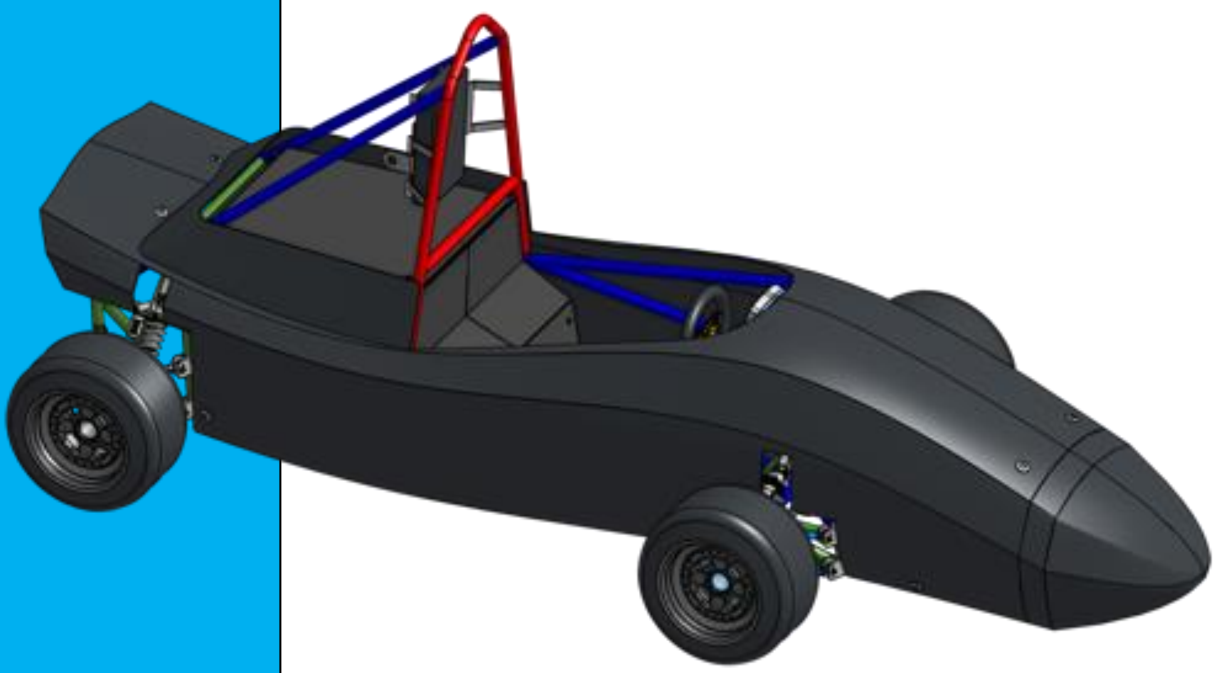
REAR ELECTRONICS NODE (REN) DESIGN NU23 – PART B



Nicolas Lyall

2023

Preamble

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Acknowledgments

The author would like to thank Dr Alex Gregg for his support to the NuRacing team. Without the enthusiasm toward the team and car, I believe I may have dropped out of university. The NuRacing team reignited my love for engineering and design. I would also like to thank my parents who have helped me throughout my degree and helped facilitate me with home-cooked meals and financial support across my degree. Without this support, I would not have been able to be as dedicated as I have been over the past 12 months. I would also like to thank Malcolm Sidney for his support and the late nights that he worked alongside the students to make sure that everyone was safe and able to complete their work.

To the team of 2023, I would like to thank you all for making my final year at NuRacing one of the best experiences I have ever had, all working together without any issues allowing us to finish second in two of the dynamic events marking the first time in NuRacing's history that we have been able to achieve such a high result. I would like to wish the team the best of luck with their future endeavours and let them know that they have made a lifelong friend in me.

Lastly, I would like to thank my partner, Shae, for her patience and understanding over the year. Without her support, I would not have been able to complete such a large project.

Abstract

The project undertaken aimed to design, manufacture, and compete with a fully operation Rear Electronic node for NuRacing's 2023 competition car NU23. The project completed entailed working on a subsystem of the Low Voltage system. The Low Voltage system makes up a large majority of the car and is vital for the competition. NU23 is an all-electric car that relies on the Low Voltage system to manage; CAN messaging, data acquisition, brake light, ready-to-drive state, UEN light, power distribution, throttle controls, and anything else associated with being able to drive the car.

The Rear Electronics Node (REN) is a vital component of the Low Voltage system on NU23. This report will describe the journey undertaken by the author of this report designing and implementing each iteration of the REN simplifying the subsystem, reducing part count while also maintaining reliability and serviceability.

The functionality that the REN aims to satisfy includes powering the cooling system while also fusing the power provided. The REN also provides power along with sending and receiving CAN signals to the DEN, FEN, and MoTec systems. Further improvements that have been made to the REN in later months include moving towards a surface-mounted configuration integrating the brake light and sounder into the surface-mount configuration as well as moving towards Deutch connectors to decrease the overall size and weight of each of the low voltage systems packages. Throughout the design and integration phases of the REN, rules compliance must be maintained including that of the brake light, brake light positioning, and sounder.

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1. Introduction

This report summarises the events and work of the author in creating a Low voltage subsystem on NU23 on open wheeled race car. The FSAE competition is a student design competition that is held globally, in which Newcastle University has entered and competed in for the last 20 years. In 2023 NuRacing (University of Newcastle's racing team) created a car to compete in said competition called NU23. NU23 is the culmination of work completed amongst 16 final year project students. Students are required to use interdisciplinary skills as well as work as part of a team with both Mechatronics and Mechanical engineers. By doing so the team can create an open-wheeled race car, in preparation for the FSAE competition. Newcastle University has been actively participating in the student design competition for two decades, and in 2023, NU23 was produced as a contender. The car was the culmination of the work of 16 final-year project students who pooled their multidisciplinary skills to deliver an impressive and high-performing vehicle.

During the FSAE competition in 2023, NU23 underwent vigorous testing as it was evaluated based on a series of dynamic and static events, competing against other university teams' cars. The car with the highest score at the end of the competition was declared the winner. In 2022, Newcastle's competition car, EV.Three, achieved NuRacing's highest result in history by completing all dynamic events and performing exceptionally well in the static events.

The Low Voltage system makes up a large majority of the car and is vital for the competition. NU23 is an all-electric car that relies on the Low Voltage system to manage; CAN messaging, data acquisition, brake light, ready-to-drive state, UEN light, power distribution, throttle controls, and anything else associated with being able to drive the car.

In 2022, Patrick Gleeson, the low voltage systems engineer, made significant strides in improving the low voltage subsystems, identifying areas that required attention. Through his research, he discovered that a new REN was necessary as the existing one was bulky, heavy, and overly complex. Consequently, a new REN was developed in 2023, building on the foundation laid by Patrick's research and design implementation.

The following sections provide a structured overview of each of these developments, highlighting their significance in creating a high-performance vehicle.

1.1 GREN

The GREN aims to simplify and reduce the number of parts when compared to the previous systems of EV Three known as the REN (Rear Electronic Node) and the GEN (Guse Electronic Node). The functionality that the GREN aims to satisfy includes powering the cooling system while also fusing the power provided. The GREN also provides power along with sending and receiving CAN signals to the PEN, DEN and MoTec systems. Another important feature that was aimed to be preserved was the overall reliability of the system, as reliability of the car has been one of the main focuses for the 2023 team.

1.2 REN V3

The functionality that REN V3 aims to satisfy is the complete implementation of a surface mounted rear brake light, while being reliable and remaining rules compliant. REN V3 will continue to use the same circuitry and functionality including, power dispersion, cooling control, ready to drive signalling and fusing the power electronics. As REN V3 contains the same circuitry and functionality the aim of the board is to teach any lessons that may need to be learnt when using high current through surface mounted components. Designed in unison with REN V3.

1.3 REN V3.5

REN V3.5 was designed following on with the experimentation of surface mounted components aiming to reduce the complexity of the REN while maintaining all the functionality as well as increasing the reliability of the Low Voltage systems. By introducing the use of Deutsch connectors, the total part count was able to be reduced over the board and the overall footprint of the combined PCB and housing was able to be significantly reduced. By performing the testing of the new connectors on the REN a number of new standardised components and circuitry was able to be produced that would see use over the entire Low Voltage system. Further experimentation with surface mounted components included the use of surface mounted Piezo buzzers that can produce the same decibel range of sound as the previously used sounder.

1.4 REN V4

REN V4 was intended to serve as a power distribution board while also maintaining all of the other functionality required of the Rear Electronic Node including, cooling control, brake light functionality, ready to drive state notification through the sounder, as well as temperature relaying. REN V4 was made in conjunction with Brock Symons who designed the enclosure for the system, who completed further testing with diffusing of the brake light.

1.5 REN V4.5

The REN V4.5 was created with the intention of fine tuning the REN V4. REN V4.5 also known as the REN V4 “slimline” has had most of the functionality of the REN V4 removed only keeping the critical components and requirements of a competition setting. This included cooling power control, CAN messaging capabilities, brake light functionality as well as a functional sounder.

2. Background

2.1 FSAE Competition

Figure 1: FSAE Australasia Website logo - (Formula SAE Australasia, 2024)

Formula SAE also known as FSAE is a student design competition held globally where students design, build and compete a race car. The Australian competition was founded in the year 2000 and has run every year since (minus years affected by COVID). The competition is traditionally held at Winton Raceway, however in 2023 the event was hosted at Calder Park Raceway down by Melbourne. 35 University teams from across Australia, New Zealand, Philippines and Japan entered the competition racing both electric and internal combustion (IC) cars (Wikipedia, 2023).

The concept behind the competition is that a fictional manufacturing company has contracted a student design team to develop and build an open wheeled formula style car. This car designed and built by the students is then graded and evaluated as a potential production vehicle. The car is then tested and graded against a rubric similarly to what follows:

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

Newcastle University has been competing in FSAE Australia since 2012 entering both IC cars and Electric cars into the event. In 2023 Newcastle prepared an electric car to compete with marking the 12th year of competition.

2.2 NU23

Figure 2: NU23

NU23 is the name given to the electric race car built by students of the university of Newcastle in 2023 for the FSAE Australasia competition. NU23 set out with the goals of being the most reliable and serviceable car the University of Newcastle has ever produced. With this at the heart of all design ventures NuRacing was able to develop a car that had the most track testing time and most driving time that the University has ever made. NU23 took a lot of inspiration from EV3 (2022 NuRacing competition car) improving on the chassis to meet rules requirements. With the 2022 team managing to secure 4th place overall EV3 proved to be a great starting point for the 2023 team to develop from.

NU23 absorbed EV3 using the car as a testing platform for the integration of the electronic systems that would be used in NU23. By utilising this strategy, the 2023 NuRacing team was able to commence testing of the new systems in July. This allowed for 6 months in development leading into the largest developmental overhaul and implementation the team has seen.

NuRacing is currently in year 2 of a five-year plan working towards an AWD (all-wheel drive) drive train and full aero package design. In 2023 a 50kg weight reduction, a 50-point increase in dynamic events and utilizing 300 km of track testing time. To achieve this leadership set several goals and emphasized a few key attributes to maintain throughout the year including, aligning bottlenecks, reliability/serviceability, knowledge transfer, and prioritizing long-term team performance.

In line with these goals set by leadership, a further introduction to the systems used and implemented will be highlighted through this report.

2.3 Low Voltage Electrical

In this section of the report, a brief background to the Low voltage system employed by NU23 will be given. As will be highlighted through this section, NU23 utilisies point-to-point node design incorporating much of the 2022 Low voltage system design, however fine fine-tunes the system to become more serviceable and more reliable. A side-by-side comparison of NU23 and EV.Three low-voltage systems can be seen below:

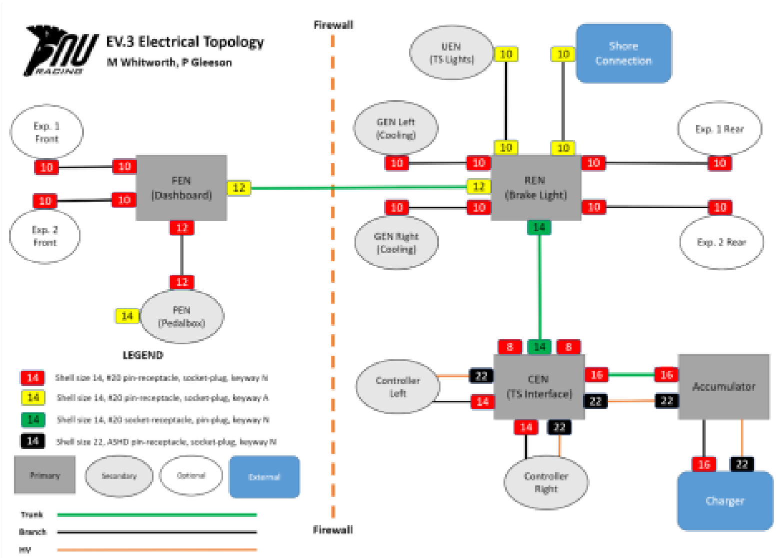


Figure 3: 2022 EV.Three Topology - Taken from Patrick Gleeson's Report

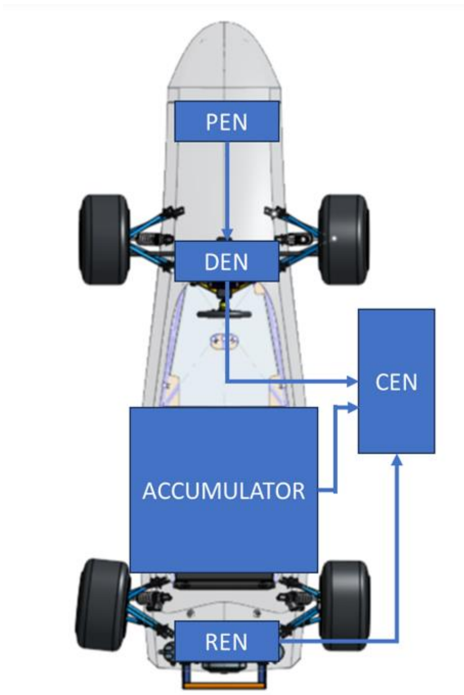


Figure 4:2023 NU23 Topology - Taken from the 2023 design portfolio

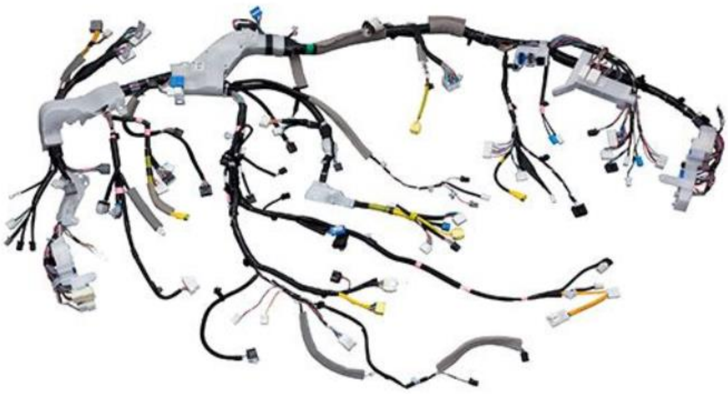


Figure 5: Example of a standard automotive wiring harness - (SUMITO ELECTRIC, 2023)

After the outcomes of the 2022 competition, the Low Voltage electrical team set out at the start of 2023 with three main goals in mind, reliability serviceability, and simplicity. As depicted in the image above the layout of the car symbolizes these three goals, through the point-to-point node design. As represented by the arrows a point-to-point node design allows for the use of a single cable to be run between each of the nodes greatly simplifying the wiring loom design when compared to a traditional wiring loom. Below an image of a traditional automotive wiring loom can be found.

Point-to-point node design has been a tested and proven method of wiring that NuRacing has employed since 2022, greatly improving the serviceability and ultimately the reliability of the car. NuRacing followed a structured approach when preparing wiring looms, creating unique looms for specific uses. All wiring looms were created by utilizing concentric twisting as close to MILSPEC as possible. The configuration for MILSPEC concentric twisting can be seen defined in the image below depicting a similar standard to that of NuRacing:

Concentric Cables

Smooth symmetrical cables can be built up about a core of more than one wire, though this is seldom done in practice.

Wires in Concentric Cables

Number of Layers Over Core	Core of One Wire		Core of Two Wires		Core of Three Wires		Core of Four Wires	
	Wires per Layer	Total Number of Wires	Wires per Layer	Total Number of Wires	Wires per Layer	Total Number of Wires	Wires per Layer	Total Number of Wires
1	6	7	8	10	9	12	10	14
2	12	19	14	24	15	27	16	30
3	18	37	20	44	21	48	22	52
4	24	61	26	70	27	75	28	80
5	30	91	32	102	33	108	34	114
6	36	127	38	140	39	147	40	154
7	42	169	44	184	45	192	46	200

Figure 6:Concentric twist standard (Rotary Club, 2023)

Using this structure almost all NuRacing wiring configurations featured a core of two wires, CAN HIGH and CAN LOW. The core is built by twisting the wire at an approximately 1-inch cross-over in a clockwise direction. The second layer is then built up in correlation with the above image and twisted around the core in an anti-clockwise manner as shown in Figure 7

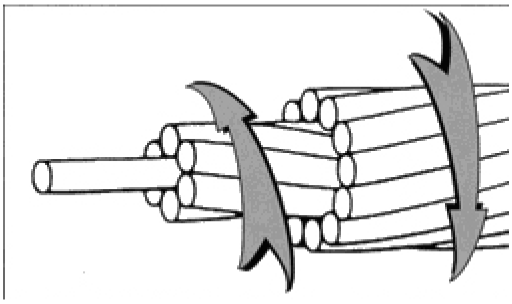


Figure 7: Clockwise and Anti-clockwise twisting diagram - (Rotary Club, 2023)

Following on from wiring looms it is important to understand what the wiring looms are connecting. The following section will give a brief description of each of the Low Voltage subsystems.

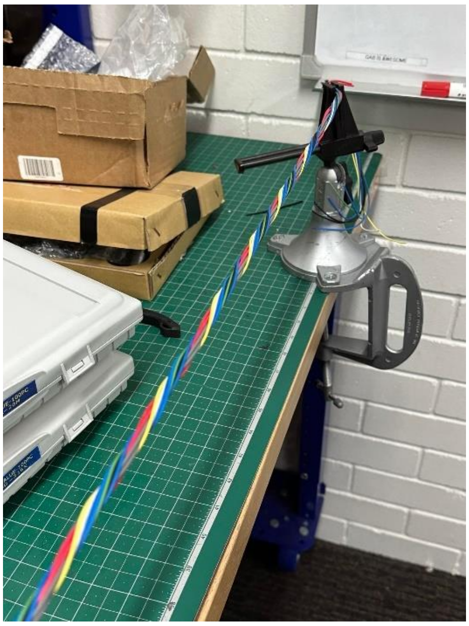


Figure 8: Wiring Loom being made in the Laboratory

2.3.1 PEN

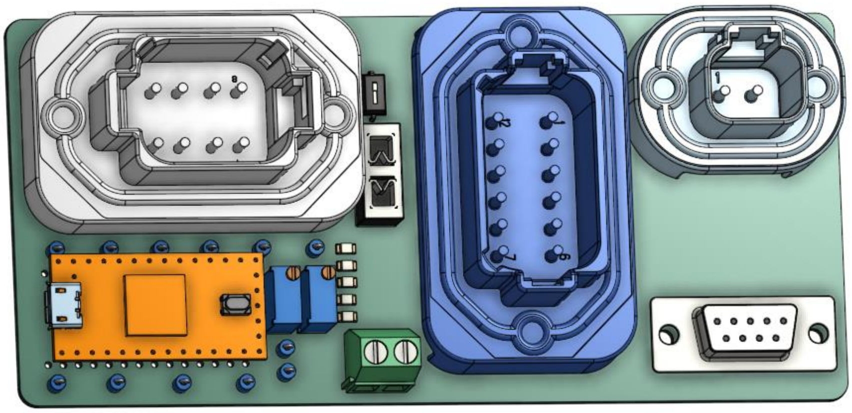


Figure 9: PEN PCB taken from Onshape

The PEN (pedal electronic node) also known as the pedal box, is the forwardmost node in NU23. The PEN is responsible for sending all of the throttle information to the CEN via CAN messaging. The PEN was also responsible for the following: aps out raw, aps out gated, the shutdown circuit, BOTS switch, pressure measurements from brake sensors, BSPD threshold, as well as current sensors for brake and throttle faults. For more information on the PEN please refer to Alec Chapman's report.

2.3.2 DEN

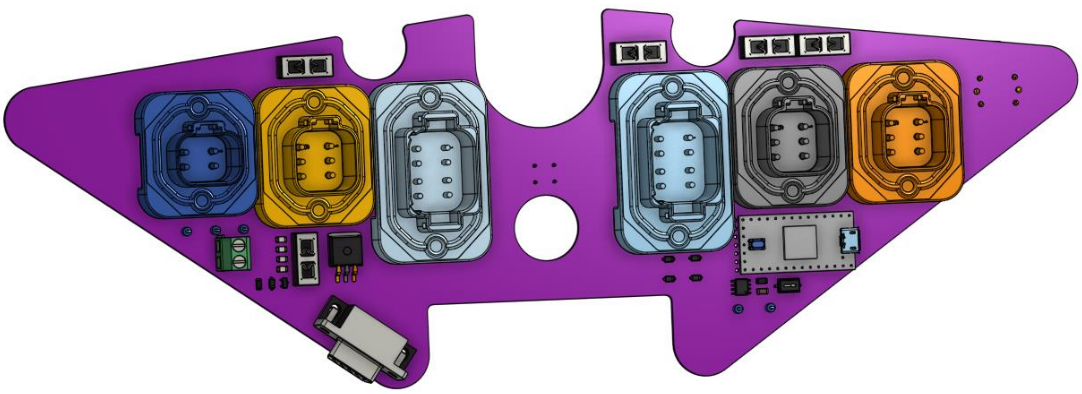


Figure 10: DEN PCB Taken from Onshape

The DEN (Dash Electronic Node) also simply known as the dash is responsible for powering the Motec dash unit, shutdown circuit, CAN transmission, ready-to-drive state selection via button press, as well as ground sensing for the shutdown circuit, and the inertia safety switch. For more information on the DEN and how it was created refer to Marisa Mclean’s report.

2.3.3 CEN

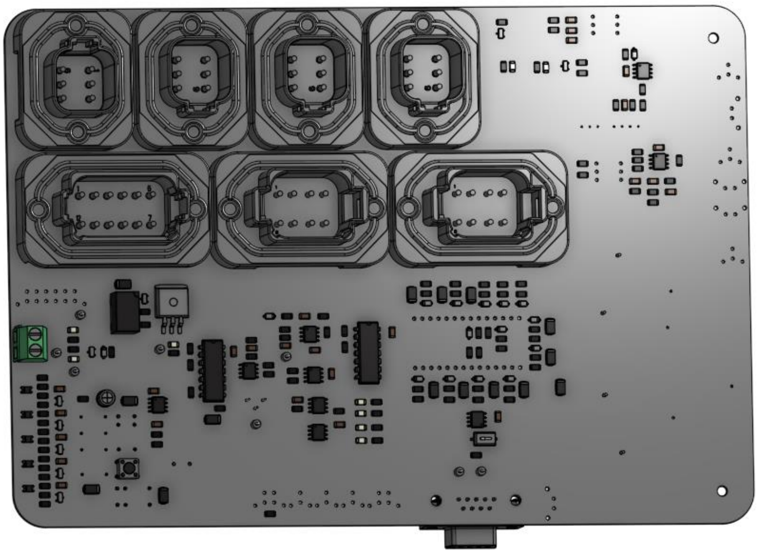


Figure 11:CEN PCB Taken from Onshape

The CEN is responsible for the power distribution across the entire Low-voltage system powering each of the respective nodes. The CEN also is responsible for the CAN messaging system and transmitting vital information across NU23's low-voltage system. The CEN also takes high voltage and distributes that where necessary as well. For further information on the CEN please refer to Imel Munday's report.

2.3.4 Accumulator

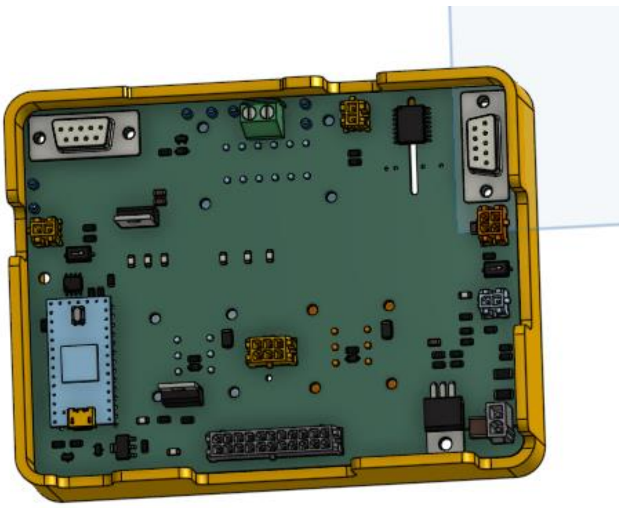


Figure 12: LVD PCB Taken from Onshape

The accumulator is one of the most complex systems associated with the low-voltage system, as the accumulator deals with both Low Voltage and High Voltage systems. The accumulator also houses the battery packs used to power NU23 as well as the low-voltage component known as the LVD (low voltage distribution board). The LVD located inside of the accumulator is responsible for power distribution between high voltage and low voltage systems powering the CEN and sending out CAN bus 1 messages as well as CAN bus 2 messages. CAN bus 2 is an isolated CAN network inside the accumulator responsible for all CAN messaging transmitted from the canamons. For further information on the accumulator, LVD and canamon boards refer to Jedd Reeves and Jacob Bush's reports.

2.3.5 REN

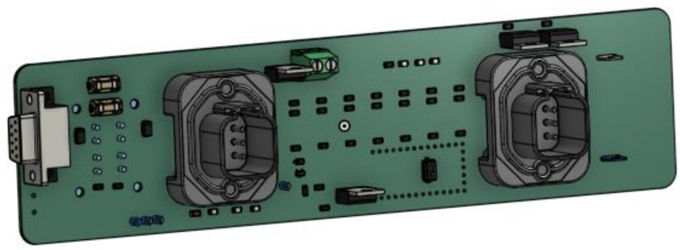


Figure 13: REN V4.5 PCB Taken from Onshape

The REN (Rear Electronic Node) is responsible for power distribution to the cooling system of the motor as well as brake light signals, ready-to-drive state sounding, as well as CAN messaging capabilities. Then REN will be further discussed in detail throughout this report.

2.4 Project Scope

After analysing the needs of the electronic systems of NU23, it was found that the current solution employed was overcomplicated and not reliable enough. Therefore it was decided that a new REN would be designed and integrated into NU23. The REN has been designed to meet the following requirements:

- Power distribution: Delivers power to the cooling system and then powers the three expansion ports used for the upper electronic node, Motec beacon system, and
- Have a functional brake light that meets the rules compliance
- Provide quick access to the CAN network
- Reduced part count
- Reliable and serviceable

2.5 CAN

The CAN network, standing for Controller Area Network, is a messaging-based system that has been integrated into NU23. The CAN network is also referred to as the CAN Bus and is used across multiple industries due to the reliability and simplicity of the system. CAN Bus was chosen for use in NuRacing due to its robustness to electrical noise and has served reliably over the past 20 years. NU23 utilises CAN to transmit important data and information between the electrical nodes for the Motec system to process and display in a useful manner. (Gregg, 2023)

When using CAN Bus several advantages can be employed; wiring can be reduced when in conjunction with point-to-point node design, integrating a CAN network is easily achievable, and the CAN network as stated before is resistant to electrical noise. The network itself communicates via a series of digital pulses using 1's and 0's, to which the network can decipher messages. These digital pulses are taken from the HIGH and LOW signals produced and the difference is taken. CAN HIGH will always remain 1 volt higher than the resting voltage and CAN LOW will remain 1V lower than the resting voltage. (Gregg, 2023)

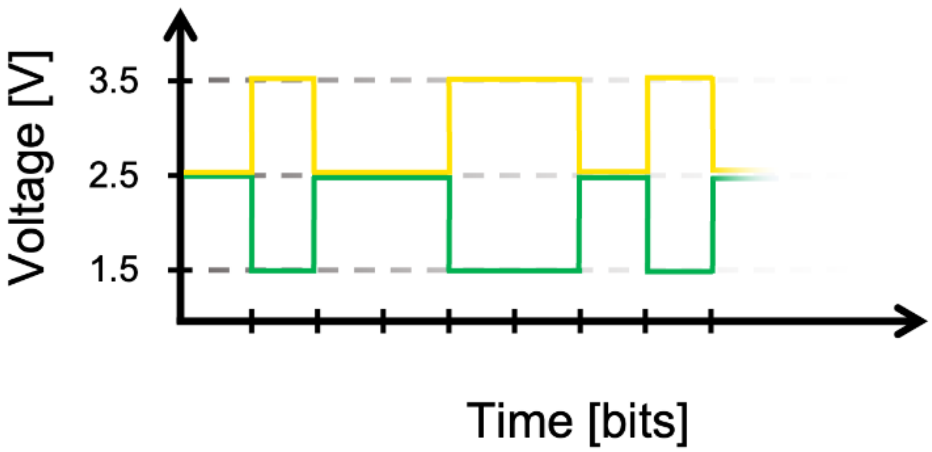


Figure 14: CAN HIGH and CAN LOW in Yellow and GREEN respectively - (Gregg, 2023)

The logic level of the bus can be calculated from these electrical pulses via subtraction:

$$\Delta = V_{\mathtt{CAN\ HIGH}} - V_{\mathtt{CAN\ LOW}}.$$

Figure 15: CAN Formula taken from CAN Zero to Hero course - (Gregg, 2023)

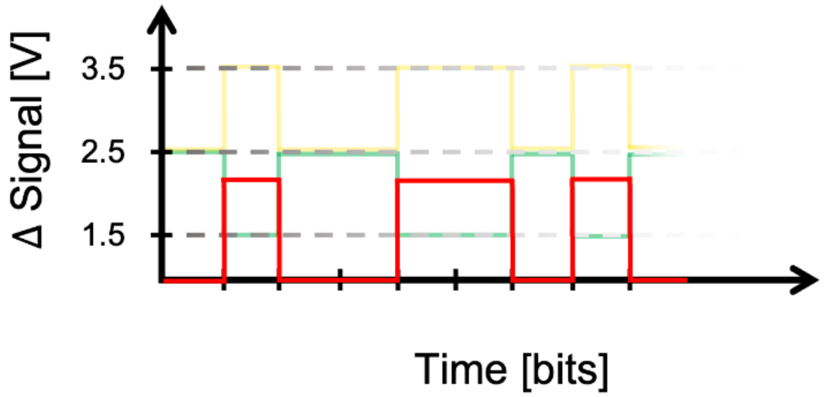


Figure 16: CAN signal can be seen in Red -

Taking the difference between CAN HIGH and CAN LOW allows the state of either CAN signal to be examined and a reliable signal-to-noise ratio is produced. (Gregg, 2023)

Connecting a CAN Bus network is straightforward when using components that have inbuilt CAN controllers. NU23 utilises Teensy microcontrollers that have built in CAN capabilities, with PCB's also been created with CAN transceivers. Where this is the case only four connections are needed with NU23 following this same connection plan;

1. Connecting the CAN TX port of the CAN controller with the CAN TX port of the transceiver (Gregg, 2023)
2. Connecting the CAN RX port of the CAN controller to the CAN RX port of the transceiver (Gregg, 2023)
3. Connecting CAN high port of the transceiver to the CAN high line on the bus (Gregg, 2023)
4. Connecting the CAN low port of the transceiver to the CAN low line on the Bus. (Gregg, 2023)

The following diagram of this interconnection can be seen below:

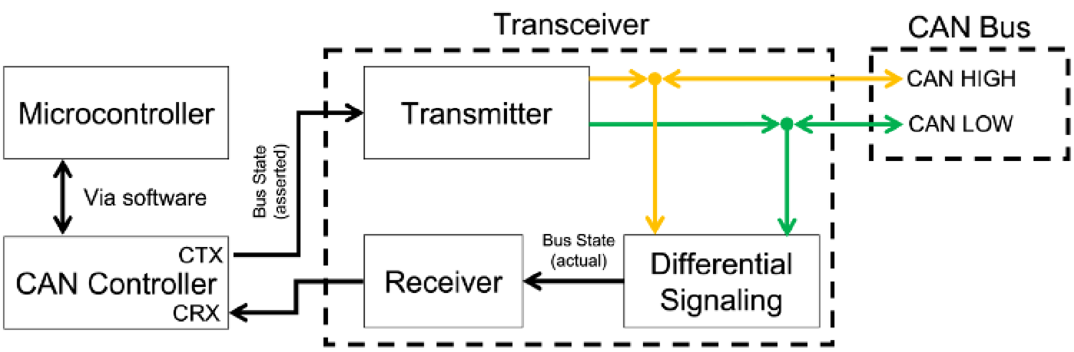


Figure 17:Block diagram depicting wiring connections of a CAN transceiver (Gregg, 2023)

The last key piece of information needed when understanding CAN is that the CAN standard requires a connection between CAN HIGH and CAN LOW. This is achieved by attaching 120 Ω resistance between the two, as shown in the image shown below. (Gregg, 2023)

Figure 18: 120 Ω resistance between CAN HIGH and CAN LOW - (Gregg, 2023)

2.6 KiCad

KiCad is the software platform that NuRacing has utilized throughout the year of 2023 to create and design the PCB'S seen in above sections of the report. KiCad allows students to be able to design electrical circuits and then take those circuits and create PCB's. KiCad has a vast number of tools that help to make the design process of circuits easy and user friendly. Below an example of the REN schematic and circuitry can be seen below:

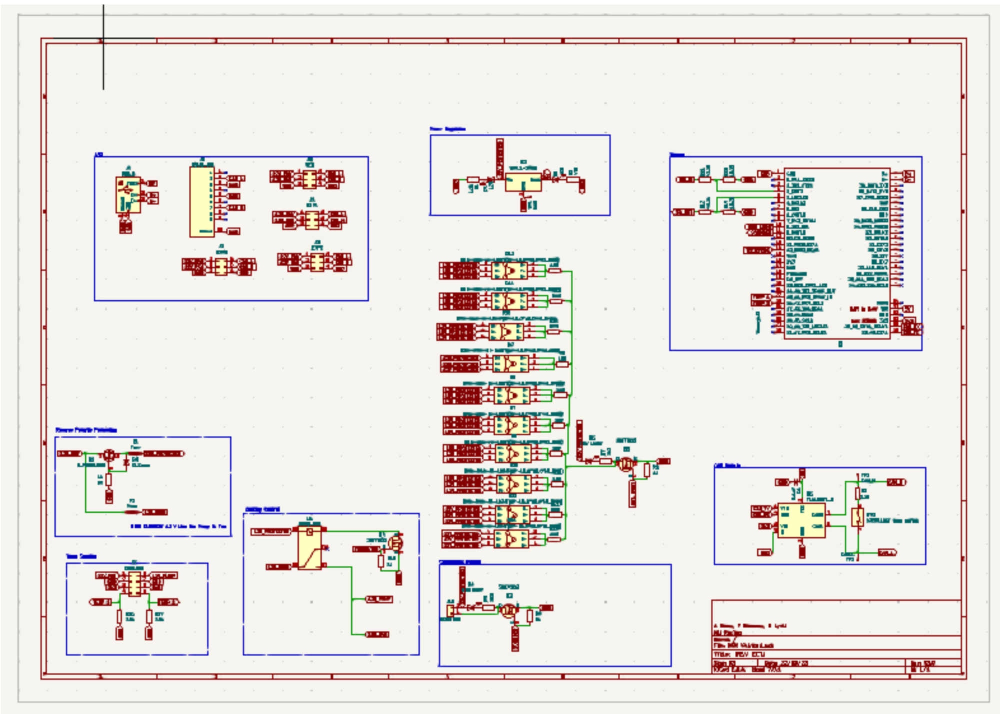


Figure 19: Example schematic created in KiCad

After creating a schematic following circuitry fundamentals each component will need to be assigned a footprint. The footprint of a component can either be downloaded from the internet or custom made in the footprint editor. Once a footprint had been assigned to each and every component a PCB is able to the be designed. The PCB is then created by setting up boundaries for the outline of the PCB itself and the components can then be arranged and placed. Once a suitable placement have been found for each of the components traces can then be run to interconnect the components, representing the wires on the PCB. An example of a PCB in the editor can be seen below:

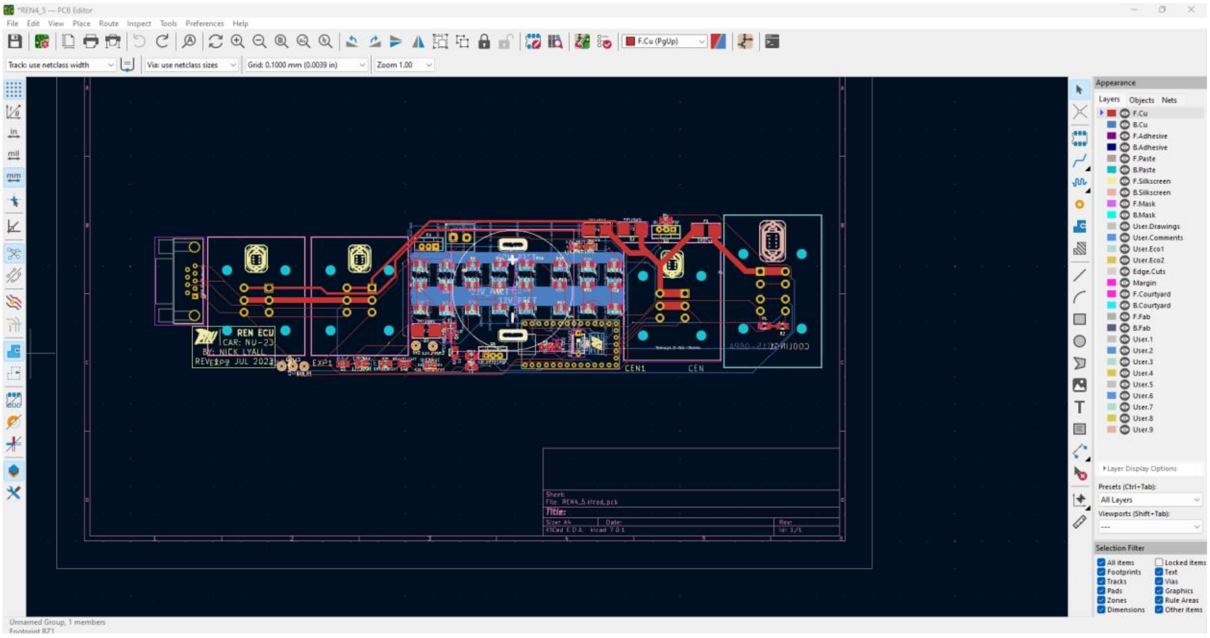


Figure 20: Example PCB editor from KiCad

2.6.1 Trace Calculations

Following on from creating a PCB trace width calculations need to be done when using high current devices. Trace width takes a few factors into consideration including the ambient temperature, thickness of copper and length of the trace. To calculate trace width the following formula is used:

First, calculate the Area:

$$A = \left(\frac{I}{\mathrm{k} \times {T_{Rise}}^{b}} \right)^{\frac{1}{\mathrm{c}}}$$

Then, calculate the Width:

$$W = \frac{A}{t \times 1.378}$$

Figure 21: Figure 5: trace width calculation formula- (DigiKey, 2023)

Utilising this formula in Digikeys in built calculator, trace width is then able to be calculated.

2.6.2 Standardised Blocks

In 2023 one of the main goals that NuRacing set out with was knowledge transfer. The Low voltage team worked towards this goal by employing the use of standardized blocks. Standardised block is the term given to a standard circuit used across NU23 and that may appear on more than one PCB. By standardizing circuits, any team member working on a PCB design in the low voltage system was able to then work on any other low voltage system with the knowledge and skills that they had already learnt being able to transfer across. A few examples of standardized circuits can now be seen:

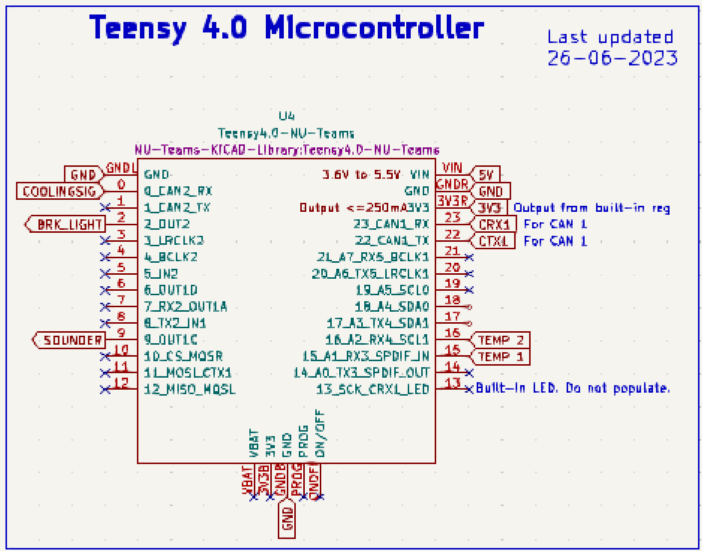


Figure 22: Standardised block - Teensy

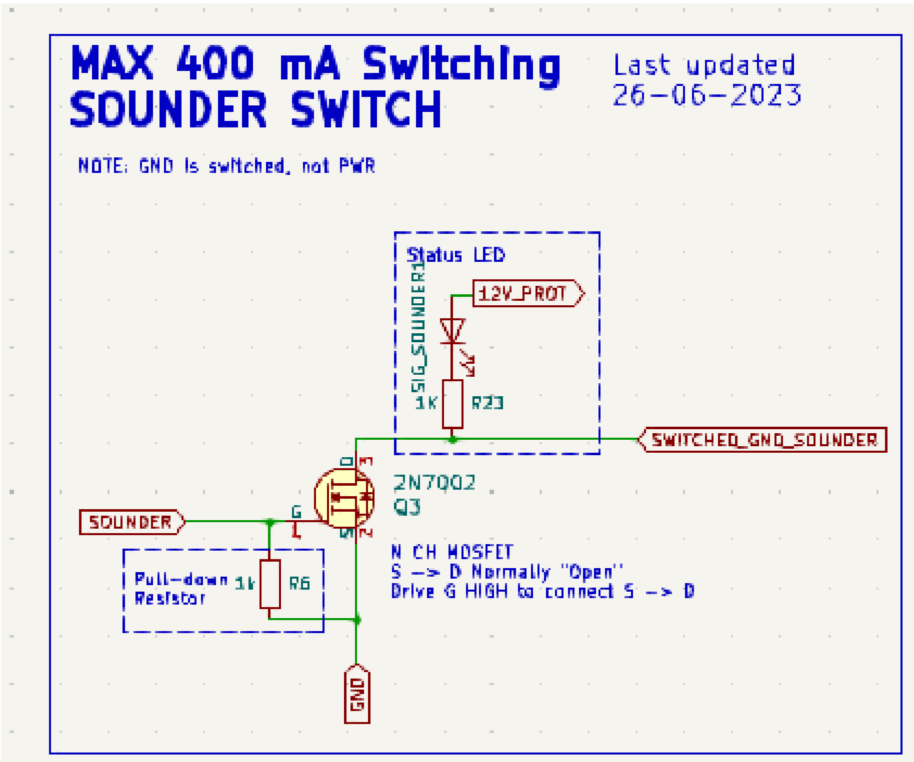


Figure 23:Standardised Mosfet/switching block for regular circuits

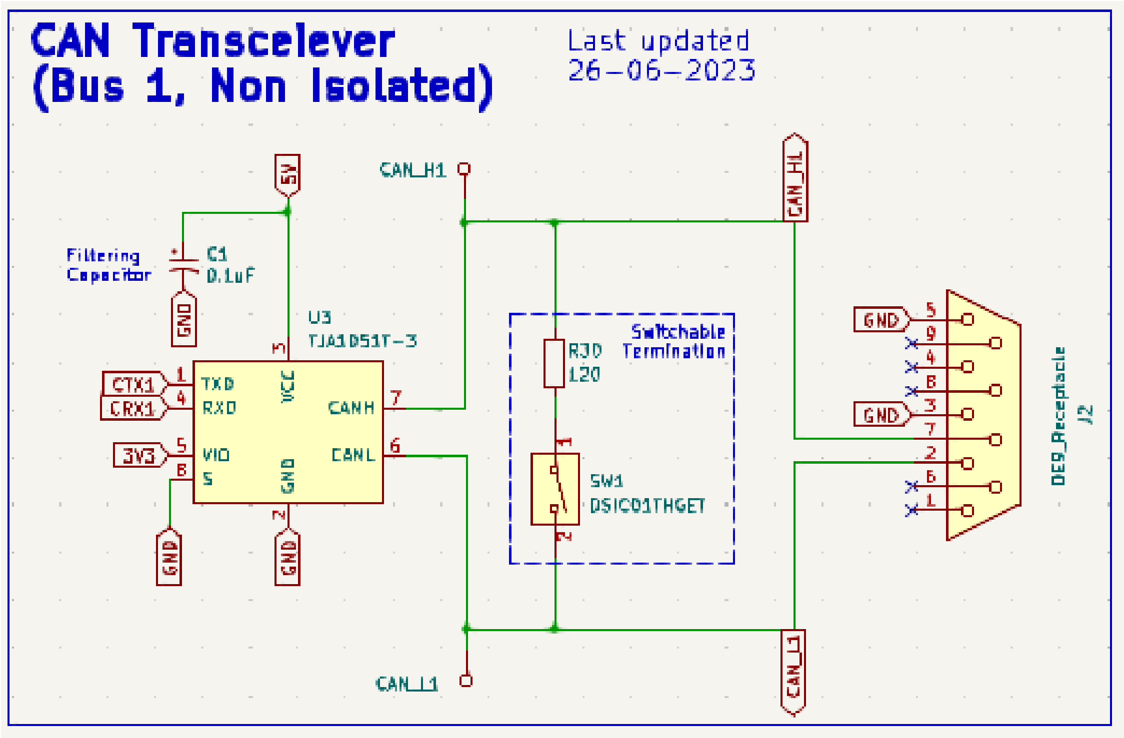


Figure 24:Standardised CAN circuit

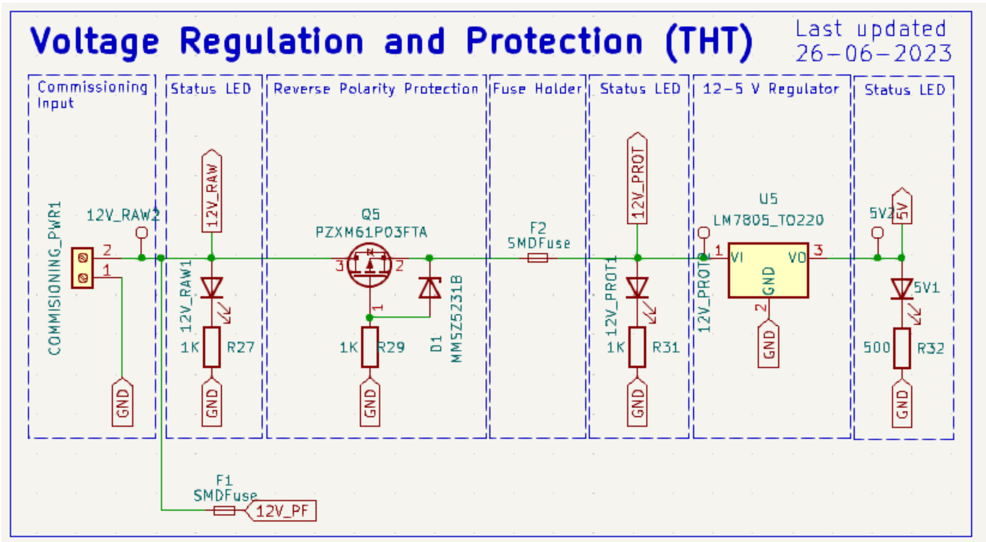


Figure 25:Standardised voltage protection circuit

By standardising these circuits, NuRacing was able to continually produce reliable and serviceable PCBs across the car, that any member of the Low voltage team could work on. This helped NuRacing to align bottlenecks and streamlined the prototyping process. Standardised blocks aided in the process of creating the REN by allowing most of the circuitry to be preserved each iteration, fast tracking the board through it’s development.

3. Compliance Report

During the 2023 FSAE competition a number of strict rules were needed to be met to meet compliance requirements at competition. To ensure safety for those involved each system and subsystem of the car needs to meet compliance. The REN in each iteration including the GREN were created in conjunction with these rules from the FSAE website as can be seen below.

The GREN, REN V3, REN V3.5, REN V4 and REN V4.5 systems were all compliant with all rules associated with the system. The 2023 FSAE rules in question are:

- T.3.3.1, The vehicle must have a Brake Light that is clearly visible from the rear in very bright sunlight.
- T.3.3.2, The Brake Light must be: a. Red in colour on a Black background b. Rectangular, triangular or near round shape with a minimum shining surface of 15 cm2 c. Mounted between the wheel centreline and driver's shoulder level vertically and approximately on vehicle centreline laterally
- T.3.3.3, When LED lights are used without a diffuser, they must not be more than 20 mm apart.
- EV 5.4.1, The GLV system must be a Low Voltage system that is grounded to the Chassis
- EV 5.4.2, The GLV System must include a Master Switch
- EV.5.4.1 The GLV System must be a Low Voltage system that is Grounded to the Chassis EV.5.4.2 The GLV System must include a Master Switch, see EV.8.9.1
- EV.5.4.3 A GLV Measuring Point (GLVMP) must be installed which is:
- Connected to GLV System Ground b. Next to the TSMP EV.6.8
- 4 mm shrouded banana jack
- Color: Black

REN DESIGN

Following on from Patrick Gleesons report written in 2022, Patrick stated that the REN system needed to be worked on further to create a more robust and reliable system. Patrick also stated that some of the features of the REN could be absorbed by other Low voltage subsystems in the aid of simplicity and reliability. Throughout this chapter an insight to why the REN subsystem was worked on as well as how the system was implemented and continually improved on will be highlighted.

4.1 Initial System Design GREN

The GREN is a combined system replacing both the REN and the GEN into one system that maintains all the previous functionality except for housing the LV battery. In the 2022 configuration of the LV battery the battery sent power from the REN, which then sent power through to the CEN. The CEN would then send power to the accumulator and then send power back to power the car. This system was needlessly complicated and so the LV battery was removed from the REN subsystem and the power wiring was changed.

After submitting initial designs for review it was determined that the GREN would be successful in combining the REN and GEN systems as long as the system was rules compliant. The main rule that would restrain the overall design of the GREN is the position of the break light as the break light needs to sit between the centre line of the wheel and the shoulder height of the driver.

The initial design of the GREN aimed to combine the efforts of both Patrick Gleeson and Ethan Guse who each designed the REN and GENs respectively. The GREN was designed to minimise the overall complexity of the system and the total part count. It was able to achieve this by replacing the GEN system which used its own individual relays to control the pumps and fans of the cooling system with a single automotive relay in the GREN itself. In 2022 the GEN proved to be an unreliable system and so a manual on/off switch was implemented to control the cooling systems. The GREN also utilised the existing foundations created by Patrick Gleeson in preserving most of their electrical designs as they had been tested and proven to work reliably at the 2022 FSAE competition. Below an image of the GEN and the 2022 REN can be seen:

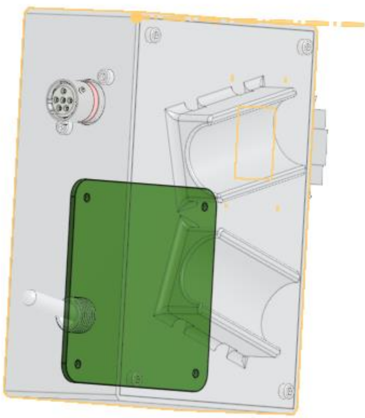


Figure 26: Ethan Guse's GEN in enclosure, taken from Onshape

The schematics for the 2022 REN by Patrick Gleeson and the schematics for the 2022 GEN by Ethan Guse can be found in the appendices.

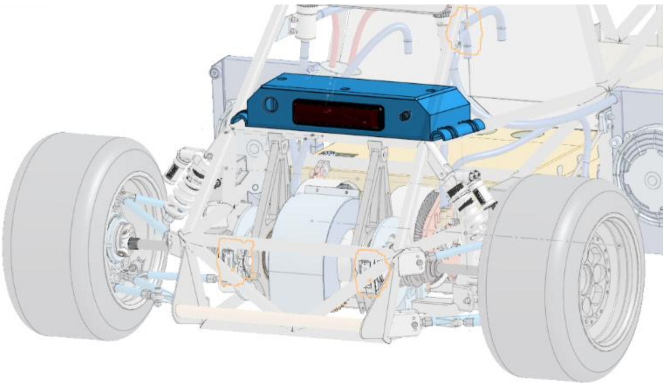


Figure 27: Patrick Gleeson's REN in enclosure mounted to EV3 (Gleeson, 2022)

Figure 28:Competition ready 2022 REN - Taken from Patrick Gleesons report (Gleeson, 2022)

The GEN systems were able to be replaced with a relay that is controlled by the TEENSY on the GREN. This relay can then only be activated after the high voltage system has been activated. By activating the relay after the high voltage system was enabled ensured that the pumps and fans of the radiator could not drain the low voltage battery of the car used to power the low voltage systems prior to being “ready to drive”. This allowed for the removal of 84 components between the two GENs. This approach was taken as the 2022 team made suggestions in their reports indicating that overheating was an issue where the pumps connected to the radiators were not activated enough to effectively keep the motors cool. It was also decided that the previous system was far too overcomplicated for the job that it was doing, as the pumps were able to run at variable speeds based on the temperatures of the inlets and outlets on the radiators. An automotive relay was chosen as the relay as they had been used previously on NU16, as well as they could be purchased easily, were reliable and priced relatively cheap.

The relay that was chosen to be used was a 12V 30 amp relay that can be seen below:

Figure 29: Relay used on GREN and REN subsystems - (RS Components, 2023)

By eliminating the GENs from the system two connection ports on the PCB of the REN were able to be removed. This allowed the design of the REN to be condensed down and shrink the overall footprint of the GREN PCB. The part count for the REN being 508 could then be brought down to 310 parts on the GREN. The GREN PCB can be seen below:

During the design phase of the GREN, the wiring looms connecting the PCB to the Autosport connectors were also rewired to create a universal wiring configuration thus eliminating any chances of creating a short, by connecting the wrong loom to the wrong connector. This issue had been highlighted in Patrick Gleeson's report and the precious iteration of the REN suffered from mistakes made by students who may have been trying to get the car ready for an event, however, are unfamiliar with the low voltage systems. By implementing the new universal wiring design, someone with minimal knowledge about the system can plug the GREN system in and be safe knowing that they cannot damage the GREN itself.

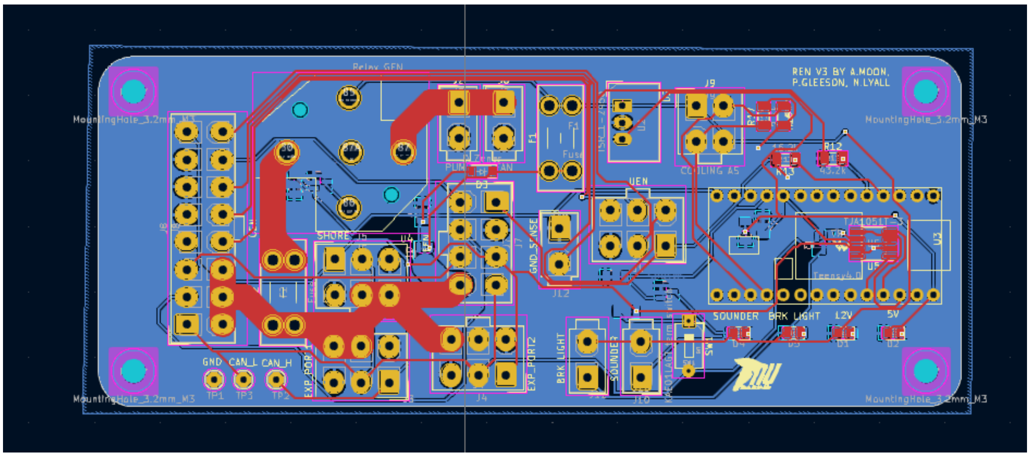


Figure 30: GREN PCB

Figure 31: Photo of the GREN in the Laborotory

The GREN system also utilised the REN's Arduino code as a foundation adding in the extra necessary functionality into the code such as the Temperature sensors and Relay activation. Gabrielle Hornsell assisted in this process by helping to debug the code. The GREN code can be found in the appendices.

4.1.2 GREN Housing Design

In the initial design phase, a new housing was made with the goal of reducing the overall footprint of the original REN design. The new GREN housing was designed aiming to fit the footprint of the system into the silhouette of the break light allowing for the system to be flexible in the placement on the rear of the car. By designing the housing to be small and compact the total weight of the component can be reduced and the shelf life of the system be extended. By making the system small the GREN could in theory be moved and placed in different sections of the back of the car allowing for the further developments of other components that may be tested and implemented on the car in the months leading up to competition.

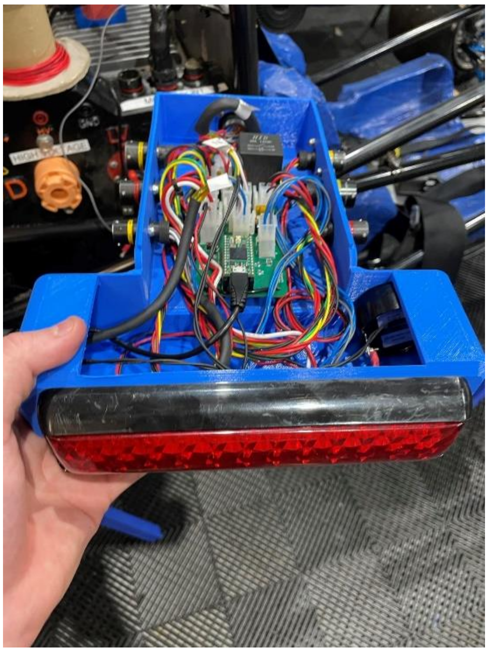


Figure 32: GREN in housing wired up to autosport connectors

4.1.3 GREN Feasibility

After successfully integrating the GREN into the NU23 Low Voltage system it was proven that both the REN and GEN systems of EV.Three could be combined. With this being the case, the GREN was deemed suitable for further development, with the three main fundamentals in mind. This would call for further experimentation into surface mounted components to eliminate any unnecessary crimps and wires to greatly reduce the part count.

4.2 Initial System Design REN V3

Having previously combined the REN and GEN systems into one singular node into a system that was now considered reliable, the REN could be reborn into the REN V3. REN V3's design carried the circuitry of the GREN system across utilising the same components for ease of use and minimal delays in order times. By using the same proven circuitry from the GREN, the reliability was able to be transferred across and into the REN V3.

The REN V3 featured a new and unchartered design in the New Racing history books where surface mounted LEDs were used to create a surface mounted brake light. Choosing the right LED's that satisfied all the requirements of a brake light in the FSAE competition proved to be a more challenging process than initially expected. With so many different options and price categories to choose from a total of three acceptable options were found. The first option was finding a suitable strip light design where several 5050 LEDs were premanufactured onto a silicone strip. While keeping the rules compliance in mind an option that was diffused as seen in Figure 33:

Figure 33: Diffused LED strip light - (Core Electronics, 2023)

This option was ultimately not chosen because wires would still need to be either soldered to the REN or a Molex clip may have been needed to be used, voiding one of the three main goals for the REN V3 (part reduction). The second option that was found was called a Cree light. These LEDs came in a few different options with brightness being the main defining feature. The two options that were considered for use in the Cree selection were the star XHP35 configuration and the XPGEWT. These LED's can be seen in Figure 34 and Figure 35:

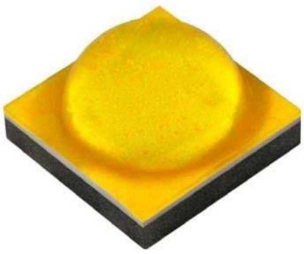


Figure 34: Cree XPGEWT - (Mouser Electronics, 2023)

Figure 35: Cree star LED - (LED Supply, 2023)

The star configuration was not chosen due to the footprint being quite large and in keeping the board as small as possible this option was not viable. The Cree star selection of LEDs were also expensive being priced between $7 and $11 each. The XPGEWT option was not chosen either due to the price being within the range of $3 - $45 per LED. Ultimately this led to the choice of using standard 5050 LED's that had three red LED's in them as opposed to RGB. This option was found from brightLED's.com and proved to also be the cheapest option.

While designing the brake light on the PCB three rules needed to be considered more so than when using the off the shelf brake light. The LED's had to light up an area of 15cm squared and if the individual LEDs were further than 20mm apart then the light would then need to be diffused, as well as specified brake light shapes could be used including non-circular shapes as well as triangles, and rectangles are allowed. With this in mind the 10 LEDs were measured out and formed into a rectangular shape. The long edge measuring at 5mm and the short edge measuring at 3cm. The LEDs were also arranged so that each of them only had a 3mm gap between each of them, thus meeting the compliance regulators.

The REN V3 can be seen in Figure 36 with the layout of the LEDs in the centre in silver:

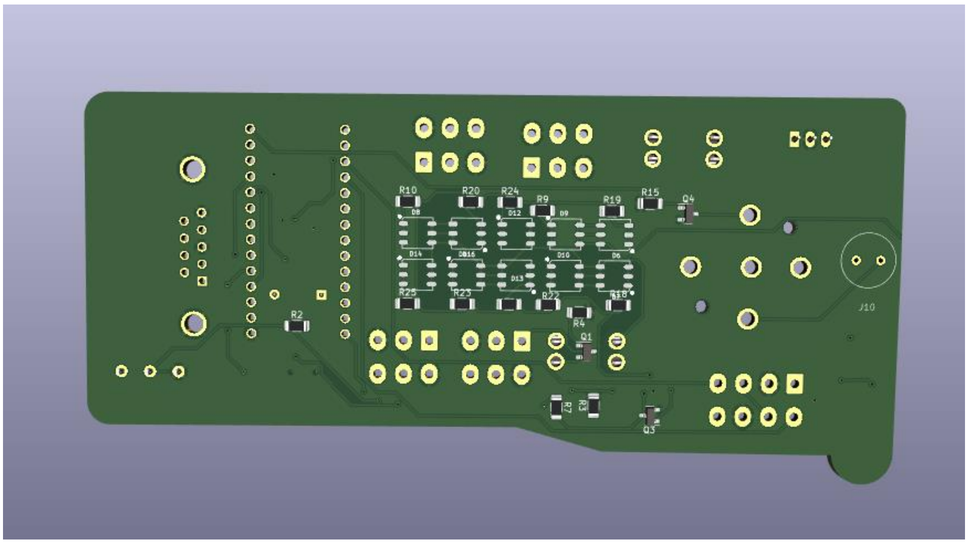


Figure 36: REN V3 PCB backside

Another design feature that should be of note especially for future students of NuRacing, is the actual footprint of the PCB should be left in either a rectangular configuration or a configuration directly impacted by where the board needs to be mounted like the DEN. Designing a PCB with a unique shape like the REN V3 is unnecessary and over complicates things.

4.2.1 REN V3 Feasibility

Having designed and tested the REN V3, it was a quick turn around to find that this board would not be feasible on the car. The testing phase of the REN V3 was streamlined due to the preservation of the code from the GREN. A test rig was then able to be created to be able to either use the teensy to send the brake light signal or manually switch the brake light on using the power unit. During this testing it was found that the surface mounted mosfets (model number) could handle the current draw of the 10 LED's. This had been an initial concern due to the fragile nature of the mosfets. Previously what had been discovered was that the mosfets due to their tiny legs were susceptible to popping off the board and initially it was a concern that these small legs would not be able to handle the current that would run through them. Even while being able to enlarge the trace size to the appropriate size the mosfet would still serve as a choke point. However as stated earlier the mosfet was able to handle the current required to light the LED's. Calculating the resistance size also then needed to be factored in to get the appropriate brightness of the LED's while managing the current. Three resistor values were chosen including a 330 Ω, 550 Ω and 600 Ω resistor. The 550 Ω resistor was chosen as it means that the total current that the LED's would draw remained under an amp holding at 0.75 Amps. Maintaining this current level also managed the heat produced by the LED's. The board would remain cool even running for long durations of time (in this case the LEDs are being utilised as a brake light so the expected time that the light would be on while the car was driving would only be a few seconds with the longest duration when putting the car into ready to drive, which can take about 30 seconds).

Therefore, the surface mounted brake light proved to be a success even with extreme testing the LED's proved to be able to handle up to 3 Amps without any failures. At the time of testing it was decided by leadership that surface mounted connectors such as the Deutch (DT) connectors were going to be used. Therefore the REN V3 became outdated and another iteration of the REN would need to be created.

4.3 Initial System Design REN V3.5

The initial system design of REN V3.5 mostly focused around integrating the Deutch connectors into the PCB and their feasibility. By introducing these connectors, the overall footprint of the PCB was able to be significantly decreased with the only restrictive factor being the connectors footprints themselves as they are respectively large connectors. Following on from REN V3 the footprint of REN V3.5 maintained a rectangular shape as opposed to the unique and custom appearance of REN V3. This decision was reached as it was determined that the footprint could be both minimised in the sense of the total footprint and maximised in the sense of running traces and placing components onto the PCB itself. The REN V3.5 can be seen in Figure 37:

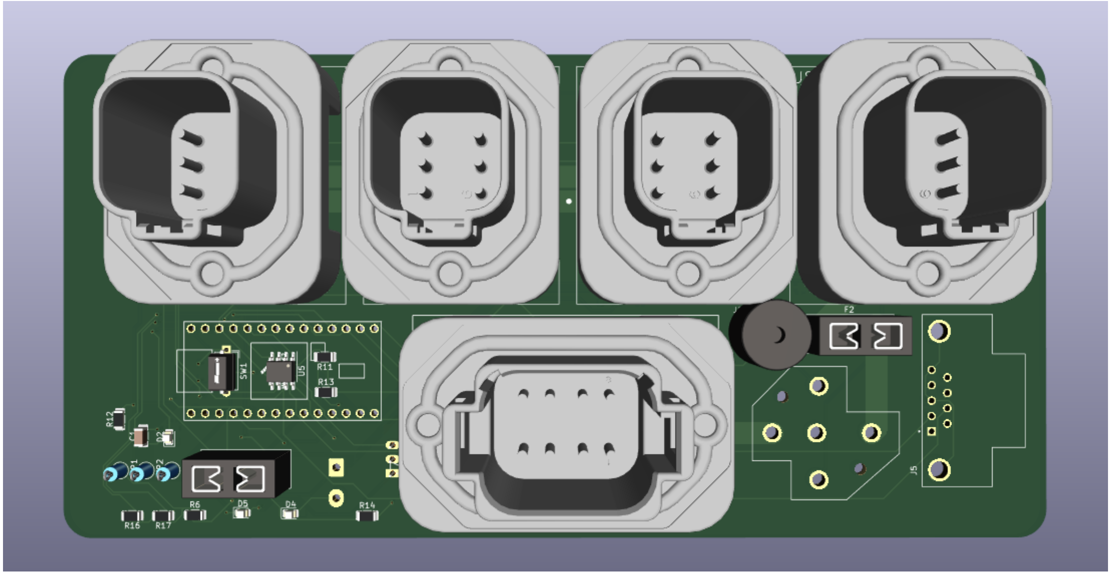


Figure 37: REN V3.5

When using the Deutsch connectors, a new method of attaching the PCB to the enclosure was also able to be used. As the Deutsch connectors came standard with gaskets and screw holes, allowing the PCB to be attached via screws directly to the housing and maintaining the integrity of the waterproofing.

Another new feature that REN V3.5 featured was a surface mounted sounder. For this a Piezo buzzer was used that ran from 3-9 volts and was capable of 90 decibels. The buzzer was chosen for the sound output that it was advertised to have on the Digikey website as well as its footprint. The buzzer has a diameter of 9mm being significantly smaller and lighter than the previous 12V buzzer. Using this new buzzer in the design meant changing the REN's code (The REN code can be found in the appendices) to enable the Teensy to be used as the driver. When writing the code, it was found that Teensy had an in-built function that was used to drive the buzzer called Melody as seen in Figure 38. This function was simple allowing for the pins of the Teensy to be initialised, the frequency to be chosen and a timer to be set for turning the buzzer on and off. The frequency used to drive the buzzer was recommended to be 2375khz.

```
uint16_t val = 0; // Initializing the variable for the voltage value
uint16_t last_val = 0; // Initializing the variable for the voltage value

#define PWM_Pin 14

void setup()
{

  pinMode(PWM_Pin, OUTPUT);
}

void loop()
{
//analogWrite(PWM_Pin, 125);
tone(PWM_Pin, 2735, 3);
}
```

Figure 38: Melody function used to initiate surface mounted sounder.

The LED's used for the brake light were also spaced in between the drill holes used in the footprints of the Deutsch connecters resulting in the distance of the LEDs to exceed the maximum distance allowed for the brake light LEDs when the light is not diffused. This meant that the design of the housing would need to consider this by either using a clear filament that can be printed directly in with the standard PETG or a sheet of Perspex that could be used and sanded to get the desired diffusing. This can be seen in Figure 39:

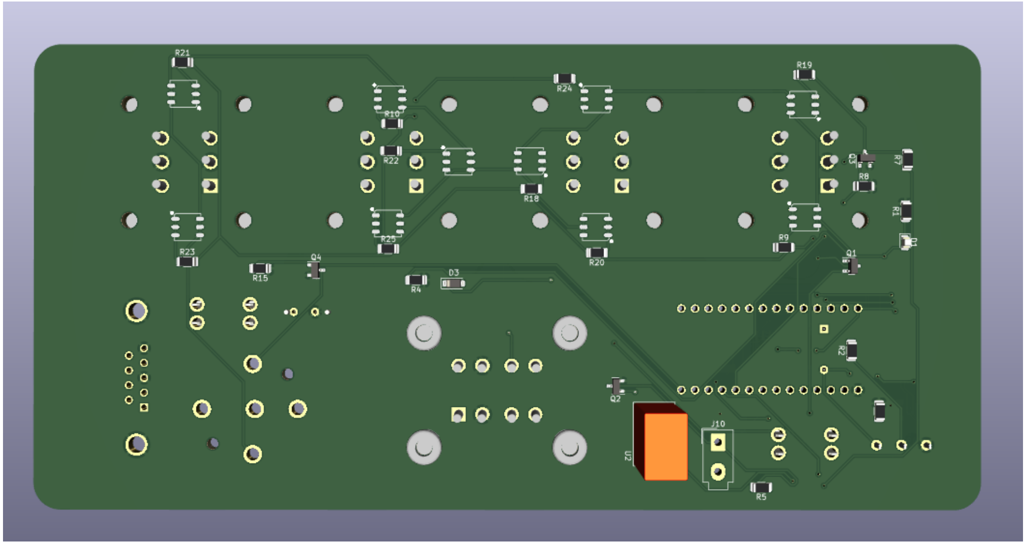


Figure 39: LED side of the REN V3.5

REN V3.5 incorporated a new standardised block updating the already standardised CAN block to integrate a serial connector onto the board. The serial connector was specked out as a standard serial DB9 connector, which has been selected and is intended to be used as a quick connection port that allows a person to connect to the CAN network and read any relevant information.

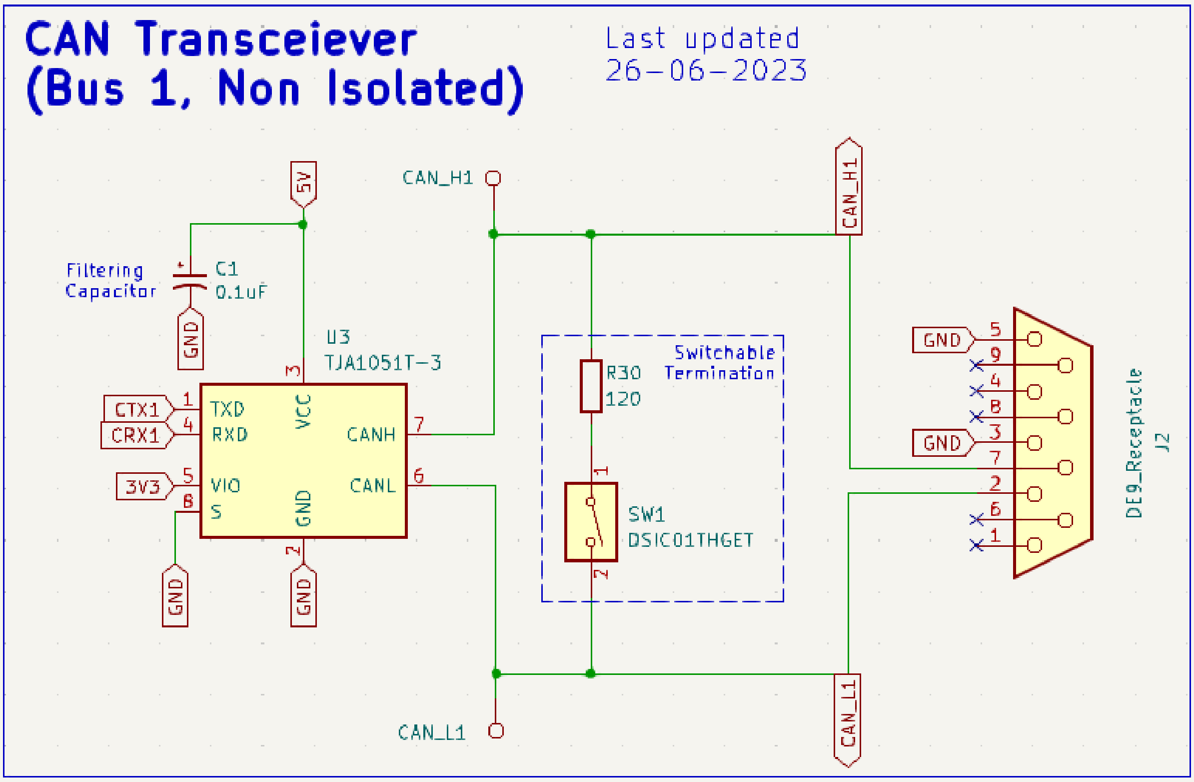
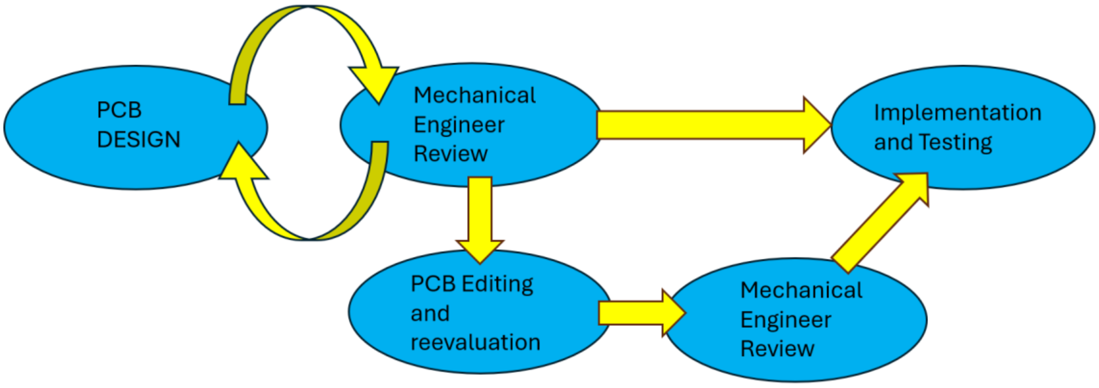


Figure 40: Updated standardised CAN block for KiCad.

4.3.1 Housing Design

Figure 41: REN V3.5 Housing

The housing that can be seen above designed by Brock Symons served as the first testing platform for the Perspex brake light cover. During this design phase a method was developed between both the Mechatronic and Mechanical engineers to be able to create the best end product. The method that was utilised can be visualised below:



The first prototype made using the Perspex incorporated hot glue on the inside with respect to the housing, in an attempt to diffuse the light. This method worked in diffusing however the impurities inside the hot glue and the general untidiness meant that the glue absorbed too much light making the brake light seem dull. This method was then quickly ruled out and further investigations were undertaken including research surrounding diffusion stickers.

4.3.2 REN V3.5 Feasibility

The REN V3.5 brought a lot of fundamentals together including the successful implementation of a surface mounted brake light, implementation of a surface mounted sounder and the surface mounted DT connectors. When mounting the REN V3.5 it quickly became apparent that this system would not work with the configuration of the body kit. Therefore is was decided that a low profile REN would need to be created so that it could fit under the body kit.

4.4 Initial System Design REN V4

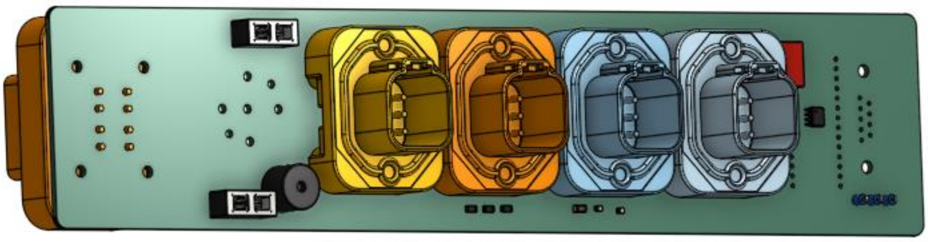


Figure 42REN V4 PCB

When initially designing the REN V4 the 2023 chassis had been delivered and aero kit modelled. This allowed for the design process of the REN V4 to incorporate the board being mounted directly to the chassis. By mounting the board directly to the chassis and being able to visualise the aero kit, a sleek and long design was able to be produced as seen in the above figure. This design was aimed to create a low-profile version of the REN V3.5 and the layout could meet the new needs of both the aero kit mounting position and FSAE rules. With this in mind a location on the chassis was able to be chosen ensuring rules compliance, on the top cross member directly on the rear of the car as this allowed the brake light to remain above the centre line of the wheels and remain lower than the drivers' shoulders. Below an image of the mounted REN V4 in the housing can be seen:

After the location had been determined the dimensions for the PCB were able to be defined and the outline of the footprint could be created, where a low-profile design was chosen. Now that this phase had been decided the layout of the board could be roughly placed prioritising power distribution. Placing the two most power consuming connections as close together as possible, being the pump and fan used for cooling, it's appropriate relay and the CEN connection port, the rest of the board was able to be laid out around them. By designing the board this way, the trace size was able to be kept to a minimum size while maintaining the appropriate width for handling up to 13 Amps. This can be seen in the figure below:

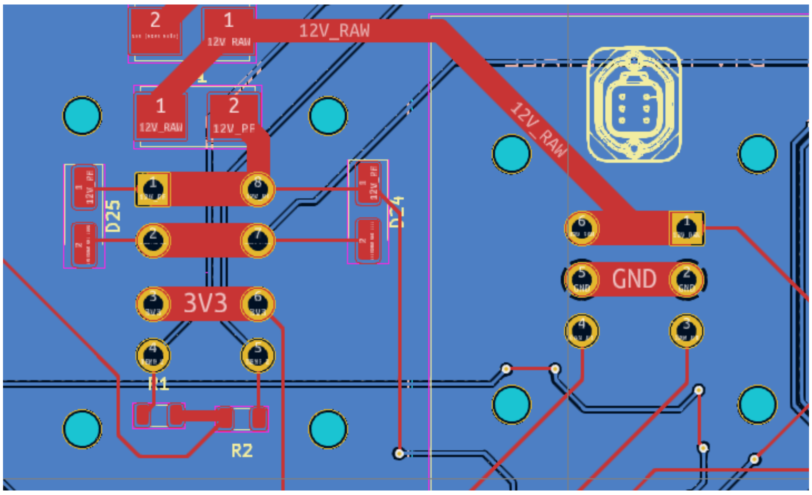


Figure 43: Power supply trace for cooling kept close by to CEN power supply.

The next consideration when designing the REN V4 was the placement of the LEDs used for the brake light. Taking into consideration what was learnt from the previous REN V3.5 the LED's were placed further away from the pins of the Deutsch connectors allowing for the LED's to be soldered on with ease.

Each subsystem on the PCB was also placed in a way where the components would be grouped together so that if there were any issues that needed to be diagnosed the schematic could be pulled up and the entire circuit could be found with all relevant components being in proximity of one another. In conjunction with this the grouping tool that is in built to Kicad was utilised so that an appropriate configuration of the components could be found to minimise their footprint and then be placed on the PCB as one circuit.

Following on from the lessons learnt on REN V3.5 two sounders were integrated onto the board to help try and increase the sound level produced (this is further explained in a later section). As a fall back a third sounder being the original 12V sounder used in the 2022 competition could be used as well. Lastly the trace width calculations were given a higher consideration with trace width changing as it went from the CEN connector to each of the expansion ports.

Another improvement made aimed to address the mistakes that had already been made was the placement of the serial DB9 connector. The connector was placed so that in the PCB design phase the connector would be hanging off the board so that the connector could successfully and reliably make a connection with its respective serial cable. This can be seen in the figure below:

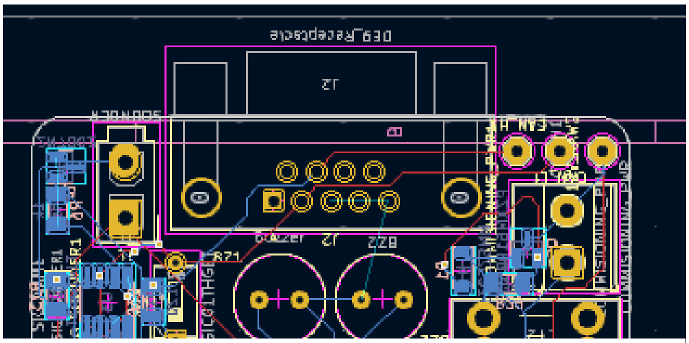


Figure 44: Screenshot of Serial connector placed on the PCB correctly

The final design feature that was integrated to REN V4 was a flyback diode for the relay. This had not previously been integrated due to the previous relay being used having an inbuilt flyback diode. This was decided to be a safe option in case the original one becoming faulty and needing replacement. This would mean that any standard automotive relay would be suitable for use as long as it met the required voltage and current ratings.

4.4.1 REN V4 Housing Design

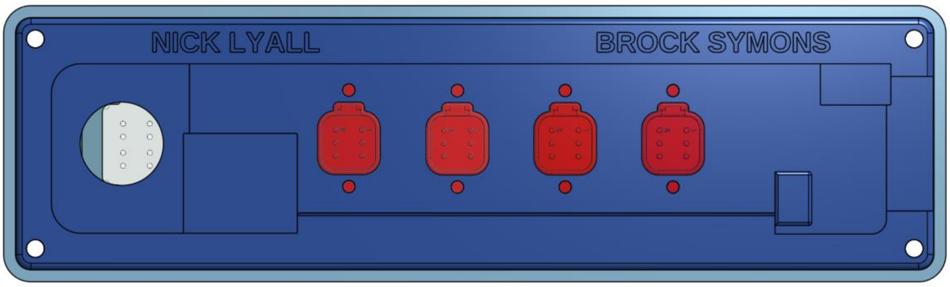


Figure 45:REN V4 Housing: Rear

Figure 46: REN V4 Housing Front

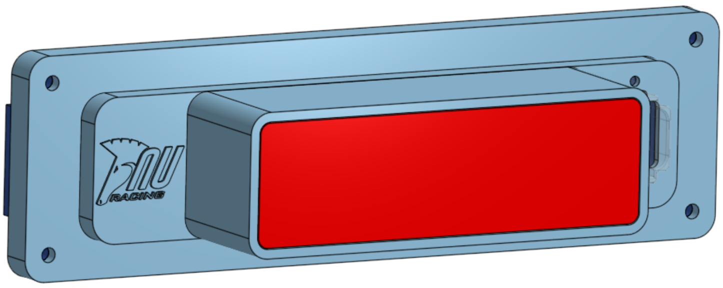


Figure 47: Ren V4 Housing distance

The REN V4 housing was again designed by Brock Symons to be the smallest profile possible. There were two housings created one being 3D printed on the standard Prusa Mk3 where the bed length and width did not allow for the housing to be printed in one piece, and the second in the 3D printer in the EC building. The housing made on the Prusa Mk3 was printed in 4 separate components with an overlapping edge created so that the two halves of the respective sides could be super glued together. The second housing that was prepared on the much larger printer in the EC workshop was able to be printed in two halves allowing the housing to be screwed together utilising the DT connector screws as well as four main bolt holes that were used to keep the housing together as well as mounted to the car.

Ultimately the Prusa Mk3 printers created superior final product as the larger print that was able to be created in the EC workshop would warp. Therefore, it was decided that printing the housing in four separate components would be better as the quality of the print was able to be monitored better. It was also chosen as the previous testing with the super glued joints proved that the glue was strong enough to handle being on the car and did not jeopardize the build quality.

4.5 Initial System Design REN 4.5

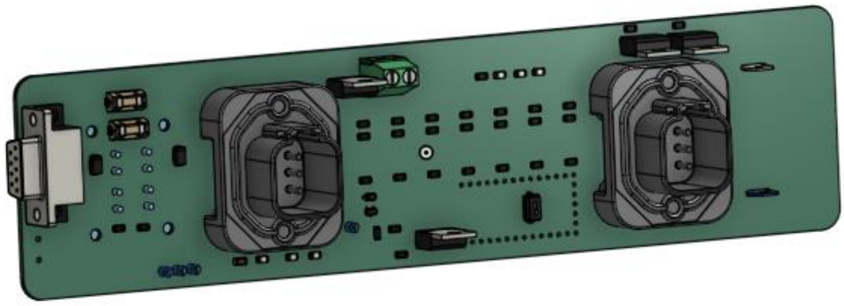
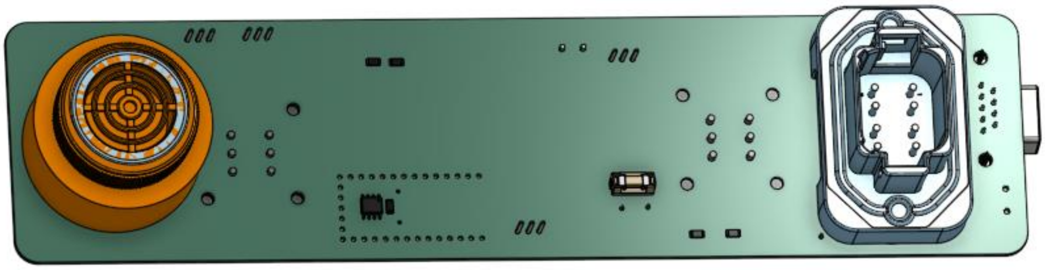


Figure 48: REN V4.5 PCB



The initial design of the REN V4.5 mimicked that of the REN V4 however removed any unnecessary components, mostly being that of the expansion ports. The number of expansion ports were reduced from 4 to 2. One of the said expansion ports was used for powering the REN from the CEN and the other used as a spare expansion point. Following on from the lessons learnt from REN V4 the power supply coming from the CEN was kept close to the cooling expansion port. Ultimately minimising the size of the trace needed to handle the 13 Amps.

A new feature that was integrated into the REN was the use of a new type of mosfet found at Core Electronics. The mosfet was different from previous being in a through hole configuration and being advertised to handle up to 60 Amps continuous. An image of this mosfet compared to the original SMD style mosfet used in previous REN boards and across the other low voltage systems associated with NU23. REN V4.5 again used the surface mounted DT connectors as well as the previous standardised circuitry blocks.

A custom footprint was also created for the original sounder used in the 2022 competition so that the sounder could be surface mounted to the PCB eliminating the need for unnecessary crimps and wires. Eliminating the wires attached to the sounder marked the final wires to be removed from inside any low voltage housing on the car. As previously discussed in earlier iterations of the REN, the traditional cause of issues on NU23 had been crimps coming loose inside housings where they could not be detected straight away, so removing all wires from the system was of the highest priority when reintegrating the original sounder onto the REN V4.5. This footprint can be seen in the below figure:

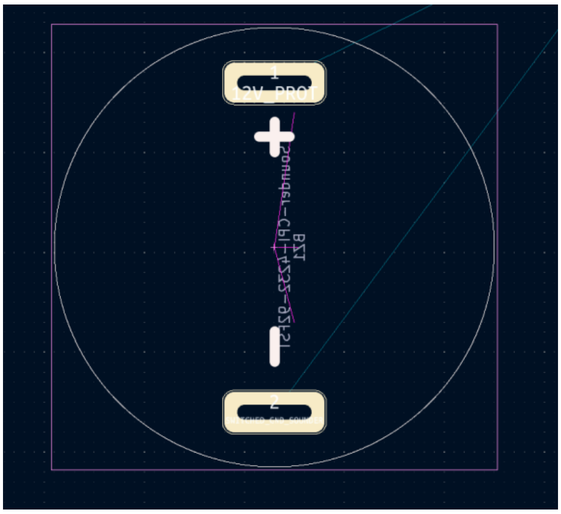


Figure 49: Sounder Footprint created to mount the sounder directly to the PCB

When creating the REN V4.5 in the design phase two heat sinks were added for the brake light as an extra 6 LEDs had been added to create a more dense light. With these extra LED's it was decided that it would be safest to add these heat sinks so that there was no risk of anything getting too hot. This decision was arrived at due to an error that had occurred on another board prior, where the board had gotten so hot that components had desoldered themselves and caused shorts on the board.

4.5.1 REN V4.5 Housing Design

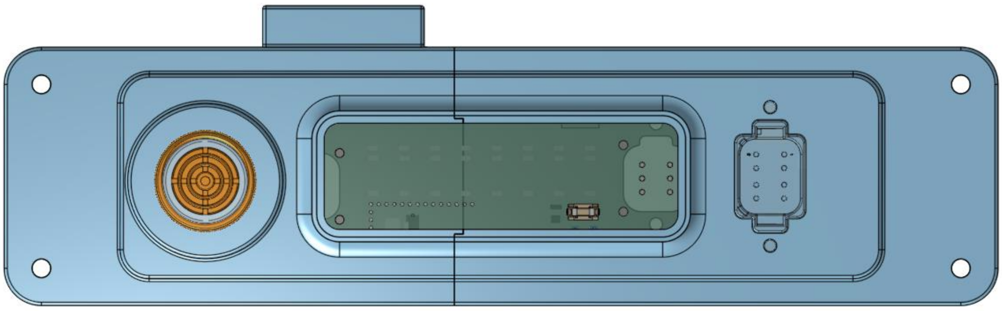


Figure 50: REN V4.5 Housing designed by Brock Symons

The design of the REN V4.5's housing required a lot of inter disciplinary teamwork between Mechatronics engineer and the Mechanical engineer. Each of the components of the board were placed in a way to best optimise the housing's low profile and slim design. As can be seen in the above figure a large bulge had to be placed at the top of the housing born from complications associated with electrical design. This design choice is further explained in the manufacturing process chapter of this report, however this bump was created out of necessity to help with cooling for the actual PCB itself. By increasing this area of the housing allowed room for a heat sink to be attached to the mosfet driving the cooling pumps and fans. Reasoning for the heat sink will then be further explained through the testing and validation section of this report.

Another design choice that was reached for the housing of the REN V4.5 was extending the brake light cover out to so that the sanded Perspex would appear in line with the body of the car and be more easily visible. This can be seen in Figure 51:

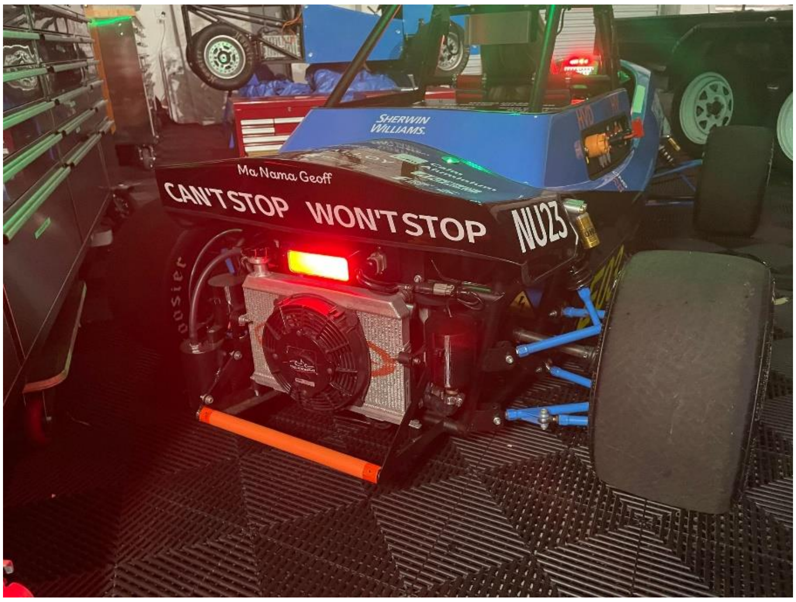


Figure 51: Final REN configuration that went to competition.

5. Manufacturing Process

This section of the report will outline the process undertaken when creating each of the REN designs and how making the boards and integrating them into NU23 highlighted the room for more improvements. Each time the REN was made through it'd different iterations new methodologies were found, and existing ones were improved upon. This process will also be explored in this section of the report.

5.1 GREN

Manufacturing of the GREN first took place in the form of ordering the PCB itself from PCBgogo where the PCB was made in compliance with the design. The next step in the manufacturing process was to 3D print the housing components where a total of five housings and two lids were printed for testing. Each of the five housings that were printed were subject to glue testing, fitment testing and review. Each print was assembled using Supa Glue, being applied in different locations. A design was then able to be chosen incorporating a 4mm lip around the ends of each section of the component being attached. Once the housing had been assembled the direct transfer of existing parts from the REN to the GREN commenced including the break light, sounder and wiring looms and Autosport connectors. These existing components were able to be preserved due to the GREN fulfilling the same requirements as the previous REN and GREN systems used in 2022.

Once the PCB arrived an initial attempt was made, to solder and attach all necessary components to the PCB board. When validation and commissioning began several tests began to fail and it was decided that the PCB needed to be rebuilt. The failure of this PCB was found to be caused by bad solder connections, that caused components such as mosfets to short and break. Once the PCB had been successfully soldered under the supervision and guidance of both Alex Gregg and Malcom Sidney the PCB was able to be commissioned after passing the validation testing. This validation and testing process was then structured and transferred into a Matlab script so that the process could be repeated and utilised in future designs. This script can be found in the appendices.

During the manufacturing period it was discovered that the PCB had been designed poorly with respect to the spacing between the Molex mini fit Jnr's. The connectors had been placed so close together that the clips needed to be cut off to connect the headers to the wiring looms. However, during testing the frictional force between the header and the wiring loom was deemed to be sufficient to keep a reliable connection between the pins due to the tightly configured nature of the board itself.

5.2 REN V3

Manufacturing of REN V3 like the manufacturing process of the GREN first took place in the form of ordering the PCB itself from PCBgogo where the PCB was soldered and the components attached. The next step in the manufacturing process was to 3D print the housing components. Using Onshape a basic housing was created to allow the board to be mounted to the car. The housing for the REN V3 was not ever manufactured as stated in the initial design section of the report that REN V3 was decided not to be used due to the transition and need for surface-mounted DT connectors.

Once the parts and board had arrived the board was able to be manufactured by soldering all of the components on. Having learned from the previous soldering mistakes of the GREN, with more attention to detail being given to the soldering an initial board was able to be made. The board was ordered in a non-traditional silkscreen colourway in the hopes that a better option than green could be found when presenting boards to judges. The colour chosen for the REN V3 was purple, which highlighted traces and connections in pink creating a good contrast.

5.3 REN V3.5

Using Onshape a basic housing was created to allow the board to be mounted to the car. With the help of Brock Symons two housings were made in preparation for testing with the brake light and sounder. One housing used a new clear filament that was printed simultaneously to the standard black PETG as a window for the brake light. This print required a few test prints to understand the clear filament and how to change the final look between clear, opaque and solid. The layer height that was found to be ideal was 0.3mm. This allowed the brake light to be rules compliant with rule T.3.3.3 diffusing the light. As well as this printed housing two Perspex cut outs were also prepared to be glues in to the second housing. One Perspex piece was diffused by sanding the inside side with 800 grit sandpaper giving a rough enough surface that the Perspex would light up as a solid piece. The other method of preparation that was used was a piece of diffusing tape that is traditionally used on shower screens and windows was stuck in the inside.

Once the parts and board had arrived the board was able to be assembled by soldering all of the components on. The manufacturing of the PCB was relatively similar to the previous boards, however when soldering the Deutsch connectors on it was found the by screwing the connector on to the board first before soldering allowed for a better connection and the connector to have a stronger mounting.

REN V3.5 was the first board on NU23 to successfully integrate the Deutsch connectors allowing for the development of a standard wiring connection layout. The pinout that was chosen to become a standard across the car was the six-pin connector with a layout that consisted of pins 1 and 6 being 12V, pins 2 and 5 being ground, and pins 3 and 5 being CAN high and low. This configuration can be seen below:

A completed REN V3.5 can be seen below:

5.4 REN V4

The manufacturing process like that of the previous REN designs began when the components and PCB arrived. A new method was used to solder the components to the board with the introduction of solder paste. The solder paste made soldering process much quicker and easier as it was able to be applied and the with the use of a heat gun the components can be quickly soldered to the board. To be able to properly utilise the solder paste a stencil of the PCB was also created via PCBgogo, where an exact cut out of the footprints of the components was made. Using this stencil, the PCB could then be lined up and taped to the bottom of the stencil and the solder is then smeared across the stencil. The board would then be removed from the stencil, the components placed on their respective pads the heat gun would then be used to melt the solder and create the bond between the components and PCB pads. By using this method, the average PCB build time was able to be decreased from 4 – 6 hours down to 2 – 4 hours depending on the board. In the case of the REN, it was able to be bult in 2 hours.

5.5 REN V4.5

The manufacturing process that was undertaken started once the PCB had been delivered to the university. Soldering and manufacturing the REN V4.5 was a smooth operation following on and using the same techniques as the manufacturing process of the REN V4. Again, a stencil was ordered so that solder paste could be used instead of traditional solder allowing for the total production time of the REN V4.5 including integration time to be 4 hours. One new piece of equipment was used when creating the REN V4.5, as two power planes had been utilised to work as heat sinks in both the ground planes and the power planes. The new equipment mentioned was that of a PCB oven. This helped in streamlining the process of manufacturing the PCB as the 5050 SMD LEDs would start to melt before the solder would melt due to the heat sinks soaking up so much of the heat. The oven allowed the PCB itself to absorb the heat and heat up with the solder allowing for a much neater finished product. The final product can be seen in Figure 52

Figure 52: Final LED chosen for the brake light (superbrightleds.com, 2023)

6. Commissioning and Validation

6.1 GREN

After the PCB for the GREN had correctly been soldered the PCB was put through a series of tests for validation. These tests included going over the board with multi metres and using an oscilloscope to feed power into specified areas of the PCB to test every component on the board. This validation testing is what led to the discovery of the first boards critical issues, which was identified as bad solder joints, where the components were not making direct contact with the pads of the board. After fixing this issue with the implementation of another PCB, and under the supervision of Alex Gregg, further testing and validation of the GREN was able to be undertaken. This testing allowed for the implementation of the code that was written with the help of Gabrielle Horsnell. This code tested well and led to the integration of the GREN to the car where further testing was undertaken to test with the car powering the GREN and a simulation of the car sending and receiving the CAN signals via the Kvaser system. These tests ultimately confirmed the validation testing done in the MECHA laboratory and the GREN was able to be attached to the car.

After completing the first track day after implementing the GREN onto the car it was found that the temperature sensors for the radiators water in and water out were giving faulty readings. The readings consistently staying at 200 degrees Celsius. As the temperature never changed a multimeter was used to find out what the power reading was on the output pin of the Teensy, where it was found that 4V was being supplied. This was causing the sensors to read the maximum temperature reading that they could read. To fix this issue two cuts were made to the traces entering the temperature sensor connector to isolate it from the system. The sensors were then reconnected using jumper wires into the system where they would be given the correct voltage and the Teensy would be able to read the temperatures correctly and then send the information on to the appropriate subsystem.

6.2 REN V3

Once the REN V3 had been correctly manufactured unit testing could take place. As all the functionality of the GREN had been preserved the previously written unit testing code was able to be used. This streamlined the unit testing of the board and allowed for the testing of the brake light to be undertaken.

A test rig was then able to be created to be able to either use the teensy to send the brake light signal or manually switch the brake light on using the power unit. During this testing it was found that the surface mounted mosfets could handle the current draw of the 10 LED's. This had been an initial concern due to the fragile nature of the mosfets. Previously what had been discovered was that the mosfets due to their tiny legs were susceptible to popping off of the board and initially it was a concern that these small legs would not be able to handle the current that would run through them. Even while being able to enlarge the trace to the appropriate size the mosfet would still serve as a choke point. However as stated earlier the mosfet was able to handle the current required to light the LED's.

Calculating the resistance size also then needed to be factored in to get the appropriate brightness of the LED's while managing the current. Three resistor values were chosen including a 330Ω, 550 Ω and 600 Ω resistor. The 550 Ω resistor was chosen as it meant that the total current that the LED's would draw remained under an amp holding at 0.75 Amps. Maintaining this current level also managed the heat produced by the LED's. The board would remain cool even running for long durations of time (in this case the LEDs are being utilised as a brake light so the expected time that the light would be on while the car was driving would only be a few seconds, with the longest duration, when putting the car into ready to drive, which can take about 30 seconds).

Therefore, the surface mounted brake light proved to be a success even with extreme testing, the LED’s proved to be able to handle up to 3 Amps without any faults. By testing the extremes, it was decided that moving forward and in the next iteration a heat shield should be put in place to help ensure that there are no heating issues while the board is on the car. The surface mounted LEDs met the requirements of rules and showed the compatibility of the new system within the NU23 low voltage systems.

6.3 REN V3.5

Once the REN V3.5 had been correctly manufactured unit testing could take place. As all the functionality of the REN V 3 had been preserved the previously written unit testing code was able to be used. This streamlined the unit testing of the board and allowed for the testing of the brake light to be undertaken. Testing of the Relay and the sounder was also carried out during this time where in the lab environment the sounder running at 2375khz was found to be loud enough. However, when the board was integrated to NU23 the sounder was found to be almost too quiet when enclosed in the housing. To combat this a few small holes were cut into the enclosure making the sounder slightly louder. The sounder measured at 40 decibels, significantly quieter than intended for use. For further experimentation a cone piece was made to slide over the top of the sounder to see if this would successfully amplify the sounder appropriately. This however ultimately failed only providing a slight increase in noise and made the sounder a more directional noise, defeating the purpose of sounder that could be heard all around the car.

Testing the brake light with 3 different light covers each prepared as stated in the manufacturing process were then tested. The housing that featured the clear filament worked well in a dark environment however when the brake light was not on the housing would have a large white rectangular feature that was prominent. This created worry that when the light was not lit up that the white housing section may be perceived as another signal light. When testing the standard, the sanded Perspex the light was diffused well however depended on how well the Perspex was sanded. If it was sanded poorly when the brake light would come on, the scratches would be shown and be obvious, whereas when using the 800-grit sandpaper and sanding it more carefully the result resembled that of frosted glass. Finally, the third method was tested with the frosted glass sticker being applied. The sticker diffused the light however the LEDs were still clearly visible through the Perspex. Ultimately this led to the decision that the sanded Perspex using 800 grit sandpaper would be used, as it met the rules requirements as well as having the professional final look.

All the above methods for testing highlighted the same principal for when making an enclosure. The further away the Perspex was from the LED’s the more diffused the brake light would be. After discovering this, the Perspex was tested at several different lengths, 10mm, 11mm, 12mm, 13mm, 14mm, 15mm away. Once each of these lengths had been tested 13mm was determined to be the best distance from the LED’s allowing the LED’s to still be bright while also diffusing the light correctly.

REN V3.5 was then determined to be a success, fulfilling all requirements set out for the board to achieve including custom making the brake light through surface mounted LED’s and integrating Deutsch connectors to NU23. The surface mounted sounder functioned well however, it was determined through the testing that the number of sounders would need to increase to increase the level of sound produced.

When mounting and soldering the serial DB9 connector to the physical PCB it was found that the footprint that was used did not correctly line up with the physical component. When the serial connector was soldered to the board, the respective female connector could not be connected securely. This happened as the connecter was not actually close enough to the edge of the board and the width of the female connector was too large. Therefore, to combat this issue for the next iteration of the board the serial connector will need to be placed over hanging the edge of the board in the initial design phase of the board.

6.4 REN V4

Commissioning the REN V4 followed the same process as boards previous, where sections of the board were made and then tested. By designing the PCB in blocks this process was made simple as each individual circuit on the PCB was able to be tested in stages. The first circuit to be tested was the main power supply circuit and the 5V regulator. Once this had been tested the relay was integrated and tested, along with each of the associated LEDs to indicate that the circuit was getting power. This process was then followed integrating the rest of the circuit blocks that can be seen in the REN V4 schematic, with the final circuit being implemented and tested the brake light circuit.

During the testing of the sounder circuit the sound was significantly increased by using two of the piezo buzzers each receiving 6V. The Piezo buzzers when enabled reached a peak of 80 decibels much higher than that of the single buzzer. When the sounder reached the car, it was also determined that the sounder reached a satisfactory sound level in a more open environment (that being the TA workshop). However, when further testing was done on track days it was found that with everyday background noise the sounders were no longer loud enough. This led to the reintegration of the original 12V piezo buzzer used in the 2022 competition. A photo of the makeshift integration can be seen in Figure 53:

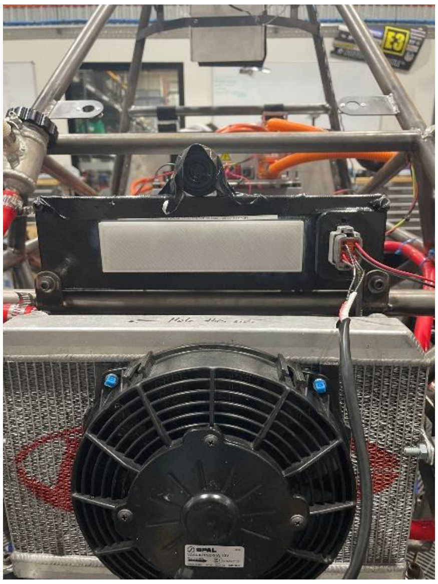


Figure 53: REN V4 testing original sounder

This rudimentary quick fix helped solidify the need for the old sounder. It was found that in the pursuit of making everything smaller that there was no substitute for a larger speaker. In this photo a 3d printed cover for the brake light (white plastic section) can be seen. During the testing phase for the brake light the resistance was again dropped down from 550 Ω to 150 Ω. This greatly increased the brightness in bright and sunny daylight conditions. However, the white plastic again was not chosen as was discovered in testing for the REN V3.5 that the sanded Perspex performed the best when sanded with a fine enough grit (800 grit sandpaper).

During the testing phase with the REN V4 on the car it was found that the CAN bus would drop out and send error frames with everything plugged in. This error seemed to only happen occasionally and over the course of 2 to 3 track days the error was able to be narrowed down the Motec beacon being plugged into the REN. This error was caused due to a miss match in board rates as the Teensy was running at 250 kbits and the Motec was running at 100000 kbits. This issue was solved by plugging in an intermediate board that allowed the board rate to be adjusted so that the REN would be able to send the correct CAN messages.

6.5 REN V4.5

During the commissioning phase of the REN V4.5 it was found that the new mosfet component was heating up to an alarming rate. In this initial testing it was recorded that the mosfet reached 110° Celsius. To test the heat output of the mosfet to see if the component would reach a dangerous level, that could lead to other components being damaged, a make shift power supply set up was created. Using three power supplies in series, the desired 15 Amps of current were able to be fed into the REN V4.5, to power four fans. The fans that were used were 12V, 3 Amp cooling fans that could be found in the accumulator. This set up was then run for 30 minutes where the mosfet reached a temperature of 150 degrees Celsius. Once this temperature was reached the set up was turned off and the mosfet was allowed to cool before attaching a heat sink directly to the mosfet. The set up was then turned back on and run for another 30 minutes. During this test the mosfet only reached a temperature of 60 degrees. This was deemed safe enough to run however further investigation was led into why this was happening.

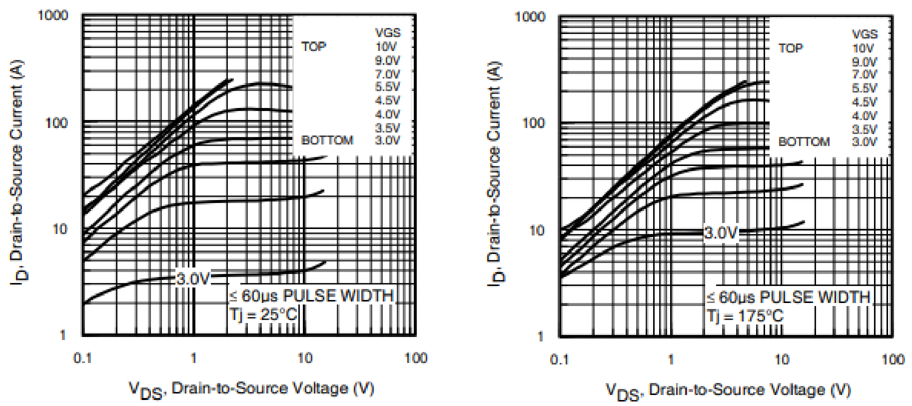


Fig 1. Typical Output Characteristics **Fig 2.** Typical Output Characteristics

Figure 54: Core electronics data sheet screen shot

As can be seen in the above graphs, it was determined that the drain to source voltage was not high enough based on the drain to source current. To successfully run the mosfet at 15 Amps, the schematic for the PCB would need to be redesigned so that the drain to source voltage could be 10 volts, or in the case of NU23 12V. By increasing the voltage, the gate is able to be opened further, thus decreasing the amount of resistance and ultimately reducing the amount of heat produced.

6.6 Cost Report

A cost report which was prepared for the static events associated with the competition can be found in this section of the report for the REN V4.5 competition used board. The 2022 cost report for the REN can also be found in this section to serve as comparison between the years.

Name	Quantity	Total cost	Supplier	Notes
Molex Mini-fit 2x1	4	$4.44	Element14	
Molex Mini-fit 2x3	6	$10.86	Element14	
Molex Mini-fit 2x4	1	$2.8	Element14	
Molex Mini-fit 2x8	1	$4.87	Element14	
2N7002	2	$1.18	Digikey	
Q_PMOS	1	$0.58	Digikey	
Dip switch	1	$2.00	Digikey	
TJA1051T-E	2	$4.86	Digikey	
LM1117-5.0	1	$2.72	Digikey	
Fuse holder	1	$2.05	Digikey	
Blade fuse mini 10A	1	$1.22	Digikey	
Resistor 120Ω	1	$0.15	Digikey	SMD 1206 3216 Metric footprint
Resistor 475 Ω	1	$0.15	Digikey	SMD 1206 3216 Metric footprint
Resistor 1K Ω	4	$0.60	Digikey	SMD 1206 3216 Metric footprint
Resistor 1.1K Ω	1	$0.15	Digikey	SMD 1206 3216 Metric footprint
Resistor 2KΩ	1	$0.15	Digikey	SMD 1206 3216 Metric footprint
Resistor 3.3KΩ	1	$0.15	Digikey	SMD 1206 3216 Metric footprint
Resistor 16.2KΩ	4	$0.60	Digikey	SMD 1206 3216 Metric footprint
Resistor 43,2KΩ	4	$0.60	Digikey	SMD 1206 3216 Metric footprint
Capacitor 0.1uF	1	$0.42	Digikey	SMD 1206 3216 Metric footprint
Zener Diode	1	$0.51	Digikey	
LED	4	$2.18	Digikey	SMD 0805_2012 Metric footprint
REN V2 PCB	1	$11.14	pcbgogo	$37usd for 5 pcbs
12V, 6Ah LFP Battery (PVC, BLF-1206A) + charger	1	$142.66	Bioenno Power	
Anderson connector	1	$5.50	Jaycar	Battery connector
Brake light	1	$60.48	LED auto lamps	
Sounder	1	$23.37	Digikey	
PETG	~560g	$36.4	Prusa	1kg prusament + shipping = $65. $65 * 0.56kg = $36.4
M5 x 20 bolt	4	$0.96	NHTB	
Name	Quantity	Total cost	Supplier	Notes
M3 nyloc nut	16	$3.84	NHTB	

Figure 55: Screen shot of Bill of materials taken from Patrick Gleesons Report 2022 (Gleeson, 2022)

M3 x 10 bolt	16	$5.44	NHTB	
Rubber gromet	2	$0.56	Digikey	
M6 ring terminal	2	$0.47	Element14	
Red wire	3.3m	$4.73	Digikey	30m = $43
Black wire	2.6m	$3.73	Digikey	30m = $43
Green wire	1.6m	$2.29	Digikey	30m = $43
Yellow wire	1.6m	$2.29	Digikey	30m = $43
White wire	1m	$1.43	Digikey	30m = $43
Blue wire	1.4m	$2.00	Digikey	30m = $43
Brown wire	0.4	$0.57	Digikey	30m = $43
AS010-98PN	4	$284	Racespec	Red size 10 flanged AS
AS010-98PA	2	$162	Racespec	Yellow size 10 flanged AS
AS614-19SN	1	$99	Racespec	Red inverse size 14 flanged AS
AS012-98PA	1	$99	Racespec	Yellow size 12 flanged AS
4mm red banana jack	1	$3.15	Jaycar	GLVMP
Size 10 AS gasket	6	$36	Racespec	
Size 12 AS gasket	1	$6	Racespec	
Size 14 AS gasket	1	$6	Racespec	
Male AS pins	40	$N/A	Racespec	Included with connectors
Female AS pins	16	$N/A	Racespec	Included with connectors
Teensy 4.0	1	$37.78	Digikey	

Figure 56: Screen shot of Bill of materials taken from Patrick Gleesons report 2022 (Gleeson, 2022)

Electrical	A4002	AA	REN	
	40004			PCB
	40005			REN Enclosure

Figure 57:First half of the cost report table for the REN 2023

	$17.89	1	-	$16.70	$1.19	-	$17.89
	$11.22	1	$9.50	$0.56	$1.16	-	$11.22
	$16.21	1	$1.76	$14.45	-	-	$16.21

Figure 58:Second half of the cost table for the REN 2023

7 Sponsorship Procurement

In 2022 NuRacing was lucky enough to secure sponsorship with Sherwin Williams. Sherwin Williams is the largest automotive paint manufacturer in the world, sponsoring all kinds of automotive related teams including the Mercedes Benz formula E car.

In 2023 NuRacing approached Sherwin Williams again securing a labor and paint supply sponsorship to the value of $3000. During this time leadership along with a few team members including Mitchel Boots, Marisa Mclean, Jye Hollier and Nicolas Lyall met with Dr Alex Gregg to design a livery for NU23. During this time NuRacing worked alongside Sherwin Williams to produce one of the cleanest and well-polished designs NuRacing has ever produced. Keeping to the fundamentals that less is more, a two tone colour scheme brought NU23 to life. Sherwin Williams offered insight into suggesting the colour scheme and helped to line up and straighten the body of the aero kit.

Through this time Sherwin Williams offered their expertise allowing students to learn the limitations of paint and how to make the colours of NU23 shine brightest. Sherwin Williams also helped make suggestions on how the car should be prepared for the car to look its best. With this insight and knowledge transfer the students of NuRacing were able to create and prepare the initial molds and final aero kit.

7.1 Body Kit Involvement

In 2023 a new design of aero kit was created by Mitchell Boots, prioritizing low drag and low weight. Mitchell was able to create a design that met these requirements allowing other students to help in manufacturing stages of the design. During this time Mitchell was able to transfer his knowledge that was taught to him by Bill McBride. In this time the students of NuRacing were able to learn about how the structure of fiber glass works and the importance of the layup process. Creating the initial molds as well as creating the final aero kit was a process that took about two weeks. A more detailed entry into the design and process that was undertaken in creating the body kit can be found in Mitchell Boots report.

Once the aero kit had been created Sherwin Williams was able to guide and suggest tips to the students on how to prepare the aero kit for painting. These suggestions included methods of sanding that can preserve hard edges as well as how to apply body filler in a manner that you would not be able to see that holes have been filled.

8 COMPETITION PERFORMANCE

At the 2023 competition NU23 performed exceptionally placing second in two of the five dynamic events, skidpan and autocross. 2023 marked the first year that NuRacing had managed to achieve such a high result in any of the dynamic events and at the competition proved to be a reliable and consistently high paced car. Throughout the competition the REN performed flawlessly even on the hot days the mosfet for the cooling did not exceed too high temperatures. A factor to note while at the competition and sitting on top of the hill overlooking the track, the sounder could be heard from nearly 100 meters away.

Nu23 performed better than expected having NuRacing on track to place top three before reaching the 11th lap in the endurance race. Temperatures appeared fine and there were no signs of faults on the car when suddenly NU23 cut out eliminating NU23 from the endurance competition. This was an unfortunate end the all the efforts put in by the 2023 students, being robbed of a podium finish with so few laps remaining.

Ultimately NuRacing finished 7th place not scoring as highly as the students of the team would have liked, however placing second in skidpan and autocross was not easily achieved feat and the students of 2023 are proud of their achievements.

Figure 59:NuRacing Team 2023 at Calder Park

9. Other Works

9.12024 Designs and Research

In the months leading up to competition and before the decision was made to make the REN V4.5, research was undertaken looking into both brake temperature sensors and wheel speed sensors. During this time several sensors were researched. Avenues for both wheel speed sensors and temperature sensors were explored.

During the research phase two options for brake temperature sensors were found, where an infrared sensor was chosen. This option was chosen over other alternatives such as thermocouple temperature sensors. This decision was reached quickly due to the fact that the brake temperature sensor market offered very few options. Most sensors were advertised as a part of a package which included an inbuilt monitoring system that is designed to be displayed inside a normal car alongside the regular dashboard. This would not meet the requirements due to the fact that the temperature sensors need to be integrated through CAN.

Thermocouple brake temperature sensors were not chosen due to the mounting of them needing to be so close to the brake discs. The brake disc on the rear axle of the car would not have any problems mounting a thermocouple sensor however, the front brake discs were located inside the wheels. This meant that the margins inside the wheel would be very thin and there was not much freedom regarding mounting them.

The infrared sensor was chosen due to the fact that mounting the sensor could be done on both the front brake and rear with relative ease. As the temperature was read through infrared the sensor could be optimized through code and setting to read at different distances as opposed to the thermocouple sensor that had a defined reading distance. The IZZE racing sensor was chosen as this product was the only product on the market not to feature the built in screen display as discussed above and the sensors were CAN compatible. The IZZE racing sensors can be custom configured including being able to configure the sample frequency, emissivity, and the sensor feature customizable CAN IDs for temperature range.

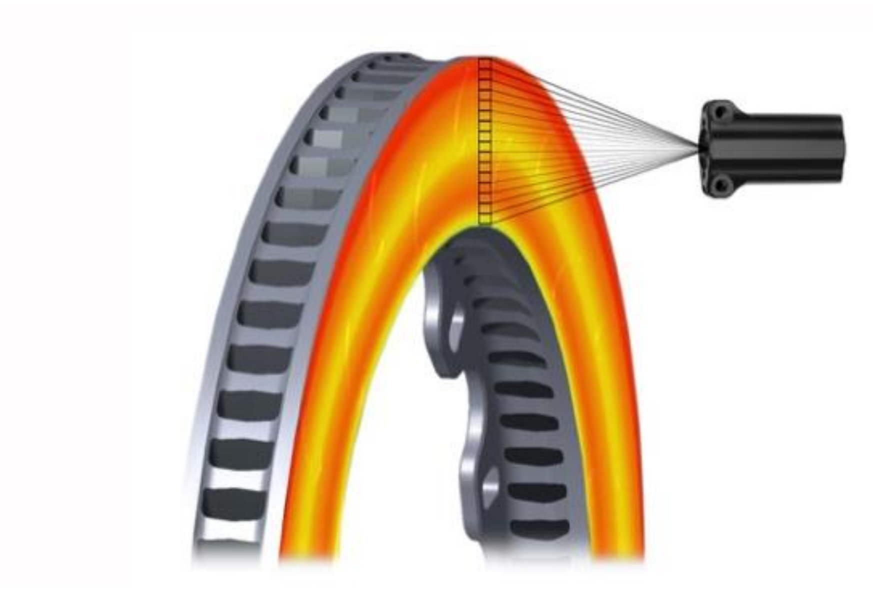


Figure 60: IZZE Brake temperature sensor diagram - (IZZE , 2023)

Choosing the configurations for this sensor, it was decided to order the sensor at 32hz, so that the CAN bus would not become overloaded. The channel count was also chosen to be either 4 to 8 channels as the brake temperature does not need to take too frequently nor too many temperature readings across the disc. The sensor would also be able to be directly integrated into a "test circuit" that has been provisioned but not completed. This board was called the GOOBER which is a board designed to be plugged into an expansion port and relay CAN information giving both temperatures and wheel speeds.

By looking into wheel speed sensors, it was decided that getting a standard OEM hall-effect sensor due to the wide availability of the sensor and the cost. A hall-effect sensor has a permanent magnet inside the which is then triggered when a metallic object rotates past it. A Porsche hall-effect sensor made by Bosch was then selected. The data sheet for the wheel speed sensor can be found in the appendices.

Figure 61:Hall Effect Wheel speed sensor made by Bosch (Bosch, 2023)

A test rig was created to do testing with the wheel speed sensor. To do this, Onshape was used to create a stand that the wheel speed sensor could be mounted to. This stand can be seen in Figure 62:

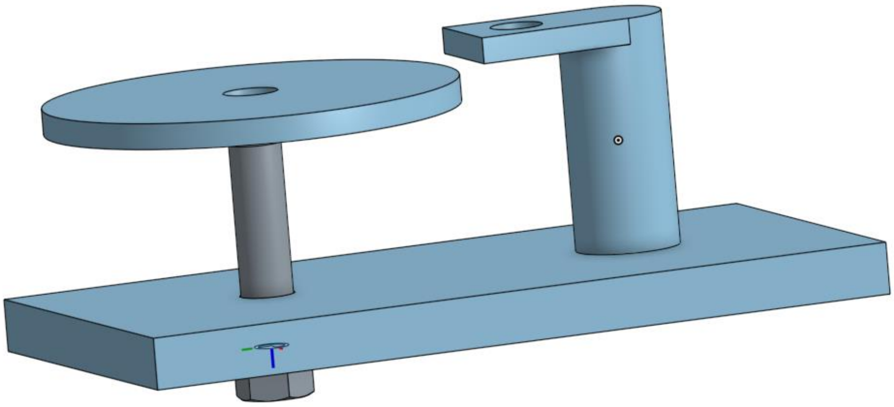


Figure 62: Wheel speed sensor test jig

A wheel was then also created in Onshape and 3D printed which a number of washers were glued to. The wheel was then placed on a bolt with nuts so that the wheel could be adjusted to the required 1.3mm air gap as stated in the data sheet. Once the sensor had been wired up and connected to an oscilloscope, the wheel was spun past the sensor. This showed an interesting reading which showed that a few more circuitry components would be required. While keeping in mind that the wheel was spinning at relatively low speeds compared to what the wheel of the car would be spinning at (approx. 6000 rpm). The voltage produced only produced a peak voltage of 1mV which would be far too small for a teensy to be able to detect. The Teensy detecting the signal is important as code would need to be written to convert the analog signal produced into a digital number.

A circuit was then able to be created in LT Spice which allowed a correct signal to be produced. By creating this circuit, the required components were able to be identified. The main component needed was an Op am. This Op amp allows for the conversion of a analog wave to be converted to a digital square wave while simultaneously increasing the signal to 1V peak.

Through this research a circuit was found online that can serve as the building blocks for future students to investigate. The following circuit can convert a sine wave into a digital wave as well as increasing the peak voltages.

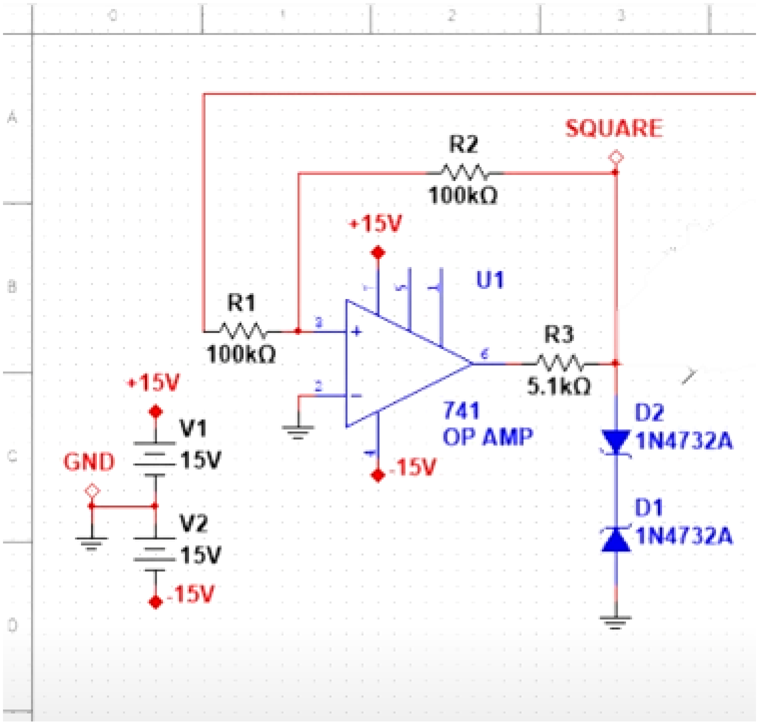


Figure 63: OP Amp circuit for wheel speed sensor - (Blueprint, 2020)

The next challenge presented for the wheel speed sensors and brake temperature sensors is finding mounting locations. The rear mounting location for the brake temperature sensor is relatively easier to implement as the power box provides ample room and the right angles to get readings for the brake temperature sensor, as the rear wheels are directly connected to the motor wheel speed is already able to be calculated.

Mounting positions for the front wheel speed sensors have proved to be difficult to decide due to the tightly packed nature of the brake discs inside the wheels. However one possible location that could serve this purpose is mounting the sensor to the upright of the wheel. A bracket would then need to be made to meet the air gap requirements of the sensor. Work with a Mechanical engineer would then need to be undertaken to either turn the brake into a wheel encoder by making cut outs around the outside diameter or to integrate a wheel encoder onto the hub. The upright can be seen highlighted in Figure 64.

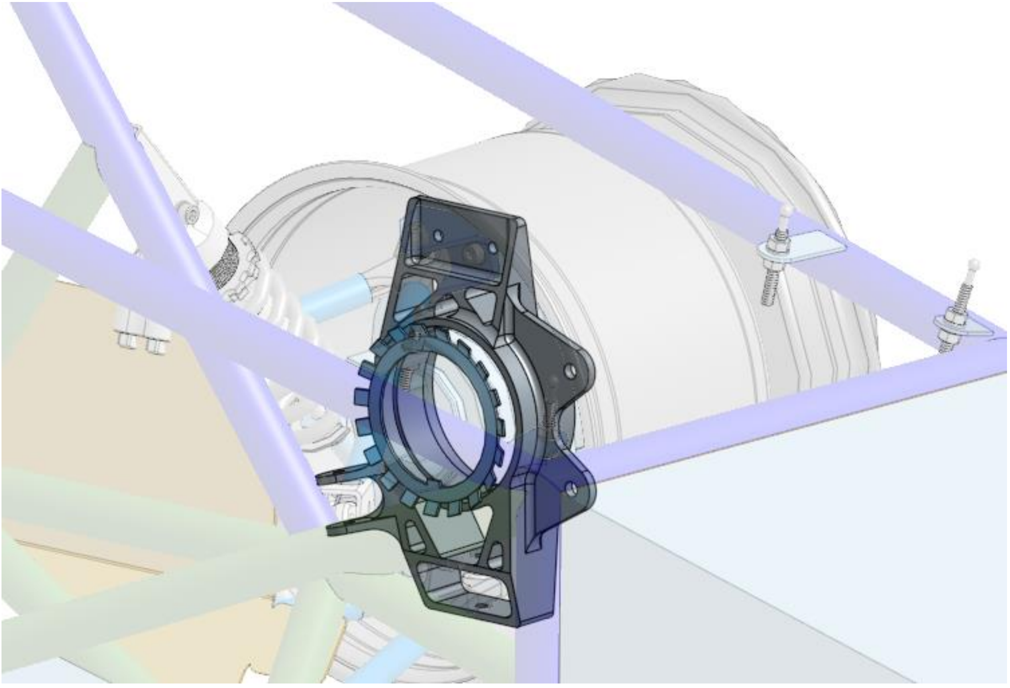


Figure 64: NU23 Front wheel upright

The research conducted into the placement of sensors and circuitry associated with the sensors is intended to help future students carry on and create this system. By creating this system, valuable data would be able to be gained at track days and allow team members to tune the motor controllers far more accurately.

9.2 2023 Involvement

Over the course of 2023 many challenges and opportunities presented themselves. This section of the report will give a brief overview into the other projects and works undertaken, to help bring the car together in time for competition.

- **PCB review** – Reviewed PCB's such as the DEN, PEN and LVD by giving a detailed design review to each of the designers.
- **Body kit design** – Due to previous knowledge of automotive paint, assistance with the design and colour scheme of the body kit was given to give a "clean" finished product.
- **Body kit manufacture** – Assisted in making the body kit laying up the moulds, the body kit itself, as well as sanding of the plug. Assisted in the final sanding phase in preparation of painting.
- **Body Kit Delivery -** Delivered body kit to Sherwin Williams maintaining good relations with sponsors.
- **Chassis Preparation** - Prepared the chassis for powder coating, by sanding it down and creating a paint ready surface.
- **Motor controller installation** – completed a 16-hour installation and tuning of the new Cascadia motor controller with Josh Dawson, Jye Hollier, Malcolm Sidney, and Jacob Bush.
- **Cleanliness** - Helped maintain cleanliness of workshop and laboratory, routinely cleaning and tidying up both workspaces.
- **Track day attendance** – attended track days assisting with data collection, marshalling, set up and pack down.
- **Leadership** - Organised and attended a special track day two months out from competition to gather important wheel and tire data.
- **Accumulator** - Helped pull apart and rebuilt the accumulator including the transition from the 8 segment, to 9 segment accumulator. Assisted in the cable management implementation of the accumulator also.
- **PCB Repair** - Performed diagnosis and repair of the LVD the night before a track day so that the track day could still go ahead.
- **Wiring looms** - Built wiring looms for low voltage electrical systems across the car following the centripetal twist standard.
- **Event Driving** - University approved driver for events.
- **Competition Readiness** - Built spare PCB's for competition.
- **Waterproofing** - Waterproofed the electrical components for competition, utilizing silicone on the PCB housings.
- **Design Event** - Presented the Low Voltage system to design judges.
- **Track Day Preparation** - Packed for tracks days and competition.
- **Car Rebuild and Tear Down** - Assisted with all car tear downs and rebuilds, including transitioning from EV.Three to NU23.

10. Conclusion and Recommendations For 2024

Over the course of 2023 many lessons were learnt regarding creating a Low voltage system. The REN that was taken to competition was created to be small, reliable and to absorb all previous functionality that previous systems had in place. The REN V4.5 while meeting all these requirements can undergo one final touch up design iteration, however in doing this no more functionalities would be able to be gained. The competition REN had two flaws that can be immediately addressed in 2024, the first being a miscalculation in trace width between the cooling block and the mosfet, and secondly the cooling mosfet be provided with a higher voltage.

To correctly give the cooling mosfet the required voltage of 10-12 volts, the circuit would need to be connected to the main power supply to the REN. This would require a secondary mosfet to drive the main mosfet. By reaching this conclusion the Low Voltage team in 2024 could safely integrate this system in this way or revert back to using a automotive relay. Both integrations would be as reliable as each other with the only exception being that by continuing to use the mosfet the boards overall footprint would not need to be increased. However, by using the relay, reinstalling an easily obtainable part.

Finally, a third option to be explored is to remove the REN entirely. To be able to do this the cooling control and sounder would need to be absorbed by the CEN. Once these circuits have been absorbed by the CEN another board can then be created that simply works as power distribution, providing power to any testing components necessary. This then leaves the brake light where three suggestions can made. The first suggestion is to just use the old brake light; however, this is large and bulky, not leaving much room for imagination and mounting. Secondly move the surface mounted brake light across to the expansion node and have the expansion node absorb become the new REN. The third option is to research a new type of LED. The LED that would most likely bring the greatest improvement and have the flexibility to be mounted on the surface of a PCB or mounted to the chassis, is the LED that NU Marine use on the team's boat. This LED is a 5V COB Strip LED. This LED can be seen in Figure 65:

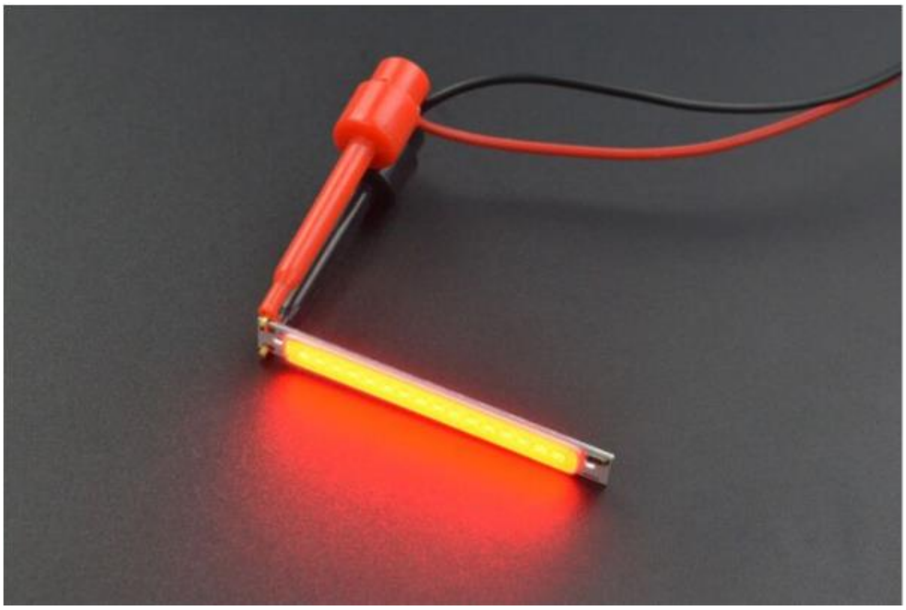


Figure 65:5V COB Strip LED - https://core-electronics.com.au/5v-cob-led-strip-light-red.html

The 5V COB strip LED would provide the most flexibility and has been proven in the harshest of daylight to perform well on the NU Marine boat. The LED is also compliant with FSAE rules of compliance already being diffused as standard.

In conclusion the FSAE competition has been summarized, how NU23 fits into that competition and the importance of the Low Voltage electrical system been explained. The process of then creating the REN throughout all of its design and manufacturing phases has also been explained.

Throughout this process a competition ready and rules compliant board was able to be created working flawlessly throughout the competition at Calder Park raceway. Contributing to the successes of the team. Future works have also been discussed setting any of the low voltage team in 2024 up for success and helping to show the thought process of the 2023 team more clearly.

With this being stated I wish the 2024 team all the best and hopefully NuRacing can secure a podium finish.

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Appendices

Appendix.1. Letter of Sponsorship from Sherwin Williams

SHERWIN-WILLIAMS.

To Nick Lyall and the University of Newcastle.

Thank you for approaching Sherwin Williams as a sponsor for the University E-car project.

Sherwin Williams is the largest Paint manufacturer in the world, being sponsors of Mercedes E-car globally, therefore it was a wonderful opportunity for us to be involved in a local Australian project while keeping in the automotive area.

When you approached us, we found that your professionalism of how you conducted your self and the University, showed us this project was of high standards.

After going over your business plan of sponsorship, Sherwin Williams Australia were happy to invest the value of $3,000 dollars towards the paint coatings of your E-car project.

Your organisation of keeping us in the loop and sticking to time frames were of the most importance. Sherwin being a large Machine has limited time at our facility and fitting your project into our schedule worked seamlessly due to your correspondence with us.

The sponsorship was to supply products and skilled labour to prep and respray the E-Car parts. Working with you and the engineering team, made it very clear how you needed these parts to look after going through your detailed plan of the colour scream.

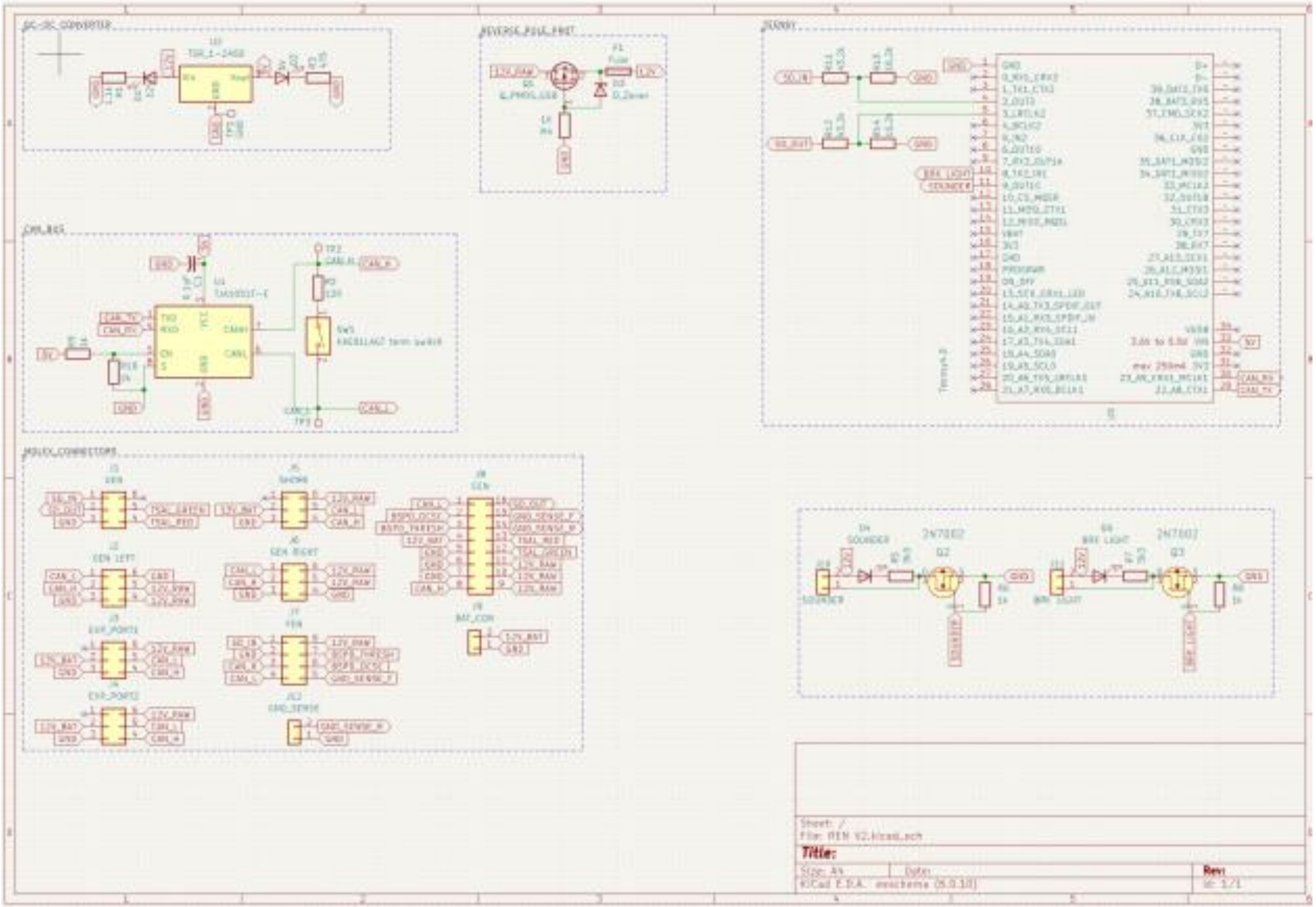
It was a pleasure to help our local University of Newcastle and work with the Head tutor Alex Gregg.

Alex guiding his students on approaching Companies for sponsorship shows a very good strategy

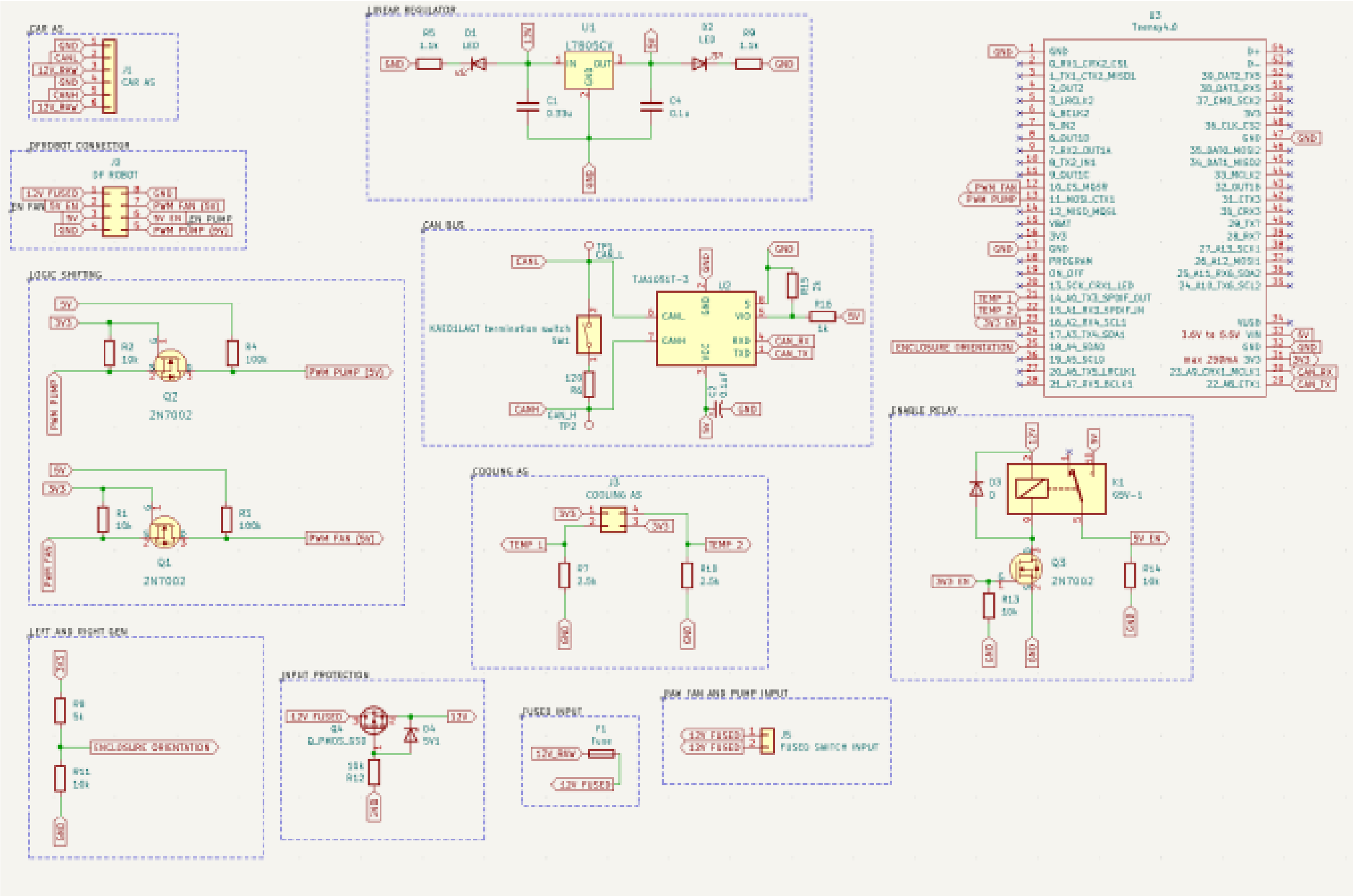
Regards

Richard Reneman
General Manager – Automotive ANZ & ASEAN
The Sherwin-Williams Company

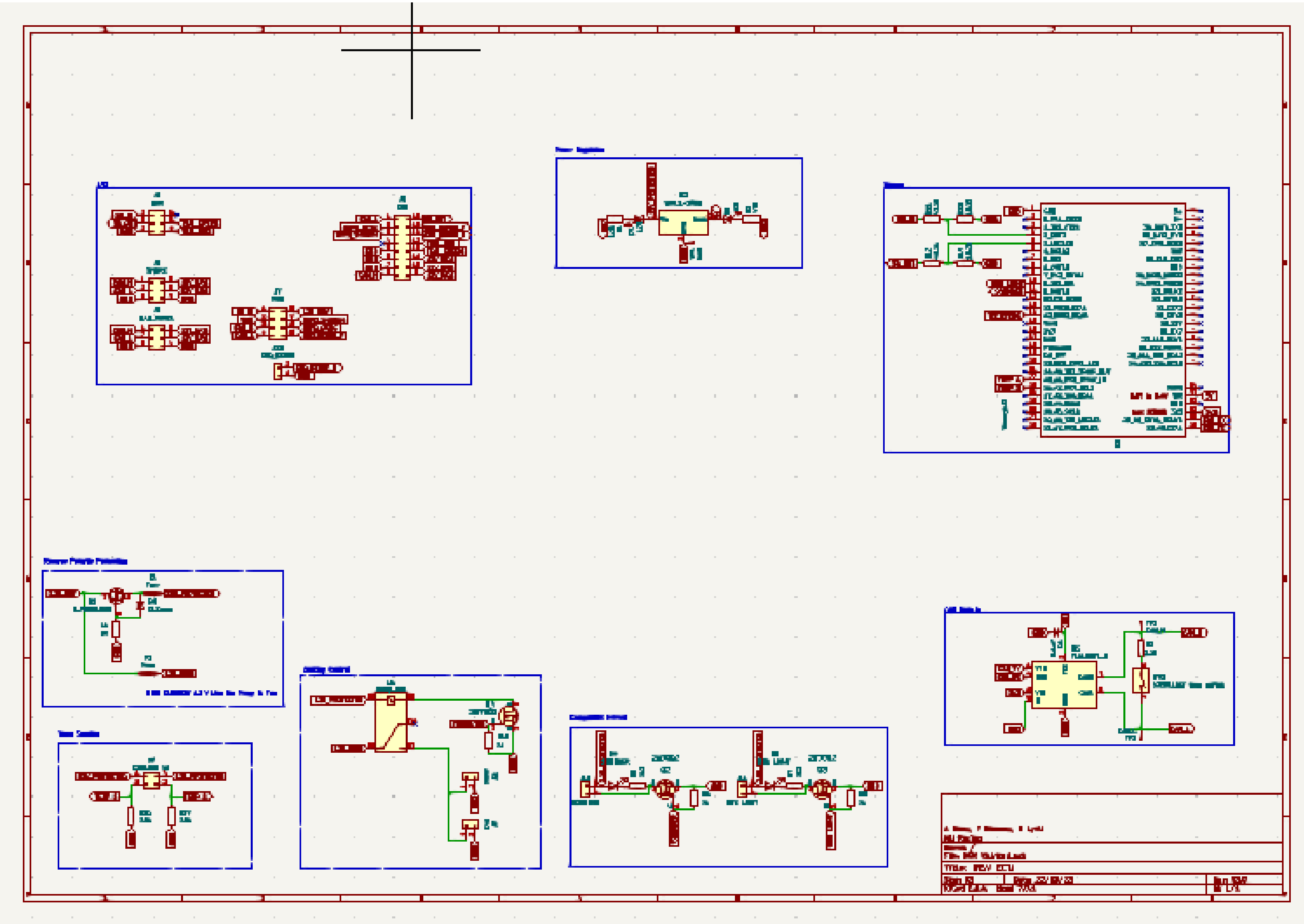
Appendix 2. REN Schematic By Anthony Moon (Gleeson, 2022)



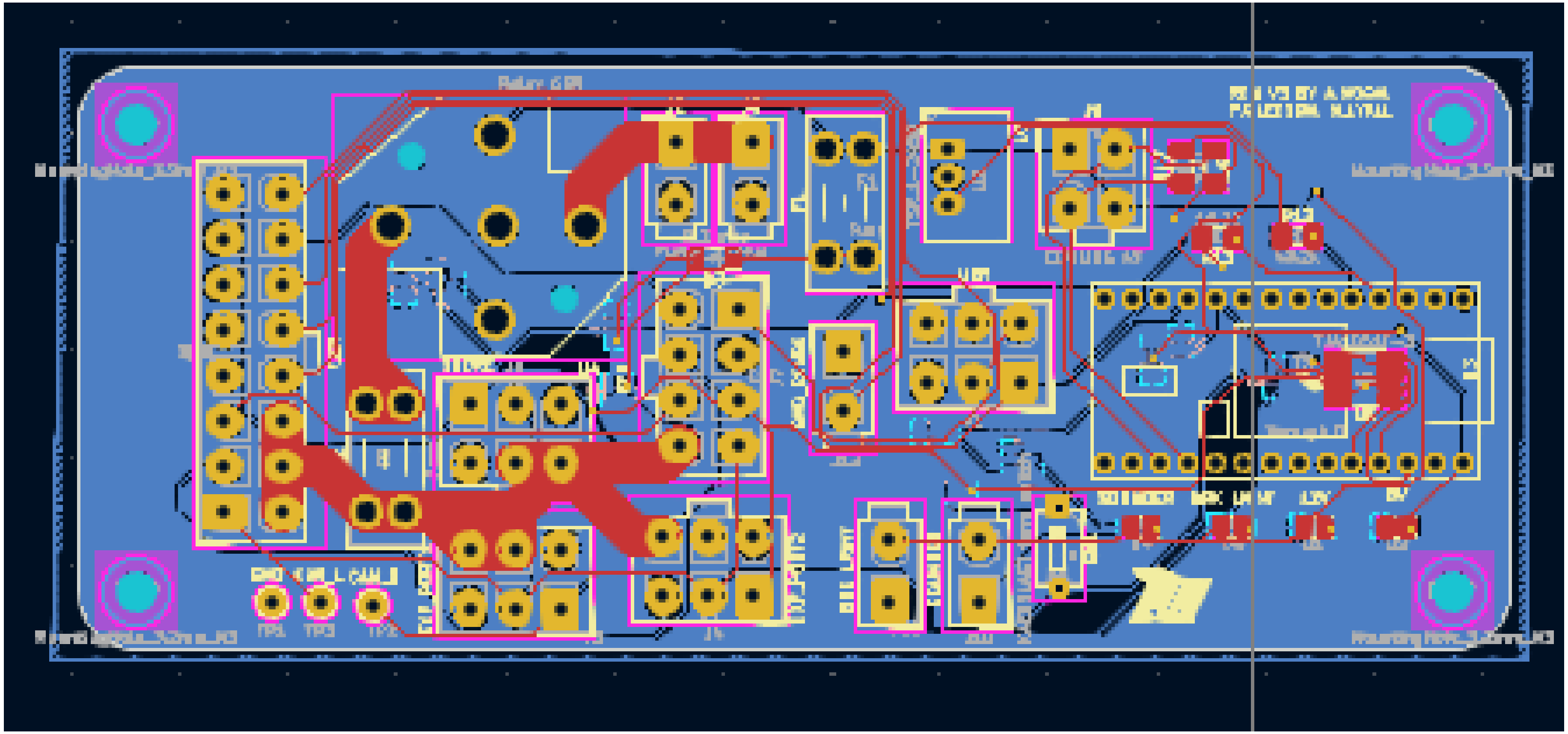
Appendix 3. GEN Schematic By Ethan Guse (Gleeson, 2022)



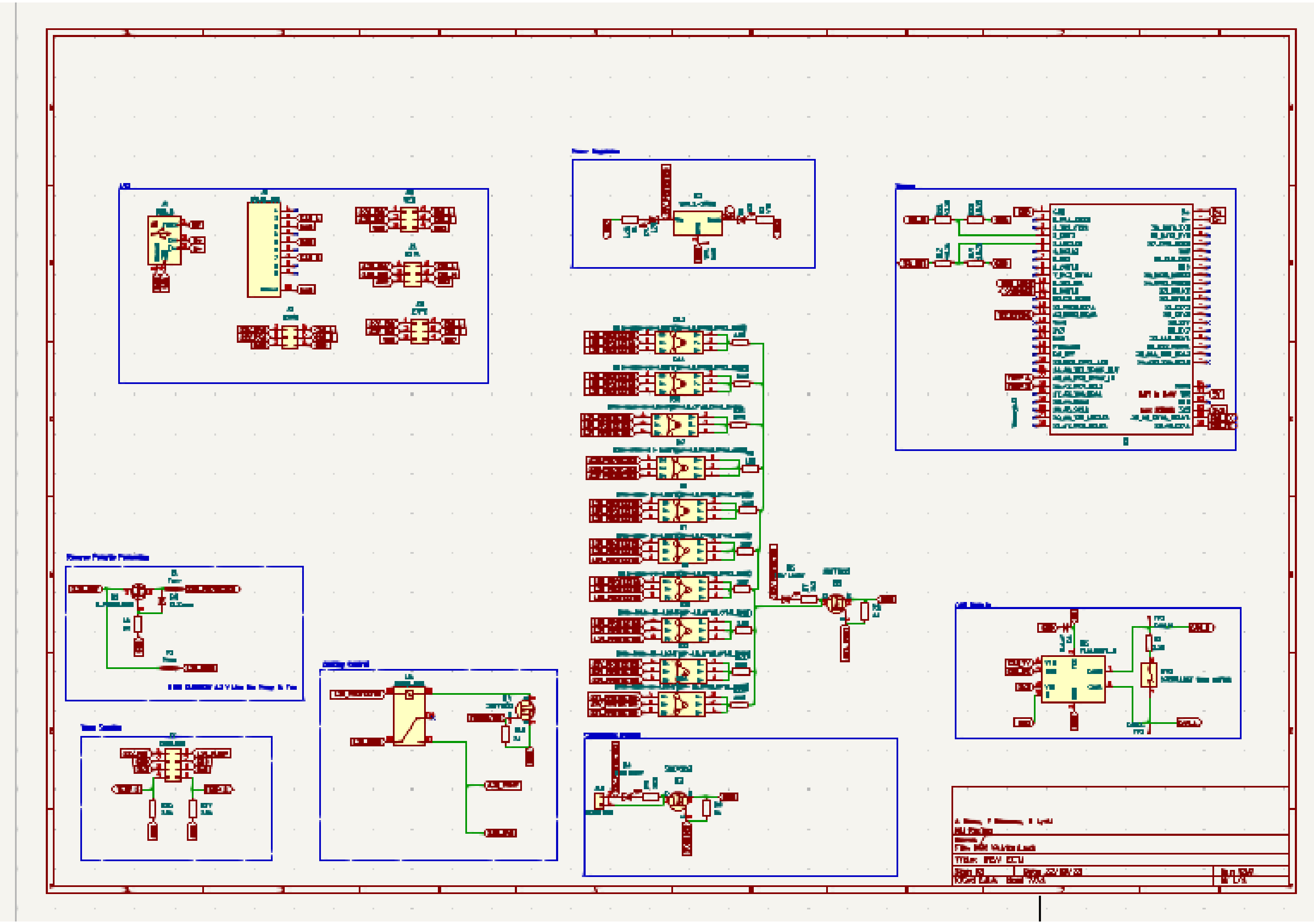
Appendix 4 GREN Schematic



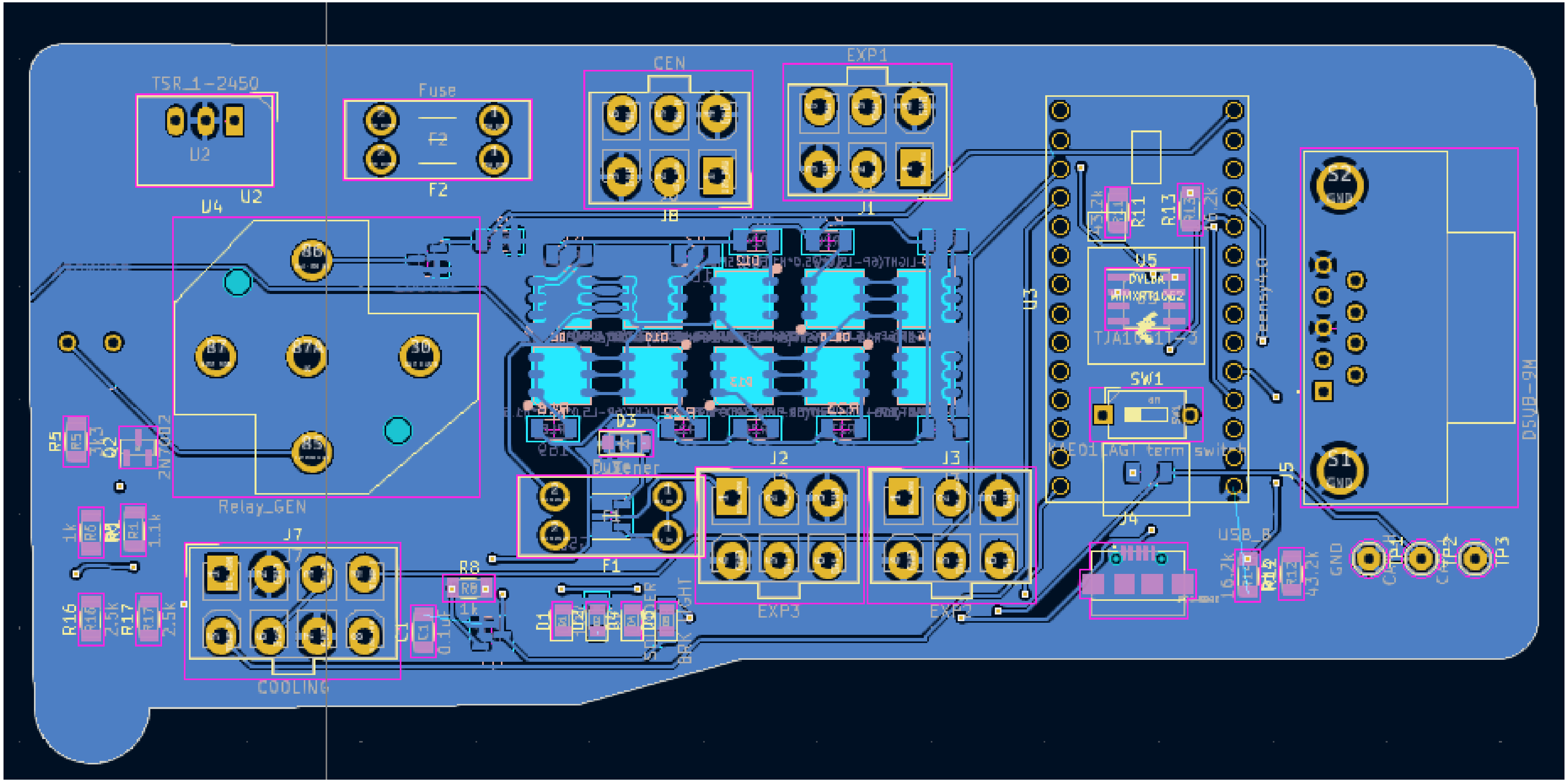
Appendix 5. GREN PCB Design



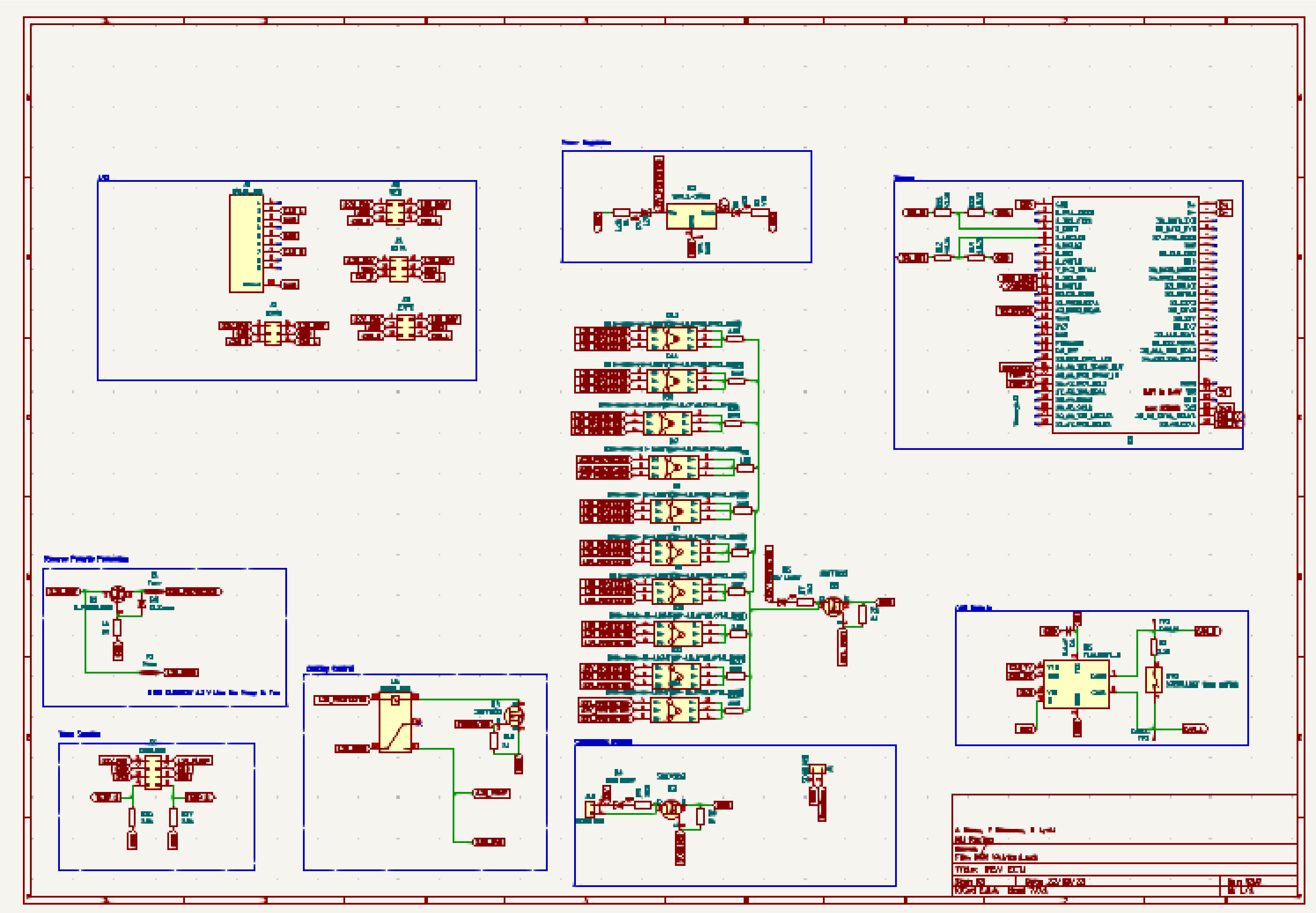
Appendix 6. REN V3 Schematic



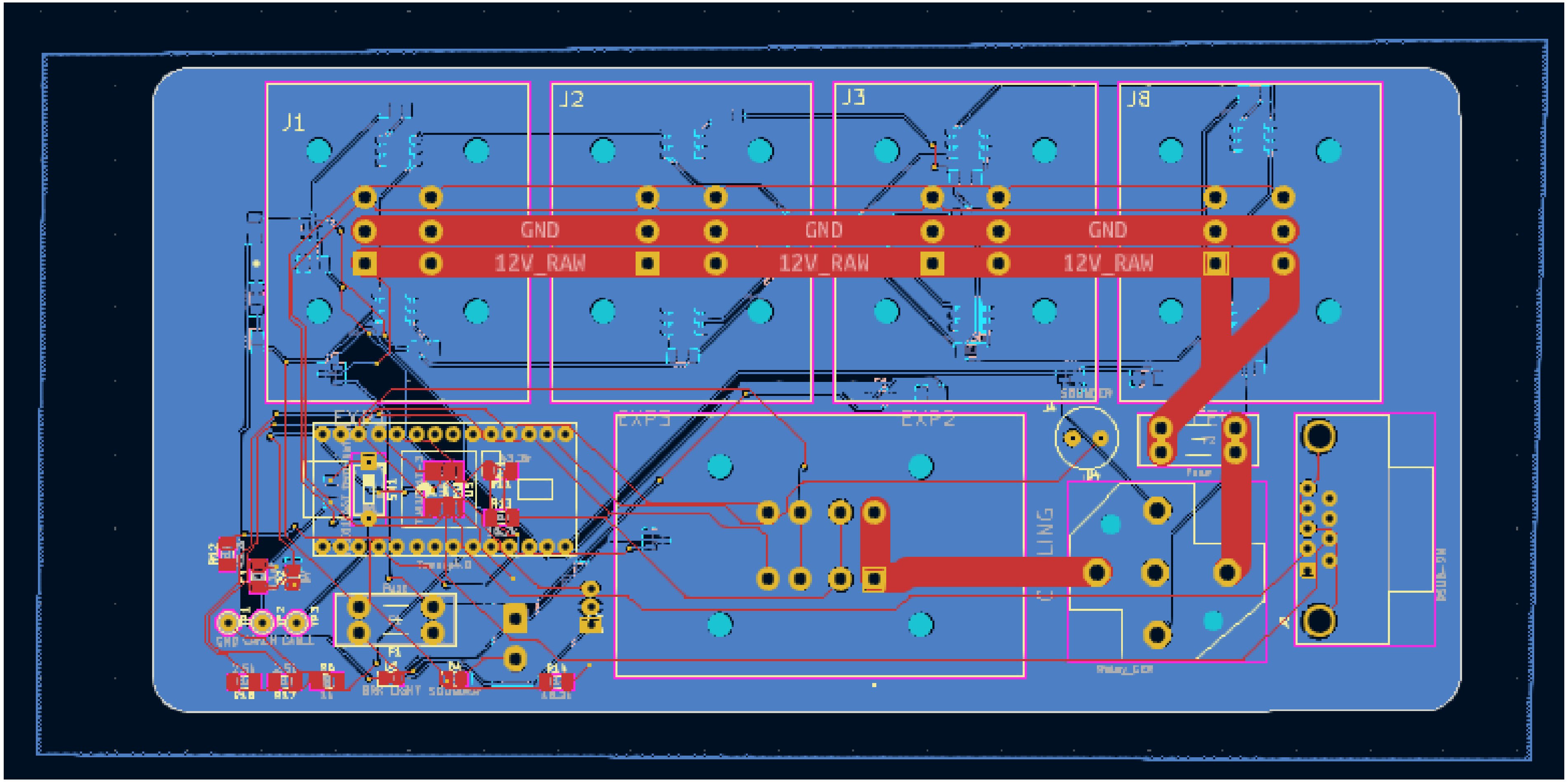
Appendix 7. REN V3 PCB Design



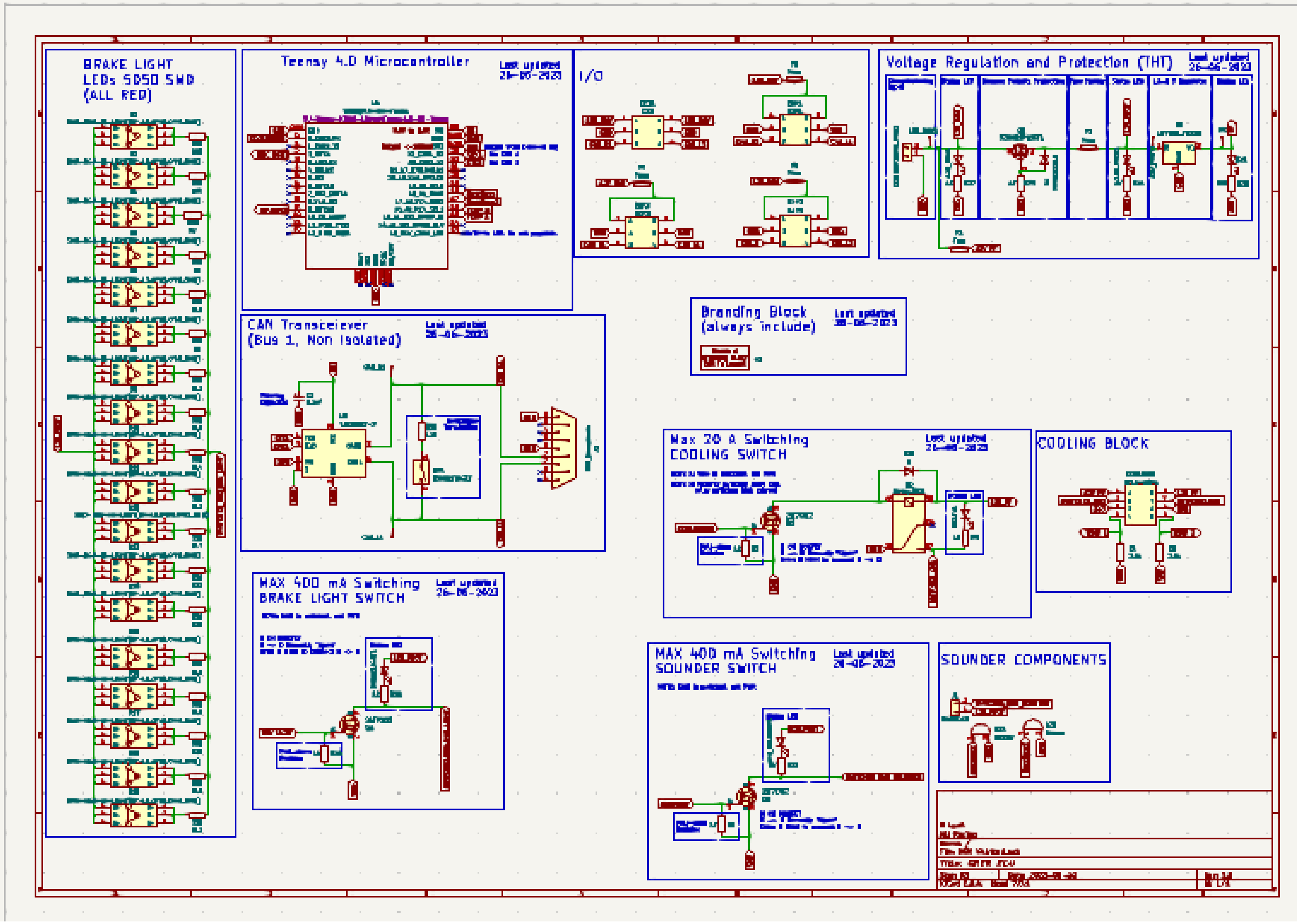
Appendix 8. REN V3.5 Schematic



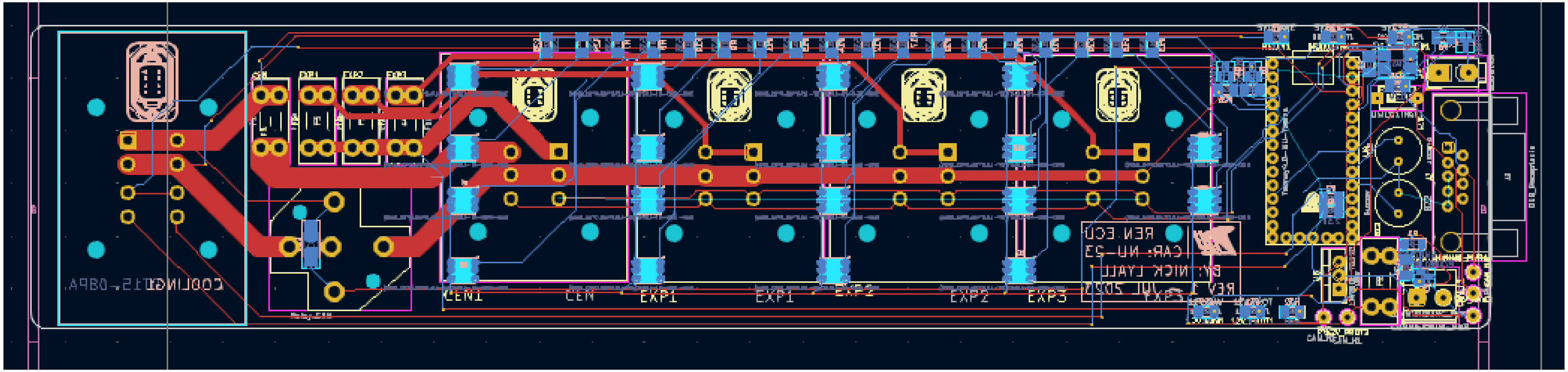
Appendix 9 REN V3.5 PCB Design



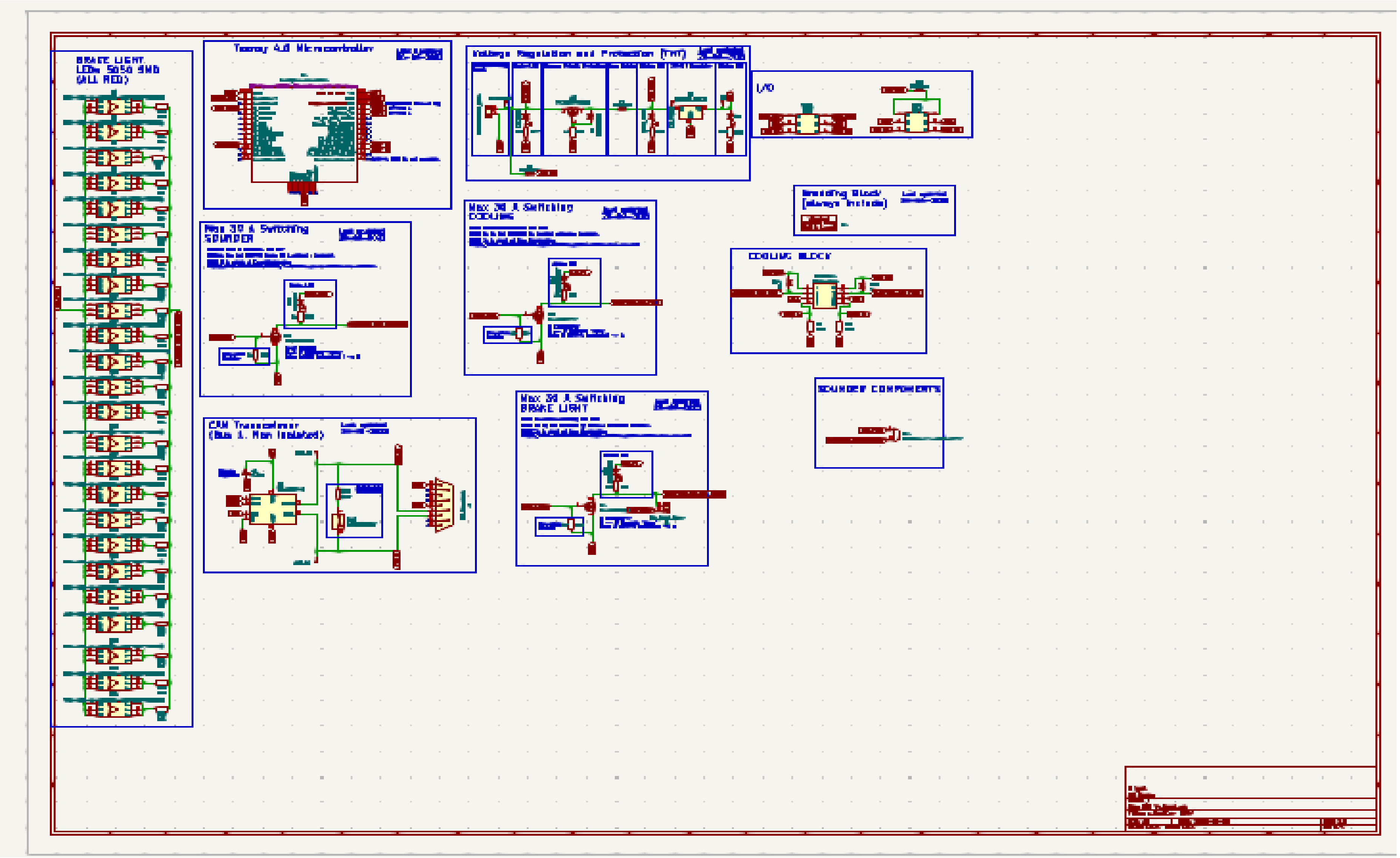
Appendix 10 REN V4 Schematic



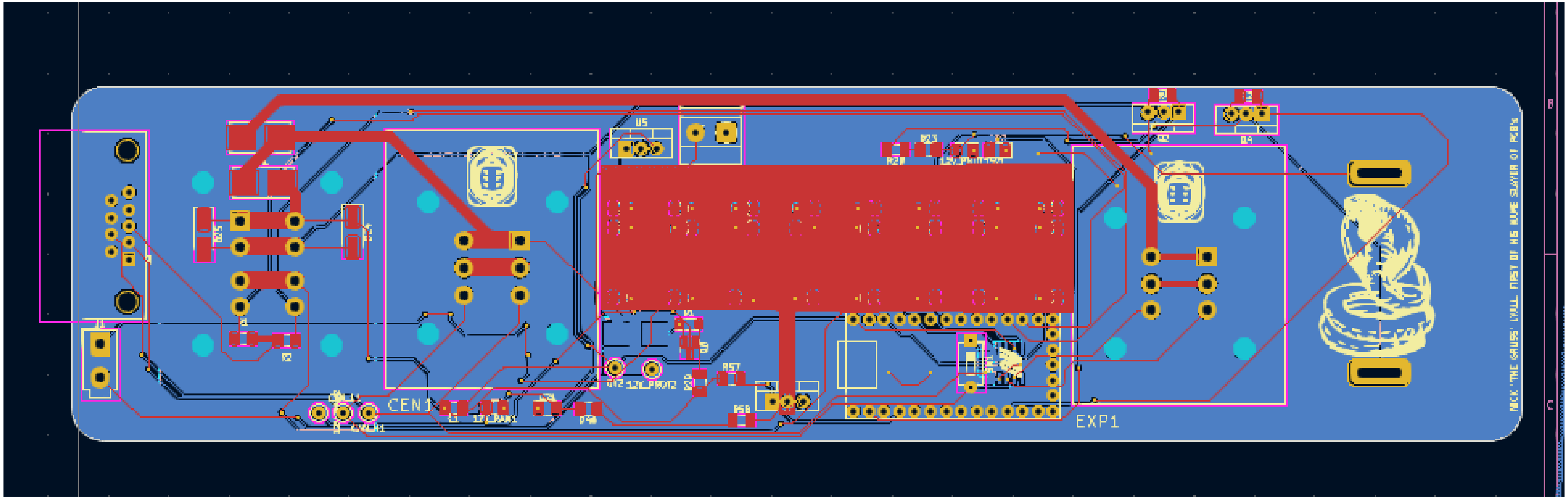
Appendix 11 REN V4 PCB Design



Appendix 12 REN V4.5 Schematic



Appendix 13 REN V4.5 PCB Design



Appendix 14 REN CODE

```
// REN ECU V1.0
// Patrick Gleeson (star)
// Nick Lyall
// This is nice code
//  Addition of GEN operation

// Include necessary libraries and define pins
#include <EV3_CAN.h>
#define BRAKE_PIN 8
#define SOUNDER_PIN 9
#define TEENSY_SIG_PIN 14 // pump and fan enable signal
#define TEMP_OUT_PIN 16 // Temp sensor Output
#define TEMP_IN_PIN 15 // Temp Sensor Input

// Sounder state machine states
enum STATEVAR {
  STATE_STANDBY,
  STATE_SOUNDING,
  STATE_SOUNDED,
  STATE_UNDEFINED,
  STATE_ERROR
};


// Initialise and declare variables
//elapsedMillis timer;
float BRAKE_LIGHT_CMD = 0;    //[boolean] CAN input to drive brake light relay
float RTD_State = 0;           //[boolean] CAN input to driver sounder relay
STATEVAR state = STATE_STANDBY;             // Initialise RTD in standby mode
int soundStart = 0;              // RTD sound timer var
float TS_state = 0 ;             // State of the tractive system
float pre_voltage;
float post_voltage;
float pre_temp = 0;
float post_temp = 0;
float resistance = 0;
//CAN variables
//inputmsgs defines message, outputVar defines location for incoming data
float *outputVar[] = {&BRAKE_LIGHT_CMD, &RTD_State,&TS_state};
canmsg *inputmsgs[] = {&BRK_SIG, &RTD_STATE, &TS_STATE};
int numreceive = 3;
int numsend = 1;

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

  // Set pin modes
  pinMode (BRAKE_PIN, OUTPUT);
  pinMode (SOUNDER_PIN, OUTPUT);
  // Initialise brake light and sounder in off position
  digitalWrite(BRAKE_PIN, LOW);
  digitalWrite(SOUNDER_PIN, LOW);

  // Intialise pump and fan enable pin
  pinMode(TEENSY_SIG_PIN, OUTPUT);
  digitalWrite(TEENSY_SIG_PIN, LOW);
  pinMode(TEMP_IN_PIN, INPUT);
  pinMode(TEMP_OUT_PIN, INPUT);
  // CAN Bus initialisation
  NUCAN_init(numsend, numreceive);
}

```

```
void loop() {

  //Read desired CAN messages, store results in outputVar
  NUCAN_read(outputVar, inputmsgs, numreceive);
  //digitalWrite(SOUNDER_PIN, HIGH);

  EVERY_N_MILLIS(500) {
    updateSounder();
    Serial.print("BRK SIG = ");
    Serial.println(BRAKE_LIGHT_CMD);
    Serial.print("RTD STATE = ");
    Serial.println(RTD_State);

  }
  EVERY_N_MILLIS(100) {
    updateBrakeLight();
    pumpfan();
    updateTemp();
  }
  NUCAN_heartbeat(&HB_REN);
}

void updateBrakeLight(void) {
  if (BRAKE_LIGHT_CMD == 1) {
    digitalWrite(BRAKE_PIN, HIGH);
  } else {
    digitalWrite(BRAKE_PIN, LOW);
  }
}
void updateTemp(void){
  pre_voltage = analogRead(TEMP_IN_PIN) * (3.3 / 1024.0);
  post_voltage = analogRead(TEMP_OUT_PIN) * (3.3 / 1024.0);
  pre_temp = tempCalc(resistanceCalc(pre_voltage));
  post_temp = tempCalc(resistanceCalc(post_voltage));
  NUCAN_write(&T_RAD_H_R, pre_temp);
  NUCAN_write(&T_RAD_C_R, post_temp);
}
//temperature sensor resistance calculator
float resistanceCalc(float outputV) {
  resistance = 2500 * (3.3 - outputV) / outputV;
  return resistance;
}

//fits resitance to a function to determine temperature
float tempCalc(float res) {
  float temp = -31.03 * log(res) + 262.55;
  return temp;
}

```

```
void pumpfan(void){
    if( TS_state == 1){
      digitalWrite (TEENSY_SIG_PIN, HIGH);
    }
    else if (TS_state == 0){
      digitalWrite (TEENSY_SIG_PIN, LOW);
    }
    }
void updateSounder(void) {

  switch (state) {
    case STATE_STANDBY:
      // turn sounder off
      digitalWrite(SOUNDER_PIN, LOW);
      if (RTD_State == 1) {
        state = STATE_SOUNDING;
        soundStart = millis();
      }
      break;
    case STATE_SOUNDING:
      // turn sounder on
      digitalWrite(SOUNDER_PIN, HIGH);
      if (RTD_State == 0) {
        state = STATE_STANDBY;
      }
      if ((millis() - soundStart) >= 2000) {   // 2 second timer
        state = STATE_SOUNDED;
      }
      break;
    case STATE_SOUNDED:
      // turn sounder off
      digitalWrite(SOUNDER_PIN, LOW);
      if (RTD_State == 0) {
        state = STATE_STANDBY;
      }
      break;
    default:
      // statements
      break;
  }


}
```

Appendix 15 Relay Datasheet (RS Components, 2023)

Tyco Electronics

CUSTOMER DATA

PART NO.	SHT. 1 OF 2
1432785–1	

DRAWN	APPROVAL	DATE	SCALE	CUSTOMER
E.SIMPSON	B. TOEPFER	05–26–05	1:1	TYCO_ELECTRONICS_STANDARD

TOLERANCE UNLESS SPECIFIED OTHERWISE	
0.X	= +/–
0.XX	= +/–
0.XXX	= +/–
ANGLES	= +/–

DO NOT SCALE THIS DRAWING

CHANGES

REV.	DATE	CO	APP.
A	08–19–05	RELEASE EDS	B.T.
B	27APR2010	ECR–10–008018	BT

ELECTRICAL CHARACTERISTICS: (ALL DATA APPLIES @ 23°C UNLESS OTHERWISE SPECIFIED)

COIL DATA:

NOMINAL VOLTAGE:	12 VDC
OPERATE VOLTAGE:	7.8 VDC MAXIMUM
RELEASE VOLTAGE:	1.2 VDC MINIMUM
COIL RESISTANCE:	90 OHMS +/– 10%
OPERATE TIME:	8 mSEC. MAXIMUM EXCLUDING BOUNCE
RELEASE TIME:	5 mSEC. MAXIMUM EXCLUDING BOUNCE
TEMPERATURE RANGE:	OPERATING –40°C TO +85°C

CONTACT DATA: (CONTACT DATA IS FORMATTED N.O./N.C.)

CONTACT ARRANGEMENT:	1 FORM C (SPDT)
CONTACT MATERIAL:	AgSn0 (SILVER TIN–OXIDE)
CONTACT MILLIVOLT DROP:	200mv @ 35A ON N.O. CONTACTS (AFTER SWITCHING) 250mv @ 20A ON N.C. CONTACTS (AFTER SWITCHING)
MAXIMUM MAKE CURRENT:	90A/30A (LAMP) @ 16 VDC
MAXIMUM BREAK CURRENT:	40A/30A @ 16 VDC RESISTIVE
MAXIMUM CONTINUOUS CURRENT:	40A/30A @ 23°C , 35A/20A @ 85°C
INITIAL BREAKDOWN CURRENT	500V RMS CONTACTS TO COIL

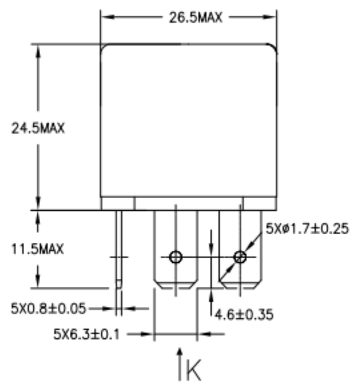
EXPECTED LIFE:	100,000 OPERATIONS, 40 A, 14 VDC RESISTIVE ON NORMALLY OPEN CONTACT

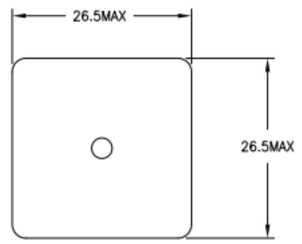
MECHANICAL CHARACTERISTICS:

EXPECTED LIFE:	10 MILLION OPERATIONS, NO CONTACT LOAD
TERMINALS	BRASS, UNPLATED

Tyco Electronics				CUSTOMER DATA	PART NO. 1432785–1	SHT. 2 OF 2
DRAWN E.SIMPSON	APPROVAL B. TOEPFER	DATE 05–26–05	SCALE 1:1	CUSTOMER TYCO_ELECTRONICS_STANDARD		
TOLERANCE UNLESS SPECIFIED OTHERWISE	0.X = +/– 0.XX = +/– 0.XXX = +/– ANGLES = +/–				REV B	
				DO NOT SCALE THIS DRAWING	MILLIMETERS	

MARKING TO INCLUDE:
TYCO ELECTRONICS NAME, TYCO ELECTRONICS PART NUMBER, SCHEMATIC, COIL VOLTAGE, COUNTRY OF ORIGIN, AND DATE CODE





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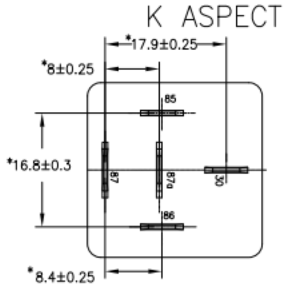
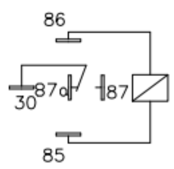
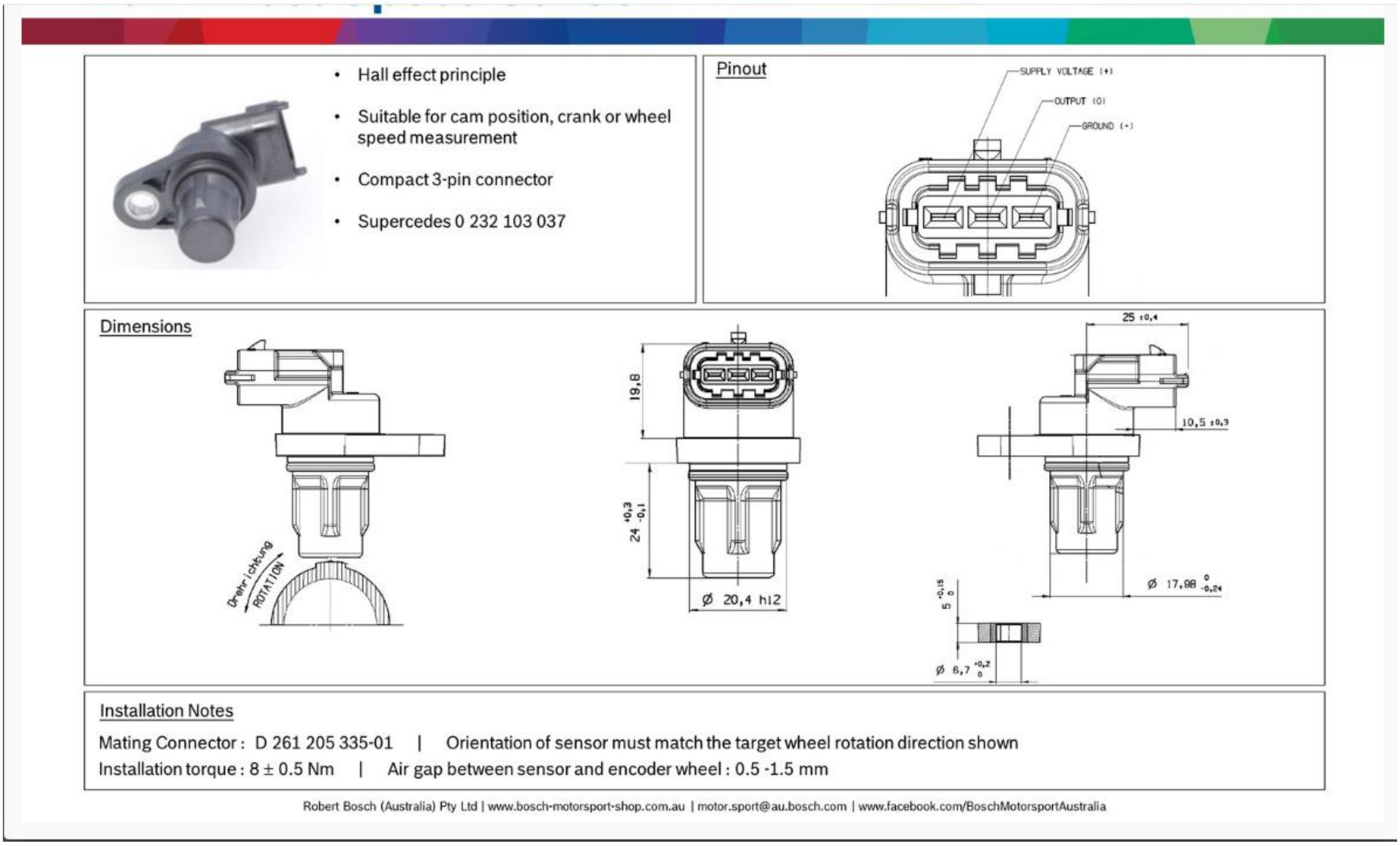




SCHEMATIC DRAWING
(BOTTOM VIEW)

* TERMINAL LOCATIONS APPLY AT THE BASE OF THE TERMINALS

Appendix 16 Bosch Wheel Speed Sensor Datasheet (Bosch, 2023)



- Hall effect principle
- Suitable for cam position, crank or wheel speed measurement
- Compact 3-pin connector
- Supercedes 0 232 103 037

Pinout

Dimensions

Installation Notes

Mating Connector : D 261 205 335-01 | Orientation of sensor must match the target wheel rotation direction shown
Installation torque : 8 ± 0.5 Nm | Air gap between sensor and encoder wheel : 0.5 -1.5 mm

Robert Bosch (Australia) Pty Ltd | www.bosch-motorsport-shop.com.au | motor.sport@au.bosch.com | www.facebook.com/BoschMotorsportAustralia

Appendix 17 IRLB8721PbF 60 Amp N-Channel Mosfet (Core Electronics, 2023)

PD - 97390

International
IOR Rectifier

IRLB8721PbF

HEXFET® Power MOSFET

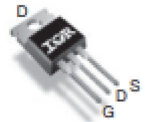
V_{DSS}	$R_{DS(on)}$ max	Qg (typ.)
30V	8.7mΩ@V_{GS} = 10V	7.6nC

Applications

- Optimized for UPS/Inverter Applications
- High Frequency Synchronous Buck Converters for Computer Processor Power
- High Frequency Isolated DC-DC Converters with Synchronous Rectification for Telecom and Industrial Use

Benefits

- Very Low RDS(on) at 4.5V V_{GS}
- Ultra-Low Gate Impedance
- Fully Characterized Avalanche Voltage and Current
- Lead-Free



TO-220AB
IRLB8721PbF

G	D	S
Gate	Drain	Source

Absolute Maximum Ratings

	Parameter	Max.	Units
V_{DS}	Drain-to-Source Voltage	30	V
V_{GS}	Gate-to-Source Voltage	± 20	
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	62	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	44	
I_{DM}	Pulsed Drain Current ①	250	
P_D @T_C = 25°C	Maximum Power Dissipation ⑤	65	W
P_D @T_C = 100°C	Maximum Power Dissipation ⑤	33	
	Linear Derating Factor	0.43	W/°C
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 screw	10lb·in (1.1N·m)	

Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case ⑤	——	2.3	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat Greased Surface	0.5	——	
$R_{\theta JA}$	Junction-to-Ambient ④	——	62	

Notes ① through ⑤ are on page 9

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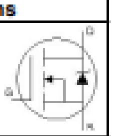
Static @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
BV_{DSS}	Drain-to-Source Breakdown Voltage	30	—	—	V	V_{GS} = 0V, I_D = 250μA
$\Delta BV_{DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	—	21	—	mV/°C	Reference to 25°C, I_D = 1mA
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	6.5	8.7	mΩ	V_{GS} = 10V, I_D = 31A ③
		—	13.1	16		V_{GS} = 4.5V, I_D = 25A ③
$V_{GS(th)}$	Gate Threshold Voltage	1.35	1.80	2.35	V	V_{DS} = V_{GS}, I_D = 25μA
$\Delta V_{GS(th)}/\Delta T_J$	Gate Threshold Voltage Coefficient	—	-7.0	—	mV/°C	
I_{DSS}	Drain-to-Source Leakage Current	—	—	1.0	μA	V_{DS} = 24V, V_{GS} = 0V
		—	—	150		V_{DS} = 24V, V_{GS} = 0V, T_J = 125°C
I_{GSS}	Gate-to-Source Forward Leakage	—	—	100	nA	V_{GS} = 20V
	Gate-to-Source Reverse Leakage	—	—	-100		V_{GS} = -20V
gfs	Forward Transconductance	35	—	—	S	V_{DS} = 15V, I_D = 25A
Q_g	Total Gate Charge	—	7.6	13	nC	
Q_{gs1}	Pre-Vth Gate-to-Source Charge	—	1.9	—		V_{DS} = 15V
Q_{gs2}	Post-Vth Gate-to-Source Charge	—	1.2	—		V_{GS} = 4.5V
Q_{gd}	Gate-to-Drain Charge	—	3.4	—		I_D = 25A
Q_{godr}	Gate Charge Overdrive	—	2.0	—		See Fig. 16
Q_{sw}	Switch Charge (Q_{gs2} + Q_{gd})	—	4.6	—		
Q_{oss}	Output Charge	—	7.9	—	nC	V_{DS} = 15V, V_{GS} = 0V
R_G	Gate Resistance	—	2.3	3.8	Ω	
$t_{d(on)}$	Turn-On Delay Time	—	9.1	—	ns	V_{DD} = 15V, V_{GS} = 4.5V ③
t_r	Rise Time	—	93	—		I_D = 25A
$t_{d(off)}$	Turn-Off Delay Time	—	9.0	—		R_G = 1.8Ω
t_f	Fall Time	—	17	—		See Fig. 14
C_{iss}	Input Capacitance	—	1077	—	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	—	360	—		V_{DS} = 15V
C_{rss}	Reverse Transfer Capacitance	—	110	—		f = 1.0MHz

Avalanche Characteristics

	Parameter	Typ.	Max.	Units
E_{AS}	Single Pulse Avalanche Energy ②	—	98	mJ
I_{AR}	Avalanche Current ①	—	25	A

Diode Characteristics

	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	—	—	62	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ①	—	—	250		
V_{SD}	Diode Forward Voltage	—	—	1.0	V	T_J = 25°C, I_S = 25A, V_{GS} = 0V ③
t_{rr}	Reverse Recovery Time	—	16	24	ns	T_J = 25°C, I_F = 25A, V_{DD} = 15V
Q_{rr}	Reverse Recovery Charge	—	14	21	nC	di/dt = 200A/μs ③

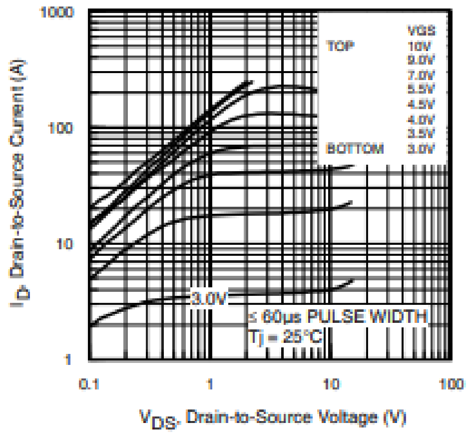


Fig 1. Typical Output Characteristics

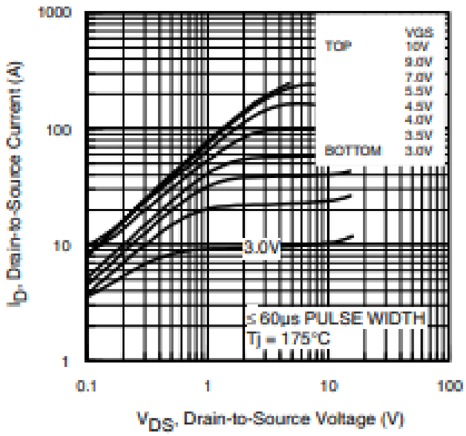


Fig 2. Typical Output Characteristics

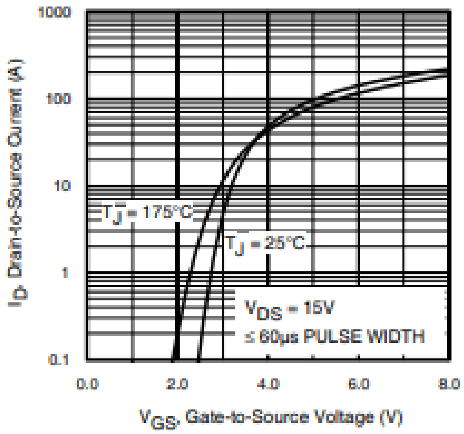


Fig 3. Typical Transfer Characteristics

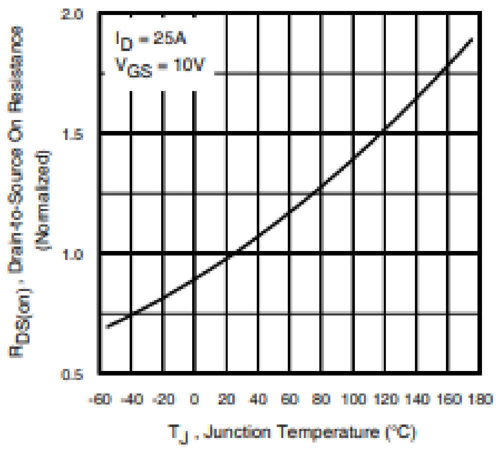


Fig 4. Normalized On-Resistance vs. Temperature

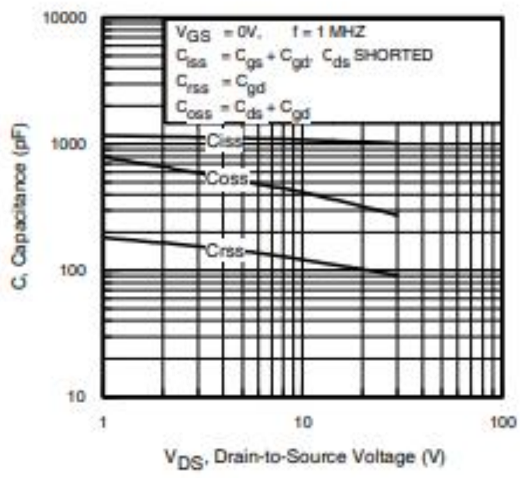


Fig 5. Typical Capacitance vs. Drain-to-Source Voltage

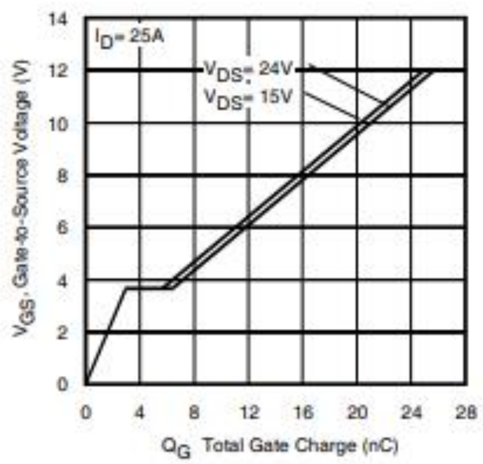


Fig 6. Typical Gate Charge vs. Gate-to-Source Voltage

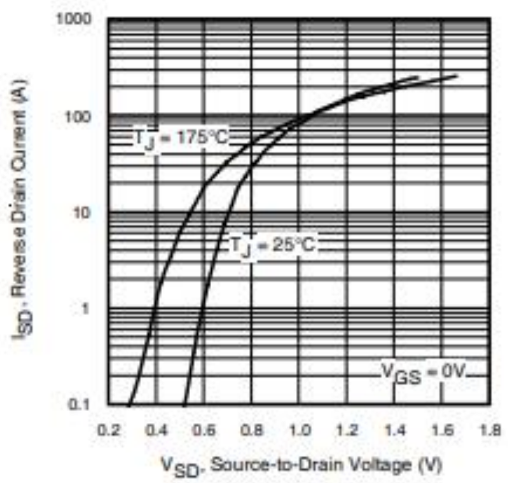


Fig 7. Typical Source-Drain Diode Forward Voltage

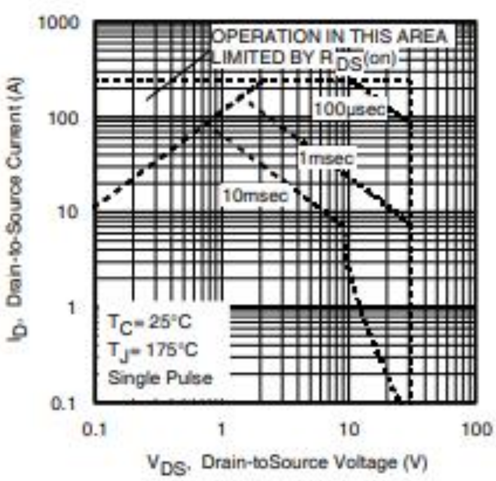


Fig 8. Maximum Safe Operating Area

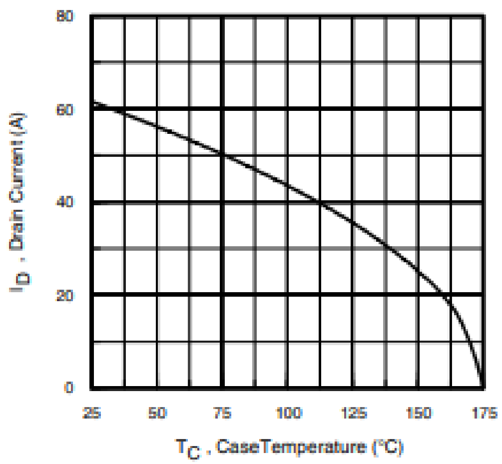


Fig 9. Maximum Drain Current vs. Case Temperature

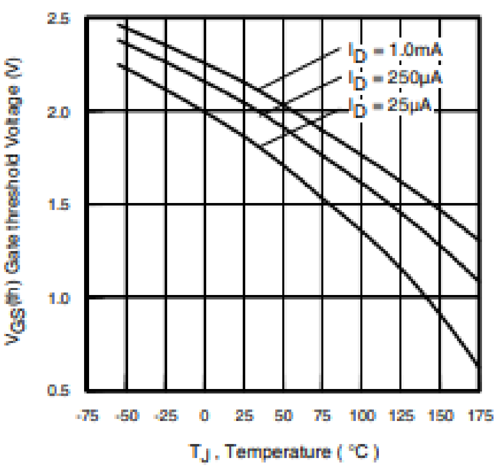


Fig 10. Threshold Voltage vs. Temperature

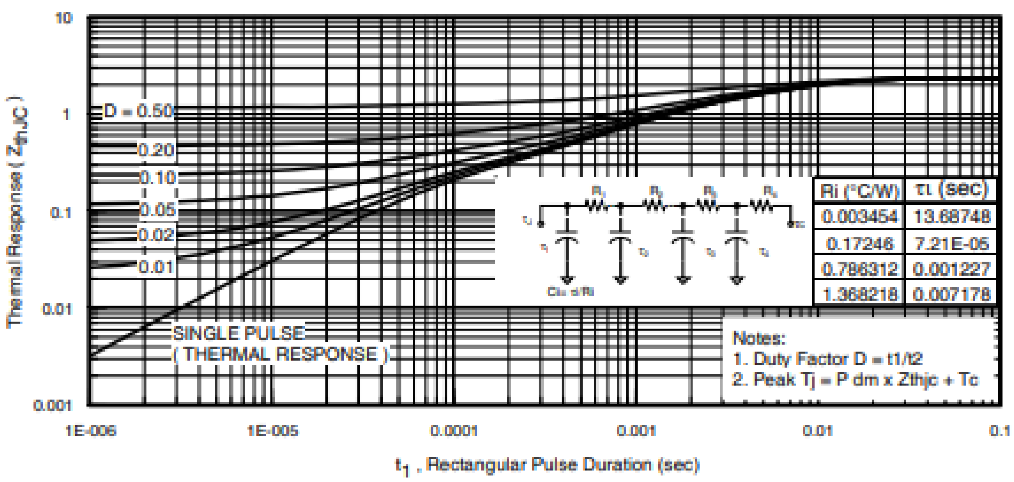


Fig 11. Maximum Effective Transient Thermal Impedance, Junction-to-Case

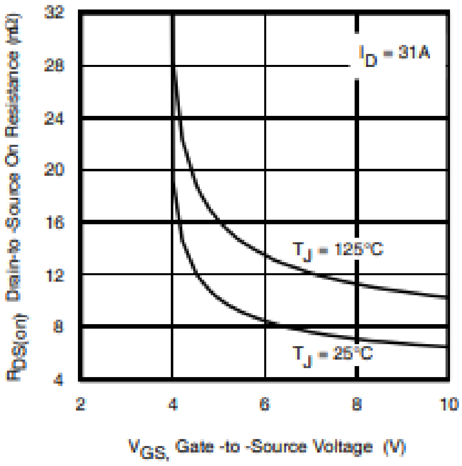


Fig 12. On-Resistance vs. Gate Voltage

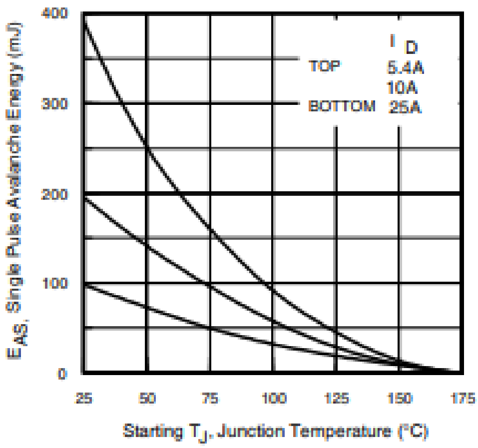


Fig 13a. Maximum Avalanche Energy vs. Drain Current

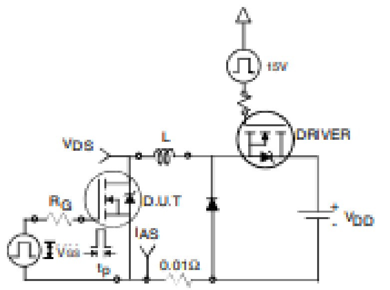


Fig 13b. Unclamped Inductive Test Circuit

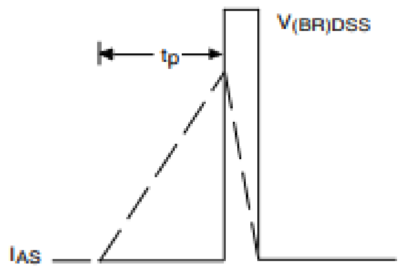


Fig 13c. Unclamped Inductive Waveforms

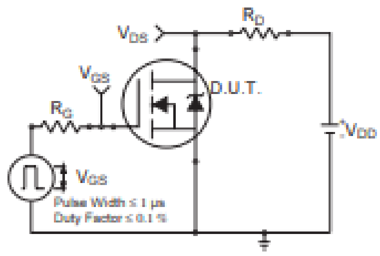


Fig 14a. Switching Time Test Circuit

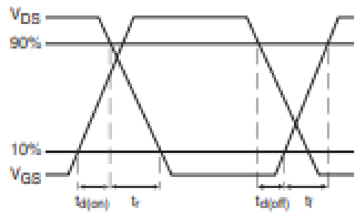


Fig 14b. Switching Time Waveforms

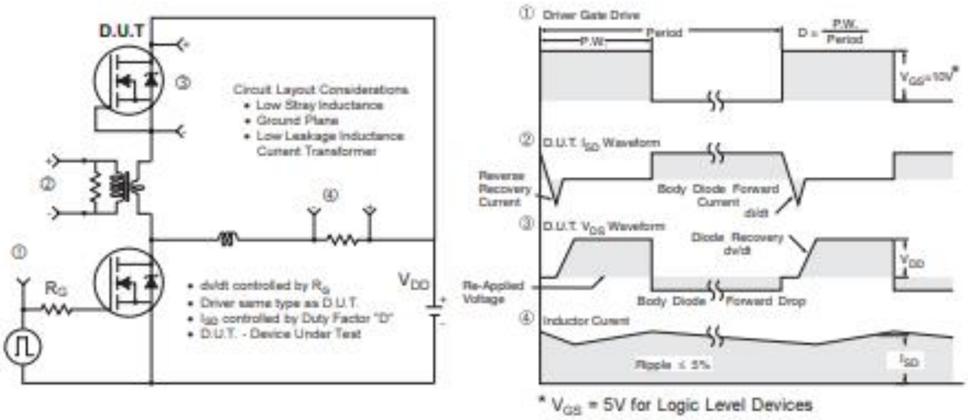


Fig 15. Peak Diode Recovery dv/dt Test Circuit for N-Channel HEXFET® Power MOSFETs

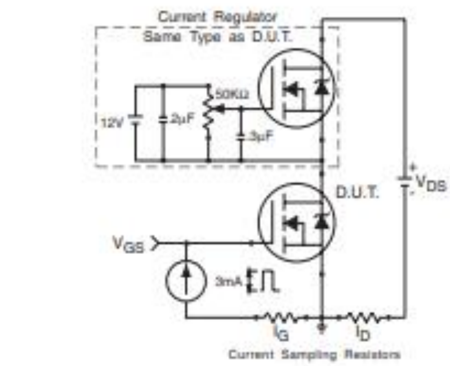


Fig 16a. Gate Charge Test Circuit

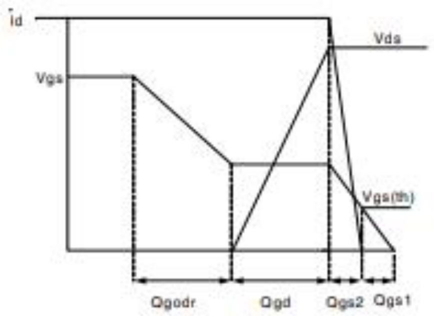
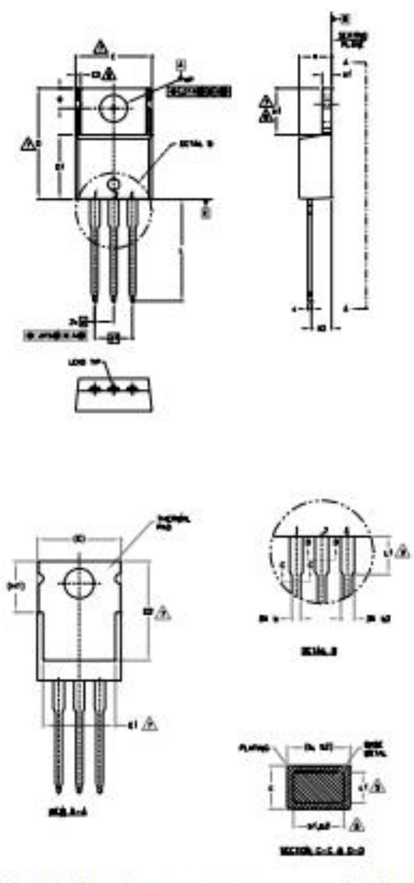


Fig 16b. Gate Charge Waveform

TO-220AB Package Outline (Dimensions are shown in millimeters (inches))



NOTES:

1.- DIMENSIONING AND TOLERANCING AS PER ASME Y14.5 M- 1994.
2.- DIMENSIONS ARE SHOWN IN INCHES [MILLIMETERS].
3.- LEAD DIMENSION AND FINISH UNCONTROLLED IN L1.
4.- DIMENSION D, D1 & E DO NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED .005" (0.127) PER SIDE. THESE DIMENSIONS ARE MEASURED AT THE OUTERMOST EXTREMES OF THE PLASTIC BODY.
5 DIMENSION b1, b3 & c1 APPLY TO BASE METAL ONLY.
6.- CONTROLLING DIMENSION : INCHES.
7.- THERMAL PAD CONTOUR OPTIONAL WITHIN DIMENSIONS E, H1, D2 & E1
8.- DIMENSION E2 X H1 DEFINE A ZONE WHERE STAMPING AND SINGULATION IRREGULARITIES ARE ALLOWED.
9.- OUTLINE CONFORMS TO JEDEC TO-220, EXCEPT A2 (max.) AND D2 (min.) WHERE DIMENSIONS ARE DERIVED FROM THE ACTUAL PACKAGE OUTLINE.

SYMBOL	DIMENSIONS				NOTES
	MILLIMETERS		INCHES		
	MIN.	MAX.	MIN.	MAX.	
A	3.56	4.83	.140	.190	
A1	0.51	1.40	.020	.055	
A2	2.03	2.92	.080	.115	
b	0.38	1.01	.015	.040	
b1	0.38	0.97	.015	.038	5
b2	1.14	1.78	.045	.070	
b3	1.14	1.73	.045	.068	5
c	0.36	0.61	.014	.024	
c1	0.36	0.56	.014	.022	5
D	14.22	16.51	.560	.650	4
D1	8.38	9.02	.330	.355	
D2	11.68	12.88	.460	.507	7
E	9.65	10.67	.380	.420	4,7
E1	6.86	8.89	.270	.350	7
E2	-	0.76	-	.030	8
e	2.54 BSC		.100 BSC		
e1	5.08 BSC		.200 BSC		
H1	5.84	6.86	.230	.270	7,8
L	12.70	14.73	.500	.580	
L1	3.56	4.06	.140	.160	3
ØP	3.54	4.08	.139	.161	
Q	2.54	3.42	.100	.135	

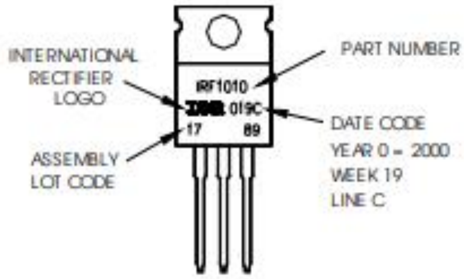
TO-220AB packages are not recommended for Surface Mount Application.

Note: For the most current drawing please refer to IR website at: http://www.irf.com/package/

TO-220AB Part Marking Information

EXAMPLE: THIS IS AN IRF1010
LOT CODE 1789
ASSEMBLED ON WW 19, 2000
IN THE ASSEMBLY LINE "C"

Note: "P" in assembly line position indicates "Lead - Free"



Note: For the most current drawing please refer to IR website at: http://www.irf.com/package/

Notes:

① Repetitive rating; pulse width limited by max. junction temperature.
② Starting $T_J = 25°C$, $L = 0.32mH$, $R_G = 25\Omega$, $I_{AS} = 25A$.
③ Pulse width ≤ 400µs; duty cycle ≤ 2%.
④ When mounted on 1" square PCB (FR-4 or G-10 Material). For recommended footprint and soldering techniques refer to application note #AN-994.
⑤ R_θ is measured at T_J approximately 90°C.

Data and specifications subject to change without notice.
This product has been designed and qualified for the Industrial market.
Qualification Standards can be found on IR's Web site.

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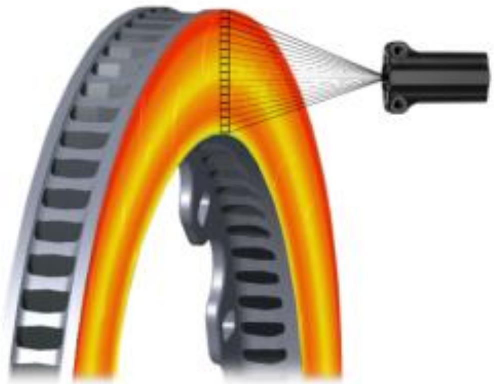
Appendix 18 IZZE Racing Brake Temperature Datasheet (IZZE , 2023)

IZZE RACING

Multichannel Brake IR Temperature Sensor, IRTS-60-V3 - Datasheet

The Izze-Racing Multichannel Brake Infrared Temperature Sensor is specifically designed to measure the highly transient surface temperature of a brake rotor at multiple points, making it possible to acquire the time-based temperature distribution across a rotor's surface in order to evaluate & optimize the pad pressure distribution, cooling efficiency, braking efficiency, and hot spot formation from thermoelastic instabilities.

The sensor is capable of measuring temperature at 16, 8, or 4 points at a sampling frequency of up to 100Hz, object temperature between -20 to 1100˚C, using CAN 2.0A protocol, enclosed in a compact IP66 rated aluminum enclosure.



SENSOR SPECIFICATIONS

Temperature Measurement Range, T_o	-20 to 1100˚C
Package Temperature Range, T_p	-20 to 85˚C
Accuracy	< ±2.0% FS
Uniformity	±1.0% FS $T_{sensor} < 85$˚C
Noise Equivalent Temperature Difference, NETD	0.8˚C 32Hz, $\varepsilon = 0.85$
Field of View, FOV	60˚x 8˚
Number of Channels	16, 8, or 4
Sampling Frequency	100, 64, 32, 16, 8, 4, 2, or 1Hz
Thermal Time Constant	2 ms
Emissivity	0.01 to 1.00 (steel = 0.55, carbon = 0.85)
Spectral Range	8 to 14 µm

ELECTRICAL SPECIFICATIONS

Supply Voltage, V_s	5 to 8 V
Supply Current, I_s (typ)	30 mA
Features	• Reverse polarity protection • Over-temperature protection (125˚C)

MECHANICAL SPECIFICATIONS

Weight	< 16.0 g
L x W x H (max)	37.6 x 26.0 x 12.3 mm
Protection Rating	IP66

Rev.D

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CAN SPECIFICATIONS

Standard	CAN 2.0A (11-bit identifier), ISO-11898
Bit Rate	1 Mbit/s (configurable)
Byte Order	Big-Endian / Motorola
Data Conversion	0.1˚C per bit, -100˚C offset, unsigned
Base CAN ID's (Default)	LF Sensor: 1220 (Dec) / 0x4C4 (Hex) RF Sensor: 1225 (Dec) / 0x4C9 (Hex) LR Sensor: 1230 (Dec) / 0x4CE (Hex) RR Sensor: 1235 (Dec) / 0x4D3 (Hex)
Termination	None

CAN ID: Base ID

Infrared Temp, CH 1		Infrared Temp, CH 2		Infrared Temp, CH 3		Infrared Temp, CH 4	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

CAN ID: Base ID+1

Infrared Temp, CH 5		Infrared Temp, CH 6		Infrared Temp, CH 7		Infrared Temp, CH 8	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

CAN ID: Base ID+2

Infrared Temp, CH 9		Infrared Temp, CH 10		Infrared Temp, CH 11		Infrared Temp, CH 12	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

CAN ID: Base ID+3

Infrared Temp, CH 13		Infrared Temp, CH 14		Infrared Temp, CH 15		Infrared Temp, CH 16	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

CAN ID: Base ID+4

Sensor Temperature		Unused		Unused		Unused	
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4 (MSB)	Byte 5 (LSB)	Byte 6 (MSB)	Byte 7 (LSB)

WIRING SPECIFICATIONS:

Wire	26 AWG M22759/32, DR25 jacket
Cable Length (typ.)	500 mm
Connector	None

Supply Voltage, V_s	Red	(twisted)
Ground	Black	
CAN +	Blue	(twisted)
CAN -	White	

SENSOR CONFIGURATION:

To modify the sensor's configuration, send the following CAN message at 1Hz for at least 10 seconds and then reset the sensor by disconnecting power for 5 seconds:

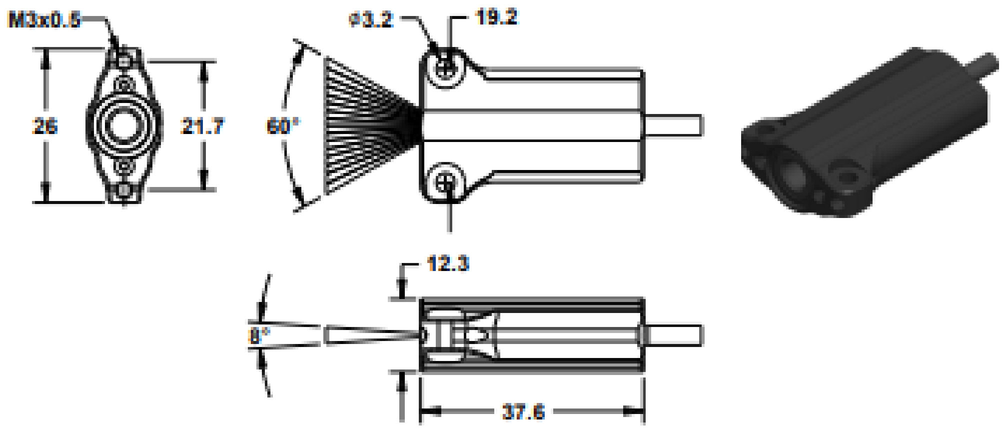
CAN ID: Current Base ID

Programming Constant		New CAN Base ID (11-bit)		Emissivity	Sampling Frequency	Channels	Bite Rate
Byte 0 (MSB)	Byte 1 (LSB)	Byte 2 (MSB)	Byte 3 (LSB)	Byte 4	Byte 5	Byte 6	Byte 7
30000 = 0x7530		1 = 0x001 ⋮ 2047 = 0x7FF		1 = 0.01 ⋮ 100 = 1.00	1 = 1Hz 5 = 16Hz 2 = 2Hz 6 = 32Hz 3 = 4Hz 7 = 64Hz 4 = 8Hz 8 = 100Hz	40 = 4 Ch 80 = 8 Ch 160 = 16 Ch	1 = 1 Mbit/s 2 = 500 kbit/s 3 = 250 kbit/s 4 = 100 kbit/s

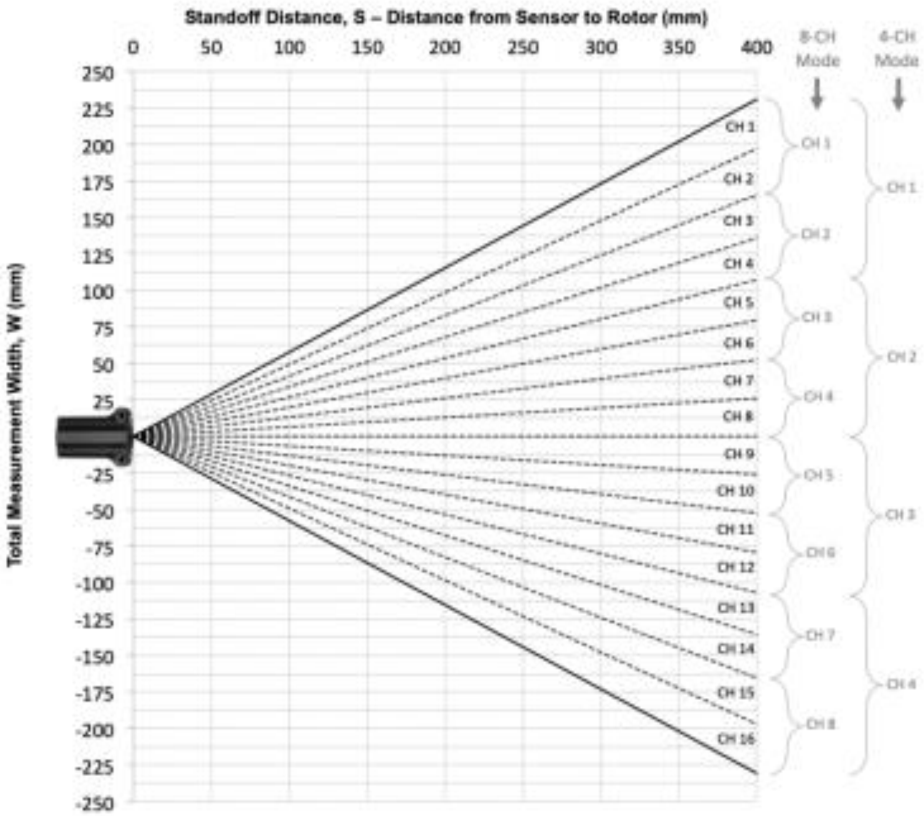
CAN messages should only be sent to the sensor during the configuration sequence.
DO NOT continuously send CAN messages with the same Base CAN ID to the sensor.

DIMENSIONS:

60° Field-of-View, IRTS-60-V3



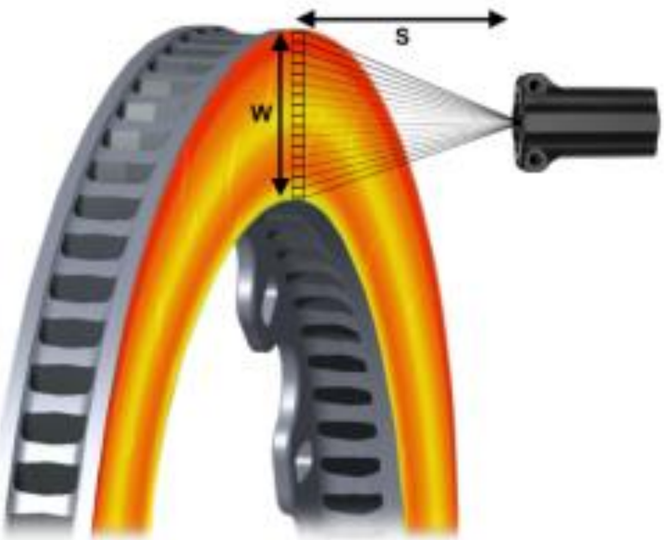
60° Field-of-View, IRTS-60-V3:



(Angle offset, z-axis rotation, between -5° and +5°, mounts should allow adjustment accordingly)

SENSOR PLACEMENT & INSTALLATION:

For most applications, the sensor should be placed such that its measurement width is along the radial axis of the rotor. An example is illustrated below. Note that W is the sensor's total measurement width and S is the standoff distance from the rotor's face to the sensor. Use the field-of-view graph on page 4 to approximate the standoff distance (S) for the total measurement width (W) needed.



The sensor's temperature is transmitted via a CAN message (see page 2) and should be monitored. The sensor's temperature should ideally never exceed 85˚C, but excursions < 125˚C are survivable.

ADDITIONAL INFORMATION:

- Stated accuracy is under isothermal package conditions; for utmost accuracy, avoid abrupt temperature transients and gradients across the sensor's package.
- Periodically check the sensor's lens for contamination and, if necessary, clean the lens using a cotton swab with isopropyl alcohol.
- An emissivity of 0.55 and 0.85 is a good starting point for cast iron / steel and carbon rotors, respectively.
    - The exact emissivity of cast iron rotors is **not** constant and depends on many factors, such as: rotor temperature, oxide layer growth, surface roughness/grooves, pad material, arrangement of holes/slots, and rotational speed. Generally, the emissivity will increase with temperature; accordingly, an emissivity of 0.50 to 0.60 is a recommended starting point for rotor temperatures greater than 400˚C. It is the user's responsibility to calibrate the sensor if utmost temperature accuracy is important.
- Noise Equivalent Temperature Difference (NETD) increases with increasing sampling frequency and decreasing emissivity:
    - Provided that brake rotor temperature is highly transient, it is usually advantageous to use a higher sampling frequency at the cost of increased noise.