THE UNIVERSITY OF WESTERN AUSTRALIA
Achieving International Excellence

With the School of Electrical and Electronic Engineering Presents

Electrical Designs for the Renewable Energy Vehicles within the REV Project

By Cameron Watts

Supervised by Thomas Braunl

2009

Cameron Watts

Unit 8/116 Royal Street

Tuart Hill

WA 6060

The Dean
Faculty of Engineering Computing and Mathematics
The University of Western Australia
35 Stirling Highway
CRAWLEY WA 6009

Dear Sir,

I submit to you this dissertation entitled “Electrical Designs for the Renewable Energy Vehicles within the REV Project” in partial fulfilment of the requirement of the award of Bachelor of Engineering.

Yours Faithfully,

Cameron Watts

Acknowledgements

I would like formally acknowledge the assistance of the following people; without the support and guidance of these people the electrical design of the REV electrical vehicles would not have come into fruition.

Kirstie Watts for all of her encouragement and support throughout the year

Assoc Prof Thomas Braunl for his supervision and guidance during the project.

Carrie Harper, Jason Fairclough, William Price for being invaluable members of the REV electrical team and assisting me throughout the year

Daniel Kingdom, Jonathan Wan, Ian Hooper and the rest of the REV Team for their technical support and dedication to the renewable energy vehicle project.

Ken, John, Don and the rest of the workshop staff for turning our designs into reality.

Contents

Abstract

The Renewable Energy Vehicle (REV) project is endeavouring to produce reliable, high performing, efficient electric vehicles that are powered completely by renewable energy sources. REV accomplishes this by retrofitting existing production cars with electrical drive systems powered through a system of rechargeable batteries. In order for these conversions to be successful a reliable and effective electrical system must be developed for the vehicles. As such detailed planning and development of the electrical system needs to be undertaken in order for the conversion of an electrical vehicle to be a success. Thus, this project will be focused on the development of functional electrical systems for the Getz electric vehicle and the Lotus Elise Electric conversion.

The Electrical modifications to the existing installations in the Getz were quite extensive. It consisted of rewiring the entire 12V system and redesigning the power distribution system and relay safety interlock. These modifications were preformed in order to increase the reliability and aesthetic appeal of the electrical conversion. In addition to the modifications, several new systems were added to the Getz Electric Vehicle.

The design work completed in the Lotus was also very successful. A well thought out design for the conversion to electric power was developed which enabled all parts associated with the installation of the electrical system to be ordered. In addition to this, all printed circuit boards have been designed, etched, constructed and tested and as such, are ready for installation. The installation of the electrical system of the Lotus has only just begun due to holdups caused by complications in the development of battery cages. Despite this, due to the detailed planning and design of the electrical system, the REV project anticipates a stream-lined installation of the designed electrical system and expect to have a functional high performance electric vehicle by December 2009.

The electrical work done on these two vehicles in 2009 shown that, through the implementation of recent advances in technology and intelligent design of electrical systems, the massive potential of electric vehicles can be realised. A new era of electrically powered vehicles is fast approaching and the REV project is helping to power it forward.

List of Figures

List of Figures

Nomenclature

AC	Alternating Current
DC	Direct Current
DIY	Do It Yourself
DPI	Department of Planning and Infrastructure
EV	Electric Vehicle
HV	Hazardous Voltage
ICE	Internal Combustion Engine
ICV	Internal Combustion Vehicle
LED	Light Emitting Diode
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
REV	Renewable Energy Vehicle
RTD	Resistance Temperature Device

1.1 Introduction

Due to the current social environmental climate (1) and fear of depleting world oil resources (2) there has been a recent strengthening in the movement to research and develop technologies that reduce the 'carbon footprint' of the average person. One of the main conceptual benefactors of this recent interest has been the Electric Vehicle. Recently, major technological advances in battery construction have made it viable to create a car that is run solely on the power supplied by batteries. However, historical, these new advances in technology have been met with a great deal of resistance from the automotive industry (3).

Due to this lack of support and the rapid development of Electric Vehicle technologies there are many myths circulating about the performance of electric vehicles. Thus, in order to dispel these myths, the Renewable Energy Vehicle (REV) project is endeavouring to produce reliable, high performing, efficient electric vehicles that are powered completely by renewable energy sources. REV accomplishes this by retrofitting existing production cars with electrical drive systems powered through a system of rechargeable batteries. These batteries can in turn be charged from solar panels installed on the roof of the main Electrical Engineering building, giving the opportunity to the REV vehicles to be completely carbon emission free (4).

In order for these conversions to be successful a reliable and effective electrical system must be developed for the vehicles. As such detailed planning and development of the electrical system needs to be undertaken in order for the conversion of an electrical vehicle to be a success. Thus, this project will be focused on the development of functional electrical systems for the REV electric vehicle conversions.

1.2: The engineering problem

Using batteries to power an electric engine in a vehicle is a concept that has been around since the dawn of the automobile. In fact, in the early stages of the automobile, electric cars dominated over the internal combustion cars (5). The concept consists of simply connecting a set of rechargeable batteries directly to an electric motor which then drove the wheels. This design is simpler than the internal combustion design because of the following points:

- The heat generated from electric motors is insignificant when compared to internal combustion motors.
- There is less vibration present in an electric car due to the lack of combustion
- There is no need to be concerned with the transport of fuel to the motor in electric vehicles.
- There is no need to store explosive fuel in electrical vehicles.

However, despite the simplicity of the electrical vehicle concept, converting an internal combustion vehicle to an electric vehicle is a complex issue with many engineering design problems to overcome. These problems are quite varied and as such a team with a wide base in expertise is necessary for a conversion to be successful. As such, the team within the REV project came with various mechanical, electrical and computational skills. To optimise the performance of each team member, the tasks and engineering problems that needed to be addressed were divided into three sections:

- Mechanical
- Electrical
- Instrumentation

As mentioned before, this thesis will focus on electrical engineering associated with converting an electric car. The engineering design considerations encountered throughout this project are as follows:

Development of a functional electrical system: The first and primary problem associated with electric vehicle conversions is the development of functional electrical systems. One must develop a functional design before any work can commence on the conversion.

Vehicle safety: Safe operation of the vehicle is vital above all other design considerations. As such, extensive thought and planning must be put into the safety of the design.

Vehicle Robustness: The conditions that vehicles operate under can be very harsh. They can be exposed to intense sunlight or heavy rain. As such, if the electric vehicle solution is to be practical, a robust system must be developed.

Electric Vehicle Standards: The Department of Planning and Infrastructure have developed a set of electric vehicle standards that must be adhered to in order for the converted car to be licensed (6). As such, the upmost effort should be made to meet those standards in order for the vehicle to be considered road worthy.

Implementation of systems reliant on the internal combustion motor: In a internal combustion vehicle, there are various systems which rely on the presence of the motor in order for them to function. When the internal combustion motor is removed those systems may no longer functions. As such, a viable alternative needs to be developed in order for the vehicle to maintain all of its functionality.

Size Restrictions: Due to the fact that many varying systems are being installed in an engine bay that was not designed for an electric motor system, there may be physical restrictions on the size and position of each component of the electrical system. As such, extensive planning must be done in order to ensure that all of the new systems appropriately fit the area given.

Motor Control: If the vehicle is to be a practical alternative to internal combustion motors, the control of the vehicles systems should be as similar as possible to the original vehicle. As such, the motor should be started via the ignition key and controlled by a brake and accelerator pedal.

2: Review of Relevant Literature

Due to an increase in public awareness about the concept of electric vehicles there has been a lot of interest surrounding the field in recent times. As such there has been a lot of recent research and development into the viability of electric vehicles. The current literature on electric vehicle technology can be split into three sections; Public and professional opinion, technical information and standards and regulations.

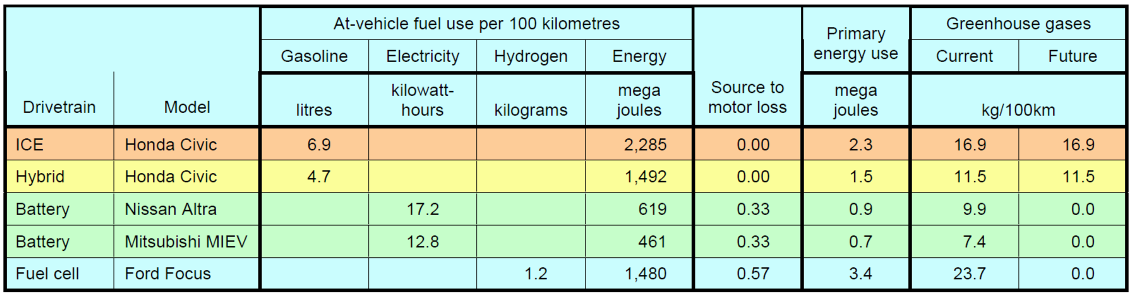
2.1: Public and professional opinion

There has also been a lot of government interest in electric cars, with many viability and feasibility papers being funded by the government. One such paper is "Action Plan for Electric Mobility in Canada" (7)

However, after the disaster of the Zero Emission Mandate in California, most governments have been afraid to commit to solid changes in policy and regulations. The Zero Emission Mandate was a mandate passed in 1994 by the California Air Recourses Board that specified that 10% of all sales of Automobiles by 2010 should be Emission free (8). This mandate experienced heavy opposition from the automotive company and was amended in 2001 to be strictly optional. Many environmental activists saw this as a defeat and the California Air Recourses Board came under heavy criticism from the public (3).

Most of the reports released about electric vehicle technology are very positive and cite many benefits to society of Electric Vehicles. One of the benefits sited by the "Action plan for mobility in Canada" is that the well to wheel efficiency of battery power electric vehicles will always be superior to that of petrol and hydrogen cars (7). The well to wheel efficiency can be defined as the total efficiency of the energy produced by the burning of fossil fuels from the extraction to the energy placed on the wheels of a vehicle. The total well to wheel efficiency of electric motors is approximately 50% where as the internal combustion engine has a well to wheel efficiency of about 20% (9). From the table below it can be seen that if battery powered vehicles were powered purely from fossil fuel power stations then they would still emit 60% less green house gases than the internal combustion engine equivalent.

Table 1: Green House Gas Emissions of Various Vehicle Platforms



		At-vehicle fuel use per 100 kilometres				Source to motor loss	Primary energy use	Greenhouse gases	
		Gasoline	Electricity	Hydrogen	Energy			Current	Future
Drivetrain	Model	litres	kilowatt-hours	kilograms	mega joules		mega joules	kg/100km	
ICE	Honda Civic	6.9			2,285	0.00	2.3	16.9	16.9
Hybrid	Honda Civic	4.7			1,492	0.00	1.5	11.5	11.5
Battery	Nissan Altra		17.2		619	0.33	0.9	9.9	0.0
Battery	Mitsubishi MIEV		12.8		461	0.33	0.7	7.4	0.0
Fuel cell	Ford Focus			1.2	1,480	0.57	3.4	23.7	0.0

Table data from (7)

However, they all site one major downfall of electric vehicles, limited range. At the moment the generally accepted maximum range of an electric vehicle is approximately 300km. This is cited as the main weakness in electric vehicles by both government and individual reports. As stated by “Ten steps to a sustainable Future” this weakness is likely to persist for quite some time (10). Although, most reports do predict that battery technology will eventually advance to a point where battery driven vehicles are able to power a vehicle for a range comparable to that of an internal combustion vehicle (1) (10).

2.2: Electric Vehicle Technical Information

There are many self help texts and DIY manuals for the conversions of electrical vehicles but there are few well documented and researched publications existing for modern electrical vehicles. Books like Bob Brant’s *Build Your Own Electric Car* (11) held a lot of information about converting an electrical car but lacked two things:

1: Detailed information of the interconnection of the electrical systems contained within the electric vehicle.

2: Up to date technology (11). This was the case with the majority of sourced texts, Either they focused on obsolete technology or they lacked electrical system detail.

However, a basic electrical schematic was sourced from Zero Emission Vehicles Australia (12). This schematic would be used as a starting point in the design of the REV EV’s circuit design. In addition to this, many other sources of information assisted in the development of the electrical designs such as *The Art of Electronics* by Paul

Horowitz and Winfield Hill and *Lessons In Electric Circuits* by Tony R. Kuphaldt (13) (14).

In addition to these sources specific information about the existing vehicle systems was found in the Hyundai Getz owner's manual and the Lotus Elise owner's manual (15) (16). These manuals enabled the effective integration of the designed electrical systems into the existing electrical systems.

Finally, in order to ensure the suitability of the appropriate parts that were purchased for the conversion of electric vehicles, many data sheets were referenced. The data sheets and part manuals used are to numerous to list here. As such Appendix A shows all data sheets used throughout the year.

2.3: Electric Vehicle Standards and Regulations

The final section of the literature review is a review of the current Electric Vehicle conversion standards. A set of standards have been released by the Department of Planning and Infrastructure that detail all of the requirements of any electric vehicle conversion. The standard has been given the code VSB 14 and is titled "National Guidelines for the Installation of Electric Drives in Motor Vehicles" (6). The standard is available to the public and can be downloaded at the Department of Planning and Infrastructures website. The standard contains a number of key regulations that pertain to all aspects of an electric vehicle conversion. The regulations that impact on the electrical design of the vehicle are summarised below:

- Vehicles must have a functional demister
- Vehicles must have a visual warning light to indicate a failure in the brake vacuum pump.
- The batteries that power the vehicle must be fixed in position
- The design of the batteries, or battery compartments, must provide for venting directly to atmosphere of all gases given off by normal battery operation.
- All components in the vehicle containing a connection to a HV battery pack, or which contain HV relative to the chassis, must be clearly labelled.

- All wiring in the vehicle connected to a HV battery pack must be coloured orange or be installed in orange conduit.
- Direct contact with HV parts of the vehicle must be prevented either by insulation or by the use of a reliably secured guard.
- All HV wiring should be located outside the passenger compartment or load space in order to minimise the possibility of contact by the operator.
- The power on procedure must be applied via a key switch.
- It must not be possible to remove this key in any position that energises the drive train or makes active driving possible.
- Disconnection of the traction pack from the rest of the traction circuit must be by a contactor operated by the ignition switch.
- An inertia switch must be employed to disconnect the traction pack from the rest of the traction circuit in the event of a collision.
- A battery pack over-current protection device (e.g. fuse or overload relay) must be installed in the traction supply circuit.
- Electrical propulsion circuit must be isolated from other circuits in the vehicle
- Vehicles not fitted with a conventional gearbox and using a voltage reversal. switch to select reverse drive must be designed so that they cannot be accidentally placed in reverse.
- The vehicle must not be capable of being driven in either direction if the vehicle is connected to an energy supply network or an off-board charger.
- All onboard appliances using traction pack voltages need to be protected from current overload.

The other national standard that is relevant to the vehicle conversion is the Australian/New Zealand Standard AS/NZS 3000:2000*: Electrical installations.* This standard details the regulatory guide lines for installing electrical equipment. It outlines the minimum safety requirements and details the work that each electrical licensee can perform (17). This standard can be found at the Australian standards website (18).

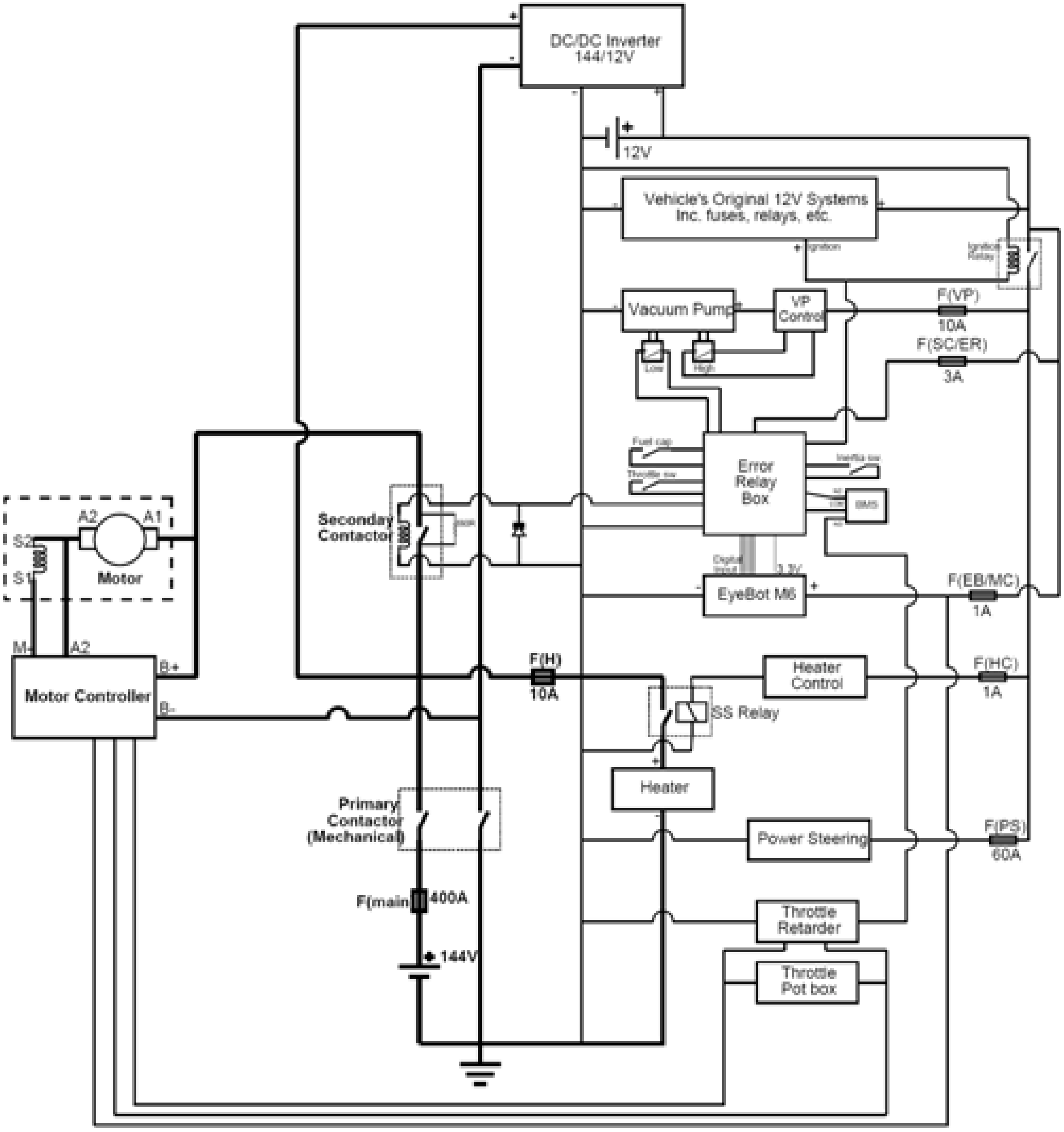
3: Modifications to Electrical Systems in the Hyundai Getz

3.1: Introduction to the Converted Hyundai Getz

The Hyundai Getz was converted from an internal combustion engine vehicle to an electric vehicle in 2008. The conversion primarily consisted of removing the original internal combustion engine and replacing it with a 144V, 28kW brushed DC motor. This motor is powered by a traction pack that consists of 45 units of 3.2V, 90Ah Lithium Iron Phosphate (LiFePO4) batteries, giving a total energy storage capacity of approximately 13kWh. In addition to this, the mechanically driven power steering pump and vacuum pump were removed and replaced with an electrically driven equivalent. These were powered by a modified 12V distribution system. There was also a heater installed and a safety interlock system. A basic system layout of the Getz as it was at the beginning of the year is shown in Figure 2.

Figure 1: Electrical Schematic of the Converted Hyundai Getz 2008

Developed By Stephen Whitley (19)



Airconditioning is currently omitted due to lack of specification.
Charging circuit is omitted as it is independent of these systems.

Stephen Whitely
10119492
UWA REV Project 2008

3.2: Issues with existing design of Hyundai Getz

However there were a number of issues with the initial electrical design and installation. The first of which was that the electrical equipment was distributed in many small unsecured boxes. At the beginning of the year there were separate boxes for the safety interlock system, 12V power distribution, heater relay, air conditioner relay and power steering relay. This combined with an abundance of mid wire joins caused a number of reliability and aesthetic issues. That is, a system wired with a large number of distributed connections will encounter the following three issues:

1: The system will be more prone to causing faults. This is because the way the system was connected meant that there were many more termination points then was necessary. An increase in termination points will increase the number of possible fault locations and will therefore, at least statistically, increase the number of faults that a given system will experience.

2: If a fault does occur it becomes harder to locate as wires may not be easily traceable and the fault location could occur at various locations.

3: An electrical system with many termination locations gives the installation a ‘messy’ look, taking reputability away from the project.

A second issue with the existing installation is that the 12V system was not intelligently installed. At the beginning of the year, when the vehicle was not active, a constant static power dissipation of approximately 300mA was present. This caused the backup battery to constantly run flat. This is undesirable for two main reasons. The first of which is that the start up system relies on the 12V battery in ordered to start the car. The second is that 12V is needed to power the eyebot which needs constant power in order to modify the software on the system.

A final issue with the existing installation is that there were many pieces of equipment that were unfused. The unfused pieces of equipment are as follows: voltage converter, air conditioner, vacuum pump, Eyebot, throttle switch or heater control system. This is obviously a major safety issue, especially with regards to the converter. The converter is connected directly to the high voltage system which means that the only protection it has is the main 400A fuse. This means that 57kW of power can pass through the 600W converter without the fuse blowing. At that power level, if a fault occurs the converter would fail catastrophically and an electrical fire could occur.

3.3: 12V system redesign

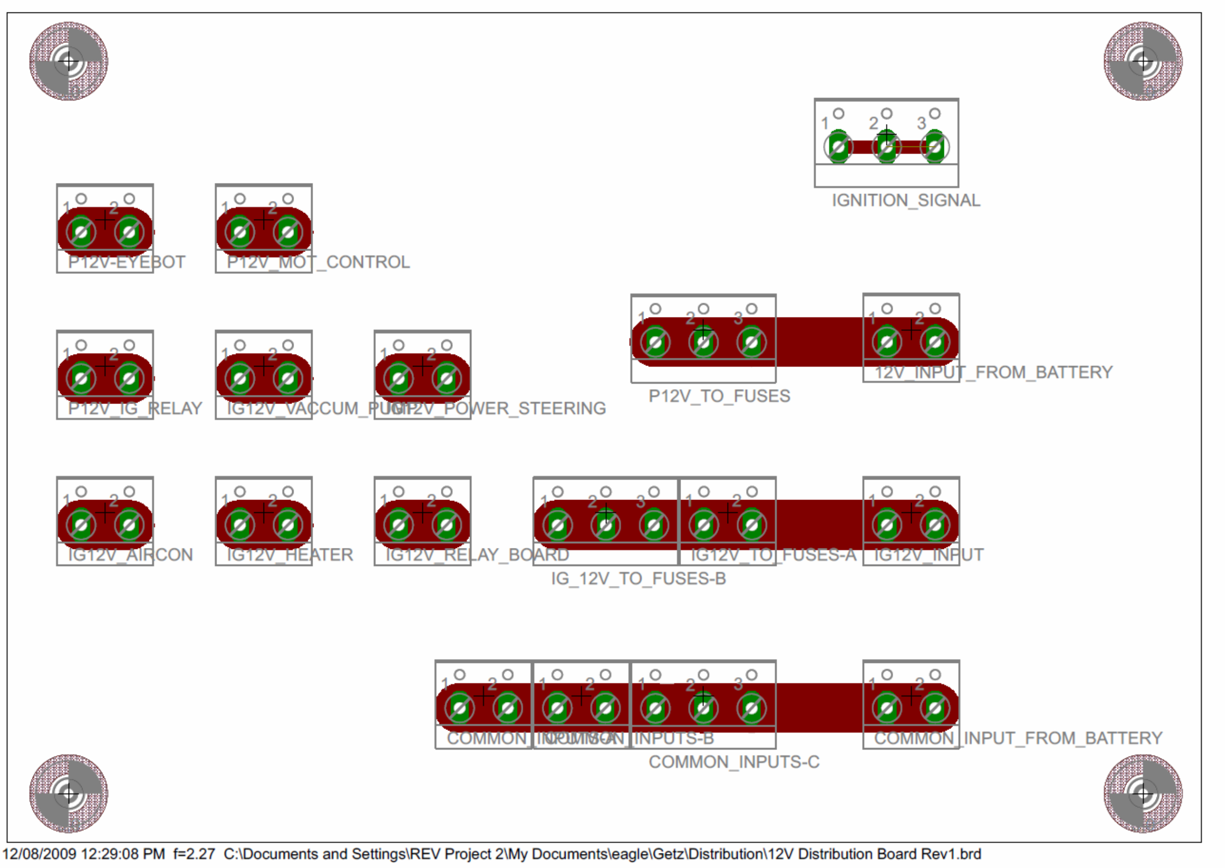
Due to the reasons mentioned in the previous section it was determined that a complete redesign of the electrical system was necessary if the car was to be taken out of lab conditions and into the real world. This total redesign started with a complete electrical rewire in order to terminate all the cables in a central location. After this a design had to be developed to distribute the 12V power supply to all of the installed systems.

3.3.1: 12V power distribution system redesign

The 12V distribution design's main goals were to reduce the static power dissipation, protect the 12V equipment and efficiently interconnect the 12V supply system with the 12V electrical equipment.

After some consideration and debate it was decided to create the 12V distribution system on a Printed Circuit Board (PCB). The decision to do this was due to a number of factors. Firstly, it enabled the neat termination of a large number of wires into a small space in a logical and ordered manner. Also, once the design was complete, it enabled the creation of a schematic of the distribution system, allowing us to easily trace the interconnections of the wires. Finally, it allowed the elimination of wire to wire connections within the 12V distribution system which are problematic and fault prone. Instead, each wire is terminated into individual screw terminals that are mounted on the PCB and are interconnected by copper tracks. The copper tracks were etched to a thickness of approximately 250thouwhich gave them a current carrying capacity of about 13Amps. As the total current going through this section of the 12V distribution system is 12Amps, the track width should be sufficient. The design of this PCB is in the figure three.

Figure 2: Getz 12V Distribution System PCB Layout



The distribution system board design consists of 40 terminations organised in a logical and flowing manner. The input power connections come in from the right, then out from the board to a set of 12V system fuses in the middle right, in to the board from the fuses in the middle left of the board and then out on the left to the various pieces of equipment. This design enables us to easily and safely connect all the equipment to appropriate fuses. The increase in safety is caused by giving both the input and output of the fuses individual termination points. This is important because it takes the pressure, which can occur when tugging on external cables, and transfers it to the termination blocks on the PCB instead of solder connections on the fuse itself, which by their nature, can be less reliable. As the new design contained many more fuses, a layout of the fusing was required. This is shown on the previous page. Note that future intentions' are to transfer this design on to clear adhesive plastic and attach it to the exterior of the box.

Figure 3: Getz Fuse Layout

FUSE LAYOUT

EYEBOT	RELAY BOARD
MOTOR CONTROLLER	MAIN POWER IN
IGNITION POWER	VACCUUM PUMP
POWER STEERING	HEATER

In addition to this, the design enabled the separation of the 12V power distribution system into two distinct levels, ‘Permanent Power’ and ‘Ignition Power’. Permanent Power is active all the time and powers the Eyebot and motor controller. The Eyebot is permanently powered in order for its software to be easily activated and modified when the car is not in use. The motor controller is permanently powered because it has low static power dissipation and a long boot up time. Therefore, by having the motor controller always on, any delay in motor activation that could be caused by boot up delay is eliminated. Ignition power is only active when the key in the ignition is turned to the ‘ON’ position. The Eyebot, relay board, vacuum pump, heater control system and the air-conditioner control system are powered from this level. Separating the power levels in this way enabled the reduction of the static power consumption in the vehicle from 300mA to 30mA.

3.3.2 Safety Relay Board description

After the 12V distribution system was installed the next step in the redesign process was to redesign the safety relay system. The safety relay system is a PCB installed in the car that controls the status of a normally open secondary contactor on the 144V supply line. If the contactor is open, no power is allowed to flow to the motor controller and the motor is prevented from starting. The signal to the contactor is controlled by a series of checking relays that monitor the status of the car. If the car is determined to be safe, 12V is supplied to the secondary contactor allowing it to close. The decision to use a system of relays, instead of a microchip, to control the safety system contained within the car was made because relay based systems tend to be more robust and reliable. In addition to this, the design and installation of the system tends to be simpler and more efficient.

The relay safety system works by monitoring five primary safety signals:

1: Fuel Cap Signal: The fuel cap signal is generated from a micro switch contained within the charging socket. When there is a plug present in the socket the switch opens and the 12V signal to the relay board goes low, indicating an “unsafe” status.

2: Inertia switch: This was installed in order to meet standards set by the Department of Planning and Infrastructure. If the inertia switch has a force acting on it greater then XN the switch will open and the 12V signal will go low, indicating an “unsafe” status.

3: Vacuum Low Signal: This signal indicates the status of the vacuum developed within the vacuum pump. The vacuum pump is used to boost the pressure on the brakes, making it easier for the driver to apply the brakes. If the pressure switch on the vacuum pump detects a low vacuum pressure, the switch will close and a 12V signal will be sent which indicates an “unsafe” status.

4: Ignition: This indicates the status of the ignition key. When the key is on the 'OFF' position a 0V signal is provided. When the key is turned to the 'ON' position a 12V signal is provided. This ensures that the motor will not start unless the key is in the 'ON' position.

5: Throttle switch: This is a switch that activates when the driver presses the accelerator foot pedal contained within the car. When the pedal is pushed, a12V signal is sent from the switch. This function essentially ensures that the motor will be off as long as the throttle is not being pressed.

3.3.3 Safety Relay Board Design 1

In the first design of the safety relay board, the five signals mentioned above are fed directly into the coil of a corresponding double pole, double throw relay. The relay then controlled the state of two isolated switches based on the signal through the relay. One side of the relay is connected to a daisy chain that controlled the 12V supply to the secondary contactor. A daisy chain is essentially a set of controlled switches connected in series; if any one switch is open, continuity is disrupted and input becomes isolated from the output. Note that this is essentially an “AND” function. All of the controlled contacts in the daisy chain, except for the ones contained in the vacuum low relay, are wired such that they are normally open, requiring a 12v signal to be passed through the relay for them to close. The other side of the relay was connected to a 3.3V supply from the Eyebot, which enabled the relays to provide a 3.3V digital output, from a given 12V input. The digital output from the relay will then connect back to the Eyebot in order to give a digital indication of the status of the safety system. In addition to this diodes were placed across the contacts of the relay in order to protect the relay from back EMF that it may be generated during switching.

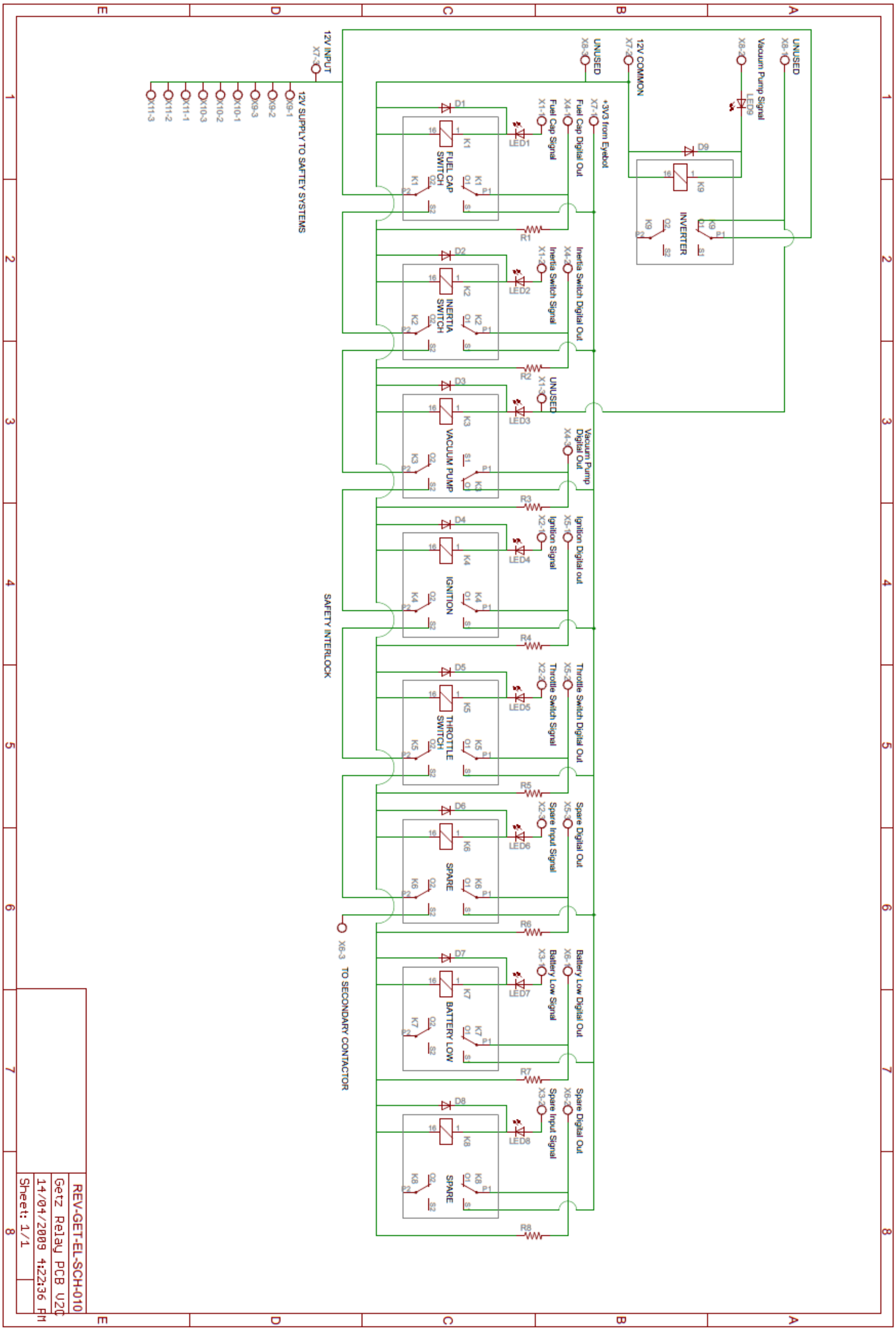
There were a few reasons that the safety relay system needed to be redesigned. Firstly, the digital outputs that were to indicate the status of the various pieces of safety equipment were not functional. This combined with the fact that there was no visual indication of the status of each individual piece of safety equipment, meant that if the safety system tripped out there was no way to determine which piece of equipment determined the car was unsafe. This would make it very hard to trace the source of an error in a real life situation. The final reason to redesign the safety relay PCB was that the safety relay board only existed on proto board, which is flimsy and not very robust. As safety systems need to be highly reliable due to their nature, having it exist on an unreliable medium was unacceptable.

With all these factors in mind, a design for the safety relay board was developed that should address all these issues. At the time of the design it was believed that the cause of the fault was that the digital output lines were left floating when the relay contact was open. To repair this, a high value resistor was placed in parallel with the digital output line. This is commonly known as a bleed resistor, allowing the line to slowly dissipate any stored charge contained within the line. The lower the value of the resistor the faster the current would dissipate from the circuit, but more power that is wasted when the switch is closed. A value of 12K ohms was chosen for the resistance, allowing a maximum current of 0.275mA through the resistor and a power dissipation of

0.9075mW. In addition to this LED's were placed in series with the input signal. This allows for a visual indication of the status of the safety equipment.

As it was unconfirmed how many safety systems would exist at the end of the development, provision for additional safety systems was made by including two spare relays on the board, one contained within the daisy chain and one external to the daisy chain. Also, an additional relay was included in the design that would convert a 12V signal generated by the battery management system into a 3.3V signal for use by the eye bot. In addition to this, it was necessary at the time to install an additional relay in order to invert the signal generated from the vacuum pump. The signal needed to be changed from an active low system to an active high system. This was necessary in order for the LEDs to be uniformly lit, i.e. in order for all the LEDs to be active when a safe state is indicated. A schematic of this design was developed and is shown in figure five.

Figure 4: Safety Relay Board 1 Schematic



The design was successfully transferred to a printed circuit board. The final layout of the board is shown below. The board was forced to be two sided due to area constraints placed by Eagle. Eagle is the software that is used by the REV team to develop PCB designs. The cramped design was highly undesirable as the electrical workshop finds making vias through the PCB particularly difficult. A photo of the constructed PCB can be found in appendix C.

Figure 5: Top layer of Safety Relay Board PCB

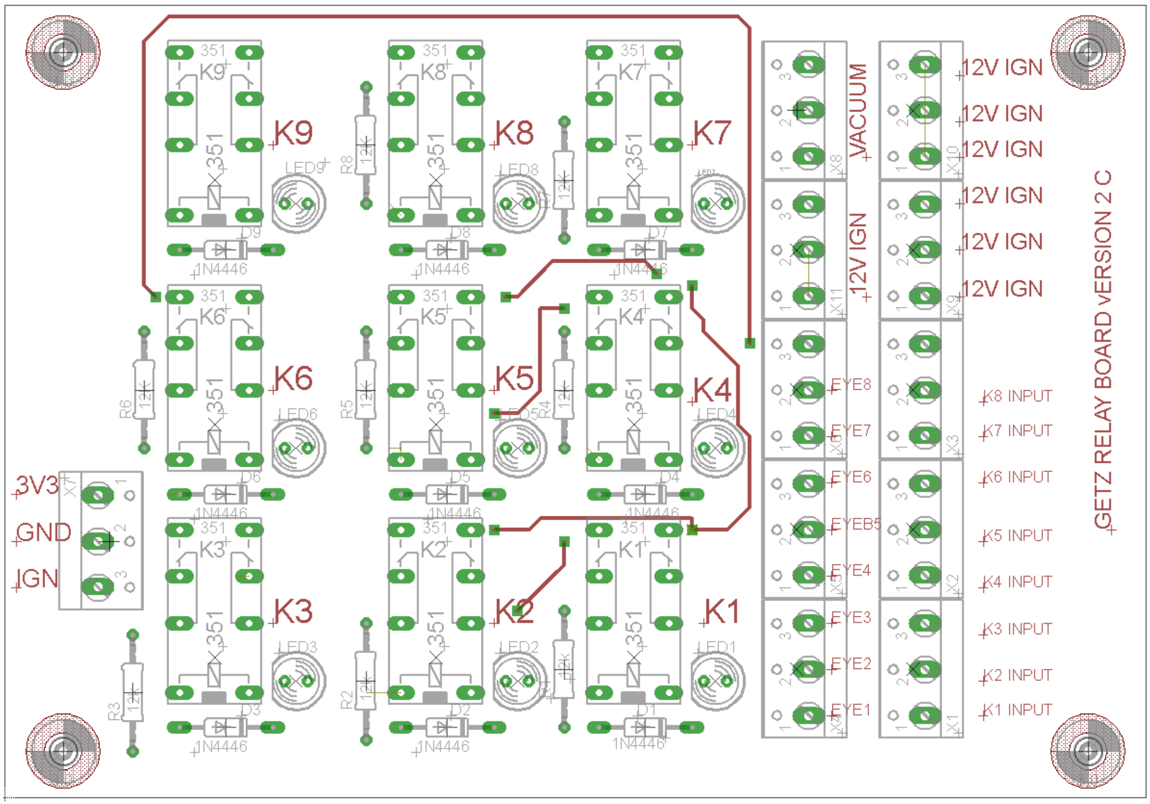
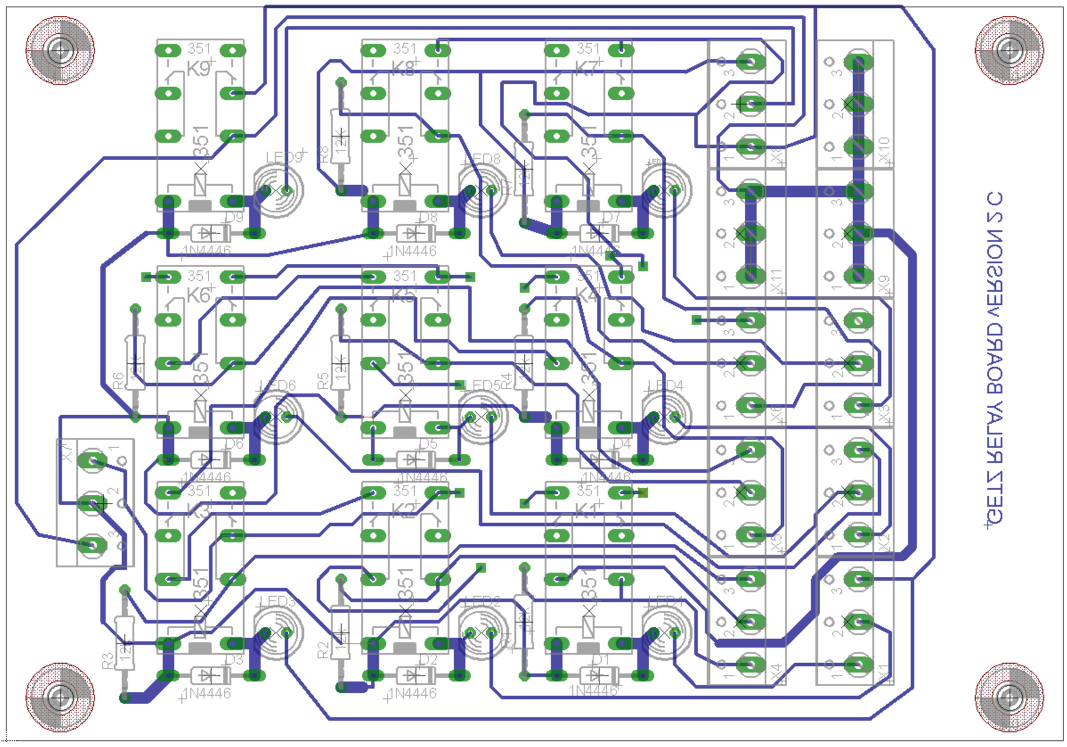


Figure 6: Bottom Layer of Safety Relay Board PCB



3.3.4 Safety Relay Board Design 2

There were however still a few issues with the existing designs. Firstly the digital outputs were still not functional despite the modifications. This was investigated further and it was found that there was a significant impendence between the ground reference for the relay board and the Eyebot. This resulted in a potential difference between the two references which caused a false high to be given when the circuit switched to a low state. As such the design was modified to accommodate two separate ground references, 12V ground and digital ground, with the digital ground reference being fed via a new wire, directly from the Eyebot. This was tested using a wire modification to the existing board. A photo of this wire modification is shown in appendix D. The test showed that with the direct ground wire a true reference was given and the eyebot correctly registered the status of the digital lines. Note that doing this increased the complexity of the board as there were now two interlacing ground tracks, one for the 12V system and one for the 5V system.

To combat this increased complexity, minimalisation of the design was necessary. To do this, an attempt was made to minimise the number of relays that existed on the PCB, starting with the spare relays. These relays were installed in the board at the time because the exact number of safety signals that were required was unknown. As such, once the overall design became established and well developed, the redundant relays were able to be removed. In addition to this, the presence of the Vacuum low signal in the daisy chain was unnecessary as the vacuum pump was not a critical system. However, the status of the vacuum pump still needed to be communicated to the driver due to the standards set in the National Code of Practice (6). As such the vacuum pump relay was removed from the daisy chain and wired such that it provided a digital signal output.

In addition, the way the board was designed in figure five caused the functionality of the safety relay system to be reliant on the LED indictors, i.e. if the LED indictors malfunctioned the safety relay system would not work. Due to this reason, the way that the LED's were connected to the signal was changed; instead of placing the LED's in series with the relay they were placed in parallel. In order to limit the current going through the LED to 10mA a 800Ω resistor was placed in series with each indication LED.

Also, due to concerns about the heat generated by the motor controller a relay was added to the safety relay system that monitored the temperature of the motor controller. If the motor controller gets too hot the signal will go low and the relay will open, breaking the daisy chain and shutting down the motor, allowing it to cool. In addition to this, a terminal block was added that allows for the bypass of the safety system. The out puts from the terminal will be connected to a switch. If the safety system needs to be bypassed then the user simply presses the switch which effectively bypasses all except the throttle relay. A red LED indicator is used to indicate the status of the bypass system. The switch for this system will be mounted in the bonnet.

Finally, the safety relay system needed an extra relay to be installed in order to operate a bonnet lighting system. In order for the designed system to work, a relay was needed to control power to the bonnet lights via a control signal hooked up to a bonnet compression switch. The relay needed to be permanently powered. It was to control two light power lines via the bonnet switch control signal. A more detailed description of this design is given in section 4.3. This small independent system was installed on the PCB as well.

The final schematic of this design is shown in figure 8.

This schematic was constructed and installed. All digital outputs now seem to be functioning correctly and the new bypass system functions correctly. In addition to this, the relay that controls the bonnet light also works correctly. The final layout of the PCB is shown in figures 9 and 10.. Note that the simplification to the design enabled the etching of the board to be simplified to a one layered design with no vias.

Figure 7: Safety Relay Board 2 Schematic

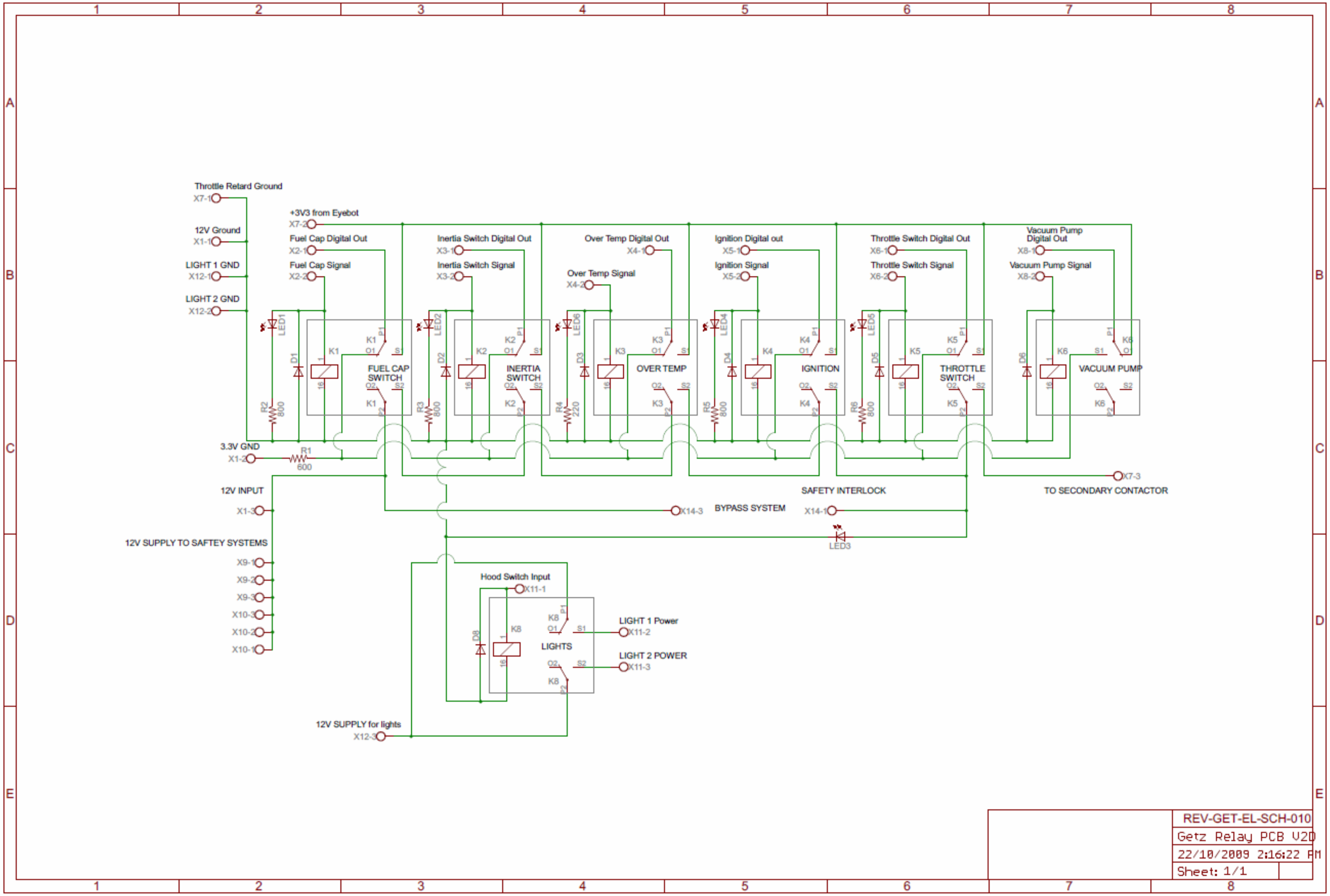


Figure 8: Safety Relay Board 2 PCB top Layer

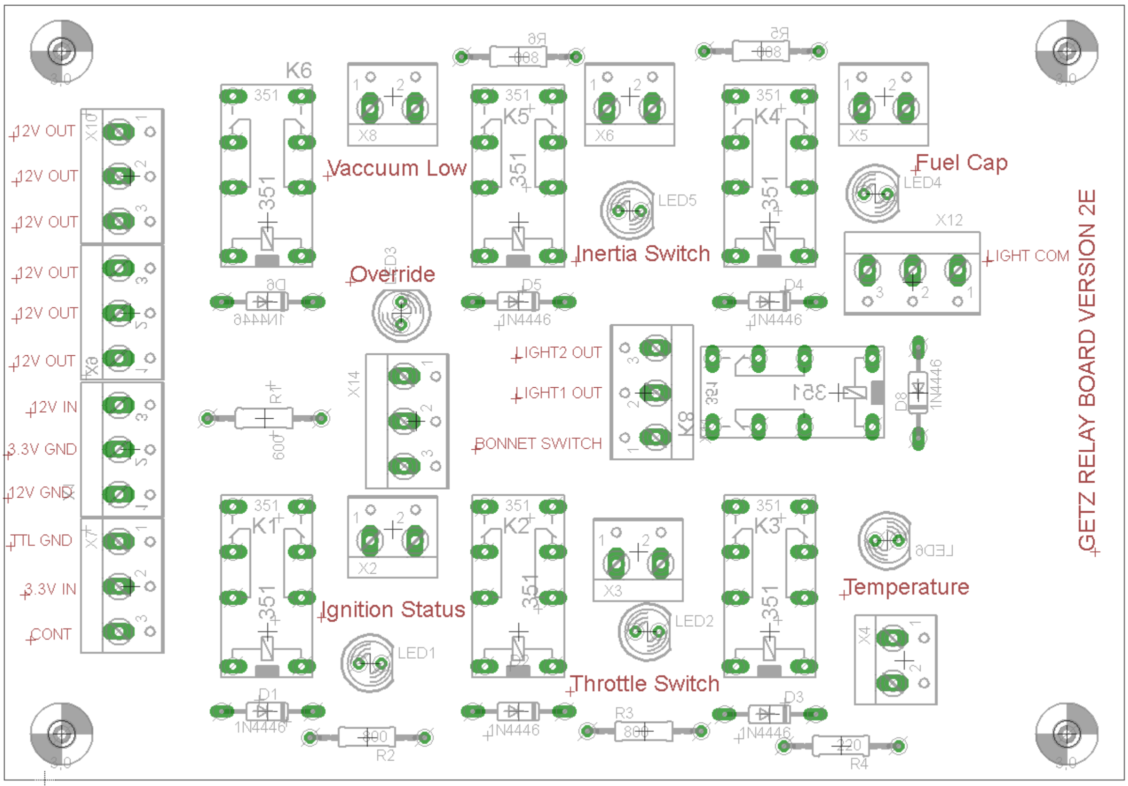
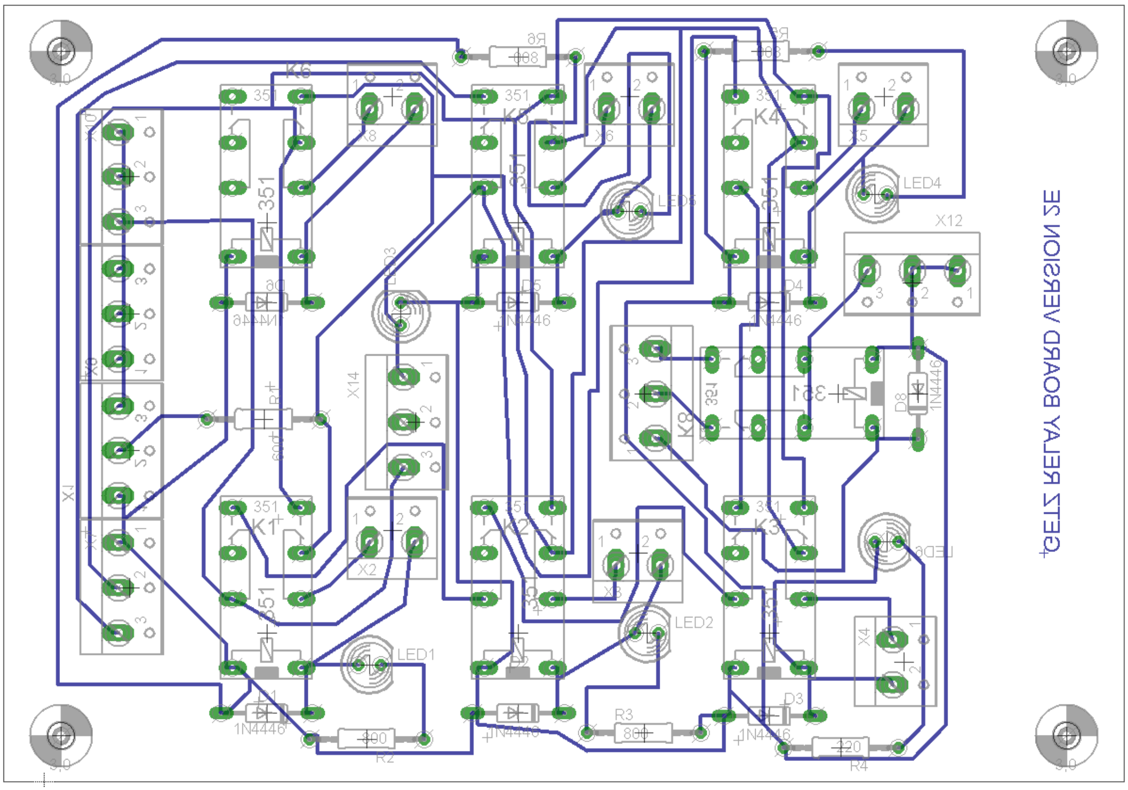


Figure 9: Safety Relay Board 2 PCB Bottom Layer



3.4 Other Modifications to the System

The final step in the modifications to previously installed systems in the Getz electric vehicle was to fuse the 144V equipment appropriately and relocate the high voltage solid state fuses to a more appropriate location. Excluding the motor, the equipment that is powered directly from the 144V battery supply is as follows: A 144V-12V DC-DC converter, a heater and an air conditioner. Please note that a 144V power system existed for the air conditioner last year, but a 12V interfacing control system did not.

3.4.1 Fuses

In order to appropriately protect the equipment two fuses were installed. One 20A fuse was placed in the 144V supply line that powers both the air conditioner and heater. This was determined to be the most effective solution due to the fact that the smallest in line fuse we could find to suit a 10mm wire was 20A. In addition to this the two systems are exclusive, which indicates that if the heater is on the air-conditioner will be off and vice-versa. This is different to a normal auto-mobile as no heating element is required in combustion engine vehicles.

3.4.2 Solid State Relay Relocation

The solid state relays that controlled power to the heater and air conditioner via a 12V signal were then relocated to a more appropriate location. This was necessary due to two key reasons.

1: The heater relay was not securely installed initially, it was installed on line dangling and unsecured. This unsecure installation could have easily resulted in a major fault if the 144V supply line was pulled out of the terminal it could have easily shorted to the chassis; this could result in electrical fires and damage to equipment.

2: A design concept was developed where the 144V and 12V electronic equipment are contained in two completely separate locations. Doing this would increase the safety associated with working on the vehicle as it would become obvious where 144V exists and where 12V exists. Thus, due to the before mentioned reasons, the high voltage relays were relocated to a single box that is located above the 12V relay box. Once this task was completed the redesign work on the was Getz concluded.

4: Electrical systems Added to the Getz Electric Vehicle

The next task that was to be done on the Getz electric vehicle was to add functionality to the electrical system. This would be done by installing new equipment and implementing new features. The new features that were to be installed in the Getz were: air-conditioning control, extraction fans and bonnet lighting.

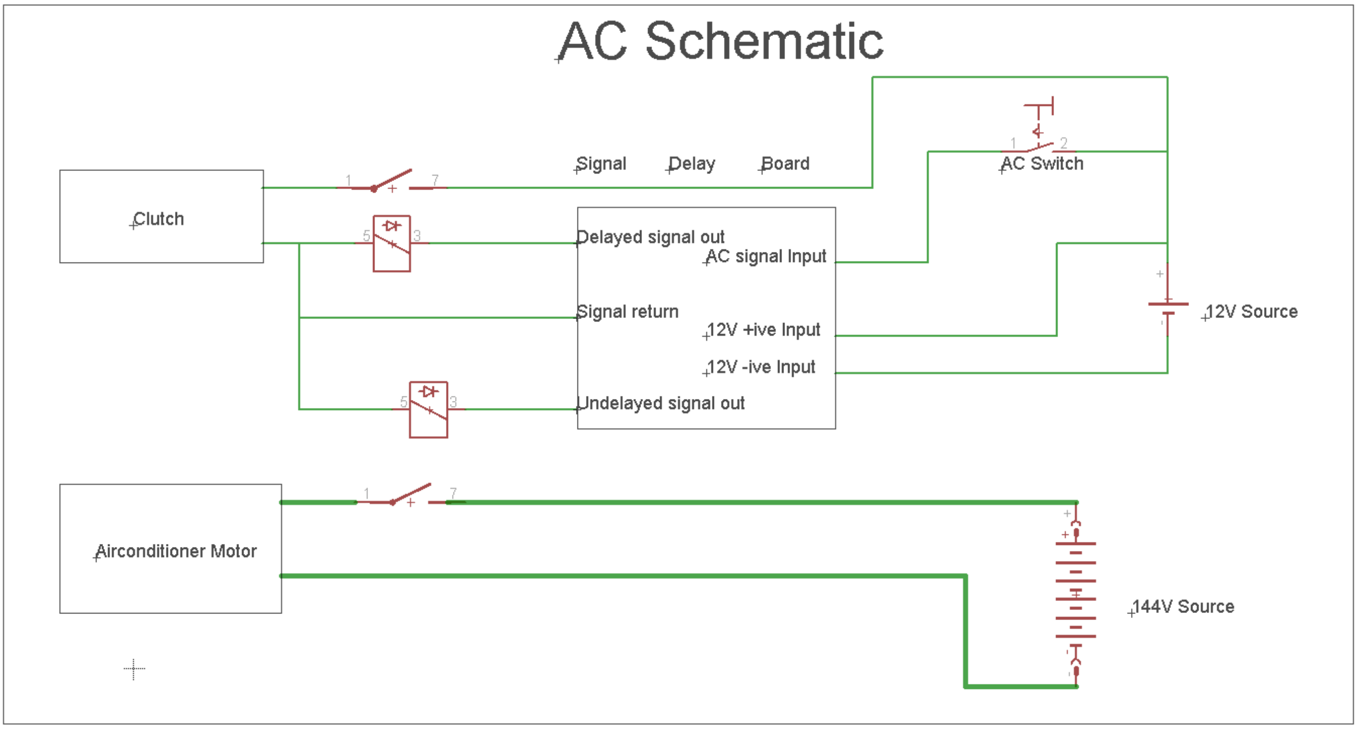
4.1: Air Conditioning

The first system that was added to the Getz was air-conditioning. The air conditioning system works by using a 500W motor to power the stock air conditioning compressor in the Getz. The decision to use a second motor to drive the compressor and not the primary motor was made for two main reasons.

Firstly, the primary motor does not idle and turns off when the accelerator is not being pressed. As such, if the air conditioner was powered from the main motor it would cut out whenever the accelerator is released. Secondly, using a secondary motor to run the air-conditioner compressor is a lot simpler then running it directly from the motor as less gears and belts are needed. In addition to this, it may not have been possible to mount the compressor close enough to the new motor for a pulley system to be effective.

There was already a 144V power system existing to power the air conditioning motor. However, no control system existed at the time. As such, a control system was developed that interfaced with the pre-existing air conditioner control in the cabin of the vehicle. This was particularly difficult as separate control signals had to be generated for the compressor motor and motor clutch. This is necessary as the compressor motor needs to be spun up before it is engaged to prevent the motor from stalling out. To do this the activation signal was duplicated and then delayed. The initial activation signal is sent to a control relay which powers the air conditioner motor. The delayed signal is then sent to the clutch which pulls in the compressor. The signal is delayed by the use of capacitance based pull-up transistor circuits. This circuit was originally designed by Daniel Kingdom and was etched, built and installed by Cameron Watts. A schematic of this design is attached in appendix F. A schematic of the overall system is shown in figure 11.

Figure 10: Air Conditioning Circuit Schematic



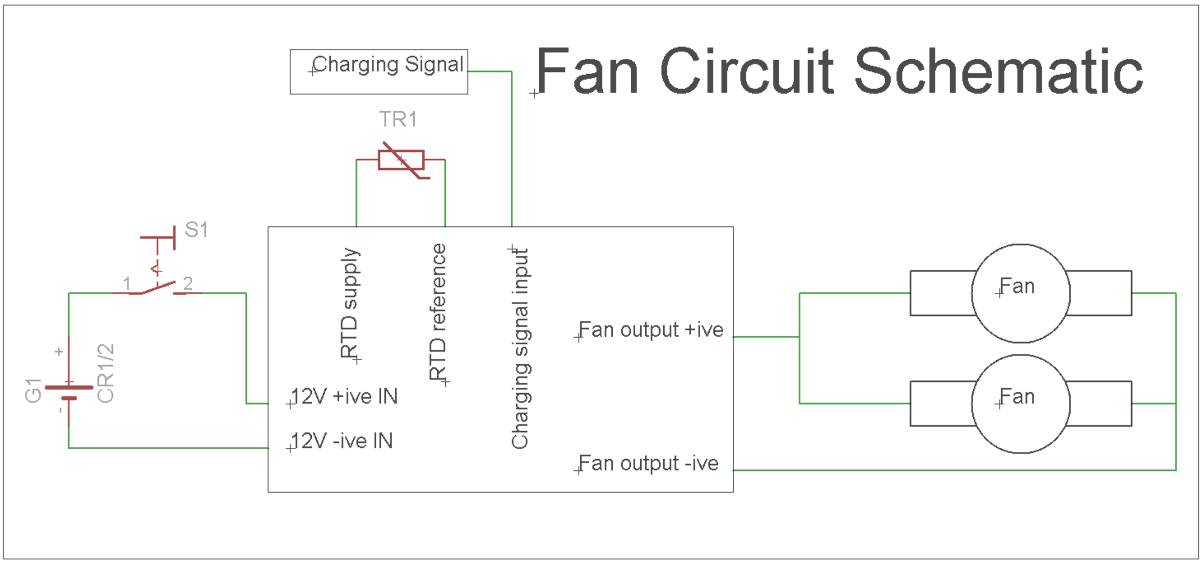
4.2: Extraction Fans

The second system installed in the Getz was the extraction fans. There are two extraction fans installed directly below the battery pack and are used to actively cool the batteries and extract any possible fumes. This was necessary for to two main reasons; the first was that there were concerns with the battery packs overheating. By actively cooling the pack, one is able to control the temperature of the battery pack more effectively. The second reason to install the extraction fans was that there were complaints of foul smells developing in the cabin of the Getz. It was thought that these smells were caused by fumes from the battery pack, and as such they should be vented to improve the comfort of the driver. A sample of the fumes was taken and were analysed by the chemistry department. The analysis determined that The fan extraction system consisted of two fans controlled initially via a relay system installed by the Cameron Watts but was later updated to a micro controller system by Jonathan Wan. The system works by activating the fans when either of the following conditions were met:

- Detection of the charging system or
- Over temperature indicated by RTD probes

In addition to this, the fans are activated once every hour for thirty seconds in order to regularly circulate air on order to prevent the build up of fumes. An override switch was also installed in the system because the fans can be quite noisy and if they cause too much discomfort the user of the car can shut them off manually. A schematic of the fan controller is attached as appendix G. A schematic of the system is shown in figure 12.

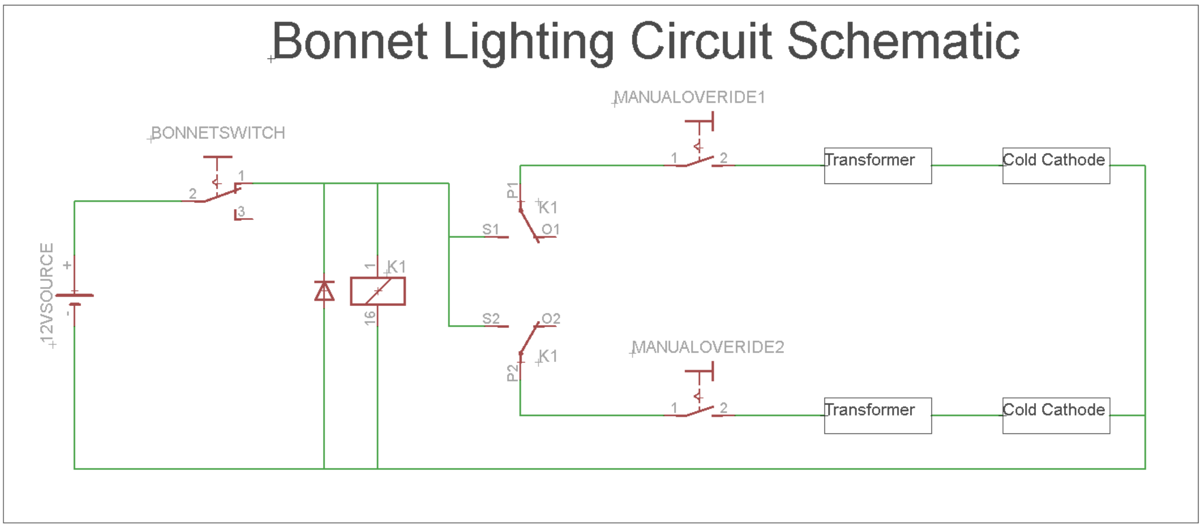
Figure 11: Fan Circuit Schematic



4.3: Bonnet Lighting

The final addition to the Getz functionality is bonnet lighting. This is a system which lights up the interior of the engine bay when the bonnet is open. When the bonnet closes the lights automatically turn off. This system is very similar to the way that fridge lighting works. The lights were installed in order to increase the aesthetic appeal of the engine bay. This circuit works by controlling the 12V input signal into a relay. The signal is controlled by a normally closed switch which is activated by closing the bonnet. Two manual override switches were also installed in the circuit in order for the lights to be turned off easily in case the charge of the battery needed to be preserved. A schematic of the installed system is shown in figure 13.

Figure 12: Bonnet Lighting Circuit Schematic



5: Electrical Designs for the Lotus Elise Conversion

The second vehicle that was worked on during 2009 is the 2002 Lotus Elise that was imported from England this year. The Internal combustion motor was removed and replaced with a 400V, 400A, 75kW three phase brushless DC motor. This motor is to be powered by 99, 3.2V, 60Ah Lithium Iron Phosphate batteries giving a total energy storage capacity of 19kWh. Power is fed to the motor by firstly going through a series of contactors and then through a motor controller which takes a DC input and outputs the PWM DC Power signals. The Lotus runs a 12V auxiliary and safety relay system that is simpler and smaller then the Getz system. This is because the Lotus was designed for performance and as such, in order to maximise the power into the motor and minimise weight, the auxiliary systems were kept to a minimal level. The total cost of conversion, including the purchase, for the Lotus Elise was approximately $80,000.

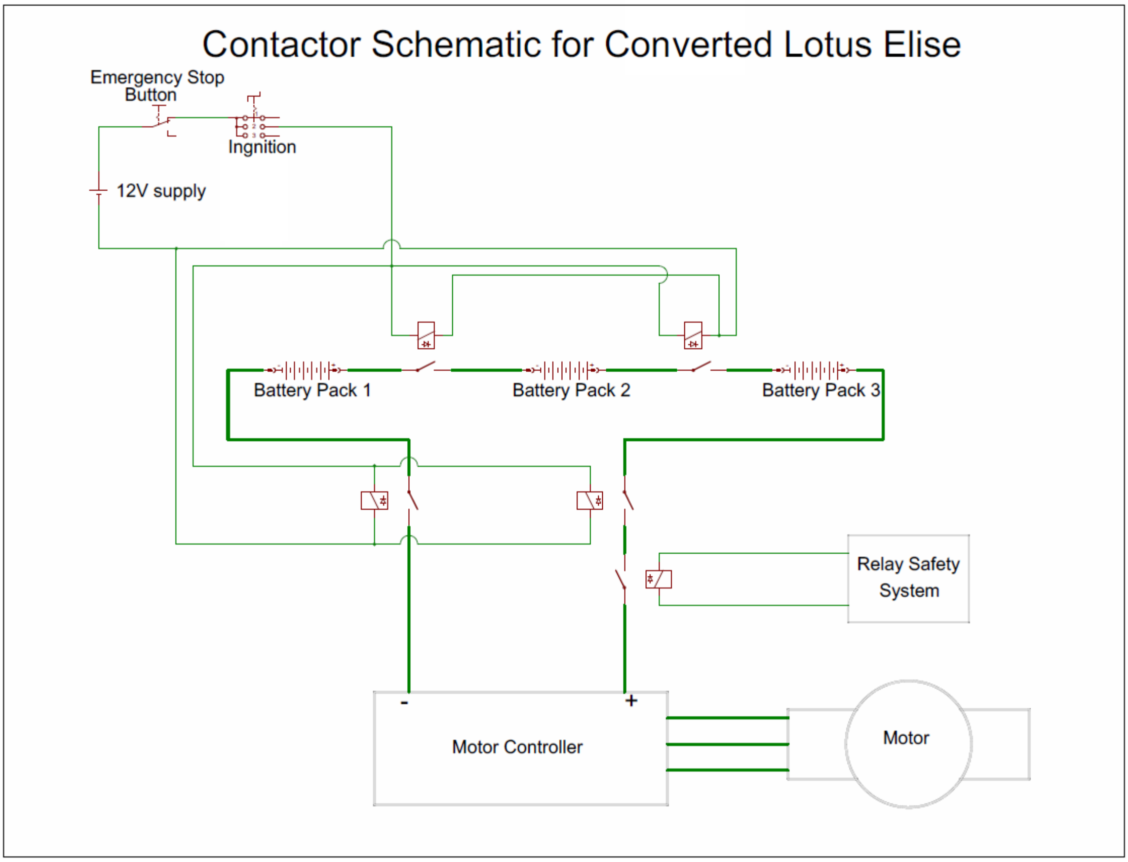
5.1: High Voltage Design

The main restriction in the design of the high voltage electrical system for the Lotus Elise was space. As the Lotus is a weight reduced stream lined sports car, there is not as much space to work with. This caused the battery pack to be split into three different sections. The first section was to contain 28 batteries, the second section contained 49 batteries and the third section contained 22 batteries. Each pack is isolated by an electrically controlled contactor that is normally open.

5.1.1: High Voltage Contactor layout

A set of main power controlling contactors is located on the main 400V line. These contactors are used to isolate the high voltage power supply from the motor controller and voltage converter. These isolators will are controlled from two points, an emergency stop button located near the motor in the boot of the car and via a signal from the ignition key. The first control system is setup so that if the emergency stop button is pressed, all the contactors break. The second control system is such that if the ignition key is rotated to the ‘Accessory’ position the four contactors make. This allows power to flow to the DC-DC converter, which enables it to supply 12V to the auxiliary system. The final isolation point is a sole secondary contactor on the positive high voltage positive supply line. This secondary contactor is controlled by a safety relay system, which monitors the status of the car and will only supply power to the contactor if all the safety equipment within the car indicate a safe status. The layout of this system is shown in figure 14.

Figure 13: Contactor connection Schematic for the Lotus Elise



The high voltage contactor system was designed this way for a number of reasons. Firstly and perhaps primarily, by choosing the contactors to be normally open the contactor system was made fail safe. Meaning that if there was a power supply or transmission fault within the system, the contactors would open. This helps prevent false isolation. False isolation is a very dangerous situation where an isolation action is ineffective and the piece of equipment is still active. If the person who attempted to isolate the piece of equipment starts to work on it assuming that it is safe to touch, an electric shock is very likely to occur.

Another key outcome from this design is that the high voltage DC will be completely isolated from the rest of the system when the ignition key is in the “OFF” position. This is a new safety standard that is being developed by the Western Australian Department of Planning and Infrastructure. The new standard is necessary primarily because when someone who is unfamiliar with the vehicle turns the key to the “OFF” position, the vehicle is perceived as being deactivated and safe to work on. In particular, if an emergency respondent is at a vehicle accident, procedure dictates that to ensure the vehicle is safe and isolated the ignition is turned “OFF” and the keys are placed on the dash. Therefore, it is necessary for us to comply with that standard in order to ensure the safety of unfamiliar car users such as emergency respondents.

If all five contactors activate, power is allowed to flow from the traction pack to the motor controller. The motor controller currently installed in the Lotus is a DD45-400L Inverter/Controller. It takes a positive and negative high voltage DC input and outputs three pulse width modulated DC signals. The controller is able to output 400VDC for an input voltage that ranges between 150 and 400VDC. If the supply voltage exceeds these limits the motor controller will shut down. These three pulse width modulated signals are then passed to the motor as three phases.

5.1.2: Motor controller

The motor controller takes a 19 pin input connector that is used to control the various functions of the motor. However, control of just six of these inputs will enable the user to fully control the motor (20).

Pin D, the first controlled input is a simple 12V enable signal; this signal is used to enable and disable the motor. If a constant 12V signal is applied to the line, an enable signal is read by the controller and the motor controller starts to receive commands. This 12V signal is connected directly to the output of the ignition. When the ignition is turned to the “run” position a 12V signal is sent down this line, essentially enabling the activation of the motor.

Pin E, is an input that defines the direction of the motor. When 12V is put on this pin the motor moves in a clockwise or “forward” direction. When the pin is connected to ground, the direction of motor rotation is anticlockwise or “Reverse”. This signal will be controlled via a 12V relay; the relay will be activated via a switch that will be located in the cabin. When the button is pushed the switch contact will close and the relay will activate, switch from 5V to GND. The reverse signal will have no effect if the motor is rotating.

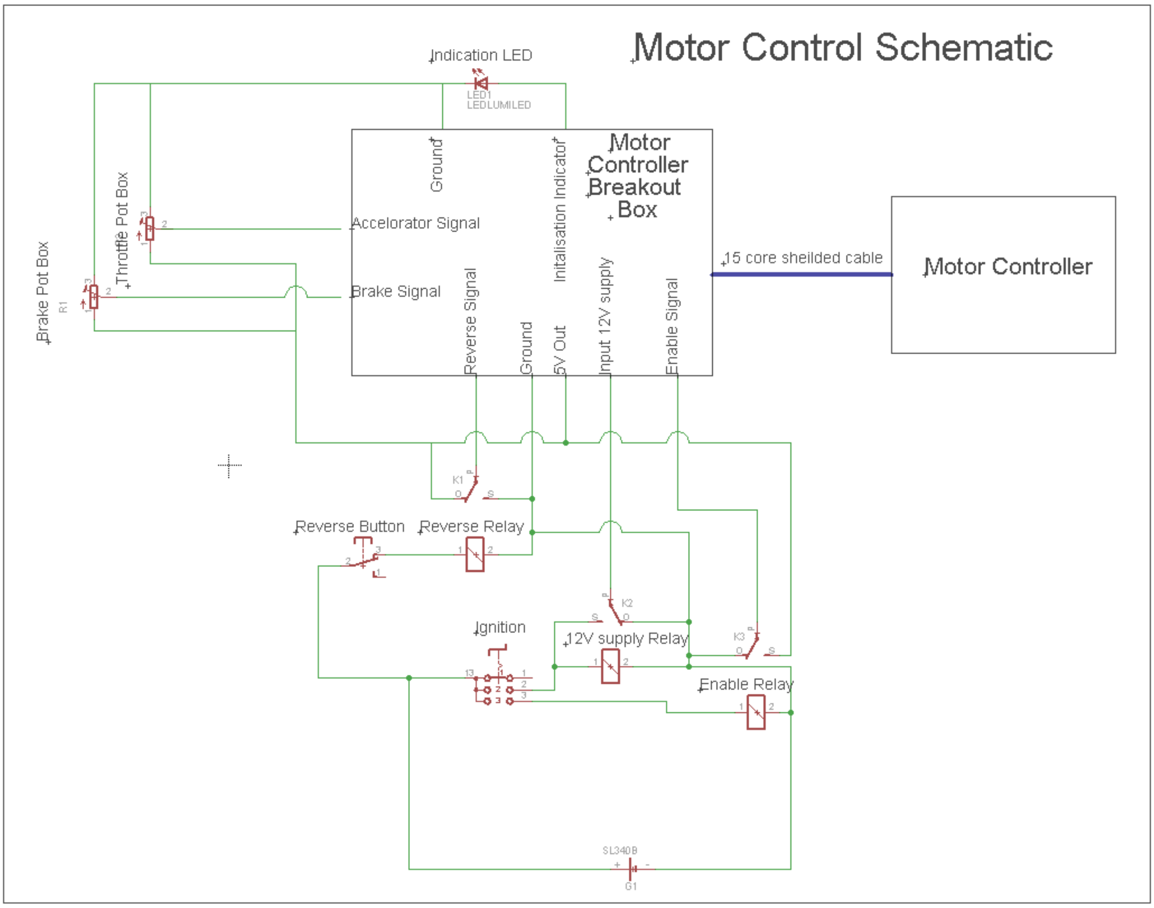
Pin F is an output that indicates that the software drivers on the motor controller have initialised correctly and are ready to receive inputs. This output is for LED indication status only as the output is limited to 3mA at 12V. This output will be used to drive two LEDs in series. One LED will be in the breakout box in the rear of the car and the other LED will be in the cabin of the car. The LED in the cabin will be a visual indication to the driver that the car is on and in a driveable state. It was determined that this was needed after numerous test drivers commented that they could not tell if the car had started.

Pin L, is to control the magnitude of regenerative braking occurring in the motor. The pin accepts a 0.5V to 4.5V input signal to control the magnitude of the total braking capacity. The magnitude response of the regenerative breaking system to the input control voltage can be set via software for greater control. The factory standard gives this a totally linear relationship; that is, for each 0.1V increase in the input signal, the total magnitude of the possible regenerative breaking is increased by 2.5%. This input signal will be controlled via lever “Pot Box”. The Pot Box used in the Lotus conversion is a three wire Curtis PB-6. The operation principle of the Pot Box can be described as the following; the top and the bottom of a 5kΩ resistor are bound to 5V and 0V respectively. A movable tap is then placed on the resistor that can move from end to end. The output is then taken from this tap. In this way, a voltage divider is essentially set up. By varying the position of the tap, one is essentially varying the resistor values above and below the output, which achieves a very linear voltage variation. In this case the tap position is controlled by a lever. This lever is then connected to a steel wire which connects to the brake pedal through a system of pulleys developed by William Price and Jennifer Berry. The mechanical brakes have been left unchanged and as such the regenerative braking is activated in parallel with the mechanical braking. In the future we plan to adjust the regenerative breaking profile to achieve 100% breaking at a lower input voltage.

Pin M and is used to control the power to, and hence the acceleration of, the electric motor. Like the brake, the acceleration control takes a 0.5V to 4.5V input voltage signal and controls the power being sent to the motor. The relationship between voltage and magnitude response can be set in software in a similar way to the regenerative braking. As a factory standard, the relationship between voltage and magnitude response is linear, with each 0.1V increase in control signal corresponding to an increase of 2.5% of maximum power output. This may be tweaked at a later date after extensive testing of the Lotus is completed. This control signal is controlled in the same way that the regenerative braking input signal is controlled; via a three wire Pot Box. The Pot Box's output is controlled by a pre-existing steel wire that runs from the accelerator to the rear of the car.

A schematic of the interconnection of the system is shown in figure 15. Note that the relays that control the signals fed to the motor controller will be integrated into the 12V power distribution and safety contact board, which will be discussed later.

Figure 14: Motor Control Signal Circuit Schematic



The break out board is a simple printed circuit board design that enables easy connection of the 19 pin connector to the various signal wires. It is simply a system of pluggable input screw terminals that directly connect with either output screw terminals or a DB9 connector. The pluggable screw terminals carry either 12V or 5V control signals, where as the DB9 connector is used for a serial interface with the controller. The board is shaped to be 5cm by 10cm in order to fit neatly into a space in the engine bay. The board also has a sole LED that is placed in series with the software initialisation line. This was done to give a visual indication in the engine bay that the motor controller software had initialized correctly. The decision to place the LED in series and not parallel was made due to the fact that the output of the indication line is limited to 5mA. The break-out box design was collaboration between Cameron Watts, Dashk Varhma and William Price. The final layout of the PCB is shown in figure 16 and 17.

Figure 15: Motor Controller breakout PCB Top Layer

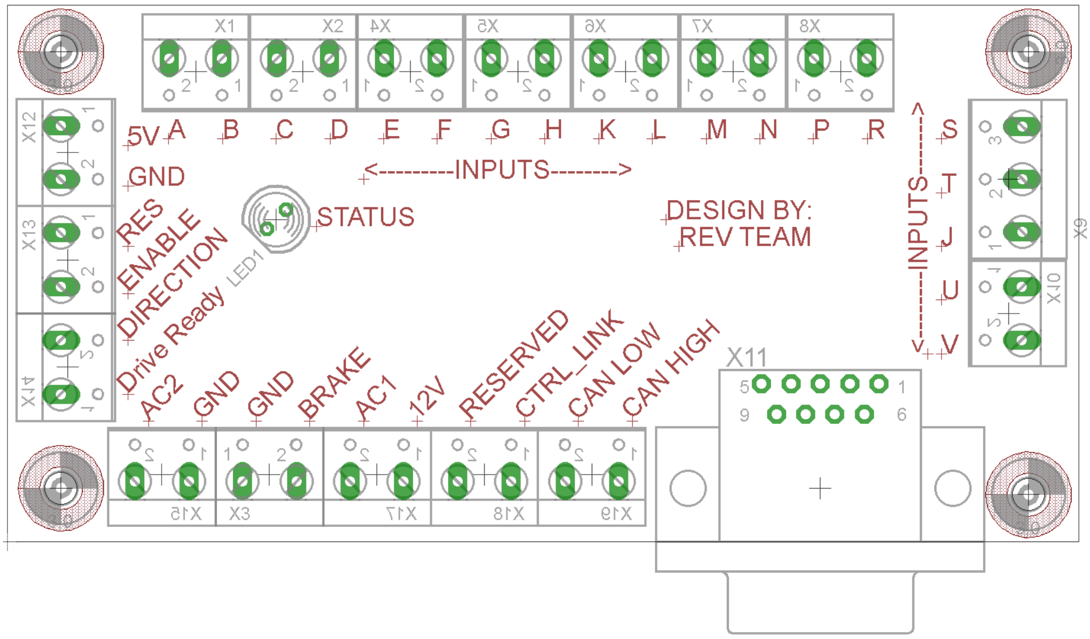
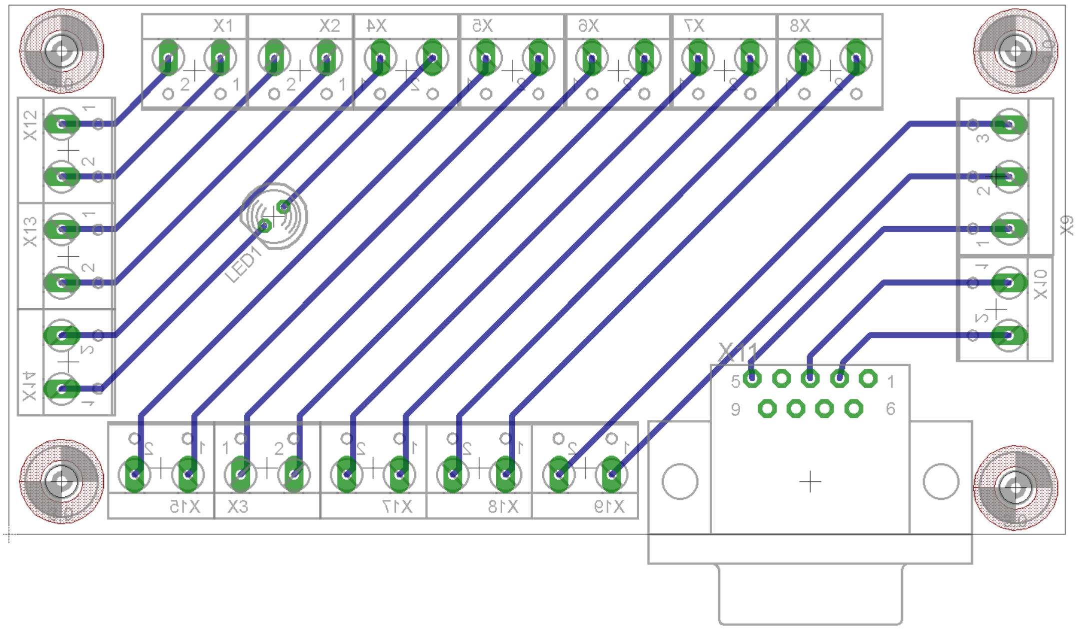


Figure 16:Motor Controller Breakout PCB Bottom Layer



5.1.3: Charging system.

The purchase of the battery charger for the Lotus had to meet a number of difficult objectives. Firstly, it had to convert 240VAC to 400VDC; this is problematic as there are very few commercial chargers that will output such a high voltage. The charger also must be able to be powered from a 15A power outlet that would be present in most homes. These are the only two mandatory requirements for the charger. If a potential charger met these requirements, it would be ranked by a set of secondary requirements. They are as follow:

Parallel abilities: The charger had to have the ability to be placed in parallel with another charger. This was necessary as a concept has been developed that involves charging electric vehicles from high power recharge points. The points are able to supply high currents at variable voltages, which enables a rapid or "fast charge" of the battery pack. In order for this implementation to be successful, we must have a system in the Lotus that is able to take both this high power input and a regular 15A household input.

Price: Chargers can be quite expensive, ranging from $2,000 to $10,000 dollars. Obviously, the cheaper the charger is the more it would be considered.

Flexibility: We would ideally like a charger with a fully programmable charging profile allowing us complete control of the output voltage and current profile of the charger. This will enable us to more effectively charge the batteries and will also enable some research into the effectiveness of different charging profiles.

Weight: Every kilogram we add will decrease the performance of the vehicle and as we are designing the Lotus to be a performance car, the added weight should be minimised.

Output power: The higher the total output power the shorter the charge time of the batteries will be.

With these factors in mind a list of potential chargers was developed. This list is shown Table 2.

Table 2: Comparison of Battery Charger Quotes

	Power	Max Voltage	Max Current	Price (AUD)	Weight	Programmable	Parralelable
Metric mind NLG523-SA	6.7kW	400V	25A	$9,605	6kg	Yes	Yes
Metric mind NLG513-SA	3.3kW	400V	12.5A	$5,565	3kg	Yes	Yes
Manzanita Micro PFC75M	15kW	400V	50A	$4,980	22kg	No	No
Manzanita Micro PFC20	6kW	400V	20A	$2,330	8kg	No	No
Battery Space HV Li-Ion Smart Charger	3kW	400V	12A	$2,518	10kg	No	No

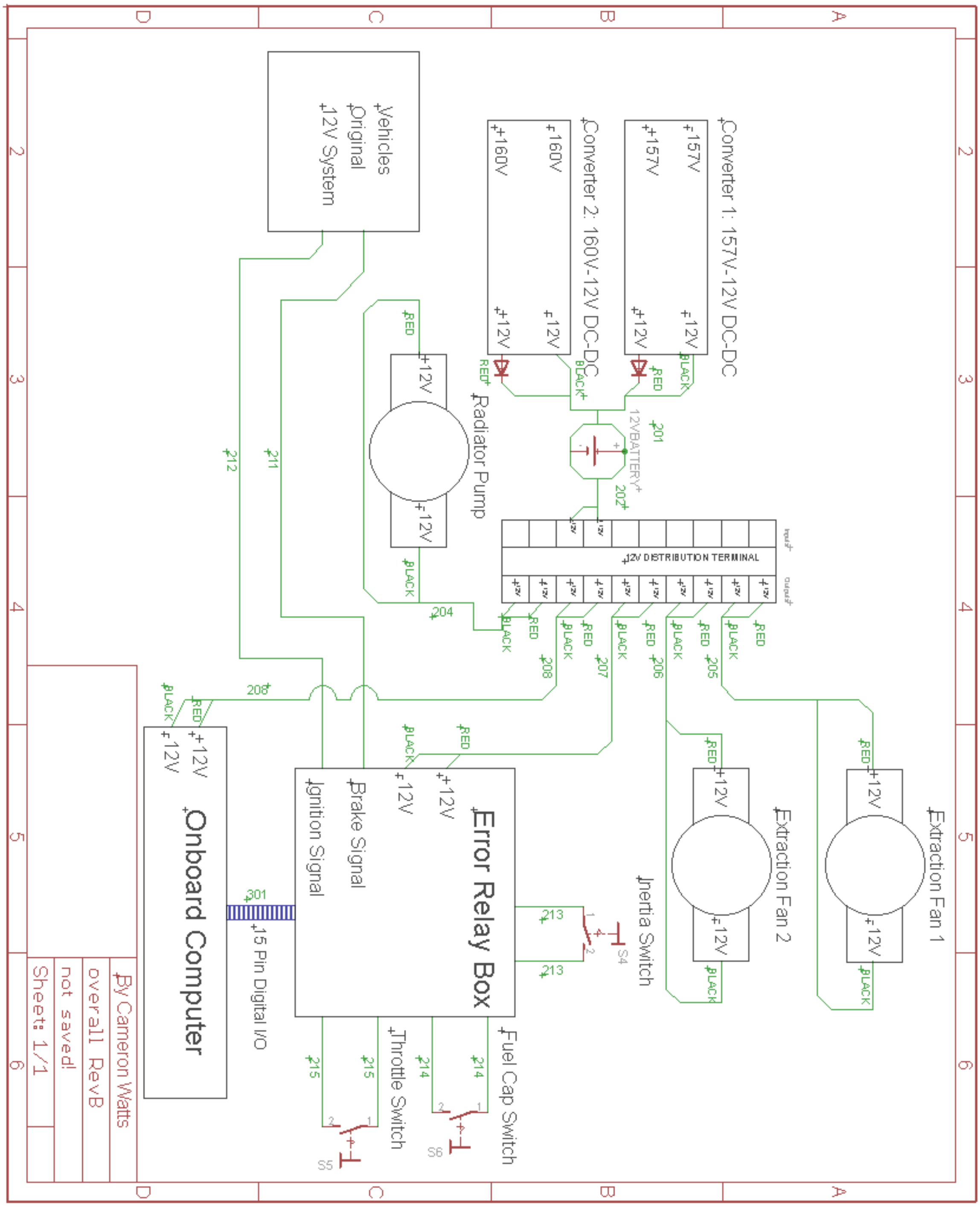
After detailed discussion with the project supervisor and manufacturer, it was decided to purchase the Brusa NLG513-SA charger. Despite the high price of the charger, it was justifiable to purchase due to the fact that it was the only charger to be fully programmable and easily placed in parallel. The NLG5 is a 3.3kW charger that was imported from the United States of America. The charger can take an input voltage of 240V at 50HZ and can output 0-400VDC and 12.5A (21). Software is provided with the charger that will enable us to program various modes of the charger. This will enable us to easily switch the charging profile that is used depending on the power source available. The most likely cases being a 10A input, 15A input or specialised charge station input. The formal quote comparison can be found in Appendix H of this report.

As mentioned before, the traction pack that exists in the Lotus consists of 99 units of 3.2V, 60Ah Lithium Iron Phosphate batteries. These batteries have a total energy storage capacity of approximately 19kWh. If the converter was running at full power the entire duration of charging time, it would take approximately 5 hours to fully charge the battery pack. In the future, plans can be made to purchase a second NLG5 charge which can be easily put in parallel. This would double the output power of the charging system and thus half the charging time.

5.2: The 12V System.

The 12V system in the Lotus Elise is generally simpler then the Hyundai Getz. This is due to the fact that there are fewer supplemental systems in the Lotus, there is no Air-conditioning, power steering or assisted braking. The main components contained within the 12V system are as follows: two 180VDC-12VDC converters, 12V battery, 12V power distribution and safety relay board, radiator pump, on-board PC and multiple extraction fans. In addition to this, provision has been made for the addition of an Engine Audio Replication System (EARS) to the vehicle. A schematic of the 12V system is shown in figure 18

Figure 17: Lotus Elise 12V System Design



5.2.1: DC-DC Converters

The DC-DC voltage converters were one of the more complicated installations of the 12V equipment. The first challenge was determining how much power was required to run the 12V system. To do this the current draw was determined from the manufacturer's data sheets to approximate the required current for the radiator pump, extraction fans, Lead acid battery and on-board PC. The power being used by the pre-existing 12V system was then measured by placing a clamp meter around the 12V battery output. Finally, to approximate the power required by the EARS, we used a clamp meter to measure the current going through an equivalent sound system. The measured data can be found in the table below:

Table 3: Measured current values in the 12V system.

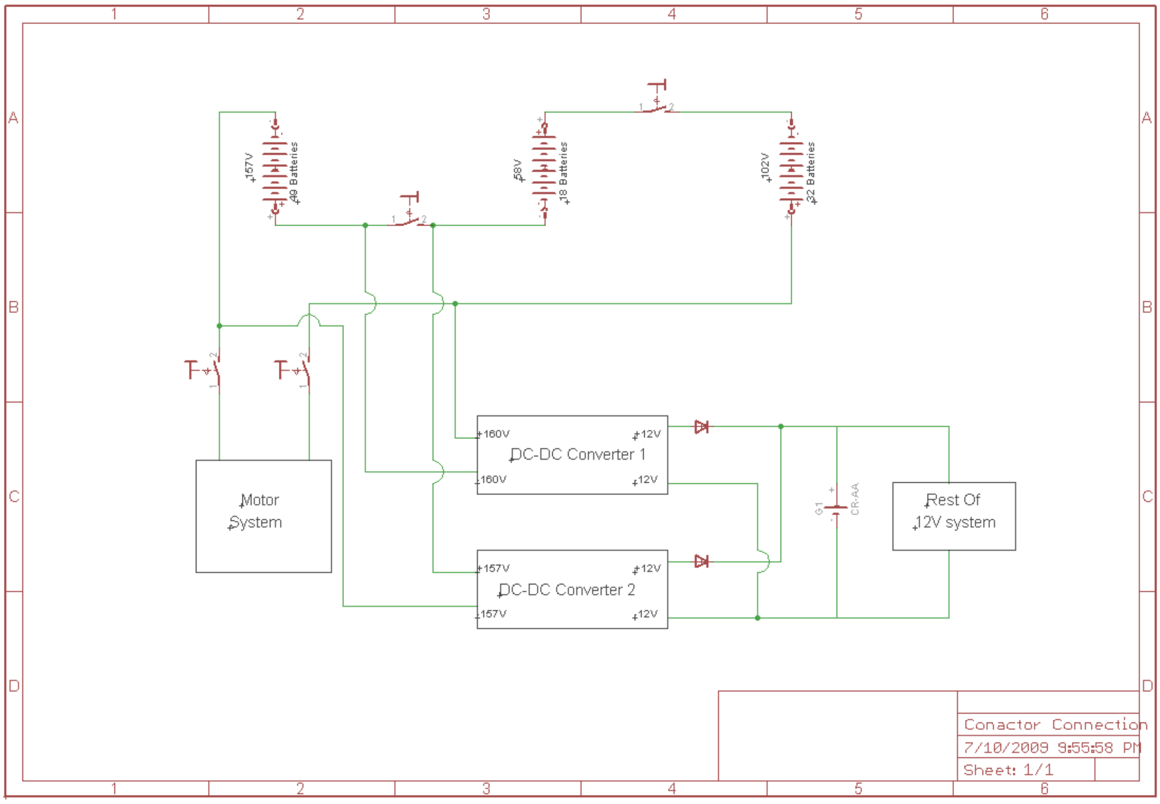
Item	Max sustained Current Draw	Equivalent Power
Radiator	2 Amps	24 Watts
Extraction Fans	2-6 Amps	72 Watts
On Board PC	3 Amps	36 Watts
Pre-existing systems	7 Amps	84 Watts
Battery Recharge	10 Amps	120 Watts
EARS System	20 Amps	240 Watts
Total	49 Amps	588 Watts

From these measurements it can be seen that we require about 50A or a 600W power supply in order to appropriately power the 12V system. The initial idea for the voltage converter setup was very similar to the Getz, where all the power is supplied from a single unit. As such, an attempt was made to find a 600W 400VDC-12VDC converter. However, a converter with these specifications was very hard to source. The closest mass produced converter was a 600W 370VDC to 12VDC converter. Although the nominal battery pack voltage was well below this level at 317VDC, the battery management system that is being developed for the Lotus will charge the battery pack up to a level of 376VDC. The battery pack charge voltage could have been reduced to 370VDC but that would have extended the charge time of the batteries considerably. This is because the higher the battery voltage goes above the nominal value the faster the charge can be distributed throughout the individual cells (provided the voltage level is within safe values). As such, it was decided that an alternative solution had to be developed.

There were two primary alternatives to this design. We could either have a custom converter ordered at high cost and long lead time or we could use two converters, each powered from half of the battery pack, effectively halving the input voltage. The decision was made to go with the dual converter configuration. This was because the custom converter would be more expensive and a long lead time could not be afforded as the deadline for the Lotus was fast approaching.

As such two 300W 200VDC to 12VDC converters were ordered and a design was developed. The design consisted of connecting one converter across a single 49 cell traction pack and the other converter across the 18 cell and 32 cell battery packs. This gives a nominal input voltage of 157V and 160V respectively. These are connected such that when the battery packs are isolated the power supply for the converters is cut. By connecting the input in this way ensures that the converters are off when the car is idle and will activate when the key switches to the ‘accessories’ position. This is vital as the converters have a standby power of 18W each, which would unnecessarily waste power. Blocking diodes were also placed on the positive output of the converter. This was done to prevent any damage that may be done by the battery applying 12V across the output terminals of the converter when it is switched off. A diagram of this setup is shown on the next page. Note that the input voltages to the converters are nominal.

Figure 18: 12V Supply Circuit Schematic for the Lotus Elise



5.2.2: Lead Acid Battery

The next item installed in the 12V system is the 12V Lead acid battery. The 12V battery that will be used in the Lotus is likely to be reduced size sealed Lead acid battery. The battery used is a 10AH sealed Lead acid battery. This battery has 25 minutes of reserve power at a power draw of 300W. It has a maximum discharge current of about 115Amps and a maximum charge current of about 10Amps. A 12V battery is necessary in this system due to the fact that having a battery in parallel with the converter system causes the battery to essentially behave like a large capacitance. This enables the 12V system to briefly draw high amounts of energy from the supply system without straining the converters. In addition to this, the 12V battery is essential to the safety of the vehicle. In the event of an accident, the high voltage connection to the battery pack is severed, meaning that power is no longer fed to the converters. It follows that if a 12V battery was not present in the system, then the 12V system would not have power and safety critical systems like hazard lights and head lights would be non-functional. As such it is essential to have some form of battery backup for the 12V in order to keep the 12V system running in an emergency situation. In the future, the

Lead acid battery mat be downgraded or changed to a Lithium based battery in order to reduce the weight of the vehicle.

5.2.3: Lotus 12V Distribution System

The next critical piece of equipment in the 12V system is the 12V distribution system. The 12V distribution system is responsible for safely and efficiently distributing power to the various pieces of 12V equipment. The pieces of equipment the 12V is responsible for powering are the radiator pump, on-board PC, relay safety system, motor control relay system and 2-6 cooling fans. In addition to distributing power, the distribution system is also responsible for the fusing of all of the 12V equipment. This is done in a similar way to the Getz, using screw terminals to provide an input to and output from various fuses. Using this design stops pressure being applied to the solder connection on the fuse and enables easy connection and disconnection of the fuse connection wires.

Unlike the Getz, the static power dissipation of the Lotus 12V system is relatively low because there is no hydraulic pump or vacuum pump. As such, there is no need to split the power distribution into two levels. This enables a much simpler distribution design. Because of this simplified design, the distribution printed circuit board was combined with the relay board in order to give a more compact installation.

5.2.4: Lotus Safety Relay System

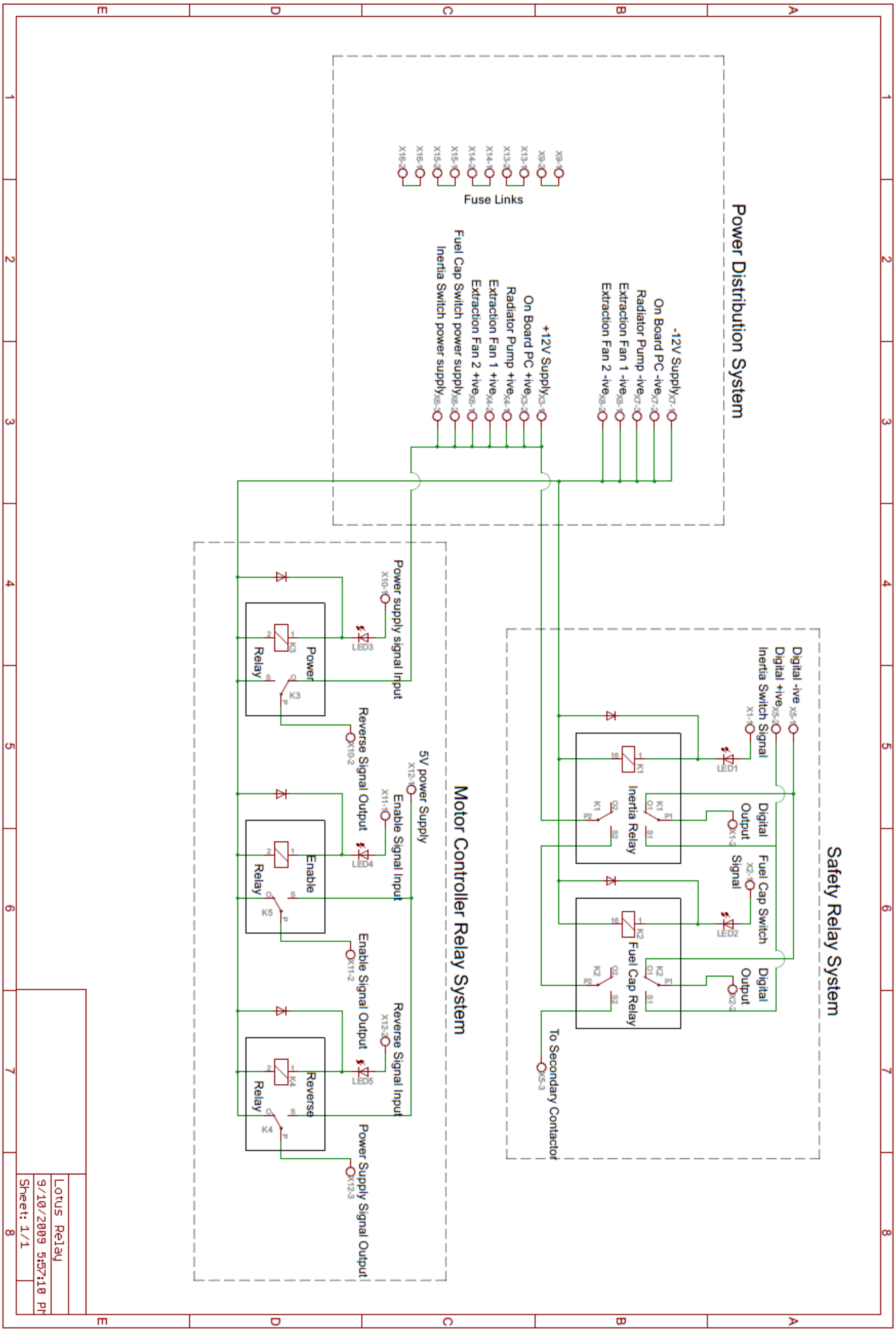
The safety relay board in the Lotus is quite simple in comparison to the Getz with only two external safety signals being monitored. Those two signals are the inertia switch signal and the fuel cap switch. The fuel cap signal is generated from a micro switch contained within the charging socket. When there is a plug present in the socket the switch opens and the 12V signal to the relay board goes low, indicating an “unsafe” status. The inertia switch was installed as a requirement of licensing issued from the DPI. If the inertia switch has force acting on it greater then 14N the switch will open and the 12V signal will go low, indicating an “unsafe” status.

In a similar manner to the Getz, the signals are fed into two individual double pole, double throw relays. One of the outputs from the inertia relay is connected to the switched input of the fuel cap relay forming a small daisy chain. 12V is then put on this line and the output is fed directly to the secondary contactor. Both relays are connected in a normally open configuration meaning that both coils of the relay must be activated in order for the circuit to be closed and allow power to flow to the secondary contactor. In this way the safety system is made to be fail-safe, i.e. if the power supply fails for some reason the secondary contactor will not close. The other side of the relay will provide a 5V digital output that can be fed into the onboard PC for monitoring.

5.2.5: Lotus PCB Schematic and Layout

In addition to these two systems, for convenience, the motor control relay system will also be put on the same board. The final schematic for this board is shown in figure 20.

Figure 19: 12V distribution and Relay Schematic



Etching this board was relatively simple; as the two relay systems are independent of each other, no cross over between the two necessary. As such it was possible to modularise the board design. The top left hand side of the board contains the relay safety system. The bottom left hand side of the board contains the motor control relay system and the lower right hand side of the board contains the power distribution system. The track that runs though the 12V distribution terminals was made to be approximately 250thouwide. This would give it the ability to carry approximately 13A continuously. As the maximum required current from the 12V system is approximately 11A, the track width should be sufficient to provide adequate current to the system. Each fuse terminal link is etched with a track width of approximately 100thouwhich gives the tracks a current carrying capacity of approximately 5A. The track width that runs from the power distribution line to the first single pole relay was also increased. This was because this line needed to provide power to the motor controller in the situation where the motor controller needed to be powered without the high voltage input being connected. The track width for this line is approximately 100thouwhich gives a current carrying capacity of five Amps as required. The rest of the tracks are etched with a thickness of approximately 16 thou. The final board layout of this design is shown below.

Figure 20: 12V Distribution and Relay PCB Top Layer

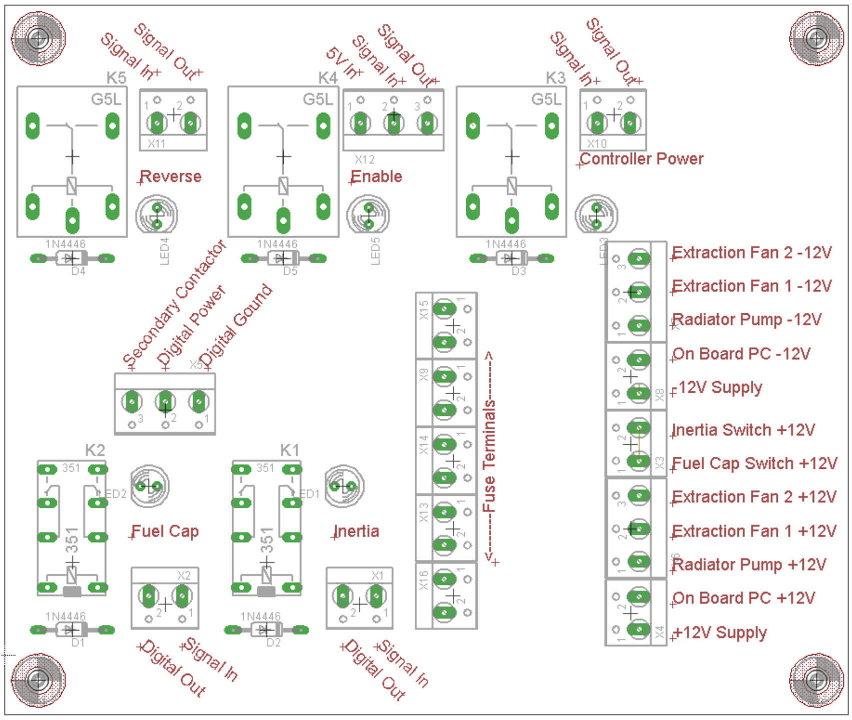
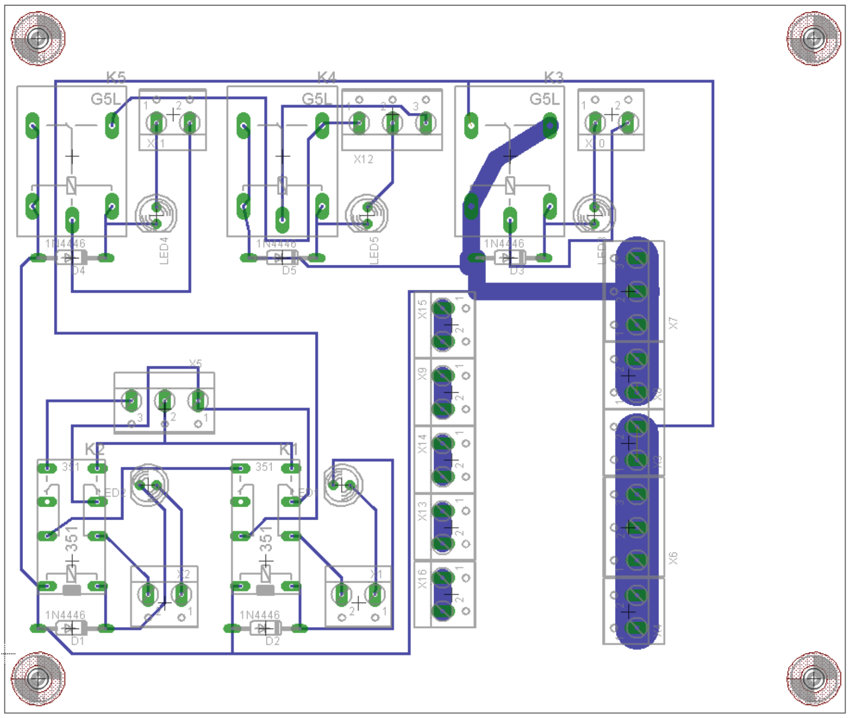


Figure 21: 12V Distribution and Relay PCB Bottom Layer



5.2.4: Miscellaneous 12V Equipment

The other miscellaneous pieces of 12V equipment are the onboard PC, radiator pump and extraction fans. The onboard PC was selected by Dashk Varhma and Daniel Kingdom. As such, electrically speaking, the only thing that needed to be done was to connect a power supply to it. The radiator pump is similar, with Daniel Harris and Christian Tietzel responsible for its selection. Again, electrically speaking, only power needed to be supplied to this piece of equipment in order for it to function correctly.

The final piece of 12V equipment that needs to be considered is the extraction fans. At the time this thesis was written, the exact quantity and nature of the extraction fan system was unspecified. This is due to a lack of output from other sections of the REV team. As such, no specific design has been developed for the inter-connection of the fan extraction system. However, provision has been made for the inclusion of this system at a later date. These provisions consist of the following:

- A reserved power generating capacity in the 12V system of 72 watts
- Two free +12V connections on the power distribution board
- Two free –12V connections on the power distribution board
- Two free fuse link connectors.

6: Administrative tasks associated with work

During work on the Hyundai Getz and the Lotus Elise a number of administrative tasks had to be performed in order for the project's electrical team to be successful. The main facets of these can be divided into two sections: Documentation and Safety.

6.1: Documentation

At the beginning of the year it became obvious to those being the project that no documentation system existed for the REV Project. This made familiarising ourselves with the project very difficult. There was no formal data base and no document reference system. As a result, finding information on the conversion of the car was problematic. It was later discovered that not all modifications that were made to the car were documented. Furthermore, it had become evident that some of the documentation pertaining to the conversion was inaccurate, and as such could not be reliably used. Due to this lack in documentation our productivity during the beginning of the year was diminished.

Because of this experience it was decided early in the year to develop a formal documentation system that efficiently referenced the documents associated with the project. As such a numbering system was developed. This system consisted of five fields.

The first field is constant. It consists of the letters "REV", this prefix associates the document with the REV project. Any documents that exist within the REV project data base should have this prefix.

The next field is used to identify the vehicle that the document is associated with. At the moment, the options for this field are: "GET" or "ELI". The field "GET" associated the document with the Getz electric vehicle and the field "ELI" associates the document with the Lotus Elise Electric Vehicle.

The third field determines what discipline the document is associated with. The options for this field are as follows:

- E: Electrical
- G: General
- I: Instrumentation
- M Mechanical

The fourth field is used to identify the type of document. There are options for this field they are:

- DAT: Data sheet or manual
- DWG: Drawing
- SCH: Schematic
- SPE: Specification
- TER: Termination

The final field in the system is a number. This field ensures that each document has a unique identification code. In the future, it could be set up such that groups of numbers refer to specific topics within the specified field but as the documentation system is still quite new, a system like that has not been set up yet. An example of a document number that uses this system is: REV-GET-ELI-SCH-010. This document number would reference an electrical schematic associated with the electric Hyundai Getz.

Using the lessons learnt from the beginning of the year, the electrical team strived to document all the modifications made to the electrical system of both the Lotus and the Getz. This resulted in a large data base being developed that held all of the electrical information.

A table of the documents contained within the electrical database is shown below:

Table 4: Electrical document contained within the document system

Number	Description
REV-GET-E-SCH-1005	Getz 12V power Distribution Schematic
REV-GET-E-LAY-1002	Getz 12V power Distribution Layout
REV-GET-E-SCH-1004	Getz Safety Relay System Schematic
REV-GET-E-LAY-1001	Getz Safety Relay System Layout
REV-GET-E-LAY-1000	Getz Overall connection
REV-GET-E-SPE-1000	EV POWER TS90 Battery Management
REV-GET-E-SPE-1001	Getz 500W DCDC Converter
REV-GET-E-SPE-1002	Thunder sky Battery Manual
REV-GET-E-SCH-1012	Air conditioner connection schematic
REV-GET-E-SCH-1013	Bonnet lighting connection schematic
REV-GET-E-SCH-1014	Extraction Fan Connection Schematic
REV-ELI-E-LAY-1000	Lotus Overall Layout
REV-ELI-E-SPE-1000	UQM PowerPhase75 Manual
REV-ELI-E-SPE-1001	Brusa Charger Manual
REV-ELI-E-SPE-1002	Lotus 300W DCDC converter Data Sheet
REV-ELI-E-SCH-1001	Lotus Relay and 12V distribution Board Schematic
REV-ELI-E-LAY-1001	Lotus Relay and 12V distribution Board Layout
REV-ELI-E-SCH-1002	Lotus motor Controller Breakout Board Schematic
REV-ELI-E-LAY-1002	Lotus motor Controller Breakout Board Layout
REV-ELI-E-SPE-1003	Lotus 28W DCDC converter Data Sheet
REV-ELI-E-SCH-1000	Lotus contactor interconnection Schematic
REV-ELI-E-SCH-1003	Lotus Motor Control Schematic
REV-ELI-E-SPE-1004	National Guidelines for the Installation of Electric Drives

6.2: Safety

The other key consideration taken into account when working on the electric vehicles is safety. Individual and group safety is paramount to the continued success of the REV project. The project has implemented a number of safety standards in order to protect the team members from potential harm.

The first safety standard implemented by the REV team is the use of lab inductions. Lab inductions consist of introducing new team members to the lab conditions via a power point presentation and guided tour. These are essential to the safety of the team members as there are many potential hazards in the lab. The presentation and guided tour enables them to identify potential hazards and will help them act appropriately in emergency situations.

The next standard implemented by the REV project was that there must be a minimum of two people present when working on the electrical system. This is a vital safety standard. If a person who was working on the electrical vehicle was to accidentally shock his or her self a second person would be near to disconnect the power. This is essential due to the fact that when electrically shocked, muscles spasm and the person who received the shock may not be able to disengage from the source of the electrical shock.

The final safety standard that pertains to the electrical team is to have hazardous voltage work completed by a qualified electrician. This safety standard was implemented to ensure that all of the hazardous voltage equipment would be terminated safely. This is required as, if a fault developed on the hazardous voltage system, serious injury to the persons using the car may occur.

7 Results

7.1 Results of the Work done on the Hyundai Getz

The work completed on the Hyundai Getz can be separated into two main sections: Getz electrical system redesign and addition of functionality to the Getz.

7.1.1: Getz electrical system redesign

Below is a photo of the Getz before the redesign work commenced. It is obvious to see the ‘tangle’ of wires mentioned in section 3.2. In addition to this, some of the previously existing electrical boxes are visible.

Figure 22: Picture of the Hyundai Getz Before Commencement of Works

The next picture below is a picture of the Getz 12V power distribution and relay box. Note that the' tangle' of wires has been effectively removed and all wires now terminate neatly into one centralised easily accessible location. Going into this box are 42 cables and over 90 individual terminations are made inside. A transparent lid was placed on the 12V box in order to see the LED indicators that were put on the Safety Relay Board.

Figure 23: Photo of the Installed 12V distribution and Relay Box

The system redesign can be considered a big success as it had achieved the following key outcomes:

- The static power dissipation was reduced from 300mA to 30mA.
- The reliance on the 12V battery for start up was removed.
- The aesthetic appeal of the bonnet area has been improved.
- The digital outputs for the safety relay system were repaired.
- A visual indication of the status of all the safety systems contained within the electric vehicle was created.
- The entire electrical system is now appropriately fused.
- The robustness of the installed system has been improved.
- The safety of the electrical system has also been improved.

7.1.2: Review of the Additional Functionality of the Getz

The bonnet lighting was an excellent addition to the Getz as it allowed for a more visually appealing presentation of the vehicle. It was particularly effective at highlighting components that were installed in the lower sections of the engine bay. The lights were also useful during work on the car as it increased the visibility of the area substantially. However, at the moment, the lights are only secured on the car with cable ties. If the bonnet lighting is to be a permanent addition to the Getz, then proper mounts must be developed for the installation.

The extraction fans were also an effective addition to the Getz. They were fully functional as of September 2009. Microchip control was successfully implemented and a serial port was added to the installation. The serial port enabled us to actively monitor the battery temperatures. The extraction fans effectively keep the battery pack cool. They are currently set to turn on at 45°c and when they are active, the average pack temperature does not exceed 48°c. They also actively circulate the air contained within the battery pack for thirty seconds every hour. However, the discomforting smell that was detected is still present. As such, it may be necessary to circulate the air within the battery pack more regularly or for longer intervals.

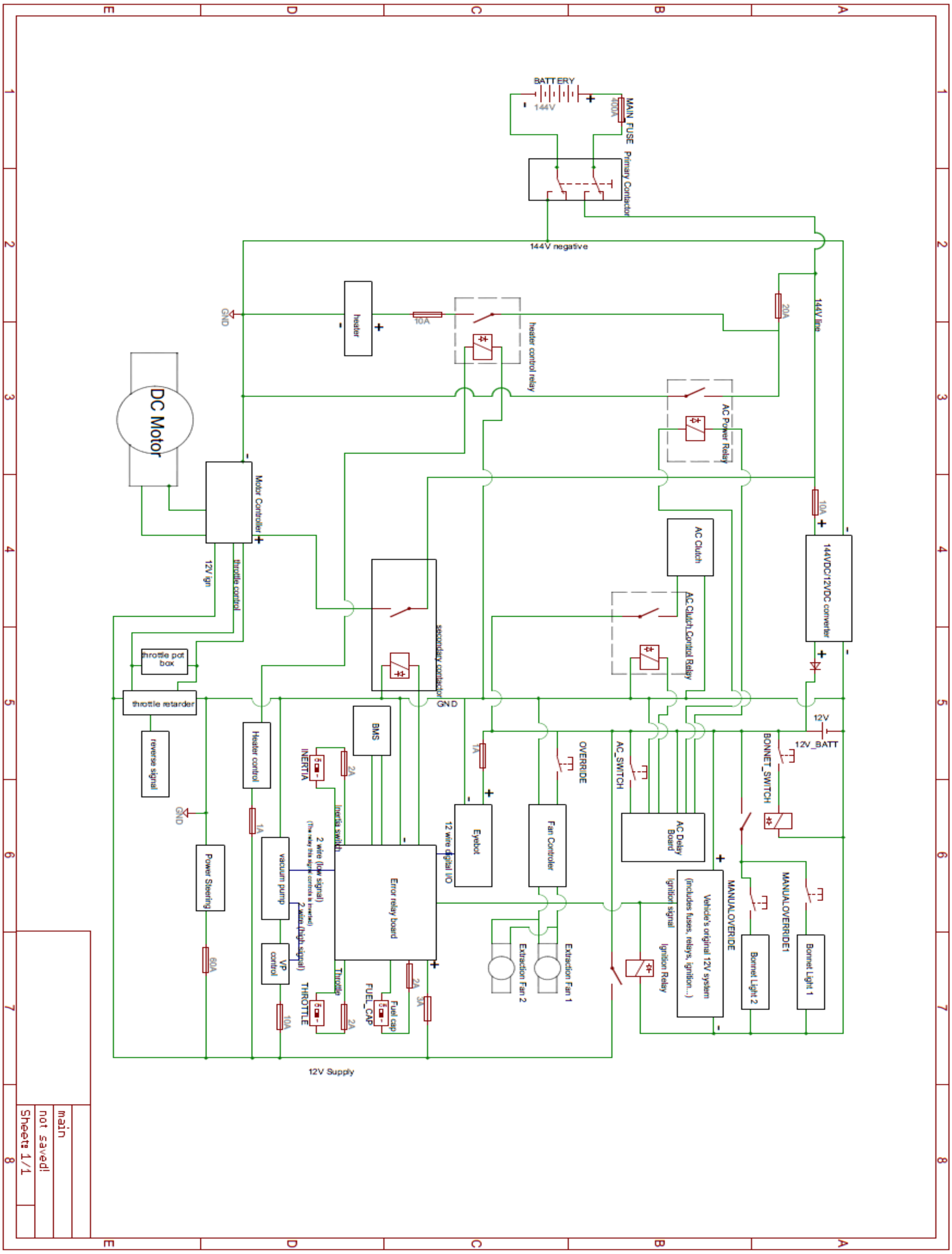
The air conditioner installation was partially successful. The air conditioner is fully powered and fused now. It is also controllable via a 12V signal controlling contacting relays. The installed delay board works well, delaying the signal approximately 2.4 seconds before activating. This gives the motor sufficient time to spin up before the clutch is engaged. However, as of October 2009, the 12V input signal has not been wired through the air conditioner button. This has not been done yet due to issues associated with integrating the pressure control of the air conditioner to the control signal. As such, the driver does not have control over the air conditioning system yet. It is suggested that in the future, a detailed investigation into this system be performed.

A picture of the Hyundai Getz as it was in October 2009 is shown in figure 25. One can see the new air-conditioner, the newly installed 12V power distribution and relay box.

Figure 24: Picture of the Hyundai Getz EV after completion of Works

A schematic of the overall layout of the Hyundai Getz Electric Vehicle is shown in figure 26. Note that this schematic was accurate as of the 11-11-2009.

Figure 25: Overall Electrical Design of the Hyundai Getz EV



]

7.2: Reveiw of the Electrical Design of the Lotus Elise Electric Vehicle

The design work done on the Lotus Elise resulted in a functional and practical electric vehicle design. As of October 2009 only a few of the systems had been built and tested. The motor controller system has been built and tested successfully. Also, thanks to the efforts of William Price and Cameron Watts, the brake and accelerator signals have also been constructed and tested. Each system generates a linear signal from 0.5V to 4.5V based on the respective pedal position. Photos of this system can be found in appendix X.

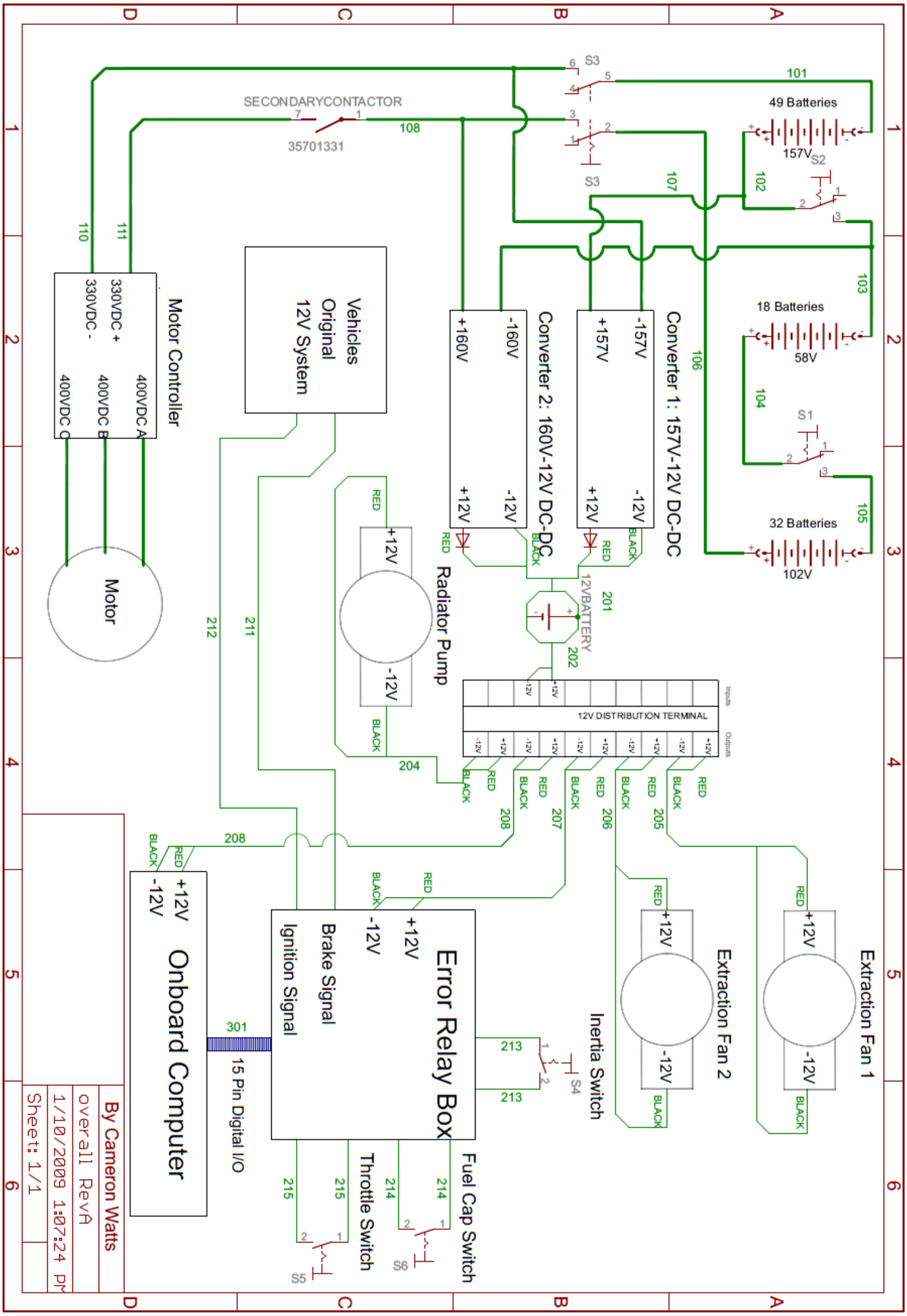
In addition to this the detailed design of the Lotus enabled us to purchase the charger, converter, cables, fuses, contactors, stop buttons, batteries and motor well in advance of the installation date. As well as this, the '12V distribution and relay board' and 'Motor Controller Breakout board' have both been etched and assembled. Photos of the boards are shown in figure 27 and 28..

The major holdup on the progression of the electrical installation is the finalisation and installation of the traction pack enclosures as they are yet to be completed. The mechanical team that are in charge of designing and constructing these cages have experienced multiple setbacks and as such have pushed the final installation date of the traction pack enclosures from mid August to late October. As the enclosures are not yet installed, the batteries were not able to be installed, and as such, the high voltage systems that have been designed have not been able to be installed and tested yet. In addition to this, until the battery cages have been installed in the motor controller and supporting systems cannot be mounted in the car.

Despite this fact, the design work done on the Lotus was vital to the progression of the REV project. It enabled us to purchase all of the equipment necessary for the installation of the electric motor. In addition to this, the delay in installation meant that the electrical design of the Lotus has been given time to be well thought out, and as such, the installation of the purchased systems should be fairly stream-lined and issue free.

A schematic of the final electrical design for the Lotus Elise is shown in figure 29.

Figure 26: Overall Electrical Design of The Lotus Elise EV



8: Conclusion and Future work

8.1: Conclusion

The work done on the electrical systems of the REV electric vehicles during 2009 can be considered very successful. The Hyundai Getz EV's electrical systems are now more robust and aesthetically appealing than ever. In addition to this, the electrical systems that were added to the Getz increased the comfort, reliability and appeal of the electric vehicle. By doing this, the project was able to move the Getz from a proof of concept status to a functional, practical and realisable electric vehicle model. And thus, by creating functional, practical and realisable electric vehicle models the REV project will establish that electric vehicle conversions are both practical and realistic.

In support of this concept, designs have been developed and the components have been purchased, for the electrical conversion of a 2002 Lotus Elise. With the designs complete and parts ordered and delivered the REV project believes that the Lotus Elise High Performance Electric Vehicle will be running by December 2009. Once this electric vehicle is running it will show the massive potential that electric vehicles have, particularly in terms of performance.

The work done on these two vehicles shows that through the implementation of recent advances in technology and the intelligent design of electrical systems, the massive potential of electric vehicles can be realised. A new era of electrically powered vehicles is fast approaching and the REV project is helping to power it forward.

Due to the nature of the vehicle conversions, there will always be the opportunity to do more work with them. From an electrical point of view there are a number of pertinent tasks that could be performed in order to improve the quality of the electric vehicle conversions.

8.2: Future Work

8.2.1: Engine Audio Replication System (EARS)

The Engine Audio Replication System is currently a software system that takes a variable input and outputs a replicated engine sound. The pitch at which the sound is generated depends on the input signal. As such, if the input of the EARS system is connected to the output of the tachometer then a simulated engine noise will be generated that is directly linked to the rate of revolution of the motor. The processing and interconnection of this system will be quite complex, as the ultimate aim of this project is to modularise the project. This would enable it to, hypothetically, be connected to any car system.

8.2.2: Accelerator and Brake Tuning

The UQM motor controller came with software that enable the user to program the response of the motor to the variable accelerator and brake input signals. In order for an optimum response of the motor system to be achieved, extensive tuning of the motor response would need to be completed. This may be a lengthy process, especially when tuning the regenerative braking due to the many interlinking factors involved in regenerative braking. Some of these factors are:

- braking distance
- braking feel
- diminishing braking effect at lower motor speeds
- power absorption of the batteries
- overall system efficiency

8.2.3: Charger Tuning

The traction pack charger also comes with software that allows the charging profile to be tuned. The chargers output power can be fully profiled by adjusting both the out current and output voltage. The suggested way to charge Lithium Iron Phosphate batteries is to firstly provide an optimal constant input current at approximately 0.3C and then, when the chargers power capacity has been reached, switch to a fixed voltage supply (22). However, where this point lies will change with each traction pack and with the available power the charger has. As such, charging profiles need to be developed for the following power sources:

- A 10A, 240V mains outlet
- A 15A, 240V mains outlet
- A theoretical specialised charge point with semi-infinite power

As a part of this project, parameters for this specialised charging station could be developed.

8.2.4: Evaluation of the Converted Vehicles

At the time this thesis was written, there was no documentation on the performance of the Lotus Elise or the Getz electric vehicle. In order for these vehicles to be considered a serious alternative to combustion engine vehicles, official research papers must be developed that are dedicated to documenting the performance of the converted electric vehicles. Areas that these papers should consider include the following:

- Acceleration: 0-100 kph and 0-60kph
- Braking: 0-100 kph and 0-60kph
- Handling: oversteer and understeer
- Cost effectiveness
- Design weaknesses
- Consumer response

References

1. *The Rise of Renewable Energy.* **Kammen, Daniel M.** 113, s.l. : The Scientific American, September,2006, Scientific American, Vol. VII, pp. 85-93.

2. **United States Government Accoutability Office.** *Uncertainty about Future Oil Supply.* s.l. : United States Government, 2007. GAO-07-283.

3. **Paine, Chris.** *Who Killed the Electric Car.* Sony Pictures, 2006.

4. **Renewable Energy Vehicles website.** The REV Project. [Online] Univeristy of Western Australia, Department of Electrical and Electronic Engineering, 2009. [Cited: 6 April 2009.] http://therevproject.com/.

5. **Advanced Vehicle Testing Activity.** The History of Electric Cars. [Online] [Cited: 10 October 2009.] http://avt.inel.gov/pdf/fsev/history.pdf.

6. **Deparment of Planning and Infrastructure.** *National Guidelines for the Installation of Electric Drives in Motor Vehicles.* s.l. : Deparment of Planning and Infrastructure, 2009. VSB 14.

7. **Gilbert, Richard.** *Action Plan for Electric Mobility in Canada.* s.l. : The Centre for Sustainable Transport, 2005.

8. **Shaheen, Susan.** *California's Zero Emission Mandate.* s.l. : Institute of Transportation Studies, 2004.

9. **Tesla Motors inc.** *21st Century Electric Car.* s.l. : Tesla Motors inc, 2006.

10. **Rechsteiner, Rudolf.** *Ten Steps to a Sustainable Energy Future.* s.l. : Swiss Parliament, 2007.

11. **Brant, Bob.** *Buil Your Own Electric Vehicle.* s.l. : TAB Books, 1993.

12. **Zero Emmision Vehicles Australia.** Technical Info: Circuit Diagrams. [Online] 2009. [Cited: 6 7 2009.] http://www.zeva.com.au/tech.php?section=circuits.

13. **Horowitz, Paul and Hill, Winfield.** *The Art of Electronics, second edition.* s.l. : Cambridge University Press, 1989.

14. **Kuphaldt, Tony R.** *Lessons in Electric Curcuits.* 18 July 2009.

15. **Hyundai.** *Hyundai Getz owner's manual.* s.l. : Hyundai Pty Ltd, 2008.

16. **Lotus.** *Lotus ELise Owners Manual.* s.l. : Lotus Pty Ltd, 2002.

17. **Australian and New Zealand Electrical Standards Board.** *AS/NZS 3000:2000: Electrical Installations.* s.l. : Australian and New Zealand Electrical Standards Board, 2009. AS/NZS 3000:2000.

18. **Standards Australia.** *International Standards and Technical Recource Infostore.* [Online] 10 October 2009. http://infostore.saiglobal.com.

19. **Whitely, Stephen.** *Electrical Schematic of the Hyandia Getz.* s.l. : REV, 2008.

20. **UQM Technoligies Inc.** *UQM Motor Systems Users Manual.* s.l. : UQM Technoligies Inc., 2009.

21. **Brusa Elektronik .** *NLG5 Battery Charger Users Manual.* s.l. : Brusa Elektronik , 2009.

22. **Thundersky Battery Limited.** *Lithium Iron Phosphate Battery Manual.* s.l. : Thundersky Lithium Power Batteries, 2007.

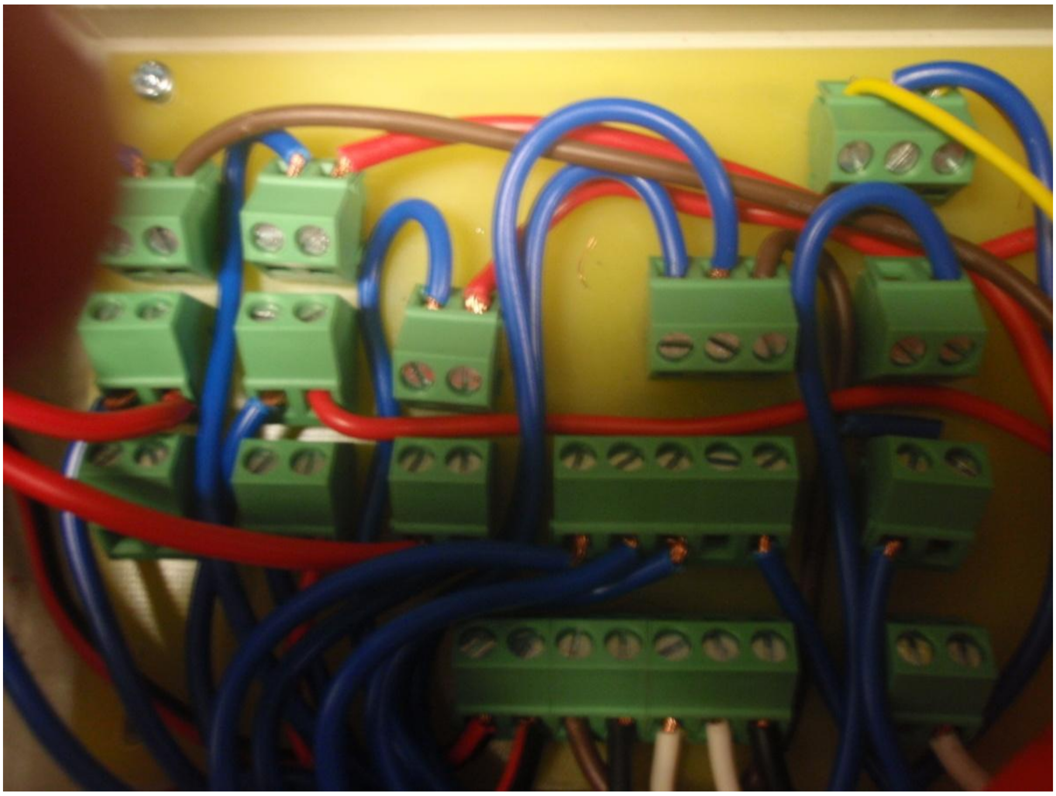
Appendices

Appendix A: List of Data Sheets

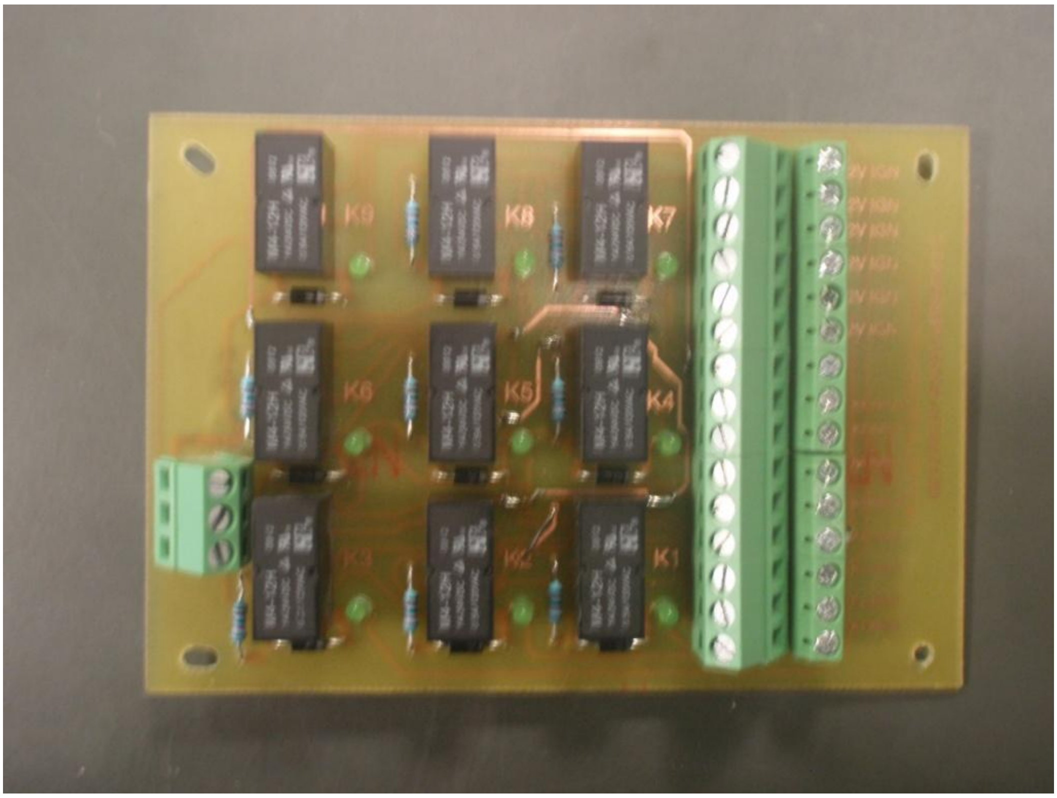
The primary data sheets that have been used throughout the year are:

- Lambda SWS-600 600W DC-DC Converter Data Sheet
- Mouser 300W DC-DC Converter Data Sheet
- Mouser 28W DC-DC Converter Data Sheet
- Gigavac GX14BC Contactor Data Sheet
- Gordos GF Series Solid state Relay Data Sheet
- Solid State Relay 2 Data Sheet
- Bussmann FWH 400A Fuse Data Sheet
- Power Diode Data Sheet
- Onboard PC Data Sheet
- Extraction Fan Data Sheet
- Radiator Pump Data Sheet
- Inertia Switch Data Sheet

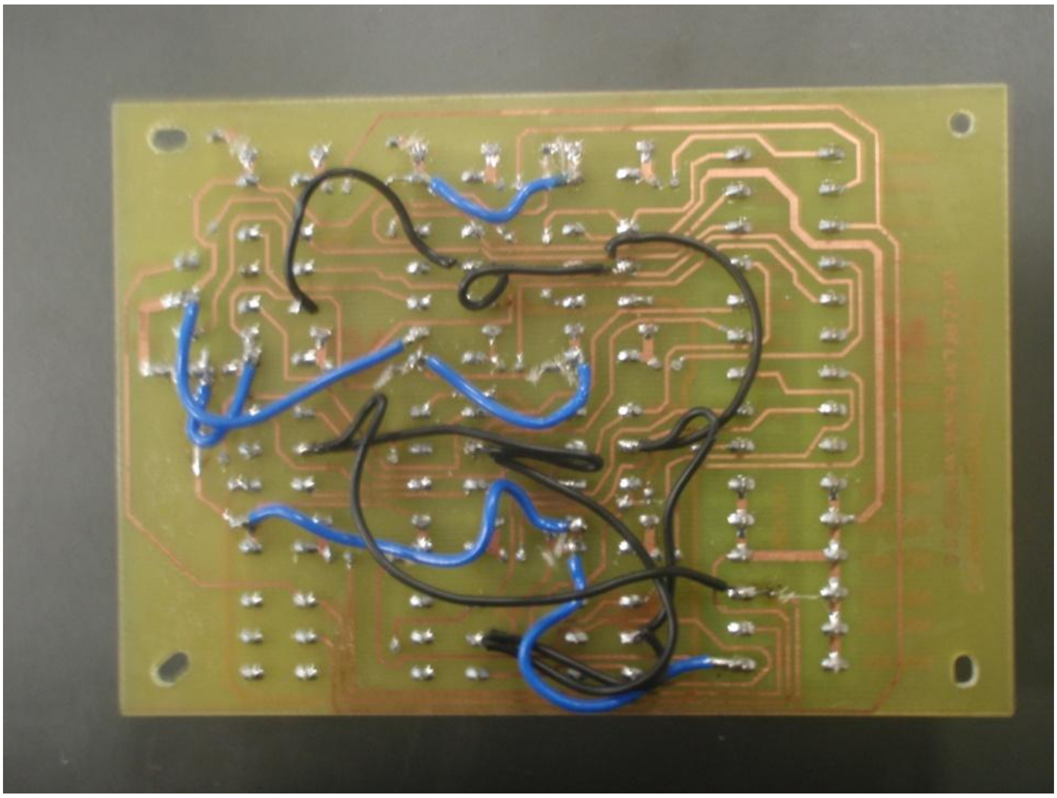
Appendix B: Photo of the installed Getz 12V distribution system



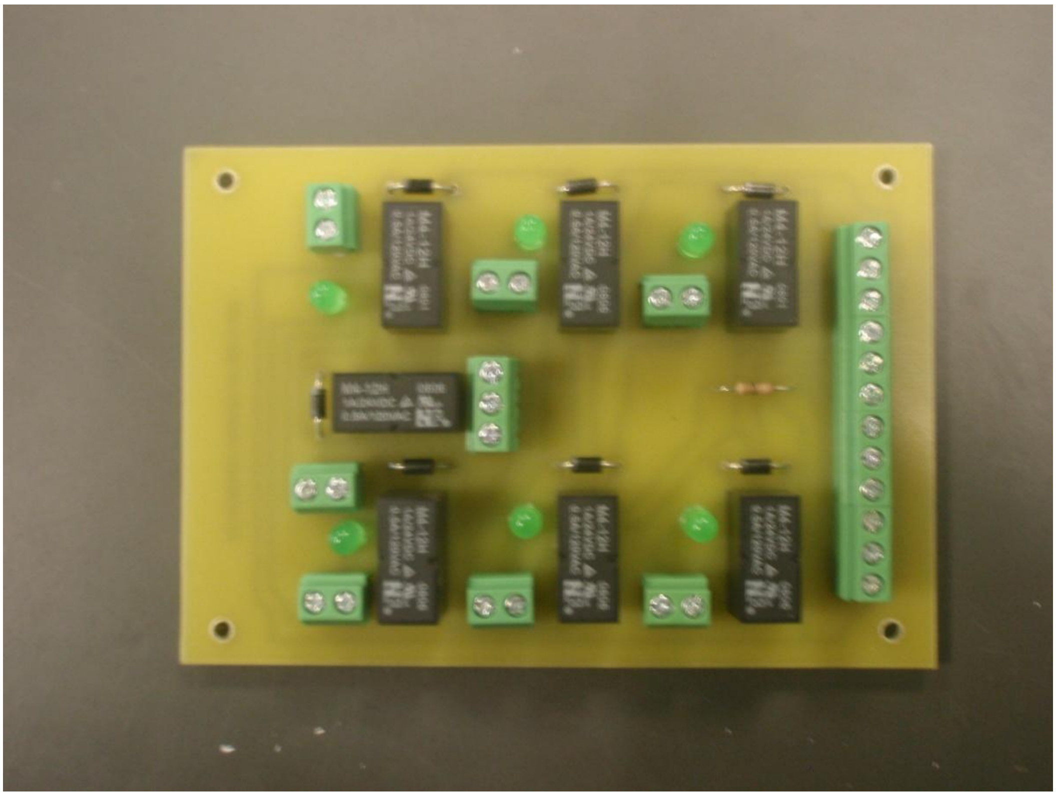
Appendix C: Photo of the first safety relay board



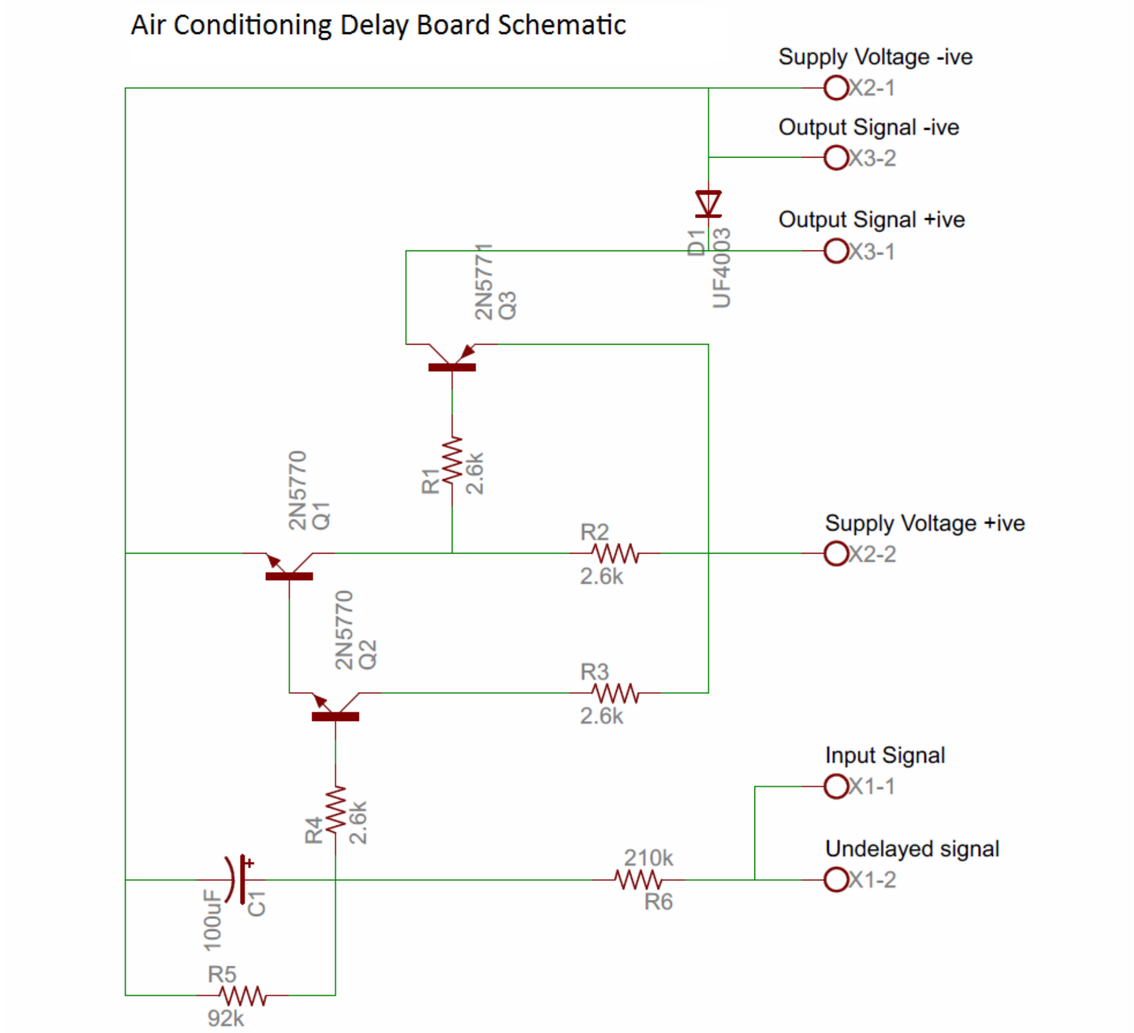
Appendix D: Photo of the wire modifications made to the first relay board



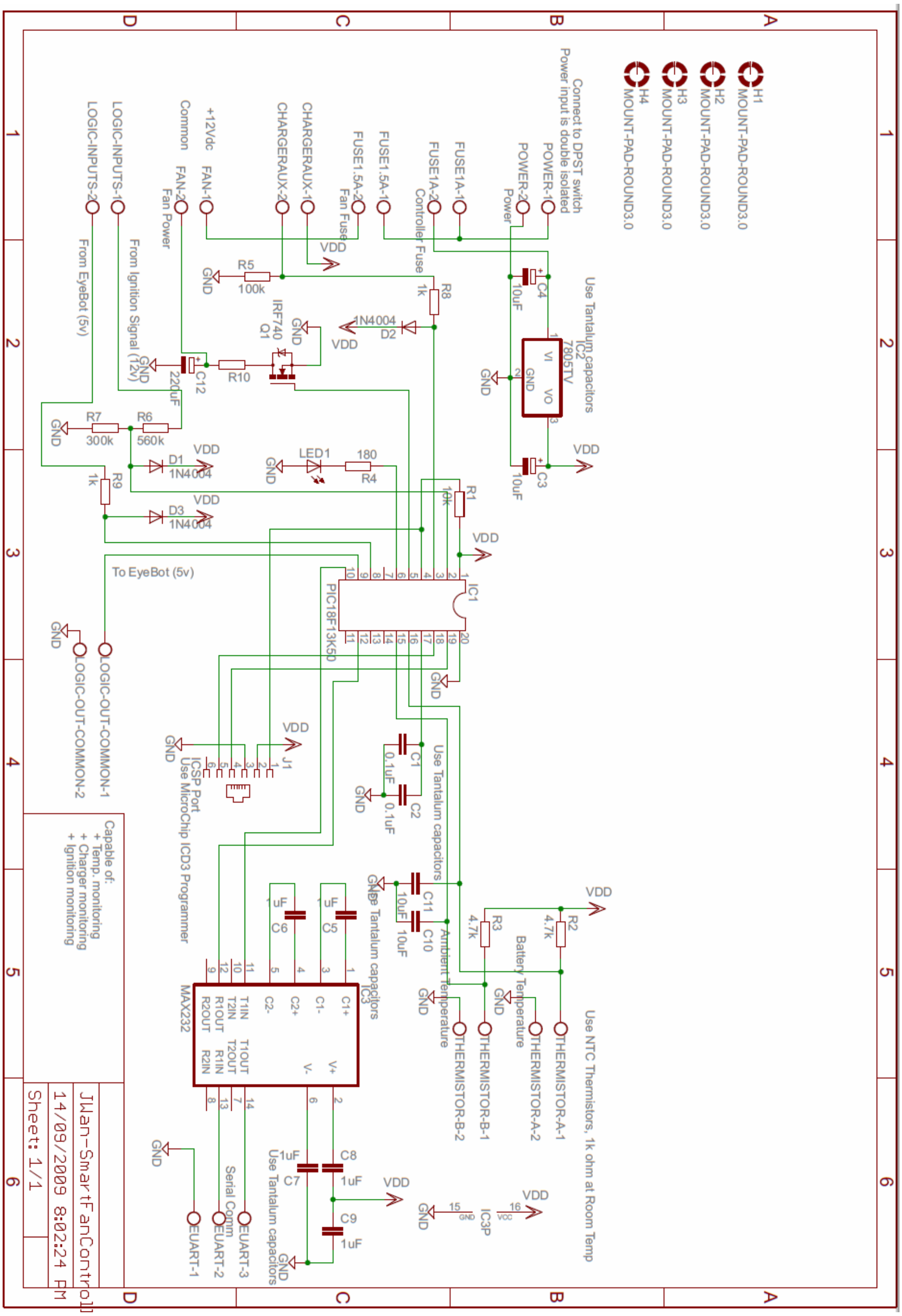
Appendix E: Photo of the second safety relay board



Appendix F: Air conditioning delay board schematic



Appendix G: Fan control board schematic



Appendix H: Summary of Charger Quotes

Quoted Items

The following items have been quoted:
Metric mind NLG523-SA
Metric mind NLG13-SA
Manzanita Micro PFC75M
Manzanita Micro PFC20
Battery Space HV Li-Ion Smart Charger for LiCo/LiFP
Southern Electric Transformer 415v 50Hz / Single phase 240v @ 75A (18KVA)

Results

Table of quotes and major specs:

	Power	Max Voltage	Max Current	Price (AUD)	Weight	Programmable	Parralelable
Metric mind NLG523-SA	6.7kW	400V	25A	$9,605	6kg	Yes	Yes
Metric mind NLG513-SA	3.3kW	400V	12.5A	$5,565	3kg	Yes	Yes
Manzanita Micro PFC75M	15kW	400V	50A	$4,980	22kg	No	No
Manzanita Micro PFC20	6kW	400V	20A	$2,330	8kg	No	No
Battery Space HV Li-Ion Smart Charger	3kW	400V	12A	$2,518	10kg	No	No

Southern Electric Transformer three phase 415v 50Hz / Single phase 240v @ 75A (18KVA) cost= $4650

Discussion

The NGL523-SA is the most preferred option as it is well documented, supported and easily customisable. It also comes with software that allows you to interface with the charger and modify its charging profile. The NLG523-SA is just 2 NLG513-SA chargers joined in parallel, so if we do not have the funds at the moment to purchase a 523 model, we could just purchase a 513 model with the intent to buy a second 513 model in the future. This would be my second choice.
My third choice would be the Manzanita Micro PFC20 as it is a simple device and we should be able to modify the charging profile via a custom modification to the charger by the REV team. However, this will be intricate and may hinder the performance of the charger and as such I am cautious to take this rout. The Manzanita Micro PFC75M will require some kind of three phase transformer as the current draw will be 75A. The cost of a transformer will be about $4650, making it an unfeasible solution. However, in the future, if we develop a battery pack that can handle high currents this will be a good candidate for fast charging as it would be able to completely charge the lotus in about 50 mins. The Battery Space HV Li-Ion Smart Charger for LiCo/LiFP is a cheap alternative. It is low power and non-customisable. I do not recommend it.