for future historical performance analysis.

Hardware: Since the group will be capturing both analog and digital signals, there are a number of readily available A/D converters that can be used for this subsystem. Many of these use the standard SPI protocol and are very simple in addition to being very fast. Hybrid's Angels will use a number of these to accomplish the initial data capture tasks for this subsystem. Once the data is transferred to the microcontroller, it can then be stored for future use. A number of memory products are available that also use the simple SPI protocol for information transfer. The group will use a microSD device (one that uses SPI) for our embedded data storage needs. 1GB memory cards are available for $10 for these devices which should provide plenty of storage for our needs. The SPI protocol can be run at relatively high speeds so should not present a delay issue for program execution.

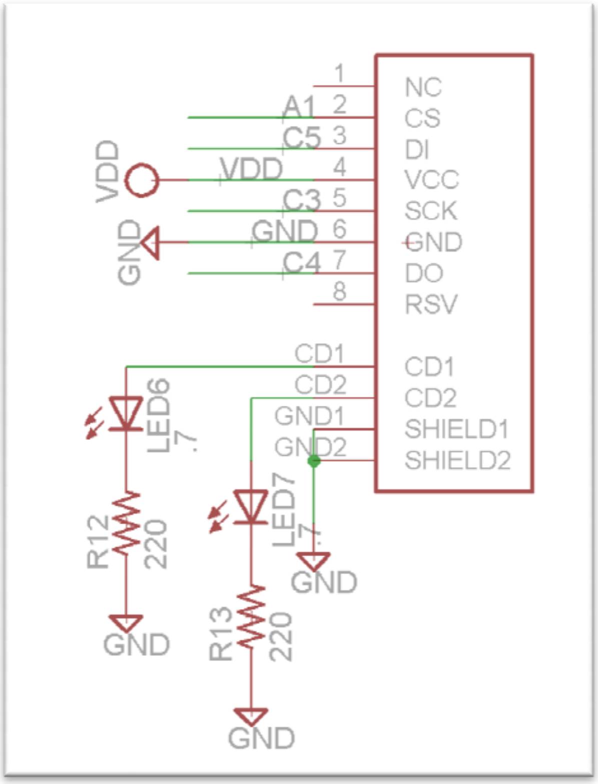


Figure 15: Data Storage Schematic

Software: The real-time analysis will take place within some sort of looping scheme where all relevant sensors are checked on a periodic basis. As a final step within this loop, the critical variable values can then be sent to the embedded memory device and stored for future use.

5.4.2 DATA ANALYSIS

This subsystem will enable historical data analysis in a PC environment. It includes not only the hardware connections between the microcontroller and the PC, but also the software that must run in both environments.

Hardware: There will be two possible data links between the embedded microcontroller and a PC. The primary connection will be enabled through a Lantronix WiPort device; this device converts serial communications through 802.11 b/g. By using software provided by the OEM it allows a PC to treat the microcontroller as though it was connected directly to a physical serial port. A secondary backup connection will be in place that utilizes a standard RS-232 set of hardware. In either case, the PC will interact with the microcontroller through an RS-232 interface.

Software: There are two components to the software required for this subsystem: one part in the microcontroller that retrieves the data stored in the embedded storage device, then transmitting this data to the connected PC and another part in the PC that receives this data, stores it in a more permanent fashion, and analyzes it.

Interaction between the two systems will be accomplished in the following way: when the user is ready to download information to the PC, he will start the PC based program and use the motorcycle's UI to put it into a "Download" mode. This mode will cause the microcontroller to pulse a message over the serial interface, essentially a "Hello" signal to the PC. The PC will listen for this signal from the PIC; if the signal is detected, the PC will send back a "I'm here" message to the PIC. The PIC acknowledges the presence of the PC and data transfer can commence. A set sequence of bits will signal the PC that the transmission is complete. In the event that the PC does not respond to the PIC's 'Hello' signal, the PIC will only try to communicate for a set number of com pulses before timing out.

On the PC side, there are some other software components in addition to the functionality already described. The PC software will be written using the Microsoft Visual Basic .Net programming language. Microsoft offers a free version of Visual Studio for Visual Basic .Net for students so this is readily available. In addition, long-term data storage will be accomplished using Microsoft SQL Server Express, again provided free for students. Between these two programs, a user interface and data storage scheme will be devised. When the PC program starts, the user will be presented with a menu of possible actions, including data capture and data analysis. Visual Basic .Net contains a number of powerful tools for creating a UI and host program while SQL Server Express offers advanced analytical tools for analyzing the captured data.

5.4.3 TESTING PLAN

Overall integration testing should not prove overly complicated between these subsystems. The hardware components can be tested using a number of simple exercises. The storage can be tested using a simple PIC program that writes known values into the storage device, retrieves these values, and presents the results on the LCD screen. The data link between the PIC and the PC can be tested using HyperTerminal and simple PIC programs that either capture incoming data from the PC or present it on the LCD. It can also be tested using programs that generate known characters, observing the results in HyperTerminal. The analytical and data storage components on the PC end are readily tested by generating fake data with known statistical values, uploading it into the database, and using the crafted tools to analyze it. Furthermore, 'fake' data can be stored in the embedded storage device, then extracted and sent to the PC as a further functionality test.

6 PRELIMINARY BILL OF MATERIALS

6.1 GENERATOR

Part:	Description:
GENTRON PRO2 - 3500W	3500W Generator with push button start

Figure 16: Preliminary Bill of Materials for Generator Subsystem

6.2 CHARGING CIRCUITRY

Part Number	Description	Quantity
APTDF30H601G	Diode Full Bridge Power Module	1
LP2983	Voltage regulator (to 1V)	8
ISL9000	Voltage regulator (to 3V)	1
753 Series	1k Resistor Array (9 total)	1
MNR18	2k Resistor (8 total)	1
STB40NF10T4	Power MOSFET	1
Custom	Isolation Transformer (actransformer.com)	1

Figure 17: Preliminary Bill of Materials for Charging Circuitry Subsystem

6.3 CONTROL SYSTEM

Part:	Value:	Device:	Package:	Description:
JP6		JP1Q		Pin Header
D1		1N5400	DO201-15	Diode
C4	10uF	CPOL-USE2-5	E2-5	Capacitor, American symbol
IC3	5V	LM1117-5.0	TO-220	Voltage Regulator
C6	1mF	C-USO50-025X075	C050-025X075	Capacitor, American symbol
C7	1mF	C-USO50-025X075	C050-025X075	Capacitor, American symbol
C8	1mF	C-USO50-025X075	C050-025X075	Capacitor, American symbol
C9	1mF	C-USO50-025X075	C050-025X075	Capacitor, American symbol
C10	1mF	C-USO50-025X075	C050-025X075	Capacitor, American symbol
S1		DT	PBSWITCH	ITT Switch
R1	100	R-US_0207/7	0207/7	Resistor, American symbol
R2	1000	R-US_0207/7	0207/7	Resistor, American symbol
JP2		PINHD-2X10	2X10	Pin Header
JP1		PINHD-2X12	2X12	Pin Header
JP5		PINHD-2X7	2X07	Pin Header
R4	270	R-US_0207/7	0207/7	Resistor, American symbol
R3	1000	R-US_0207/7	0207/7	Resistor, American symbol
Q2	10MHz	CrystalHC49U-V	HC49U-V	Crystal Resonator
C1	22pF	C-US075-032X103	C075-032X103	Capacitor, American symbol
C2	22pF	C-US075-032X103	C075-032X103	Capacitor, American symbol
IC2		18F46204P	DIL40	Microcontroller
JP3		PINHD-2X10	2X10	Pin Header
JP4		PINHD-2X10	2X10	Pin Header
U$3		USD-SOCKETUSD	LCP,UL 94V-0	Data Storage with SPI Interface
LED4		LEDCHIPLED_0805	0805/	LED
LED5		LEDCHIPLED_0805	0805/	LED
R10	220	R-US_0207/7	0207/7	Resistor, American symbol
R11	220	R-US_0207/7	0207/7	Resistor, American symbol
U$1		151-1083-ND		USB Series B Connector
C12	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
C14	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
C13	4.7uF	C-US025-024X044	C025-024X044	Capacitor, American symbol
R8	4.7k	R-US_0207/7	0207/7	Resistor, American symbol
R9	10000	R-US_0207/7	0207/7	Resistor, American symbol
C5	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
LED3		LEDCHIPLED_0805	0805/	LED
LED2		LEDCHIPLED_0805	0805/	LED

Part:	Value:	Device:	Package:	Description:
LED1		LEDCHIPLED_0805	0805/	LED
R7	270	R-US_0207/7	0207/7	Resistor, American symbol
R6	270	R-US_0207/7	0207/7	Resistor, American symbol
R5	270	R-US_0207/7	0207/7	Resistor, American symbol
IC1		FT232RL	SSOP-28	USB to Serial Converter
R1-A	8870	R-US_0207/10	0207/10	Resistor, American symbol
R2-A	1000	R-US_0207/10	0207/10	Resistor, American symbol
R3-A	2000	R-US_0207/10	0207/10	Resistor, American symbol
R4-A	4020	R-US_0207/10	0207/10	Resistor, American symbol
C1-A	100nF	C-US025-024X044	C025-024X044	LED
IC1-A		LM392	DIP8	Comparator/OPAmp
R5-A	4020	R-US_0207/10	0207/10	Resistor, American symbol
R6-A	2000	R-US_0207/10	0207/10	Resistor, American symbol
C2-A	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
ZD1-A	15V	1N4728	Tape and Reel	Zener Diode
C15	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
R7-A	8870	R-US_0207/10	0207/10	Resistor, American symbol
R8-A	1000	R-US_0207/10	0207/10	Resistor, American symbol
R9-A	2000	R-US_0207/10	0207/10	Resistor, American symbol
R10-A	4020	R-US_0207/10	0207/10	Resistor, American symbol
C3-A	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
IC2-A		LM392	DIP8	Comparator/OPAmp
C16	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
R11-A	4020	R-US_0207/10	0207/10	Resistor, American symbol
R12-A	2000	R-US_0207/10	0207/10	Resistor, American symbol
C4-A	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
ZD2-A	15V	1N4728	Tape and Reel	Zener Diode
R13-A	8870	R-US_0207/10	0207/10	Resistor, American symbol
R14-A	1000	R-US_0207/10	0207/10	Resistor, American symbol
R16-A	4020	R-US_0207/10	0207/10	Resistor, American symbol
R15-A	2000	R-US_0207/10	0207/10	Resistor, American symbol
C5-A	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
IC3-A		LM392	DIP8	Comparator/OPAmp
C17	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
C6-A	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
R17-A	4020	R-US_0207/10	0207/10	Resistor, American symbol
R18-A	2000	R-US_0207/10	0207/10	Resistor, American symbol
ZD3-A	15V	1N4728	Tape and Reel	Zener Diode

Part:	Value:	Device:	Package:	Description:
C18	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
ZD4-A	15V	1N4728	Tape and Reel	Zener Diode
C8-A	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
R24-A	2000	R-US_0207/10	0207/10	Resistor, American symbol
R23-A	4020	R-US_0207/10	0207/10	Resistor, American symbol
R21-A	2000	R-US_0207/10	0207/10	Resistor, American symbol
R22-A	4020	R-US_0207/10	0207/10	Resistor, American symbol
C7-A	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
R19-A	8870	R-US_0207/10	0207/10	Resistor, American symbol
R20-A	1000	R-US_0207/10	0207/10	Resistor, American symbol
IC4-A		LM392	DIP8	Comparator/OPAmp
R25-A	8870	R-US_0207/10	0207/10	Resistor, American symbol
R26-A	1000	R-US_0207/10	0207/10	Resistor, American symbol
R28-A	4020	R-US_0207/10	0207/10	Resistor, American symbol
R27-A	2000	R-US_0207/10	0207/10	Resistor, American symbol
C9-A	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
IC5-A		LM392	DIP8	Comparator/OPAmp
C19	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
R29-A	4020	R-US_0207/10	0207/10	Resistor, American symbol
R30-A	2000	R-US_0207/10	0207/10	Resistor, American symbol
C10-A	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
ZD5-A	15V	1N4728	Tape and Reel	Zener Diode
R31-A	8870	R-US_0207/10	0207/10	Resistor, American symbol
R32-A	1000	R-US_0207/10	0207/10	Resistor, American symbol
R34-A	4020	R-US_0207/10	0207/10	Resistor, American symbol
R33-A	2000	R-US_0207/10	0207/10	Resistor, American symbol
C11-A	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
IC6-A		LM392	DIP8	Comparator/OPAmp
R35-A	2000	C-US025-024X044	C025-024X044	Capacitor, American symbol
R36-A	4020	C-US025-024X044	C025-024X044	Capacitor, American symbol
C12-A	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
ZD6-A	15V	1N4728	Tape and Reel	Zener Diode
IC1-C		MCP3208	DIP16	A/D Converter
IC2-C		MCP3208	DIP16	A/D Converter
C21	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
C22	100nF	C-US025-024X044	C025-024X044	Capacitor, American symbol
		OPA445	DIP8	High Voltage Operational Amplifier
		OPA445	DIP8	High Voltage Operational Amplifier

Part:	Value:	Device:	Package:	Description:
		OPA445	DIP8	High Voltage Operational Amplifier
		OPA445	DIP8	High Voltage Operational Amplifier
		OPA445	DIP8	High Voltage Operational Amplifier
		STB40NF10T4	D^2Pak	Power MOSFET
		STB40NF10T4	D^2Pak	Power MOSFET
		STB40NF10T4	D^2Pak	Power MOSFET
		STB40NF10T4	D^2Pak	Power MOSFET
		MAX635	DIP8	Voltage Inverter Chip
		LM3480-15	Tape and Reel	Voltage Regulator
		LM3480-15	Tape and Reel	Voltage Regulator

Figure 18: Preliminary Bill of Materials for Control Circuitry Subsystem

6.4 MONITORING SYSTEM

Part:	Description:
MicroSD Socket – 15882	Housing case for MicroSD chip
1 GB MicroSD Card	Nonvolatile memory

Figure 19: Preliminary Bill of Materials for Monitoring Subsystem

7 MAJOR COMPONENT COSTS

Item:	Cost:
Class Budget	$500
Gigot Center Winnings	$375
Generator	($400)
Transformer	($450)
Charging Circuitry	($100)
Control Circuitry	($100)
Monitoring Circuitry	($50)
Steel for Generator Mounting	($100)
Selling Two Generators	$200
Energy Center Funding	$660
Unanticipated Costs	($400)
Total:	$135

Figure 20: Major Component Costs

8 CONCLUSIONS

The Hybrid's Angels have progressed nicely in outlining the proposed solution to solve the complex engineering challenge of constructing a series hybrid electric motorcycle. Although it is believed that the plan outlined in the preceding pages will allow the group to accomplish the ambitious goals and requirements that it set, engineering obstacles will certainly arise as the group begins to execute the test plans. Reacting to the obstacles that arise will be as critical to the success of this project as this document will be. Moving into the building and execution stage of this project, the group anxiously looks forward to taking steps towards physically realizing the goals set forth earlier this semester.

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