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FINAL YEAR PROJECT

PROJECT TITLE

NU24 Accumulator Electronics Engineer

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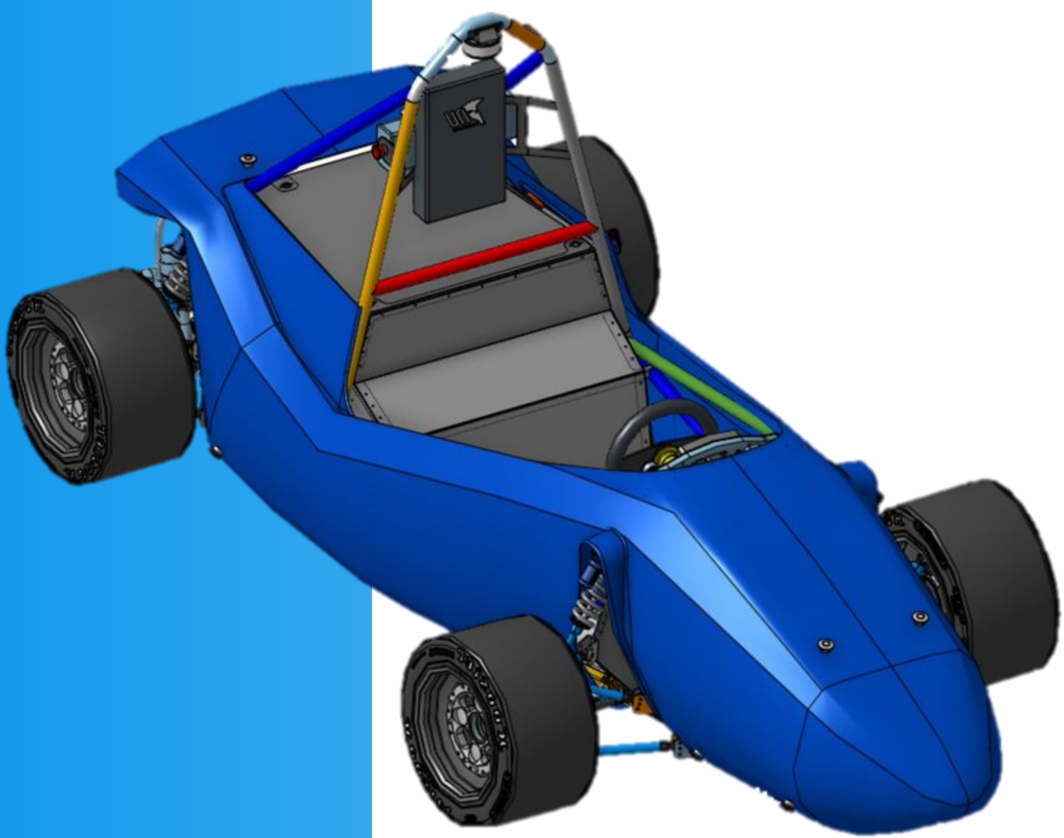
NU24 Accumulator Electronic Systems Engineer

DESIGN REPORT

NU24



[Daniel Iveson]

2024

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Abstract

This report outlines in detail, the development and refinement of the Low Voltage Board (LVD) on NU Racing's NU24 car. A significant portion of time and resources went into researching and understanding other PCBs on the car and adapting them to suit current competition requirements and new car specifications. Key contributions were the refinement of the LVD, design and transition of the standalone AIL circuit, research and modifications to the PreCharge board and maintenance of the cells and CANaMons. While not all components in this report were redesigned or used, the research and development of them is crucial for the team to understand and learn. Overall the work done on this project increased reliability, efficiency and safety of the car and contributed to the success at the 2024 competition. This success and improvements will increase knowledge and help the future teams in years to come.

Acknowledgements

I would like to start by thanking Dr Dylan Cuskelly for being such a key role in my university engineering experience, and so many others. This year Dylan stepped up to take over the running of NU Teams and did so extremely well. Dylan's way of educating and leading led to the success of so many teams and the development of so many great engineers within those teams.

I want to thank Malcolm for the huge amount of work that he has done throughout this year for all of us on a daily basis. From assisting us with troubleshooting to educating us on designs and setting us up to go in the right direction with our ideas. I especially want to thank Malcolm for sourcing and driving myself to pick up fuses and wire in Melbourne on the day of the accumulator technical inspection, without him we would not have passed accumulator tech as quickly and smoothly as we did.

I want to thank Tim for being our amazing team leader this year, having someone with so much knowledge in the team and organising all us engineers takes many hours and headaches. Without his guidance and kindness we would have absolutely struggled this year. I want to thank Tim for always looking ahead and seeing the best in us.

Next I thank Alec more than anyone. Being the mechatronics lead, Alec had to teach me so much and always looking after me. I have learnt so much this year from him and feel he alone has given me the tools and taught me to be a better engineer. Without Alec I would have been so lost and unsure what I was supposed to be doing, his unwavering support was the biggest blessing for me stepping outside of my comfort zone and I am forever thankful for that.

I want to thank my family for supporting me through school, encouraging me to follow my dream of engineering and constantly pushing me to do better as they supported me through university. I can not thank them enough for all the times there was food waiting for me at home or they made me a coffee before I left, allowing me to use their cars to get to uni when mine were not working. Without them I would not have been able to do as well as I did in university and with NU Racing.

I want to thank my amazing partner Ellie, who gave up so much for me to pursue NU Racing. Spending many hours at university and doing assignments back at home, she lost so much time with me this year. She continued to push me to do well and was always supportive and without her I would never have been able to complete this degree or do as well in NU Racing as I did this year.

Lastly I want to thank the entire team from NU Racing, NU Rocketry, NU Marine and NU Brewing. All these teams of people I was surrounded by all year supported me and created an amazing culture to grow and succeed as an engineer. I especially want to thank NU Racing team members for the amazing year we all had together, from lifting each other up to the laughs we all shared, it was a year I will never forget.

Abbreviations

Abbreviation	Definition
AIL	Accumulator Indicator Light
AIRs	Accumulator Isolation Relays
AMS	Accumulator Management System
BMS	Battery Management System
BOM	Bill of Materials
CAN	Controller Area Network
DDR	Detailed Design Review
ESO	Electrical Safety Officer
FSAE-A	Formula Society of Automotive Engineers Australasia
GLV	Grounded Low Voltage
IMD	Insulation Monitoring Device
LVD	Low Voltage Distribution
OKHS	OK High Signal
PCB	Printed Circuit Board
PC	PreCharge
PWM	Pulse Width Modulation
SMD	Surface Mount Device
SOC	State of Charge
THT	Through Hole Technology
TS	Tractive System
TSAL	Tractive System Active Light
Z2H	Zero to Hero

Table 1: Abbreviations used for NU24

Term	Meaning
Accumulator	Contains the housing, batteries and associated electrical components
AIL	A safety device indicating the presence of HV (60V+) at the accumulator connectors
AIRs	The relays responsible for connecting the car's tractive system to the accumulator's high voltage
AMS	The collection of subsystems responsible for monitoring and managing the accumulator
BMS	The Orion BMS2 system used to monitor lithium-ion cells in the accumulator
CAN Bus	The communication protocol bus where all the messages and signals are sent over
CANaMons	The monitoring PCBs that sit on top of each accumulator segment to track voltage and temperature
DDR	A process used in NU Racing to evaluate and refine PCB and electrical system designs
ESO	A designated person responsible for ensuring safe handling of high-voltage systems
FSAE-A	The Australasia competition where university teams design and build single seater race cars and compete against each other in a series of dynamic and static events
High Voltage	Voltages greater than 60V are considered high voltage by FSAE-A rules
IMD	A device monitoring insulation resistance in the high-voltage system to detect potential faults
LVD	A PCB that distributes power and signals throughout the car's low-voltage system
MOSFET	A semiconductor used for switching in the electrical system
NU24	NU Racing's 2024 competition single seater, open-wheel race car
PCB	Circuit boards that are used extensively in NU Racing cars
PreCharge	PCB to safely precharge the tractive system
RadLok	A type of high-current connector used in the accumulator
Service Handle	A physical disconnect mechanism used to break the accumulator's high-voltage connections for safe servicing
Tractive System	The high current path of the car's electrical system involving accumulator, motor controller, and motor
TSAL	A light that indicates when the tractive system is energized and high voltage is present
UL94V-0	Flammability rating needed for all materials used as insulation within the accumulator
Z2H	A training program for NU Racing members to quickly onboard new students into their roles

Table 2: Terms used in report

1 Introduction

1.1 LVD V3.0

The LVD V3.0 was created to fix a BMS short circuit and make the boards fan switching circuit more robust by using a MOSFET to drive a MOSFET. The AIL circuit that was on the LVD last year was removed with the idea of making it a standalone board.

1.2 LVD V3.1

Changes were made to the LVD V3.1 due to improper research of MOSFETs that were placed on the board in the earlier version. These were removed and the Interpose relay and capacitors were added onto the board which were previously on the CEN and PreCharge. The team replaced the MOSFET for the fan switching with an automotive relay right before the competition.

1.3 PreCharge

The PreCharge was originally a research task but became a re-spin after realising there was not adequate fusing on the board and the Interpose capacitors needed to go inside the accumulator. Once the board had been commissioned and bench tested the team came to the conclusion it was best to not replace a board that has worked for years.

1.4 AIL

The AIL was moved off of the LVD and onto a separate PCB. Previously the AIL was a mechanical voltage dial. The AIL was designed using different functional circuit blocks from other AIL designs. Unfortunately due to an oversight the AIL works the opposite way it is intended and therefore the old mechanical dial was implemented onto NU24.

1.5 CANaMons

The CANaMons were troublesome late in semester 2 leading up to the FSAE-A competition in December. There were problems with bad cells and the CANaMons when being removed to get to the cells were slowly breaking as well. Due to close proximity of ground traces, being close to positive HV, there was a short circuit which ultimately caused the CAN to stop working. That as well as high resistances in the traces of the far voltage taps, required temporary wire fixes while waiting for new CANaMon boards to arrive from manufacturing. They did not arrive in time to be replaced for the competition.

2 Background

2.1 FSAE-A

Formula Society of Automotive Engineers Australasia is an engineering competition at an international level where university teams design and build their own open wheel, single seater car. The competition involves both static and dynamic events.

The static events include cost, design and a business event. The cost event involves costing up all parts and labour used to build the car. All parts and assemblies of the car are costed within an excel document and are then marked before the actual competition dates. The teams are then given the chance to explain why they made certain decisions within the report. The design event is used to assess teams on their engineering knowledge of the car they have just designed and built. Questions are asked by a board of judges on research, testing and validating their designs. The business event is used to assess the teams on their ability to create a business case that their car can be commercially viable in the Australian motor-sports sector.

The dynamic events include Skidpad, Acceleration, Autocross, Endurance and Efficiency. Each event is targeting a different area of performance out of the car.

Skidpad involves the cars having to do a number of laps in a style of figure 8 as quickly as possible, this tests the car's manuverability and speed in turns.

Acceleration is a test of the cars raw speed down a straight as the teams are trying to be the fastest to cross the line. This shows how much power a car can output for a short amount of time and the amount of traction control the cars have.

Autocross is a mixture of turns and straight in a two lap shoot out per driver. This takes into account how quickly a driver can turn their car through the cones and their speed and down the straight before braking into another corner. For many teams this is the cars raw pace in a mixture of acceleration and skidpad.

Endurance is the same course as Autocross except of 21 km. This measures a cars ability to be reliable over distance with a good amount of speed. For many teams this is the main event at the competition as there are multiple cars on the track at once and opportunities to overtake. At the end of endurance the efficiency scores are released and are based on how efficiently teams used the power of their accumulator.

2.2 NU Racing

NU Racing is part of the University of Newcastle's NU Teams organisation. NU Racing is a team made up of student engineers who design, build, test and compete single seater, open wheel electric race cars. The team is made up of many different engineering fields and takes students from the end of their first year, right through to their final year.

NU Racing has two main focus areas for students. Mechanical and Mechatronics, there two teams work together to build a competitive and reliable FSAE-A race car. The team runs out of the TA building on the University's campus, here they are given the facilities, support and tools to complete their projects.

2.3 LV Systems

The Low Voltage system makes up the majority of electrical systems on NU24. There are LV nodes all over the car that are all connected through the onboard CAN bus network. Even the HV components of the car such as the Accumulator PCB's have LV systems running on them. The car can not run without an LV system, it covers basic functionality of every circuit on the car, it powers everything that is not the motor, is used to send and receive signals and the cars control systems are all made using low voltage.

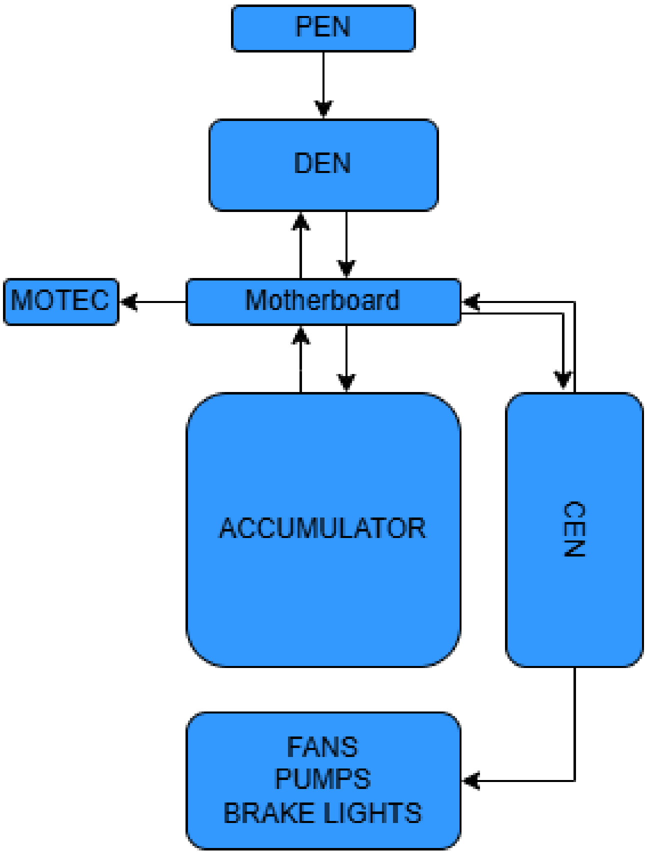


Figure 1: NU24 LV Topology

NU24 runs off of a 12 V GLV system for the cars signals and power. The car has an onboard 12 V battery for when the accumulator is not connected. Figure 1 shows how all the different nodes and PCBs on the car connect and interface with one another in terms of LV, the accumulator can of course be removed and the LV systems will still work for a period of time before the 12 V battery is too low.

2.4 HV Systems

NU Racing and FSAE refer to voltage higher than 60 V as High Voltage. NU24 High voltage systems start in the accumulator which has a maximum voltage of 453.6 V.

	Minimum	Nominal	Maximum
Voltage (V)	270	388.8	453.6
Current (A)	180		
Power (kW)	48.6	69.98	81.6

Table 3: High Voltage Specifications

The High Voltage system include the Accumulator, all components inside the accumulator and the tractive system. The tractive system includes the cables running to the motor controller, parts of the CEN, the phase cables and the motor.

Because the inside of the accumulator is live at all time when the service handle is connected, this is explained in Section 3.9, it must be serviced in the designated HV bay within the TA building.

3 NU24 Accumulator Electrical Topology

3.1 Non Physical Components

3.1.1 Shutdown Circuit

The Shutdown circuit is a 12 V circuit that runs through most electrical components on the car. Each of these components will have some sort of switching mechanism that can open and close the Shutdown circuit. For the car to operate all components of the car need to be operating correctly for all sections of the Shutdown circuit to be closed.

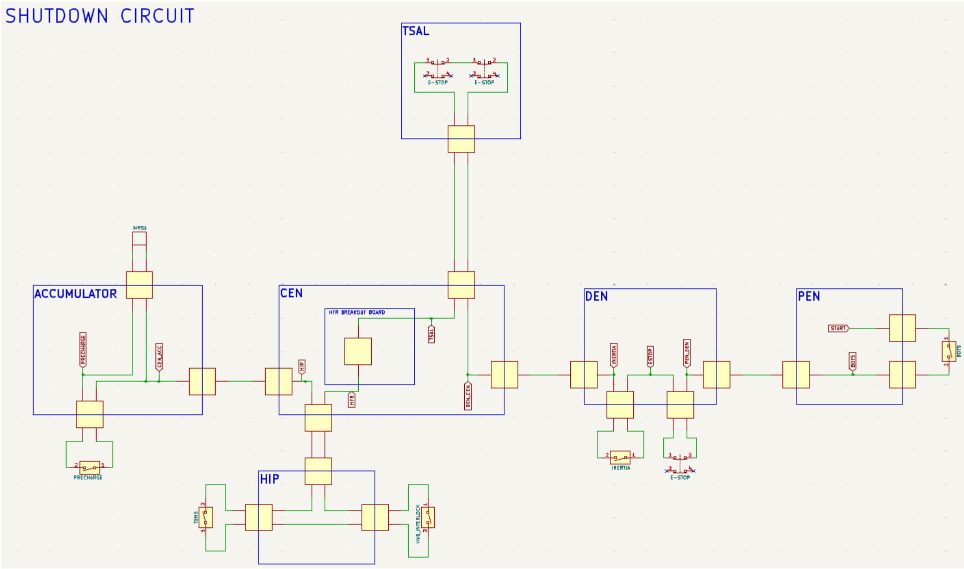


Figure 2: Shutdown circuit throughout the car

When the Shutdown circuit is fully closed the final components it goes through are the AIRs, with everything working on the car and all checks completed the Shutdown circuit will close the AIRs and allow the accumulator to power the tractive system. While the car is running and any of the systems in Figure 2 open the Shutdown circuit, this can occur for multiple reasons, the car will open the AIRs and no longer be in HV.

3.1.2 Accumulator Electrical Paths

The Accumulator is a collection of many different electrical components, circuits and electrical paths. Two major electrical paths within the Accumulator are the different sides of the high current path. The high current path is 450 V and 180 A maximum. This path is then split into two sides; the Accumulator high current path and the tractive system side high current path. The difference between these two is that the accumulator side is between the cells and up to the AIRs, whereas the tractive system side goes from the AIRs up to the connectors on the lid. The tractive system high current path extends out of the accumulator and connects to the motor controller, however within the accumulator container the tractive system is up to the connectors on the lid.

The Accumulator side of the high current path connects the cells to the segments through busbars, held down by bolts. From here the path moves onto the top plate through busbars on the negative side and RadLoks on the positive side. Before both sides are connected to the AIRs, the negative side runs through a fuse for the high current path.

The Tractive system side runs straight from the AIRs to RadLok pins bolted to the top plate, the negative wire running through a current sensor on the top plate. RadLok connectors are placed on the pins and the wire connects them to the lid. This RadLok connection on the top plate is so that the lid can be removed easily and quickly without having to unbolt the wires.

3.2 LVD

The purpose of the Low Voltage Distribution (LVD) board is to provide power into the accumulator for the 12 V systems and send signals to and from the accumulator to the rest of the cars control systems. The LVD interfaces with the BMS, IMD, PreCharge, AIRs and CANaMons; without the LVD none of these other components would have power or be able to send and receive signals. While also interfacing with all these components the main Shutdown circuit that runs through out the car also goes through the LVD and in it's final iteration; allows for a delay in the shutdown of the accumulator for electrical safety reasons.

3.3 PreCharge

The PreCharge is a PCB designed to allow the AIRs to close safely. When the AIRs close without a PreCharge in place, the inrush of current to charge the capacitance of the tractive system can weld the AIRs shut. If the car exits HV mode and the Shutdown circuit turns off, HV will remain active because the AIRs cannot open. This poses a high safety risk trying to remove the AIRs while they have anywhere between 350 V up to 450 V, for NU24, live through out the accumulator.

3.4 AIL

The Accumulator Indicator Light, while it does not stop the car from running, is a very important safety device on the car. It indicates the presence of HV (60 V+) at the connectors of the accumulator. Knowing if there is voltage present at the connectors is a major safety concern, an example where the team needs to be aware of the presence of voltage is outlined in the PreCharge section. The AIL measures voltage from the Tractive System side of the accumulator, specifically at the connectors on the lid. The AIL is needed for FSAE-A Competition.

3.5 AIRs

Accumulator Isolation Relays are the main relays that sit on the top plate, responsible for connecting the tractive system of the car to the accumulator's HV. These are controlled by the cars Shutdown circuit.

3.6 BMS

The battery management system is done through an Orion BMS2 system. This is an off the shelf part that can monitor most lithium Ion cells on the market and up to 120 cells in series.

Figure 3: Orion BMS 2

3.6.1 AMS

The FSAE-A rules often mention AMS instead of BMS. The BMS as stated in Section 3.6 is a product bought off the shelf and integrated into the accumulator, where as the AMS incorporates the BMS, CANaMons, PreCharge, IMD and all the systems used to manage the accumulator. The AMS is the collection of subsystems responsible for making sure the accumulator functions a certain way.

3.7 CANaMons

The CANaMons, which is their in house name at NU Racing, are the PCBs that sit on top of each segment and are used to monitor temperatures and voltage of all the different cell modules within a segment, these are relayed to the BMS through voltage taps on the board. The CANaMons also utilises an isolated CAN network to communicate with the rest of the car and MOTEC.

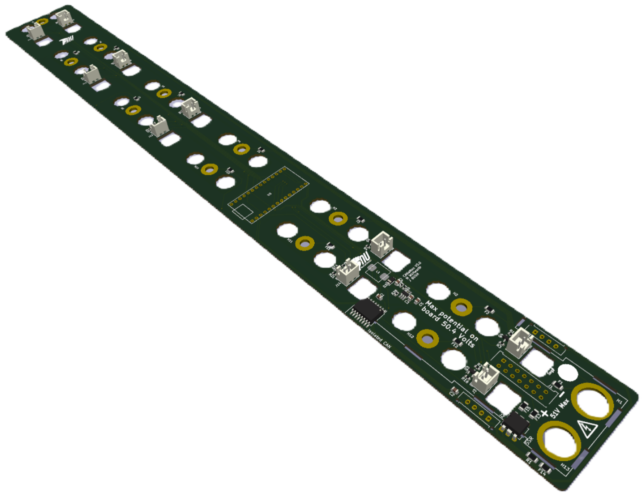
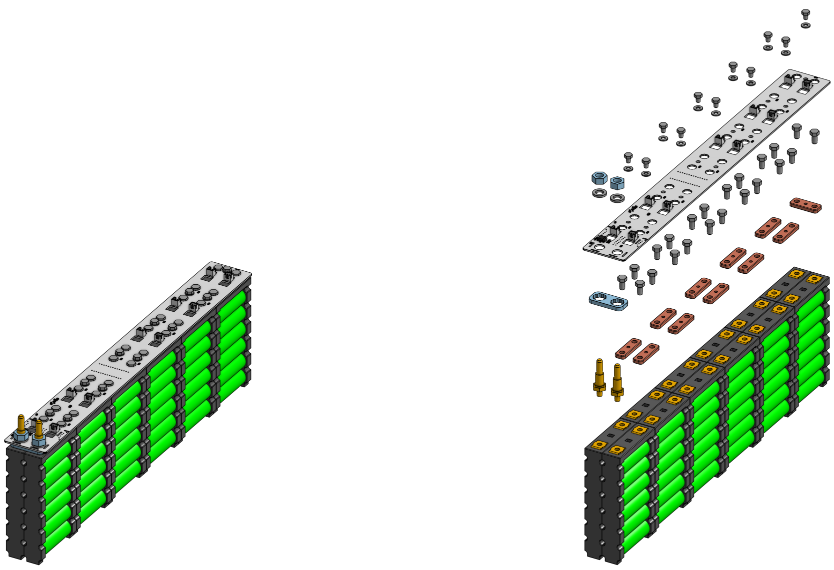


Figure 4: CANaMon board that sits on top of segments

3.8 Segments

The Segments are an assembly of 12 cells, busbars, RadLok pins, CANaMon and respective locking bolts and nuts. The combination of all of these creates what NU Racing calls a segment and nine of these connected in series make up the 2024 Accumulator. Figure 5 shows how all these components are assembled together.



(a) Assembled view (b) Exploded view

Figure 5: Comparison of assembled and exploded views of the battery pack.

Each of these segments has voltage taps running to the BMS and are daisy chained to other segments through CAN Bus and with 12 V and Ground. Each segment is 50 V maximum with a total discharge current of 180 A.

3.8.1 Cells

The cells used by NU Racing are Enepaq 1s-6p VTC6 modules. Enepaq is the manufacturer of the cell packs but the individual cells are made by Sony. The naming convention for cells in FSAE is As-Bp where A is the number of cells in series and B is the number of cells in parallel. The total cell formation for the accumulator is a 108s-6p.

Figure 6: 1s-6p VTC6 cell module

3.9 Service Handle

The service handle, or maintenance plug in the FSAE-A rules, is a device used to separate or connect the individual segments. The service handle is made of multiple different busbars, enclosed in FR4 insulating material, that connect one segment to another in series creating the total voltage of the system, maximum 450 V.

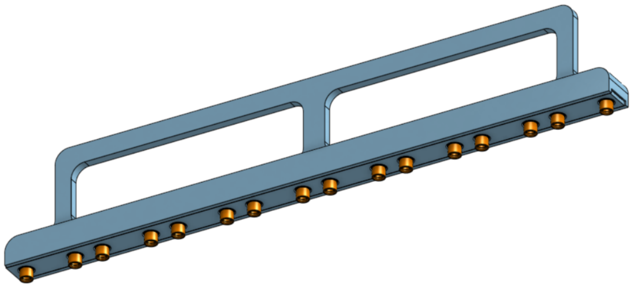


Figure 7: Service Handle

When servicing the accumulator this handle needs to be pulled out to safely work within the accumulator container. When pulled out of the accumulator, the voltage drops from 450 V to a maximum of 50 V within each segment. The service handle can be pictured in Figure 10 interfacing with the rest of the accumulator.

3.10 Top Plate

The Top plate sits on top of the segments and is pressed down by the lid to stop any movement as seen in Figure 10

There are 3 main sections of the top plate and they are separated by electrically and thermally insulating walls. The first section is the BMS section where only the BMS sits and has a singular slot in the wall for the Voltage taps. The next area is the PCB Low Current area, 450 V is still seen in this area but the current is quite low at less than 1 A. This section encumbrances the LVD, PreCharge, IMD and most of the wires connecting all the PCBs. The final and most dangerous area of the top plate is the HV high current area. This is where the AIRs, Current sensor, fuse, voltage taps and the high current cables are situated. This area has wire moving into the other areas, such as the wires that the PreCharge uses to check the voltage of the tractive system, and wires like this are appropriately fused.

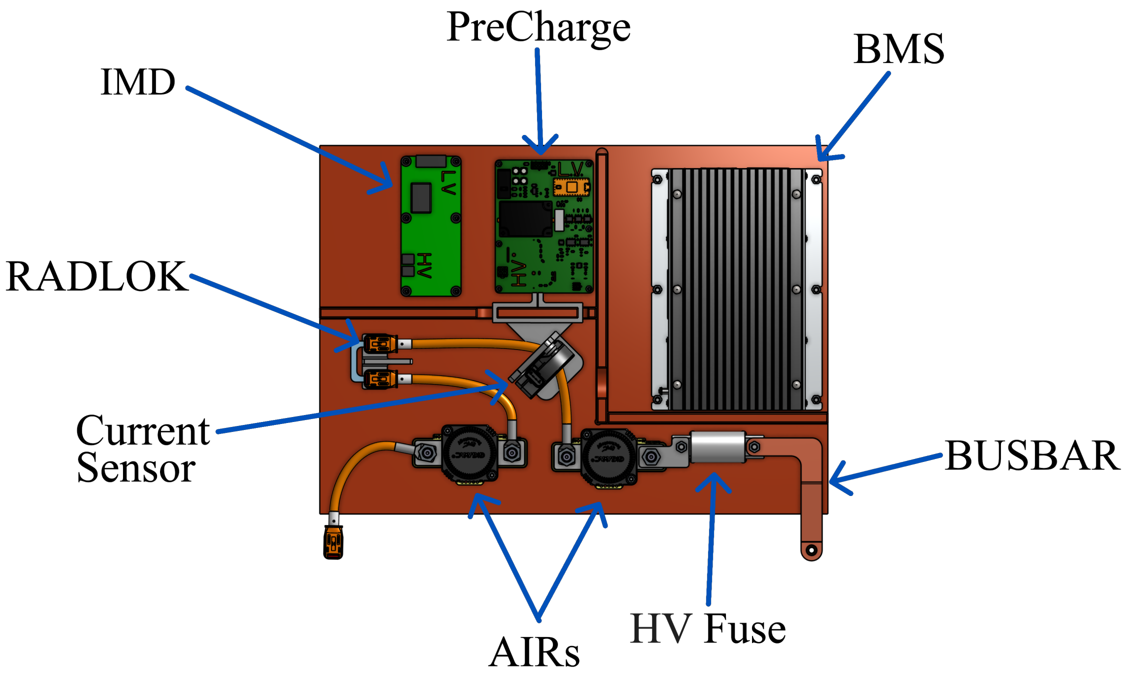
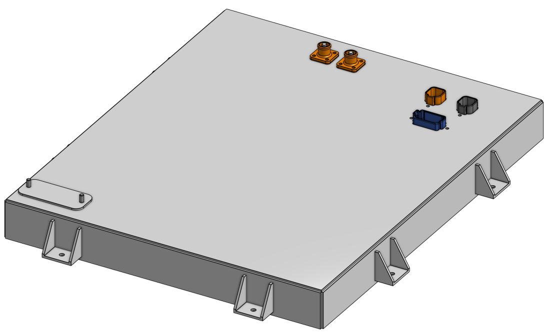


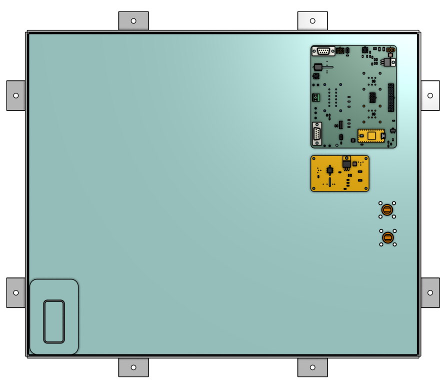
Figure 8: Components of the Top Plate

3.11 Accumulator Lid

The Accumulator Lid is primarily used to enclose the accumulator while also pressing the top plate down onto the segments to prevent unwanted movement when the car is running. The components on the Lid are the LVD, AIL, HV connectors for the high current path and the service hatch.



(a) Lid Top Side



(b) Lid Under Side

Figure 9: Top and Underside of lid with LVD, connectors and service hatch

The service hatch is placed so that in parc ferme after competition, the thermal strip can be seen to make sure the accumulator did not overheat. The LVD is on the lid so that it can easily be connected to the rest of the cars GLV system. The AIL is a safety featured used to indicate the presence of 60V+ at the HV connectors which are also located on the lid so the best place for the AIL was in fact the lid.

3.12 Accumulator

The accumulator is the collection of all the components in Section 3 combine into a single unit. Without all of these parts the accumulator would not be safe, competition compliant or work at all. All components must integrate with the other components, nothing inside should ever compromise safety.

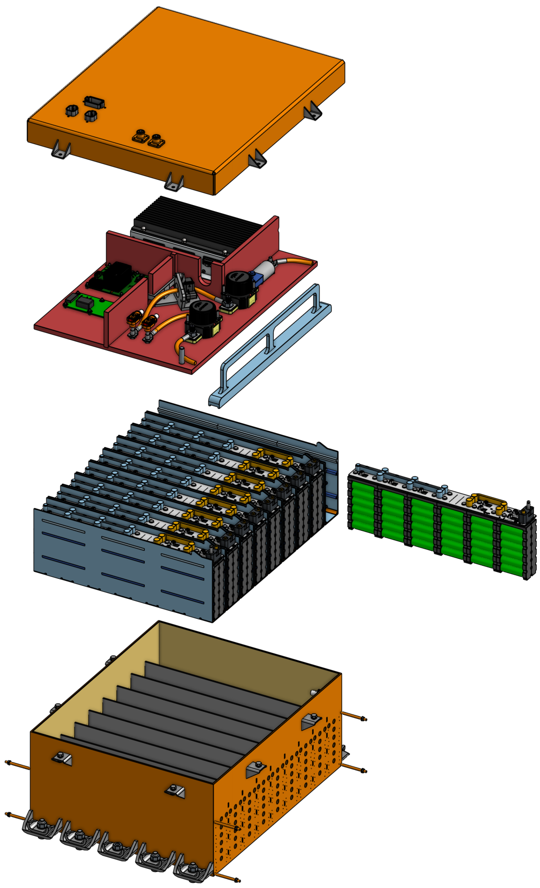


Figure 10: NU24 Accumulator

With all the 9 segments inside the accumulator placed in series the current remains the same as each individual cell where as the voltage multiplies by the number of segments in series.

	Voltage (V)	Current (A)
Maximum	350	180
Nominal	400	
Minimum	450	

Table 4: Accumulator Voltage and Current

4 Scope

4.1 Initial Scope

The Scope given in the first week with NU Racing was to manage and advance the LV electronics within the accumulator. This would initially involve updating boards to fit within rule changes and make them safer, lighter, smaller and more robust.

Part of the initial scope was researching how the PreCharge worked but not changing or redesigning. This research was necessary as nobody in the team currently understood how it operated. If there was a fault or modifications to connecting boards, that could have impacts on the PreCharge, having knowledge on these boards could save time in the fault finding and design process

4.2 Starter Project

The starter project for the author was to make the current LVD 2.1 smaller and try to fix an issue involving overheating MOSFETs. This involved researching the purpose of the LVD and understanding all the functional circuit blocks in the schematic and then changing the design, commissioning and having it work on the car.

4.3 FYP Project

After the completion of the starter project, the focus shifted to researching, redesigning, and modifying other components of the Accumulator, specifically the AIL and PreCharge systems.

While the AIL has had 3 previous iterations that are all completely different, the task was to decide which design worked best and create an AIL that will stay on the car for years to come.

The PreCharge board was set as a research task, being unchanged for many years, a redesign could happen if there was sufficient time.

4.4 Scope Changes

Due to a lack of mechatronics engineers and problems arising through out the year, the scope changed, more parts of the accumulator were needing to be worked on, this included the CANaMons and the segments themselves. The starter project of redesigning the LVD became a major focus area of the year and was no longer a starter project as major issue were found, outline in Section 6.2, that needed to be research and fixed.

4.5 Final Scope

The final scope completed at the end of the year was much larger than originally intended as it involved more components of the accumulator than first set in the scope.This involved a great deal of research, designing and commissioning on both the bench and inside the accumulator, requiring repetitive testing on track days. The components involved in the final scope were the LVD, AIL, PreCharge, CANaMons, Segments and Cells, wiring, top plate, charging and at the end of the year was accumulator technical inspection at competition.

5 Electrical On boarding

5.1 Introduction

Joining NU Racing on boarding is quick and very broad to cover all areas of being on the team. This is structured through Z2H modules, which are an easy-to-learn video and text series presented by different NU Teams alumni. Through these series, the basics and structure of how the teams run are presented and taught. However, the learning of electrical circuits used on the racing team is vast and, on some PCBs, quite complex. This section outlines common circuits used on many PCBs and the different electrical terms needed to understand how the different parts of the car interact with each other. Outlined in Section 5.5 will explain what circuits were used that worked and did not work; this will be useful for new team members of racing starting out with PCB design and debugging.

5.2 Standard Circuits and Components

5.2.1 Introduction

The standard circuits used by NU Teams are designed to reduce time, complexity, and errors with components and combined circuitry that will be seen on many PCBs and easily interface with off-the-shelf components. By using this standard circuitry and understanding how they work the amount of errors and time spent debugging is drastically reduced. The sections to follow will briefly explain why they are used as standard circuits and how they work.

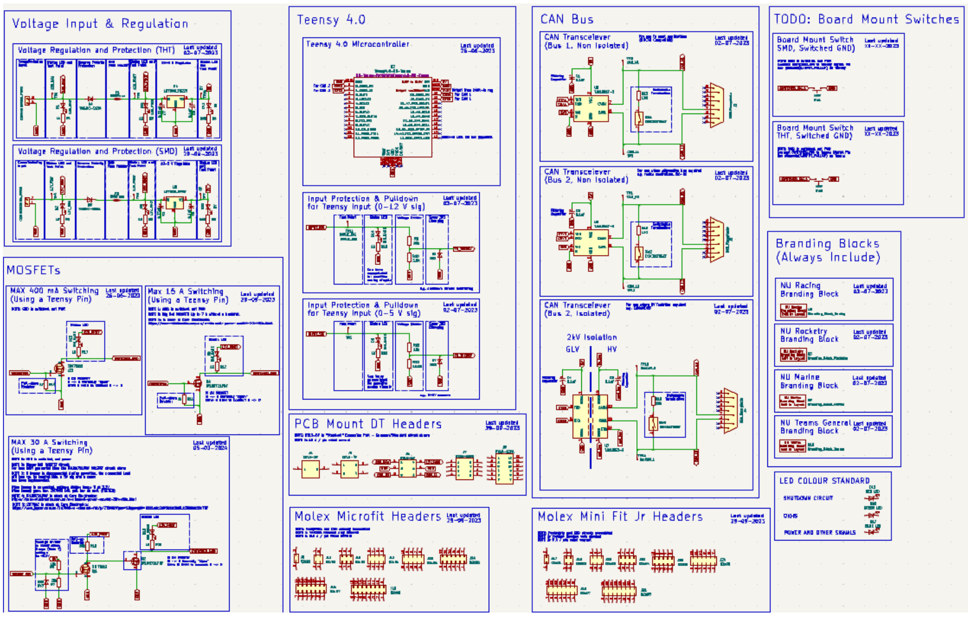


Figure 11: Standard Circuits Schematic

Standard circuits can be found on the NU Teams GitHub following the path:

`...\Github\NU-Teams-KiCAD-Library\Standard-Circuits\Standard-Circuits.kicad_sch`

5.2.2 Teensy 4.0

The Teensy 4.0 is the only micro controller used on NU Racing's NU24. To program these board you will need to have the Arduino IDE, install the boards from here and follow the steps to start programming on the Teensy.

Understanding CAN Bus is essential for programming any PCB installed in the car. Failure to fully understand how it works can result in one or multiple PCBs failing to function correctly.

CAN Bus uses to signals, a high and a low line. These are used to reduce noise on the bus and is highly effective against most noise. Care should still be taken to properly shield the CAN High and CAN Low wires from noise such as the motor controller.

NU Racing uses the FlexCan_T4 package which is built into the in house CAN Bus library for Arduino making programming with CAN much easier and accessible with much less lines of code.

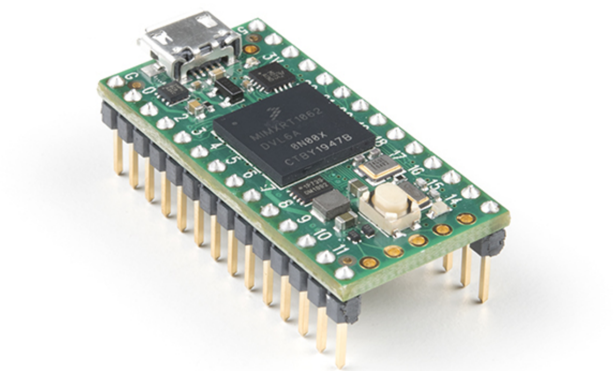


Figure 12: Teensy 4.0

Selected for its small form and CAN Bus capabilities, the Teensy 4.0 has 3 CAN buses which is needed for an isolated CAN Bus network used on the car.

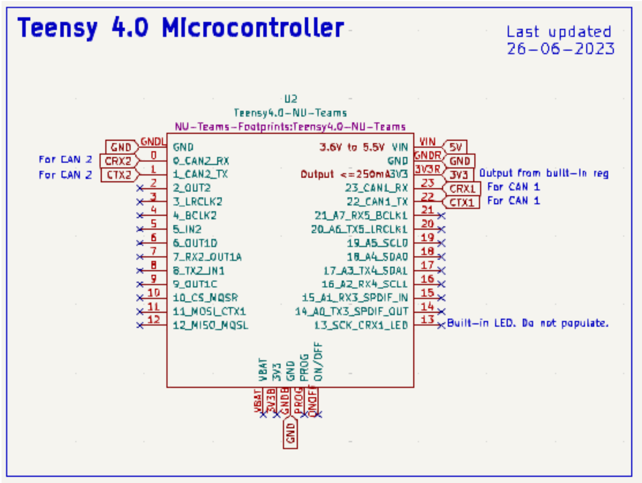


Figure 13: Teensy 4.0 Standard Schematic

5.2.3 Voltage Input & Regulation

This regulation and protection block is important because it ensures that the power coming into the board is properly fused, regulated, and equipped with LEDs and test points for easy troubleshooting. This keeps the power input for all boards the same and uses the same standard components stocked in the mechatronics lab used by NU Racing. The outputs from this standard block interface with other standard blocks used by NU Racing such as the Teensy 4.0 and CAN Bus

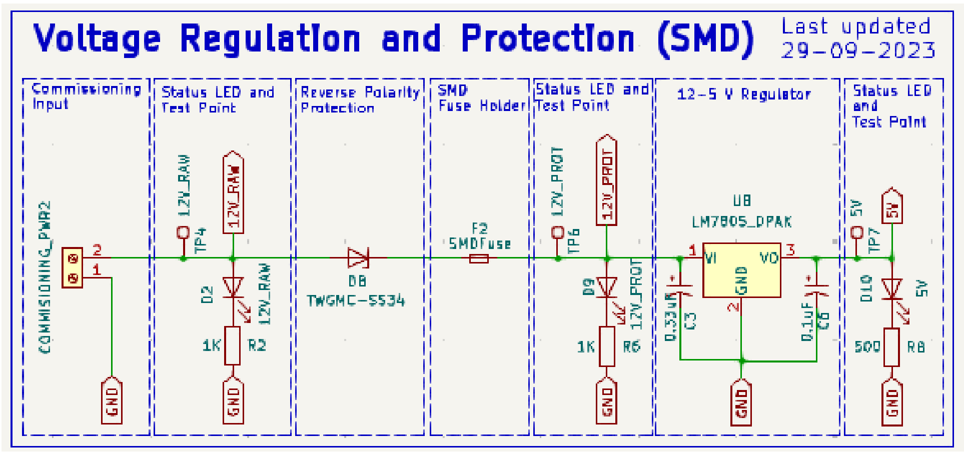


Figure 14: Voltage Regulation SMD block Standard Circuit

The standard circuit block for inputs and regulation of voltage comes in a through hole or surface mount option depending on the boards needs. The circuit pictured in Figure 14 is the SMD variant and will have different footprints and components to the THT variant. the SMD block is more preferred as it is more common on other boards, easier to use when stencilling and the components are more commonly stocked.

5.2.4 CAN Bus

CAN Bus is the communication protocol used by NU Racing and is used to transfer all the signals and necessary messages to communicate with student built boards and off the shelf components. CAN Bus is taught using the Z2H modules which can be found at training.nuteams.org.

5.2.5 MOSFETs

MOSFETs are used by NU Racing as a switching mechanism on PCBs, they are used similarly to relays except are solid state and much smaller in size. The standard blocks used have 2 variants, 1 for 500 mA and the other for 15 A.

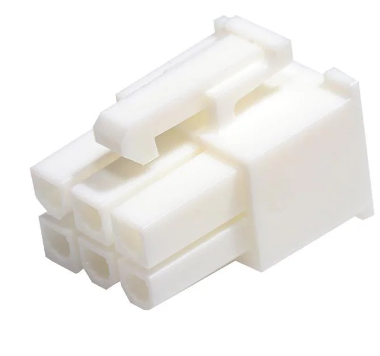
When using standard MOSFETs from the mechatronics lab, or other MOSFETs not commonly used, always consult the data sheet and the requirements of the board being designed. The main property to look for with MOSFETs initially is current draw and voltage, these were a major area of concern and are outlined in section 5.5.

5.2.6 Molex

Molex connectors are a style of electrical connector used in electrical and automotive industries. They are widely used as they are readily accessible and simple to use. There are two main types of Molex connectors that NU Racing uses, the Micro Fit and the Mini Fit Junior.

Micro Fit Molex connectors are the more commonly used connector on the car. They come in a wide range of wire and board mount connectors and have a small form factor which can be really useful when space is limited. While these are commonly used they caused many unnecessary problems in 2024 which are outline is Section 5.5.

(a) Molex Micro Fit



(b) Molex Mini Fit Jnr

Figure 15: Two different Molex styles used by NU Racing

The other Molex connector is the Mini Fit Jnr, these are easily identifiable on the car as being white and some being transparent. These are found inside the accumulator going to the BMS and the Pre-

Charge. unlike the Micro Fit connector, these connectors never had problems and were more reliable. The major different is that the pins and connector housing are all much larger and when connecting to a board they take up more surface area.

5.2.7 Deutsch Connectors

Deutsch connectors, commonly referred to as DT connectors, are a a common connector used in many different fields such as marine and automotive for their high durability and environmental sealing capabilities.

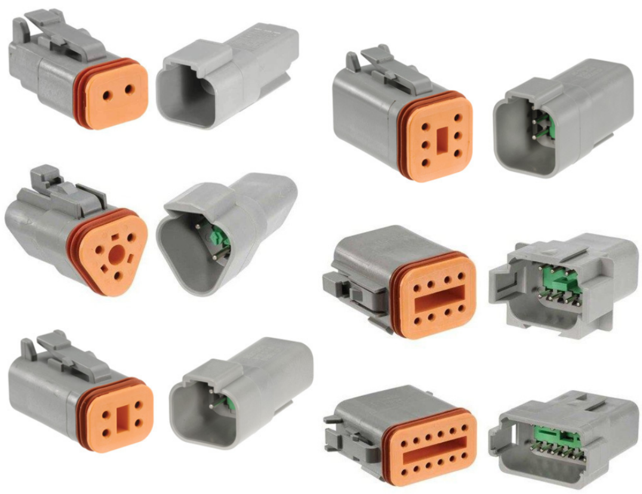


Figure 16: Different pin outs for Deutsch connectors

NU Racing use these connectors for all major wiring looms which connect all of the different electrical nodes. The only place on NU24 where these are not used is the accumulator due space limitations, the DT connectors take up more room than regular connectors.

5.2.8 Branding Blocks

Branding blocks are simple and easy to use. In KiCad they are used to put the board name, car intended for, designers name and board version onto the PCB to easily distinguish the board when it is completed commissioning. Many versions of a single board can be created and by different people so this is a visual and easy way to indicate the board version. In the schematic editor of KiCad they are simply placed in the schematic anywhere, one for the front of the PCB and another for the back.

Figure 17: Branding Block on Schematic

Once the Schematic is completed, the Branding Block will need to be editted in the PCB design section. This is where the actual details and information about the board and the designer are inserted as seen in Figure 18.

Figure 18: Branding Block on PCB

5.3 Software

5.3.1 Introduction

There are many programs used my NU Racing for electrical research, simulation and design. Many of these can have similar functionality and which is used comes down to user preference. Whether you use Matlab or Python for coding simulations is up to the user, however some programs are necessary for certain tasks. When designing a PCB it is mandatory to use KiCad as the in house PCB design software, other programs are available to design PCBs but this creates conflict when other team members are trying to review and change a board. Same goes for Arduino as this is the only language used for use with the Teensy 4.0 micro controller and the CAN Bus network.

5.3.2 KiCad

KiCad is the software used to design and create PCBs. NU Teams has a Z2H for PCB design, manufacturing and commissioning for within KiCad. This Z2H course, like all the others, has an associated video series to following along with.

Many mechatronics team members will spend a lot of time in KiCad schematics designing and trying different circuits for boards. The schematic section of KiCad is easy to use and understand, with many components already built into the standard library. It is very simple and many non standard components cane easily be imported into KiCad for use in the schematic editor.

Once the circuits have been built, the next step is to enter the PCB layout section of KiCad. In this part you will design the size of the board, mounting holes, component placement and where most time ends up going to is trace layout. Traces are the 'wires' on a PCB and are used to connect all the electrical components to one another. On a standard PCB there are two sides, the front and back of the board. Traces and components can be placed on either side.

KiCad has a built in Gerber exporter, Gerbers being the files used by manufacturing companies to build the board, traces and pads for the electrical components to be placed on. Depending on the company you decide to go with will decide which Gerber files will need to be exported and sent to them. It is to be noted that many Gerber viewers on websites will say it failed to load the board, checking the board is important but this error occurs most of the time even when there is nothing wrong with the board. Figure 30 shows the Gerbers used for PCBGOGO, which is a PCB manufacturing company overseas. After this the drill files need to be generated in a similar way using the settings in Figure 31.

KiCad has a built in Plugin for generating a BOM seen in Figure 19, which is simple plugin to use and makes manufacturing the board much more efficient. This BOM along with the schematic and PCB layout are all used to manufacture and solder the board as well as for undergoing commissioning tests that are within the DDR.

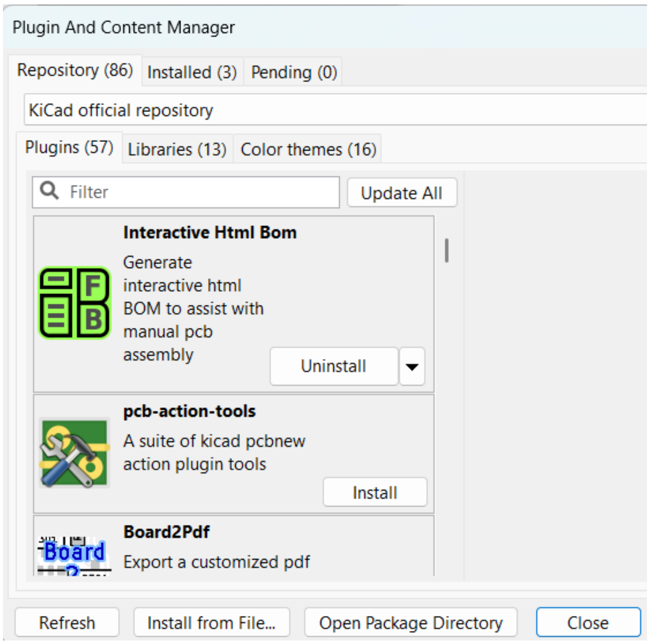


Figure 19: KiCad Plugin for interactive BOM

Once the board has been installed there are time when KiCad PCB Layout needs to be accessed again for troubleshooting. Pressing the k̃ey while hovering over a trace highlights all the other traces connecting to this trace or node.

5.3.3 LT Spice

LT Spice is a program used for simulating circuits. LT Spice has very little documentation on starting out and has some complex ways to simulate simple electrical concepts, such as changing a voltage from 450 V down to 12 V.

Despite the limited learning resources, LTSpice is a powerful tool for simulating both simple and complex circuits. It is highly recommended for engineers designing or modifying boards to ensure proper circuit functionality.

An example of an LT Spice workspace and results can be seen in Figure 39.

5.3.4 Arduino

Arduino is the main language used by NU Racing for the programming of the Teensy 4.0. This language is used for most control and CAN Bus message signal sending and receiving, and therefore it is the most important language to learn.

Arduino has a large amount of documentation on their website and is an easy language to learn, many others in NU Teams are extremely fluent in Arduino and can support new students learning Arduino. To start programming on the Teensy follow the steps from Section 5.2.2.

Arduino is a must learn language for any student involved in the making of PCBs or the control systems implemented on the NU Racing cars.

5.3.5 Matlab/Python

Matlab and Python both have areas they excel in and from the Authors experience in 2024, both can be used for majority of applications and simulations.

Matlab and Python were used to generate many of the plots needed to visualise and verify data of different electrical components and systems. In particular most of the simulating and research done on the PreCharge board was done in Matlab, such as Figure 46.

While not strictly necessary, these programs made visualisation of information much easier. This is necessary in a team setting such as NU Racing where a decision needs to be shown to team leaders and validation of why the decision is being made.

5.4 Non Standard Circuits

5.4.1 Introduction

There are many non standard circuits on the NU Racing cars. many of them are blended into other circuitry and are on almost every board. This section outlines a few used within the accumulator than can be applied to other boards or used as a concept for similar circuits.

5.4.2 Interpose Relay

The interpose relay is used to bring the sagging 12 V which can get as low as 7 V, inside the accumulator, and bring output 12 V again. This circuit is very useful if the voltage of a circuit drops below what it is required. This circuit can very easily be adapted to suit other designs and is shown in Figure 20 in red.

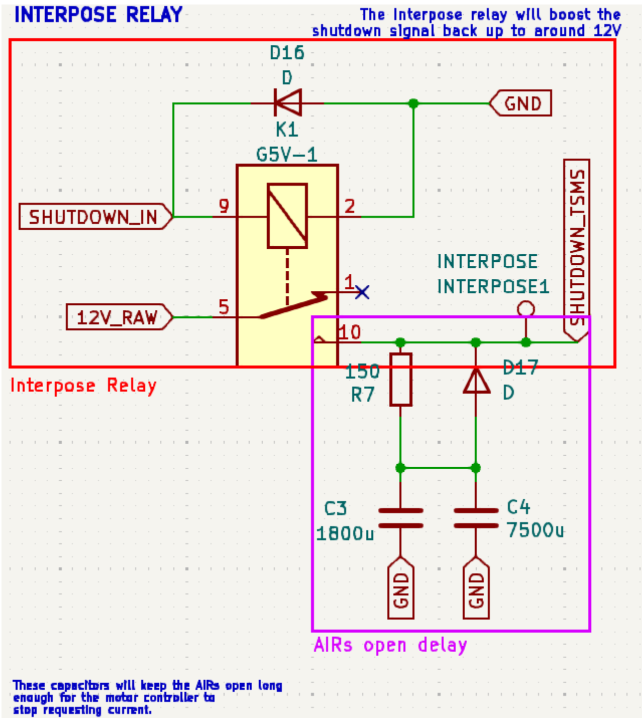


Figure 20: The Interpose relay with the AIRs delay capacitor

5.4.3 AIRs Delay Capacitors

The AIRs delay capacitors are used as a safety mechanism. If the motor controller is under load and the car faults, the AIRs open up in a state where large amounts of current was being drawn. This can be harmful and dangerous to both the accumulator cells and the motor controller among many other smaller components. This capacitor delay is a 208 ms delay, verified in Figure 41, that gives time for other components to shut off when the car faults. The rules state that this must be within 250 ms. The pink box in Figure 20 shows the delay capacitors which are connected to the Interpose relay.

5.4.4 MOSFET Driving a MOSFET

The MOSFET driving a MOSFET circuit is a tricky circuit still being developed at NU Racing, particularly with applications involving continuous high current draw over 16 A.

The concept of the circuit is that the Teensy 4.0 uses 3.3 V to trigger a smaller MOSFET that has 12 V at the drain. This 12 V essentially triggers the second MOSFET in the circuit which now has a higher voltage than 3.3 V present at the gate. This allows less internal resistance of the MOSFET and allows it to draw more current than 10 A and generates less heat.

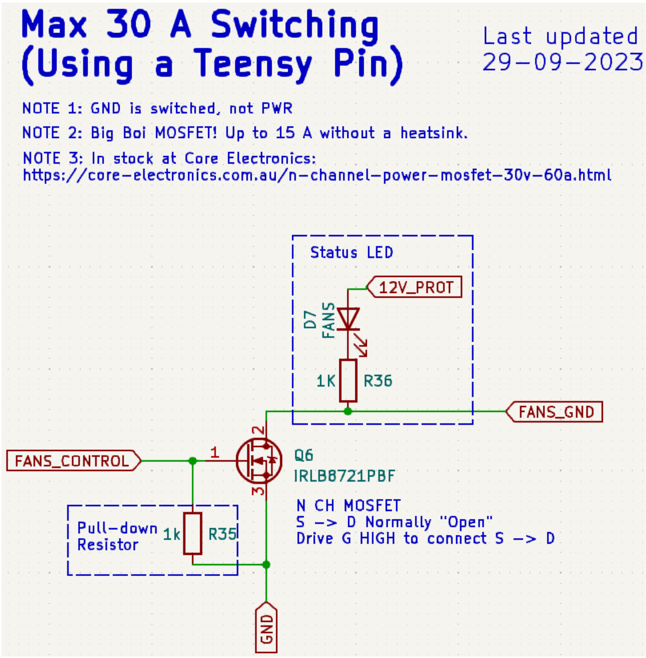


Figure 21: LVD V2.1 Fan switching circuit with single MOSFET

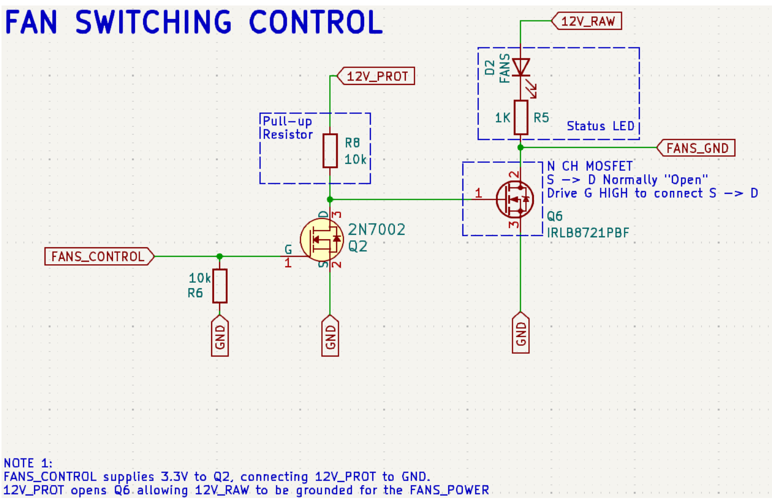


Figure 22: LVD V3.0 Fan Switching circuit using 2 MOSFETs

5.4.5 HV Detection

The HV detection circuit is a circuit used on many boards over the last couple of years at NU Racing. The circuit is most commonly found on the TSAL and variations of it are found on the PreCharge and previous AILs.

This circuit does not give a voltage measurement, rather a digital HIGH or LOW signal when it detects voltage over a certain pre-defined number. Figure 23 shows in blue how to configure the voltage that the circuit switches at.

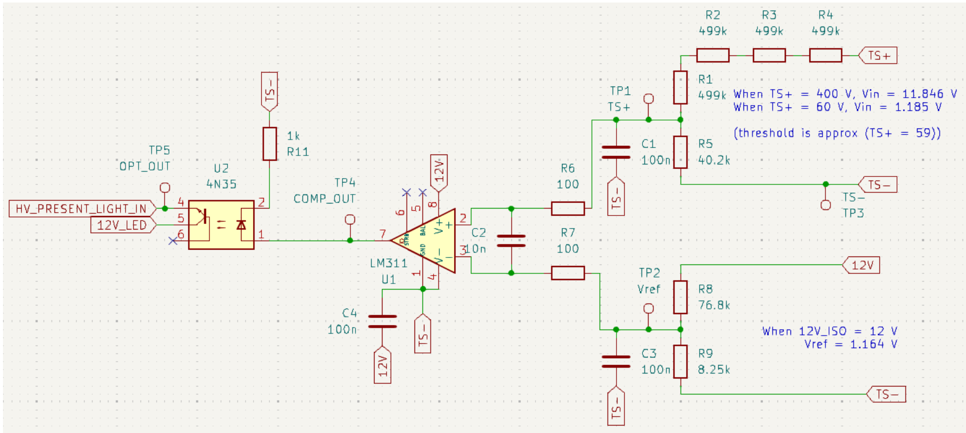


Figure 23: HV detection circuit from AIL

This circuit is very modifiable and can be used for many High Voltage applications. It should be noted that the above figure is used on the AIL and is set up inversely to how the TSAL is configured.

5.5 Key Findings

5.5.1 MOSFETs

It became evident towards the back end of 2024 that not enough research had been done into the type of MOSFETs used in some of NU Racing's circuits. Most notably is the fan switching MOSFET to drive a MOSFET circuit on the 2024 LVDs. This circuit heated up rapidly due to the current draw of the fans and is outlined in Section 7.1.1.

These circuits are still good if the current drawn is less than 16 A if used without a heatsink.

5.5.2 Molex Micro Fit

The Molex Micro Fit connectors are used extensively through out the accumulator of NU24. During the year many times the car would fault or a board would not heartbeat, and after many more hours the team would often find that it was due to a faulty Molex pin connection.

When the accumulator is being serviced the lid has to be removed or wire need to be moved out of the way and this often means that molex connectors have to be disconnected to access parts of the accumulator. Having so many issues with PCBs in the accumulator in 2024, the connectors were constantly being disconnected and reconnected. This in caused the female connector pin to stretch and in many cases, not contact the male pin at all.

(a) Molex Male Pin

(b) Molex Female Pin

Figure 24: The male pin and the fouling female pin

The LVD has a 22 pin Molex Micro Fit connector at the bottom of the board for sending signals and power to all the other electrical components inside the accumulator. This connector needed to be removed every time the lid came off for a prolonged amount of time, which is quite often. This 22 pin connector was extremely difficult to get off and without realising, the wires on the connector were being pulled on to better leverage the connector out. This combined with the twisting and bending of such a long connector caused power and signal problems within the accumulator on multiple occasions.

Figure 25: Molex Micro Fit 22 Pin connector

This can be quite a dangerous problem to have as the car can be working prior to comp but during the tech inspection of the accumulator, when this connectors have to be removed to take the lid off, a pin can fould and cause the car to no longer run as intended.

In future years this should be the first part to check if a board is not working as intended. For the LVD the 22 pin connector should be removed with a better connector or continue using Molex, except split it into four connectors and not one single 22 pin connector.

5.6 Changes for NU25

Going forward in 2025 there are a few changes being recommended for the electrical systems used within the accumulator, these recommendations would also be really good when applied to all electrical systems on the cars going forward.

MOSFETs have been mentioned as standard blocks in the above sections, and they work well in low current draw situations. Unfortunately on the LVD and any area that has high current draw, MOSFETs are far too vulnerable to overheating and it is recommended that they are replaced with standard automotive relays which can handle much higher currents. They are however much larger and require more components to connect to PCBs. Given adequate time it is reccomended that the MOSFETs, that were intended for use on the LVD V3.1, be tested to validate the calculations done in sections 5.5 in order to fully understand current.

Op-Amps were used in V3.0 of the LVD and on the HFR boards, these were put in to avoid voltage divides happening so that status LEDs could still be used. Unfortunately not much research had been conducted on how these work on NU Racing's PCBs. Due to this numerous problems arose and many Op-Amps became nonfunctioning resulting in functionality of the PCBs becoming limited. To remedy this the Op-Amps were completed removed from the board. They should remain off the boards until more research can be done on how they work.

Used extensively throughout the accumulator as the main connectors between PCBs are the Molex mini fit junior connectors.

Figure 26: Molex connector used in accumulator prone to pins losing good contact

These Molex connectors were far too prone to losing good connection between the male and female pins. The 2024 team re-crimped and replaced the Molex pins on multiple occasions and was the cause of faults, usually PDOC, CAN or IMD faults. For NU25 changing to a different connector or separating the pins that are OKHS so that they are removed less often when the lid is removed or the accumulator needs servicing.

6 Low Voltage Distribution Board V3.0

6.1 Outline

The Low Voltage Distribution Board (LVD) is used to send power to the electrical components within the accumulator. LVD V3.0 was initially meant to be a re-spin of the LVD V2.1, with few changes being applied. These minor changes included a reduce in part count, smaller board and removal of certain functional blocks due to rule changes. Initially this was meant to be a starter project but the complexity increased soon after starting.

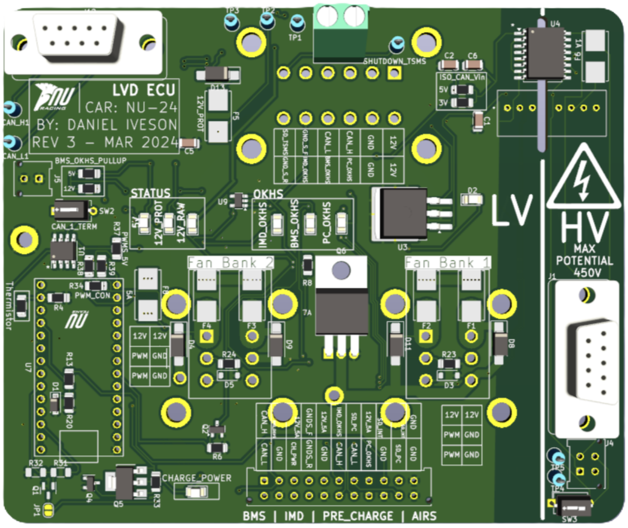


Figure 27: LVD V3.0 front on

6.2 Findings

During the research and learning stage, It was found that a 0 ohm resistor being used on the BMS_OKHS_PULLUP circuit was causing the 5 V regulator to short to ground in the case of a BMS_OKHS being pulled to ground, also known as a BMS fault. This was causing the 5 V regulator on the LVD to overheat and components using the 5 V regulator would stop working. In this case the BMS would not get pulled up to high. The 0 ohm resistor was put in place to avoid a voltage divide, created by having the status LED for the BMS_OKHS.

This was found to be the cause of the NU23 car failing to complete the endurance event at competition. A way fix for this is outlined in Section 6.3 and Figure 28.

6.3 Changes

The largest change to the LVD was the removal of the AIL, this greatly reduced the board size with the reduction in components. The issues outlined in Findings were resolved by adding Op-Amps to stop a voltage divide and a MOSFET was used to drive a MOSFET so that more current could flow through without causing overheating.

One of the major problems with the previous LVD models was the MOSFET for the fan circuit overheating and falling off. Figure 22 shows a circuit of a MOSFET being used to drive a MOSFET, this allows the 2n7002 to switch using 3.3 V from the micro-controller and does not need much current to pass through, the Drain to Source voltage of this MOSFET is 12 V and is connected to the gate of the IRLB8721PBF MOSFET so that the current aloud to run through it is higher than 10 A which was the limiting figure shown in Figure 34

The next major change to the LVD was the addition of Op-Amps

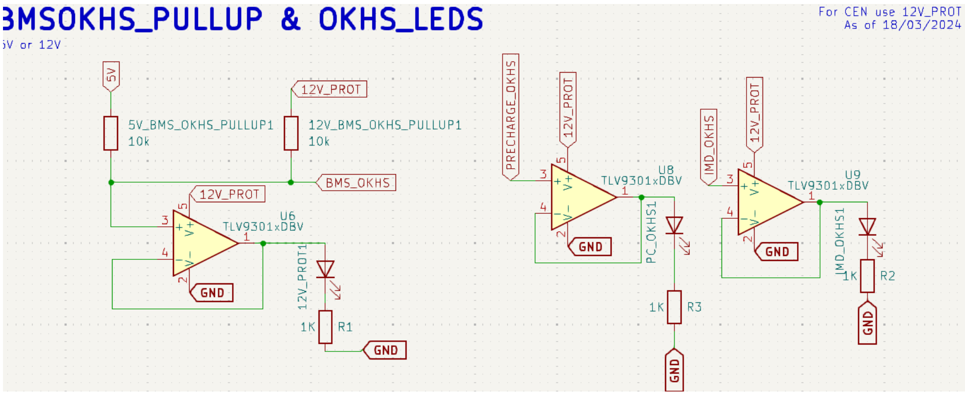


Figure 28: LVD V3.0 Op-Amps used to stop voltage divide on status LEDs

To stop the BMS fault from reoccurring through the LVD a 1 k or 10 k resistor needed to replace the 0 ohm resistor. This would in turn create a voltage divide which was also going to have negative implications on the BMS_OKHS being pulled up to less than 12 V or 5 V, which ever is selected. To avoid the voltage divide Op-Amps were placed into the circuit, as seen in Figure 28, stopping the voltage divide from occurring but allowing the resistance to be 1 k or 10 k. During commissioning and the initial track days, just after installation on the car, there were no problems. Until after several track days and tests there became a problem and is outline in Section 6.6.

6.4 Manufacturing

The LVD V3.0 was manufactured using KiCad, this involved using previous schematics and design of the board and adapting them with the new changes stated above. Once the design has been completed and all Design and Electrical checks have been passed within KiCad, all NU Racing PCBs must undergo a DDR, this involves another member of the team who is well versed in electrical systems doing a review of the board using the standard DDR template.

	Designer	Reviewer	NOTES
Title Block Checklist			
Has the title block been completed to the same standard as the example below?	YES	YES	
Neatness / Quality Of Life			
Distinct circuits are in blocks:	YES	YES	
All Blocks are labelled:	YES	YES	*please make the same size font and bold*
Nonstandard Blocks have functionality / explanation labelled:	YES	YES	
Standard blocks used where possible:	YES	YES	
All unused pins on components have 'no connection flags' (x)	YES	YES	
All names are logical	YES	YES	
All test points and LEDS labelled as reference signal (NOT Dx or TPx)	YES	YES	

Figure 29: Example of LVD V3.0 DDR from schematic section

Gerber files, which are used for PCB fabrication, are generated within KiCad and sent to PCBGOGO to be manufactured. Every PCB manufacturer will have different requirements on which Gerber files they want and different options they want selected, which can easily be found on their website. The files generated can be seen in Figure 30.

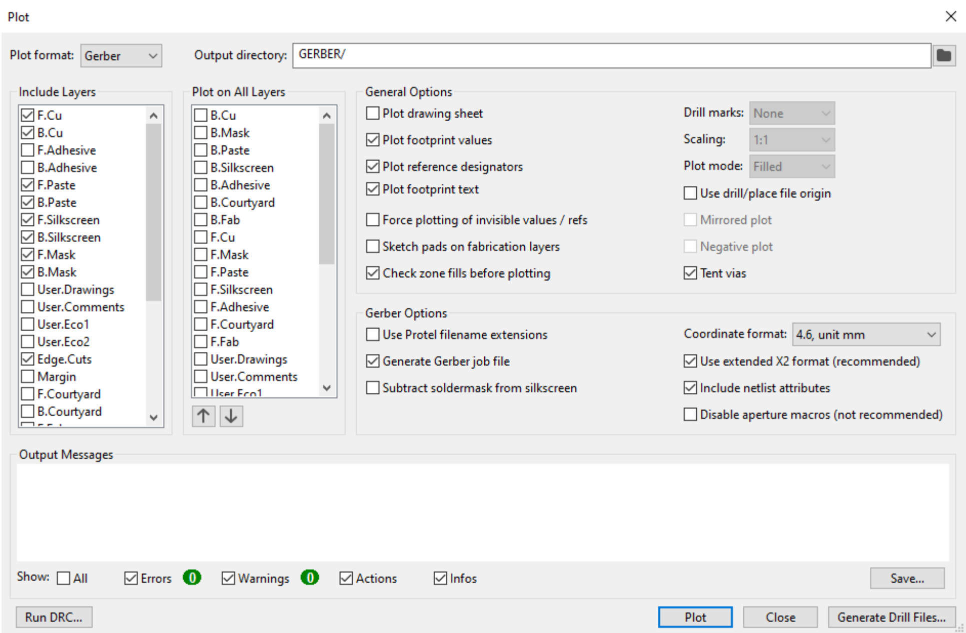


Figure 30: KiCad V8 Gerber Plotter

Once the main Gerbers files have been generated, the next step in the process is to generate the drill and map files by clicking generate drill files. Figure 31 shows the settings used to generate these for PCBgogo.

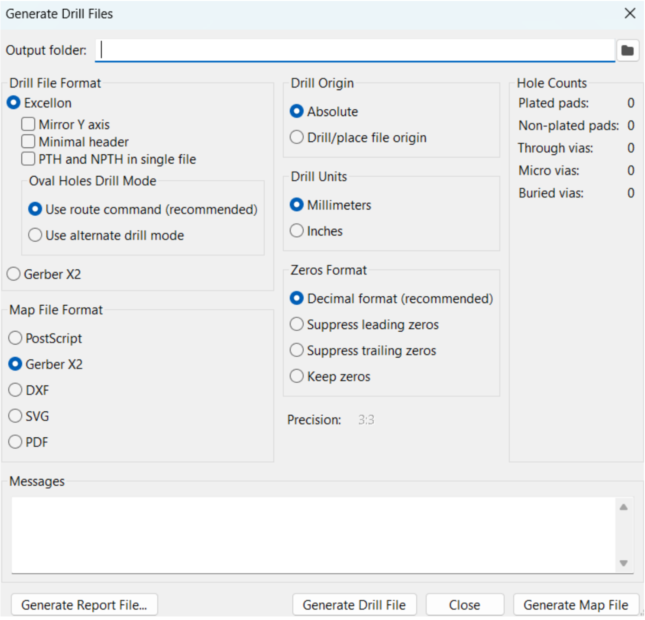


Figure 31: Gerber Drill file settings recommendation

Before being sent of for manufacturing it is important to go through every Gerber file and make sure that everything is as it should be. KiCad has a built in Gerber viewer shown in Figure 32.

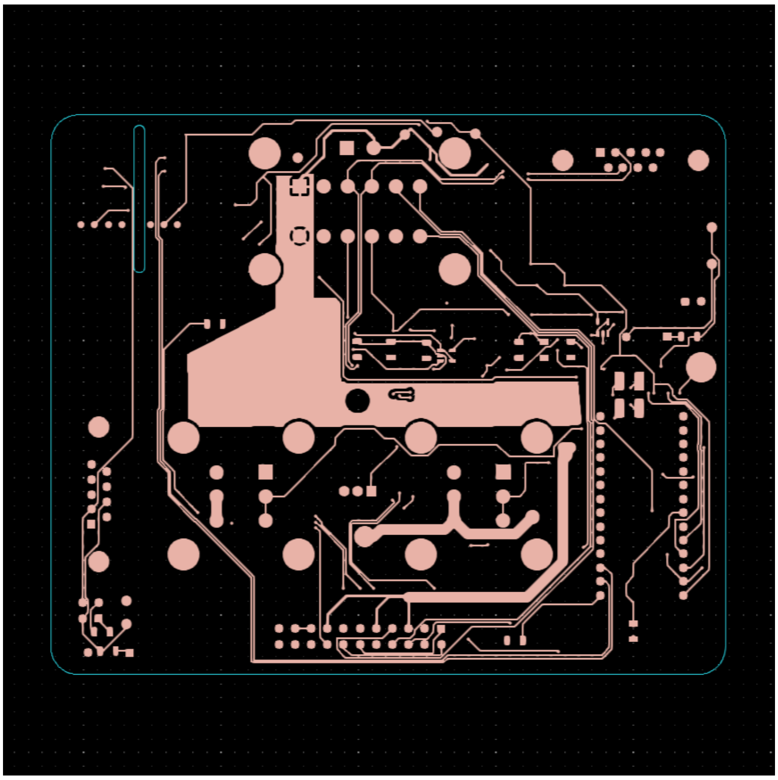


Figure 32: Gerber Viewer of LVD V3.0 for front copper layer and edge cuts

This is an easy way to check that all layers are complete and that they will be manufactured correctly. This Gerber viewer can also be used for circuit evaluation in the commissioning step or troubleshooting.

Because majority of the components are on the back side and are SMD, a stencil was also order for the LVD V3.0 for ease of commissioning.

6.5 Commissioning

Once the board had been manufactured and delivered, the components could be placed on the board. Due to the majority of components being placed on the back side of the board and minimal components on the front side of the board, the back side could be assembled by using a stencil.

The stencil allows for quick and easy placement of parts. The board is placed under the thin stencil sheet. Solder paste is then applied over the stencil and is placed on all the pads. Then all the components are placed on the board after the stencil is removed, and the components will stay in place on the board because of the solder paste on the pads. Once all the SMD back side components were placed it could be placed in the reflow oven which in turn soldered the components to the board. The other side of the board was then soldered by hand and all the THT components on both sides.

Once the board was fully assembled it could then be tested for functionality. All different parts of the board need to be tested on the bench to makes sure they work before it can be put into the accumulator.

The first test is to make sure all the traces are connected using continuity, this includes 12 V, GND, CAN_H, CAN_L and more signals that have traces running through the board.

After this functionality for the CAN bus network needs to be tested, this is done using a program called CAN King. CAN King uses a Kvaser adaptor to plug into the DB-9 connector, CAN King can be used to send the signals corresponding to IDs from the CAN network to test for certain functions based on signals. For the LVD this was the signal for charging and LV_Power_Status, if these IDs are received the fans will turn on and change speed.

6.6 Problems

During the commissioning stage it became apparent that not all CAN signals worked all the time. This is not normal behaviour of CAN when working nor when it is not working. If CAN stops working it fully stops working. What was happening on the LVD V3.0 was it would receive and send certain signals but not others. When a new Teensy was placed on the board the signals acting up would change to different signals.

Some times the board could receive LV_POWER_STATUS but with another Teensy it would be unable to receive the same signal. This was apparent with multiple signals and different Teensy micro-controllers. Hours of testing and research was done to try and resolve the issue with multiple boards being made, however the problem persisted until randomly when the code was pushed to the LVD V3.0 and all the signals worked. The board worked without issue and was used in the accumulator for several track days. This problem persisted and every time the LVD V3.0 needed code pushed to it the entire cycle was started once again.

This was a major problem with the board as it was the bridge between inside and outside the accumulator for important signals. Luckily many of the OKHS were analog signals and are sent both over CAN and as their own 12 V line exiting the accumulator. Figure 33 shows in red the signals that are sent both by CAN bus and by analog signal.

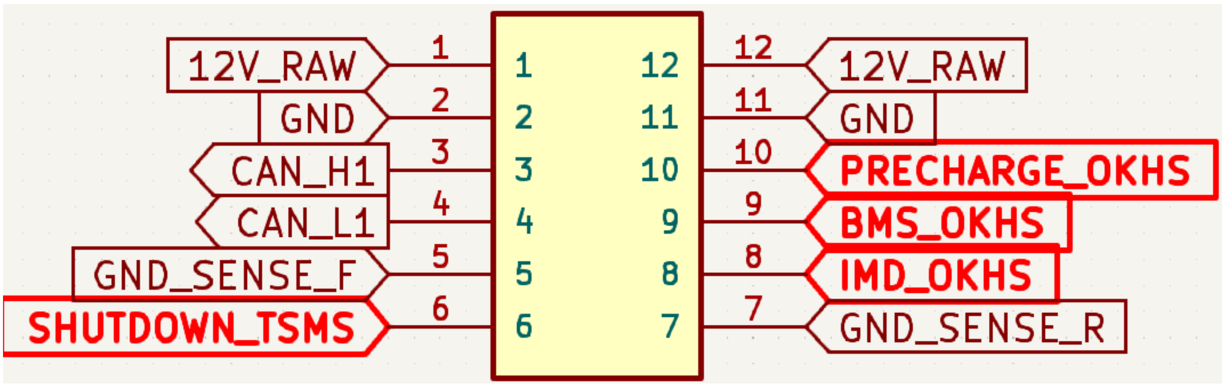


Figure 33: Critical Signals sent both by CAN bus and Analog in red

However these signals in red were not being sent to the LVD, which in turn is sent to other boards, or sent to the rest of the car. It was found that the fans on the accumulator were not turning on when

NU24 went into HV or charging. This is because the fans turn on when they receive the signal that the car is detecting HV outside of the accumulator or the charging signal, all via CAN Bus.

This problem with the CAN bus not working as intended was due to different lengths in CAN High and CAN Low trace paths. Section 6.3 outlines more about this problem and the solution.

7 Low Voltage Distribution Board V3.1

7.1 Findings

Upon commissioning the LVD V3.0 it became apparent there were underlying problems with the boards layout in regards to the CAN network. Once on the car and after several test days the LVD V3.0 showed more and more problems with the OP-AMPs added to the board to fix the voltage divide and BMS fault that was labelled in Section 6.2.

7.1.1 MOSFETs

The single MOSFET circuit block in Figure 21 utilises a IRLB8721 MOSFET. Due to overheating it was discovered that using 3.3 V from the Teensy 4.0 micro-controller, the small current and voltage being supplied to the gate of the MOSFET creates a high resistance path as it closes and in turn generates enough heat and if operating for long periods of time, the MOSFET will de-solder itself from the LVD.

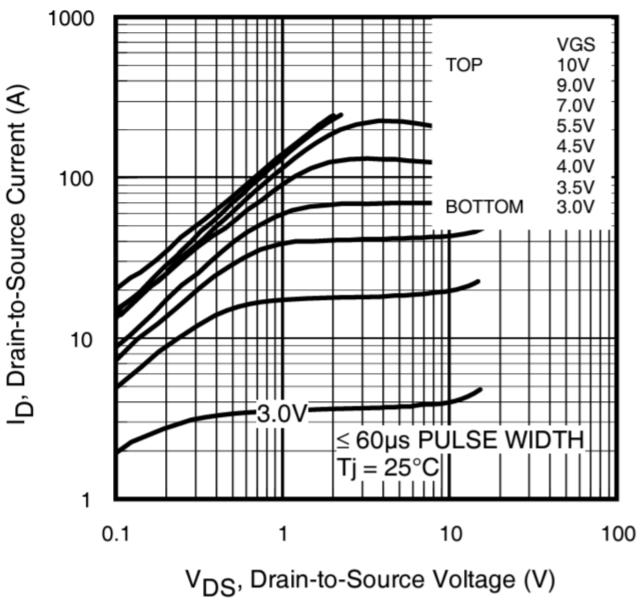


Figure 34: Maximum current of 10 A for MOSFET from 3.3 V micro-controller

When supplied with 3.5 V, Figure 34 shows that 12 V would supply a maximum current of approximately 20 A. The fans on NU24 are expected to pull and operate at 24 A, this meant that the current being draw was exceeding the current limit of the MOSFET. Any voltage over 4 V would allow for sufficient operating current for operating the fans. 12 V which is common on most PCBs on NU24 will also offer sufficient operating current.

For the MOSFETs to operate with the Teensy logic and also have a drain to source voltage of 12 V, a MOSFET needs to be used to drive another MOSFET with 12 V. This gave way to the MOSFET driving a MOSFET circuit that was used on the LVD V3.0 and until late testing at comp it worked without failure.

Towards the lead up to competition the MOSFET began to de-solder itself after long periods of time running the fans on the car. The MOSFETs were removed for the competition and replaced with a relay, the reason for the MOSFETs de-soldering and becoming extremely hot to touch has not been fully verified except in the calculations below

The IRLB8721 data sheet gives values for the thermal resistances for thermodynamic calculations for the temperature with respect to time.

The junction temperature rise over time is given by:

$$T_j(t) = T_{\text{ambient}} + \Delta T_{\text{steady}} \cdot \left(1 - e^{-t/\tau}\right)$$

The steady-state temperature rise is given by:

$$\Delta T_{\text{steady}} = P \cdot R_{\theta JA}$$

The power dissipation P is calculated from the equation:

$$P = I_D^2 \cdot R_{DS(on)}$$

Where the MOSFET operates at $I_D = 24A$ and has an on-state resistance of $R_{DS(on)} = 8.7\text{m}\Omega = 0.0087\Omega$.

$$P = 24^2 \times 0.0087 = 5.01W$$

The thermal resistance $R_{\theta JA}$ is taken from the MOSFET data sheet and represents how much the junction temperature rises per watt of power dissipated.

Substitute the values:

$$P = 5.01\,\text{W}, \quad R_{\theta JA} = 62\,°\text{C/W}$$

$$\Delta T_{\text{steady}} = 5.01 \cdot 62 = 310.6\,°\text{C}$$

The thermal time constant is given by:

$$\tau = R_{\theta JA} \cdot C_{\text{th}}$$

The thermal capacitance C_{th} is estimated based on typical MOSFET values and represents how much heat energy the MOSFET can absorb before its temperature changes significantly.

$$\tau = 62 \times 0.1 = 6.2\,\text{seconds}$$

Substitute the values:

$$R_{\theta JA} = 62\,°\text{C/W}, \quad C_{\text{th}} = 0.1\,\text{J/°C}$$

$$\tau = 62 \cdot 0.1 = 6.2\,\text{seconds}$$

For the time to reach the maximum operating temperature (175°C):

$$T_j(t) = 175$$

Substitute:

$$175 = 25 + 310.6 \cdot \left(1 - e^{-t/6.2}\right)$$

Simplify:

$$150 = 310.6 \cdot \left(1 - e^{-t/6.2}\right)$$

$$\frac{150}{310.6} = 1 - e^{-t/6.2}$$

$$e^{-t/6.2} = 1 - \frac{150}{310.6} \approx 0.516$$

$$-t/6.2 = \ln(0.516)$$

$$t \approx 6.2 \cdot 0.661 \approx 4.1\,\text{seconds}$$

For the time to reach solder melting temperature (220°C):

$$T_j(t) = 220$$

Substitute:

$$220 = 25 + 310.6 \cdot \left(1 - e^{-t/6.2}\right)$$

Simplify:

$$195 = 310.6 \cdot \left(1 - e^{-t/6.2}\right)$$

$$\frac{195}{310.6} = 1 - e^{-t/6.2}$$

$$e^{-t/6.2} = 1 - \frac{195}{310.6} \approx 0.37$$

$$-t/6.2 = \ln(0.37)$$

$$t \approx 6.2 \cdot 0.994 \approx 6.2\,\text{seconds}$$

Here it is estimated that the MOSFETs will overheat quickly and will not be suitable for high continuous currents such as 24 A.

The IRLB8721 MOSFET being used for fan switching is a high current MOSFET (62 A), however it is only high current under certain conditions. For constant high current operation, greater than 16 A, a heat sink must be used so prevent the MOSFET from overheating.

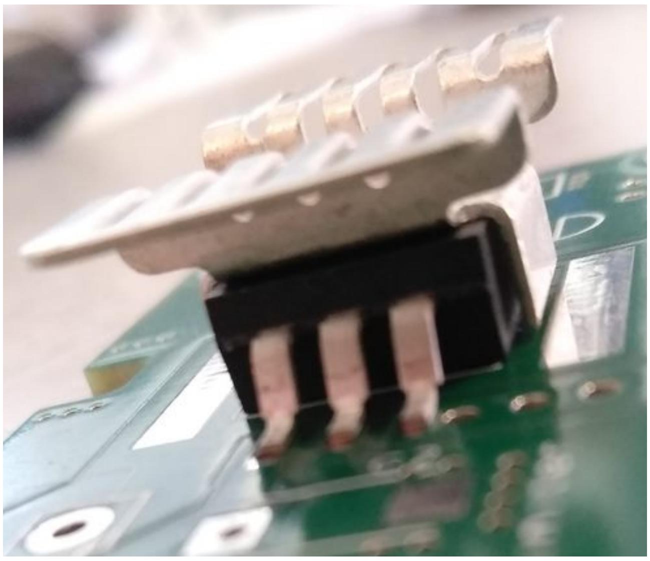


Figure 35: Example SMD Heat sink

With constant 24 A running through the MOSFET, the power generates a high amount of heat and requires a very low thermal resistance heat sink.

The junction temperature is given by:

$$T_j = T_{\text{ambient}} + P_{\text{dissipation}} \times R_{\theta JA}$$

Where:

$$R_{\theta JA} = R_{\theta JC} + R_{\theta CS} + R_{\theta SA}$$

Rearranging for the heatsink's thermal resistance $R_{\theta SA}$:

$$R_{\theta SA} = \frac{T_j - T_{\text{ambient}}}{P_{\text{dissipation}}} - R_{\theta JC} - R_{\theta CS}$$

Substitute the known values:

$$T_j = 175\,^{\circ}\text{C}, \quad T_{\text{ambient}} = 25\,^{\circ}\text{C}, \quad P_{\text{dissipation}} = 5.01\,\text{W}$$

$$R_{\theta JC} = 2.3\,^{\circ}\text{C/W}, \quad R_{\theta CS} = 0.5\,^{\circ}\text{C/W}$$

$$R_{\theta SA} = \frac{175 - 25}{5.01} - 2.3 - 0.5$$

Simplify:

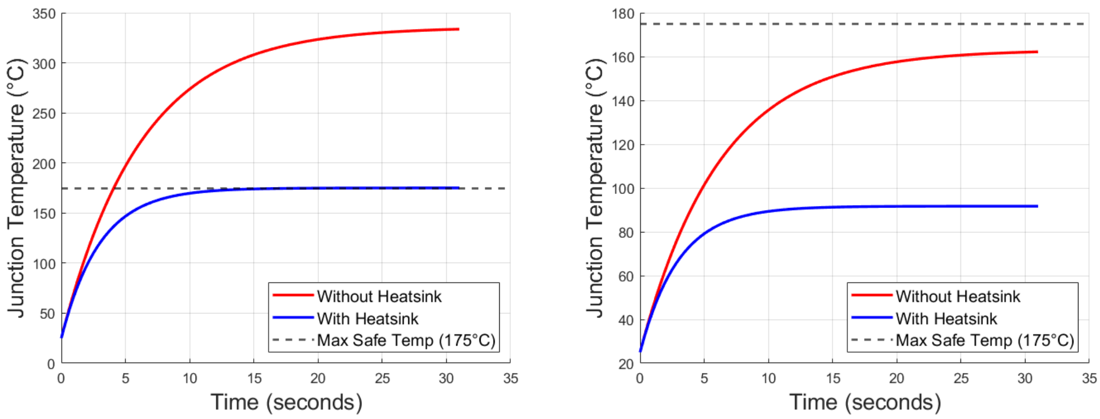
$$R_{\theta SA} = \frac{150}{5.01} - 2.8$$

$$R_{\theta SA} \approx 29.94 - 2.8 = 27.14\,°\text{C/W}$$

The heatsink must have a thermal resistance of:

$$R_{\theta SA} \leq 27.14\,°\text{C/W}$$

This will ensure the MOSFET operates within its safe temperature range under the given conditions.



(a) 24 A fan draw (b) 16 A fan draw

Figure 36: 24 A compared to 16 A MOSFET temperature rise for fans

As seen in Figure 36, If the current is reduced to 16 A the MOSFET can run without a heat sink and has a factor of safety so that it will not hit the maximum operating temperature.

7.2 Changes

The changes added to the LVD V3.1 were primarily fixes from the LVD V3.0. Removal of all Op-Amps, restructure the CAN Bus components and traces, and the addition of the interpose relay and capacitors are all major changes of the LVD V3.1.

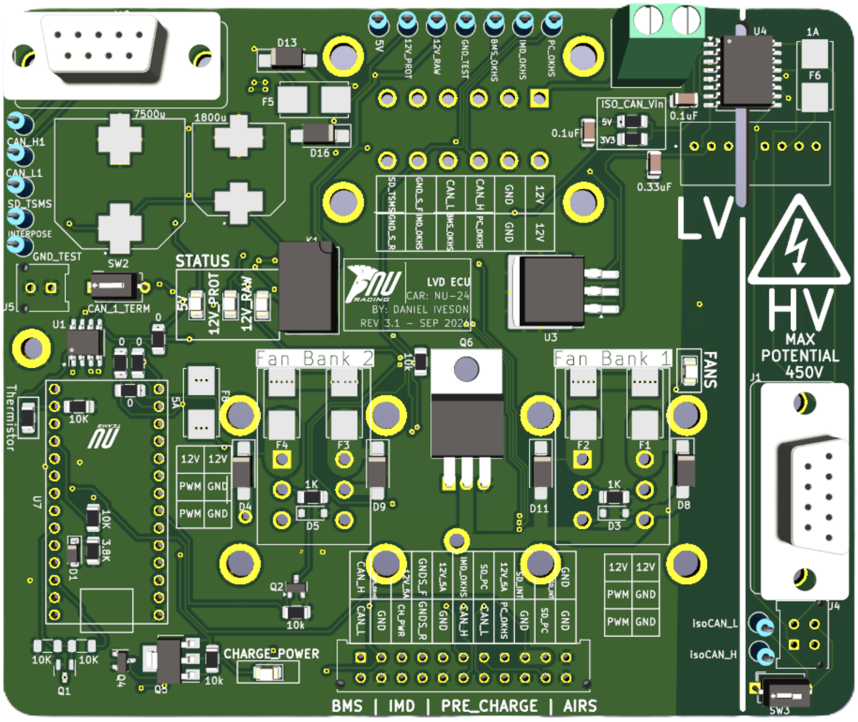


Figure 37: LVD V3.1 with interpose relay

The removal of the Op-Amps was a time sensitive decision. If more research could be conducted on the Op-Amps, or to find out why they were losing functionality, then they could have remained. Unfortunately the removal of the Op-Amps meant the voltage divider on the BMS Pull Up signal was a major issue again. This led to the decision to remove all the OKHS LEDs connected to MOSFETs from the board to take away the opportunity for voltage divides to occur. Test points were still all over the board for these relevant OKHS, therefore the issue of having no LEDs was not a major impact on the team. When the LVD was running and the lights were illuminated, the accumulator container was closed and they could not be seen unless bench testing.

The time consuming issue with fault finding the LVD V3.0 was the CAN network working temperamentally, with the reason being uneven board trace lengths. This was fixed by making sure that the traces for CAN High and CAN Low were the same length and just to be sure all the components for the CAN Bus communication network were deleted in KiCad and replaced with all new equal length traces.

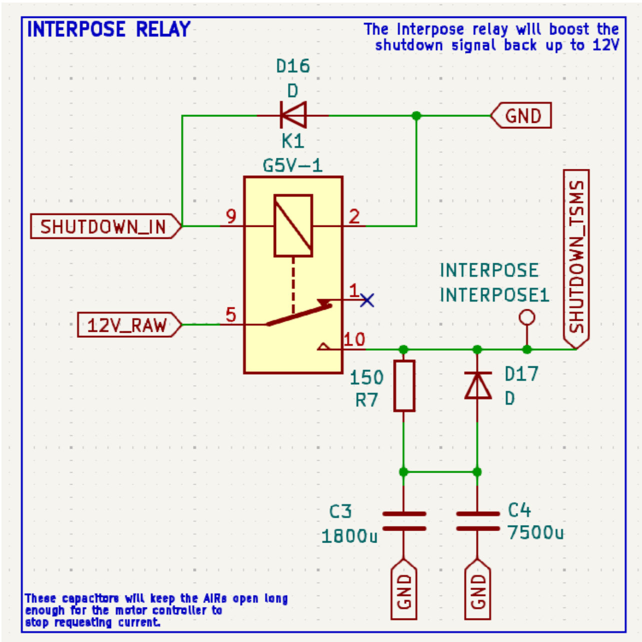


Figure 38: Interpose Relay and Capacitors for increasing Shutdown Voltage to 12 V and keeping it open for 250 ms

The addition of the Interpose to the LVD V3.1 was chosen after it was placed on the PreCharge, more about this is outline in Section 8.4. The Interpose relay is used to keep the voltage of the Shutdown circuit at 12 V, the Shutdown circuit voltage slowly decreases as it passes through different boards and components of the car until it finally reaches the AIRs to close them, due to the large drop in voltage the Shutdown circuit is unable to close the AIRs and the car will not enter HV. This is where the Interpose relay closes at much lower voltages than the AIRs and is able to boost the Shutdown circuit back to 12 V. Figure 38 show the schematic for the interpose circuit including two large capacitors on the 12 V boosted Shutdown side of the interpose relay, these are known as the Shutdown capacitors and are used to keep the Shutdown circuit closed for less than 250ms after the Shutdown circuit is turned off.

7.3 Manufacturing

The LVD V3.1 was manufactured using the same programs and processes as the LVD V3.0. While being largely the same board with a few additions and removals, only the new interpose relay and capacitors needed to be purchased.

7.4 Commissioning

The vast majority of the LVD V3.1 is unchanged from Section 6.5, this is due to the board layout being majority unchanged apart from the major changes which were critical to the car competing successfully.

The interpose capacitors, due to their large form, were challenging to get onto the board correctly. The 1800 uF capacitor could be placed on the board with solder paste and put into the reflow oven, along with all the other SMD components. This capacitor unfortunately when put into the reflow oven, for which it is rated to and is manufactured with the intent of being in a reflow oven, became too hot and swelled up. The capacitor still worked but for safety and reliability it was removed and hand soldered. The 7500 uF capacitor was much larger than the smaller 1800 uF, this meant it was too tall to fit into the reflow oven. The larger capacitor along with the smaller capacitor both being hand soldered became challenging due to the difficulty in heating up the large solder pads underneath the capacitors. This was placed on using two people, one with a soldering iron and the other with the heat gun.

The commissioning tests undertaken on the LVD V3.0 were repeated on the LVD V3.1 with the addition of new tests for the Interpose relay and resistors. The LVD V3.1 was connected to 12 V for power, 7 V for the Shutdown circuit and ground. Once the board was operating, a multimeter was used to probe the inputs and outputs of the relay to make sure everything worked correctly, the output showed 12 V for the Shutdown circuit which is high enough to close the AIRs.

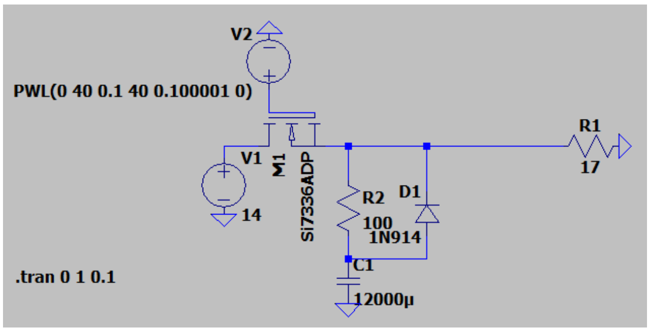


Figure 39: Set up of Shutdown circuit with capacitor

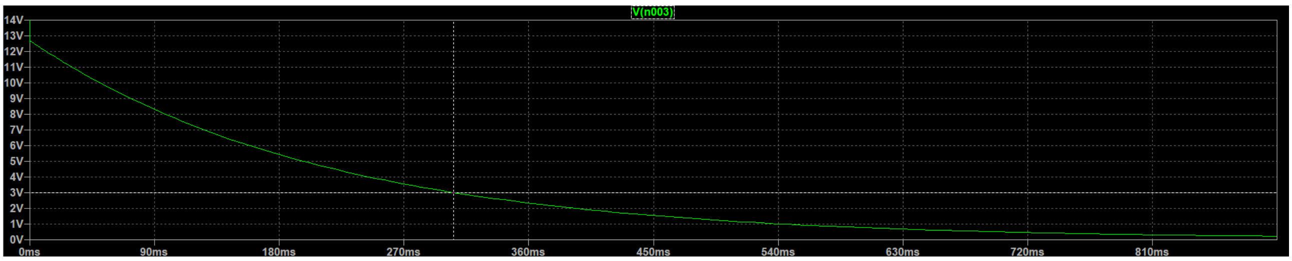


Figure 40: Results of the Shutdown circuit going to the AIR

To test the Interpose capacitors were working as intended, the output of the Shutdown circuit was connected to an oscilloscope. Then the Shutdown circuit was connected to 10 V and the boards power input and ground are powered by a separate 12 V power supply. Once everything is connected and powered, the shutdown circuit into the board is powered off and the oscilloscope will visualise and calculate the drop in voltage over time as shown in Figure 41.

Figure 41: Testing the Time out of the Interpose Capacitors is less than 250 ms

With the removal of the Op-Amps there was no longer any problems with Op-Amps not functioning properly and did not need to be validated in the commissioning stage of the LVD V3.1.

The final test on the board was to trial if the CAN bus network was still being temperamental. The LVD V3.1 was hooked up to one of the two banks of accumulator fans, in order to not draw more current than the power supply could supply, and was powered using 12 V and Ground. The LVD was then connected via Kvaser adaptor to CAN King, and with the correct code pushed to the Teensy, signals could be sent and received by CAN King. Straight away the correct signals were being received and sent. Based on the findings of the LVD V3.0, if the Teensy was changed this could change what signals were being sent and received correctly, therefore a different Teensy was placed on the LVD and it continued to work without fault, validating that the problem was due to uneven CAN High and CAN Low traces on the LVD V3.0

7.5 Competition Changes

Leading up to the competition NU24 underwent many track days of testing. Through this testing the team found that the MOSFETs for the fan, previously mention in Section 6.3, were still overheating. The calculated Current at 12 V is as follows:

$$I_D = \frac{V_{DS}}{R_{DS(on)}} \tag{7.1}$$

Equation 7.1: This equation calculates the drain current I_D using Ohm's Law.

$$I_D = \frac{1\,\mathrm{V}}{0.0087\,\Omega} \approx 115\,\mathrm{A} \tag{7.2}$$

Equation 7.2: Calculation for I_D with $V_{DS} = 1\,\mathrm{V}$ and $R_{DS(on)} = 0.0087\,\Omega$.

$$I_D = 62\,\mathrm{A} \tag{7.3}$$

Equation 7.3: This is the maximum safe continuous operating current for the MOSFET at a case temperature of 25°C.

The maximum current at 12 V being supplied to the MOSFET is 62 A as this is much lower than that of the 115 A calculated based on resistance and Ohm's law. However the fans on the accumulator are pulling a total of 24 A and therefore within the safe operating limit of the MOSFET.

To remedy the MOSFET overheating and de soldering itself, a relay was substituted. The MOSFET was removed and wires were soldered to the board. The wires were attached to the drain of the 2N7002 MOSFET (12 V), GROUND, FANS_GROUND and 12 V_RAW. This allowed the fans to switch ground using a relay instead of a MOSFET which did not overheat on track days when tested.

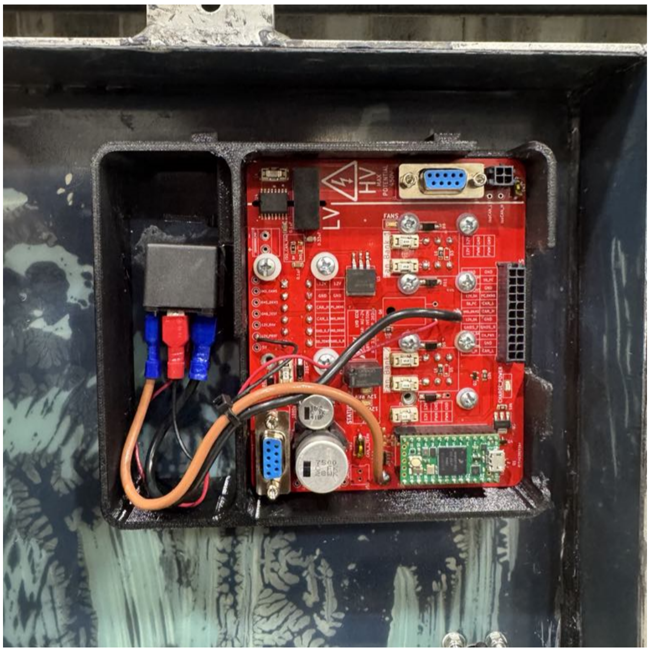


Figure 42: Mechanical relay used to replace SMD MOSFET

This relay was fitted to a new LVD enclosure made especially for the addition of the relay. This setup worked successfully during the competition without any problems.

7.6 Recommendations

For LVDs in future years research into the current draw of the fans is necessary in order to know what current the fans pull at different PWM, this will show what PWM the fans can operate at. Knowing what the current draw and PWM are, this will set the fan speed limit and the 2025 team can test weather this fan speed is adequately cooling the accumulator.

With 2024 team's problem with overheating MOSFETs, in particular the IRLB8721, this can be solved in a number of ways. Firstly the fans are currently running at 80% PWM. If they are able to keep the accumulator at a reasonable temperature at a lower PWM, this will reduce the current draw on the MOSFET and in turn reduce the heat. If the fans still require a high PWM than has a similar current draw above 16 A, this will require a heat sink to be placed on the MOSFET.

Alternatively instead of trying to make the current IRLB8721 MOSFET work, the 2024 team ran a automotive mechanical relay instead for reliability and lack of time to fix the MOSFET. The relay was wired into the LVD and placed in a new enclosure, however a better way to connect the relay to the board is recommended. If there is limited room or the 2025 team wants to continue with MOSFETs, the IRLB8721 is at end of life and is being replaced with the IRLB3813. This new MOSFET handles continuous current draw much better and has the same THT foot print as the previous MOSFET.

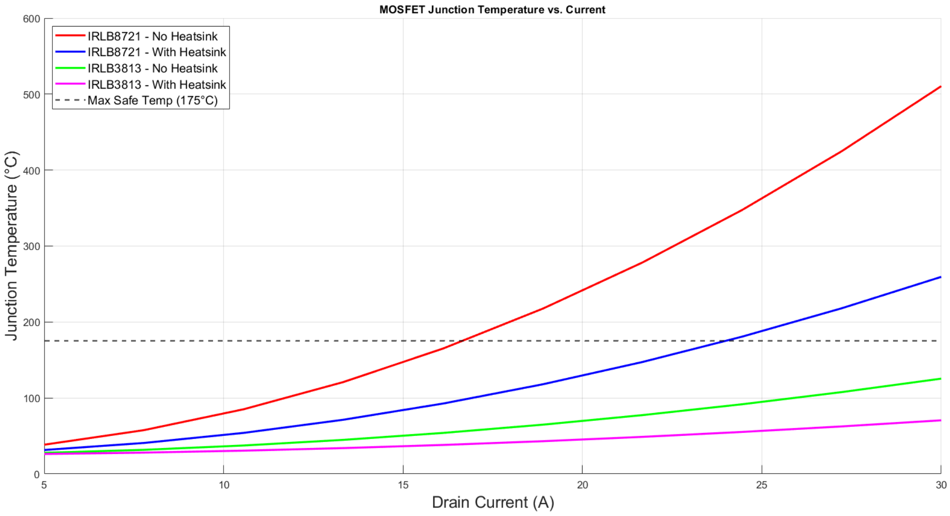


Figure 43: Comparison of old IRL MOSFET against new IRL MOSFET

The new IRLB3813 is able to run a higher currents before overheating as can be seen in Figure 43. This is a direct replacement onto the current board and will not require a new LVD.

The LVD V3.0 and V3.1 never implemented the circuit in Figure 44 and is recommended to be put on any following versions of the LVD.

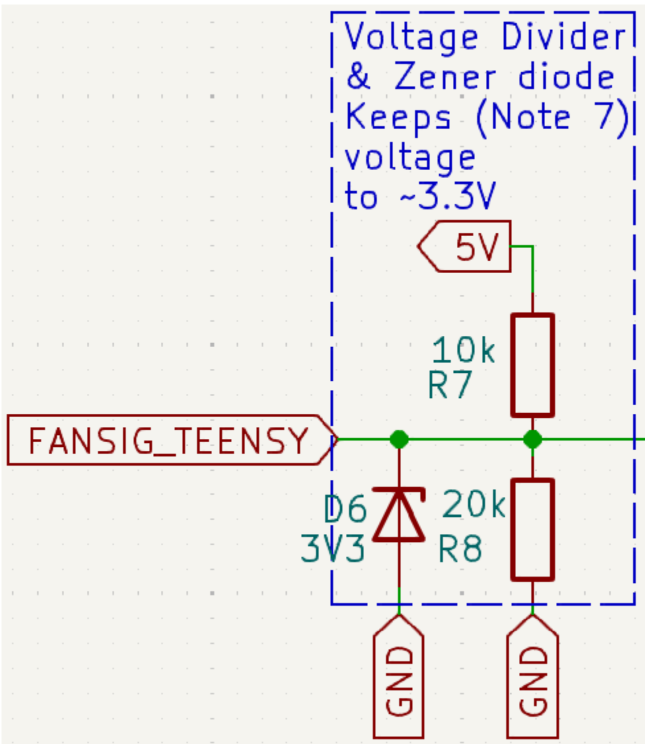


Figure 44: Zener diode circuit to stop fans spinning on start up

When the car first turns on the fans begin to spin

8 PreCharge

8.1 Research

The PreCharge has been in many iterations of NU Racing accumulators, originally made by Michael Ruppe in 2021. Because of how robust and easily adaptable to different accumulator voltages the PreCharge is, the same board has been used every year since. There was an attempt to make a more up to date PreCharge in 2023. But due to time constraints and major problems arising, it was never fully commissioned and completed.

Because the PreCharge has not been changed in so long, originally research into how it operated was needed, just to know how it integrated with the rest of the components within the accumulator. There are many complex circuits which make up the PreCharge and when the accumulator voltage changes, some of these circuits and components need to be changed for the rated voltage. However most of the PreCharge circuits remain unchanged regardless of voltage and capacitance change of the tractive system. The only component that needs to be changed is the PreCharge Resistor, which is used to charge the tractive system before closing both AIRs, and is required to be correctly sized for the tractive system voltage and capacitance.

$$V_{\text{Tractive System}} = V_{\text{Accumulator}} \cdot \left(1 - e^{-\frac{t}{RC}}\right)$$

The tractive system capacitance is the rated capacitance of the motor controller. Most motor controller manufacturers will specify a PreCharge resistor size. In previous years the PreCharge resistor had not been correctly sized, there was no damage caused by this, however it can be put down to the lack of understanding of how the board worked. Using the equations above, the required PreCharge resistor can be selected.

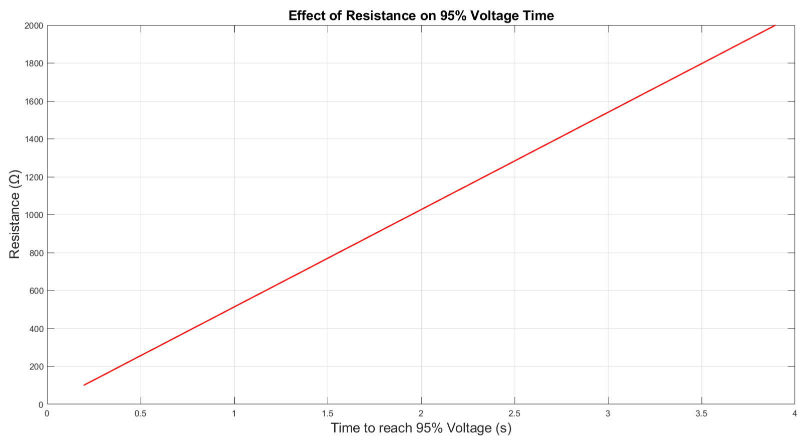


Figure 45: PreCharge Resistance vs 95% PreCharge time

At the beginning of 2024, no research had yet been conducted on the PreCharge, at this time there were motor controller problems and eventually a new motor controller. This meant that the capacitance had changed and the behaviour of the PreCharge changed. However because nobody was aware of how the PreCharge board operated, nobody was able to change the resistor to appropriately match the rest of the new system. These changes are highlighted in Table 5 and their effects on the PreCharge of the accumulator.

	NU23	**NU24 Old MC**	**NU24 New MC**
Motor Controller Capacitance (μF)	320	255	650
PreCharge Resistor (Ω)	1000	1000	560
PreCharge Time (s)	0.959	0.764	1.091
Capacitance full time (s)	1.473	1.174	1.676
Inrush current (kA)	56.7	56.7	56.7
Inrush current time (us)	0.6	0.48	1.23

Table 5: 2024 Variants of PreCharge characteristics

The key part of the PreCharge is to reduce the amount of inrush through the AIRs, which are rated to a maximum switching current of 500 A. In the above calculation it is assumed that the only resistance is the internal resistance of 4 m(Ω) of the AIRs. This creates a very high inrush current but for an incredibly small amount of time.

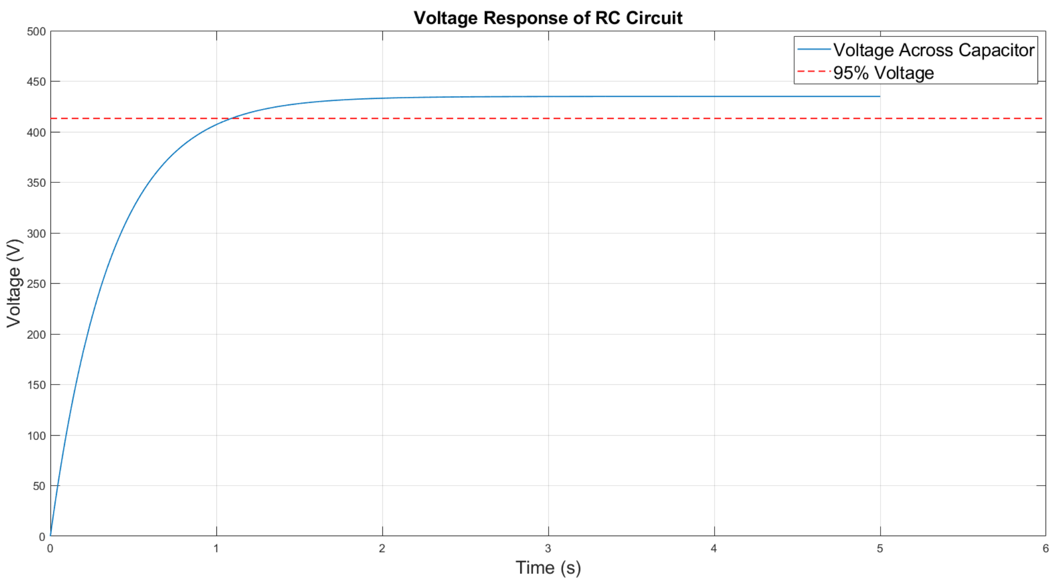


Figure 46: PreCharge Resistor Voltage during PreCharge stage

The rules for the PreCharge state that the circuit needs to safely charge the tractive system to a minimum of 90% of the accumulator system voltage and within twice the time to charge to 90%. Figure 46 shows the PreCharge resistor voltage changing over time. This is based on the specifications in Table 6 which is what was used at the 2024 competition.

Maximum Voltage (V)	453.6
95% Voltage (V)	430.92
PreCharge Maximum Time (s)	3
95% Voltage Time (s)	1.091

Table 6: PreCharge Resistor Voltage

When selecting a resistor for the PreCharge, it needs to be able to withstand the inrush current a high power. For this high power resistors need to be selected, the HS series resistors by TE Connectivity are what are used by NU Racing on the PreCharge currently. They offer resistors in different power ratings, from 5 W to 500 W.

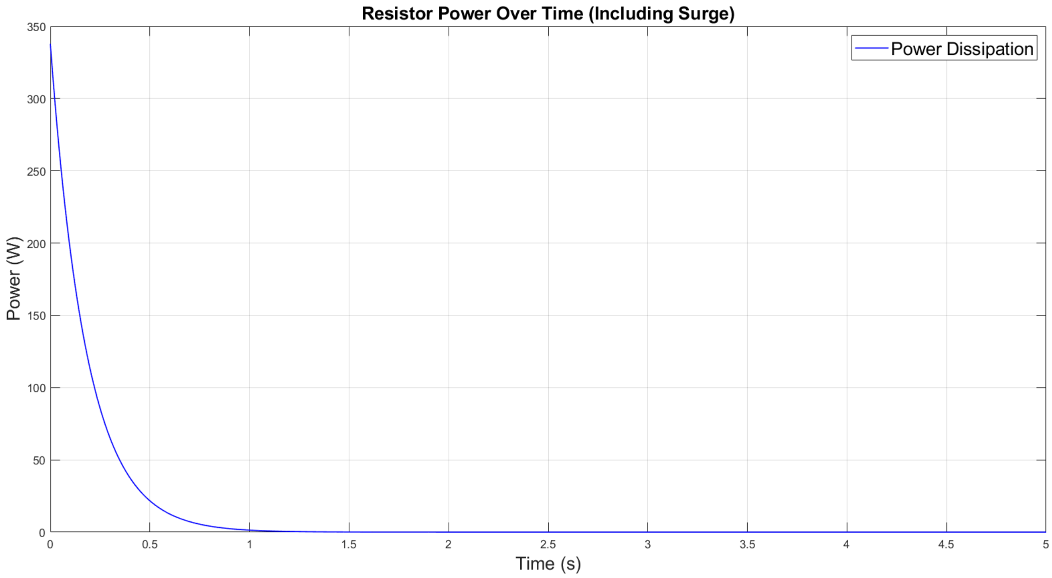


Figure 47: Power dissipated from the PreCharge resistor

NU Racing uses the HSA255605J, which is a 25 W 560Ω high power resistor capable of the large spike in power. Many different sizes of this style of resister are stocked in the mechatronics lab in the TA building.

Resistance (Ohms)	560
Rated Power(W)	25
Maximum Power Dissipation (W)	367.4
Multiples of rated power	14.7
Time allowed at overload (s)	1.5
Resistor Overpower time (s)	0.49

Table 7: PreCharge Resistor Power

8.2 Design

8.3 Commissioning

For testing functionality of the PreCharge on the bench, a tractive system needs to be constructed. For this a capacitor and resistor need to be selected that match the cars ideal capacitance and resistance, this value is usually found on a data sheet for the motor controller.

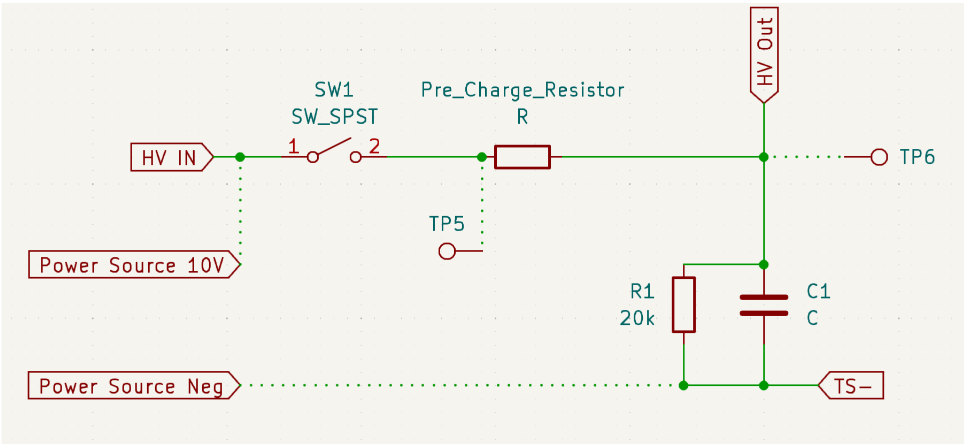


Figure 48: Bench Test system of motor controller to test PreCharge

The dotted lines in Figure 48 are wire which should be soldered to the board, this set up is skipping the voltage divider part of the circuit and using your power source input value instead. This is necessary as High voltage is not being used to test this.

8.4 Conclusion & Recommendations

After the PreCharge had gone through commissioning and testing it was decided that it would not go onto the car for competition. The reason for this was that the previous board had no problems and the team was trying to fix a problem that did not exist.

Although it should not be modified or change, unless damaged in future years, it is still important to have a member of future teams know how it works as it is extremely important to the car running safely and having a member know how it works will make fault finding and fixing a much quicker process.

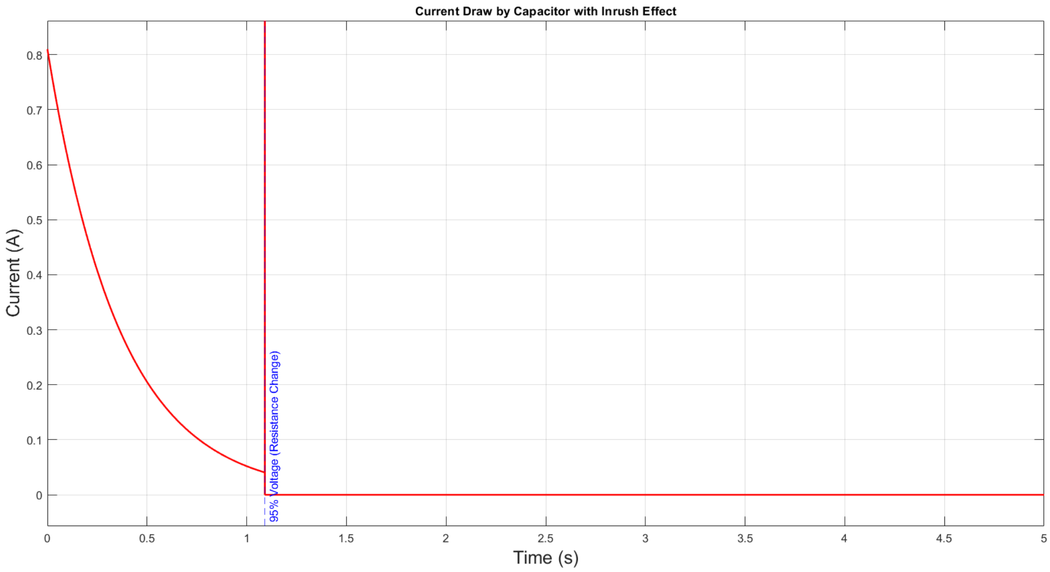


Figure 49: Current during the PreCharge

After competition research was done into the PreCharge and the capacitance of the motor controller. In Table 5 it can be seen the the capacitor 99% charge time is 1.676 seconds however the PreCharge was reaching 95% and opening the AIRs at 1.091 seconds. This is enough time to greatly increase the amount of inrush current going through the AIRs. For future students researching, designing or changing either the PreCharge or motor controller checking for other resistors inline that reduce in inrush current or potentially increase the PreCharge time to 98% in order to increase the life of the AIRs and the safety of the system.

	95%	**98%**
Capacitor charge time (s)	1.676	
PreCharge time (s)	1.091	1.42
Inrush Current (kA)	56.7	22.68
Time over 500 A (μs)	1.23	0.99

Table 8: Different PreCharge values

These inrush values are still quite high and should be verified that there is more resistance than the 4 mΩ of the AIRs. if there is more resistance in series, than the current will decrease. This should be verified before any other modifications are done to the motor controller or PreCharge.

9 Accumulator Indicator Light

9.1 Previous Iterations

Throughout the years there have been many different AIL designs within NU Racing. 2 previous designs to be noted are the designs on the LVD V2.1 and a design done by Michael Ruppe. The LVD V2.1 used a complex series of Integrated Electrical Components. This design was tested successfully on the bench, however when testing on the car it was unable to function as intended. The other previous design be Michael Ruppe was to use 2 voltage regulators in series to drop the voltage down to 12 V and power the LED. This was a simple design using minimal components and could be used over a large voltage range for the accumulator.

9.2 Rules

The AIL must be compliant with all other PCB and electrical rules of the competition, however there are specific rules for the AIL which dictates how the board will be designed and operated. The most important of these rules is that the AIL must be able to operate when the accumulator is not in the car or connected to the cars 12 V system. This is so that if the accumulator has HV at the connectors when disconnected from the rest of the car and its 12 V, the team will be able to tell that there is HV present.

9.3 Design

The design of the 2024 AIL was late in the 2024 year and needed to be designed for multiple different voltage ranges. For this the TSAL detection circuit was recreated for the AIL with its output input inverted to suit the circuit that followed after. The NU24 AIL was designed for 450 V and to turn to the indicator light at any voltage over 60 V. The 12 V logic of the AIL needed to come from the HV of the accumulator so that the PCB could operate when disconnected from the GLV of NU24, for this two voltage regulators were chosen from previous AIL designs. The reason for having two voltage regulators, one for the LED and the other for the comparator and optocoupler, is that the voltage regulators have a maximum current of 30 mA and a single regulator would not be able to power the comparator circuit and the LED. Therefore two voltage regulators are needed in order to power both the optocoupler, comparator and the LED.

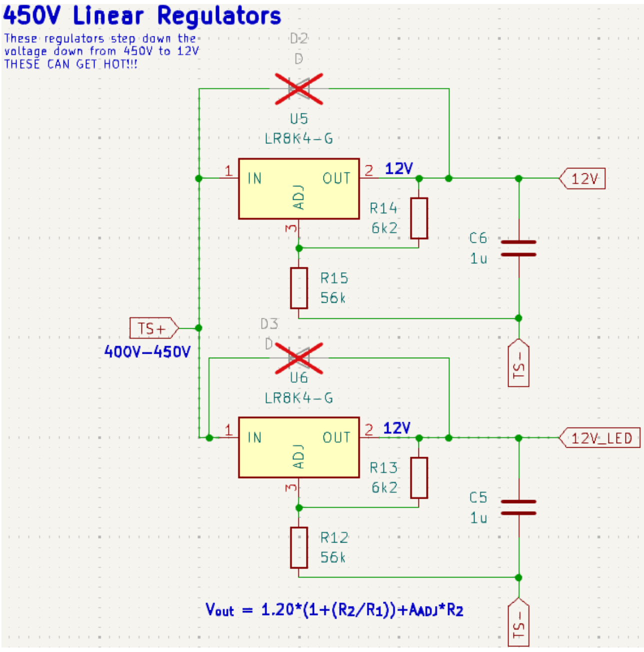


Figure 50: Two AIL voltage regulators for different current draw

The space available on the top plate is very limited in the 2024 accumulator. This and the fact that the AIL was going to have connections to the lid, meant the AIL was designed for the lid of the accumulator. The lid also having limited space meant the AIL needed to be as small of a form factor as possible.

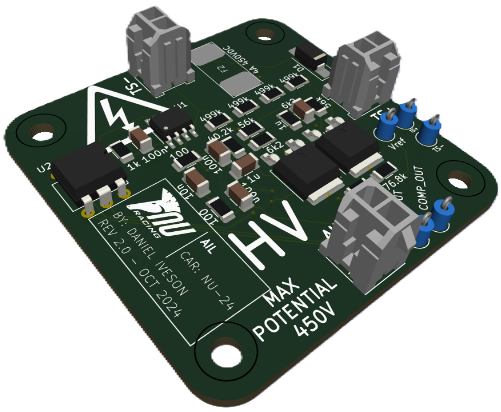


Figure 51: AIL V2.0

9.4 Commissioning

Commissioning of the AIL occurred days before leaving for competition due to manufacturing and shipping delays from the supplier's end. The board was tested for all the standard commissioning tests.

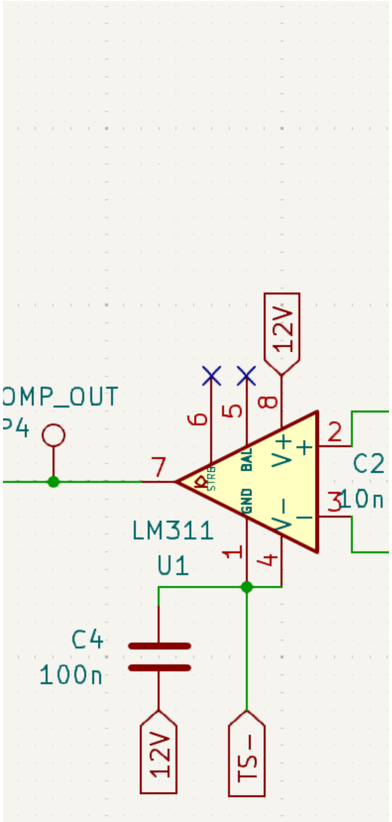
To properly commission the AIL the functionality of all the circuits needed to be tested. 12 V was supplied to the test point just after the positive input for 450 V. When the accumulator is fully charged to 450 V at the input, after the voltage divider, the voltage will then be around 12 V at the test point. This is why 12 V is connected to the test point for commissioning. With 12 V applied to the test point, ground is the connected to the ground test point and the LED is connected to the boards LED connector. Once the board is powered the LED should turn on. If the 12 V power supply is turned down to less than 1 V, the LED will turn off. If this all happens then the AIL is working as intended and can be tested inside the accumulator, on the lid.

Once the AIL is inside the accumulator, to test the entire circuit still works with 450 V at the input, charge the accumulator.

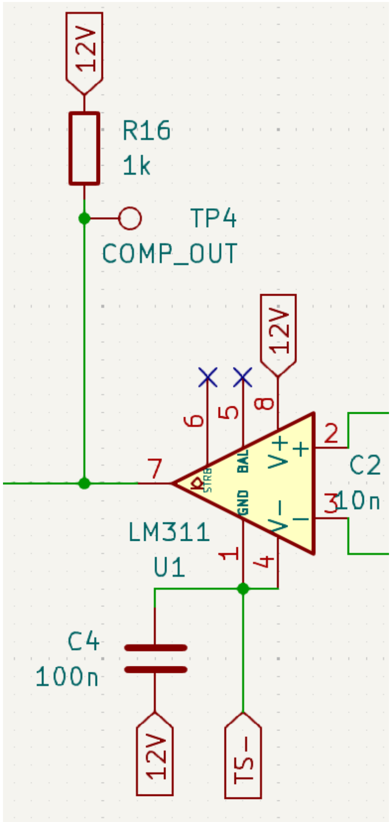
9.5 AIL Issues

Days before competition the AIL was tested and was unable to work on the bench as intended and never made it onto the car. The AIL's detection circuit entering the comparator was thought to be backwards, due to a lack of time this was never properly investigated.

It is confirmed that the output of the comparator was not properly set up. The output was different to that of the TSAL and needed a pull up resistor before the optocoupler.



(a) 2024 AIL Output



(b) 2025 AIL Output

Figure 52: Changes to make the 2025 AIL operational

The changes seen above in Figure 52 allow for the comparator to actually work properly, previously there was a floating voltage that was unable to activate the light in the optocoupler.

9.6 AIL Recommendations

The AIL has not been succesful in testing due to small design errors. This project can be given as a starter project to investigate if this design work or if it should be changed to be identical to the TSAL design.

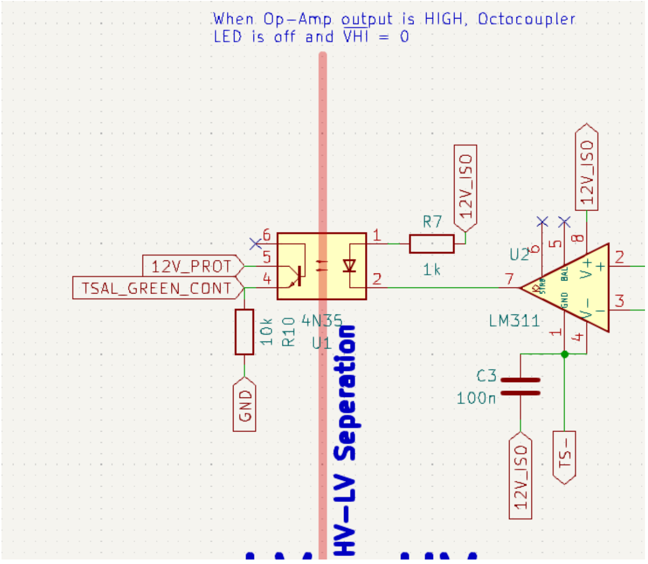


Figure 53: TSAL circuit for detecting HV to turn on a light

The difference between the TSAL and the AIL HV detection circuit currently is in the logic. When there is more than 60V present the TSAL goes HIGH and optocoupler output is LOW. The AIL design is set so that when the comparator goes to HIGH, the optocoupler output is HIGH and turn the connected LED on.

The board is pretty much complete with small amounts of research going into testing to make sure the HV detection circuit works as intended once the pull up resistor is added to the circuit as mentioned in Section 9.5.

10 Top Plate

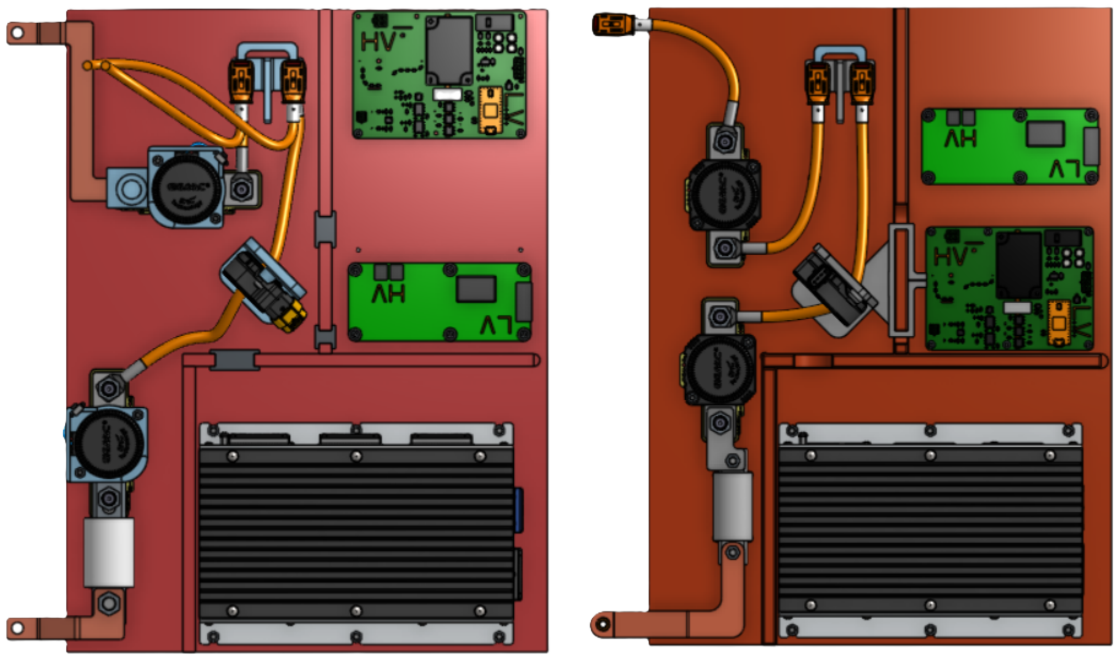
10.1 Reason for change

The top plate was previously used in the 2023 accumulator and was also to be used in the 2024 accumulator. The reason for changing is a new material had been selected for the top plate base and walls, this as well as the accumulator overall dimensions were changing due to the accumulator container material changing.

10.2 Changes

10.2.1 HV Size

New thicker gauge cable of 25 mm^2 was to be used which had a bending radius of 60 mm, this was much more restrictive compared to the 16 mm^2 cable used in 2023 which had a minimum bending radius of 50 mm. This new bending radius restriction meant that everything in the HV area of the top plate had to be moved into areas the cable could bend to without exceeding the minimum bending radius, the AIRs, current sensor and Fuse all had to be moved.



(a) NU23 Top Plate (b) NU24 Top Plate

Figure 54: Different component positioning between NU23 and NU24

10.2.2 Fuse

The main fuse for the accumulator and tractive system sits on the top plate, close to the most negative segment pin. In 2023 this fuse was not appropriate for the HV system and had to be changed at competition, on short notice a better fuse was sourced although not the perfect fuse.

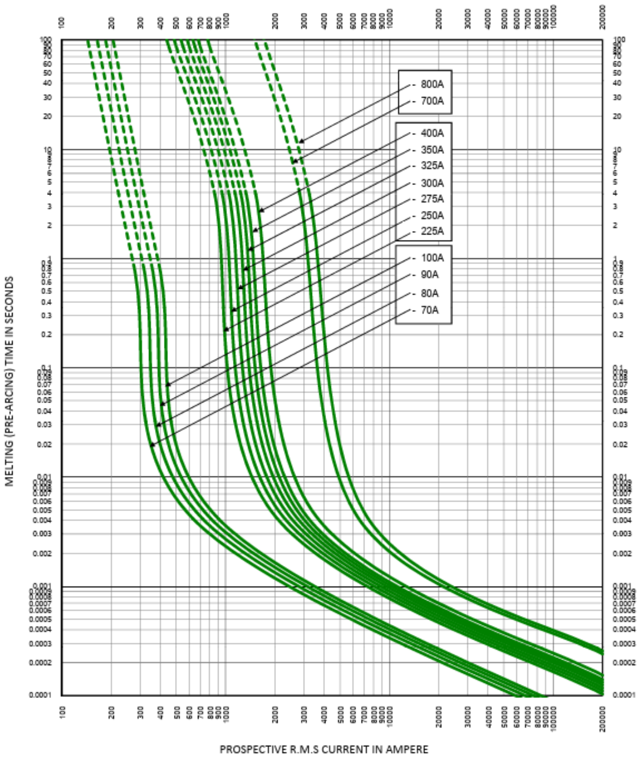


Figure 55: Different fuse ratings and their allowable time over rated current

The Fuse being selected must be able to blow out within NU24's current range, meaning the fuse must be rated below 180 A. There is no data for the 125 A and higher rated fuses and so most fuses considered were 125 A and under.

Fuse Series	Rated Current (A)	Time to Blow Out		Voltage DC (V)
		200 A (s)	150 A (s)	
L50S	125	NA	NA	450
L50S	100	10	NA	450
L50QS	100	100	>100	500
L50QS	90	50	>100	500
L50QS	80	20	>100	500
L50QS	70	10	100	500

Table 9: Fuse options based on blow out times

This style of fuse is intended to go over the rated current for short amounts of time. Table 9 is a summary of the graph in Figure 55. The two most appealing Fuses are the L50QS-100 and the L50QS-090, these being a 100 A and 90 A fuse.

Torque Value (A)	Longest Duration (s)	Total Time (s)
90	2.86	242.86
100	2.81	189.95
150	1.53	33.01
180	1.17	8.88

Table 10: Competition Endurance times spent at Current values

During the 2024 Endurance at competition, the amount of time spent at certain current values is listed in Table 10. Here it can be seen that NU24 spends a maximum of 2.81 seconds over 100 A. For this reason the 100 A L50QS is suitable as a fuse and will not blow in the competition events. The Fuse continuously can operate at 100 A, more current can run through this fuse for a limited amount of time seen in Figure 55

Potentially this fuse is too safe and will never blow out with the current set up of the 2024 accumulator cells.

10.3 Complications

The First completed Top Plate for 2024 was deemed not suitable for competition as the bakelite material that the Top Plate is made out of, which is supposed to be UL94V-0, had no actual rating on the data sheet or any other information on the material that could be sourced. For this reason the Top Plate was made a second time using GPO3.

Originally the 2024 Top Plate was intended to have cable coming off the accumulator side of both AIRs and connecting to the segments by the means of RadLok connectors. The negative AIR cable had to be replace with a busbar when the rules changed and stated that instead of using the I-Button to detect temperature of the cells a new thermal strip needed to be place in direct contact with part of the most negative terminal.

This could not be done with cable and as seen in Figure 54 there is a busbar on the negative AIR leading to where the segments would be once assembled.

11 Track Days

11.1 Responsibilities

On track days the accumulator engineer is responsible for making sure the accumulator works properly, repair any problems encountered and charge. They also need to assists the mechanical engineer in removal and install of the accumulator before and after charging

11.2 Packing

Throughout the year there were problems within the accumulator that required the lid to be removed and service handle be removed. On some track days the segments themselves were taken out and pulled apart. The HV gear was not packed on all occasions and made working within the accumulator quite difficult or not possible at track days. Packing the HV equipment is not just to make the work easier but is a safety concern.

12 CANaMons

12.1 Current Design

The CANaMons were not redesigned in 2024, they were left the same as no extra functionality needed to be added to them and the segments as a whole were never meant to be touched or worked on. However, as the cells began to degrade and cause NU24 to fault, they needed to be exchanged with new cells and this meant the CANaMons needed to be removed.

The current version of the CANaMon works well and there are minimal issues with this PCB and does not warrant a whole new version unless they stop the accumulator from operating safely.

12.2 Issues

The author had no scope or plans to investigate and handle the CANaMons in 2024, however there quickly became issues that required knowledge on how they work and how to pull them off in order to get to the cells.

Cells do not last for ever and during testing it became apparent that certain cells were becoming old and while they still worked, they were causing the BMS to fault due to fluctuations, too high or too low voltage levels. Once the cells had been replaced it became apparent that the CANaMons were experiencing noticeable wear and are quite easy to mishandle when removing to service the cells. When putting back on every bolt head that is on top of the segment busbars, needs to be positioned in the exact way it was taken off to match the mounting locations of the CANaMon, this can be time consuming and if done wrong and with too much force will break the CANaMon.

When removing the bolts on the top of the CANaMons that connect to the voltage tap, metal within the insulated socket set began to show and shorted 46V to ground, cutting the ground trace to the isolated CAN transceiver. This short circuit is seen in Figure 56 and also depicts where a wire had to be soldered from a, still operational, ground trace to the CAN transceiver.

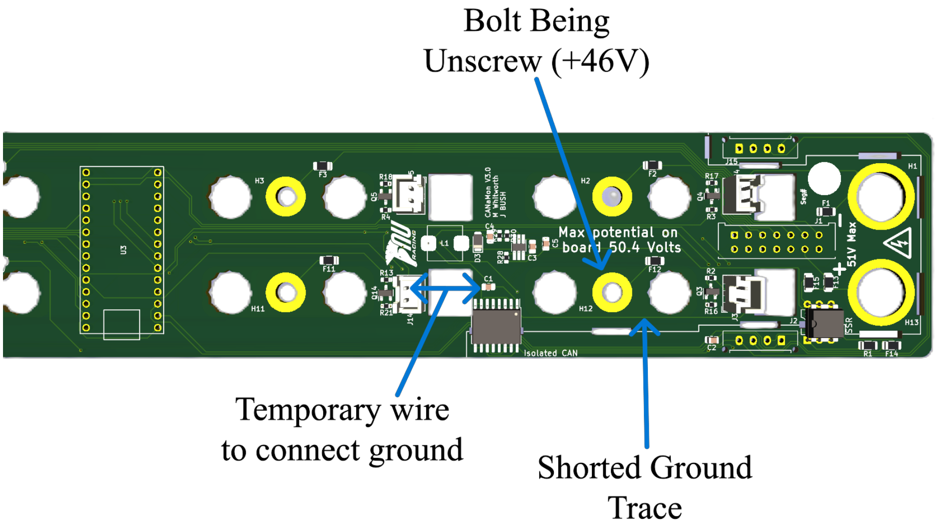


Figure 56: CANaMon short circuit location

This mistake can very easily be repeated as the ground trace runs right next to, and on the same side, as the 46 V voltage tap bolt. This bolt needs to be removed in order to get the CANaMon off to service the busbars or the cells.

The CANaMons do not need to be removed from the segments except when servicing the cells typically. Unfortunately as so many cells happened to go bad during testing, many of the segments had to be removed from the accumulator and their respective CANaMons needed to be removed. It was after the segments had been serviced several times that cells 6 and 7, which had already been replaced, continued reporting to the BMS that they had either too high or too low of a voltage. This was because the voltage tap, which is the bolt and trace in Figure 57 deteriorated and its resistance became too high.

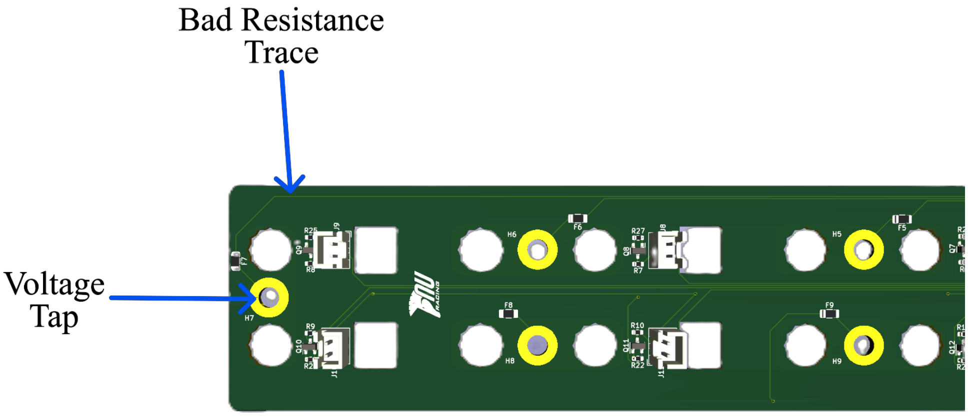


Figure 57: Voltage tap trace with too high resistance

This was temporarily fixed by soldering a wire from the voltage tap bolt, as close to cells 7 and 8 as possible, to the underside of the voltage tap connector that connects to the BMS loom.

12.3 Recommendations

It is highly recommended that new CANaMons are ordered to replace the faulty board on segment 1, as well as ordering some as spares. The 2024 team when encountering problems only had spare V2.0 CANaMons. Having no spares resulted in having to place wires on the board as a temporary fix going to the competition, this is not ideal due to reliability issues. Parts from the previous V2.0 CANaMons had to be scavenged in order to fix the faulty segment 1. For these reasons it is highly important and recommended to have spare boards and electrical components to go with them for replacements.

Given time and resources available, a new version of the CANaMons should be designed with the only change being the placement of certain traces away from the voltage tap bolts. If there is adequate space there is less chance of shorting like what is outlined in Figure 56. The CANaMon does not need any other electrical changes as it works as intended and until more functionality is added, there is no reason to change.

The CANaMon mounting holes for the cell busbars may need to have a larger tolerance in the future. If only 1 of the 11 busbar bolts is not tightened to the correct angle then the board will not be seated properly on the segment or will not fit at all. More than likely two or three of these bolts are usually not at the correct angle and trying to find them takes time and patience. This process is far too likely to lead to improper seating of the CANaMon and could decrease the life of the board.

13 Cost Report

13.1 Contribution

The Author contributed to the electrical systems section of the Cost Report, as well as busbars which were being used inside the accumulator. The costing required time spent learning the system and implementing this into the extremely large excel document.

13.2 Changes for 2024

There was a major change for the 2024 competition cost report. This is the first year that the FSAE-A required teams to individually cost every circuit board and every component on them instead of doing 1 singular circuit board ,which has been the case in previous years. NU Racing uses many PCBs on their car and this added a larger than expected work load to the electrical aspect of the cost report.

All Cost report contributions can be found in Cost Report Appendix

13.3 2025 Recommendations

From the results of the 2024 Cost Report there were areas that could be improved on. This most obvious being correct part selection, 2024's team selected batteries for the accumulator incorrectly. There are certain cells every year in the cost report that are purposely put there as the accumulator costed cells.

Many of the connectors were costed with their relevant PCBs, this was not mentioned in the feedback from the Cost Report and was much more efficient and well organised. When designing PCBs doing a practice cost report can be a good way to learn how the cost report works and will ease the need to constantly search and remember how the PCB was made.

Many team members worked on the cost report in 2024 and this spread the work load out. The more team members in following years that can learn and contribute to the cost report will be much more beneficial and efficient.

14 Competition

14.1 Accumulator Tech

The author's main purpose during the competition was Accumulator Technical Inspection. The technical inspection involves scrutineers going through a checklist and looking outside and inside the accumulator. The NU Racing team had 4 people in this inspection; two ESOs, a data sheet handler and the mechanical engineer in charge of the accumulator's structural components. One of the ESOs and the mechanical engineer were gloved and in full PPE as they were required to remove the lid and service handle of the accumulator so that it is safe to inspect. Prior to inspecting of the accumulator, in the same room and inspection, the tools and PPE used by the students were required to be inspected by a scrutineer for safety. As the scrutineers were shown parts of the accumulator they were shown data sheets for all of the parts that they asked questions about and were given a brief explanation by the ESOs on the contents of the data sheet.

During the 2024 NU Racing Accumulator Technical Inspection, the scrutineers were quite impressed with the amount of photos, data sheets and sample provided by the students. The Accumulator was required to be moved off of the trolley and onto a bench for the inspection, this was unexpected and required more time and tools that were not readily available to make the process faster. Once on the bench the inspection went smoothly and only one section of the inspection did not get a pass, that being the inline fuses leaving the high current path to go to PCBs which is outline in Section 14.3

14.2 Thermal Strip

During the Accumulator inspection a thermal strip was placed on the negative busbar connecting the fuse to the segments, by a scrutineer doing the inspection.

This thermal strip is inspected after endurance, in parc ferme, to make sure the car did not exceed the rules for temperature limit of the accumulator. There was a major change inside the accumulator that is outlined in Section 10.3.

14.3 Fuses

The fuses that left the high current HV path and went to the IMD, PreCharge and AIL, were deemed not suitable under FSAE-A standards. The reason for this was not the fuses themselves but the Fuse holders which did not have a data sheet and therefore no voltage or temperature rating. The fuse holders and fuses were the 5 A 3AG Inline Fuse Holders from Jaycar.

Figure 58: Jaycar fuse not suitable for FSAE-A Rules

On the day of failing the first Accumulator Technical Inspection, suitable inline fuses were found in stock on the other side of Melbourne. These were the Bussmann HEB-AA Fuse holders

Figure 59: Bussman Fuse suitable for FSAE-A Rules

With the new fuses successfully retrieved, they were then fitted into the accumulator where the old fuses were originally. The difficulty with the new fuses was that they were much larger than the original Jaycar fuses. They were successfully fitted into the accumulator, however the fitment was tight and currently does not allow any movement of anything in the HV area of the top plate.

14.4 CANaMons

Leading up to the competition there were problems and constant removal and install of the CANaMons as mentioned in Section 12, and just prior to leaving for Calder Park Raceway there were no faults or known problems. Spare electrical components and cells were taken to the competition in case they needed to be replaced or fixed in the event of a problem. New CANaMon PCBs were ordered as well to begin replacing known faulty CANaMons which are outline in Section 12.

14.5 AMS Fault

Having known problems on the CANaMons leading up to comp with high resistances on the cell taps for reading voltages, during the 2nd running of the Autocross event the car hit an AMS fault causing it to leave HV. Checking the BMS and the data leading up to this fault, the reason for the fault was too high of a voltage on one cell and too low of a voltage on the adjacent cell once again. On the day of autocross the BMS and Motor controller engineer successfully changed the fault conditions of the BMS. The team was still able to monitor all the voltages and temperatures, the value needed to cause a fault was set too low and slight vibrations from the track caused the contact on the voltage tap to jump too high.

These problems with the were due to the CANaMon being removed so many times throughout 2024 and the bumps of the track were causing the PCB to move enough to cause jumps in the measured voltage. A potential fix for this could be investigated in 2025.

14.6 Cells

At competition there our cells apart from the AMS Fault, which was not actually a problem with the cells, had no issues. It did become apparent that our accumulator may be over sized. At the end of the endurance run there was plenty of SOC remaining and this meant our car was not utilising the full capacity of the accumulator.

The author spent a lot of time speaking with other teams and learning more about what cells and the specifications of their accumulators. Very few teams ran as high a voltage as the 2024 accumulator. This was very apparent as the size of the other team's accumulators had a much smaller form factor.

This May be an area to look into for 2025 to decrease overall weight of the car and increase the efficiency.

14.7 Results

The 2024 FSAE-A competition ended with NU Racing having their best points finish, 733.92 points, and equal place finish, fourth place as well as going under 4 seconds in the acceleration event. The team was well prepared for the event and due to this we came away from the event with very high spirits having completed every event and recorded some new internal records for the team.

Event	2023 (7th)	2024 (4th)	Difference
Presentation	72.55	54.05	-18.5
Cost	51.06	75.55	+24.49
Design	130.33	120	-10.33
Skidpad	65.77	42.64	-23.13
Acceleration	50.92	71.79	+20.87
Autocross	120.99	78.13	-42.86
Endurance	9.0	250.87	+241.87
Efficiency	52.52	40.89	-11.63
Total	**553.14**	**733.92**	**+180.78**

Table 11: Comparison of 2023 and 2024 competition results

NU24 exceeded expectations in the Acceleration event completing the fastest run in 3.9 seconds and completing Endurance, which had not be achieved the year before. These 2 events alone boosted NU Racing's 2024 campaign by 262.74 points alone. Unfortunately the team lost points in other areas compared to the previous year, most noticeably in Skidpad where the wrong tyres were chosen for the first run.

15 Recommendations

15.1 Why Recommendations

The Recommendations made here and earlier in the report are here to advise on possible and necessary changes that will effect the performance of the car next year and are to help leaders for 2025 begin generating a scope for the new NU Racing members starting.

These Recommendations are here because they were discovered late in the year when the design phase was too far along to change, appeared at competition or where discovered while reviewing data and researching information for this report.

15.2 Summary

The main components that need work for 2025 and beyond is the LVD and the AIL. The PreCharge board only needs the resistor changed on it when a new motor controller is being utilised.

The LVD has a major problem in regards to the overheating of the MOSFET this with the many other smaller issues that arose before comp makes this board a must fix component. The other component is the AIL, currently the AIL board is not functional on the bench or car but most of the work has been done and a small schematics change should fix this. Currently on the car is the mechanical voltage meter, but this was troublesome to get to the correct reading over 60 V. The recommendations to fix these components are listed below along with other PCBs that are not as important.

15.3 2025 Recommendations

Component	Changes for 2025
LVD	Remove 22 pin Molex connector Add better connector to replace 22 pin Molex Add zener diode to prevent fans spinning on start up Research overheating fan MOSFET solutions Considering add new IRL3813 MOSFET
CANaMons	Fix faulty CANaMon on Segment 1
PreCharge	Change PreCharge percentage from 95% to 98% Research Voltage-Frequency relationship
AIL	Add pull up resistor to comparator output circuit Or change Comparator output circuit to match TSAL

Table 12: Key areas of focus for 2025

15.4 2024 Changes

Component	2024 Changes
LVD V3.0	Removed the AIL off the board Removed interlocks from board Modified Board dimensions (smaller) Added new MOSFET fan circuit
LVD V3.1	Removed OKHS LEDs Modified CAN bus trace routing Replaced MOSFET fan circuit with relay Added Shutdown circuit delay capacitors Added Interpose Relay
CANaMons	No Changes were made
PreCharge	Added fusing for protection Added Interpose relay Added Shutdown circuit delay capacitors
AIL	Moved to standalone PCB Removed complex circuit Added similar HV detection circuit as the TSAL
Cells	Research pouch cells Research affects of reducing accumulator by 1 segment Research potential ways to load test Accumulator

Table 13: Key Changes in Electrical Components

16 ENGG2200

16.1 Introduction

The Author was a student of ENGG2200 in 2023 and was the gateway to doing their final year project with NU Racing in 2024. The life skills and confidence learnt in this course set the Author up to become a better engineer.

16.2 Concept

ENG2200 is an elective that introduces students at the University of Newcastle to NU Teams. It is a well structured and self directed course, that teaches students how to problem solves and turn ideas into functioning prototypes or designs. It uses knowledge learnt in the classroom and extends on it with hands on real world applications.

16.3 Engagement

The Author spent time reviewing ENGG2200 student's schematics for their projects, teaching them how to use the software and hardware properly and safely. During the semester and competition the author taught students how to remove the accumulator from the car, charge it and put it all back in NU24. This is vital for them to have jobs at track days and in the TA building. The ENGG2200 students also assisted in the commissioning of PCBs, while helping here they were taught all about how these boards interfaced with the rest of the car and the jobs each PCB has.

This process helps strengthen the team from juniors to senior members and should be repeated by all NU Racing team members in following years. This is extrememly useful for knowledge transfer and ensuring new students maintain interest in the team.

17 NU Racing

17.1 Attendance

The author lived on the Central Coast and commuted on average 2 hours to and 2 hours back from university by train. The time spent on the train was used to study for other subjects or complete work for NU Racing that can be done without internet or assistance from other team members.

Being present in the TA building, track days, Industry Sponsor days and webinars increased the productivity of the author and the quality of their work. This allowed for collaboration and support from others within the team.

While learning engineering is important part of NU Teams, being able to work in a team is far more important and beneficial.

17.2 TA Building

The TA building in which NU Racing and Teams is based out of is extremely well equipped for succeeding in a final year project. The mechatronics lab has a variety of tools for building PCBs, wiring looms, test rigs for electrical components and much more. THe building offers a HV bay for working on the accumulator safely and away from others. The TA workshop is a large area that all the NU Teams work out of and has all the tools needed to assemble or disassemble the car.

For a student led team, the TA building is well equipped.

17.3 Track Days

Track days are absolutely necessary for testing and making sure a car is reliable, they required early mornings and late nights but were key for dynamic testing of the car. Most track days highlighted areas for improvement for how the team was set up and what jobs were distributed around to team members.

When a new component is installed onto the car it undergoes bench testing and a spin test on the stands in the TA workshop. However, the track days are were components are tested under the full load of the car driving. Most problems with the car were flagged early in the year or early enough that they could be fixed before competition. Without track days some of these faults or failures may not have been picked up until competition.

Track days were either at Sydney Motor Sport Park or at the university carpark. SMSP had two tracks that could be hired out, the figure 8 or the skidpad. The figure eight had elevation and was of course in the shape of an eight, so was only good for testing the manoeuvrability of the car, endurance reliability and different vehicle set ups. The skid pad was ideal as it could be used to test all of the different competition events, there was some error in the results as the skidpad was quite bumpy and rough in some areas, unsettling the car.

17.4 Competition

Leading up to competition is a stressful and time sensitive time of the year where everything is being finalised and the car is being made competition ready and everyone is preparing for their respective roles at competition.

Those in previous years who have attended a competition in previous years were knowledgeable leading up to the event and were extremely important in the preparation. In particular, those who attended previous competitions were conducting practice technical inspections as they knew what questions would be asked and how it would proceed.

17.5 Recommendations

As a NU Racing team member the more time you spend at campus with the other members, the more high quality work can be achieved. The support offered while being at campus is incredibly useful. Being present for meetings and even studying for other subjects, creates a strong and embracing community.

From the author's own experience, during 2025, being present in the building and being willing to lend a hand makes a really strong team and great learning environment. The author learnt more during their time with NU Racing than most of their other subjects.

18 Conclusion

Overall the LVD has become a more versatile PCB than previous version and the research done on it has set up future years to succeed with this PCB. The board's complexity and component count have been reduced. The complexity of the AIL that was originally on the LVD was taken off the board and made its own standalone board with a simpler, more common circuit. Similarly, the LVD's redesign has positioned future team members to focus their time on other components. The PreCharge board while the new version created was not used on the car, the research done and the modifications to the previous version, has produced a safer PreCharge system. This year's work focused on designing and testing new circuitry for existing boards. These improvements will benefit future teams while also contributing to the success of the 2024 competition. These modifications not only streamlined the design process but also improved reliability, which was crucial in meeting competition requirements.

Appendix A

LVD Code

```
// Include necessary libraries and define pins
// Code by Josh Dawson and Co 1/11/2023
// Purpose: Minimal wokring code for LVD. N_milliseconds must be set below 1002ms at most ( ideally x < 600ms) or AMS flicker due to BMS update frequency at 2.2 seconds
//          Added charge case code that will trigger when charging. sets pwm to 60 PWM
//          Added CAN2 HB rebroadcasting
//          Added Max Temp and index extraction from CAN2 and rebroadcasting to NUCAN
//          Added Max seg temps and warning for loss of communication with a segment
//          Added Temp over 60 degrees, TEMP_OKHS fault state
//          Added FindTempData

// JEDD
//        Added charge power pin to put the BMS into charge mode
//        Added fan control to switch FET for fans GND
//        Added state for charge mode, if Charge CAN message is recieved Charge Pin will go High
//        Added shutdown circuit logging
//        Changed max fan speed
// DANIEL
//        Added fanstatus value to turn fans on or off to avoid idle current draw
//        Changed LV_POWER_STATUS to TS_STATE
//        Changed digitalWrite(FAN_CONTROL_PIN, LOW) instead of HIGH

#include <NU24_CAN.h>  // Include the NU23_CAN library for CAN communication

// Pin Definitions
#define IN_PWM_PIN 11         // Pin for PWM input to control a fan
#define OUT_PWM_PIN 12        // Pin for PWM output to control a fan

#define SD_TSMS_PIN 16        // Pin for TSMS shutdown


#define CHARGE_POWER_PIN 20   //Pin for switching charge power to put the BMS into charge mode
#define FAN_CONTROL_PIN 5     //Pin for switch fans GND to have the ability to turn them completly off
#define BUSPEED 250000        // Set the Buspeed for CAN

// defines for
#define SEG_TEMP_MILLIS_TIMEOUT 10000  // time period for loss of seg temp to trigger dash warning
#define FAULT_TEMP 60                  // Fault temperature for segments
#define DELAY_TIME 5000                // Fault delay time for overTemp
#define NSEGS 9                        // number of segments


// CAN 2 setup block
FlexCAN_T4<CAN2, RX_SIZE_256, TX_SIZE_16> can2;                           // Initialize CAN2 communication
CAN_message_t msg;                                                        // Define an incoming/Outgoing CAN message for pass through
int heartBeatIDs[] = { 1001, 1002, 1003, 1004, 1005, 1006, 1007, 1008, 1009 };  // Define HB IDs for Canamons to Rebroadcast
int minMaxAvgIDs[] = { 1210, 1220, 1230, 1240, 1250, 1260, 1270, 1280, 1290 };  //IDs for minMaxAvg segment temps
float averageTemps[] = { 1, 1, 1, 1, 1, 1, 1, 1, 1 };                     // initialise segment average temps
float maxTemps[] = { 1, 1, 1, 1, 1, 1, 1, 1, 1 };                         // initialise segment max temps
int LastUpdate[] = { 0, 0, 0, 0, 0, 0, 0, 0, 0 };                         // update based on 'x' milliseconds since last update
float RAMPTIME = 10;                       // Ramp time for fans full beans IN SECONDS
float FANMAX = 200;             // Fan max speed setting


//shutdown vars
float sdTSMS = 0;              // [boolean] CAN output shutdown logging


```

```
// Cooling Control Parameters
float lvPowerStatus = 0;  // Temperature value representing power status
float charge = 0;         // charge fan speed control parameter
int fanPWM = 0;           // PWM speed
int fanstatus = 0;        // value for fans on or off
float coolingFlag = 0;      // cooling on flag when lvPowerStatus is on

// Temperature Fault Parameters
float tempOKHS = 1;         // OKHS (Overheat Shutdown) status, HIGH when no temperature fault
int tempSetTime = 0;        // Timer for overtemp beyond 5 seconds over 60 degrees C
float avgSegTemp = 0;       // Average Seg Temp
float segsPresentOKHS = 1;  // serial out for SEG_PRESENT_OKHS state
float maxIndex = 0;         // segment number that has the highest temp
float maxSegTempInd = 0;    // number of segment with max temperature
float maxSegTemp = 0;       // maximum segment temperature

// NUCAN Variables
// CAN messages for input and output
float *outputVar[] = {&lvPowerStatus, &charge, &avgSegTemp};
canmsg *inputmsgs[] = {&TS_STATE, &CHARGE, &AVG_SEG_TEMP};
int numReceive = 3;       // Number of CAN messages to receive
int numSend = 27;  // Number of NUCAN messages + Number of rebroadcast messages to send(HBs and MaxAvgTemps per segment)

// Temperature Fault State Machine parameters
enum STATEVAR {
  STATE_GOOD,  // GOOD state
  STATE_WAIT,  // WAIT state
  STATE_BAD    // BAD state
};
STATEVAR state = STATE_GOOD;  // Initialize the state as GOOD


/* -----------------------------------------------------------------------------------------------------*/
// Setup Function

void setup() {
  Serial.begin(9600);                             // Initialize serial communication at 9600 baud
  NUCAN_init(numSend, numReceive, BUSPEED);       // Initialize the NUCAN communication
  can2.begin();                                   // Start CAN communication
  can2.setBaudRate(BUSPEED);                      // Set the CAN bus baud rate to 1 Mbps

  // Set pin modes
  pinMode(IN_PWM_PIN, OUTPUT);        // Set the IN_PWM_PIN as an output for PWM
  pinMode(OUT_PWM_PIN, OUTPUT);       // Set the OUT_PWM_PIN as an output for PWM

  pinMode(CHARGE_POWER_PIN, OUTPUT); // Set the CHARGE_POWER_PIN as an output for HIGH or LOW
  pinMode(FAN_CONTROL_PIN, OUTPUT);  // Set the FAN_CONTROL_PIN as an output for HIGH or LOW

  digitalWrite(FAN_CONTROL_PIN, LOW); //Sets the FAN_CONTROL_PIN LOW so fans are GND
  digitalWrite(CHARGE_POWER_PIN, LOW);
}

/* -----------------------------------------------------------------------------------------------------*/
// Main Loop
void loop()
{
  // Read CAN messages and distribute to variables...
  NUCAN_read(outputVar, inputmsgs, numReceive);  //Read desired CAN messages, store results in outputVar
  // Read CAN2 messages and rebroadcast
  CAN2_read();
  // Rebroadcast LVD Heartbeat
  NUCAN_heartbeat(&HB_LVD);

  EVERY_N_MILLIS(1000)
  {
    lostSegCheck();    // Check for loss of segment communication
```

```
    // findMaxInd();               // Find the index of the maximum segment temperature
    // findMax();                  // Find the maximum segment temperature
    findTempData();  //Find Temp data
    updateShutdown();     // update the shutdown interlock status
    serialOut();     // uncomment to output variables to serial monitor for debugging
  }
  // Write tempOKHS to NUCAN every 500ms to prevent BMS timeout (BMS timeout is 1 second)
  EVERY_N_MILLIS(500)
  {
    NUCAN_write(&TEMP_OKHS, tempOKHS);
    updateFanSpeed(charge);  // Update the fan speed based on charge and LV power status
  }

  updateTempOKHS();  // Update the temperature fault state machine

  chargeMode(charge);      //Enables BMS charge mode signal if plugged into charger
}
/* ----------------------------------------------------------------------------------------------------*/
// This function updates the fan speed based on the charge and LV power status
void updateFanSpeed(float charge) {
  if (lvPowerStatus == 1) {
    if (coolingFlag < RAMPTIME) {
        fanPWM = (FANMAX * (coolingFlag/RAMPTIME));
        coolingFlag = coolingFlag + 1;
    }
    else {
      // Set the fan to full beans
      fanPWM = FANMAX;
    }
    fanstatus = 1;    //Turn fans on
  }
  else if (charge == 1) {
      fanstatus = 1;      //Turn fans on
      // Charge speed based on LV supply from charger (12V, 10A)
      fanPWM = 60;
  }
  else {
    // Turn off the fans if DCDC is off
    fanstatus = 0;      //Turn fans off
    fanPWM = 0;
    coolingFlag = 0;
  }
  NUCAN_write(&FAN_SPD_ACC, fanPWM/255); // Write fan PWM to NUCAN
  digitalWrite(FAN_CONTROL_PIN, fanstatus);
  analogWrite(IN_PWM_PIN, fanPWM);   // Write the fan speed to the fan
  analogWrite(OUT_PWM_PIN, fanPWM);  // Write the fan speed to the fan
}
/* ----------------------------------------------------------------------------------------------------*/
//This function reads CAN2 and rebroadcasts the messages
void CAN2_read(void) {
  if (can2.read(msg)) {
    for (int i = 0; i < 9; i++) {
      if (msg.id == heartBeatIDs[i]) {
        NUCAN_direct_write(msg);  //  write the heartbeat of each segment
      } else if (msg.id == minMaxAvgIDs[i]) {
        maxTemps[i] = msg.buf[0] * 0.4;      // read maxtemp*tempscale
        // minTemps[i] = msg.buf[1] * 0.4;      // read mintemp*tempscale
        averageTemps[i] = msg.buf[2] * 0.4;  // read averagetemp * tempscale
        NUCAN_direct_write(msg);             //  write the minMaxAvg temps of each segment
        LastUpdate[i] = millis();
      }
    }
  }
}
/* ----------------------------------------------------------------------------------------------------*/
// This function checks for loss of segment communication
void lostSegCheck(void) {
```

```
  segsPresentOKHS = 1;
  for (int i = 0; i < 9; i++) {
    int timeSinceLastUpdate = millis() - LastUpdate[i];
    // Serial.print("Segment ");Serial.print(i+1);Serial.print(" LastUpdate = "); Serial.println(timeSinceLastUpdate);

    if (timeSinceLastUpdate > SEG_TEMP_MILLIS_TIMEOUT) {
      segsPresentOKHS = 0;
    }
  }
  NUCAN_write(&SEGS_PRESENT_OKHS, segsPresentOKHS);  // Writes the float casted value of the lost segment to NUCAN
}
/* -------------------------------------------------------------------------------------------------------*/
// This function finds the maximum segment temperature
void findTempData(void) {
  maxSegTemp = maxTemps[0];      // Assume the first element is the maximum
  avgSegTemp = averageTemps[0];  // Assume the first element is the average
  // Iterate through the array to find the maximum value
  for (int i = 1; i < NSEGS; i++) {
    if (maxTemps[i] > maxSegTemp) {
      maxSegTemp = maxTemps[i];  // Update the maximum value if a larger value is found
      maxSegTempInd = i;
    }
    avgSegTemp = avgSegTemp + averageTemps[i];
  }
  avgSegTemp = avgSegTemp / NSEGS;                // divide by 9 for all the segments
  NUCAN_write(&AVG_SEG_TEMP, avgSegTemp);         // Finds the average segment temp and writes to NUCAN
  NUCAN_write(&MAX_SEG_TEMP, maxSegTemp);         // Finds the maximum segment temp and writes to NUCAN
  NUCAN_write(&MAX_SEG_TEMP_IND, maxSegTempInd);  // Finds the segment with the maximum temp and writes to NUCAN
}
/* -------------------------------------------------------------------------------------------------------*/
// This function updates the temperature fault state machine
void updateTempOKHS(void) {
  switch (state) {
    // GOOD state
    case STATE_GOOD:
      tempOKHS = 1;  // Set the temperature fault to LOW
      if (checkTempGood() == 0) {
        tempSetTime = millis();  // Set the timer for the WAIT state
        state = STATE_WAIT;

      }
      break;
    // WAIT state
    case STATE_WAIT:
      if (checkTempGood() == 1) {
        state = STATE_GOOD;                              // Go back to the GOOD state
      } else if ((millis() - tempSetTime) >= DELAY_TIME) {  // Check if the timer has expired
        state = STATE_BAD;                               // Go to the BAD state
      }
      break;
      // BAD state
    case STATE_BAD:
      tempOKHS = 0;  // Set the temperature fault to HIGH
      if (checkTempGood() == 1) {
        state = STATE_GOOD;  // Go back to the GOOD state
      }
      break;
  }
}
/* -------------------------------------------------------------------------------------------------------*/
int checkTempGood(void) {
  int tempCheck;
  if (maxSegTemp > FAULT_TEMP) {
    tempCheck = 0;
  } else {
```

```
    tempCheck = 1;
  }
  return tempCheck;
}
/* ---------------------------------------------------------------------------------------------------*/
void updateShutdown(void){
      sdTSMS = digitalRead(SD_TSMS_PIN);// read the input from the TSMS
      NUCAN_write(&SD_TSMS, sdTSMS);
}
/* ---------------------------------------------------------------------------------------------------*/
void chargeMode(float charge) {
  if (charge == 1){
    digitalWrite(CHARGE_POWER_PIN, HIGH);
  }
  else{
    digitalWrite(CHARGE_POWER_PIN, LOW);
  }
}
/* ---------------------------------------------------------------------------------------------------*/

// This function outputs the variables to the serial monitor for debugging
void serialOut(void) {
  // Serial.print("Temp OKHS = ");
  // Serial.println(tempOKHS);
  //Serial.print("LV Power Status = ");
  //Serial.println(lvPowerStatus);
  //Serial.print("Fan PWM = ");
  //Serial.println(fanPWM);
  // Serial.print("segsPresentOKHS = ");
  // Serial.println(segsPresentOKHS);
  // Serial.print("maxSegTemp = ");
  // Serial.println(maxSegTemp);
  // Serial.print("maxSegTempInd = ");
  // Serial.println(maxSegTempInd);
  //Serial.print("Charge = ");
  //Serial.println(charge);
  //Serial.print("IMD = ");
  //Serial.println(charge);
  // Serial.print("Average Temp = ");
  // Serial.println(avgSegTemp);
}
```

Listing 1: LVD V3.1 Code

PreCharge Code

```
/*
  Precharge - Code to drive the NU Racing Precharge module (prototype)
  Created by Michael Ruppe
  April 2020

  Watch a primer video on this device here: https://youtu.be/6-RndXZ5mR4
  For more documentation, visit: https://github.com/michaelruppe/FSAE

  Dear future FSAE engineer,
  Perform a find (Ctrl+f) for "TODO" to see if I left you any surprises :D

  Commissioning notes:
    - Make sure TARGET_PERCENT is sensible (95%). I set it much lower
      during prototyping.

  Features:
    - Voltage feedback ensures sufficient precharge before closing AIR
    - Wiring fault / stuck-discharge detection on "too-fast/slow" precharge
    - May arrest AIR chatter -> minimum precharge time triggers error state and
      requires uC reset or power cycle.

  Other Notes:
    - Consider adding a condition to the STATE_STANDBY -> STATE_PRECHARGE
      transition: Check for near-zero TS voltages ensures full discharge before
      attempting a precharge.
*/


#include "gpio.h"
#include "measurements.h"
#include "moving-average.h"
#include "states.h"
#include <NU24_CAN.h>

const float MIN_SDC_VOLTAGE = 10.0; // [Volts]

// Exponential Moving Average Filters
MovingAverage TSV_Average(0, 0.1); // Tractive system Voltage
MovingAverage ACV_Average(0, 0.1); // Accumulator (upstream of precharge resistor)
MovingAverage SDC_Average(0, 0.5); // Shutdown Circuit

STATEVAR state = STATE_STANDBY;
STATEVAR lastState = STATE_UNDEFINED;
int errorCode = ERR_NONE;

//CAN Variables
//#define LED_PIN 13
float charge=0;
float heartBeat = 0;
float TSState = 0;
//inputmsgs defines message, outputVar defines location for incoming data
float *outputVar[] = {&charge};
canmsg *inputmsgs[] = {&CHARGE};
int numreceive = 1;
int numsend = 3;

StatusLight statusLED[4] {{ STATUS_LED[0] },
                          { STATUS_LED[1] },
                          { STATUS_LED[2] },
                          { STATUS_LED[3] }};

char lineBuffer[50];
unsigned long now; // Uptime from millis()

void setup() {
```

```
  Serial.begin(9600);
  Serial.println("Hello World");
  setupGPIO();
  delay(3000);  // TODO: remove during commissioning

  //CAN Bus initialisation
  NUCAN_init(numsend, numreceive);
}

void loop() {
  NUCAN_read(outputVar, inputmsgs, numreceive); //Read desired CAN messages, store results in outputVar

  now = millis();

  // Always monitor Shutdown Circuit Voltage and react
  monitorShutdownCircuit();

  // The State Machine
  switch(state){
    case STATE_STANDBY :
      standby();
      TSState = 0;
      break;

    case STATE_PRECHARGE :
      precharge();
      TSState = 0;
      break;

    case STATE_ONLINE :
      running();
      TSState = 1;
      break;

    case STATE_ERROR :
      errorState();

    default : // You tried to enter a state not defined in this switch-case
      state = STATE_ERROR;
      errorCode |= ERR_STATE_UNDEFINED;
      errorState();
  }

  //Write precharge and acknowledge state to bus
  EVERY_N_MILLISECONDS(250){
    NUCAN_write(&TS_STATE, TSState);
    NUCAN_write(&CHARGE_ACK, charge);
  }

  updateStatusLeds();

//  teensyHeartbeat();
  NUCAN_heartbeat(&HB_PRE);
}

void monitorShutdownCircuit() {
  static unsigned long lastSample = 0;
  if (now > lastSample + 10) {
    lastSample = now;
    SDC_Average.update(getShutdownCircuitVoltage());
  }
  // Error state should be deadlocked - no way out.
  if ( SDC_Average.value() < MIN_SDC_VOLTAGE && state != STATE_ERROR) {
    state = STATE_STANDBY;
  }
}
```

```
// Open AIRs, Open Precharge, indicate status, wait for stable shutdown circuit
void standby() {
  //Serial.println("---Standyby start---");
  static unsigned long epoch;
  if (lastState != STATE_STANDBY) {
    lastState = STATE_STANDBY;
    statusLEDsOff();
    statusLED[3].on();
    Serial.println(F(" === STANDBY"));
    Serial.println(F("* Waiting for stable shutdown circuit"));
    epoch = millis(); // make sure to reset if we've circled back to standby

    // Reset moving averages
    TSV_Average.reset();
    ACV_Average.reset();
    SDC_Average.reset();
  }

  // Disable AIR, Disable Precharge
  digitalWrite(PRECHARGE_CTRL_PIN, LOW);
  digitalWrite(SHUTDOWN_CTRL_PIN, LOW);

  // Check for stable shutdown circuit
  const unsigned int WAIT_TIME = 200; // ms to wait for stable voltage
  if (SDC_Average.value() >= MIN_SDC_VOLTAGE){
    if (millis() > epoch + WAIT_TIME){
      state = STATE_PRECHARGE;
    }
  }
//  else if (charge == 1){
//    state = STATE_PRECHARGE;
//  }
  else {
    epoch = millis(); // reset timer
  }

}

// Close the precharge relay, monitor precharge voltage.
// Trip error if charge-time looks unusual
void precharge() {
  //Serial.println("---PreCharge start---");
  // Look for "too fast" or "too slow" precharge, indicates wiring fault
  const float MIN_EXPECTED = 500; // [ms]. Set this to something reasonable after collecting normal precharge
     sequence data
  const float MAX_EXPECTED = 3000; // [ms]. Set this to something reasonable after collecting normal precharge
     sequence data
  // If a precharge is detected faster than this, an error is
  // thrown - assumed wiring fault. This could also arrest oscillating or
  // chattering AIRs, because the TS will retain some amount of precharge.
  const float TARGET_PERCENT = 88.0;   // TODO: Requires suitable value during commissioning (eg 95%)
  const unsigned int SETTLING_TIME = 200; // [ms] Precharge amount must be over TARGET_PERCENT for this long
     before we consider precharge complete
  static unsigned long epoch;
  static unsigned long tStartPre;

  if (lastState != STATE_PRECHARGE){
    digitalWrite(PRECHARGE_CTRL_PIN, HIGH);
    lastState = STATE_PRECHARGE;
    statusLEDsOff();
    statusLED[1].on();
    sprintf(lineBuffer, " === PRECHARGE   Target precharge %4.1f%%\n", TARGET_PERCENT);
    Serial.print(lineBuffer);
    epoch = now;
    tStartPre = now;
  }

```

```
  // Sample the voltages and update moving averages
  const unsigned long samplePeriod = 10; // [ms] Period to measure voltages
  static unsigned long lastSample = 0;
  if (now > lastSample + samplePeriod){  // samplePeriod and movingAverage alpha value will affect moving average response.
    lastSample = now;
    ACV_Average.update(getAccuVoltage());
    TSV_Average.update(getTsVoltage());
  }
  double acv = ACV_Average.value();
  double tsv = TSV_Average.value();

  // The precharge progress is a function of the accumulator voltage
  double prechargeProgress = 100.0 * tsv / acv; // [%]

  // Print Precharging progress
  static unsigned long lastPrint = 0;
  if (now >= lastPrint + 100) {
    lastPrint = now;
    sprintf(lineBuffer, "%5lums %4.1f%%   %5.1fV\n", now-tStartPre, prechargeProgress, TSV_Average.value());
    Serial.print(lineBuffer);
  }

  // Check if precharge complete
  if ( prechargeProgress >= TARGET_PERCENT ) {
    // Precharge complete
    if (now > epoch + SETTLING_TIME){
      state = STATE_ONLINE;
      sprintf(lineBuffer, "* Precharge complete at: %2.0f%%   %5.1fV\n", prechargeProgress, TSV_Average.value());
      Serial.print(lineBuffer);
    }
    else if (now < tStartPre + MIN_EXPECTED && now > epoch + SETTLING_TIME && charge==0) {    // Precharge too fast - something's wrong!
      state = STATE_ERROR;
      errorCode |= ERR_PRECHARGE_TOO_FAST;
    }

  } else {
    // Precharging
    epoch = now;

    if (now > tStartPre + MAX_EXPECTED) {       // Precharge too slow - something's wrong!
      state = STATE_ERROR;
      errorCode |= ERR_PRECHARGE_TOO_SLOW;
    }
  }

}

void running() {
  //Serial.println("---Running start---");
  const unsigned int T_OVERLAP = 500; // ms. Time to overlap the switching of AIR and Precharge
  static unsigned long epoch;
  if (lastState != STATE_ONLINE){
    statusLEDsOff();
    statusLED[2].on();
    Serial.println(F(" === RUNNING"));
    lastState = STATE_ONLINE;
    //Serial.println("Before Epoc");
    epoch = now;
    //Serial.println("After Epoc");

  }
  //Serial.println("Before If statement");
  digitalWrite(SHUTDOWN_CTRL_PIN, HIGH);
  //Serial.println(now - (epoch + T_OVERLAP));
  if (now > epoch + T_OVERLAP)
```

```
  {
    //Serial.println("Errorrrr");
    digitalWrite(PRECHARGE_CTRL_PIN, LOW);
  }

}

void errorState() {
  //Serial.println("---Error start---");
  digitalWrite(PRECHARGE_CTRL_PIN, LOW);
  digitalWrite(SHUTDOWN_CTRL_PIN, LOW);

  if (lastState != STATE_ERROR){
    lastState = STATE_ERROR;
    statusLEDsOff();
    statusLED[3].update(50,50); // Strobe STS LED
    Serial.println(F(" === ERROR"));

    // Display errors: Serial and Status LEDs
    if (errorCode == ERR_NONE){
      Serial.println(F("   *Error state, but no error code logged..."));
    }
    if (errorCode & ERR_PRECHARGE_TOO_FAST) {
      Serial.println(F("   *Precharge too fast. Suspect wiring fault / chatter in shutdown circuit."));
      statusLED[0].on();
    }
    if (errorCode & ERR_PRECHARGE_TOO_SLOW) {
      Serial.println(F("   *Precharge too slow. Potential causes:\n   - Wiring fault\n   - Discharge is stuck-on\n   - Target precharge percent is too high"));
      statusLED[1].on();
    }
    if (errorCode & ERR_STATE_UNDEFINED) {
      Serial.println(F("   *State not defined in The State Machine."));
    }
  }

}


// Loop through the array and call update.
void updateStatusLeds() {
  for (uint8_t i=0; i<(sizeof(statusLED)/sizeof(*statusLED)); i++){
    statusLED[i].update();
  }
}
void statusLEDsOff() {
  for (uint8_t i=0; i<(sizeof(statusLED)/sizeof(*statusLED)); i++){
    statusLED[i].off();
  }
}
void updateStatusLeds(long ton, long toff) {
  for (uint8_t i=0; i<(sizeof(statusLED)/sizeof(*statusLED)); i++){
    statusLED[i].update(ton, toff);
  }
}

//void teensyHeartbeat(void) {
//
//    EVERY_N_MILLISECONDS(500){
//      digitalWrite(LED_PIN, heartBeat);
//       if (heartBeat == 0) {
//            heartBeat = 1;
//       } else {
//            heartBeat = 0;
//       }
//       NUCAN_write(&PRE_HEARTBEAT, heartBeat);
//    }
```

```
//}
```

Listing 2: PreCharge Code

CANaMon Code

```
  /*Canamon code V4 - JBush
Todo:
  Restructure IDs (in DBC too)
  Further assess power consumption/saving
  Handle out of bounds readings
*/
#include <FlexCAN_T4.h>
#include "microsmooth.h"
#include <FastLED.h> // For EVERYNMILLISECONDS

// CANaMon Module Number
#define SEGMENT_NUMBER 9
#define SAMPLE_T 750 //msec

#define THERMISTOR_COUNT 10
#define LED_PIN 13

// Microsmooth variables/*
#define MICROSMOOTH_WINDOW_SIZE 30 //ensure same size as SMA_LENGTH in microsmooth.h file

uint16_t *hist1, *hist2, *hist3, *hist4, *hist5, *hist6, *hist7, *hist8, *hist9, *hist10;

uint16_t *tempHist[THERMISTOR_COUNT] = {hist1, hist2, hist3, hist4, hist5, hist6, hist7, hist8, hist9, hist10};

// Arrays to hold control and signal pin numbers for each thermistor
uint8_t ctrlPin[THERMISTOR_COUNT] = {2,3,4,5,6,7,8,9,10,11};
uint8_t sigPin[THERMISTOR_COUNT] = {14,15,16,17,18,19,20,21,22,23};

// Variables for cell voltages and temperatures
float cellVolts[THERMISTOR_COUNT] = {0,0,0,0,0,0,0,0,0,0};  // Variable [V] Array of min segment sensor voltages
float cellTemps[THERMISTOR_COUNT] = {0,0,0,0,0,0,0,0,0,0};  // Variable [C] Array of max cell temps
int cellsGood[THERMISTOR_COUNT] = {0,0,0,0,0,0,0,0,0,0};  // Cell temps are in range
int nBadCells = 0;

float voltGain = 1.0;   // Gain for voltage readings
float CANScale = 0.4;   // CAN bus scaling factor

float maxCellTemp = 0;  // Max segment temperature
float minCellTemp = 0;  // Min segment temperature
float avgCellTemp = 0;  // Avg segment temperature
float maxInd = 0;

// CAN communication setup
FlexCAN_T4<CAN2, RX_SIZE_256, TX_SIZE_16> can2;
CAN_message_t hbMsg;
CAN_message_t minmaxmsg;


void setup() {
  Serial.begin(9600);

  delay((int)(SEGMENT_NUMBER*1000/9));    // Delay to offset CAN messages from each CANaMons

  thermisterInit();
  CANinit();
  //Initialise LED pin
  pinMode(LED_PIN, OUTPUT);
  digitalWrite(LED_PIN, LOW);
}

void loop() {
  // Periodically read sensors, send data over CAN, and update heartbeat
  EVERY_N_MILLIS(SAMPLE_T){
    //Serial.println("reading");
    takeMeasurements();
```

```
    updateMinMax();
    updateHeartbeat();
  }

}

void thermisterInit(){
  // Initialize measurement pins
  for (uint8_t i = 0; i < THERMISTOR_COUNT; i++) {
    pinMode(ctrlPin[i], OUTPUT);
    pinMode(sigPin[i], INPUT_PULLUP);
    digitalWrite(ctrlPin[i], LOW); // Replace later

    // Initialize Microsmooth history arrays
    tempHist[i] = ms_init(SMA);

    // Initialize the history array with some initial values
    for (uint8_t j = 0; j < MICROSMOOTH_WINDOW_SIZE; j++) {
      sma_filter(600, tempHist[i]); // 600 initializes to approximately 20 degrees
    }
  }
}

void CANinit() {
  //Initialise CAN Comms
  can2.begin();
  can2.setBaudRate(250000);

  minmaxmsg.id = 1200 + 10 * (int)SEGMENT_NUMBER;   //minmax CAN ID
  minmaxmsg.len = 5;
  minmaxmsg.flags.extended = 0;

  hbMsg.id = 1000 + (int)SEGMENT_NUMBER;    //Heartbeat CAN ID
  hbMsg.len = 1;
  hbMsg.flags.extended = 0;
}

void takeMeasurements(void)
{
  nBadCells = 0;
  // Read voltages from thermistors
  for (uint8_t i = 0; i < THERMISTOR_COUNT; i++)
  {
    // Take raw reading of ADCs
    cellVolts[i] = analogRead(sigPin[i]);

    // Dealing with outliers
    // 680 = 0 deg C (Negative-Tempature-Coefficent (NTC))
    // 446 = 75 deg C
    if (cellVolts[i] < 446){
      cellVolts[i] = 680;
      cellsGood[i] = 0;
      nBadCells = nBadCells + 1;
    }
    else if (cellVolts[i] > 680) {
      cellVolts[i] = 680;
      cellsGood[i] = 0;
      nBadCells = nBadCells + 1;
    } else {
      cellsGood[i] = 1;
    }

    // Smooth the raw reading using Microsmooth
    cellVolts[i] = sma_filter(cellVolts[i], tempHist[i]);
    // Convert the reading to volts
    cellVolts[i] = cellVolts[i] * 3.3 / 1024 * voltGain;
    // Convert volts to temperatures
```

```
    cellTemps[i] = voltToTemp(cellVolts[i]);

    /*
    // Removed so that the temps can be read before conversion
    Ensure temperature is within a valid range
    if (cellTemps[i] < 0){
      cellTemps[i] = 0;
    }
    else if (cellTemps[i] > 100) {
      cellTemps[i] = 100;
    }
    */
  }
}

// Function to convert voltage to temperature
float voltToTemp(float x){
  float temp = -225.7*pow(x, 3) + 1310.6*pow(x,2) - 2594.8*x + 1767.8;
  return temp;
}

void updateMinMax(void) {
  // Reset all variables
  maxCellTemp = cellTemps[0]; // Re-initialise as temp of the first segment
  minCellTemp = cellTemps[0]; // Re-initialise as temp of the first segment
  avgCellTemp = cellTemps[0]; // Re-initialise as temp of the first segment
  maxInd = 0;

  Serial.print("Cell: "); Serial.print(0); Serial.print("Temp: "); Serial.println(cellTemps[0]);
  // Loop over thermistors to find min, max and average temperatures
  for(int i = 1; i < THERMISTOR_COUNT; i++){
    Serial.print("Cell: "); Serial.print(i); Serial.print("Temp: "); Serial.println(cellTemps[i]);

    if(cellsGood[i] == 1){
      if(cellTemps[i] > maxCellTemp){
        maxCellTemp = cellTemps[i];
        maxInd = i;
      }
      if(cellTemps[i] < minCellTemp){
        minCellTemp = cellTemps[i];
      }
      avgCellTemp = avgCellTemp + cellTemps[i];
    }
  }
  // Calculate total average outside of loop
  avgCellTemp = avgCellTemp / (THERMISTOR_COUNT-nBadCells);

  Serial.print("Max = "); Serial.println(maxCellTemp);
  Serial.print("Min = "); Serial.println(minCellTemp);
  Serial.print("Avg = "); Serial.println(avgCellTemp);
  Serial.print("Ind = "); Serial.println(maxInd);
  Serial.print("Number of Bad Cells = "); Serial.println(nBadCells);


  // Prepare and send the CAN message with min and max temperatures

  minmaxmsg.buf[0] = maxCellTemp / CANScale;
  minmaxmsg.buf[1] = minCellTemp / CANScale;
  minmaxmsg.buf[2] = avgCellTemp / CANScale;
  minmaxmsg.buf[3] = maxInd;
  minmaxmsg.buf[4] = (float)nBadCells;
  can2.write(minmaxmsg);

}

void updateHeartbeat(void)
{
```

```
  hbMsg.buf[0] = 1 - hbMsg.buf[0];
  digitalWrite(LED_PIN, hbMsg.buf[0]);
  can2.write(hbMsg);
}
```

Listing 3: CANaMon Code

Matlab PreCharge Voltage Code

Listing 4: Matlab code for voltage response of PreCharge

```
%% Define Parameters
t = 0:0.001:5; % Time vector (1ms step up to 5s)
R = 560; % Resistance in ohms (Precharge resistor)
C = 650; % Capacitance in microfarads
RC = R * C / 1e6; % Time constant in seconds
V = 453.6; % Maximum voltage
R_AIR = 0.0004; % Contactor resistance

%% USER-DEFINED: Change PreCharge Percentage
PreCharge_Percent = 95; % Change this to any desired percentage (e.g., 90, 99, etc.)

%% Voltage & Current Calculations
V_C = V * (1 - exp(-t/RC)); % Voltage across capacitor
V_R = V * exp(-t/RC); % Voltage across resistor
I = V_R / R; % Current through the precharge resistor
P = V_R.^2 / R; % Power dissipated in the resistor

%% Find Time to Reach PreCharge_Percent Voltage
Threshold_VC = (PreCharge_Percent / 100) * V;
Index_VC = find(V_C >= Threshold_VC, 1); % Find first occurrence
Time_VC = t(Index_VC); % Time when it reaches PreCharge_Percent

%% Find Time When Power Falls Below 25W
Threshold_P = 25;
Index_25W = find(P < Threshold_P, 1);
Time_25W = t(Index_25W); % Time when power drops below 25W

%% Compute Inrush Current Values
V_C_Target = Threshold_VC; % Voltage at chosen percentage
I_inrush = (V - V_C_Target) / R_AIR; % Inrush current when contactor closes

%% Display Results in Command Window
disp(['Time␣to␣reach␣', num2str(PreCharge_Percent), '%␣of␣final␣voltage:␣', num2str(Time_VC),
disp(['Initial␣Inrush␣Current␣(through␣precharge␣resistor,␣t=0):␣', num2str(V / R), '␣A']);
disp(['Inrush␣Current␣After␣Contactor␣Closes:␣', num2str(I_inrush), '␣A']);
disp(['Time␣for␣Power␣to␣drop␣below␣25W:␣', num2str(Time_25W), '␣s']);

%% Voltage Response Graph
figure(1)
plot(t, V_C, 'LineWidth', 1, 'DisplayName', 'Voltage␣Across␣Capacitor')
ylim([0 500]);
hold on;
yline(Threshold_VC, 'r--', 'LineWidth', 1, 'DisplayName', [num2str(PreCharge_Percent), '%␣Volt
legend('show', 'FontSize', 16);
```

```
xlabel('Time (s)', 'FontSize', 16);
ylabel('Voltage (V)', 'FontSize', 16);
title(['Voltage Response with ', num2str(PreCharge_Percent), '% PreCharge'], 'FontSize', 16);
grid on;

%% Power Dissipation Graph
figure(2)
plot(t, P, 'b-', 'LineWidth', 1, 'DisplayName', 'Power Dissipation');
xlabel('Time (s)', 'FontSize', 16);
ylabel('Power (W)', 'FontSize', 16);
title('Resistor Power Over Time (Including Surge)', 'FontSize', 16);
legend('show', 'FontSize', 16);
grid on;

%% Time to reach PreCharge_Percent voltage for different resistor values
R_values = 100:50:2000; % Range of resistor values from 100   to 2000
Time_VC_values = zeros(size(R_values)); % Preallocate array

for i = 1:length(R_values)
    RC_i = R_values(i) * C / 1e6; % Time constant for this R value
    V_C_i = V * (1 - exp(-t/RC_i)); % Compute voltage curve
    Index_VC_i = find(V_C_i >= Threshold_VC, 1); % Find time for PreCharge_Percent voltage
    Time_VC_values(i) = t(Index_VC_i); % Store time
end

%% Plot Resistor Value vs. Time to reach PreCharge_Percent Voltage
figure(3)
plot(Time_VC_values, R_values, 'r-', 'LineWidth', 1.5);
ylabel('Resistance (  )', 'FontSize', 16);
xlabel(['Time to reach ', num2str(PreCharge_Percent), '% Voltage (s)'], 'FontSize', 16);
title(['Effect of Resistance on ', num2str(PreCharge_Percent), '% Voltage Time'], 'FontSize',
grid on;

%% Current Over Time Graph
figure(4)
plot(t, I, 'g-', 'LineWidth', 1.5);
xlabel('Time (s)', 'FontSize', 16);
ylabel('Current (A)', 'FontSize', 16);
title('Current Through Resistor Over Time', 'FontSize', 16);
grid on;
```

Matlab PreCharge Current Code

Listing 5: Code for PreCharge current models

```
% Define parameters
R = 560; % Resistance in ohms (Precharge resistor)
C = 650e-6; % Capacitance in farads
RC = R * C; % Time constant in seconds
V = 453.6; % Maximum voltage

% Define voltage percentage at which resistance changes (easily changeable)
V_percent = 98; % Change this to any percentage (e.g., 98, 90, etc.)

% Define time vector before resistance change (in seconds)
t = 0:1e-6:5; % Time in seconds (1  s  step up to 5 seconds)

% Voltage across the capacitor
V_C = V * (1 - exp(-t/RC));

% Current draw by the capacitor before resistance change
I_C = (V / R) * exp(-t/RC);

% Find time when capacitor reaches the chosen voltage percentage
t_V_percent = -RC * log(1 - (V_percent / 100)); % Time in seconds
t_V_percent_us = t_V_percent * 1e6; % Convert to microseconds

% Print the calculated time
fprintf('Time␣to␣reach␣%.2f%%␣of␣final␣voltage:␣%.2f␣s␣(%.2f␣ s )\n', V_percent, t_V_percent,

% Truncate time, voltage, and current up to this percentage voltage
idx = find(t >= t_V_percent, 1);
t_truncated = t(1:idx);
I_C_truncated = I_C(1:idx);

% New resistance in parallel with 0.0004 ohm resistor after voltage reaches V_percent
R_parallel = (R * 0.0004) / (R + 0.0004); % Parallel resistance calculation

% Compute new inrush current
V_C_target = (V_percent / 100) * V; % Voltage at chosen percentage
I_inrush = (V - V_C_target) / R_parallel; % Maximum inrush current

% Fine time step for inrush current (1 ns step, calculations in  s )
t_fine_us = t_V_percent_us:0.001:t_V_percent_us + 1000; % 1 ns step for 1  s  range
t_fine = t_fine_us * 1e-6; % Convert to seconds
I_C_fine = I_inrush * exp(-(t_fine - t_V_percent) / (R_parallel * C)); % Inrush current decay

% Continue simulation after inrush with normal time step (in seconds)
t_after = (t_V_percent + 1e-6):1e-6:5; % Regular time step after inrush event
```

```
I_C_after = I_inrush * exp(-(t_after - t_V_percent) / (R_parallel * C)); % Decay after inrush

% Combine all time and current data
t_combined = [t_truncated, t_fine, t_after];
I_C_combined = [I_C_truncated, I_C_fine, I_C_after];

% Calculate duration current stays above 500A (calculations in  s )
I_threshold = 500; % Amps
t_above_threshold_us = t_fine_us(I_C_fine > I_threshold); % Time points where current > 500A

if ~isempty(t_above_threshold_us)
    duration_above_500A_us = t_above_threshold_us(end) - t_above_threshold_us(1); % Duration i
else
    duration_above_500A_us = 0; % If it never exceeds 500A
end

% Display results in MATLAB command window
fprintf('Maximum␣Inrush␣Current:␣%.2f␣A\n', I_inrush);
fprintf('Duration␣above␣500A:␣%.2f␣ s \n', duration_above_500A_us);

% Plot the current over time
figure;
plot(t_combined, I_C_combined, 'r', 'LineWidth', 1.5);
hold on;
xline(t_V_percent, '--b', sprintf('%.0f%%␣Voltage␣(Resistance␣Change)', V_percent), 'LabelVert
xlabel('Time␣(s)', 'FontSize', 16);
ylabel('Current␣(A)', 'FontSize', 16);
title('Current␣Draw␣by␣Capacitor␣with␣Inrush␣Effect');
grid on;
hold off;
```

Matlab MOSFET Temperature Code

Listing 6: Code for MOSFET Temperatures

```
clc; clear; close all;

% Constants
R_DS_ON = 8.7e-3;    % MOSFET on-resistance (  )
R_TH_JA_NO_HS = 62; % Junction-to-Ambient resistance without heatsink ( C /W)
R_TH_JC = 2.3;       % Junction-to-Case resistance ( C /W)
R_TH_CS = 0.5;       % Case-to-Sink resistance ( C /W)
R_TH_SA_HS = 27.14; % Heatsink-to-Ambient resistance with heatsink ( C /W)
T_AMBIENT = 25;      % Ambient temperature ( C )
C_TH = 0.1;          % Thermal capacitance (J/ C ) - estimated

% Define current values (5A to 50A)
currents = linspace(5, 30, 10);

% Calculate Junction Temperature for each current
T_no_heatsink = zeros(size(currents));
T_with_heatsink = zeros(size(currents));
Tau_no_heatsink = zeros(size(currents));
Tau_with_heatsink = zeros(size(currents));

for i = 1:length(currents)
    I_D = currents(i);
    P_dissipation = I_D^2 * R_DS_ON; % Power dissipation (W)

    % Without Heatsink
    T_no_heatsink(i) = T_AMBIENT + (P_dissipation * R_TH_JA_NO_HS);
    Tau_no_heatsink(i) = R_TH_JA_NO_HS * C_TH; % Thermal time constant (s)

    % With Heatsink
    R_TH_JA_HS = R_TH_JC + R_TH_CS + R_TH_SA_HS;
    T_with_heatsink(i) = T_AMBIENT + (P_dissipation * R_TH_JA_HS);
    Tau_with_heatsink(i) = R_TH_JA_HS * C_TH; % Thermal time constant (s)
end

% Plot steady-state temperatures
figure;
hold on;
plot(currents, T_no_heatsink, 'r-', 'LineWidth', 2);
plot(currents, T_with_heatsink, 'b-', 'LineWidth', 2);
yline(175, 'k--', 'LineWidth', 1.5); % Max Safe Temp (175 C )
xlabel('Drain␣Current␣(A)', 'FontSize', 16);
ylabel('Junction␣Temperature␣( C )', 'FontSize', 16);
title('MOSFET␣Junction␣Temperature␣vs.␣Current');
legend('Without␣Heatsink', 'With␣Heatsink', 'Max␣Safe␣Temp␣(175 C )', 'FontSize', 16);
```

```
grid on;
hold off;

% --- Thermal Time Constant Analysis ---
% Simulate heating over time for one selected current (e.g., 24A)
I_selected = 16; % Change this to test different currents
P_selected = I_selected^2 * R_DS_ON;

T_steady_no_HS = T_AMBIENT + P_selected * R_TH_JA_NO_HS;
T_steady_HS = T_AMBIENT + P_selected * (R_TH_JC + R_TH_CS + R_TH_SA_HS);

Tau_selected_no_HS = R_TH_JA_NO_HS * C_TH;
Tau_selected_HS = (R_TH_JC + R_TH_CS + R_TH_SA_HS) * C_TH;

% Time vector (simulate heating up to 5 x Tau)
t = linspace(0, 5 * max(Tau_selected_no_HS, Tau_selected_HS), 100);

% Temperature over time following exponential rise:
T_time_no_HS = T_AMBIENT + (T_steady_no_HS - T_AMBIENT) .* (1 - exp(-t / Tau_selected_no_HS));
T_time_HS = T_AMBIENT + (T_steady_HS - T_AMBIENT) .* (1 - exp(-t / Tau_selected_HS));

% Plot temperature rise over time
figure;
hold on;
plot(t, T_time_no_HS, 'r-', 'LineWidth', 2);
plot(t, T_time_HS, 'b-', 'LineWidth', 2);
yline(175, 'k--', 'LineWidth', 1.5);
xlabel('Time␣(seconds)', 'FontSize', 16);
ylabel('Junction␣Temperature␣( C )', 'FontSize', 16);
%title(['MOSFET Heating Over Time (I = ' num2str(I_selected) 'A)']);
legend('Without␣Heatsink', 'With␣Heatsink', 'Max␣Safe␣Temp␣(175 C )', 'FontSize', 12);
grid on;
hold off;

% Display calculated time constants
fprintf('For␣I_D␣=␣%.1f␣A:\n', I_selected);
fprintf('␣␣-␣Without␣Heatsink:␣Tau␣=␣%.2f␣sec,␣T_steady␣=␣%.2f C\n', Tau_selected_no_HS, T_st
fprintf('␣␣-␣With␣Heatsink:␣Tau␣=␣%.2f␣sec,␣T_steady␣=␣%.2f C\n', Tau_selected_HS, T_steady_H
```

LVD V3.0 BOM

Item	Quantity	References	Value	Footprint
1	4	C2, C5, C6, C7	0.1uF	C_1206_3216Metric
2	1	C1	0.33uF	C_1206_3216Metric
3	8	R1, R2, R3, R5, R9, R10, R27, R29	1K	R_1206_3216Metric
4	6	R6, R8, R13, R31, R32, R33	10K	R_1206_3216Metric
5	4	R34, R37, R38, R39	0	R_1206_3216Metric_Pad1.30x1.75mm_ Hand-Solder
6	2	R12, R15	120	R_1206_3216Metric
7	2	R23, R24	1K	R_1206_3216Metric_Pad1.30x1.75mm_ Hand-Solder
8	1	R4	10K	R_1206_3216Metric_Pad1.30x1.75mm_ Hand-Solder
9	1	R11	500	R_1206_3216Metric
10	1	R20	3.8K	R_1206_3216Metric
11	4	D4, D8, D9, D11	0 TO HERO	D_SMA_Handsoldering
12	3	D1, D3, D5	3V3	D_SOD-123
13	3	D7, D10, D13	TWGMC-SS34	D_SMA_Handsoldering
14	1	D2	FANS	LED_1206_3216Metric
15	1	D6	CHARGE_POWER	LED_1206_3216Metric
16	1	D12	12V_RAW	LED_1206_3216Metric
17	1	D15	5V	LED_1206_3216Metric
18	3	U6, U8, U9	TLV9301xDBV	SOT-23-5
19	2	U2, U5	∼	BRANDING_RACING
20	1	U1	TJA1051T-3	SOIC-8_3.9x4.9mm_P1.27mm
21	1	U3	LM7805_DPAK	TO-263-3_TabPin2
22	1	U4	TJA1052i-2	SOIC-16W_7.5x10.3mm_P1.27mm
23	1	U7	Teensy4.0-NU-Teams	Teensy4.0-NU-Teams

Item	Quantity	References	Value	Footprint
24	4	F1, F2, F3, F4	7A	Fuseholder_Littelfuse_Nano2_154x
25	1	F5	SMDFuse	Fuseholder_Littelfuse_Nano2_154x
26	1	F6	Fuse 1A	Fuseholder_Littelfuse_Nano2_154x
27	1	F8	5A	Fuseholder_Littelfuse_Nano2_154x
28	1	SW2	CAN_1_TERM	SW_DIP_SPSTx01_Slide_6.7x4.1mm _W7.62mm_P2.54mm_LowProfile
29	1	SW3	DSIC01THGET	SW_DIP_SPSTx01_Slide_6.7x4.1mm _W7.62mm_P2.54mm_LowProfile
30	4	12V_PROT1, D14, IMD_OKHS1, PC_OKHS1	12V_PROT	LED_1206_3216Metric
31	3	Q1, Q2, Q4	2N7002	SOT-23
32	2	3V, 5V	0	R_1206_3216Metric_Pad1.30x1.75mm_ Hand-Solder
33	2	5V_BMS_ OKHS_PULLUP1, 12V_BMS_ OKHS_PULLUP1	10k	R_1206_3216Metric_Pad1.30x1.75mm_ Hand-Solder
34	2	CAN_L1, SHUT-DOWN_TSMS1	CAN_L1	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
35	1			
36	1	CAN_H1	CAN_H1	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
37	1	COMMISIONING_ PWR1	COMMISIONING_ PWR	TerminalBlock_Phoenix_MKDS-1,5-2_1x02 _P5.00mm_Horizontal
38	1	H2	used as via	MountingHole_2.2mm_M2_DIN965_Pad
39	1	JP1	SolderJumper_2_Open	SolderJumper-2_P1.3mm_Open_ Rounded-Pad1.0x1.5mm
40	1	PS1	SPAN02A-12	SPAN02A12
41	1	Q5	MCT06P10	SOT-223
42	1	Q6	IRLB8721PBF	TO-220-3_Horizontal_TabDown

Item	Quantity	References	Value	Footprint
43	1	TH1	Thermistor	R_1206_3216Metric_Pad1.30x1.75mm_ HandSolder
44	1	TP1	12V_RAW	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
45	1	TP2	12V_PROT	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
46	1	TP3	5V	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
47	1	TP4	isoCAN_H	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
48	1	TP5	isoCAN_L	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
49	2	J1, J12	DE9_Receptacle	DSUB-9_Female_Vertical_P2.77x2.84mm_MountingHoles
50	1	J2	Fan Bank 2	DT15-6P
51	1	J3	Fan Bank 1	DT15-6P
52	1	J4	CANaMon	microfit-2x02
53	1	J5	GND	microfit-2x01
54	1	J16	AIRS — PRE_CHARGE — IMD — BMS	Molex_Micro-Fit_3.0_43045-2212_2x11_P3.00mm_Vertical
55	1	J17	ACC LV	DT15-12PA
			Total Component Count	97

LVD V3.1 BOM

Item	Quantity	References	Value	Footprint
1	4	C2, C5, C6, C7	0.1uF	C_1206_3216Metric
2	1	C1	0.33uF	C_1206_3216Metric
3	1	C3	1800u	CAP_EEEFK1C182SV
4	1	C4	7500u	CAP_EEEFK1C752SV
5	6	R6, R8, R13, R31, R32, R33	10K	R_1206_3216Metric
6	5	R5, R9, R10, R27, R29	1K	R_1206_3216Metric
7	4	R34, R37, R38, R39	0	R_1206_3216Metric_Pad1.30x1.75mm_ Hand-Solder
8	2	R12, R15	120	R_1206_3216Metric
9	2	R23, R24	1K	R_1206_3216Metric_Pad1.30x1.75mm_ Hand-Solder
10	1	R4	10K	R_1206_3216Metric_Pad1.30x1.75mm_ Hand-Solder
11	1	R7	150	R_1206_3216Metric
12	1	R11	500	R_1206_3216Metric
13	1	R20	3.8K	R_1206_3216Metric
14	4	D4, D8, D9, D11	0 TO HERO	D_SMA_Handsoldering
15	3	D1, D3, D5	3V3	D_SOD-123
16	3	D7, D10, D13	TWGMC-SS34	D_SMA_Handsoldering
17	1	D2	FANS	LED_1206_3216Metric
18	1	D6	CHARGE_POWER	LED_1206_3216Metric
19	1	D12	12V_RAW	LED_1206_3216Metric
20	1	D14	12V_PROT	LED_1206_3216Metric
21	1	D15	5V	LED_1206_3216Metric
22	1	D16	D	D_SMA_Handsoldering
23	1	D17	D	D_SMA
24	2	U2, U5	$\sim$	BRANDING_RACING

Item	Quantity	References	Value	Footprint
25	1	U1	TJA1051T-3	SOIC-8_3.9x4.9mm_P1.27mm
26	1	U3	LM7805_DPAK	TO-263-3_TabPin2
27	1	U4	TJA1052i-2	SOIC-16W_7.5x10.3mm_P1.27mm
28	1	U7	Teensy4.0-NU-Teams	Teensy4.0-NU-Teams
29	4	F1, F2, F3, F4	7A	Fuseholder_Littelfuse_Nano2_154x
30	1	F5	SMDFuse	Fuseholder_Littelfuse_Nano2_154x
31	1	F6	Fuse 1A	Fuseholder_Littelfuse_Nano2_154x
32	1	F8	5A	Fuseholder_Littelfuse_Nano2_154x
33	1	SW2	CAN_1_TERM	SW_DIP_SPSTx01_Slide_6.7x4.1mm_W7.62mm_P2.54mm_LowProfile
34	1	SW3	DSIC01THGET	SW_DIP_SPSTx01_Slide_6.7x4.1mm_W7.62mm_P2.54mm_LowProfile
35	3	Q1, Q2, Q4	2N7002	SOT-23
36	2	3V_pullup2, 5V_pullup2	0	R_1206_3216Metric_Pad1.30x1.75mm_ Hand-Solder
37	2	5V_BMS_OKHS_PULLUP1, 12V_BMS_OKHS_PULLUP1	10k	R_1206_3216Metric_Pad1.30x1.75mm_ Hand-Solder
38	2	TP9, TP10	GND_TEST	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
39	1	CAN_H1	CAN_H1	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
40	1	CAN_L1	CAN_L1	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
41	1	COMMISIONING_PWR1	COMMISIONING_ PWR	TerminalBlock_Phoenix_MKDS-1,5-2_1x02_P5.00mm_Horizontal
42	1	H2	used as via	MountingHole_2.2mm_M2_DIN965_Pad
43	1	INTERPOSE1	INTERPOSE	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
44	1	JP1	SolderJumper_2_Open	SolderJumper-2_P1.3mm_Open_ Rounded-Pad1.0x1.5mm
45	1	K1	G5V-1	Relay_SPDT_Omron_G5V-1
46	1	PS1	SPAN02A-5	SPAN02A12
47	1	Q5	MCT06P10	SOT-223

Item	Quantity	References	Value	Footprint
48	1	Q6	IRLB8721PBF	TO-220-3_Horizontal_TabDown
49	1	SHUTDOWN_TSMS	SD_TSMS	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
50	1	TH1	Thermistor	R_1206_3216Metric_Pad1.30x1.75mm_ Hand-Solder
51	1	TP1	12V_RAW	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
52	1	TP2	12V_PROT	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
53	1	TP3	5V	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
54	1	TP4	isoCAN_H	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
55	1	TP5	isoCAN_L	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
56	1	TP6	IMD_OKHS	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
57	1	TP7	PC_OKHS	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
58	1	TP8	BMS_OKHS	TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
59	2	J1, J12	DE9_Receptacle	DSUB-9_Female_Vertical_P2.77x2.84mm_ MountingHoles
60	1	J2	Fan Bank 2	DT15-6P
61	1	J3	Fan Bank 1	DT15-6P
62	1	J4	CANaMon	microfit-2x02
63	1	J5	GND	microfit-2x01
64	1	J16	AIRS — PRE_CHARGE — IMD — BMS	Molex_Micro-Fit_3.0_43045-2212_2x11_P3.00mm_Vertical
65	1	J17	ACC LV	DT15-12PA
			Total Component Count	99

Appendix C

University	University of Newcastle	A/N	E03-20-DR-051000-01	Part Cost	N/A
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	N/A
Year	2024	Assembly	Accumulator	Extended Cost	$ 14,847.97
Car #	E03	Part	N/A		

Parts

ID	P/N	Description	Part Cost	QTY	Sub Total
	E03-20-DR-052001-01	Accumulator Container	$ 1,273.69	1	$ 1,273.69
	E03-20-DR-052004-01	Accumulator Lid	$ 478.77	1	$ 478.77
	E03-20-DR-052012-01	Segments 1 & 9	$ 799.68	2	$ 1,599.36
	E03-20-DR-052011-01	Segments 2-8	$ 834.95	7	$ 5,844.66
	E03-20-DR-052020-01	Service handle	$ 340.57	1	$ 340.57
	E03-20-DR-052024-01	Top Plate	$ 5,283.36	1	$ 5,283.36
Total					$ 14,820.41

Processes / Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Assemble, 5 kg, Line-on-Line	Insert Segments 2- 8 into container	unit	1	None	1	Repeat 7	7	$ 0.63	$ 4.41
	Assemble, 5 kg, Line-on-Line	Insert Segments 1 & 9 into container	unit	1	None	1	Repeat 2	2	$ 0.63	$ 1.26
	Assemble, 5 kg, Loose	locate Top Plate in container	unit	1	None	1	None	1	$ 0.31	$ 0.31
	Assemble, 1 kg, Line-on-Line	connect positive Radlok conector	unit	1	None	1	None	1	$ 0.13	$ 0.13
	Assemble, 1 kg, Line-on-Line	connect Negative Radlok conector	unit	1	None	1	None	1	$ 0.13	$ 0.13
	Assemble, 1 kg, Loose	connect Positive lead on lid to Air, Running it through	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 1 kg, Loose	Place washer on AIR terminal	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Hand - Start Only	Start Nut on AIR terminal	unit	1	None	1	None	1	$ 0.12	$ 0.12
	Hand, Tight <= 6.35 mm	Hand Tighten Nut on AIR Terminal	unit	1	None	1	None	1	$ 0.50	$ 0.50
	Tensioning Tool <=6.35 mm	Tighten Nut on AIR Terminal	unit	1	None	1	None	1	$ 0.25	$ 0.25
	Assemble, 1 kg, Loose	connect Negative lead on lid to Air	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 1 kg, Loose	Place washer on AIR terminal	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Hand - Start Only	Start Nut on AIR terminal	unit	1	None	1	None	1	$ 0.12	$ 0.12
	Hand, Tight <= 6.35 mm	Hand Tighten Nut on AIR Terminal	unit	1	None	1	None	1	$ 0.50	$ 0.50
	Tensioning Tool <=6.35 mm	Tighten Nut on AIR Terminal	unit	1	None	1	None	1	$ 0.25	$ 0.25
	Assemble, 1 kg, Line-on-Line	Fit Service Handle	unit	1	None	1	None	1	$ 0.13	$ 0.13
	Assemble, 1 kg, Loose	Connect LVD to	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 1 kg, Loose	Connect AIL	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 3 kg, Loose	Lower Lid onto Container	unit	1	None	1	None	1	$ 0.19	$ 0.19
	Assemble, 1 kg, Loose	Place washer on M6 Bolt For Lid	unit	1	None	1	Repeat 8	8	$ 0.06	$ 0.48
	Assemble, 1 kg, Loose	Locate Bolt and washer on Lid and Container	unit	1	None	1	Repeat 9	9	$ 0.06	$ 0.54
	Assemble, 1 kg, Loose	place wash on underside of M6 bolt	unit	1	None	1	Repeat 10	10	$ 0.06	$ 0.60
	Assemble, 1 kg, Loose	Locate Nut on M6 bolt	unit	1	None	1	Repeat 11	11	$ 0.06	$ 0.66
	Hand - Start Only	Start M6 Nut	unit	1	None	1	Repeat 12	12	$ 0.12	$ 1.44
	Hand, Tight <= 6.35 mm	Hand Tighten M6 Nut	unit	1	None	1	Repeat 13	13	$ 0.50	$ 6.50
	Reaction Tool <= 6.35 mm	Place reaction tool on nut	unit	1	None	1	Repeat 14	14	$ 0.25	$ 3.50
	Tensioning Tool <=6.35 mm	Tighten M6 Bolt	unit	1	None	1	Repeat 15	15	$ 0.25	$ 3.75
	Assemble, 1 kg, Line-on-Line	Connect Fan Manifolds Leads to LVD	unit	1	None	1	None	1	$ 0.13	$ 0.13
Total										$ 26.26

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Bolt, Grade 12.9	M6 bolt to secure lid to container	6	mm	20	mm	8	$ 0.07	$ 0.58
	Nut, Grade 12.9	M6 nuts to secure lid to container	6	mm		0	8	$ 0.05	$ 0.40
	Washer, Grade 12.9	M6 Washer to secure lid to container	6	mm		0	8	$ 0.01	$ 0.09
	Nut, Grade 12.9	M10 Nut For AIRs	10	mm		0	2	$ 0.11	$ 0.22
Total									$ 1.29

University	University of Newcastle
Competition Code	FSAE-A
Year	2024
Car #	E03

A/N	E03-20-DR-052004-01
System	Engine/Tractive Path and Drivetrain
Assembly	Accumulator Lid
Part	N/A

Part Cost	N/A
QTY	1
Extended Cost	$ 478.77

Parts

ID	P/N	Description	Part Cost	QTY	Sub Total
	E03-20-DR-053005-01	Container Lid	$ 91.90	1	$ 91.90
	E03-20-DR-053006-01	AIL PCB	$ 54.90	1	$ 54.90
	E03-20-DR-053007-01	Loom, LVD to AIL	$ 10.25	1	$ 10.25
	E03-20-DR-053008-01	HV Lid Surlok Connectors	$ 6.10	1	$ 6.10
	E03-20-DR-053009-01	LVD PCB	$ 246.17	1	$ 246.17
	E03-20-DR-052010-01	HV Wires - Lid	$ 15.05	2	$ 30.10
Total					**$ 439.43**

Processes / Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Assemble, 1 kg, Loose	Place AIL in lid	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 1 kg, Loose	Bolts through Lid to AIL	unit	1	None	1	Repeat 2	2	$ 0.06	$ 0.12
	Assemble, 1 kg, Loose	Washers on AIL bolts	unit	1	None	1	Repeat 2	2	$ 0.06	$ 0.12
	Hand - Start Only	Hand start nut to secure AIL in Lid	unit	1	None	1	Repeat 2	2	$ 0.12	$ 0.24
	Reaction Tool <= 6.35 mm	Reaction tool on AIL nuts	unit	1	None	1	Repeat 2	2	$ 0.25	$ 0.50
	Wrench <= 6.35 mm	Tighten M3 Bolt to secure AIL to Lid	unit	1	None	1	Repeat 2	2	$ 1.00	$ 2.00
	Connector Install	Connect the 2 pin connectors for the LVD to AIL loom	unit	1	None	1	None	1	$ 0.11	$ 0.11
	Assemble, 1 kg, Loose	Place DT connectors for LVD in lid	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 1 kg, Loose	Bolts through Lid to LVD	unit	1	None	1	Repeat 6	6	$ 0.06	$ 0.36
	Hand - Start Only	Hand start nut to secure LVD in lid	unit	1	None	1	Repeat 6	6	$ 0.12	$ 0.72
	Ratchet <= 6.35 mm	Tighten nut to secure LVD to Lid	unit	1	None	1	Repeat 6	6	$ 0.50	$ 3.00
	Assemble, 1 kg, Loose	Place Surlok sockets into Lid	unit	1	None	1	Repeat 2	2	$ 0.06	$ 0.12
	Assemble, 1 kg, Loose	Bolts through Surloks and Lid	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 1 kg, Loose	Washers on Surloks bolts	unit	1	None	1	Repeat 8	8	$ 0.06	$ 0.48
	Assemble, 1 kg, Loose	Nuts on Surloks bolts	unit	1	None	1	Repeat 8	8	$ 0.06	$ 0.48
	Hand - Start Only	Hand start nut to secure Surloks to Lid	unit	1	None	1	Repeat 8	8	$ 0.12	$ 0.96
	Ratchet <= 6.35 mm	Tighten nut to secure Surloks to Lid	unit	1	None	1	Repeat 8	8	$ 0.50	$ 4.00
	Assemble, 1 kg, Loose	allign Lid HV wire to Surlok Connector	unit	1	None	1	Repeat 2	2	$ 0.06	$ 0.12
	Assemble, 1 kg, Loose	Put Washer on M4 Bolt	unit	1	None	1	Repeat 2	2	$ 0.06	$ 0.12
	Assemble, 1 kg, Loose	Put Bolt Through HV wire and Surlok connector	unit	1	None	1	Repeat 2	2	$ 0.06	$ 0.12
	Assemble, 1 kg, Loose	Put Washer on M4 Bolt	unit	1	None	1	Repeat 2	2	$ 0.06	$ 0.12
	Hand - Start Only	Hand start nut to secure Surloks to Lid HV wire	unit	1	None	1	Repeat 2	2	$ 0.12	$ 0.24
	Reaction Tool <= 6.35 mm	put reaction tool on M4 Bolt	unit	1	None	1	Repeat 2	2	$ 0.25	$ 0.50
	Wrench <= 6.35 mm	Tighten nut to secure Surloks to Lid HV wire	unit	1	None	1	Repeat 2	2	$ 1.00	$ 2.00
Total										**$ 16.61**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Bolt, Grade 12.9	M3 bolts to secure AIL and LVD	3	mm	15	mm	8	$ 1.25	$ 10.00
	Bolt, Grade 12.9	M4 Bolts for Surloks	4	mm	15	mm	10	$ 1.25	$ 12.50
	Washer, Grade 12.9	M4 Washer for Surloks	4	mm		0	10	$ 0.01	$ 0.08
	Nut, Grade 12.9	M4 Nuts for Surloks	4	mm		0	10	$ 0.02	$ 0.15
Total									**$ 22.73**

University	University of Newcastle	P/N	E03-20-DR-053006-01	Part Cost	$ 53.44
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	1
Year	2024	Assembly	Top Plate	Extended Cost	$ 53.44
Car #	E03	Part	AIL PCB		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	Molex 2 pin	2	pin		0					2	$ 4.00	$ 8.00
	Printed Circuit Board	PCB from PCBGOGO	6000	mm^2	2	0					1	$ 24.00	$ 24.00
	Simple PCB component	Resisors and Capacitors	15	unit		0					1	$ 0.02	$ 0.02
	Simple Integrated Circuit	Regulators, OpAmps, Comparators	1	Unit		0					2	$ 2.00	$ 4.00
	Conformal Coating		6000	mm^2	2	unit					1	$ 0.02	$ 0.02
Total											**7**		**$ 36.04**

Processes / Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Solder Paste Apply		unit	1	Repeat 2	2	None	1	$ 1.00	$ 2.00
	Machining Setup, Install and remove	Pick and place set up	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Pick and Place	Placement of all components Front	unit	15	None	1	None	1	$ 0.01	$ 0.15
	Machining Setup, Install and remove	Reflow oven set up	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Reflow Oven	Reflow oven front side	unit	1	None	1	None	1	$ 1.00	$ 1.00
	Machining Setup, Install and remove	Reflow oven machine removal	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Hand Soldering	Hand solder remaining components	unit	2	None	1	None	1	$ 0.05	$ 0.10
	Conformal Coat Apply	Conformal Coat both sides	unit	1	Repeat 2	2	None	1	$ 5.00	$ 10.00
Total										**$ 17.15**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
				#N/A		#N/A			$ -
Total									**$ -**

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
	PCB Stensil		0	1	3000	1	$ 700.00	$ 0.23
	PCB component positioning jig		0	1	3000	1	$ 50.00	$ 0.02
Total								**$ 0.25**

University	University of Newcastle	P/N	E03-20-DR-053025-01	Part Cost	$ 120.00
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	2
Year	2024	Assembly	Top Plate	Extended Cost	$ 240.00
Car #	E03	Part	AIRs		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Relay, High Power, Tractive Path	GIGAVAC GX12 (wires attached)	1	unit		0					1	$ 120.00	$ 120.00
Total											**1**		**$ 120.00**

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
Total										$ -

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
									$ -
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	P/N	E03-20-DR-053026-01
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain
Year	2024	Assembly	Top Plate
Car #	E03	Part	BMS

Part Cost	$ 2,160.00
QTY	1
Extended Cost	$ 2,160.00

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Battery Management System, Commercial	Orion BMS 2	108	channel		0					1	$ 2,160.00	$ 2,160.00
Total											1		$ 2,160.00

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
Total										$ -

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	P/N	E03-20-DR-053016-01	Part Cost	$	172.03
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY		9
Year	2024	Assembly	Segments 1 & 9	Extended Cost	$	1,548.25
Car #	E03	Part	CANaMON PCB			

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Printed Circuit Board	CANaMON PCB	18987	mm^2		0					1	$ 75.95	$ 75.95
	Simple PCB component	Resistors, Capacitors, Fuse holders	1	unit		0					45	$ 0.02	$ 0.90
	Relay, Signal and Control	TLP3543	1	unit		0					1	$ 2.00	$ 2.00
	Fuse, Signal and Control	Fuses for the Fuse holders	1	unit		0					15	$ 0.50	$ 7.50
	Simple Integrated Circuit	Step Down Converter, CAN Transistor	1	Unit		0					2	$ 2.00	$ 4.00
	Semi-complex PCB component	MOSFETs, Diodes	1	unit		0					11	$ 0.05	$ 0.55
	Development Board, Hobby	Teensy	1	unit		0					1	$ 20.00	$ 20.00
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	Molex MicroFit	2	pin		0					10	$ 2.00	$ 20.00
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	Molex MicroFit	4	pin		0					2	$ 4.00	$ 8.00
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	Molex MicroFit	14	pin		0					1	$ 13.00	$ 13.00
	Conformal Coating		18987	mm^2	2	unit					1	$ 0.05	$ 0.05
Total											90		$ 151.95

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Solder Paste Apply	Front solder	unit	1	None	1	None	1	$ 1.00	$ 1.00
	Machining Setup, Install and remove	Pick and place set up	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Pick and Place	Placement of all components Front	unit	58	None	1	None	1	$ 0.01	$ 0.58
	Machining Setup, Install and remove	Pick and place machine removal	unit	2	None	1	None	1	$ 1.30	$ 2.60
	Machining Setup, Install and remove	Reflow oven set up	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Reflow Oven	Reflow oven front side	unit	1	None	1	None	1	$ 1.00	$ 1.00
	Machining Setup, Install and remove	Reflow oven removal	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Hand Soldering	Hand solder all through-hole components and pins	unit	15	None	1	None	1	$ 0.05	$ 0.75
	Programming, Dataset Upload, End of Line	Program Teensy	Unit	1	None	1	None	1	$ 5.00	$ 5.00
	Conformal Coat Apply	Conformal coat both sides	unit	1	None	1	None	1	$ 5.00	$ 5.00
Total										$ 19.83

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
	PCB Stensil		0	1	3000	1	$ 700.00	$ 0.23
	PCB component positioning jig		0	1	3000	1	$ 50.00	$ 0.02
Total								$ 0.25

University	University of Newcastle	**P/N**	E03-20-DR-053014-01	**Part Cost**	$ 1.46
Competition Code	FSAE-A	**System**	Engine/Tractive Path and Drivetrain	**QTY**	99
Year	2024	**Assembly**	Segments 1 & 9	**Extended Cost**	$ 144.43
Car #	E03	**Part**	Segment Busbar		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Copper (by Dimensions)	Copper plate for busbars		kg			4mm plate	416	4	8940	1	$ 2.20	$ 0.03
Total													**$ 0.03**

Processes / Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Machining Setup, Install and remove	Setup Waterjet Cutter	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Waterjet Cut	Cut Busbar	cm	12.62035	None	1	None	1	$ 0.01	$ 0.13
Total										**$ 1.43**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	P/N	E03-20-DR-053030-01
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain
Year	2024	Assembly	Top Plate
Car #	E03	Part	Current Sensor

Part Cost	$ 7.08
QTY	1
Extended Cost	$ 7.08

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Sensor, Hall Effect	LEM DHAB S/137	1	unit		0					1	$ 4.00	$ 4.00
	Plastic, UL94 Compliant, Any Composition (per kg)	Sensor Mount	0.027	kg		0					1	$ 0.27	$ 0.27
Total											2		$ 4.27

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Rapid Prototype - Plastic	3D Print Current Sensor Mount	kg	0.027	None	1	None	1	$ 32.00	$ 0.86
	Assemble, 1 kg, Interference	Push in threaded inserts	unit	1	Repeat 2	2	None	1	$ 0.19	$ 0.38
	Assemble, 1 kg, Loose	Assemble Current Sensor onto Mount	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 1 kg, Loose	Put M4 Washer on M4 Bolt	unit	1	Repeat 2	2	None	1	$ 0.06	$ 0.12
	Hand - Start Only	Hand Start M4 Bolt to Fasten Current Sensor to Mount	unit	1	Repeat 2	2	None	1	$ 0.12	$ 0.24
	Ratchet <= 6.35 mm	Ratchet M4 Bolt to Fasten Current Sensor to Mount	unit	1	Repeat 2	2	None	1	$ 0.50	$ 1.00
Total										$ 2.66

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Bolt, Grade 8.8 (SAE 5)	M4 Bolt	4	mm	10	mm	2	$ 0.01	$ 0.03
	Washer, Grade 8.8 (SAE 5)	M4 Washer	4	mm		0	2	$ 0.01	$ 0.01
	Thread Insert, Female Threads, Knurled Type	M4 Threaded Insert	4	mm	8	mm	2	$ 0.05	$ 0.10
Total									$ 0.14

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	P/N	E03-20-DR-053031-01	Part Cost	$ 1.00
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	1
Year	2024	Assembly	Top Plate	Extended Cost	$ 1.00
Car #	E03	Part	HV Fuse		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Fuse, Power	HV Fuse L50QS100.T	1	unit		0					1	$ 1.00	$ 1.00
Total											1		$ 1.00

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
Total										$ -

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	P/N	E03-20-DR-053033-01	Part Cost	$ 3.66
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	1
Year	2024	Assembly	Top Plate	Extended Cost	$ 3.66
Car #	E03	Part	HV Fuse Bus Bar		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Copper (by Dimensions)	Copper plate for top plate busbars		kg		0		1501	4	8940	1	$ 0.12	$ 0.12
Total											**1**		**$ 0.12**

Processes / Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Machining Setup, Install and remove	Set up waterjet cutter	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Waterjet Cut	Waterjet cut the positive the fuse bus bar	cm	223.79	None	1	None	1	$ 0.01	$ 2.24
Total										**$ 3.54**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	P/N	E03-20-DR-053008-01	Part Cost	$ 2.00
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	1
Year	2024	Assembly	Accumulator Lid	Extended Cost	$ 2.00
Car #	E03	Part	HV Lid Surlok Connectors		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Connector, HC-HV incl. Interlock	Surlock connectors	1	pin		0					2	$ 1.00	$ 2.00
Total											**2**		**$ 2.00**

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
Total										$ -

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle		P/N	E03-20-DR-053032-01		Part Cost	$ 68.47
Competition Code	FSAE-A		System	Engine/Tractive Path and Drivetrain		QTY	1
Year	2024		Assembly	Top Plate		Extended Cost	$ 68.47
Car #	E03		Part	HV Wires - Top Plate			

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Wire, HV Power	25 mm^2 HV wire	0.3	m		0					1	$ 3.00	$ 3.00
	Connector, HC-HV incl. Interlock	Radlok Connectors	1	pin		0					2	$ 30.00	$ 60.00
	Connector, HC-HV Lug Type	Lug	1	pin		0					2	$ 1.00	$ 2.00
	Heat Shrink Tubing	heat shrink	0.05	m		0					2	$ 0.03	$ 0.05
Total											**7**		**$ 65.05**

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Cut wire	Cut wires to length	unit	1	Repeat	2	None	1	$ 0.08	$ 0.16
	Strip Wire	Strip both ends of wire	unit	2	Repeat	2	None	1	$ 0.08	$ 0.32
	Insert Bundle Into Tube or Sleeve	Put heat shirnk on wires	m	0.03	None	1	None	1	$ 0.02	$ 0.00
	Connector Assembly, Crimp	Crimp Radlok on to one er	contact	1	Repeat	2	None	1	$ 0.36	$ 0.72
	Connector Assembly, Crimp	Crimp Lug onto remaining	contact	1	Repeat	2	None	1	$ 0.36	$ 0.72
	Shrink Tube	Heat Shrink to cover crimp	cm	5	Repeat	2	None	1	$ 0.15	$ 1.50
Total										**$ 3.42**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									**$ -**

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								**$ -**

University	University of Newcastle	P/N	E03-20-DR-052010-01	Part Cost	$	15.05
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY		1
Year	2024	Assembly	Accumulator Lid	Extended Cost	$	15.05
Car #	E03	Part	HV Wires - Lid			

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Wire, HV Power	25 mm^2 HV wire	0.3	m		0					2	$ 4.50	$ 9.00
	Connector, HC-HV Lug Type	Lug Terminals	1	pin		0					4	$ 1.00	$ 4.00
	Heat Shrink Tubing	heat shrink	0.015	m		0					4	$ 0.03	$ 0.12
Total													$ 13.12

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Cut wire	Cut wire to length	unit	1	None	1	Repeat 2	2	$ 0.08	$ 0.16
	Strip Wire	Strip each end of wire	unit	2	None	1	Repeat 2	2	$ 0.08	$ 0.32
	Insert Bundle Into Tube or Sleeve	Slide Heat shrink onto wires	m	0.03	Repeat 2	2	Repeat 2	2	$ 0.02	$ 0.00
	Connector Assembly, Crimp	Crimp each end with lugs	contact	1	Repeat 2	2	Repeat 2	2	$ 0.36	$ 1.44
	Shrink Tube	Shrink Heat Shrink to cover lug crimp	cm	0.015	Repeat 4	4	None	1	$ 0.15	$ 0.01
Total										$ 1.93

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle		P/N	E03-20-DR-053027-01		Part Cost	$ 300.00
Competition Code	FSAE-A		System	Engine/Tractive Path and Drivetrain		QTY	1
Year	2024		Assembly	Top Plate		Extended Cost	$ 300.00
Car #	E03		Part	IMD PCB			

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Isolation Monitoring Device	Bender ISOMETER® IR155-3203/IR155-3204	1	unit		0					1	$ 300.00	$ 300.00
Total											1		$ 300.00

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
Total										$ -

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	P/N	E03-20-DR-053037-01	Part Cost	$ 20.34
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	1
Year	2024	Assembly	Top Plate	Extended Cost	$ 20.34
Car #	E03	Part	Loom, AIRs - Precharge/IMD (HV)		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Wire, Signal and Control	Precharge to HV AIRs signal wires	0.27	m		0					4	$ 0.27	$ 1.08
	Connector, OEM Quality, High Power (>2A/25W)	Precharge 4 pin molex connector HV in/out	4	pin		0					1	$ 4.00	$ 4.00
	Connector, OEM Quality, High Power (>2A/25W)	Precharge (TS neg), IMD (Pos/Neg) 2 pin molex connector	2	pin		0					3	$ 2.00	$ 6.00
	Connector, Single Wire	Ring terminals	4	Unit		0					1	$ 0.20	$ 0.20
	Heat Shrink Tubing	Heat shrink for ring terminals	0.05	m		0					4	$ 0.03	$ 0.10
Total											13		$ 11.38

Processes / Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Cut wire	Cut each wire to length	unit	4	None	1	None	1	$ 0.08	$ 0.32
	Strip Wire	Strip each end of wire	unit	2	None	1	Repeat 5	5	$ 0.08	$ 0.80
	Connector Assembly, Crimp	Crimp ends and insert into 2 pin molex connectors	contact	3	Repeat 2	2	None	1	$ 0.36	$ 2.16
	Connector Assembly, Crimp	Crimp ends and insert into 4 pin molex connector	contact	1	Repeat 2	2	None	1	$ 0.36	$ 0.72
	Insert Bundle Into Tube or Sleeve	Insert bundle into heat shrink	m	0.05	None	1	Repeat 4	4	$ 0.02	$ 0.00
	Connector Assembly, Crimp	Crimp Ring terminal to wire end	contact	1	None	1	Repeat 4	4	$ 0.36	$ 1.44
	Shrink Tube	Shrink heat shrinks	cm	5	None	1	Repeat 4	4	$ 0.15	$ 3.00
	Install Tie Wrap (Zip Tie, Cable Clamp)	Grouping loom	unit	1	None	1	Repeat 4	4	$ 0.09	$ 0.36
Total										$ 8.80

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Tie Wrap, Plastic	Group the Loom together	1	Unit		0	4	$ 0.04	$ 0.16
Total									$ 0.16

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	P/N	E03-20-DR-053034-01	Part Cost	$	26.74
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY		1
Year	2024	Assembly	Top Plate	Extended Cost	$	26.74
Car #	E03	Part	Loom, BMS - Current Sensor (LV)			

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Wire, Power	BMS to Current sensor power wires	0.7	m		0					2	$ 2.10	$ 4.20
	Wire, Signal and Control	BMS to Current sensor signal wires	0.7	m		0					2	$ 0.70	$ 1.40
	Connector, OEM Quality, Low Power (≤2A/25W)	BMS Connector	28	pin		0					1	$ 14.00	$ 14.00
	Connector, OEM Quality, Low Power (≤2A/25W)	Current Sensor Connector	4	pin		0					1	$ 2.00	$ 2.00
Total											**6**		**$ 21.60**

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Cut wire	cut each wire to length	unit	1	None	1	Repeat 4	4	$ 0.08	$ 0.32
	Strip Wire	Strip each end of wire	unit	2	None	1	Repeat 4	4	$ 0.08	$ 0.64
	Connector Assembly, Crimp	Crimp and Insert wire into connector	contact	1	Repeat 2	2	Repeat 4	4	$ 0.36	$ 2.88
	Install Tie Wrap (Zip Tie, Cable Clamp)	Grouping loom	unit	1	None	1	Repeat 10	10	$ 0.09	$ 0.90
Total										**$ 4.74**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Tie Wrap, Plastic	Group the Loom together	1	Unit		0	10	$ 0.04	$ 0.40
Total									**$ 0.40**

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	P/N	E03-20-DR-053036-01	Part Cost	$ 82.82
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	1
Year	2024	Assembly	Top Plate	Extended Cost	$ 82.82
Car #	E03	Part	Loom, BMS to Segments (LV)		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Wire, Power	ground wire for segments	0.5	m		0					3	$ 1.50	$ 4.50
	Wire, Signal and Control	BMS to segment signal wires	0.5	m		0					33	$ 0.50	$ 16.50
	Connector, OEM Quality, Low Power (≤2A/25W)	BMS 40 pin molex connector	40	pin		0					1	$ 20.00	$ 20.00
	Connector, OEM Quality, Low Power (≤2A/25W)	CANaMON 14 pin molex connector	14	pin		0					1	$ 7.00	$ 7.00
Total											**38**		**$ 48.00**

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Cut wire	Cut each wire to length	unit	36	None	1	None	1	$ 0.08	$ 2.88
	Strip Wire	Strip each end of wire	unit	36	Repeat 2	2	None	1	$ 0.08	$ 5.76
	Connector Assembly, Crimp	Crimp ends and install into 14 pin molex	contact	3	Repeat 12	12	None	1	$ 0.36	$ 12.96
	Connector Assembly, Crimp	Crimp ends and install into 40 pin molex connector	contact	1	Repeat 12	12	Repeat 3	3	$ 0.36	$ 12.96
	Install Tie Wrap (Zip Tie, Cable Clamp)	Connect zip ties to group loom	unit	2	None	1	None	1	$ 0.09	$ 0.18
Total										**$ 34.74**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Tie Wrap, Plastic	zip ties to group loom		Unit		0	2	$ 0.04	$ 0.08
Total									**$ 0.08**

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								**$ -**

Change to be the colour of the system and 5 wide

University	University of Newcastle
Competition Code	FSAE-A
Year	2024
Car #	E03

P/N	E03-20-DR-053039-01
System	Engine/Tractive Path and Drivetrain
Assembly	Top Plate
Part	Loom, CANaMONs Daisy Chain (LV)

Part Cost	$ 4.07
QTY	90
Extended Cost	$ 366.30

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Wire, HV Power	Power and GND	0.025	m		0					2	$ 0.08	$ 0.15
	Connector, OEM Quality, Low Power (≤2A/25W)	CANaMON 2 pin molex connector	2	pin		0					1	$ 1.00	$ 1.00
	Connector, OEM Quality, Low Power (≤2A/25W)	Cell 2 pin molex connector	2	pin		0					1	$ 1.00	$ 1.00
Total											**4**		**$ 2.15**

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Cut wire	Cut each wire to length	unit	1	None	1	Repeat 2	2	$ 0.08	$ 0.16
	Strip Wire	Strip each end of wire	unit	2	None	1	Repeat 2	2	$ 0.08	$ 0.32
	Connector Assembly, Crimp	Crimp and insert ends into 2 pin CANaMON molex connector	contact	1	None	1	Repeat 2	2	$ 0.36	$ 0.72
	Connector Assembly, Crimp	Crimp and insert ends into 2 pin Segment molex connector	contact	1	None	1	Repeat 2	2	$ 0.36	$ 0.72
Total										**$ 1.92**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	None								$ -
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								**$ -**

University	University of Newcastle	P/N	E03-20-DR-053007-01	Part Cost	$ 15.24
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	1
Year	2024	Assembly	Accumulator Lid	Extended Cost	$ 15.24
Car #	E03	Part	Loom, LVD to AIL		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Wire, Power	Wires from LVD to AIL	1.8	m		0					2	$ 5.40	$ 10.80
	Connector, OEM Quality, Low Power (≤2A/25W)	Molex connectors for each PCB	2	pin		0					2	$ 1.00	$ 2.00
Total											**4**		**$ 12.80**

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Cut wire	cut each wire to length	unit	1	None	1	Repeat 2	2	$ 0.08	$ 0.16
	Strip Wire	Strip each end of wire	unit	2	None	1	Repeat 2	2	$ 0.08	$ 0.32
	Connector Assembly, Crimp	Crimp and Install into connectors	contact	2	None	1	Repeat 2	2	$ 0.36	$ 1.44
	Install Tie Wrap (Zip Tie, Cable Clamp)	Grouping loom	unit	4	None	1	None	1	$ 0.09	$ 0.36
Total										**$ 2.28**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Tie Wrap, Plastic	Keeping loom bundled	1	Unit		0	4	$ 0.04	$ 0.16
Total									**$ 0.16**

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								**$ -**

University	University of Newcastle	P/N	E03-20-DR-053038-01	Part Cost	$ 16.04
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	1
Year	2024	Assembly	Top Plate	Extended Cost	$ 16.04
Car #	E03	Part	Loom, LVD to CANaMONs (LV)		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Wire, Power	Wires from LVD to Canamon	0.96	m		0					2	$ 2.88	$ 5.76
	Wire, Signal and Control	Signal Wires LVD to Canamon	0.96	m		0					2	$ 0.96	$ 1.92
	Connector, OEM Quality, Low Power (≤2A/25W)	Molex Microfit Connectors for each PCB	4	pin		0					2	$ 2.00	$ 4.00
Total											**6**		**$ 11.68**

Processes

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Cut wire	Cut each wire to length	unit	1	None	1	Repeat 4	4	$ 0.08	$ 0.32
	Strip Wire	Strip each end of wire	unit	2	None	1	Repeat 4	4	$ 0.08	$ 0.64
	Connector Assembly, Crimp	Insert crimped ends into connectors	contact	4	None	1	Repeat 2	2	$ 0.36	$ 2.88
	Install Tie Wrap (Zip Tie, Cable Clamp)	Grouping loom	unit	1	None	1	Repeat 4	4	$ 0.09	$ 0.36
Total										**$ 4.20**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Tie Wrap, Plastic	Group Loom together	1	Unit		0	4	$ 0.04	$ 0.16
Total									**$ 0.16**

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								**$ -**

University	University of Newcastle	P/N	E03-20-DR-053035-01	Part Cost	$ 82.55
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	1
Year	2024	Assembly	Top Plate	Extended Cost	$ 82.55
Car #	E03	Part	Loom, LVD-BMS,IMD,Precharge,AIR (LV)		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Wire, Power	Wires from BMS to LVD	0.47	m		0					5	$ 1.41	$ 7.05
	Wire, Signal and Control	Signal Wires BMS to LVD	0.47	m		0					2	$ 0.47	$ 0.94
	Connector, OEM Quality, Low Power (≤2A/25W)	32 pin molex connector	32	pin		0					1	$ 16.00	$ 16.00
	Wire, Power	Wires from AIRs to LVD	0.63	m		0					4	$ 1.89	$ 7.56
	Wire, Power	Wires from IMD to LVD	0.32	m		0					3	$ 0.96	$ 2.88
	Wire, Signal and Control	Signal Wires IMD to LVD	0.32	m		0					2	$ 0.32	$ 0.64
	Connector, OEM Quality, Low Power (≤2A/25W)	8 pin molex connector	8	pin		0					1	$ 4.00	$ 4.00
	Wire, Power	Wires from PreCharge to LVD	0.4	m		0					5	$ 1.20	$ 6.00
	Wire, Signal and Control	Signal Wires PreCharge to LVD	0.4	m		0					2	$ 0.40	$ 0.80
	Connector, OEM Quality, Low Power (≤2A/25W)	8 pin molex connector	8	pin		0					1	$ 4.00	$ 4.00
	Connector, OEM Quality, Low Power (≤2A/25W)	22 pin molex connector	22	pin		0					1	$ 11.00	$ 11.00
Total											27		$ 60.87

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Cut wire	cut each wire to length	unit	21	None	1	None	1	$ 0.08	$ 1.68
	Cut wire	Cut wires that come with AIRs	unit	2	None	1	None	1	$ 0.08	$ 0.16
	Strip Wire	Strip each end of wire	unit	21	Repeat 2	2	None	1	$ 0.08	$ 3.36
	Strip Wire	Strip wires that come with AIRs	unit	2	None	1	None	1	$ 0.08	$ 0.16
	Connector Assembly, Crimp	Crimp ends and install into 22 pin molex connector	contact	1	Repeat 22	22	None	1	$ 0.36	$ 7.92
	Connector Assembly, Crimp	Crimp ends and install into 8 pin molex connector	contact	1	Repeat 7	7	None	1	$ 0.36	$ 2.52
	Connector Assembly, Crimp	Crimp ends and install into 8 pin molex connector	contact	1	Repeat 5	5	None	1	$ 0.36	$ 1.80
	Connector Assembly, Crimp	Crimp ends and install into 32 pin BMS connector	contact	1	Repeat 7	7	None	1	$ 0.36	$ 2.52
	Install Tie Wrap (Zip Tie, Cable Clamp)	Grouping loom	unit	12	None	1	None	1	$ 0.09	$ 1.08
Total										$ 21.20

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Tie Wrap, Plastic	Group the Loom together	1	Unit		0	12	$ 0.04	$ 0.48
Total									$ 0.48

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	P/N	E03-20-DR-053009-01	Part Cost	$	247.00
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY		1
Year	2024	Assembly	Accumulator Lid	Extended Cost	$	247.00
Car #	E03	Part	LVD PCB			

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Connector, OEM Quality, High Power (>2A/25W)	6 pin Deutsch	6	pin		0					2	$ 6.00	$ 12.00
	Connector, OEM Quality, High Power (>2A/25W)	12 pin Deutsch	12	pin		0					1	$ 12.00	$ 12.00
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	Molex 2 pin	2	pin		0					1	$ 4.00	$ 4.00
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	Molex 4 pin	4	pin		0					1	$ 8.00	$ 8.00
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	Molex 22 pin	22	pin		0					1	$ 44.00	$ 44.00
	Printed Circuit Board	Actual PCB from PCBGOGO	12813.997	mm^2	2	0					1	$ 51.26	$ 51.26
	Simple PCB component	Back Resistors and Capacitors	21	unit		0					1	$ 0.42	$ 0.42
	Simple PCB component	Front Resisors and Capacitors	11	unit		0					1	$ 0.18	$ 0.18
	Fuse, Power	Fusing	1	unit		0					7	$ 1.00	$ 7.00
	Lamp, LED	LEDs	1	unit		0					5	$ 0.50	$ 2.50
	Relay, Signal and Control	G5V-1	1	unit		0					1	$ 2.00	$ 2.00
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	CANBUS Connector	9	pin		0					2	$ 18.00	$ 36.00
	Simple Integrated Circuit	TJA1052i-2, LM7805_DPAK, TJA1051T-3, MCT06P10, IRLB8721PBF, SPAN02A-05, MCT06P10	1	Unit		0					5	$ 2.00	$ 10.00
	Development Board, Hobby	Teensy 4.0	1	unit		0					1	$ 20.00	$ 20.00
	Semi-complex PCB component	MOSFETS, Diodes	19	unit		0					1	$ 0.95	$ 0.95
	Switch, Toggle	CANBUS termination	1	unit		0					2	$ 1.00	$ 2.00
	Conformal Coating		12813.997	mm^2	2	unit					1	$ 0.03	$ 0.03
Total											**34**		**$ 212.34**

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Solder Paste Apply		unit	1	Repeat 2	2	None	1	$ 1.00	$ 2.00
	Machining Setup, Install and remove	Pick and place set up	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Pick and Place	Placement of all components Front	unit	11	None	1	None	1	$ 0.01	$ 0.11
	Machining Setup, Change	Pick and place change for 2nd side	unit	1	None	1	None	1	$ 0.65	$ 0.65
	Circuit Card Assembly Labor - Pick and Place	Placement of all components Back	unit	55	None	1	None	1	$ 0.01	$ 0.55
	Machining Setup, Install and remove	Pick and place machine removal	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Machining Setup, Install and remove	Reflow oven set up	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Reflow Oven	Reflow oven front side	unit	1	None	1	None	1	$ 1.00	$ 1.00
	Machining Setup, Change	Reflow oven change for 2nd side	unit	1	None	1	None	1	$ 0.65	$ 0.65
	Circuit Card Assembly Labor - Reflow Oven	Reflow oven back side	unit	1	None	1	None	1	$ 1.00	$ 1.00
	Machining Setup, Install and remove	Reflow oven machine removal	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Hand Soldering	Hand solder remaining components	unit	6	None	1	None	1	$ 0.05	$ 0.30
	Hand - Start Only	Hand start screws to secure Deutsch connectors to PCB	unit	4	Repeat 3	3	None	1	$ 0.12	$ 1.44
	Screwdriver > 1 Turn	Tighten screws to secure Deutsch connectors to PCB	unit	4	Repeat 3	3	None	1	$ 0.50	$ 6.00
	Circuit Card Assembly Labor - Hand Soldering	Solder Deutsch and other connectors to board	unit	8	None	1	None	1	$ 0.05	$ 0.40
	Programming, Dataset Upload, End of Line	Programming Teensy	Unit	1	None	1	None	1	$ 5.00	$ 5.00
	Conformal Coat Apply	Conformal Coat both sides	unit	1	Repeat 2	2	None	1	$ 5.00	$ 10.00
Total										**$ 34.30**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Bolt, Grade 12.9	M3 screws to secure deutsch connectors	3	mm	15	mm	6	$ 0.02	$ 0.12
Total									**$ 0.12**

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
	PCB Stensil		0	1	3000	1	$ 700.00	$ 0.23
	PCB component positioning jig		0	1	3000	1	$ 50.00	$ 0.02
Total								**$ 0.25**

University	University of Newcastle	P/N	E03-20-DR-053015-01	Part Cost	$ 5.65
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	16
Year	2024	Assembly	Segments 1 & 9	Extended Cost	$ 90.44
Car #	E03	Part	Methode Pins		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Copper (by Dimensions)	Hex bar for methode pins		kg		0		177	82	8940	1	$ 0.29	$ 0.29
Total													$ 0.29

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Machining Setup, Install and remove	Set up lathe for methode pins	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Machining	Machine first side of pin	cm^3	2.5162	None	1	None	1	$ 0.04	$ 0.10
	Machining	cut bottom side of pin	cm^3	1.365945	None	1	None	1	$ 0.04	$ 0.05
	Machining Setup, Change	change tool to thread cutter	unit	1	None	1	None	1	$ 0.65	$ 0.65
	Machining	Cut thread into top side of pin	cm^3	0.1	None	1	None	1	$ 0.04	$ 0.00
	Machining	Cut thread into bottom side of pin	cm^3	0.1	None	1	None	1	$ 0.04	$ 0.00
	Machining Setup, Change	change to parting tool	unit	5	None	1	None	1	$ 0.65	$ 3.25
	Machining	cut off pin	cm^3	0.098175	None	1	None	1	$ 0.04	$ 0.00
Total										$ 5.37

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle		P/N	E03-20-DR-053019-01		Part Cost	$ 1.30
Competition Code	FSAE-A		System	Engine/Tractive Path and Drivetrain		QTY	9
Year	2024		Assembly	Segments 1 & 9		Extended Cost	$ 11.68
Car #	E03		Part	Methode Pin Locker			

Change to be the colour of the system and 5 wide

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Plastic, UL94 Compliant, Any Composition (per kg)	segment fastener positive locking block	0.02468	kg		0	Firewire Fillament roll				1	$ 3.30	$ 0.08
Total											**1**		**$ 0.08**

Processes

Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Rapid Prototype - Plastic	3D print methode pin locker	kg	0.008	None	1	None	1	$ 32.00	$ 0.26
	Rapid Prototype - Plastic	3D print segment fastener positive locking block	kg	0.03	None	1	None	1	$ 32.00	$ 0.96
Total										**$ 1.22**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	P/N	E03-20-DR-053028-01	Part Cost	$ 225.66
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	1
Year	2024	Assembly	Top Plate	Extended Cost	$ 225.66
Car #	E03	Part	Precharge PCB		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	Molex 2 pin	2	pin		0					1	$ 4.00	$ 4.00
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	Molex 4 pin	4	pin		0					1	$ 8.00	$ 8.00
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	Molex 8 pin	8	pin		0					1	$ 44.00	$ 44.00
	Printed Circuit Board	PCB from PCBGOGO	12949	mm^2	2	0					1	$ 51.80	$ 51.80
	Simple PCB component	Back Resistors and Capacitors	11	unit		0					1	$ 0.42	$ 0.42
	Simple PCB component	Front Resisors and Capacitors	64	unit		0					1	$ 0.18	$ 0.18
	Lamp, LED	LEDs	1	unit		0					4	$ 0.50	$ 2.00
	Relay, Signal and Control	G5V-1	1	unit		0					1	$ 2.00	$ 2.00
	Relay, Power	G7L-2A-X-L, G2RL-24	1	unit		0					2	$ 4.00	$ 8.00
	Connector, General Purpose, Unsealed, Low Power (≤2A/25W)	CANBUS Connector	9	pin		0					2	$ 18.00	$ 36.00
	Simple Integrated Circuit	Regulators, OpAmps, Comparators	1	Unit		0					10	$ 2.00	$ 20.00
	Development Board, Hobby	Teensy 4.0	1	unit		0					1	$ 20.00	$ 20.00
	Semi-complex PCB component	MOSFETS, Diodes	13	unit		0					1	$ 0.95	$ 0.95
	Switch, Toggle	CANBUS termination	1	unit		0					1	$ 1.00	$ 1.00
	Conformal Coating		12949	mm^2	2	unit					1	$ 0.03	$ 0.03
Total											**29**		**$ 198.38**

Processes / Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Solder Paste Apply		unit	1	Repeat 2	2	None	1	$ 1.00	$ 2.00
	Machining Setup, Install and remove	Pick and place set up	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Pick and Place	Placement of all components Front	unit	92	None	1	None	1	$ 0.01	$ 0.92
	Machining Setup, Change	Pick and place change for 2nd side	unit	1	None	1	None	1	$ 0.65	$ 0.65
	Circuit Card Assembly Labor - Pick and Place	Placement of all components Back	unit	11	None	1	None	1	$ 0.01	$ 0.11
	Machining Setup, Install and remove	Pick and place machine removal	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Machining Setup, Install and remove	Reflow oven set up	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Reflow Oven	Reflow oven front side	unit	1	None	1	None	1	$ 1.00	$ 1.00
	Machining Setup, Change	Reflow oven change for 2nd side	unit	1	None	1	None	1	$ 0.65	$ 0.65
	Circuit Card Assembly Labor - Reflow Oven	Reflow oven back side	unit	1	None	1	None	1	$ 1.00	$ 1.00
	Machining Setup, Install and remove	Reflow oven machine removal	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Circuit Card Assembly Labor - Hand Soldering	Hand solder remaining components	unit	10	None	1	None	1	$ 0.05	$ 0.50
	Conformal Coat Apply	Conformal Coat both sides	unit	1	Repeat 2	2	None	1	$ 5.00	$ 10.00
	Programming, Dataset Upload, End of Line	Program teensy 4.0	Unit	1	None	1	None	1	$ 5.00	$ 5.00
Total										**$ 27.03**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									**$ -**

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
	PCB Stensil		0	1	3000	1	$ 700.00	$ 0.23
	PCB component positioning jig		0	1	3000	1	$ 50.00	$ 0.02
Total								**$ 0.25**

University	University of Newcastle	P/N	E03-20-DR-053018-01	Part Cost	$ 6.31
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	2
Year	2024	Assembly	Segments 1 & 9	Extended Cost	$ 12.62
Car #	E03	Part	Radlok Pins		

Materials

ID	Material	Description	Size 1	Unit 1	Size 2	Unit 2	Area Name	Area (mm^2)	Length (mm)	Density (kg/m^3)	QTY	Unit Cost	Sub Total
	Copper (by Dimensions)	Hex bar for methode pins		kg		0		177	82	8940	1	$ 0.29	$ 0.29
Total													$ 0.29

Processes / Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Machining Setup, Install and remove	Set up lathe for methode pins	unit	1	None	1	None	1	$ 1.30	$ 1.30
	Machining	Machine first side of pin	cm^3	3.459362	None	1	None	1	$ 0.04	$ 0.14
	Machining	cut threaded side	cm^3	0.651451	None	1	None	1	$ 0.04	$ 0.03
	Machining Setup, Change	change tool to thread cutter	unit	1	None	1	None	1	$ 0.65	$ 0.65
	Machining	Thread top side of pin	cm^3	0.1	None	1	None	1	$ 0.04	$ 0.00
	Machining	Thread Bottom side of pin	cm^3	0.1	None	1	None	1	$ 0.04	$ 0.00
	Machining Setup, Change	Change to gouging tool	unit	1	None	1	None	1	$ 0.65	$ 0.65
	Machining	cut groove in top of pin	cm^3	0.01442	None	1	None	1	$ 0.04	$ 0.00
	Machining Setup, Change	change to parting tool	unit	5	None	1	None	1	$ 0.65	$ 3.25
	Machining	cut off pin	cm^3	0.098175	None	1	None	1	$ 0.04	$ 0.00
Total										$ 6.03

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
Total									$ -

Tooling

ID	Tooling	Use	Unit	QTY	PVF	Frac. Incl	Unit Cost	Sub Total
Total								$ -

University	University of Newcastle	A/N	E03-20-DR-052012-01	Part Cost	N/A
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	N/A
Year	2024	Assembly	Segments 1 & 9	Extended Cost	$ 799.68
Car #	E03	Part	N/A		

Parts

ID	P/N	Description	Part Cost	QTY	Sub Total
	E03-20-DR-053013-01	Cell	$ 39.00	12	$ 468.00
	E03-20-DR-053014-01	Segment Busbar	$ 1.46	1	$ 1.46
	E03-20-DR-053015-01	Methode Pins	$ 5.65	1	$ 5.65
	E03-20-DR-053016-01	CANaMON PCB	$ 172.03	1	$ 172.03
	E03-20-DR-053017-01	Segment Housing	$ 76.59	1	$ 76.59
	E03-20-DR-053018-01	Radlok Pins	$ 6.31	1	$ 6.31
	E03-20-DR-053019-01	Methode Pin Locker	$ 1.30	1	$ 1.30
Total					$ 731.34

Processes / Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Assemble, 1 kg, Loose	Assemble cell stacks in formation	unit	1	None	1	Repeat 12	12	$ 0.06	$ 0.72
	Hand, Tight <= 6.35 mm	Hand tighten methode pins into first cell stack	unit	1	None	1	None	1	$ 0.50	$ 0.50
	Hand, Tight <= 6.35 mm	Hand tighten Radlok connector pin to cell stack	unit	1	None	1	None	1	$ 0.50	$ 0.50
	Assemble, 1 kg, Loose	Place busbars in correct location on cell stack	unit	1	None	1	Repeat 12	12	$ 0.06	$ 0.72
	Assemble, 1 kg, Loose	Place structural bolts through bolt holes	unit	22	None	1	None	1	$ 0.06	$ 1.32
	Hand - Start Only	Hand start the M5 structural bolts	unit	1	None	1	Repeat 22	22	$ 0.12	$ 2.64
	Ratchet <= 6.35 mm	Tighten M5 structural bolts	unit	1	None	1	Repeat 22	22	$ 0.50	$ 11.00
	Assemble, 1 kg, Loose	Place CANaMON in cell stack	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 1 kg, Loose	Place conductive bolts through bolt holes	unit	11	None	1	None	1	$ 0.06	$ 0.66
	Assemble, 1 kg, Loose	Hand start the M4 conductive bolts	unit	1	None	1	Repeat 11	11	$ 0.06	$ 0.66
	Ratchet <= 6.35 mm	Tighten M4 conductive bolts	unit	1	None	1	Repeat 11	11	$ 0.50	$ 5.50
	Assemble, 1 kg, Loose	Place methode washer over methode pin	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Hand - Start Only	Hand tighten methode pin nut over methode pin	unit	1	None	1	None	1	$ 0.12	$ 0.12
	Ratchet <= 6.35 mm	Tighten methode pin nut over methode pin	unit	1	None	1	None	1	$ 0.50	$ 0.50
	Assemble, 1 kg, Loose	Place Radlok washer over Radlok pin	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Hand - Start Only	Hand tighten Radlok pin nut over Radlok pin	unit	1	None	1	None	1	$ 0.12	$ 0.12
	Ratchet <= 6.35 mm	Tighten Radlok pin nut over Radlok pin	unit	1	None	1	None	1	$ 0.50	$ 0.50
	Assemble, 3 kg, Line-on-Line	Slide segments into segment housing	unit	1	None	1	None	1	$ 0.38	$ 0.38
	Assemble, 3 kg, Line-on-Line	Place segments and housing into accumulator container	unit	1	None	1	None	1	$ 0.38	$ 0.38
	Assemble, 1 kg, Loose	Place service handle on top of Methode and Radlok pins	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 1 kg, Loose	Place 3D printed segment fastener positive locking cover on each segment	unit	1	None	1	None	1	$ 0.06	$ 0.06
Total										$ 26.52

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Bolt, Grade 12.9	M5 structural bolts for busbar		mm		mm	22	$ 1.25	$ 27.50
	Nut, Grade 12.9	M5 structural nut for busbar		mm		0	22	$ 0.02	$ 0.33
	Bolt, Grade 12.9	M4 conductive bolts for busbar		mm		mm	11	$ 1.25	$ 13.75
	Nut, Grade 12.9	M4 conductive nut for busbar		mm		0	11	$ 0.02	$ 0.17
	Washer, Grade 12.9	M4 conductive washer for busbar		mm		0	11	$ 0.00	$ 0.04
	Washer, Grade 12.9	Methode washer		mm		0	1	$ 0.00	$ 0.00
	Nut, Grade 12.9	Methode nut		mm		0	1	$ 0.02	$ 0.02
	Washer, Grade 12.9	Radlok washer		mm		0	1	$ 0.00	$ 0.00
	Nut, Grade 12.9	Radlok nut		mm		0	1	$ 0.02	$ 0.02
Total									$ 41.83

University	University of Newcastle	A/N	E03-20-DR-052011-01	Part Cost	N/A		
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	N/A		
Year	2024	Assembly	Segments 2-8	Extended Cost	$ 834.95		
Car #	E03	Part	N/A				

Parts

ID	P/N	Description	Part Cost	QTY	Sub Total
	E03-20-DR-053013-01	Cell	$ 39.00	12	$ 468.00
	E03-20-DR-053014-01	Segment Busbar	$ 1.46	11	$ 16.05
	E03-20-DR-053015-01	Methode Pins	$ 5.65	2	$ 11.31
	E03-20-DR-053016-01	CANaMON PCB	$ 172.03	1	$ 172.03
	E03-20-DR-053017-01	Segment Housing	$ 76.59	1	$ 76.59
	E03-20-DR-053019-01	Methode Pin Locker	$ 1.30	1	$ 1.30
Total					**$ 745.26**

Processes / Process Multipliers

ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Assemble, 1 kg, Loose	Assemble cell stacks in formation	unit	1	None	1	Repeat 12	12	$ 0.06	$ 0.72
	Hand, Tight <= 6.35 mm	Hand tighten methode pins into first cell stack	unit	1	None	1	Repeat 2	2	$ 0.50	$ 1.00
	Assemble, 1 kg, Loose	Place busbars in correct spot on cell stacks	unit	11	None	1	None	1	$ 0.06	$ 0.66
	Assemble, 1 kg, Loose	Place structural bolts through bolt holes	unit	22	None	1	None	1	$ 0.06	$ 1.32
	Hand - Start Only	Hand start the M5 structural bolts	unit	1	None	1	Repeat 22	22	$ 0.12	$ 2.64
	Ratchet <= 6.35 mm	Tighten M5 structural bolts	unit	1	None	1	Repeat 22	22	$ 0.50	$ 11.00
	Assemble, 1 kg, Loose	Place CANaMON PCB on cell stack	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 1 kg, Loose	Place conductive bolts through bolt holes	unit	11	None	1	None	1	$ 0.06	$ 0.66
	Hand - Start Only	Hand start the M4 conductive bolts	unit	1	None	1	Repeat 11	11	$ 0.12	$ 1.32
	Power Tool <= 6.35 mm	Tighten M4 conductive bolts	unit	1	None	1	Repeat 11	11	$ 0.25	$ 2.75
	Assemble, 1 kg, Loose	Place methode washer over methode pins	unit	2	None	1	None	1	$ 0.06	$ 0.12
	Hand - Start Only	Hand start methode nut over methode pins	unit	1	None	1	Repeat 2	2	$ 0.12	$ 0.24
	Ratchet <= 6.35 mm	Tighten methode nut over methode pins	unit	1	None	1	Repeat 2	2	$ 0.50	$ 1.00
	Assemble, 3 kg, Line-on-Line	Slide segment into segment housings	unit	1	None	1	None	1	$ 0.38	$ 0.38
	Assemble, 1 kg, Loose	Place Methode pin Locker onto methode pins	unit	1	None	1	None	1	$ 0.06	$ 0.06
Total										**$ 23.93**

Fasteners

ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Bolt, Grade 12.9	M5 Structural Bolts for busbar		mm		mm	22	$ 1.25	$ 27.50
	Nut, Grade 12.9	M5 structural Nut for busbar		mm		0	22	$ 0.02	$ 0.33
	Bolt, Grade 12.9	M4 conductive Bolts for busbar		mm		mm	11	$ 1.25	$ 13.75
	Washer, Grade 12.9	M4 conductive Washer for busbar		mm		0	11	$ 0.00	$ 0.04
	Nut, Grade 12.9	M4 conductive Nut for busbar		mm		0	11	$ 0.02	$ 0.17
	Washer, Grade 12.9	Methode washer		mm		0	2	$ 0.00	$ 0.01
	Nut, Grade 12.9	Methode nut		mm		0	2	$ 0.02	$ 0.03
Total									**$ 41.83**

University	University of Newcastle	A/N	E03-20-DR-052024-01	Part Cost	N/A
Competition Code	FSAE-A	System	Engine/Tractive Path and Drivetrain	QTY	N/A
Year	2024	Assembly	Top Plate	Extended Cost	$ 5,283.36
Car #	E03	Part	N/A		

Parts

ID	P/N	Description	Part Cost	QTY	Sub Total
	E03-20-DR-053025-01	AIRs	$ 120.00	2	$ 240.00
	E03-20-DR-053026-01	BMS	$ 2,160.00	1	$ 2,160.00
	E03-20-DR-053027-01	IMD PCB	$ 300.00	1	$ 300.00
	E03-20-DR-053028-01	Precharge PCB	$ 225.66	1	$ 225.66
	E03-20-DR-053029-01	Top Plate	$ 1,655.56	1	$ 1,655.56
	E03-20-DR-053030-01	Current Sensor	$ 7.08	1	$ 7.08
	E03-20-DR-053031-01	HV Fuse	$ 1.00	1	$ 1.00
	E03-20-DR-053032-01	HV Wires - Top Plate	$ 68.47	1	$ 68.47
	E03-20-DR-053033-01	HV Bus Bar	$ 3.66	1	$ 3.66
	E03-20-DR-053034-01	Loom, BMS - Current Sensor (LV)	$ 26.74	1	$ 26.74
	E03-20-DR-053035-01	Loom, LVD-BMS,IMD,Precharge,AIR (LV)	$ 82.55	1	$ 82.55
	E03-20-DR-053036-01	Loom, BMS to Segments (LV)	$ 82.82	1	$ 82.82
	E03-20-DR-053037-01	Loom, AIRs - Precharge/IMD (HV)	$ 20.34	1	$ 20.34
	E03-20-DR-053038-01	Loom, LVD to CANaMONs (LV)	$ 16.04	1	$ 16.04
	E03-20-DR-053039-01	Loom, CANaMONs Daisy Chain (LV)	$ 4.07	90	$ 366.30
Total					**$ 5,256.22**

Processes

Process Multipliers

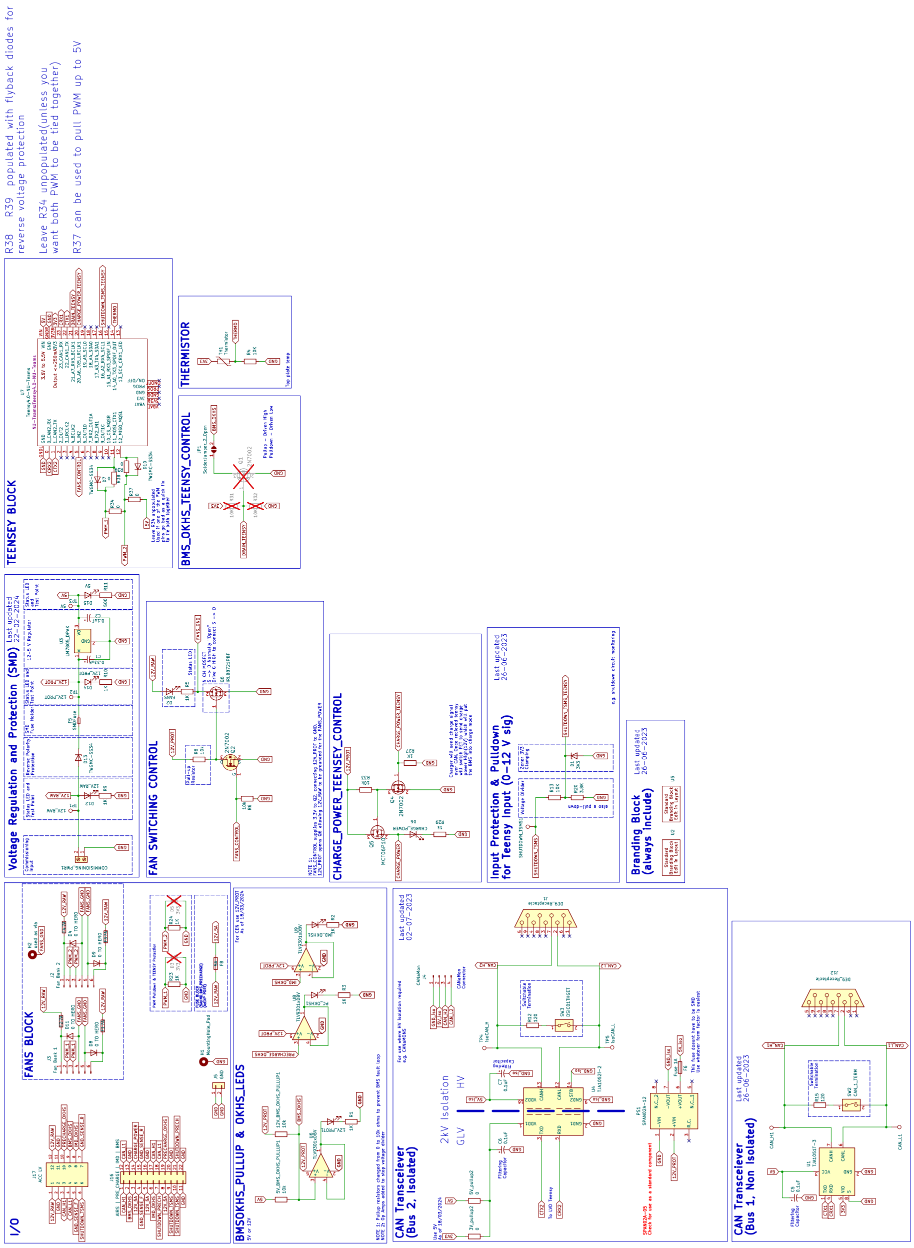
ID	Process	Use	Unit	QTY	Multiplier	Mult. Val.	Multiplier 2	Mult. Val. 2	Unit Cost	Sub total
	Assemble, 10 kg, Loose	Place top plate in position	unit	1	none	1	None	1	$ 0.63	$ 0.63
	Assemble, 1 kg, Loose	Place airs on board with bolts	unit	2	None	1	None	1	$ 0.06	$ 0.12
	Hand - Start Only	Hand start M4 bolts	unit	2	Repeat 2	2	None	1	$ 0.12	$ 0.48
	Wrench <= 25.4 mm	Tighten M4 bolts	unit	2	Repeat 2	2	None	1	$ 1.50	$ 6.00
	Assemble, 1 kg, Loose	Place BMS on board with bolts	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Hand - Start Only	Hand start M5 bolts	unit	6	None	1	None	1	$ 0.12	$ 0.72
	Ratchet <= 6.35 mm	Tighten M5 bolts	unit	6	None	1	None	1	$ 0.50	$ 3.00
	Assemble, 1 kg, Loose	Place IMD on board with bolts	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Hand - Start Only	Hand start M3 bolts	unit	6	None	1	None	1	$ 0.12	$ 0.72
	Ratchet <= 6.35 mm	Tighten M3 bolts	unit	6	None	1	None	1	$ 0.50	$ 3.00
	Assemble, 1 kg, Loose	Place PreCharge on board with bolts	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Hand - Start Only	Hand start M3 bolts	unit	6	None	1	None	1	$ 0.12	$ 0.72
	Ratchet <= 6.35 mm	Tighten M3 bolts	unit	6	None	1	None	1	$ 0.50	$ 3.00
	Assemble, 1 kg, Loose	Place HV fuse with bolts	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Assemble, 1 kg, Loose	Place fuse bus bar	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Hand - Start Only	Hand start M6 bolts	unit	2	None	1	None	1	$ 0.12	$ 0.24
	Ratchet <= 25.4 mm	Tighten M6 bolts	unit	2	None	1	None	1	$ 0.75	$ 1.50
	Resin application, Manual	Apply resin to under side of board and sensor mount	m^2	0.001649	None	1	None	1	$ 5.00	$ 0.01
	Assemble, 1 kg, Loose	Place Currently sensor mount on board	unit	1	None	1	None	1	$ 0.06	$ 0.06
	Connector Install	Connect BMS to current sensor	unit	1	Repeat 2	2	None	1	$ 0.11	$ 0.22
	Connector Install	BMS, IMD, PreCharge and AIR loom connected	unit	1	Repeat 4	4	None	1	$ 0.11	$ 0.44
	Connector Install	AIRs to Precharge and IMD	unit	1	Repeat 4	4	None	1	$ 0.11	$ 0.44
	Connector Install	BMS to segments connector installed	unit	1	None	1	None	1	$ 0.11	$ 0.11
	Attach Wire, Ring	Connect HV wires to AIRs	unit	2	None	1	None	1	$ 0.48	$ 0.96
	Hand - Start Only	Hand start M10 bolts	unit	2	None	1	None	1	$ 0.12	$ 0.24
	Ratchet <= 6.35 mm	Tighten M10 bolts	unit	2	None	1	None	1	$ 0.50	$ 1.00
	Lay Wire	Lay all wires neatly in top plate	m	38.32	None	1	None	1	$ 0.02	$ 0.77
	Install Tie Wrap (Zip Tie, Cable Clamp)	tie looms together and out of the way	unit		None	1	None	1	$ 0.09	$ -
Total										**$ 24.67**

Fasteners

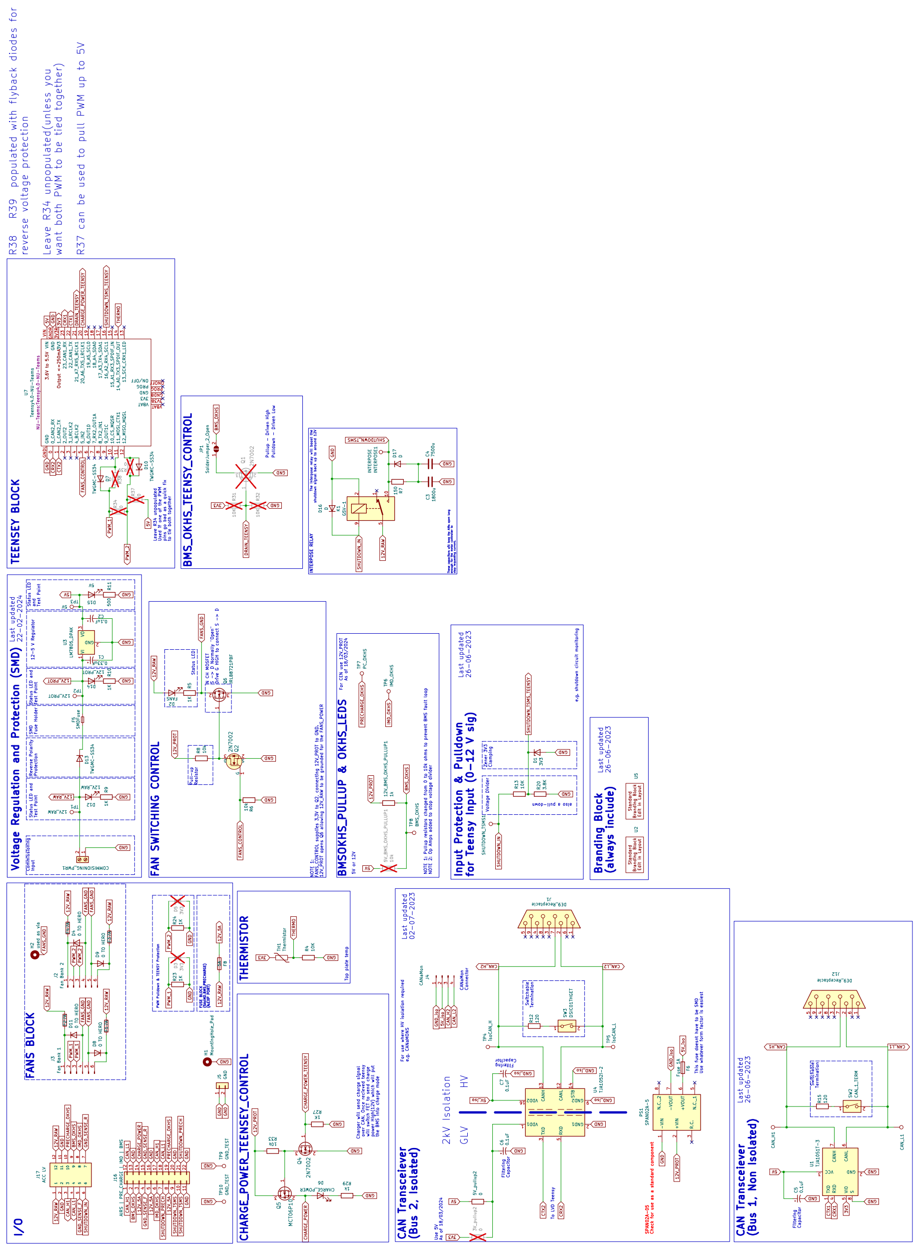
ID	Fasteners	Use	Size 1	Unit 1	Size 2	Unit 2	QTY	Unit Cost	Sub Total
	Bolt, Grade 12.9	M6 fuse bolt	6	mm	30	mm	2	$ 0.10	$ 0.21
	Washer, Grade 12.9	M6 fuse washer	6	mm		0	2	$ 0.01	$ 0.02
	Nut, Grade 12.9	M6 fuse nut	6	mm		0	4	$ 0.05	$ 0.20
	Nut, Grade 12.9	M10 AIRs nut	10	mm		0	4	$ 0.11	$ 0.44
	Washer, Grade 12.9	M10 AIRs washer	10	mm		0	4	$ 0.02	$ 0.10
	Bolt, Grade 12.9	M4 AIRs bolt	4	mm	45	mm	4	$ 0.08	$ 0.30
	Nut, Grade 12.9	M4 AIRs nut	4	mm		0	4	$ 0.03	$ 0.13
	Bolt, Grade 12.9	M5 BMS bolt	5	mm	15	mm	6	$ 0.04	$ 0.25
	Nut, Grade 12.9	M5 BMS nut	5	mm		0	6	$ 0.04	$ 0.24
	Bolt, Plastic, PolyAmide	M3 PCB bolts	3	mm		mm	12	$ 0.02	$ 0.24
	Nut, Grade 12.9	M3 PCB nut	3	mm		0	12	$ 0.03	$ 0.33
Total									**$ 2.47**

Appendix D

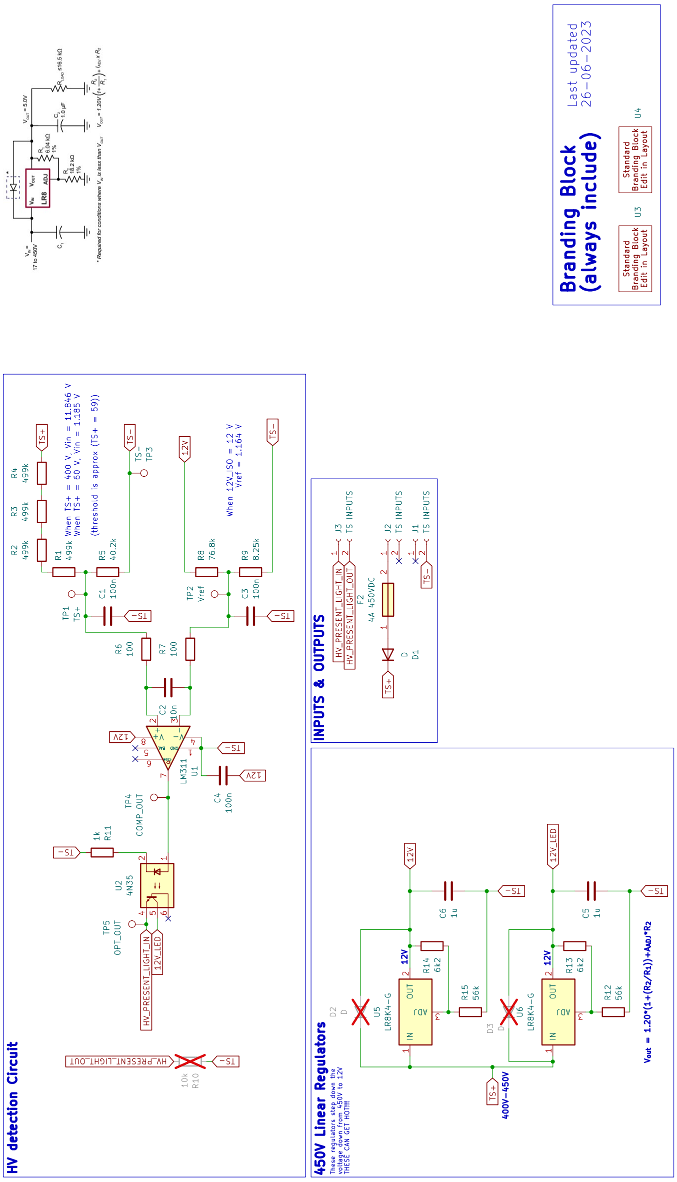
LVD V3.0 Schematics



LVD V3.1 Schematics



AIL V2.0 Schematics



PreCharge V1.2 Schematics