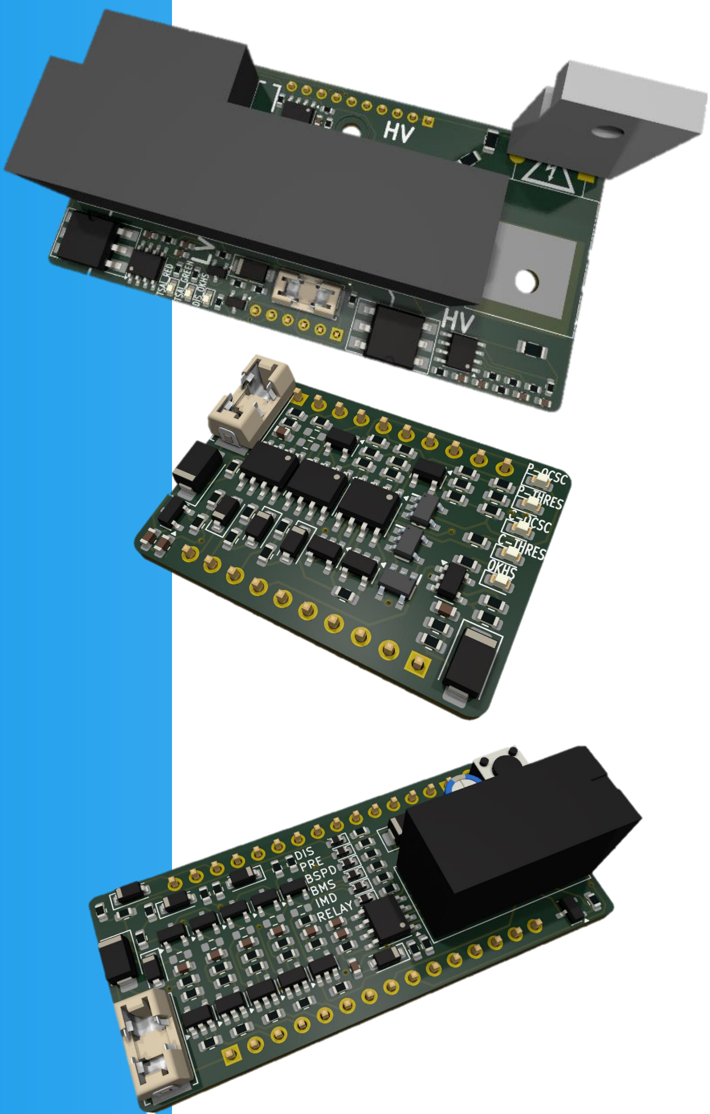
CEN BREAKOUT BOARDS

DESIGN REPORT



Jacob Bush

2024

Contents

- List of Figures v
- Introduction vi

TSAL BREAKOUT BOARD 1

- Abstract 2
- Introduction 3
  - Rules 6
  - Topology Implementation 7
- Topology/Schematic 8
  - HV/Measurement 9
  - LV 10
- Implementation/Layout 12
  - Component Selection 12
  - Layout 14
  - Footprint/Pinout 17
  - Commissioning and Unit Tests 18
- Prototype Commissioning 19
- Conclusion 20
- Future Work 21
  - Replacing Comparators with Op-amps 21
  - Replace Optocoupler 21
  - Resistor/Capacitor Sizes 21
  - Replace N Channel MOSFETs 21
  - Larger pulldown Resistor Values 21
  - Fusing TS+ 21
- Appendix 22
  - Schematic 22
  - PCB 23
  - Symbol 26
  - Footprint 26
  - Pinout 26
  - BOM 27
  - HV/LV Voltage Separation components 28

DISCHARGE BREAKOUT BOARD 45

- Abstract 46

Introduction ... 47
Rules ... 49
Topology Implementation ... 50
Topology/Schematic ... 51
Discharge ... 52
Discharge OKHS ... 53
Implementation/Layout ... 54
Component Selection ... 54
Layout ... 56
Footprint/Pinout ... 59
Commissioning and Unit Tests ... 60
Prototype Commissioning ... 61
Conclusion ... 62
Future Work ... 63
Replacing Comparators with Op-amps ... 63
Replace Optocoupler ... 63
Thermistor/Resistor/Capacitor Sizes ... 63
Larger pulldown Resistor Values ... 63
Replace Discharge Resistor ... 63
Replace Relay ... 63
Appendix ... 64
Schematic ... 64
PCB ... 65
Symbol ... 68
Footprint ... 68
Pinout ... 68
BOM ... 69
HV/LV Voltage Separation components ... 70
BSPD BREAKOUT BOARD ... 87
Abstract ... 88
Introduction ... 89
Rules ... 91
Topology Implementation ... 92
Topology/Schematic ... 93
Current Threshold ... 93
Current OCSC ... 94

Pressure Threshold and OCSC 94
BSPD Logic 95
Implementation/Layout 97
Component Selection 97
Layout 99
Footprint/Pinout 101
Commissioning and Unit Tests 102
Prototype Commissioning 103
Conclusion 104
Future Work 105
Replacing Comparators with Op-amps 105
Resistor/Capacitor Sizes 105
Larger pulldown Resistor Values 105
Comparator Op-amps instead of Follower 105
Appendix 106
Schematic 106
PCB 107
Symbol 110
Footprint 110
Pinout 110
BOM 111
HFR BREAKOUT BOARD 112
Abstract 113
Introduction 114
Rules 116
Topology Implementation 117
Topology/Schematic 118
Interface 119
Latching 120
Starter 121
Implementation/Layout 123
Component Selection 123
Layout 125
Footprint/Pinout 126
Commissioning and Unit Tests 127
Prototype Commissioning 128

Conclusion 129
Future Work 130
Make All Components Solid State 130
Op-amp for HFR LED 130
Resistor/Capacitor Sizes 130
Change OKHS Op Amps to Comparator Circuit Instead of Amplifier 130
Larger pulldown Resistor Values 130
Appendix 131
Schematic 131
PCB 132
Symbol 135
Footprint 135
Pinout 135
BOM 136

List of Figures

Figure 1 NU23 Picture from 2023 Competition, with TSAL Labelled 3
Figure 2 NU23 CEN, with TSAL Components Labelled 4
Figure 3 NU24 TSAL Implementation 7
Figure 4 TSAL Schematic 8
Figure 5 TSAL HV Schematic 9
Figure 6 TSAL LV Schematic 10
Figure 7 Original 555 Timer Astable Setup 11
Figure 8 TSAL Voltage Separation Distance 14
Figure 9 TSAL HV/LV Voltage Separation Distance 15
Figure 10 Discharge Board Size 15
Figure 11 TSAL/Discharge Symbol 17
Figure 12 TSAL/Discharge Footprint 17
Figure 13 NU23 CEN, with Discharge Components Labelled 47
Figure 14 NU24 Discharge Implementation 50
Figure 15 Discharge Schematic 51
Figure 16 Discharge HV Schematic 52
Figure 17 Discharge OCSC Schematic 53
Figure 18 TSAL Voltage Separation Distance 56
Figure 19 TSAL HV/LV Voltage Separation Distance 57
Figure 20 Discharge Board Size 57
Figure 21 TSAL/Discharge Symbol 59
Figure 22 TSAL/Discharge Footprint 59
Figure 23 NU23 CEN, with BSPD Components Labelled 90
Figure 24 BSPD NU24 Implementation 92
Figure 25 BSPD Schematic 93
Figure 26 Current Threshold Schematic 94
Figure 27 Current OCSC Schematic 94
Figure 28 Pressure Threshold and OCSC Schematic 95
Figure 29 BSPD Logic Schematic 96
Figure 30 BSPD Board Size 99
Figure 31 BSPD Symbol 101
Figure 32 BSPD Footprint 101
Figure 33 NU23 CEN (HFR Labelled) 115
Figure 34 HFR NU24 Layout 117
Figure 35 HFR Schematic 118
Figure 36 HFR Interface Schematic 119
Figure 37 HFR Latching Schematic 120
Figure 38 a) 555 Timer Astable Setup b) 555 Timer Modified 121
Figure 39 HFR Starter Schematic 121
Figure 40 HFR Starter LT Spice 122
Figure 41 HFR Starter LT Spice Output 122
Figure 42 HFR Board Size 125
Figure 43 HFR Symbol 126
Figure 44 HFR Footprint 126

Introduction

This report contains 4 reports, to detail the design and implementation of the:

- TSAL,
- DISCHARGE,
- BSPD, and
- HFR.

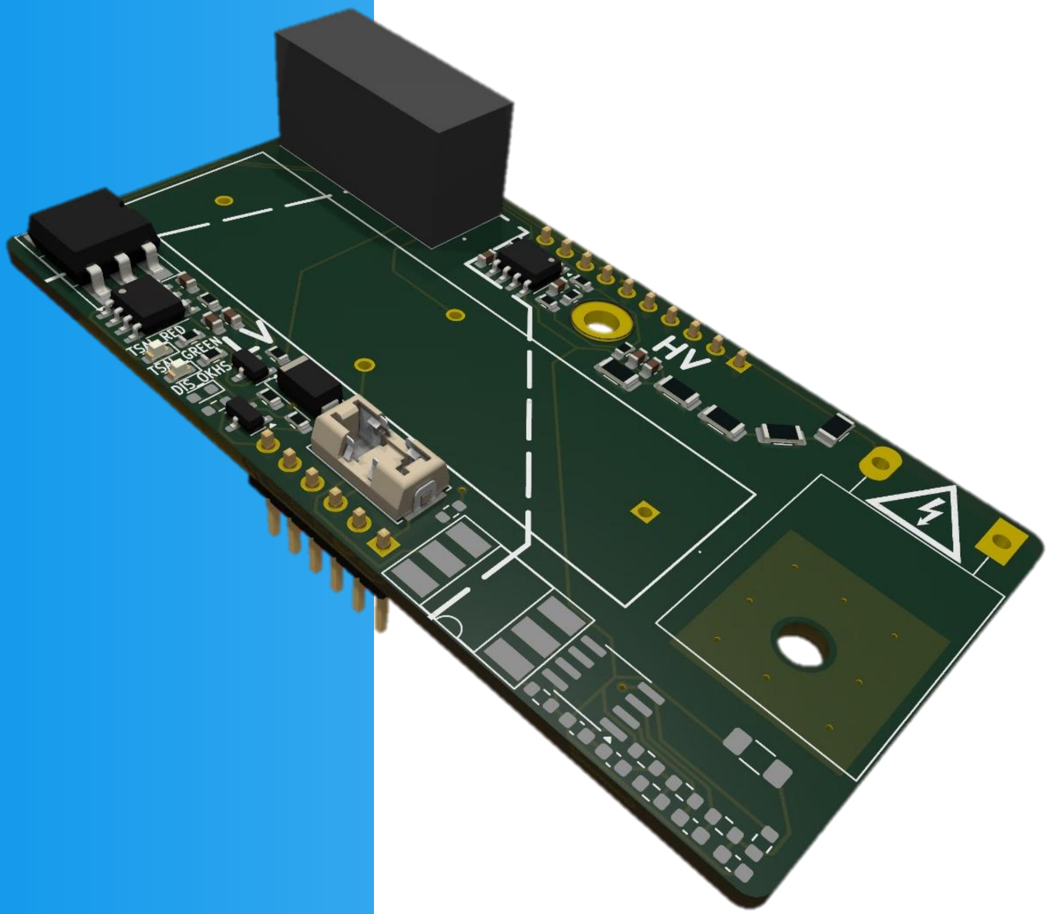
These boards were created as breakout boards to allow an isolated system that can be implemented onto a master board. These boards were designed in a similar way to a teensy, where the board is connected to the master board through header pins. This system is designed to be robust, easy to understand and easy to implement onto the master board. Creating the systems in this breakout board approach means this could be used for multiple years, with only the master board being changed.

The TSAL and DISCHARGE are designed on the same breakout board due to both boards requiring HV, meaning HV doesn't need to be transferred onto multiple breakout boards.

Each report will detail what each system does, how it works, changes that were made, and future improvements that could be made.

TSAL BREAKOUT BOARD

DESIGN REPORT



Abstract

The tractive system active light (TSAL) is a system that uses visual indicators to display whether high voltage (HV) is present within the Tractive System (TS). The TSAL system displays a green light when the TS voltage is safe (<60V) and flashes a red light when the TS voltage is dangerous (>=60V).

The TSAL is composed of three parts:

1. a measurement system, which measures the TS voltage and when the voltage goes above the safe voltage, outputs a low signal,
2. a control system, which uses this measurement output and controls the red and green light depending on the output of the measurement circuit, and,
3. a light system, which is mounted on the roll hoop on the car and contains a green and red light, that is controlled by the control system.

This report details the design and implementation of an isolated measurement and control 'Breakout' PCB for the TSAL.

Previous iterations of the TSAL utilised a variety of components for the control system, and the measurement system that were locations on the central electronics node (CEN). This board contained other systems such as the HFR, BSPD, and Discharge.

Due to the complexity of the circuit, it was decided a breakout board approach would be the standard design for the TSAL. This method allows iterations of the motherboard to be created while having a system that is known to be good, moving the complexity away from the motherboard.

The completed TSAL Breakout PCB board has now been commissioned, and found to be robust, easy to test, and easy to manufacture with PCB-A.

Introduction

The TSAL (Tractive System Active Light) is a system necessary for the indication on the car whether HV is on or off.

The TSAL measures the presence of high voltage in the tractive system (TS), and displays:

1. A green light if the TS voltage is safe (i.e. <60 V DC), and
2. A red, flashing light, if the TS voltage is live/dangerous (>=60 V DC).

Figure 1 NU23 Picture from 2023 Competition, with TSAL Labelled

A Typical implementation of the TSAL consists of three parts:

1. A “Measurement” system that interacts with the HV tractive system and lives within an existing HV enclosure,
2. A “Control” system, that uses this measurement output to switch between red and green light signals, and,
3. An indicator/light system that lives on the roll hoop.

Past NU Racing TSAL circuits by Michael Ruppe & Imel Munday have utilised:

- A combination of comparators and voltage dividers to determine when HV is present,
- An optocoupler to isolate the comparator output to the control system,
- A combination of MOSFETs and a 555 timer to switch and deliver a constant (for green) or pulsing (for red) voltage to the display/light system, and,
- Red and green LED lamps on the roll hoop of the car for indication.

In 2022 and 2023, NU Racing utilised a single board to house both the measurement and control systems. This implementation involved:

1. A measurement/control system that lives within the CEN HV Enclosure, and,
2. A light system that lives on the roll hoop.

In these systems, the TSAL measurement and control was on a PCB that had multiple functions including, BSPD, Discharge and HFR. This system was complicated, involved complex schematics and PCB design with specialised parts. This caused:

1. Complex boards that were difficult to understand and design,
2. Increased Complexity in schematics,
3. Large PCBs footprints, and,
4. Increased complexity while troubleshooting.

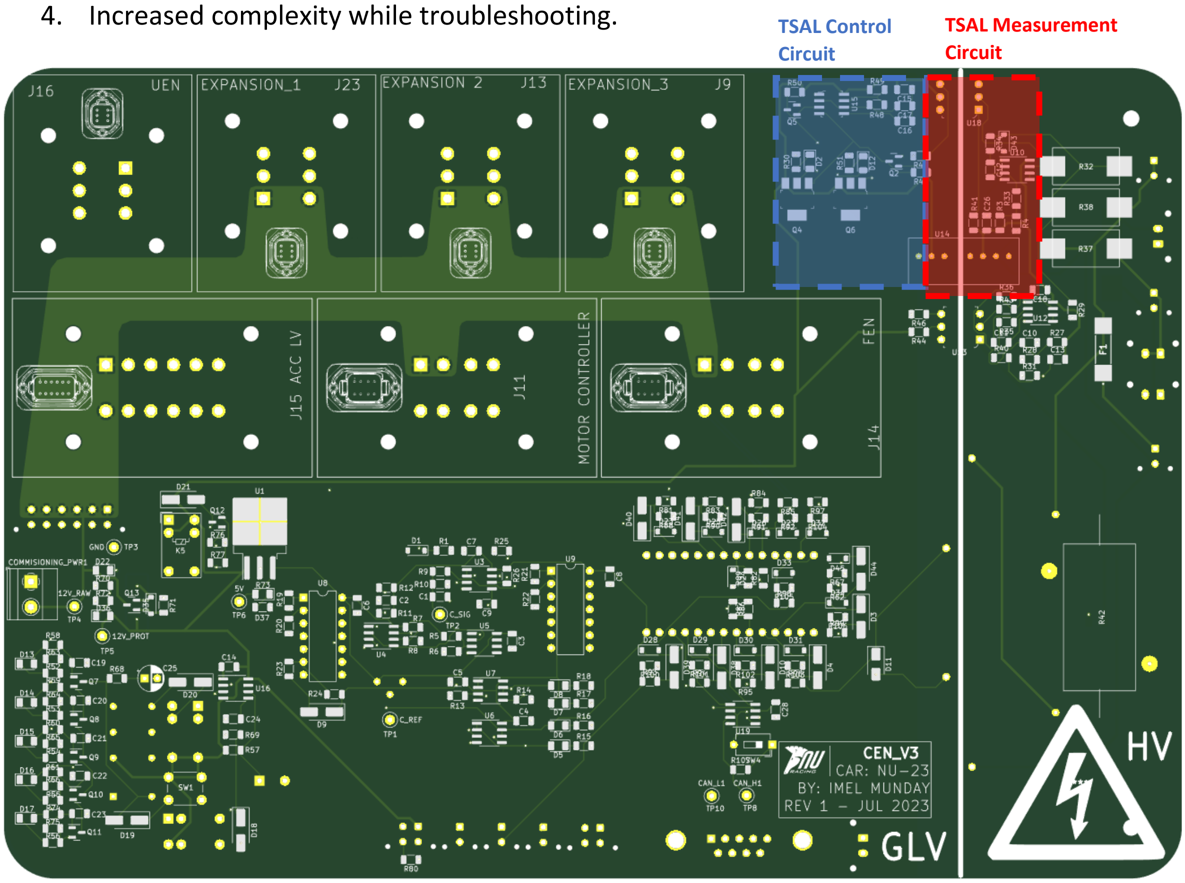


Figure 2 NU23 CEN, with TSAL Components Labelled

To simplify this system, it was decided to create a breakout board for the TSAL. This included removing all the TSAL functionality from a main board, and creating a teensy like board, that has the functionality of the TSAL and attaches to the main board through header pins. This allows the complexity to be removed from the master board.

Proposed benefits of this solution include:

1. Reduced complexity of the master board,
2. Reduced knowledge requirement to implement TSAL measuring and control,
3. Provide a known good, ready to use board that can be implemented,
4. Maintenace of flexibility for topological changes and/or motherboard geometry without remaking TSAL circuitry.

This circuity had to be designed to a specification to:

1. Allow for easy unit testing,
2. Be robust,
3. Utilise as many standard/stocked components as possible,
4. Manufactured utilising PCB-A,
5. Rules compliant,
6. Useable for multiple years, and,
7. Minimal footprint to enable flexibility in motherboard geometry.

Rules

For the FSAE-A competition, rules are required to be followed to ensure safety. The TSAL has certain rule requirements it needs to follow. These include the ones below.

<table>
<tr><th>Rule</th><th></th></tr>
<tr><td>EV.5.9.1 The vehicle must include a Tractive Systems Active Light (TSAL) that must:
a. Illuminate when the GLV System is energized to indicate the status of the Tractive System
b. Be directly controlled by the voltage present in the Tractive System using hard wired electronics. Software control is not permitted.
c. Not perform any other functions.</td><td></td></tr>
<tr><td>EV.5.9.3 When the voltage outside the Accumulator Container(s) exceeds T.9.1.1, the TSAL must:
a. Be Colour: Red
b. Flash with a frequency between 2 Hz and 5 Hz</td><td></td></tr>
<tr><td>EV.5.9.4 When the voltage outside the Accumulator Container(s) is below T.9.1.1, the TSAL must:
a. Be Colour: Green
b. Stay continuously illuminated</td><td></td></tr>
<tr><td>EV.6.5.1 Separation of Tractive System and GLV System:
a. The entire Tractive System and GLV System must be completely galvanically separated.
b. The border between Tractive and GLV System is the galvanic isolation between both systems. Therefore, some components, such as the Motor Controller, may be part of both systems.</td><td></td></tr>
<tr><td>EV.6.5.7 If Tractive System and GLV are on the same circuit board:
a. They must be on separate, clearly defined and clearly marked areas of the board
b. Required spacing related to the spacing between traces / board areas are as follows:
<table>
<tr><td>Voltage</td><td>Over Surface</td><td>Thru Air (cut in board)</td><td>Under Conformal Coating</td></tr>
<tr><td>0-50 V DC</td><td>1.6 mm</td><td>1.6 mm</td><td>1 mm</td></tr>
<tr><td>50-150 V DC</td><td>6.4 mm</td><td>3.2 mm</td><td>2 mm</td></tr>
<tr><td>150-300 V DC</td><td>9.5 mm</td><td>6.4 mm</td><td>3 mm</td></tr>
<tr><td>300-600 V DC</td><td>12.7 mm</td><td>9.5 mm</td><td>4 mm</td></tr>
</table></td><td></td></tr>
<tr><td>EV.6.6.1 All electrical systems (both Low Voltage and High Voltage) must have appropriate Overcurrent Protection/Fusing.</td><td></td></tr>
<tr><td>EV.6.6.2 Unless otherwise allowed in the Rules, all Overcurrent Protection devices must:
a. Be rated for the highest voltage in the systems they protect. Overcurrent Protection devices used for DC must be rated for DC and must carry a DC rating equal to or more than the system voltage
b. Have a continuous current rating less than or equal to the continuous current rating of any electrical component that it protects
c. Have an interrupt current rating higher than the theoretical short circuit current of the system that it protects</td><td></td></tr>
</table>

Topology Implementation

Utilising the breakout board, future implementations of the TSAL system will consist of 2 parts:

1. A measurement and control PCB, and
2. A TSAL light/indicator.

The measurement and control PCB is the focus of this project and will live as a daughter board on the human interface panel (HIP) at the side of the car. This is due to the HIP already being a HV enclosure with HV already being present within and can be utilised by the TSAL.

The TSAL indicator light will remain atop the roll hoop and requires only minimal changes for compatibility with the new system.

The CEN will be utilised to pass-through the signals up to the TSAL light/indicator.

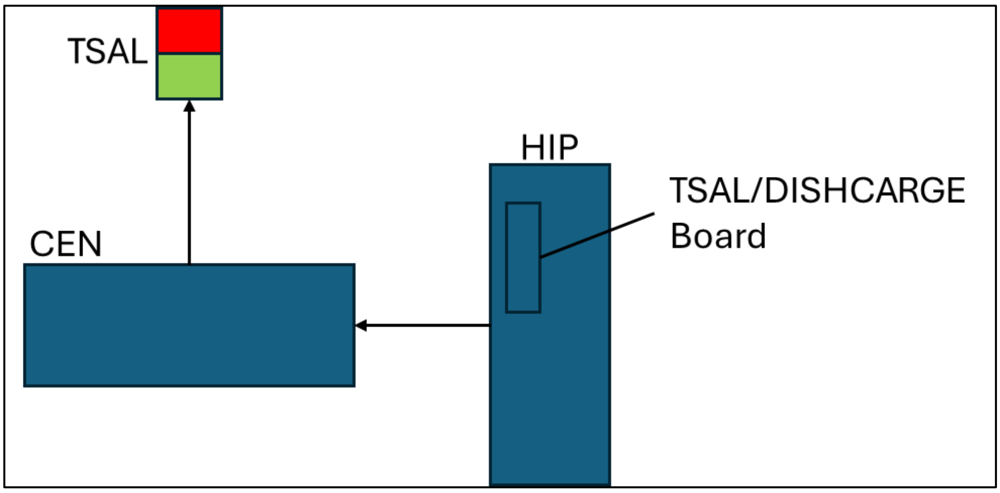


Figure 3 NU24 TSAL Implementation

Topology/Schematic

Due to the functionality of the TSAL the board is made up of two separate parts. These are:

1. A “Measurement” module that lives on the HV side of the board, and creates a “SAFE_OKHS” (also called “STATUS”) signal when HV is not present on the board,
2. A “Control” module that lives on the LV side of the board and uses this “SAFE_OKHS” signal to switch the green and red LEDs on and off, with the red LED being gated with a 555 timer to create the flashing signal.

Figure 4 TSAL Schematic

HV/Measurement

The TSAL measures the tractive system voltage utilising a simple comparator circuit, this uses:

1. A voltage divider across TS+ and TS- to bring the voltage down to a workable input for the comparator, even up to 600V.
2. A reference voltage generated using an isolated power supply and a voltage divider, that is equal to the voltage out of the TS voltage divider when TS is at 60V.

This comparator circuit then uses an optocoupler to isolate this signal for the LV Control system.

Finally, the measurement system has the outputs as followed:

- When “SAFE_OKHS” is “HIGH” the TS is <60V,
- When “SAFE_OKHS” is “LOW” the TS is >=60V.

Figure 5 TSAL HV Schematic

LV

The LV Components consist of 2 sections:

- A green TSAL control, and
- A red TSAL control.

Figure 6 TSAL LV Schematic

Green TSAL Control

The green TSAL control is a simple switching circuit. It consists of an n-channel enhancement MOSFET that will turn on when “SAFE_OKHS” is “HIGH”. This circuit also has a LED for on-board visual functionality.

Red TSAL Control

The Red TSAL control is a more complicated circuit than the green TSAL Control circuit. It still has the n-channel enhancement MOSFET for global switching and the LED for indication, but it also uses a 555 timer to flash/pulse the output whenever the “SAFE_OKHS” is “LOW”.

The design of the 555 circuit is done utilising the datasheet where the frequency and duty cycle can be calculated.

$$frequency \approx \frac{1.44}{(R_A + 2R_B)C}$$

$$Duty\ Cycle = \frac{R_B}{R_A + 2R_B}$$

Utilising these equations the values of R_A, R_B and C were 47.5kΩ, 475kΩ and 470nF. This gave a frequency and duty cycle of 3.07Hz and 0.48. It was necessary to change this circuit slightly to make it work for the TSAL, this included removing R_L and instead having a pulldown on the output to ensure the output is off when this circuit isn’t operating. The other change is connecting the reset to the $\overline{\text{SAFE\_OKHS}}$. This allowed the control for the circuit to be simplified and therefore green and red cannot occur at the same time.

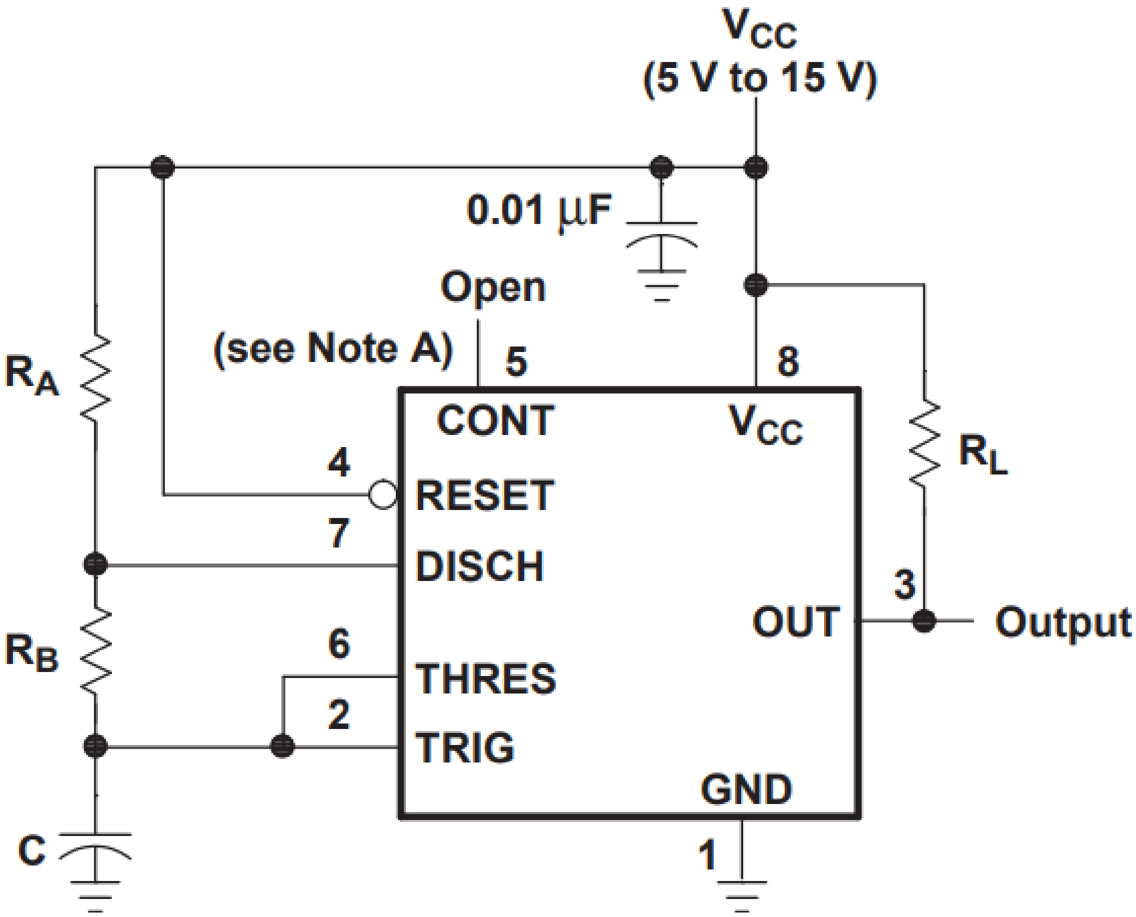


Figure 7 Original 555 Timer Astable Setup

Implementation/Layout

This section will discuss component selection and the layout of the components.

Component Selection

The choice of components was based on availability of components, voltage ratings and cost. This was also influenced by factors such as:

- Wanting components being commonly used within NU Teams (this includes the comparator, isolated power supply, optocoupler, and the n-channel MOSFET),
- Wanting single channel components over multi-channel, and,
- Choosing components based on size.

With these factors, the following components were the ones chosen.

Comparator (LM311)

The comparator chosen was the LM311. This was chosen due to it being a single channel comparator and it being in a similar family to the one used on NU23 CEN, which was the LM393, a dual channel comparator.

The LM311 is capable of being powered up to 36V with a max differential input between the inputs being 30V. This is much more voltage than what will be used on the car, where it will only be powered by 12V (up to 14V) and a max differential voltage of 11V. This comparator is only capable of grounding its output and therefore requires a pullup resistor to output a “HIGH” signal.

To ensure more accurate readings capacitors are used on the inputs and for the supply. This smooths the inputs allowing less noise to impact the readings.

Isolated Power Supply (SPAN-02A-12)

The isolated power supply chosen was the SPAN-02A-12. The power supply can work with a voltage range from 9V to 18V and can output a maximum power of 2W. It has an isolation rating of 1.5kVDC which is much more than the 600V max.

Optocoupler (4N35)

The optocoupler chosen was a 4n35 SMD optocoupler. The optocoupler has a forward voltage of 1.2V at 10mA but, is capable up to 50mA. The isolation voltage over the optocoupler is 5000Vrms. This optocoupler can switch voltages up to 30V and up to 100mA output.

555 Timer (SE555)

The 555-timer chosen was the SE555. This was chosen as there is no difference between the NE, NA, SA, or SE other than temperature ratings. It was therefore chosen due to availability and cost. The circuit necessary for the functionality of the flashing is a standard circuit within the datasheet.

N-Channel Enhancement MOSFET (2N7002)

The n-channel enhancement MOSFET chosen was the 2N7002. This component has a max current drawer of 115mA, which has been found to be not enough for the TSAL. The power dissipation of this component is 225mW, where the expected power dissipation is 100mW. With this it was thought that this component should be able to handle the current from the TSAL.

Issues were noticed during commissioning where the MOSFET may be overheating, therefore it may be necessary to replace with a better suited MOSFET.

Resistor, Capacitors and LED

The choice for resistors, LED and capacitors was done for size constraints, voltage ratings and power rating. Most of the resistors on the board are 0603 except for the voltage divider for the HV. This was due to the voltage ratings of the Resistors with 1206 being rated for 200V, whereas 0603 is only good for 50V. The only resistor that was slightly different was the 0603 LED resistors. This is due to the power requirement for the resistor with most 0603 being rated for 100mW, but the resistors will be dissipating a power of 144mW. Therefore, the resistors are rated for 250mW.

All the capacitors and LEDs are 0603.

The downside of 0603 is that components are more difficult to solder than 1206. This was justified as packaging was more important and the components will be soldered on with JLCPCB

Schottky Diode, Fuse Holder and 3V3 Zener Diode (SS34, 0154001.DRT, and BZT52C3V3)

The components for the schottky diode, fuse holder and 3V3 zener diode are SS34, 0154001.DRT, and BZT52C3V3. These components were all chosen for the standard footprints utilised within the team, the 3V3 Zener diode is not the same part as the one used in the team due to part availability, this doesn’t matter though as it has the same performance and specifications.

Layout

The layout for the PCB was to make the PCBs as small as possible and allow manufacturing using JLC PCB. This meant all SMD components needed to be placed on one side. The other reason for this is how the board will be mounted to the main board.

Other things to consider for the layout is HV spacing ensuring TS+ and TS- is not to close to each other to cause issues such as arcing, HV/LV isolating ensuring there is adequate distance between the HV and LV sides of the board and traces, and the placement of the header pins.

HV Spacing

For compliance and safety, it is required to keep adequate spacing. This mean ensuring components that are grounded to TS- are not too close to components that are or could be at TS+ Voltage. It was therefore required, to try to maintain all components that are powered by TS- to be close to the negative terminal and ensure >4mm spacing between HV+ traces and components. It is also required to ensure the header pins has enough spacing between TS+ and TS-.

Minimum spacing for HV on the TSAL is 4.8mm.

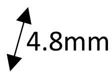


Figure 8 TSAL Voltage Separation Distance

HV/LV Isolation

For compliance, a minimum distance between LV and HV is required on PCB’s. This distance is 4mm for conformal coated PCB’s. Therefore, the layout needs to have this into consideration. With this board being shared by the discharge.

Minimum HV/LV isolation distance on board is 5mm.

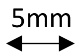


Figure 9 TSAL HV/LV Voltage Separation Distance

Board Size

For simplicity it was decided to make boards to 5mm increments. Therefore, a logical layout, trying to fit as many components as close together was done to allow the minimum board size to be achieved.

Figure 10 Discharge Board Size

Header Pins

The header pins for the LV side required enough for all the LV signals into and out of the board. This included 12V, ground, TSAL_RED_SWITCHED_GROUND, and TSAL_GREEN_SWITCHED _GROUND. The other two pins are the one necessary for the Discharge.

For the HV side it was chosen to use a 10-pin header as this gave enough voltage separation and allowed better tracing where TS+ and TS- would sit.

Logical Layout

Due to the size of the board, it was required to have a logical layout of components to ensure tracing was possible.

Footprint/Pinout

Due to these boards being place onto a master board, it was necessary to create a footprint for the component and ensure the pinout for the component is known. With this board being shared with the Discharge, the pinout is shared.

Pin	Name
1	12V
2	GND
3	SHUTDOWN_TSMS
4	TSAL_GREEN_SWITCHED_GND
5	TSAL_RED_SWITCHED_GND
6	DISCHARGE_OKHS
7	TS-
8	TS+

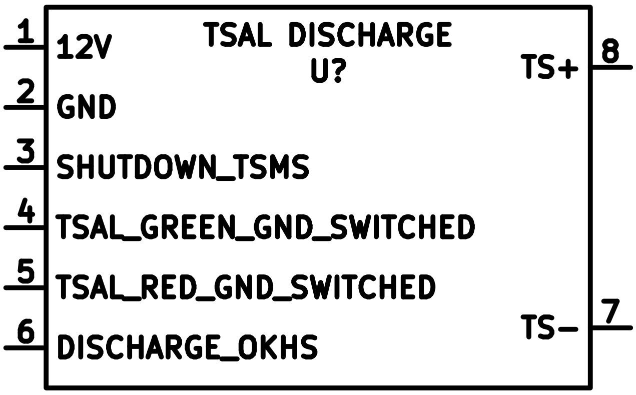


Figure 11 TSAL/Discharge Symbol

Figure 12 TSAL/Discharge Footprint

Commissioning and Unit Tests

Utilising JLCPCB to create the boards, most of the components could be assembled by JLC, the components that were not soldered onto the board was the isolated DCDC, and the header pins due to them being through hole components.

To commission this board, tests were completed to ensure proper operation of the board without any issues.

Test Type	**Test**	**What should happen**	**Did it?**
Visual Inspection	Inspect all pre-solder components, ensure soldering is adequate and components are correct. Ensure there is no shorts or excess solder	All components are correct	
Setup	Solder on Header pins		
LV Power	Connect 12V to the LV side	Red TSAL starts flashing	
Setup	Solder on the isolated DCDC		
LV Power	Connect 12V to the LV side	Green TSAL is on	
HV Setup	Connect power supply to HV side		
HV Power	With the HV Power still turned off turn on the LV Power supply	Green TSAL is on	
HV Power	Set HV power supply up to 50V and turn it on, Turn on LV power supply	Green TSAL is on	
HV Power	With the power supplies turned on, slowly increase the voltage of the HV power supply	Red TSAL starts flashing when the voltage is about 60V	
HV Power	Turn HV power supply up and down, ensuring LED changes from Green and Red when it should	Green and Red turn on when required	
TSAL Car Test	Connect TSAL_GREEN_SWITCHED_GND to the TSAL, Turn on LV Power	The green LED on the TSAL should turn on	
TSAL Car Test	Set HV voltage to 50V, Turn HV power supply ON and increase voltage	The green LED turns off when the HV approaches 60V	
TSAL Car Test	Turn HV Power supply off. Connect TSAL_RED_SWITCHED_GND to the TSAL, Turn on LV Power	Both LEDs on the TSAL should be OFF	
TSAL Car Test	Set HV voltage to 50V, Turn HV power supply ON and increase voltage	The Red LED on the TSAL starts flashing when the HV approaches 60V	
HV Power supply test	Connect the HV to the HV Power supply, set Voltage to 50V, Ensure LV is turned ON. Turn HV Supply ON, increase voltage to 450V	Red TSAL starts flashing red when HV approaches 60V, stays on the whole time, nothing else should happen	
HV Power supply test	Turn HV power supply down to 50V while LV is still on	Green TSAL turns on when the voltage approaches 60V	

Prototype Commissioning

Initially utilising the base design of the CEN, the only main changes for the first iteration was changing resistor and capacitor values. This was to reduce power being wasted. The only other change for this circuit was changing the 4n35 from a through hole to a SMD.

During commissioning, it was found that the SMD 4n35 did not fit the footprint correctly, and therefore had to be changed. The footprint change was to the dip 6 SMD long pad. The only other change for this schematic after this first iteration was changing the resistors, LEDs, and capacitors to 0603.

During testing it was also seen that if the 555-timer failed, the red led would turn on when it wasn't supposed to and be constantly on. To fix this, a new 555-timer was soldered on and tested.

Another thing noted during testing is the 2N7002 MOSFET could break due to too much current flowing through it. This would require a new MOSFET to be spec that can achieve the current, but they are widely available. This will be noticed if both the red and green LEDs are on at the same time.

Conclusion

The TSAL is a component on the car that is necessary to determine if HV is present in the tractive system. Utilising a measurement circuit, a control circuit, and the lights themself, this allows an easy visual indicator.

The measurement circuit is done by comparing HV to a reference voltage and outputting a “LOW” signal when HV is present. This signal is then used by the control circuit to control whether the green light is on or the red light flashing with the use of a 555 timer.

The system designed for the measurement and control circuit was designed on the same board and is designed in a way to make it:

- Robust
- Rules compliant
- Utilise as many standard components as possible, and
- Usable for many years

Through making these breakout boards, multiple benefits were achieved, such as:

- Decreasing the complexity of the mother board it will be attached to,
- Allowing easier unit testing,
- Allowing easier manufacturing utilising PCB-A,
- Allowing a standard schematic for this system.

Future Work

There are multiple things that could be changed on this circuit.

Replacing Comparators with Op-amps

To reduce different part counts on the system the LM311 could be removed and replaced with a standard op-amp that would be common to the car, this is currently the TLV9301xDBV. The downside of using an op-amp instead of a comparator is a slightly slower response time, and slightly less accurate. For our purposes where the components do not have to be highly accurate, this isn't an issue, and having less components to explain what they do can be beneficial.

Replace Optocoupler

Another change that could be beneficial could be replacing the optocoupler with a smaller form factor, or a different galvanically isolated component.

Resistor/Capacitor Sizes

To make the board even smaller it could be possible to use 0402 resistors for some of them. The resistors for the HV voltage divider should remain as 1206 or possibly 0805 or 0603, the only necessary thought for these is the voltage rating. The other thing to think about would be wattage the resistors are dissipating.

Replace N Channel MOSFETs

Replace the MOSFETs with ones that are better suited to the current. At the time, this current is 290mA (300mA with the onboard LED), this MOSFET should have the same footprint as the 2n7002, such as DMN6075S-7, which is rated for a much higher current.

Larger pulldown Resistor Values

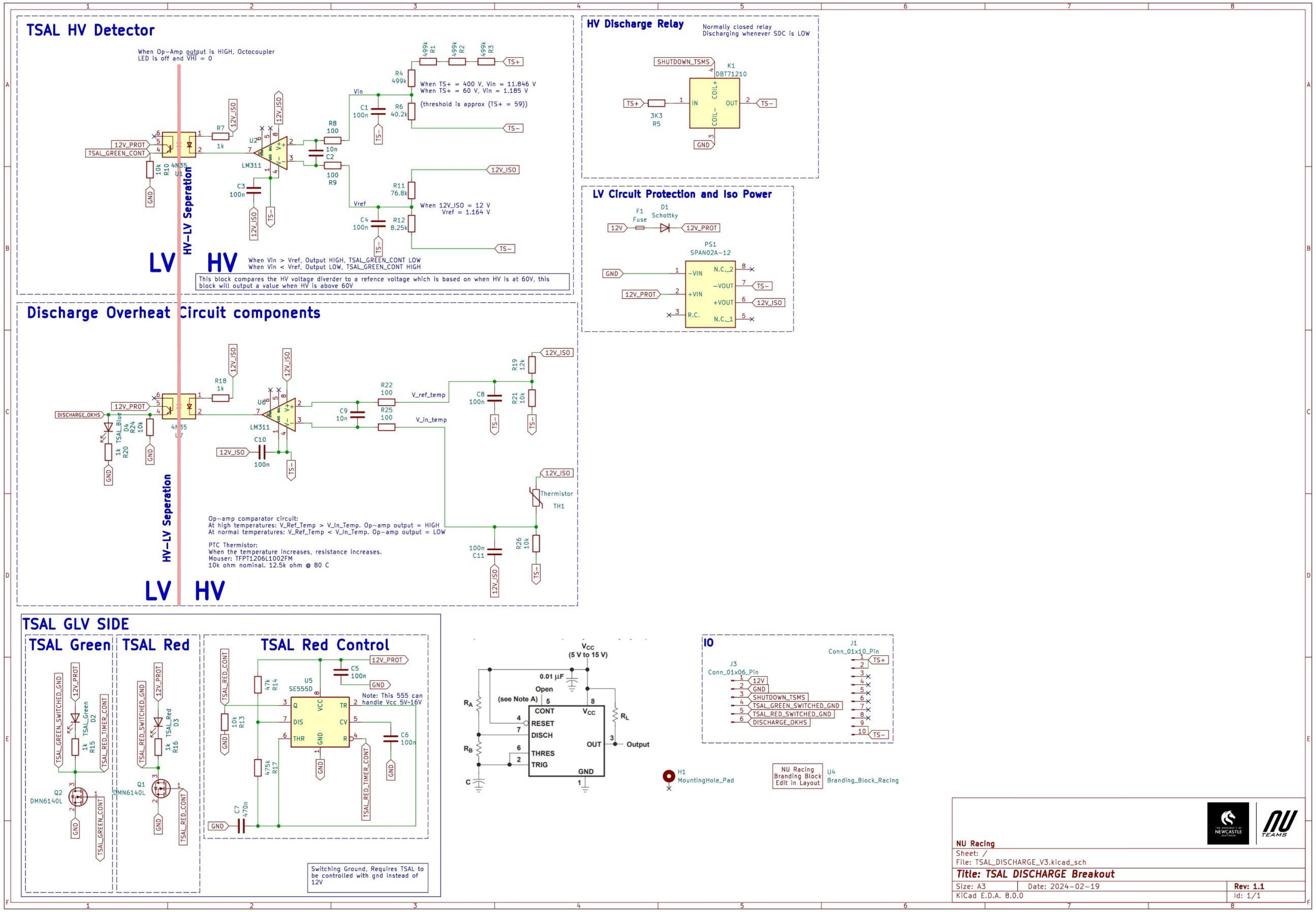
Making the pulldown resistor values larger would reduce current drawer when the circuit is operating. It would be worth testing to ensure no unstable operations occur. This could be as simple as changing the values from 10k to 100k.

Fusing TS+

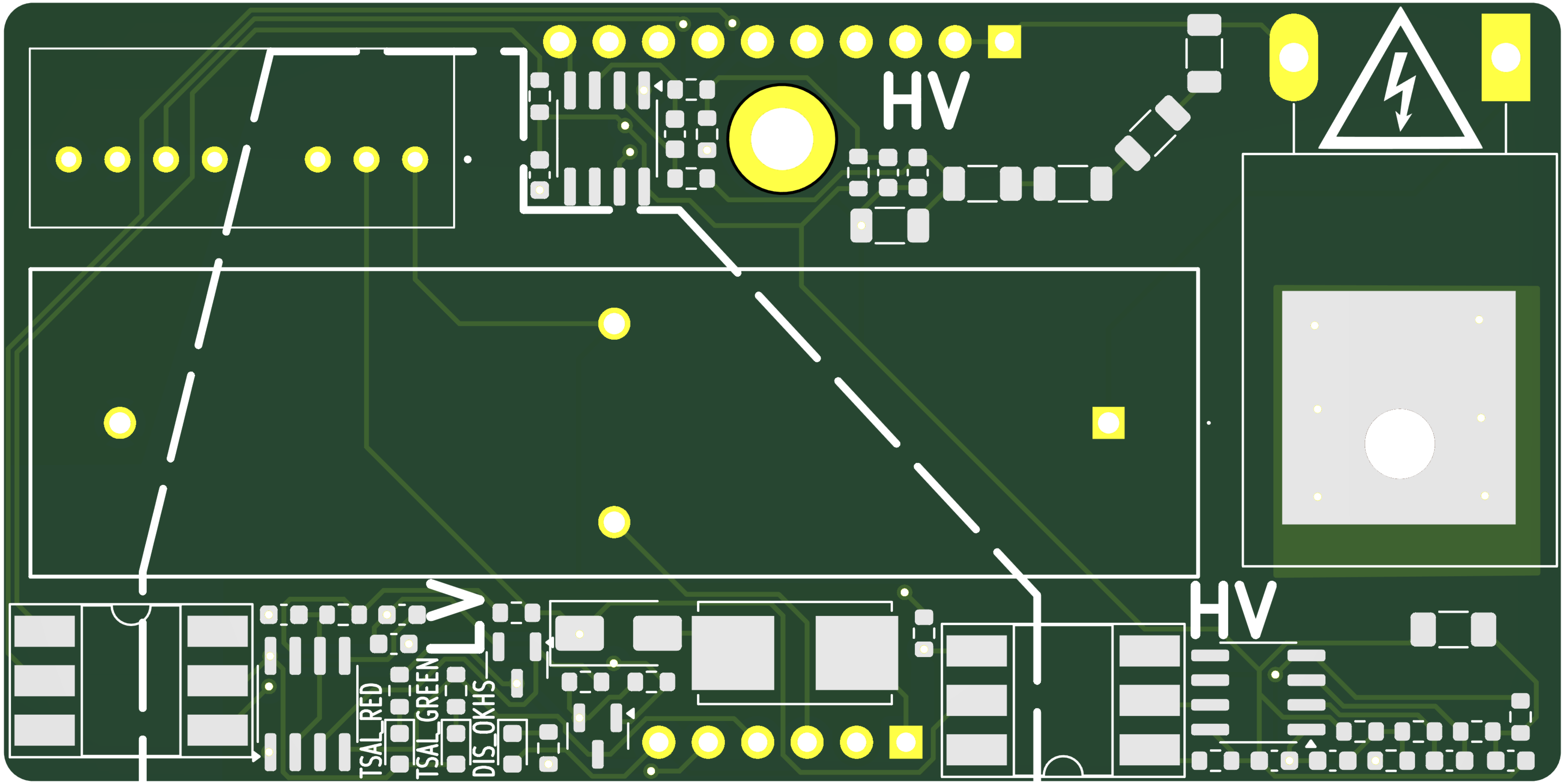
To ensure the circuit doesn't break, it could be beneficial to have a fuse on the TS+ for the circuitry on the HV side.

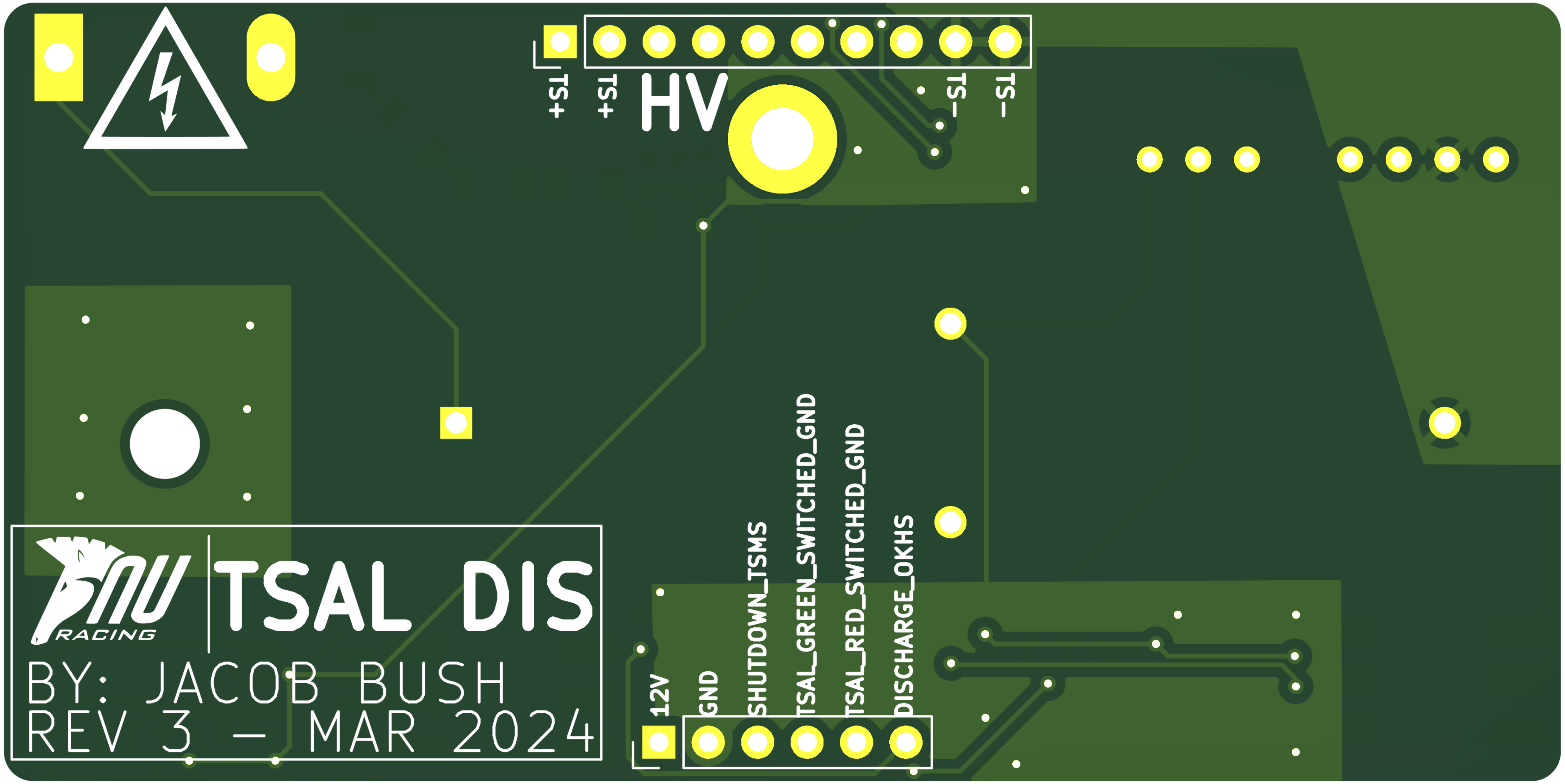
Appendix

Schematic

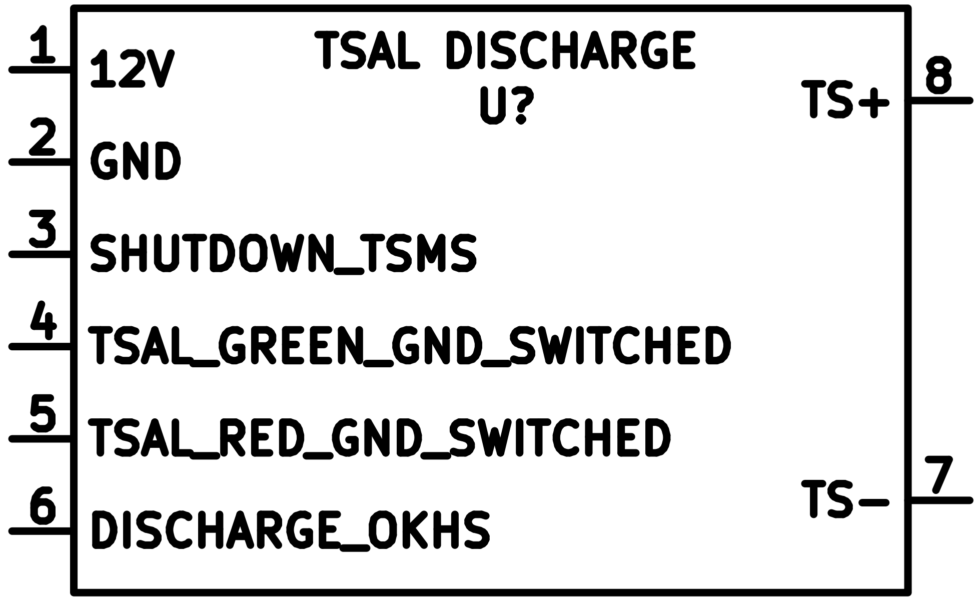


PCB


HV
HV
LV
TSAL_RED
TSAL_GREEN
DIS_OKHS


TS+
TS+
HV
TS−
TS−
TSAL DIS
BY: JACOB BUSH
REV 3 – MAR 2024
12V
GND
SHUTDOWN_TSMS
TSAL_GREEN_SWITCHED_GND
TSAL_RED_SWITCHED_GND
DISCHARGE_OKHS

Symbol



Footprint

Pinout

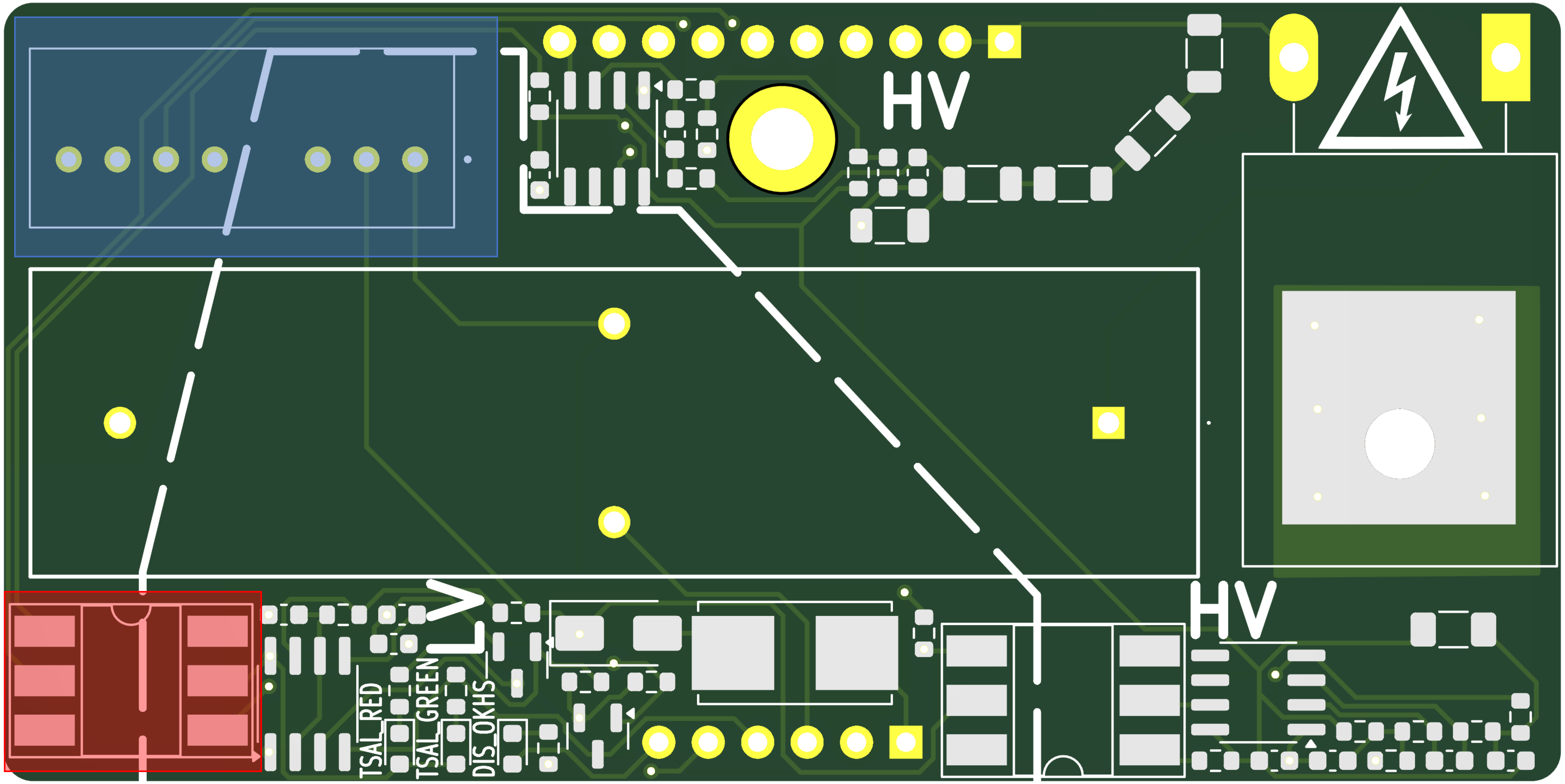
Pin	Name
1	12V
2	GND
3	SHUTDOWN_TSMS
4	TSAL_GREEN_SWITCHED_GND
5	TSAL_RED_SWITCHED_GND
6	DISCHARGE_OKHS
7	TS-
8	TS+

BOM

Comment	Designator	Footprint	JLCPCB #	Datasheet
10nF	C2	0603	C57112	https://datasheet.lcsc.com/lcsc/2304140030_FH--Guangdong-Fenghua-Advanced-Tech-0603B103K500NT_C57112.pdf
470nF	C7	0603	C1623	https://datasheet.lcsc.com/lcsc/2304140030_Samsung-Electro-Mechanics-CL10B474KA8NNNC_C1623.pdf
4N35	U1	DIP-6_W8.89mm_SMDSocket_LongPads	C115444	https://datasheet.lcsc.com/lcsc/1810161110_Lite-On-4N35S-TA1_C115444.pdf
Fuse	F1	Fuseholder_Littelfuse_Nano2_154x	C206909	https://datasheet.lcsc.com/lcsc/2304140030_Littelfuse-0154001-DRT_C206909.pdf
Schottky	D1	D_SMA	C2909963	https://datasheet.lcsc.com/lcsc/2110280930_YONGYUTAI-SS34_C2909963.pdf
47k	R14	0603	C25819	https://datasheet.lcsc.com/lcsc/2206010045_UNI-ROYAL-Uniroyal-Elec-0603WAF4702T5E_C25819.pdf
1k	R7, R15, R16, R18, R20	0603	C2653986	https://datasheet.lcsc.com/lcsc/2304140030_ROHM-Semicon-ESR03EZPF1001_C2653986.pdf
100	R8, R9	0603	C22775	https://datasheet.lcsc.com/lcsc/2206010130_UNI-ROYAL-Uniroyal-Elec-0603WAF1000T5E_C22775.pdf
40.2k	R6	0603	C620614	https://datasheet.lcsc.com/lcsc/2205311816_UNI-ROYAL-Uniroyal-Elec-1206W4F4022T5E_C620614.pdf
Green LED	D2	0603	C12624	https://datasheet.lcsc.com/lcsc/1806151818_Hubei-KENTO-Elec-KT-0603G_C12624.pdf
100nF	C1, C3, C4, C5, C6	0603	C14663	https://datasheet.lcsc.com/lcsc/2211101700_YAGEO-CC0603KRX7R9BB104_C14663.pdf
76.8k	R11	0603	C218144	https://datasheet.lcsc.com/lcsc/2304140030_Viking-Tech-ARG03FTC7682_C218144.pdf
LM311	U2	SOIC-8_3.9x4.9mm_P1.27mm	C12597	https://datasheet.lcsc.com/lcsc/1809172023_Texas-Instruments-LM311DR_C12597.pdf
475k	R17	0603	C103668	https://datasheet.lcsc.com/lcsc/2304140030_RALEC-RTT034753FTP_C103668.pdf
10k	R10, R13	0603	C25804	https://datasheet.lcsc.com/lcsc/2206010045_UNI-ROYAL-Uniroyal-Elec-0603WAF1002T5E_C25804.pdf
8.25k	R12	0603	C706011	https://datasheet.lcsc.com/lcsc/2010201809_YAGEO-RT0603DRD078K25L_C706011.pdf
2N7002	Q1, Q2	SOT-23	C8545	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_Jiangsu-Changjing-Electronics-Technology-Co---Ltd--2N7002_C8545.pdf
SE555	U3	SOIC-8_3.9x4.9mm_P1.27mm	C967980	https://datasheet.lcsc.com/lcsc/2302221730_Texas-Instruments-SE555DR_C967980.pdf
Red LED	D3	0603	C2286	https://datasheet.lcsc.com/lcsc/1810231112_Hubei-KENTO-Elec-KT-0603R_C2286.pdf
499k	R1, R2, R3, R4	1206	C3152280	https://datasheet.lcsc.com/lcsc/2207281800_Sunway-SC1206F4993F8ANRH_C3152280.pdf
SPAN02A-12	PS1			https://datasheet.datasheetarchive.com/originals/distributors/DKDS-2/37032.pdf

HV/LV Voltage Separation components

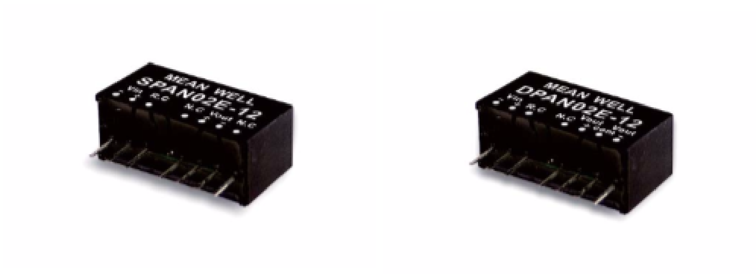
12V Isolated DCDC



Optocoupler

12V Isolated DCDC Datasheet

2W SIP Package DC-DC Regulated Converter **SPAN02 & DPAN02 series**



CE

■ Features

- SIP8 package with industry standard pinout
- 2:1 wide input range
- Operating temperature range -40 ~ +90℃
- No minimum load required
- Comply to EN55032 radiated Class A without additional components
- High efficiency up to 85%
- Protections: Short circuit (Continuous) / Overload
- 1.5KVDC I/O isolation
- Remote ON/OFF control
- 3 years warranty

■ Applications

- Telecom/datacom system
- Wireless network
- Industrial control facility
- Instrument
- Analyzer
- Detector
- Data switch

■ Description

SPAN02 and DPAN02 series are 2W isolated and regulated module type DC-DC converter with SIP8 package. It features international standard pins, a high efficiency up to 85%, wide working temperature range -40~+90℃, 1.5KVDC I/P-O/P isolation voltage, compliance to EN55032 radiated class A without additional components, overload and continuous-mode short circuit protection, etc. The models account for different input voltage 4.5~9V, 9~18V, 18~36V and 36~75V 2:1 wide input range, and various output voltage, 5V/12V/15V for single output and ±5V/±12V/±15V for dual outputs, which are suitable for all kinds of systems, Such as industrial control, telecommunication field, distributed power architecture, and so on.

■ Model Encoding

S PAN02 E – 12

- 12 — Output voltage (5/12/15Vdc，±5/±12/±15Vdc)
- E — Input voltage (E: 4.5~9Vdc，A: 9~18Vdc，B: 18~36Vdc，C: 36~75Vdc)
- PAN02 — Rated wattage
- S — Series name { S:Single output; D:Dual output }

File Name: SPAN02,DPAN02-SPEC 2017-03-06

MEAN WELL 2W SIP Package DC-DC Regulated Converter **SPAN02 & DPAN02 series**

MODEL SELECTION TABLE

ORDER NO.	INPUT			OUTPUT		EFFICIENCY (TYP.)	CAPACITOR LOAD (MAX.)
	INPUT VOLTAGE (RANGE)	INPUT CURRENT		OUTPUT VOLTAGE	OUTPUT CURRENT		
		NO LOAD	FULL LOAD				
SPAN02E-03	5V (4.5 ~ 9V)	60mA	452mA	3.3V	0 ~ 500mA	74%	500μF
SPAN02E-05		60mA	526mA	5V	0 ~ 400mA	78%	400μF
SPAN02E-12		60mA	501mA	12V	0 ~ 167mA	80%	167μF
SPAN02E-15		65mA	503mA	15V	0 ~ 134mA	80%	134μF
DPAN02E-05		60mA	519mA	±5V	±0 ~ 200mA	78%	*200μF
DPAN02E-12		60mA	504mA	±12V	±0 ~ 83mA	80%	*83μF
DPAN02E-15		60mA	503mA	±15V	±0 ~ 67mA	80%	*67μF
SPAN02A-03	12V (9 ~ 18V)	30mA	181mA	3.3V	0 ~ 500mA	76%	500μF
SPAN02A-05		32mA	211mA	5V	0 ~ 400mA	80%	400μF
SPAN02A-12		32mA	204mA	12V	0 ~ 167mA	83%	167μF
SPAN02A-15		32mA	202mA	15V	0 ~ 134mA	84%	134μF
DPAN02A-05		31mA	211mA	±5V	±0 ~ 200mA	79%	*200μF
DPAN02A-12		31mA	202mA	±12V	±0 ~ 83mA	82%	*83μF
DPAN02A-15		31mA	202mA	±15V	±0 ~ 67mA	83%	*67μF
SPAN02B-03	24V (18 ~ 36V)	18mA	90mA	3.3V	0 ~ 500mA	76%	500μF
SPAN02B-05		19mA	105mA	5V	0 ~ 400mA	79%	400μF
SPAN02B-12		19mA	102mA	12V	0 ~ 167mA	82%	167μF
SPAN02B-15		19mA	101mA	15V	0 ~ 134mA	83%	134μF
DPAN02B-05		18mA	105mA	±5V	±0 ~ 200mA	79%	*200μF
DPAN02B-12		19mA	102mA	±12V	±0 ~ 83mA	81%	*83μF
DPAN02B-15		19mA	100mA	±15V	±0 ~ 67mA	85%	*67μF
SPAN02C-03	48V (36 ~ 75V)	9mA	46mA	3.3V	0 ~ 500mA	75%	500μF
SPAN02C-05		9mA	53mA	5V	0 ~ 400mA	80%	400μF
SPAN02C-12		9mA	51mA	12V	0 ~ 167mA	82%	167μF
SPAN02C-15		9mA	50mA	15V	0 ~ 134mA	83%	134μF
DPAN02C-05		12mA	53mA	±5V	±0 ~ 200mA	78%	*200μF
DPAN02C-12		12mA	51mA	±12V	±0 ~ 83mA	82%	*83μF
DPAN02C-15		9mA	50mA	±15V	±0 ~ 67mA	84%	*67μF

* For each output

File Name:SPAN02,DPAN02-SPEC 2017-03-06

MEAN WELL 2W SIP Package DC-DC Regulated Converter **SPAN02 & DPAN02 series**

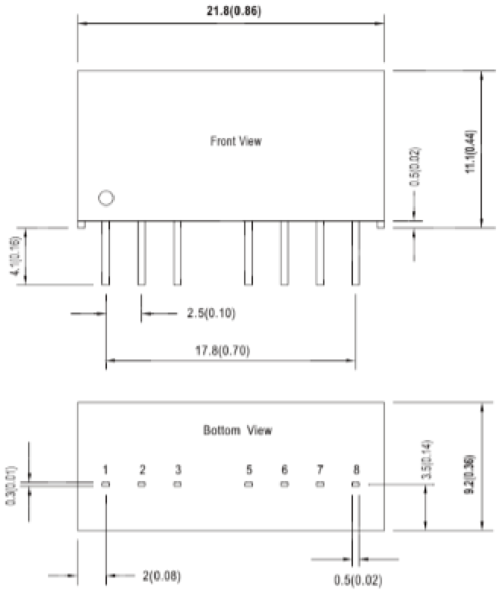
SPECIFICATION				
INPUT	VOLTAGE RANGE	E: 4.5~9Vdc , A: 9~18Vdc , B: 18~36Vdc , C: 36~75Vdc		
	SURGE VOLTAGE (100ms max.)	5Vin models : 15Vdc ; 12Vin models : 25Vdc ; 24Vin models : 50Vdc ; 48Vin models : 100Vdc		
	FILTER	Internal capacitor		
	PROTECTION	Fuse recommended. 5Vin models: 1000mA Slow-Blow Type, 12Vin models: 500mA Slow-Blow Type, 24V and 48Vin models: 250mA Slow-Blow Type		
	INTERNAL POWER DISSIPATION	500mW		
OUTPUT	VOLTAGE ACCURACY	±1.5%		
	RATED POWER	2W		
	RIPPLE & NOISE Note.2	75mVp-p		
	LINE REGULATION Note.3	±0.5%		
	LOAD REGULATION Note.4	Single output models: ±0.5%, Dual output models: ±1%		
	SWITCHING FREQUENCY (Typ.)	100KHz		
PROTECTION	SHORT CIRCUIT	Protection type : Continuous, automatic recovery		
	OVERLOAD	Protection type : Recovers automatically after fault condition is removed		
	UNDER VOLTAGE LOCKOUT	Start-up voltage	5Vin : 4.2Vdc ; 12Vin : 7.3Vdc ; 24Vin : 15.5Vdc ; 48Vin : 31Vdc	
		Shutdown voltage	5Vin : 3Vdc ; 12Vin : 5.8Vdc ; 24Vin : 12Vdc ; 48Vin : 24Vdc	
FUNCTION	REMOTE CONTROL	Power ON: R.C. ~ -Vin <0.8Vdc or open circuit; Power OFF: R.C. ~ -Vin >4 ~ 15Vdc or short		
ENVIRONMENT	COOLING	Free-air convection		
	WORKING TEMP.	-40 ~ +90℃ (Refer to "Derating Curve")		
	CASE TEMPERATURE	+100℃ max.		
	WORKING HUMIDITY	20% ~ 90% RH non-condensing		
	STORAGE TEMP., HUMIDITY	-55 ~ +125℃, 10 ~ 95% RH non-condensing		
	TEMP. COEFFICIENT	0.03% / ℃ (0 ~ 85℃)		
	SOLDERING TEMPERATURE	1.5mm from case of 1 ~ 3sec./260℃ max.		
	VIBRATION	10 ~ 500Hz, 2G 10min./1cycle, period for 60min. each along X, Y, Z axes		
SAFETY & EMC (Note.5)	WITHSTAND VOLTAGE	I/P-O/P:1.5KVDC		
	ISOLATION RESISTANCE	I/P-O/P:100M Ohms / 500VDC / 25℃/ 70% RH		
	ISOLATION CAPACITANCE (Typ.)	10pF		
	EMC EMISSION	Parameter	Standard	Test Level / Note
		Conducted	EN55032(CISPR32)	N/A
		Radiated	EN55032(CISPR32)	Class A
	EMC IMMUNITY	Parameter	Standard	Test Level / Note
		ESD	EN61000-4-2	Level 2, ±8KV air, ±4KV contact
		Radiated Susceptibility	EN61000-4-3	Level 2, 3V/m
		EFT/Burest	EN61000-4-4	Level 1, 0.5KV
		Surge	EN61000-4-5	Level 1, 0.5KV Line-Line
		Conducted	EN61000-4-6	Level 2, 3V(e.m.f.)
		Magnetic Field	EN61000-4-8	Level 2, 3A/m
OTHERS	MTBF	2500Khrs MIL-HDBK-217F(25℃)		
	DIMENSION (L*W*H)	21.8*9.2*11.1mm (0.86*0.36*0.44 inch)		
	CASE MATERIAL	Non-Conductive black plastic (UL 94V-0 rated)		
	PACKING	4.8g		
NOTE	1.All parameters are specified at normal input(E:5Vdc, A:12Vdc, B:24Vdc, C:48Vdc), rated load, 25℃ 70% RH ambient. 2.Ripple & noise are measured at 20MHz by using a 12" twisted pair terminated with a 0.1μf & 47μf capacitor. 3.Line regulation is measured from low line to high line at rated load. 4.Load regulation is measured from 10% to 100% rated load. 5.The final equipment must be re-confirm that it still meet EMC directives. For guidance on how to perform these EMC tests, please refer to "EMI testing of component power supplies."(as available on http://www.meanwell.com)			

File Name:SPAN02,DPAN02-SPEC 2017-03-06

MEAN WELL 2W SIP Package DC-DC Regulated Converter **SPAN02 & DPAN02 series**

Mechanical Specification

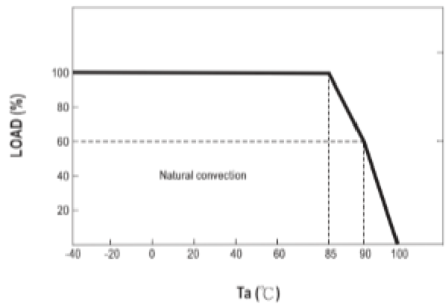
- All dimensions in mm(inch)
- Tolerance:x.x±0.5mm(x.xx±0.02")
- Pin pitch tolerance: ±0.05mm (±0.002")



Plug Assignment

Pin-Out		
Pin No.	SPAN02 (Single output)	DPAN02 (Dual output)
1	-Vin	-Vin
2	+Vin	+Vin
3	R.C.	R.C.
5	N.C.	N.C.
6	+Vout	+Vout
7	-Vout	Common
8	N.C.	-Vout

Derating Curve



Installation Manual

Please refer to : http://www.meanwell.com/manual.html

File Name:SPAN02,DPAN02-SPEC 2017-03-06

Optocoupler Datasheet

LITEON OPTOELECTRONICS

Photocoupler
Product Data Sheet
4N35/ 4N37
(M, S, S-TA1)

Spec No.: DS-70-99-0012
Effective Date: 12/13/2011
Revision: C

LITE-ON DCC
RELEASE

BNS-OD-FC001/A4

LITE-ON Technology Corp. / Optoelectronics
No.90,Chien 1 Road, Chung Ho, New Taipei City 23585, Taiwan, R.O.C.
Tel: 886-2-2222-6181 Fax: 886-2-2221-1948 / 886-2-2221-0660
http://www.liteon.com/opto

LITE-ON TECHNOLOGY CORPORATION

Property of LITE-ON Only

FEATURES

* High crrent transfer ratio
  (CTR : MIN. 100% at $I_F = 10mA$, $V_{CE} = 10V$)
* Response time
  (t_{on} : TYP. 3μs at $V_{CC} = 10V$, $I_C = 2mA$, $R_L = 100\Omega$)
* Input-output isolation voltage
  4N35 series : $V_{iso} = 3{,}550Vrms$
  4N37 series : $V_{iso} = 1{,}500Vrms$
* Dual-in-line package :
  4N35, 4N37
* Wide lead spacing package :
  4N35M, 4N37M
* Surface mounting package :
  4N35S, 4N37S
* Tape and reel packaging :
  4N35S-TA1, 4N37S-TA1
* Safety approval
  UL& cUL, VDE, FIMKO, CQC approved
* RoHS compliant

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 1 of 11

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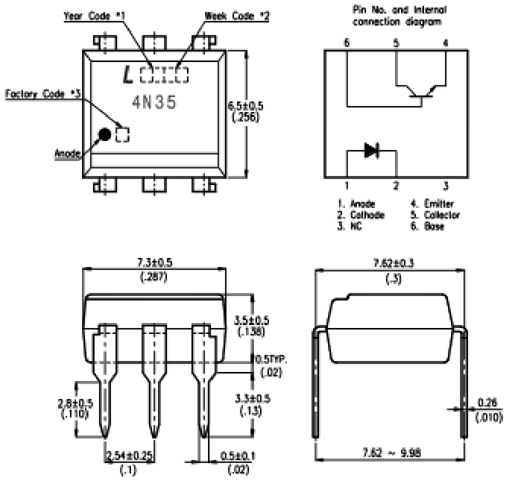
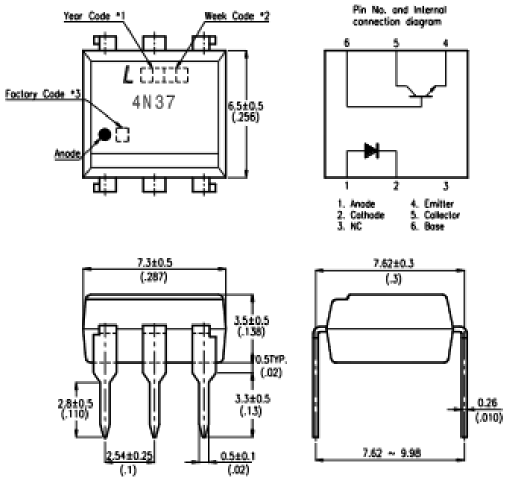
OUTLINE DIMENSIONS

4N35 :



4N37 :



*1. Year date code.
*2. 2-digit work week.
*3. Factory identification mark shall be marked
(Y : Thailand, X : China-TJ, W : China-CZ)

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 2 of 11

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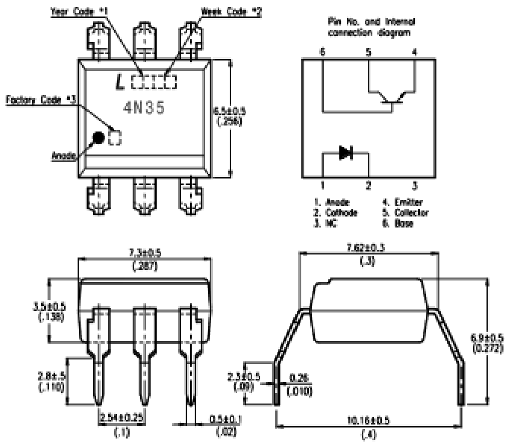
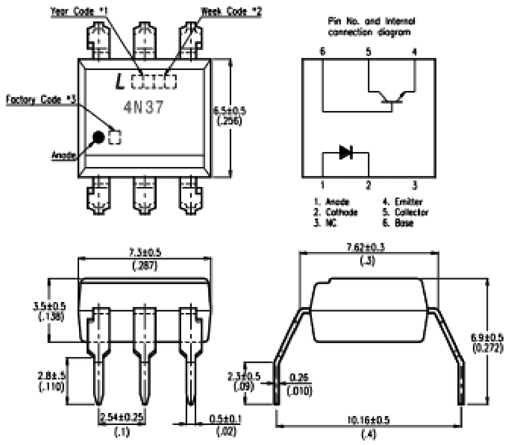
OUTLINE DIMENSIONS

4N35M :



4N37M :



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*2. 2-digit work week.
*3. Factory identification mark shall be marked
(Y : Thailand, X : China-TJ, W : China-CZ)

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 3 of 11

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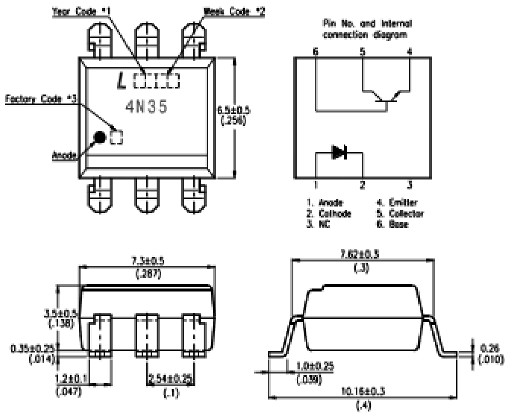
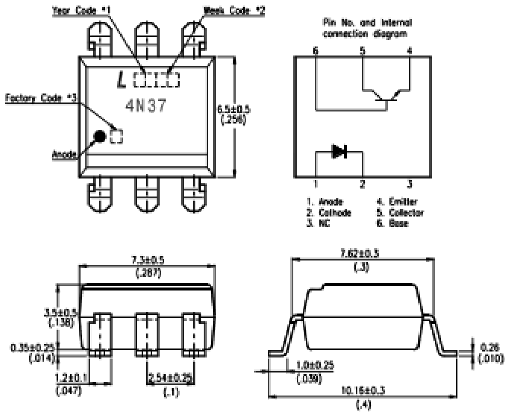
OUTLINE DIMENSIONS

4N35S :



4N37S :



*1. Year date code.
*2. 2-digit work week.
*3. Factory identification mark shall be marked
(Y : Thailand, X : China-TJ, W : China-CZ)

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 4 of 11

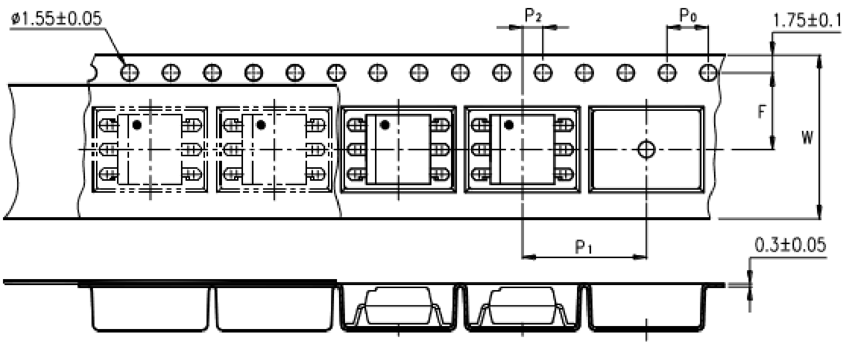
BNS-OD-C131/A4

LITEON | LITE-ON TECHNOLOGY CORPORATION

Property of LITE-ON Only

TAPING DIMENSIONS

4N35S-TA1 , 4N37S-TA1 :



Description	Symbol	Dimensions in mm (inches)
Tape wide	W	16 ± 0.3 (.63)
Pitch of sprocket holes	P0	4 ± 0.1 (.15)
Distance of compartment	F P2	7.5 ± 0.1 (.295) 2 ± 0.1 (.079)
Distance of compartment to compartment	P1	12 ± 0.1 (.472)

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011) | Page : 5 of 11

BNS-OD-C131/A4

LITE-ON TECHNOLOGY CORPORATION

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ABSOLUTE MAXIMUM RATING

(Ta = 25°C)

PARAMETER			SYMBOL	RATING	UNIT
INPUT	Forward Current		I_F	60	mA
	Reverse Voltage		V_R	6	V
	Power Dissipation		P	100	mW
OUTPUT	Collector - Emitter Voltage		V_{CEO}	30	V
	Emitter - Collector Voltage		V_{ECO}	7	V
	Collector - Base Voltage		V_{CBO}	70	V
	Collector Current		I_C	100	mA
	Collector Power Dissipation		P_C	300	mW
Total Power Dissipation			P_{tot}	350	mW
*1 Isolation Voltage		4N35 series	V_{iso}	3550	Vrms
		4N37 series		1500	
Operating Temperature			T_{opr}	-55 ~ +100	°C
Storage Temperature			T_{stg}	-55 ~ +150	°C
*2 Soldering Temperature			T_{sol}	260	°C

*1. AC For 1 Minute, R.H. = 40 ~ 60%

Isolation voltage shall be measured using the following method.

(1) Short between anode and cathode on the primary side and between collector, emitter and base on the secondary side.

(2) The isolation voltage tester with zero-cross circuit shall be used.

(3) The waveform of applied voltage shall be a sine wave.

*2. For 10 Seconds

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 6 of 11

BNS-OD-C131/A4

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ELECTRICAL - OPTICAL CHARACTERISTICS

(Ta = 25°C)

PARAMETER		SYMBOL	MIN.	TYP.	MAX.	UNIT	CONDITIONS
INPUT	Forward Voltage	V_F	—	1.2	1.5	V	I_F=10mA
	Reverse Current	I_R	—	—	10	μA	V_R=4V
	Terminal Capacitance	C_t	—	50	—	pF	V=0, f=1KHz
OUTPUT	Collector Dark Current, Ta=25°C	I_{CEO}	—	—	50	nA	V_{CE}=10V, I_F=0
	Collector Dark Current, Ta=100°C		—	—	500	μA	V_{CE}=30V, I_F=0
	Collector-Emitter Breakdown Voltage	BV_{CEO}	30	—	—	V	I_C=0.1mA, I_F=0
	Emitter-Collector Breakdown Voltage	BV_{ECO}	7	—	—	V	I_E=10μA, I_F=0
	Collector-Base Breakdown Voltage	BV_{CBO}	70	—	—	V	I_C=0.1mA, I_F=0
TRANSFER CHARACTERISTICS	Collector Current	I_C	10	—	—	mA	I_F=10mA, V_{CE}=10V
	* Current Transfer Ratio	CTR	100	—	—	%	
	Collector-Emitter Saturation Voltage	$V_{CE(sat)}$	—	—	0.3	V	I_F=50mA, I_C=2mA
	Isolation Resistance	R_{iso}	5×10^{10}	1×10^{11}	—	Ω	DC500V, 40 ~ 60% R.H.
	Floating Capacitance	C_f	—	1	2.5	pF	V=0, f=1MHz
	Response Time (Turn-on)	t_{on}	—	3	10	μs	V_{CC}=10V, I_C=2mA, R_L=100Ω
	Response Time (Turn-off)	t_{off}	—	3	10	μs	

$$* \ CTR = \frac{I_C}{I_F} \times 100\%$$

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 7 of 11

BNS-OD-C131/A4

CHARACTERISTICS CURVES

Fig.1 Forward Current vs. Ambient Temperature

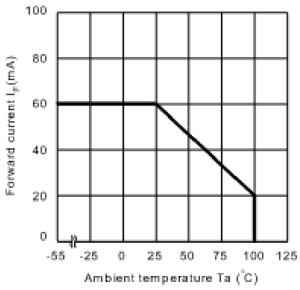


Fig.2 Collector Power Dissipation vs. Ambient Temperature

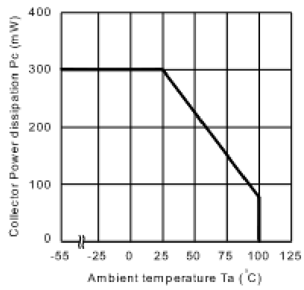


Fig.3 Forward Current vs. Forward Voltage

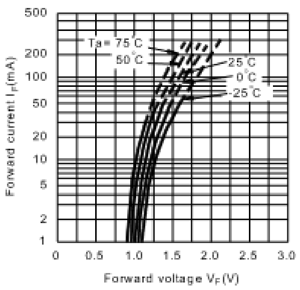


Fig.4 Current Transfer Ratio vs. Forward Current

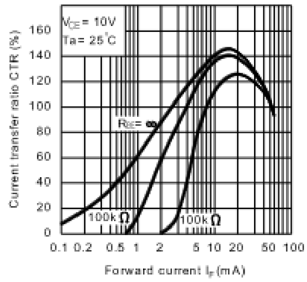


Fig.5 Collector Current vs. Collector-emitter Voltage

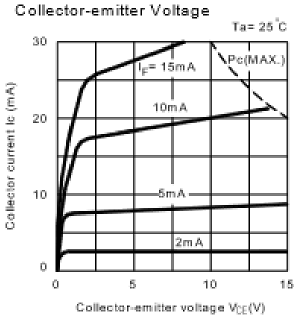
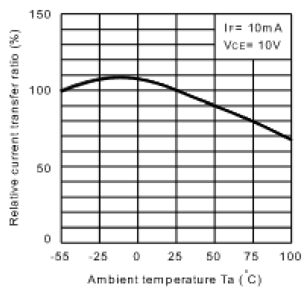


Fig.6 Relative Current Transfer Ratio vs. Ambient Temperature



Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 8 of 11

BNS-OD-C131/A4

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CHARACTERISTICS CURVES

Fig.7 Collector-emitter Saturation Voltage vs. Ambient Temperature

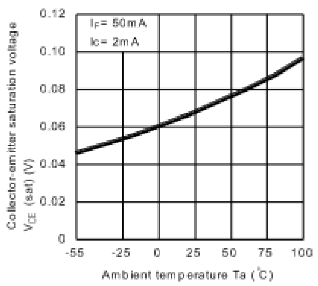


Fig.8 Collector Dark Current vs. Ambient Temperature

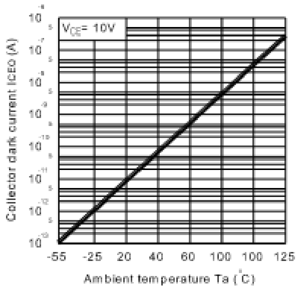


Fig.9 Response Time vs. Load Resistance

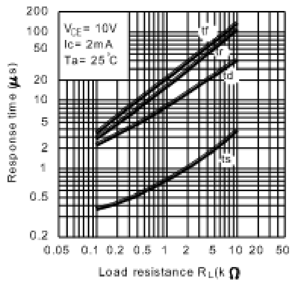


Fig.10 Frequency Response

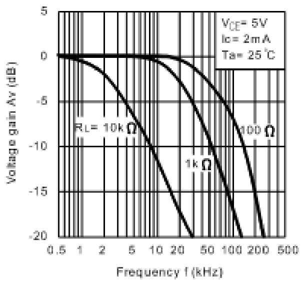
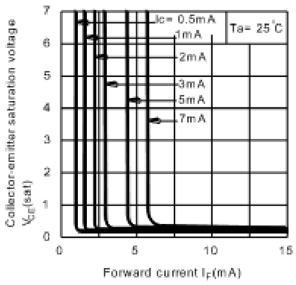
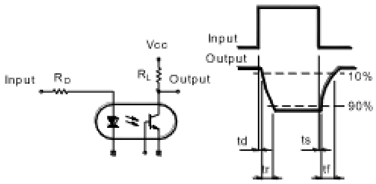


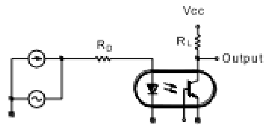
Fig.11 Collector-emitter Saturation Voltage vs. Forward Current



Test Circuit for Response Time



Test Circuit for Frequency Response



Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 9 of 11

BNS-OD-C131/A4

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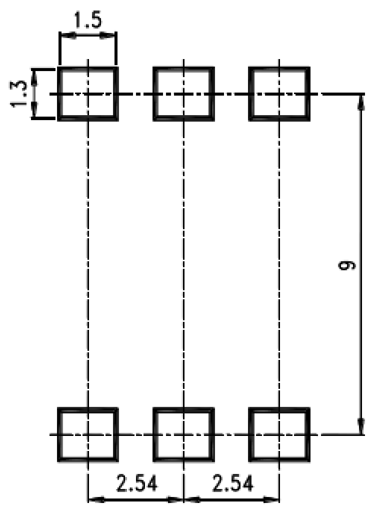
RECOMMENDED FOOT PRINT PATTERNS (MOUNT PAD)

Unit : mm



Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 10 of 11

BNS-OD-C131/A4

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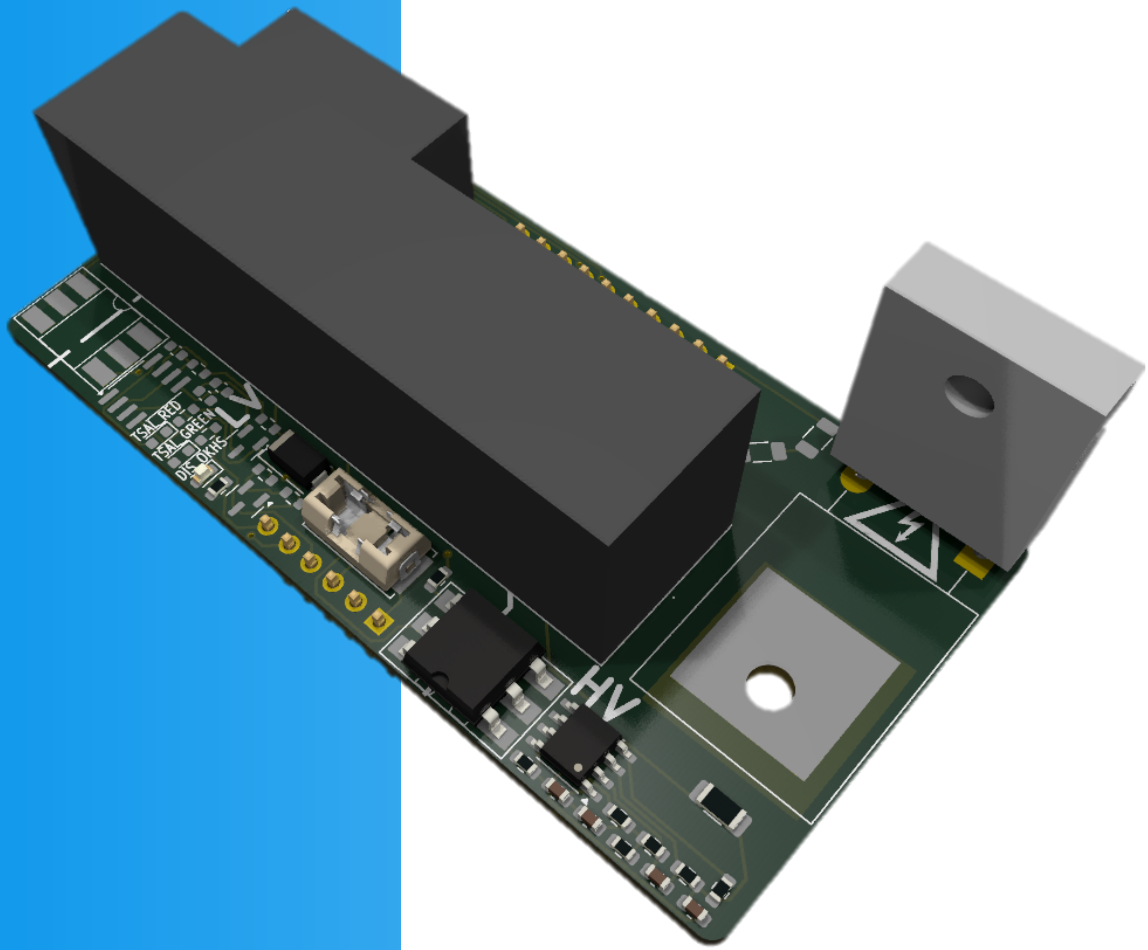
- For equipment/devices where high reliability or safety is required, such as space applications, nuclear power control equipment, medical equipment, etc, please contact our sales representatives.
- When requiring a device for any " specific" application, please contact our sales in advice.
- If there are any questions about the contents of this publication, please contact us at your convenience.
- The contents described herein are subject to change without prior notice.
- Immerse the unit's body into solder paste is not recommended.

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 11 of 11

DISCHARGE BREAKOUT BOARD

DESIGN REPORT



Abstract

The Discharge is a system that uses a resistor to dissipate the stored energy in the controllers when the Tractive System (TS) is turned off. This system is controlled with the shutdown system.

The Discharge is composed of two parts,

1. The discharge component, which is controlled with the shutdown circuit and will connect a resistor between TS+ and TS-, dissipating the energy within the motor controller,
2. A discharge safety system, that measures the temperature of the discharge resistor and opens the shutdown circuit if the temperature gets too hot.

This report details the design and implementation of the system within a Breakout" PCB

Previous iterations of the TSAL utilised a variety of components that were locations on the central electronics node (CEN). This board contained other systems such as the HFR, BSPD, and TSAL.

Due to the complexity of the circuit, it was decided a breakout board approach would be the standard design for the Discharge. This method allows iterations of the motherboard to be created while having a system that is known to be good, moving the complexity away from the motherboard.

The completed Discharge Breakout PCB board has now been commissioned, and found to be robust, easy to test, and easy to manufacture with PCB-A.

Introduction

The Discharge is a system that is used to make the tractive system (TS) safe whenever the shutdown circuit opens.

The discharge is composed of two parts:

1. A discharge circuit that will activate whenever the shutdown circuit is open, and dissipate the voltage in the controller, and
2. The discharge safety circuit, that is used to ensure the discharge circuit doesn't get too hot and output a LOW signal and open the shutdown circuit if the system does get hot.

Past NU Racing Discharge circuits by Gabby and Imel Munday have utilised:

- A power resistor and relay, and,
- A comparator and PTC thermistor to determine if the resister gets too hot, and an optocoupler to isolate this output.

For 2022 and 2023, the Discharge system was on a PCB that had multiple functions including BSPD, TSAL and HFR, this system was complicated, involving complex schematics and pcb design with specialised parts. This caused.

1. Complex boards that are difficult to understand and design,
2. Increase Complexity in schematics,
3. Large PCBs footprints, and,
4. Increase complexity while troubleshooting.

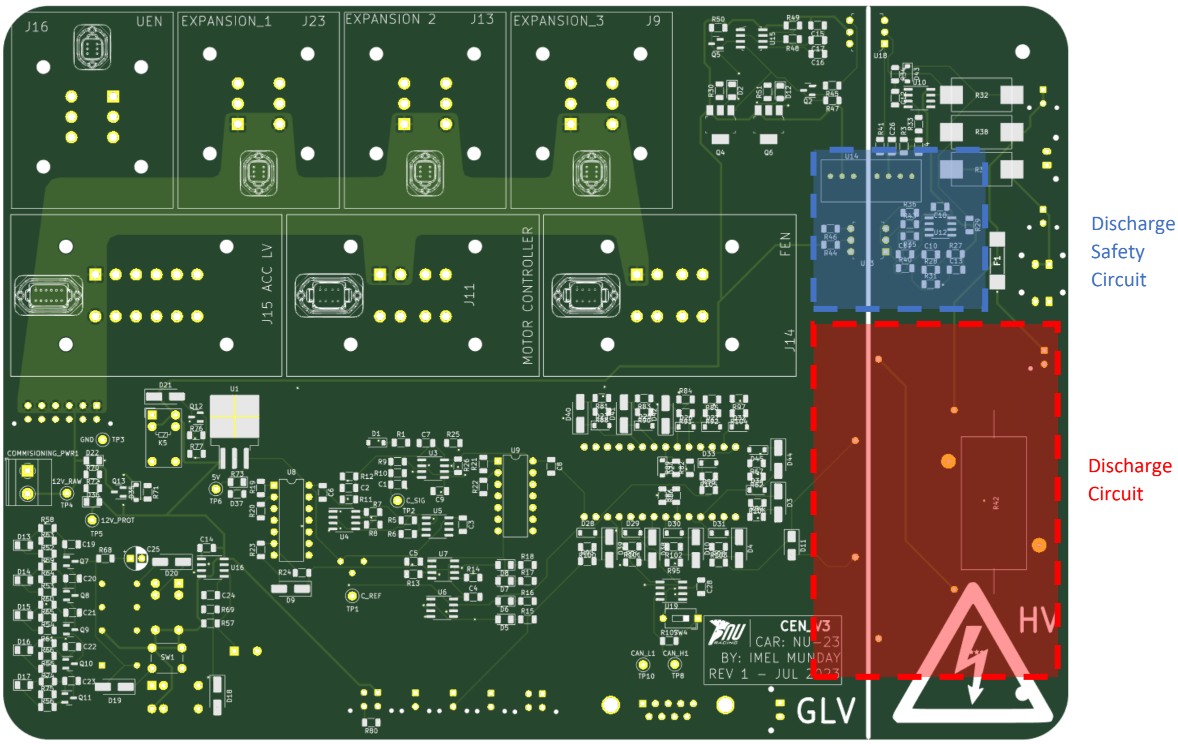


Figure 13 NU23 CEN, with Discharge Components Labelled

To simplify this system, it was decided to create a breakout board for the Discharge. This included removing all the Discharge functionality from a main board, and creating a teensy like board, that has the functionality of the Discharge and attaches to the main board through header pins. This allows the complexity to be removed from the master board.

Proposed benefits of this solution include:

1. Reduced complexity of the master board,
2. Reduced knowledge requirement to implement the discharge system,
3. Provide a known good, ready to use board that can be implemented,
4. Maintenace of flexibly for topological changes and/or motherboard geometry without remaking discharge circuitry.

This circuity had to be designed to a specification to:

1. Allow for easy unit testing,
2. Be robust,
3. Utilise as many standard/stocked components as possible,
4. Manufactured utilising PCB-A,
5. Rules Compliant,
6. Useable for multiple years, and,
7. Minimal footprint to enable flexibility in motherboard geometry.

Rules

For the FSAE-A competition, rules are required to be followed to ensure safety. The Discharge has certain rule requirements it needs to follow. These include the ones below.

Rule	
EV.5.6.3 The Tractive System must contain a Discharge Circuit. The Discharge Circuit must be: a. Wired in a way that it is always active when the Shutdown Circuit is open b. Able to discharge the Intermediate Circuit capacitors if the HVD has been opened c. Not be fused d. Designed to handle the maximum Tractive System voltage for minimum 15 seconds	
EV.5.6.4 Positive Temperature Coefficient (PTC) devices must not be used to limit current for the Precharge Circuit or Discharge Circuit	
EV.6.5.1 Separation of Tractive System and GLV System: a. The entire Tractive System and GLV System must be completely galvanically separated. b. The border between Tractive and GLV System is the galvanic isolation between both systems. Therefore, some components, such as the Motor Controller, may be part of both systems.	
EV.6.5.7 If Tractive System and GLV are on the same circuit board: a. They must be on separate, clearly defined and clearly marked areas of the board b. Required spacing related to the spacing between traces / board areas are as follows: Voltage / Over Surface / Thru Air (cut in board) / Under Conformal Coating 0-50 V DC / 1.6 mm / 1.6 mm / 1 mm 50-150 V DC / 6.4 mm / 3.2 mm / 2 mm 150-300 V DC / 9.5 mm / 6.4 mm / 3 mm 300-600 V DC / 12.7 mm / 9.5 mm / 4 mm	
EV.6.6.1 All electrical systems (both Low Voltage and High Voltage) must have appropriate Overcurrent Protection/Fusing.	
EV.6.6.2 Unless otherwise allowed in the Rules, all Overcurrent Protection devices must: a. Be rated for the highest voltage in the systems they protect. Overcurrent Protection devices used for DC must be rated for DC and must carry a DC rating equal to or more than the system voltage b. Have a continuous current rating less than or equal to the continuous current rating of any electrical component that it protects c. Have an interrupt current rating higher than the theoretical short circuit current of the system that it protects	
EV.7.2.2 When the Shutdown Circuit Opens: a. The Tractive System must Shutdown b. All Accumulator current flow must stop immediately EV.5.4.3 c. The voltage in the Tractive System must be Low Voltage T.9.1.2 in five seconds or less d. The Motor(s) must spin free. Torque must not be applied to the Motor(s)	

Topology Implementation

Future implementations of the Discharge PCB will live as a daughter board on the human interface panel (HIP) at the side of the car. This is due to the HIP already being a HV enclosure with HV already being present within and can be utilised by the Discharge.

The DISCHARGE_OKHS will be sent to the HFR within the CEN

Figure 14 NU24 Discharge Implementation

Topology/Schematic

Due to the functionality of the discharge the board is made is of two separate parts, these are:

1. The Discharge module that will discharge the controller when the shutdown opens, and
2. The Discharge OKHS module that measures the temperature and outputs a LOW value when the temperature goes above a certain temperature.

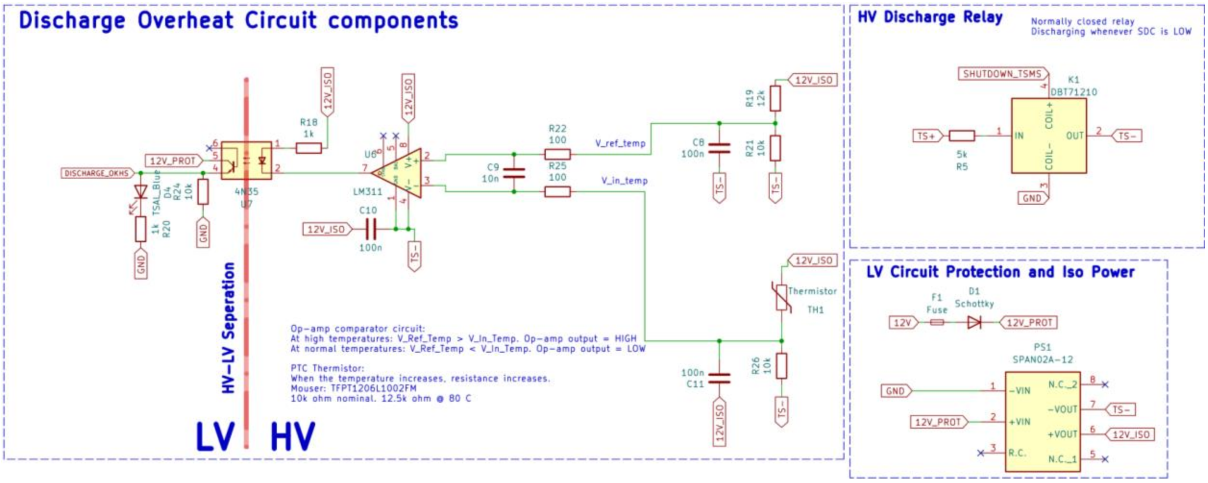


Figure 15 Discharge Schematic

Discharge

The discharge circuit consists of a relay and a resistor.

The relay is required to be closed whenever the shutdown circuit is open, therefore it is required for this relay to be a normally closed (Type B) relay.

The resistor size is dependent on the length of time wanted to dissipate the controller to below 60V. The considerations for this also include:

- The max power that will be going through the resistor,
- The max voltage of the system, and,
- The size of the controller capacitance.

With this, it was chosen to use a 5kΩ resistor, as this gave fast discharge time. The time the resistor takes to discharge is calculated with the equation below.

$$t = ln(V_{initial}/60) * R * C$$

Using this equation, with the capacitance of the Cascadia CM200dz being 255µF. This gave a value of 2.6 seconds, and the max power dissipation is calculated with the equation below.

$$P = V_{initial}^2/R$$

The resister max power dissipation is found to be 40.5W.

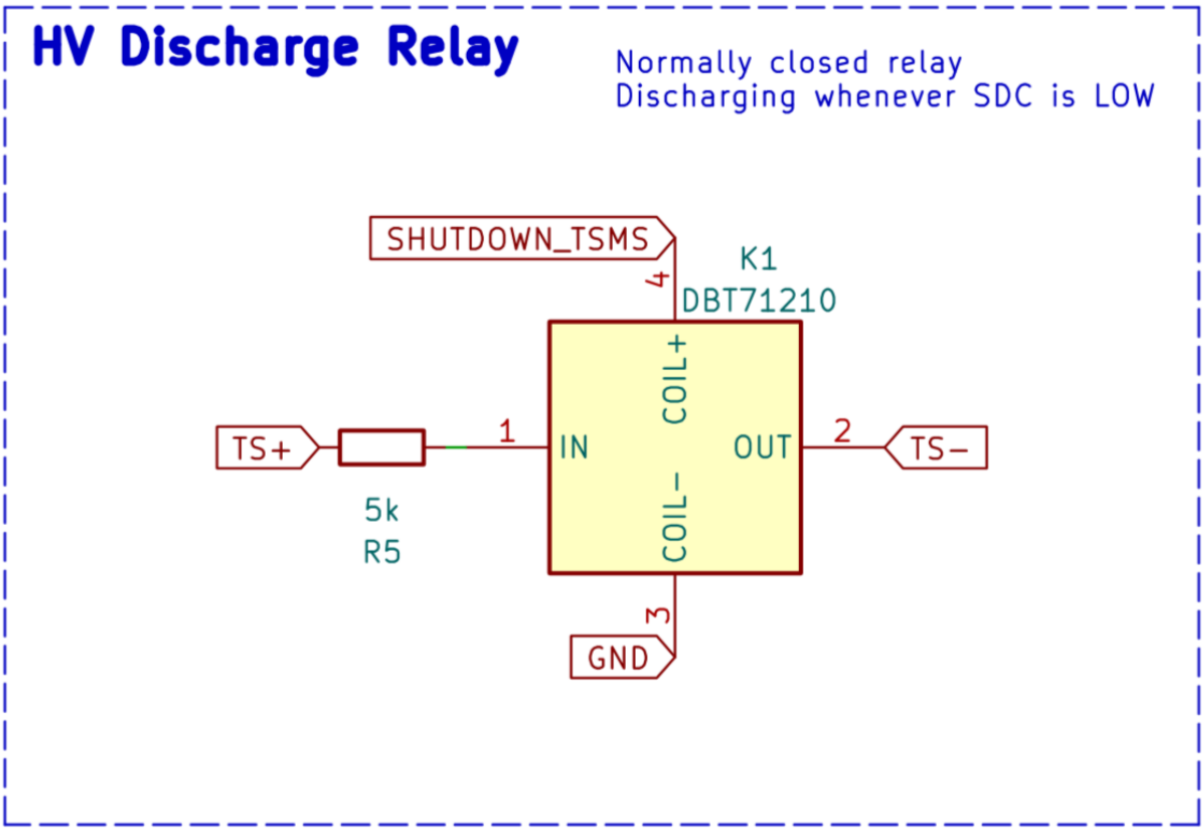


Figure 16 Discharge HV Schematic

Discharge OKHS

The Discharge OKHS circuit uses a simple comparator circuit where the inputs are:

1. A voltage divider, generated using the isolated power supply, and replacing the top resistor with a thermistor, and,
2. A reference voltage, generated using the isolated power supply and a voltage divider where the output is equal to the thermistor voltage divider output when the thermistor is at 80C.

This comparator circuit then uses an optocoupler to isolate this signal and output it to the HFR.

This circuit also has a LED for on-board visual functionality.

This circuit has the outputs:

- When DISCHARGE_OKHS is HIGH, the thermistor is <80C,
- When DISCHARGE_OKHS is LOW, the thermistor is >=80C.

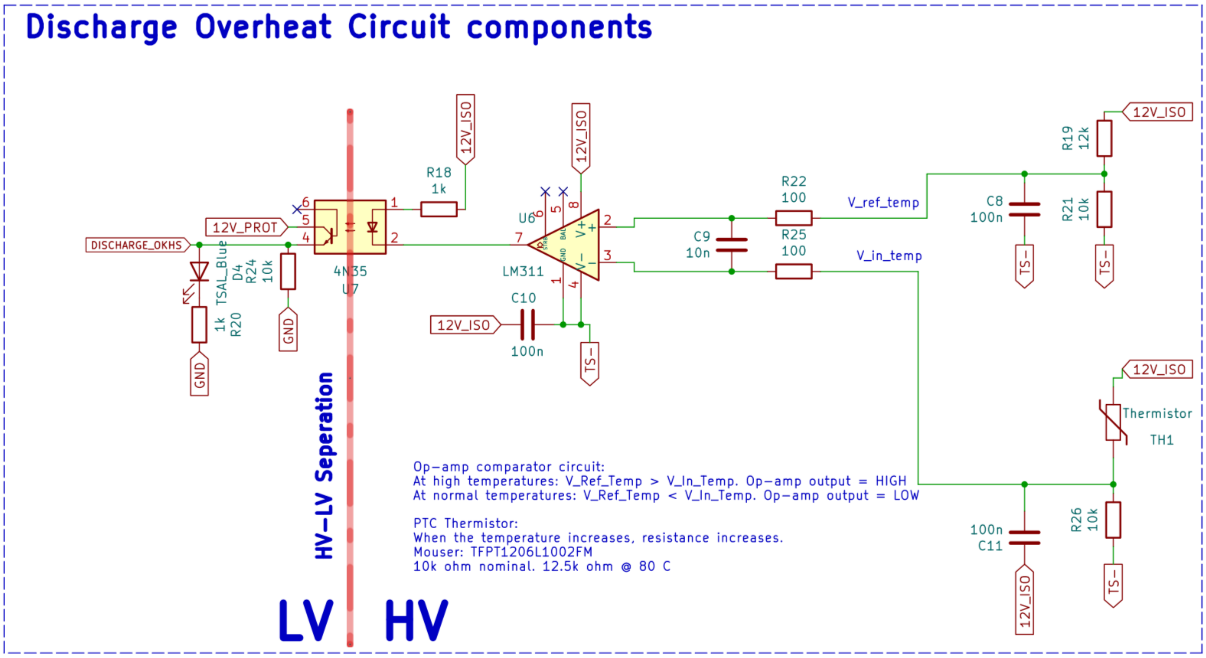


Figure 17 Discharge OCSC Schematic

Implementation/Layout

Component Selection

The choice of components was based on available of components, voltage ratings and cost. This was also influenced by factors such as:

- Wanting components being commonly used within NU Teams (this includes the comparator, isolated power supply, and the optocoupler),
- Wanting single channel components over multi-channel, and,
- Choosing components based on size.

With these factors, the following components were the ones chosen.

Comparator (LM311)

The comparator chosen was the LM311. This was chosen due to it being a single channel comparator and it being in a similar family to the one used on NU23 CEN, which was the LM393, a dual channel comparator.

The LM311 is capable of being powered up to 36V with a max differential input between the inputs being 30V. This is much more voltage than what will be used on the car, where it will only be powered by 12V (up to 14V) and a max differential voltage of 11V. This comparator is only capable of grounding its output.

To ensure more accurate readings capacitors are used on the inputs and for the supply. This smooths the inputs allowing less noise to impact the readings.

Isolated Power Supply (SPAN-02A-12)

The isolated power supply chosen was the SPAN-02A-12. The power supply can work with a voltage range from 9V to 18V and can output a maximum of 2W of power. It has an isolation rating of 1.5kVDC which much more than necessary.

Optocoupler (4N35)

The optocoupler chosen was a 4n35 SMD optocoupler. The optocoupler has a forward voltage of 1.2V at 10mA but, is capable up to 50mA. The isolation voltage over the optocoupler is 5000Vrms. This optocoupler can switch voltages up to 30V and up to 100mA output.

Resistor, Capacitors and LED

The choice for resistors, LED and capacitors was done for size constraints and power rating. All the resistors for the board are 0603 except for the power resistor. The only resistor that was slightly different was the 0603 LED resistors. This is due to the power requirement for the resistor with most 0603 being rated for 100mW, but the resistors will be dissipating a power of 180mW. Therefore, the resistors are rated for 250mW.

All the capacitors and the LED are 0603.

The downside of 0603 is that components are more difficult to solder than 1206. This was justified as packaging was more important and the components will be soldered on with JLCPCB.

Power Resistor (PF2472-5KF1)

The choice of power resistor was the PF2472-5KF1. This was chosen due to its high-power rating, where it is good for 100W, with a heatsink, and a dielectric strength of 2500VAC. Due to this resistor only being used for short periods of time, this resistor should be sufficient for the discharge of the car.

Relay (DBT71210)

The relay chosen was the DBT71210. This relay was chosen due to its voltage isolation being 10kV, a switching voltage of 1000V, and it being one of the cheapest type-B relays. It was also chosen due to it being relatively small, and pcb mounted.

Schottky Diode, Fuse Holder and 3V3 Zener Diode (SS34, 0154001.DRT, and BZT52C3V3)

The components for the schottky diode, fuse holder and 3V3 zener diode are SS34, 0154001.DRT, and BZT52C3V3). These components were all chosen for the standard footprints utilised within the team, the 3V3 Zener diode is not the same part as the one used in the team due to part availability, this doesn’t matter though as it has the same performance and specifications.

Layout

The layout for the PCB was to make the PCBs as small as possible and allow manufacturing using JLCPCB. This meant all SMD components needed to be placed on one side. The other reason for this is how the board will be mounted to the main board.

Other things to consider for the layout is HV spacing ensuring TS+ and TS- is not to close to each other to cause issues such as arcing, HV/LV isolating ensuring there is adequate distance between the HV and LV sides of the board and traces, and the placement of the header pins.

HV Spacing

For compliance and safety, it is required to keep adequate spacing. This mean ensuring components that are grounded to TS- are not too close to components that are or could be at TS+ Voltage. It was therefore required, to try to maintain all components that are powered by TS- to be close to the negative terminal and ensure >4mm spacing between HV+ traces and components. It is also required to ensure the header pins has enough spacing between TS+ and TS-.

Minimum spacing for HV on the TSAL is 4.8mm.

Figure 18 TSAL Voltage Separation Distance

HV/LV Isolation

For compliance, a minimum distance between LV and HV is required on PCB's. This distance is 4mm for conformal coated PCB's. Therefore, the layout needs to have this into consideration. With this board being shared by the TSAL.

Minimum HV/LV isolation distance on board is 5mm.

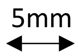


Figure 19 TSAL HV/LV Voltage Separation Distance

Board Size

For simplicity it was decided to make boards to 5mm increments. Therefore, a logical layout, trying to fit as many components as close together was done to allow the minimum board size to be achieved.

Figure 20 Discharge Board Size

Header Pins

The header pins for the LV side required enough for all the LV signals into and out of the board. This included 12V, GND, SHUTDOWN_HVD, and DISCHARGE_OKHS. The other two pins are the two pins necessary for the TSAL. The choice of using a 10-pin header gave enough voltage separation and allowed tracing where TS+ and TS- would sit.

Logical Layout

Due to the size of the board, it was required to have a logical layout of components to ensure tracing was possible.

Footprint/Pinout

Due to these boards being place onto a master board, it was necessary to create a footprint for the component and ensure the pinout for the component is known. With this board being shared with the TSAL, the pinout is shared.

Pin	Name
1	12V
2	GND
3	SHUTDOWN_TSMS
4	TSAL_GREEN_SWITCHED_GND
5	TSAL_RED_SWITCHED_GND
6	DISCHARGE_OKHS
7	TS-
8	TS+

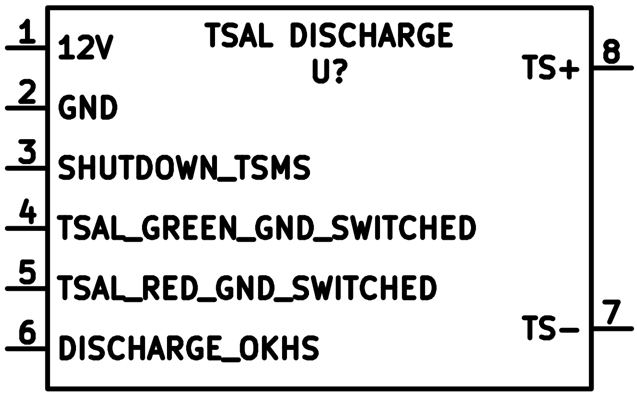


Figure 21 TSAL/Discharge Symbol

Figure 22 TSAL/Discharge Footprint

Commissioning and Unit Tests

Utilising JLCPCB to create the boards, most of the components could be assembled by JLCPCB, the components that were not soldered onto the board was the isolated DCDC, the relay, the discharge resistor, and the header pins due to them being through hole components.

To commission this board, tests were completed to ensure proper operation of the board without any issues.

Test Type	Test	What should happen	Did it?
Visual Inspection	Inspect all pre-solder components, ensure soldering is adequate and components are correct. Ensure there is no shorts or excess solder	All components are correct	
Setup	Solder on Header pins		
LV Power	Connect 12V to the LV side	DISCHARGE_OKHS LED stays OFF	
Setup	Solder on the isolated DCDC		
Setup	Solder on PTC Thermistor		
LV Power	Connect 12V to the LV side	DISCHARGE_OKHS LED turns ON	
Non powered Test	Disconnect power and measure resistance between TS+ and TS-	5kΩ measured	
Shutdown Power	Connect 12V to SHUTDOWN_IN, measure resistance between TS+ and TS-	Open circuit measured	
LV Power	Connect LV to the LV side, Using heat gun, heat thermistor up	DISCHARGE_OKHS LED turns ON and then turns OFF when heat is applied	
HV Power	Connect TS+ and TS- to HV power Supply. Turn power supply to 450V, and turn on for 3 seconds, using thermal camera measure temperature of resistor	Resistor gets hot.	
HV Power	Connect 12V to SHUTDOWN_IN, and turn HV Supply on	Resistor doesn’t get hot, and no current is drawn from power supply	

Prototype Commissioning

Initially utilising the base design of the CEN, the only main changes for the first iteration was changing resistor and capacitor values. Another change was replacing the large power resistor with a much smaller form factor resistor.

Another change was the possibility of removing the discharge OKHS. This would reduce complexity within the car. BUT it was found to be not very feasible, unless there was VERY large heatsink, or much larger resistors are used. This was tested utilising a long thing piece of aluminium, and this still achieved temperatures up to 160C. This is impractical due to them requiring to be able to dissipate the max TS voltage indefinitely without affecting components nearby.

Another change that was tested was the use of a depletion n-channel MOSFET instead of a relay. This was done due to the cost associated with normally closed relays that are rated for the voltage and pcb mounted. It was found the method to do this would use an isolated DCDC to send the shutdown signal through and apply a negative voltage to the MOSFET gate (the negative connection on the isolated DCDC being connected to the gate, and the positive being connected to TS-.

Conclusion

The discharge is a system on the car that is necessary to dissipate the power within the motor controller when the tractive system is turned off. This system also includes a safety system that will disconnect the tractive system if the resistor gets too hot.

The discharge circuit us done by using a normally closed relay, and a high-power resistor. The safety system is done utilising a comparator and a reference voltage where if a thermistor gets too hot, the signal goes LOW.

For this board, it needed to be designed in a certain way will a few objectives. These include making the system:

- Robust
- Rules Compliant
- Utilise as many standard components as possible, and
- Usable for many years

Through making these breakout boards, it made these systems:

- Decrease the complexity of the mother board it will be attached to,
- Allow easier unit testing,
- Able to be made using PCB-A,
- Allow a standard schematic for these systems.

Future Work

Replacing Comparators with Op-amps

To reduce different part counts on the car it could be removing the LM311 and replacing them with other op-amps that are used on the car TLV9301xDBV. The downside of using an op-amp instead of a comparator is a slightly slower response time, and slightly less accurate. For our purposes where the components do not have to be highly accurate, this isn't an issue, and having less components to explain what they do can be beneficial.

Replace Optocoupler

Another change that could be beneficial could be replacing the optocoupler with whether a smaller form factor, or a different galvanically isolated component.

Thermistor/Resistor/Capacitor Sizes

To make the board even smaller it could be possible to use 0402 resistors for some of them. The thing to think about would be wattage the resistors are dissipating. It was also not possible to get JLC to solder the thermistor on due to them not having any 1206 PTC thermistor, whereas they have 0402 PTC Thermistors.

Larger pulldown Resistor Values

Making the pulldown resistor values larger would reduce current drawer when the circuit is operating. I would be worth testing to ensure no unstable operations occur. This could be as simple as changing the values from 10k to 100k.

Replace Discharge Resistor

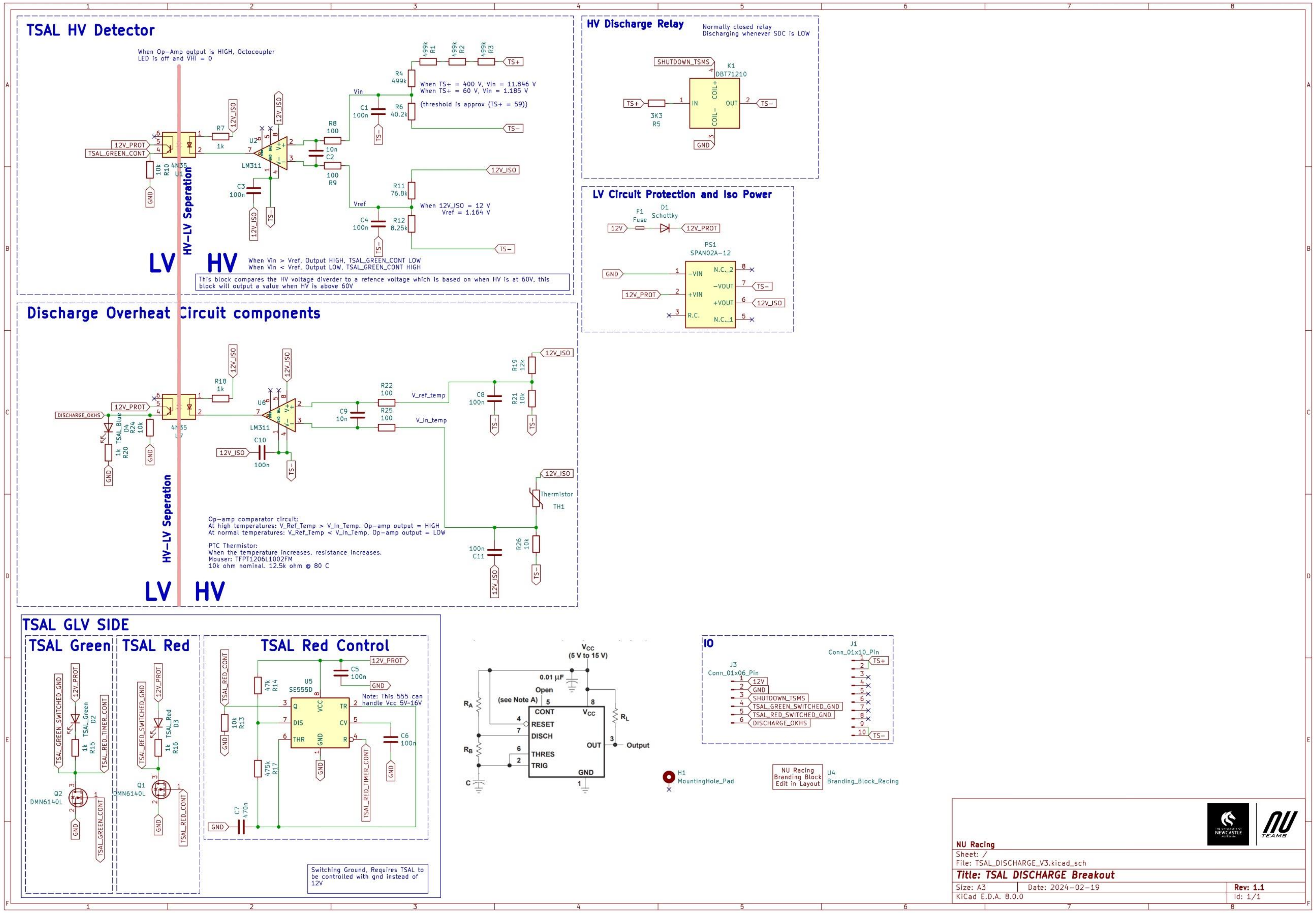
Due to the power dissipation of the resistor, it may be necessary to replace this resistor with something more suitable, this should be tested, turning the shutdown on and off, ensuring that the shutdown can be tested at comp without faulting the DISCHARGE_OKHS.

Replace Relay

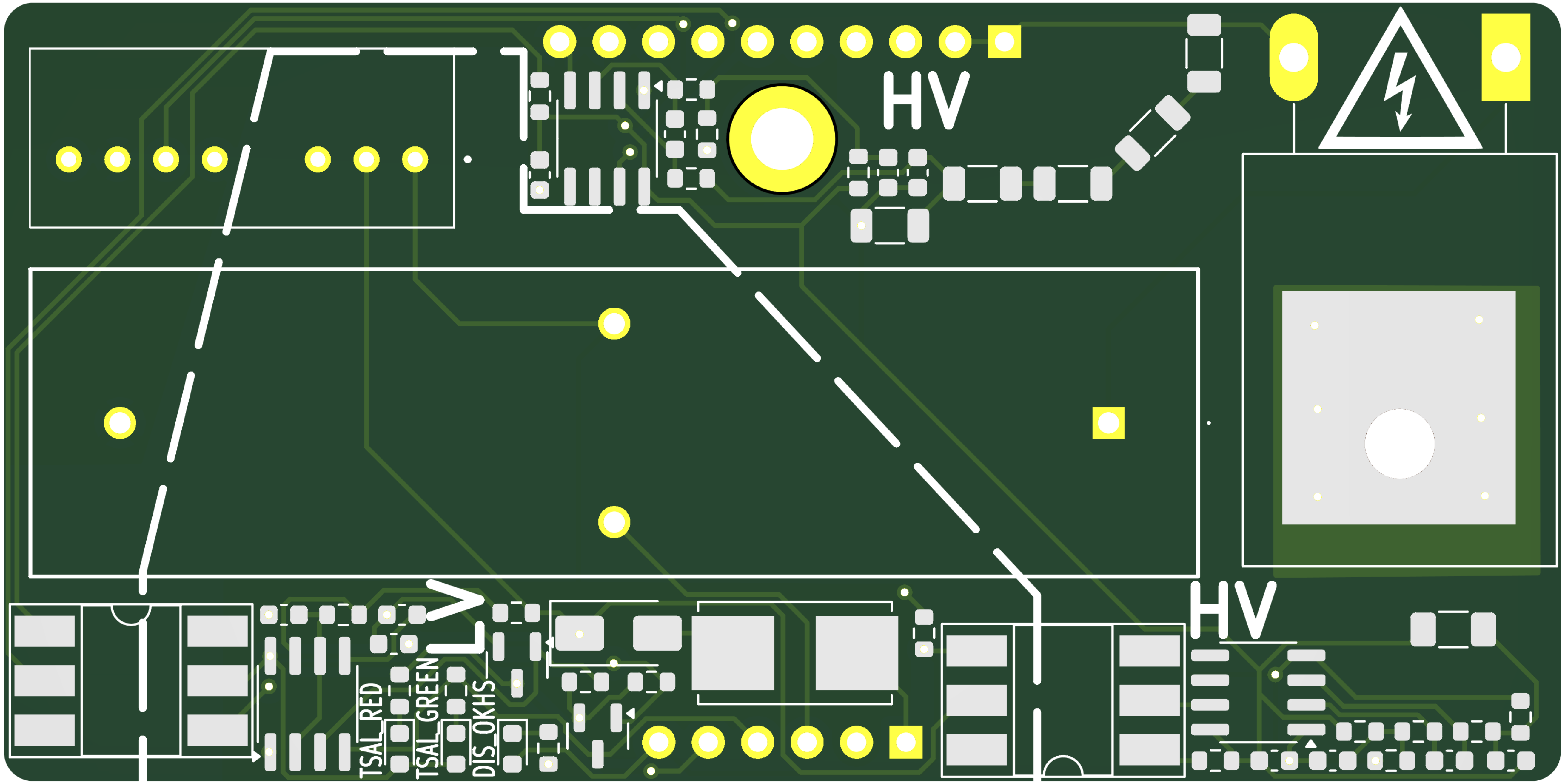
Due to the cost and size, it could be beneficial to use a depletion type n channel MOSFET instead of the relay. This change would require an additional isolated DCDC, to make a negative voltage for the MOSFET, but would allow the board to be smaller. This would decrease the cost of the board, where the resistor is $80 alone, instead it would cost around $15 for the MOSFET and isolated DCDC.

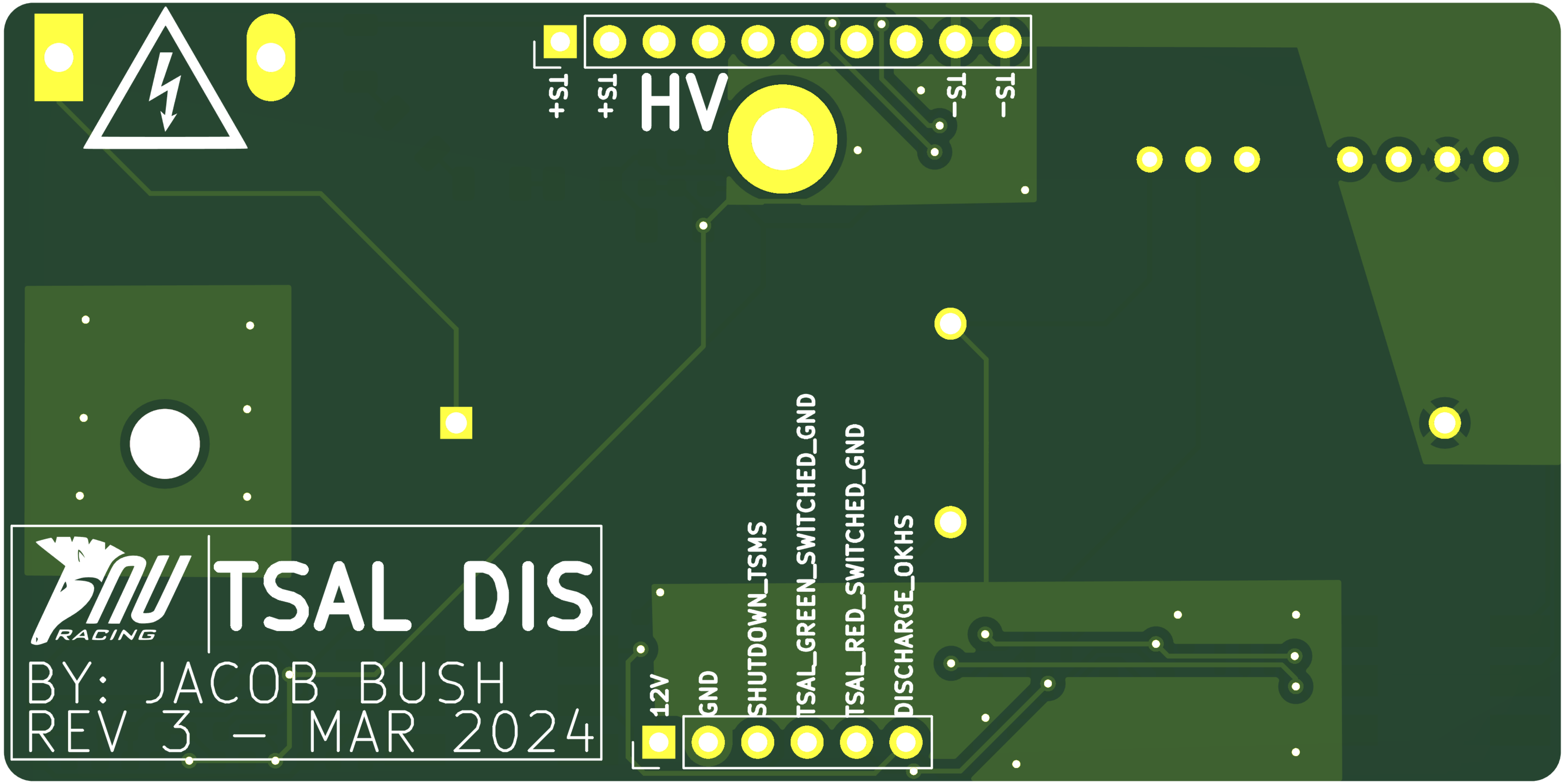
Appendix

Schematic

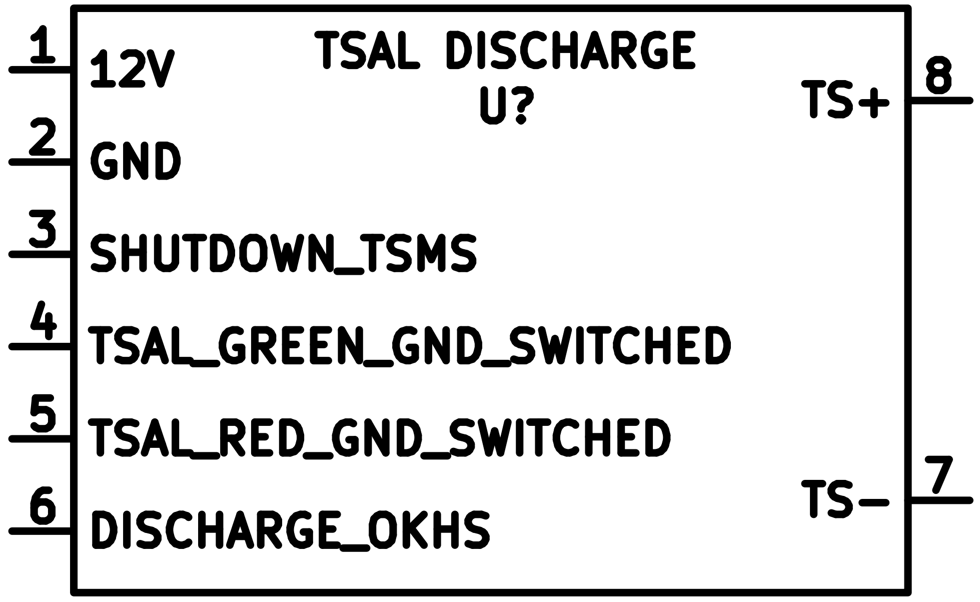


PCB


HV
HV
LV
TSAL_RED
TSAL_GREEN
DIS_OKHS


TS+
TS+
HV
TS−
TS−
TSAL DIS
BY: JACOB BUSH
REV 3 – MAR 2024
12V
GND
SHUTDOWN_TSMS
TSAL_GREEN_SWITCHED_GND
TSAL_RED_SWITCHED_GND
DISCHARGE_OKHS

Symbol



Footprint

Pinout

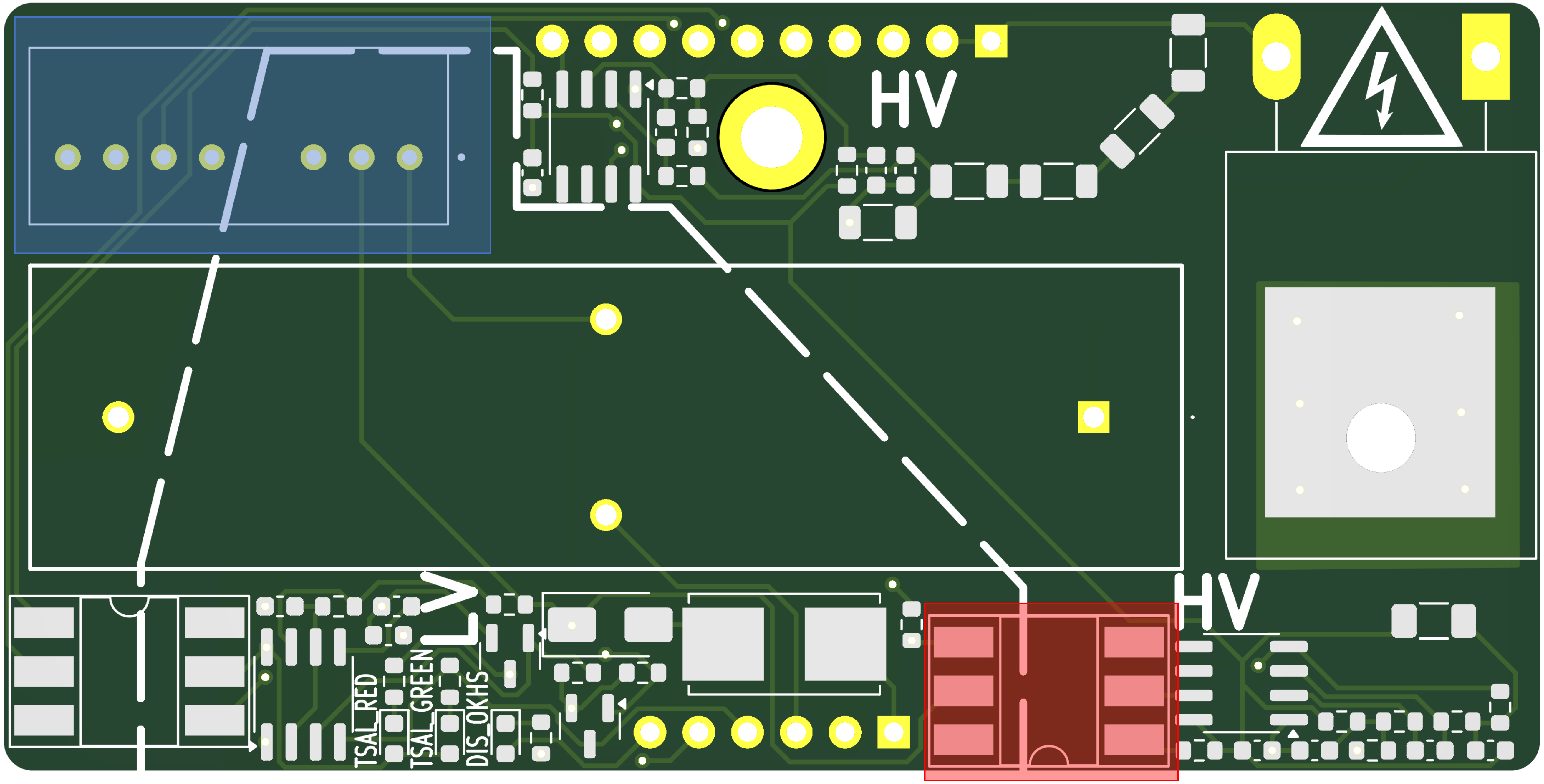
Pin	Name
1	12V
2	GND
3	SHUTDOWN_TSMS
4	TSAL_GREEN_SWITCHED_GND
5	TSAL_RED_SWITCHED_GND
6	DISCHARGE_OKHS
7	TS-
8	TS+

BOM

Comment	Designator	Footprint	JLCPCB #	Datasheet
10nF	C9	0603	C57112	https://datasheet.lcsc.com/lcsc/2304140030_FH--Guangdong-Fenghua-Advanced-Tech-0603B103K500NT_C57112.pdf
4N35	U7	DIP-6_W8.89mm_SMDSocket_LongPads	C115444	https://datasheet.lcsc.com/lcsc/1810161110_Lite-On-4N35S-TA1_C115444.pdf
Fuse	F1	Fuseholder_Littelfuse_Nano2_154x	C206909	https://datasheet.lcsc.com/lcsc/2304140030_Littelfuse-0154001-DRT_C206909.pdf
Schottky	D1	D_SMA	C2909963	https://datasheet.lcsc.com/lcsc/2110280930_YONGYUTAI-SS34_C2909963.pdf
1k	R18, R20	0603	C2653986	https://datasheet.lcsc.com/lcsc/2304140030_ROHM-Semicon-ESR03EZPF1001_C2653986.pdf
100	R22, R25	0603	C22775	https://datasheet.lcsc.com/lcsc/2206010130_UNI-ROYAL-Uniroyal-Elec-0603WAF1000T5E_C22775.pdf
100nF	C10, C8, C11	0603	C14663	https://datasheet.lcsc.com/lcsc/2211101700_YAGEO-CC0603KRX7R9BB104_C14663.pdf
LM311	U6	SOIC-8_3.9x4.9mm_P1.27mm	C12597	https://datasheet.lcsc.com/lcsc/1809172023_Texas-Instruments-LM311DR_C12597.pdf
10k	R21, R24, R26	0603	C25804	https://datasheet.lcsc.com/lcsc/2206010045_UNI-ROYAL-Uniroyal-Elec-0603WAF1002T5E_C25804.pdf
SPAN02A-12	PS1	CUSTOM		https://datasheet.datasheetarchive.com/originals/distributors/DKDS-2/37032.pdf
12K	R19	0603	C22790	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2206010130_UNI-ROYAL-Uniroyal-Elec-0603WAF1202T5E_C22790.pdf
TFPT1206L1002FM	TH1	1206		https://www.vishay.com/docs/33017/tfpt.pdf
TSAL_Green	D2	0603	C12624	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/1806151818_Hubei-KENTO-Elec-KT-0603G_C12624.pdf
PF2472-5KF1	R5	TO-247-2		https://riedon.com/media/pdf/PF2470.pdf
DBT71210	K1	CUSTOM		https://www.cynergy3.com/sites/default/files/cynergy3-d-v3.pdf

HV/LV Voltage Separation components

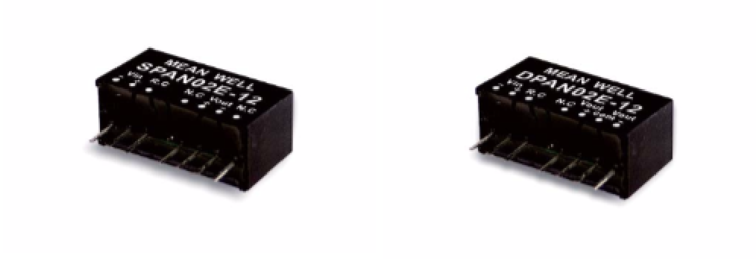
12V Isolated DCDC



Optocoupler

12V Isolated DCDC Datasheet

MEAN WELL 2W SIP Package DC-DC Regulated Converter **SPAN02 & DPAN02 series**



CE

■ Features

- SIP8 package with industry standard pinout
- 2:1 wide input range
- Operating temperature range -40 ~ +90℃
- No minimum load required
- Comply to EN55032 radiated Class A without additional components
- High efficiency up to 85%
- Protections: Short circuit (Continuous) / Overload
- 1.5KVDC I/O isolation
- Remote ON/OFF control
- 3 years warranty

■ Applications

- Telecom/datacom system
- Wireless network
- Industrial control facility
- Instrument
- Analyzer
- Detector
- Data switch

■ Description

SPAN02 and DPAN02 series are 2W isolated and regulated module type DC-DC converter with SIP8 package. It features international standard pins, a high efficiency up to 85%, wide working temperature range -40~+90℃, 1.5KVDC I/P-O/P isolation voltage, compliance to EN55032 radiated class A without additional components, overload and continuous-mode short circuit protection, etc. The models account for different input voltage 4.5~9V, 9~18V, 18~36V and 36~75V 2:1 wide input range, and various output voltage, 5V/12V/15V for single output and ±5V/±12V/±15V for dual outputs, which are suitable for all kinds of systems, Such as industrial control, telecommunication field, distributed power architecture, and so on.

■ Model Encoding

S PAN02 E – 12

- 12 — Output voltage (5/12/15Vdc，±5/±12/±15Vdc)
- E — Input voltage (E: 4.5~9Vdc，A: 9~18Vdc，B: 18~36Vdc，C: 36~75Vdc)
- PAN02 — Rated wattage
- S — Series name { S:Single output / D:Dual output }

File Name:SPAN02,DPAN02-SPEC 2017-03-06

MEAN WELL 2W SIP Package DC-DC Regulated Converter **SPAN02 & DPAN02 series**

MODEL SELECTION TABLE

ORDER NO.	INPUT			OUTPUT		EFFICIENCY (TYP.)	CAPACITOR LOAD (MAX.)
	INPUT VOLTAGE (RANGE)	INPUT CURRENT		OUTPUT VOLTAGE	OUTPUT CURRENT		
		NO LOAD	FULL LOAD				
SPAN02E-03	5V (4.5 ~ 9V)	60mA	452mA	3.3V	0 ~ 500mA	74%	500μF
SPAN02E-05		60mA	526mA	5V	0 ~ 400mA	78%	400μF
SPAN02E-12		60mA	501mA	12V	0 ~ 167mA	80%	167μF
SPAN02E-15		65mA	503mA	15V	0 ~ 134mA	80%	134μF
DPAN02E-05		60mA	519mA	±5V	±0 ~ 200mA	78%	*200μF
DPAN02E-12		60mA	504mA	±12V	±0 ~ 83mA	80%	*83μF
DPAN02E-15		60mA	503mA	±15V	±0 ~ 67mA	80%	*67μF
SPAN02A-03	12V (9 ~ 18V)	30mA	181mA	3.3V	0 ~ 500mA	76%	500μF
SPAN02A-05		32mA	211mA	5V	0 ~ 400mA	80%	400μF
SPAN02A-12		32mA	204mA	12V	0 ~ 167mA	83%	167μF
SPAN02A-15		32mA	202mA	15V	0 ~ 134mA	84%	134μF
DPAN02A-05		31mA	211mA	±5V	±0 ~ 200mA	79%	*200μF
DPAN02A-12		31mA	202mA	±12V	±0 ~ 83mA	82%	*83μF
DPAN02A-15		31mA	202mA	±15V	±0 ~ 67mA	83%	*67μF
SPAN02B-03	24V (18 ~ 36V)	18mA	90mA	3.3V	0 ~ 500mA	76%	500μF
SPAN02B-05		19mA	105mA	5V	0 ~ 400mA	79%	400μF
SPAN02B-12		19mA	102mA	12V	0 ~ 167mA	82%	167μF
SPAN02B-15		19mA	101mA	15V	0 ~ 134mA	83%	134μF
DPAN02B-05		18mA	105mA	±5V	±0 ~ 200mA	79%	*200μF
DPAN02B-12		19mA	102mA	±12V	±0 ~ 83mA	81%	*83μF
DPAN02B-15		19mA	100mA	±15V	±0 ~ 67mA	85%	*67μF
SPAN02C-03	48V (36 ~ 75V)	9mA	46mA	3.3V	0 ~ 500mA	75%	500μF
SPAN02C-05		9mA	53mA	5V	0 ~ 400mA	80%	400μF
SPAN02C-12		9mA	51mA	12V	0 ~ 167mA	82%	167μF
SPAN02C-15		9mA	50mA	15V	0 ~ 134mA	83%	134μF
DPAN02C-05		12mA	53mA	±5V	±0 ~ 200mA	78%	*200μF
DPAN02C-12		12mA	51mA	±12V	±0 ~ 83mA	82%	*83μF
DPAN02C-15		9mA	50mA	±15V	±0 ~ 67mA	84%	*67μF

* For each output

File Name:SPAN02,DPAN02-SPEC 2017-03-06

MEAN WELL 2W SIP Package DC-DC Regulated Converter **SPAN02 & DPAN02 series**

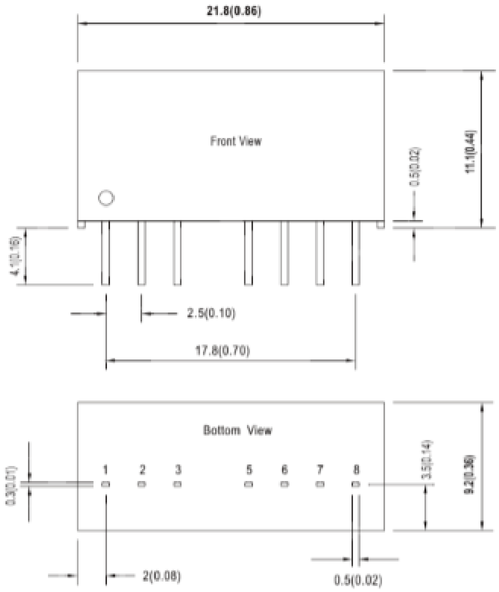
SPECIFICATION				
INPUT	VOLTAGE RANGE	E: 4.5~9Vdc , A: 9~18Vdc , B: 18~36Vdc , C: 36~75Vdc		
	SURGE VOLTAGE (100ms max.)	5Vin models : 15Vdc ; 12Vin models : 25Vdc ; 24Vin models : 50Vdc ; 48Vin models : 100Vdc		
	FILTER	Internal capacitor		
	PROTECTION	Fuse recommended. 5Vin models: 1000mA Slow-Blow Type, 12Vin models: 500mA Slow-Blow Type, 24V and 48Vin models: 250mA Slow-Blow Type		
	INTERNAL POWER DISSIPATION	500mW		
OUTPUT	VOLTAGE ACCURACY	±1.5%		
	RATED POWER	2W		
	RIPPLE & NOISE Note.2	75mVp-p		
	LINE REGULATION Note.3	±0.5%		
	LOAD REGULATION Note.4	Single output models: ±0.5%, Dual output models: ±1%		
	SWITCHING FREQUENCY (Typ.)	100KHz		
PROTECTION	SHORT CIRCUIT	Protection type : Continuous, automatic recovery		
	OVERLOAD	Protection type : Recovers automatically after fault condition is removed		
	UNDER VOLTAGE LOCKOUT	Start-up voltage	5Vin : 4.2Vdc ; 12Vin : 7.3Vdc ; 24Vin : 15.5Vdc ; 48Vin : 31Vdc	
		Shutdown voltage	5Vin : 3Vdc ; 12Vin : 5.8Vdc ; 24Vin : 12Vdc ; 48Vin : 24Vdc	
FUNCTION	REMOTE CONTROL	Power ON: R.C. ~ -Vin <0.8Vdc or open circuit; Power OFF: R.C. ~ -Vin >4 ~ 15Vdc or short		
ENVIRONMENT	COOLING	Free-air convection		
	WORKING TEMP.	-40 ~ +90℃ (Refer to "Derating Curve")		
	CASE TEMPERATURE	+100℃ max.		
	WORKING HUMIDITY	20% ~ 90% RH non-condensing		
	STORAGE TEMP., HUMIDITY	-55 ~ +125℃, 10 ~ 95% RH non-condensing		
	TEMP. COEFFICIENT	0.03% / ℃ (0 ~ 85℃)		
	SOLDERING TEMPERATURE	1.5mm from case of 1 ~ 3sec./260℃ max.		
	VIBRATION	10 ~ 500Hz, 2G 10min./1cycle, period for 60min. each along X, Y, Z axes		
SAFETY & EMC (Note.5)	WITHSTAND VOLTAGE	I/P-O/P:1.5KVDC		
	ISOLATION RESISTANCE	I/P-O/P:100M Ohms / 500VDC / 25℃/ 70% RH		
	ISOLATION CAPACITANCE (Typ.)	10pF		
	EMC EMISSION	Parameter	Standard	Test Level / Note
		Conducted	EN55032(CISPR32)	N/A
		Radiated	EN55032(CISPR32)	Class A
	EMC IMMUNITY	Parameter	Standard	Test Level / Note
		ESD	EN61000-4-2	Level 2, ±8KV air, ±4KV contact
		Radiated Susceptibility	EN61000-4-3	Level 2, 3V/m
		EFT/Burest	EN61000-4-4	Level 1, 0.5KV
		Surge	EN61000-4-5	Level 1, 0.5KV Line-Line
		Conducted	EN61000-4-6	Level 2, 3V(e.m.f.)
		Magnetic Field	EN61000-4-8	Level 2, 3A/m
OTHERS	MTBF	2500Khrs MIL-HDBK-217F(25℃)		
	DIMENSION (L*W*H)	21.8*9.2*11.1mm (0.86*0.36*0.44 inch)		
	CASE MATERIAL	Non-Conductive black plastic (UL 94V-0 rated)		
	PACKING	4.8g		
NOTE	1.All parameters are specified at normal input(E:5Vdc, A:12Vdc, B:24Vdc, C:48Vdc), rated load, 25℃ 70% RH ambient. 2.Ripple & noise are measured at 20MHz by using a 12" twisted pair terminated with a 0.1μf & 47μf capacitor. 3.Line regulation is measured from low line to high line at rated load. 4.Load regulation is measured from 10% to 100% rated load. 5.The final equipment must be re-confirm that it still meet EMC directives. For guidance on how to perform these EMC tests, please refer to "EMI testing of component power supplies."(as available on http://www.meanwell.com)			

File Name:SPAN02,DPAN02-SPEC 2017-03-06

2W SIP Package DC-DC Regulated Converter **SPAN02 & DPAN02 series**

Mechanical Specification

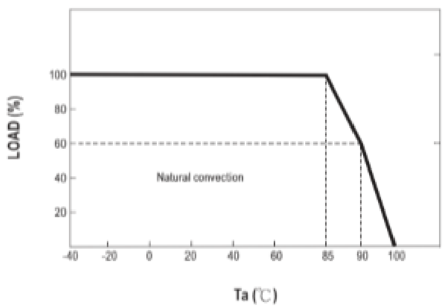
- All dimensions in mm(inch)
- Tolerance:x.x±0.5mm(x.xx±0.02")
- Pin pitch tolerance:±0.05mm (±0.002")



Plug Assignment

Pin-Out		
Pin No.	SPAN02 (Single output)	DPAN02 (Dual output)
1	-Vin	-Vin
2	+Vin	+Vin
3	R.C.	R.C.
5	N.C.	N.C.
6	+Vout	+Vout
7	-Vout	Common
8	N.C.	-Vout

Derating Curve



Installation Manual

Please refer to : http://www.meanwell.com/manual.html

File Name:SPAN02,DPAN02-SPEC 2017-03-06

Optocoupler Datasheet

LITEON® OPTOELECTRONICS

Photocoupler
Product Data Sheet
4N35/ 4N37
(M, S, S-TA1)

Spec No.: DS-70-99-0012
Effective Date: 12/13/2011
Revision: C

LITE-ON DCC
RELEASE

BNS-OD-FC001/A4

LITE-ON Technology Corp. / Optoelectronics
No.90,Chien 1 Road, Chung Ho, New Taipei City 23585, Taiwan, R.O.C.
Tel: 886-2-2222-6181 Fax: 886-2-2221-1948 / 886-2-2221-0660
http://www.liteon.com/opto

LITE-ON TECHNOLOGY CORPORATION

Property of LITE-ON Only

FEATURES

* High crrent transfer ratio
  (CTR : MIN. 100% at $I_F = 10mA$, $V_{CE} = 10V$)
* Response time
  (t_{on} : TYP. 3µs at $V_{CC} = 10V$, $I_C = 2mA$, $R_L = 100\Omega$)
* Input-output isolation voltage
  4N35 series : $V_{iso} = 3{,}550Vrms$
  4N37 series : $V_{iso} = 1{,}500Vrms$
* Dual-in-line package :
  4N35, 4N37
* Wide lead spacing package :
  4N35M, 4N37M
* Surface mounting package :
  4N35S, 4N37S
* Tape and reel packaging :
  4N35S-TA1, 4N37S-TA1
* Safety approval
  UL& cUL, VDE, FIMKO, CQC approved
* RoHS compliant

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 1 of 11

BNS-OD-C131/A4

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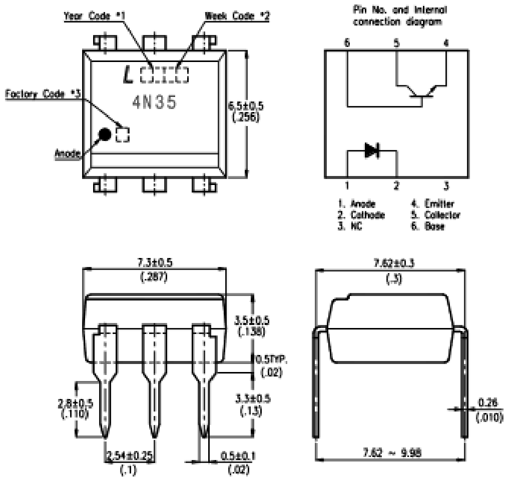
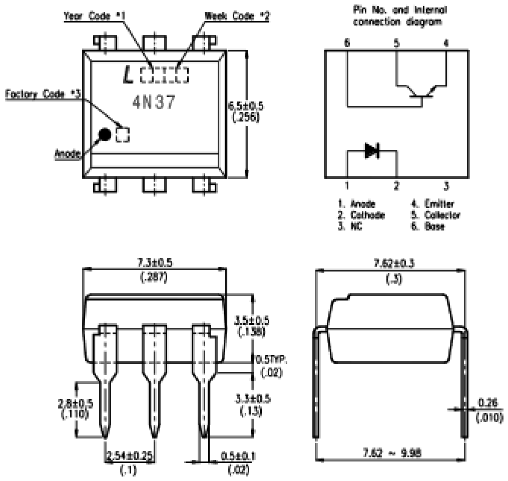
OUTLINE DIMENSIONS

4N35 :



4N37 :



*1. Year date code.
*2. 2-digit work week.
*3. Factory identification mark shall be marked
(Y : Thailand, X : China-TJ, W : China-CZ)

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 2 of 11

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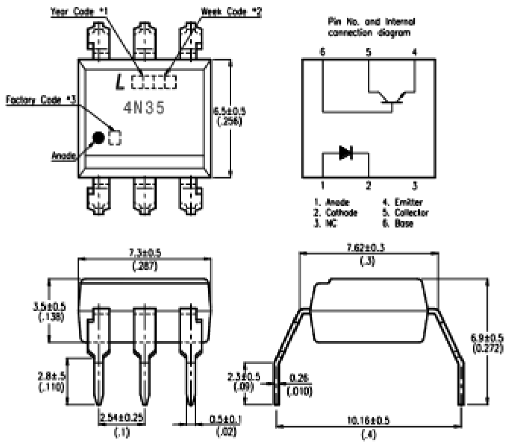
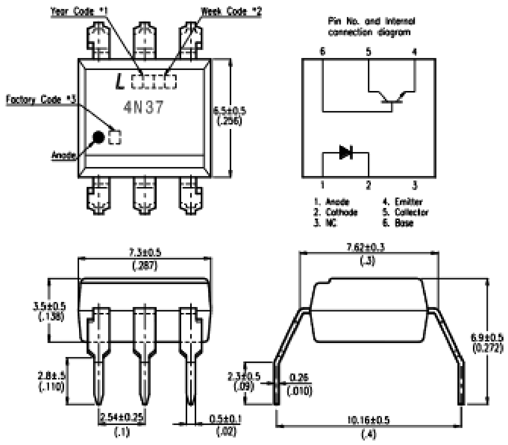
OUTLINE DIMENSIONS

4N35M :



4N37M :



*1. Year date code.
*2. 2-digit work week.
*3. Factory identification mark shall be marked
(Y : Thailand, X : China-TJ, W : China-CZ)

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 3 of 11

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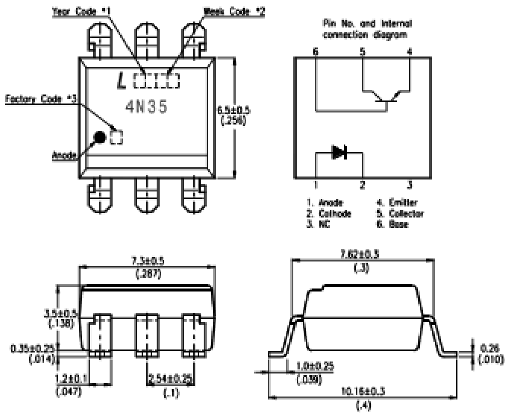
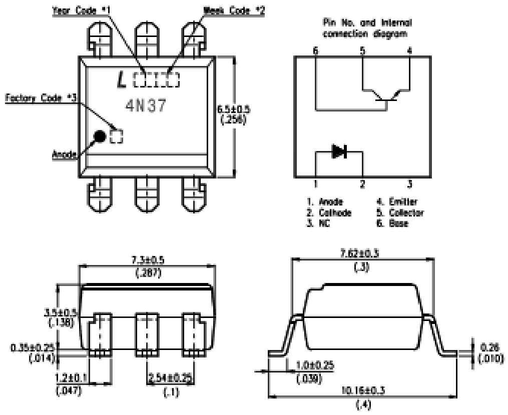
OUTLINE DIMENSIONS

4N35S :



4N37S :



*1. Year date code.
*2. 2-digit work week.
*3. Factory identification mark shall be marked
(Y : Thailand, X : China-TJ, W : China-CZ)

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 4 of 11

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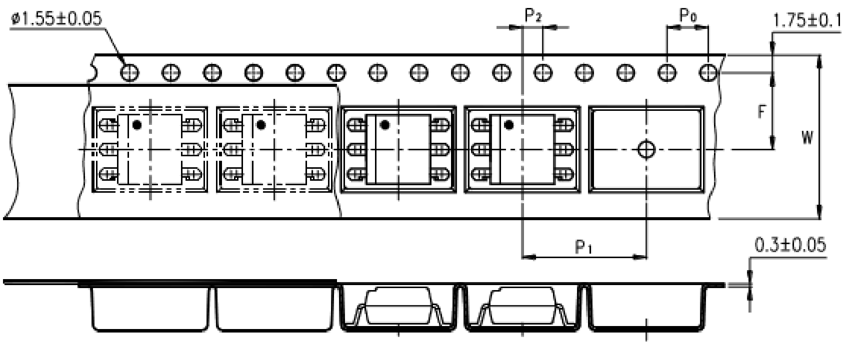
TAPING DIMENSIONS

4N35S-TA1 , 4N37S-TA1 :



Description	Symbol	Dimensions in mm (inches)
Tape wide	W	16 ± 0.3 (.63)
Pitch of sprocket holes	P_0	4 ± 0.1 (.15)
Distance of compartment	F P_2	7.5 ± 0.1 (.295) 2 ± 0.1 (.079)
Distance of compartment to compartment	P_1	12 ± 0.1 (.472)

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011) | Page : 5 of 11

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ABSOLUTE MAXIMUM RATING

(Ta = 25°C)

PARAMETER			SYMBOL	RATING	UNIT
INPUT	Forward Current		I_F	60	mA
	Reverse Voltage		V_R	6	V
	Power Dissipation		P	100	mW
OUTPUT	Collector - Emitter Voltage		V_{CEO}	30	V
	Emitter - Collector Voltage		V_{ECO}	7	V
	Collector - Base Voltage		V_{CBO}	70	V
	Collector Current		I_C	100	mA
	Collector Power Dissipation		P_C	300	mW
Total Power Dissipation			P_{tot}	350	mW
*1 Isolation Voltage		4N35 series	V_{iso}	3550	Vrms
		4N37 series		1500	
Operating Temperature			T_{opr}	-55 ~ +100	°C
Storage Temperature			T_{stg}	-55 ~ +150	°C
*2 Soldering Temperature			T_{sol}	260	°C

*1. AC For 1 Minute, R.H. = 40 ~ 60%

Isolation voltage shall be measured using the following method.

(1) Short between anode and cathode on the primary side and between collector, emitter and base on the secondary side.

(2) The isolation voltage tester with zero-cross circuit shall be used.

(3) The waveform of applied voltage shall be a sine wave.

*2. For 10 Seconds

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 6 of 11

BNS-OD-C131/A4

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ELECTRICAL - OPTICAL CHARACTERISTICS

(Ta = 25°C)

<table>
<tr><th colspan="3">PARAMETER</th><th>SYMBOL</th><th>MIN.</th><th>TYP.</th><th>MAX.</th><th>UNIT</th><th>CONDITIONS</th></tr>
<tr><td rowspan="3">INPUT</td><td colspan="2">Forward Voltage</td><td>V_F</td><td>—</td><td>1.2</td><td>1.5</td><td>V</td><td>I_F=10mA</td></tr>
<tr><td colspan="2">Reverse Current</td><td>I_R</td><td>—</td><td>—</td><td>10</td><td>μA</td><td>V_R=4V</td></tr>
<tr><td colspan="2">Terminal Capacitance</td><td>C_t</td><td>—</td><td>50</td><td>—</td><td>pF</td><td>V=0, f=1KHz</td></tr>
<tr><td rowspan="5">OUTPUT</td><td rowspan="2">Collector Dark Current</td><td>Ta=25°C</td><td rowspan="2">I_{CEO}</td><td>—</td><td>—</td><td>50</td><td>nA</td><td>V_{CE}=10V, I_F=0</td></tr>
<tr><td>Ta=100°C</td><td>—</td><td>—</td><td>500</td><td>μA</td><td>V_{CE}=30V, I_F=0</td></tr>
<tr><td colspan="2">Collector-Emitter Breakdown Voltage</td><td>BV_{CEO}</td><td>30</td><td>—</td><td>—</td><td>V</td><td>I_C=0.1mA
I_F=0</td></tr>
<tr><td colspan="2">Emitter-Collector Breakdown Voltage</td><td>BV_{ECO}</td><td>7</td><td>—</td><td>—</td><td>V</td><td>I_E=10μA
I_F=0</td></tr>
<tr><td colspan="2">Collector-Base Breakdown Voltage</td><td>BV_{CBO}</td><td>70</td><td>—</td><td>—</td><td>V</td><td>I_C=0.1mA
I_F=0</td></tr>
<tr><td rowspan="7">TRANSFER CHARACTERISTICS</td><td colspan="2">Collector Current</td><td>I_C</td><td>10</td><td>—</td><td>—</td><td>mA</td><td rowspan="2">I_F=10mA
V_{CE}=10V</td></tr>
<tr><td colspan="2">* Current Transfer Ratio</td><td>CTR</td><td>100</td><td>—</td><td>—</td><td>%</td></tr>
<tr><td colspan="2">Collector-Emitter Saturation Voltage</td><td>$V_{CE(sat)}$</td><td>—</td><td>—</td><td>0.3</td><td>V</td><td>I_F=50mA
I_C=2mA</td></tr>
<tr><td colspan="2">Isolation Resistance</td><td>R_{iso}</td><td>5×10^{10}</td><td>1×10^{11}</td><td>—</td><td>Ω</td><td>DC500V
40 ~ 60% R.H.</td></tr>
<tr><td colspan="2">Floating Capacitance</td><td>C_f</td><td>—</td><td>1</td><td>2.5</td><td>pF</td><td>V=0, f=1MHz</td></tr>
<tr><td colspan="2">Response Time (Turn-on)</td><td>t_{on}</td><td>—</td><td>3</td><td>10</td><td>μs</td><td rowspan="2">V_{CC}=10V, I_C=2mA
R_L=100Ω</td></tr>
<tr><td colspan="2">Response Time (Turn-off)</td><td>t_{off}</td><td>—</td><td>3</td><td>10</td><td>μs</td></tr>
</table>

$$* \ CTR = \frac{I_C}{I_F} \times 100\%$$

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011) | Page : 7 of 11

BNS-OD-C131/A4

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CHARACTERISTICS CURVES

Fig.1 Forward Current vs. Ambient Temperature

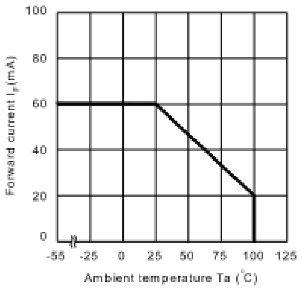


Fig.2 Collector Power Dissipation vs. Ambient Temperature

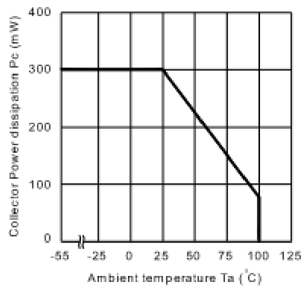


Fig.3 Forward Current vs. Forward Voltage

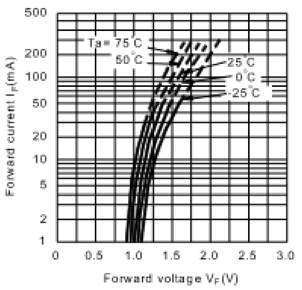


Fig.4 Current Transfer Ratio vs. Forward Current

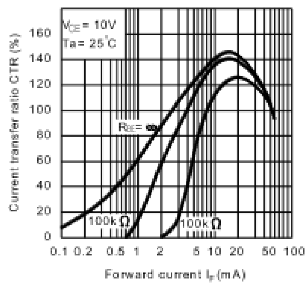


Fig.5 Collector Current vs. Collector-emitter Voltage

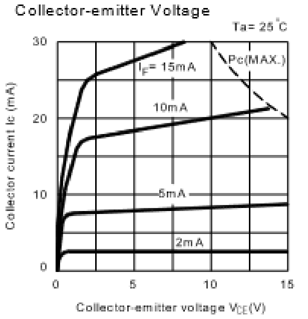
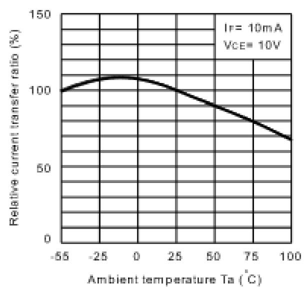


Fig.6 Relative Current Transfer Ratio vs. Ambient Temperature



Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 8 of 11

BNS-OD-C131/A4

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CHARACTERISTICS CURVES

Fig.7 Collector-emitter Saturation Voltage vs. Ambient Temperature

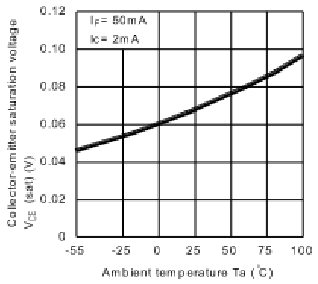


Fig.8 Collector Dark Current vs. Ambient Temperature

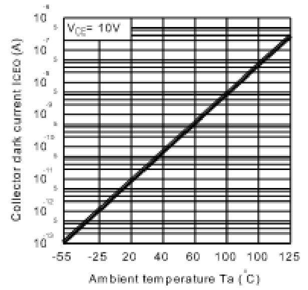


Fig.9 Response Time vs. Load Resistance

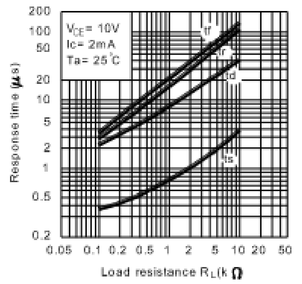


Fig.10 Frequency Response

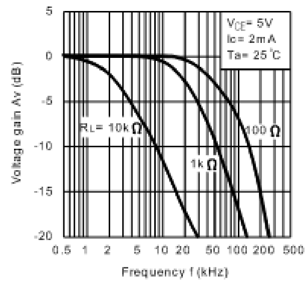
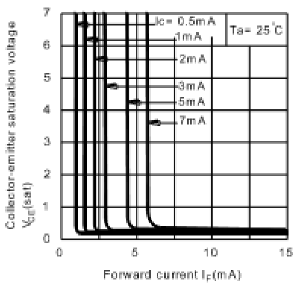
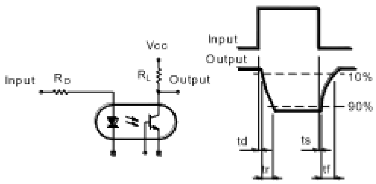


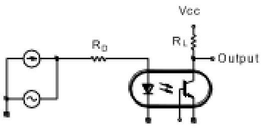
Fig.11 Collector-emitter Saturation Voltage vs. Forward Current



Test Circuit for Response Time



Test Circuit for Frequency Response



Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 9 of 11

BNS-OD-C131/A4

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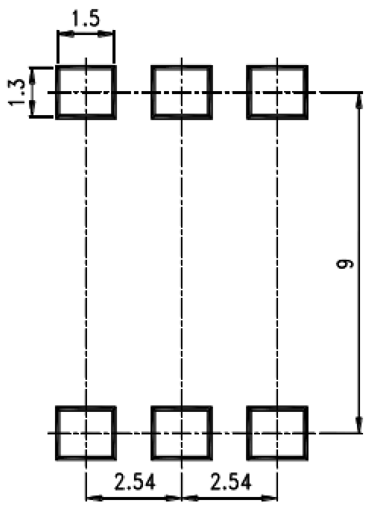
RECOMMENDED FOOT PRINT PATTERNS (MOUNT PAD)

Unit : mm



Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 10 of 11

BNS-OD-C131/A4

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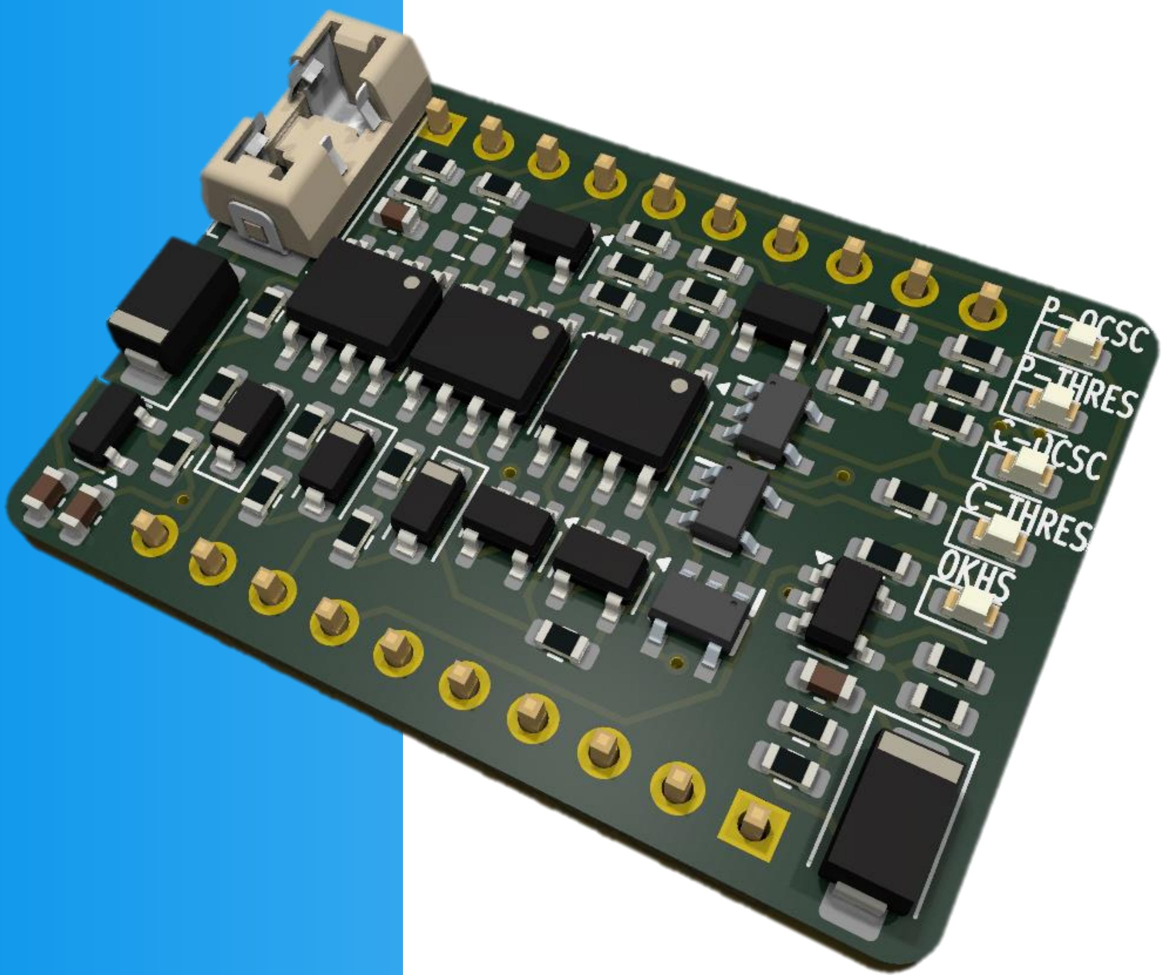
- For equipment/devices where high reliability or safety is required, such as space applications, nuclear power control equipment, medical equipment, etc, please contact our sales representatives.
- When requiring a device for any " specific" application, please contact our sales in advice.
- If there are any questions about the contents of this publication, please contact us at your convenience.
- The contents described herein are subject to change without prior notice.
- Immerse the unit's body into solder paste is not recommended.

Part No. : 4N35 / 4N37 (M, S, S-TA1) (Rev.- October 17 2011)	Page : 11 of 11

BSPD BREAKOUT BOARD

DESIGN REPORT



Abstract

The brake system plausibility device (BSPD) is a system that is used to ensure that power isn't being applied to the motor and the brakes aren't pressed hard at the same time. If this was to occur for a time greater than 500ms, the shutdown circuit will open.

The BSPD is composed of 3 parts:

1. A measurement system for the brakes, and a logic circuit to determine if a threshold has been met and the values are within a specified range (open circuit short circuit, OCSC),
2. A measurement system for the current to the controller, and a logic circuit to determine if a threshold has been met and the values are within a specified range (OCSC),
3. A logic circuit to use the threshold values where if both current and pressure values are above, or either system is outside of the range for OCSC, a timer circuit is started and if it occurs for longer than 500ms the shutdown circuit will be opened.

This report details the design and implementation of a measurement system for the current sensor, and logic circuit "Breakout" PCB for the BSPD.

Previous iterations of the BSPD utilised a variety of components for the system, where the measurement system for the brakes was located in the pedal box electrical node (PEN), and the measurement system for the current and logic circuit was located in the central electrical node (CEN). The CEN board was also the location of the HFR, TSAL, and Discharge.

Due to the complexity of the circuit, it was decided a breakout board approach would be the standard design for the BSPD. This method allows iterations of the motherboard to be created while having a system that is known to be good, moving the complexity away from the motherboard.

The completed BSPD Breakout PCB board has now been commissioned, and found to be robust, easy to test, and easy to manufacture with PCB-A.

Introduction

The BSPD is a logical circuit that ensures that the brakes and power system is working as expected. It is composed of:

- A system to measure the brake pressure,
- A system to measure the current to the motor controller, and
- A logic circuit to ensure safe operations.

This logic circuit uses both the brake sensor readings and current sensor reading to ensure:

1. The brake sensor is within operating voltage (>0.5V and <4.5V),
2. The current senor is within operating voltage (>0.5V and <4.5V), and
3. Check for high brake pressure and high current draw at the same time.

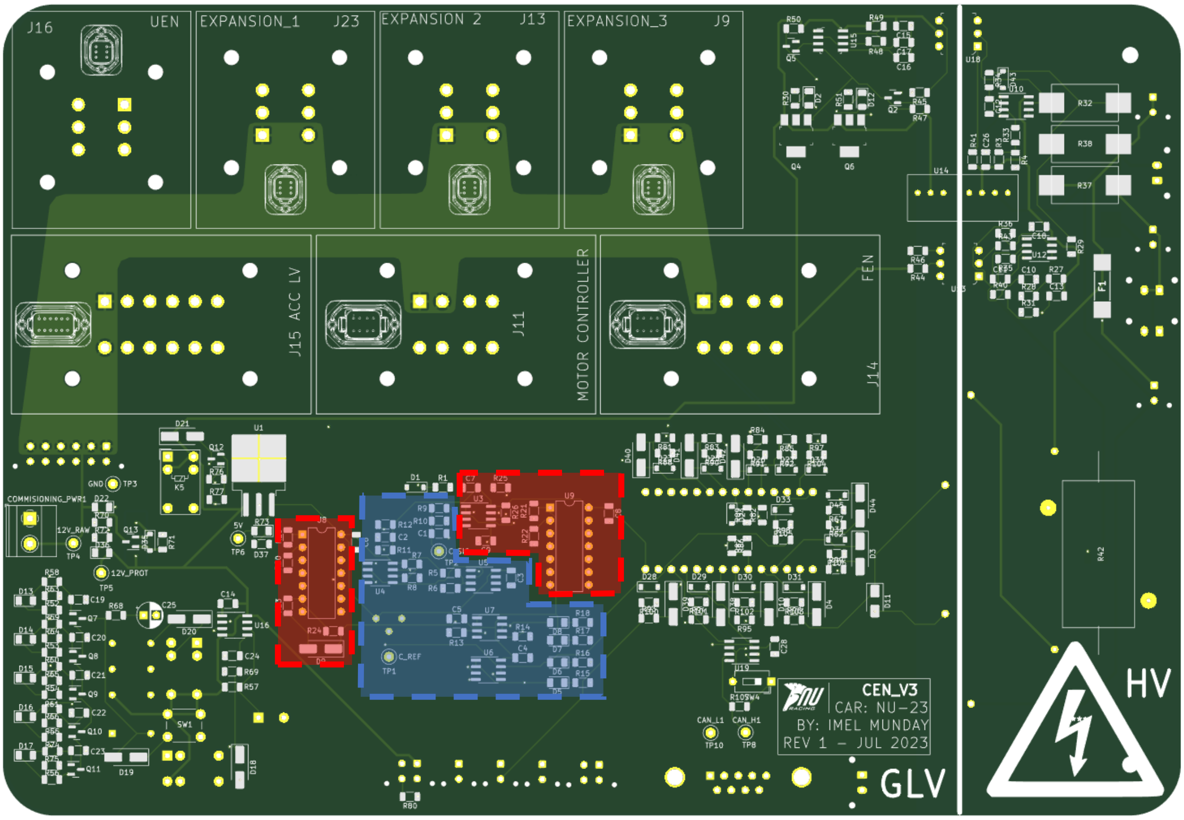
Past NU Racing BSPD circuits have utilised:

- Within the PEN, a combination of comparators and voltage dividers to determine if the threshold values for the brake pressure have been reached or gone above or below the OCSC values,
- Within the CEN, a combination of comparators and voltage dividers to determine if the threshold values for the current sensor have been reached or gone above or below the OCSC values,
- The signals above are sent to the CEN, where with the use of logic gates, will output a HIGH signal when the signals are in the expected states, and,
- A capacitor, diode, resistor and op-amp circuit to delay the timeout for the BSPD.

This report will only discuss the CEN components of the BSPD circuit.

In the CEN, the BSPD current measurement and logic was on a PCB that had multiple functions including, TSAL, Discharge and HFR, this system was complicated, involved complex schematics and PCB design with specialised parts. This caused:

1. Complex boards that were difficult to understand and design,
2. Increased Complexity in schematics,
3. Large PCBs footprints, and,
4. Increased complexity while troubleshooting.



BSPD Threshold and OCSC Circuit

BSPD Logic Circuit

Figure 23 NU23 CEN, with BSPD Components Labelled

To simplify this system, it was decided to create a breakout board for the BSPD. This included removing all the BSPD functionality from a main board, and creating a teensy like board, that has the functionality of the BSPD and attaches to the main board through header pins. This allows the complexity to be removed from the master board.

Proposed benefits of this solution include:

1. Reduced complexity of the master board,
2. Reduced knowledge requirement to implement BSPD current measurement and logic,
3. Provide a known good, ready to use board that can be implemented,
4. Maintenace of flexibly for topological changes and/or motherboard geometry without remaking BSPD circuitry.

This circuity had to be designed to a specification to:

1. Allow for easy unit testing,
2. Be robust,
3. Utilise as many standard/stocked components as possible,
4. Manufactured utilising PCB-A,
5. Rules Compliant,
6. Useable for multiple years, and,
7. Minimal footprint to enable flexibility in motherboard geometry.

Rules

For the FSAE-A competition, rules are required to be followed to ensure safety. The BSPD has certain rule requirements it needs to follow. These include the ones below.

Rule	
EV.6.6.1 All electrical systems (both Low Voltage and High Voltage) must have appropriate Overcurrent Protection/Fusing.	
EV.6.6.2 Unless otherwise allowed in the Rules, all Overcurrent Protection devices must: a. Be rated for the highest voltage in the systems they protect. Overcurrent Protection devices used for DC must be rated for DC and must carry a DC rating equal to or more than the system voltage b. Have a continuous current rating less than or equal to the continuous current rating of any electrical component that it protects c. Have an interrupt current rating higher than the theoretical short circuit current of the system that it protects	
EV.7.1.4 The AMS, IMD and BSPD must have completely independent circuits to Open the Shutdown Circuit. The design of the respective circuits must ensure that a failure cannot result in electrical power being fed back into the Shutdown Circuit.	
EV.7.7.1 The vehicle must have a standalone nonprogrammable circuit to check for simultaneous braking and high power output The BSPD must be provided in addition to the APPS / Brake Pedal Plausibility Check (EV.4.7)	
EV.7.7.2 The BSPD must Open the Shutdown Circuit EV.7.2.2 when the two of these exist: • Demand for Hard Braking EV.4.6 • Motor/Accumulator current is at a level where 5 kW of electrical power in the DC circuit is delivered to the Motor(s) at the nominal battery voltage The BSPD may delay opening the shutdown circuit up to 0.5 sec to avoid false trips	
EV.7.7.3 The BSPD must Open the Shutdown Circuit EV.7.2.2 when there is an open or short circuit in any sensor input	

Topology Implementation

The Topology of the BSPD consists of 3 different parts.

1. A system to measure the brake pressure.
2. A system to monitor the current through the TS, and
3. A system to compare these values and open the shutdown circuit if a value is not correct.

NU Racings implementation of this involves.

1. The Pedal box Electrical Node (PEN) to be the location that the brake pressures are measured, and the logic for the PRESSURE_OCSC and PRESSURE_THRESHOLD is calculated, these signals are sent through the dash electrical node (DEN) and into the central electrical node (CEN).
2. The Current is measured in the Human Interface Panel (HIP) and sent to the CEN, and,
3. The BSPD Breakout board, that calculated CURRENT_OCSC and CURRENT_THRESHOLD, and completes the logic to determine if the system is in a fault state or not.

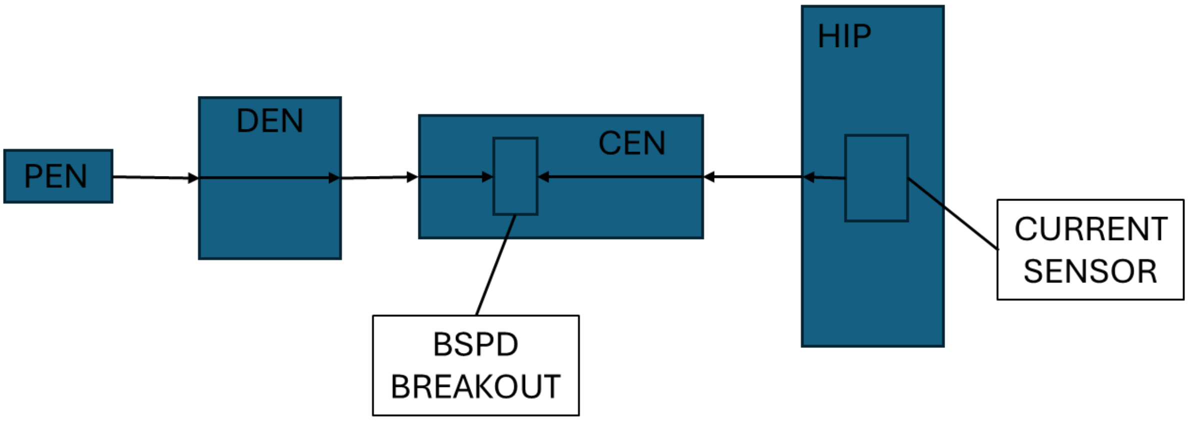


Figure 24 BSPD NU24 Implementation

Topology/Schematic

The BSPD breakout takes 3 inputs:

- PRESSURE_OCSC,
- PRESSURE_THRESHOLD, and
- CURRENT_SENSE.

For the logical components of the car, CURRENT_OCSC and CURRENT_THRESHOLD need to be calculated.

Figure 25 BSPD Schematic

Current Threshold

The CURRENT_THRESHOLD is calculated with the use of a comparator. This takes the input CURRENT_SENSE value and compares it to a reference value, if the CURRENT_SENSE value is above the reference the output goes LOW.

This is then put through a follower op-amp to isolate the signal to be sent to the Logic gates.

The input circuity is used to smooth the input from the current sensor. This is required due to the signal being noisy.

Values for the reference resistors need to be calculated, depending on the maximum TS voltage and the current sensor being used.

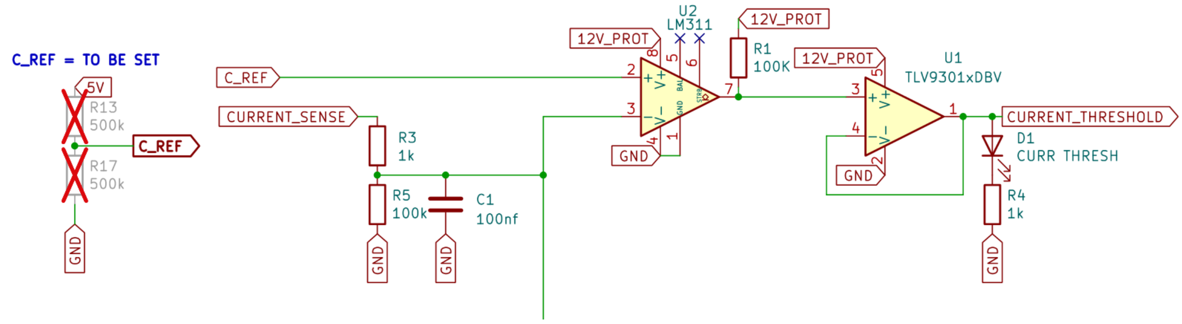


Figure 26 Current Threshold Schematic

Current OCSC

Current OCSC is a circuit that defines if the current sensor value is above or below a certain value. These values are 4.5V, and 0.5V. if these voltages are achieved by the circuit that would mean there is either a short on the current sensor circuit or an open circuit. To do this the use of two comparators are used, using the same CURRENT_SENSE input, they are put into the comparator.

The short circuit check is completed with the CURRENT_SENSE input being on the negative of the comparator, meaning the value went above the 4.5V, the comparator will go LOW.

The open circuit comparator has the CURENT_SENSE on its positive input. This means the comparator will only go LOW, when the CURRENT_SENSE voltage goes below the 0.5V reference.

This is then put through a follower op-amp to isolate the signal to be sent to the Logic gates.

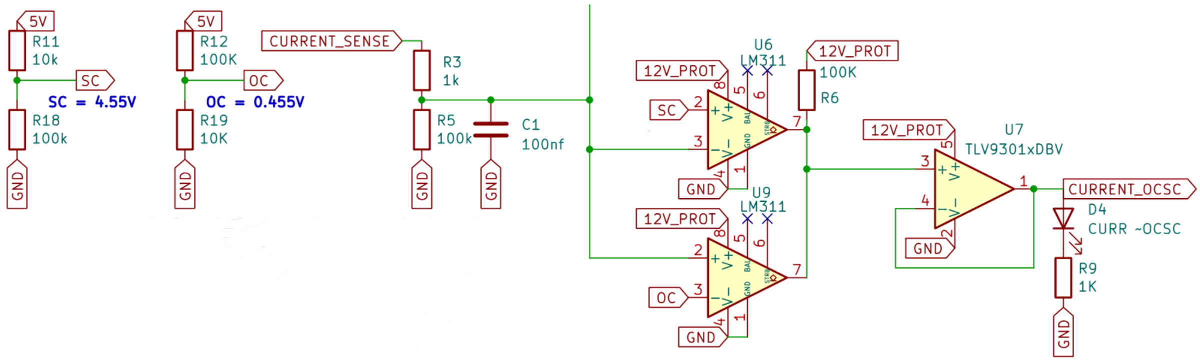


Figure 27 Current OCSC Schematic

Pressure Threshold and OCSC

Pressure threshold and OCSC are outputs from the PEN, ad are values that are when the pressure is above a threshold value or is an open circuit or short circuit state. These signals, using an amplifier op-amp are changed from a 5V signal up to a 12V signal.

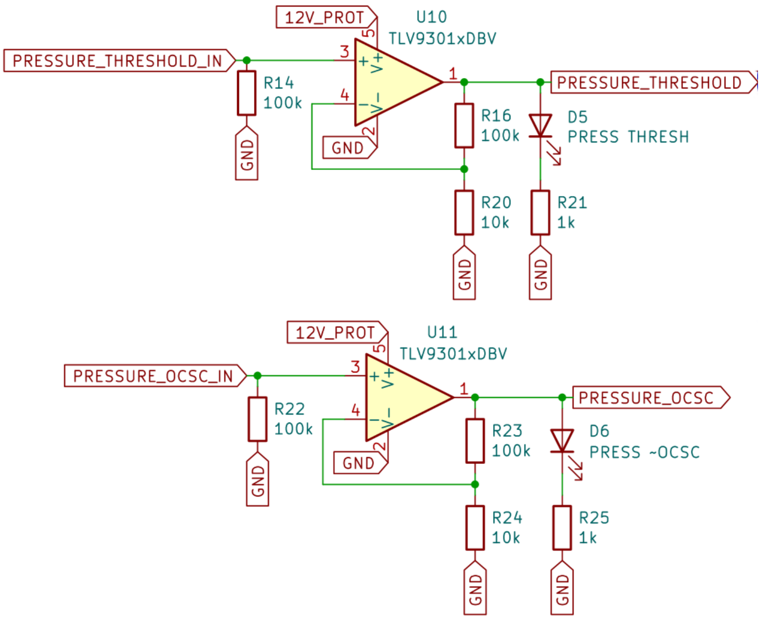


Figure 28 Pressure Threshold and OCSC Schematic

BSPD Logic

The BSPD Logic involves the use of logic gates to determine if the system is correct.

The first gate is a OR gate, which will output LOW when both the PRESSURE_THRESHOLD and CURRENT_THRESHOLD is LOW, otherwise it will output a HIGH signal. This will only occur under heavy braking and while current is still being applied to the motor.

The next gate is a AND gate, which will output HIGH only when CURRENT_OCSC and PRESSURE_OCSC are HIGH, this indicates that both systems are healthy. If either signal goes LOW, the output goes LOW.

The final AND gate uses the output from both previous gates and will output HIGH only when the other gates are HIGH.

The BSPD Timeout Filter is used to provide a 500ms delay before BSPD will activate. This utilises a capacitor (C2) and resistor (R7) to discharge the capacitor when the logic gates are LOW. This resistor and capacitor combo, along with the following op-amp determine the time before the BSPD will fault. The resistor (R2) and diode (D2) provide a fast reset time when the gate goes HIGH.

Finally, the op-amp uses a reference voltage and the output from the capacitor. When the capacitor voltage goes below the 2.5V refence voltage, the BSPD_OKHS goes LOW.

The system will go LOW when.

- PRESSURE_OCSC goes LOW,
- CURENT_OCSC goes Low, or
- CURRENT_THRESHOLD and PRESSURE_THRESHOLD both go LOW.

Otherwise, the output will be HIGH when.

- PRESSURE_OCSC, CURRENT_OCSC are high, and CURRENT_THRESHOLD and/or PRESSURE_THRESHOLD is HIGH.

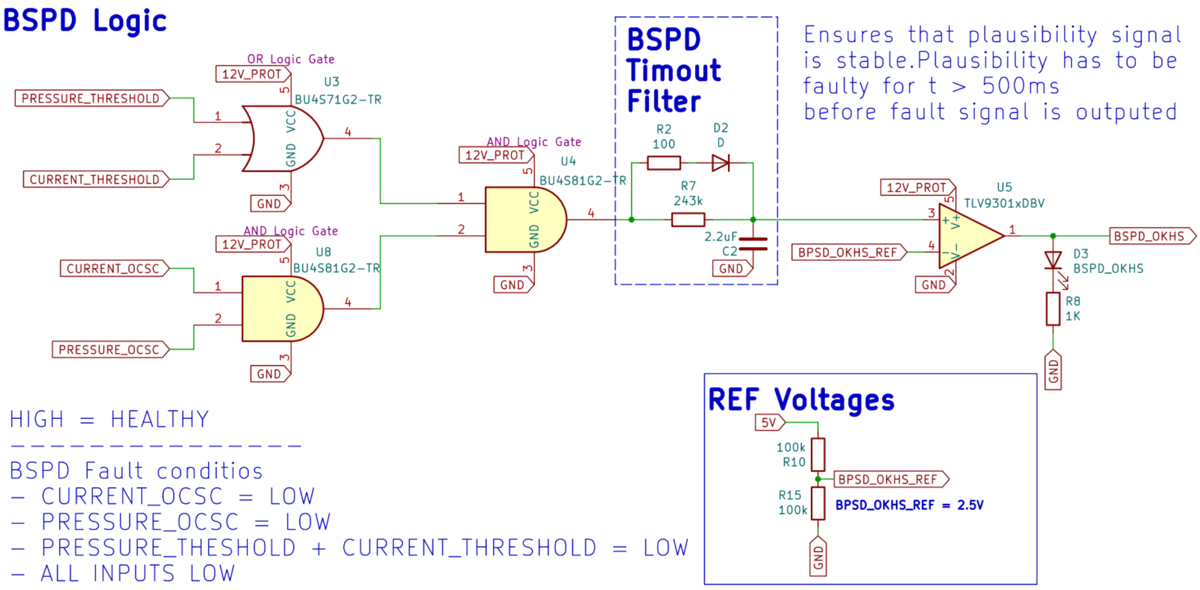


Figure 29 BSPD Logic Schematic

Implementation/Layout

This section will discuss component selection and the layout of the components.

Component Selection

The choice of components was based on available of components, voltage ratings and cost. This was also influenced by factors such as:

- Wanting components being commonly used within NU Teams,
- Wanting single channel components over multi-channel, and,
- Choosing components based on size.

With these factors, the following components were the ones chosen.

Comparator (LM311)

The comparator chosen was the LM311. This was chosen due to it being a single channel comparator and it being in a similar family to the one used on NU23 CEN, which was the LM393, a dual channel comparator.

The LM311 is capable of being powered up to 36V with a max differential input between the inputs being 30V. This is much more voltage than what will be used on the car, where it will only be powered by 12V (up to 14V) and a max differential voltage of 11V. This comparator is only capable of grounding its output.

To ensure more accurate readings capacitors are used on the inputs and for the supply. This smooths the inputs allowing less noise to impact the readings.

Op-amp (TLV9301IDBVR)

The op-amp chosen was the TLV9301IDBVR. This was chosen due to it being a readily available part from mouser, the choice not to use the op-amp that was originally on the CEN was due to it being a quad channel op-amp. Due to the size constraint and trying to make the schematics and PCB easier to read, it was chosen to use a single channel op-amp. This op-amp is capable of an input voltage up to 42V and can output a max current of 10mA.

OR Gate (BU4S71G2-TR)

The OR gate chosen was the BU4S71G2-TR. This was chosen due to it being tolerant up to 40V, it was one of the few that was single channel, and capable to work at 12V, therefore not needing to be powered off the 5V supply. This gate is capable of outputting current up to 2mA.

AND Gate (BU4S81G2-TR)

The AND gate chosen was the BU4S81G2-TR. This was chosen due to it being tolerant up to 40V, it was one of the few that was single channel, and capable to work at 12V, therefore not needing to be powered off the 5V supply. This gate is capable of outputting current up to 2mA.

5V Supply (MAX6035BAUR50+T)

The 5V supply chosen was the MAX6035BAUR50+T. This was chosen due to its size, being a very small package. This was only expected to deal with very little current and was therefore determined to be suitable for the few voltage dividers it was dealing with.

Resistor, Capacitors and LED

The choice for resistors, LED and capacitors was done for size constraints, voltage ratings and power rating. Most of the resistors on the board are 0603 except for the voltage divider for the HV. This was due to the voltage ratings of the Resistors with 1206 being rated for 200V, whereas 0603 is only good for 50V. The only resistor that was slightly different was the 0603 LED resistors. This is due to the power requirement for the resistor with most 0603 being rated for 100mW, but the resistors will be dissipating a power of 180mW. Therefore, the resistors are rated for 250mW.

All the capacitors are 0603.

All the LEDs are 0603, with the only difference being colour.

The downside of 0603 is that components are more difficult to solder than 1206. This was justified as packaging was more important and the components will be soldered on with JLCPCB.

Schottky Diode, Fuse Holder and 3V3 Zener Diode (SS34, 0154001.DRT, and BZT52C3V3)

The components for the schottky diode, fuse holder and 3V3 zener diode are SS34, 0154001.DRT, and BZT52C3V3). These components were all chosen for the standard footprints utilised within the team, the 3V3 Zener diode is not the same part as the one used in the team due to part availability, this doesn't matter though as it has the same performance and specifications.

Layout

The Layout of the PCB was determined by a few factors:

- Design the PCB to be as small as possible,
- Fit all components on one side to allow PCB-A,
- Teensy like connection,
- PCB size to nearest 5mm,
- Header pins offset by 2mm.

Using these requirements the board layout was completed.

Board Size

For simplicity it was decided to make boards to 5mm increments. Therefore, a logical layout, trying to fit as many components as close together was done to allow the minimum board size to be achieved.

Figure 30 BSPD Board Size

Header Pins

The header pins for the LV side required enough for all the LV signals into and out of the board. This included 12V, GND, CURRENT_SENSE, PRESSURE_THRESHOLD, PRESSURE_OCSC, BSPD_OKHS, CURRENT_THRESHOLD_TEENSY, CURRENT_OCSC_TEENSY, and CURRENT_SENSE_TEENSY. For this board it was chosen to use 2 10 pin header pins with inputs and outputs opposing each other. This allowed the teensy like, friction fit connections, and meant if the board was put in backwards nothing would happen.

Logical Layout

Due to the size of the board, it was required to have a logical layout of components to ensure tracing was possible.

Footprint/Pinout

Due to these boards being place onto a master board, it was necessary to create a footprint for the component and ensure the pinout for the component is known.

Pin	Name
1	12V
2	GND
3	CURRENT_SENSE
4	PRESSURE_THRESHOLD
5	PRESSURE_OCSC
6	UNUSED
7	BSPD_OKHS
8	CURRENT_THRESHOLD_TEENSY
9	CURRENT_OCSC_TEENSY
10	CURRENT_SENSE_TEENSY

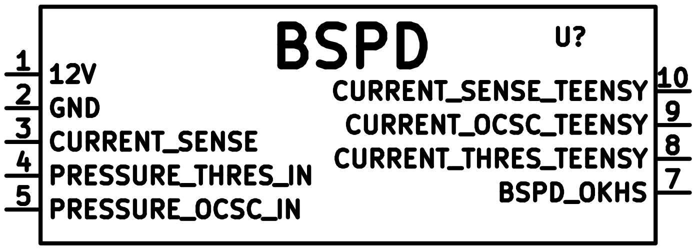


Figure 31 BSPD Symbol

Figure 32 BSPD Footprint

Commissioning and Unit Tests

Utilising JLC to create the boards, most of the components could be assembled by JLC, the components that were not soldered onto the board was the header pins, and the current threshold reference resistors.

Test Type	Test	What should happen	Did it?
Visual Inspection	Inspect all pre-solder components, ensure soldering is adequate and components are correct. Ensure there is no shorts or excess solder	All components are correct	
Setup	Solder on Header pins		
LV Power	Connect 12V to the input	No LEDs should turn ON (Possibly CURRENT_THRESHOLD LED)	
LV Power	Connect 5V to PRESSURE_THRESHOLD and PRESSURE_OCSC pins	PRESSURE_THRESHOLD, AND PRESSURE_OCSC LEDs ON	
Setup	Solder CURRENT_THRESHOLD_REF resistors, Turn power off to PRESSURE_THRESHOLD and PRESSURE_OCSC pins		
LV Power	Turn power supply ON	CURRENT_THRESHOLS LED ON	
LV Power	Connect 1V to CURRENT_SENSE	CURRENT_THRESHOLD and CURRENT_OCSC turns ON	
LV Power	Connect power to PRESSURE_THRESHOLD, and PRESSURE_OCSC. Turn CURRENT_SENSE voltage to 1V	All LEDs Turn on	
LV Power	Turn Current sense voltage to 4V	CURRENT_THRESHOLD turns OFF	
LV Power	Disconnect power to PRESSURE_THRESHOLD	PRESSURE_THRESHOLD and BSPD_OKHS turn OFF	
LV Power	Turn Current Sense down to 1V	CURRENT_THRESHOLD and BSPD_OKHS turns on	
LV Power	Set Current Sense to 2.5V when all systems are good, disconnect PRESSURE_OCSC. Observe delay between PRRESSURE_OCSC disconnecting and BSPD_OKHS going LOW	BSPD_OKHS LED turns off after 500ms delay	

Prototype Commissioning

Utilising the design from the CEN was the starting point of this project, changes that was made included replacing the op-amps with the single channel ones, changing from the LM393 to the LM311, use a new 5V power supply and utilising new, single channel 5V Logic Gates.

During commissioning of this prototype issues occurred where the open circuit fault condition would not occur. It was found that the comparators, have an upper bound to what they can compare which is 1.5V less than the power supply, therefore, the max value they could do was 3.5V. To fix this issue, powering the comparators with 12V fixed the issue without any complications.

The next revision it was wanted to remove the 5V power supply, this changed due to issues where a steady reference voltage couldn't be achieved without this 5V supply, therefore it was decided to replace the one with a much smaller 5V reference since this would now only be supplying 4 voltage dividers. Other changes included replacing the logic gates with gates that could be used with 12V and including amplifier op-amps for the PRESSURE_THRESHOLD and PRESSURE_OCSC signal. The final change was to make the output for this circuit 12V instead of 5V. This was to try and reduce the 5V signals into the HFR.

Conclusion

The BSPD is a system within the car that is necessary to ensure high brake pressure and high current drawer does not occur at the same time. Using the measurement and logic circuits for current and pressure, this will allow the shutdown circuit to open if this was to occur.

This circuit is done by comparing a reference value for current threshold, open circuit, and short circuit values, and using the output from the PEN for pressure threshold and OCSC to output HIGH when the system is within specified values and below both pressure and current thresholds. Otherwise, the shutdown circuit will be opened after 500ms if either Current or Pressure OCSC values are reached, or both threshold values are reached.

The system designed for the current measurement and logic circuit was designed on the same board and is designed in a way to make it:

- Robust
- Rules Compliant
- Utilise as many standard components as possible, and
- Usable for many years

Through making these breakout boards, it made these systems:

- Decrease the complexity of the mother board it will be attached to,
- Allow easier unit testing,
- Able to be made using PCB-A,
- Allow a standard schematic for these systems.

Future Work

There are multiple changes that could be made to the circuit to reduce components or simplify complexity. These include:

Replacing Comparators with Op-amps

To reduce different part counts on the car it could be removing the LM311 and replacing them with other op-amps that are used on the car TLV9301xDBV. The downside of using an op-amp instead of a comparator is a slightly slower response time, and slightly less accurate. For our purposes where the components do not have to be highly accurate, this isn't an issue, and having less components to explain what they do can be beneficial. This may not be possible for all, but will be possible for CURRENT_THRESHOLD

Resistor/Capacitor Sizes

To make the board even smaller it could be possible to use 0402 resistors for some of them. The thing to think about would be wattage the resistors are dissipating.

Larger pulldown Resistor Values

Making the pulldown resistor values larger would reduce current drawer when the circuit is operating. I would be worth testing to ensure no unstable operations occur. This could be as simple as changing the values from 10k to 100k.

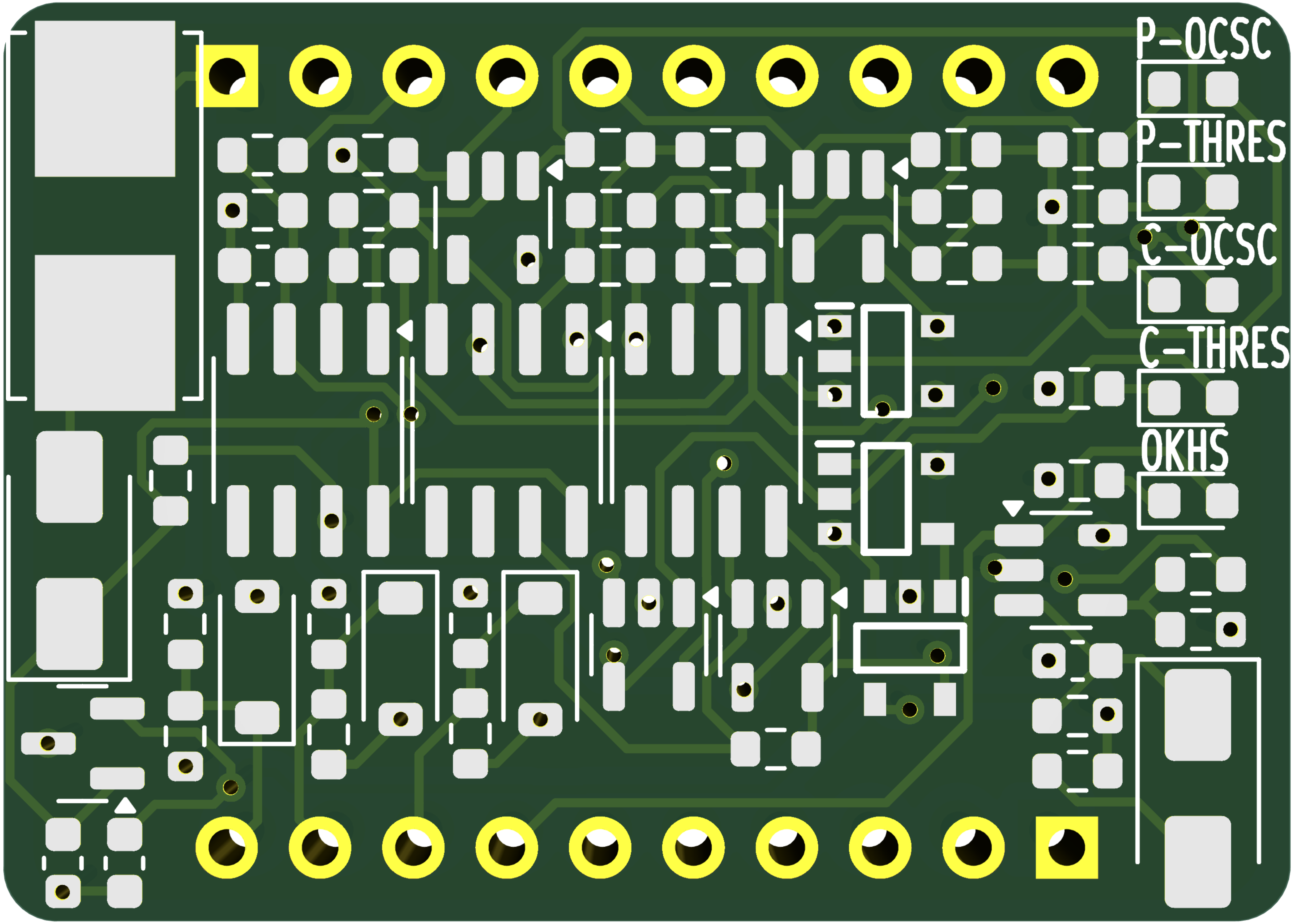
Comparator Op-amps instead of Follower

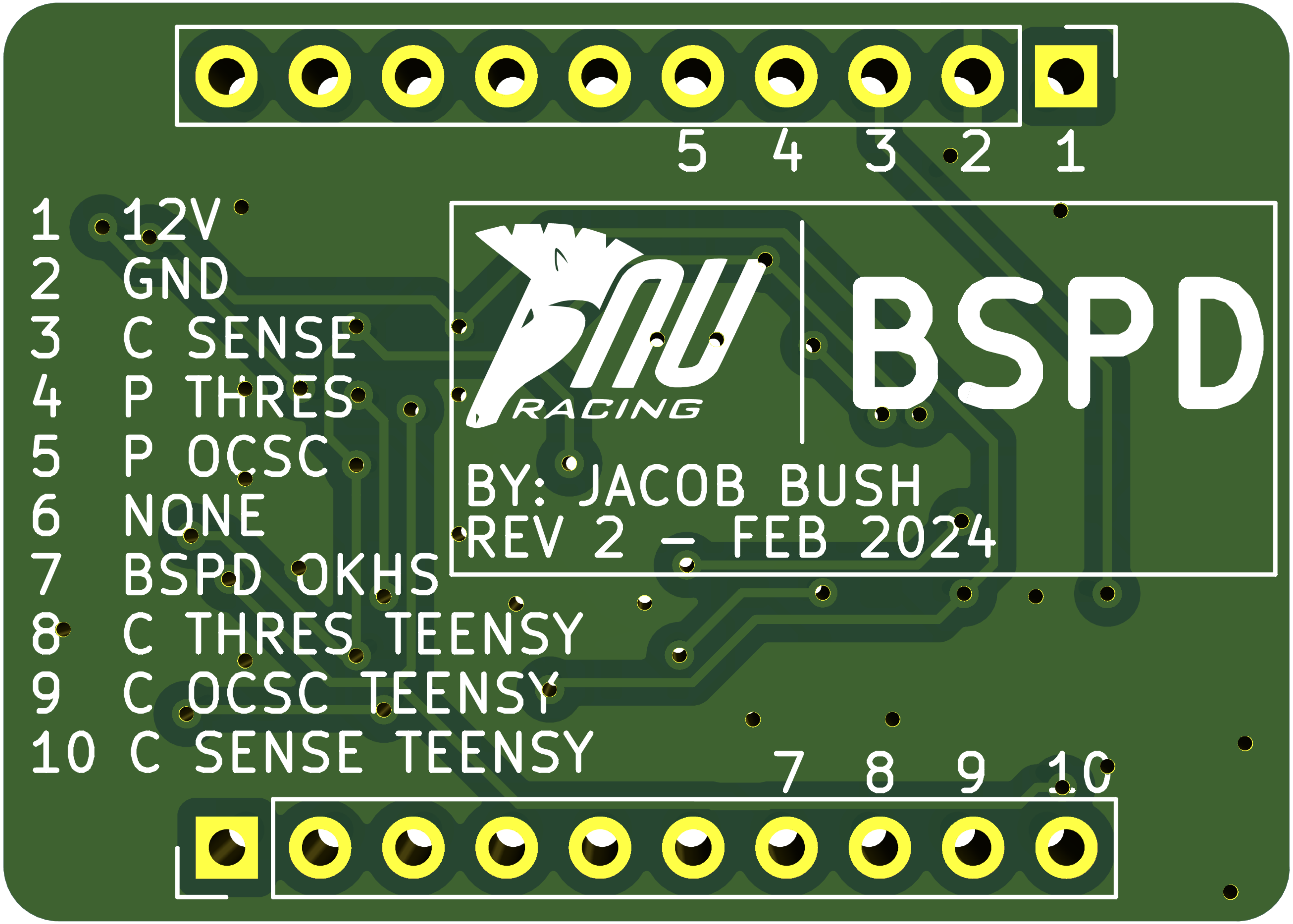
This would allow the removal of multiple resistors, simplifying the circuit, and making the outputs more consistent.

Appendix

Schematic

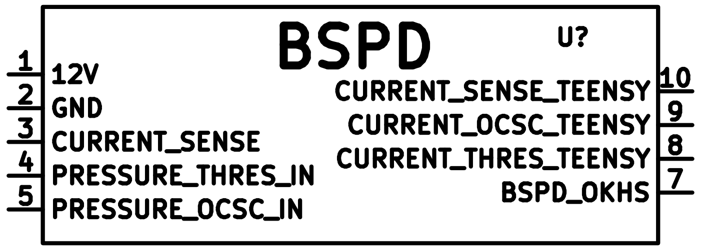
PCB


P-OCSC
P-THRES
C-OCSC
C-THRES
OKHS



5 4 3 2 1
1 12V
2 GND
3 C SENSE
4 P THRES
5 P OCSC
6 NONE
7 BSPD OKHS
8 C THRES TEENSY
9 C OCSC TEENSY
10 C SENSE TEENSY
NU RACING
BSPD
BY: JACOB BUSH
REV 2 - FEB 2024
7 8 9 10

Symbol



Footprint

Pinout

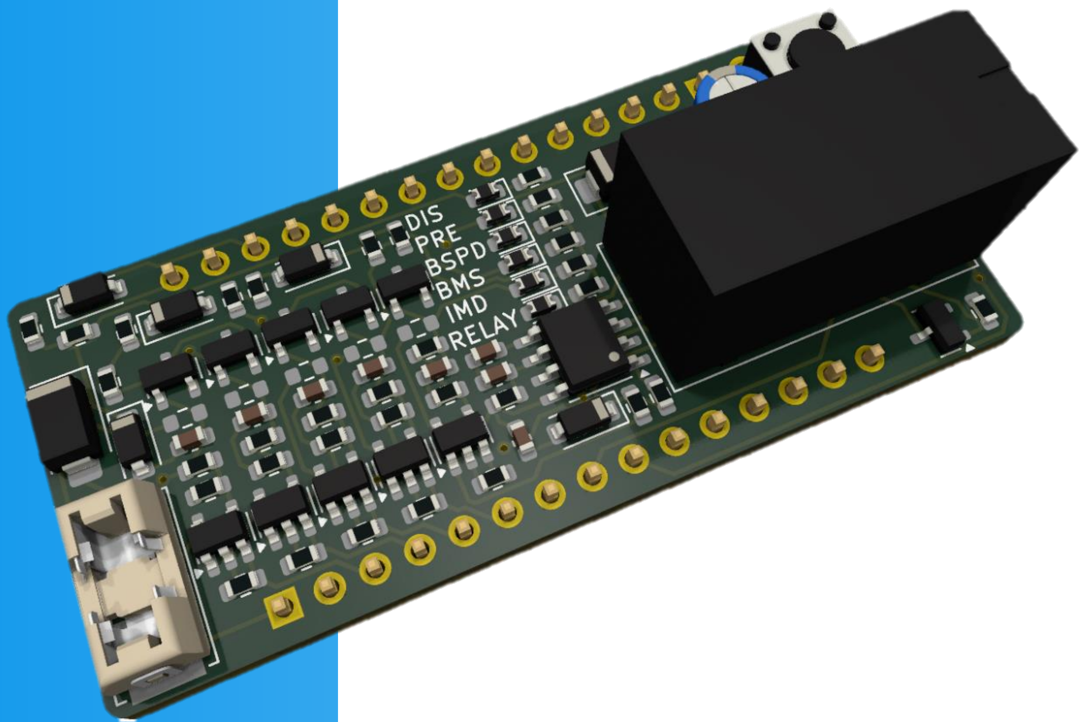
Pin	Name
1	12V
2	GND
3	CURRENT_SENSE
4	PRESSURE_THRESHOLD
5	PRESSURE_OCSC
6	UNUSED
7	BSPD_OKHS
8	CURRENT_THRESHOLD_TEENSY
9	CURRENT_OCSC_TEENSY
10	CURRENT_SENSE_TEENSY

BOM

Comment	Designator	Footprint	JLCPCB #	Datasheet
3V3 Zener	D7, D8, D9	D_SOD-123	C173413	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2308231017_MDD-Microdiode-Electronics--BZT52C3V3_C173413.pdf
Green LED	D3	0603	C12624	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/1806151818_Hubei-KENTO-Elec-KT-0603G_C12624.pdf
Blue LED	D1, D4, D5, D6	0603	C2288	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/1810220913_Hubei-KENTO-Elec-KT-0603B_C2288.pdf
Schottky	D2, D10	D_SMA	C2909963	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2110280930_YONGYUTAI-SS34_C2909963.pdf
Fuse	F1	Fuseholder_Littelfuse_Nano2_154x	C206909	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_Littelfuse-0154001-DRT_C206909.pdf
100	R2	0603	C22775	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2206010130_UNI-ROYAL-Uniroyal-Elec-0603WAF1000T5E_C22775.pdf
1k	R21, R25, R3, R4, R8, R9	0603	C2653986	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_ROHM-Semicon-ESR03EZPF1001_C2653986.pdf
10k	R11, R19, R20, R24, R26, R27, R28	0603	C25804	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2206010045_UNI-ROYAL-Uniroyal-Elec-0603WAF1002T5E_C25804.pdf
20k	R29, R30, R31	0603	C4184	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2206010230_UNI-ROYAL-Uniroyal-Elec-0603WAF2002T5E_C4184.pdf
100K	R1, R10, R12, R14, R15, R16, R18, R22, R23, R5, R6	0603	C25803	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2206010045_UNI-ROYAL-Uniroyal-Elec-0603WAF1003T5E_C25803.pdf
245K	R7	0603	C203447	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_BOURNS-CR0603-FX-2433ELF_C203447.pdf
100n	C1, C5	0603	C14663	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2211101700_YAGEO-CC0603KRX7R9BB104_C14663.pdf
1u	C3	0603	C15849	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_Samsung-Electro-Mechanics-CL10A105KB8NNNC_C15849.pdf
2.2uF	C2	0603	C23630	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_Samsung-Electro-Mechanics-CL10A225KO8NNNC_C23630.pdf
LM311	U2, U6, U9	SOIC-8_3.9x4.9mm_P1.27mm	C12597	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/1809172023_Texas-Instruments-LM311DR_C12597.pdf
TLV9301xDBV	U1, U10, U11, U5, U7	SOT-23-5	C2867945	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2303010500_Texas-Instruments-TLV9301IDBVR_C2867945.pdf
BU4S71G2-TR	U3	SOT95P280X125-5N	C2837802	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2109290030_ROHM-Semicon-BU4S71G2-TR_C2837802.pdf
BU4S81G2-TR	U4, U8	SOT95P280X125-5N	C509846	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2109182030_ROHM-Semicon-BU4S81G2-TR_C509846.pdf
MAX6035xxUR50	U14	SOT-23	C967081	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2310091226_Analog-Devices-Inc--Maxim-Integrated-MAX6035BAUR50-T_C967081.pdf

HFR BREAKOUT BOARD

DESIGN REPORT



Abstract

The hard fault reset (HFR) is a system that uses inputs from the Precharge, Discharge, BMS, IMD, and BSPD.

The system can be split into 3 parts:

1. The "Interface" system that uses the inputs from the Precharge, Discharge, BMS, IMD, and BSPD, and if any of the signals go low, the output gets disconnected,
2. The "Latching" system that uses the output from the "Interface" system and delays the shutdown opening for 500ms, once it has opened, it will need to be reset to start again, and,
3. The "Starter" system that will turn the "Latching" system on initially and can also contain a mechanism to reset the system if a fault occurs.

This report details the design of the HFR "Breakout" PCB that contains this whole system.

Previous iterations of the system utilised a variety of components for the BSPD that was located on the central electrical node (CEN). This board contained other systems such as BSPD, TSAL and Discharge.

A breakout board approach was considered to reduce complexity on the motherboard, and ease implementation across multiple future generations of cars.

Due to the complexity of the circuit, it was decided a breakout board approach would be the standard design for the HFR. This method allows iterations of the motherboard to be created while having a system that is known to be good, moving the complexity away from the motherboard.

The completed HFR Breakout PCB board has now been commissioned, and found to be robust, easy to test, and easy to manufacture with PCB-A.

Introduction

The hard fault reset (HFR) is a system, that is necessary to cause the shutdown system to open the shutdown circuit in case of a hard fault. These faults include:

- A BMS fault,
- A IMD fault,
- A BSPD fault,
- A PRECHARGE fault, and
- A DISCHARGE fault.

When one of these faults occurs, a 500ms delay is to occur before the shutdown circuit opens. If the signal goes good after a fault, the shutdown circuit should stay open, until the car is power cycled, or a button is pressed to reset the circuit.

A typical implementation of the discharge is composed of 3 parts:

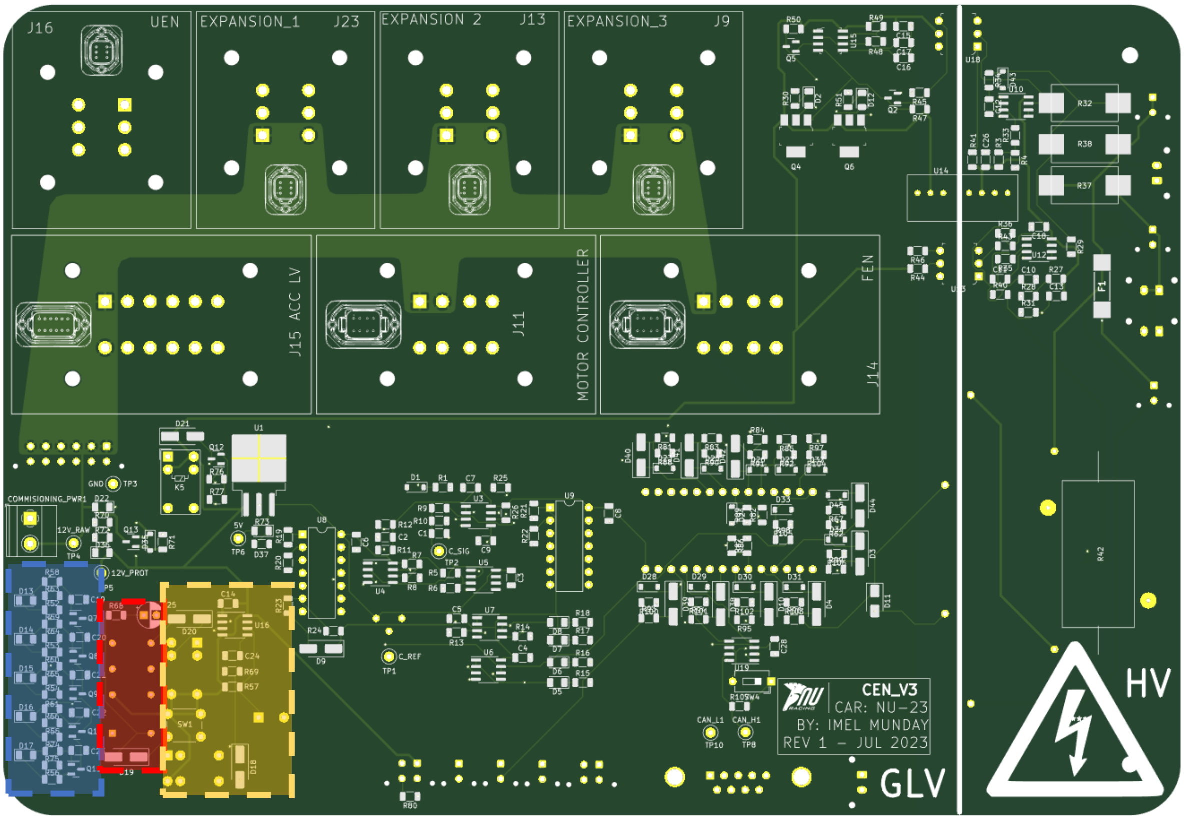
1. A "Interface" system that takes the faults and will allow the system to turn on,
2. A "Latching" system, that takes uses the "Interface" to switch the shutdown on and off, and
3. A "Starter" system, that will initially make the system HIGH.

Past NU Racing HFR Circuit, utilise:

- A MOSFET driven by the fault signals,
- A Latching Relay using a capacitor to allow the 500ms delay,
- A 555 timer to start the system as healthy.

For 2022 and 2023, the HFR system was on a PCB that had multiple functions including, BSPD, Discharge and TSAL, this system was complicated, involving complex schematics and PCB design with specialised parts. This caused:

1. Complex boards that are difficult to understand and design,
2. Increase Complexity in schematics,
3. Large PCBs design,
4. Increase complexity while troubleshooting.



Interface System   Latching System   Starter System

Figure 33 NU23 CEN (HFR Labelled)

To simplify this system, it was decided to create a breakout board for the HFR. This included removing all the HFR functionality from a master board, and creating a teensy like board, that has the functionality of the HFR and attaches to the master board through header pins. This allows the complexity to be removed from the master board.

Proposed benefits of this solution include:

1. Reduced complexity of the master board,
2. Reduced knowledge requirement to implement the HFR,
3. Provide a known good, ready to use board that can be implemented,
4. Maintenace of flexibly for topological changes and/or motherboard geometry without remaking HFR circuitry.

This circuity had to be designed to a specification to:

1. Allow for easy unit testing,
2. Be robust,
3. Utilise as many standard/stocked components as possible,
4. Manufactured utilising PCB-A,
5. Rules Compliant,
6. Useable for multiple years, and,
7. Minimal footprint to enable flexibility in motherboard geometry.

Rules

For the FSAE-A competition, rules are required to be followed to ensure safety. The HFR has certain rule requirements it needs to follow. These include the ones below.

Rule	
EV.5.9.1 The vehicle must include a Tractive Systems Active Light (TSAL) that must: a. Illuminate when the GLV System is energized to indicate the status of the Tractive System b. Be directly controlled by the voltage present in the Tractive System using hard wired electronics. Software control is not permitted. c. Not perform any other functions.	
EV.6.6.1 All electrical systems (both Low Voltage and High Voltage) must have appropriate Overcurrent Protection/Fusing.	
EV.6.6.2 Unless otherwise allowed in the Rules, all Overcurrent Protection devices must: a. Be rated for the highest voltage in the systems they protect. Overcurrent Protection devices used for DC must be rated for DC and must carry a DC rating equal to or more than the system voltage b. Have a continuous current rating less than or equal to the continuous current rating of any electrical component that it protects c. Have an interrupt current rating higher than the theoretical short circuit current of the system that it protects	
EV.7.1.1 The Shutdown Circuit consists of the following components, connected in series: a. Accumulator Management System (AMS) EV.7.3 b. Insulation Monitoring Device (IMD) EV.7.6 c. Brake System Plausibility Device (BSPD) EV.7.7 d. Interlocks (as required) EV.7.8 e. Master Switches (GLVMS, TSMS) EV.7.9 f. Shutdown Buttons EV.7.10 g. Brake Over Travel Switch (BOTS) T.3.3 h. Inertia Switch T.9.4	
EV.7.1.3 The AMS, IMD, and BSPD parts of the Shutdown Circuit must be Normally Open	
EV.7.1.4 The AMS, IMD and BSPD must have completely independent circuits to Open the Shutdown Circuit. The design of the respective circuits must ensure that a failure cannot result in electrical power being fed back into the Shutdown Circuit.	
EV.7.2.3 When the AMS, IMD or BSPD Open the Shutdown Circuit: a. The Tractive System must stay disabled until manually reset b. The Tractive System must be reset only by manual action of a person directly at the vehicle c. The driver must not be able to reactivate the Tractive System from inside the vehicle d. Operation of the Shutdown Buttons or TSMS must not reset the Shutdown Circuit	

Topology Implementation

The HFR breakout board will live as a daughter board on the CEN. This board uses the signals from the Precharge, AMS, IMD, BSPD, and Discharge. This board will also have the shutdown circuit running through it.

Figure 34 HFR NU24 Layout

Topology/Schematic

The design of the HFR is composed of three parts:

1. The “Interface” module that takes the OKHS, and will output a grounded output when all the signals are good, or an OPEN signal when one or more is bad,
2. The “Latching” module that uses this grounded system and when activated will keep the shutdown good until a OKHS goes bad, and,
3. The “Starter” module that starts the system in a good state.

Figure 35 HFR Schematic

Interface

The HFR takes the OKHS and uses an amplifier op-amp, to isolate the signal and driver circuit.

This output is then put into a n channel MOSFET. This will allow the output to be grounded when the system is good.

The outputs for this system is:

- If all OKHS are HIGH, the output will be GROUNDED,
- If any OKHS are LOW, the output will be OPEN.

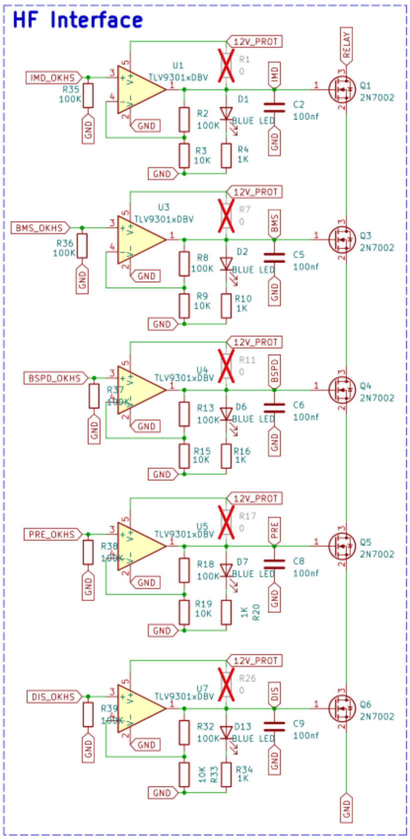


Figure 36 HFR Interface Schematic

Latching

The HFR Latching circuit uses a 2 channel normally open relay, and when the system is started, the relay closes and locks closed, until the Interface disconnects the ground.

This then charges a capacitor, creating a 500ms delay before the system will open.

This circuit also has a LED for on-board visual functionality.

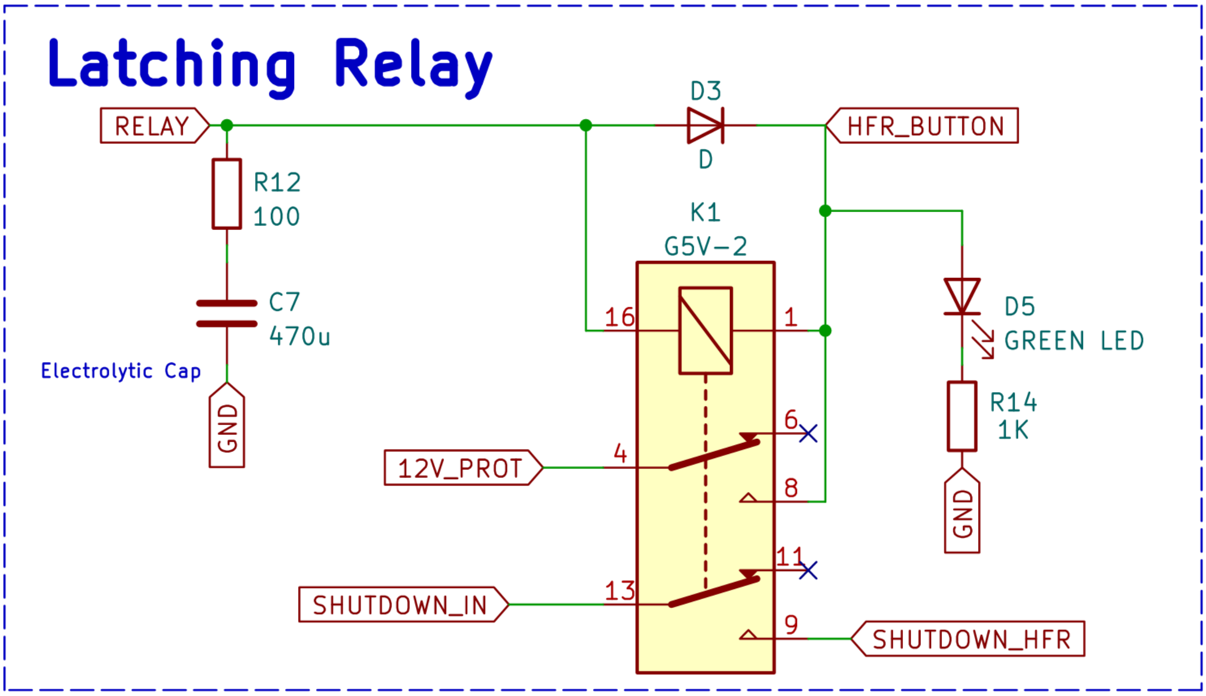


Figure 37 HFR Latching Schematic

Starter

The starter circuit is used to initialise the system and attempt to open the latching relay.

This system uses a 555 timer, set up in a similar method to the astable operation, but removing the connection to the discharge. This will cause the 555 timer to trigger for the initial time period and then go LOW. The output of the 555 timer is also pulled low to ensure the system is normally LOW.

There is also a button that can allow the system to be reset in case of a fault.

A LT Spice sim is created to show this operating.

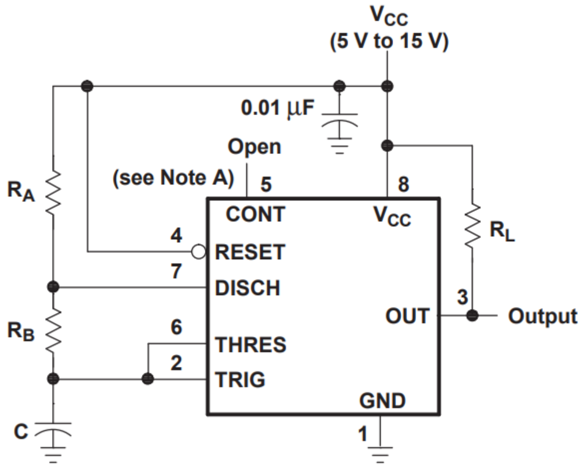


Figure 38 a) 555 Timer Astable Setup b) 555 Timer Modified

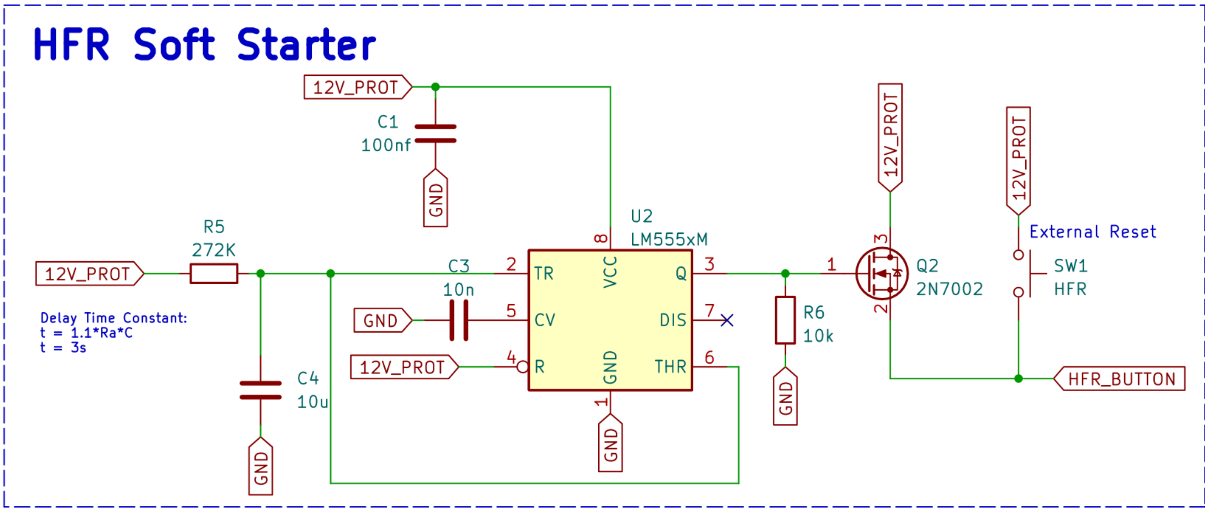


Figure 39 HFR Starter Schematic

Figure 40 HFR Starter LT Spice

Figure 41 HFR Starter LT Spice Output

Implementation/Layout

The choice of components was based on available of components and cost. This was also influenced by factors such as:

- Wanting components being commonly used within NU Teams (this includes the n-channel MOSFET, the schottky diode and the fuse holder),
- Wanting single channel components over multi-channel, and,
- Choosing components based on size.

With these factors, the following components were the ones chosen.

Component Selection

Op-amp (TLV9301IDBVR)

The op-amp chosen was the TLV9301IDBVR. This was chosen due to it being a readily available part from mouser, the choice not to use the op-amp that was originally on the CEN was due to it being a quad channel op-amp. Due to the size constraint and trying to make the schematics and PCB easier to read, it was chosen to use a single channel op-amp. This op-amp is capable of an input voltage up to 42V and can output a max current of 10mA.

555 Timer (SE555)

The 555-timer chosen was the SE555. This was chosen as there is no difference between the NE, NA, SA, or SE other than temperature ratings. It was therefore chosen due to availability and cost.

N-Channel Enhancement MOSFET (2N7002)

The n-channel enhancement MOSFET chosen was the 2N7002. This component has max current of 115mA, which is enough for the relay.

Schottky Diode, Fuse Holder and 3V3 Zener Diode (SS34, 0154001.DRT, and BZT52C3V3)

The components for the schottky diode, fuse holder and 3V3 zener diode are SS34, 0154001.DRT, and BZT52C3V3). These components were all chosen for the standard footprints utilised within the team, the 3V3 Zener diode is not the same part as the one used in the team due to part availability, this doesn't matter though as it has the same performance and specifications.

Relay (G5V-2-DC12)

The Relay chosen was the G5V-2. This relay was chosen as it was the one that has been commonly utilised for this function. This relay also has a coil current of 41.7mA at 12V, and a switching current of 2A. The other benefit of this relay is the small form factor.

Resistor, Capacitors and LED

The choice for resistors, LED and capacitors was done for size constraints, voltage ratings and power rating. Most of the resistors on the board are 0603 except for the voltage divider for the HV. This was due to the voltage ratings of the Resistors with 1206 being rated for 200V, whereas 0603 is only good for 50V. The only resistor that was slightly different was the 0603 LED resistors. This is due to the power requirement for the resistor with most 0603 being rated for 100mW, but the resistors will be dissipating a power of 180mW. Therefore, the resistors are rated for 250mW.

All the capacitors are 0603, except for the latching relay capacitor due to it needing to have such a large capacitance to hold the relay open. It was therefore decided to use a through hole, cylindrical capacitor.

All the LEDs are 0603, with the only difference being colour.

The downside of 0603 is that components are more difficult to solder than 1206. This was justified as packaging was more important and the components will be soldered on with JLCPCB

Layout

The layout for the PCB was to make the PCBs as small as possible and allow manufacturing using JLCPCB. This meant all SMD components needed to be placed on one side. The other reason for this is how the board will be mounted to the main board.

Board Size

For simplicity it was decided to make boards to 5mm increments. Therefore, a logical layout, trying to fit as many components as close together was done to allow the minimum board size to be achieved.

Figure 42 HFR Board Size

Header Pins

The header pins for the board, it was decided to utilise a teensy like mounting using the same header pins, using friction fit, it was decided to use 15 long header pins 2mm off either side of the board. With the input connections on one side of the board and the outputs on the other.

Logical Layout

Due to the size of the board, it was required to have a logical layout of components to ensure tracing was possible.

Footprint/Pinout

Due to these boards being place onto a master board, it was necessary to create a footprint for the component and ensure the pinout for the component is known.

Pin	Name
1	12V
2	GND
3	DISCHARGE_OKHS
4	PRECHARGE_OKHS
5	BSPD_OKHS
6	BMS_OKHS
7	IMD_OKHS
8	SHUTDOWN_IN
9	HFR_EXTERNAL_BUTTON_INPUT
10	SHUTDOWN_HFR
11	IMD_TEENSY
12	BMS_TEENSY
13	BSPD_TEENSY
14	PRECHARGE_TEENSY
15	DISCHARGE_TEENSY

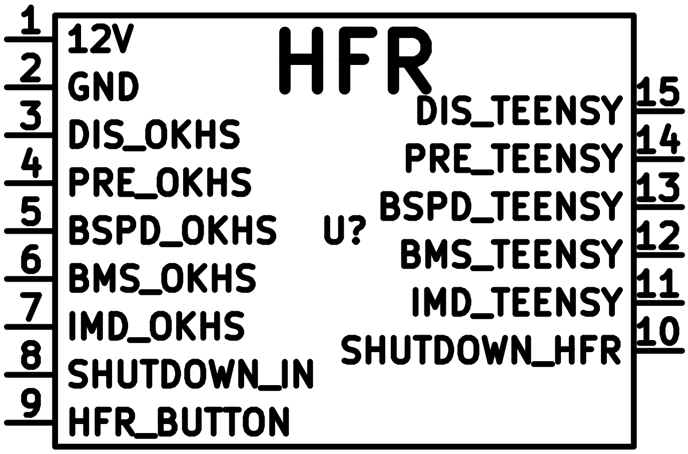


Figure 43 HFR Symbol

Figure 44 HFR Footprint

Commissioning and Unit Tests

Utilising JLC to create the boards, most of the components could be assembled by JLC, the components that were not soldered onto the board was the relay, the capacitor, and the header pins due to them being through hole components.

Test Type	Test	What should happen	Did it?
Visual Inspection	Inspect all pre-solder components, ensure soldering is adequate and components are correct. Ensure there is no shorts or excess solder	All components are correct	
Setup	Solder on Header pins		
LV Power	Connect 12V to the LV side	All LEDs stay OFF	
LV Power	Connect 12V to DISCHARGE_OKHS	DISCHARGE_OKHS LED turns ON	
LV Power	Connect 12V to PRECHARGE_OKHS	PRECHARGE_OKHS LED turns ON	
LV Power	Connect 12V to BSPD_OKHS	BSPD_OKHS LED turns ON	
LV Power	Connect 12V to BMS_OKHS	BMS_OKHS turns ON	
LV Power	Connect 12V to IMD_OKHS	IMD_OKHS turns ON	
Setup	Solder on Relay		
LV Power	Connect 12V to DISCHARGE_OKHS, PRECHARGE_OKHS, BSPD_OKHS, BMS_OKHS, and IMD_OKHS	HFR_OKHS turns ON	
LV Power	Disconnect the DISCHARGE_OKHS	HFR_OKHS turns OFF	
LV Power	Reconnect DICHARGE_OKHS, reset the circuit, disconnect PRECHARGE_OKHS	HFR_OKHS turns OFF when PRECHARGE_OKHS disconnects	
LV Power	Reconnect PRECHARGE_OKHS, reset the circuit, disconnect BSPD_OKHS	HFR_OKHS turns OFF when BSPD_OKHS disconnects	
LV Power	Reconnect BSPD_OKHS, reset the circuit, disconnect BMS_OKHS	HFR_OKHS turns OFF when BMS_OKHS disconnects	
LV Power	Reconnect BMS_OKHS, reset the circuit, disconnect IMD_OKHS	HFR_OKHS turns OFF when IMD_OKHS disconnects	
LV Power	Reconnect IMD_OKHS, turn OKHS voltages down to 0V	LEDs starts dimming at 1.2V and turns off at 0V.	
Setup	Solder on Capacitor		
LV Power	Turn OKHS voltages up to 12V, disconnect DISCHARGE_OKHS	HFR_OKHS LED starts dimming after 500ms.	

Prototype Commissioning

During commissioning, no issues seemed to occur, the board worked as expected. A few changes were necessary after the first revision. This includes:

- Adding a LED to the Relay to allow a visual indicator for when the relay was on. An unintended side effect was made though, where the resistor gets dimmer as the capacitor discharges.
- Added back PRECHARGE_OKHS and DISCHARGE_OKHS after it was determined with the discharge breakout it wouldn't be feasible to remove PDOC.
- Larger resistor size and smaller capacitor size for the 555-timer circuit to allow the system to be 0603.
- Adding pulldown resistors onto the interface circuits was necessary as it was noticed when the system was disconnected the system would be good and output HIGH from the op-amps.

Conclusion

The HFR is a component on the car that is necessary to ensure hard faults open the shutdown circuit and cannot be reset unless a button is pressed.

The circuit is done in three parts, having an interface system that's takes the inputs from the Precharge, BMS, IMD, BSPD and Discharge, and puts them through an op-amp to isolate the signal to power a MOSFET. This MOSFET grounds a relay that will latch closed when the system is good, and either the starter circuit starts the system, or a button is pressed to reset.

For this board, it needed to be designed in a certain way will a few objectives. These include making the system:

- Robust,
- Rules compliant,
- Utilise as many standard components as possible, and,
- Usable for many years

Through making these breakout boards, it made these systems:

- Decrease the complexity of the mother board it will be attached to,
- Allow easier unit testing,
- Able to be made using PCB-A,
- Allow a standard schematic for these systems.

Future Work

There are multiple changes that could be made to the circuit to reduce components or simplify complexity. These include:

Make All Components Solid State

A good change to make would be to make the whole board solid state. This could be done with a MOSFET for shutdown control, and an op-amp circuit, that will compare a value, if shutdown go bad, a capacitor will discharge until the circuit goes below a value then turn off, otherwise it will stay on, a button or timer could be used to turn the system on.

Op-amp for HFR LED

Utilising a comparator op-amp on this led will make the LED turn off instantly when the system goes bad, this will allow a better indicator for when this system goes bad.

Resistor/Capacitor Sizes

To make the board even smaller it could be possible to use 0402 resistors for some of them. The thing to think about would be wattage the resistors are dissipating.

Change OKHS Op Amps to Comparator Circuit Instead of Amplifier

This could be done, allowing the removal of multiple resistors, removing 8 resistors.

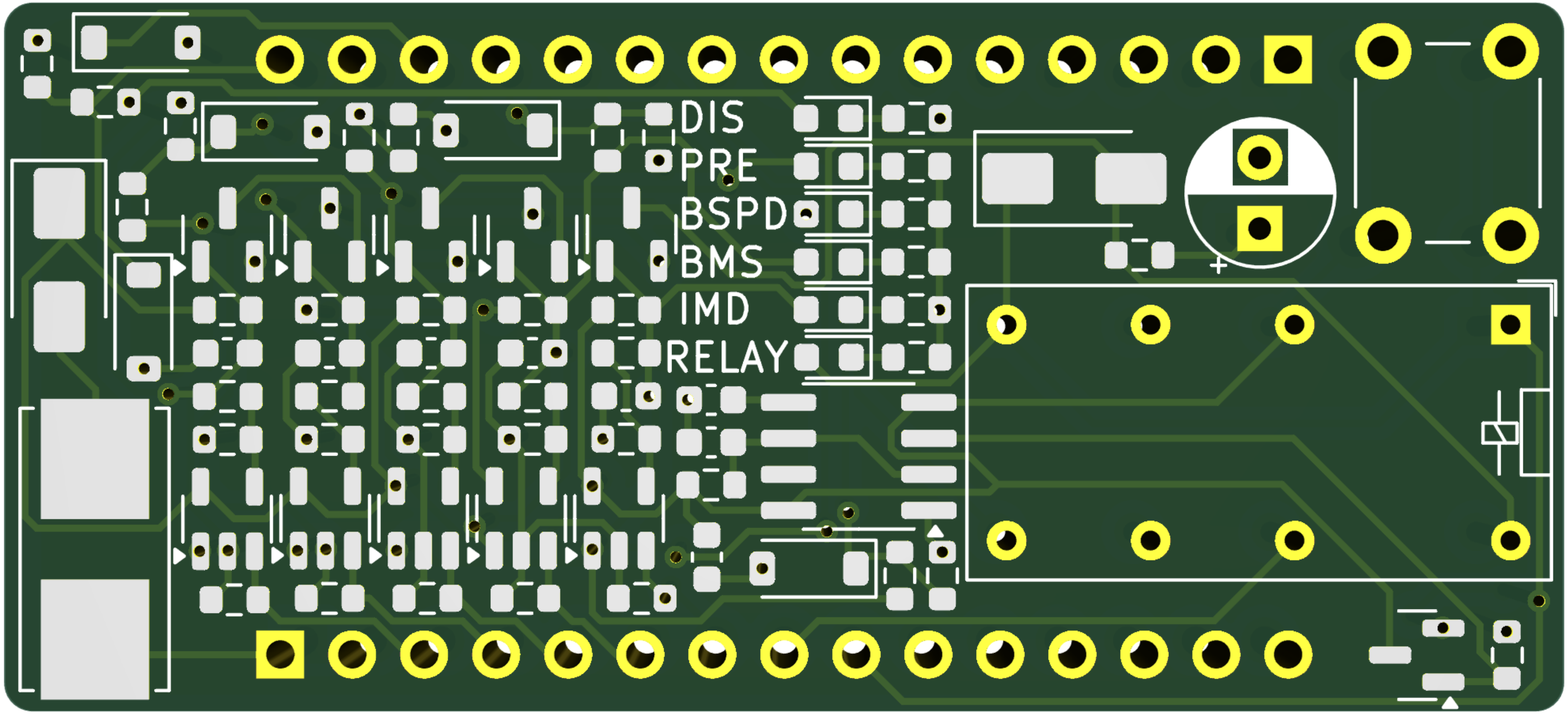
Larger pulldown Resistor Values

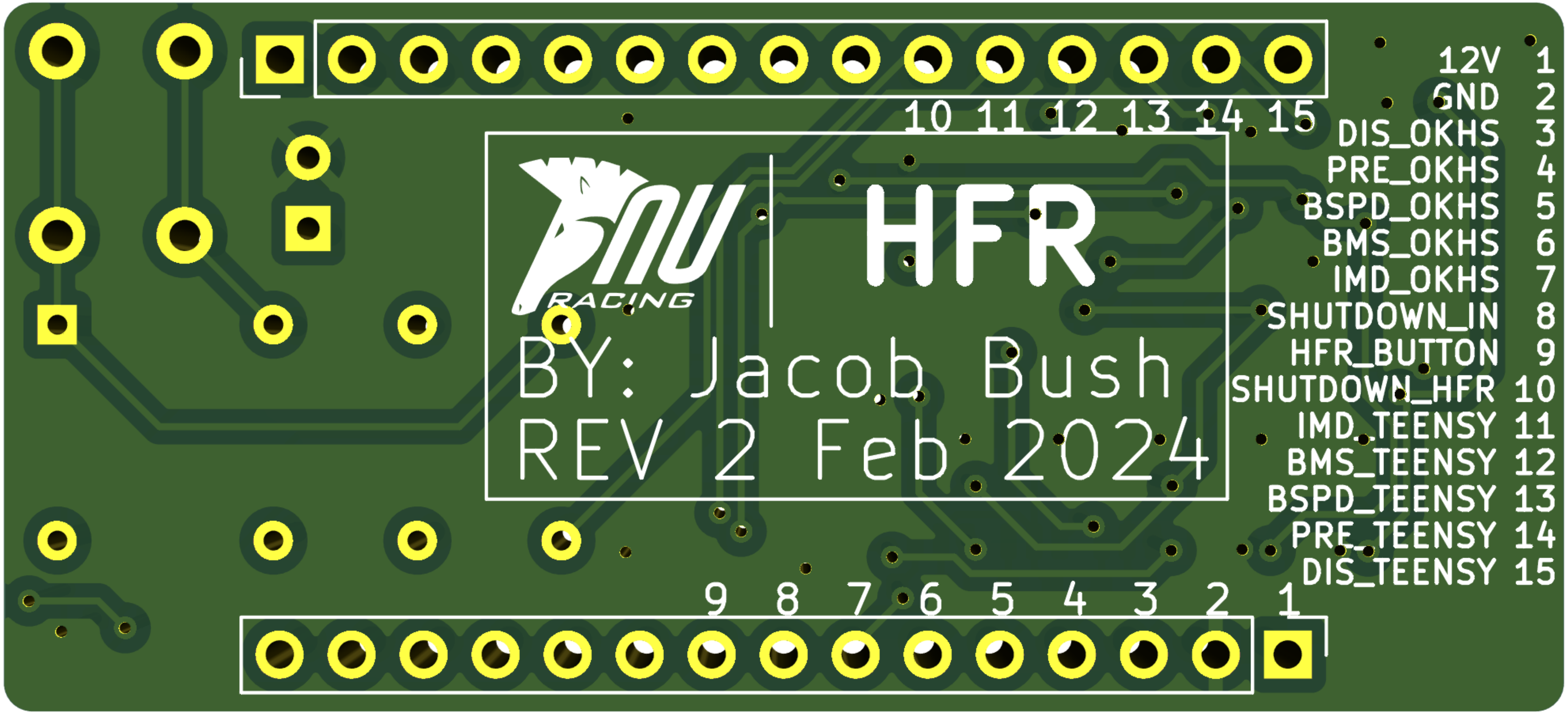
Making the pulldown resistor values larger would reduce current drawer when the circuit is operating. I would be worth testing to ensure no unstable operations occur. This could be as simple as changing the values from 10k to 100k.

Appendix

Schematic

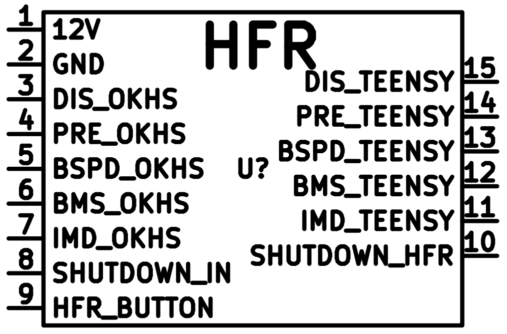
PCB


DIS
PRE
BSPD
BMS
IMD
RELAY



10 11 12 13 14 15
HFR
BY: Jacob Bush
REV 2 Feb 2024
9 8 7 6 5 4 3 2 1
12V 1
GND 2
DIS_OKHS 3
PRE_OKHS 4
BSPD_OKHS 5
BMS_OKHS 6
IMD_OKHS 7
SHUTDOWN_IN 8
HFR_BUTTON 9
SHUTDOWN_HFR 10
IMD_TEENSY 11
BMS_TEENSY 12
BSPD_TEENSY 13
PRE_TEENSY 14
DIS_TEENSY 15

Symbol



Footprint

Pinout

Pin	Name
1	12V
2	GND
3	DISCHARGE_OKHS
4	PRECHARGE_OKHS
5	BSPD_OKHS
6	BMS_OKHS
7	IMD_OKHS
8	SHUTDOWN_IN
9	HFR_EXTERNAL_BUTTON_INPUT
10	SHUTDOWN_HFR
11	IMD_TEENSY
12	BMS_TEENSY
13	BSPD_TEENSY
14	PRECHARGE_TEENSY
15	DISCHARGE_TEENSY

BOM

Comment	Designator	Footprint	JLCPCB #	Datasheet
3V3 Zener	D10, D11, D12, D8, D9	D_SOD-123	C173413	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2308231017_MDD-Microdiode-Electronics--BZT52C3V3_C173413.pdf
10n	C3	0603	C57112	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_FH--Guangdong-Fenghua-Advanced-Tech-0603B103K500NT_C57112.pdf
Schottky	D3, D4	D_SMA	C2909963	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2110280930_YONGYUTAI-SS34_C2909963.pdf
Fuse	F1	Fuseholder_Littelfuse_Nano2_154x	C206909	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_Littelfuse-0154001-DRT_C206909.pdf
272K	R5	0603	C5126128	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2308241947_FOJAN-FRC0603F2743TS_C5126128.pdf
10u	C4	0603	C96446	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_Samsung-Electro-Mechanics-CL10A106MA8NRNC_C96446.pdf
BLUE LED	D1, D13, D2, D6, D7	0603	C2288	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/1810220913_Hubei-KENTO-Elec-KT-0603B_C2288.pdf
TLV9301xDBV	U1, U3, U4, U5, U7	SOT-23-5	C2867945	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2303010500_Texas-Instruments-TLV9301IDBVR_C2867945.pdf
1K	R10, R14, R16, R20, R34, R4	0603	C2653986	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_ROHM-Semicon-ESR03EZPF1001_C2653986.pdf
100	R12	0603	C22775	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2206010130_UNI-ROYAL-Uniroyal-Elec-0603WAF1000T5E_C22775.pdf
GREEN LED	D5	0603	C12624	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/1806151818_Hubei-KENTO-Elec-KT-0603G_C12624.pdf
100nF	C1, C2, C5, C6, C8, C9	0603	C14663	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2211101700_YAGEO-CC0603KRX7R9BB104_C14663.pdf
SE555	U2	SOIC-8_3.9x4.9mm_P1.27mm	C967980	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2302221730_Texas-Instruments-SE555DR_C967980.pdf
3.3k	R27, R28, R29, R30, R31	0603	C22978	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2206010116_UNI-ROYAL-Uniroyal-Elec-0603WAF3301T5E_C22978.pdf
10K	R15, R19, R21, R22, R23, R24, R25, R3, R33, R6, R9	0603	C25804	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2206010045_UNI-ROYAL-Uniroyal-Elec-0603WAF1002T5E_C25804.pdf
2N7002	Q1, Q2, Q3, Q4, Q5, Q6	SOT-23	C8545	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_Jiangsu-Changjing-Electronics-Technology-Co---Ltd--2N7002_C8545.pdf
100K	R13, R18, R2, R32, R35, R36, R37, R38, R39, R8	0603	C25803	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2206010045_UNI-ROYAL-Uniroyal-Elec-0603WAF1003T5E_C25803.pdf
470u	C7	CP_Radial_D5.0mm_P.2.5mm	C1020067	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2304140030_KEMET-A750EQ477M1CAAE015_C1020067.pdf
G5V-2	K1	Relay_DPDT_Omron_G5V-2	C28089	https://wmsc.lcsc.com/wmsc/upload/file/pdf/v2/lcsc/2211282300_Omron-Electronics-G5V-2-DC12_C28089.pdf
6mm Push	SW1	SW_PUSH_6mm	C4364281	https://jlcpcb.com/parts/componentSearch?searchTxt=C173413