College of Engineering, Science and Environment
School of Engineering

Mechanical Engineering Project B

Semester 2 - 2023 ENGG4801 B

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

FINAL YEAR PROJECT

PROJECT TITLE

LVD/Accumulator Electronics

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LVD/Accumulator Electronics

DESIGN REPORT

NU23

Jedd Reeves

2023

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Abbreviations

By Jedd R

AIL: Accumulator Indicator Light

AIRs: Accumulator Inline Relays

BMS: Battery Management System

BOTS: Brake Over Travel Switch

BSPD: Brake System Plausibility Device

CAN: Controller Area Network

ECU: Electronic Control Unit

GLV: Grounded Low Voltage

GND_SENSE_F: Ground Sense Front

GND_SENSE_R: Ground Sense Rear

HV: High voltage (voltage > 60 V)

IMD: Insulation Monitoring Device

LV: Low voltage (voltages < 60 V)

LVD: Low Voltage Distribution board

OKHS: Ok High Signal- a signal that is HIGH (12 V) in its healthy state

PBD: Power Distribution Board

SMD: Surface Mount Device

TS: Tractive System Voltage – voltage of the tractive system and tractive system components (TS+-)

Acknowledgements

The author would like to acknowledge and thank Dr Alexander Gregg for his incredible support and encouragement through out the year. The author would also like to acknowledge the leadership team of NURacing for their impeccable planning and execution of the whole NURacing/NU23 project. (Marisa McLean, Jye Hollier, Jacob Bush and Robert Stanley).

Acknowledgement also needs to be given to Malcolm Sydney who had a massive input in trouble shooting and solving problems both relevant to the report and NU23. Last year's team did an amazing job in giving NURacing 2023 a amazing platform to work on and modify which gave the 2023 team a massive head start.

Lastly the 2023 NURacing team for their amazing determination and hard work throughout the year

Appendix

By Jedd R

This report outlines the design and implementation of the LVD PCB in NU23. The LVD was designed to reduce the complexity of wires and electronics within the accumulator. With the removal of the connector box from EV3's accumulator another way to distribute powers and signals around the accumulator was needed. The LVD addresses this challenge and has successfully reduced the complexity of the accumulator electronics for NU23. This report also addresses results from the 2023 FSAE competition, along with recommendations for changes and developments that can be undertaken by next year's team.

Introduction

By Jedd R

This report details the design, manufacture and commissioning of the multiple iterations of the LVD board. It also details the design of an updated HV (High Voltage) isolated AIL PCB (Accumulator Indicator Light). Additional works and recommendation for next year's team are also included in this report.

NU23 is the University of Newcastle's student built electrical race car that competed in the 2023 FSAE Australasia competition. The NURacing team was made up of roughly 18 FYP students. The team was comprised of students in Aerospace, Mechanical and Mechatronic disciplines of engineering. This report outlines the works of the author in NURacing and on NU23 throughout 2023 as well as the results and learnings from the 2023 FSAE competition. The 2023 competition took place in Calder Park Raceway, Victoria between the 14-17th of December.

LVD V1

The goal of the V1 LVD was to reduce the complexity of the wiring and layout of the accumulator. This board is responsible for fan control, power distribution, CAN communication and the interlock on the HV accumulator plug. This board was designed to make the task of removing the lid and servicing the accumulator a simpler task. The LVD has minimized the number of wires and PCBs needed in the accumulator.

LVD V2

The LVD V2 was designed to be mounted to the lid of the accumulator LID. V2 of the LVD uses PCB mounted DT connected as opposed to the Autosport connectors. This change was made due to the rest of the car using DT connectors. The LVD V2 uses one 12 pin DT connector for the LV connector which is responsible for the low voltage powers and signals and two 6 pin DT connectors for powering and controlling the 2 banks of fans. Because of the change to board mounted DT connectors only 12 pins could be used for the LV connector as opposed to the 24 pin Autosport connector. This meant that certain signals could no longer be sent to the accumulator using the LV connector. In this version of the LVD the Charge_Power signal is now switched using a MOSFET circuit on the LVD.

LVD V2.1

The LVD V2.1 was a slight improvement on the V2. The V2.1 was 11.5mm shorter in height and 1mm smaller in width this help keep the board further away from the internal and external walls of the accumulator. The V2 board had an issue where the board would scrap on one of the external walls if the lid was not put on flat. The Charge_Power switching circuit was fixed so that signal could now be automatically switched when the relevant CAN message was received. A MOSFET circuit was also added which allows the functionality of been able to completely switch off the fans using a 3.3V output from the LVD Teensy. A grounding issue that was also present on the V2 board was resolved.

AIL

The AIL PCB (Accumulator Indicator Light PCB) is responsible for the indicating when HV is present at the TS+ TS- (Tractive system) terminals on the accumulator. The aim of updated AIL was to have the 12V powering the LED be isolated from HV. This would allow the LED power wires to be run and grouped with the other LV wires in the accumulator. The previous version had to be isolated from all LV wires and PCBs.

Background

By Jedd R

NU23

NU23 is Newcastle University's 2023 student built and designed electric race car that competed in the 2023 FSAE competition in Calder Park Victoria. NU23 uses a single motor which drives a chain connected to the solid rear axle. NU23 weighed in at 259 Kg at competition and had a maximum tractive system voltage of 453.6 V. The philosophies and goals of the 2023 team were to design an extremely reliable and serviceable car while reducing part count from the previous year's car, EV3.

FSAE

Formula SAE is a competition run by SAE international where student-based teams design and race electric and ICE cars. Teams from around the world come together to compete in both static and dynamic events. These events are used to compare and judge the teams and cars. At the end of the competition the event results are announced, and the overall team standings are released. The following table shows the different static and dynamic events and the points weighing for each event.

Static Events	**Points**
Design	150
Cost	100
Business Presentation	75
Dynamic Events	
Skidpan	100
Acceleration	75
Autocross	125
Endurance	275
Efficiency	100
Total Available Points	**1000**

Low Voltage system

This section of the report briefly outlines the topology and functions of each of the electrical nodes. The LV system used on NU23 shares an extremely similar topology to EV3. NU23 LV system incorporates a multi node topology with point-to-point harness. This is done to both simplify and break the system down into much smaller parts as opposed to one large central ECU.

The goals of the LV team during 2023 was to take the framework of EV3 and align bottle necks, use simple self-documenting systems, reduce part count and prioritise long term team performance.

The NU23 LV system is made up of 5 electrical nodes located all over the car. The locations of these nodes can be seen in Figure 1. The use of multiple nodes and point to point harnesses creates an extremely simple system which means fault finding and isolating issues can be done much more efficiently. The use of separate nodes for different purposes also allows for isolated bench testing. Because of this multi node topology, one single node can be upgraded and worked on in isolation, commissioned on the bench and verified before been installed on the car. This allows for much smaller changes and iterations to be made to nodes without a whole system overhaul.

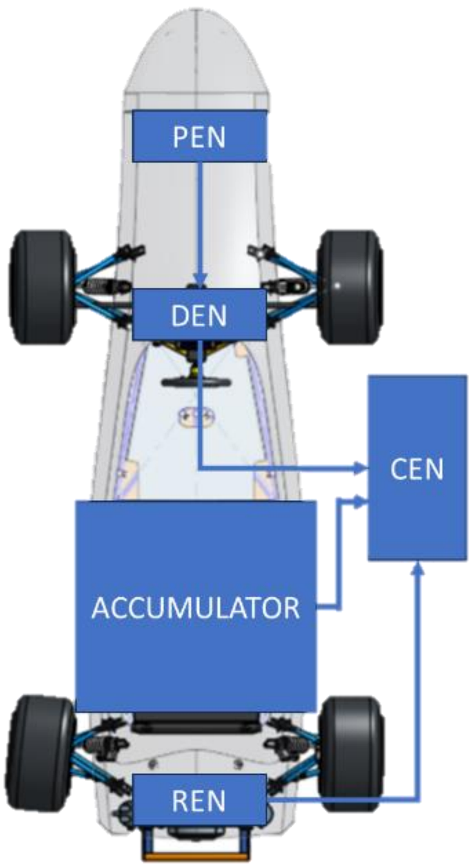


Figure 1. NU23 LV system topology

PEN

The PEN is the pedal box electrical node. This node is responsible for signals related to the throttle and brake pedals. The PEN sends throttle signals to the CEN over CAN. The is also responsible for monitoring BOTS, BSPD, aps out gated and aps out raw. This can be seen in more detail in (De Gruchy, 2023).

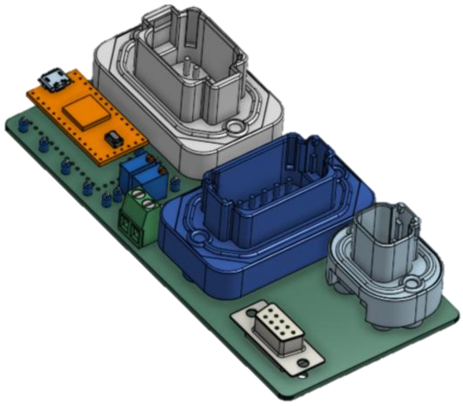


Figure 2. PEN PCB

DEN

The Dash Electrical Node is responsible for power distribution to the PEN and MoTec display. It also has CAN capabilities which are used to supply the MoTec display with relevant data for the driver. The DEN has a PCB mount E-stop which is in reach of the driver, this gives the driver the ability to put the car in LV if necessary. The enable button for ready to drive is also located on this node. The GND_SENSE_F (ground sense front) is grounded in the DEN, this sense wire is used by the IMD to determine if HV is shorted to the chassis or any other conductive material on the car. The DEN is also connected to the inertial safety of switch. This can be seen in more detail in (McLean, 2023).

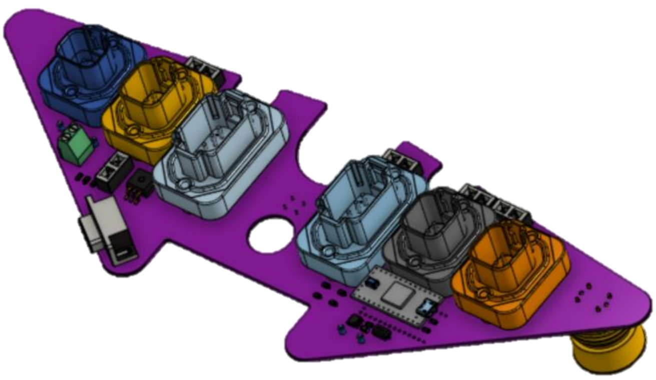


Figure 3. DEN PCB

CEN

Central electrical node is responsible for LV and HV power distribution as well as CAN and signal distribution. This node is located on the right side of the NU23 just rear of the driver. The CEN is responsible for the TSAL which is an indicator LED that displays whether the car is in ready to drive or LV. The CEN is also a crucial part in the shutdown circuit and has multiple interlocks on the main HV plugs. This can be seen in more detail in (Munday, 2023)

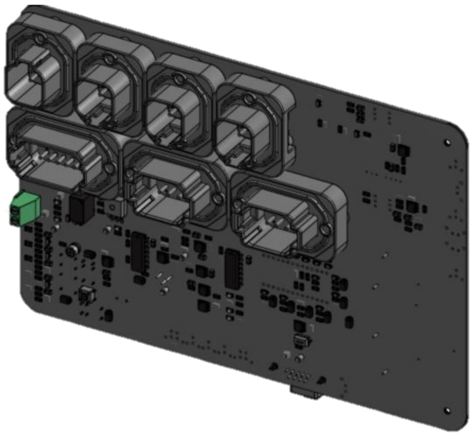


Figure 4. CEN PCB

REN

The Rear Electrical Node is responsible for power distribution and control of NU23's cooling system. It is also a CAN enabled node that broadcasts water temperatures of the cooling system over CAN. The ready to driver signal is read over CAN and when received the PCB mounted sounder alarms. The Ren is also responsible for housing and controlling the brake light. This can be seen in more detail in (Lyall, 2023).

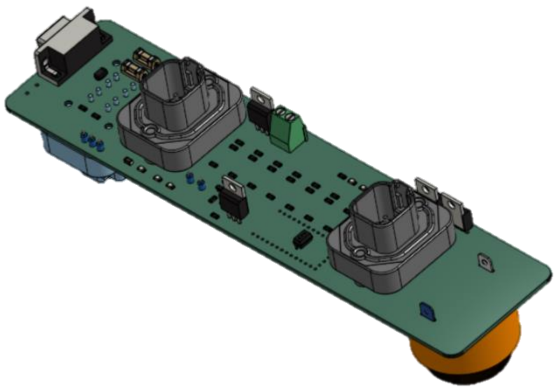


Figure 5. REN PCB

Accumulator

The accumulator houses both LV and HV components. The accumulator is comprised of the battery cells which supply HV, as well as the BMS, IMD, Pre-Charge, CANaMons, LVD and accumulator cooling fans. The accumulator broadcast cell voltages, cell temperatures, current draw and other crucial data over CAN. The accumulator is responsible for supplying the car with high voltage. The LVD is responsible for suppling all LV components inside the accumulator with 12 V and CAN. The accumulator also has CAN bus 2 which is an isolated CAN bus that is used by the CANaMons to broadcast cell temperatures. The LVD has both CAN 1 and CAN 2 on board and rebroadcasts relevant data from CAN 2 onto the CAN 1 bus (main bus used by the rest of the NU23). The LVD interfaces with the CEN to pass various signals such as OKHS and CAN. The LVD receives its power from the CEN.

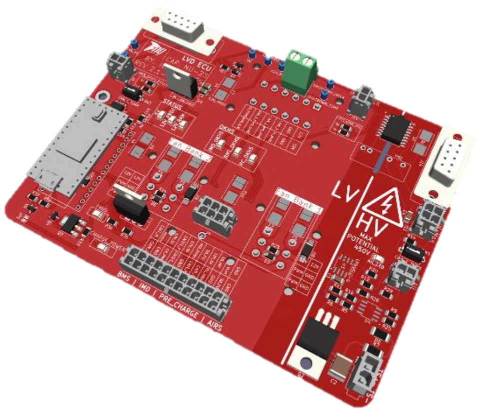


Figure 6. LVD PCB (Low Voltage distribution board in accumulator)

Accumulator components & Electronics

Cells

The accumulator is the assembly of all the components that make up the HV battery. It is responsible for supplying the car with HV or TS+, TS-. The accumulator is comprised of 648 18650 cells. There are 6 cells in a stack, 12 stacks to a segment and 9 segments in the NU23 accumulator. The NU23 accumulator had a total of 9 segments which resulted in 453.6 V at top of charge, as opposed to EV3 8 segment accumulator which had 403.2 V at top of charge.

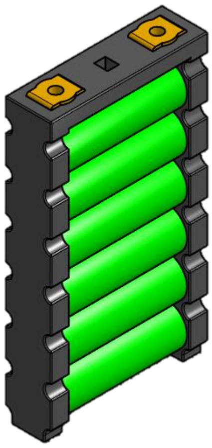


Figure 7. 18650 Cell stack

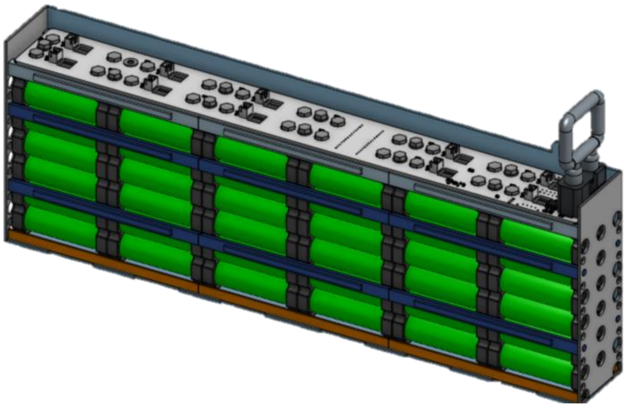


Figure 8. NU23 Segment comprised of 12 cell stacks in series

Top plate

The top plate is a made from GP10 and is a plate that is sandwiched by the lid when the accumulator is closed. The top plate is responsible for keeping the segments pressed down as well as a surface that is used to mount all the accumulator related electronics (BMS, IMD, Pre-Charge, LVD). The top plate has been designed in such a way that the LV and HV components and wires can be placed and routed to avoid HV and LV been in close proximity. This can be seen in more detail in (Searle, 2023).

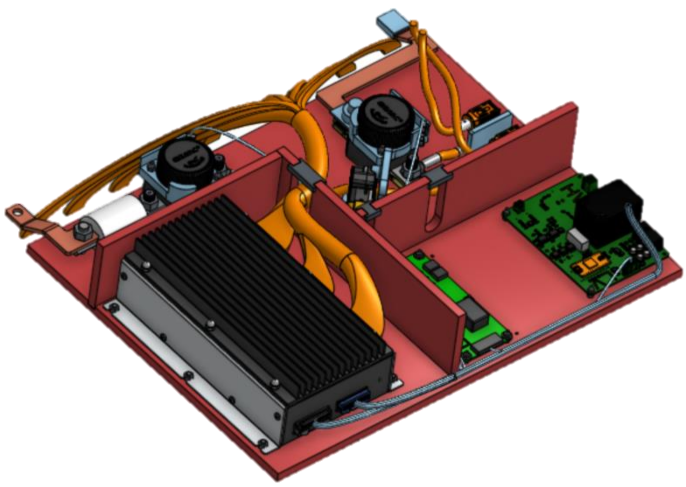


Figure 9. NU23 Top Plate

BMS

The BMS is responsible for monitoring the voltages and internal resistance of all the cells. It is also used in charging to balance all the cell voltages to maintain a low delta (the difference between the highest cell voltage and the lowest cell voltage). The BMS writes various data to CAN such as total accumulator voltage, current draw and other battery related information.

Pre-Charge

The Pre-Charge board's function is to slowly bring the accumulator up to voltage over a few seconds. This is to reduce the risk of relays or contacts been welded closed. The Pre-Charge board is also integrated into the shutdown circuit, this means if a pre charge can't be complete the AIRs will not close therefore causing the car to not enter HV.

IMD

The IMD is responsible for monitoring HV leaks. The IMD injects a PWM signal over HV and monitors for that signal on LV GND. If the PWM is detected on LV GND then a hard fault is triggered which closes the AIRs and disables the car. This protects the driver and any persons that come into contact with the any other cars conductive surfaces from a possible electric shock.

AIRs

The AIRs are relays that are placed in line with both TS+ and TS- (Positive and Negative for HV). The AIRs are powered using the 12V shutdown circuit. These relays will only close if the shutdown circuit is completed which means that all interlocks are connected, and no hard faults are present. If a hard fault is triggered at any instant that the car is in HV the AIRs will open causing the car to leave HV.

CANaMons

The CANaMons are responsible for monitoring cell temperatures. There are 9 CANaMons in total (located on top of every segment). The CANaMons monitor cells temperatures and write the maximum, minimum and average cell temperature to CAN Bus 2. The CANaMons interface with the HV side of the LVD were the CAN message from CAN Bus 2 are read and rewritten to CAN Bus 1.

LVD

The LVD is a power and signal distribution board which is responsible for power all low voltage components contained within the accumulator box as well as powering and controlling the accumulator fans using an on board Teensy to output a PWM. The LVD also distributes CAN and relays messages from the CANaMons and writes the cell temperatures to CAN Bus 1.

AIL

AIL is a light or indicator that must indicate when TS + is greater than 60 V.

High Voltage system

The high voltage system is comprised of the Accumulator, CEN, Motor Controller and Motor. The accumulator is the source/origin of high voltage in NU23. The accumulator supplies 450 V at full charge to the CEN. The high voltage side of the 4-layer CEN PCB distributes this power to the motor controller. The motor controller then converts the 450 V DC TS (tractive system voltage) to 3 phase which is used to drive the motor.

Looms

All the applicable looms that are used/manufacture for NU23 are constructed using a concentric twist method. This method of manufacturing looms means that the loom remains flexible keeps all the wires neat and reduces the stress on individual wires and makes sure no wires have more stress than other. All looms created by the author used CAN H and CAN L twisted at approximately a 1 inch cross over to create the first centre layer. The 2nd layer is then twisted in the opposite direction, this pattern continued until the current layer is full in which case another layer would be stated in the opposite direction of the previous layer. This process continued until all the needed wires were neatly wrapped. The process of concentric twisting can be seen in Figure 10.

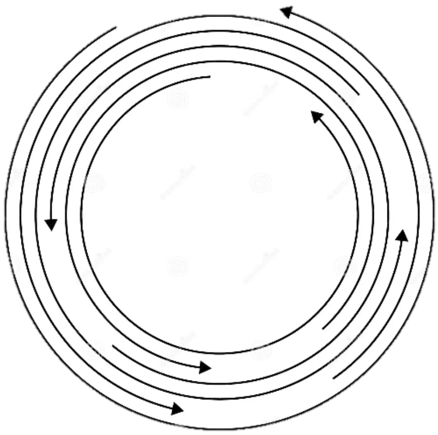


Figure 10. Concentric twist method

LVD

By Jedd R

LVD: Project Overview

The initial goals of the LVD were to simplify the power and signal distribution in the accumulator as well as incorporate fan control, shutdown circuit functionality, CAN functionality and top plate and cell temperature logging over CAN.

The LVD is responsible for all distribution of LV powers and signal that are interfaced between the CEN and accumulator. The LVD replaced the connector box which was used in the EV3 accumulator, it was used to distribute the powers and signals in the EV3 accumulator. This was done by manually breaking out the wires from the LV Autosport connector and routing the wires to 2 micro-Molex headers which were mounted on the side of the box. One of the Molex connectors were responsible for all the signals needed inside the accumulator (CAN, OKHS, etc.) the other connector was responsible for powers and GNDs. In EV3 the DC/DC converter was located inside the accumulator this meant that all the GLV had to be distributed to the rest of the car from the accumulator. The way that the 12V devices inside of the accumulator were power was inefficient as the GLV output by the DC/DC was first routed back to the connector box. From there GLV was then routed back across the top plate to the PDB which then finally distributed the GLV to the necessary devices and PCBs.

The LVD drastically reduce the complexity of the signal and power routing within the accumulator. On NU23 the DC/DC converter was removed from inside the accumulator and place on top of the motor controller. This now meant that GLV would be coming into the accumulator as opposed to been distributed from it. The LVD made it possible to remove roughly 50 wires and 3 PCBs from within the accumulator. This means roughly 150 components were removed from last years accumulator. With the help of Micheal Dalton's and Jacob Searle's mechanical design of the accumulator it now meant that the lid could be removed by disconnecting 2 LV micro-Molex connectors and 2 HV rad locks. The top plate could then be removed after unplugging the BMS's three voltage tap connectors. A segment could be removed from NU23's accumulator after unplugging 2 connectors on the LVD, 2 HV rad locks and the BMS voltage tap connectors. This task could be completed in less than 5 minutes and the only tools required are the M6 Allen key and socket used to unbolt the lid. This is a massive improvement on last year's accumulator which require isolated spanners to remove multiple HV wires from the AIRs terminals. To remove a segment from EV3 it would take roughly 20 minutes. In the time it takes to remove just the EV3 top plate the NU23 accumulator can be fully disassembled.

The LVD also has a HV section on the PCB, this section is populated with components for an isolated CAN transceiver. This section of the board is used to receive the cell temperatures from the CANaMons which is extremely important data that is required to be monitored by FSAE rules.

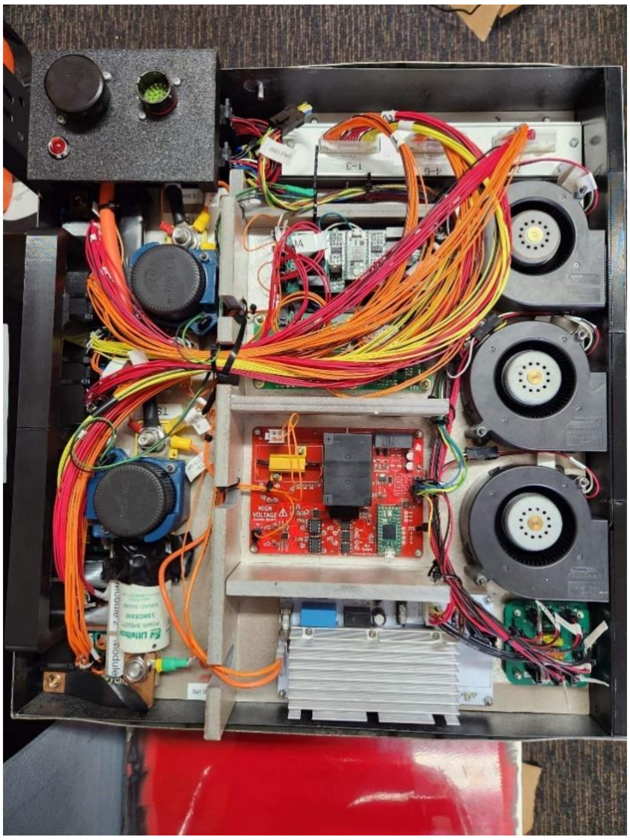


Figure 11. EV3 Accumulator Top Plate

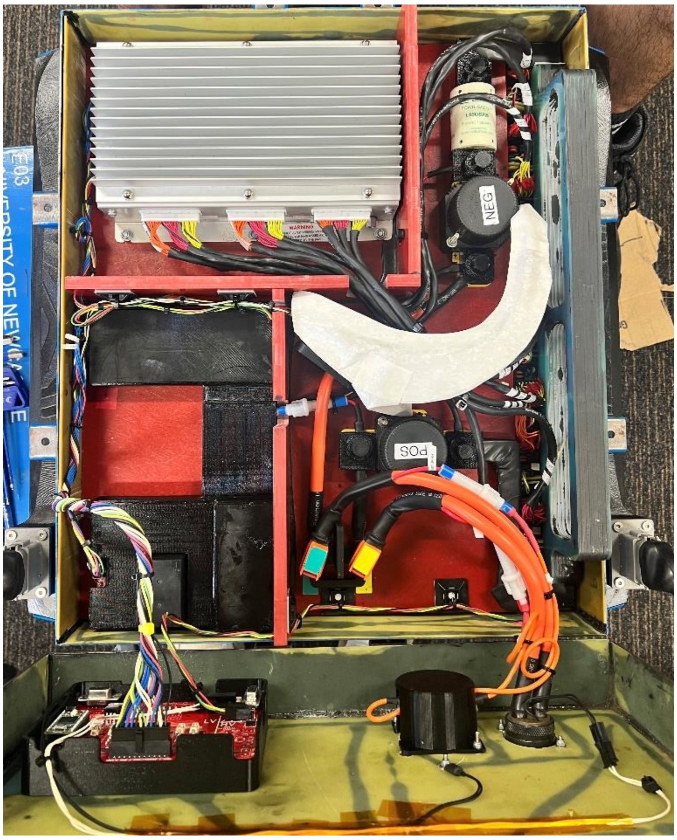


Figure 12. NU23 Accumulator Top Plate

The final version of the LVD that was installed on the car for the 2023 FSAE competition had the following functionality:

- Power distribution to all LV components on the top plate.
- Signal distribution to all components on the top plate, these include GND_SENSE_F, GND_SENSE_R, CAN H, CAN L, BMS_OKHS, IMD_OKHS and PC_OKHS.
- Board mounted DT connectors: allows for the LVD to be mounted to the underside of the accumulator lid.
- Fan control as well as supplying fan power.
- SMD thermistor: can be used to for logging of top plate temperature.
- Board mounted BMS, IMD and Pre-Charge OKHS status indicator LEDs.
- Board mounted 12 V raw, 12 V protected and 5 V status indicator LEDs.
- CAN 1: CAN used by the rest of the car.
- CAN 2: CAN Bus used by the CANaMons, LVD rebroadcasts relevant CAN 2 messages onto the main bus (CAN 1).
- Functionality to power on board components with different voltages depending what resistor pad is used.
- Functionality to pull up BMS OKHS to either 5 V or 12 V depending on what resistor pad is used.
- 30 A switching MOSFET circuit that can be used to complete turn off the accumulator fans using a Teensy.
- Built in solder pads that can be used to connect both PWM signals, giving the fans the ability to be run of a single PWM signal.
- Built in solder pads that can be used to pull up the PWM pins to 5V, this means that fans could be powered and spin at 100% without the need for a Teensy.
- MOSFET circuit that is capable of pulling the BMS's Charge_Power signal up to 12V using a 3.3 V Teensy pin. This charge power signal is what enables the BMS cell balancing mode. (This signal was originally hard wired from the charger but with the use of DT connectors this was no longer possible).

LVD V1

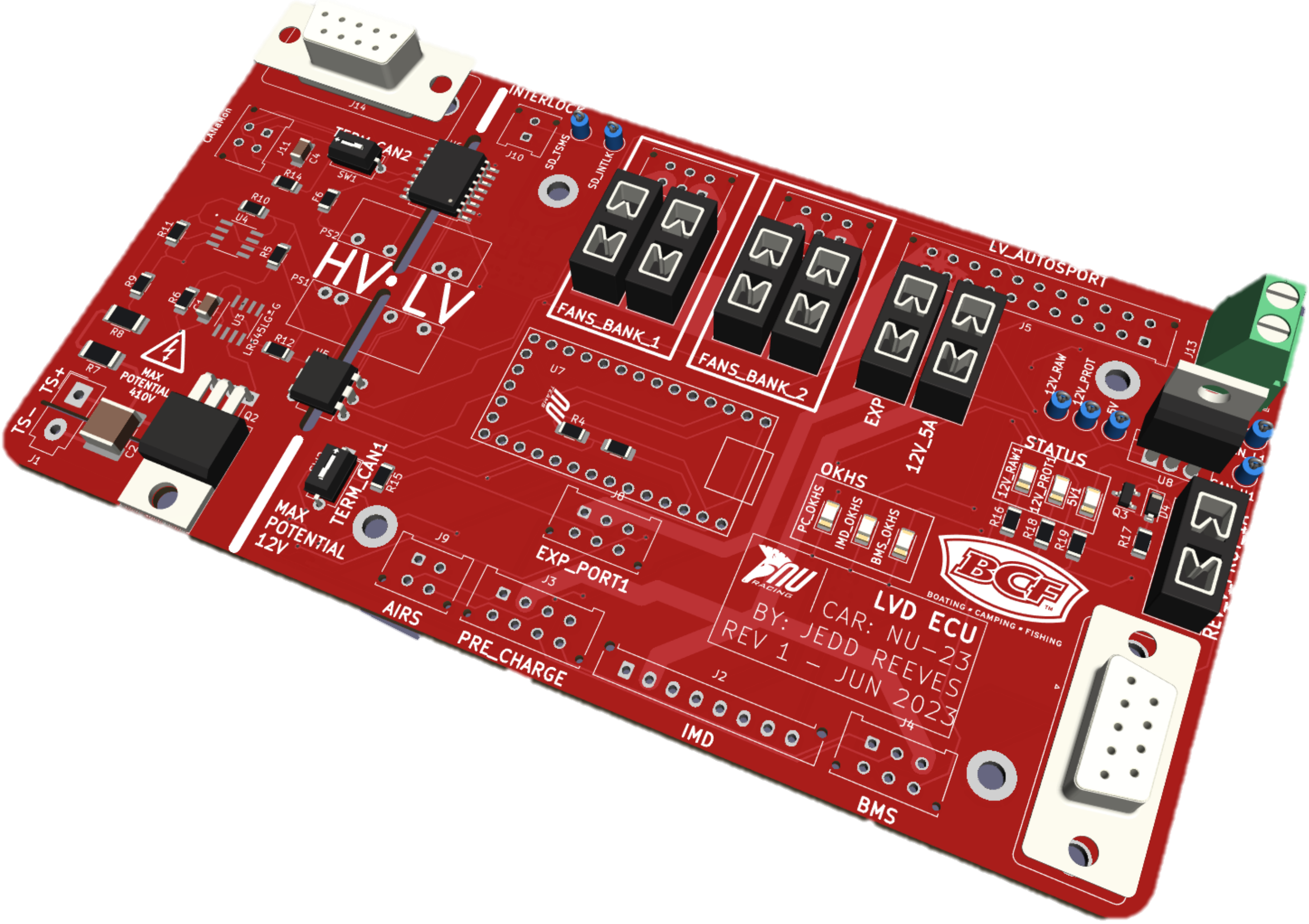


Figure 13. LVD V1

LVD V1: Initial Design

The LVD V1 was responsible for all distribution of LV powers and signal that were interfaced between the CEN and accumulator. A board mounted 2x11 micro-Molex connected which is connected to a 28 pin Deutsch Autosport's connector on the lid of the accumulator was used to interface the LVD V1 with the rest of the car (this LV Autosport's loom comes from the CEN). The pinout for these powers and signals that are distributed by the LVD can be seen in Figure 14.

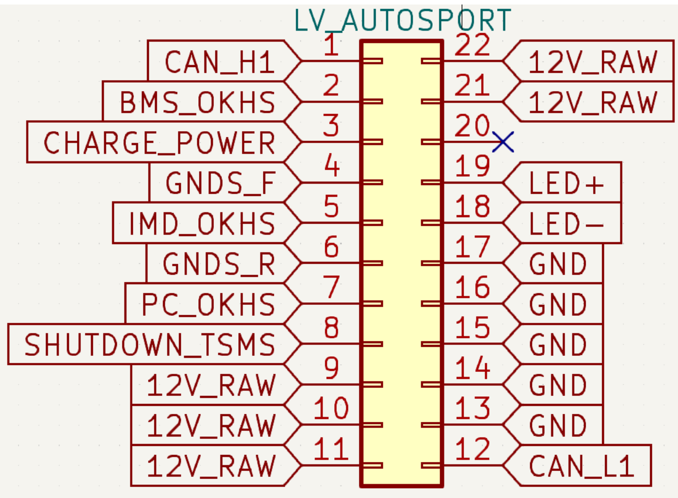


Figure 14. LV Autosport's to micro-Molex LVD V1

Because this board is used for power distribution, trace widths had to considered. 5A was designated to the BMS, IMD, Pre-Charge connectors and a GND plane was placed on the whole bottom of the LV side of the PCB. This trace can be seen in Figure 15.

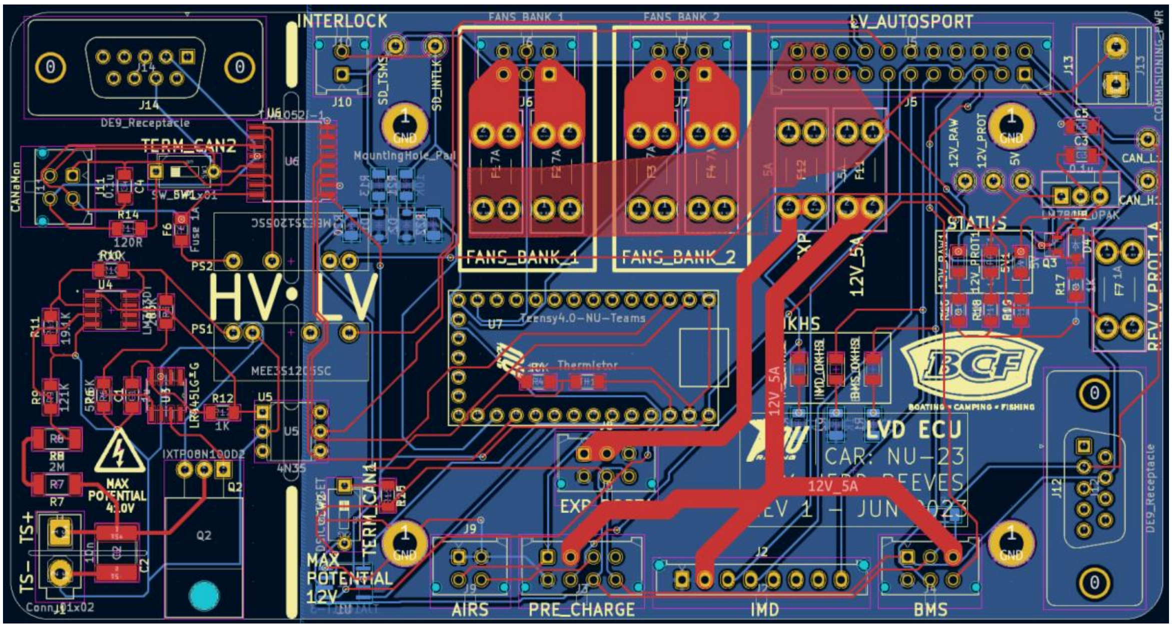


Figure 15. LVD V1 PCB Layout (KiCAD)

AIL

The isolated AIL PCB was integrated into the LVD V1, this can be seen in Figure 15 in the bottom left of the PCB. This is due to the initial goal of creating a simpler electrical system. The more boards and wires that can be reduced the simpler and more reliable the accumulator node can become.

Fans

The LVD V1 controls the 2 banks of accumulator fans using PWM signals from the board mounted Teensy. A separate PWM signal is used for each bank, this allows for customisation of intake and exhaust fan speeds. The fans are powered from the board using two 2x3 pin micro-Molex connectors (one connector per bank). The pin outs for these connectors are shown in Figure 16.

Each connector is responsible for powering 4 fans, these fans have a max current draw of 3.2 A. Every pair of fans shares a power, ground and a PWM. A 7 A mini blade fuse is used to fuse every pair of fans. Because of this large current draw the board was manufactured with 2Oz copper and power and GND planes were used to deliver this current to reduce the risk of blowing traces. The fan connectors are also placed at a close distance to the Autosport connector that is responsible for powering everything. This minimises the length of trace and make it much easier to route. This power plane can be seen in Figure 15 which contains the PCB layout in KiCAD.

BMS

The BMS is connected to the LVD V1 using a 2x3 board mounted micro-Molex connector. The loom between these two components has a 2x3 micro-Molex connector at the LVD end and a BMS specific connector at the BMS end. This means the loom can only be plugged in one way and completely eliminates the risk of been plugged into the wrong connector. This supplies the BMS with power, GND, CAN HIGH, CAN LOW, BMS_OKHS and Charge_Power.

IMD

The IMD is connected to the LVD V1 using a 1x8 micro-Molex connector. This connector footprint was selected as it is the same connector that is on the IMD. The pinouts on both the LVD connector and IMD connector are identical, this means that the wiring loom is reversable, and it is not crucial as to what way it is plugged in. The LVD V1 is responsible for supplying the IMD with power, GND, GND_SENSE_F, GND_SENSE_R and IMD_OKHS.

Pre-Charge

The Pre-Charge board is connected to the LVD V1 using a 2x4 micro-Molex connector. The pinout and connector on the LVD V1 match that of the connector and pin out on the pre charge board. This means the loom is reversible and eliminates the risk of plugging into the wrong spot and or shorting components.

AIRs

The AIRs are connected to the LVD V1 with a 2x2 board mounted micro-Molex header. This supplies the AIRs with GND, GND, Shutdown Interlock and Shutdown Pre-Charge. The loom for this is a 2x2 micro-Molex connector at the LVD V1 side and it then split into two 2x1 micro-Molex connected which goes to each of the 2 AIRs.

Shutdown Circuit

The shutdown circuit also passes through the LVD, a 2x1 micro-Molex connector is used to distribute the signals.

Expansion Port

This version 1 of the LVD also has an expansion port. This is a 2x3 micro-Molex header that has two powers, two GND's, CAN HIGH and CAN LOW. This expansion port was utilized for a short period of time before the CANaMons were fully commissioned.

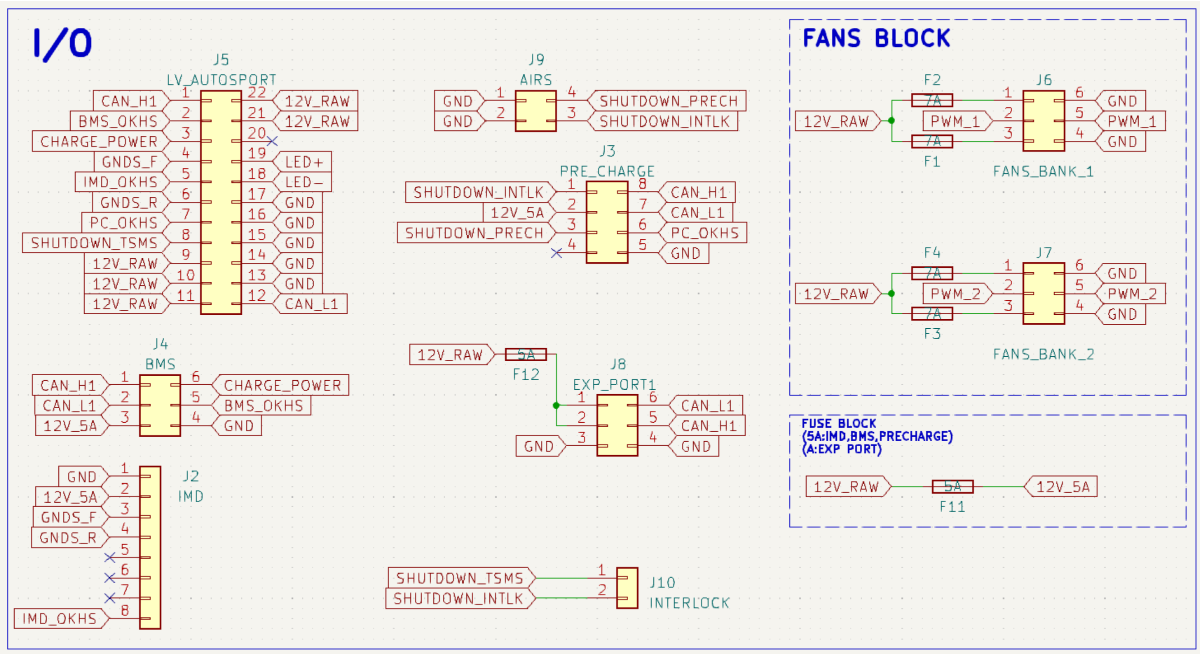


Figure 16. Input/Output Block LVD V1

LVD V1: Manufacturing

The LVD V1 was designed using KiCAD. Once the design had passed relevant DDRs and checks the Gerber files were exported and submitted to PCBGOGO. A purchase order was placed for all the required components needed that were not stocked in the MCHA Lab.

Because the LVD changed the electrical topology of the accumulator top plate new wiring looms needed to be manufactured. 9 point to point looms needed to be manufactured. 3 of these had Autosport's connectors on one end that were mounted to the lid. The remaining 6 mainly comprised of micro-Molex connectors at both ends and went from the connectors on the LVD to the relevant PCBs that the LVD was powering.

Once the board and components arrived the heat gun and solder paste were used to solder all the SMD components on the board. The soldering iron was then used to solder all the through hole components onto the board.

LVD V1: Commissioning

Once the necessary 12 V components were soldered onto the board a multi metre was used to verify that 12 V and GND was measured to be in the correct location. The lower voltage components such as the 5 V regulator and CAN transceivers were then soldered on and checked. Finally, the Teensy was plugged into the board and fan PWM signals could be checked. To check this, simple code was written to set the PWM of one fan bank to 25% and the other bank to 50%. The voltages of the fan PWM pins were tested at the fan connectors and were found to be correct and working as expected. As seen in Figure 17 this code sets pin 11 and 12 as output pins. Then the analogwrite function is used to set the required PWM. PWM is scaled from 0-255 where 0 is 0% and 255 is 100%. The following code sets the PWM of pin 11 to 50% and the PWM on pin 12 to 25%, this means if a voltage metre is used to measure between GND and pin 11 the voltage should be 50% of 3.3 V (1.65 V) and the voltage between pin 12 and GND should be 25% of 3.3 V (0.825 V).

```

// 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

void setup() {

    // 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
}

void loop() {
    analogWrite(IN_PWM_PIN, 255/2);
    analogWrite(OUT_PWM_PIN, 255/4);
}

```

Figure 17. Code used to verify PWM control

The CAN code was then added and uploaded onto the Teensy. Using MATLAB and plugging into the LVD V1's DE9 connector the CAN was verified to be working and it was writing the correct messages to the bus.

Once the LVD V1 had been verified to be working in isolation the top plate was removed from the accumulator and testing with top plate components could begin. The LVD was powered using one of the MCHA Lab power supplies at 12 V with a low current limit to reduce the risk of destroying components if something was to go wrong.

The BMS was plugged into the LVD and powered on. The BMS_OKHS was seen to be working and CAN was verified to be working.

Next the IMD was plugged in and the LVD was powered up. The IMD_OKHS was good for roughly 30 seconds and then went bad. This verified that the IMD was working as expected as the IMD was not connected to the rest of the car which therefore meant that the OKHS would go bad after 30 seconds.

The next component to be plugged in was the Pre-Charge board. The indicator lights on the Pre-Charge board lit up when powered and the Teensy heartbeat could be seen over CAN which verified that the board was both getting power and CAN. This verified that the Pre-Charge board worked with the LVD.

The AIRs were the last top plate devices to get tested. A power supply was used to simulate the shutdown circuit. The AIRs were plugged into the LVD, and the simulated shutdown circuit was injected in to the LVD.

Once the top plate and its components had been tested and validated in isolation it was time to assembly the accumulator and test with the rest of the car. Once the accumulator was plugged into the car, the car was switched into LV, everything was worked as expected. The car was then switched into HV, but the car failed to Pre charge. This was due to a voltage divider that had been created between TS+ the AIL and the Pre-Charge board. This meant that the Pre-Charge PCB was only able to charge up to 91% of its required 95% which meant that a pre-charge could not be completed. The AIL was unplugged from the LVD V1 for testing and it was verified that the AIL was stopping the car from successfully going into HV. This meant the AIL required some further changes and testing, this can be found in a later section.

LVD V1: Issues/Improvements

There was multiple minor issues that surfaced once the LVD was tested in the car over multiple track days.

Initially the AIL which is now located on the LVD was found to be restricting the car from completing a Pre-Charge. This was due to the 12-5 V isolated DC/DC drawing power even when the LED was not illuminated. Because of this a large voltage divider was created between the Pre-Charge Board and the AIL which limited the voltage that the Pre-Charge Board could access.

An issue arose after some track time and on car testing where the fans would be locked on a certain speed and became uncontrollable. After numerous on and off car tests, it was found that if the PWM pin was left floating before the Teensy powered on, then the fans would get lock on roughly 50% speed and remain there independent of the PWM signal that was supplied to them (The Teensy took longer to boot up compared to the fans receiving 12 V). To solve this problem a 1K ohm pulldown resistor was solder between the PWM and GND pin of each fan connector.

Whilst investigating the issue of the stuck fan speed another issue was unsurfaced. If the fans were receiving 12 V to the positive pin and GND was disconnected, then the PWM pin will be pulled up to 10 V. Because the Teensy's pins are only 3.3 V capable this 10 V signal would feed back to the Teensy and destroy it. To fix this a 3.3 V Zenner diode is needed.

The fix for these issues is discussed in the next revolution of the LVD.

LVD V2

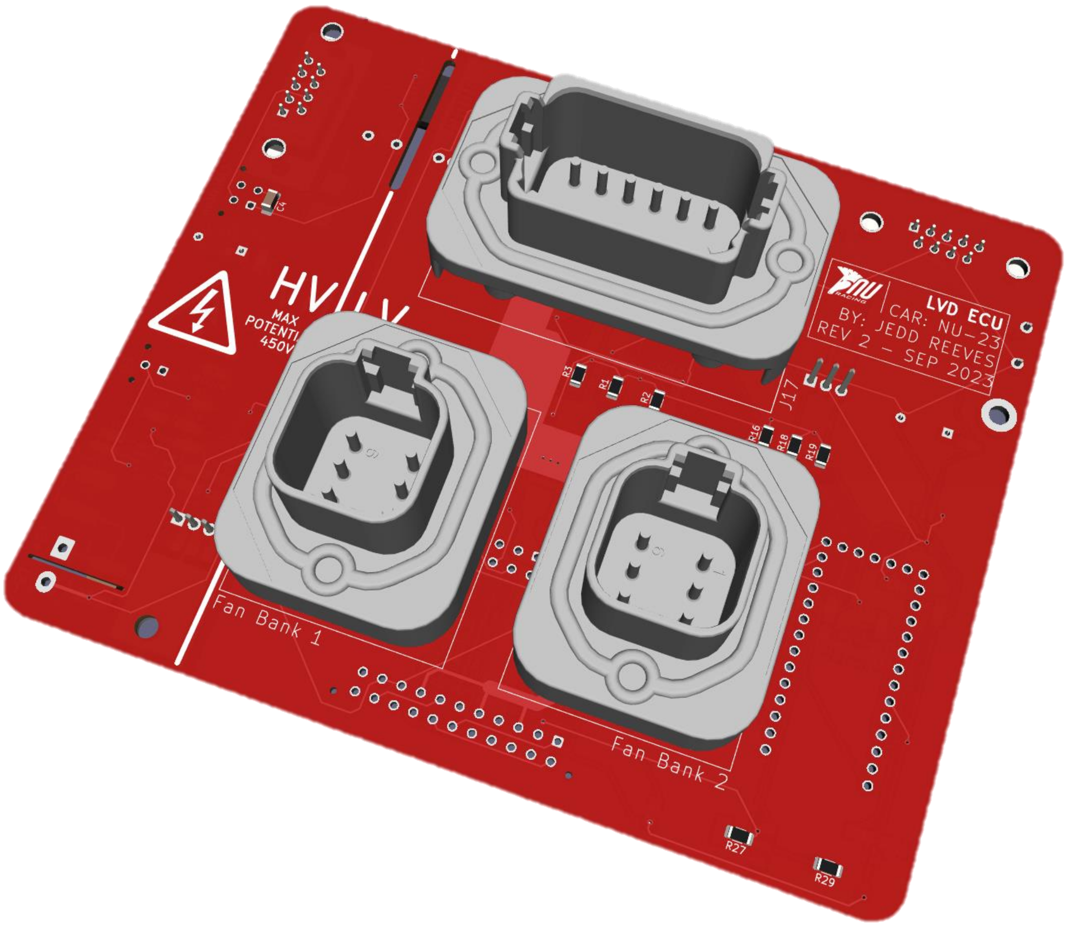


Figure 18. LVD V2

LVD V2: Initial Design

The version 2 of the LVD was quite a big change. At this stage in the cars design most of the other connectors on PCBs had been changed from a Deutsch Autosport's connector to a board mounted DT connector. This change was partly due to the fact that by mounting the connectors directly to the PCBs the enclosures could be smaller, and it also reduced the need for wires running from the PCBs to the plugs/connectors on the enclosures/cases. These wires can be seen in Figure 19.

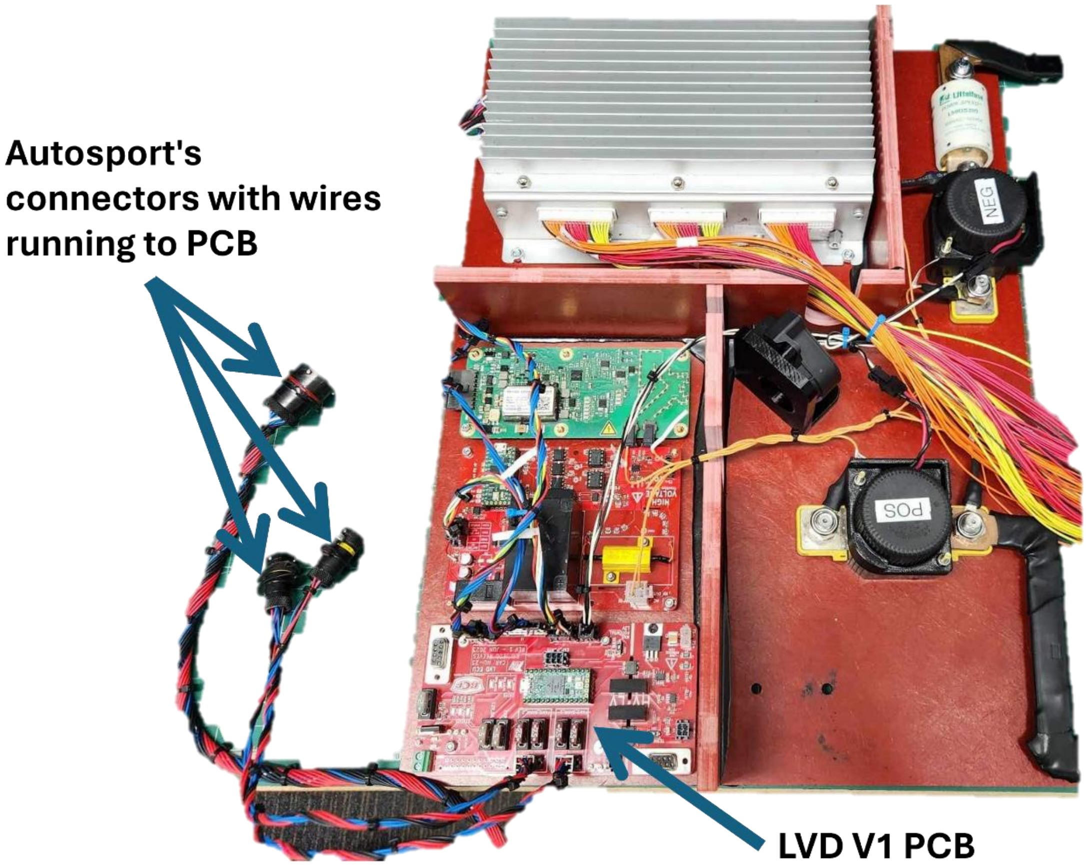


Figure 19. LVD V1 assembled on top plate (Autosport's connectors wired to board)

Because of the connector overhaul the design of the version 2 LVD would incorporate board mounted DT connectors. Because the V1 of the LVD was plugged into Autosport connectors that were on the lid of the accumulator this meant some changes to the location of the LVD V2 needed to occur. The LVD V2 must now be mounted directly to the lid using the DT connectors.

Connectors

The use of these DT connectors meant a massive change needed to be made to the layout of board. The 3 Autosport connectors that originally resided on the lid, used to interface with the LVD are now replaced by one 12 pin DT connector (CEN to Accumulator) and two 6 pin DT connectors (Fans). The original CEN to Accumulator Autosport's connector used 19 pins, but because of this reduction in available pins, changes needed to be made with how signals and powers were dealt with. The reduction in powers and signals can be shown in Figure 20 and Figure 21.

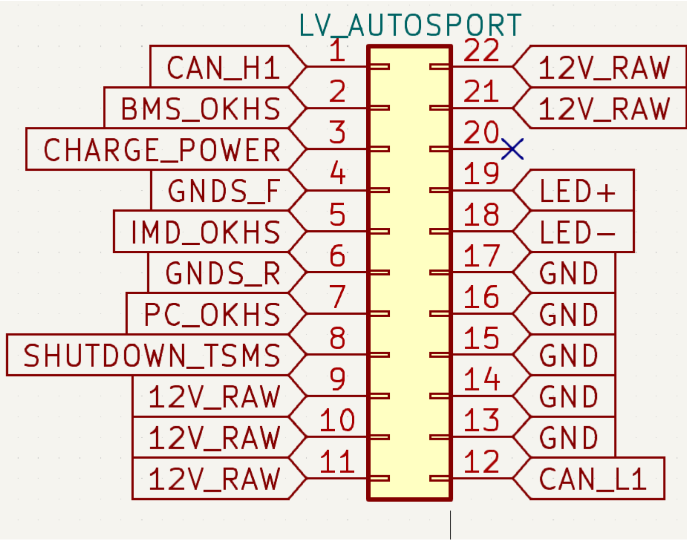


Figure 20.LVD V1- LV Accumulator to CEN connector

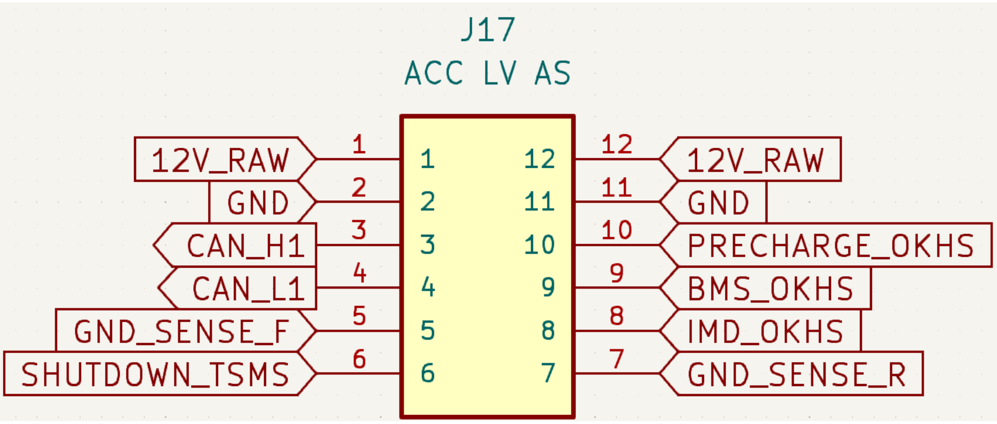


Figure 21. LVD V2- Accumulator to CEN connector

The pins on the DT connectors can handle 13 A as opposed to the pins on the micro-Molex header that were on the version 1 board which could only handle 5 A. Because the DT connectors could handle more current the power pins could be reduced from five powers and five GND's down to two powers and two GND's on the V2 setup. This initial reduction of pins needed for carrying power meant that there was now only one extra signal which needed to be eliminated from the connector. The GND_SENSE_F and GND_SENSE_R along with the three OKHS, CAN HIGH, CAN LOW and the shutdown circuit signals could not be eliminated from the connector as these crucial signals are needed for the functionality of the car and to comply with FSAE competition rules. This meant that the Charge_Power signal needed to be removed from the connector. This signal is used to put the BMS in to charge mode which allows for cell balancing to be enabled. This meant a new way to supply the BMS's charge power pin would need to be investigated when the accumulator was charging.

The next change that had to be made was the board mount micro-Molex connectors. To take the lid of the accumulator off with the version 1 board, four LV connectors/plugs needed to be disconnected. For the change to DT connectors to be worth it, the number of connector/plugs that are required to be unplugged to remove the lid would have to stay the same or be reduced. This all comes back to the goals of creating a simply reliable system with a lower part count than last year's car.

If the configuration of the board mount micro-Molex connectors that power the devices on the top plate stay the same from version 1 to 2, six connectors would have to be unplugged to remove the lid. This is because on the old board you only had to remove the two fan connectors and the LV Autosport connector. But now with the board been mounted on the lid all the top plate components/devices had to be unplugged.

To overcome this the AIRs, IMD, Pre-Charge and BMS micro-Molex connectors were combined into a single 2x11 micro-Molex connector. The only connector/devices that couldn't be combined into the big connector are the HV components, the AIL and CANaMons. Because these are HV they must remain isolated from the LV connectors and parts.

This meant the number of connectors that needed to be unplugged to remove the lid remain the same between V1 and V2 of the boards.

Charge_Power Switching Circuit

A MOSFET circuit was designed which give the LVD V2 the ability to supply the BMS with a 12V signal once a charge message was received over CAN. Once this message was received the LVD Teensy would set a pin HIGH which was connected to the gate pad of the switching MOSFET. This would close the MOSFET and pull the CHARGE_POWER pin high which supplies the BMS with the needed charge signal to enable cell balancing. This circuit can be seen in Figure 22.

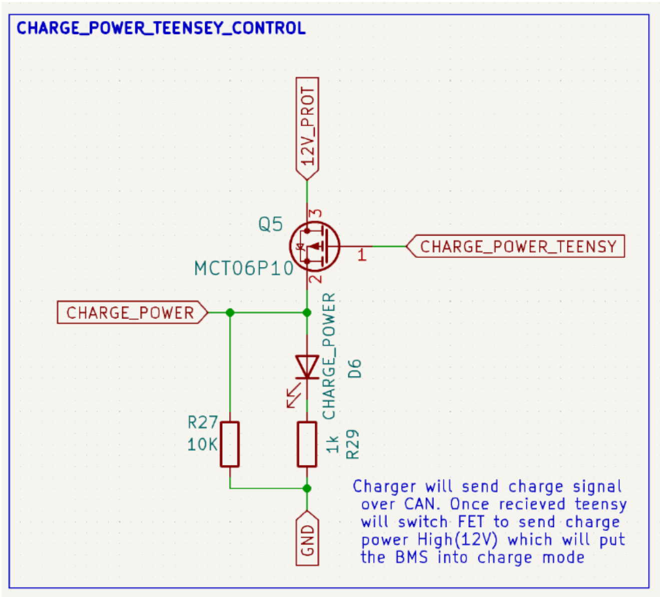


Figure 22. LVD V2 Charge Power switching circuit

Wiring Harness

Because of the change to the connector configuration that supplied power and signals to the top plate devices a new harness had to be designed. The measurements and space requirements were considered and the conclusion that was made was that a harness would have a single 2x11 micro-Molex connector at one end that split off into separate little branches to power the top plate components. The length and plug configuration of these branches was designed in such a way that it would be difficult to plug in the wrong components.

Components

SMD fuses were used in the design as opposed to the old mini blade fuses. This change allowed components to be more closely spaced and stacked on opposite side of the board as the fuses were no longer through hole components. This aided in keeping the PCB footprint to a minimum. But because of the size and footprint of the board mounted DT connectors they were still the dictating factor in the size and layout of the board.

AIL

To solve the issues encounter with the isolated AIL used on the LVD V1, the AIL circuit was reverted to an un-isolated circuit that was very closely based on David Birdsall's AIL. The only changes were the use of different footprint resistors and different resistor values which made the newer version turn on at a closer value to 60 V.

During the use of the version 1 LVD issues were found where the fans speed could not be changed using the Teensy. After testing both on and off the car the conclusion was made that the PWM signal had to be pulled down using a resistor. If a pull down was not used the PWM pin would float before the Teensy was powered on, causing the fans to be unpredictable and unreliable. The majority of the time the fans would be stuck at around 50% and be unresponsive to changes in PWM speed that was supplied. Because of this issue a 1K ohm pulldown resistor was added to the LVD V2 between the PWM pins and GND. This update circuit can be seen in Figure 23.

Another issue that was found was that if the GND of the fans was disconnected and they were receiving 12 V to the positive pin, the PWM pin would be pulled up to 10 V. This 10 V signal would feed back to the PWM pin on the Teensy responsible for controlling fan speed and destroy the Teensy. To combat this issue a 3.3 V Zener diode was used to snap that voltage back to 3.3 V if the GND ever became disconnected. This circuit is shown in Figure 23.

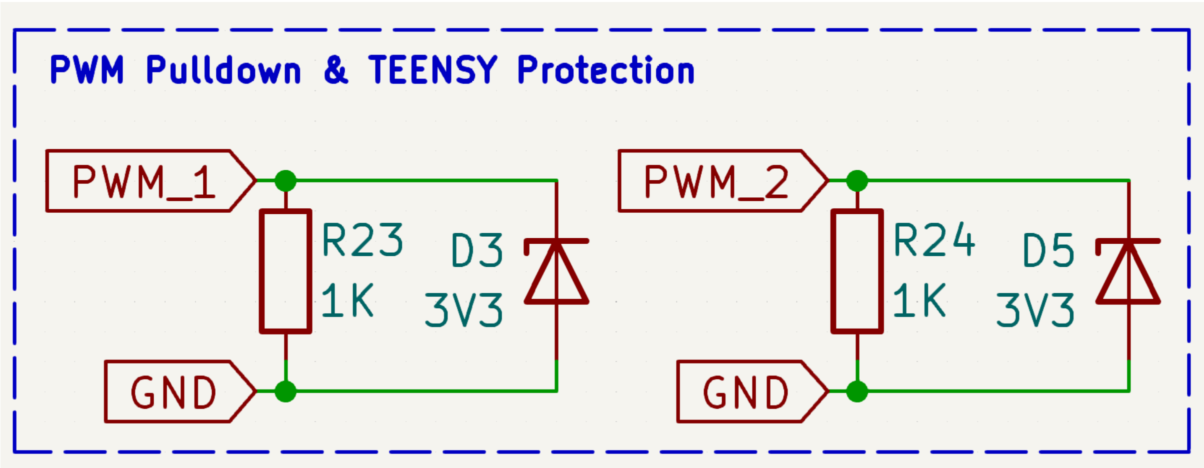


Figure 23. PWM pulldown and Teensy protection circuit

LVD V2: Manufacturing

The LVD V2 was designed on KiCAD. Once the design was finalised and the board passed relevant DDRs and checks the Gerber file was exported and uploaded to PCBGOGO to be manufactured. Because multiple components had been changed to a SMD footprint and the MECHA Lab now had a soldering oven, a solder stencil was order for the bottom side of the board. The bottom side of the board had most SMD components, the top side only had 8. The solder oven can only be used to solder components on one side of the board. If one side was solder and then the board was put back into the oven to solder the other side all the components on the bottom side would melt off.

No new components need to be purchased for this board as it either used the same components from version 1 or they were already stocked in the MECHA Lab. Once the PCBs and stencil arrived the manufacturing of the board could begin. The board was slide under the stencil with the bottom side facing up (side with the majority of SMDs). The pads on the PCB were then lined up with the holes in the stencils. Once the board and stencil were aligned solder paste was scrapped across the stencil using a scrapper. Once all the pads had in even amount of solder paste on them, the stencil was removes and the SMD's were placed on the board. After all the components were placed on the board, the PCB could now be put in the soldering oven. The board was placed in the oven and preset one was selected. It takes roughly 7 minutes for the oven to finish. After the oven is finish the drawer is opened and the board is left to cool for a few minutes. After the board is cool to touch all the solder joints are examined and checked to make sure a solid connection has been made between the pads and the components. After all the SMDs have been solder and checked, soldering can begin on the through hole components.

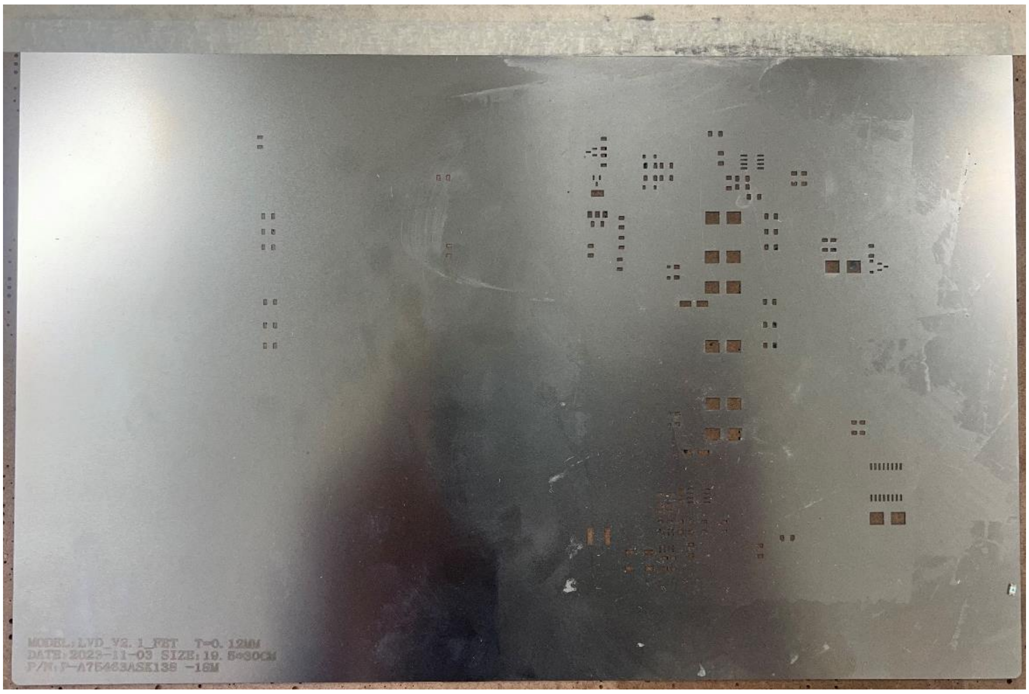


Figure 24. Stencil used to flow solder LVD

A new wiring harness had to be made to supply the top plate with relevant powers and signals from the LVD. Because of the version 2's new location on the lid a single wiring harness with multiple short branches was constructed. This harness has a single 2x11 micro-Molex connector at one end which then had 5 branches. This harness contained 23 wires (2 BMS_OKHS wires are crimped in the same in crimp). This harness was concentrically twisted like all other suitable NU23 harnesses and looms. The concentrically twisted harness can be seen in Figure 25

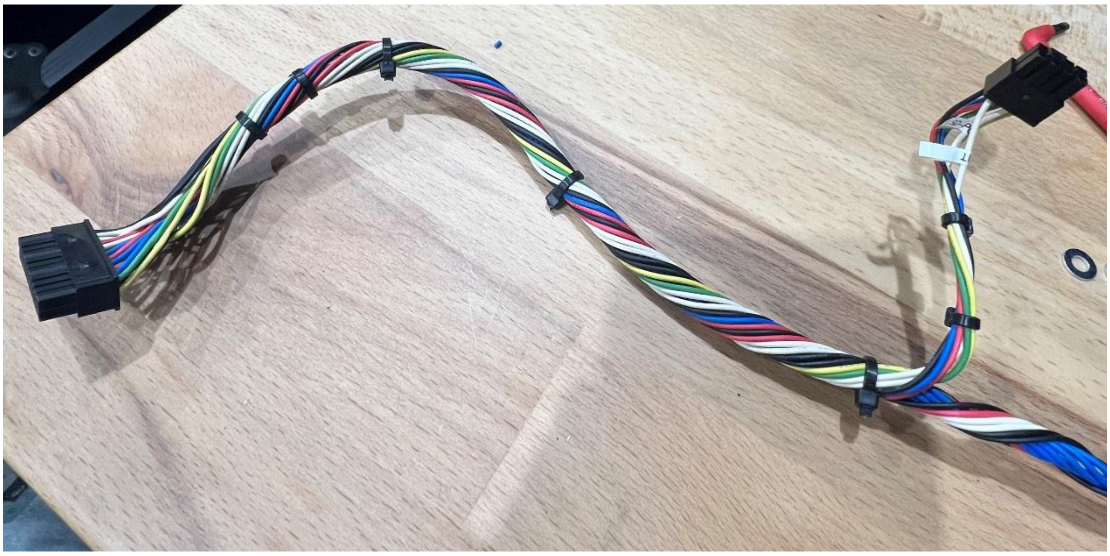


Figure 25. LVD V2 branched wiring harness

LVD V2: Commissioning

Once all the SMDs and necessary through hole devices were solder onto the board a multi metre was used to check if 12 V, 5 V and GND was active and in the correct locations on the PCB. A multi metre was used to check that the isolated 12 V to 5 V regulator was been supplied with 12 V and GND on the LV side of the board and there was isolated 5 V been outputted onto the HV side of the board. Once it was verified that the correct voltages were been supplied a Teensy was plugged into the board. Using a computer with MATLAB and plugging into the LVD V2 DE9 connector both CAN 1and CAN 2 were verified to be working correctly. One of the MECHA Lab power supplies was used in series mode to supply the AIL part of the board with a voltage range from 0V-64V. This was used to verify that the LED became illuminated at roughly 60V.

The new LVD multi branch wiring harness was tested next using a multi metre on continuity mode. One by one the pins were checked to make sure the wires were pinned in the correct location. After the harness was verified the accumulator top plates would be powered by the LVD one by one in isolation.

The testing of top plate devices with the LVD was done extremely similar to how the LVD V1 was commissioned. CAN and power was verified to be working on all CAN enabled components in the accumulator. The CANaMons were then plugged in, and CAN 2 was checked using the DE9 connector on the HV side of the LVD V2. The cell temperatures could be seen and the CANaMons interacted as expected.

Next the PWM signals were verified using the code in Figure 26. The next Teensy related circuit to be commissioned was the charge power MOSFET circuit in Figure 22. This was also tested using simple code. The code sends pin 20 on the Teensy high which saturates the MOSFET and pulls up the Charge_Power signal to 12V. This code is shown in Figure 26.

```


#define CHARGE_POWER 20       //Pin for switching charge power to put the BMS into charge mode
#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


void setup() {
  // put your setup code here, to run once:

  pinMode(CHARGE_POWER, OUTPUT);    // Setup charge power switching pin
}

void loop() {
  // put your main code here, to run repeatedly:

  digitalWrite(CHARGE_POWER, HIGH);

  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

  analogWrite(IN_PWM_PIN, 255);
  analogWrite(OUT_PWM_PIN, 255);

}

```

Figure 26. LVD V2 PWM and Charge_Power commissioning code

With the Teensy pin been set to HIGH the LED status indicator for the Charge_Power signal should be illuminated to show the signal has been pulled up. This was not the case; this is discussed further in LVD V2: Issues/problems.

LVD V2: Issues/problems

The first issue that was found with the version 2 board was the Charge_Power MOSFET switching circuit. After numerous test using a Teensy to set the gate pin of the MOSFET high it was found that the circuit wasn't functional. Because it is a signal that needed to be pulled up to 12 V a high side MOSFET switching circuit is needed. The solution is discussed in the initial design section of the LVD V2.1 PCB.

The Zenner diodes used to snap the voltage to 3.3 V for Teensy protection ended up not been sufficient. The Zenner diodes worked for a few times to protect the Teensy but the 10 V voltage was too high for the 3.3 V diode to handle constantly.

A major grounding issue was also found with the LVD V2 when assembled and used on the car for the first time. The power traces were sufficient for running the fans but the ground plane between the input and the fan connectors was separated and the only thing connecting them was a 0.25 mm signal trace. This trace was not sufficient for the 24 A that the fans draw at max speed. Within 5 seconds of the fans been on the trace was blown and the car Hard Faulted and left HV. This Hard Fault was due to the PCBs on the top plate not receiving power as the LVD had lost GND. This issue was temporally fixed by soldering external wires to PCB to sufficiently connect all the boards GNDs.

The PCB was also extremely close to the external walls of the accumulator and the internal wall of the top plate. This meant if the lid was not put on perfectly square the board would fowl on these walls causing connectors and wires to be disconnected or pinched.

LVD V2.1

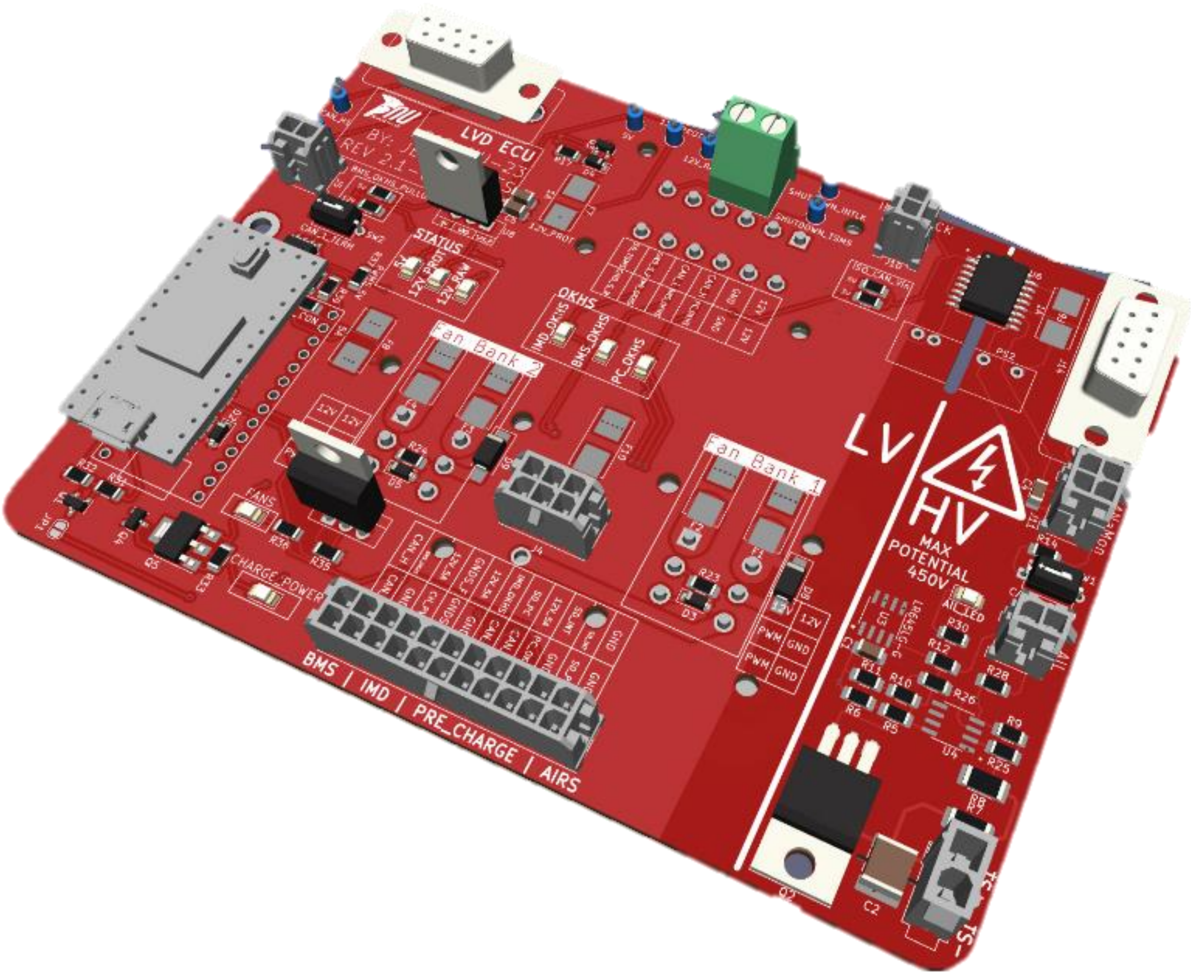


Figure 27. LVD V2.1

LVD V2.1: Initial Design

Size Changes

The LVD V2.1 is based very closely on the V2 board. It uses the same DT connector layout as the previous PCB but has some slight upgrades and fixes. V2.1 is 11.5 mm shorter in height, and 1 mm smaller in width compared to the previous version. This change is due to the issue of the version 2 PCB fowling on the external wall when the accumulator is closed. The LVD V2 also scraped on the internal wall of the top plate if the lid was not placed on square. To resolve this issue the overall footprint of the PCB was shrunk to increase clearance from all walls this differences between V2 and V2.1 can be seen in Figure 28 and Figure 29.

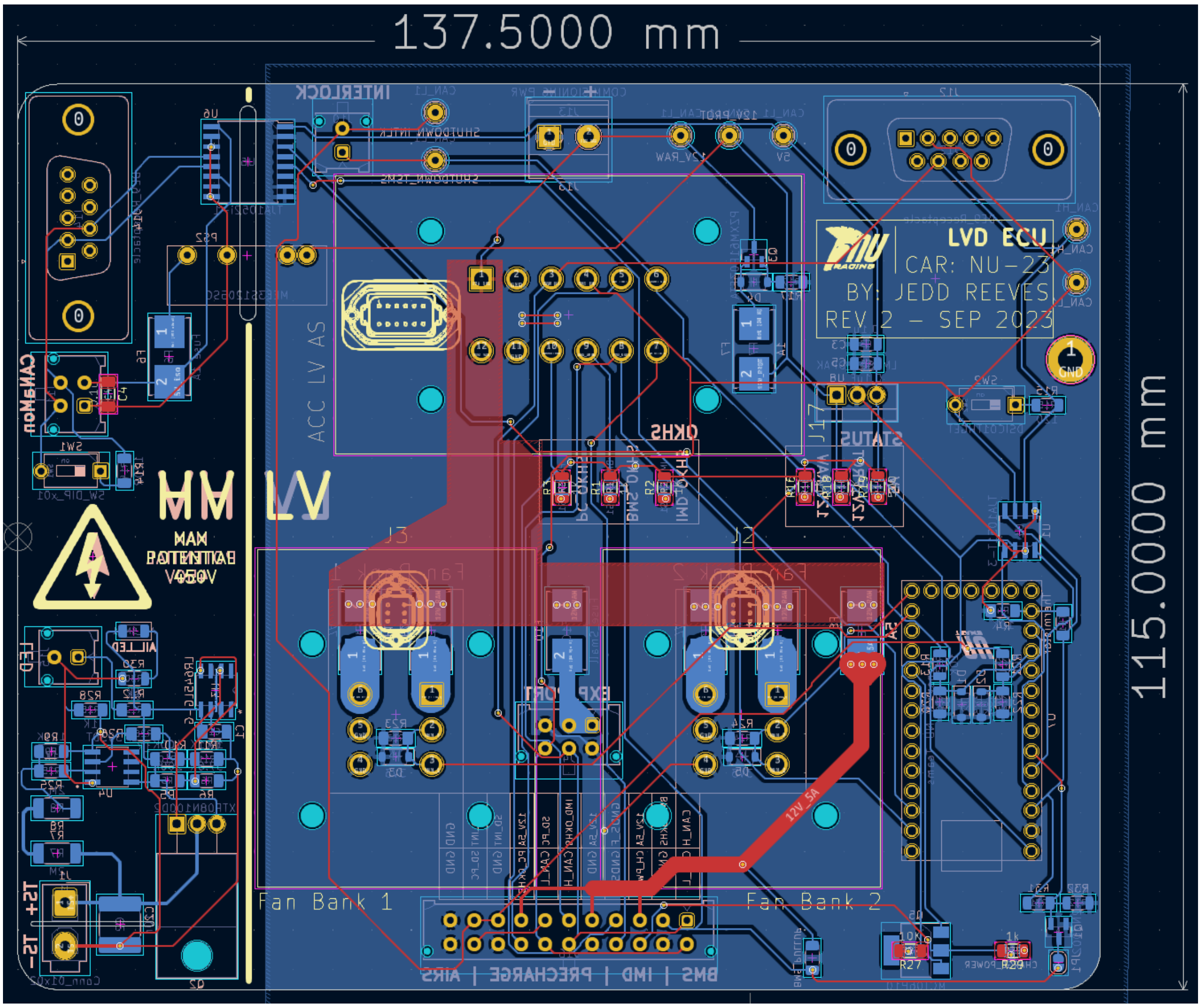


Figure 28. Dimensions of LVD V2

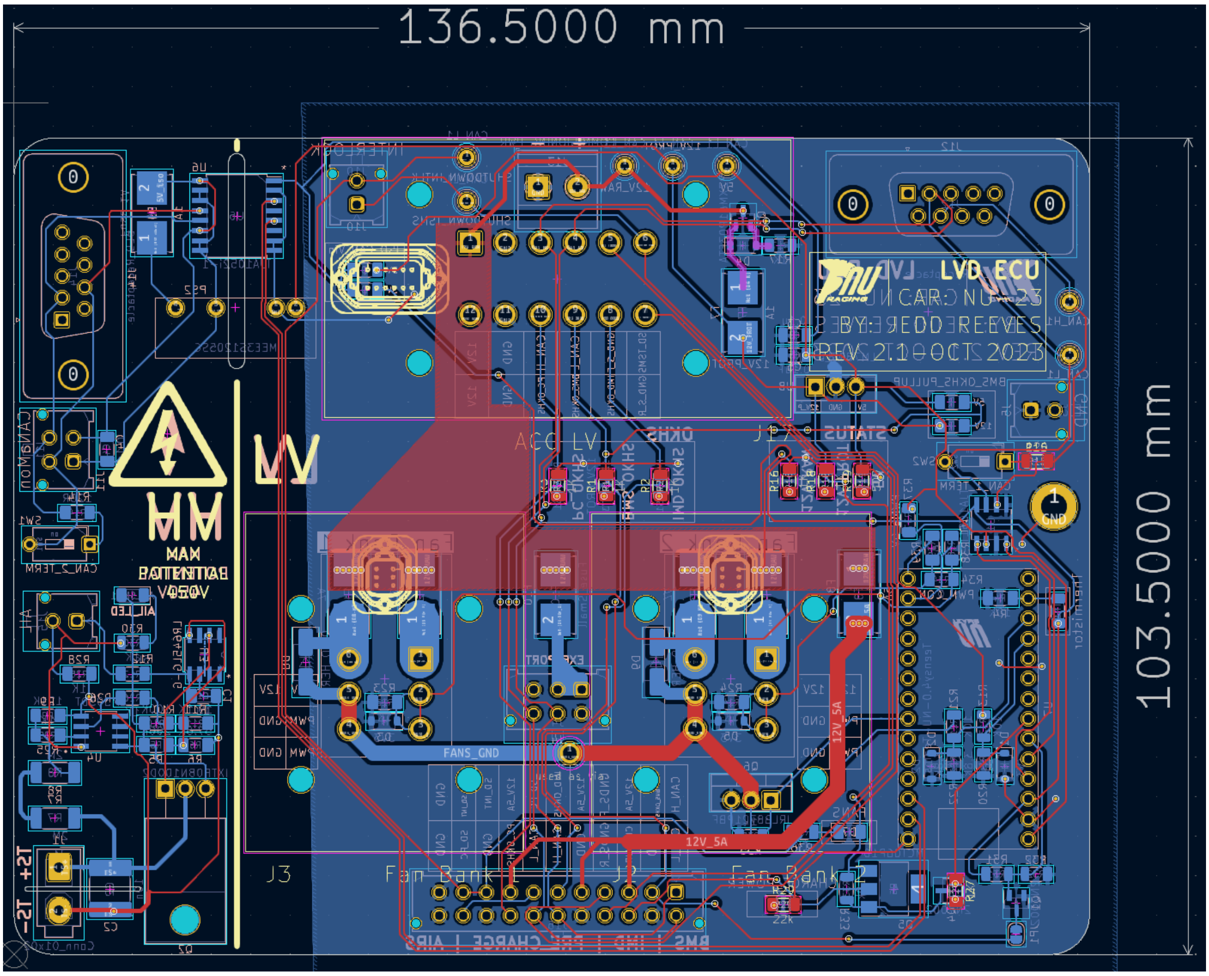


Figure 29. Dimensions of LVD V2.1

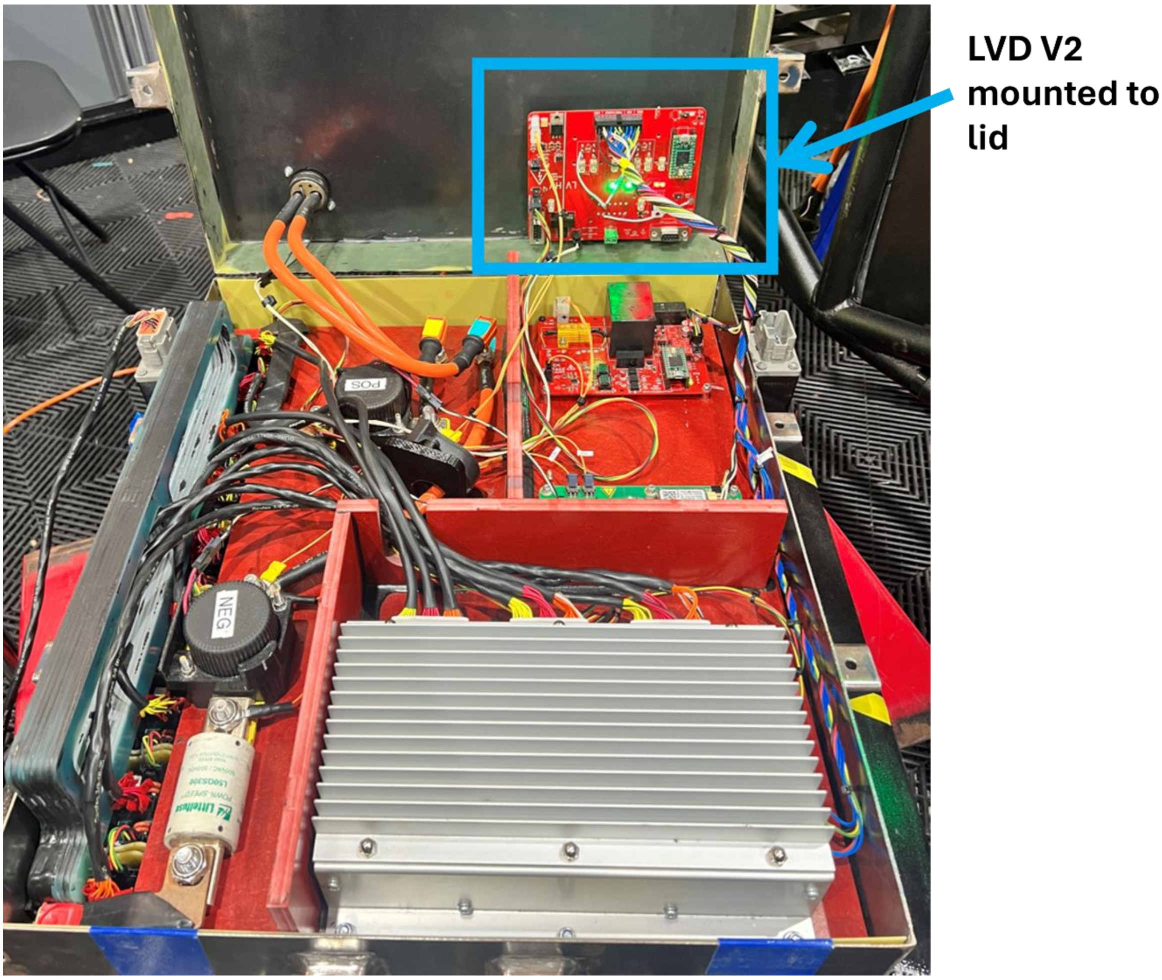


Figure 30. LVD V2 mounted to lid. It can be seen how close the PCB is to the walls of the lid/accumulator.

Grounding

The grounding issue that was present on the V2 board was fixed on the V2.1 by making sure a completed ground plane is present at all the high current components (fans). This was done in KiCAD using the high contrast mode and following the ground plane to make sure there were no breaks or separations. V2 was verified using KiCAD's built in DRC tool, the board passed all checks as the grounds were connected but the KiCAD DRC is not setup to take into account the high current that would be flowing through the ground plane.

Figure 31 shows the LVD V2 in high contrast mode, it can be seen that there is not a continuous ground plane that stretches over the whole LV side of the board. The ground plane is broken up into multiple sections with no high current paths between the different sections. The LVD V2.1 improved ground plane can be seen in Figure 32.

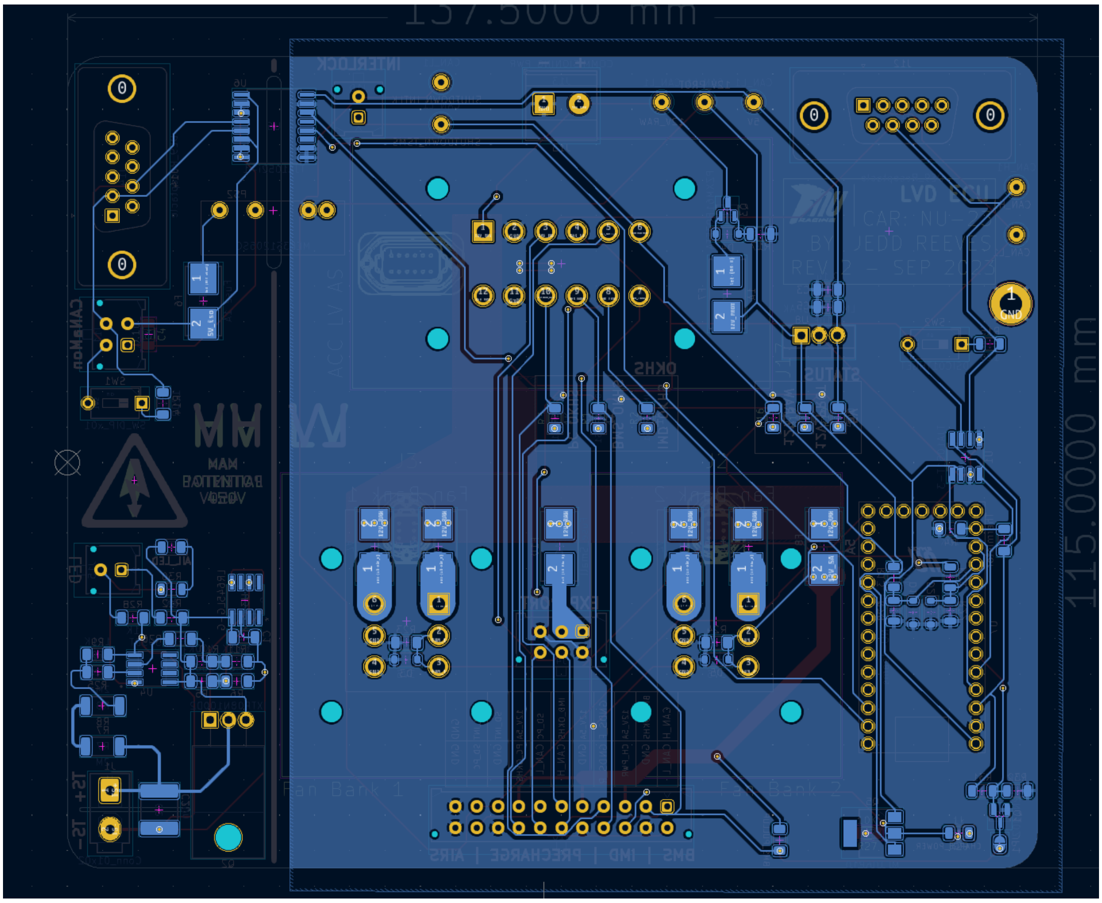


Figure 31. LVD V2 ground plane shown in high contrast mode

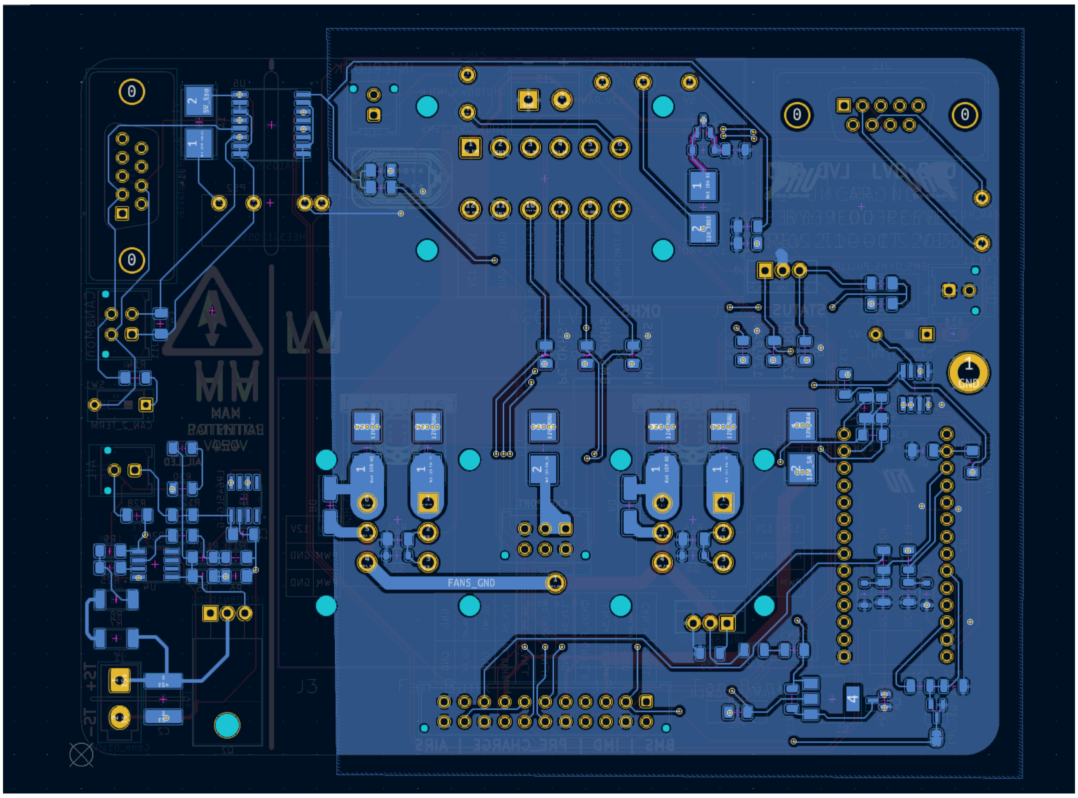


Figure 32. LVD V2.1 ground plane shown in high contrast mode

Improved Charge_Power switching circuit

The charge power signal switching circuit was fixed in this version. The improved/working circuit uses a P channel MOSFET as the device to pull up the Charge_Power signal to 12 V. This is accomplished using a Teensy to control an N channel MOSFET which when supplied with 3.3 V from the Teensy's digital output pin, grounds the 12 V source that is supplied to the P channels MOSFET's gate and source pins. When the N channel MOSFET completes the circuit from 12 V to GND the source and gate pin of the P channel MOSFET are supplied with that 12 V source which in turn closes the P channel MOSFET and drives the Charge_Power signal HIGH. This circuit was verified on LT-Spice before the PCB schematic was finalised to guarantee the correct functionality of the circuit. This functional Charge_Power switch circuit used on the LVD V2.1 is shown in Figure 33.

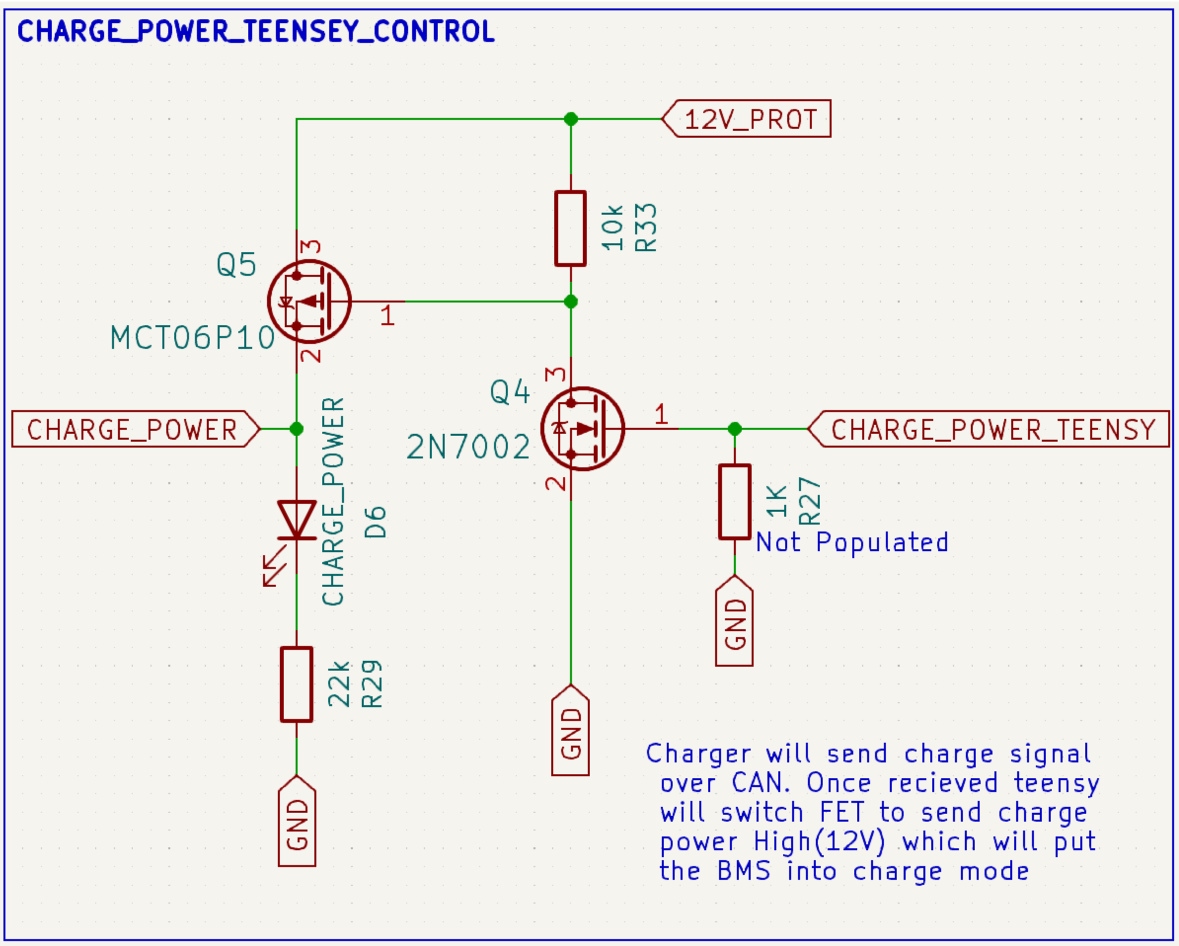


Figure 33. Charge_Power signal switching circuit present on LVD V2.1

Customisable Pull Up/Powering Options

Functionality was added to this board to have the have the ability pull up or power devices with different voltages depending on what pad a 0 ohm resistor was soldered to. This means the board is customisable and makes it easier to use a slightly different setup without the need for whole new board.

Two resistor pads were added on the BMS_OKHS pull-up to allow for the option to pull up the signal to either 5 V or 12 V. When the old EV3 CEN was used on the car the BMS_OKHS was pulled up to 12 V but with the NU23 CEN the BMS_OKHS is only pulled up to 5 V. Two voltage pull up options were added to that board to allow for customisation in the future without the need for a new board or jumper wires. These two resistor pads can be seen in Figure 34. Depending on what resistor is populated determines what voltage the BMS_OKHS is pulled up too. For example, if the 12 V pad is populated with a 0 ohm resistor the BMS_OKHS will be pulled up to 12 V.

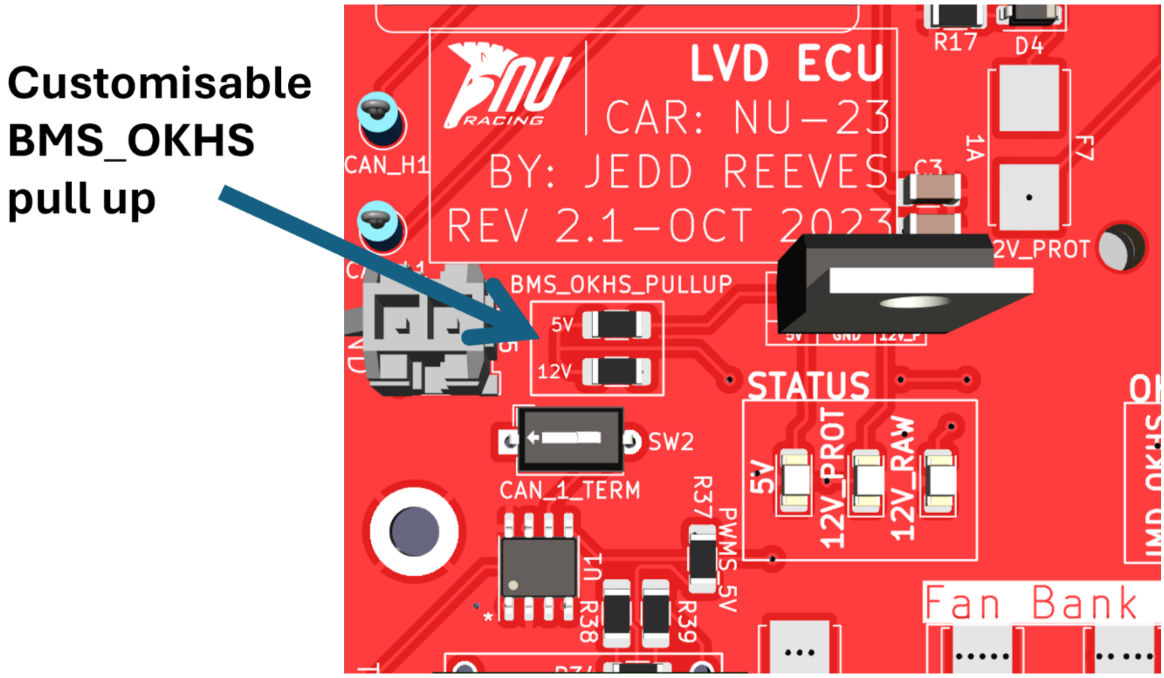


Figure 34. Customisable BMS_OKHS pull-up

There are also two sets of pads that can be populated to power the isolated CAN transceiver responsible for communication with the CANaMons. The two options are either 3.3 V or 5 V. This section of the board is shown in Figure 35. For example, if the 3.3 V pad is populated with a 0 ohm resistor and the 5 V pad is left unpopulated the isolated CAN transceiver will be power using 3.3 V.

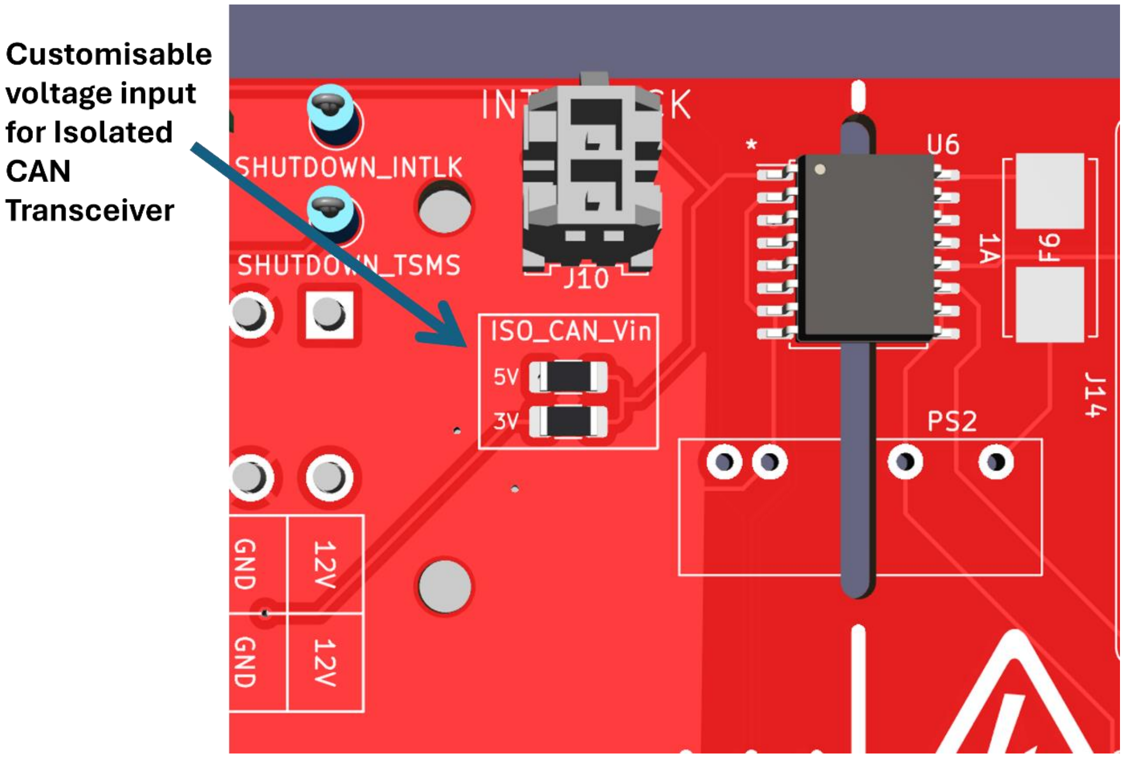


Figure 35. Customisable voltage input for isolated CAN transceiver

Pads were also added that can be used to connect both PWM signals. This allows for the fans to be controlled using one single Teensy pin as opposed to one pin per fan bank. A PWM pull up pad was added that can be populated using a 0 ohm resistor to pull the PMW signals up to 5 V. This allows for the fans to be locked on 100% PWM speed without the need for a Teensy supplying a PWM signal. These pads are shown in Figure 36. R38 and R39 are inline pads that are populated with an SS34 flyback diode. This protects the Teensy pins from the 10 V feedback that is cause when the fans are unplugged when still powered. R37 (PWMS_5V) is used to pullup the PWM pins to 5 V. R34 (PWM_CON) when populated connects both PWM signals.

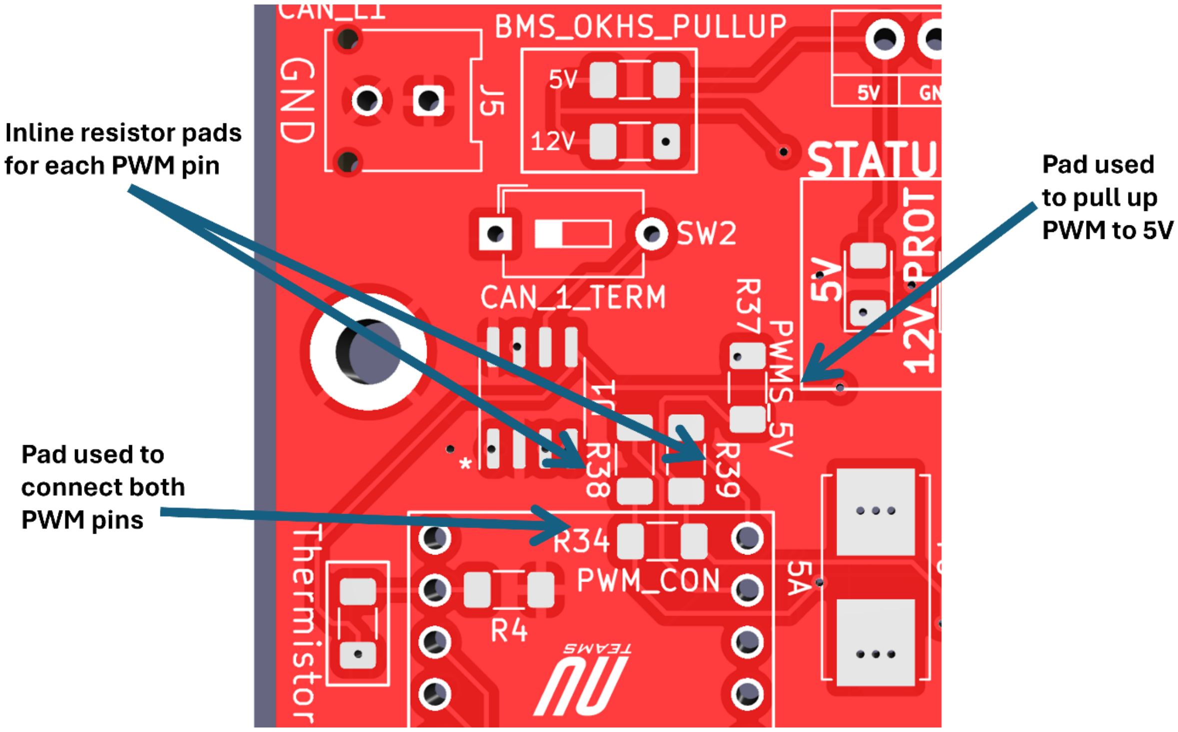


Figure 36. Customisable PWM setup

Fan switching MOSFET

A MOSFET capable of switching 30 A at 12 V is integrated into this circuit which allows for the fans to be completely turned off. The fans used to cool the accumulator still spin at 25% when supplied with no PWM. This circuit allows for the fans to be completely turned off using the Teensy to switch a MOSFET. The MOSFET is used to ground the fans. This is a N Channel MOSFET, when the Teensy pin is set to LOW the MOSFET is open resulting in the fans ground been disconnected. When the fans ground is disconnected the fans are completely turned off.

Because the ground is disconnected and the positive pin of the of the fans are receiving 12 V the Teensy protection diodes must be functional. Hence why both the in line and fly back diode have been added to the V2.1. When the Teensy pin controlling the MOSFET is driven HIGH the fans become grounded and work as normal. This circuit is shown in Figure 37. This is a NUTeams standard block that is used available on the NUTeams GITHUB.

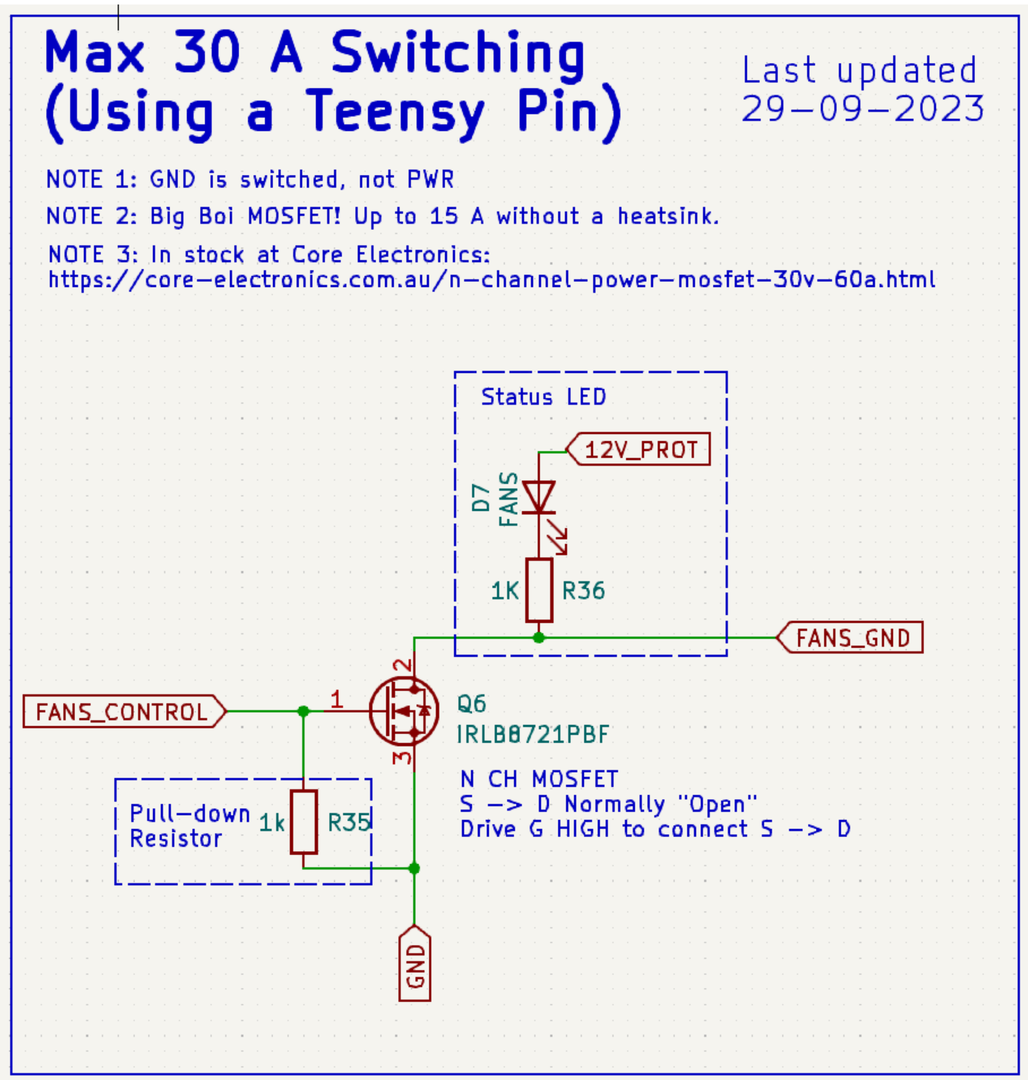


Figure 37. Fan ground switching circuit

Fly Back Diode

To increase the level of protection for the Teensy pin responsible for outputting the PWM signals to the banks off fans, a fly back diode was added between the power and GND of each fan bank. This diode allows for current to flow from negative to positive. This reduces the effects of sudden voltage spikes across the inductive load when the supply current is reduced or interrupted. These flyback diodes are shown in Figure 38. The same diodes are used as inline reverse voltage protection on pads R38 and R39. This is once again to protect the Teensy from reverse voltage feedback from the fans. Pads R38 and R39 are shown in Figure 36.

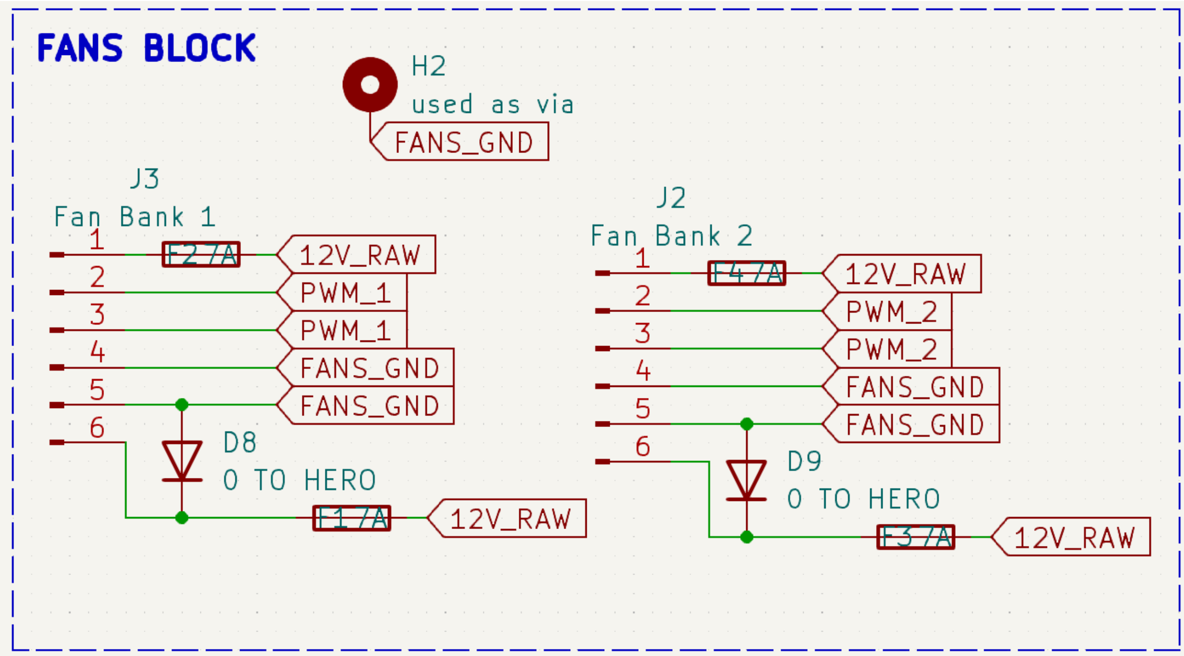


Figure 38. Fan block used in LVD V2.1 schematic

LED Status indicators

SMD LEDS are also incorporated into both the Charge_Power switching circuit and fan switching circuit. These LEDs become illuminated when the Charge_Power signal is pulled up to 12 V and when the fans are grounded and operational. These LEDs were used to make bench testing easier and act as an obvious indicator that the circuit is working as expected.

SMD LEDs are also used to indicator the status of 12 V raw, 12 V protected, 5 V, BMS_OKHS, IMD_OKHS and Pre_Charge_OKHS. These 6 status LEDs were present on all previous versions of the LVD and aid in quick trouble shooting and fault finding.

LVD V2.1: Manufacturing

Like the previous versions of the LVD the final revolution of the board was designed on KiCAD. Once the PCB had passed both NURacing and KiCAD DDR's and DRC's and issues present on previous boards were verified to be resolved, the final LVD Gerber file was exported from KiCAD and uploaded to PCBGOGO. No new components needed to be ordered as V2.1 shares the same components as V2 and the new components like the switching MOSFETs were used on the CEN and other NURacing PCBs so there was stock available in the MCHA Lab.

A stencil was order for this board and was used to flow solder all SMD components on the bottom side of the board using the soldering oven in the MCHA Lab. The bottom side was soldered in the oven as there are many more components on the bottom side. The SMD were then solder on the top side of the board using the heat guns supplied in the MCHA Lab.

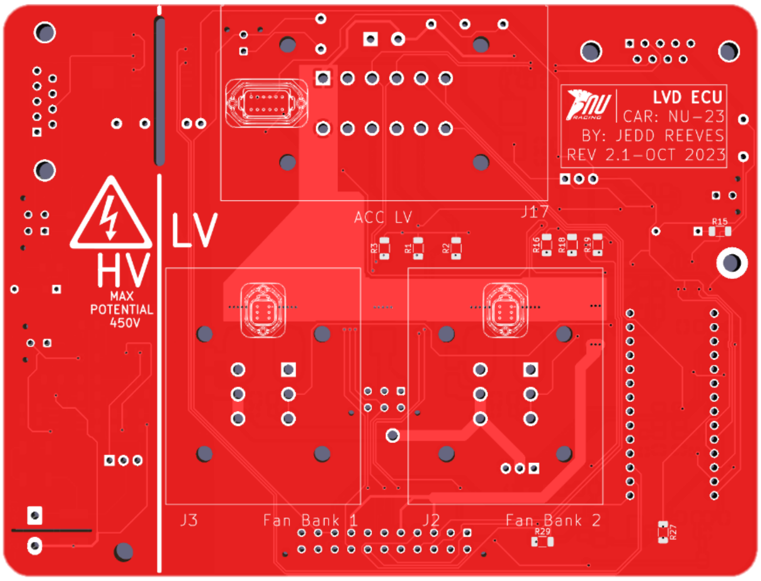


Figure 39. LVD V2.1 front/top side of PCB

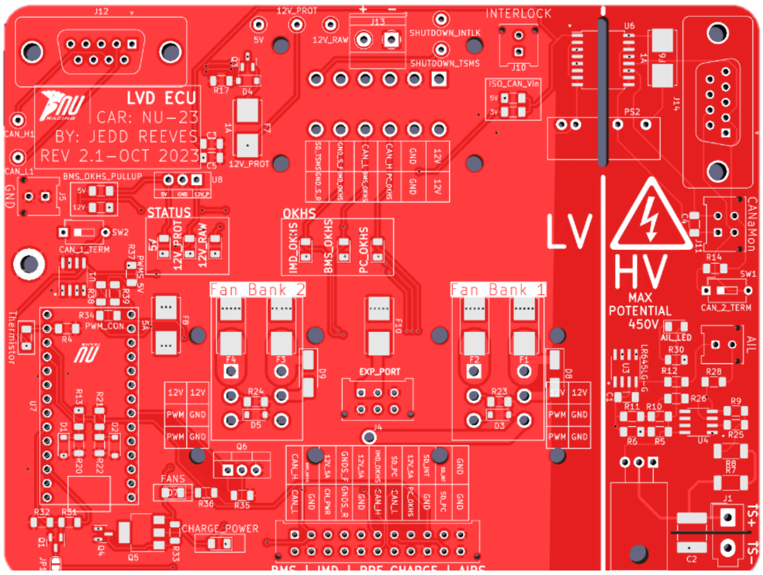


Figure 40. LVD V2.1 back/bottom side of PCB

The through hole components were then soldered on. The final parts to be soldered onto the board were the DT connectors. This is due to the fact that some components were placed under the DT connectors to save space and help reduce the overall size of the LVD V2.1.

The same wiring harness could be used to power all the top plate devices/components that was used on the previous LVD therefore no manufacturing of wiring harnesses was needed.

LVD V2.1: Commissioning

Because the majority of the circuitry didn't change between V2 and V2.1 the only difference in commissioning this board was testing the improved Charge_Power switching circuit and the fans switching circuit.

The code in Figure 41 is the code that was used to verify the two MOSFET circuits. This code is also used to make sure the PWM pins are working. Pin 20 is defined as CHARGE_POWER and is used to switch the circuit for the BMS's charge power signal. Pin 5 is defined as FANSWITCH and is used to switch the MOSFET responsible for grounding the fans. Both pins are defined and setup as OUTPUT mode. They are then set HIGH (3.3 V). Using this code, the on-board status LEDs become illuminated, this shows that both switching circuits are working as expected. A multi metre was still used to verify that the voltage of the Charge_Power signal was 12 V and that the ground of the fans was connected to the boards common ground.

The code was then changed to set both pins LOW (0 V), the status LEDs for both circuits were observed to be off as expected. A multi metre was then used to verify the Charge_Power signal was at 0 V and that the fans ground is now disconnected from the LVDs common ground.

```

#define CHARGE_POWER 20       //Pin for switching charge power to put the BMS into charge mode
#define FANSWITCH 5           //Pin used to switch Fans ground
#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


void setup() {
  // put your setup code here, to run once:
  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, OUTPUT);    // Setup charge power switching pin
  pinMode(FANSWITCH, OUTPUT);       // Setup Fan switch pin
}

void loop() {
  // put your main code here, to run repeatedly:

  digitalWrite(CHARGE_POWER, HIGH);
  digitalWrite(FANSWITCH, HIGH);

  analogWrite(IN_PWM_PIN, 255);
  analogWrite(OUT_PWM_PIN, 255);

}
```

Figure 41. LVD V2.1 MOSFET circuits commissioning code

The LVD V2.1 was then assembled in the accumulator and plugged into the charger. The charger was used to verify both the fan switching circuit and Charge_Power signal. The Charge_Power circuit was setup in such a way that when the accumulator received a charge message over CAN the Teensy would send pin 20 HIGH which closes the MOSFET and pulls the Charge_Power signal up to 12 V. This was tested on the charger and was verified to be working, the BMS also began to cell balance which only occurs when it receives a charge power signal, this also verifies that the BMS is receiving the signal.

The fan switch circuit was hard coded as there wasn't enough time to integrate a mode or switch that could be triggered to turn the fans completely off while the car was still on. The fan switching circuit was verified to work on the charger. But an issue occurred with the MOSFET when the accumulator was in the car and the fans were on 100%. The MOSFET got so hot that it desoldered its self-off the board and caused the car to hard fault. This issue is discussed below in the LVD V2.1 Issues/problems section.

LVD V2.1: Issues/problems

There was an issue with the fan switching MOSFET that was found when the LVD V2.1 was used in the car for the first time. With the fans running between 80-100% there is roughly 24 A going through the MOSFET, all though the MOSFET is rated above this current it still got extremely hot and desoldered its self-off the board.

This due to the Teensy not been able to fully saturate the MOSFET with its 3.3 V output. When the gate pin of the MOSFET was supplied with 3.3 V there was a 110 ohm resistance between the Drain and Source pins. This large resistance cause the MOSFET to heat up and fall of the board.

This could be fixed by adding another MOSFET to switch a 12 V signal which controls the fan switching MOSFET. By supplying the MOSFET's gate pin with 12 V it would become fully saturated and the resistance between the Drain and Source pin would be dramatically reduced. This reduction in resistance would equate to a reduction in heat generated by the MOSFET. This was never tested as there was very limited time left until the competition.

A larger heat sink was added to the MOSFET and the board was tested on the bench with spare fans which pulled 16 A. A Flir gun was used to monitor the temperature of the MOSFET/heat sink. The MOSFET reached steady state at 87 °C. The heat sink appeared to work but it was difficult to simulate a real on car test on the bench, the MOSFET and heat sink were never tested on the car as there was limited time before competition and it was not worth risking an untested part. Because of this the MOSFET was removed and a wire was soldered between the fans ground and the LVD's ground. Because of this the fans acted the same as they did on previous LVD boards.

There were issues with the LVD during the endurance event in the competition. The LVD's Teensy dropped out at the end of lap 10 and the heartbeat could not be seen over CAN. This caused the car to hard faulted due to the CANaMons cell temperatures been lost. The LVD Teensy is responsible for rebroadcasting the CANaMons cell temperatures back onto the main bus used by the rest of the car.

The cause of the issue was/has not been found as there was limited time after the competition to fault find. It is believed that the Teensy used on the LVD during the competition was faulty. More track time would be needed to trouble shoot the exact issue but the main theory at the current time is that the issue was caused by a faulty Teensy.

LVD code

LVD V1: code

The code use on the LVD V1 had the following functionally:

- Top plate temperature readings calculated from SMD thermistor
- CAN communication for Bus 1
- Shutdown circuit logging over CAN
- CAN communication for Bus 2 (CANaMons)
- Basic fan control (fans PWM constantly on 80% when on car, 25% PWM when charging)

This code is shown in the appendix

LVD V2-V2.1: code

The majority of the code for the LVD V2 and V2.1 code was written by Josh Dawson and can be seen in (Dawson, 2023).

Code for shutdown circuit logging, Charge_Power signal switching, fan MOSFET switching and thermistor was written by the author of this report.

The code use on the LVD V2-V2.1 had the following functionally:

- Top plate temperature readings calculated from SMD thermistor
- CAN communication for Bus 1
- Shutdown circuit logging over CAN
- CAN communication for Bus 2 (CANaMons)
- Basic fan control (fans PWM constantly on 80% when on car, 25% PWM when charging). A ramp function was added which gradually increased the fan speed from 0-80% over 5 seconds.
- Automatic Charge_Power switching signal enabled by CAN
- Fan switching code which gives the ability to fully turn of the accumulator fans

This code is shown in the appendix

AIL

By Jedd R

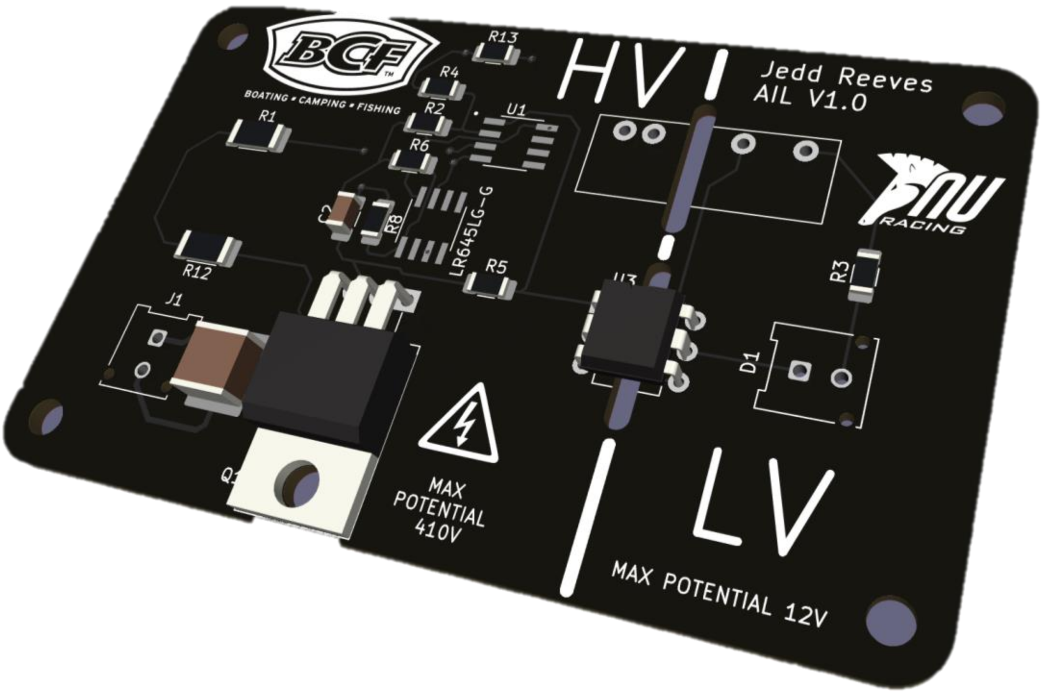


Figure 42. Isolated AIL 3D model KiCAD

AIL: Project Overview

The AIL is the Accumulator Indicator Light. This light must be visible on the accumulator and must become illuminated when TS voltage is greater than 60 V. The initial goal for the 2023 AIL was to power the LED using a galvanically isolated voltage. The power used for the LED still had to be from TS as the rules state that TS+ and TS- must solely control the LED. By powering the LED with an isolated low voltage there would be no need to keep the wires and LED away from other LV components inside the accumulator. This allows for more freedom when it comes to routing wires and locating PCBs.

The isolated AIL PCB was manufactured and bench tested where it appeared to work. This isolated AIL was then integrated into the LVD V1 board where issues with the AIL circuitry arose. An un-isolated AIL was then added to the second version of the LVD which remained the same on the final competition version of the LVD board (LVD V2.1).

Before competition the AIL was replaced with an analogue voltage metre that was mounted on the lid.

AIL: Initial Design

The AIL V1 designed by David Birdsall used a SMD 8 pin voltage regulator that is capable of regulating a 450 V input to an 8-12 V output. The output voltage value was determined depending on the resistor ratio used on the trim pin on the linear voltage regulator. This ratio vs output voltage graph can be seen in Figure 43.

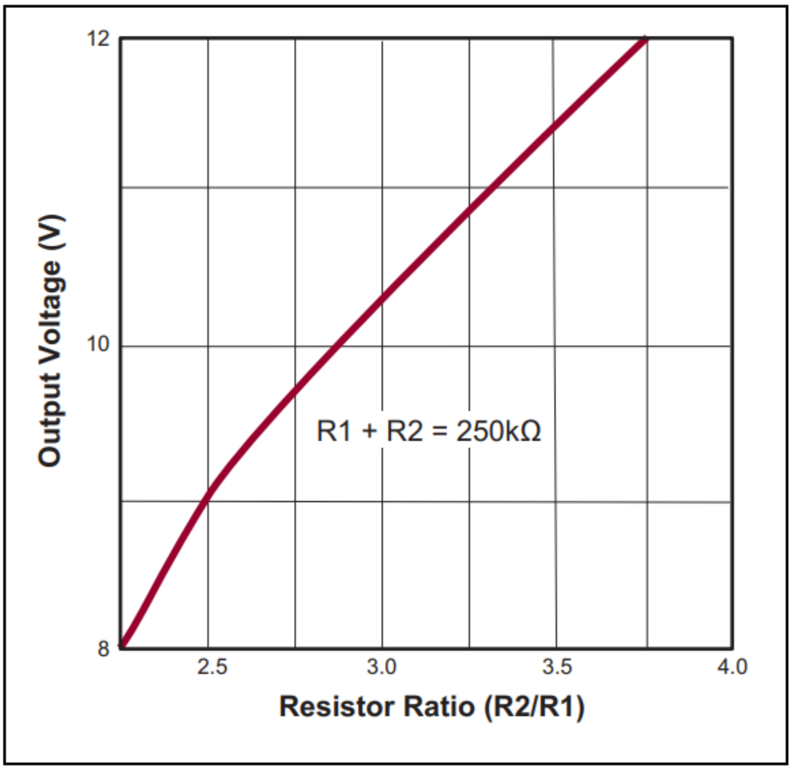


Figure 43. Resistor Ratio vs Output Voltage for LR645LG-G

An LM393DT dual comparator op amp is used to switch the GND for the LED when TS is greater than 60 V. One of the inputs for the comparator is the output of a TS voltage divider, this voltage is known as TS_Scaled. This voltage divider scales TS in such a way that when TS is equal to 60 V the output of the divider is 1.75 V and when the value of TS is 400 V the output of the divider is 11.55 V. This TS_Scaled input is compared to the scaled output of the linear voltage regulator (V_Reg). This is at a constant voltage of 1.771 V. Whenever TS is greater than 60 V TS_Scaled will be greater than 1.75 V which will cause the output of the comparator op amp to be pulled to GND thus completing the circuit which will illuminate the LED and indicate that HV is present at the TS+ TS- terminals. This AIL circuit is shown in Figure 44. The voltage dividers used can be seen in the bottom left corner of the schematic and the comparator circuit is shown in the bottom right corner.

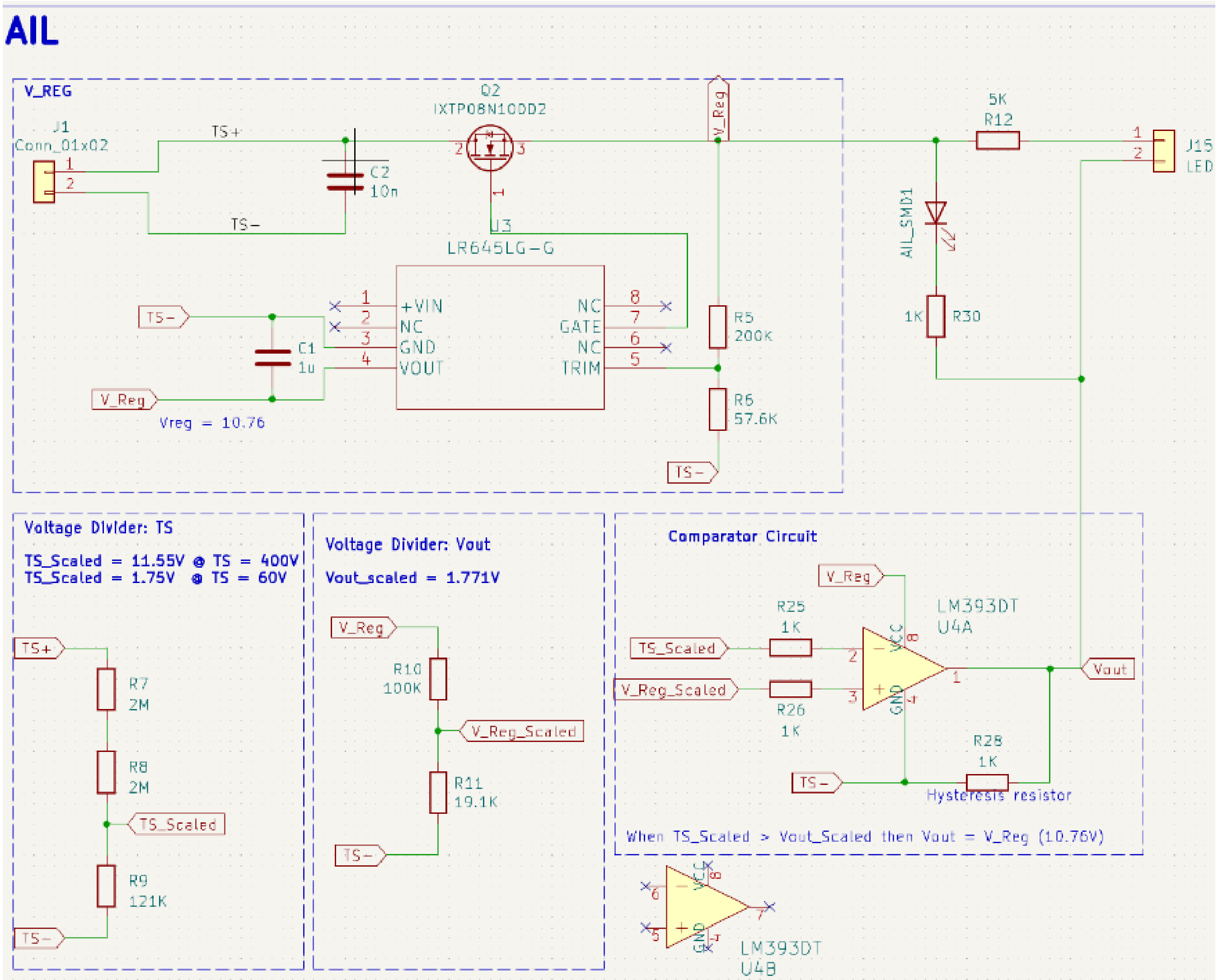


Figure 44. Un-isolated AIL circuit

The goal of the new AIL was to power the LED with an isolated supply. This means the LED and wires powering the LED could be located in the LV wiring loom inside the accumulator and also means the LED could be placed in closer proximity to the other LV components.

The voltage regulator and comparator circuit used to determine if the tractive system voltage (TS) was above 60 V is the same circuit used in the previous AIL that was designed by David Birdsall.

The AIL must solely be powered by TS and a separate source cannot be used to power the light. Because of this a component needs to be selected that can create an isolated source from the HV which can power the LED.

The initial plan was to create isolated 12 V using a galvanically isolated voltage regulator that could regulator 400 V to 12 V. No suitable regulator could be sourced that would satisfy requirements of this problem.

The isolated AIL uses an optocoupler and an Isolated DCDC converter to isolate the two sources.

An optocoupler is a device which contains an infrared LED and a photosensitive transistor and can be used to coupler isolated circuits. The optocoupler used was a 4n35.

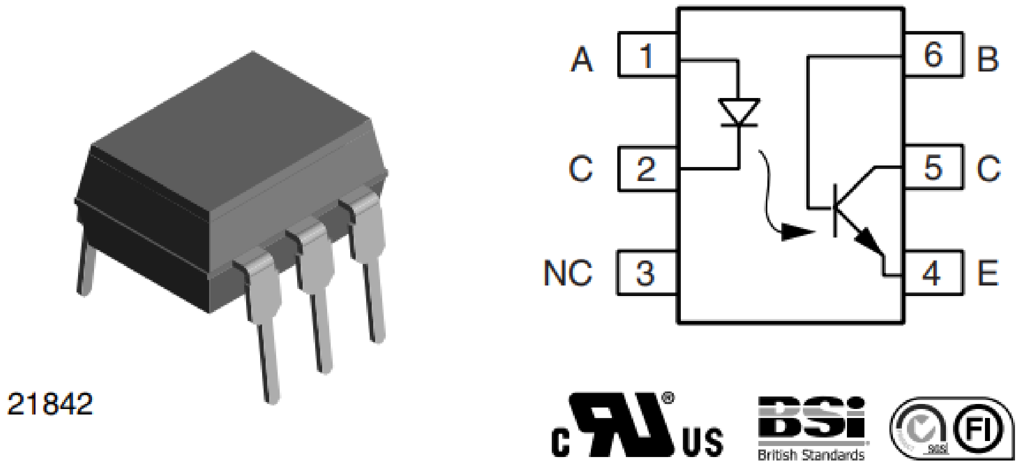


Figure 45. 4n35 Optocoupler inner circuitry

The optocoupler was paired with a PUC1205S1B which is a 12 V to 5 V 1 W isolated DCDC converter which supplied the LED with an isolated voltage.

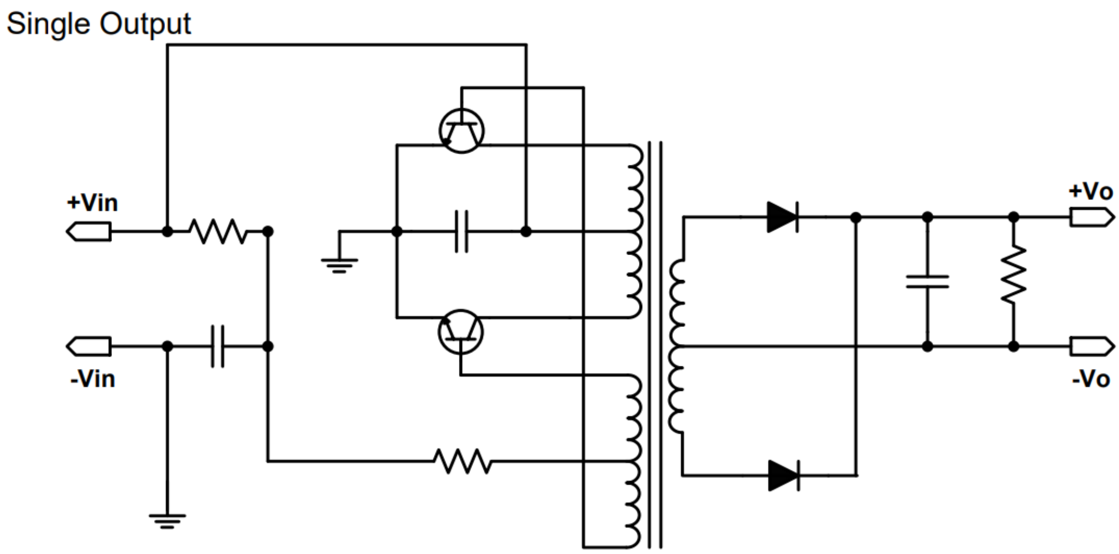


Figure 46. PUC1205S1B isolated DCDC converter inner circuitry

The input of the optocoupler is powered by the output of the comparator. If TS is greater than 60 V the optocoupler is powered thus allowing current to flow through the photosensitive transistor which grounds the isolated circuit that powers the LED.

This worked but the optocoupler required more power than what the output of comparator could supply so the photosensitive transistor was not fully saturated. This meant that the transistor acted as a current limiting resistor which cause the LED to be poorly lit.

To overcome this, the optocoupler was replaced by a solid-state relay. This relay had the same footprint as the optocoupler, this meant that it could easily be switched out and testing. The solid-state relay could be control with a much smaller current with allowed for a much lower resistance on the isolated LED side of the circuit.

AIL: Manufacturing

The isolated AIL PCB was designed using KiCAD. Once the board was finalised in KiCAD the Gerber files were submitted to PCBGOGO. Once the physical PCB was received, the through hole components were hand soldered and SMD components were flow soldered using the heat guns and solder paste supplied in the Mecha Lab.

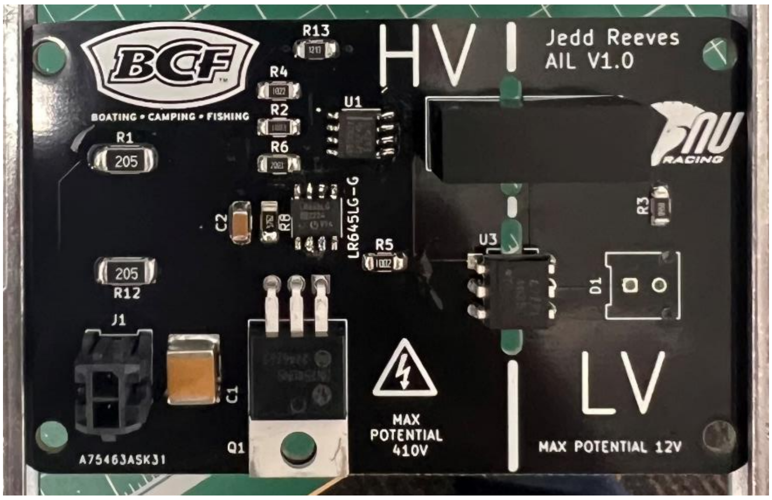


Figure 47. Assembled isolated AIL PCB

AIL: Commissioning

The AIL is a completely analogue circuit. To test and commission it a MECHA Lab power supply was used in series mode so a voltage of 60 V and greater could be supplied to the PCB. After numerous tests of supplying the AIL PCB with a range of voltages between 0 V- 64 V, a few resistor values needed to be changed to make the LED turn on at a closer value to 60V.

This board was never tested on the car. This was a massive oversight and is addressed in a later section.

AIL: Issues/problems

This section of report details all the AIL issues that were present on the different version of the LVD PCB.

LVD V1 AIL

The AIL used on V1 of the LVD was the isolated circuit. This worked perfectly on the bench but when used on the car the car was unable to pre charge. This is due to the extra power draw of the isolated DCDC converter. The isolated AIL created a voltage divider between TS and the pre charge, which limited the voltage supplied to the pre charge PCB which meant the accumulator was unable to complete a pre charge and therefore limiting the car from going into HV. Figure 48 shows the isolated part of the AIL circuit in the “OPTOCOUPLER” block in the top right-hand corner.

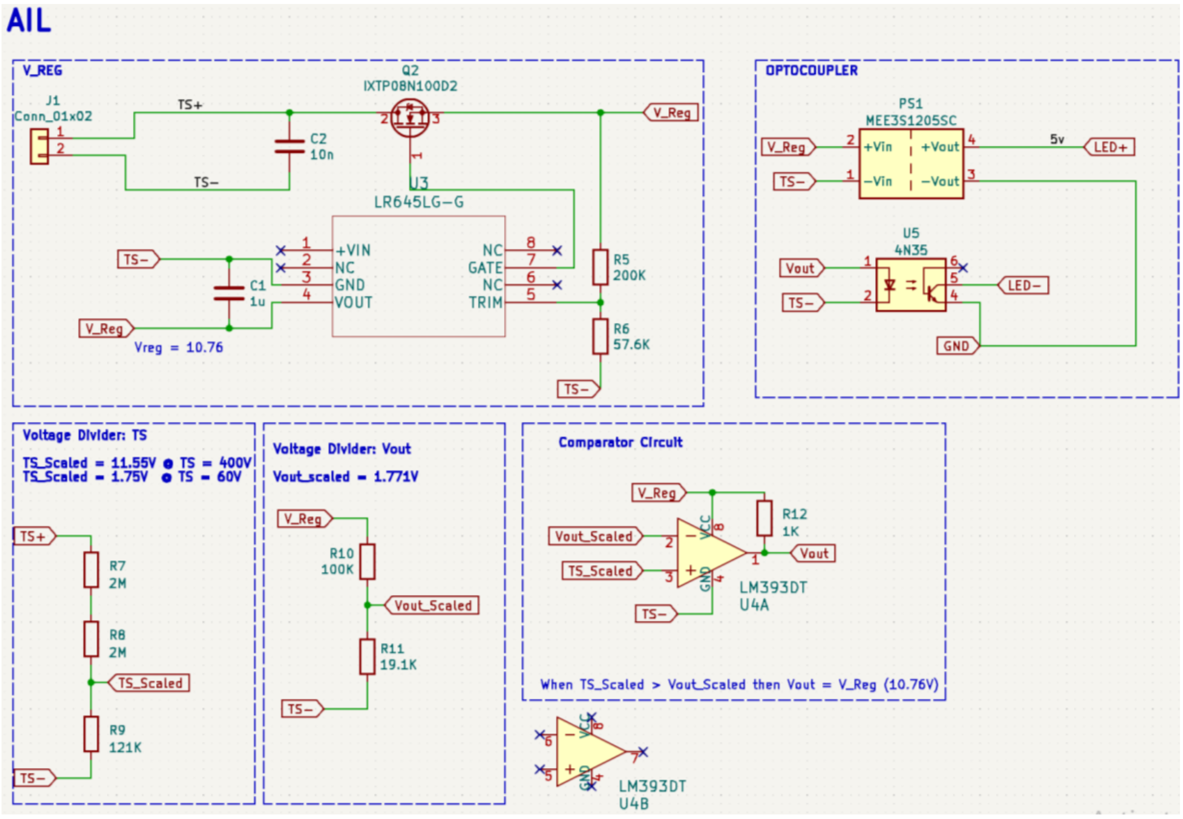


Figure 48. Isolated AIL schematic

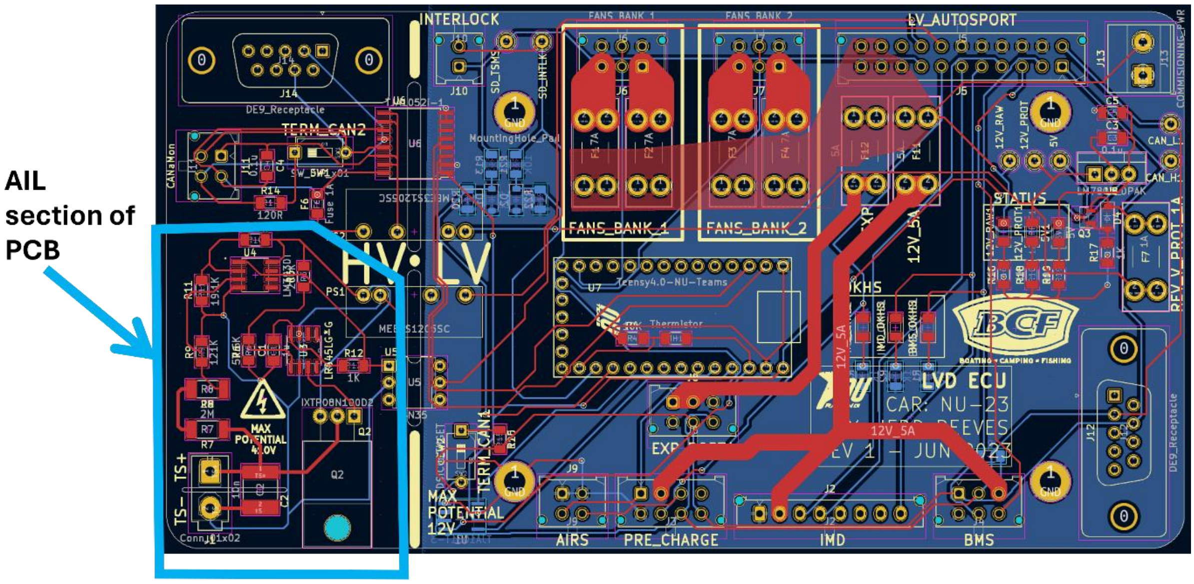


Figure 49. LVD V1 PCB: AIL section of the board outlined

LVD V2 & V2.1 AIL

The AIL circuits used on both the LVD V2 & V2.1 PCBs were exactly the same. The AIL circuit present on the V2, V2.1 boards was very closely based of off David Birdsall's AIL with the exception of slight adjustments that were made to resistor values and resistor footprints. The isolated circuit was removed and the LED was now powered off un-isolated 12 V. This AIL circuit was functional with the 8-segment accumulator as the maximum voltage supplied to the circuit was 400 V. With the upgraded to the 9-segment accumulator the maximum voltage was increased to 450 V. This voltage increase caused the N Channel MOSFET present on the board to heat up to 180 °C after 4 minutes. This temperature was verified using the Flir gun. This render the AIL section of the LVD PCB useless, and it was not used on the car.

When this issue was found there was not enough time to redesign an AIL circuit/PCB before the competition. Because of this time constraint an analogue voltage metre was used instead. This was an extremely simple fix. It is also an extremely reliable part as there is no circuitry and it uses a low amount of power.

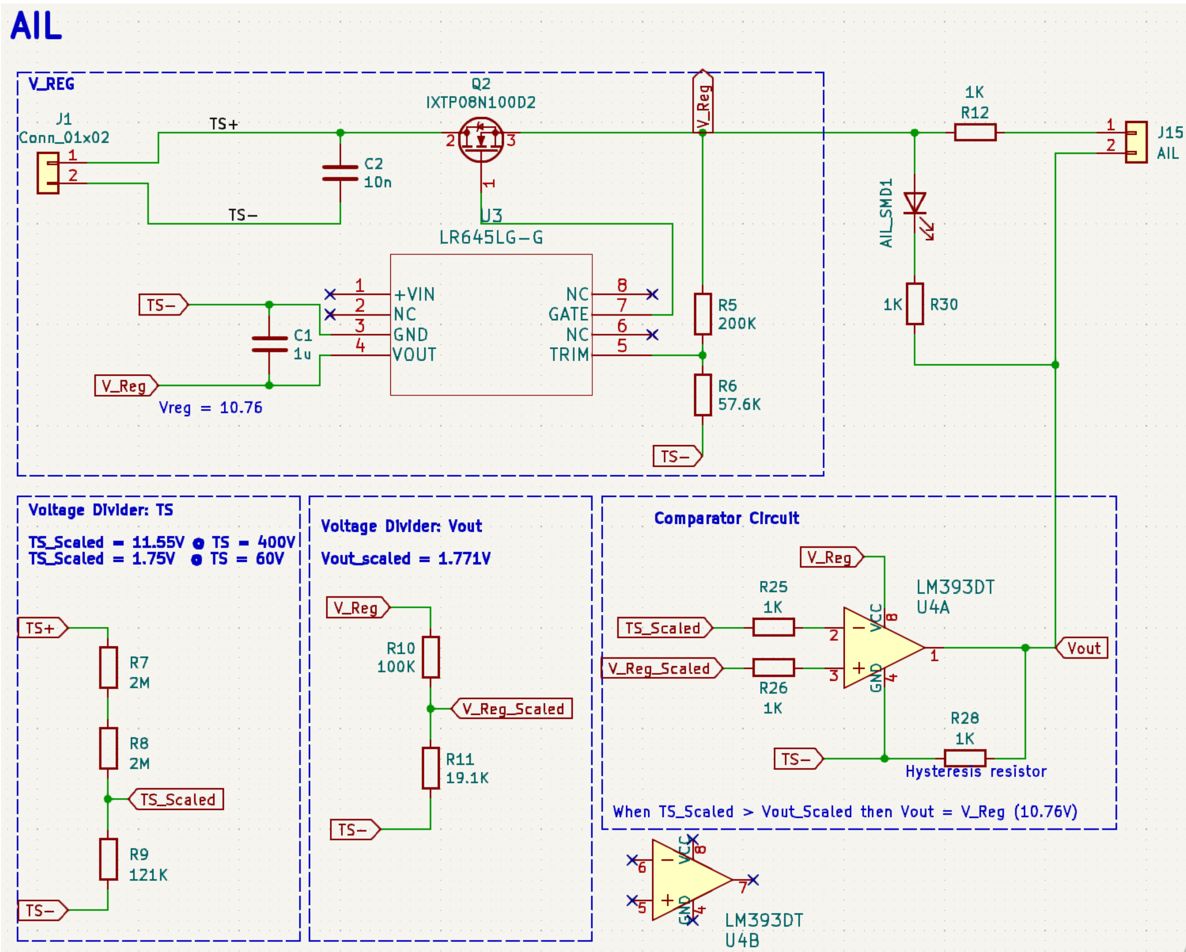


Figure 50. AIL schematic used on the LVD V2 & V2.1

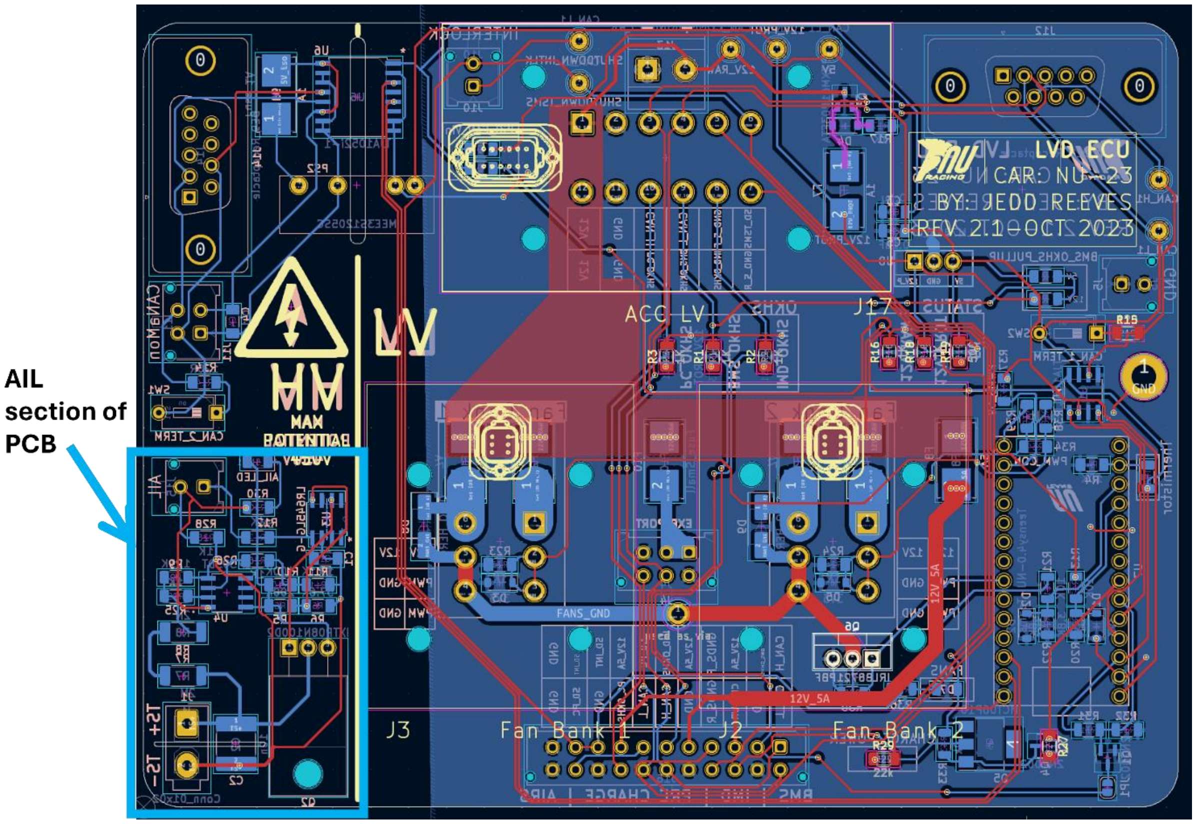


Figure 51. LVD V2.1 PCB: AIL section of the board outlined

Bill of Materials

By Jedd R

BOMS for isolated AIL PCB, LVD V1 PCB, LVD V2 PCB and LVD V2.1 PCB can all be found in the appendix.

Compliance Report

By Jedd R

This section of the report outlines competition rules that are relevant to the systems that the author worked on.

EV.6.7 Voltage Indicator

Each Accumulator Container must have a prominent indicator when High Voltage T.9.1.1 is present at the vehicle side of the AIRs.

EV.6.7.1 The Voltage Indicator must always function, including when the Accumulator Container is disconnected or removed.

EV.6.7.2 The voltage being present at the connectors must directly control the Voltage Indicator using hard wired electronics with no software control.

EV.6.7.3 The control signal which closes the AIRs must not control the Voltage Indicator.

EV.6.7.4 The Voltage Indicator must:

a. Be located where it is clearly visible when connecting/disconnecting the Accumulator Tractive System connections.

b. Be labelled "High Voltage Present".

EV.7.3 Wiring

EV.7.3.1 All wires and terminals and other conductors used in the Tractive System must be sized for the continuous current they will conduct.

EV.7.3.2 All Tractive System wiring must:

a. Be marked with wire gauge, temperature rating and insulation voltage rating. A serial number or a norm printed on the wire is sufficient if this serial number or norm is clearly bound to the wire characteristics for example by a data sheet.

b. Have temperature rating greater than or equal to 90°C.

EV.7.3.3 Sizing of the conductors for the 'continuous Tractive System current' may consider the:

a. RMS or average electrical current that will be used.

b. Anticipated duration of time at maximum electrical current.

EV.7.3.4 Tractive System wiring must be:

a. Done to professional standards with sufficient strain relief.

b. Protected from loosening due to vibration.

c. Protected against damage by rotating and / or moving parts.

d. Located out of the way of possible snagging or damage.

EV.7.3.5 Any Tractive System wiring that runs outside of electrical enclosures:

a. Must meet one of:
   • Enclosed in separate orange nonconductive conduit
   • Use an orange shielded cable.
b. Must meet one of:
   • Run in a fully enclosed container. Bodywork is not an enclosure.
   • The conduit or shielded cable is securely anchored at each end to allow it to withstand a force of 200 N without straining the cable end crimp
c. Any shielded cable must have the shield grounded.

EV.7.3.6 Wiring that is not part of the Tractive System must not use orange wiring or conduit.

EV.7.5 Voltage Separation

EV.7.5.1 Separation of Tractive System and GLV System:

a. The entire Tractive System and GLV System must be completely galvanically separated.

b. The border between Tractive and GLV System is the galvanic isolation between both systems. Therefore, some components, such as the Motor Controller, may be part of both systems.

Voltage	Over surface	Thru Air (cut in board)	Under conformal coating
0-50V DC	1.6mm	1.6mm	1mm
50-150V DC	6.4mm	3.2mm	2mm
150-300V DC	9.5mm	6.4mm	3mm
300-400V DC	12.7mm	9.5mm	4mm

EV.7.5.2 There must be no connection between the Chassis of the vehicle (or any other conductive surface that might be inadvertently touched by a person), and any part of any Tractive System circuits.

EV.7.5.3 Tractive System and GLV circuits must not run through the same conduit or connector, except as allowed in EV.8.8.4

EV.7.5.4 GLV Systems other than the AIRs EV.6.4, parts of the Precharge and Discharge Circuits EV.6.6, HV DC/DC converters, the AMS EV.8.3, the IMD EV.8.6, parts of the TSAL EV.6.9.1 the Energy Meter EV.4.2 and cooling fans must not be inside the Accumulator Container.

Competition Results

By Jedd R

The NURacing team in 2023 achieved a placement of 7th overall. Achieving 2nd place in auto-cross, skid pan and the business event. This was the first time NURacing had ever achieved a podium position in any dynamic events. NU23 proved to be a reliable and fast car for the majority of the competition. It was also one of the simplest setup in the entire fields on cars, as it used a single motor, with a solid rear axle driven by a chain. Even with this basic design, NU23 punched well above its weight and held its ground against much more mechanically and electrically complex cars which had multiple hub motors and torque vectoring capabilities. This goes to show that NURacing's goals of been reliable, simple and reducing part count work and helped to allow us to compete with larger teams with our much smaller budget and resources.

The LVD was flawless in in skid pan, acceleration, auto cross and the first half of half of endurance. Unfortunately, the LVD Teensy failed during endurance causing a hard fault to be triggered because the cell temps were lost. It is believed that it was a fault Teensy but there hasn't been enough time to trouble shoot and workout the exact issue/problem that cause the Teensy to drop out. The car was power cycled after the hard fault and everything returned to a functional state, this is was frustrating as it clearly wasn't a major fault or complete component failure.

Apart from the not completing endurance NURacing and NU23 had an extremely successful competition with many amazing results in the other events. If the car was able to complete endurance NURacing would have been on track to finish in the top 3 teams and achieve an overall podium finish. As a whole, the team did an amazing job all year where numerous challenges were encountered and overcome.

Conclusions and Recommendations

By Jedd R

Overall, the LVD was a reliable PCB which drastically reduced the complex of the accumulator and the wiring of the top plate. The LVD along with the mechanical work of Michael Dalton and Jacob Searle made NU23's accumulator less complex than the accumulator used in EV3, both in the mechanical and electrical categories. More information about the mechanical details of the accumulator can be found in (Dalton, 2023) & (Searle, 2023). NU23's accumulator is extremely simple to work on and disassemble. Once the issue that occurred during endurance is solved NU23's accumulator would become 100% reliable and contain many less parts than last year's accumulator. Because the LVD has simplified the electrical complexity of the accumulator is also easier to trouble shoot. The NU23 accumulator is much easier to understand/follow as opposed to EV3's accumulator. Because of this reduction in complexity, it will take a much shorter amount of time for a new member of the team to understand the inner workings of the accumulator allowing for a much small learning curve to understand the HV system on the car.

Recommendations

AIL

To avoid future issues with the AIL circuitry, Micheal Ruppe's AIL circuit should be investigated and tested. This is an extremely simple circuit compared to the AIL comparator circuit used in 2023.

The analogue voltage metre is also a great solution that was proven to work at the 2023 competition and should be considered alongside Micheal Ruppe's design.

If Micheal Ruppe's AIL design is shown to be reliable and work a board mounted LED could be installed on the LVD and a hole could be cut in the lid to expose the light. This would reduce the wires and connectors needed within the accumulator.

Status LEDs/Accumulator lid

A clear Perspex section could also be installed on the lid of the accumulator to show the status LEDs for 12 V raw, 12 V protected, 5 V, BMS_OKHS, IMD_OKHS and Pre_Charge_OKHS this would allow for quicker trouble shooting and it would make it possible to fault find without CAN and the need to remove the lid of the accumulator to see what is wrong.

30 A switching MOSFET

A slightly modified fan switch circuit should be investigated where the gate pin would be supplied with a 12 V signal as opposed to a 3.3 V signal from the Teensy. This would be an extremely similar circuit to the Charge_Power signal switch circuit where the Teensy controls a MOSFET which is then used to control a larger MOSFET. By supplying the 30 A switch MOSFET with a 12 V signal the resistance between the Drain and Source pin should be drastically reduced which would reduce the heat generated. This may reduce the need for a heat sink needing to be added, which is quite large and bulky. This needs to be bench tested and investigated.

Multiple tests still need to be undertaking with these high current switching MOSFET. A heat sink should still be installed and tested to see what works and what is most efficient.

LVD

The LVD should be tested to see if the issue that occurred during the endurance event can be replicated and fixed. The LVD should be tested at different temperatures as the issue that occurred in endurance was when the cells were around 50 °C, the current theory is that the Teensy that was installed on the LVD was faulty and the hot environment cause an intermittent issue that went away after a power cycle. Accidental voltage dividers should also be looked for, as hidden voltage dividers have caused issues in the past. The LVD code should also be checked for any code/functions that could cause an intermittent issues.

Additional Work

By Jedd Reeves

- Pack for track
- Unpacking for track
- Marshalling at track
- Setting up cones for track layouts
- Late night trouble shooting
- Loom manufacturing
- Wiring harness manufacturing
- Assemble/disassembly of car
- Assembly/disassembly of accumulator
- LV rescue course St Johns
- Made multiple wire looms and harness used both on the car and internally in the accumulator
- Weekly team meetings
- Expo days
- Industry partner site tour days
- Costing looms and PCBs for cost report
- Tech inspection practice for competition
- Member on the accumulator tech inspection team at competion
- Accumulator charging

Bibliography

Dalton, M. (2023). *FYP Report.* Newcastle: The University of Newcastle.

Dawson, J. (2023). *FYP Report.* Newcastle: The University of Newcastle.

De Gruchy, L. (2023). *FYP Report.* Newcastle: The University of Newcastle.

Dreamstime. (2000-2024). *Circular arrows - Random concentric circles with arrows for twist, rotation, centrifuge, cycle concepts.* Retrieved from Dreamstime: https://www.dreamstime.com/stock-illustration-circular-arrows-random-concentric-circles-arrows-twis-twist-rotation-centrifuge-cycle-concepts-royalty-free-vector-image81822719

Inc, M. T. (2015). *LR645LG-G.* Retrieved from DigiKey: https://www.digikey.com.au/en/products/detail/microchip-technology/LR645LG-G/4902842

Inc., L.-O. (n.d.). *4N35.* Retrieved from DigiKey: https://www.digikey.com.au/en/products/detail/liteon/4N35/385766

Lyall, N. (2023). *FYP Report.* Newcastle: The University of Newcastle.

McLean, M. (2023). *FYP Report.* Newcastle: The University of Newcastle.

Modules, F. P. (2023, March). *PUC1205S1B.* Retrieved from DigiKey: https://www.digikey.com.au/en/products/detail/flex-power-modules/PUC1205S1B/13149008

Munday, I. (2023). *FYP Report.* Newcastle: The University of Newcastle.

Searle, J. (2023). *FYP Report.* Newcastle: The University of Newcastle.

Appendix

LVD V1 Code

```
// Include necessary libraries and define pins

////////////Do thermistor stuff, convert resistance to temp


#include <EV3_CAN.h>                              /* Check whether these should
be < > brackets */
#define IN_PWM_PIN 11                         // PWM Driver Pin 11 - for Fan
Control
#define OUT_PWM_PIN 12                          // PWM Driver Pin 12 - for Fan
Control
#define THERMISTOR_PIN 14                       //Pin for thermistor
#define SD_TSMS_PIN 16                          // Pins for shutdown circuit
#define SD_INTERLOCK_PIN 17
int Vo;
int R1 = 10000;                  //Resistor in series used for thermistor
voltage divider
float logR2, R2, T;
float c1 = 1.009249522e-03;
float c2 = 2.378405444e-04;
float c3 = 2.019202697e-07;


// CAN2 for canamon interaction
FlexCAN_T4<CAN2, RX_SIZE_256, TX_SIZE_16> can2;
CAN_message_t in_msg;

// CAN Message Variables
// CAN DBC
float tempscale = 0.4;
float tempoffset = 0;

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

// Cooling
float lvPowerStatus = 0;                          // CAN Output [C] Max segment
temperature
float charge = 0;                           // CAN Output [C] Max segment
temperature
float maxSegTemp = 0;                       // CAN Output [C] Max segment
temperature
```

```
int fanPWM = 255;
int chargePWM = 60;
int fanPWMmax = 255;
int coolingOnTemp = 25;
int coolingMaxTemp = 40;

// NUCAN Variables
canmsg *inputmsgs[] = {&LV_POWER_STATUS, &CHARGE, &MAX_SEG_TEMP};
float* outputVar[] = {&lvPowerStatus,&charge,&maxSegTemp};
int numreceive = 3;
int numsend = 0;                              // OKHS, Max, MaxInd, Min, Ave,
HeartBeat, 8 seg temps, PWM request


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

void setup() {
   Serial.begin(9600);             // Initialise serial
   NUCAN_init(11, 11);            // Initialise NUCAN
   can2.begin();
   can2.setBaudRate(1000000); // kb/s
      // Set pin modes
   pinMode(IN_PWM_PIN, OUTPUT);
   pinMode(OUT_PWM_PIN, OUTPUT);

   pinMode(THERMISTOR_PIN, INPUT);

   pinMode(SD_TSMS_PIN, INPUT);
   pinMode(SD_INTERLOCK_PIN, INPUT);
}

/* ---------------------------------------------------------------------------
-------------------------*/
// Main Loop

void loop() {
  // Read CAN messages and distribute to variables...
  readCANmsgs();
  // Rebroadcast
  NUCAN_heartbeat(&HB_LVD);

  // Cooling Code
  NUCAN_read(outputVar, inputmsgs, numreceive); //Read desired CAN messages,
store results in outputVar
  EVERY_N_MILLIS(1000) {
    updateThermistor();
    updateShutdown();
```

```
    updateFanSpeed();
  }
}

void updateThermistor(void){
  float Thermistor;

  Thermistor = analogRead(THERMISTOR_PIN);

  Serial.print("Analog reading ");
  Serial.println(Thermistor);

  // convert the value to resistance
  Thermistor = (1023 / Thermistor)  - 1;      // (1023/ADC - 1)
  Thermistor = R1 / Thermistor;  // 10K / (1023/ADC - 1)

  Serial.print("Thermistor resistance ");
  Serial.println(Thermistor);

  Vo = analogRead(THERMISTOR_PIN);
  R2 = R1 * (1023.0 / (float)Vo - 1.0);
  logR2 = log(R2);
  T = (1.0 / (c1 + c2*logR2 + c3*logR2*logR2*logR2));
  T = T - 273.15;

  Serial.print("Temperature: ");
  Serial.print(T);
  Serial.println("C");

  NUCAN_write(&LVD_TEMP, T);

}


/* ---------------------------------------------------------------------------
-------------------------*/

void updateShutdown(void){
	sdInterlock = digitalRead(SD_INTERLOCK_PIN);// read the input from the 
interlock
	NUCAN_write(&SD_INTERLOCKS, sdInterlock);
	sdTSMS = digitalRead(SD_TSMS_PIN);// read the input from the TSMS
	NUCAN_write(&SD_TSMS, sdTSMS);
}

/* ---------------------------------------------------------------------------
-------------------------*/

void readCANmsgs() {
```

```
  float temp = 255;
    if (can2.read(in_msg)){
      // A message was read
     if (in_msg.id==1001) {
        NUCAN_write(&HB_SEG1,in_msg.buf[0]);
      } else {
      temp = in_msg.buf[0]*tempscale+tempoffset;
      }
      if (in_msg.id==1101) {
        NUCAN_write(&TEMP1_SEG1,temp);
      } else if (in_msg.id==1102) {
        NUCAN_write(&TEMP2_SEG1,temp);
      } else if (in_msg.id==1103) {
        NUCAN_write(&TEMP3_SEG1,temp);
      } else if (in_msg.id==1104) {
        NUCAN_write(&TEMP4_SEG1,temp);
      } else if (in_msg.id==1105) {
        NUCAN_write(&TEMP5_SEG1,temp);
      } else if (in_msg.id==1106) {
        NUCAN_write(&TEMP6_SEG1,temp);
      } else if (in_msg.id==1107) {
        NUCAN_write(&TEMP7_SEG1,temp);
      } else if (in_msg.id==1108) {
        NUCAN_write(&TEMP8_SEG1,temp);
      } else if (in_msg.id==1109) {
        NUCAN_write(&TEMP9_SEG1,temp);
      } else if (in_msg.id==1110) {
        NUCAN_write(&TEMP10_SEG1,temp);
      }
    }
}

void updateFanSpeed(void) {
   if (charge == 1) {
      // constant speed fans for PWM when charging
      // 60/255
      fanPWM = chargePWM;
  } else if (lvPowerStatus==0) {
      // Turn off the fans if TS is off
      fanPWM = 0;
  } else if (maxSegTemp < coolingOnTemp) {
      // Turn off the fans if Temp < 25 C
      fanPWM = 100;
  } else if ((maxSegTemp >= coolingOnTemp) && (maxSegTemp <= coolingMaxTemp))
{
      // Set the fan speed somewhere between 0% and max%
      // y = y1 + ((y2-y1)/(x2-x1))*(x-x1)
```

```
      //fanPWM = 0 + ((fanPWMmax-0)/(coolingMaxTemp-
coolingOnTemp))*(maxSegTemp-coolingOnTemp);
      fanPWM = 200;
  } else if (maxSegTemp > coolingMaxTemp) {
    // Set the fan to full beans
      fanPWM = fanPWMmax;
  }
    analogWrite(IN_PWM_PIN, fanPWM);
    analogWrite(OUT_PWM_PIN, fanPWM);
  Serial.print("TS State = "); Serial.println(lvPowerStatus);
  Serial.print("Charge State = "); Serial.println(charge);
  Serial.print("Fan PWM = "); Serial.println(fanPWM);
}
```

LVD V2.1 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

#include <EV3_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 SD_INTERLOCK_PIN 15   // Pin for interlock 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 FANMAX 200             // Fan max speed setting
#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
```

```
#define RAMPTIME 5                      // Ramp time for fans full beans IN
SECONDS

// 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


//shutdown vars
float sdInterlock = 0;          // [boolean] CAN output shutdown logging
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 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
canmsg *inputmsgs[] = { &LV_POWER_STATUS, &CHARGE, &AVG_SEG_TEMP};
float *outputVar[] = { &lvPowerStatus, &charge, &avgSegTemp};
int numReceive = 2;        // Number of CAN messages to receive
```

```
int numSend = 8 + 2 * 9;  // 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_initialise(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

  //FAN GND FET
??????????????????????????????????????????????????????????????????
  digitalWrite(FAN_CONTROL_PIN, HIGH); //Sets the FAN_CONTROL_PIN HIGH 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_MILLISECONDS(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_MILLISECONDS(500) {
    updateFanSpeed();  // Update the fan speed based on charge and LV power
status
    NUCAN_write(&TEMP_OKHS, tempOKHS);
  }
  updateTempOKHS();  // Update the temperature fault state machine

  chargeMode();      //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(void) {
  if (lvPowerStatus == 1) {
    if (coolingFlag < RAMPTIME) {
      fanPWM = FANMAX *coolingFlag / RAMPTIME;
      coolingFlag = coolingFlag + 1;
    } else {
      // Set the fan to full beans
      fanPWM = FANMAX;
    }
  } else if (charge == 1) {
    // Charge speed based on LV supply from charger (12V, 10A)
    fanPWM = 60;
  } else {
    // Turn off the fans if DCDC is off
    fanPWM = 0;
    coolingFlag = 0;
  }
```

```
  NUCAN_write(&FAN_SPD_ACC, fanPWM/255); // Write fan PWM to NUCAN
  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
        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) {
        state = STATE_WAIT;
        tempSetTime = millis();  // Set the timer for the WAIT state
      }
      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);
      sdInterlock = digitalRead(SD_INTERLOCK_PIN);// read the input from the
interlock
      NUCAN_write(&SD_LVD_INTERLOCK, sdInterlock);
}
/* ---------------------------------------------------------------------------
-------------------------*/
void chargeMode(void) {
  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("Average Temp = ");
Serial.println(avgSegTemp);
```

AIL BOM

Component Count:	18				
Item	**Qty**	**Reference(s)**	**Value**	**LibPart**	**Footprint**
1	1	C1	10n	Device:C	Capacitor_SMD:C_2220_5650Metric_Pad1.97x5.40mm_HandSolder
2	1	C2	1u	Device:C	Capacitor_SMD:C_1206_3216Metric_Pad1.33x1.80mm_HandSolder
3	1	D1	LED	Device:LED	Connector_Molex:Molex_Micro-Fit_3.0_43045-0212_2x01_P3.00mm_Vertical
4	1	J1	Conn_01x02	Connector_Generic:Conn_01x02	Connector_Molex:Molex_Micro-Fit_3.0_43045-0212_2x01_P3.00mm_Vertical
5	1	PS1	MEE3S1205SC	Converter_DCDC:MEE3S1205SC	motherboardAnalog_footprints:PUC1205S1B
6	1	Q1	IXTP08N100D2	Device:Q_NMOS_GDS	Package_TO_SOT_THT:TO-220-3_Horizontal_TabDown
7	2	R1, R12	2M	Device:R	Resistor_SMD:R_2010_5025Metric_Pad1.40x2.65mm_HandSolder
8	1	R2	100K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
9	1	R3	0	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
10	1	R4	19.1K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
11	1	R5	1K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
12	1	R6	200k	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
13	1	R8	57k 57.6 is closest	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
14	1	R13	121K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
15	1	U1	LM393DT	EV3-AIL-rescue:LM393DT-dk_Linear-Comparators	Components:LM393DR2G

16	1	U2	LR645LG-G	HV_Regulator:LR645LG-G	footprints:LR645LG-G
17	1	U3	4N35	Isolator:4N35	Package_DIP:DIP-6_W7.62mm

LVD V1 BOM

Component Count:	81				
Item	**Qty**	**Reference(s)**	**Value**	**LibPart**	**Footprint**
1	1	5V1	5V	Device:LED	LED_SMD:LED_1206_3216Metric
2	6	5V2, 12V_PROT2, 12V_RAW2, CAN_L1, SD	CAN_L1	Connector:TestPoint	TestPoint:TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
3	4	12V_PROT1, BMS_OKHS1, IMD_OKHS1, PC_OKHS1	12V_PROT	Device:LED	LED_SMD:LED_1206_3216Metric
4	1	12V_RAW1	12V_RAW	Device:LED	LED_SMD:LED_1206_3216Metric
5	1	BMS_OKHS_PULLUP1	R	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
6	1	C1	1u	Device:C	Capacitor_SMD:C_1206_3216Metric_Pad1.33x1.80mm_HandSolder
7	1	C2	10n	Device:C	Capacitor_SMD:C_2220_5650Metric_Pad1.97x5.40mm_HandSolder
8	1	C3	0.1u	Device:C	Capacitor_SMD:C_1206_3216Metric
9	1	C4	0.1u	Device:C	Capacitor_SMD:C_1206_3216Metric_Pad1.33x1.80mm_HandSolder
10	1	C5	0.1uF	BSPD-rescue:CP1_Small-Device	Capacitor_SMD:C_1206_3216Metric
11	1	CAN_H1	CAN_H1	Connector:TestPoint	TestPoint:TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
12	2	D1, D2	3V3	Device:D_Zener	Diode_SMD:D_SOD-123
13	1	D4	MMSZ5231B	Device:D_Zener	Diode_SMD:D_SOD-123
14	4	F1, F2, F3, F4	7A	Device:Fuse	Fuse:Fuseholder_Blade_Mini_Keystone_3568
15	1	F6	Fuse 1A	Device:Fuse	Fuse:Fuse_1206_3216Metric
16	1	F7	1A	Device:Fuse	Fuse:Fuseholder_Blade_Mini_Keystone_3568

17	2	F11, F12	5A	Device:Fuse	Fuse:Fuseholder_Blade_Mini_Keystone_3568
18	1	J1	Conn_01x02	Connector_Generic:Conn_01x02	Connector_Molex:Molex_Mini-Fit_Jr_5566-02A_2x01_P4.20mm_Vertical
19	1	J2	IMD	Connector_Generic:Conn_01x08	Connector_Molex:Molex_Micro-Fit_3.0_43650-0815_1x08_P3.00mm_Vertical
20	1	J3	PRE_CHARGE	Connector_Generic:Conn_02x04	Connector_Molex:Molex_Micro-Fit_3.0_43045-0812_2x04_P3.00mm_Vertical
21	1	J4	BMS	Connector_Generic:Conn_02x03	Connector_Molex:Molex_Micro-Fit_3.0_43045-0612_2x03_P3.00mm_Vertical
22	1	J5	LV_AUTOSPORT	Connector_Generic:Conn_02x11	Connector_Molex:Molex_Micro-Fit_3.0_43045-2212_2x11_P3.00mm_Vertical
23	1	J6	FANS_BANK_1	Connector_Generic:Conn_02x03	Connector_Molex:Molex_Micro-Fit_3.0_43045-0612_2x03_P3.00mm_Vertical
24	1	J7	FANS_BANK_2	Connector_Generic:Conn_02x03	Connector_Molex:Molex_Micro-Fit_3.0_43045-0612_2x03_P3.00mm_Vertical
25	1	J8	EXP_PORT1	Connector_Generic:Conn_02x03	Connector_Molex:Molex_Micro-Fit_3.0_43045-0612_2x03_P3.00mm_Vertical
26	1	J9	AIRS	Connector_Generic:Conn_02x02	Connector_Molex:Molex_Micro-Fit_3.0_43045-0412_2x02_P3.00mm_Vertical
27	1	J10	INTERLOCK	Connector_Generic:Conn_01x02	Connector_Molex:Molex_Micro-Fit_3.0_43045-0212_2x01_P3.00mm_Vertical
28	1	J11	CANaMon	Connector:Conn_01x04_Male	Connector_Molex:Molex_Micro-Fit_3.0_43045-0412_2x02_P3.00mm_Vertical
29	2	J12, J14	DE9_Receptacle	Connector:DE9_Receptacle	Connector_Dsub:DSUB-9_Female_Vertical_P2.77x2.84mm_MountingHoles
30	1	J13	COMMISIONING_PWR	Connector:Screw_Terminal_01x02	TerminalBlock_Phoenix:TerminalBlock_Phoenix_MKDS-1,5-2_1x02_P5.00mm
31	2	PS1, PS2	MEE3S1205SC	Converter_DCDC:MEE3S1205SC	Components:PUC1205S1B
32	1	Q2	IXTP08N100D2	Device:Q_NMOS_GDS	Package_TO_SOT_THT:TO-220-3_Horizontal_TabDown
33	1	Q3	PZXM61P03FTA	Device:Q_PMOS_GSD	Package_TO_SOT_SMD:SOT-23
34	6	R1, R2, R3, R16, R17, R18	1K	Device:R	Resistor_SMD:R_1206_3216Metric
35	1	R4	10K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
36	1	R5	200K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
37	1	R6	57.6K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
38	2	R7, R8	2M	Device:R	Resistor_SMD:R_2010_5025Metric_Pad1.40x2.65mm_HandSolder

39	1	R9	121K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
40	1	R10	100K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
41	1	R11	19.1K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
42	1	R12	1K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
43	2	R13, R21	10K	Device:R	Resistor_SMD:R_1206_3216Metric
44	1	R14	120R	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
45	1	R15	120	Device:R	Resistor_SMD:R_1206_3216Metric
46	1	R19	500	Device:R	Resistor_SMD:R_1206_3216Metric
47	2	R20, R22	3.8K	Device:R	Resistor_SMD:R_1206_3216Metric
48	1	SW1	SW_DIP_x01	Switch:SW_DIP_x01	Button_Switch_THT:SW_DIP_SPSTx01_Slide_6.7x4.1mm_W7.62mm_P2.54mm
49	1	SW2	DSIC01THGET	Switch:SW_DIP_x01	Button_Switch_THT:SW_DIP_SPSTx01_Slide_6.7x4.1mm_W7.62mm_P2.54mm
50	1	TH1	Thermistor	Device:Thermistor	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
51	1	U1	TJA1051T-3	Interface_CAN_LIN:TJA1051T-3	Package_SO:SOIC-8_3.9x4.9mm_P1.27mm
52	1	U2	~	NU-Teams-KiCAD-Library:Branding_Block	NU-Teams-KiCAD-Library:RACING_BRANDING
53	1	U3	LR645LG-G	HV_Regulator:LR645LG-G	Components:LR645LG-G
54	1	U4	LM393DT	LM393DT-dk_Linear-Comparators	Components:LM393DR2G
55	1	U5	4N35	Isolator:4N35	Package_DIP:DIP-6_W7.62mm
56	1	U6	TJA1052i-1	Interface_CAN_LIN:TJA1052i-1	Package_SO:SOIC-16W_7.5x10.3mm_P1.27mm
57	1	U7	Teensy4.0-NU-Teams	Teensy4.0-NU-Teams	NU-Teams-KiCAD-Library:Teensy4.0-NU-Teams
58	1	U8	LM7805_DPAK	Regulator_Linear:LM7805_TO220	Package_TO_SOT_THT:TO-220-3_Vertical

LVD V2 BOM

Component Count:	94				
Item	**Qty**	**Reference(s)**	**Value**	**LibPart**	**Footprint**
1	1	5V1	5V	Device:LED	LED_SMD:LED_1206_3216Metric
2	6	5V2, 12V_PROT2, 12V_RAW2, CAN_L1, SD	CAN_L1	Connector:TestPoint	TestPoint:TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
3	4	12V_PROT1, BMS_OKHS1, IMD_OKHS1, PC_OKHS1	12V_PROT	Device:LED	LED_SMD:LED_1206_3216Metric
4	1	12V_RAW1	12V_RAW	Device:LED	LED_SMD:LED_1206_3216Metric
5	1	AIL_SMD1	AIL_LED	Device:LED	LED_SMD:LED_1206_3216Metric
6	1	BMS_OKHS_PULLUP1	R	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
7	1	C1	1u	Device:C	Capacitor_SMD:C_1206_3216Metric_Pad1.33x1.80mm_HandSolder
8	1	C2	10n	Device:C	Capacitor_SMD:C_2220_5650Metric_Pad1.97x5.40mm_HandSolder
9	1	C3	0.1u	Device:C	Capacitor_SMD:C_1206_3216Metric
10	1	C4	0.1u	Device:C	Capacitor_SMD:C_1206_3216Metric_Pad1.33x1.80mm_HandSolder
11	1	C5	0.1uF	BSPD-rescue:CP1_Small-Device	Capacitor_SMD:C_1206_3216Metric
12	1	CAN_H1	CAN_H1	Connector:TestPoint	TestPoint:TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
13	4	D1, D2, D3, D5	3V3	Device:D_Zener	Diode_SMD:D_SOD-123
14	1	D4	MMSZ5231B	Device:D_Zener	Diode_SMD:D_SOD-123
15	1	D6	CHARGE_POWER	Device:LED	LED_SMD:LED_1206_3216Metric

16	4	F1, F2, F3, F4	7A	Device:Fuse	Fuse:Fuseholder_Littelfuse_Nano2_154x
17	1	F6	Fuse 1A	Device:Fuse	Fuse:Fuseholder_Littelfuse_Nano2_154x
18	1	F7	1A	Device:Fuse	Fuse:Fuseholder_Littelfuse_Nano2_154x
19	1	F8	5A	Device:Fuse	Fuse:Fuseholder_Littelfuse_Nano2_154x
20	1	F10	Fuse_Small	Device:Fuse_Small	Fuse:Fuseholder_Littelfuse_Nano2_154x
21	1	J1	Conn_01x02	Connector_Generic:Conn_01x02	Connector_Molex:Molex_Mini-Fit_Jr_5566-02A_2x01_P4.20mm_Vertical
22	1	J2	Fan Bank 2	Connector:Conn_01x06_Pin	NU-Teams-KiCAD-Library:DT15-6P
23	1	J3	Fan Bank 1	Connector:Conn_01x06_Pin	NU-Teams-KiCAD-Library:DT15-6P
24	1	J4	EXP_PORT1	Connector_Generic:Conn_02x03	Connector_Molex:Molex_Micro-Fit_3.0_43045-0612_2x03_P3.00mm
25	1	J10	INTERLOCK	Connector_Generic:Conn_01x02	Connector_Molex:Molex_Micro-Fit_3.0_43045-0212_2x01_P3.00mm
26	1	J11	CANaMon	Connector:Conn_01x04_Male	Connector_Molex:Molex_Micro-Fit_3.0_43045-0412_2x02_P3.00mm
27	2	J12, J14	DE9_Receptacle	Connector:DE9_Receptacle	Connector_Dsub:DSUB-9_Female_Vertical_P2.77x2.84mm_MountingHoles
28	1	J13	COMMISIONING_PWR	Connector:Screw_Terminal_01x02	TerminalBlock_Phoenix:TerminalBlock_Phoenix_MKDS-1,5-2_1x02_P5.00mm
29	1	J15	LED	Connector_Generic:Conn_01x02	Connector_Molex:Molex_Micro-Fit_3.0_43045-0212_2x01_P3.00mm
30	1	J16	AIRS|PRE_CHARGE |IMD|BMS	Connector_Generic:Conn_02x11	Connector_Molex:Molex_Micro-Fit_3.0_43045-2212_2x11_P3.00mm
31	1	J17	ACC LV AS	DT15-12PA	NU-Teams-KiCAD-Library:DT15-12PA
32	1	JP1	SolderJumper_2_Open	Jumper:SolderJumper_2_Open	Jumper:SolderJumper-2_P1.3mm_Open_RoundedPad1.0x1.5mm
33	1	PS2	MEE3S1205SC	Converter_DCDC:MEE3S1205SC	Components:PUC1205S1B
34	1	Q1	2N7002	Transistor_FET:2N7002	Package_TO_SOT_SMD:SOT-23
35	1	Q2	IXTP08N100D2	Device:Q_NMOS_GDS	Package_TO_SOT_THT:TO-220-3_Horizontal_TabDown
36	1	Q3	PZXM61P03FTA	Device:Q_PMOS_GSD	Package_TO_SOT_SMD:SOT-23

37	1	Q5	MCT06P10	Device:Q_PMOS_GSD	Package_TO_SOT_SMD:SOT-223
38	7	R1, R2, R3, R16, R17, R18, R30	1K	Device:R	Resistor_SMD:R_1206_3216Metric
39	1	R4	10K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
40	1	R5	200K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
41	1	R6	57.6K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
42	2	R7, R8	2M	Device:R	Resistor_SMD:R_2010_5025Metric_Pad1.40x2.65mm_HandSolder
43	1	R9	121K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
44	1	R10	100K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
45	1	R11	19.1K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
46	1	R12	5K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
47	5	R13, R21, R27, R31, R32	10K	Device:R	Resistor_SMD:R_1206_3216Metric
48	1	R14	120R	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
49	1	R15	120	Device:R	Resistor_SMD:R_1206_3216Metric
50	1	R19	500	Device:R	Resistor_SMD:R_1206_3216Metric
51	2	R20, R22	3.8K	Device:R	Resistor_SMD:R_1206_3216Metric
52	5	R23, R24, R25, R26, R28	1K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
53	1	R29	1k	Device:R	Resistor_SMD:R_1206_3216Metric
54	1	SW1	SW_DIP_x01	Switch:SW_DIP_x01	Button_Switch_THT:SW_DIP_SPSTx01_Slide_6.7x4.1mm_W7.62mm_P2.54mm
55	1	SW2	DSIC01THGET	Switch:SW_DIP_x01	Button_Switch_THT:SW_DIP_SPSTx01_Slide_6.7x4.1mm_W7.62mm_P2.54mm
56	1	TH1	Thermistor	Device:Thermistor	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
57	1	U1	TJA1051T-3	Interface_CAN_LIN:TJA1051T-3	Package_SO:SOIC-8_3.9x4.9mm_P1.27mm

58	1	U2	~	Branding_Block	NU-Teams-KiCAD-Library:RACING_BRANDING
59	1	U3	LR645LG-G	HV_Regulator:LR645LG-G	Components:LR645LG-G
60	1	U4	LM393DT	LM393DT-dk_Linear-Comparators	Components:LM393DR2G
61	1	U6	TJA1052i-1	Interface_CAN_LIN:TJA1052i-1	Package_SO:SOIC-16W_7.5x10.3mm_P1.27mm
62	1	U7	Teensy4.0-NU-Teams	Teensy4.0-NU-Teams	NU-Teams-KiCAD-Library:Teensy4.0-NU-Teams
63	1	U8	LM7805_DPAK	Regulator_Linear:LM7805_TO220	Package_TO_SOT_THT:TO-220-3_Vertical

LVD V2.1 BOM

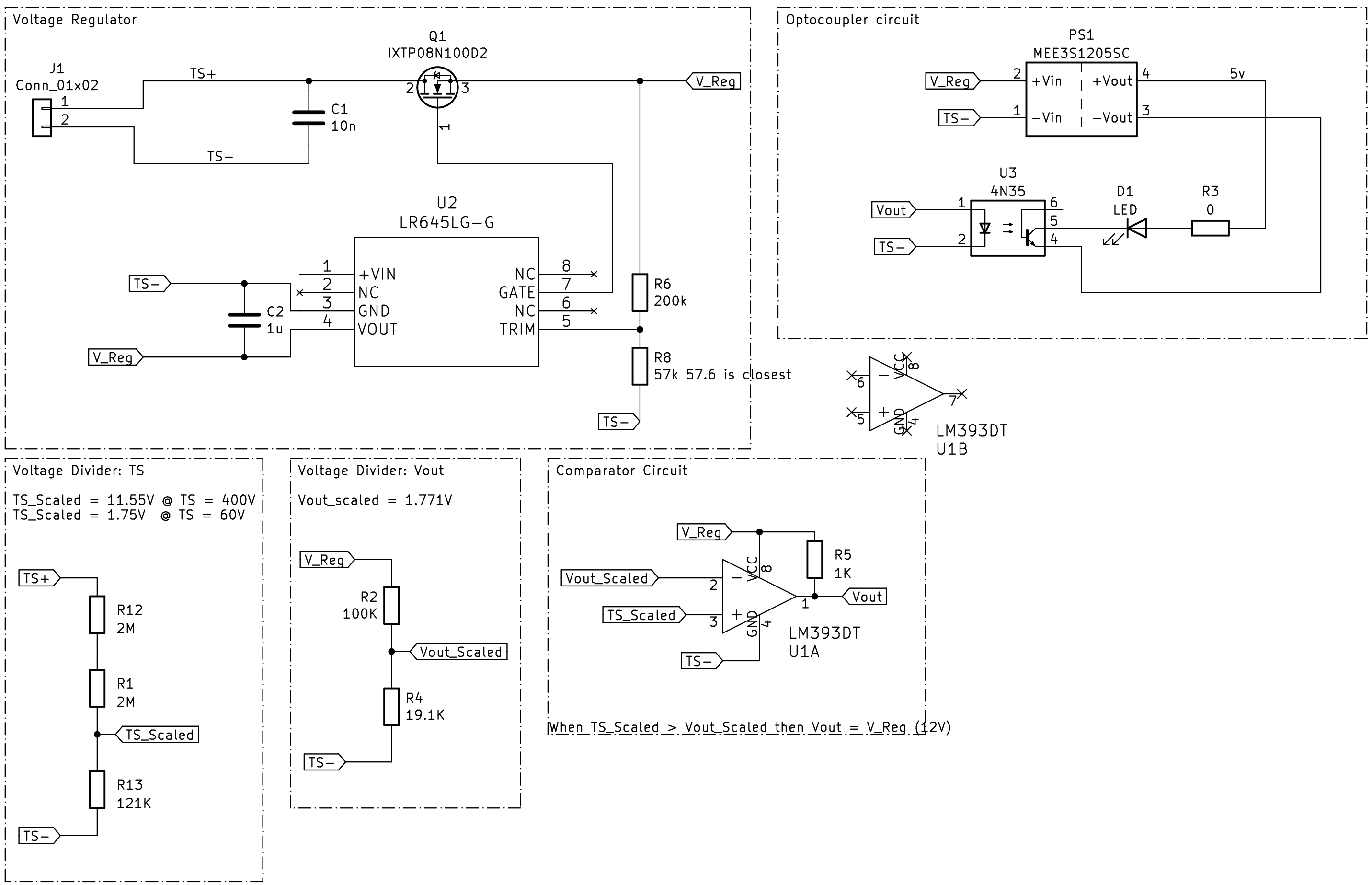
Component Count:	112				
Item	**Qty**	**Reference(s)**	**Value**	**LibPart**	**Footprint**
1	6	3V_pullup1, 5V_pullup1, R34, R37, R38, R39	0	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
2	1	5V1	5V	Device:LED	LED_SMD:LED_1206_3216Metric
3	6	5V2, 12V_PROT2, 12V_RAW2, CAN_L1, SD	CAN_L1	Connector:TestPoint	TestPoint:TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
4	2	5V_BMS_OKHS_PULLUP1, 12V_BMS_OKHS_PULLUP1	R	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
5	4	12V_PROT1, 12V_PROT3, I MD_OKHS1, PC_OKHS1	12V_PROT	Device:LED	LED_SMD:LED_1206_3216Metric
6	1	12V_RAW1	12V_RAW	Device:LED	LED_SMD:LED_1206_3216Metric
7	1	AIL_SMD1	AIL_LED	Device:LED	LED_SMD:LED_1206_3216Metric
8	1	C1	1u	Device:C	Capacitor_SMD:C_1206_3216Metric_Pad1.33x1.80mm_HandSolder
9	1	C2	10n	Device:C	Capacitor_SMD:C_2220_5650Metric_Pad1.97x5.40mm_HandSolder
10	1	C3	0.1u	Device:C	Capacitor_SMD:C_1206_3216Metric
11	1	C4	0.1u	Device:C	Capacitor_SMD:C_1206_3216Metric_Pad1.33x1.80mm_HandSolder
12	1	C5	0.1uF	BSPD-rescue:CP1_Small-Device	Capacitor_SMD:C_1206_3216Metric
13	1	CAN_H1	CAN_H1	Connector:TestPoint	TestPoint:TestPoint_Loop_D1.80mm_Drill1.0mm_Beaded
14	4	D1, D2, D3, D5	3V3	Device:D_Zener	Diode_SMD:D_SOD-123
15	1	D4	MMSZ5231B	Device:D_Zener	Diode_SMD:D_SOD-123

16	1	D6	CHARGE_POWER	Device:LED	LED_SMD:LED_1206_3216Metric
17	1	D7	FANS	Device:LED	LED_SMD:LED_1206_3216Metric
18	2	D8, D9	0 TO HERO	Diode:1N4001	Diode_SMD:D_SMA_Handsoldering
19	4	F1, F2, F3, F4	7A	Device:Fuse	Fuse:Fuseholder_Littelfuse_Nano2_154x
20	1	F6	Fuse 1A	Device:Fuse	Fuse:Fuseholder_Littelfuse_Nano2_154x
21	1	F7	1A	Device:Fuse	Fuse:Fuseholder_Littelfuse_Nano2_154x
22	1	F8	5A	Device:Fuse	Fuse:Fuseholder_Littelfuse_Nano2_154x
23	1	F10	Fuse_Small	Device:Fuse_Small	Fuse:Fuseholder_Littelfuse_Nano2_154x
24	1	H2	used as via	Mechanical:MountingHole_Pad	MountingHole:MountingHole_2.2mm_M2_DIN965_Pad
25	1	J1	Conn_01x02	Connector_Generic:Conn_01x02	Connector_Molex:Molex_Mini-Fit_Jr_5566-02A_2x01_P4.20mm_Vertical
26	1	J2	Fan Bank 2	Connector:Conn_01x06_Pin	NU-Teams-Footprints:DT15-6P
27	1	J3	Fan Bank 1	Connector:Conn_01x06_Pin	NU-Teams-Footprints:DT15-6P
28	1	J4	EXP_PORT1	Connector_Generic:Conn_02x03	NU-Teams-Footprints:microfit-2x03
29	1	J5	GND	Connector_Generic:Conn_01x02	NU-Teams-Footprints:microfit-2x01
30	1	J10	INTERLOCK	Connector_Generic:Conn_01x02	NU-Teams-Footprints:microfit-2x01
31	1	J11	CANaMon	Connector:Conn_01x04_Male	NU-Teams-Footprints:microfit-2x02
32	2	J12, J14	DE9_Receptacle	Connector:DE9_Receptacle	Connector_Dsub:DSUB-9_Female_Vertical_P2.77x2.84mm_MountingHoles
33	1	J13	COMMISIONING_PWR	Connector:Screw_Terminal_01x02	TerminalBlock_Phoenix:TerminalBlock_Phoenix_MKDS-1,5-2_1x02_P5.00mm
34	1	J15	AIL	Connector_Generic:Conn_01x02	NU-Teams-Footprints:microfit-2x01
35	1	J16	AIRS|PRE_CHARGE |IMD|BMS	Connector_Generic:Conn_02x11	Connector_Molex:Molex_Micro-Fit_3.0_43045-2212_2x11_P3.00mm_Vertical
36	1	J17	ACC LV	DT15-12PA	NU-Teams-Footprints:DT15-12PA

37	1	JP1	SolderJumper_2_Open	Jumper:SolderJumper_2_Open	Jumper:SolderJumper-2_P1.3mm_Open_RoundedPad1.0x1.5mm
38	1	PS2	MEE3S1205SC	Converter_DCDC:MEE3S1205SC	Components:PUC1205S1B
39	2	Q1, Q4	2N7002	Transistor_FET:2N7002	Package_TO_SOT_SMD:SOT-23
40	1	Q2	IXTP08N100D2	Device:Q_NMOS_GDS	Package_TO_SOT_THT:TO-220-3_Horizontal_TabDown
41	1	Q3	PZXM61P03FTA	Device:Q_PMOS_GSD	Package_TO_SOT_SMD:SOT-23
42	1	Q5	MCT06P10	Device:Q_PMOS_GSD	Package_TO_SOT_SMD:SOT-223
43	1	Q6	IRLB8721PBF	Transistor_FET:IRLB8721PBF	Package_TO_SOT_THT:TO-220-3_Vertical
44	9	R1, R2, R3, R16, R17, R18, R27, R30, R36	1K	Device:R	Resistor_SMD:R_1206_3216Metric
45	1	R4	10K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
46	1	R5	200K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
47	1	R6	57.6K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
48	2	R7, R8	2M	Device:R	Resistor_SMD:R_2010_5025Metric_Pad1.40x2.65mm_HandSolder
49	1	R9	121K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
50	1	R10	100K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
51	1	R11	19.1K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
52	6	R12, R23, R24, R25, R26, R28	1K	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
53	4	R13, R21, R31, R32	10K	Device:R	Resistor_SMD:R_1206_3216Metric
54	1	R14	120R	Device:R	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
55	1	R15	120	Device:R	Resistor_SMD:R_1206_3216Metric
56	1	R19	500	Device:R	Resistor_SMD:R_1206_3216Metric
57	2	R20, R22	3.8K	Device:R	Resistor_SMD:R_1206_3216Metric

58	1	R29	22k	Device:R	Resistor_SMD:R_1206_3216Metric
59	1	R33	10k	Device:R	Resistor_SMD:R_1206_3216Metric
60	1	R35	1k	Device:R	Resistor_SMD:R_1206_3216Metric
61	1	SW1	CAN_2_TERM	Switch:SW_DIP_x01	Button_Switch_THT:SW_DIP_SPSTx01_Slide_6.7x4.1mm_W7.62mm_P2.54mm
62	1	SW2	CAN_1_TERM	Switch:SW_DIP_x01	Button_Switch_THT:SW_DIP_SPSTx01_Slide_6.7x4.1mm_W7.62mm_P2.54mm
63	1	TH1	Thermistor	Device:Thermistor	Resistor_SMD:R_1206_3216Metric_Pad1.30x1.75mm_HandSolder
64	1	U1	TJA1051T-3	Interface_CAN_LIN:TJA1051T-3	Package_SO:SOIC-8_3.9x4.9mm_P1.27mm
65	2	U2, U5	~	Branding_Block	NU-Teams-Footprints:BRANDING_RACING
66	1	U3	LR645LG-G	HV_Regulator:LR645LG-G	Components:LR645LG-G
67	1	U4	LM393DT	LM393DT-dk_Linear-Comparators	Components:LM393DR2G
68	1	U6	TJA1052i-1	Interface_CAN_LIN:TJA1052i-1	Package_SO:SOIC-16W_7.5x10.3mm_P1.27mm
69	1	U7	Teensy4.0-NU-Teams	Teensy4.0-NU-Teams	NU-Teams-Footprints:Teensy4.0-NU-Teams
70	1	U8	LM7805_DPAK	LM7805_TO220	Package_TO_SOT_THT:TO-220-3_Vertical

PCB Schematics



Jedd Reeves

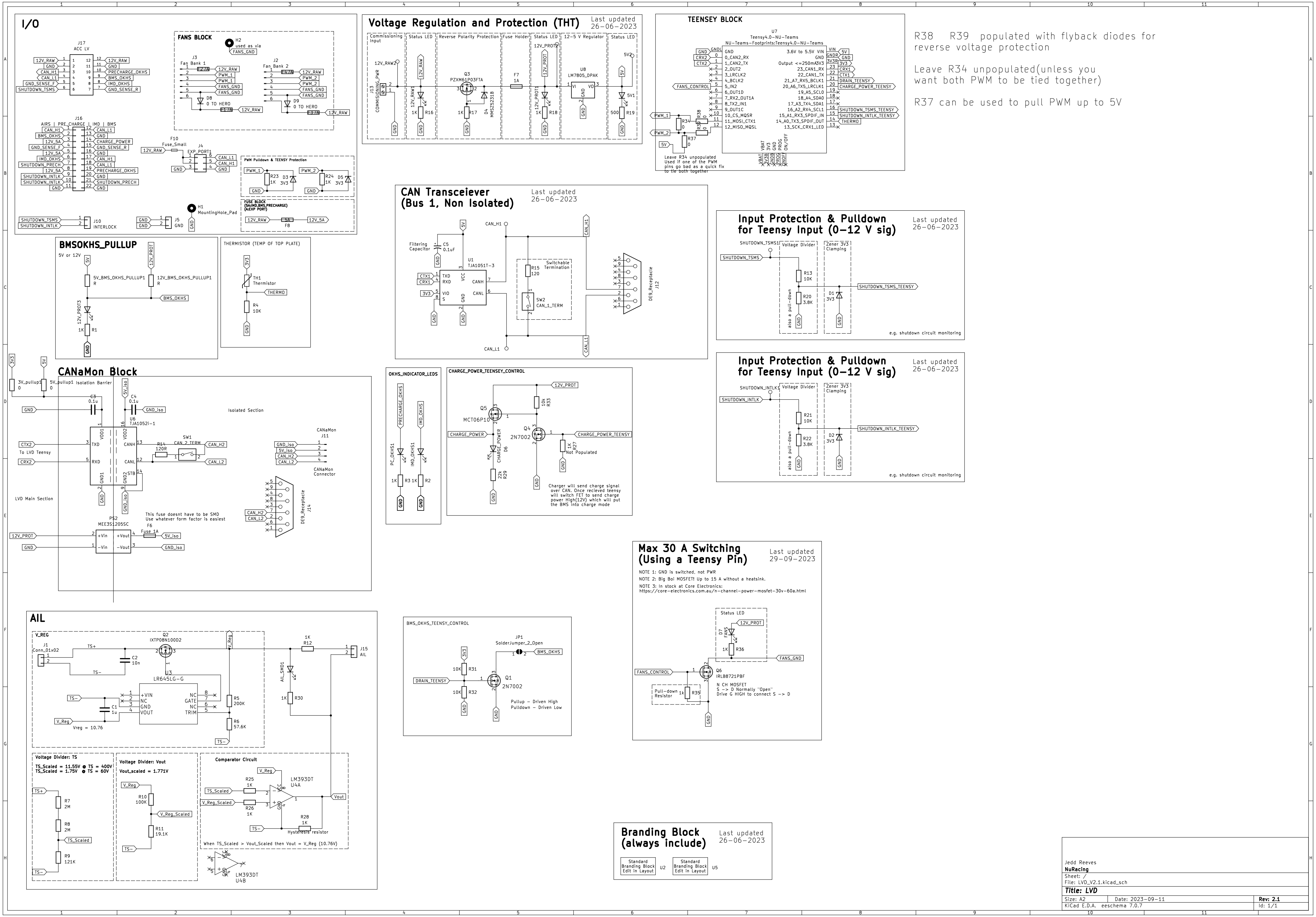
NURacing

Sheet: /

File: AIL_JR.kicad_sch

Title: Isolated AIL PCB

Size: A4	Date: 28/05/2023	**Rev: 1**
KiCad E.D.A. eeschema 7.0.7		Id: 1/1


I/O
FANS BLOCK
Voltage Regulation and Protection (THT)
Last updated 26-06-2023
Commissioning Input
Status LED
Reverse Polarity Protection
Fuse Holder
12-5 V Regulator
TEENSEY BLOCK
Teensy4.0-NU-Teams
R38 R39 populated with flyback diodes for reverse voltage protection
Leave R34 unpopulated(unless you want both PWM to be tied together)
R37 can be used to pull PWM up to 5V
Leave R34 unpopulated
Used if one of the PWM pins go bad as a quick fix to tie both together
PWM Pulldown & TEENSY Protection
FUSE BLOCK
CAN Transceiever (Bus 1, Non Isolated)
Last updated 26-06-2023
Filtering Capacitor
Switchable Termination
Input Protection & Pulldown for Teensy Input (0-12 V sig)
Last updated 26-06-2023
Voltage Divider
Zener 3V3 Clamping
also a pull-down
e.g. shutdown circuit monitoring
BMSOKHS_PULLUP
5V or 12V
THERMISTOR (TEMP OF TOP PLATE)
CANaMon Block
Isolation Barrier
Isolated Section
To LVD Teensy
LVD Main Section
CANaMon Connector
This fuse doesnt have to be SMD
Use whatever form factor is easiest
OKHS_INDICATOR_LEDS
CHARGE_POWER_TEENSEY_CONTROL
Charger will send charge signal over CAN. Once recieved teensy will switch FET to send charge power High(12V) which will put the BMS into charge mode
Max 30 A Switching (Using a Teensy Pin)
Last updated 29-09-2023
NOTE 1: GND is switched, not PWR
NOTE 2: Big Boi MOSFET! Up to 15 A without a heatsink.
NOTE 3: In stock at Core Electronics: https://core-electronics.com.au/n-channel-power-mosfet-30v-60a.html
Status LED
Pull-down Resistor
N CH MOSFET
S -> D Normally "Open"
Drive G HIGH to connect S -> D
AIL
V_REG
Vreg = 10.76
Voltage Divider: TS
TS_Scaled = 11.55V @ TS = 400V
TS_Scaled = 1.75V @ TS = 60V
Voltage Divider: Vout
Vout_scaled = 1.771V
Comparator Circuit
Hysteresis resistor
When TS_Scaled > Vout_Scaled then Vout = V_Reg (10.76V)
BMS_OKHS_TEENSY_CONTROL
Pullup - Driven High
Pulldown - Driven Low
Branding Block (always include)
Last updated 26-06-2023
Standard Branding Block Edit in Layout
Jedd Reeves
NuRacing
Sheet: /
File: LVD_V2.1.kicad_sch
Title: LVD
Size: A2
Date: 2023-09-11
Rev: 2.1
KiCad E.D.A. eeschema 7.0.7
Id: 1/1