THE UNIVERSITY OF WESTERN AUSTRALIA

REV Electric Jet Ski

Safety Systems

Riley White
20742356
School of Mechanical and Chemical Engineering
University of Western Australia

Supervisor: Professor Thomas Bräunl
School of Electrical and Electronic Engineering
University of Western Australia

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University of Western Australia

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Project Summary

The aim for this project is to design the safety systems for an electric-powered jet ski. The REV project in the past has converted several petrol powered cars to electric power, but this is the first time a water vehicle has been attempted. There are obvious reasons for converting from fossil fuel to electric power, such as lower emissions, less noise pollution and lower running costs. With a push from society as a whole towards clean energy vehicles and lowering emissions, this project finds itself highly relevant to the current climate.

Although the idea is similar to previous REV projects, converting a petrol powered vehicle to electric power, a water craft has its own unique challenges not found in a car. Water, for example, can be very hazardous to electric systems, as anyone who has dropped their phone in the pool would know. The REV Jet Ski will be exposed to water in its operating environment, and so extra care will need to be taken to ensure water proofing of the critical components, to which water exposure would be damaging. Water leakage sensing is one aspect this project deals with, in addition to temperature sensing, battery management, a deadman's switch and safe charging.

A large consideration for this project is adaptability, taking into account future work. At the present time the REV jet ski is not complete, and so the safety requirements may grow to incorporate unforseen needs as the project develops. With this in mind, it was necessary to design a safety system that could be added to as required, and be easy to understand for future students who are new to the project, so that they may add to it as work on the REV jet ski progresses. A modular design that is easy to troubleshoot and modify has been developed, using off-the-shelf, relatively inexpensive, standard parts from local Perth vendors. This ensures that future additions in the form of additional modules will be easy to construct, cost effective and fit uniformly with existing safety modules.

Acknowledgments

I would firstly like to thank my project supervisor, Professor Thomas Bräunl, for guiding through the course of this project, and giving me the fantastic opportunity to work on a real design project such as this.

I would also like to thank my fellow REV team members who I have greatly enjoyed working alongside of, and have learnt much from.

Finally I would like to thank my family and friends for being so supportive during this stressful and busy time.

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Nomenclature

REV	Renewable Energy Vehicle
V	Volts
A	Amps
Ah	Amp-Hours
BMS	Battery Management System
SME	Submersible Motors Engineering
PWR	Power Line
CRG	Charge Line
SAE	Society of Automotive Engineers
DESS	Digitally Encoded Security System
IC	Integrated Circuit

1 Introduction

1.1 Background

The REV project has been designing, creating and converting electric vehicles since 2008, starting with the conversion of a Hyundai Getz from petrol to electric power. The REV project has continued to grow stronger, converting a BMW, Ford Focus and Lotus Elise to electric power, installing electric charging stations and designing and building formula SAE cars. The REV Jet Ski project is the first time the team has taken on a water craft.

The REV Jet Ski project began in semester 2, 2012. A SEADOO GTI130 was purchased with no motor or fuel tank. With the exception of the fuel tank and petrol engine, the jet ski contained all the parts from its previous life as a petrol-powered vehicle. This included steering, a controller, a display, reverse mechanism, impellor, deadman's switch and fuse box. Although some of these components are not utilised by the new electrically powered design, the hull would serve as the base for the rest of the project.

The new electric motor was built by Submersible Motors Engineering (SME) who specialise in motors for water-based applications. In a great show of generosity, SME agreed to build and install the motor for free as a sponsorship deal with the REV team. Once the motor was selected, the appropriate batteries were selected and purchased, and the battery housing was designed as part of a thesis project by Rajinda Jayamanna. At the same time, a cooling system was designed as part of a thesis project by Rowan Clark.

This thesis deals with the safety systems of the jet ski. These include temperature sensing, water leakage detection, battery management systems (BMS), a deadman's switch and safe charging. As work continues on the REV jet ski project, and it is not complete at the present time, adaptability to future requirements has been at the forefront of the design of the safety systems. The design features modular components, with a different module for each sensor. This gives the system a neat, contained and easy to use feel, and makes additions to the safety system easy to do in the form of extra modules.

1.2 Literature Review

Whilst the concept of an electric jet ski is a new idea, and to our knowledge, the first of its kind in Australia, there are still aspects of other safety systems that can be relevant to the one intended for the jet ski. The temperature cut off is of particular interest, as there are a number of requirements, as well as a number of ways of satisfying them.

A possible way to detect temperature and enable a soft cut-off (gradual instead of instantaneous shutoff at a certain point) can be modelled on the systems developed by James Dinh and George Korinsky in their 1993 patent for "Temperature Dependent Fan Control Circuit For Personal Computer". The aim of the invention is to create a personal computer cooling fan that changes speed with the temperature, rather than having two set speeds, low or high. The invention makes use of a thermistor, which is a resistor with high resistance at low temperatures and low resistance and high temperatures (Dinh & Korinsky 1993). In the fan control circuit, as the temperature at the thermistor rises and the resistance decreases, the voltage across the fan proportionately increases, as a result of the way the circuit is structured. Figure 4 in the patent shows that there is a linear relationship between temperature and voltage supplied to the fan between 30 and 50 degrees Celsius, where the system is most often operated. Outside of this range the system may still be operated, however the relationship between the temperature and voltage supplied to the fan may not be linear (Dinh & Korinsky 1993).

This design also includes an overheating protection mechanism, through use of a transistor. As the temperature increases the thermistor resistance gets lower until the voltage across the base of a particular transistor becomes low enough to turn said transistor on, which causes a current to be sent to other components which result in a silicon control rectifier redirecting current around the circuit to send a signal to the power supply to shut off (Dinh & Korinsky 1993). This patent effectively includes a controlled approach to monitoring temperature with a soft-cut, as well as an instantaneous cut-off for when the temperature is too high.

Another method of temperature control in an electrical circuit is the patent for "Safety Feature For Electric Vehicle Control" by Francis Thompson in 1974. The patent refers to a field controlled direct current drive motor for an electric vehicle, but the temperature control is of particular interest. In this invention a temperature sensor is connected to the drive motor which provides an excess temperature output signal when the temperature of the drive motor exceeds a certain value (Thompson 1975). When this happens, operating characteristics of the vehicle are altered to reduce performance, allowing the temperature to cool, but while still enabling continued operation (Thompson 1975). The reason this can happen is because there is an amplifier in the armature current feedback circuit (used for comparing with desired armature current to provide control for the system) which is responsive to the temperature sensor so as to increase the feedback signal when the temperature exceeds a certain value (Thompson 1975). This would cause the control system to have feedback higher than usual, causing it to lower current into the motor to match the desired armature current. In this way the motor will still be operational, but just in a reduced capacity in accordance with the temperature.

Both of these patents refer to the control of a motor when temperature approaches or exceeds an acceptable value, which could possibly result in damage to the components. Whether it be a thermistor being used to proportionally change the voltage supplied to a cooling fan based on the inversely proportional relationship between temperature and resistance of the thermistor, or using an amplifier taking inputs from a temperature sensor to increase the feedback signal to a comparator, both methods have their strengths. The method used by James Dinh and George Korinsky in their 1993 patent seems simpler and more direct, however in the context of a vehicle safety system it may be difficult to apply. The method employed by Francis Thompson in 1975 seemed more complex at first, however the principle of control on which the temperature sensing is based could translate well to the context of a jet ski safety system. This patent was after all, for the safety features of an electric vehicle. Through review of both patents, it is evident that it is possible to design a temperature shut off system for both the instantaneous emergency case, and a soft cut in a controlled sense to limit performance to allow the systems to cool, whilst still being able to navigate until a safe place to stop is found.

2 Project Management and Engineering Practice

2.1 Introduction

The project team consists of final year students completing their thesis using the REV Electric Jet Ski as the basis for a final year project. The students are from a variety of disciplines, and the team is run under the guidance and supervision of Professor Thomas Bräunl. The project was started in semester 2, 2012, and has seen 2 students graduate and leave the project, 3 students about to complete their theses, and another two students set to finish semester 1, 2014. Currently the team consists of 5 members. With the constant flux of members, documentation and communications management has been paramount.

On many occasions team members have been required to interact with members of industry in various formats, and so a professional standard has been upheld at all times.

2.2 Budget

Budget constraints have played a large part in the design and construction of various components in the project. The exact budget is confidential, however the lack of funding able to be sourced has meant that cost effectiveness has been taken into consideration at every step of the project.

Sponsorship was obtained from the following companies:

Altronics	For use of the entire REV project, a store credit was donated to the team. This has been highly useful as a lot of the electrical components have been able to be sourced from Altronics, which is a local Perth vendor.
SME	The motor for the electric powered jet ski was built for free by SME, as part of a sponsorship deal.

Unfortunately, despite applying for various sponsorship programs, monetary sponsorship was unable to be obtained, which has meant that low-cost has had to be at the forefront of design.

2.3 Timeline

At the commencement of semester 1, 2013, a project plan was produced to help give the newer members of the team a foundation to begin understanding the project. This project plan included overviews of team member roles, contact information and communications management, milestone list and a Gantt chart, among other items. The timeline for the project specified at this time was soon outdated as updating the Gantt chart became difficult and near impossible due to unpredictable delays beyond our control. The main delay was in the motor construction and installation. The estimated time by the external company was 2 weeks for construction and installation, once they had received the jet ski. After weekly checkups and continuous postponements, the jet ski was finally ready to be collected some 3 months later. This delay had a huge impact on the timeline of the project, and saw the graduation of 2 team members during its time.

2.4 Communications Management

Communications management is defined as "Generating, collecting, disseminating, storing and disposing of timely and appropriate project information" - (Kloppenborg 2012). In the REV Jet Ski team all relevant information, including designs, proposals, project plans, datasheets and images have been stored and shared using the Dropbox collaborative storage application. This has allowed each team member to access information on the project from anywhere, and has proved invaluable. The main form of communication has been a group emailing list, ensuring that all team members and supervisors can stay in touch. Weekly meetings have been held, however due to the student nature of the team, it has been difficult to consistently get attendance from all team members. However, as a result of the Dropbox and the emailing list, team members who are unable to attend meetings are kept in the loop with any important information they may have missed. This has kept good cohesion in the group and enabled everyone to stay up to date on all matters of the project.

3 Component Overview

3.1 Introduction

The REV Jet Ski is made up of 3 key electrical components: the motor, the batteries and the controller. These 3 systems are critical to the operation of the jet ski, and have the most dire consequences if they are damaged. For this reason, they are focussed on such that the greatest understanding of the component is gained to better help design a safety system that can protect it.

3.2 Motor

The motor was built and installed by Submersible Motors Engineering (SME). This was done free of charge, however when the jet ski came back with the motor installed, it wasn't fitted correctly, and so the motor mounting points had to be readjusted. The datasheet for the motor can be found in Appendix A. Key points from the data sheet are as follows:

Output Power	50kW
Rated Voltage	96V
Given Speed	8000rpm
Operating Temperature	75°C

The AC motor is to be driven by the Curtis controller (see section 3.4). Which will regulate the voltage to vary the speed of the motor accordingly.

The motor, having been designed and built by SME (who specialise in submersible motors), is designed to be waterproof, and as such does not need to be in an enclosure.

3.3 Batteries

The batteries used to power the REV Electric Jet Ski are Headway 10Ah Li-Ion cells. They were sourced from EV works, a local vendor that supplies components to electric vehicles, and use Lithium Iron Phosphate ($LiFePO_4$) as the main ingredient (International Battery Inc 2010). The datasheet can be found in appendix B, and a full list of ingredients, their percentage of the battery composition and hazards can be seen in table 3.3.1.

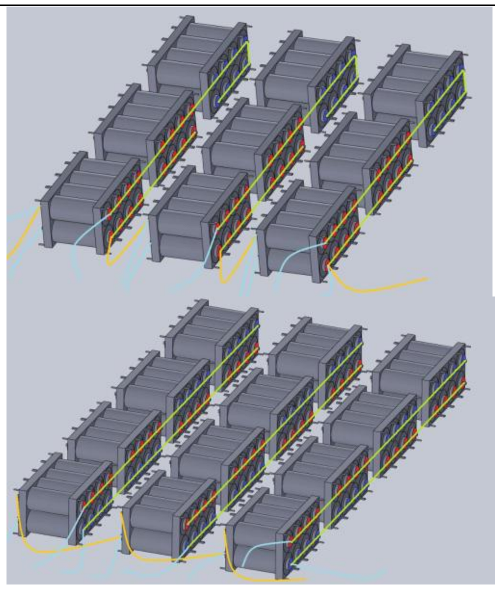
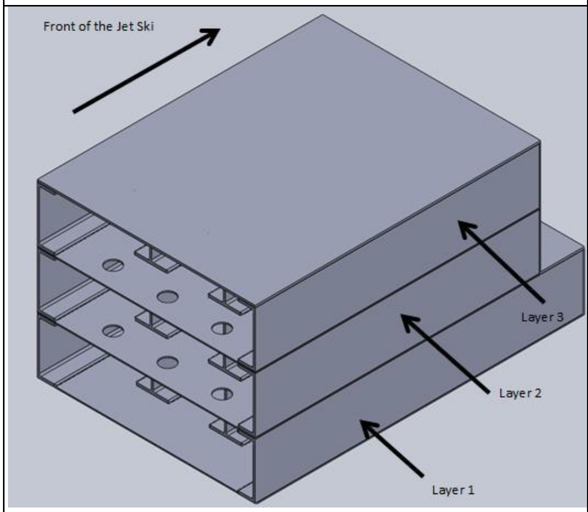
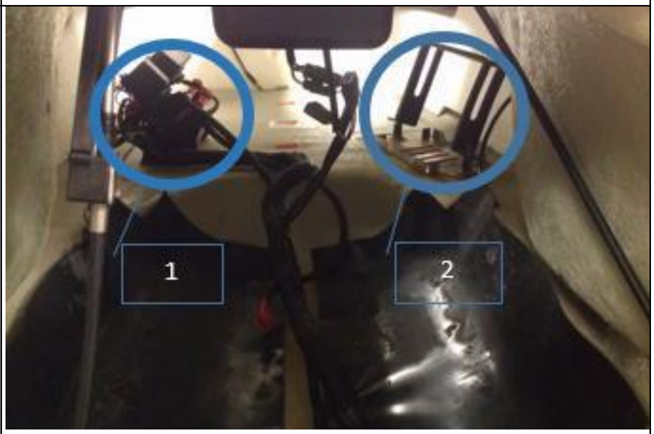
Common Chemical Name	CAS #	Percent of Content (%)	Classification and Hazard Labelling
Lithium Iron Phosphate ($LiFePO_4$)	15365-14-7	30-33	Eye, Skin, Respiratory Irritant
Carbon, as Graphite	7440-44-0	15-17	Eye, Skin, Respiratory Irritant
Aluminum metal	7429-90-5	5-7	Inert
Copper metal	7440-50-8	7-9	Inert
Electrolyte		15-20	Mixture: Flammable; Reactive; Sensitizer; Eye, Skin & Respiratory Irritant
Ethylene carbonate	96-49-1		
Dimethyl carbonate	616-38-6		
Ethyl methyl carbonate	623-53-0		
Lithium Hexafluorophosphate	21324-40-3		

Table 3.3.1: Li-Ion Battery Cell Composition/Ingredient List - (International Battery 2010)

These batteries are grouped together in series in modules of 8 cells. This provides them with 80Ah. 30 of these 8 cell modules are then linked together to provide them with the 96 volts needed to power the jet ski systems.

"Lithium batteries have been a revolution in energy storage and a major enabling factor in the resurgence of electric vehicles. However lithium batteries can be damaged if their voltage goes out of safe operating range – either too high (overcharging) or too low (over-discharging). " -(EV Works 2010) To combat the risk of overcharging or over discharging the battery cells, a battery management system is used (BMS). The BMS is responsible for signalling if the battery cells go out of safe operating range and begin to either over charge or over discharge. The BMS is discussed in greater detail in section 4.2.3.

The batteries are to be housed in the front section of the jet ski, shown in figure 3.3.2. The battery placement and housing was the topic of the thesis by Rajinda Jayamanna, and the recommended configuration is shown in figure 3.3.3, and the proposed housing in figure 3.3.4. The configuration of the bottom layer being larger than the top two is due to the interior space in the front of the jet ski. The hull narrows in towards the top, where the upper two layers are located. Therefore, these layers were made smaller and the bottom one larger. The reasoning behind the placement of the batteries at the front of the jet ski is that the petrol fuel tank was previously located on the mounting points shown in figure 3.3.5. By placing the batteries here and the motor at the back, the weight distribution is kept as close to the original petrol-powered design as possible.

 Figure 3.3.2: The front section of the jet ski	 Figure 3.3.3: Recommended battery configuration (Above- top two layers, Underneath- bottom layer) - (Jayamanna 2013)
 Figure 3.3.4: Proposed housing design - (Jayamanna 2013)	 Figure 3.3.5: Fuel tank mounting points - (Jayamanna 2013)

The battery box is made out of aluminium alloy, and so care is taken to ensure that the battery cell terminals do not make contact with the metal housing, so as to prevent a short circuit. To this end, the battery cell terminals are currently coated with layers of electrical tape, shown in figure 3.4.6, and there are plans to purchase thin polycarbonate sheets to line the inner edges of the battery box, to prevent contact with the terminals.

Figure 3.3.6: Battery cells lined with tape.

Figure 3.3.7: Battery box test fit

The battery box was produced as per Rajinda Jayamanna's specifications by the physics workshop at UWA. Unfortunately, when attempting to assemble it within the jet ski, it was found that the housing was too large and did not fit as it was designed. At the time of writing modifications are being made to the design by another mechanical engineering student on the REV team to enable the box to fit within the confines of the jet ski hull. A mock-up and test

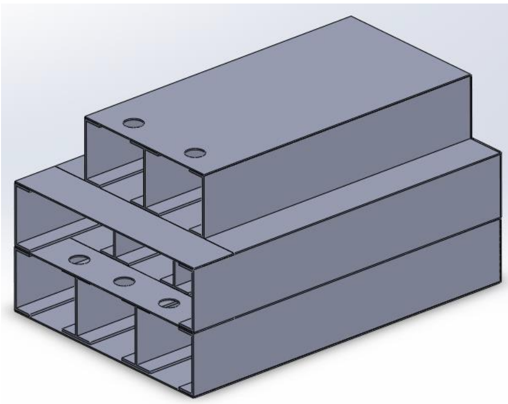


Figure 3.3.8: Revised battery box design, credit: Christopher Corke

fit of this design can be seen in figure 3.3.7, and the proposed Solidworks model is shown in figure 3.3.8. This new design takes into account the space constraints at the top of the jet ski interior.

3.4 Controller

The controller used is a Curtis 1238 AC motor controller, and was purchased from Bylong Industries at a price of $3,113. The controller can be seen in figure 3.4.1. The controller arrived without software or a manual, but through some research datasheets were obtained and software was downloaded. A connector had to be constructed, as the controller required inverted TTL logic (Curtis Instruments, Inc 2009) , whereas the PC user interface used USB inputs. A USB to TTL converter was obtained, and so all that was left was to invert the signal to match the Curtis controller input. The schematic for this connector was developed by Alex Beckley, and is shown in figure 3.4.2. The connector was then constructed utilising a waterproof connector on the end attached to the jet ski, and is shown in figure 3.4.3.

Figure 3.4.1: Curtis 1238 AC controller

Figure 3.4.3: Finished Curtis-PC connector

Figure 3.4.2 shows the TTL ports that were on a USB to TTL converter wired into an inverter, which are then outputted to the controller. In figure 3.4.3 the USB to TTL connector is seen mounted in the right hand side of the box, whilst a 3 pin water-proof connector is wired to the TTL controller outputs on the left. The reason for the waterproof connector is that the other half of the connector (not seen in the above figures) will remain with the controller in the jet ski, where water may be present, and so has to be waterproof.

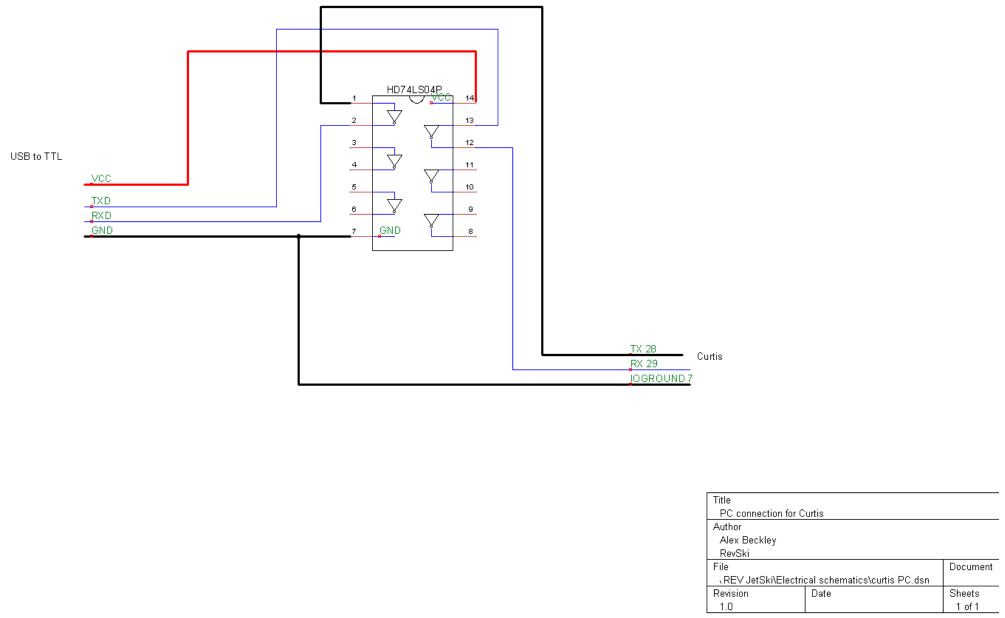


Figure 3.4.2: Curtis - PC connector schematic- Credit, Alex Beckley

4 Safety System Overview

4.1 Introduction

The safety systems on any vehicle are crucial. They ensure the safety and functionality of both the user and the vehicle itself. As such, these systems need to be reliable and effective, leaving nothing to chance. For this reason, a system of relays was used in the REV Jet Ski safety circuit. These relays are linked to sensors that measure temperature and water levels. Originally it was intended that a microcontroller would be used to take inputs from the temperature and water sensors and run a single relay, serving as the complete safety circuit. This idea was dropped however, in favour of the relay-only system due to the reliability and robustness of the relays compared to the chance that something could go wrong with the microcontroller.

4.1.1 Requirements

The REV Jet Ski has a number of vital components that are crucial to operation, and present a large consequence if they are damaged and/or left untreated. These vital components are the batteries, the motor, the controller, and of course the user. In order to identify the potential threats to these components that may damage or disrupt their operation a FMEA chart was constructed. This can be found in appendix C. "An FMEA (Failure Mode and Effect Analysis) is a systematic method of identifying and preventing product and process problems before they occur ... Ideally, FMEAs are conducted in the product design or process development stages" - (McDermott, Mikulak & Beauregard 2009) . A hazard is defined as "a potential source of harm"- (ISO/IEC 1999), where as a risk is the consequence, and likely hood of that consequence occuring (ISO/IEC 2009). The main hazards identified were high temperature, extreme low temperature, water leakage, short circuit, crash and user dismount. The risks associated with these hazards varied between components, damage or disruption of operation was common to most. Often it is not practical to remove a hazard completely (such as removing the hazard of water from a jet ski, a water craft), and so while the safety systems may not be able to remove the hazard, but it is the aim to do what is possible to prevent damage and mitigate the risk of each hazard.

4.1.2 Failsafe

Failsafe is defined as "causing a piece of machinery to revert to a safe condition in the event of a breakdown or malfunction" (Oxford University Press 2013). It is important for the safety systems of a vehicle to be failsafe, so that should something cause the safety system to fail, it will automatically prevent (to the best of its ability) further damage to subsequent systems. In the case of the REV Jet Ski safety systems, the system should be failsafe such that if power is lost to the safety system, power will be shutoff and operation will cease. This is to prevent possible damage to the vital components occurring during continued operation without the protection of the safety system.

4.1.3 Charging

The 240 battery cells are charged using a GWL/Power Charger 96V/25A, designed for LiFePO4 / LiFeYPO4 + BMS. This charger takes a nominal input voltage of 230V AC, and outputs a charge of 96V at 25A (Ev-power.eu, 2013). As each module contains a total of 80Ah, as shown in equation 4.1.3.1, it will take up to 3.2 hours to fully charge the batteries.

$$Charge\ Time\ (hours) = \frac{Total\ charge\ of\ batteries\ (Amp\ Hours)}{Current\ supplied\ by\ charger\ (Amps)}$$

$$3.2 = \frac{80}{25} \qquad (equation\ (4.1.3.1))$$

The vehicle should not be in operation whilst charging. This is for the safety of the operator, as the charging port is located within the jet ski, where there are potentially dangerous voltages and fast moving parts. The charger and cable, shown in figure 4.1.3.2, is plugged into the charging port. The charging port must be water proof, as it may be exposed to water when not in use. Due to the expense of a water proof connector, a waterproof box that contains the charging port is proposed. This box will be closed during normal operation of the jet ski (when not charging), and thus will be water proof. A diagram of this proposed assembly is shown in figure 4.1.3.3.

Figure 4.1.3.2: Charger

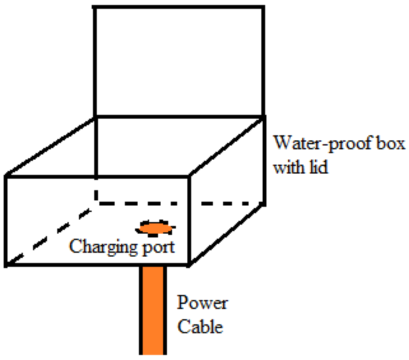


Figure 4.1.3.3: Water-proof box for charging port assembly

4.2 Requirement Specifics

4.2.1 Temperature

The components that are most sensitive and at risk to high temperatures are the batteries. The controller has its own built in temperature sensor that protects it from operation in high temperature, and is also cooled by a heat exchanger plate (Clark 2013). The motor is also water-cooled. Currently, the batteries lack a dedicated cooling system due to the space restrictions in the front section of the jet ski, where the battery housing is located. The batteries also have the most dangerous consequence to high temperature. At elevated temperatures such as 100°C the batteries may vent flammable liquids and gases (International Battery Inc 2010). It is also recommended that the batteries are not stored below -33°C or above 55°C. A Queensland survey by RACQ conducted in 2009 reported that temperatures within sealed test vehicles (cars) reached up to 60.4°C when left in the sun on a sunny Brisbane day when the ambient temperature reached a peak of 33°C (Ewing & Manning 2009). The report also concluded that on a sunny day temperatures inside cars typically doubled the ambient temperature when left in the sun (Ewing & Manning 2009). Therefore, on summer days in Perth (the location of the jet ski) where temperatures are commonly known to reach above 40°C, the jet ski must be parked in the shade where it is not exposed to the sun for extended periods of time when not in use.

Given the recommendation that the batteries not be stored above 55°C, an ideal temperature limit would be below 55°C, to ensure that no harm could possibly come to the batteries as a result of temperature. However, given the study by RACQ, this temperature limit could be surpassed on a summer day during normal operation. The manufacturer also recommends that the batteries are not discharged above approximately 60°C (see Appendix B). This, and the information that flammable liquids and gases are vented when the temperature reaches approximately 100°C, indicates the temperature limit should be somewhere below 100°C, at a point which could not be reached whilst the jet ski is not operating or during normal operating conditions. Therefore a limit of approximately 60°C should be used. This is only an estimate however, as testing has not yet been conducted on the jet ski systems as they are incomplete at the time of writing.

4.2.2 Water

Water is an ever present hazard to the jet ski during normal operation, as it is intended for use on the water (almost certainly not pure water). The main danger (in terms of the jet ski) with water located in oceans and rivers is that it is an excellent conductor of electricity. As a result, a water leak into the hull of the jet ski could potentially bridge exposed wires or terminals, causing a short circuit, damage to the systems, or in the worst case, harm to the driver.

Currently, every measure is being taken to ensure water-proofing where possible. The connectors that connect the batteries together are all IP67 rated waterproof (Altronics 2013). These can be seen in figure 4.2.2.1. The motor was produced by Submersible Motors

Engineering and is also waterproof. Exposed connections, such as the connector to the controller, also utilise water proof connectors. The charging port will also feature a water proof design, with the proposed design featuring a water-proof box to encase the port when

Figure 4.2.2.1: Waterproof connector (Altronics, 2013)

not charging. However, despite these efforts, should water leak into the hull of the jet ski, it is possible that there may be exposed wires or terminals that could cause damage if in contact with water. To this end, water sensors are needed to shut off power to prevent damage, should water be detected.

4.2.3 BMS

As mentioned previously, the BMS is responsible for signalling if the batteries go outside of their safe operating range by either over charging or over discharging. The BMS modules used in this project are ZEVA 8-Cell Battery Monitor Modules, purchased from EV works. Each module can only monitor a limited number of cells, and so there are multiple BMS modules all working concurrently. These modules then feed to a single master module, the ZEVA BMMCU. This master module outputs a 12V signal (ZEVA, n.d), on if the batteries are operating within their safe range, or off if they are not. The four BMS modules as well as the master module can be seen in figure 4.2.3.1.

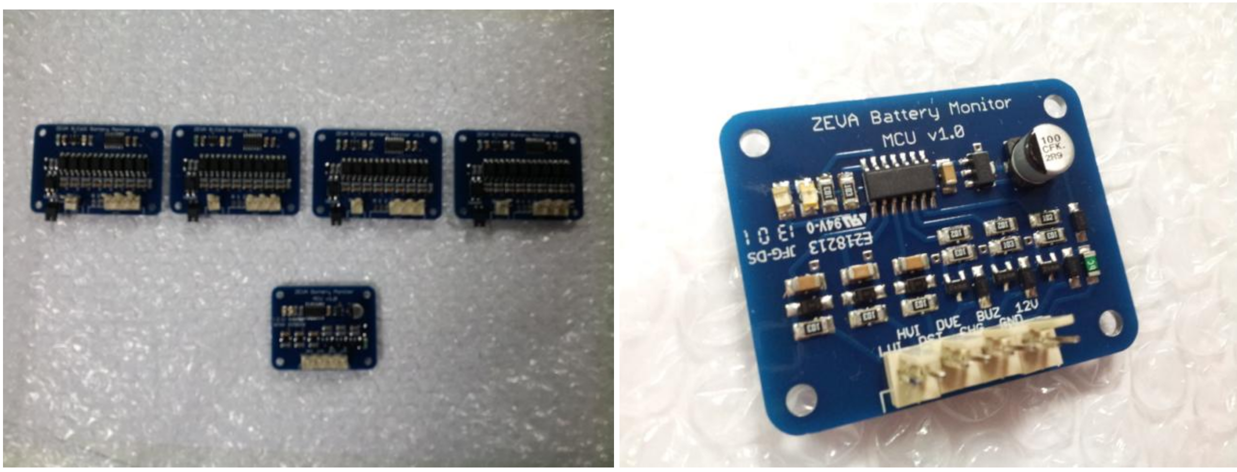


Figure 4.2.3.1 BMS Modules & Master (Right)

4.2.4 Deadman's Switch

The emergency switch, commonly known as a Deadman's switch, is a device connected to the user via clip or other attachment, that is required for the vehicle to be operational. By connecting the switch to the user, the vehicle is prevented from running should the user fall off during use. In the context of the REV jet ski, the Deadman's switch is located at the base of the handle bars (shown in figure 4.2.4.1), and serves as a key, similar to the ignition key of a car, that is required to start, and operate, the vehicle. In the workshop manual of the SEADOO jet ski, the switch is referred to as a DESS (Digitally Encoded Security System), and are somehow encoded to unlock different capabilities of the jet ski. There are, according to the workshop manual, 3 different DESSs, all which limit the running speed of the motor to a certain degree. However, only two DESSs belonging to this particular jet ski are known to exist, one of which is the white DESS, which according to the workshop manual, is the training key. This training key was once used to limit the top speed of the jet ski (Seadoo 2008). Unfortunately, as we have removed the original petrol engine and control systems, this key is no longer functional. Possible future work is to look into utilising these limits with the new controller and electric motor.

A deadman's switch that would serve as a key to start the vehicle is however, still a desired component. Therefore testing was undertaken to see if modifications could be made to the white DESS to utilise it without the previous restrictions relating to the petrol motor system. The old control system was still attached to the jet ski, and using the relevant sections of the workshop manual (shown in figure 4.2.4.2), it was found that wires BK and WH-GY were the outputs of the switch. By testing the resistance across these wires using a multimeter, and

Figure 4.2.4.1: Deadman's switch

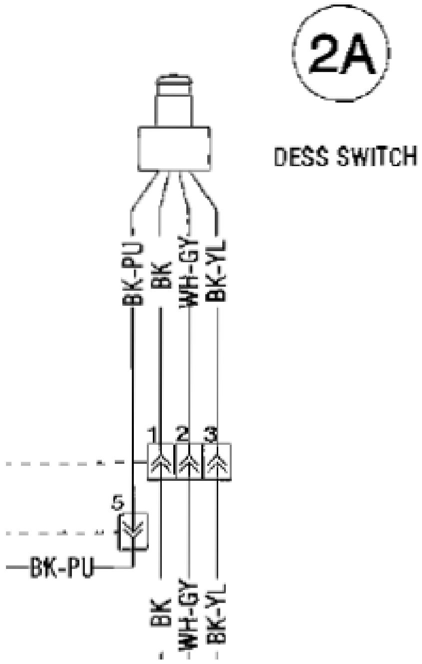


Figure 4.2.4.2: DESS Wiring Diagram (Seadoo 2008)

bridg igure 4.2.4.1), it was found that a closed loop could be made by simply bridging the two switch terminals. This fact means that modifications can be made to the DESS, and it can be included in the design of the safety systems.

4.2.5 Safe to Charge

For the batteries to be charged, they must be in a stable, safe condition, in the same way they must be safe and stable when the vehicle is in operation, because the batteries are still in use, whether they are charging or discharging. Therefore, in addition to a system to shut off power in the presence of water and high temperature, there should also be a system to allow the safe charging of the batteries in the same manner. This system should also prevent the batteries from charging whilst the system is in use.

The charging port is also only water proof when the lid is closed. This can be seen in figure 4.1.3.3.

4.3 Relays vs. Microcontroller

Relays have been chosen in this project due to their robustness over microcontrollers. Previous experience on other REV projects has shown that systems using relays have been more reliable than those using microcontrollers. Whether this has been due to faults with the microcontroller itself or the coding is unknown, but for logic as simple as on/off when a fault is detected, the added functionality of a microcontroller is not needed. Therefore in order to keep things as simple and robust as possible, a system utilising relays has been used instead of microcontrollers.

4.4 Design Overview

The overall design will feature relays at each sensor to determine whether or not the system is safe. Figure 4.4.1 depicts this in a flowchart format.

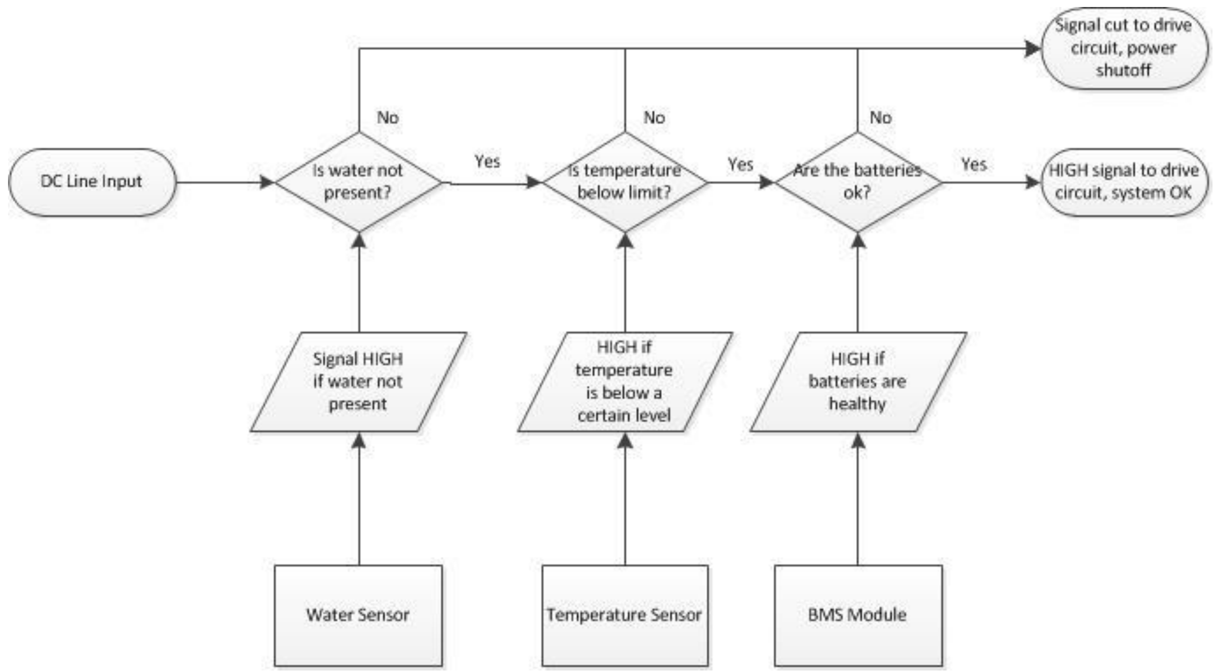


Figure 4.4.1: Flowchart of safety system

This flowchart format closely resembles three of the modules in the modular design that will be discussed in greater detail in section 5.3. Simply put, if a hazard is detected at any point, power to the drive system will be cut in order to protect the components and the user. If a fault is not detected, the signal will travel to the next module, and unless it is stopped by a hazard being detected, it will reach then end and allow the system to have power.

5 Design

5.1 Introduction

The physical design of the safety system has to take into account several factors. These include the power available, the power of the output signal required, the functionality required (emergency cut-off, safe to charge), as well as non-technical issues, such as budget and time constraints. Budget constraints have been a large consideration of the project, as discussed in the project overview section (2.2). The budget constraint has influenced the choice of sensors purchase.

Due to the student nature of the project, with new students coming on board as old ones leave, it is also important to consider future work on the project. At the time of writing the jet ski is not complete, and so it is likely that systems will change as the project develops. For this reason, the safety system features a design that can be added to as the project develops and the jet ski needs more sensors. This is discussed in the sections below.

5.2 Design Criteria and Requirements

Input:	12V DC
	<3A
Output:	12V DC to run relay for 96V DC
	12V DC signal for charge
Functionality:	Temperature shutoff at approx 60°C
	Water leakage detection
	BMS
	Deadman's switch/Ignition key
	Charging box open/closed

The input is determined by the drive circuit. This was developed by Alex Beckley and was pre-existing at the time of developing the safety system.

The first output is to drive a 12V relay that switches a 96V load. This first 12V output is responsible for shutting off the power to the drive systems in case of danger. The second 12V output is to go to the charger, to allow the charger to operate. The charger takes a 12V input to activate it. By having an output of the safety system control this activation, it can be safeguarded against charging when it is not safe to do so, or turning the jet ski on whilst it is still charging.

5.3 Modular Design

One important requirement for the safety system is the need to account for future works on the project. Due to the jet ski being incomplete at the time of writing, it is important to have a safety system that can grow and adapt to issues that may be unforeseen at this time. At the present time, the issues of temperature, water leakage, battery management, Deadman's switch and safe charging have been identified, and are being accounted for. There may however, be more safety issues that develop as the jet ski is completed and subsequently tested. This is why a safety system that can be added to as the jet ski develops is important. This is why the safety system features a modular design.

In essence, the modular design features a different module for each sensor. Each module will feature an identical shell, as shown in the physical drawing in Appendix D. This shell is made of standard parts that can be purchased from local Perth vendors Jaycar or Altronics. Each module will have the same inputs and outputs, as well as spaces for sensor wires. These inputs and outputs then plug into a pre-made veroboard, as shown in figure 5.3.1. There are 4 lines on the veroboard, 12V supply, ground (GND), safe power line (PWR) and safe charge line (CRG).

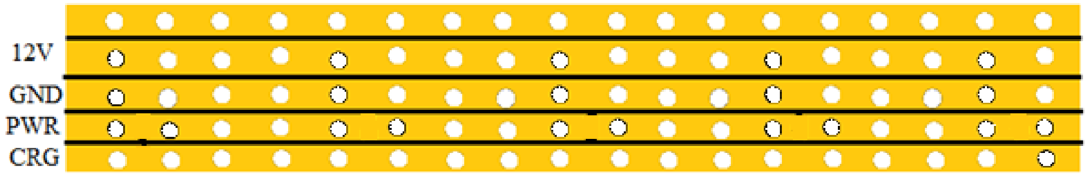


Figure 5.3.1: Sketch of a veroboard strip. Each row represents a different line, 12V, GND, PWR or CRG

The 12V supply is the input line that comes from the drive circuit. This supplies power to the sensors and relays in each module. Each module is linked to the 12V supply and GND in parallel, such that each will operate independent of the others. The PWR line is broken at each module, and so has two pins across it per module. The reason for this is that if the sensors detects that it is safe to run, the relay will be closed, and current will be allowed to flow from one PWR pin to the other, bridging the gap. The CRG line operates in a similar fashion, however it is only necessary on one module at this stage. The individual modules will be discussed in the sections below.

5.4 Sensors

5.4.1 Water

The water module was based around a relatively inexpensive and robust water sensor that could be purchased from local vendors. The selected water sensor for the prototype is a *Kemo Electronic Water Level Sensor 9 V/DC*. The datasheet for this module can be found in Appendix E. The reasons for selection are as follows:

- Availability- purchased from local Perth vendor Jaycar Electronics
- Low cost- $9.95 (Jaycar Electronics, 2013)
- Simple to use - if water bridges the two bare wire contacts, an LED lights up. A relay can also be put in place as well that will be driven when water is in contact with the sensing wires. (Kemo Electronic 2012)

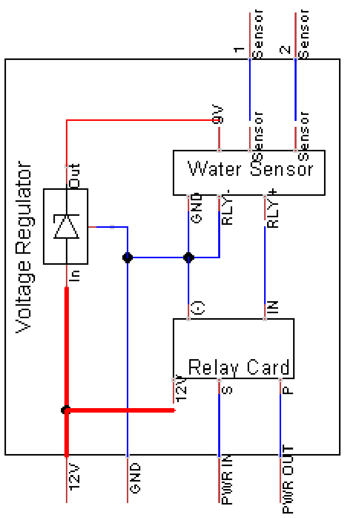


Figure 5.4.1: Water module wiring diagram

This particular water sensor outputs a small voltage of approximately 2V. This output signal is then coupled with a relay card, also purchased from Jaycar Electronics, and the datasheet can be found in Appendix F. The water sensor requires a 9V signal, however, and the supply line is 12V. For this a voltage regulator is used, L7809CV. This voltage regulator steps down the voltage from 12V to 9V. The 12V line still runs to power the relay card, and GND is connected to both the relay card and the water sensor. The load side of the relay card switches between on and off (off if water is detected), and allows the PWR line to pass through, should water not be detected. The sensor wires head out from the module encasing to detect water. The wiring diagram for this module is shown in figure 5.4.1, and the physical drawing is shown in Appendix G. Notice that the shell is the same as the generic model, with the inside changed. It should be noted that the CRG line does not appear on the wiring diagram, yet there is a port for one on the physical drawing. This is because it is not in use for this particular module, but the standard module design still features one.

5.4.2 Temperature

The temperature module has been based around a similar sensor, again one that is relatively inexpensive and from local Perth vendors, should future REV Jet Ski team members wish to purchase more. The temperature sensor to be used is a *Kemo Electronic Temperature switch 12V/DC B048*. The datasheet for this module can be found in Appendix H. The reasons for selecting this particular sensor are as follows:

- Availability- purchased from local Perth vendor Jaycar Electronics
- Low cost- $24.95 (Jaycar Electronics, 2013)

- Range encompasses expected operating range, approximately -30°C to 150°C (Kemo Electronic 2012)
- Variable temperature switch value (within accuracy of approximately ±10° (Kemo Electronic 2012)

In our application, the temperature accuracy is not of the utmost importance. The temperature sensor only needs to switch the relay once the temperature is outside of an acceptable range. The accuracy of ±10° is an acceptable range.

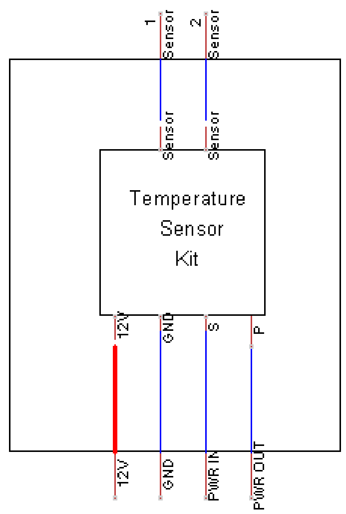


Figure 5.4.2.1: Temperature Module Wiring Diagram

This particular sensor comes with a relay built in, and so the wiring is less complex. The 12V supply line runs directly to the sensor, as does GND. The two wires for the thermistor, which is responsible for sensing the temperature, head off outside the enclosure to the desired temperature sensing position. The PWR line runs in one end of the load side of the relay, and out the other. This can be seen in the wiring diagram in figure 5.4.2.1, and in the physical diagram in Appendix I. It should be noted that the CRG line does not appear on the wiring diagram, yet it does appear on the physical drawing. This is because the CRG line is not in use for this particular module, and the standard module design does feature a CRG port. Therefore the port is on the module, but not in use.

5.4.3 BMS

The BMS modules themselves are located near the batteries they are monitoring, to make it easy to associate each module with its respective cell group. This also helps to reduce on wiring mess. Each BMS monitoring module will signal to a master module, that will throw a 12V signal low or high if any battery cell has crossed its safe operating threshold. In terms of the safety system BMS module, this 12V signal will be used as the input to a relay card- the same Kemo Electric B197 relay card used in the water module. The wiring diagram for this module is shown in figure 5.4.3.1.

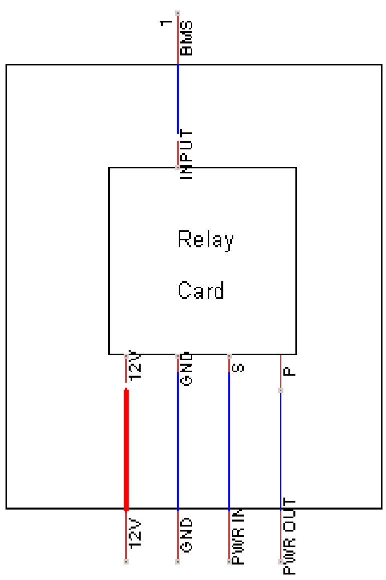


Figure 5.4.3.1: BMS safety module wiring diagram

5.4.4 Charging Box

It is requirement for safety that the vehicle does not operate while charging (see section 4.1.3). In addition, the charging box should not be open whilst the vehicle is in use, as this negates the waterproof properties of the box shielding the charging port. From these two statements, it can be deduced that

$$PWR = CRG^\wedge$$

where

$$CRG = BOX^\wedge$$

therefore

$$PWR = BOX$$

where BOX is the digital logic 1 when the charge box is closed.

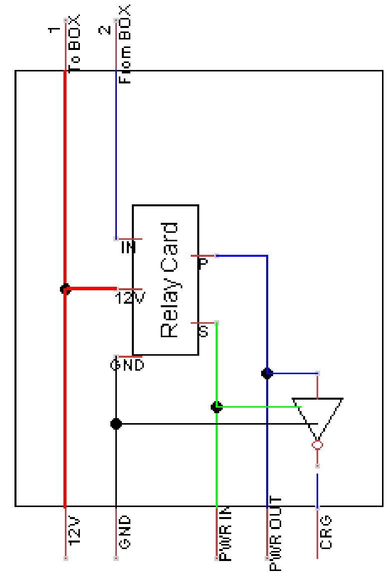


Figure 5.4.4.1: Charging box wiring diagram

With this in mind, the charge box module wiring diagram can be designed. Shown in figure 5.4.4.1, 12V supply is sent to the relay supply and to the switch for the charging box. If the box is closed the switch is closed, and so there is a 12V input to the relay as well. On the load side, the PWR IN line is on one side, and PWR OUT on the other. Joined to PWR OUT is a NOT logic gate, which negates the value of PWR OUT and sends it to CRG. The NOT logic gate is powered by PWR IN. This ensures that should there be a problem with another module that has shutoff power (for example water was detected), CRG will still return a value of 0. This is critical as it is a requirement that the batteries are charged in a safe condition, just as if they were being discharged (see section 4.2.5). Table 5.4.4.2 shows a truth table depicting the logic in this module.

PWR IN	BOX (closed = 1)	PWR OUT	CRG
0	0	0	0
0	1	0	0
1	0	0	1
1	1	1	0

Table 5.4.4.2: Truth table for Charging box module

Table 5.4.4.2 shows that

PWR OUT = (PWR IN)(BOX)

and CRG = (PWR IN)(BOX^)

This ensures that there is no way from this module that the jet ski can be in use and charged at the same time.

5.4.5 Deadman's switch/Ignition Key

As discussed in section 4.2.4, despite having removed the functionality of the DESS, it would still be a desirable function to have a Deadman's switch from a safety point of view, as well as an ignition key to ensure that the vehicle has an easy way to be turned on and off. By using the two existing wires that are attached to the switch (see section 4.2.4) and modifying the DESS key a simple switch could be created that would enable a closed loop when the key switch is plugged in.

Modifying the DESS key would involve placing conductive material around the inside of the plug such that when it is connected to the switch it joins the two terminals, as shown in figure 5.4.5.1.

Figure 5.4.5.1: Terminals of the Ignition key

Once the DESS key is modified, the two wires connected to the switch could be fed into the ignition key safety module as inputs. The wiring diagram for this safety module is shown in figure 5.4.5.2. This module features the same relay card used previously, the Kemo Electric B197 Relay Card. The data sheet can be found in Appendix F.

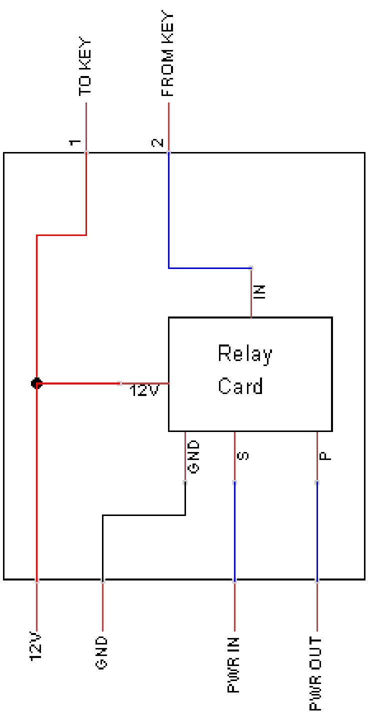


Figure 5.4.5.2: Ignition module wiring diagram

5.5 Final Wiring

The final wiring design takes into account all the individual modules. The key feature of this design is that if one module is faulty, it can be removed and replaced with a replica, or better, more improved module that is more reliable. In this way the system is highly adaptable to the growth of the REV Jet Ski project.

There are 3 main lines, a 12V supply line (red), a ground line GND (black) and a PWR line (blue). The PWR line is used to power the 12V - 96V relay. If each module is safe, then the current will pass through to the end. If however, one module detects a fault, current will be stopped at that module, and will not make it to the end to switch the 96V relay. In addition to this PWR line output, there is a safe to charge line, CRG. The charge line requires all the things that the PWR line requires, such as temperature and water, except the ability to charge or run, as discussed in section 5.4.4. Therefore, in the charging box module, the output of CRG goes to its own line, where it will be inverted from PWR (unless there is a fault previously) so that the jet ski cannot be operated and charging at the same time. This wiring diagram is shown in figure 5.5.1.

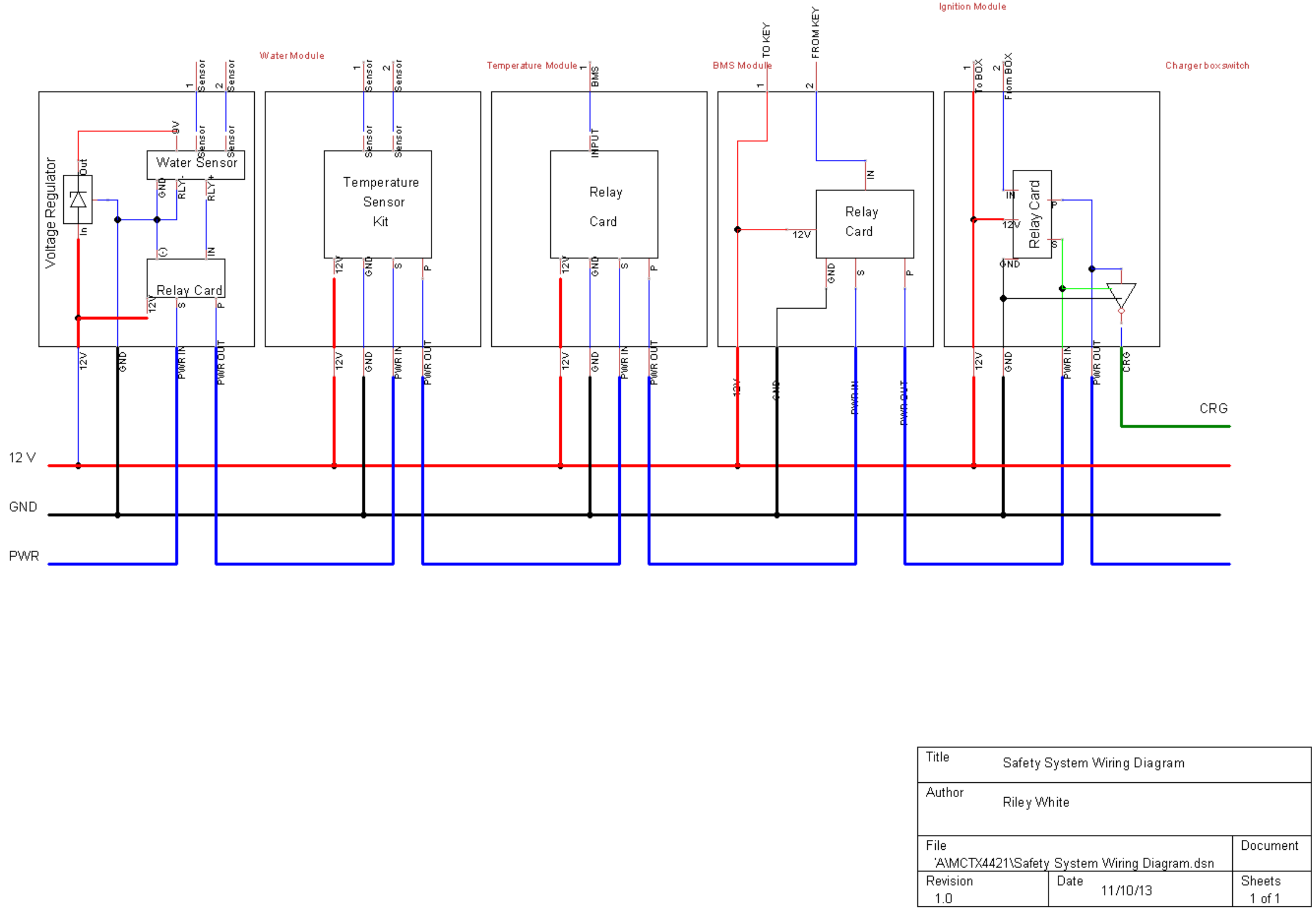


Figure 5.5.1 Safety System Modular Wiring Diagram

6 Implementation

6.1 Construction

6.1.1 Introduction

A requirement for this safety system is that it is adaptable. To achieve this, it was designed to be built with standard, off the shelf components that can be sourced from local Perth vendors. By designing it in this way, future modules can be easily manufactured, should they be required, using inexpensive components that are easily sourced.

The shell for the modules is a standard jiffy box that can be purchased from Jaycar Electronics or Altronics (multiple store locations across Perth). They are 83mm x 54mm x 31mm and cost $3.95 from Jaycar Electronics (Jaycar Electronics, 2013). The reasoning behind this is that these shells are commonly available, a standard size and cost effective. They themselves do not need to be waterproof, as it is intended that the entire system will be housed within a waterproof enclosure.

No specialist skills are required to construct the safety system, beyond being able to solder and drill holes. This once again adds to the adaptability of the system for future work, as future students on the project will be able to construct or modify future modules without having to hire or pay someone else to do it, which could be costly. Each module has a near identical shell design (the charging module will have an extra output pin). The design for this shell is found in appendix D, and shows the locations of holes to be drilled. Once the holes are drilled, interlocking pin sockets are glued in. The pins are 2 pin crimp style headers, and can be purchased from Jaycar Electronics for $0.50. One half is glued into the module shell, the other the veroboard. Holes for the wires are drilled and the wires for the sensors are placed through.

6.1.2 Water Module

The water module was constructed using the Kemo Electric Water Sensor (see section 5.4.1) and the Kemo Electric Relay Card (for the datasheet see Appendix F). The water sensor required a 9V input, whereas the relay card required a 12V input. For this reason a voltage regulator that took the 12V input down to 9V was used. The 12V input was thus connected in parallel to the voltage regulator and the relay card supply. This is done according to the wiring diagram shown in figure 5.4.1. The completed water module can be seen in figures 6.1.2.1 and 6.1.2.2 with the cover off and on, respectively. The connections are shown in figure 6.1.2.1 before the sensor is mounted, so that the wires can be seen for the purposes of the photograph. In reality it would be mounted to the inside of the box and be harder to see.

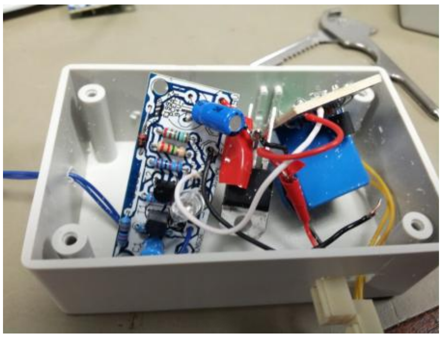


Figure 6.1.2.1: The water module prior to mounting

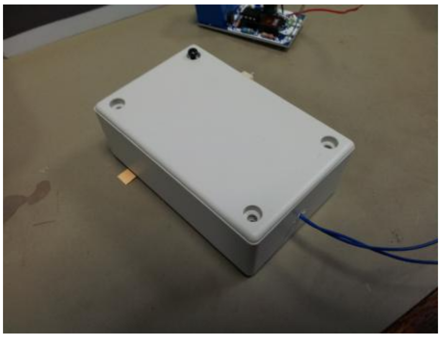


Figure 6.1.2.2: The completed water module

A key benefit to this particular water sensor is that since the requirement for water to be detected is that the gap between to two sensor wires is bridged, additional wires can be joined in parallel to be placed at different locations in the jet ski. If water bridges any of these wire pairs the module will cut off power. This is explained visually in figure 6.1.2.3. Note that the

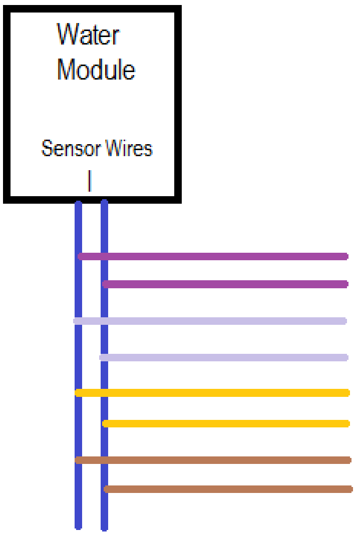


Figure 6.1.2.3: Different sensor lines from the water module.

different colours indicate a different sensor wire pair that would stem off to a different location in the jet ski. This allows the water module to be expanded without making an entirely new module.

6.1.3 Temperature Module

The temperature module was built using the Kemo Electric Temperature Sensor, as described in section 5.4.2. This module only requires the one board, and such is simpler to mount. The 12V supply and GND pins are soldered to the inputs on the board (the board schematics can be found in appendix H), and the PWR in and out pins are soldered to the S and P ports on the relay side of the board. The thermistor sensor is to be cut and extended with wires to the desired location on the jet ski. For now this will stay intact until the exact location is known once thermal testing of the jet ski is undertaken. The complete temperature sensor to be mounted is shown in figure 6.1.3.1. Note the thermistor on the right is still attached to the board. When the location of the temperature recording is known wires of appropriate length will be inserted.

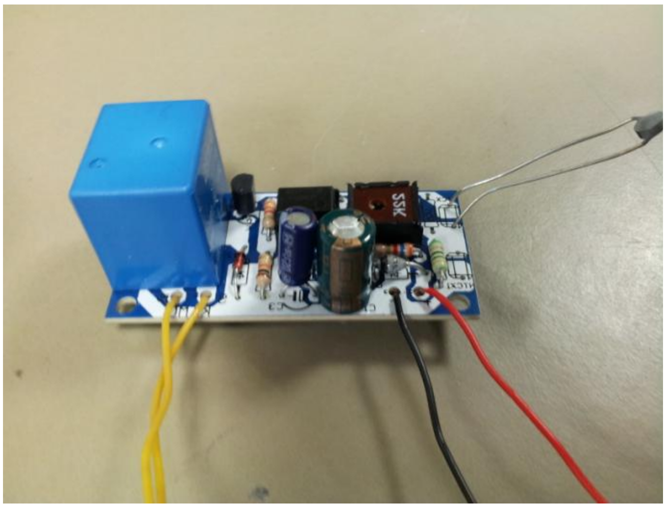


Figure 6.1.3.1: Temperature module ready to be

6.1.4 BMS Module

The BMS module features only an input from the BMS sensors into a relay card, and so is relatively simple to make. The BMS sensors themselves will not be located in the safety system, as they will be mounted close to the batteries. The reason the safety system is not close to the batteries too is that there are significant space restrictions near the batteries. There would not be enough room for the safety system to be securely mounted near the batteries. The sensor wire coming into the module is from the master BMS module (see section 5.4.3). This is either a 12V high or low signal and so can be soldered straight onto the relay IN port. The 12V supply and GND pins are soldered onto the relay card 12V and (-) pins, and the PWR in and out pins are soldered onto the S and P ports as usual.

6.1.5 Charging Module

The charging module requires the use of an inverter (see figure 5.4.4.1). The reason for this, as discussed in section 5.4.4, is that charging and running the jet ski are mutually exclusive events, that is they cannot occur at the same time. This is shown in table 5.4.4.2, where the CRG output is HIGH if PWR IN is HIGH and the box is open (BOX = 0). Conversely, the CRG output is LOW and the PWR OUT output is HIGH if PWR IN is HIGH and the box is closed (BOX = 1). As PWR IN is a requirement to both, an inverter that is powered by PWR IN is used. This means that if PWR IN is LOW, CRG will also be low (in addition to PWR OUT). This is best demonstrated by figure 6.1.5.1. This figure shows the circuit diagram for

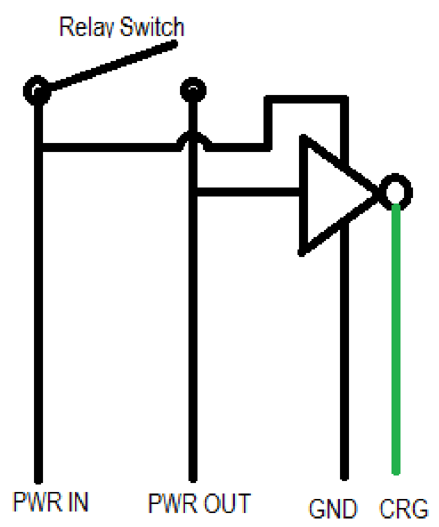


Figure 6.1.5.1: Circuit diagram for PWR IN, PWR OUT, CRG and

PWR IN, PWR OUT, and the inverted signal of PWR OUT, CRG. Note that PWR IN is connected to PWR OUT by the relay switch, as well as CRG via the power supply to the inverter. Thus it is common to both, and both outputs will be 0 if PWR IN is also 0. This module is placed at the end of the series (shown in figure 5.5.1). By doing this, if there is a problem with previous modules it will ensure that there system is not allowed to run or charge.

The system was constructed using the common quadruple NOR gate IC, SN74HC02 from Texas Instruments. An excerpt from the data sheet for this component can be found in Appendix J. The sensor is wired up to the IC as shown in figure 6.1.5.2. This particular IC was chosen due to it being very common and inexpensive, as well as being able to be used at

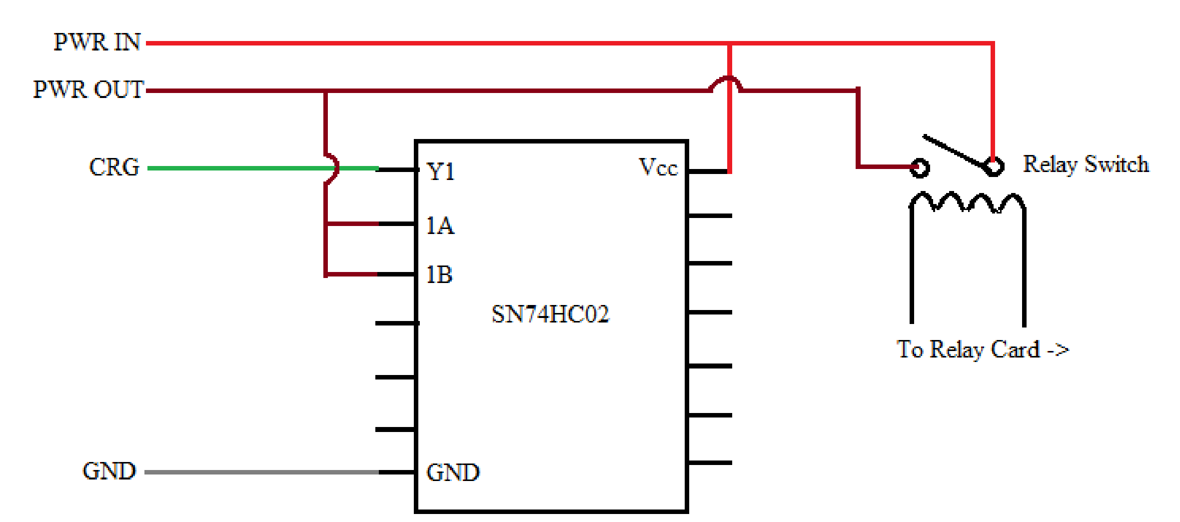
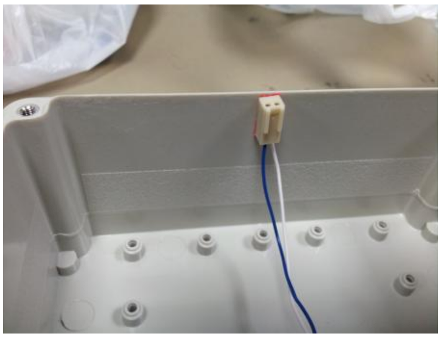
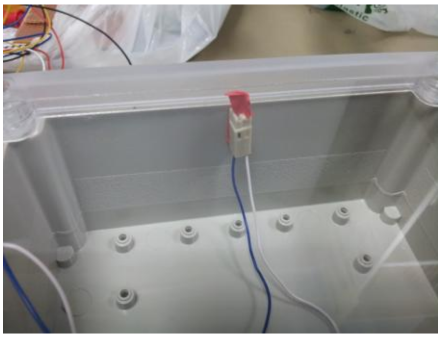


Figure 6.1.5.2: Wiring diagram of IC SN74HC02

12V.

This module utilises the same relay card as all the others (shown in Appendix F), and is constructed and put in the same standard jiffy box with the pin design as shown in Appendix D.

The sensor to detect whether or not the box is open or closed is to be a switch that will be closed when the lid is down, completing a circuit. As discussed in section 4.1.3, a water proof box with a lid is intended to be used to house the charging port instead of a costly waterproof connector. As the battery box has not yet been installed, the batteries have not been able to be inserted and so wiring has not yet been attempted. For this reason the exact location and size requirements of the charging port are unknown at this stage. Therefore a mock-up of the assembly with a switch to display the proof-of-concept of the charging module was constructed. This can be seen in figures 6.1.5.3 and 6.1.5.4, where the lid of the box is open and closed, respectively. Note that when the lid is closed the other half of the connector is plugged in, which is bridged at the top and so forms a connection across the two pins. This completes the circuit from the charging module and so provides a HIGH input into the relay card.

 Figure 6.1.5.3: Water-proof box mock-up with lid open	 Figure 6.1.5.3: Water-proof box mock-up with lid closed

6.1.6 Ignition Key Module

The construction of this module involves utilising the existing wires from the DESS (see section 4.2.4). The two wires are the inputs to the module, and form a closed circuit using the contact terminals (figure 5.4.5.1) and the 12V supply line. The input wires serve as the inputs to drive the relay, and when the contact terminals are bridged the input is the 12V from the supply line, and as such the relay is closed, allowing PWR IN to connect to PWR OUT, and the PWR signal to pass through to the next module.

It was built using the same Kemo Electric Relay Card used in the other modules. As the DESS key supplied from the original SEADOO GTI130 was encoded to limit the performance of the petrol powered jet ski, it is not desirable to modify it in such a way that would prevent future encoding of the key. At the present time it has not been able to be coded as according to the workshop manual, coding requires a special hardware interface to plug the DESS into and special software called B.U.D.S (Seadoo, 2008). Future works on the project may be able to look into programming the DESS key, but for now a simple bridge across the terminals will suffice. This particular module has not been completed at the time of writing as the interior of the jet ski and the mounting points for the safety system and other components are still being modified. If it were to be implemented now it would get in the way and merely have to be removed later to put all the other components in. The reason for this is that it is attached to the DESS terminal, which cannot be removed from the jet ski.

6.1.7 Final Assembly

To join all the modules together, a strip of veroboard is used. The pins are soldered into the 12V, GND and PWR lines, with a single pin for each module on the 12V and GND lines and 2 pins for each module on the PWR line, one for PWR IN and the other for PWR OUT. 12V and GND are continuous, that is the veroboard is not scratched. By scratching the veroboard, the connection along a strip is broken. As the 12V and GND lines connect to each module in parallel, these lines are not scratched. Between each PWR IN and PWR OUT pin pair however, the veroboard is scratched to prevent current from flowing. This ensures that current must flow through the relay switch in order to carry onto the end. Figure 6.1.7.1

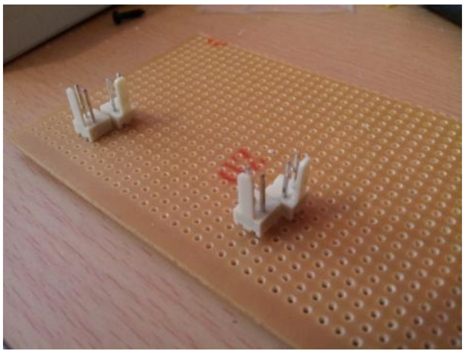


Figure 6.1.7.1: Pins in veroboard

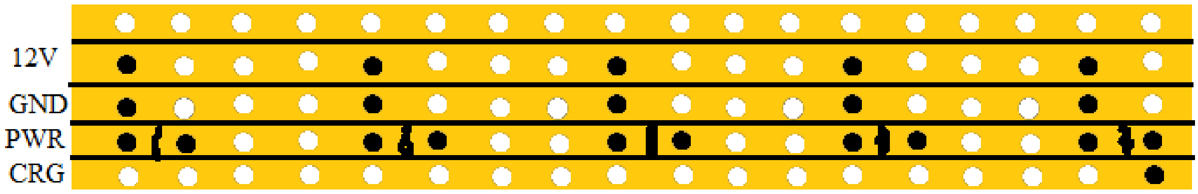


Figure 6.1.7.2: Sketch of veroboard 12V, GND and PWR lines depicting scratches

shows the two sets of module pins in a board. In this view however, the copper lines they are soldered to are on the other side, and so it is impossible to see the scratches. Figure 6.1.7.2 shows a sketch detailing the pins, lines and scratches.

The next step in the construction is to plug in all the modules. This is shown in figure 6.1.7.3 and figure 6.1.7.4. The modules are not incredibly stable in their current position, and so in the future it is intended that a dedicated housing for the modules will be developed to help them remain in position. Once the modules are in position, input wires to the start of each line on the veroboard (with the exception of CRG) can be soldered in, as well as output wires at the other end. The output wires are PWR and CRG. CRG goes to an input on the charger that is allows it to charge or not based on whether it is safe to do so. The PWR output line is used to drive a larger relay that switches the 96V supply to the motor controller on or off (as outlined in the requirements in section 5.2).

Figure 6.1.7.3: Plugging in the modules

Figure 6.1.7.4: Plugging in the modules

At the present time, the jet ski is not ready for the safety system to be mounted. There are still many things to be done first, including properly installing the motor, installing the revised battery box, installing the batteries, as well as installing a platform for the motor controller and safety system to be mounted on. Hence the safety system cannot be fully completed until the exact locations of sensors, other components and wires are known. This will be discussed further in section 7.

6.2 Testing

At the present time, the water sensor module is the only completed module. It is intended that LED indicators be added to all modules, and so there is still much work to be done, this will be discussed in section 7. The remaining modules are incomplete due to the rest of the jet ski not being ready as planned. A major hold up with the construction of the motor (as discussed in section 2.3) meant that physical work on the jet ski was delayed by approximately 3 months. Critical components such as the batteries and their housing, the motor and a platform to mount auxiliary systems (controller, safety systems etc) have therefore not yet been able to be installed or fully designed or constructed. Since the sensors rely on the batteries (temperature sensor placement, BMS) and knowing the location of the mounting platform, they have not yet been able to installed, and hence have not been able to be tested.

However, the water module has been tested. The testing for this module involved pouring approximately 10mL (one cap-full) onto a flat surface and placing the sensor wires (see section 5.4.1) at either end of the puddle. A 12V power supply was provided at the input, and a multimeter measuring resistance was placed at the PWR IN and PWR OUT ports. When the 12V power supply was connected the resistance on the multimeter went to near 0Ω. When water bridged the gap between the two wires the resistance on the multimeter went to infinity (in practise the resistance was not actually infinity however it was beyond the capabilities that the multimeter could measure). This indicated an open circuit, which is the desired response.

The temperature sensor itself was also tested. The temperature sensor requires manual tuning of the potentiometer (see the datasheet in Appendix H) to adjust the cut-off to the desired value. For this test, the potentiometer was tuned so that the cut-off was low, approximately 35°C. The reason for this temperature value was that it was easy to replicate in the lab. Similar to the test for the water module, a 12V power supply was connected to the 12V and GND pins, and a multimeter connected to the relay ports on the opposite side. When the 12V power supply was connected, the multimeter was measuring a resistance of near 0Ω. As the thermistor was warmed up using body heat, the relay contact opened and the multimeter could not measure the resistance anymore. This is again the desired response and once a thermal test of the rest of the jet ski components is done and a temperature cut-off decided further testing can be done.

The rest of the modules have not been tested yet as they are still in the construction phase. However, they utilise the same relay card as the water sensor and so should produce a similar result. This can only be confirmed however once they are built and tested.

7 Conclusions and Future Work

7.1 Current Status

At the time of writing, the physical construction of the safety system is nearing completion. The water module is complete and the materials for the other modules purchased and ready to build once the corresponding systems in the jet ski to the modules are ready. The design of each individual module is complete to a stage where it satisfies the design criteria and requirements as stated in section 5.2. There is however, future work planned for the modules, and this is discussed in section 7.2.

Currently the jet ski is being fitted rubber mountings for the revised battery box. The revised battery box has been designed by Christopher Corke, a mechanical engineering student that joined the project in August of 2013. This revised battery box (figure 3.3.8) is currently being manufactured by the UWA Physics Workshop and will be installed onto the rubber mountings when it is complete. The motor from SME has been constructed, however when it was installed it was done so incorrectly, as so had to be removed. It is currently not installed in the jet ski. New mounting points for this motor have been made and will be installed once the battery box has been installed. The reason for this is that the space requirements inside the jet ski are such that there is not enough room to install the battery box whilst the motor is inside. The battery box has to be made and installed first, then the motor can be put in afterwards. Before any electrical components are installed, a water test to check if the hull leaks or not will be conducted. In order for this to happen all exhaust pipes from the previous petrol motor must be sealed. Currently 2 of the 3 exhaust pipes are sealed, and the last one is expected to be sealed in the coming weeks.

The battery modules (seen in figure 3.3.6), have been assembled and wired up, ready to be installed into the battery box. Unfortunately, as the design for the battery box has been changed, these modules will have to be re-wired to the new configuration to fit with the design shown in figure 3.3.8.

7.2 Future Work

7.2.1 LED Indicators

At present time, without the use of a multimeter, there is no way to tell if the modules have power or if they have detected a fault. This is a necessary feature, and one that it is intended to be implemented in the near future. The design for the module shell in appendix D features 2 holes at the top of the module for LEDs. It is intended that there will be one LED that will light up when power is supplied to the module from the 12V line, and another LED that will show that the PWR line is passing through the module, that is that there is no fault. This way the user will be able to tell if something has gone wrong, which module has detected it, and hence be able to potentially fix the problem.

7.2.2 Safety System Enclosure

The safety system will need to be in a waterproof enclosure to protect the individual modules. This enclosure will need to have a waterproof grommet to allow the sensor cables through without allowing water to leak into the safety systems. This enclosure would be then be securely mounted to a platform in a position that it is accessible should modules need to be changed in and out.

7.2.3 Early Warnings, Data logging and Microcontroller Outputs

With the present design, if a fault is detected, power is cut without warning. This is not desirable, and ideally there would some form of warning prior to the cut-off. This would be possible to implement with a microcontroller such as an Arduino, or a Raspberry-Pi. The most obvious module to implement this in is temperature. Temperature could be measured using the existing sensors, or new ones, connected to an Arduino or Raspberry-Pi. If the existing sensors are used to monitor temperature, the microcontroller must not interfere with their role in the existing design. The current safety system design must remain dedicated to the emergency cut-off of power, keeping things as simple as possible. The microcontroller could easily piggyback off the signals outputted by the relays however, or from new sensors.

Data logging could also be a worthwhile area to look in to. This could also be done with a microcontroller. Should an error occur, it may be useful to know when it happened and under what conditions each sensor was. Future modules could also be added, such as an accelerometer, or a clock, so that if faults occur the conditions of use and time are known. For warnings and data logging purposes, it would be useful if each module had an additional output to send to a microcontroller. This microcontroller could in addition control a display, where the current status of all modules could be shown. If temperature is approaching a range close to the cut-off, lights could flash or alarms could sound alerting the driver to either slow down or return to shore. These would be ideal features and should be looked into in the future.

7.2.4 Sensor Placement

At the present time the other components (batteries, motor etc) have not been installed in the jet ski. Once they are installed, sensors will be able to be placed in the appropriate locations. Exactly how many sensors are required, where they are required and what lengths of wire are required to reach them will all need to be decided once the other components are installed in the jet ski.

7.2.5 User Override

Should power cut off because of a fault whilst the jet ski is in use, the user could effectively be stranded in a body of water some distance from shore. This is not ideal, and so a safety system override is required. This is a dangerous feature however, as it is possible that it would enable users to ignore dangerous hazards such as high temperature or water leakages, and simply override the safety system to continue using the jet ski. One possible solution to this would be to place an override switch with a timer in the jet ski, so that the user only has a short space of time to get back to shore before the power shuts off again. There are risks associated with this override function, as stated above, however being stranded is very undesirable, and so this is an area that requires examination in the future.

7.2.6 Fire Extinguisher System

Currently there is no protection or detection for fire in the safety systems. Hopefully ones of the other safety modules would cut off power to prevent a fire from occurring, however if a fire does break out there needs to be some protection. It is likely that the fire would be inaccessible to the user, so suppression using a handheld fire extinguisher would be near impossible, as well as quite dangerous, given the close proximity the user would have to be to the fire in order to put it out. A better option would be a remotely operated fire extinguisher. Lifeline Fire and Safety Systems Ltd. is a company that specialises in these devices. Their product, the Zero ZERO Remote Electric CD is designed specifically for single seat vehicles and is activated remotely (Lifeline Fire and Safety Systems Ltd, 2013). This is a critical and potentially life-saving safety feature and definitely requires future work.

7.2.7 Relay Upgrades and Testing

Currently the relays used in the safety system are Pasi BV1719 model relays, and as far as can be seen, are not tested for automotive use. It is possible that they would be suitable for use in the REV Jet Ski safety systems, however as a datasheet cannot be located it cannot be assured. Automotive relays designed for use in cars or vehicles that experience similar conditions to the REV Jet Ski are required to ensure reliable functionality from the safety system.

The safety systems should also be tested under conditions replicating what will be experienced in the jet ski, including high temperature, possible humidity (although hopefully not if housed in a waterproof box) and vibrations. The safety system must be able to function reliably under all these conditions, and so this is a necessary task to be done in the near future.

7.3 Outcomes and Conclusions

The objective of this project was to design a safety system for the REV Electric Jet Ski that took into account temperature, water leakage, battery management (BMS modules), charging and a deadman's switch, whilst being cost effective and highly adaptable to the ongoing nature of the project. These objectives have been met, and so the project to design the safety system could be considered a success. Each sensor area has been accounted for, and the design is highly adaptable and cost effective. The modular design from standard off-the-shelf parts is the main reason for this. Through the modular design, each current sensor area can be accounted for, as well as any new requirements thought up as the project develops. The modular design also allows individual modules, components to be upgraded or modified without affecting other sensors.

Whilst the project could be considered a success in that it has delivered a design that satisfies the objectives, there is still much work to be done to improve the safety system to a point where it can be used reliably and effectively to protect the user and critical systems of the jet ski from the hazards outlined in section 4.4.1. This work, for the foreseeable future, is outline in section 7.2, however there will likely be new safety requirements appear as the project develops. This once again emphasises the need for an adaptable safety system design, which this project has endeavoured to deliver.

9 References

Altronics 2013 Waterproof Connectors Available from: <http://www.altronics.com.au/index.asp?area=item&id=P9344> [26/10/2013]

Clark, R 2013 *REVjet: Electric Jetski Project Investigation and proposal of thermal management system and auxiliary mounting assembly* Bachelor thesis, The University of Western Australia

Curtis Instruments, Inc 2009 *1310 Manual* Available from : <www.curtisinstruments.com> [26/10/2013]

Dinh, J & Korinsky, G 1993 *Temperature Dependent Fan Control For Personal Computer* US Patent 5,526,289

Ev-power.eu 2013 *GWL/Power Charger 96V/25A for LiFePO4 / LiFeYPO4 + BMS con.* Available from: < http://www.ev-power.eu/Chargers-48V-to-96V/Charger-96V-25A-for-LiFePO4-LiFeYPO4-BMS-option.html> [26/10/2013]

EV Works 2010 *ZEVA 8 Cell Batter Monitor Module.* Available from: < http://www.evworks.com.au/index.php?product=BMM-AModule> [26/10/2013]

Ewing, Manning, 2009 *Temperature In Cars* Available from: <http://www.racq.com.au/__data/assets/pdf_file/0007/48796/09_Temperature_in_Cars.pdf> [10/10/2013]

Headway Headquarters 2013 *Headway 38120S Spec Sheet* Available from: <http://headway-headquarters.com/38120s/> [26/10/10]

International Battery Inc 2010 *$LiFePO_4$ Material Safety Data Sheet* International Battery, Inc, USA

ISO 2009 *Risk Management- Principles and Guidelines* ISO 31000:2009 Available from International Organisation for Standardisation [26/10/2013]

ISO/IEC 1999 *Safety aspects - Guidelines for their inclusion in standards*. ISO/IEC Guide 51:1999. Available from International Organisation for Standardisation. [26/10/2013]

Jayamanna, R 2013 *Design of the Battery Restraining System and the Motor Mounting system for the REV Jet Ski* Bachelor thesis, The University of Western Australia

Jaycar Electronics 2013 *2013 Jaycar Electronics Engineering & Scientific Catalogue* Available from: < http://www.jaycar.com.au/printed.asp> [26/10/2013]

Kemo Electronic 2012 *Kemo Electric Water Sensor B192 Data Sheet* Available from: <http://www.kemo-electronic.de/datasheets/b192.pdf> [26/10/2013]

Kemo Electronic 2012 *Kemo Temperature Sensor B048 Datasheet* Available from: <http://www.kemo-electronic.de/datasheets/b048.pdf> [26/10/2013]

Kemo Electronic 2012 *Kemo Electric Relay Card B197 Data Sheet* Available from: <http://www.kemo-electronic.de/datasheets/b197.pdf> [26/10/2013]

Kloppenborg, TJ 2012 *Contemporary Project Management*, South-Western, Ohio, USA

Lifeline Fire and Safety Systems Ltd 2013 *Zero ZERO Remote Electric CD* Available from: <http://www.lifeline-fire.co.uk/motorsport/details.asp?product=zero-zero-remote-electric-cd-15> [26/10/2013]

McDermott, R, Mikulak, RJ & Beauregard, M 2011 *The Basics of FMEA, 2nd Edition* Taylor and Francis USA

Oxford University Press, 2013 *Define: Failsafe* Available from: <http://oxforddictionaries.com/definition/english/fail--safe?q=failsafe> [10/10/2013]

Seadoo 2008 *2008 Shop Manual 4-Tec Series* Available from: <www.seadoomanuals.net> [26/10/2013]

Texas Instruments 1997 *SN54HC02, SN74HC02 QUADRUPLE 2-INPUT POSITIVE-NOR GATES* Available from: <http://www.jaycar.com.au/images_uploaded/SCLS076B.PDF> [26/10/13]

Thompson, F 1974 *Safety Feature For Electric Vehicle Control* US Patent 4,090,114

ZEVA n.d *8-cell Battery Monitor Module* Available from: <http://www.evworks.com.au/store/datasheets/BMM8%20v1-3%20Manual.pdf> [26/10/2013]

Appendix

Appendix A: SME Custom Motor Datasheet

Credit: Submersible Motors Engineering

JS102-50kW 96V 135Hz 200mm

16/09/2012

				BEST
Given Output Power (kW):	50	50	50	50
Rated Voltage (V):	96	96	96	96
Winding Connection:	Delta	Wye	Wye	Wye
Number of Poles:	2	2	2	2
Given Speed (rpm):	8000	8000	8000	8000
Frequency (Hz):	135	135	135	135
Stray Loss (W):	250	250	250	250
Frictional Loss (W):	150	150	150	150
Windage Loss (W):	150	150	150	150
Type of Load:	Constant Power	Constant Power	Constant Power	Constant Power
Operating Temperature (C):	75	75	75	75
STATOR DATA				
Number of Stator Slots:	24	24	24	24
Outer Diameter of Stator (mm):	224	224	224	224
Inner Diameter of Stator (mm):	110	110	110	110
Type of Stator Slot:	3	3	3	3
Dimension of Stator Slot				
hs0_stator (mm):	1	1	1	1
hs1_stator (mm):	1.12	1.12	1.12	1.12
hs2_stator (mm):	25.98	25.98	25.98	25.98
bs0_stator (mm):	4.5	4.5	4.5	4.5
bs1_stator (mm):	8.37091	8.37091	8.37091	8.37091
bs2_stator (mm):	15.2116	15.2116	15.2116	15.2116
rs_stator (mm):	2	2	2	2
Top Tooth Width (mm):	6.6	6.6	6.6	6.6
Bottom Tooth Width (mm):	6.6	6.6	6.6	6.6
Length of Stator Core (mm):	200	180	170	165
Stacking Factor of Stator Core:	0.95	0.95	0.95	0.95
Type of Steel:	DW315_50	DW315_50	DW315_50	DW315_50
Number of lamination sectors	1	1	1	1
Press board thickness (mm):	0	0	0	0
Magnetic press board	No	No	No	No
Number of Conductors per Slot:	7	4	4	4
Number of Parallel Branches:	2	2	2	2

Number of Wires per Conductor:	5	9	9	9
Type of Coils:	11	10	10	10
Coil Pitch:	11	11	11	11
Wire Diameter (mm):	2.4	2.4	2.4	2.4
Wire Wrap Thickness (mm):	0.08	0.08	0.08	0.08
Slot Insulation Thickness (mm):	0.23	0.23	0.23	0.23
Layer Insulation Thickness (mm):	0	0	0	0
Top Free Space in Slot (%):	0	0	0	0
Bottom Free Space in Slot (%):	0	0	0	0
Conductor Length Adjustment (mm):	0	0	0	0
End Length Correction Factor	1	1	1	1
End Leakage Reactance Correction Factor	1	1	1	1
Limited Slot Fill Factor (%):	75	75	75	75
ROTOR DATA				
Number of Rotor Slots:	28	28	28	28
Air Gap (mm):	1	1	1	1
Inner Diameter of Rotor (mm):	70	70	70	70
Type of Rotor Slot:	4	4	4	4
Dimension of Rotor Slot				
hr0_top (mm):	1	1	1	1
hr01_top (mm):	1	1	1	1
hr1_top (mm):	1	1	1	1
hr2_top (mm):	11	11	11	11
br0_top (mm):	0.0001	0.0001	0.0001	0.0001
br1_top (mm):	5.3	5.3	5.3	5.3
br2_top (mm):	2.93	2.93	2.93	2.93
rr_top (mm):	0.5	0.5	0.5	0.5
Cast Rotor:	No	No	No	No
Half Slot:	No	No	No	No
Length of Rotor (mm):	200	180	170	165
Stacking Factor of Rotor Core:	0.95	0.95	0.95	0.95
Type of Steel:	DW315_50	DW315_50	DW315_50	DW315_50
Skew Width:	0	0	0	0
End Length of Bar (mm):	0	0	0	0
Height of End Ring (mm):	12	12	12	12
Width of End Ring (mm):	23	23	23	23
Resistivity of Rotor Bar				
at 75 Centigrade (ohm.mm^2/m):	0.0217391	0.021739	0.021739	0.021739
Resistivity of Rotor Ring				
at 75 Centigrade (ohm.mm^2/m):	0.0217391	0.021739	0.021739	0.021739
Magnetic Shaft:	Yes	Yes	Yes	Yes

MATERIAL CONSUMPTION				
Armature Copper Density (kg/m^3):	8900	8900	8900	8900
Rotor Bar Material Density (kg/m^3):	8900	8900	8900	8900
Rotor Ring Material Density (kg/m^3):	8900	8900	8900	8900
Armature Core Steel Density (kg/m^3):	7600	7600	7600	7600
Rotor Core Steel Density (kg/m^3):	7600	7600	7600	7600
Armature Copper Weight (kg):	13.6946	13.4328	13.085	12.911
Rotor Bar Material Weight (kg):	2.56644	2.30979	2.18147	2.11731
Rotor Ring Material Weight (kg):	1.4508	1.4508	1.4508	1.4508
Armature Core Steel Weight (kg):	31.1656	28.049	26.4907	25.7116
Rotor Core Steel Weight (kg):	5.58917	5.03025	4.75079	4.61106
Total Net Weight (kg):	54.4666	50.2727	47.9588	46.8018
Armature Core Steel Consumption (kg):	60.6851	54.6166	51.5823	50.0652
Rotor Core Steel Consumption (kg):	13.7228	12.3505	11.6644	11.3213
RATED-LOAD OPERATION				
Stator Resistance (ohm):	0.00543842	0.001646	0.001604	0.001582
Stator Leakage Reactance (ohm):	0.0697862	0.030588	0.029314	0.028663
Rotor Resistance (ohm):	0.00973848	0.002945	0.002828	0.002769
Rotor Leakage Reactance (ohm):	0.114821	0.03361	0.03196	0.031095
Resistance Corresponding to Iron-Core Loss (ohm):	66.605	19.5658	18.472	17.9222
Magnetizing Reactance (ohm):	3.20249	0.933966	0.874659	0.841934
Stator Phase Current (A):	211.085	374.624	370.868	369.366
Current Corresponding to Iron-Core Loss (A):	1.32784	2.53589	2.70646	2.79891
Magnetizing Current (A):	27.6162	53.1247	57.1579	59.5801
Rotor Phase Current (A):	200.952	355.876	351.28	349.223
Copper Loss of Stator Winding (W):	726.957	693.201	661.777	647.703
Copper Loss of Rotor Winding (W):	1179.77	1119.02	1046.85	1013.15
Iron-Core Loss (W):	352.305	377.467	405.919	421.202
Frictional and Windage Loss (W):	293.627	294.318	295.142	295.529
Stray Loss (W):	250	250	250	250
Total Loss (W):	2802.66	2734	2659.69	2627.59
Input Power (kW):	52.7998	52.7307	52.6574	52.6265
Output Power (kW):	49.9971	49.9967	49.9977	49.9989
Mechanical Shaft Torque (N.m):	60.3256	60.2539	60.1705	60.1324
Efficiency (%):	94.6919	94.8152	94.9491	95.0071
Power Factor:	0.864412	0.842504	0.849849	0.8528

Rated Slip:	0.0229212	0.021767	0.020391	0.019747
Rated Shaft Speed (rpm):	7914.34	7923.69	7934.84	7940.05
NO-LOAD OPERATION				
No-Load Stator Resistance (ohm):	0.00543842	0.001646	0.001604	0.001582
No-Load Stator Leakage Reactance (ohm):	0.0699069	0.030638	0.02936	0.028706
No-Load Rotor Resistance (ohm):	0.00973671	0.002945	0.002827	0.002769
No-Load Rotor Leakage Reactance (ohm):	1.54912	0.422163	0.371975	0.351156
No-Load Stator Phase Current (A):	29.4628	57.6597	61.5321	63.8776
No-Load Iron-Core Loss (W):	397.431	441.446	466.888	480.721
No-Load Input Power (W):	980.969	1003.95	1069.09	1080.06
No-Load Power Factor:	0.0861456	0.078639	0.080057	0.07815
No-Load Slip:	0.000117516	0.000101	0.00011	0.000106
No-Load Shaft Speed (rpm):	8099.05	8099.18	8099.11	8099.14
BREAK-DOWN OPERATION				
Break-Down Slip:	0.07	0.06	0.06	0.06
Break-Down Torque (N.m):	97.6001	88.0791	93.3874	96.258
Break-Down Torque Ratio:	1.61789	1.4618	1.55205	1.60077
Break-Down Phase Current (A):	459.015	735.892	773.1	793.152
LOCKED-ROTOR OPERATION				
Locked-Rotor Torque (N.m):	20.1279	13.9218	15.0851	15.887
Locked-Rotor Phase Current (A):	688.392	1048.63	1115.01	1156.73
Locked-Rotor Torque Ratio:	0.333655	0.231053	0.250706	0.264201
Locked-Rotor Current Ratio:	3.26121	2.79915	3.00649	3.13165
Locked-Rotor Stator Resistance (ohm):	0.00543842	0.001646	0.001604	0.001582
Locked-Rotor Stator Leakage Reactance (ohm):	0.0681067	0.030271	0.028918	0.028178
Locked-Rotor Rotor Resistance (ohm):	0.0126702	0.003807	0.003642	0.003559
Locked-Rotor Rotor Leakage Reactance (ohm):	0.0717822	0.022858	0.021015	0.019931
DETAILED DATA AT RATED OPERATION				
Stator Slot Leakage Reactance (ohm):	0.0304867	0.017918	0.016923	0.016426
Stator End-Winding Leakage Reactance (ohm):	0.0242114	0.00827	0.00827	0.00827
Stator Differential Leakage Reactance (ohm):	0.0150879	0.0044	0.004121	0.003967
Rotor Slot Leakage Reactance (ohm):	0.0964679	0.028137	0.026765	0.02606

Rotor End-Winding Leakage Reactance (ohm):	0.00370488	0.00121	0.00121	0.00121
Rotor Differential Leakage Reactance (ohm):	0.0146088	0.00426	0.00399	0.003841
Skewing Leakage Reactance (ohm):	0	0	0	0
Net Slot Area (mm^2):	315.218	315.218	315.218	315.218
Slot Fill Factor (%):	68.2906	70.2418	70.2418	70.2418
Stator Winding Factor:	0.957662	0.957662	0.957662	0.957662
Stator-Teeth Flux Density (Tesla):	1.14383	1.25414	1.32734	1.37348
Rotor-Teeth Flux Density (Tesla):	1.02331	1.122	1.18748	1.22876
Stator-Yoke Flux Density (Tesla):	1.04835	1.15148	1.22073	1.26535
Rotor-Yoke Flux Density (Tesla):	0.710646	0.780549	0.827493	0.857741
Air-Gap Flux Density (Tesla):	0.498079	0.546113	0.577986	0.598078
Stator-Teeth Ampere Turns (A.T):	4.4496	6.6522	9.64217	12.4226
Rotor-Teeth Ampere Turns (A.T):	1.44999	1.8394	2.2556	2.64017
Stator-Yoke Ampere Turns (A.T):	13.3593	17.6987	21.368	24.7974
Rotor-Yoke Ampere Turns (A.T):	1.2412	1.30733	1.34354	1.37442
Air-Gap Ampere Turns (A.T):	486.453	533.366	564.495	584.118
Correction Factor for Magnetic Circuit Length of Stator Yoke:	0.7	0.7	0.65825	0.631193
Correction Factor for Magnetic Circuit Length of Rotor Yoke:	0.562677	0.533892	0.514561	0.502105
Saturation Factor for Teeth:	1.01213	1.01592	1.02108	1.02579
Saturation Factor for Teeth & Yoke:	1.04214	1.05155	1.06131	1.07059
Induced-Voltage Factor:	0.921266	0.895197	0.901993	0.905029
Stator Current Density (A/mm^2):	4.666	4.60056	4.55443	4.53599
Specific Electric Loading (A/mm):	51.3091	52.0349	51.5131	51.3046
Stator Thermal Load (A^2/mm^3):	239.408	239.39	234.613	232.717
Rotor Bar Current Density (A/mm^2):	12.3835	12.5314	12.3694	12.2966
Rotor Ring Current Density (A/mm^2):	9.34159	9.4532	9.33094	9.27604
Half-Turn Length of Stator Winding (mm):	404.918	386.146	376.146	371.146
WINDING ARRANGEMENT				
The 3-phase, 1-layer winding can be arranged in 24 slots as below:		10	10	10
AAAAZZZZBBBBXXXXCCCCYYYY		15	15	15

		82.5	82.5	82.5
Average coil pitch is:	10	0	0	0
Angle per slot (elec. degrees):	15			
Phase-A axis (elec. degrees):	112.5			
First slot center (elec. degrees):	0			
		16	16	16
TRANSIENT FEA INPUT DATA		2	2	2
		0.001646	0.001604	0.001582
For one phase of the Stator Winding:		9.75E-06	9.75E-06	9.75E-06
Number of Turns:	28			
Parallel Branches:	2	8.31E-07	8.31E-07	8.31E-07
Terminal Resistance (ohm):	0.00543842	1.42E-09	1.42E-09	1.42E-09
End Leakage Inductance (H):	2.85E-05			
For Rotor End Ring Between Two Bars of One Side:		180	170	165
Equivalent Ring Resistance (ohm):	8.31E-07	0.95	0.95	0.95
Equivalent Ring Inductance (H):	1.42E-09	0.95	0.95	0.95
2D Equivalent Value:		0.018753	0.017711	0.01719
Equivalent Model Depth (mm):	200			
Equivalent Stator Stacking Factor:	0.95			
Equivalent Rotor Stacking Factor:	0.95			
Estimated Rotor Inertial Moment (kg m^2):	0.0208362			

Appendix B: Headway LiIon Datasheet

(Headway Headquarters 2013)

HEADWAY HEADQUARTERS

Headway 38120S(10AH) Single Cell Specification

No.	Item		Specification
1	Normal capacity		10000mAh
2	Normal Voltage		3.2V
3	Inter Impedance		<6mΩ
4	Maximum Charge Current		2C(20A)
5	Maximum Charge Voltage		3.65±0.05V
6	Maximum Continuous Discharge Current		3C(30A)
7	Maximum Peak Pulse Discharge Current		10C(100A)
8	Discharge Stop Voltage		2.0V
9	Dimension	Diameter	38±1mm
		Height	122 ±1mm (132±1mm)
10	Weight		Appro. 330g
11	Work temperature	Charge	0~45°C
		Discharge	-20~60°C
12	Store temperture	In one month	-20~45°C
		In six month	-20~35°C
13	Cycle Life	1500 cycles 1C 100% DOD	2000 cycles 1C 80% DOD

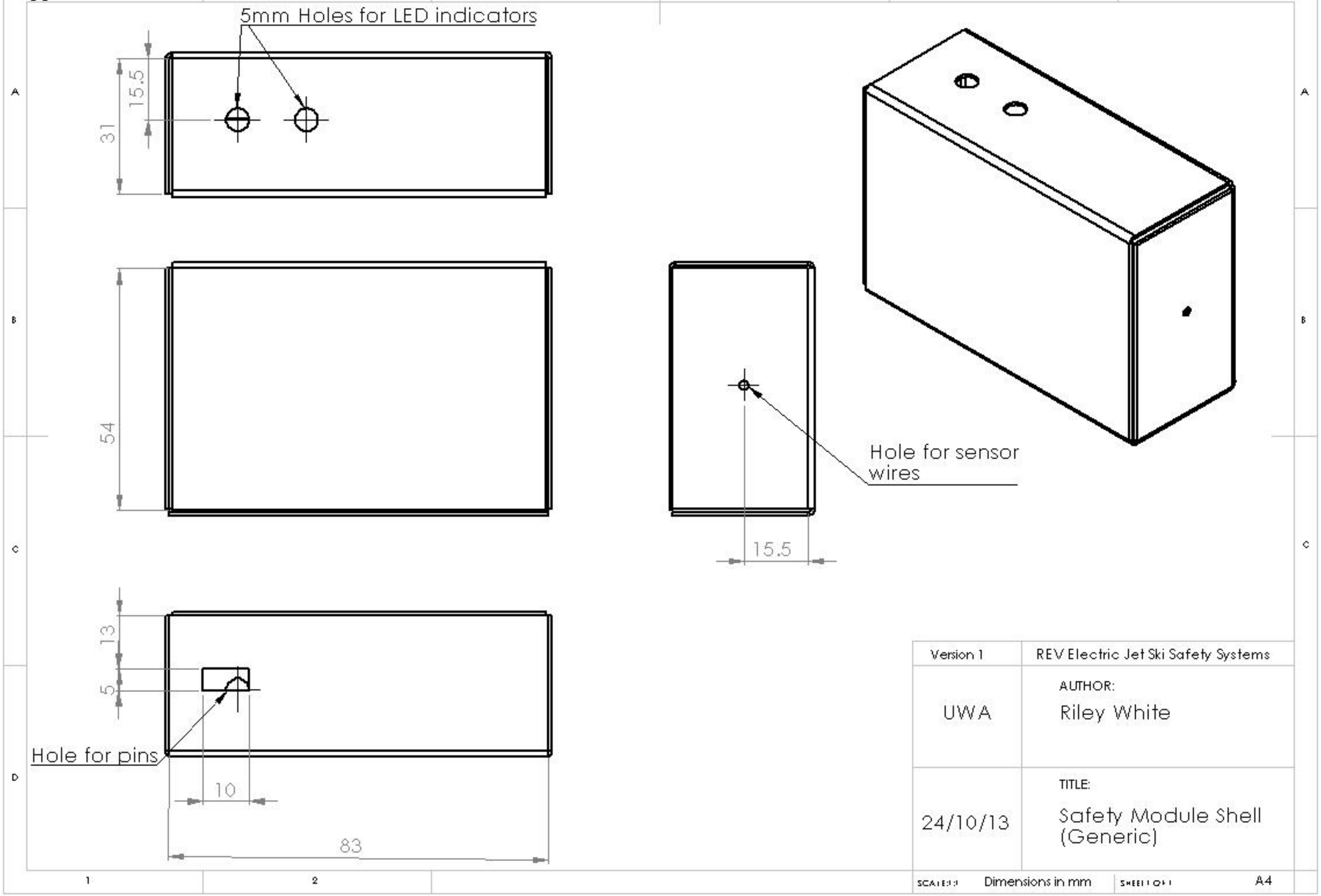
Appendix C: FMEA Chart

Item and Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) of Failure	Secondary cause (cause of cause)	Current Controls	Detection	RPN	Recommended Action
Batteries - supply power to all systems	Short circuit	No power to system, fire	Very High	Water leakage bridges contacts		Water proof-box	Fuse protection, power will shut-off. Need water sensors		Install water sensors, have an alarm. Evacuate.
				Insulation breaks and contact is made between two terminals and battery housing		Multi-layered tape insulation and silicon sheets between batteries and housing	Fuse protection, power will shut-off.		Have an alarm for notice to evacuate vehicle in case of fire.
				Uninsulated wire terminals		Heat shrink on all connections	Fuse protection, power will shut-off.		Have an alarm for notice to evacuate vehicle in case

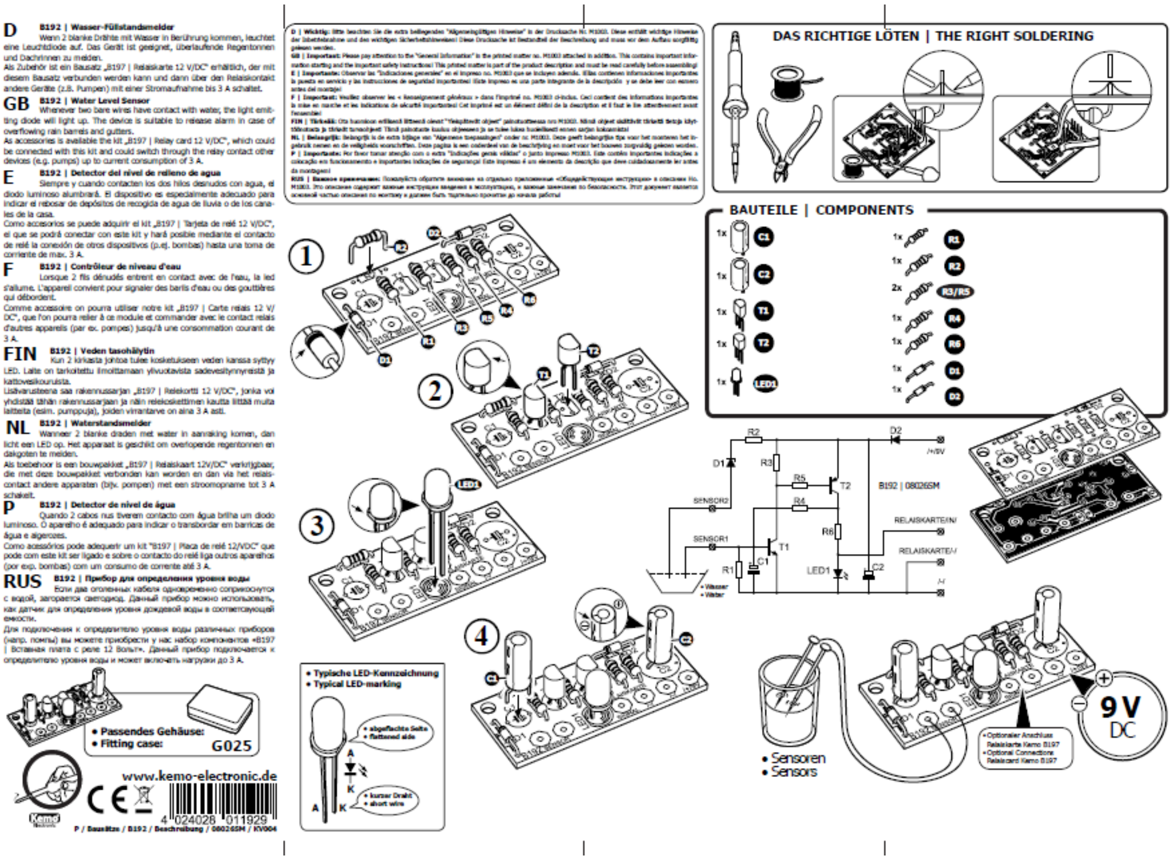
[redacted]							of fire
	Battery rupture and leakage of flammable gasses and liquids	Fire, power loss	Very High	High temperature in excess of 100°C (International Battery Inc 2010)	Water cooled insulation (intended) (Clark, 2013)	Need temperature sensor	Install temperature sensor with cut-off, and warning system. Evacuate if occurs.
				Collision, high impact	Metal housing to withstand typical forces (Jayamanna, 2013)	Visual	Ensure driver training
	No charge	No power to system	Low	Lack of charging/general use	Sensor to show remaining charge	Visual	Ensure sensor is checked before disembarking, charge batteries
				Battery charge is too low to be	BMS	Light on BMS,	Replace battery

				charged			remaining charge will be at 0.	
Motor-drives impellor	Motor stops-fails to rotate drive shaft	System halts	Medium	Damage due to collision or impact		Rubber mounts, limited vibration absorption.	Visual	Take care whilst driving, ensure driver is adequately trained
				No power to motor	Low battery charge	Sensor will show remaining charge	Visual	Charge batteries
					Short circuit	Fuse	Fuse will blow	
					Problem with controller	Controller displays error light	Inspection of light, diagnosis of error with controller data-logs	Check light and connect controller to PC
Controller - supplies power to	Error, stops supplying power	Motor has no power	Medium	No power to controller	Flat battery	Sensor to show remaining	Visual	Charge batteries

Appendix D: Generic Module



Appendix E: Kemo Electric Water Sensor B192 Data Sheet



D B192 | Wasser-Füllstandsmelder
Wenn 2 blanke Drähte mit Wasser in Berührung kommen, leuchtet eine Leuchtdiode auf. Das Gerät ist geeignet, überlaufende Regentonnen und Dachrinnen zu melden.
Als Zubehör ist ein Bausatz „B197 | Relaiskarte 12 V/DC" erhältlich, der mit diesem Bausatz verbunden werden kann und dann über den Relaiskontakt andere Geräte (z.B. Pumpen) mit einer Stromaufnahme bis 3 A schaltet.

GB B192 | Water Level Sensor
Whenever two bare wires have contact with water, the light emitting diode will light up. The device is suitable to release alarm in case of overflowing rain barrels and gutters.
As accessories is available the kit „B197 | Relay card 12 V/DC", which could be connected with this kit and could switch through the relay contact other devices (e.g. pumps) up to current consumption of 3 A.

E B192 | Detector del nivel de relleno de agua
Siempre y cuando contacten los dos hilos desnudos con agua, el diodo luminoso alumbrará. El dispositivo es especialmente adecuado para indicar el rebosar de depósitos de recogida de agua de lluvia o de los canales de la casa.
Como accesorios se puede adquirir el kit „B197 | Tarjeta de relé 12 V/DC", el que se podrá conectar con este kit y hará posible mediante el contacto de relé la conexión de otros dispositivos (p.ej. bombas) hasta una toma de corriente de max. 3 A.

F B192 | Contrôleur de niveau d'eau
Lorsque 2 fils dénudés entrent en contact avec de l'eau, la led s'allume. L'appareil convient pour signaler des barils d'eau ou des gouttières qui débordent.
Comme accessoire on pourra utiliser notre kit „B197 | Carte relais 12 V/DC", que l'on pourra relier à ce module et commander avec le contact relais d'autres appareils (par ex. pompes) jusqu'à une consommation courant de 3 A.

FIN B192 | Veden tasohälytin
Kun 2 kirkasta johtoa tulee kosketukseen veden kanssa syttyy LED. Laite on tarkoitettu ilmoittamaan ylivuotavista sadevesitynnyreistä ja kattovesikouruista.
Lisävarusteena saa rakennussarjan „B197 | Relekortti 12 V/DC", jonka voi yhdistää tähän rakennussarjaan ja näin relekoskettimen kautta liittää muita laitteita (esim. pumppuja), joiden virrantarve on aina 3 A asti.

NL B192 | Waterstandsmelder
Wanneer 2 blanke draden met water in aanraking komen, dan licht een LED op. Het apparaat is geschikt om overlopende regentonnen en dakgoten te melden.
Als toebehoor is een bouwpakket „B197 | Relaiskaart 12V/DC" verkrijgbaar, die met deze bouwpakket verbonden kan worden en dan via het relaiscontact andere apparaten (bijv. pompen) met een stroomopname tot 3 A schakelt.

P B192 | Detector de nível de água
Quando 2 cabos nus tiverem contacto com água brilha um diodo luminoso. O aparelho é adequado para indicar o transbordar em barricas de água e algerozes.
Como acessórios pode adequerir um kit "B197 | Placa de relé 12/VDC" que pode com este kit ser ligado e sobre o contacto do relé liga outros aparelhos (por exp. bombas) com um consumo de corrente até 3 A.

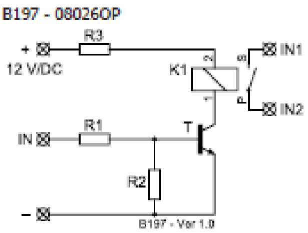
RUS B192 | Прибор для определения уровня воды
Если два оголенных кабеля одновременно соприкоснутся с водой, загорается светодиод. Данный прибор можно использовать, как датчик для определения уровня дождевой воды в соответсвующей емкости.
Для подключения к определителю уровня воды различных приборов (напр. помпы) вы можете приобрести у нас набор компонентов «B197 | Вставная плата с реле 12 Вольт». Данный прибор подключается к определителю уровня воды и может включать нагрузки до 3 A.

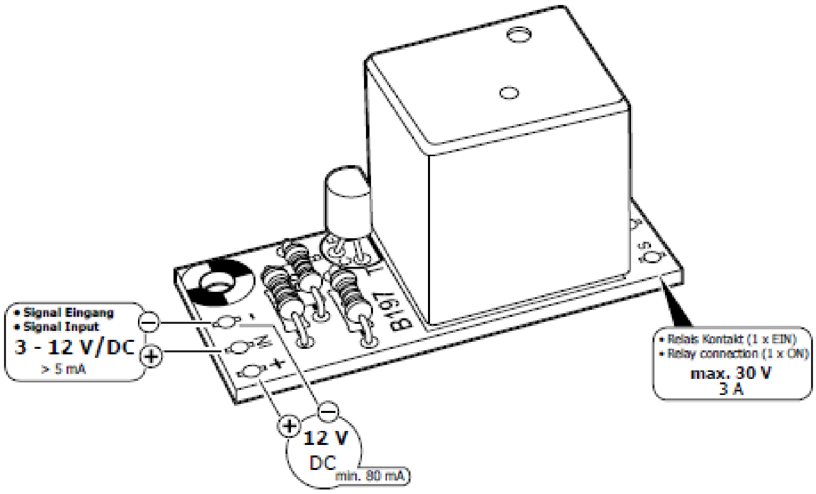
GB | Important: Please pay attention to the "General Information" in the printed matter no. M1003 attached in addition. This contains important information starting and the important safety instructions! This printed matter is part of the product description and must be read carefully before assembling!

Appendix F: Kemo Electric Relay Card B197 Data Sheet

(Kemo Electric 2012)

Note only the English translations are included





GB

Assembly instructions:

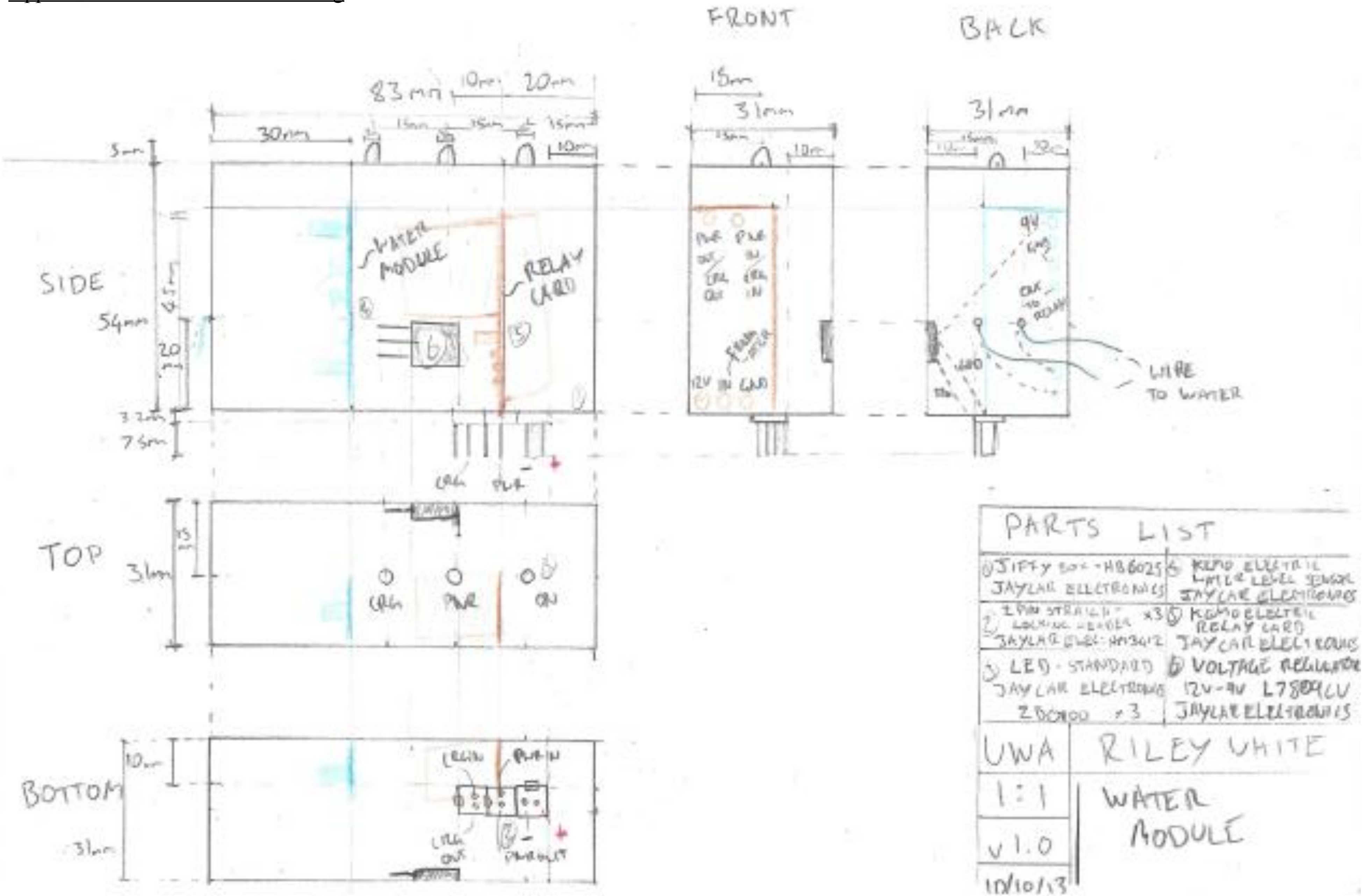
The printed board has to be equipped following the parts list and the print. Whenever there is applied at the input a control voltage of 3 - 12 V/DC, the relay will pick up.Through the relay contact it is feasible to switch loads up to 30 V, 3 A (AC + DC). The relay contact should be loaded solely with voltages up to max. 30 V! With higher voltages (e.g. 240 V/AC) it is necessary to observe the VDE-safety regulations (shock-protection, etc.). In those cases, it is required to start operation solely through an expert, which should control beforehand the mounting and fitting according to VDE!

The current consumption of this relay card is max. about 80 mA. Please take therefore care, that the current supply will be sufficiently powerfull (battery).

Technical data:

Kit: To solder yourself | **Operating voltage:** 12 V/DC | **Current consumption:** < 80 mA | **Contact capacity:** 3 A / 30 V | **Sensitivity:** < 5 mA | **Size of board:** approx. 44 x 18 mm

Appendix G: Water Module Drawing



Appendix H: Kemo Temperature Sensor B048 Datasheet

Note: Only the English translations are shown here.

GB *Intended use:* For temperature control in cases where accuracy is not the most important thing: e.g. freezers (alarm if the freezer does not cool any more), overheat detector (e.g. for machines as alarm indicator if the refrigeration breaks down), etc.

Assembly instructions:

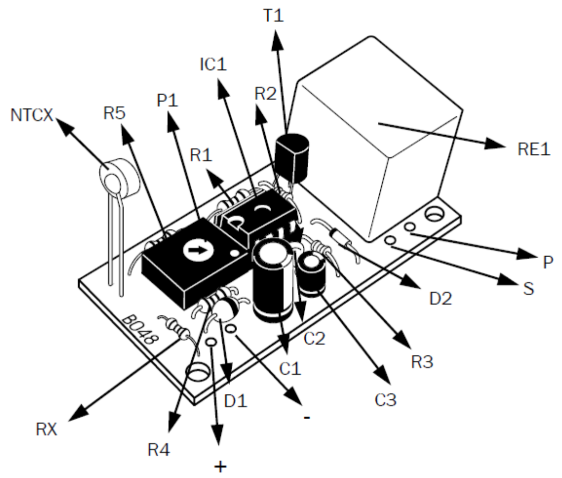
The board is assembled according to the parts list and assembly print. The NTC-resistor and the resistor RX-RX1 are connected with the board according to the desired operating mode. If the NTC resistor is mounted at „NTCX“ and the resistor „RX“ at „RX“, the relay switches on when the temperature is falling and switches off when the temperature is going up. If the NTC resistor is mounted at „NTCX1“ and the resistor „RX“ at „RX1“, the relay switches on when the temperature is going up and switches off when the temperature is falling. 3 different resistors „RX“ are attached, which are intended for different temperature ranges. Only 1 resistor is installed every time and the kit may then be adjusted approximately in the temperature range, which is mentioned in the parts list behind this resistor. So, always 2 of the 3 resistors „RX“, which are attached to the kit, are left!

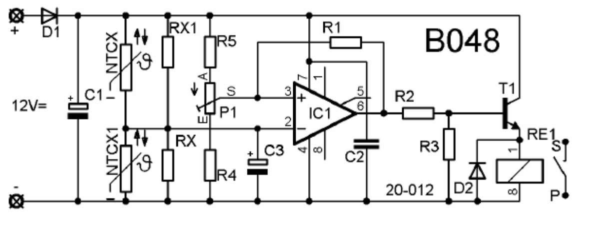
Remark: The NTC-resistor is not insulated. If you want to immerge it e.g. into liquids or to fix it at metal bodies (in order to control their temperature), the resistor and the wire leads must be insulated before (e.g. immerse into lacquer, stick into thin ceramic or plastic tubes, etc.). Then other appliances (auditory signals, lamps etc.) may be switched with the relay contact. The relay contact may only be loaded up to 25 V / 3 A at maximum. As operating voltage please use either a stabilized plug power supply 12 V > 100 mA or batteries which are strong enough (e.g. 8 round cells of 1.5 V each connected in series). Batteries which are too weak and which cannot supply the constant current of > 100 mA are not suitable!

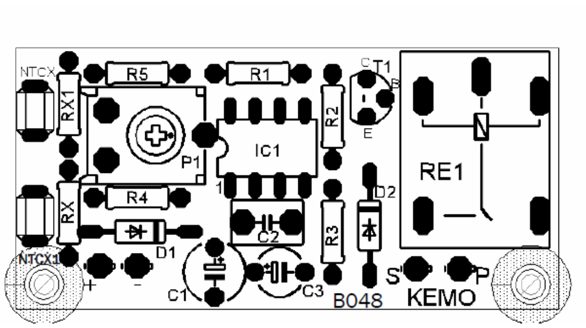
Setting into operation: The operating voltage of 12 V= is switched on, the NTC-resistor is mounted at that point where the temperature shall be controlled. The NTC-resistor can be connected with the board by means of a connecting cable of a length of up to 1 m. The board itself must not be exposed to very high or very low temperatures to be controlled. For example we have chosen the control of an air-ventilated machine which may only be heated up to approx. 100 ° C at maximum. The NTC resistor has been mounted electrically insulated and well heat-conducting at the machine. It was soldered electrically at "NTCX" or "NTCX1" on the board. If the NTC now reaches the permissible temperature, the trimming potentiometer is adjusted in such a manner that the relay just does not switch on (leave the adjustment just before the switching point). If the temperature increases now by approx. 10...20 °C (e.g. because the air cooling of the machine breaks down), the relay switches on and a connected auditory signal or lamp switches on. You have to try out the exact switching point at the trimming potentiometer, the closer you adjust towards the switching point, the earlier the alarm will be triggered. An adjustment to single degrees is not possible, merely an approximate approach to perhaps 10...20 °C.

Technical data:

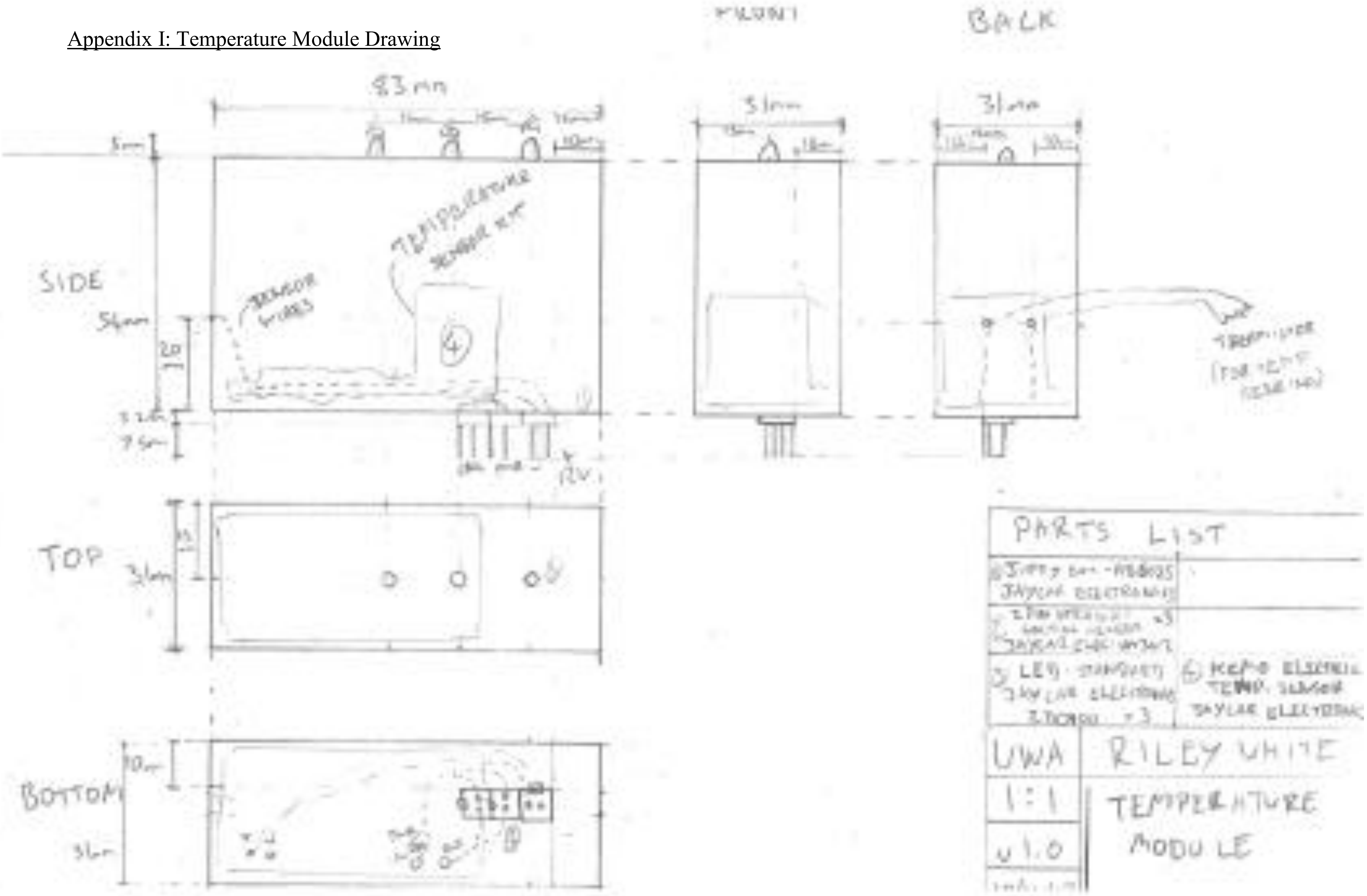
Operating voltage: 12...14 V =
Current consumption: approx. 100 mA at maximum
Temperature switching range: approx. –30...+ 150 °C
Relay contact: 1 x ON
Contact capacity relay: max. 25 V, 3 A
Dimensions of the board: approx. 55,6 x 26,7 mm







Appendix I: Temperature Module Drawing



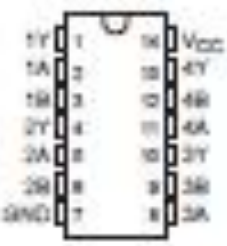
Appendix J: SN54HC02 NOR Gate Data Sheet Excerpt

(Texas Instruments 1997)

SN54HC02, SN74HC02
QUADRUPLE 2-INPUT POSITIVE-NOR GATES

- Package Options Include Plastic Small-Outline (D), Shrink Small-Outline (DB), Thin Shrink Small-Outline (PW), and Ceramic Flat (W) Packages, Ceramic Chip Carriers (FK), and Standard Plastic (N) and Ceramic (J) 300-mil DIPs

SN54HC02 . . . J OR W PACKAGE
SN74HC02 . . . D, DB, N, OR PW PACKAGE
(TOP VIEW)



description

These devices contain four independent 2-input NOR gates. They perform the Boolean function $Y = \overline{A + B}$ or $Y = \overline{A} \bullet \overline{B}$ in positive logic.

The SN54HC02 is characterized for operation over the full military temperature range of −55°C to 125°C. The SN74HC02 is characterized for operation from −40°C to 85°C.

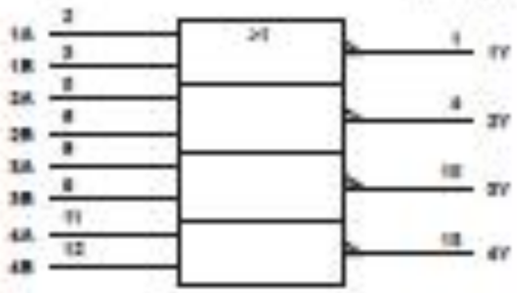
SN54HC02 . . . FK PACKAGE
(TOP VIEW)

NC – No internal connection

FUNCTION TABLE
(each gate)

INPUTS		OUTPUT
A	B	Y
H	X	L
X	H	L
L	L	H

logic symbol†



† This symbol is in accordance with ANSI/IEEE Std 91-1984 and IEC Publication 617-12.
Pin numbers shown are for the D, DB, J, N, PW, and W packages.

logic diagram (positive logic)

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

[illegible]

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