College of Engineering, Science and Environment

School of Engineering

Aerospace Engineering Project B

Semester 2- 2024 ENGG4801 B

FINAL YEAR PROJECT

PROJECT TITLE
Low Voltage Systems and Data Acquisition

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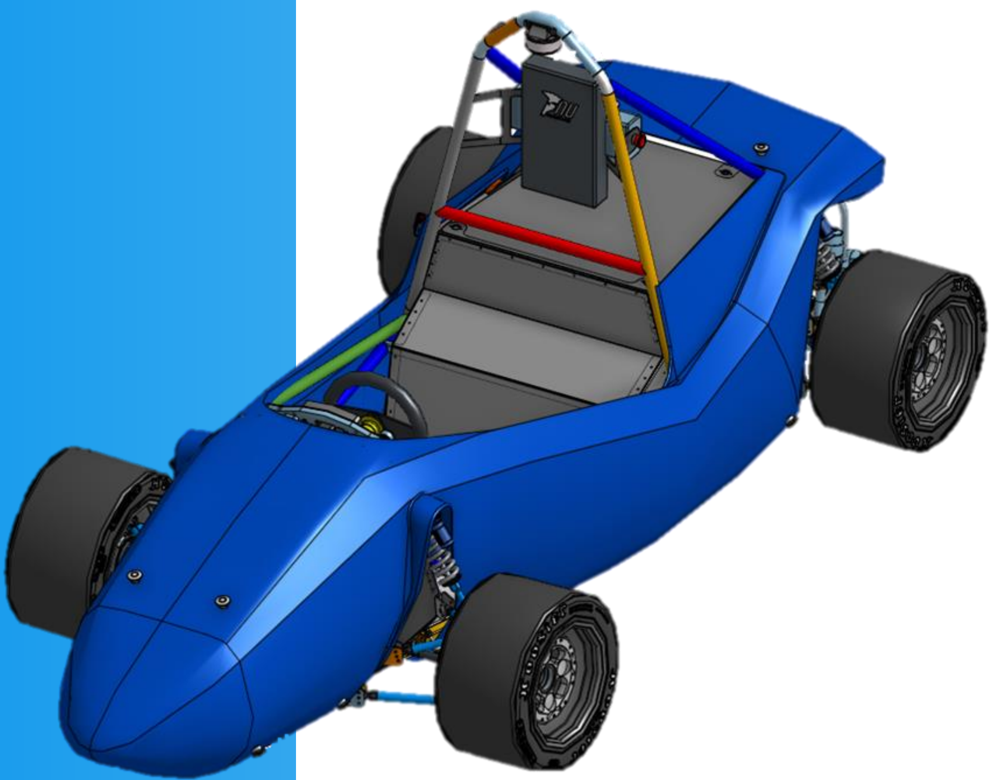
Low Voltage Systems and Data Acquisition – Part B

DESIGN REPORT

NU24



Jackson Boustany

2024

Preamble

Acknowledgement

I would like to thank Dr Dylan Cuskelly for stepping in to the role of running NU Teams. His support and enthusiasm truly encouraged myself and the NuRacing team to strive.

I would like to also thank Mr Malcolm Sidney for his technical support and knowledge. His abundance of experience within the team helped us develop skills and knowledge of our own.

I would like to extend my thanks and gratitude towards the NuRacing team leader, chief engineer and department leads for all the behind scenes work and hours sunk into ensuring the team would compete at the utmost performance possible. Without the control and confidence of the head of our team we would not have made it the distance we did.

And finally, I would like to thank the whole of NU Teams. Coming into a lively building filled with hard work and good company is one of the best motivation attributes possible.

Declaration

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Signed

Date 12/02/2025

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Abstract

Throughout this report entails the authors work and contributions within the 2024 NuRacing team. The LV system interacts with NU24 through simplistic topology comprised of five main nodes: the PEN, DEN, CEN, LVD and HIP. The ideology of building the LV system nodes around ease of maintenance and troubleshooting. Each of the nodes has a Teensy 4.0 to send messages through NU24's CAN Bus network. The LV system has a vital circuit that must be in place to ensure the car is compliant regulations: the shutdown circuit. The shutdown circuit is disconnected when any hard code fault become present or when any of the e-stops are pressed.

A detailed description of how the DEN was developed to fit NU24 and the reasonings of iterations undergone were also explained. The DEN is a critical component for data logging and data retrieval. The DEN houses a C125 MoTeC display screen which receives and records all CAN Bus messages. These messages are broadcasted over the GPS and telemetry system allowing for live data tracking. The DEN also houses the input for the inertia switch, the input for GPS and telemetry system and the dash shutdown e-stop. The DEN had two iterations within the year: V3.0 and V3.1. The DEN V3.0 was a replica of the previous teams DEN V2.1, remodelled to fit NU24. The DEN V3.1 introduced rotary switches to control torque output and regeneration of the motor. The DEN V3.0 was the choice to integrate into NU24 for competition, due to size restrictions and simplicity. Reasons for the DEN V3.1 not being utilised was size restrictions and torque and regeneration rotary switches were not necessary as the torque was set manually. Recommendations for future DEN work is to have an external PCB for the rotary switches.

The EXP was a new PCB to have research into sensor integration and sensor types. The requirement was the develop a steering angle sensor and potentially shock loading sensors to run through the EXP. The EXP was integrated into NU24 for one track day, which unfortunately the data was not set up to be read by MoTeC. The EXP PCB is recommended to be refined with more research into different sensor integration. A larger linear potentiometer (LPPS-22-075) is also recommended to replace the shorter one that bottoms out. The EXP serves as a good starting point for future incremental measuring implications.

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1. Introduction

This report entails the works of the author throughout 2024 within the University on Newcastle's Formula SAE Racing Team (NuRacing). The major projects undertaken include the design and manufacturing of the Dash Electrical Node (DEN) and the Expansion board (EXP). The DEN is a crucial part of NuRacing's Formula SAE car, NU 24 (FIGURE), allowing data from throughout the car to be tracked live and logged, and is the fundamental driver interface. The EXP is a new data acquisition board developed to find incremental movements from various locations on the car. The hope of the EXP is to improve driver training and refine car handling aspects (such as suspension tuning).

Figure 1: NuRacing's NU24 Formula SAE race car

1.1. The Dash Electrical Node (DEN)

The dash electrical node, also known as the DEN, is a custom designed PCB that is developed for data routing and logging applications. The DEN houses a C125 MoTeC digital display screen which displays information such as the state of charge (SOC), distance travelled, LV battery voltage and if the car is in a HV state. The C125 also has designated LEDs for faults that the car can experience and is tested on from the rules and regulations. There are two screen displays that can be cycled through: the driver interface (the main display) and the shutdown circuit (trouble shooting).

Figure 2: MoTeC driver display (left) and troubleshooting display (right)

The DEN predominantly routes signals between the CEN and PEN and records live data from the GPS and Telemetry. The DEN has two shutdown circuitry components, the externally connected inertia switch and the PCB mounted e-stop. The DEN is redesigned every year to fit the new chassis and refine imperfections within the PCB.

1.2. Expansion Board (EXP)

The expansion board (EXP) is a custom PCB with the notion to retrieve the steering angle and potentially shock loading. These attributes will be measured by a sensor. Comparison of different types of sensors and mounting orientation of the sensors are factors in deciding which sensor is best suited for the position. The EXP has the potential to become a node with the board having its own programable Teensy 4.0 and output channels. The EXP will have three sensor/signal input ports and two CAN expansion ports. The expansion ports allow the EXP to communicate with other parts of NU24. NuTeams has pre-existing standardised schematic blocks for KiCad which are frequently used. Items such as the CAN transceiver circuit, teensy input signal circuit and a 12 voltage to 5 voltage circuits can be transferred to newly designed boards. These standardised circuits can be found in 11.1. Schematics/Pinouts, and are the fundamental build blocks for the development of the EXP

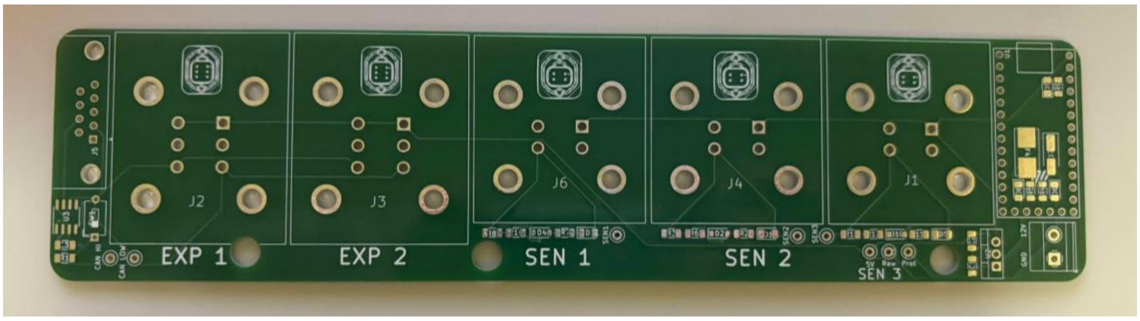

Figure 3: Unpopulated EXP PCB

2. Background

2.1. Formula SAE (F-SAE)

F-SAE (Formula – Society of Automotive Engineers) is a competition in which university students work as a team to design, build and compete a F-SAE race car. There are many rules within F-SAE, all of which must be adhered by to compete. The competition in takes place in Calder Park over four days, with the first two days being static events and the remaining for dynamic events. Static events include:

- Accumulator technical inspection
- Static EV technical inspection
- Mechanical technical inspection
- Dynamic EV technical inspection
- Tilt test
- Rain test
- Brake test
- Business event
- Cost report event
- Design event

To be able to compete in the dynamic events, the first seven of the static events listed must be passed. The dynamic events are how the cars compete, these events include:

- Skidpan
- Auto-cross
- Acceleration
- Endurance (and efficiency)

The scoring is based on the competition itself. The team that gets first place in one category receives the highest score and the remaining team scaled based on comparison, except for the cost 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

Figure 4: Competition point distribution

2.2. Low Voltage System

The low voltage (LV) system is a 12-voltage system that car is powered by before high voltage (HV) is turned on. This system is comprised of tailor-made PCBs and powers the NU24s CAN Bus network (how the car communicates within itself) and shutdown circuit.

2.2.1. Node Topology

NU24 can be broken down into low voltage systems (Figure 5):

- Pedal-box Electrical Node (PEN)
- Dash Electrical Node (DEN)
- Central Electrical Node (CEN) (is also HV)
- Human Interface Panel (HIP) (is also HV)
- Low Voltage Distribution (LVD) (housed within the accumulator, is also HV)

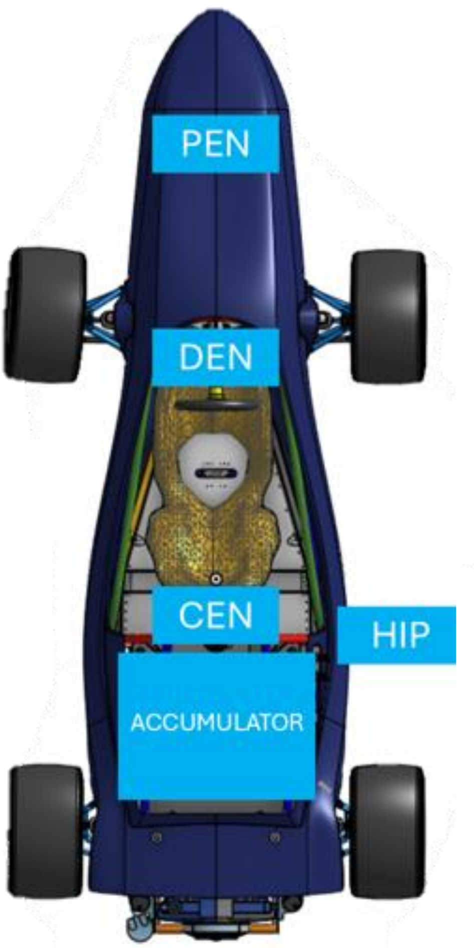

Figure 5: Distributed topology of NU 24

The node design layout allows for accessibility and maintenance work. With each node able to be removed and reinstalled with ease, troubleshooting issues or replacing boards due to new designs easily. Each node is bench tested individually using CAN Bus emulators (i.e. CAN King) and programming serial ports (i.e. Arduino IDE).

2.2.2. Shutdown Circuit

A vital component of the low voltage system is the shutdown circuit. The shutdown circuit must be in place for the safety of everyone. It spans across all nodes, with the shutdown start being at the PEN. The shutdown circuit consists of:

- Brake Over Travel Switch (BOTS):
  Placed behind the brake pedal in such a way that if the hydraulic brake system of the car fails, the driver will be able to flip this switch, turning off the tractive system [1].
- Inertia Switch:
  This must be placed in a vertical position on the car (on the steering gearbox on NU23) and will turn the shutdown circuit open in the event of a crash (8 – 11g) [1].
- Dash E-Stop:
  This is an emergency stop button on the DEN, easily accessible by the driver, and is the easiest way to turn off the tractive system from within the car [1].
- TSAL E-Stops:
  Two emergency stop buttons on either side of the main roll hoop on the car. This is the main mode of turning the car off from the outside [1].
- HVD interlock:
  The HVD is an easily accessible High Voltage disconnect on the car (on the HIP on NU24) and as this is directly connected to HV, an interlock is used to monitor if it is disconnected [1].
- Hard Fault Latch Interpose:
  This is a latch on the CEN board which goes bad if any of the OKHS go bad. These signals are BMS, PRECHARGE, IMD, BSPD, and DISCHARGE. This latch activates an interpose relay which is directly connected to the shutdown circuit (the latch isn't) [1].
- TSMS:
  This is on the HIP enclosure and is the tractive system master switch. (one for LV and one for HV) [1].

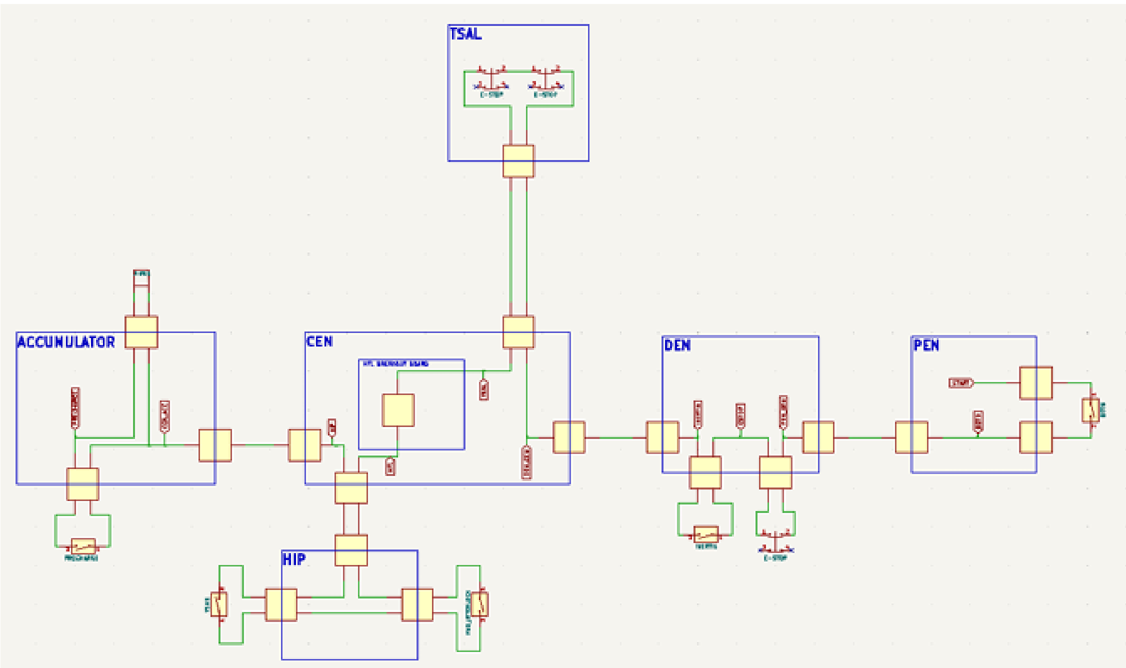

Figure 6: NU24 Shutdown circuit schematic [1]

2.2.3. Hard Faults

This is displayed on the MoTeC screen with a red LED when fault has occurred. Each fault has a designated shift light.

- Precharge Discharge Open Circuit (PDOC):
  This hard fault is triggered when communication is lost with the Precharge circuit and/or the discharge circuit. The discharge circuit must be wired in a way that it is always active when the shutdown circuit is open and must be able to handle the maximum tractive system voltage for a least 15 seconds. The Precharge circuit is supplied by the Shutdown circuit and must be able to charge the immediate circuit to 90% of the accumulator voltage before closing the second AIR. If any these events do not occur or the circuits are disconnected in anyway, the hard fault is triggered, turning the Precharge or Discharge OKHS bad. The Precharge board is located on the top plate and is communicated by the LVD. The discharge circuit located on the HIP [1].

- Insulation Monitoring Device (IMD):
  This device monitors for an insulation failure within the tractive system, and it checks to see that the device itself is working properly. If either of these events occur, the IMD_OKHS goes bad. This device is located on the top plate of the accumulator and is communicated by the LVD [1].

- Accumulator Monitoring System (AMS):
  The AMS must measure the temperatures of critical points within the accumulator, ensuring that the maximum cell temperature does not exceed 60° C. It also must ensure that at least 20% of the cells have temperature monitoring. If the temperature readings drop below 20% or reads temperatures higher than 60° C, the AMS_OKHS goes bad. This comes from the Orion BMS on the top plate and is communicated by the LVD [1].

- Brake System Plausibility Device (BPSD):
  The BSPD monitors the average brake pressure between the two pressure sensors read by the PEN and the current of the electric motor to ensure that the shutdown circuit opens when the accelerator and brake pedal are pressed at the same time. Both the brake pressure and current draw have selected values, which if both are exceeded at the same time, make the BPSD_OKHS go bad. The BPSD circuit is located on the CEN [1].

3. DEN V3.0

The NuRacing car of 2023, NU23, had a longer chassis and a wider front roll hoop. To adjust to the NU24 chassis, the current DEN needed to be remodelled. The DEN V3.0 was designed to take the previous board and allow it to fit the new chassis design.

3.1. Initial Design

The DEN V3.1 was compacted down compared to DEN V2.1 (NU23's DEN). As shown in FIGURE, the comparison between the two board sizes is substantial. The DEN V3.0 had no parts change from the previous design, only the layout of components and board outline differed. The board was designed using KiCad 8.0 software package [2].

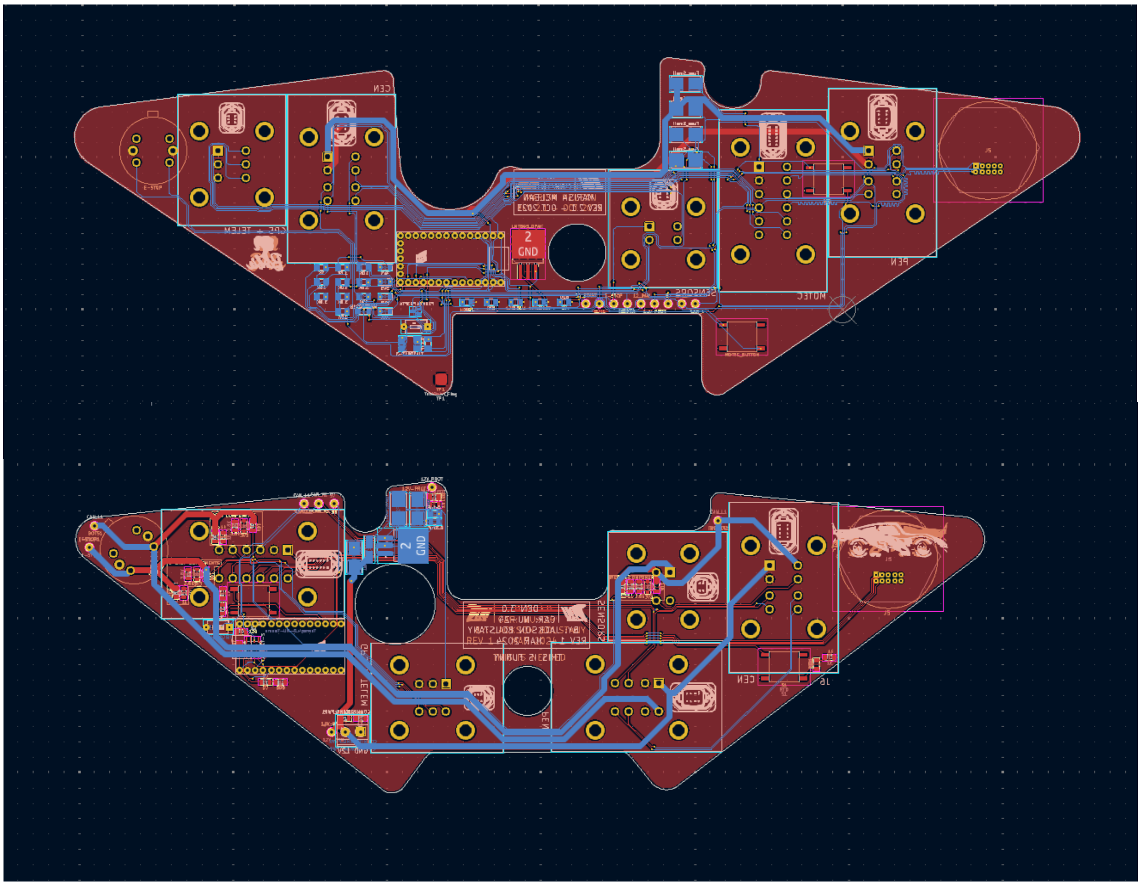

Figure 7: Board size and layout of DEN V2.1 (top) and DEN V3.0 (bottom)

As can be visible in Figure 7, the DEN V2.1 has a relatively simple layout with similar components (resistors, capacitors, etc) located together. In comparison, the DEN V3.0 designed to have certain sub-circuits of components together rather than the components themselves. i.e. each Teensy input circuit has all the components from that circuit in one location. Putting all of one sub-circuits components together results in smaller traces and ease of routing larger/longer traces. The components for a specific circuit being allocated on location allows for ease of trouble shooting if an issue becomes apparent.

As a recommendation from last year's team, the trace size of the shutdown circuit was to be comprised of 2 mm traces. Since the shutdown circuit can draw a maximum of 2 Amps, 2 mm traces are approximately the size required. The increase in trace size was reassured by using the trace width calculator built within KiCad.

	DEN V2.1	DEN V3.0	Difference
Height (mm)	111.00	101.30	-9.70
Length (mm)	330.50	295.50	-35.00

Table 1: DEN V3.0 board size comparison to DEN V2.1

Another notable difference between the two boards is the overall size (Table 1). The chassis for NU24 had a narrower front roll hoop compared to NU23, thus the DEN V3.0 was sized to accommodate the chassis change.

3.2. Manufacturing

The chassis was not completed and was still being manufactured itself, however the section needed for the DEN was finalised. Before the PCB was ordered, the board was 3D-printed and test fitted on the chassis. The 3D board was required to fit comfortably within the front roll hoop of the chassis with the MoTeC screen and DT connectors (Figure 9).

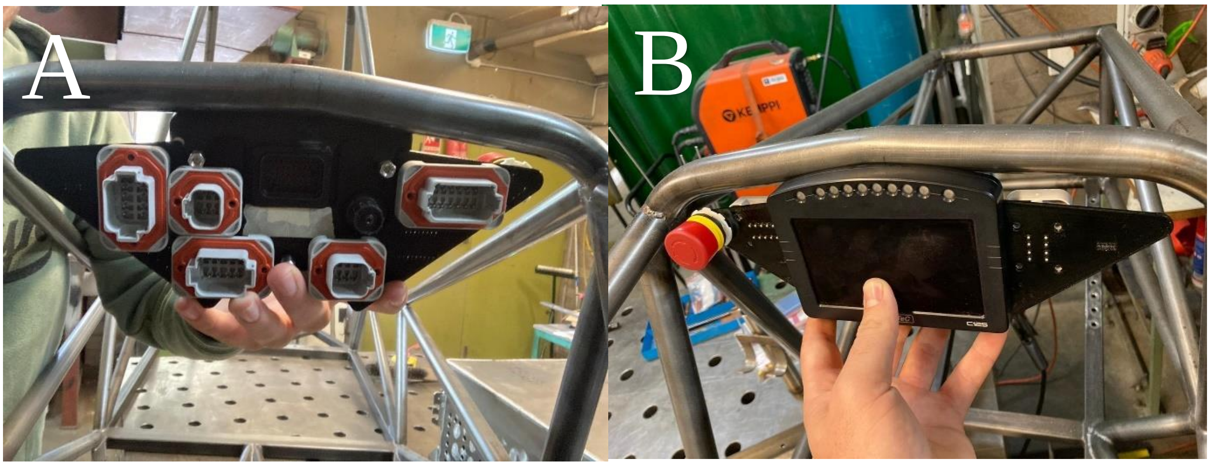

Figure 9: 3D printed board test fitted on the chassis, back view (A) and front view (B)

Since the steering gearbox and column were not on the chassis, the DEN seemed to fit flush and correctly with the chassis and gearbox independently.

3.2.1. Manufacturing Issues

Once the steering gearbox was mounted to the chassis, another issue arose. The DT connectors were extremely close to the gearbox when the board was sitting flush to the chassis. The solution was to create a standoff from the chassis to the board's enclosure. This allowed for the DT connectors to have more accessibility when maintenance was required.

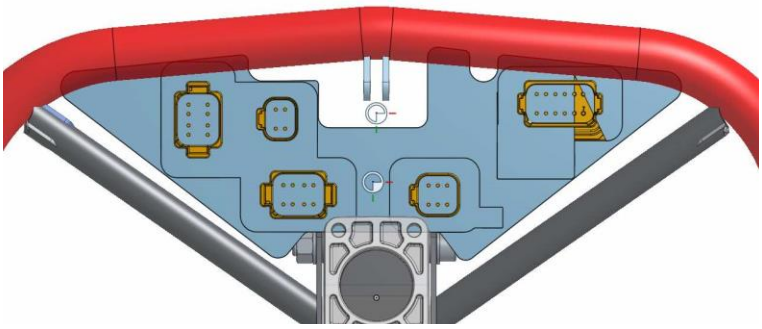

Figure 10: DEN V3.0 in Onshape model for clearance reference

3.2.2. Bill of Materials

The bill of materials (BOM) consists of all the components it takes to completely build one PCB (Table 2). The outsourced company (PCB GOGO [3]) requires a minimum of five boards to be ordered manufactured at once, thus all five boards will be included in the cost to build one. Most components are sourced from Digikey [4], except for the DT connectors which are source from Mouser [5].

Part	**Notes/Part Number**	**Amount**	**Cost total ($) (each)**
Printed Circuit Board (PCB)		5	130.40 (26.08)
Resistors (0, 120, 500, 1k, 3.8k, 10k Ω)	Size 1206	15	2.40 (0.16)
Capacitors (0.1 ,0.33 µF)	Size 1206	3	0.72 (0.24)
4 pin DT Connector *	DT15-4P-G003	1	29.45
6 pin DT Connector *	DT15-6P-G003	1	34.21
8 pin DT Connector *	DT15-08AP-G003	2	78.46 (39.23)
12 pin DT Connector *	DT15-12AB-G003	1	43.77
Ethernet *	RJS-5EPFFP-LC7002	1	12.89
E-Stop	EC-AMA-H-001-A	1	26.12
Buttons	GPTS203211B	2	17.06 (8.53)
Transceiver	TJA1051T-3	1	1.95
Voltage regulator	LM7805_DPAK	1	2.35
Screw terminal	691137710002	1	0.58
Barrier diodes	TWGMC-SS34	1	0.22
Zener diodes	BZT52-C3V3J	3	0.48 (0.16)
LEDs (red, green, blue)	Size 1206	8	2.56 (0.32)
Fuses	0452001.MRL	3	6.57 (2.19)
Fuse holders	01550900DR	3	12.96 (4.32)
Test points	5007	8	4.96 (0.62)
Dip switch	KAE01LAGT	1	2.13
Teensy 4.0	DEV-16997	1	45.60
Total		63	**455.84**

Table 2: BOM for one PCB to be completely built.

** Sourced from Mouser* [5]

Compared to the DEN V2.1 the board itself is the only difference in cost with a slight decrease from the previous $143.11.

Before the board was able to be assembled, continuity had to be present (For example, all ground points were check from the input ground). This process was to ensure that the PCB had been designed correctly and there were no issues from the manufacturer.

3.3. Commissioning and Validation

To make the DEN V3.0 work within the car, it was first bench tested. Verification that components received the correct amount of voltage was vital. Sensitive components, such as the Teensy, voltage regulator and transceiver, were tested to receive the correct voltage. The test points are designed to tap into the traces that run throughout the board (i.e. 5 V network). Indication LEDs are also present on the board and will illuminate when receiving power (circuit is complete).

3.3.1 Trouble shooting

Only a slight issue had affected the commissioning of the PCB. The MoTeC and ready to drive (RTD) buttons had no signal being received to the Teensy but would have the correct voltage supplied. The signal to the teensy would lose all voltage through the resistor and LED connecting the button to ground. The reason for this was how the code was setup to be received by the Teensy.

```
pinMode(RTD_BUTTON_PIN, INPUT_PULLUP);
pinMode(MOTEC_BUTTON_PIN, INPUT_PULLUP);
```

Figure 11: Teensy pull-up input function

The Teensy has an input function known as “pull-up”, which utilises the pins own pull-up resistor. Pull-up resistors keep a pin at a stable high state when a button is not pressed. When the button is pressed, it connects the pin to the ground (low). By having the input to the teensy as a pull-up and having a resistor and LED pulling the button to ground (when pressed), the signal from the button would remain in a high state.

Initially, the signal input was changed to a raw “input” signal. This allowed the button to change when pressed with a very unstable/unreliable output. To fix this issue removing the resistor and LED from the grounding circuit and replacing them with 0 Ω resistors, allowed the button to work as intended. It is recommended that there is no pull-down resistors or LEDs to ground on the PCB physically when using the Teensy’s pull-up input function.

3.3.2. Code Changes

The DEN V3.0 utilised similar programming as the DEN V2.1 as there were no significant changes to the board. The changes that were done to the code was the removal of the shutdown start, and a debounce time on the MoTeC button. The shutdown start was moved to the PEN code as it is at the front of NU24.

```
void updateMOTEC_STATE(void){
  // Read RTD button
  // This is an open drain ! is for change of logic
  motecButtonState = !digitalRead(MOTEC_BUTTON_PIN);
  if (motecButtonState == 1){
    motecPageNumber =+ 1;
    if (motecPageNumber == 7){
      motecPageNumber = 0;
    }
  }
  // Update button state on CAN
  NUCAN_write(&MOTEC_BUTTON, motecPageNumber);
}
```

```
void updateMOTEC_STATE(void){
  // Read RTD button
  // This is an open drain ! is for change of logic
  motecButtonState = !digitalRead(MOTEC_BUTTON_PIN);
  if (motecButtonState == 1){
    motecPageNumber++;
    if (motecPageNumber == 2){
      motecPageNumber = 0;
    }
    delay(100);  // avoids 1 press counting as multiple
  }
  // Update button state on CAN
  NUCAN_write(&MOTEC_BUTTON, motecPageNumber);
}
```

Figure 12: Change in MoTeC display code from DEN V2.1 (left) to DEN V3.0 (right)

3.4. Recommendations

From this iteration of the DEN, the 0 Ω resistors from the MoTeC and RTD buttons are not required, and the buttons can go to ground. The board size should be created via a model in Onshape rather than roughly measuring the space on the physical chassis and making slight changes to the outline. Another simple change is to put the DT connectors in a spot that will require a smaller wiring loom to reach, if the CEN and the PEN DT connectors were swapped then both looms could be reduced and tidier.

4. DEN V3.1

A new version of the current DEN was to amend for the shortcomings of the DEN V3.0 and to implement a new design that allows for torque and regeneration control. This new iteration, with slight modifications is known as the DEN V3.1.

4.1. Initial Design

The DEN V3.1 board outline was extracted from the Onshape chassis model by a mechanical team member. This allowed the board to have accurate measurements and sit flush with the front roll hoop. The outline of the board was increased (Table 3) again to allow room for trace routing and large front facing components to have more board room. However, there was a smaller geometry outlined from the model where the DT connectors must fit within.

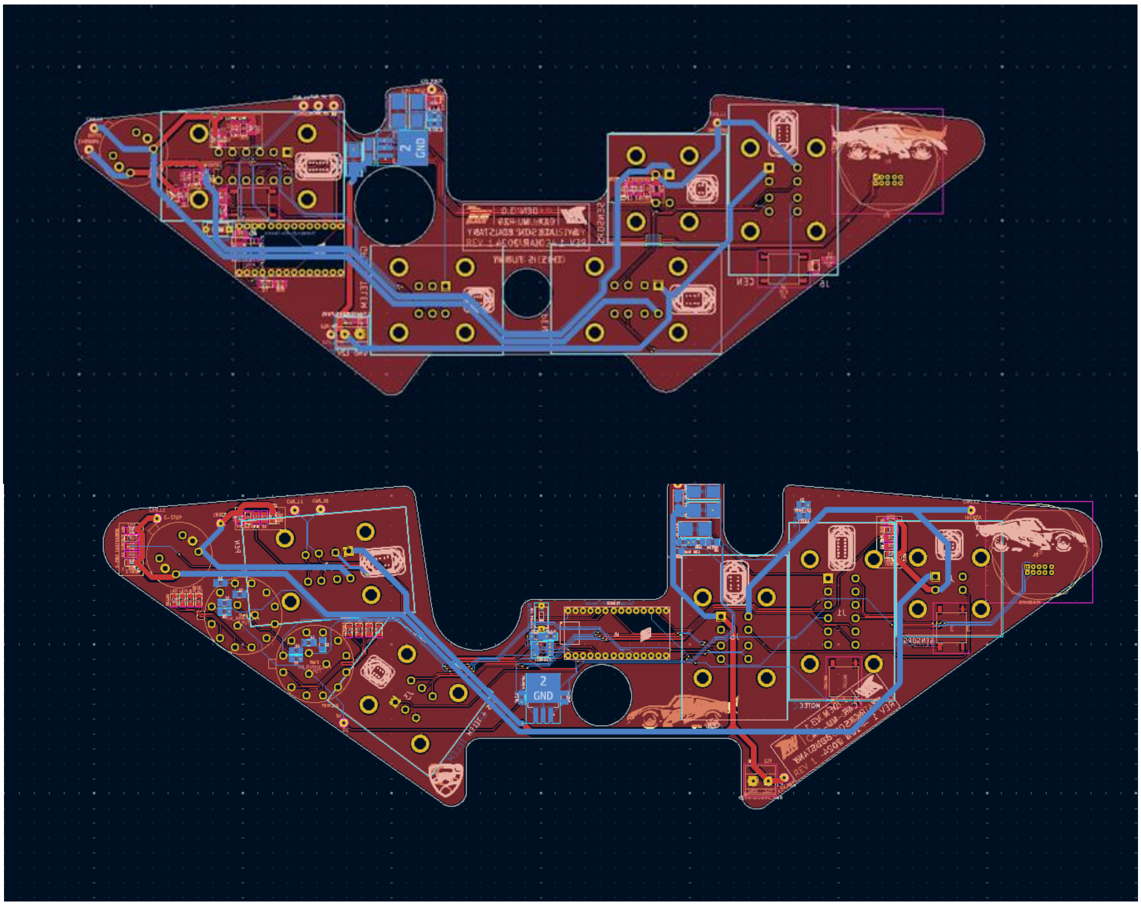

Figure 13: Board size and layout of DEN V3.0 (top) and DEN V3.1 (bottom)

	DEN V3.0	DEN V3.1	Difference
Height (mm)	101.30	111.60	+10.30
Length (mm)	295.50	335.50	+40.00

Table 3: DEN V3.1 board size comparison to DEN V3.0

The issue with the placement of the bottom two DT connectors from the DEN V3.0, was the inability to easily remove the plugs for maintenance. By adjusting the position of the connectors, a more accessible layout for the DT connectors was achieved. Figure 14 shows the overlap of the DT connectors placement. With the DT connectors moved off centre slightly, it reduced the interference of the steering gear box for removing and installing.

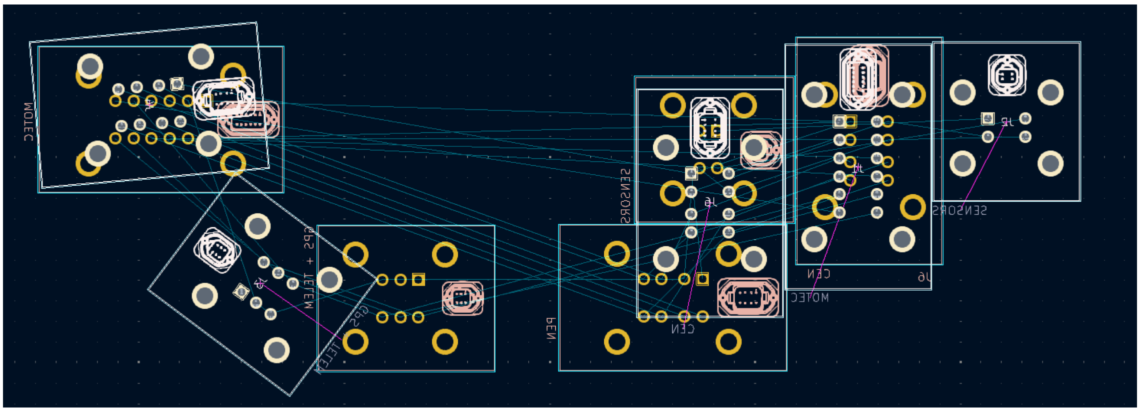

Figure 14: DT layout overlay comparison of DEN V3.0 and DEN V3.1 (in white)

The DEN V3.1 incorporates two 3-pole rotary switches for torque and regeneration control. These switches act as a voltage divider to send different voltage signals based on position setting. The Teensy will then read these signals and correspond the torque or regeneration setting to the set voltage. From the 3 poles available, two were used: one for the voltage divider and the other as LED indication (Figure 15).

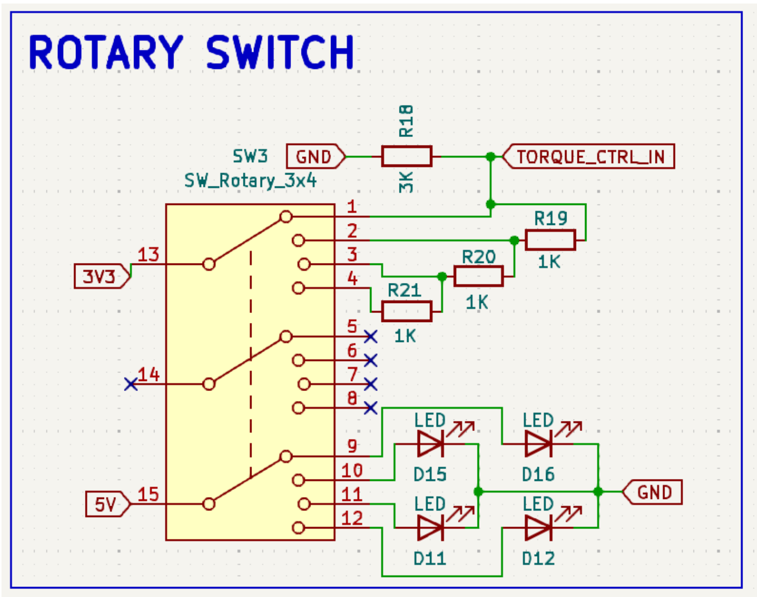

Figure 15: Rotary switch schematic

The voltage divider used three 1 kΩ resistors to branch in between position settings (see TABLE for R1 values) and one 3 kΩ resistor (R2) to connect to ground. Using the voltage divider equation (Equation 1) and accurate output voltage can be computed.

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in} \tag{1}$$

Setting	**First**	**Second**	**Third**	**Fourth**
Voltage (V)	3.30	2.48	1.98	1.65
R1 Value (kΩ)	0	1	2	3

Table 4: Torque and Regeneration voltages and R1 resistance at respective positions

This notion was bench tested and proven to work by the author and another team member before implementing into the DEN V3.1.

4.2. Manufacturing

The same process for the PCB design for the DEN V3.0 (3.2. Manufacturing) was undertaken for the DEN V3.1. A 3D-printed outline with DT connectors plugged into the 3D-print, was put up against the chassis and steering set up together to ensure the PCB would fit comfortably. As a reassurance, the PCB was also placed into the team's 3D model of NU24 in Onshape and test fitted there also.

4.2.1. Manufacturing Issues

However, the DEN V3.1 had no accountability for NU24's body kit. Without a severely large standoff the DEN V3.1 would not be able to fit the body kit at all. This large standoff was not ideal for drivers as the MoTeC display sat at an uncomfortably close distance.

Figure 16: Orientation of DEN V3.1 (without MoTeC display) with body kit installed

The distance from the front roll hoop to the back of the PCB enclosure was 98 mm, compared to the DEN V3.0's 44 mm.

4.2.2. Bill of Materials

The BOM for the DEN V3.1 has similarities to the BOM of the DEN V3.0 (3.2.2. Bill of Materials). With an addition of six resistors and six LEDs to be used alongside the newly implemented rotary switches.

Part	Notes/Part Number	Amount	Cost total ($) (each)
Printed Circuit Board (PCB)		5	154.83 (30.97)
Resistors (0, 120, 500, 1k, 3.8k, 10k Ω)	Size 1206	21	3.36 (0.16)
Capacitors (0.1 ,0.33 µF)	Size 1206	3	0.72 (0.24)
4 pin DT Connector *	DT15-4P-G003	1	29.45
6 pin DT Connector *	DT15-6P-G003	1	34.21
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12 pin DT Connector *	DT15-12AB-G003	1	43.77
Ethernet *	RJS-5EPFFP-LC7002	1	12.89
E-Stop	EC-AMA-H-001-A	1	26.12
Buttons	GPTS203211B	2	17.06 (8.53)
Transceiver	TJA1051T-3	1	1.95
Voltage regulator	LM7805_DPAK	1	2.35
Screw terminal	691137710002	1	0.58
Barrier diodes	TWGMC-SS34	1	0.22
Zener diodes	BZT52-C3V3J	3	0.48 (0.16)
LEDs (red, green, blue)	Size 1206	14	4.48 (0.32)
Fuses	0452001.MRL	3	6.57 (2.19)
Fuse holders	01550900DR	3	12.96 (4.32)
Test points	5007	8	4.96 (0.62)
Dip switch	KAE01LAGT	1	2.13
Teensy 4.0	DEV-16997	1	45.60
3 pole rotary dials/switches **	SR1214	2	9.90 (4.95)
Total		**77**	**493.05**

Table 5: BOM for the DEN V3.1

* *Sourced from Mouser* [5] ** *Sourced from Jaycar* [6]

The PCBs had a higher cost by $24.43 compared to the DEN V3.0, due to the larger size board and more through-hole inserts. With the same process taken as the DEN V3.0, the PCBs were tested for continuity.

4.3. Commissioning and Validation

The DEN V3.1 was bench tested once fully assembled. The verification process that was conducted on the DEN V3.0 was used on the DEN V3.1. The correct voltage at sensitive components was checked. Verification that components received the correct amount of voltage was vital.

4.3.1. Trouble Shooting

With the incorporation of the rotary switches, the third pole LED indication circuit had too much voltage running through the LEDs. This did not affect the use of the switches as this set up was completely for indication purposes. To resolve this a pull-down resistor or a lower voltage supply should be implemented to allow the LEDs not to break.

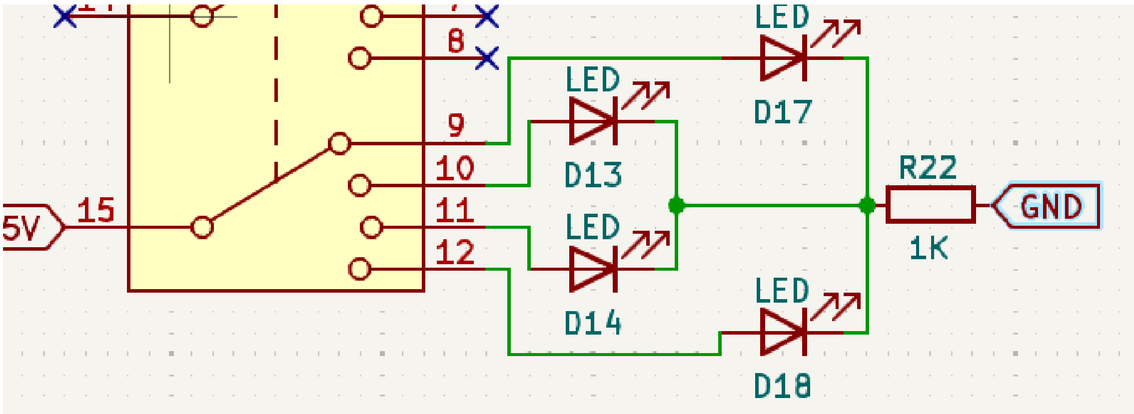


Figure 17: Updated model of indication LED for rotary switches

4.3.2. Code Changes

The DEN V3.1 utilised the programming on the DEN V3.0 but incorporated a new block of code to operate the rotary switches. The following code block (Figure 18) is for the torque state, the regeneration state is the exact same reading from pin 18.

```
// Update Torque State
void updateTorqueState(void) {
  // Read input at torque dial voltage divider pin 17
  TorqueDial = analogRead(TORQUE_DIAL_PIN);
  // Convert analog reading to voltage from 3.3V input
  TorqueStateVolt = TorqueDial * (3.3/1023.0);
  // torque state based on voltage
  if (TorqueStateVolt > 2.8)
    TorqueState = 1;
  else if (TorqueStateVolt > 2.1)
    TorqueState = 2;
  else if (TorqueStateVolt > 1.75)
    TorqueState = 3;
  else if (TorqueStateVolt > 1.3)
    TorqueState = 4;
  else
    TorqueState = 1;

  // update state over CAN
  NUCAN_write(&TORQUE_MODE, TorqueState);
}
```

Figure 18: Code block for torque control

4.4. Recommendations

Besides the DEN V3.1 not fitting with the body kit on, the PCB was successful. For future works with the torque and regeneration rotary switches, it will be recommended to discuss and work with the power box engineer to ensure the switches are allocated the correct torque/regeneration setting. It is also recommended that an external PCB is used for the rotary switches. Due to the awkward sizing the DEN is not the most suited place to mount the switches. To fix the LED receiving too much voltage, a 1k Ω resistor is recommended to sit in between the ground plane and the LEDs.

6. Expansion Board (EXP)

The EXP was designed for NU24 driver training and data logging purposes. The initial idea is to retrieve the steering angle and shock potentiometer change. The steering angle sensor would allow for ease of wheel alignments and tracking the angle of approach on cornering. The shock potentiometers would give a decent understanding of wheel loading and shock displacement on similar situations.

6.1. Initial Design

The EXP board (Figure 19) consists of three input ports, two expansion ports and a Teensy 4.0 microcontroller. The Teensy 4.0 will read the signals input through the input ports and relay them to the CAN transceiver. From the CAN transceiver, the signals will be sent through the expansion ports over the CAN network and will be readable by the car. The EXP would connect to the expansion port of the CEN from either one of its own expansion ports. This connection would require a wiring loom to be made.

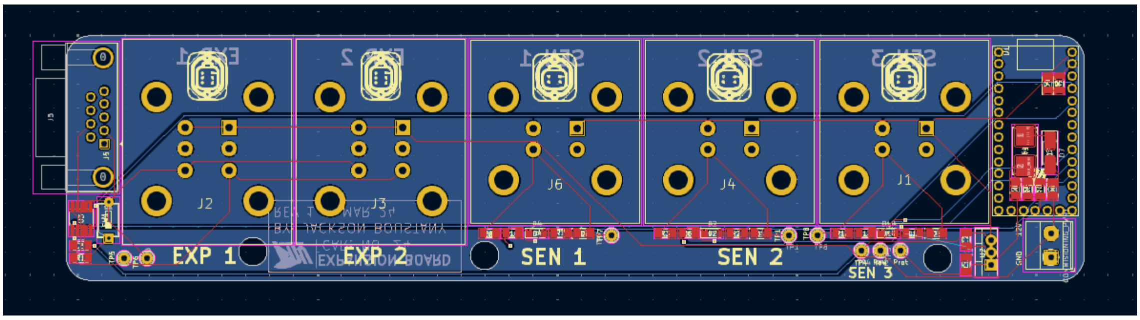


Figure 19: Expansion board PCB

To retrieve the steering angle data, a measuring device will need to be used. There are multiple types of measuring devices which allows the steering angle to be read. These devices include hall effect sensors, magnetic encoders, quadrature encoders, rotary and linear potentiometers. To measure the shock displacement, linear potentiometers will be used.

The team of 2023 had purchased two types of measuring devices: five LPPS-22-050 linear potentiometers for the shock potentiometers and an AiM 1G steering rotary potentiometer kit for the steering angle. The datasheets and specifications for these products can be found in 11.5.2. LPPS-22 Series Linear Potentiometer and 11.5.1. Rotary Potentiometer Kit respectfully.

6.1.1. Hall Effect Sensor

A Hall effect sensor is a device that detects changes magnetic fields and turns them into electrical signals. The Hall effect is the generation of measurable voltage (Hall voltage) due to deflection of electrons in the presence of a magnetic field (Figure 21).

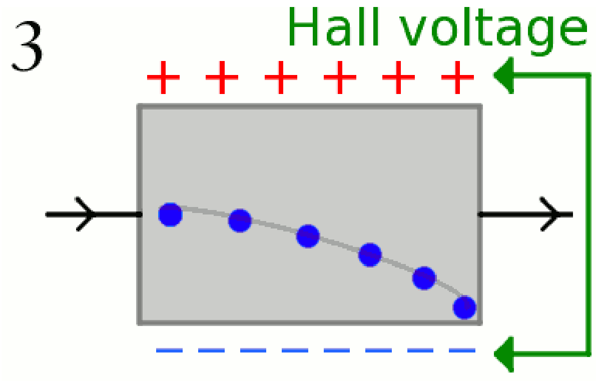


Figure 20: How electrons react to magnetic fields [11]

Magnetic field strength, alignment, distance between magnet and sensor and temperature can impact the quality of the hall voltage measure by the sensor. By placing a bipolar magnet on the bottom of the steering shaft, the steering angle can be measured by a hall effect sensor.

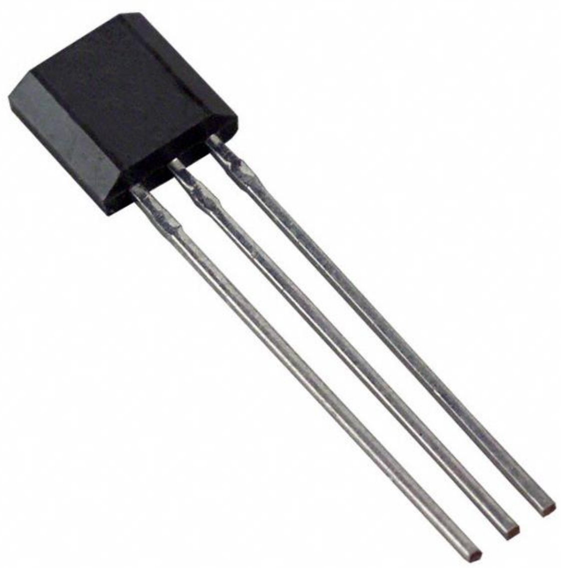
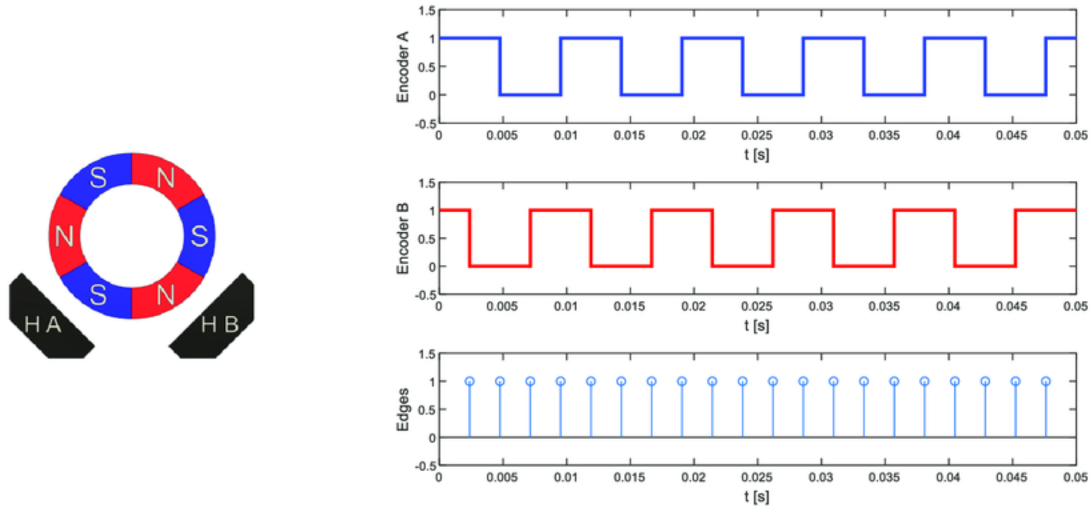


Figure 21: Hall effect sensor [4]

6.1.2. Magnetic Encoders

Magnetic encoders accurately measure angular position by using two hall effect sensors 90º from one another on the outside of a multipole magnet disc. The magnet is connected to one end of the shaft and rotates with the desired item. As the magnet rotates, the hall effect sensors detect the change in poles between north (N) and south (S). A high signal is given for N to S and a low signal is given for S to N. The offset in sensor positioning can allow for the encoder to have a positive and negative direction assignment depending on which sensor receives a high signal first.



(a) (b)

Figure 22: Magnetic encoder layout (a), output from signals from hall effect sensors (b) [14]

The shaft could be inserted inside the hollow steering column and a direct input can be measured by the magnetic encoder. This setup is simplistic and practical. Unfortunately, assembled magnetic encoders for the purpose of measuring steering angle mainly attached to DC motors.

Figure 23: Magnetic encoder assembly from a DC motor

6.1.3. Quadrature Encoders

Quadrature encoders are typically larger in size in comparison to magnetic encoders as they house photosensitive sensor with a light source and a rotating disc. Figure 24 shows the basic layout of the inside of a quadrature encoder.

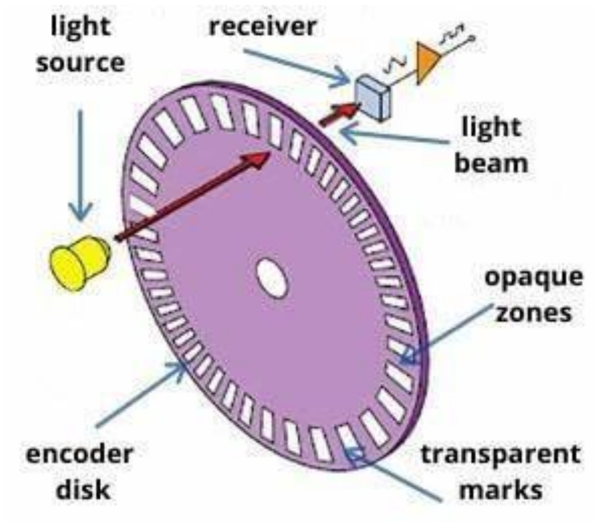


Figure 24: Inside a quadrature encoder [13]

Like the magnetic encoder outputs, the quadrature encoder takes two channel outputs positioned to have a graph offset of 90° from one another. This allows for the direction of rotation of the sensor to be allocated.

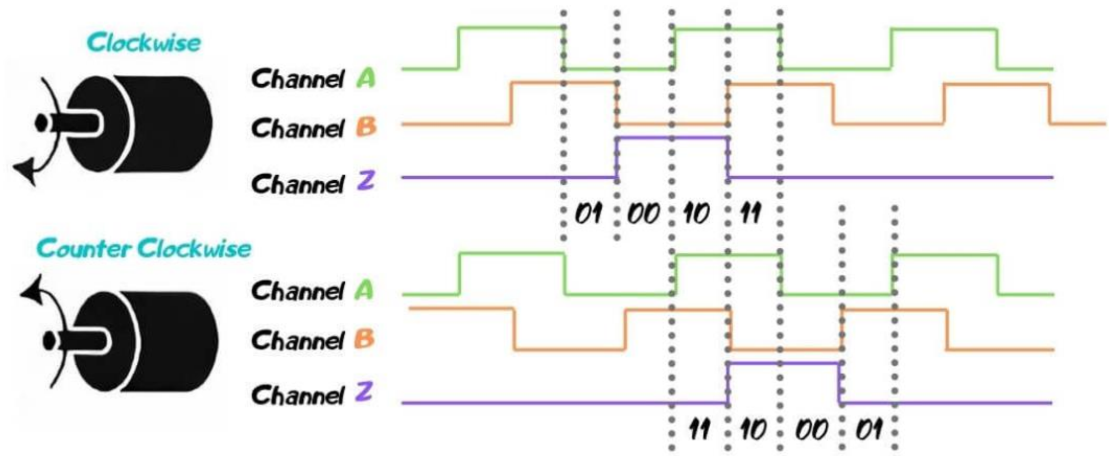


Figure 25: Quadrature encoder directional channel outputs [13]

In similarity to magnetic encoders, the quadrature encoder can be set up simply by inserting the rotating end of the encoder inside the hollow steering column. However, the size of the quadrature encoder would require either the steering column or the floor close out to be removed to install.

6.1.4. Rotary and Linear Potentiometers

As the name suggests, the rotary and linear potentiometers work the same as typical potentiometers. A potentiometer consists of a power (input voltage), and output (signal out) and a ground pin. As a contact slides along a uniform resistance, depending on position, the voltage of the output pin varies (Figure 26).

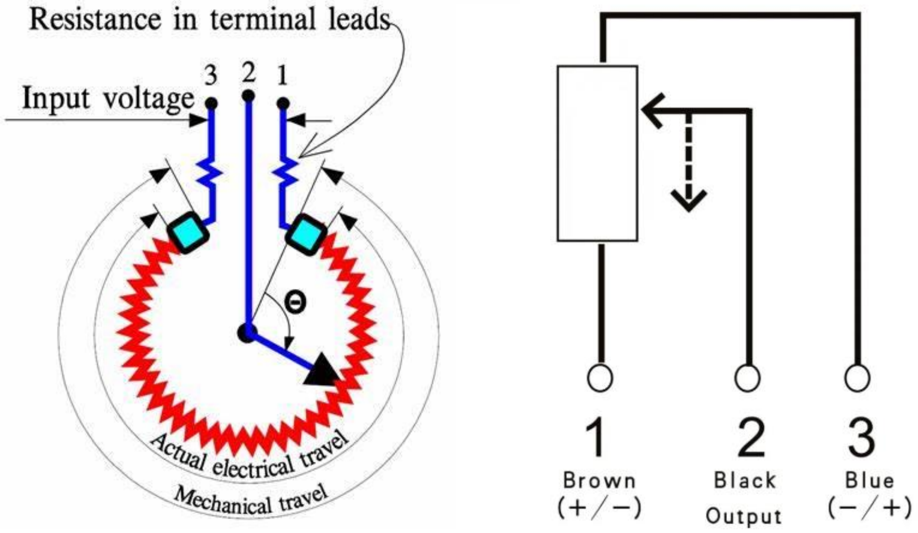


Figure 26: Rotary (left) and linear (right) potentiometer layout [15]

For the rotary potentiometer to be implemented, there are a few different methods. The first method is to mount the potentiometer inside the steering column shaft such that it rotates with the column. The other method is to have a pulley like system, like a go kart [7]. Two gears will be used, one would be mounted before the gear box, the other on the potentiometer and will be connected by a belt. This method involves some sort of tensioning, or the belt might be susceptible to slipping.

Figure 27: Go kart steering angle sensor assembly [16]

For linear potentiometers, it will lay horizontally in line with the inner tie rods and run from around the steering column shaft to the connection point between the inner and out tie rods.

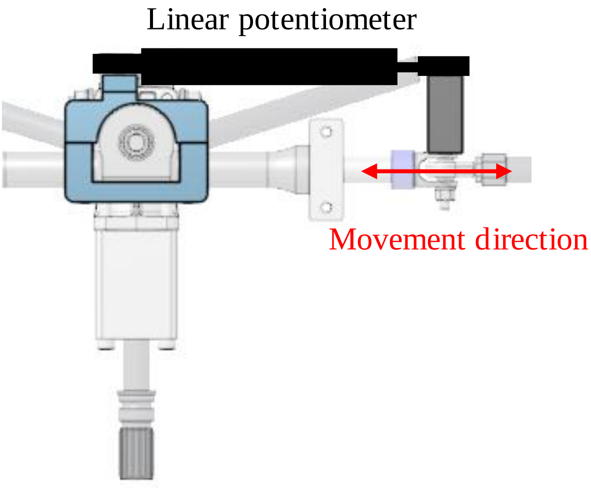


Figure 28: Rough configuration of the linear potentiometer for measuring steering angle

The shock potentiometers are linear potentiometers that will be placed along the side of the shock suspension to measure the displacement of the shock under load.

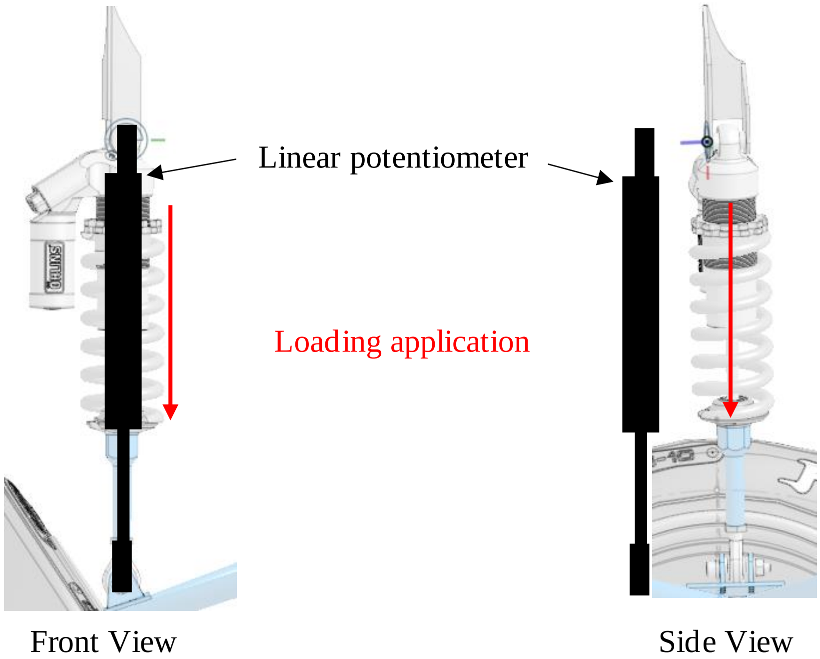


Figure 29: Rough configuration of the linear potentiometer for measuring shock displacement

6.2. Manufacturing

The EXP board was completely new and was not designed to be a permanent fixture on NU 24. The initial temporary position for the EXP was under the foot close out right next to the bottom of the steering column. With this positioning, the wiring loom could run along the inside of the chassis to the CEN.

6.2.1. Wiring Loom

The EXP wiring loom was approximately 1.32 metres in length and housed two DT 6 pin plugs. The loom consisted of six total wires: two red (12 V raw signal), two black (ground signal), a yellow (CAN high) and a green (CAN low). To create the wiring loom:

1. Cut wires to correct length
2. Pin one of each end of the wires, tug test each pin (pull on pin and wire)
3. Put the CAN Bus wires (green and the yellow wires) into the designated positions of the DT 6 pin plug
4. Using the wiring clamp, hold the wires 15 mm from the base of the DT connector
5. Twist the CAN Bus wires around each other as evenly as possible with around 15 mm between each cross over, for the length of the wires.
6. Put the red wires into the designated positions of the DT 6 pin plug
7. Coil the red wires around the twisted yellow and green pair following the cross overs (don’t twist the red wires between themselves)
8. Repeat the previous two steps for the black wires
9. Slide heat shrink over the wires
10. Pin remaining end of wires and place into remaining DT plug. Ensure that continuity is present between numbered pins (i.e. pin slot 1 from one end of the loom matches pin slot 1, 2 to 2 … etc)

The CAN Bus wires are centralised in the core of the wiring loom to prevent noise occurring within the CAN signals.

6.2.2. Manufacturing Issues

The EXP board was to sit under the foot plate close out that covered the brake lines and the inner tie rods. However, once the new close out was made, there was no clearance for the PCB to fit underneath. Since the board only needs a temporary position, this doesn't affect NU24 or the function of the board. The temporary solution was to set the board in the side section behind the A-arms.

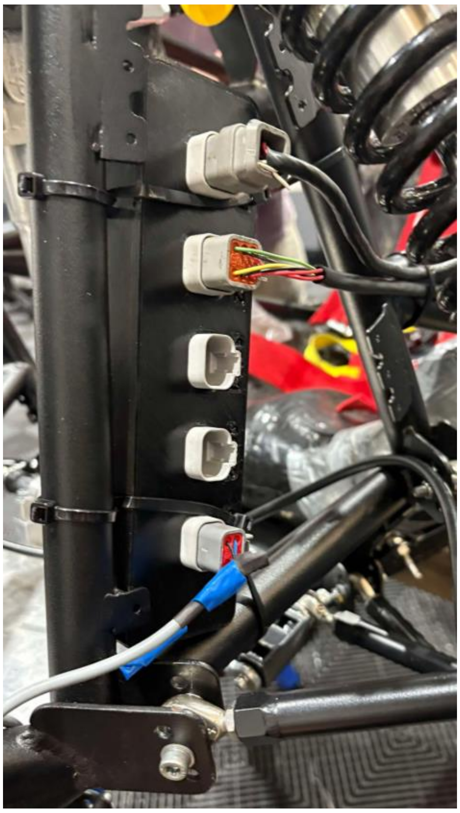


Figure 30: Mounting set up for EXP

When testing the EXP, there were a few issues: the messages were being sent over CAN Bus, the MoTeC was not set up to read the CAN messages sent from the EXP and the potentiometer sizing was slightly too short. Unfortunately, there was only one track day where the board was tested for steering angle. No tests were conducted for the shock potentiometers; however, they would work the with similarities to the steering angle.

Firstly, with the change of DBC files from EV3 (NuRacing's 2022 car) to NU24, the steering angle sensor input was changed slightly. In the 'size' section on the table in CAN King the signal was set to 1 bit instead of the required 8 bits. Once this was changed the messages were sent.

Secondly, the potentiometer size was 50 mm which was slightly too short to measure the full angle of steer. The LPPS-22-050 linear potentiometers were purchased by the 2023 team. The steering rack has approximately 55 mm from full lock right to left, a LPPS-22-075 would have enough excess to allow for the full range of steering angle to be measured without the potentiometer bottoming out (11.5.2. LPPS-22 Series Linear Potentiometer).

Figure 31: LPPS-22 series linear potentiometer

Finally, the EXP wasn't tested enough due to more prioritise tasks to be done. More track days and a refined model of the EXP would allow this PCB to take advantage of driver training and tire loading.

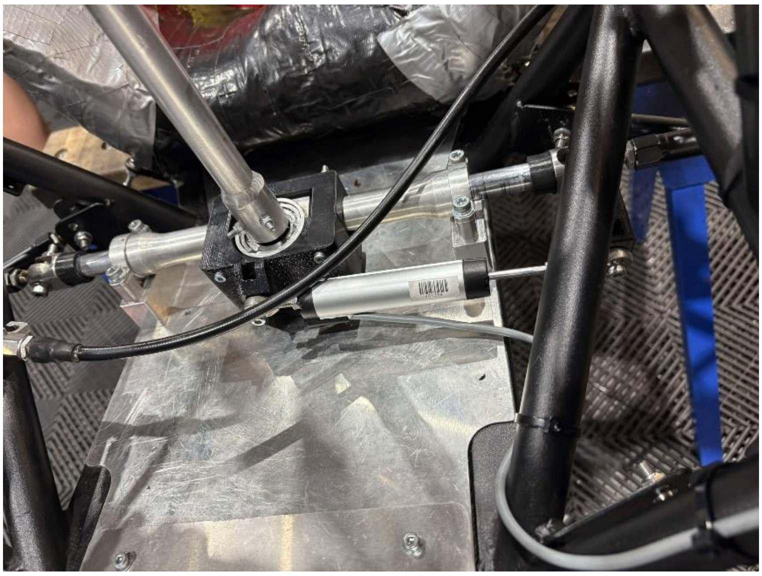


Figure 32: Steering angle set up

Another slight inconvenience occurred with the wiring loom. The wrong size heat shrink was used. The pins were crimped onto both ends already and cutting the pins off and repining would cause the wiring loom to be slightly shorter than required. The heat shrink used was 12 mm in diameter which left a slightly loose fitment of the heat shrink. For a six-wire loom, an 8 mm diameter heat shrink should be used.

6.2.3. Bill of Materials

The EXP uses the same components to DEN V3.0 (3.2.2. Bill of Materials). Where most components are sourced from DigiKey [4].

Part	Notes/Part Number	Amount	Cost total ($) (each)
Printed Circuit Board (PCB)		5	154.83 (30.97)
Resistors (0, 120, 500, 1k, 3.8k, 10k Ω)	Size 1206	10	3.36 (0.16)
Capacitors (0.1 ,0.33 μF)	Size 1206	3	0.72 (0.24)
4 pin DT Connector *	DT15-4P-G003	2	29.45
6 pin DT Connector *	DT15-6P-G003	3	34.21
D-Sub plug	DE-9P-T-NR	1	5.60
Transceiver	TJA1051T-3	1	1.95
Voltage regulator	LM7805_DPAK	1	2.35
Screw terminal	691137710002	1	0.58
Barrier diodes	TWGMC-SS34	1	0.22
Zener diodes	BZT52-C3V3J	3	0.48 (0.16)
LEDs (red, green, blue)	Size 1206	6	1.92 (0.32)
Fuses	0452001.MRL	1	2.19
Fuse holders	01550900DR	1	4.32
Test points	5007	8	4.96 (0.62)
Dip switch	KAE01LAGT	1	2.13
Teensy 4.0	DEV-16997	1	45.60
Total		**49**	**294.87**

Table 6: BOM for EXP

* *Sourced from Mouser* [5]

For the wiring loom, the 22 AWG wire costs $82.18 per 30.5 metres (one roll), simplifying down to approximately $2.70 per metre.

Part	Notes/Part Number	Amount	Cost total ($) (each)
6 pin DT Plug *	DT06-6S-E003	2	10.46 (5.73)
22 AWG wire	A2101B-100-ND	7.92 m	21.38 (2.70/m)
DT pins *	0462-203-12141	12	15.12 (1.26)
Heat shrink **	WH-5642 8.0 mm	1.32 m	23.90 (11.95/1.2m)
Total			**70.86**

Table 7: BOM for expansion loom

* *Sourced from Mouser* [5] ** *Sourced from Jaycar* [6]

6.3. Commissioning and Validation

The EXP board was bench tested once fully assembled. As with the previous two boards, continuity was tested for verification that all soldered components have a good connection. Besides the Teensy not having all traces and whoopsie wires present, the EXP was fully assembled.

6.3.1. Trouble Shooting

With the PCB ready to be commissioned, the continuity of the PCB must be verified. Unfortunately, there were a few traces missed on the EXP within the design phase. Three signal traces leading to the Teensy were not routed as well as a 3.3 voltage line in between the Teensy and the CAN transceiver. This was due to a slight grid offset when importing the Teensy schematic. To avoid this mistake, ensure that all items are aligned with the new schematic sheets grid layout.

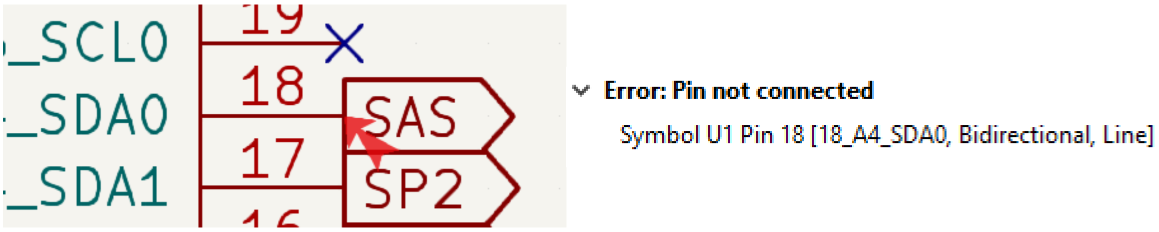


Figure 33: Replicated error pin being disconnected and the corresponding error code

An external wire (known within the team as a ‘whoopsie wire’) was soldered in place of the missing traces to create the connection required.

6.3.2. Programming

The EXP needed to be added to the pre-existing DBC file and have access to the CAN Bus network. The code to make the EXP readable within NU24's CAN network was utilised from a default template within NuTeams and modified to suit the input and output messages sent by the EXP. The potentiometers used also needed to be modified to connect to the board via DT 4 pin plug, the pin outputs for the potentiometers are in the respective data sheets in 11.5.2. LPPS-22 Series Linear Potentiometer

Before the signal was tested for CAN connection, a simple analogue input was tested for clarity. Initially done with a three-quarter turn (270°) rotary potentiometer, this simple input was then modified to output an angle. By taking away the total degrees of the sensor from mid-point and having the absolute value of that number recorded, the result will have the centre of the potentiometer as zero and a positive number for both left and right steering angles.

```
EVERY_N_MILLISECONDS(50) {
   SAS_in = analogRead(STEERING_ANGLE_PIN);  // read the input pin
   Serial.println(SAS_in/5);                 // input value divided by voltage input testing for accuracy
   SAS_out = abs(270/2-SAS_in*270/1023);     // modifying out put to be read as positive value in each direction
   Serial.println(SAS_out);                  // value to send through CAN
   NUCAN_write(&STEERING_ANGLE, SAS_out);    // Sending through NUCAN
 }
```

Figure 34: Snippet of code for the measurement of the steering angle for the rotary potentiometer

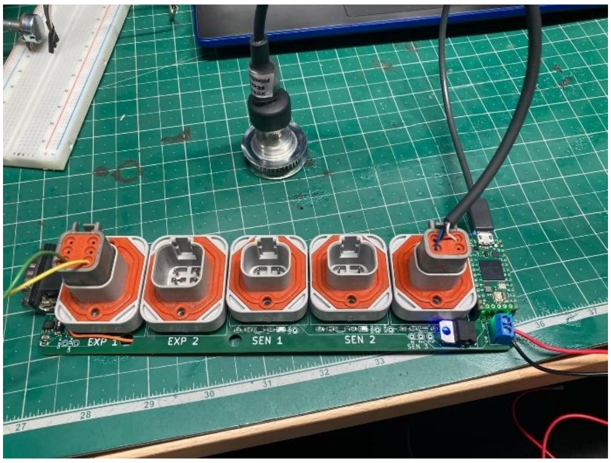


Figure 35: The EXP testing setup with a rotary potentiometer.

A similar process was conducted on the linear potentiometer. However, to get an accurate reading, the code was modified to have an offset due to the centre of the sensor not reading zero (more than likely due to the sensor bottoming out at full locks).

6.4. Steering Angle Set up

The steering angle sensor was to be mounted at the bottom of the steering rack and connect to the tie rod to steering arm joint. The notion for this set up was that as the steering wheel was fully locked one way the linear potentiometer would be either fully extended or retracted. A 3D printed bracket and standoff were needed to secure the potentiometer in place.

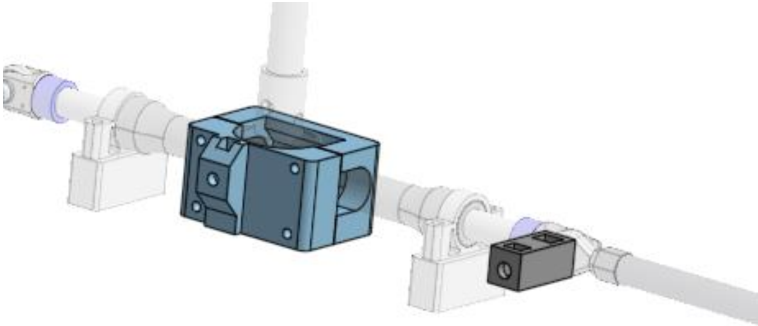


Figure 36: Brackets to hold linear potentiometer in line with steering rack

6.5. Shock Pot Set up

The shock pot set up was to be mounted in line with the shocks themselves. Since the rules state that the suspension travel must be less than 50 mm, the potentiometers fit perfectly along the shock. Since the potentiometer itself will not be under any load, 3D printed standoffs can be used to hold the potentiometer in place.

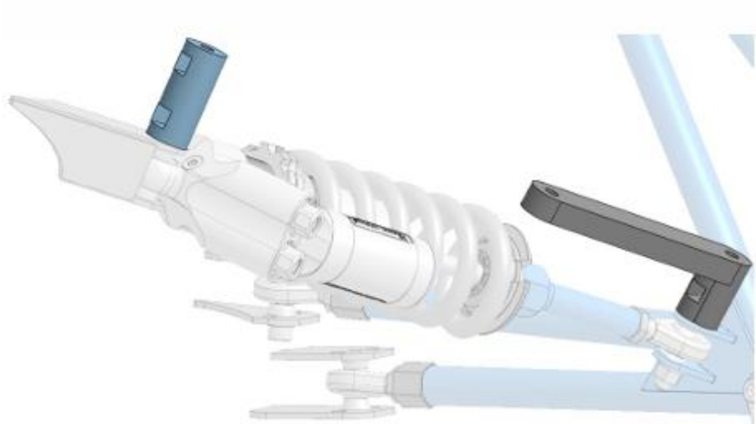


Figure 37: Standoffs to hold linear potentiometer in line with shocks

The lower standoff from initial testing was significantly too large. Approximately 35 mm was removed to ensure better fitment for the linear potentiometer.

6.6. Recommendations

More testing of the sensors on the car and being at to read the messages sent would ideally be the first recommendation. Refining the sensitivity of the code and practicality of the bracket mounts is also recommended. Choosing the correct sensor for the steering angle (i.e. the LPPS-22-075). There is a good base for the EXP to implemented into NU25 for driver training and data logging purposes.

7. Additional Contributions

This section of the report entails the other contributions to the team by the author throughout 2024.

7.1. Enclosures

For each PCB detailed above, a 3D printed enclosure was designed to protect the PCB from weathering conditions and dust. Each PCB had multiple iterations of enclosure design to ensure the PCB fit well. All PCBs were imported into Onshape and used as a ‘context’ to model the enclosures around.

7.1.1. DEN V3.0

The first iteration of the DEN V3.0 enclosure was designed by another team member and fit very well on NU24. This version had a couple hole sizing tolerance adjustments to fit the PCB well.

Figure 38: First iteration DEN V3.0 enclosure

The second iteration, done by the author, had significant changed to allow the DEN V3.0 to fit the body kit. The design of the enclosure was transferred from the successor model, the DEN V3.1. The overall shape of the enclosure had similarities on the bottom half and major change up the top. The bolt holes to screw into the standoff were pushed to just either side of the MoTeC screen. This removed unnecessary length off the previous enclosure and gave more room in between the display and driver, while fitting the enclosure within the body kit. The second iteration removed 24.5 mm of the total length of the enclosure (Figure 39).

Figure 39: Overlay of DEN V3.0 enclosures

Providing better fitment for the PCB took some time as items were forgotten bout with each test piece. Some pieces were too thin, other pieces didn't have the depth to house the PCB components. The third test piece clipped into place with very little tolerance.

Figure 40: Front face second iteration enclosure test pieces

The standoff itself had to be increased for the second iteration enclosure as the DEN V3.0 e-stop and ethernet port would clip into the body kit. The standoff was increased by only 6.0 mm, which was confirmed as still comfortable by the drivers. The second iteration standoff had sections on the left and right removed in precaution to fit the body kit without hitting the lip.

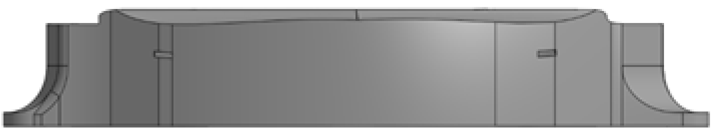


Figure 41: Top view of second iteration DEN V3.0 standoff

Moving the bolt holes allowed for the MoTeC screen cover to be bolted to the enclosure instead of being taped.

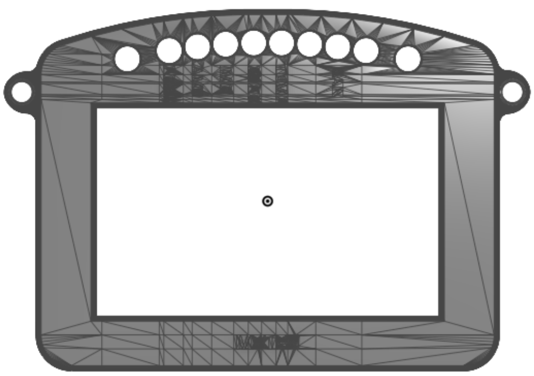
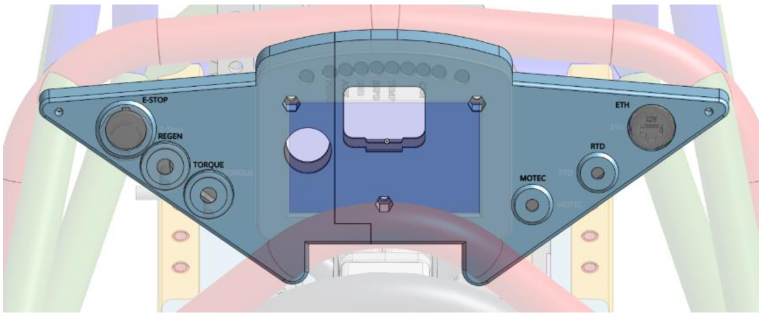


Figure 42: MoTeC cover with bolt holes

Fitment of enclousre with body kit can be found in 11.4.3. DEN V3.0 Fitment of NU24.

7.1.2. DEN V3.1

The DEN V3.1 enclosure designing and refining process followed closely to the process done on the DEN V3.0. The initial enclosure was designed by another team member and was refined by the author. Since the DEN V3.1 was significantly longer than the DEN V3.0, the initial design with the bolt holes would barely fit the front roll hoop.



The second iteration introduced the design of repositioning the bolt holes, shaving off 36.7 mm of length to the enclosure. This allowed for the DEN V3.1 to sit comfortably within NU24's chassis. The second iteration enclosure closed the gap between the front and rear halves of the enclosure, providing improved PCB fitment. Reducing the distance between the inside front and rear faces from 17.0 mm to 9.5 mm.

Figure 43: Overlay of DEN V3.1 enclosures

7.1.3. EXP

The EXP enclosure was very simple due to the shape of the PCB. The lid and casing of the enclosure have no real locking mechanism and only one attempt of enclosure was done. The PCB fit well inside with little movement.

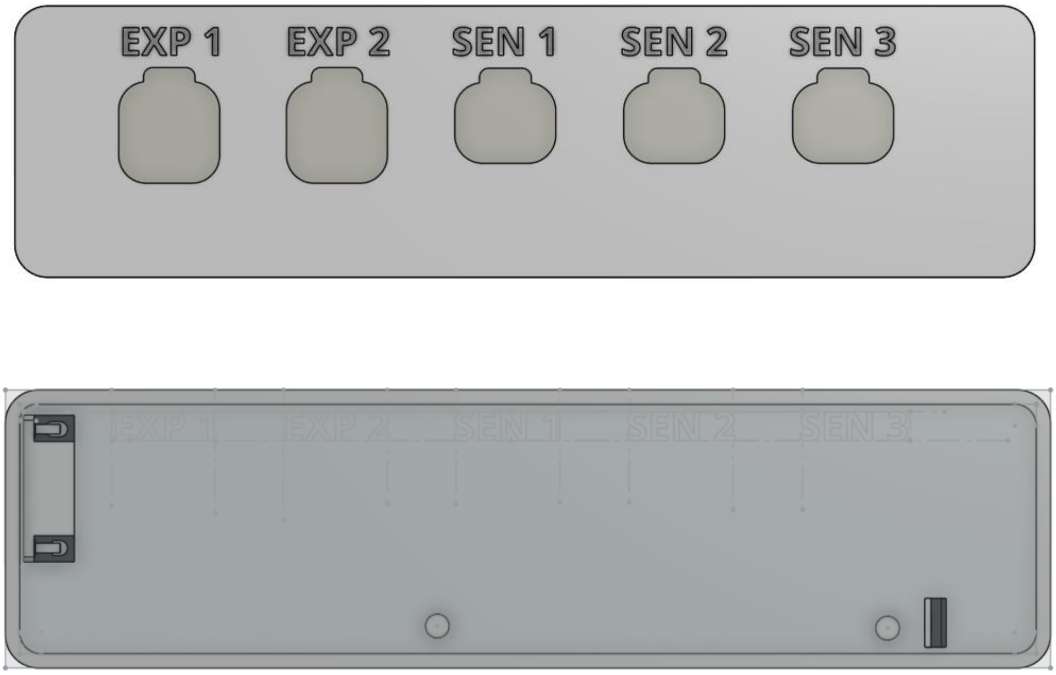


Figure 44: EXP enclosure lid (top) and casing (bottom)

7.2. Phase Cable Holder

The phase cables running from the motor controller technical inspection), any HV wiring needed to sit within the chassis (static inspection (SI.8.9) [8]). Initially, cable ties were used to hold the three phase cables in the ideal location.

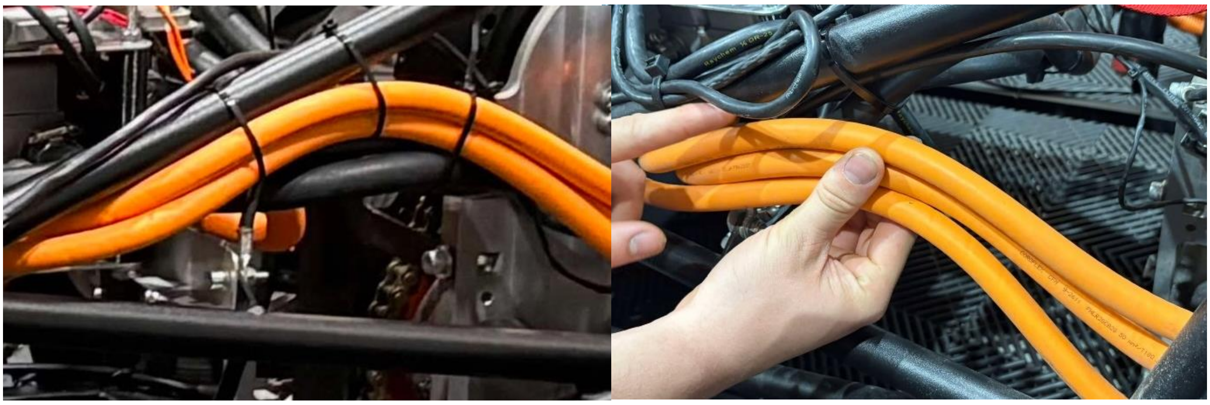


Figure 45: Phase cable ideal location with cable ties (left), manual positioning (right)

It was then recommended to have a bracket like cable holder designed to hold the cables securely. The design included an evenly spaced cable holder was designed to sit approximately where the bow was the most significant. Unfortunately, the stack (inverter, motor controller and LV battery sub assembly) had mounts that stuck up into the lower sat cable. The locations of the cables were adjusted to sit evenly spaced in the top half of the cable holder (Figure 47). The phase cable holder was also given the industry standard HV symbol as a precaution.

Figure 47: Phase cable holder designs: current (left) and previous (right)

Figure 46: Installed phase cable holder

7.3. Car Grounding

To ensure that NU24 was compliant with the rules supplied by Formula-SAE [8], conductive items within 100 mm of any HV items must have equipotential bonding. This bond must have maximum 0.3 Ω of resistance.

SI.18.1		Firewall(s)	300 mOhm
SI.18.2		Accumulator Container(s)	300 mOhm 5000 mOhm
SI.18.3		Components in proximity of Accumulator Container(s)	300 mOhm 5000 mOhm
SI.18.4	Equipotential Bonding	Motor Controller Enclosure(s)	300 mOhm 5000 mOhm
SI.18.5		Components in proximity of Motor Controller(s)	300 mOhm 5000 mOhm
SI.18.6		Motor Casings, Mounts and Scatter Shields	300 mOhm 5000 mOhm
SI.18.7		Components in proximity of Motor(s)	300 mOhm 5000 mOhm
SI.18.8		Other HV enclosure(s)	300 mOhm 5000 mOhm
SI.18.9		Components in proximity of other HV enclosures	300 mOhm 5000 mOhm
SI.18.10		Conductive HV cable channels, cable Armor and cable shielding	300 mOhm 5000 mOhm
SI.18.11		Components in proximity of HV Wires and Cables	300 mOhm 5000 mOhm
SI.18.12		Components in proximity of HVD	300 mOhm 5000 mOhm
SI.18.13		Components in proximity of the Tractive System Measurement Points	300 mOhm 5000 mOhm
SI.18.14		Components in proximity of the Energy Meter	300 mOhm 5000 mOhm
SI.18.15	Equipotential Bonding	Cooling system components including heatsinks, radiators, pumps and reservoirs	300 mOhm 5000 mOhm
SI.18.16		Seat Mounts, Seatbelt Mounts, Driver Controls, Pedals or items in the Drivers Area if in proximity to HV components	300 mOhm 5000 mOhm
SI.18.17		Other items:	300 mOhm 5000 mOhm
SI.18.18		Other items:	300 mOhm 5000 mOhm
SI.18.19		Other items:	300 mOhm 5000 mOhm
SI.18.20		Other items:	300 mOhm 5000 mOhm
SI.18.21		Other items:	300 mOhm 5000 mOhm

Figure 48: Compliance regulations for equipotential bonding [9]

Unfortunately, the hose clamps on the hoses going towards the motor were caught as not being grounded. It is recommended for 2025's team to ground anything metal, regardless of reasoning.

Photos of grounding wires can be found in 11.4.2. NU24 Grounding.

7.4. Charger and Charger Tech Inspection

NU24's HV connections was changed to Surloks from Autosport connections. The change was to reduce costs for both male and female connectors.

Figure 49: HV Surlok connectors [18] (left) and Autosport connectors [17] (right)

For the Charger to house the new Surlok connectors, the interface panel on the charger had to be adjusted. The panel is comprised of 11 mm thick perspex and is only changed at the 'HV' labelled section.

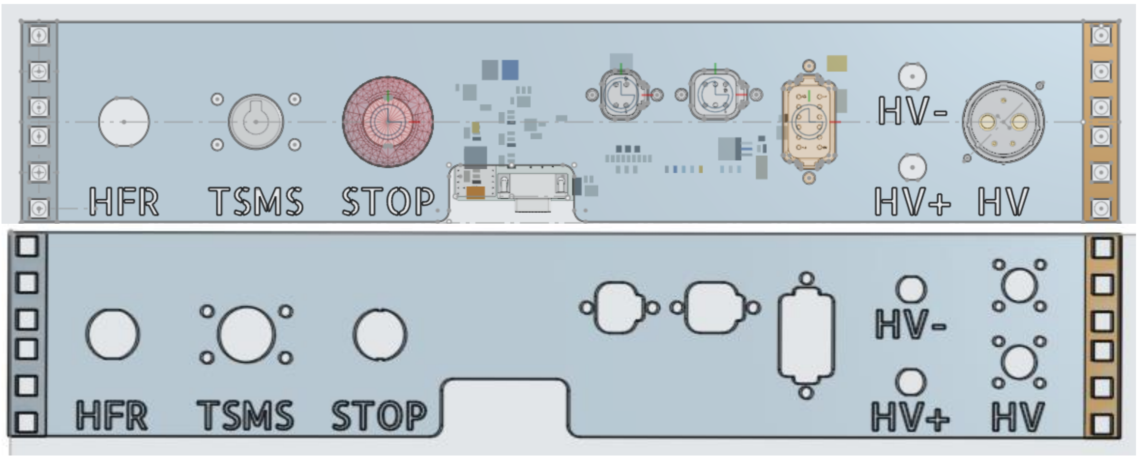


Figure 50: Charger interface panel comparison, NU23 (top) and NU24 (bottom)

An issue with removing the Autosport connectors is that the connectors have an inbuilt interlock. This interlock cuts all voltage when the plug and connector are separated. The Surlok connectors are keyed and are quick and easy to disconnect by pressing a button. The PCB on the charger had to have the interlock wire to connect to itself to allow for the charger to act in the same manner.

The accumulator isolation relay (AIR) inside the charger got welded shut and needed replacing. Instead of hard wiring the new AIR, a two pin molex connector was added in case the air needed to be replaced again.

Figure 51: AIR enclosure inside charger

For the accumulator technical inspection, the author was tasked to explain the charger operation to the judges. The accumulator tech team was comprised of an electrical safety officer (ESO), three team members and a data sheet handler. The accumulator tech was split into four sections: tools and PPE, trolley, charger and accumulator. Judges inspect and question the team on the operations and how it is compliant within the rules. Proving the components utilised and were up to standard to the rules [8] by providing datasheets for components and wires used.

7.5. Other Contributions

- **Track days** - Help laid out the cones for the track, marshalled, lifted the car when needed and charged the accumulator when low on SOC, packed and unpacked equipment, pedal box adjustment team.
- **Competition** – Apart of the body kit team, car lift team, push bar team, fitted the energy meter, EV static and dynamic tech data sheet handler, charged accumulator before dynamic events, packed and unpacked equipment.
- **Water proofing -** Conformal coated all PCBs on the car and helped silicon the enclosures shut.
- **PCB commissioning** – Slightly modified, ordered, manufactured and commissioned the HIP V1.2, commissioned a second PEN and DEN V3.0 for competition.

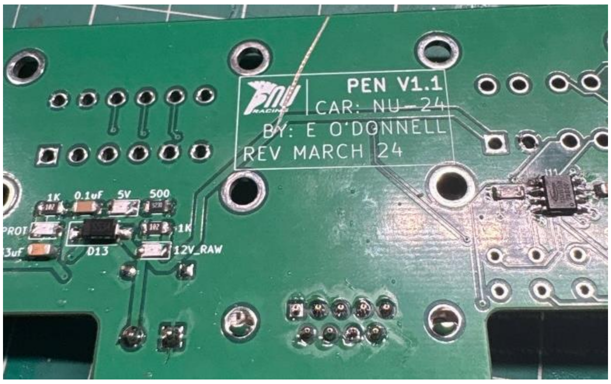


Figure 52: Scratched PEN PCB during commissioning

- **Wiring looms** – helped shorten wiring looms, boot all plugs and crimp new HV charging wires.

Figure 53: Various booting on plugs and crimps

- **Power Box** – Set up the EXP to measure if there was movement in the power box under max torque. Unfortunately, this set up was not tested due to new power box being manufactured.

8. Results and Recommendations

This section of the report details how the Formula SAE competition went. It also gives insight into recommendations to both the DEN and the EXP boards on how to improve and refine the PCBs.

8.1. DEN Recommendations

The DEN V3.1 rectified all the short comings of the DEN V3.0 but was significantly larger in size. Due to the size difference, the DEN V3.0 was selected for the competition as it fits the NU24 body kit. It is recommended working with the power box and steering engineers to find the best solution for the DEN V3.1. Another suggestion is to have a pull-down resistor to link all the LEDs from the second pole of the rotary switch to ground and to have an external PCB to the DEN for the rotary switches to mount to.

8.2. EXP Recommendations

The EXP PCB is a decent base line for small incremental measurements. With a second iteration the PCB can be refined and short comings amended. Mounts and sensors are recommended to have more design and research. Finally, for the steering angle it is recommended to use the LPPS-22-075 linear potentiometer, the LPPS-22-050 will work for the shock potentiometers.

8.3. Formula SAE Competition

Overall, NuRacing and NU24 came fourth in the 2024 Formula SAE Competition. Most technical inspections were passed first go, with the accumulator inspection requiring fuse holders to be changed to a 1000 voltage rating on the top plate and the EV static requiring hose clamps to the motor to be grounded. The results compared to NU23 placement is as follows:

EVENT	2023 (7^{th})	2024 (4^{th})	Difference
Presentation	72.55	54.05	-18.50
Cost	51.06	75.55	+24.49
Design	130.33	120	-10.33
Skidpad	65.77	42.64	-23.13
Acceleration	50.92	71.79	+20.87
Autocross	120.99	78.13	-42.86
Endurance	9.0	250.87	+241.87
Efficiency	52.52	40.89	-11.63
Total	**553.14**	**733.92**	**+180.78**

Table 8: Comparison of overall competition performance

The DEN V3.0 and enclosure used passed the EV static and dynamic and the rain test. There were no problems with the PCB at the competition.

9. Conclusion

Throughout this report details the work completed by the author within the 2024 NuRacing team. The LV system interacts with NU24 through simplistic topology and the ideology of building the system around ease of maintenance and troubleshooting. NU24's topology is comprised of five main nodes: the PEN, DEN, CEN, LVD and HIP. Each of the nodes has a Teensy 4.0 to send messages through NU24's CAN Bus network.

A detailed description of how the DEN was developed to fit NU24 and the iterations was also conducted. The DEN is a crucial component in regards to driver interface and data logging. The DEN houses the input for the inertia switch, the input for GPS and telemetry system, the dash shutdown e-stop and the MoTeC display screen. The DEN had two iterations within the year: V3.0 and V3.1. The DEN V3.0 was the choice to integrate into NU24 for competition, due to size restrictions and simplicity. Reasons for the DEN V3.1 not being utilised was size restrictions and torque and regeneration rotary switches were not necessary as the torque was set manually.

The EXP was a new PCB to have research into sensor integration and sensor types. The requirement was the develop a steering angle sensor to run through the EXP. The EXP was integrated into NU24 for one track day, which unfortunately the data was not set up to be read by MoTeC. The EXP can be refined and more research into different sensor integration is recommended as well as implementing a larger (LPPS-22-075) linear potentiometer.

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11. Appendix

11.1. Schematics/Pinouts

11.1.1. DEN V3.0

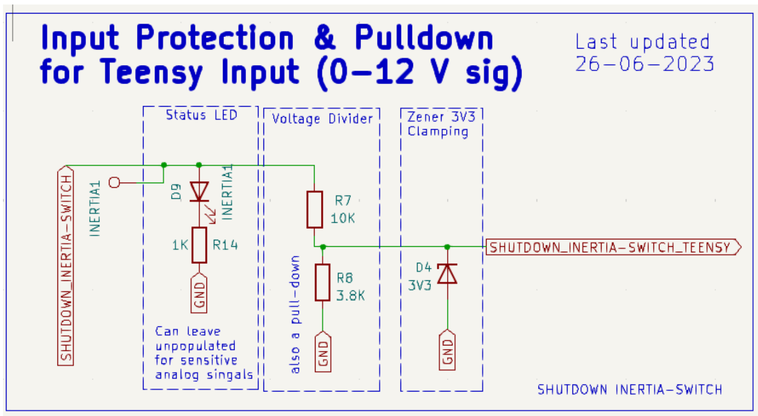


Figure 54: Inertia switch input protection circuit

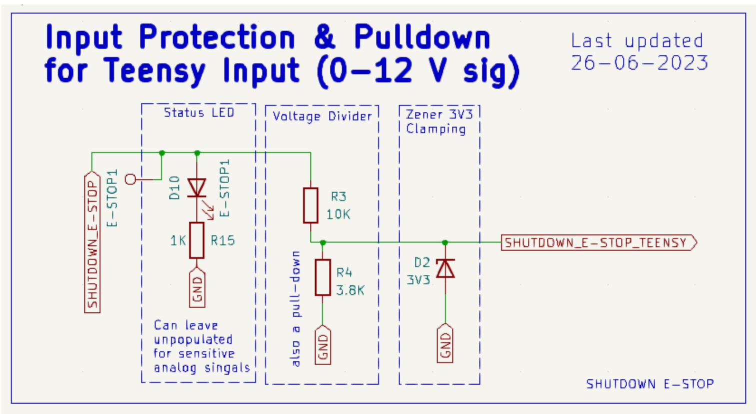


Figure 55: E-stop input protection circuit

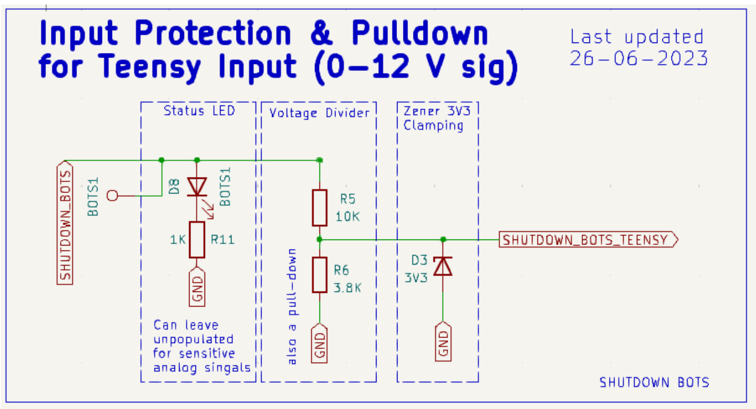


Figure 56: BOTS input protection circuit

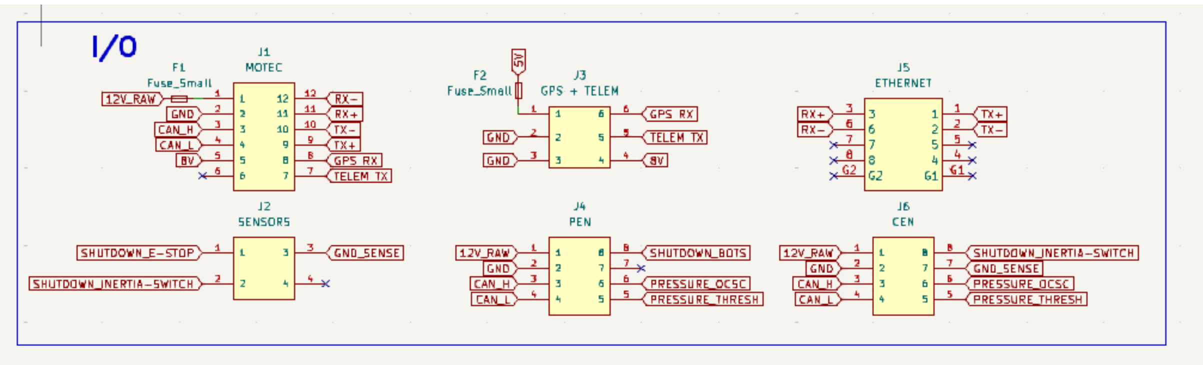


Figure 57: Pin in and out orientation

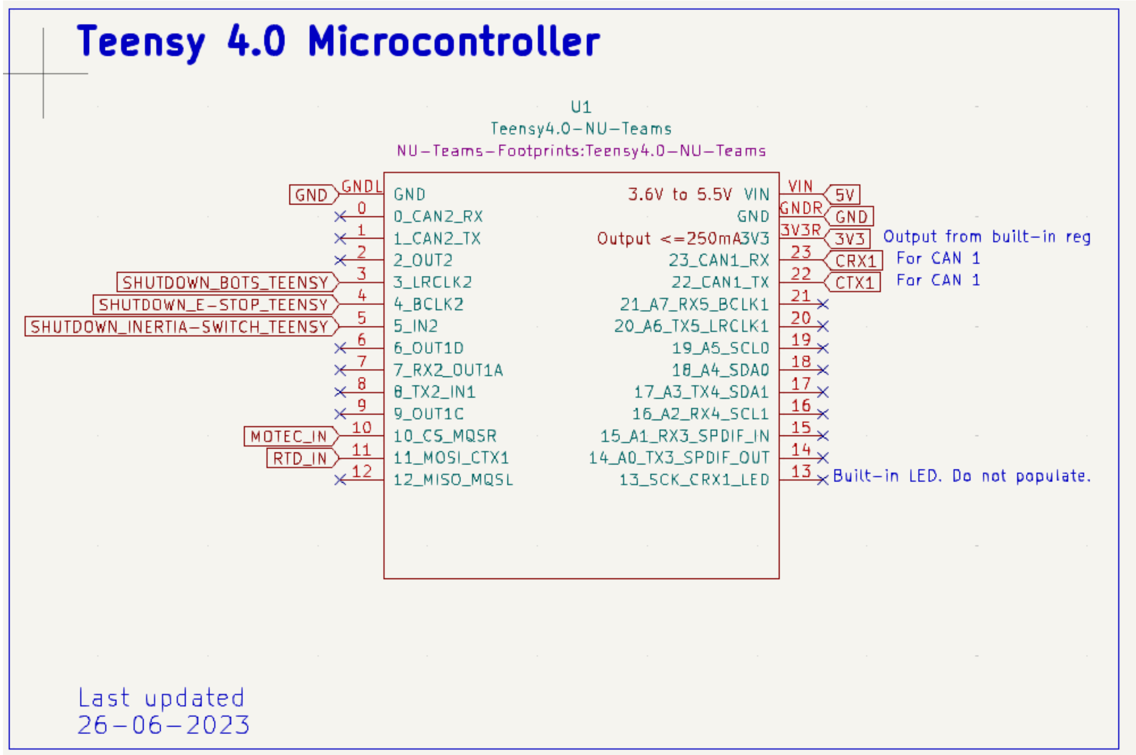


Figure 58: DEN V3.0 Teensy Pinout orientation

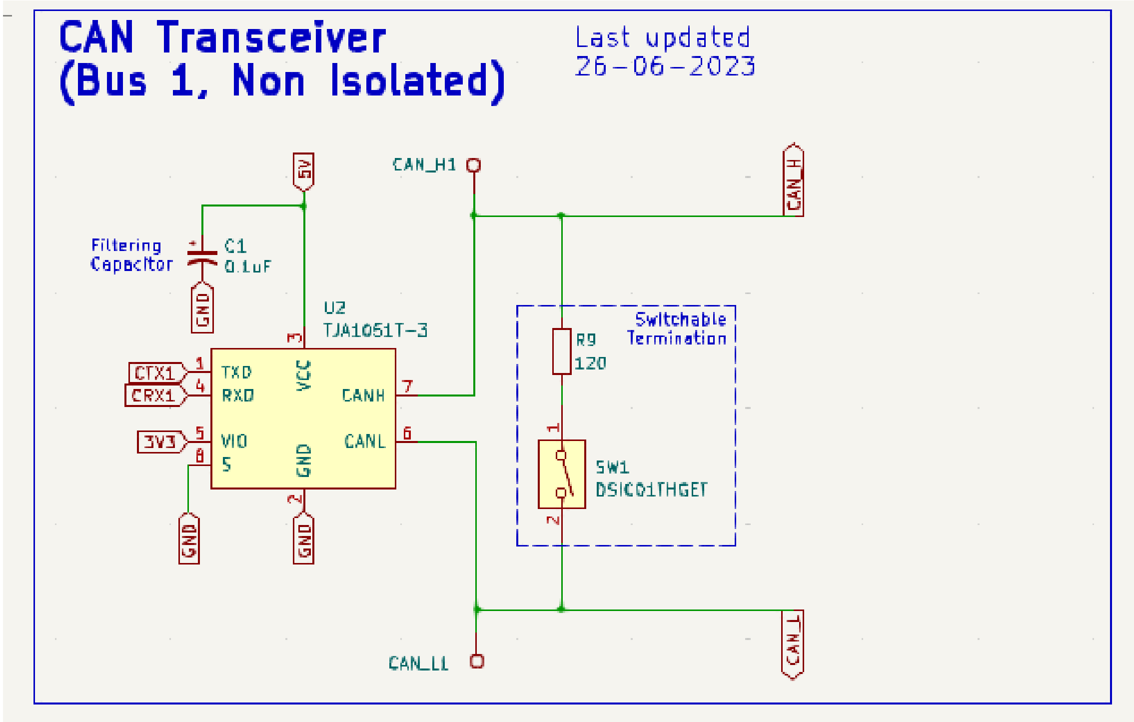


Figure 59: DEN CAN transceiver circuit

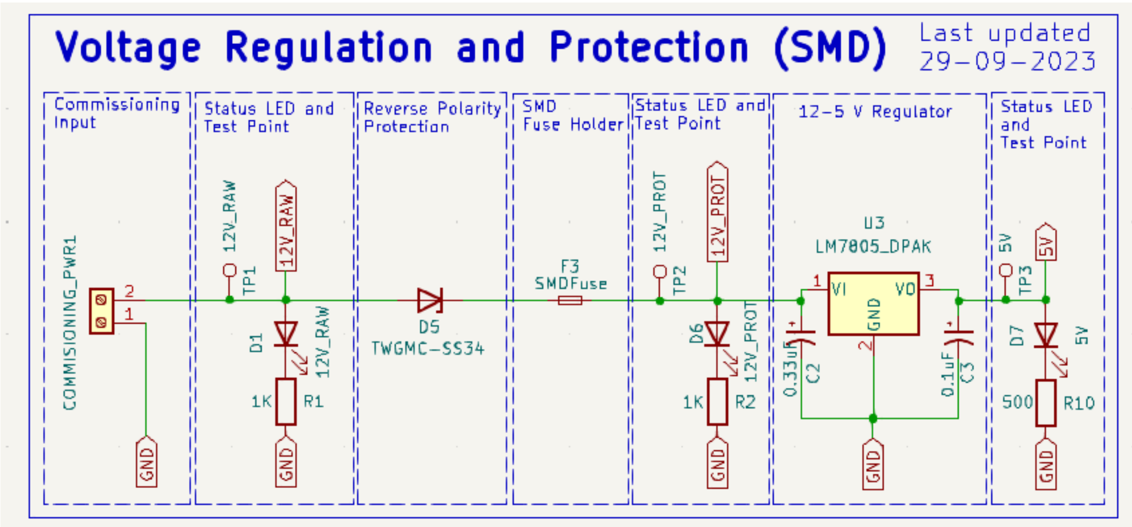


Figure 60: DEN Voltage regulation circuit

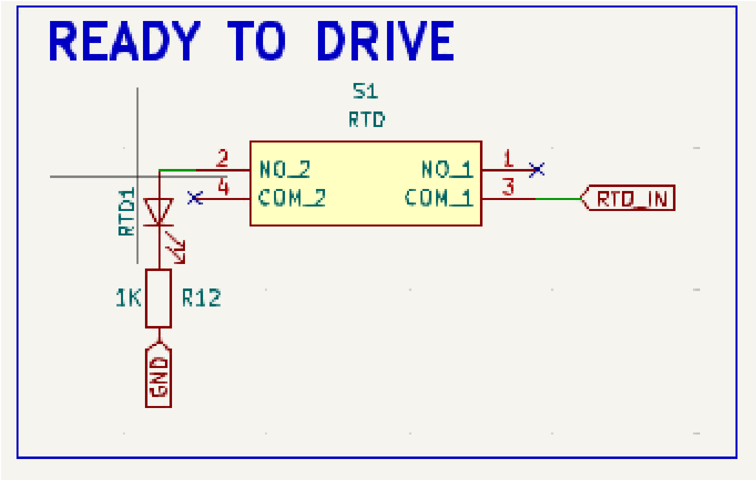


Figure 61 :DEN V3.0 Ready to drive circuit

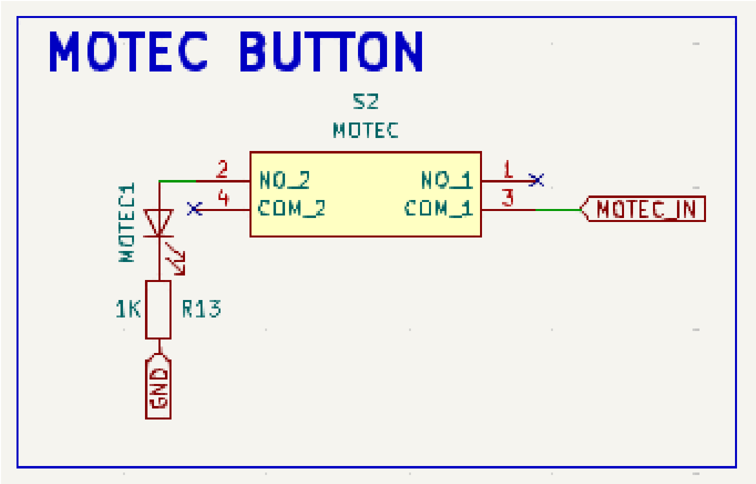


Figure 62: DEN V3.0 MoTeC button circuit

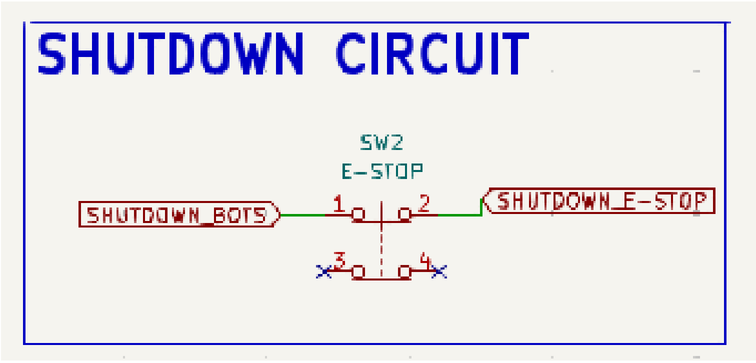


Figure 63: E-stop switch Pin in/out layout

11.1.2. DEN V3.1

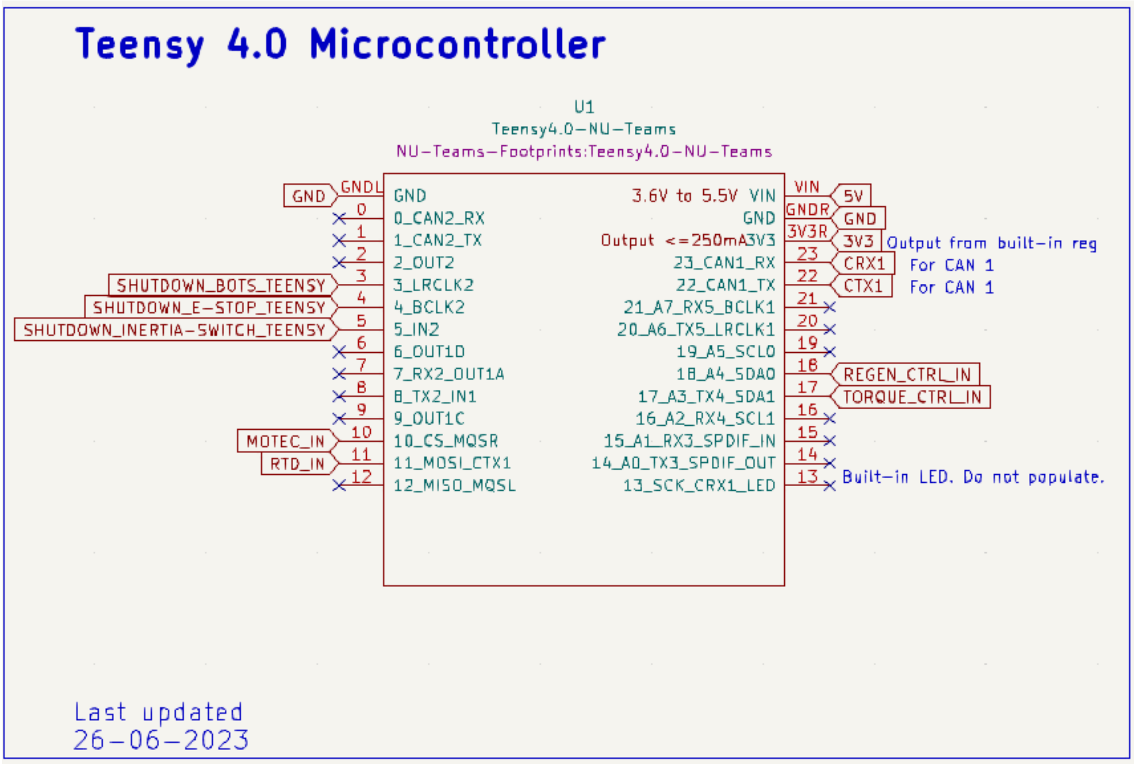


Figure 64: DEN V3.1 Teensy Pinout orientation

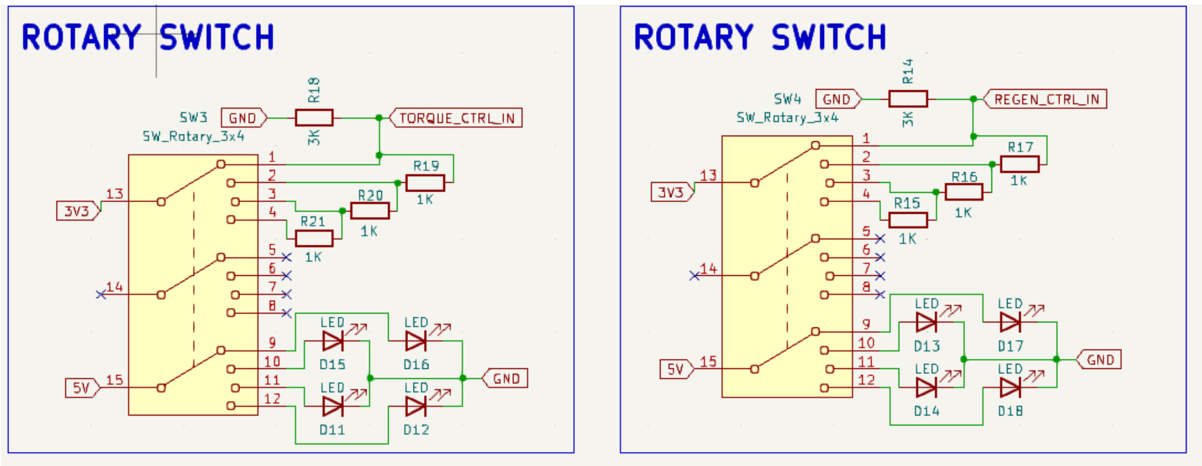


Figure 65: DEN V3.1 Torque and Regeneration control circuits

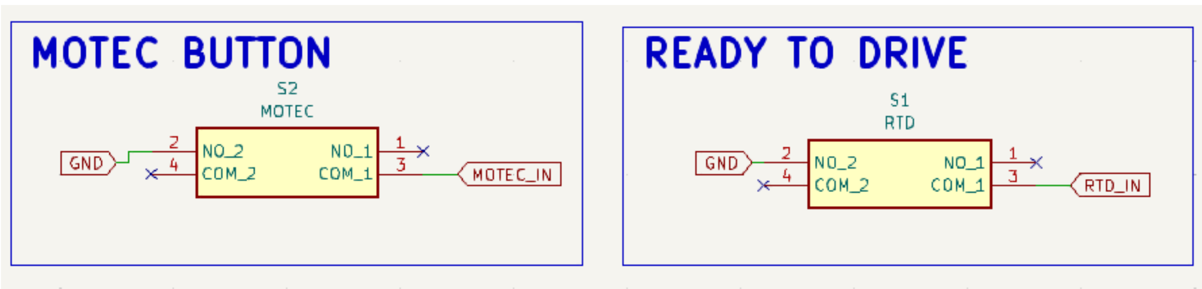


Figure 66: DEN V3.1 MoTeC and RTD button circuits

11.1.3. EXP

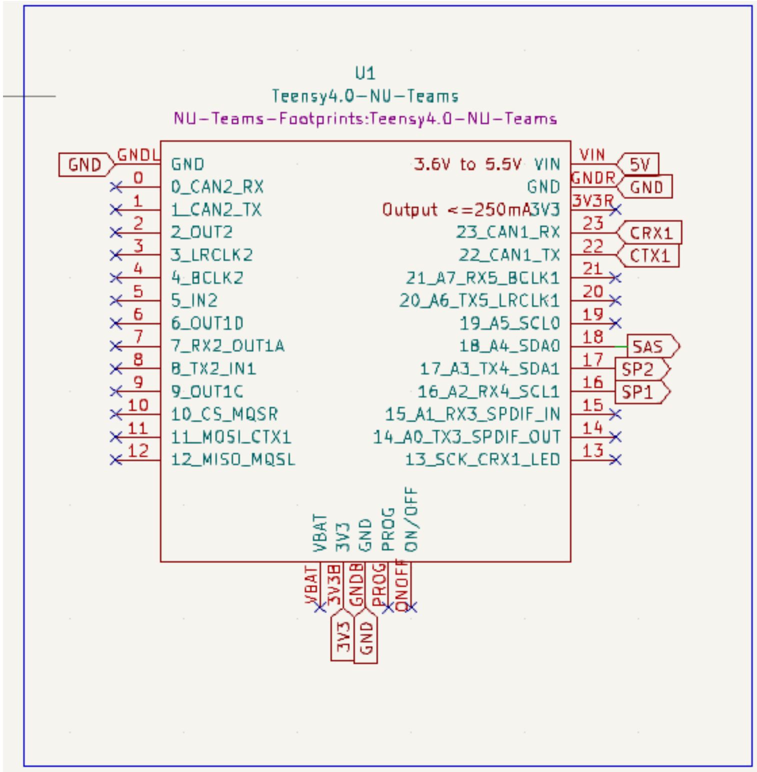


Figure 67: EXP Teensy pin layout

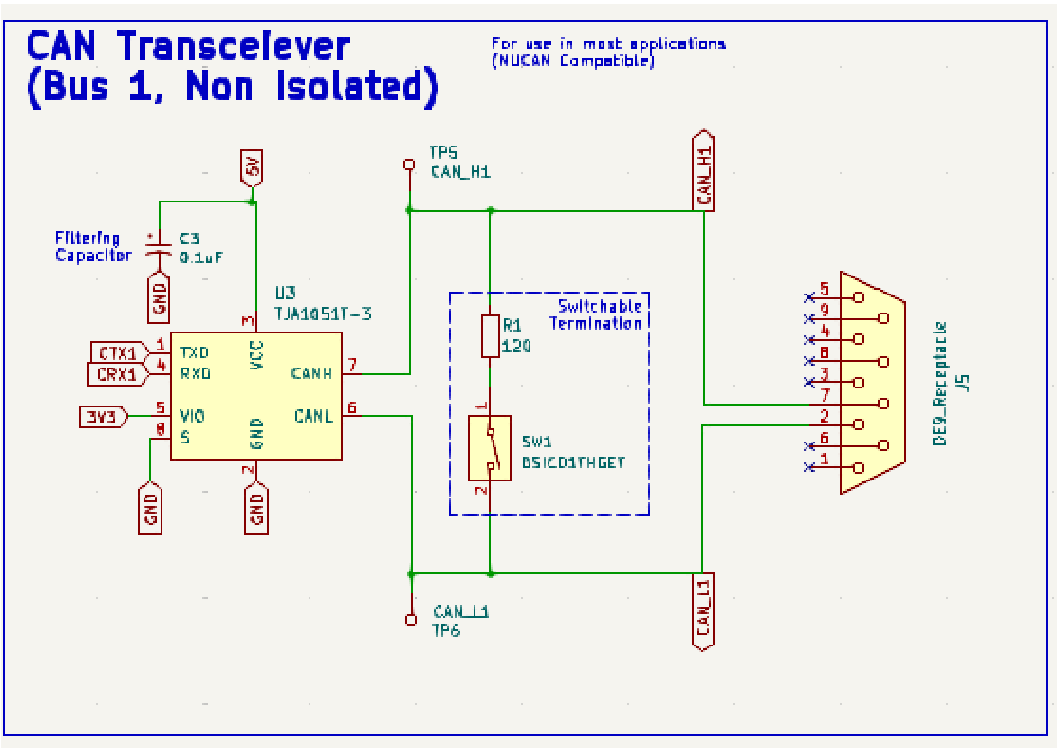


Figure 68: EXP CAN transceiver circuit

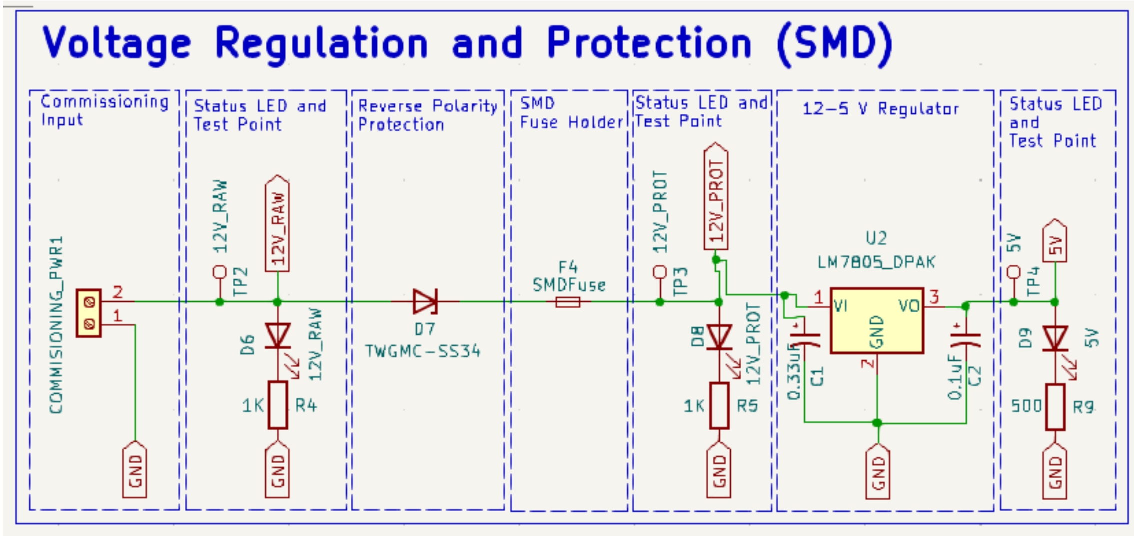


Figure 69: EXP Voltage regulation circuit

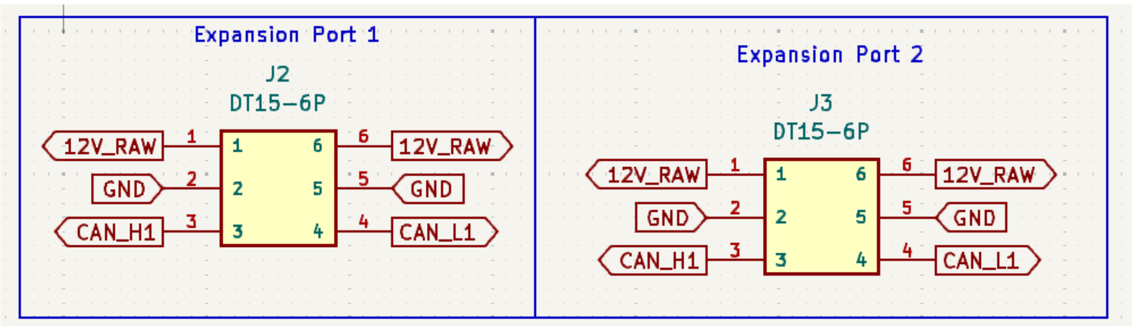


Figure 70: Expansion port pinout

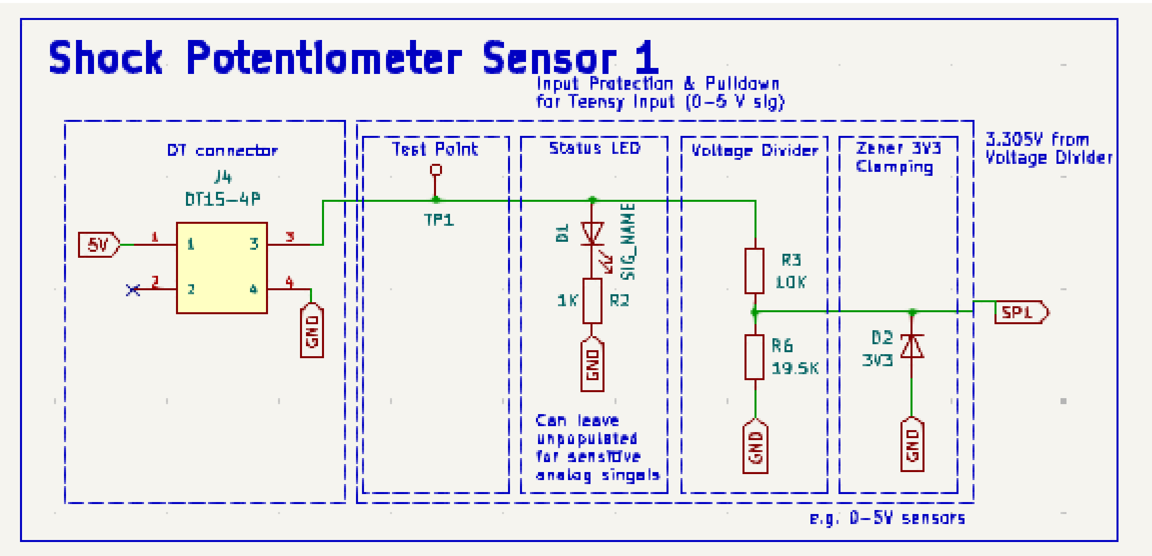


Figure 71: Shock potentiometer 1 pin layout and circuit

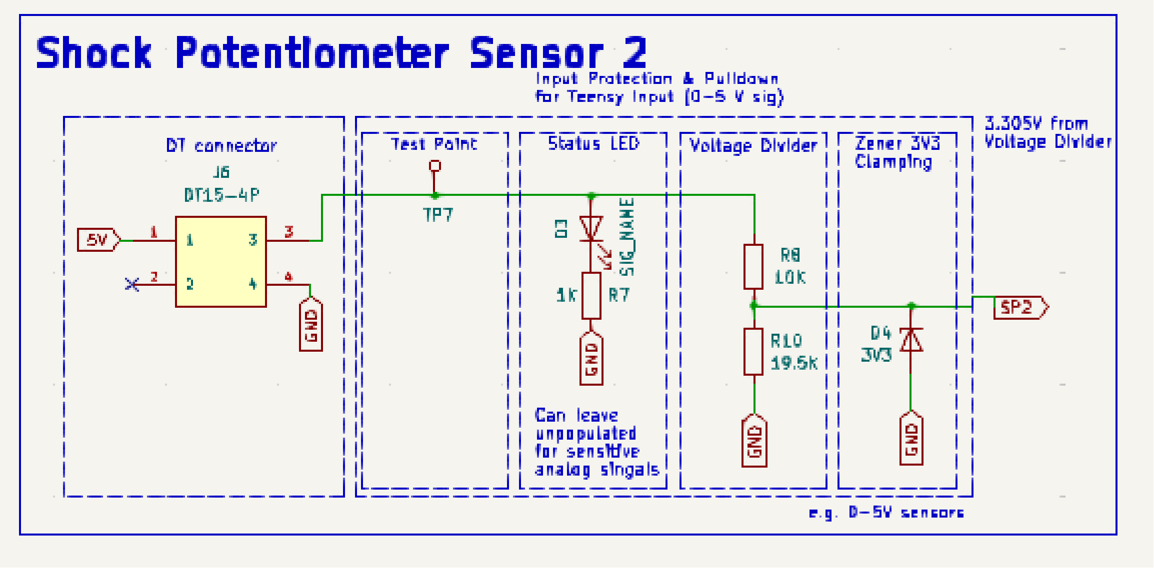


Figure 72: Shock potentiometer 2 pin layout and circuit

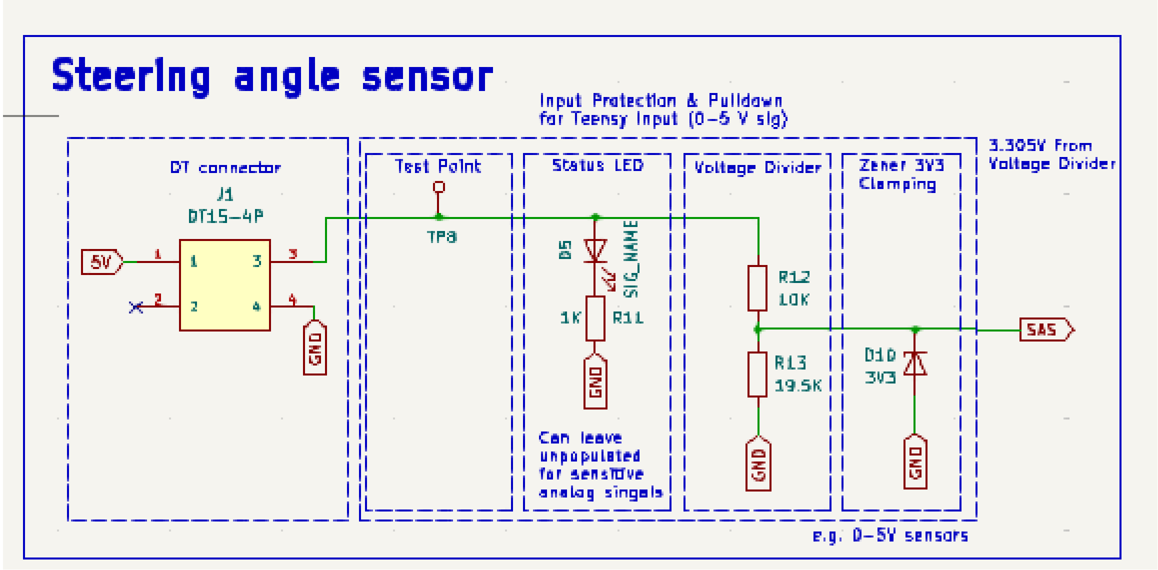


Figure 73:Steering angle sensor pin layout and circuit

11.2. PCB Views

11.2.1. DEN V3.0

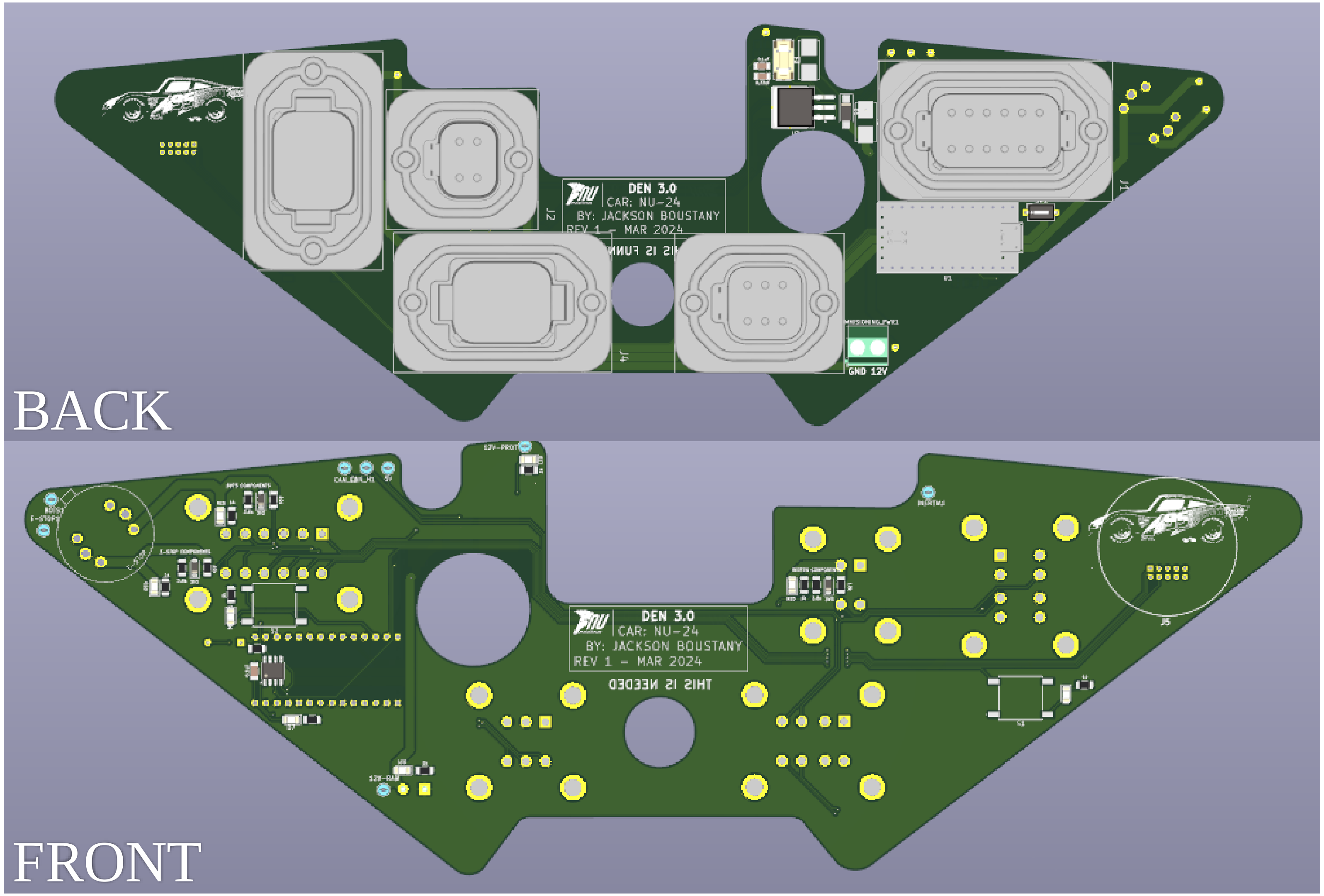


Figure 74: DEN V3.0 3D model

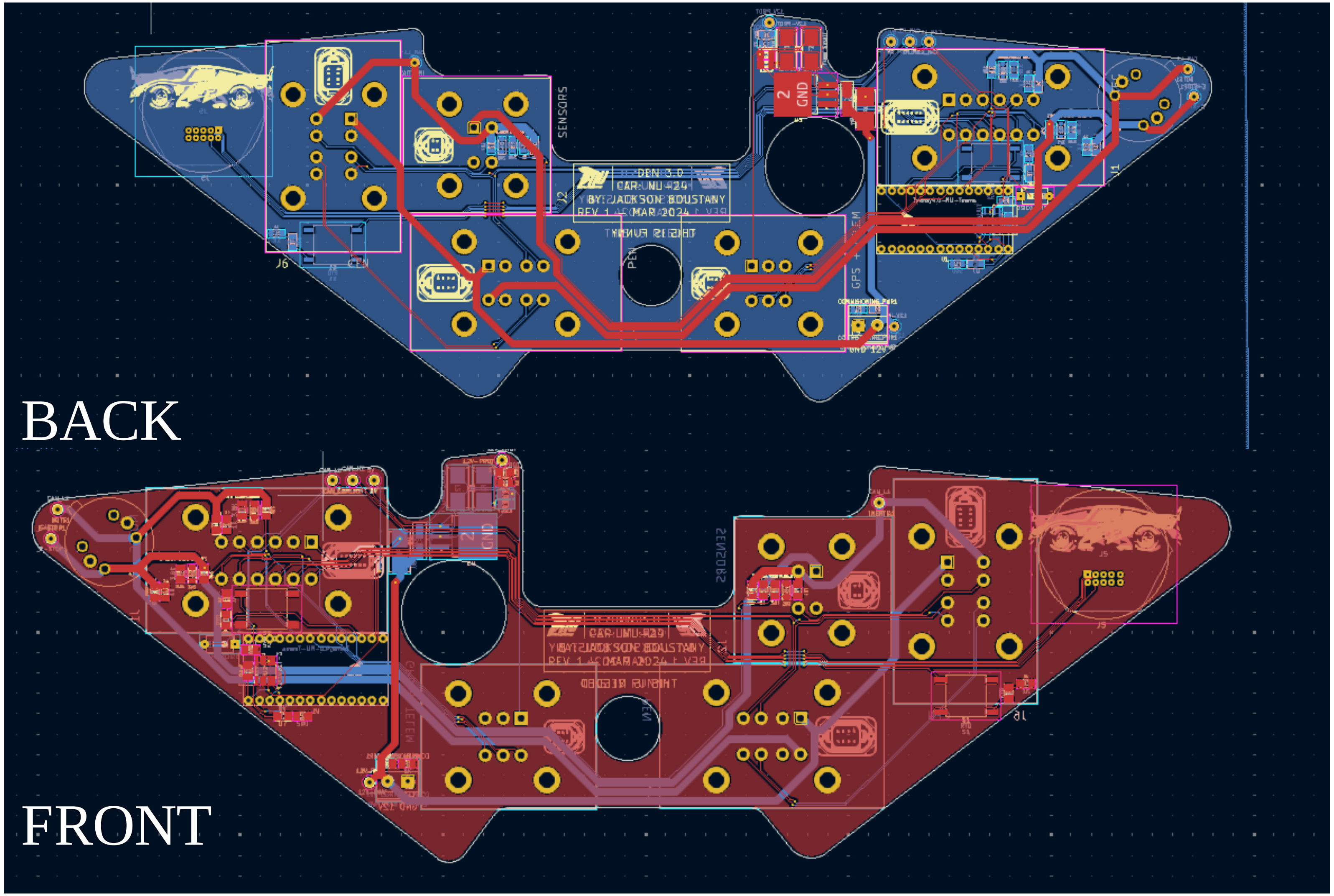


Figure 75: DEN V3.0 PCB trace layout

11.2.2. DEN V3.1

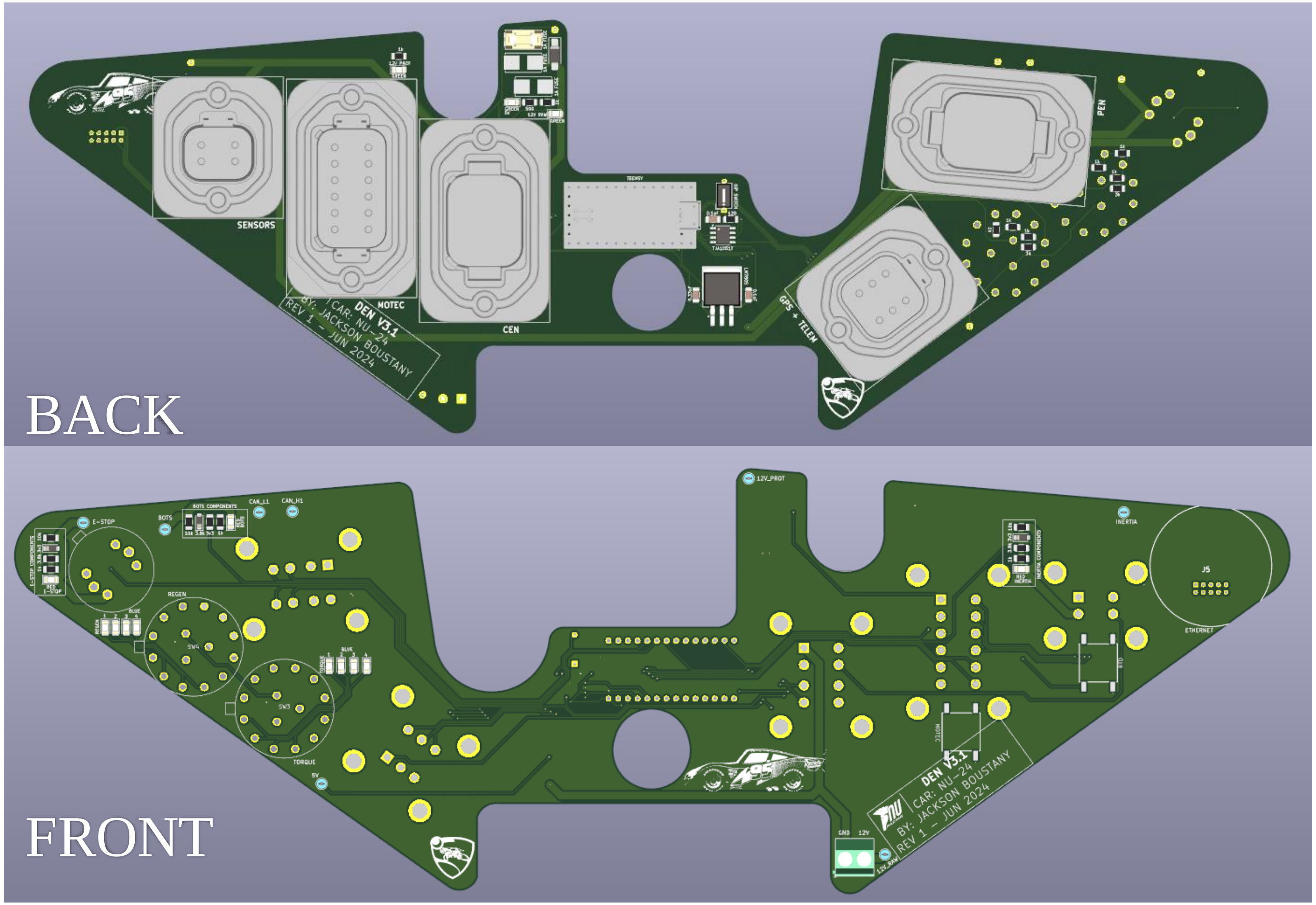


Figure 76: DEN V3.1 3D model

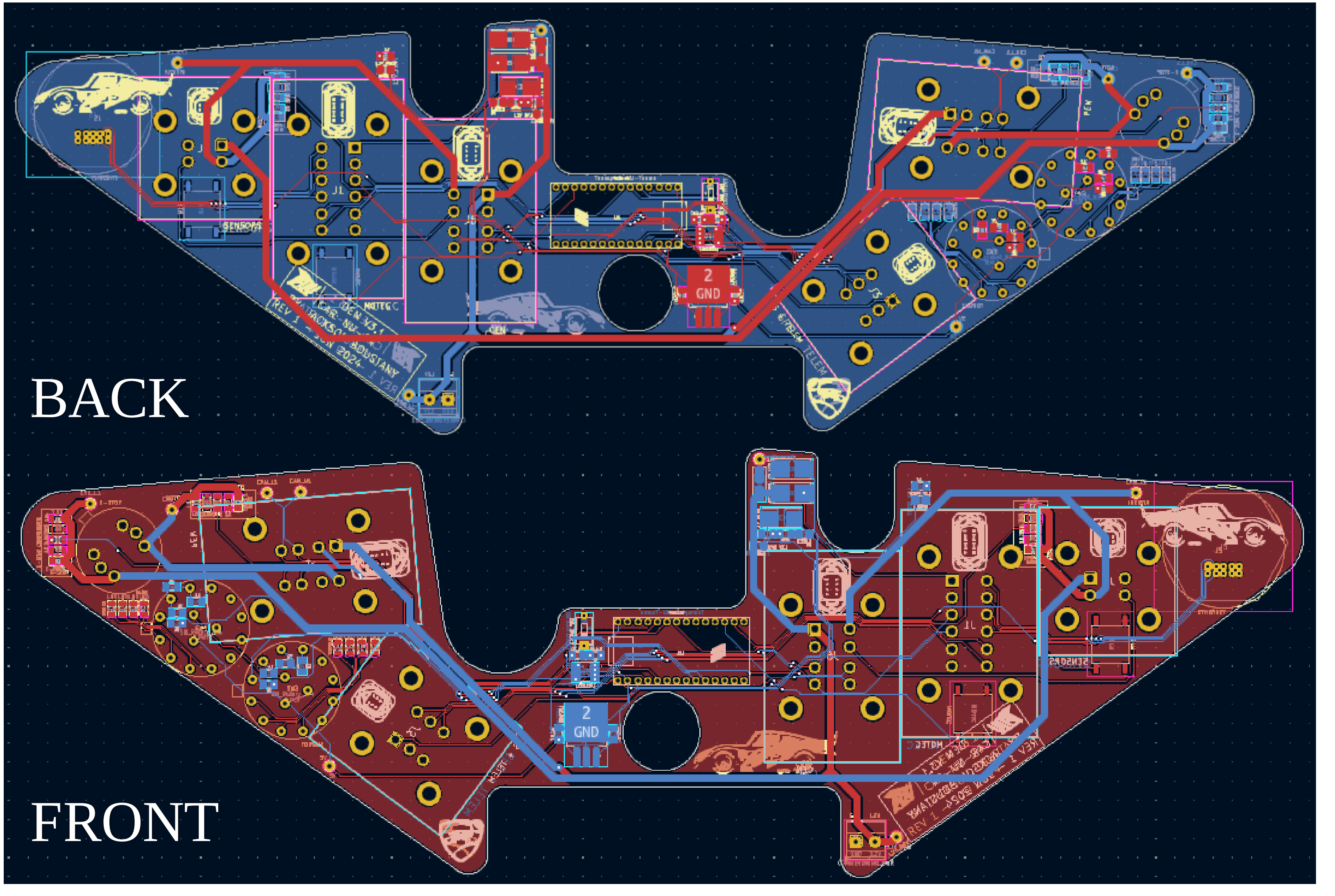
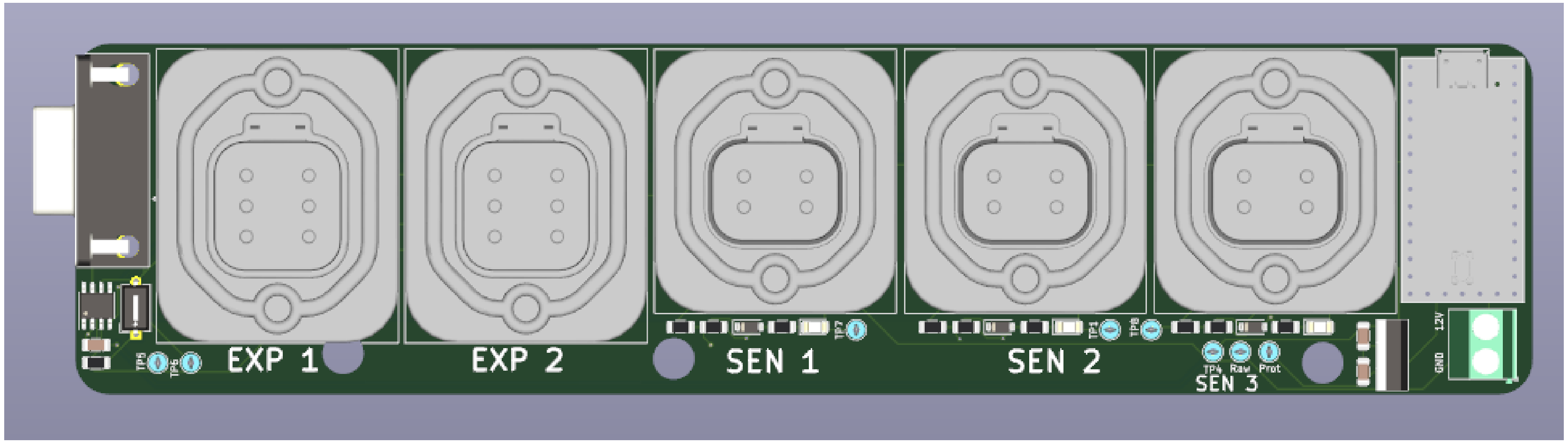
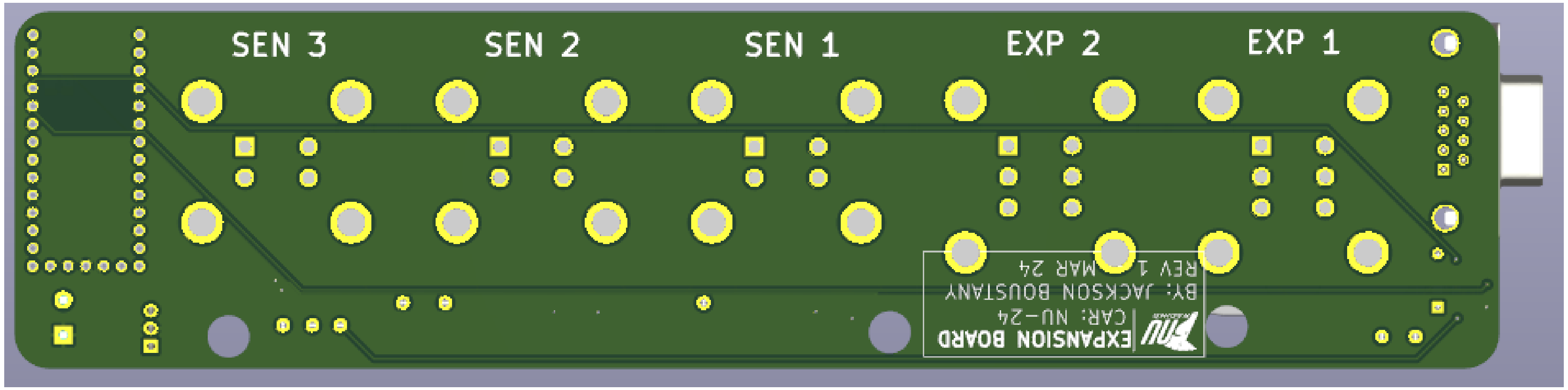


Figure 77: DEN V3.1 trace layout

11.2.3. EXP

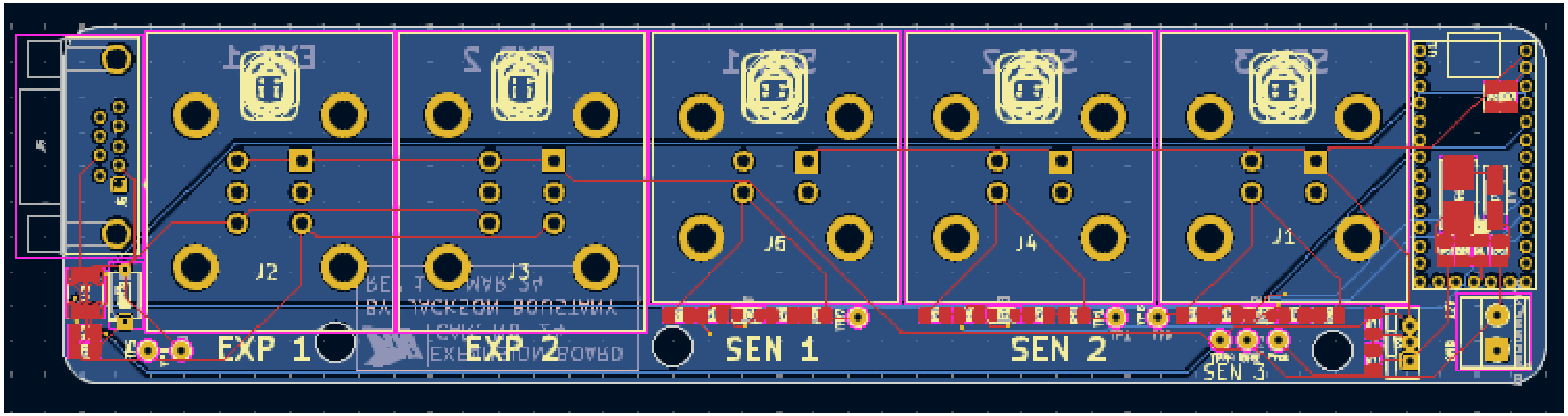


FRONT

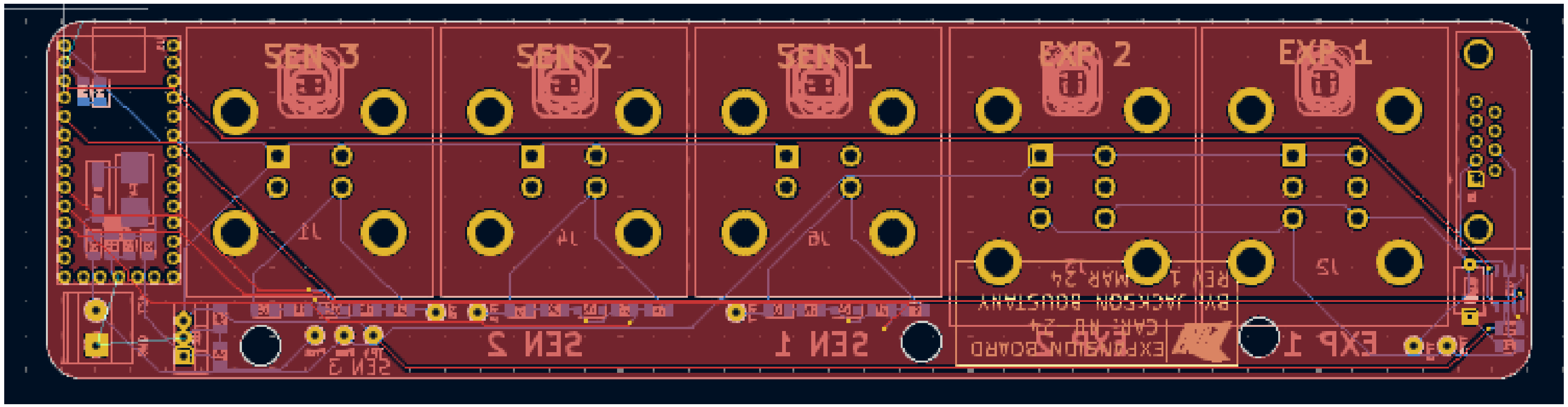


BACK

Figure 78: EXP 3D model



FRONT



BACK

Figure 79: EXP trace layout

11.3. Code

11.3.1. DEN V3.0 Code

```
// DEN V1.1
// Jackson Boustany
// 17/05/2024
// DEN V1.1
// Include necessary libraries and define pins
#include <NU24_CAN.h>
#define SHUTDOWN_BOTS_PIN 3
#define SHUTDOWN_ESTOP_PIN 4
#define SHUTDOWN_INERTIA_SWITCH_PIN 5
#define RTD_BUTTON_PIN 11
#define MOTEC_BUTTON_PIN 10
#define BUSSPEED 250000

// Initialise and declare variables
float rtdState = 0;                                   //[boolean] CAN output
vehicle ready to drive state
float tsState = 0;                                    //[boolean] CAN input TS
state signifying precharged
float brkSig = 0;                                     //[boolean] CAN input brake
switch signal
int rtdButtonState = 0;                                 //[boolean] ready to drive
button pushed OKHS
int motecButtonState = 0;
int motecPageNumber = 0;
float sdBOTS = 0;
float sdEstop = 0;
float sdInertiaSwitch = 0;

// CAN Bus variables
// inputmsgs defines message, outputVar defines location for incoming data
float *outputVar[] = {&tsState, &brkSig};
canmsg *inputmsgs[] = {&TS_STATE, &BRK_SIG};
int numreceive = 2;
int numsend = 7;

/* ---------------------------------------------------------------------------
-------------------------*/
// Setup Function
void setup() {
  // Serial Initialisation
  Serial.begin(9600);
  Serial.println("Hello world");

  // Set pin modes
  pinMode(RTD_BUTTON_PIN, INPUT_PULLUP);
  pinMode(MOTEC_BUTTON_PIN, INPUT_PULLUP);
```

```
  pinMode(SHUTDOWN_BOTS_PIN, INPUT);
  pinMode(SHUTDOWN_ESTOP_PIN, INPUT);
  pinMode(SHUTDOWN_INERTIA_SWITCH_PIN, INPUT);

  // CAN bus initialisation
  NUCAN_init(numsend, numreceive, BUSSPEED);
}

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

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

  EVERY_N_MILLISECONDS(100){
    updateRTD_STATE();
    updateMOTEC_STATE();
    logShutdown();
    serialOut();
  }
  NUCAN_heartbeat(&HB_DEN);
}

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

// Update RTD state
void updateRTD_STATE(void){
  // Read RTD button
  // This is an open drain ! is for change of logic
  rtdButtonState = !digitalRead(RTD_BUTTON_PIN);

  // Update button state on CAN
  NUCAN_write(&RTD_BUTTON, rtdButtonState);

  // Generate RTD state
  if ((tsState == 1) && (brkSig == 1) && (rtdButtonState == 1)) {
    rtdState = 1;
  } else if (tsState == 0){
    rtdState = 0;
  }

  // Update RTD state on CAN
  NUCAN_write(&RTD_STATE, rtdState);
}

/* -------------------------------*/
```

```
// Update RTD state
void updateMOTEC_STATE(void){
  // Read RTD button
  // This is an open drain ! is for change of logic
  motecButtonState = !digitalRead(MOTEC_BUTTON_PIN);
  if (motecButtonState == 1){
    motecPageNumber++;
    if (motecPageNumber == 2){
      motecPageNumber = 0;
    }
    delay(100);                 // avoids 1 press counting as multiple
  }
  // Update button state on CAN
  NUCAN_write(&MOTEC_BUTTON, motecPageNumber);
}

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

// Shutdown State Logging
void logShutdown(void) {
    //Read Estop post state
    sdBOTS = digitalRead(SHUTDOWN_BOTS_PIN);
    sdEstop = digitalRead(SHUTDOWN_ESTOP_PIN);
    sdInertiaSwitch = digitalRead(SHUTDOWN_INERTIA_SWITCH_PIN);
    // Update SD states on CAN
    NUCAN_write(&SD_BOTS, sdBOTS);
    NUCAN_write(&SD_ESTOP_DASH, sdEstop);
    NUCAN_write(&SD_INERTIA, sdInertiaSwitch);
}

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

void serialOut(void) {
  Serial.println("/*--------------*/");
  Serial.print("RTD Button State = "); Serial.println(rtdButtonState);
  Serial.print("MOTEC Button State = "); Serial.println(motecButtonState);
  Serial.print("TS State = "); Serial.println(tsState);
  Serial.print("Brk Sig = "); Serial.println(brkSig);
  Serial.print("RTD State = "); Serial.println(rtdState);
  Serial.print("Shutdown BOTS = "); Serial.println(sdBOTS);
  Serial.print("Shutdown Estop = "); Serial.println(sdEstop);
  Serial.print("Shutdown Inertia Switch = "); Serial.println(sdInertiaSwitch);
  Serial.print("Motec Page Number = "); Serial.println(motecPageNumber);
}
```

11.3.2. DEN V3.1 Code

```
// DEN V1.2
// Jackson Boustany
// 12/07/2024
// DEN V1.2
// Include necessary libraries and define pins
#include <NU24_CAN.h>
#define SHUTDOWN_BOTS_PIN 3
#define SHUTDOWN_ESTOP_PIN 4
#define SHUTDOWN_INERTIA_SWITCH_PIN 5
#define RTD_BUTTON_PIN 11
#define MOTEC_BUTTON_PIN 10
#define TORQUE_DIAL_PIN 17
#define REGEN_DIAL_PIN 18
#define BUSSPEED 250000

// Initialise and declare variables
float rtdState = 0;       //[boolean] CAN output vehicle ready to drive state
float tsState = 0;        //[boolean] CAN input TS state signifying precharged
float brkSig = 0;         //[boolean] CAN input brake switch signal
int rtdButtonState = 0;   //[boolean] ready to drive button pushed OKHS
int motecButtonState = 0;
int motecPageNumber = 0;
float sdBOTS = 0;
float sdEstop = 0;
float sdInertiaSwitch = 0;
int TorqueDial = 0;
int TorqueState = 0;
float TorqueStateVolt = 0.0;
int RegenDial = 0.0;
int RegenState = 0;
float RegenStateVolt = 0.0;

// CAN Bus variables
// inputmsgs defines message, outputVar defines location for incoming data
float *outputVar[] = { &tsState, &brkSig };
canmsg *inputmsgs[] = { &TS_STATE, &BRK_SIG };
int numreceive = 2;
int numsend = 9;

/* ---------------------------------------------------------------------------
-------------------------*/
// Setup Function
void setup() {
  // Serial Initialisation
  Serial.begin(9600);
  Serial.println("Hello world");

  // Set pin modes
```

```
  pinMode(RTD_BUTTON_PIN, INPUT_PULLUP);
  pinMode(MOTEC_BUTTON_PIN, INPUT_PULLUP);
  pinMode(SHUTDOWN_BOTS_PIN, INPUT);
  pinMode(SHUTDOWN_ESTOP_PIN, INPUT);
  pinMode(SHUTDOWN_INERTIA_SWITCH_PIN, INPUT);

  // CAN bus initialisation
  NUCAN_init(numsend, numreceive, BUSSPEED);
}

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

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

  EVERY_N_MILLISECONDS(100) {
    updateRTD_STATE();
    updateMOTEC_STATE();
    logShutdown();
    updateTorqueState();
    updateRegenState();
    serialOut();
  }
  NUCAN_heartbeat(&HB_DEN);
}

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

// Update RTD state
void updateRTD_STATE(void) {
  // Read RTD button
  // This is an open drain ! is for change of logic
  rtdButtonState = !digitalRead(RTD_BUTTON_PIN);

  // Update button state on CAN
  NUCAN_write(&RTD_BUTTON, rtdButtonState);

  // Generate RTD state
  if ((tsState == 1) && (brkSig == 1) && (rtdButtonState == 1)) {
    rtdState = 1;
  } else if (tsState == 0) {
    rtdState = 0;
  }

  // Update RTD state on CAN
  NUCAN_write(&RTD_STATE, rtdState);
```

```
}

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

// Update RTD state
void updateMOTEC_STATE(void) {
  // Read MoTeC button
  // This is an open drain ! is for change of logic
  motecButtonState = !digitalRead(MOTEC_BUTTON_PIN);
  if (motecButtonState == 1) {
    motecPageNumber++;
    delay(200); // adding time between button taps
    if (motecPageNumber == 2) {
      motecPageNumber = 0;
    }
    delay(50);  // debouncing button signal
  }
  // Update button state on CAN
  NUCAN_write(&MOTEC_BUTTON, motecPageNumber);
}

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

// Shutdown State Logging
void logShutdown(void) {
  //Read Estop post state
  sdBOTS = digitalRead(SHUTDOWN_BOTS_PIN);
  sdEstop = digitalRead(SHUTDOWN_ESTOP_PIN);
  sdInertiaSwitch = digitalRead(SHUTDOWN_INERTIA_SWITCH_PIN);
  // Update SD states on CAN
  NUCAN_write(&SD_BOTS, sdBOTS);
  NUCAN_write(&SD_ESTOP_DASH, sdEstop);
  NUCAN_write(&SD_INERTIA, sdInertiaSwitch);
}

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

// Update Torque State
void updateTorqueState(void) {
  // Read input at torque dial voltage divider pin 17
  TorqueDial = analogRead(TORQUE_DIAL_PIN);
  // Convert analog reading to voltage from 3.3V input
  TorqueStateVolt = TorqueDial * (3.3/1023.0);
  // torque state based on voltage
  if (TorqueStateVolt > 2.8)
    TorqueState = 1;
  else if (TorqueStateVolt > 2.1)
    TorqueState = 2;
```

```
  else if (TorqueStateVolt > 1.75)
    TorqueState = 3;
  else if (TorqueStateVolt > 1.3)
    TorqueState = 4;
  else
    TorqueState = 1;

  // update state over CAN
  NUCAN_write(&TORQUE_MODE, TorqueState);
}
/* ------------------------------*/

// Update Regen State
void updateRegenState(void) {
  // Read input at Regen dial voltage divider pin 18
  RegenDial = analogRead(REGEN_DIAL_PIN);
  // Convert analog reading to voltage from 3.3V input
  RegenStateVolt = RegenDial * (3.3/1023.0);
  // Regen state based on voltage
  if (RegenStateVolt > 2.8)
    RegenState = 1;
  else if (RegenStateVolt > 2.1)
    RegenState = 2;
  else if (RegenStateVolt > 1.75)
    RegenState = 3;
  else if (RegenStateVolt > 1.3)
    RegenState = 4;
  else
    RegenState = 1;

  // update state over CAN
  NUCAN_write(&REGEN_MODE, RegenState);
}
/* ------------------------------*/

void serialOut(void) {
  Serial.println("/*--------------*/");
  Serial.print("RTD Button State = ");
  Serial.println(rtdButtonState);
  Serial.print("MOTEC Button State = ");
  Serial.println(motecButtonState);
  Serial.print("TS State = ");
  Serial.println(tsState);
  Serial.print("Brk Sig = ");
  Serial.println(brkSig);
  Serial.print("RTD State = ");
  Serial.println(rtdState);
  Serial.print("Shutdown BOTS = ");
```

```
  Serial.println(sdBOTS);
  Serial.print("Shutdown Estop = ");
  Serial.println(sdEstop);
  Serial.print("Shutdown Inertia Switch = ");
  Serial.println(sdInertiaSwitch);
  Serial.print("Motec Page Number = ");
  Serial.println(motecPageNumber);
  Serial.print("Torque State = ");
  Serial.println(TorqueState);
  Serial.print("Regen State = ");
  Serial.println(RegenState);
}
```

11.3.3. EXP Steering Angle Code

```
// Created by Jackson Boustany 9/4/24
// Purpose: To read and pack values from the steering angle and shock pots to
pack and send through CAN

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

// pin definitions
#define BUSPEED 250000        // Set the Buspeed for CAN
#define STEERING_ANGLE_PIN 18  // Set sterring angle pin to analog pin a4/pin
18
//#define STEERING_ANGLE_PIN 4  // Set sterring angle pin to analog pin a4 for
later use
//#define STEERING_ANGLE_PIN 4  // Set sterring angle pin to analog pin a4 for
later

int SAS_in = 0;  // variable to store the value read
int SAS_out = 0;  // variable to store the value read

int numReceive = 0;       // Number of CAN messages to receive
int numSend = 2;  // Number of NUCAN messages

void setup() {
  Serial.begin(9600);           //  setup serial
  NUCAN_init(numSend, numReceive, BUSPEED);  // Initialize the NUCAN
communication
}

void loop() {
 // Rebroadcast LVD Heartbeat
  NUCAN_heartbeat(&HB_EXP);

  // STEERING ANGLE
    SAS_in = analogRead(STEERING_ANGLE_PIN);  // read the input pin
    SAS_MM = SAS_in*(5.0/677.0);
    SAS_out = 50*(SAS_MM/5.0);
    // float angle = abs(270.0*(SAS_MM/5.0)-135.0);
    float angle = 0.0;
    if (SAS_MM < 3.42 && SAS_MM > 3.37){;
    angle = 0.0;}
    else if (SAS_MM < 3.37){
    angle = map(SAS_MM,0,3.36,-135,-1) ;}
    else if (SAS_MM > 3.42){
    angle = map(SAS_MM,3.43,5,1,135)  ;}
    Serial.println("----------STEERING ANGLE----------");
    // Serial.println("Raw Input:");Serial.println(SAS_in);           // input
value divided int testing for accuracy
    Serial.println("Voltage Scale:");Serial.println(SAS_MM);              //
value to send through CAN
```

```
    Serial.println("Angle:");Serial.println(angle);              // value to
send through CAN
    NUCAN_write(&STEERING_ANGLE, angle);// Sending through NUCAN
      }
}
```

11.3.4. EXP Shock Potentiometer Code

```
void loop() {
 // Rebroadcast LVD Heartbeat
  NUCAN_heartbeat(&HB_EXP);

// will change from roatry pot to hall effect sensor
 EVERY_N_MILLISECONDS(100) {
    // SHOCK POTS
    int RSP_in = analogRead(RIGHT_SP);
    float RSP_MM = 10*RSP_in*(5.0/677.0);
    Serial.println("----------RIGHT SHOCK POT---------");
    Serial.println("Distance:"); Serial.println(RSP_MM);
    // NUCAN_write(&RIGHT_SP,LSP_MM);

    int LSP_in = analogRead(LEFT_SP);
    float LSP_MM = 10*LSP_in*(5.0/677.0);
    Serial.println("----------LEFT SHOCK POT----------");
    Serial.println("Distance:"); Serial.println(LSP_MM);
    // NUCAN_write(&LEFT_SP,LSP_MM);

  }
}
```

11.3.5. EXP Power Box Fatigue Code

```
void loop() {
 // Rebroadcast LVD Heartbeat
  NUCAN_heartbeat(&HB_EXP);

// will change from roatry pot to hall effect sensor
 EVERY_N_MILLISECONDS(100) {
    // SAS_in = analogRead(STEERING_ANGLE_PIN);  // read the input pin
    // Serial.println(SAS_in/3.4);           // input value divided int
testing for accuracy
    // SAS_out = abs(215*4-SAS_in)/2;        // modifying out put to be read
as positive value in each direction
    // Serial.println(SAS_out);              // value to send through CAN
    // NUCAN_write(&STEERING_ANGLE, SAS_out);// Sending through NUCAN

    PwrBoxIn = analogRead(POWER_BOX_FATIGUE);
    Serial.println("----------------");Serial.println("----------------
");Serial.println("----------------");
    Serial.print("Analog input = "); Serial.println(PwrBoxIn);         //
value to send through CAN
    float PwrBoxOut = PwrBoxIn*(2.68/680.0);
    Serial.print("Voltage Conversion = "); Serial.println(PwrBoxOut);
    int PwrBoxMM = 53*(PwrBoxOut/2.68);
    Serial.print("Movement (mm) = "); Serial.println(PwrBoxMM);

    NUCAN_write(&STEERING_ANGLE, PwrBoxMM);// Sending through NUCAN
  }
}
```

11.4. Addition Contributions

11.4.1. DEN Enclosures

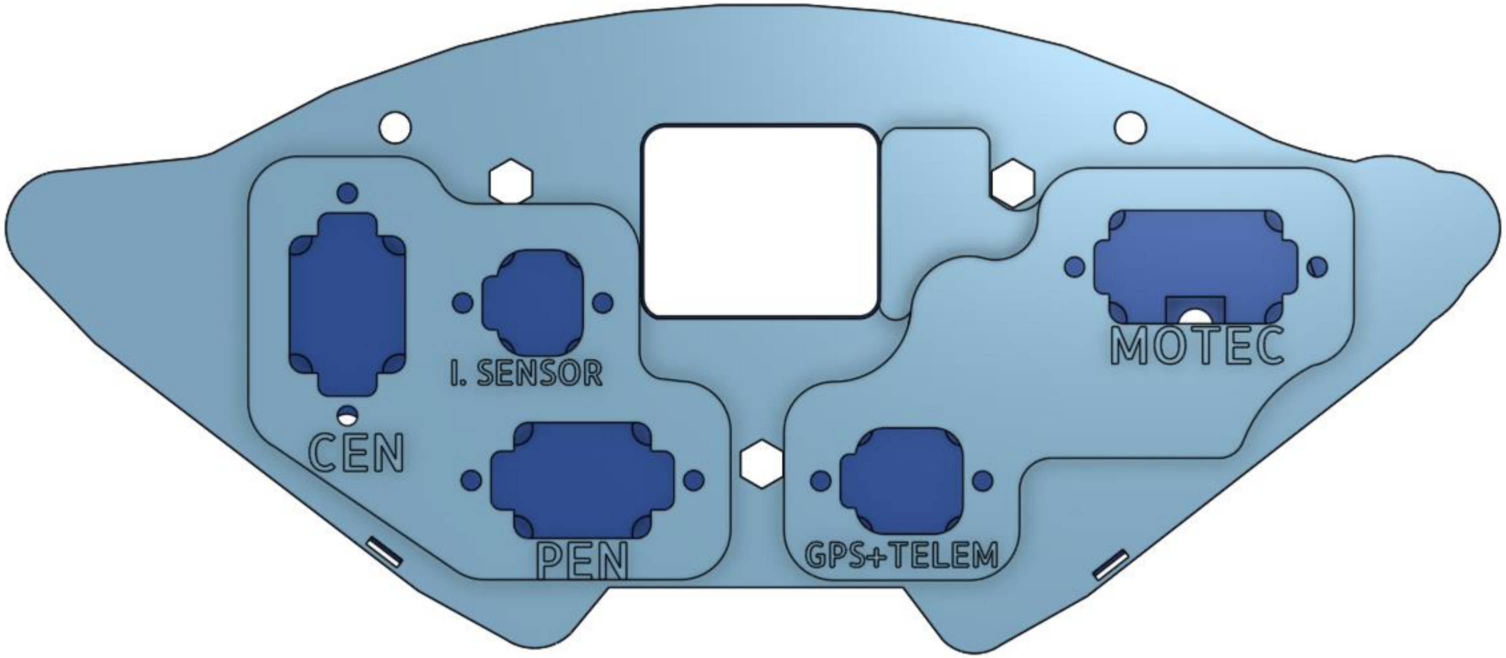


Figure 80: Second iteration DEN V3.0 enclosure (rear view)

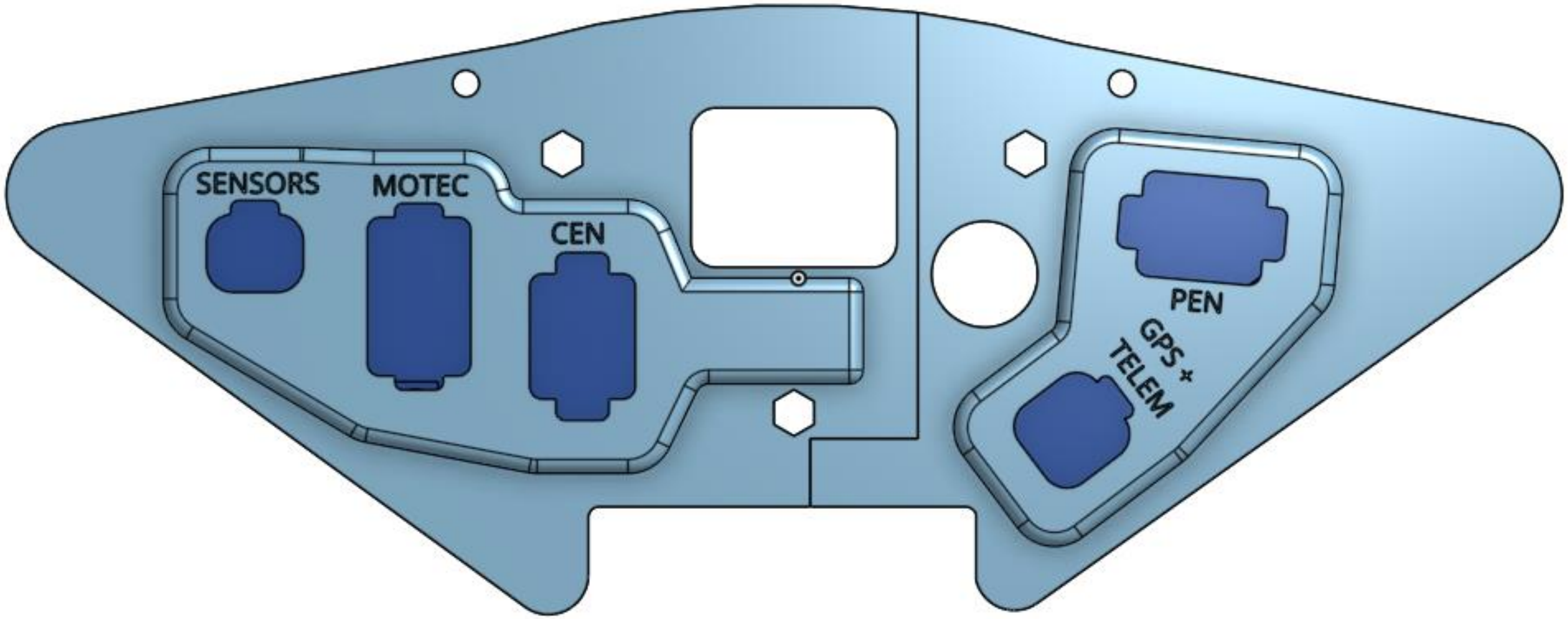


Figure 81: Second iteration DEN V3.1 enclosure (rear view)

11.4.2. NU24 Grounding

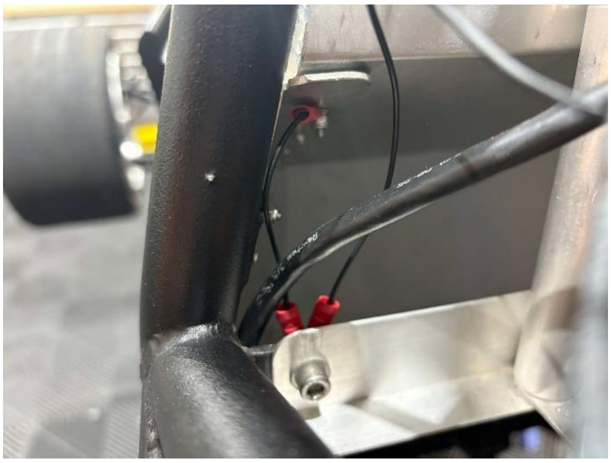


Figure 82: Driver seat fire wall grounding

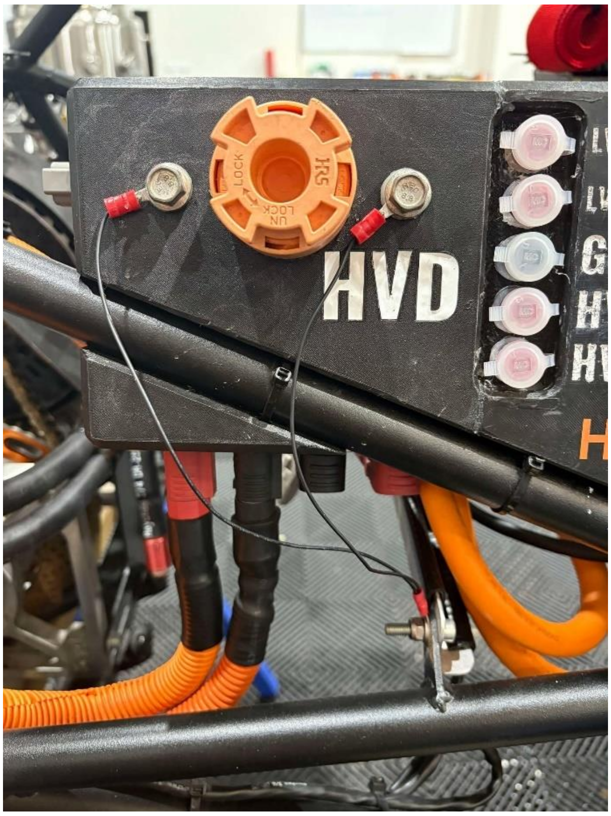


Figure 83: HVD bolts grounding

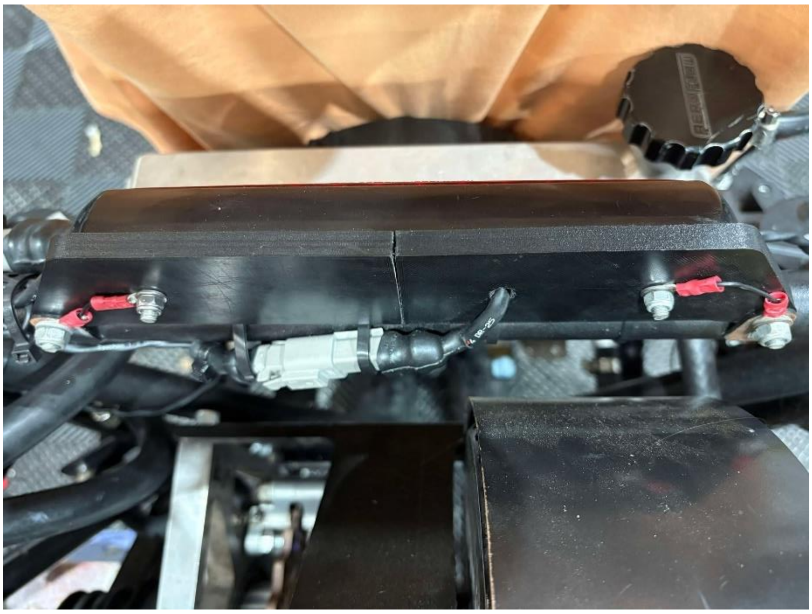


Figure 84: Rear Light grounding

Figure 85: Radiator grounding


Figure 86: Top fire wall grounding upper half

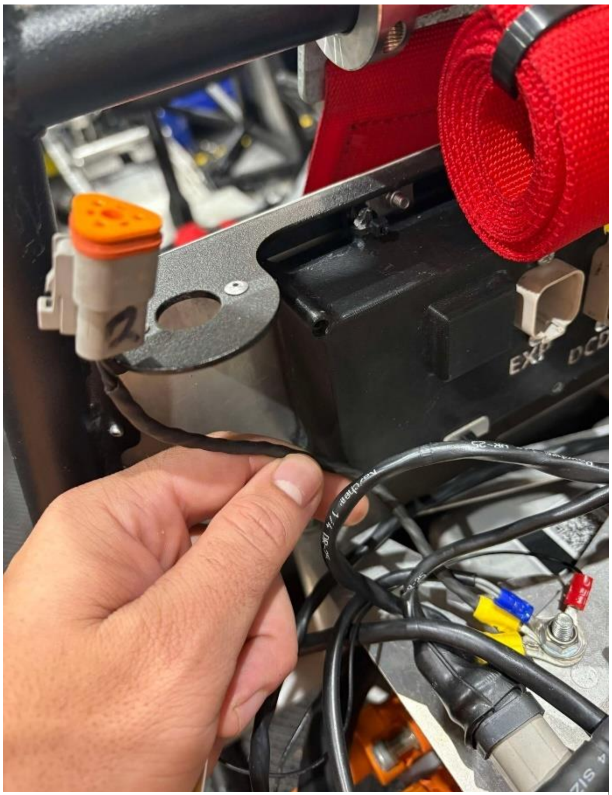


Figure 87: Top fire wall grounding lower half

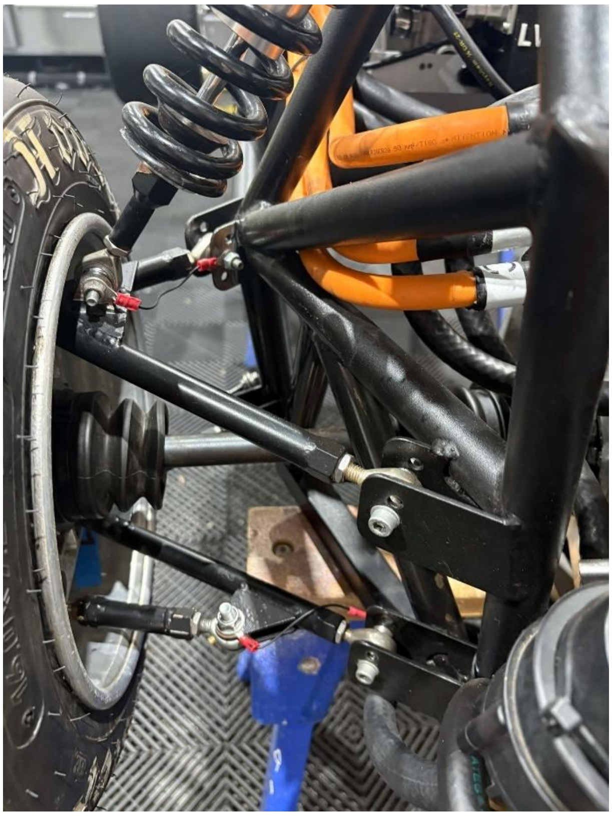


Figure 88: Rear left side of the car grounding

Figure 89: Rear right side of the car grounding

11.4.3. DEN V3.0 Fitment of NU24

Figure 90: Driver view of DEN V3.0 in NU24

Figure 91: Top view of DEN V3.0 in NU24

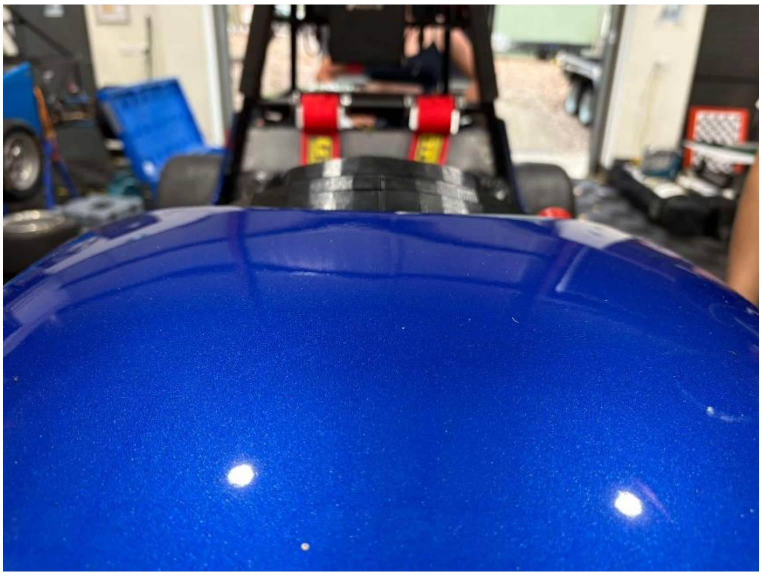


Figure 92: Front view of DEN V3.0 in NU24

Figure 93: Side view of DEN V3.0 in NU24

11.5 Data Sheets

11.5.1. Rotary Potentiometer Kit [7]

AiM InfoTech

1G steering rotary potentiometer for kart

Release 1.05

InfoTech

This datasheet explains how and where to install the 1 lap (1G) steering rotary potentiometer, showing its electrical and mechanical characteristics too.

1 Introduction

AiM loggers can use a sensor (rotating potentiometer) to measure the displacement between two points. This potentiometer can be used to measure angular displacements such as the steering position. This is why we normally call it kart steering angle potentiometer.

2 The kit

The kart steering angle potentiometer kit includes:

- 1 1G kart steering rotary potentiometer (**1**)
- 1 toothed belt (**2**)
- 1 Allen key (**3**)
- 2 toothed pulley (**4**)
- 1 bracket (**5**)

The kit part number is: **X05SNST01G**

1

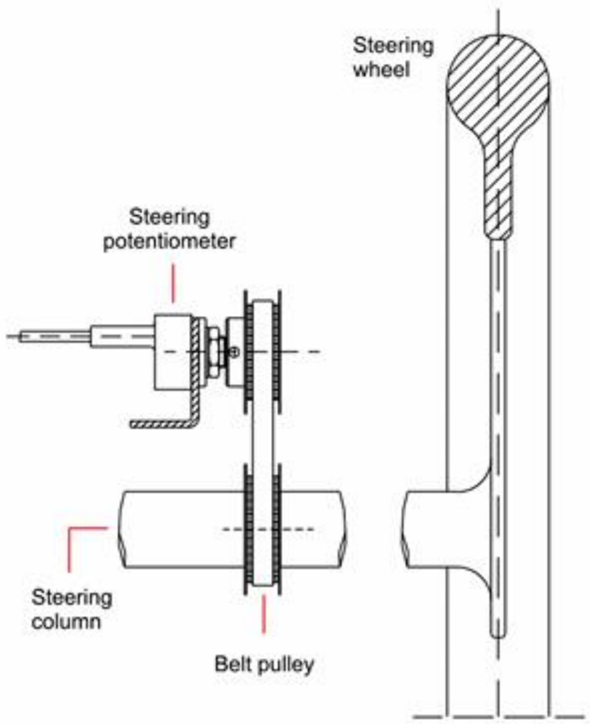
InfoTech

2.1
Installation notes

The kart steering potentiometer can be connected to MyChron5 and MyChron5 2T **only** using MyChron Expansion analog channels and to MyChron4 and MyChron4 2T **only** using MyChron Expansion and eBox Extreme analog channels, to say:

- MyChron Expansion: channels from 1 to 4
- eBox Extreme: channels from 1 to 3

The drawing here below shows the potentiometer installed.

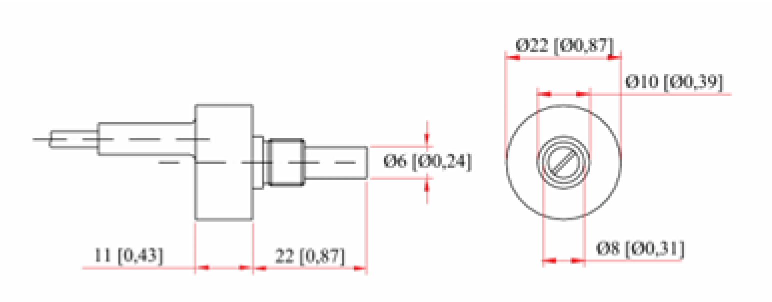


2

InfoTech

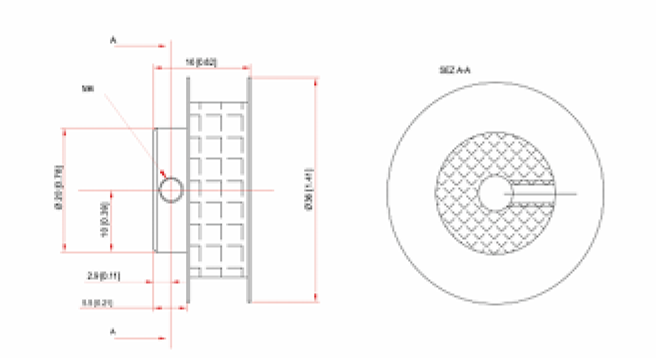
3
Dimensions, pinout and technical characteristics

The drawing here below shows the sensor dimensions in millimeters [inches].



The following images shows the pulleys dimensions in millimetres [inches]:

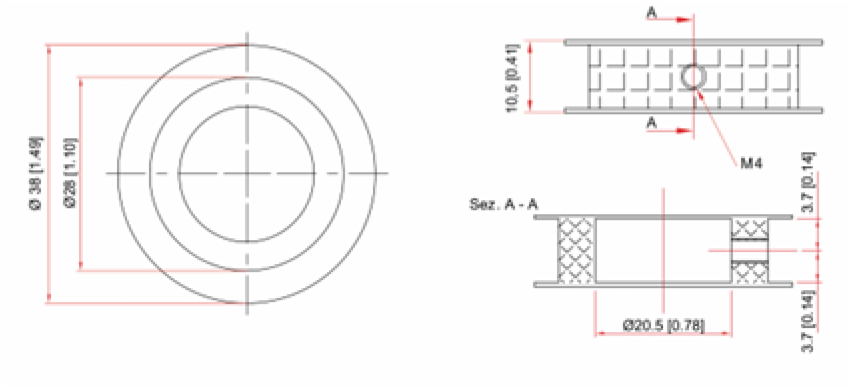
- pulley to be installed on the potentiometer



3

InfoTech

- 20 mm diameter pulley to be installed on the steering wheel for 1G steering rotary potentiometer



The potentiometer ends with a 4 pins Binder 719 male connector. The image here below shows the Binder connector from solder termination view and its pinout.

Binder connector pin	Function
1	Analog signal 0-5 V
2	GND
3	Not connected
4	V reference (4.5V)

The kart steering potentiometer **electrical characteristics** are:
- nominal resistance: 10kΩ
- tolerance on the resistance value: ±5%
- precision (%): 0.034

The kart steering potentiometer **mechanical characteristics** are:
- mechanical displacement: 360°
- temperature working range: -55/+125 °C
- dissipated power at 40°C: 1.6W
- dissipated power at 70°C: 1W

InfoTech

4
Extension cables

The sensor is sold with a 30 cm cable. Standard length extension cables are available: 0,5 m, 1m and 1,5 m.

Extension cables part number changes according to their length and to the product the sensor is to be connected to.

Extension cable for connection with:
- MyChron Expansion
- eBox Extreme:

Part number:
V02PCB05BTXG – cable length: 500mm
V02PCB10BTXG – cable length: 1000mm
V02PCB15BTXG – cable length: 1500mm
V02PCB20BTXG – cable length: 2000mm
V02PCB25BTXG – cable length: 2500mm
V02PCB30BTXG – cable length: 3000mm

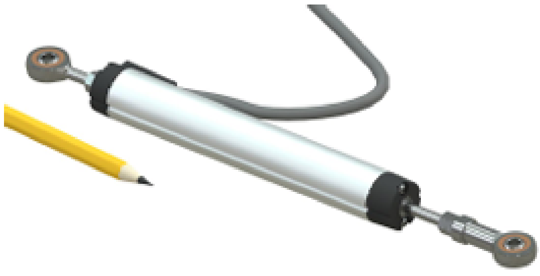
5

11.5.2. LPPS-22 Series Linear Potentiometer [7]

LINEAR POSITION SENSOR

LPPS-22 SERIES LINEAR POTENTIOMETER

Position Sensor with Rod Ends



FEATURES

- Compact lightweight design
- Cost-effective measuring system
- Stroke lengths from 25 to 300 mm (1 to 12 inches)
- Industrial duty, liquid and corrosion resistant
- Rod end joints for ease of mounting

APPLICATIONS

- Motorsport and Automotive R&D Testing
- Industrial Test Stands

OVERVIEW

LPPS-22 series Linear Potentiometer Position Sensors with Rod End Joints are used to monitor and track the linear motion or position of a target. These ruggedized sensors are ideal for use in industrial and laboratory applications including automotive R&D, motorsports, industrial, motion control, medical, military and aerospace.

Resistive potentiometric element is made from conductive plastic. The output is ratiometric; from 0% to 100% of excitation voltage. The sensor is provided with swivel rod ends for self-alignment and ease of mounting.

The LPPS-22 series sensor is made from industrial duty materials for resistance to dust, temperature, shock, and vibration.

SPECIFICATIONS

Output:	0 to 100% of Input Voltage (potentiometer circuit)
Non-Linearity, Full Stroke: Best Fit Straight Line (BFSL)	≤ ± 2.5% of FSO
Resolution:	Infinite
Repeatability:	0.01 mm (0.0004 inch)
Element Type:	Conductive Plastic
Max Operating Speed:	5 m/S (16 ft/S)
Operating Current:	Input Voltage / Potentiometer Resistance Value (refer to chart on Page 2 for Resistance Value)
Signal Cable:	3 conductor, 24 AWG, braided shield, PVC jacket, 3 foot long
Operating Temperature:	-40 to +95°C (-40 to +203°F)
Temperature Coefficient:	≤ ± 0.03% of FS / °C
Shock Rating:	50g (single hit) / IEC68-2-29
Vibration Rating:	20g / IEC68-2-6
IP Rating:	IP61

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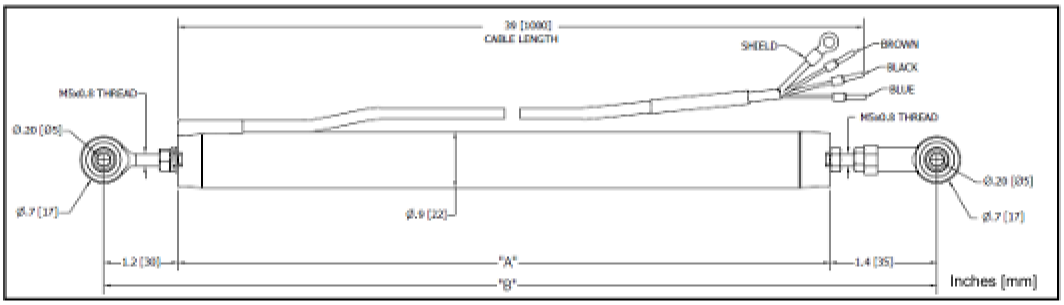
01-2024_REV27

LINEAR POSITION SENSOR

LPPS-22 SERIES LINEAR POTENTIOMETER

Position Sensor with Rod Ends



SPECIFICATIONS

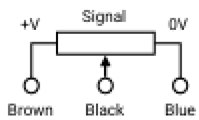
	LPPS-22-025	LPPS-22-050	LPPS-22-075	LPPS-22-100	LPPS-22-125	LPPS-22-150	LPPS-22-175	LPPS-22-200	LPPS-22-250	LPPS-22-300
Mechanical Stroke Length (inch) [mm]	1.1 [28]	2.0 [53]	3.0 [78]	4.0 [103]	5.0 [128]	6.0 [153]	7.0 [178]	8.0 [203]	9.9 [253]	11.9 [303]
Electrical Measuring Range (inch) [mm]	0.9 [25]	1.9 [50]	2.9 [75]	3.9 [100]	4.9 [125]	5.9 [150]	6.8 [175]	7.8 [200]	9.8 [250]	11.8 [300]
Resistance ± 20% (Ω)	2.0K	5.0K	5.0K	5.0K	5.0K	5.0K	5.0K	5.0K	5.0K	5.0K
Max Input Voltage (VDC)	12	24	24	24	24	24	24	24	24	24
Dimension 'A' (inch) [mm]	3.1 [79]	4.1 [104]	5.1 [129]	6.1 [154]	7.1 [179]	8.0 [204]	9.0 [229]	10.0 [254]	12.0 [304]	13.9 [354]
Dimension 'B' (inch) [mm] - Retracted Min	5.7 [144]	6.7 [169]	7.6 [194]	8.6 [219]	9.6 [244]	10.6 [269]	11.6 [294]	12.6 [319]	14.5 [369]	16.5 [419]
Dimension 'B' (inch) [mm] - Extended Max	6.8 [173]	8.7 [221]	10.6 [269]	12.6 [320]	14.6 [371]	16.6 [422]	18.6 [472]	20.6 [523]	24.4 [620]	28.4 [721]
Weight (grams)	115	130	145	165	180	190	205	215	245	270

ORDERING INFORMATION

Model	Measuring Range
LPPS-22	-□□□
	025 25 mm [1 inch]
	050 50 mm [2 inch]
	075 75 mm [3 inch]
	100 100 mm [4 inch]
	125 125 mm [5 inch]
	150 150 mm [6 inch]
	175 175 mm [7 inch]
	200 200 mm [8 inch]
	250 250 mm [10 inch]
	300 300 mm [12 inch]

WIRING PIN OUT

	Integral Cable
DC Power In	Brown
Signal Output	Black
Ground	Blue



IMPORTANT !
DO NOT CONNECT THE BLACK WIRE TO POWER SUPPLY
THIS WILL CAUSE DAMAGE TO THE SENSOR

ORDERING EXAMPLE

LPPS-22-100: 0 to 100 mm [4 inch] measuring range

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01-2024_REV27

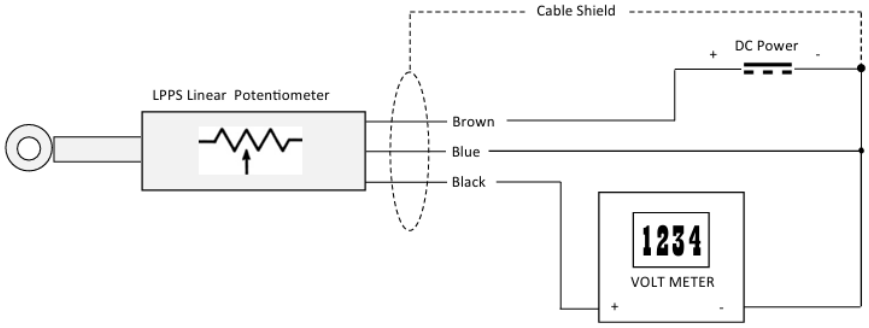
LPPS Wiring Schematic Examples:

IMPORTANT !

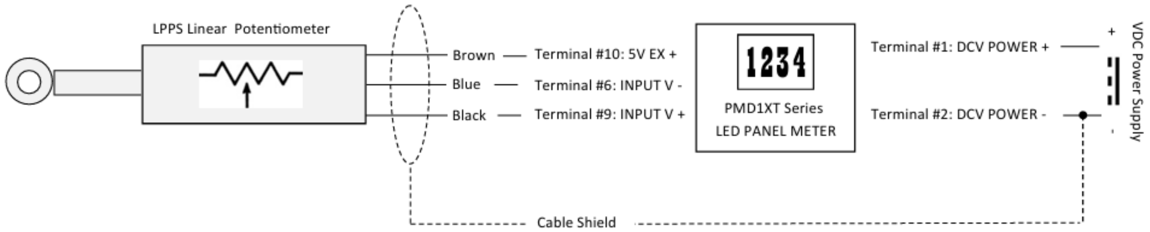
DO NOT CONNECT THE BLACK WIRE TO POWER SUPPLY

THIS WILL CAUSE DAMAGE TO THE SENSOR

Example #1: Connecting to a Volt Meter



Example #2: Connecting to a model PMD1XT Series LED Panel Meter

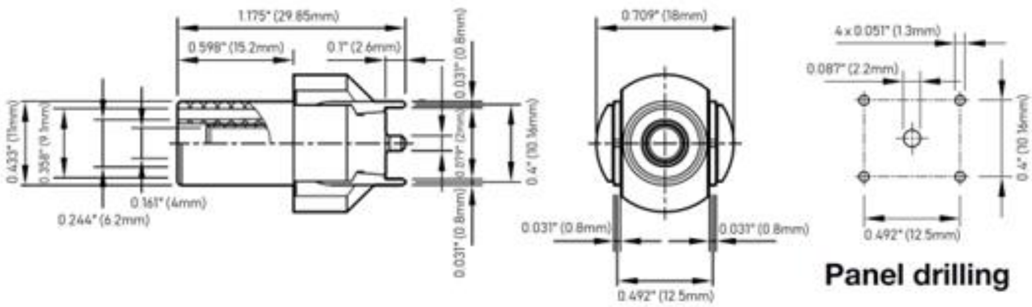


11.5.4. Charger Banana Jacks [10]

Pomona ELECTRONICS

Technical Data Sheet

Model 73096
4mm Safety Jack for PCB



Features

- In-line design is ideal for mounting on vertical printed circuit boards
- Insulated 4mm safety jack mates with sheathed banana plug test leads
- Center contact is a 2mm round pin with 0.8mm contacts (x4) for mounting on printed circuit boards
- IEC/EN 61010-1 rated for increased safety
- Machined brass
- Compatible with popular Pomona test lead models 5907A, 5908A, and 5909A test lead sets

Ratings

Voltage: CAT III 1000V / CAT IV 600V
Current: 24 A

Ordering Information

Model: 73096-***color***
Color: 0=Black, 2=Red
4mm Safety Jack for PCB

USA: Sales: 800-490-2361
Technical Support: technicalsupport@pomonatest.com
Fax: 425-446-5844
Europe: 31-(0) 40 2675 150 **International:** 425-446-5500
Where to Buy: www.pomonaelectronics.com

All dimensions are in inches. Tolerances (except noted): .xx = ± .02" (,51 mm), .xxx = ± .005" (,127 mm). All specifications are to the latest revisions. Specifications are subject to change without notice. Registered trademarks are the property of their respective companies.

11.5.5. Charger RCBO Schematic

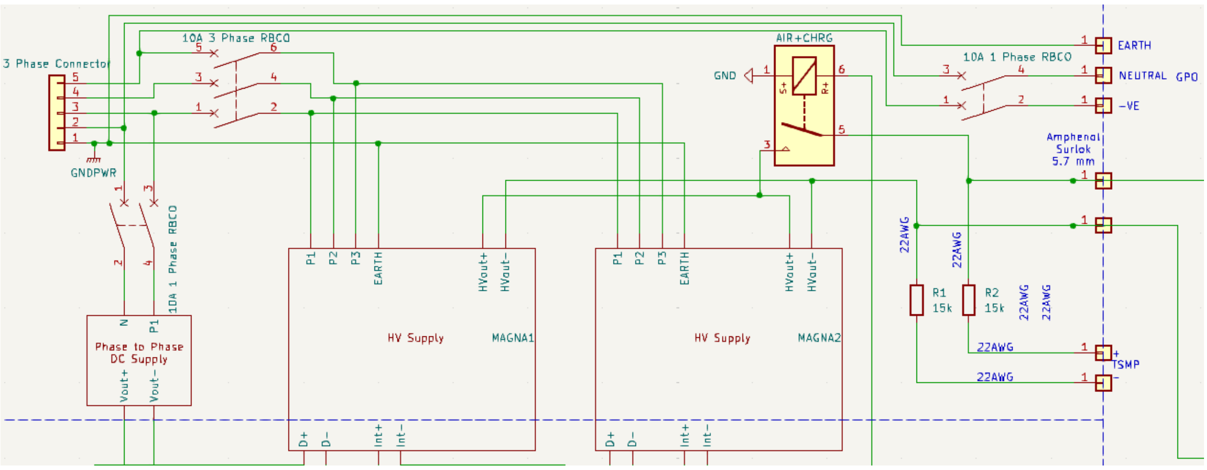


Figure 94: RCBO schematic for charger