Formula SAE
Electrical System Form Template for Electric Vehicles

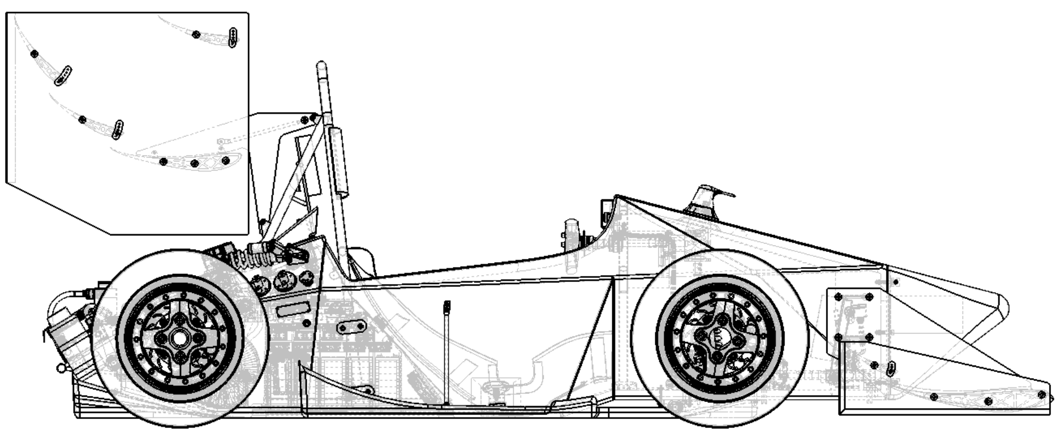
1.1 Electrical System Form FSAE-E 2019

Western University

Western Formula Racing

FSAE North Car Number: 238

FSAE Electric Car Number: E229



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Abbreviations

AIR – Accumulator Insulation Relay
AMS- Accumulator Monitoring System
BMS- Battery Monitoring System
BOTS – Brake-Over-Travel-Switch
BSPD – Brake System Plausibility Device
GLV – Grounded Low Voltage
GLVMP – Ground Low Voltage Measurement Point
HV – High Voltage
IMD – Insulation Monitoring Device
TS – Tractive System
TSAL – Tractive System Active Light
TSMP – Tractive System Measurement Point
HVIB – High Voltage Interlock Board

2 System Overview

The vehicle has a single EMRAX 228 MV LC motor driving the rear axle via a differential and a step-down gearbox. The motor is powered by a Rinehart PM100DXR inverter running on a 400VDC bus. The inverter is acting as a CAN-bus slave to a Motec M150 ECU. The M150 is running on custom firmware developed by the team and handles all non-hardware safety functions as well as torque commands and data logging. All low voltage components on the vehicle run on either 12VDC or 5VDC.

Maximum Tractive System Voltage:	399VDC
Nominal Tractive System Voltage:	342VDC
Grounded Low Voltage System Voltage:	5VDC, 12VDC
Number of Accumulator Containers:	1
Total Accumulator Capacity:	7.182kWhr
Motor Type:	Synchronous Permanent Magnet, Axial Flux
Number of Motors:	1
Maximum Combined Motor Power:	100kW

Table 2-1 - High Level Specifications

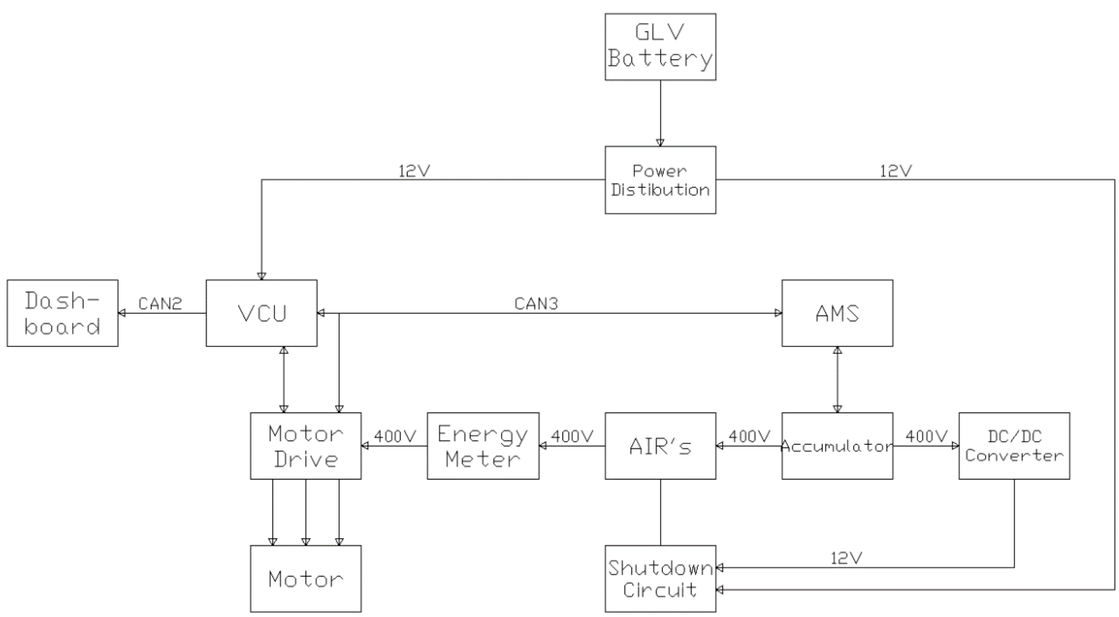
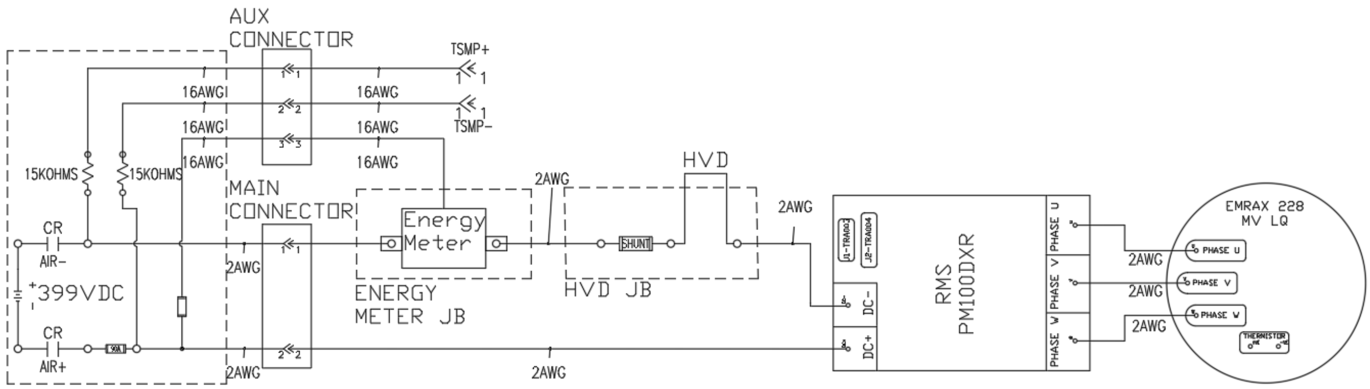


Figure 2-1 - System Block Diagram

3 Tractive System Schematics

3.1 Tractive System Schematic (Power Electronics ONLY)



Main HV cables have shields terminated at the main connector bulkhead & drive wire terminal

Figure 3-1 - HV System Schematic

3.2 Fusing Diagram

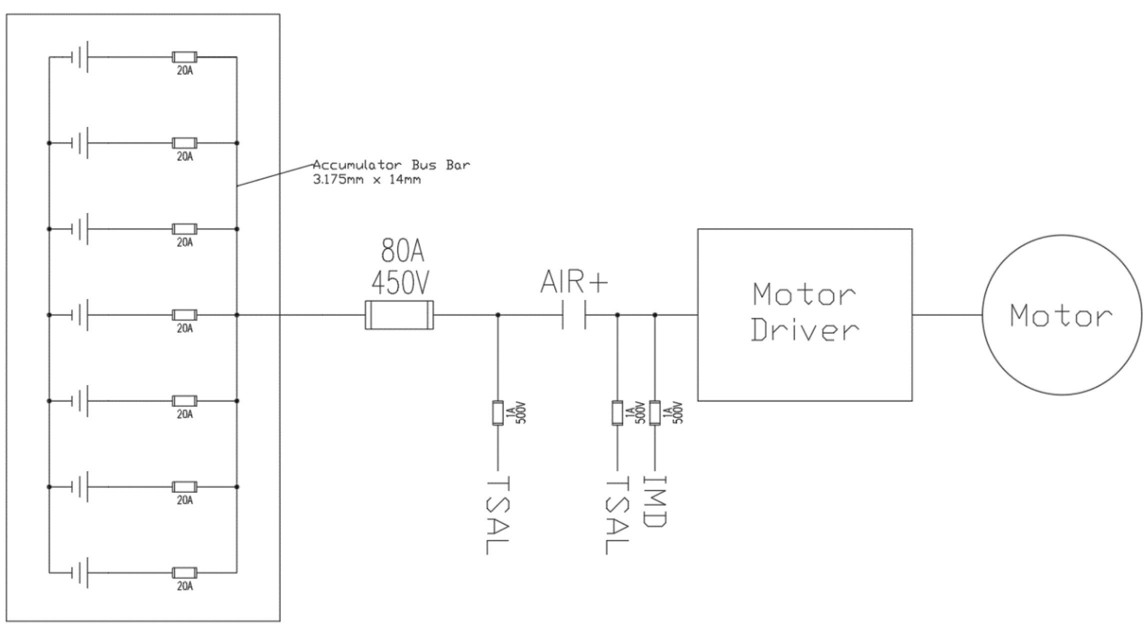


Table 3-1- Fuse Tree Diagram

3.2.1 Fuse Specifications

Fuse Location	Current Rating	Voltage Rating	Interrupt Rating	Datasheet
Main Path Fuse inside AIR + Container	80A	450 V	20KA	Link
Cell Fuses – Within Energus Modules	20A	N/A	N/A	See Section 5.2.4
TSAL Sense Line HVIB	1A	500 V	1.5KA	Link
TSAL Sense Line HVIB	1A	500 V	1.5KA	Link
IMD Sense Line HVIB	1A	500 V	1.5KA	Link

Table 3-2 - Fuse Specifications

3.2.2 Conductor Specifications

Conductor Location	Size	Voltage Rating	Ampacity	Rating of fuse providing protection	Temperature Rating	Datasheet
Cell Busbars	44.45mm^2	NA	205A	20A	NA	Team Manufactured
Tractive System DC/Phase Wire	35mm^2	1000V	158A	90A	-45°C to 150°C	Datasheet
TSMP / HV Sense Wire	16AWG	600V	13A	No fuse on TSMP	-68C to 150C	Datasheet

Table 3-3 - Conductor Specifications

3.2.3 Connector Specifications

Connector Location	Ampacity	Voltage Rating	Includes Interlock	Accepted wire gauge	Wire gauge connected	Datasheet
Accumulator Main Receptacle	200A	850V	Yes	All	2 AWG	Link
Accumulator Main Plug	200A	850V	Yes	25-50 mm^2	35mm^2	Link
High Voltage Disconnect	630A	1KV	Yes	All	35mm^2	Link
Accumulator Aux Receptacle (TSMP & Energy Meter lines)	13A	600V	Yes	30-14 AWG	18 AWG	Link
Accumulator Aux Plug (TSMP & Energy Meter lines)	13A	600V	Yes	30-14 AWG	18 AWG	Link

Table 3-4- Connector Specifications

4 Shutdown Circuit

4.1 Shutdown Circuit Schematic

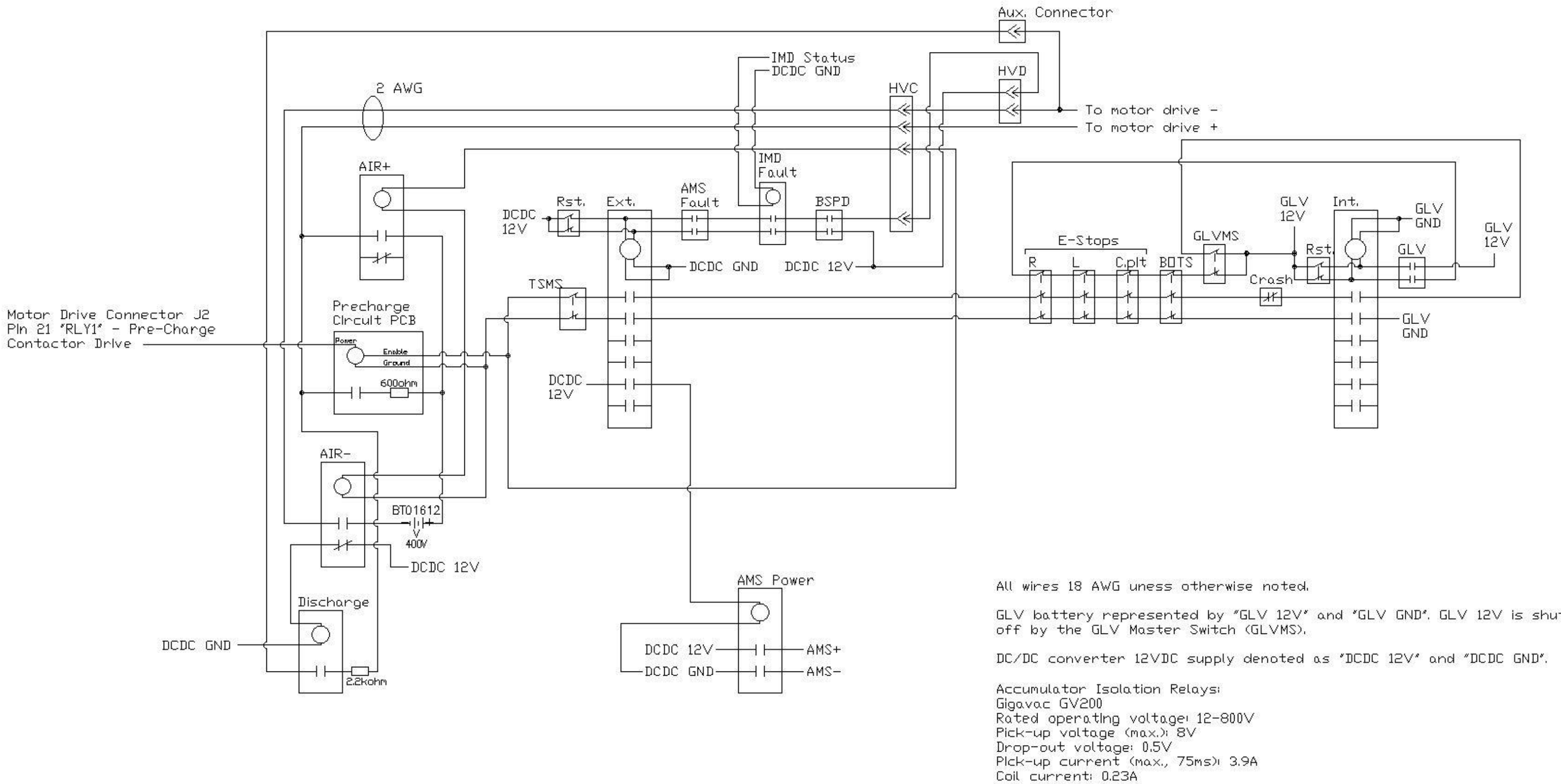


Figure 4-1 - Shutdown Circuit Schematic

4.1.1 Switch Locations

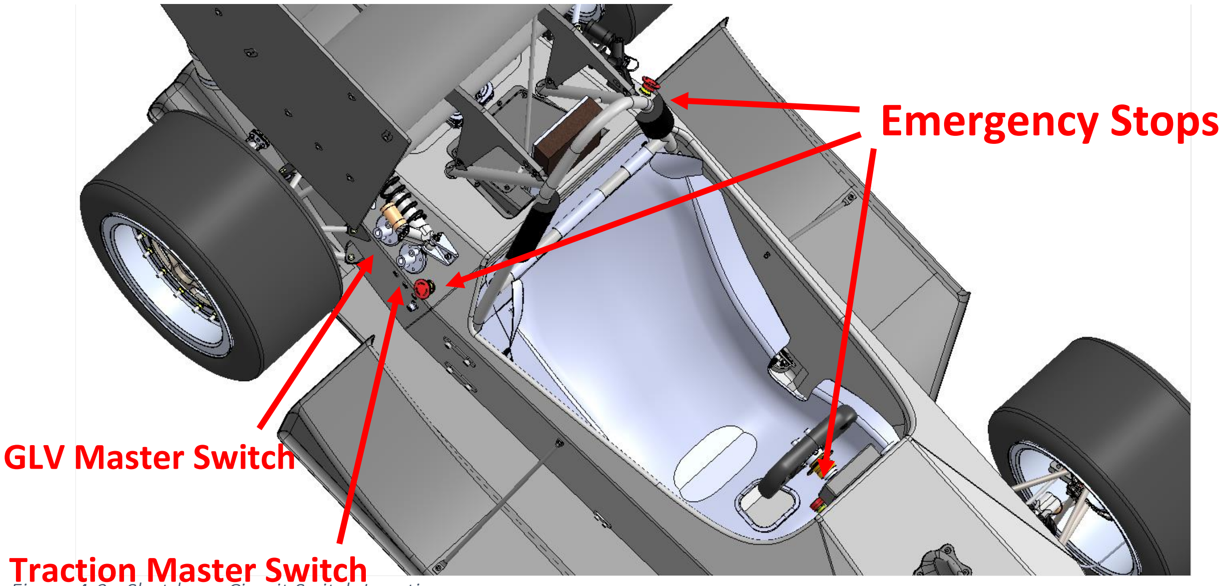


Figure 4-2 - Shutdown Circuit Switch Locations

4.2 Wiring

4.2.1 Shutdown Circuit Current

Total Number of AIRs:	2
Current per AIR:	0.23A (holding), 3.9A (inrush)
Additional parts consumption within the shutdown circuit:	0.17A (Discharge relay holding current)
Total current:	0.63A

Table 4-1 - Shutdown Circuit Loads

4.3 IMD

4.3.1 IMD Specifications

Make / Model	Bender IR155-3203
Supply voltage	12VDC
Environmental temperature range:	-40..+105°C
Self-test interval:	Every 5 minutes
High voltage range:	DC 0..1000V
Set response value:	200kΩ (500Ω/Volt)
Max. operation current:	150mA
Approximate time to shut down at 50% of the response value:	40s
Datasheet	Datasheet

Table 4-2 - IMD Specifications

4.3.2 IMD Fault Latching

Latching for all devices in the safety circuit is accomplished using a relay configuration with two channels. The relays used for each channel are interlocked with each other so that each will not turn on without the other being on as well. Once there is a fault (i.e. one or both channels goes low), neither relay will be able to turn on unless the reset button is pushed. The third relay that operates the six normally-open output contacts is powered through a contact on each of the channel relays. Thus, it will only close the contacts when there is power to both channel relays.

There are three such dual-channel relay configurations in the vehicle. These are shown in a simplified manner in the Shutdown System Schematic as “Ext.” (External), “Int.” (Internal), and “Mon.” (Monitor). The IMD is part of the circuit controlling the “Ext.” relay module.

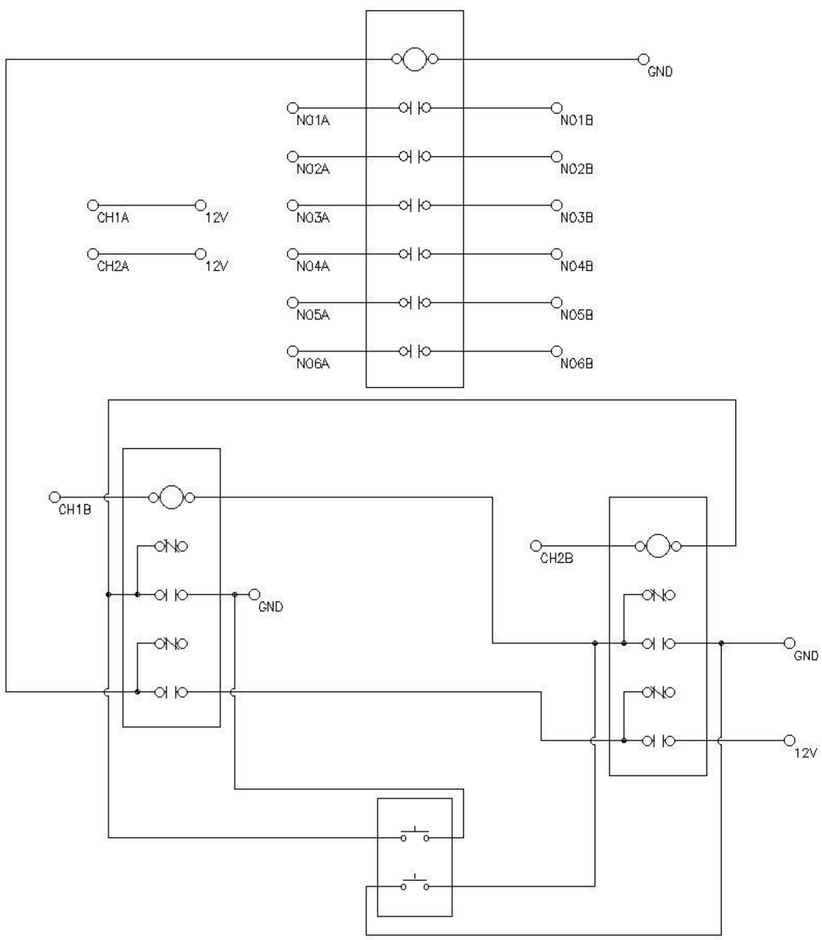


Figure 4-3 - IMD Latch Circuit Schematic

4.3.3 IMD Location

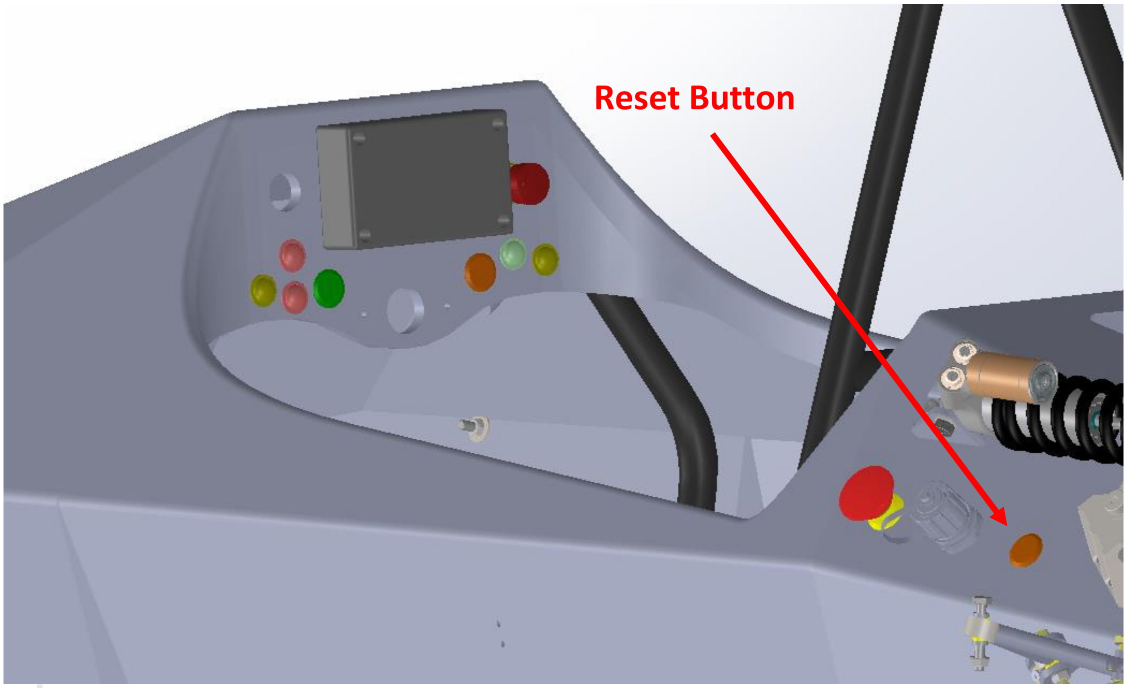


Figure 4-4 - IMD Reset Location

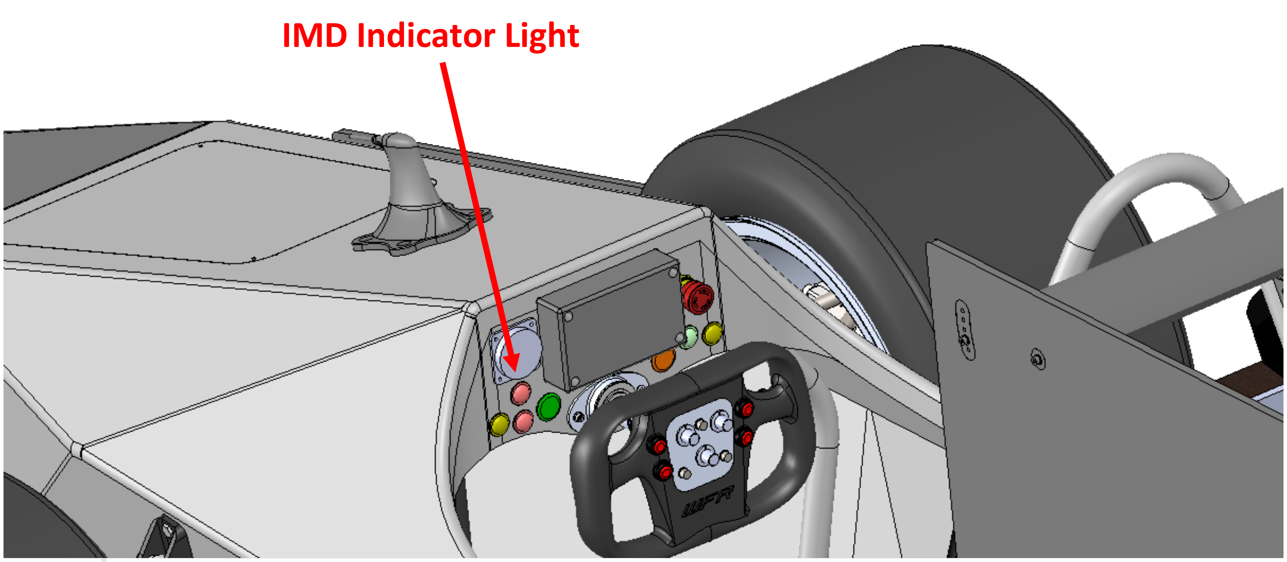


Figure 4-5 - IMD Indicator Light Position

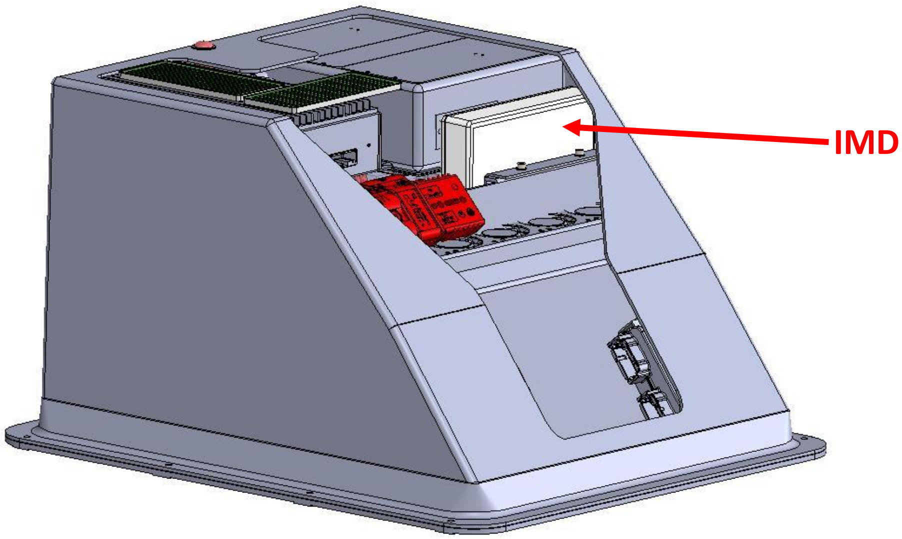


Figure 4-6 - IMD Location in Accumulator

4.3.4 IMD Demonstration

1. Power on tractive system using the Tractive System Master Switch
2. Connect one end of a 50kΩ resistor (50% of 250V/Ω as per rule IN.4.4.2) to the Tractive System Measuring Points and the other to various conductive points on the vehicle
3. Wait up to 30 seconds to observe the IMD shut down the tractive system

4.4 Brake System Plausibility Device

4.4.1 BSPD Current Sensor

Make / Model:	LEM / DHAB S/124
Current input range:	+/- 75A Ch1, +/- 500A Ch2
Output range:	0.25-4.75V
Datasheet:	Datasheet

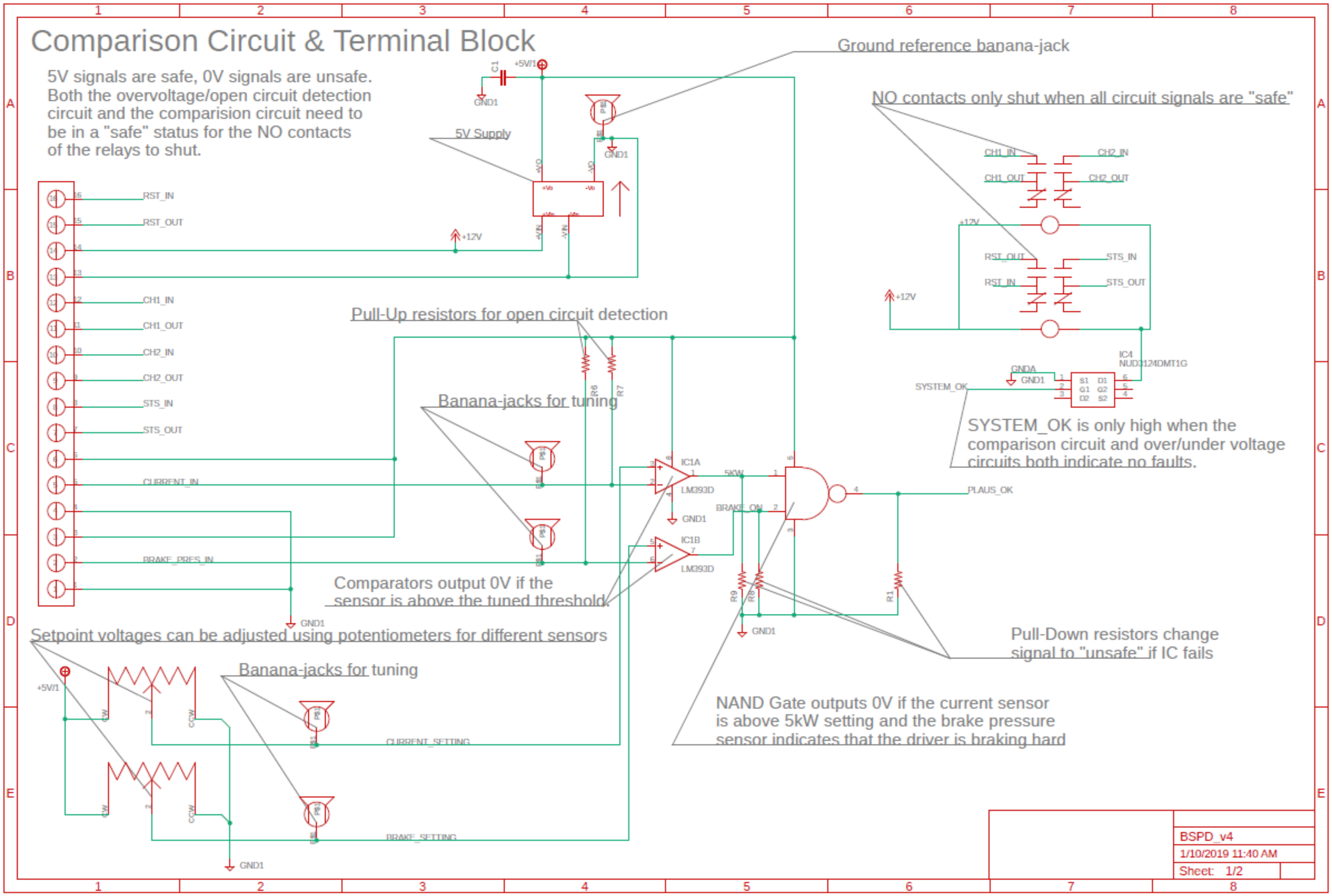
Table 4-3 - BSPD Current Sensor Specifications

4.4.2 BSPD Setpoint

Trip Current	12.5A
Current sensor output @Trip Current	2.83V
Delay time	4.05ms

Table 4-4 - BSPD Operation Details

4.4.3 BSPD Schematic



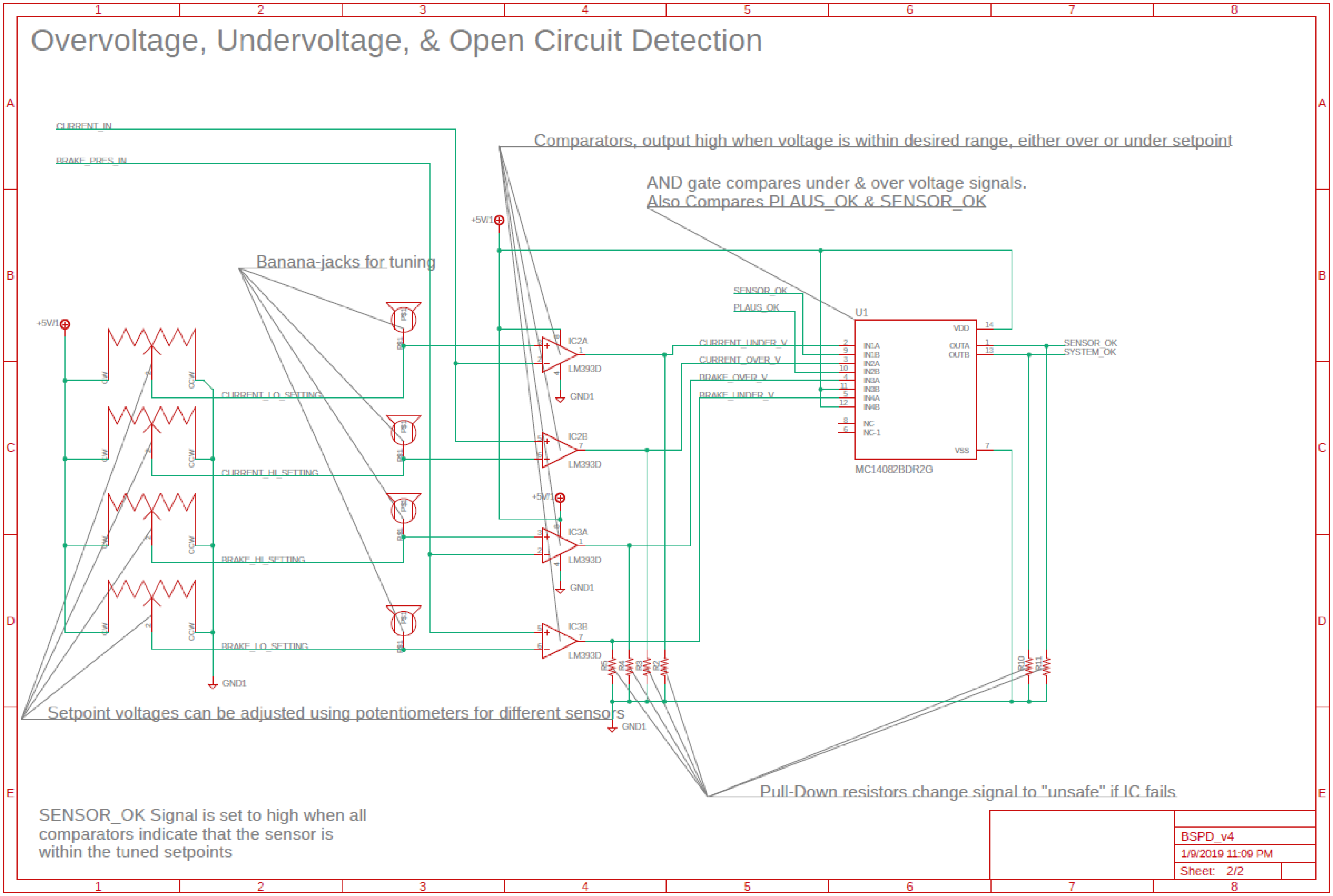


Figure 4-7 - BSPD Schematic

4.4.4 BSPD Location

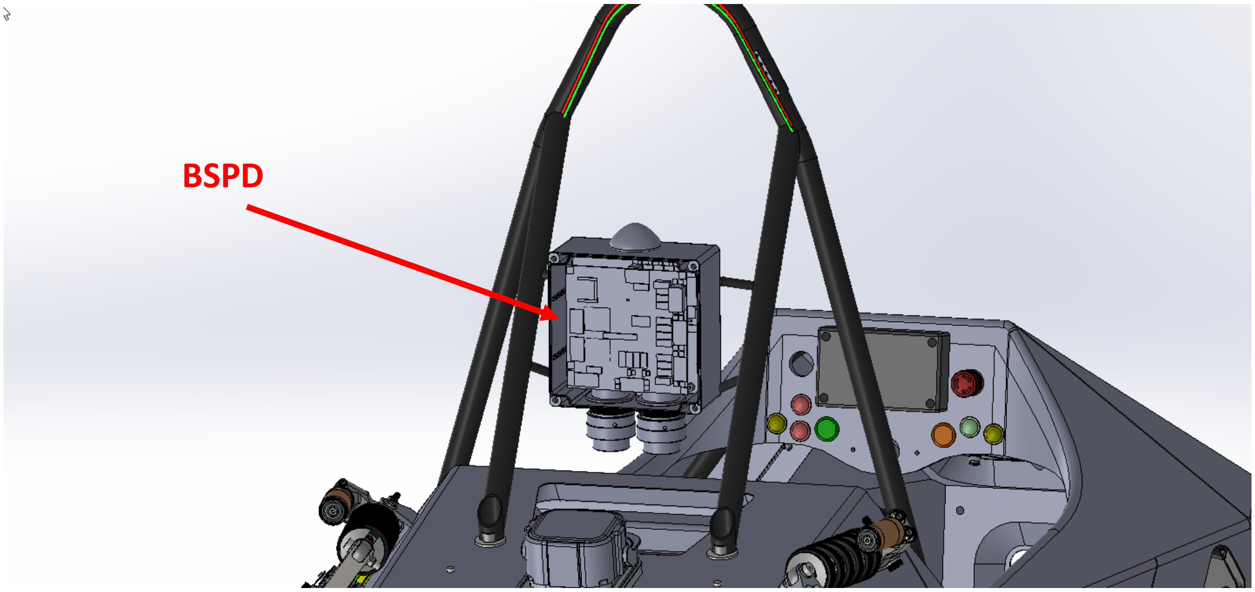


Figure 4-8 - BSPD Component Location

4.4.5 BSPD Demonstration

The BSPD demonstration is performed as follows:

- Connect power supply to the test resistor, and the testing points located in the rear of the car
- Go through the car start up procedures to place it in ready to drive mode
- Ensure that TSAL indicates HV is present and that the accumulator indicator light is on.
- Adjust current output from the power supply until it reads 12.5A
- Observe TSAL or Accumulator Light to determine if the BSPD de-activated the tractive system.

4.5 Battery Management System

4.5.1 BMS Faults

The following faults will cause the Orion BMS 2 to open the shutdown circuit:

- Over-voltage or cells above 4.2V
- Under-voltage of cells below 2.5V
- If the BMS is reading less than 20% of cell temperatures
- Cells are over 60C or under –20C
- If the Current draw from the cells is above the limit conditions determined by voltage, temperature, and state of charge.
- If the BMS determines there is a fault in any of its voltage tap connections
- If there is a fault in the current sensor

4.5.2 BMS Fault Latching

The BMS fault latching functionality is achieved through use of a dual-channel relay module as described in further detail in section 3.3.2. The BMS fault relay is part of the "Ext." relay circuit and, as such, requires the reset on the exterior of the vehicle to be depressed before the AIR's will close again.

4.5.3 BMS Demonstration

Perform the following:

1. Turn on the GLV system.
2. Connect to the Ewert CANdapter to the CAN network on the car.
3. Open Orion BMS 2 Software Utility on a Windows PC and connect to the CANdapter.
4. View live parameters in the software.
5. Show all fault conditions that can be set within the software.

5 Safety Systems

5.1 TSAL

5.1.1 TSAL Specifications

Make/Model:	Adafruit / 3860
Color:	Red
Flash Rate:	4Hz
Powered By:	GLV
Controlled By:	TS
TS Turn On Voltage:	10V
TS Turn Off Voltage:	10V

Table 5-1 - TSAL Specifications

5.1.2 TSAL Schematic

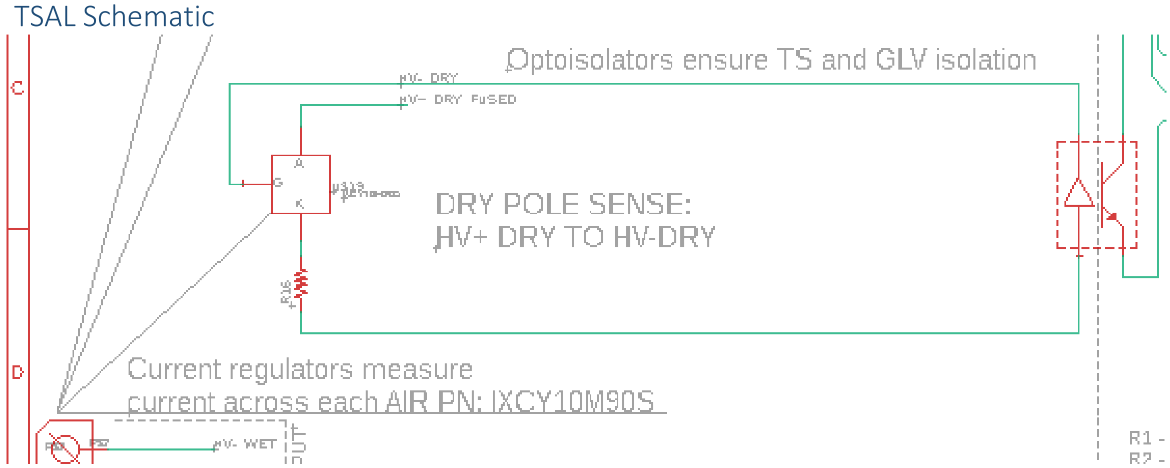


Figure 5-1 - HV Sensing Circuit

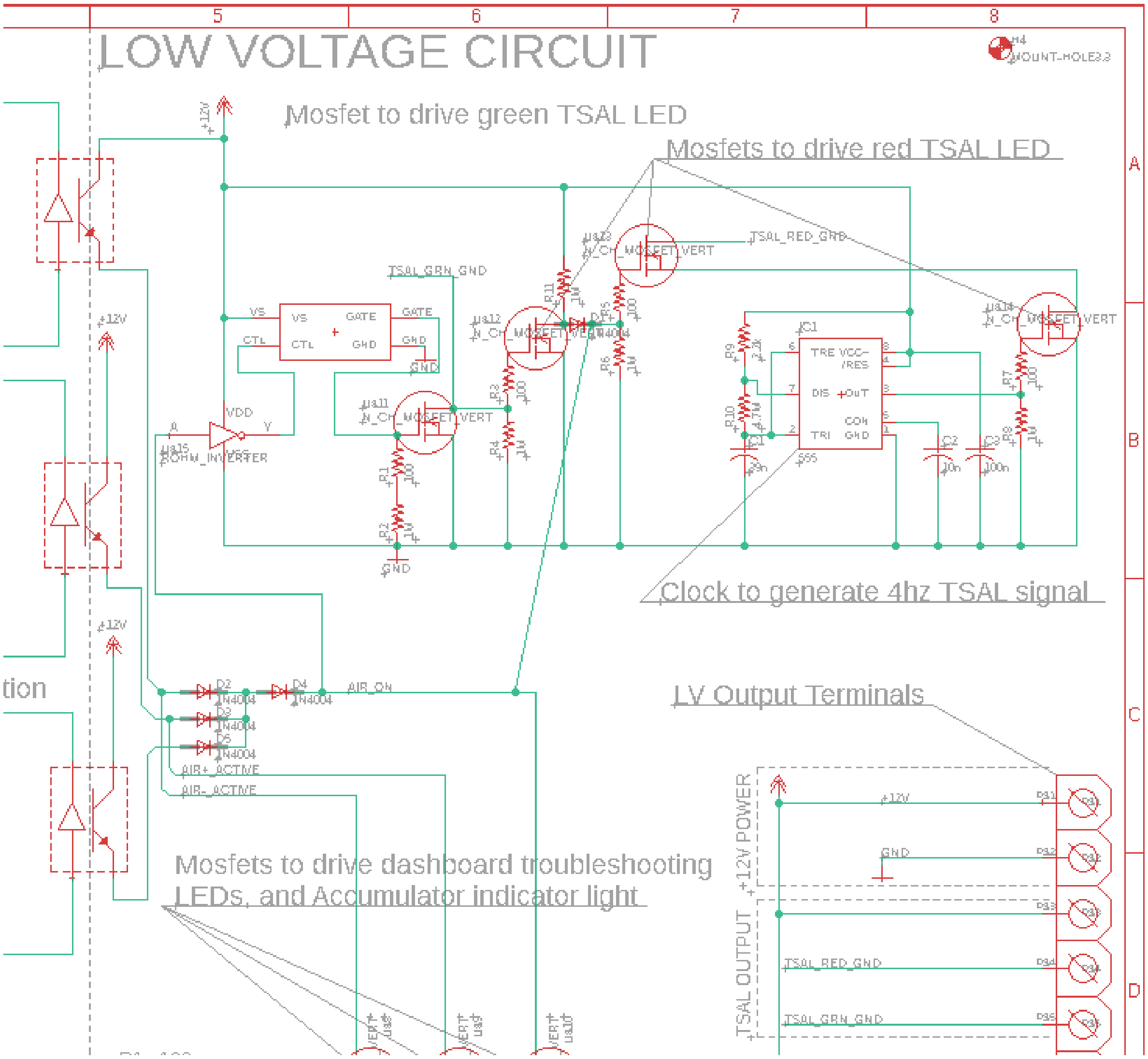


Figure 5-2 - TSAL Circuit Schematic

The HV detection circuit works by means of the current regulators on the high voltage side of the HVIB. The current regulators are coupled with an opto isolators to transmit the signals to the LV side of the board. These sensing circuits have their sense leads attached on both poles of the AIRs and measure between the following points:

- HV+ Dry and HV- Wet (AIR+ sense)
- HV+ Wet and HV- Dry (AIR- sense)
- HV+ Dry and HV- Dry (dry pole sense)

5.1.3 TSAL Location

The TSAL circuit is located on the roll hoop and is mounted as shown below:

Figure 5-3 - TSAL Location on Rollhoop

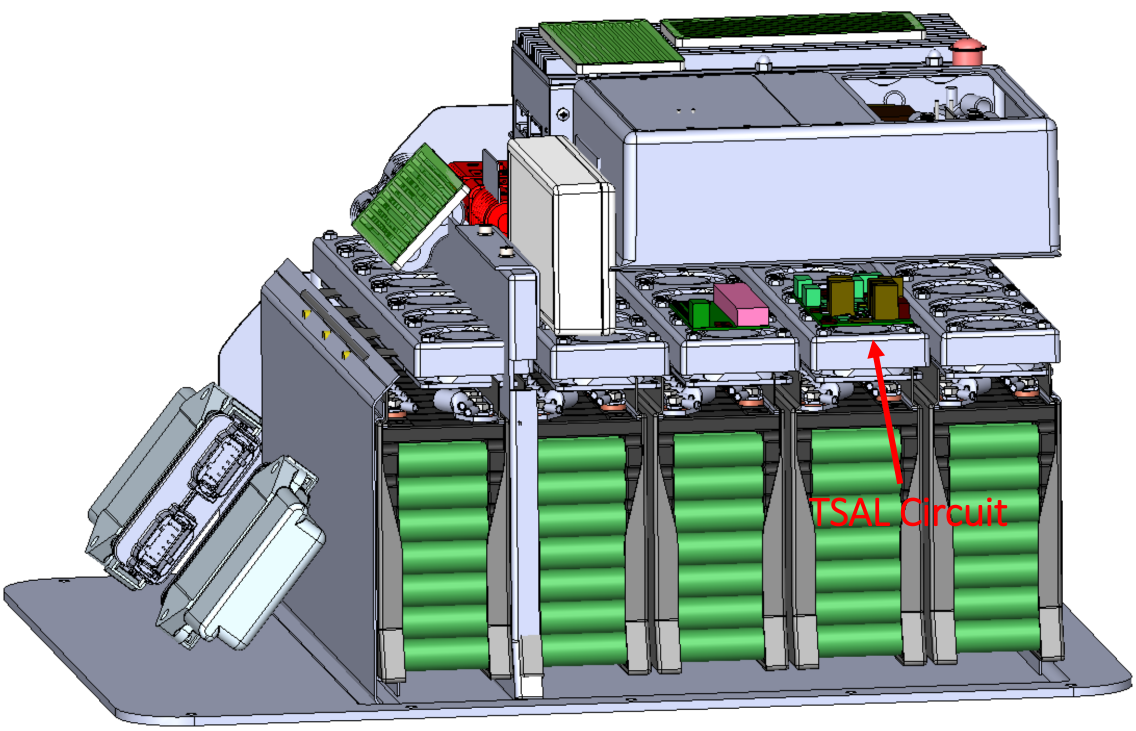


Figure 5-4 - TSAL Component Locations

5.2 Measurement Points

5.2.1 Measurement Point Specifications

Make / Model:	Tenma 76-1658
Voltage Rating:	600V
Datasheet:	Datasheet

Table 5-2 - Measurement Point Specifications

5.2.2 Measurement Point Location

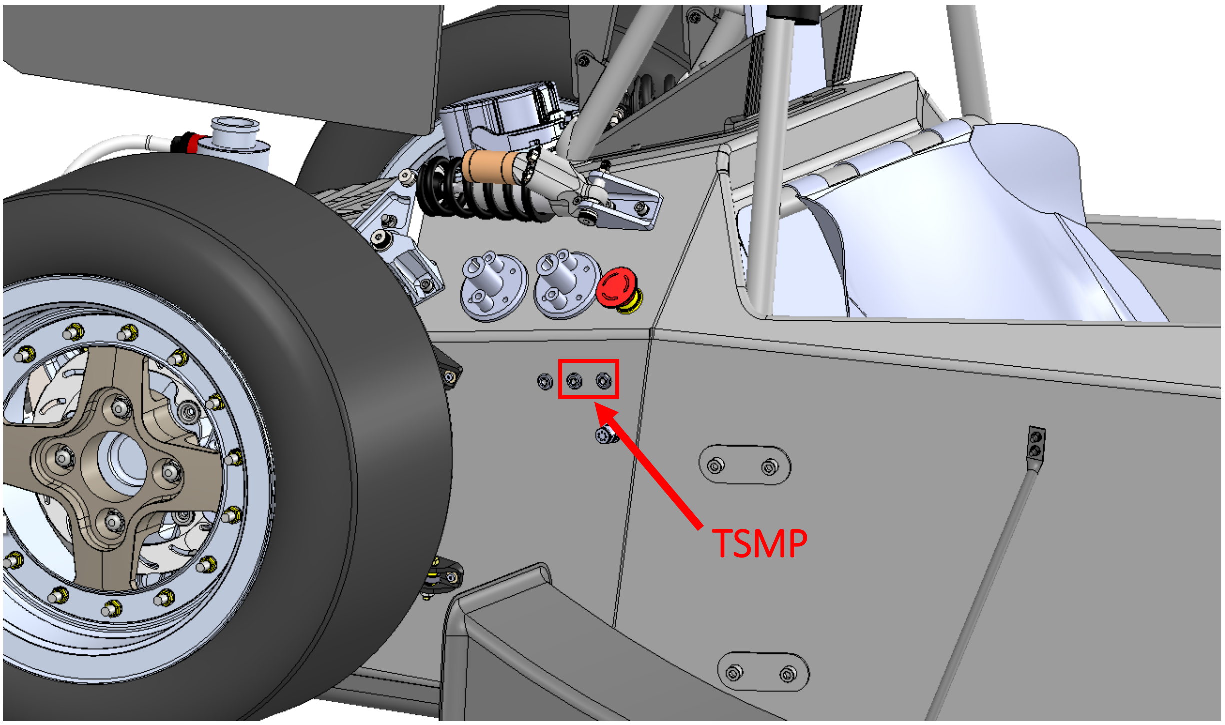


Figure 5-5 - Measurement Point Location

5.2.3 Measurement Point Protection

The backing of the TSMPs as well as the GLV measuring point Is protected by a 3D printed housing. It is designed in such a way that the through air requirements are met for the distance between HV+, HV-, and GLV. Additionally, walls are printed between each contact to ensure accidental touching between contacts or fingers does not occur. On the front of the TSMP's a cover has been 3D printed to ensure that accidental touching cannot occur and to prevent water ingress. Please see below for the front and back covers.

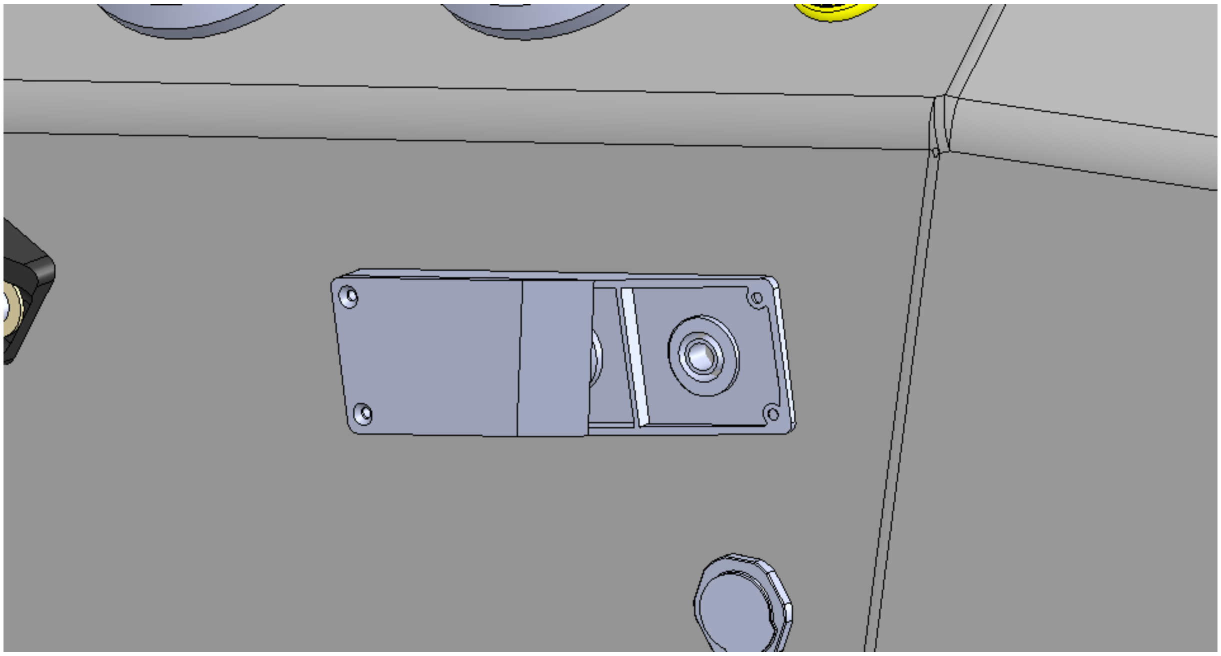


Figure 5-6 - TSMP Protection Cover

5.2.4 TSMP Protection Resistor

Make / Model:	CRCW201015K0FKEF
Resistance:	15,000Ω
Voltage Rating:	400V
Power Rating:	0.75W
Datasheet:	[Datasheet]

Table 5-3 - TSMP Protection Resistor Specifications

5.2.5 TSMP Protection Resistor Location

TSMP resistors are located on the HVIB.

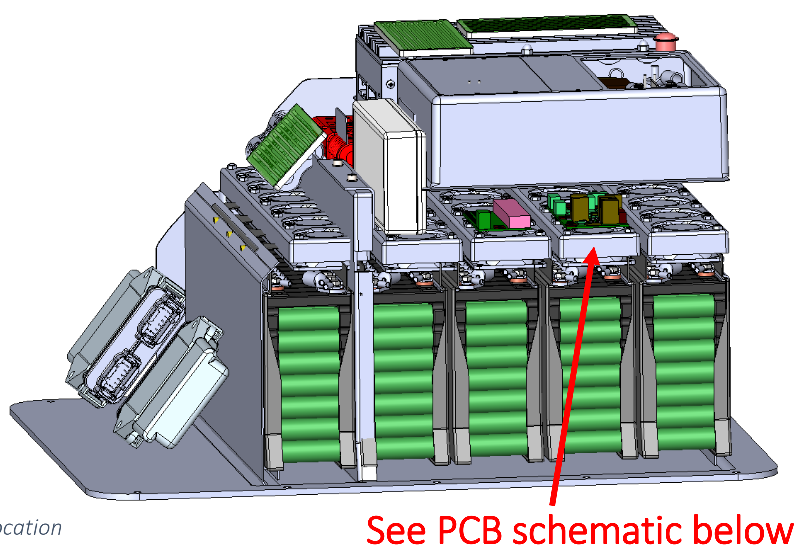


Figure 5-7 - HVIB PCB Location

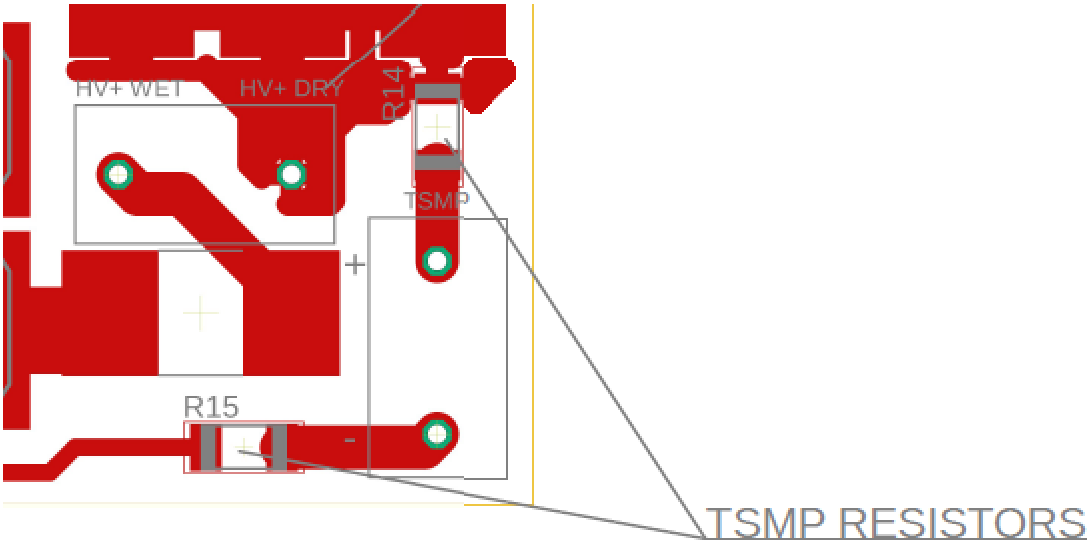


Figure 5-8 - TSMP Protection Resistor Location

5.2.6 TSMP Demonstration (Located on HVIB)

Discharge Resistance Value

1. Power down tractive system using the TSMS
2. Confirm that the TSAL is indicating that the AIR's are open
3. Measure the resistance at the TSMP
4. Subtract 25kΩ

Current Limit Resistor Value

1. Power down tractive system using the TSMS
2. Confirm that the TSAL is indicating that the AIR's are open and that there is no HV present.
3. Measure the resistance at the TSMP
4. Subtract 2.2kΩ and divide by 2 This will give the value of the TSMP resistors since they will be in series with the discharge resistor when the discharge circuit is active.

TS Voltage (Confirm Off)

1. Turn off TSMS and GLVMS
2. Confirm the TSAL is indicating that the AIR's are open
3. Measure the voltage at the TSMP

TS Voltage (Confirm On)

4. Turn on TSMS and GLVMS
5. Confirm HVD is in place
6. Press the traction system start button on the dash
7. Confirm the TSAL is indicating that the AIR's are closed
8. Measure the voltage at the TSM

5.3 HVD

5.3.1 HVD Specifications

Make / Model:	TE AMP+ Manual Service Disconnect
Ampacity:	630A
Voltage rating:	450V
Datasheet:	Datasheet

Table 5-4 - HVD Specifications

5.3.2 HVD Location

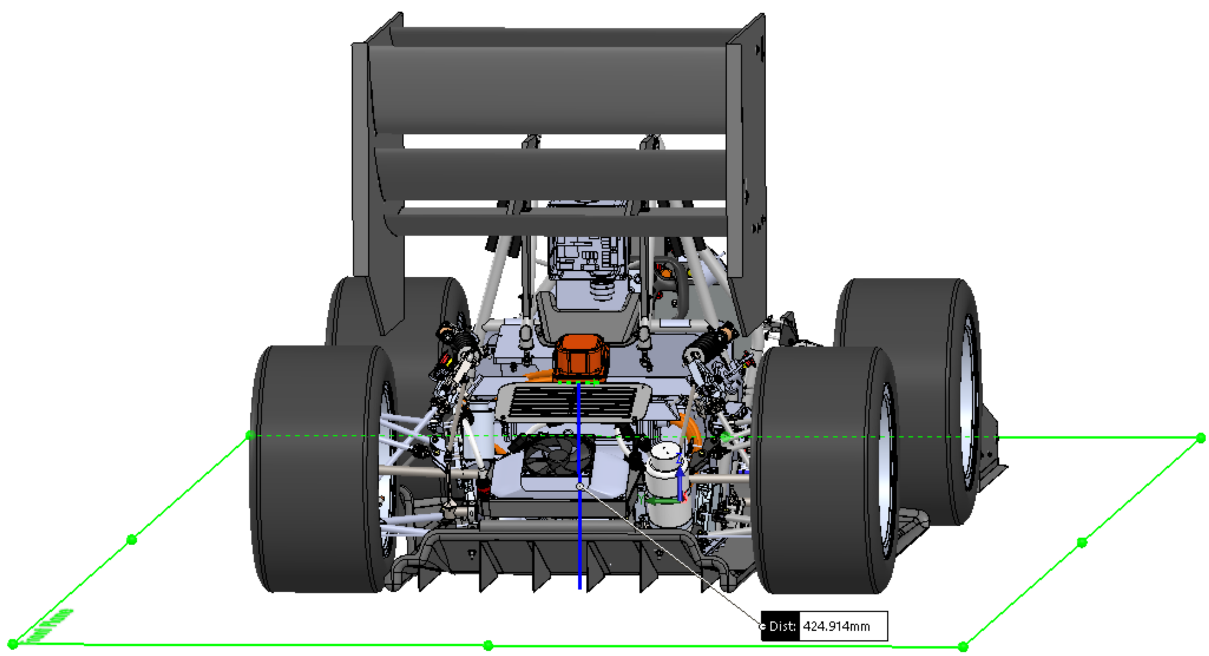


Figure 5-9 - HVD Location

5.3.3 HVD Connections

The female receptacle of the HVD is connected via ring terminals and hex bolts. The HVD is mounted on the monocoque of the vehicle and not on any removable body work. Additionally, a 3D printed housing will be fastened to the back of the female receptacle to protect it from water ingress and being touched by anyone. The male receptacle is just a loop that passes the connection from one side of the female connection though a fuse and out the other. It comes pre-assembled and will completely protect from water ingress. Additionally, a pilot line through the connector will ensure that upon opening the circuit the AIR's are decoupled so that high voltage cannot be present at the connection when the HVD is removed.

HVD Demonstration

To remove the HVD Lift the two-stage lever assisted black latch on the HVD and pull on the connector. Replace the HVD with a dummy connector to ensure the prevention of water ingress and accidental touching.

Remove the HVD if:

- Performing maintenance on the following:
  - Accumulator
  - IMD
  - Inverter
  - Any component containing high voltage in the vehicle
- Manually pushing the vehicle
- During charging
- Before technical inspection at competition
- When leaving the vehicle unattended

5.4 Ready to Drive Sound

5.4.1 RTDS Device and Control

The ready to drive signal is controlled from a half bridge output of the VCU. It is sounded before the VCU enters the ready to drive state and allows torque output.

Make / Model:	Mallory Sonalert Products / ZA016LDFP1
Control Voltage:	12V
SPL at 2m:	85 dBA
Datasheet:	Datasheet

Table 5-5 - RTDS Specifications

5.4.2 Ready to Drive Mode Demonstration

1. Set TSMS and GLVMS to ready to on position
2. Reset external circuit
3. Enter vehicle
4. Reset internal circuit
5. Press brake pedal and hold start button
6. Wait for ready to drive sound, observe light on dashboard
7. Release start button

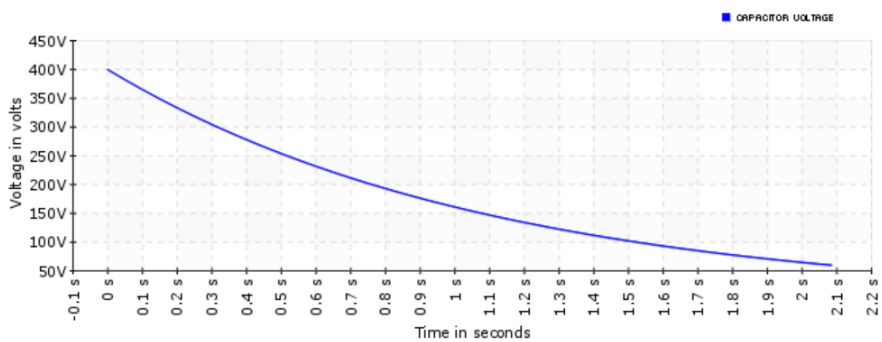
5.4.3 Discharge Circuit Component Specifications

Make / Model:	Vishay MCRL01002K200JHB00
Resistance:	2.2kΩ
Voltage:	469V
Power:	100W
Power @15sec:	2.65E-12 W
Datasheet	Datasheet

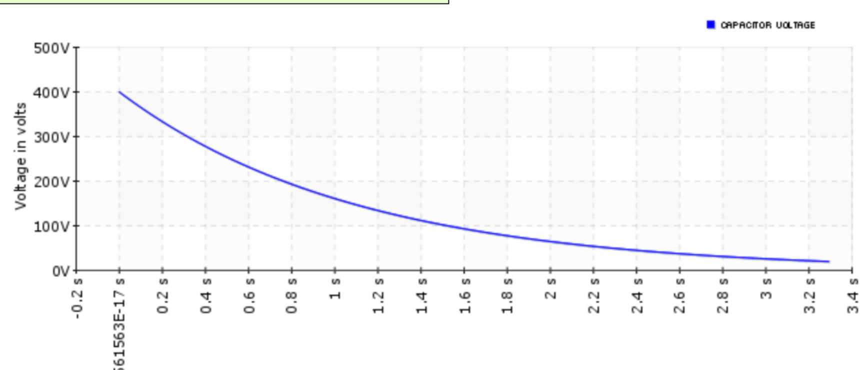
Table 5-6 - Discharge Resistor Specifications

Make / Model:	Gigavac P105
Contact Current Rating:	50A
Contact Voltage Rating:	1200V
Datasheet:	Datasheet

Table 5-7 - Discharge Relay Specifications



Results	
Time	~2.086832 seconds
Peak power of the resistor	~72.727273 watts
Peak current	~-181.818182 milliamperes



Results	
Time	~3.295306 seconds
Peak power of the resistor	~72.727273 watts
Peak current	~-181.818182 milliamperes

The Motor drive has internal capacitance of 500 uF and the DC/DC converter has input capacitance of 0.8uF. The discharge voltage is shown above using the System voltage of 399V and the discharge resistance of 2200 Ω. The Inverter takes under 2s to discharge to under 60V and 3.3 seconds to discharge to 20V (95% capacity). The DC-DC converter will be discharged though the high voltage interlock board's current regulator. The current regulator draws 15ma of current continuously until it is under 10v. With this information a discharge from 400v to 60V takes 18ms (340*0.0000008/0.015 = 0.018s).

5.4.4 Discharge Circuit Location

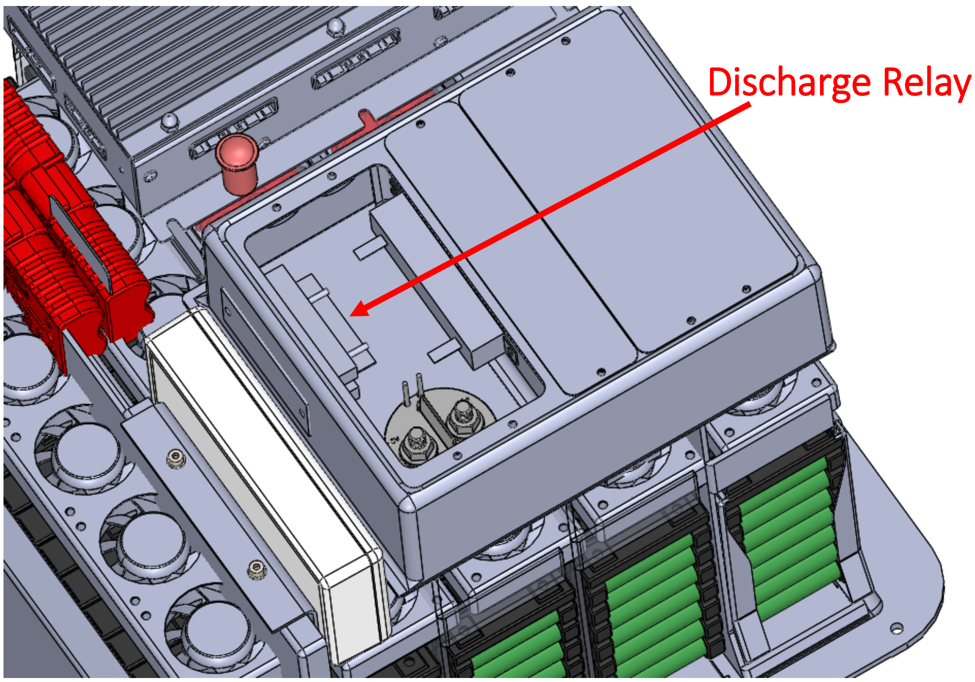


Figure 5-10 - Discharge Circuit Component Locations

5.4.5 Discharge Circuit Control

The discharge is enabled any time the AIR's are open. This is done by making use of the NC auxiliary contact on AIR -. The NC contact is fed by 12V and closes a discharge relay which connects the dry and wet side of AIR-.

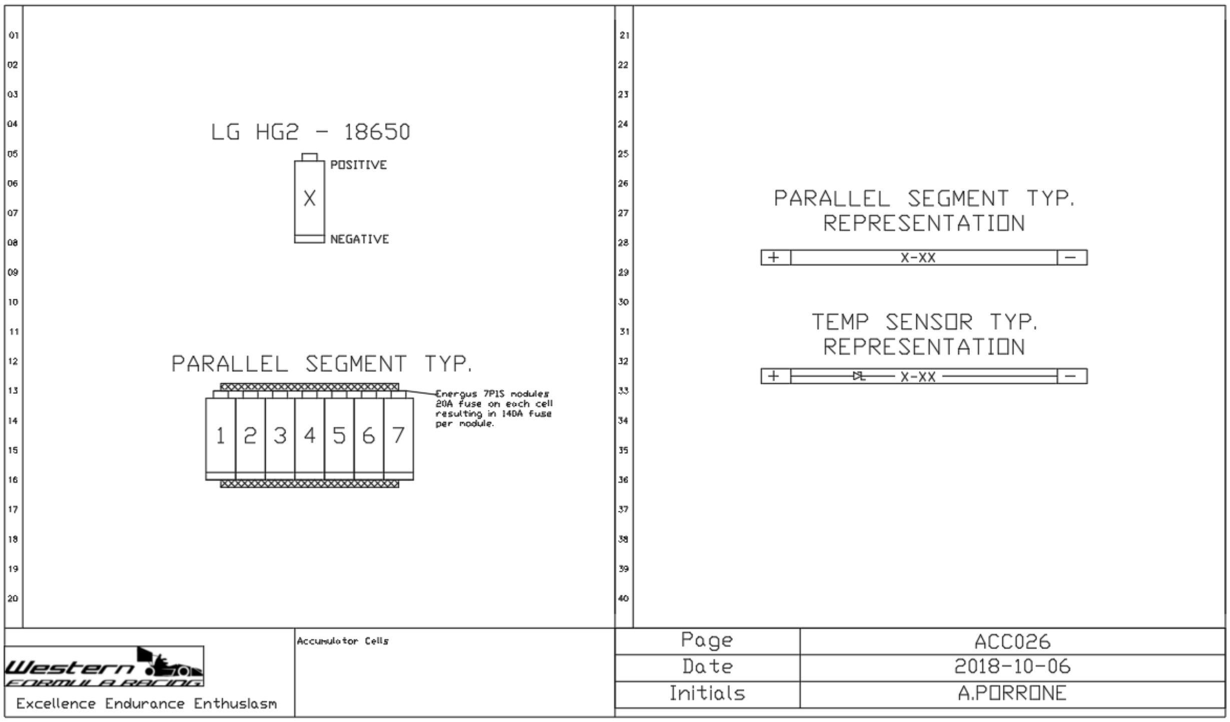
5.4.6 Discharge Circuit Demonstration

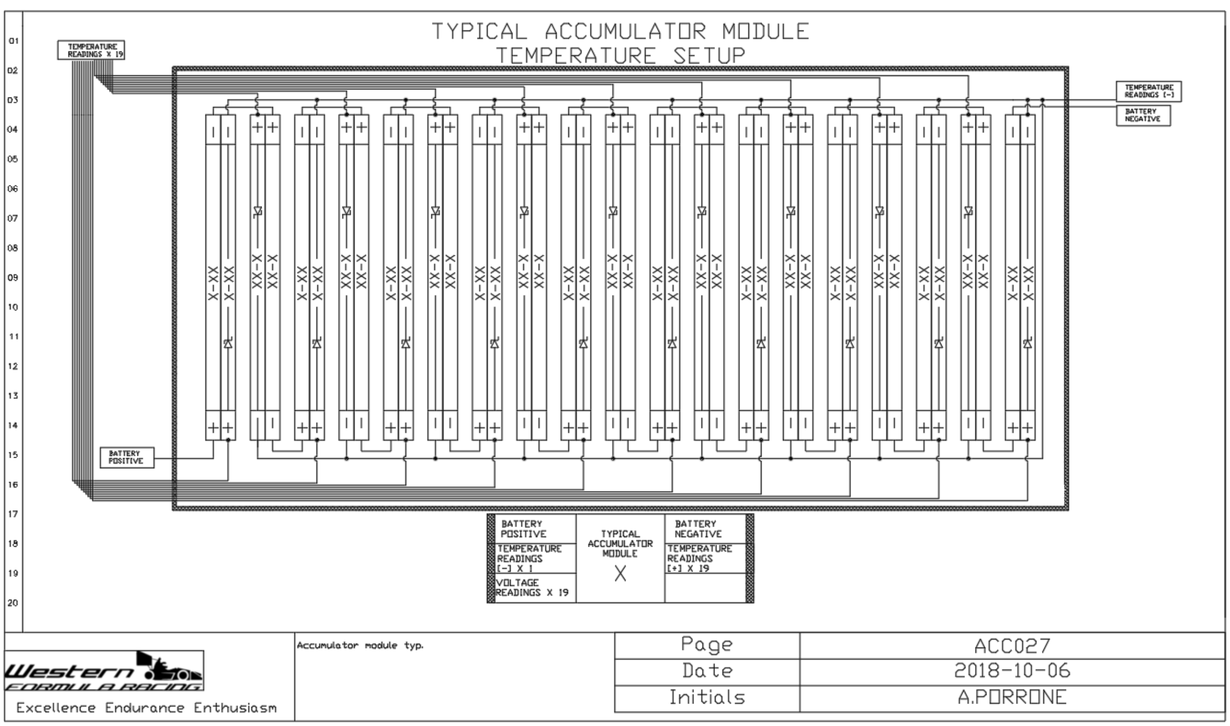
1. Power down vehicle using the Tractive System Master Switch
2. Wait 5 seconds
3. Measure voltage at Tractive System Measuring Point via the procedure in the TSMP section.

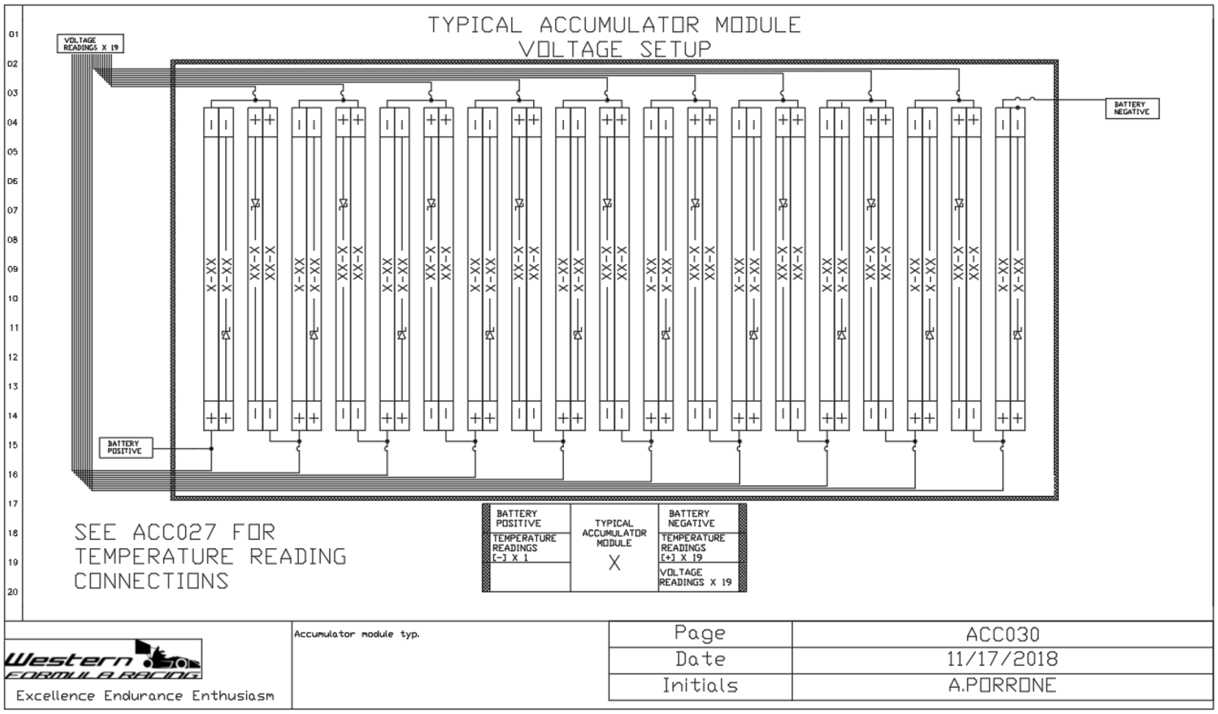
6 Accumulator

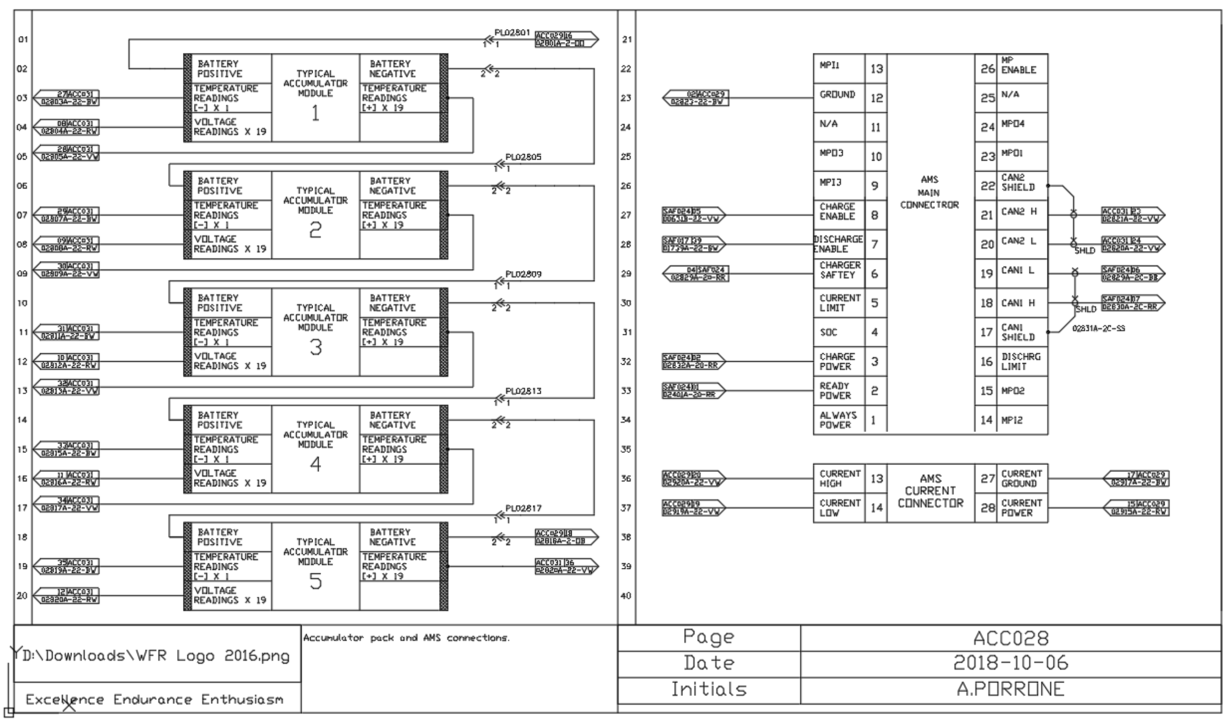
6.1 Accumulator Schematic

View DXF files here






TYPICAL ACCUMULATOR MODULE
VOLTAGE SETUP
VOLTAGE READINGS X 19
BATTERY NEGATIVE
BATTERY POSITIVE
SEE ACC027 FOR TEMPERATURE READING CONNECTIONS
BATTERY POSITIVE
TEMPERATURE READINGS [-] X 1
TYPICAL ACCUMULATOR MODULE
X
BATTERY NEGATIVE
TEMPERATURE READINGS [+] X 19
VOLTAGE READINGS X 19
Excellence Endurance Enthusiasm
Accumulator module typ.
Page
ACC030
Date
11/17/2018
Initials
A.PORRONE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VOLTAGE READINGS X 19
AMS MAIN CONNECTOR
AMS CURRENT CONNECTOR
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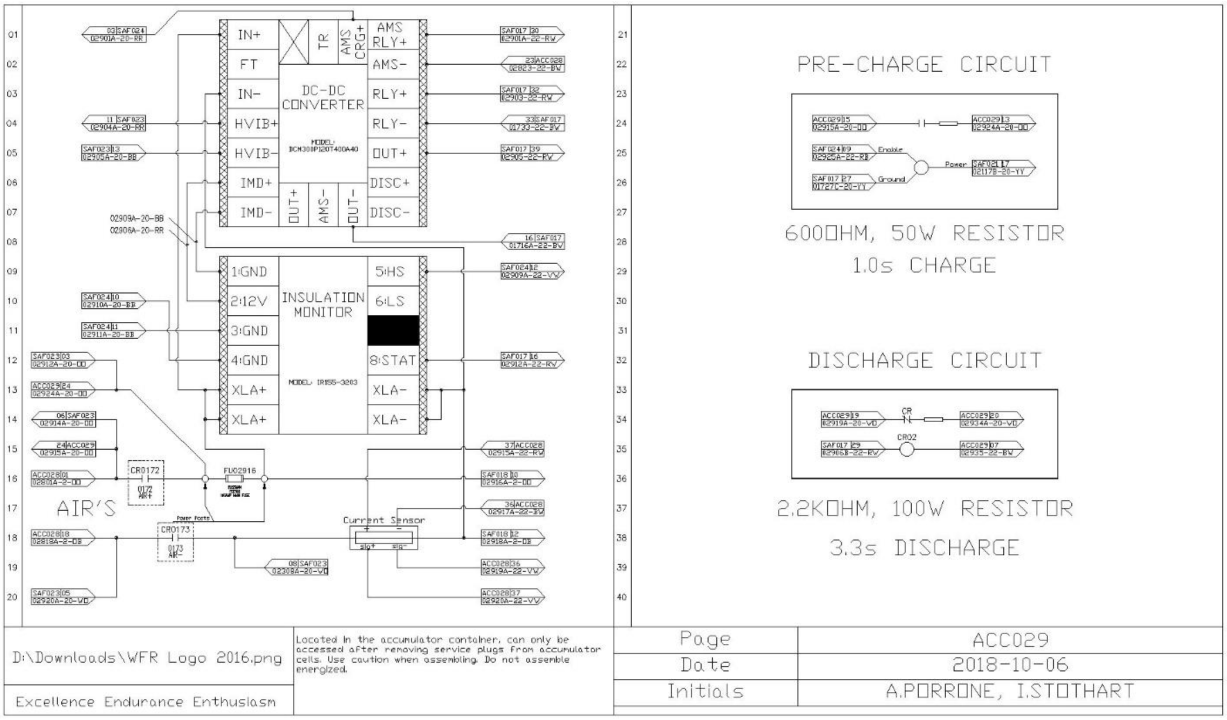
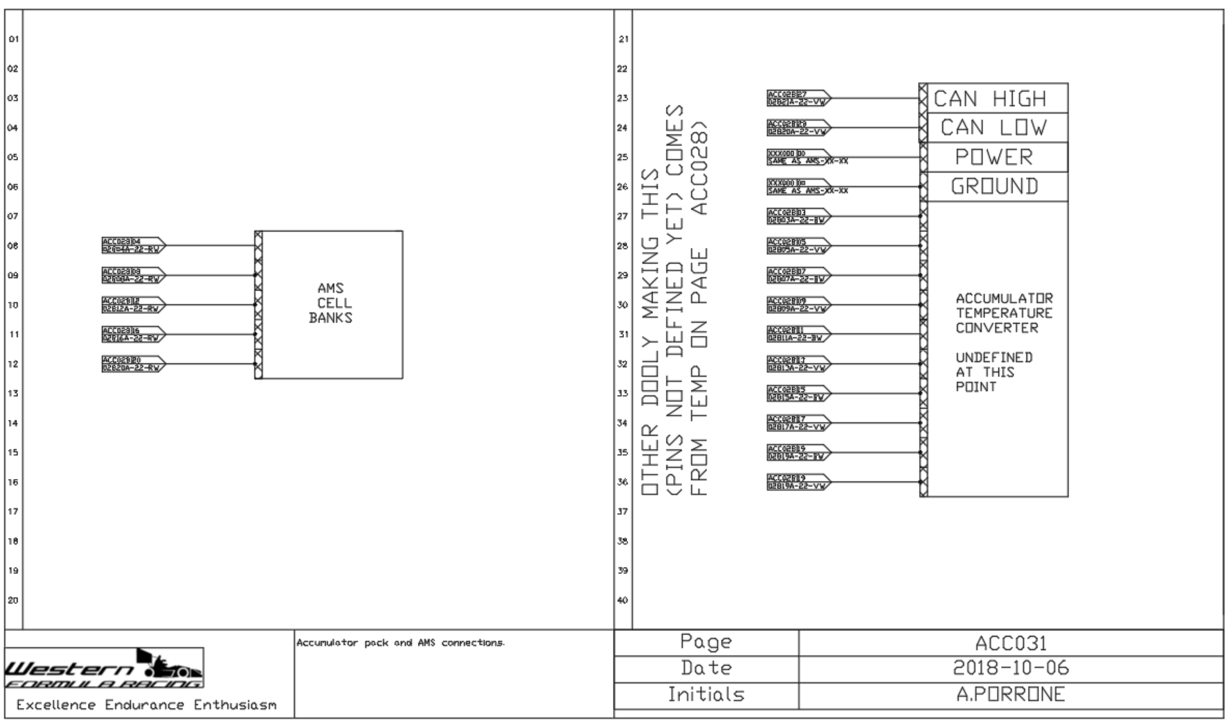
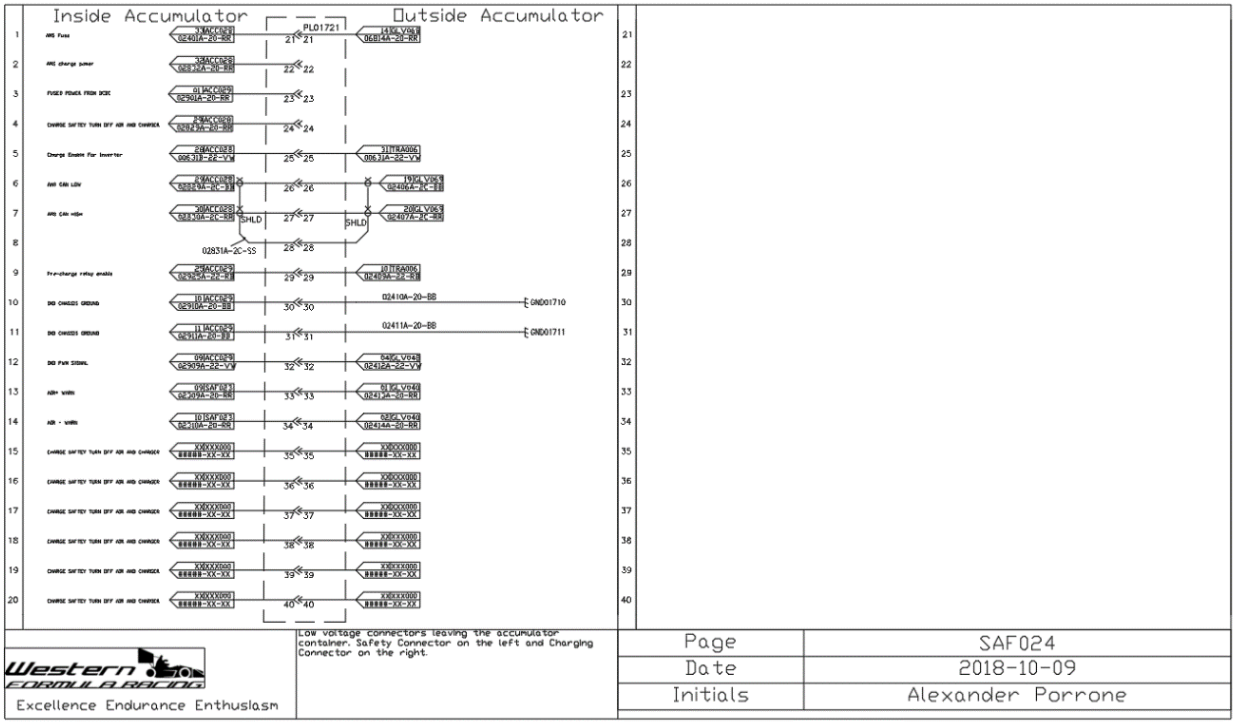
Excellence Endurance Enthusiasm
Accumulator pack and AMS connections.
Page
ACC028
Date
2018-10-06
Initials
A.PORRONE


PRE-CHARGE CIRCUIT
600OHM, 50W RESISTOR
1.0s CHARGE
DISCHARGE CIRCUIT
2.2KOHM, 100W RESISTOR
3.3s DISCHARGE
DC-DC CONVERTER
INSULATION MONITOR
AIR'S
Current Sensor
D:\Downloads\WFR Logo 2016.png
Excellence Endurance Enthusiasm
Located in the accumulator container, can only be accessed after removing service plugs from accumulator cells. Use caution when assembling. Do not assemble energized.
Page
ACC029
Date
2018-10-06
Initials
A.PORRONE, I.STOTHART


AMS CELL BANKS
OTHER DOOLY MAKING THIS (PINS NOT DEFINED YET) COMES FROM TEMP ON PAGE ACC028)
CAN HIGH
CAN LOW
POWER
GROUND
ACCUMULATOR TEMPERATURE CONVERTER
UNDEFINED AT THIS POINT
Excellence Endurance Enthusiasm
Accumulator pack and AMS connections.
Page
ACC031
Date
2018-10-06
Initials
A.PORRONE


Inside Accumulator
Outside Accumulator
PL01721
Low voltage connectors leaving the accumulator container. Safety Connector on the left and Charging Connector on the right.
Western Formula Racing
Excellence Endurance Enthusiasm
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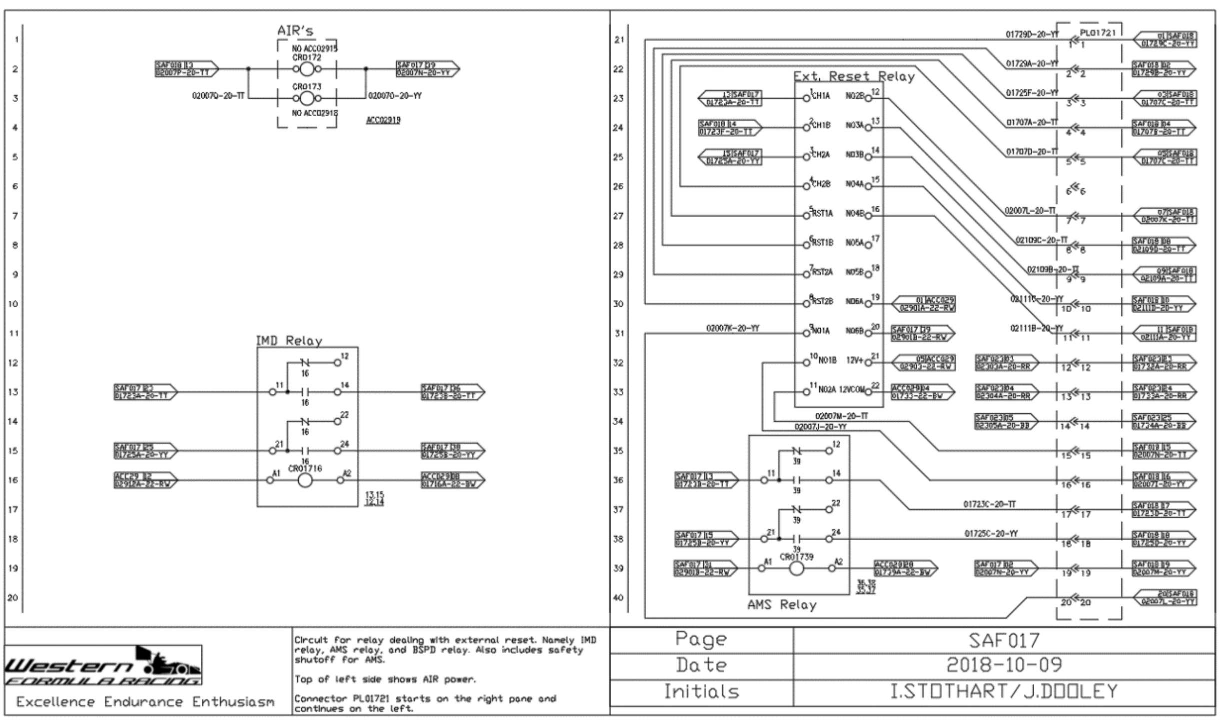
SAF024
Date
2018-10-09
Initials
Alexander Porrone


AIR's
IMD Relay
Ext. Reset Relay
AMS Relay
PL01721
Circuit for relay dealing with external reset. Namely IMD relay, AMS relay, and BSPD relay. Also includes safety shutoff for AMS.
Top of left side shows AIR power.
Connector PL01721 starts on the right pane and continues on the left.
Western Formula Racing
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I.STOTHART/J.DOOLEY

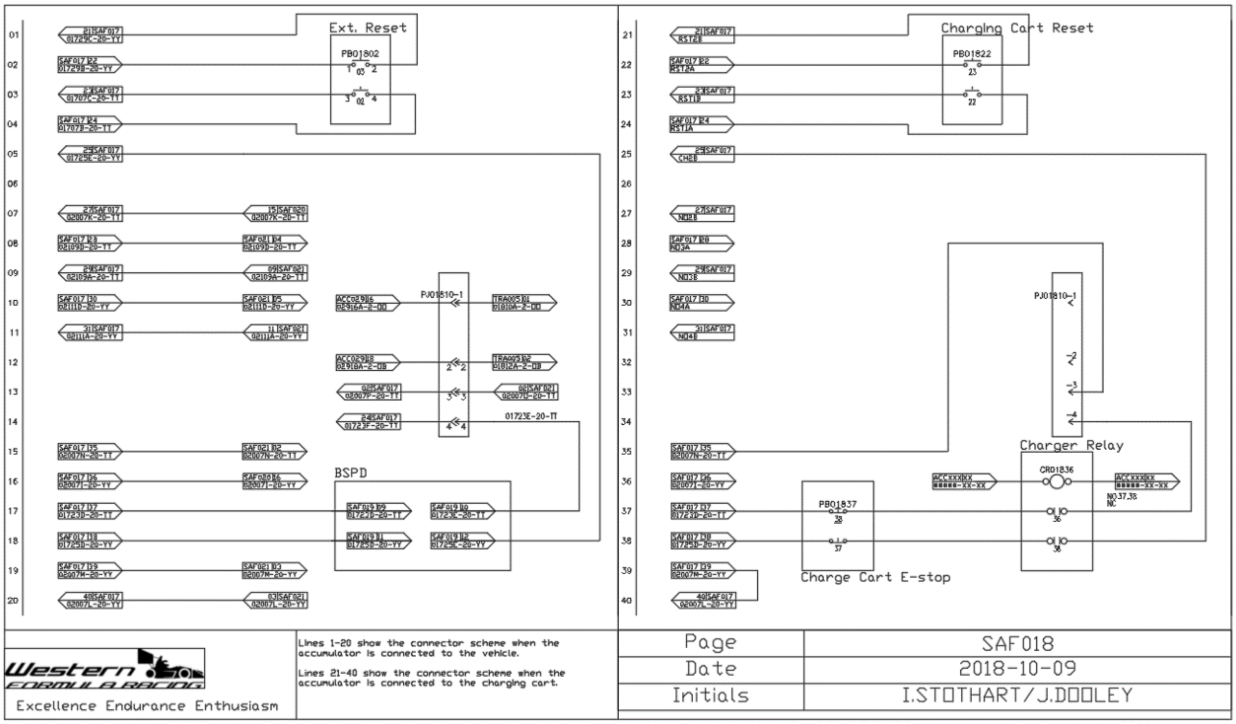

Figure 6-1 - Accumulator Schematics

6.2 Cells

6.2.1 Cell Specifications

Cell Make / Model / Style:	LG HG2 - cylindrical
Cell nominal capacity:	3.0Ah
Maximum Voltage:	4.2 V
Nominal Voltage:	3.6V
Minimum Voltage:	2.5V
Maximum output current:	35A for 4s
Maximum continuous output current:	20A
Maximum charging current:	4A
Maximum Cell Temperature (discharging)	60°C
Maximum Cell Temperature (charging)	45°C
Cell chemistry:	Li[NiMnCo]O2 (H-NMC) / Graphite + SiO

Table 6-1 - Cell Specifications

6.2.2 Cell Electrical Configuration

The battery pack is arranged in a 7P95S configuration. The pack is broken into 5 segments of 7P19S connected in series. Each segment was created through use of 19 x 7P1S modules from Energus Power Solutions connected in series.

6.2.3 Cell Connections

The individual cells are packaged into modules by Energus Power Solutions. The specific connections between the Energus modules can be found below. The modules are connected using busbars with a cross sectional area of 44.45 mm^2 and ampacity of 150 A. Positive locking is achieved using tab washers on the aluminum bolts as shown in the rendering. Once all bolts on each busbar are torqued down, the tabs are bent up around the bolt head to prevent rotation and ensure a retained connection between the cells and the busbar.

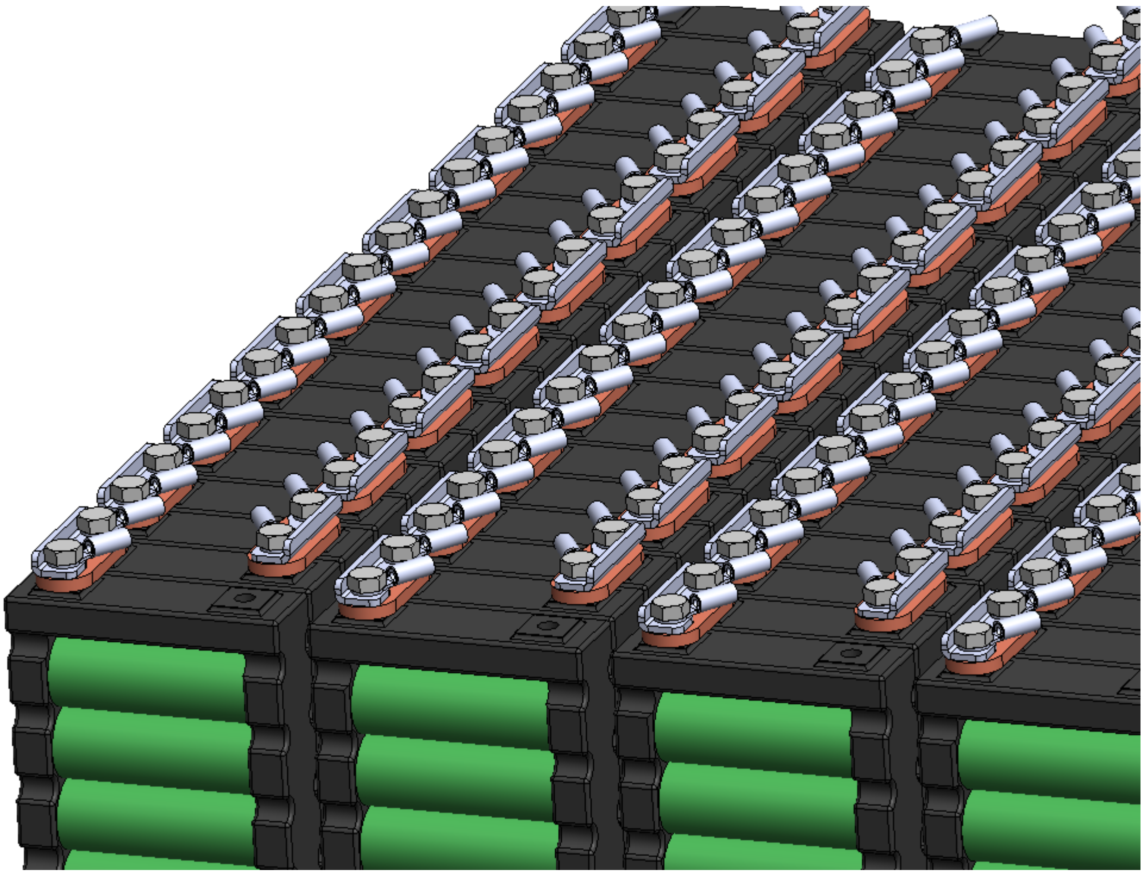

Figure 6-2 - Cell Connection Detail

6.2.4 Parallel Cell Overcurrent Protection

Each cell in a parallel series is connected to its segment's bus bar in series as denoted in the cell configuration. Each one of the parallel segments represents one of the Energus 7P1S modules. The cells in the Energus modules are individually fused as shown below in the fuse blow time chart. Each fuse will blow within 10 seconds when loaded with 45A and are rated for a continuous draw of 20A each. This gives each parallel segment a continuous rating of 140A with a blow time of under 10 seconds when 315A are drawn. A fast-acting LittleFuse L50S080 fuse will be present in line with the accumulator to blow before the Energus fuses are able to blow as shown below. For a representation of the blow time on the master fuse vs. the blow time of the Energus modules see the graph titled Blow Time vs Accumulator Current below.

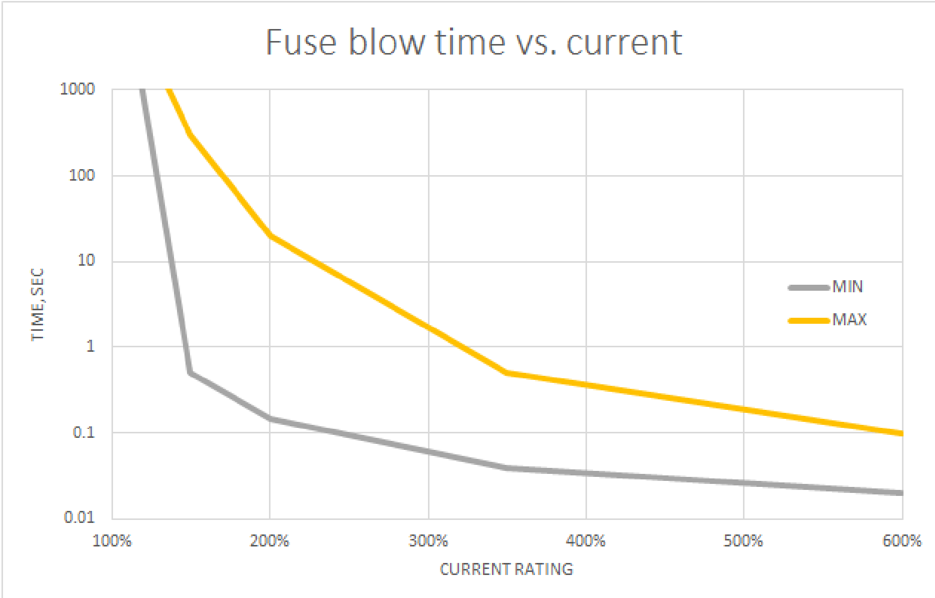

Figure 6-3 – Fuse blow time vs. current

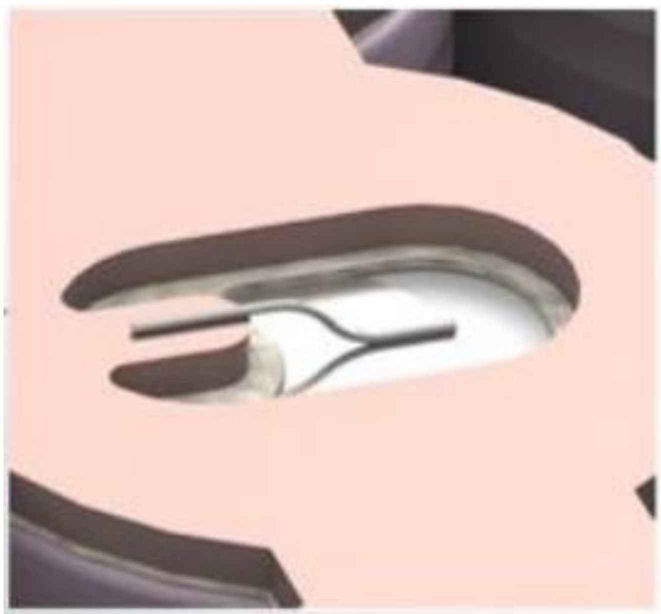

Figure 6-4 – Energus cell fuse

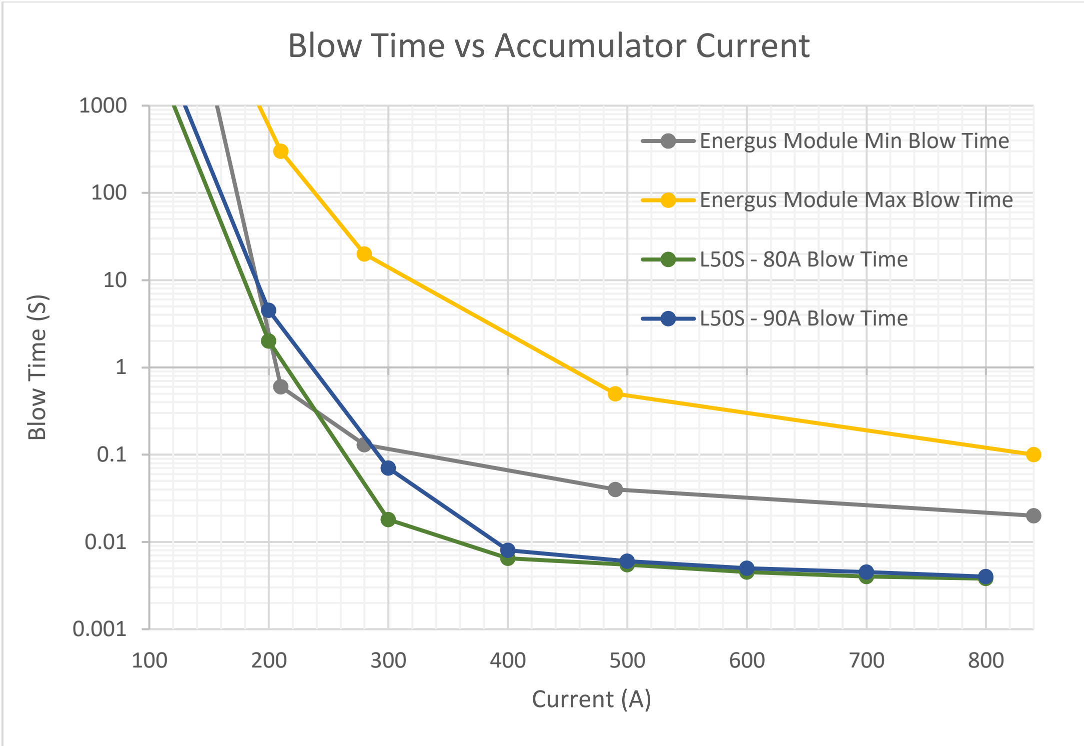

Figure 6-5 – Blow Time vs Accumulator Current

6.2.5 Cell Mounting

The Energus battery modules come as a set of seven 18650 cells encased on the top and on the sides by a structural UL94-V0 plastic. This layer of structural plastic ensures that the cells do not contact the surrounding structure. The cell modules are placed vertically in segments and connected by bus bars. Each segment acts as a rail system which slides into the accumulator. Modules are retained to each segment using side walls and clamping force. A 3D printed, ABS plastic racking system is bonded to a glass and carbon fiber reinforced polymer tray (glass fiber is used for insulation). The racking system and walls of the tray retain the cells both vertically and laterally. Longitudinal retention is attained through clamping features, glass and carbon fiber reinforced polymer parts, fastened to the bottom corners and top center of the segment rail. A total of 10, M3 fasteners will be used. PEEK plastic fasteners will be used as they offer sufficient strength properties, and dielectric breakdown properties that are acceptable to the tractive system voltage, in the case of a falling fastener.

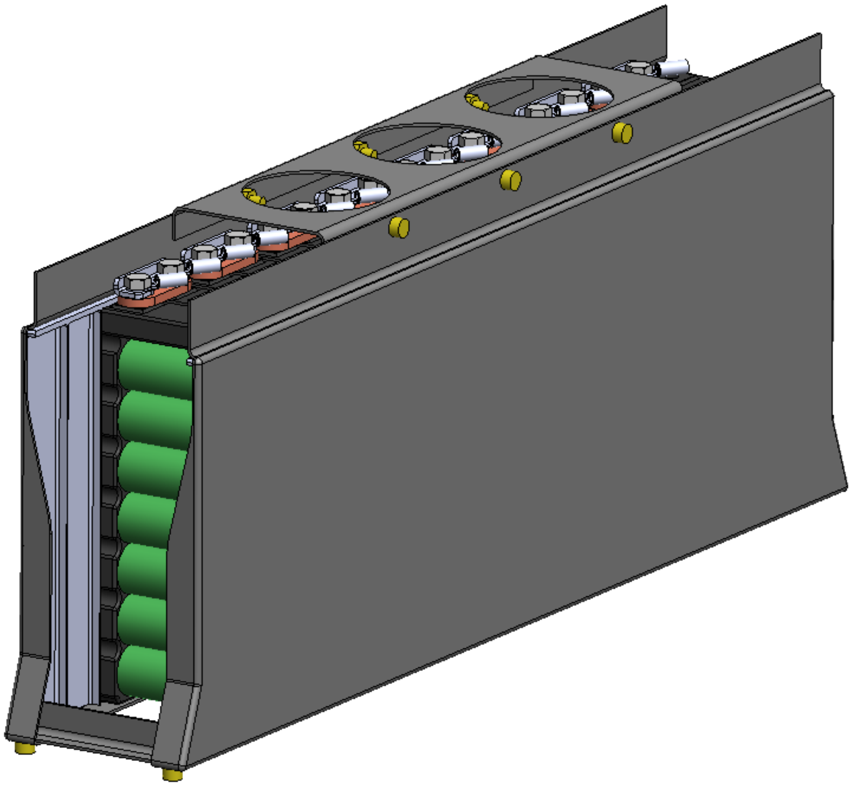

Figure 6-6 - Cell Mounting in Accumulator

6.3 Segments

6.3.1 Segment Specifications

# of Segments:	5
Cells per segment:	19 Energus Modules (133 Cells)
Cell configuration in segment:	7P19S
Energy in segment:	5.18MJ / 1.44 kWhr

Table 6-2 - Segment Specifications

6.3.2 Segment Physical Isolation

The modules are packaged into five segments of 19 modules, separated by composite walls. Each composite wall is made of carbon fiber and is insulated with glass fiber. When packaged into their sections, the only visible surface of each battery is the sidewalls. The battery box is safe from dropped tools because it is completely enclosed except for cooling vents and access hatches, which are covered by filters with <3mm of space through which a tool tip could protrude. Furthermore, the battery modules are located under all GLV components and cooling fans, whose footprint completely cover the top projected area of the batteries, protecting from tools and has a fiberglass insulated barrier between the fans and GLV components.

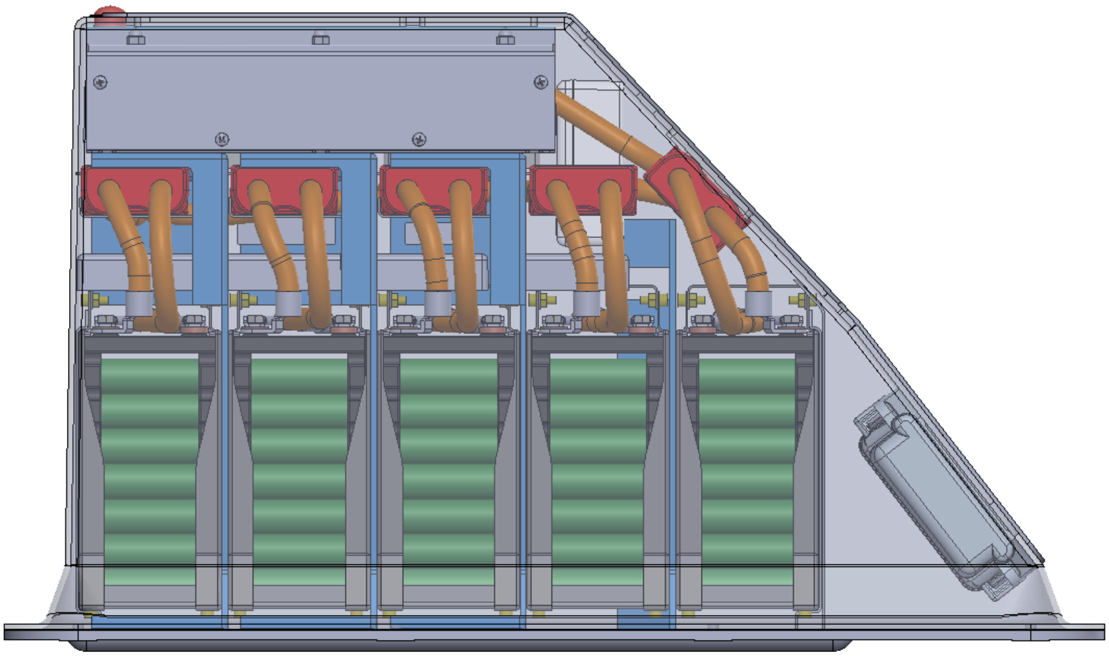

Figure 6-7 – Accumulator CAD of segments

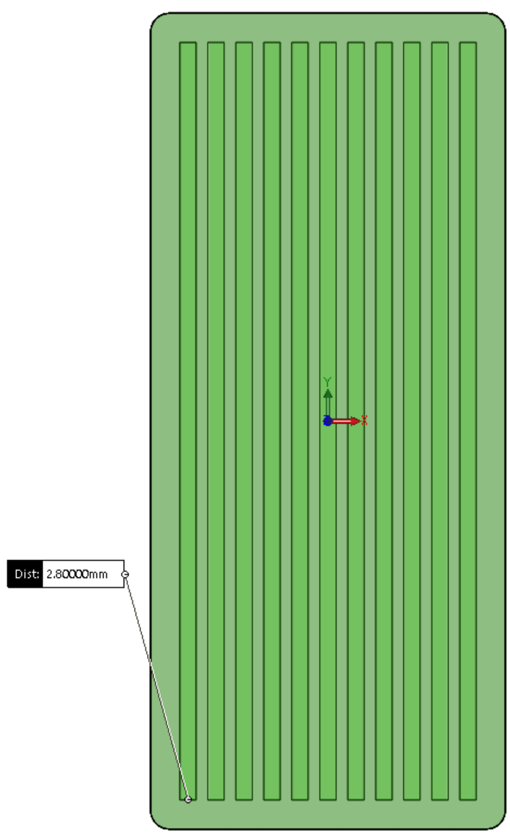

Figure 6-8 – Intake/Gore-tex barrier to accumulator

6.3.3 Maintenance Plugs

Andersons Power SB175 were used as maintenance plugs in the accumulator. The maintenance plugs were given their own housing just above the fans in the accumulator container to so that a person cannot accidently touch the accumulator cells when disconnecting the maintenance plugs. The flange for the maintenance plug access hatch covers all other hatches so that a user is mechanically guided to disconnect the maintenance plugs before opening any other hatch on the accumulator. Each plug and receptacle receives its own channel above its segment so that it cannot be accidently plugged into an incorrect connector. As shown in the rendering below each maintenance plug acts on both the positive and negative lead of each segment in the accumulator to connect all segments in a series configuration.

Make / Model:	Andersons Power SB175
Ampacity:	175A
Voltage:	600V
Datasheet:	Datasheet

Table 6-3 - Maintenance Plug Connector Specification

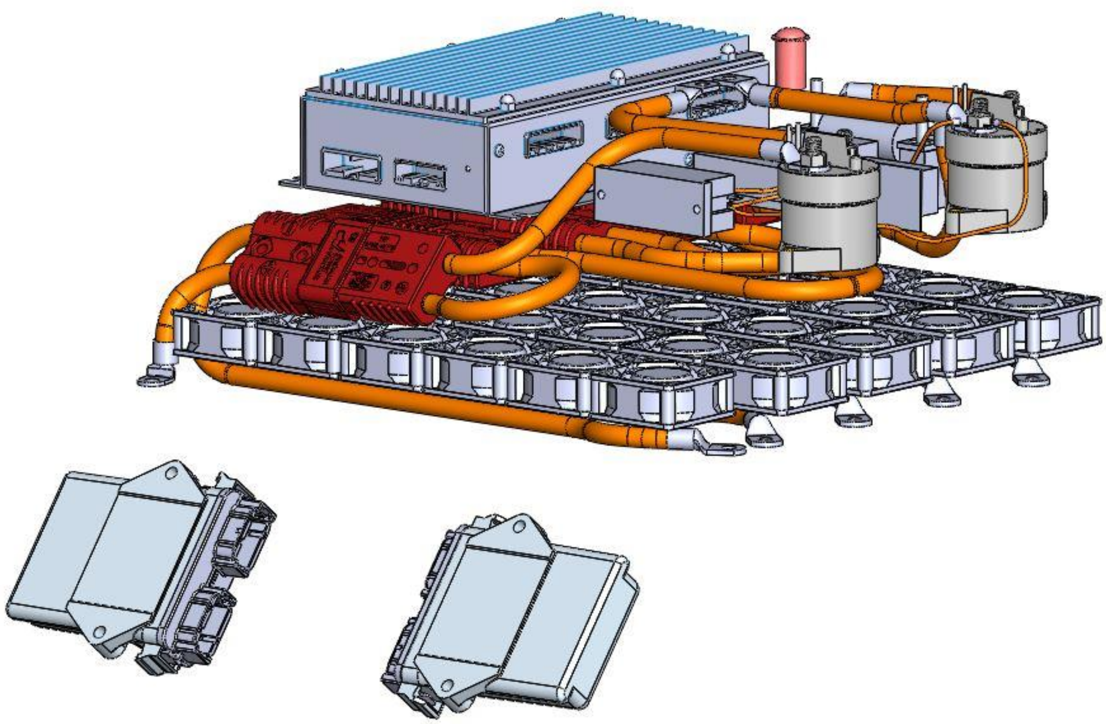

Figure 6-9 – CAD of maintenance plugs

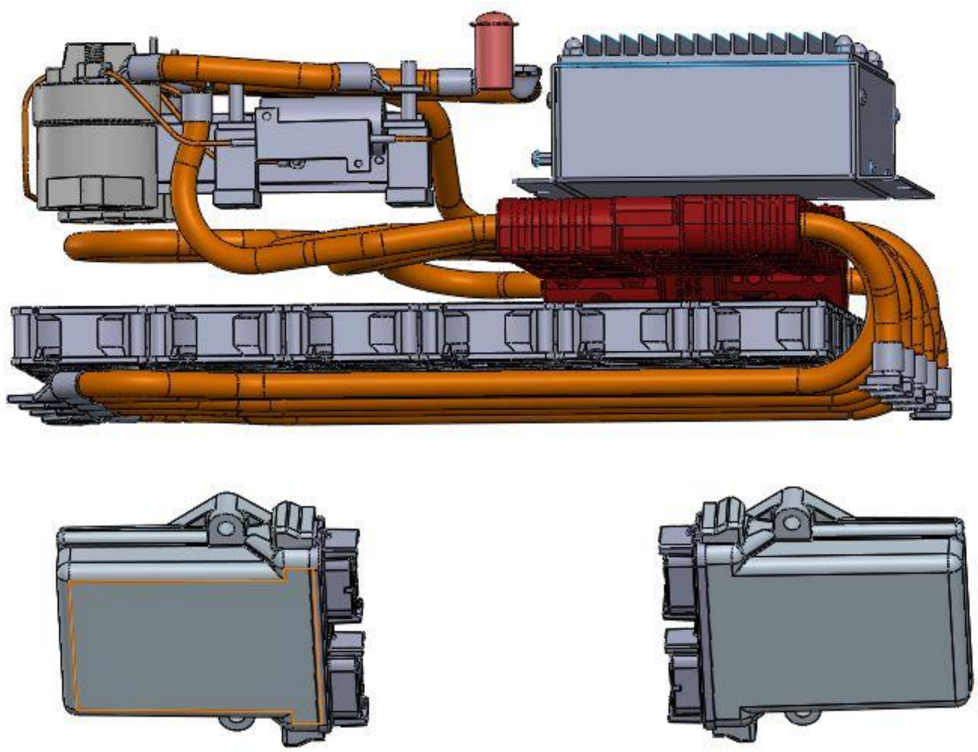

Figure 6-10 - Maintenance Plug Locations

6.3.4 Maintenance Plug Positive Locking

Andersons Power SB175 connectors satisfy the positive locking requirement through their contact retention force rating of 300lbf as clarified by a rules question.

6.3.5 Maintenance Plug Unique Configuration

As shown below the maintenance plugs are designed in such a way that there is a maintenance hatch that must be removed to access the maintenance plugs. Once the hatch is removed four channels will be exposed. Each connector gets its own channel except for the front most segment in the accumulator. This channel will be shared with the segment next to it and the connectors in this channel will be specifically keyed to ensure that they cannot be inserted into the incorrect receptacle.

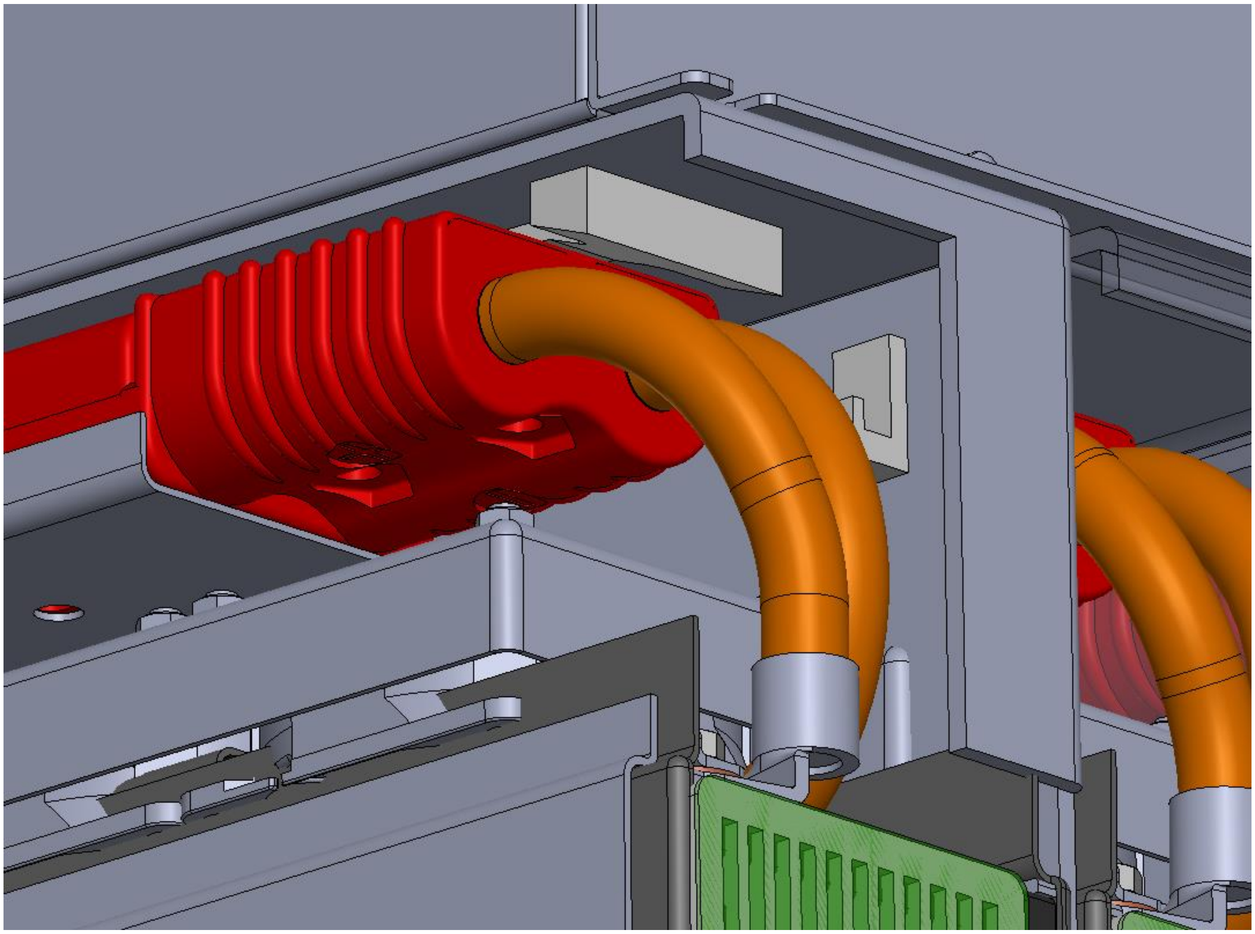

Figure 6-11 – Maintenance plug latches

6.3.6 Maintenance Plug Demonstration

Maintenance plugs can only be accessed by removing the maintenance plug hatch of the accumulator. When disconnecting the maintenance plugs, high voltage gloves, safety glasses, and insulated tools will be used.

1. Remove the Maintenance plug access panel
2. Disconnect the left most connector
3. Latch the connector into its disconnected position to ensure no accidental contact
4. Repeat steps 2 and 3 for all connectors
5. Reattach the maintenance plug access panel

6.4 Precharge Circuit

6.4.1 Precharge Circuit Component Specifications

Make / Model:	Ohmite/ AP101 620R J
Resistance:	620Ω
Voltage:	700V
Power:	100W
Power @15sec:	0W
Datasheet	Datasheet

Table 6-4 - Precharge Resistor Specifications

Make / Model:	Omron / G7L-2A-X-L DC12
Contact Current Rating:	20A
Contact Voltage Rating:	1000VDC
Datasheet:	Datasheet

Table 6-5 - Precharge Relay Specifications

6.4.2 Precharge Circuit Location

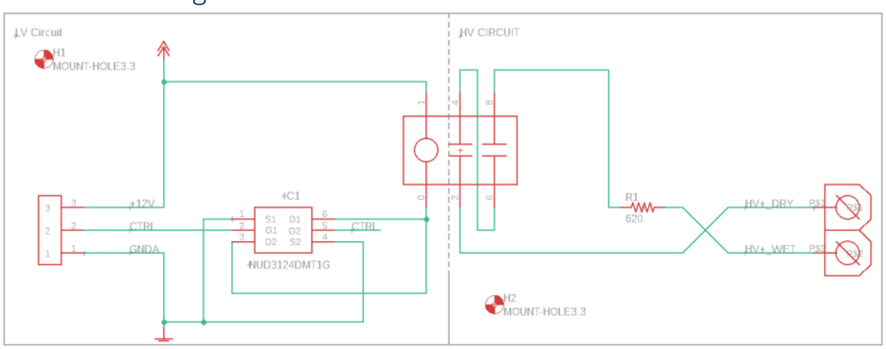

Figure 6-12 – Precharge circuit schematic

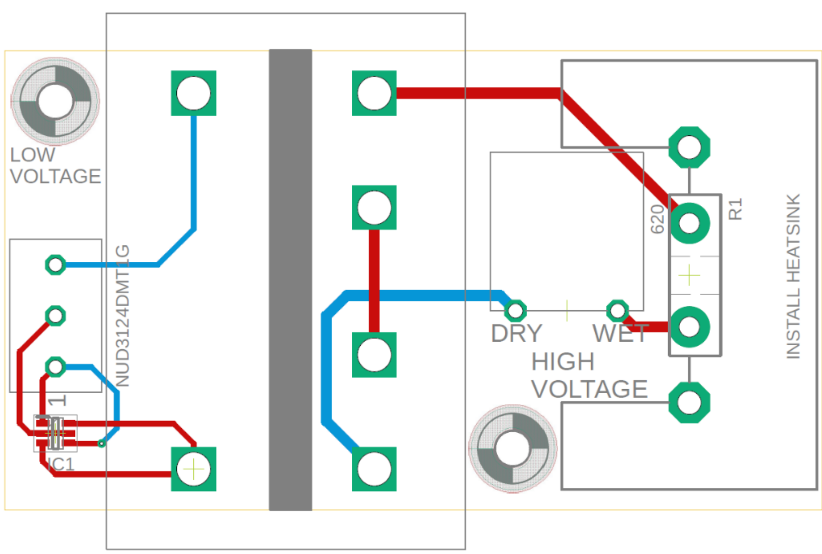

Figure 6-13 – Precharge circuit PCB layout

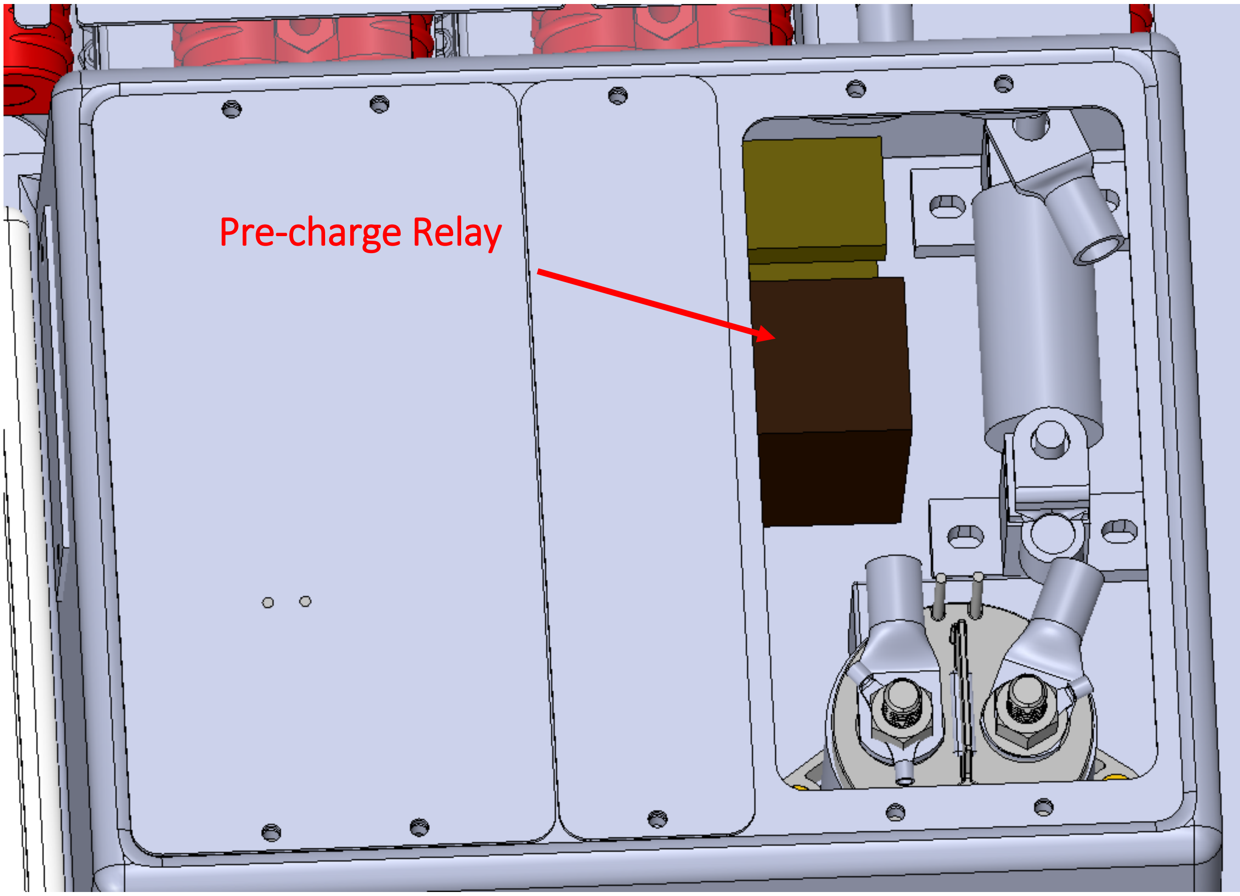

Figure 6-14 - Precharge Circuit Location

6.4.3 Precharge Circuit Controls

The precharge relay is controlled by pin J2 – 21 on the inverter, with the coil power supplied from the TSMS. When the drive receives a start request over can bus the pre-charge relay is actuated to begin charging the inverter. The internal capacitance of the PM100DXR is approximately 500uF, and the precharge resistor is 620ohms. This gives a time constant of 0.3 seconds, assuming the inverter will be charged to 95% within three-time constants, this gives a pre charge time of 0.9 seconds.

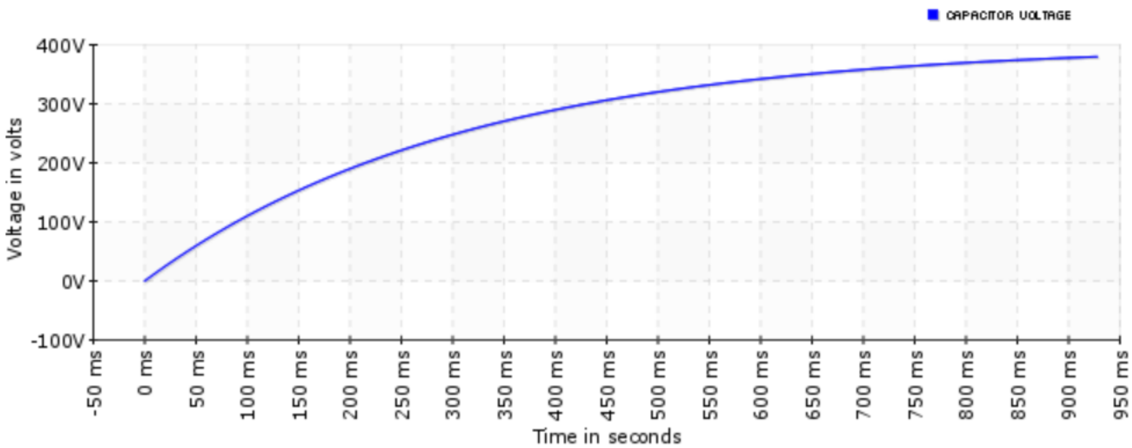

Figure 6-15 – Precharge voltage vs. time

Results	
Time	~928.677005 milliseconds
Peak power of the resistor	~258.064516 watts
Peak current	~645.16129 milliamperes

Figure 6-16 – Precharge circuit specifications

The system can determine if the vehicle is done pre-charging with the vehicle state machine of the PM100DXR. Charge completion is determined from the following set of steps taken from page 49 of the PM100DXR manual:

The following is brief description of the pre-charge sequence. Turn-on the PRE_CHG output if Vdc has not exceeded VIN_MAX. Otherwise, set VDC_OOR_HI fault and go to the FAULT state.

1. If all the following conditions are true: Vdc stops rising by less than PRECHARGE_RATE V/s Vdc is greater than VIN_MIN, Vdc is less than VIN_MAX Time has not exceeded 1 second Then do the following: Engage the MAIN_OUT output Turn-off the PRE_CHG output Go to the 30ms delay.

2. If total pre-charge time exceeds 1 second then: If the DC BUS is greater than VIN_MAX:
o Turn the PRE_CHG output off
o Declare VDC_ OOR_HI fault. If the DC BUS is less than VIN_MIN:
o Turn the PRE_CHG output off
o Declare VDC_ OOR_LOW fault If Vdc is still rising by more than or equal to PRECHARGE_RATE V/s
o Turn off the PRECHARGE_OUT output
o Declare PRECHARGE_ TIMEOUT fault

3. Delay 30ms.

4. Measure Vdc. If Vdc is above VIN_MAX, declare VDC_OOR_HI fault. If VDC is below VIN_MIN, declare VDC_OOR_LO fault.

5. Delay 15ms.

6. Take another measurement of Vdc. If Vdc is above VIN_MAX, declare VDC_OOR_HI fault. If VDC is below VIN_MIN, declare VDC_OOR_LO fault.

7. Verify that voltage is within VDC_MATCH_RANGE_THRESHOLD of the first measurement. If not, declare VDC_DATA_MISMATCH fault.

6.5 BMS

6.5.1 BMS Specifications

The Orion BMS 2 has been selected for use as a BMS. The Orion BMS 2 is a pre-packaged solution that offers galvanic isolation between the GLV and TS busses. The Orion BMS 2 datasheet can be found here.

The Orion BMS 2 has the following Isolation features:

- Cell taps isolated from input power supply, chassis and I/O
- 2.5kV isolation between each connector of cell taps
- Isolation allows for use of in-pack safety disconnects and fuses
- High voltage isolation fault detection circuit to monitor the breakdown of wire insulation

6.5.2 Temperature Sensors

Make / Model:	Texas Instruments LM 135
Accuracy of sensor:	1°C when in operating range of –20C to 60C
Datasheet:	Datasheet
# of sensors:	40
% of cells sensed:	42%

Table 6-6 - Temperature Sensor Specifications

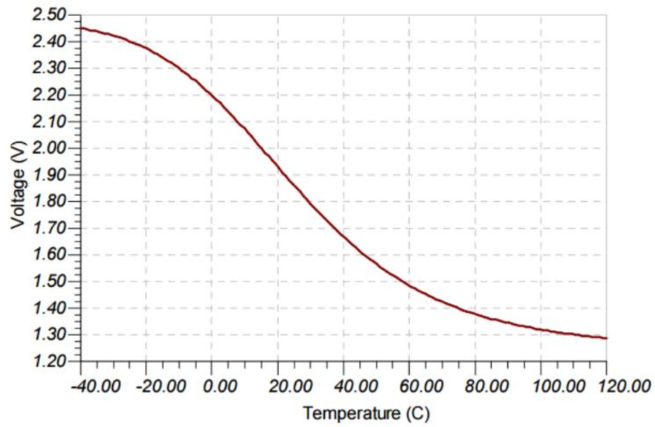

Figure 6-17 – Temperature Sensor Output

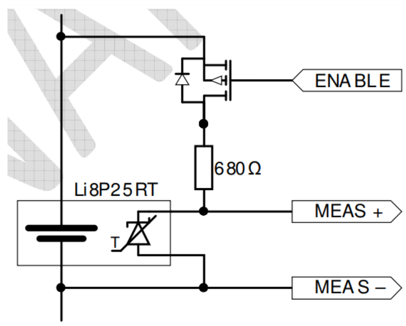

Figure 6-18 – Temperature Sensor Configuration

6.5.3 Temperature Sensor Location

The temperature sensors are directly built into the modules purchased from Energus. The temperature sensors are directly mounted to the negative terminals of each cell and are OR'd together to provide the highest temperature via to analog pins on the outside of each module. An image outlining this connection is shown below which is representative of the connection type, but not our specific modules.

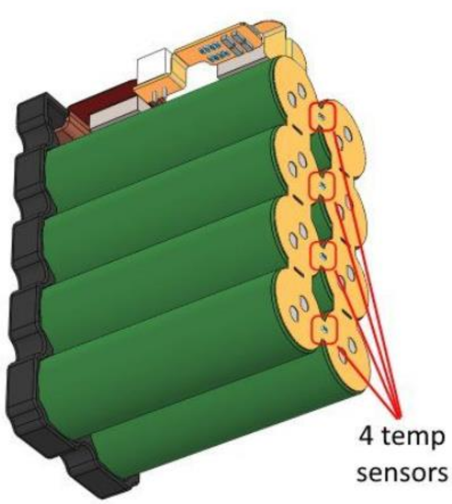

Figure 6-19 - Location of Temperature Sensors

6.5.4 BMS Voltage Sense Leads
The voltage sense leads are attached to the cells via a M5 bolt placed on top of the busbar connection to each parallel string of cells. The M5 bolt will clamp the busbar and voltage sense lead together and be positively retained via a tab washer. See below for a view of this connection.

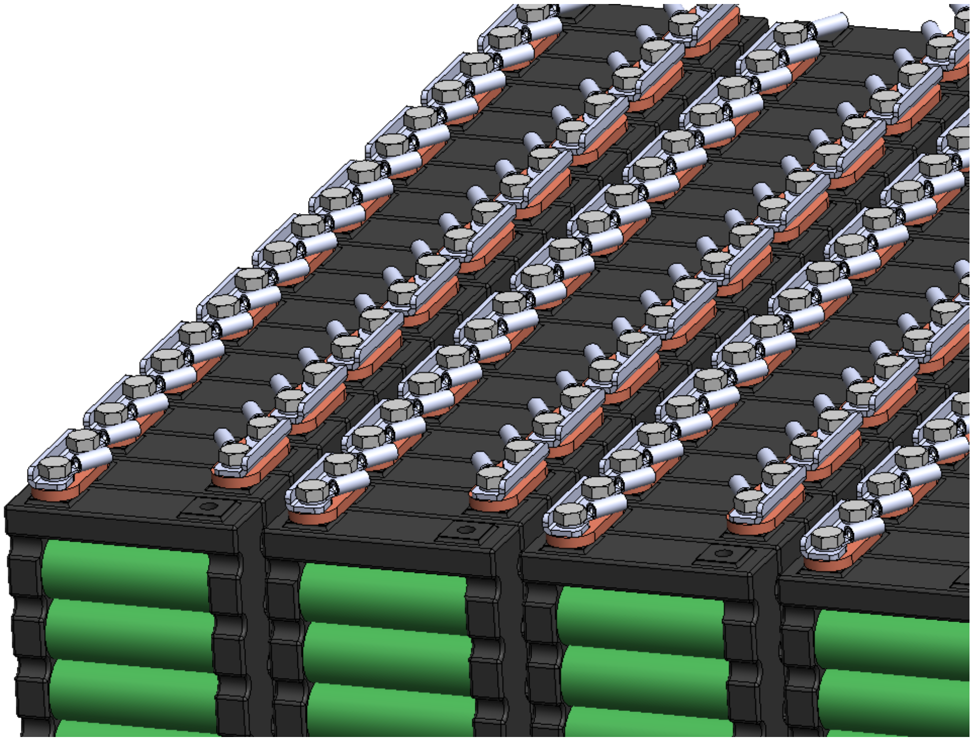

Figure 6-20 – Voltage Sense Leads

6.5.5 BMS Voltage Sense Lead Overcurrent Protection
The Voltage Sense leads are over current protected by fusible link wire that are directly connected to the voltage sense ring terminals as shown above. The sense leads are size 18AWG wire with an ampacity of 10 amps. To protect this wire, a 6 inch strand if 22AWG fusible link wire is used.

6.5.6 BMS Limits

Max Cell Voltage:	4.2V - 0.1mV (for error) – 0.2mV (for FOS)
Min Cell Voltage:	2.5V - 0.1mV (for error) + 0.2mV (for FOS)
Max Temperature:	59°C (for discharge) 49°C (for charging)
Min Temperature:	-19°C (for discharge) 1°C (for charging)

Table 6-7 - BMS Setpoints

6.5.7 BMS Location

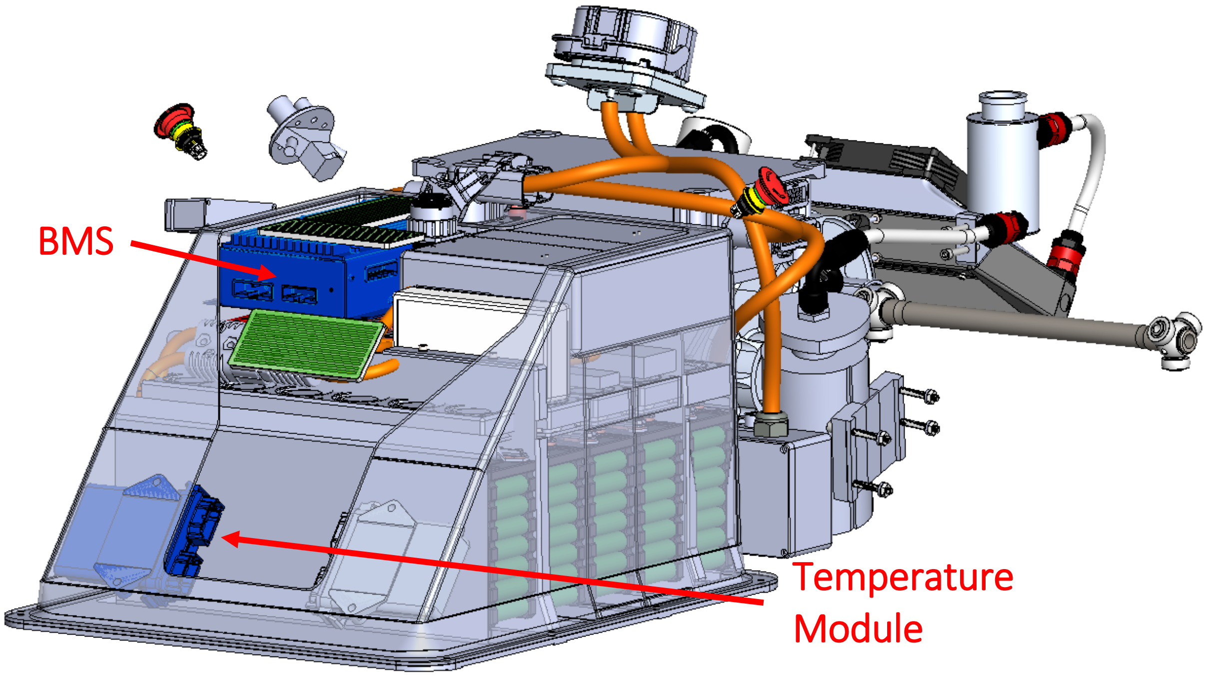

Figure 6-21 - BMS Location

6.6 AIR

6.6.1 AIR Specifications

Make / Model:	Gigavac / GV200MAC-1
Contact Current:	500A
Contact Voltage:	800V
Datasheet:	Datasheet

Table 6-8- AIR Specifications

6.7 Accumulator Indicator

6.7.1 Accumulator Indicator Schematic

The accumulator light output comes from the ACC light terminals located on the HVIB. It is activated by the same sensing lines that turn on the TSAL when the accumulator is connected to the vehicle. Further documentation on the HVIB is located at the end of the document in section 8.4.2.

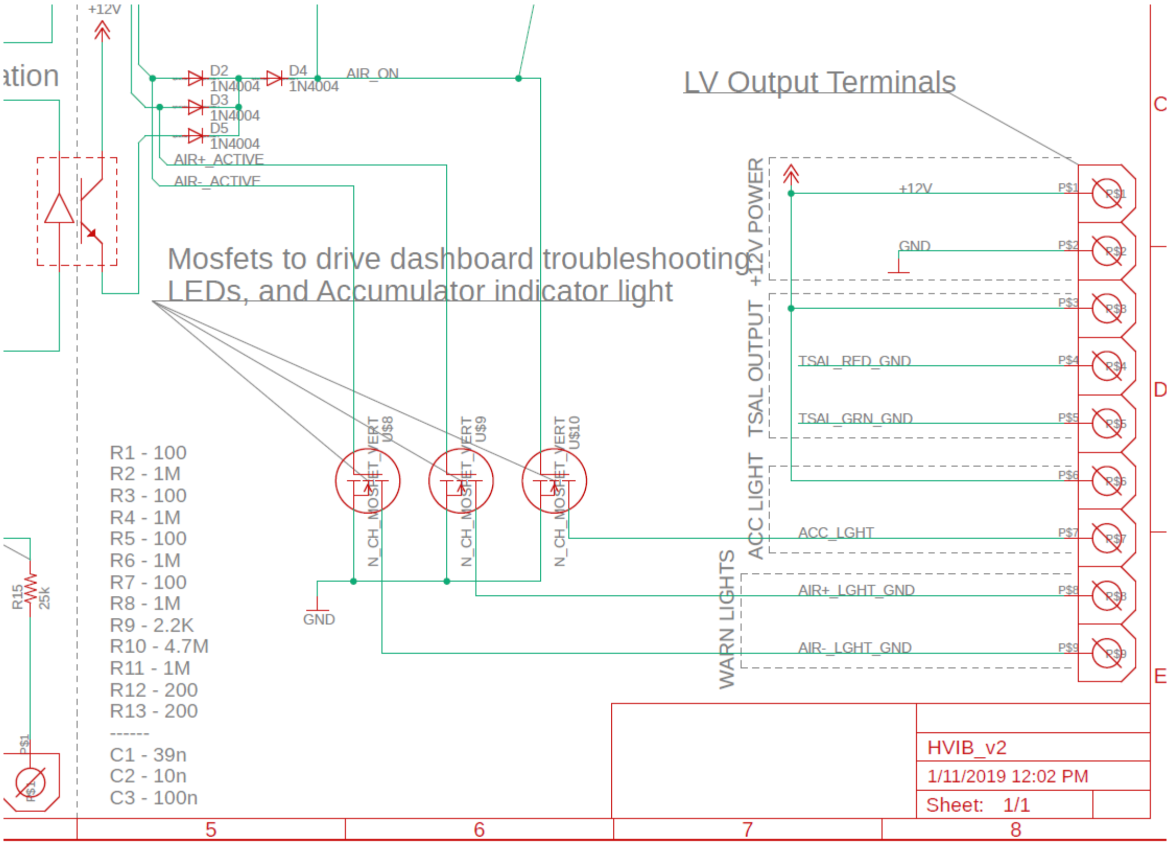

Figure 6-22 - Accumulator Indicator Light Mosfet Output

The accumulator indicator is driven by the same circuit as the TSAL circuit. Instead of driving a clock signal however, it is driven by a single MOSFET which turns on an LED on the accumulator container.

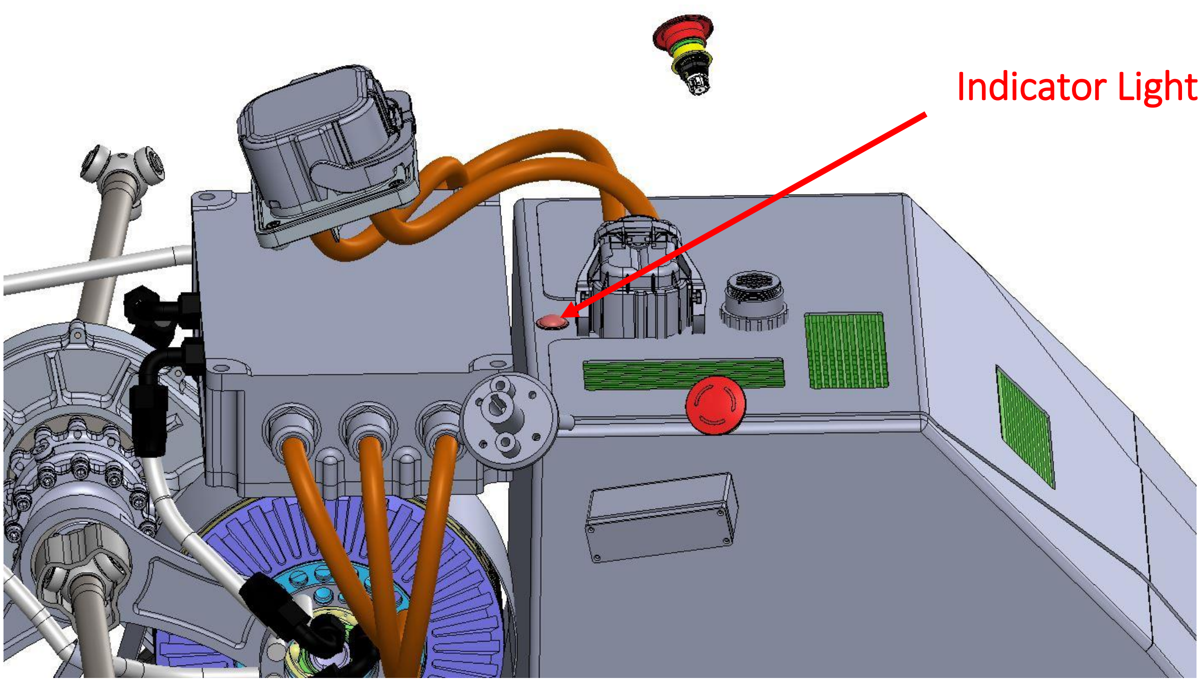

Figure 6-23 - Schematic of Accumulator Indication

6.8 Mechanical

6.8.1 Accumulator Enclosure

Each cell module is insulated from the accumulator container by means of a structural UL94 V-0 plastic that encases the cells.

The accumulator container, including all internal vertical walls, is made of sheets of carbon and glass fiber reinforced polymer. Each sheet contains some number of carbon fiber plies such that structural requirements are met as per the Structural Equivalency rules for the HV Enclosure. Each sheet also contains glass fiber plies such that it is insulated and rated to a dielectric breakdown greater than the voltage of the traction system. See below for insulation calculations:

Dielectric strength of fiberglass: ***13.5MV/m*** *(datasheet)*

Critical thickness = 400V/13.5MV/m = 0.00002962962m = 0.002mm

Finishing glass fabric has thickness between 0.1-0.2mm, meaning panels will be insulated with a factor of safety of 100-200 for dielectric breakdown.

Each sheet is infused with CELLOBOND Phenolic J2027X-1 , a phenolic resin provided to the team by Hexion (Three Data Sheets: datasheet 1, datasheet 2, datasheet 3), in order to be flame retardant to FAR25. Phenolic resin is not electrically conductive. Furthermore, the extremely fine weave of the glass plies combined with the fact that it is encased in the resin means that panel will remain insulated even if it is scratched or otherwise damaged.

6.8.2 AIR and Fuse Separation

Each Energus battery module is a set of seven 18650 cells encased on the top and on the sides by a structural UL94-V0 plastic. This layer of structural plastic ensures that the cells do not come into contact with the accumulator container, and also create separation between the cells and the AIR and/or fuses. The AIR and fuses are also situated above a layer of plastic fans that are further encased in plastic and thus create another insulating barrier between the cells.

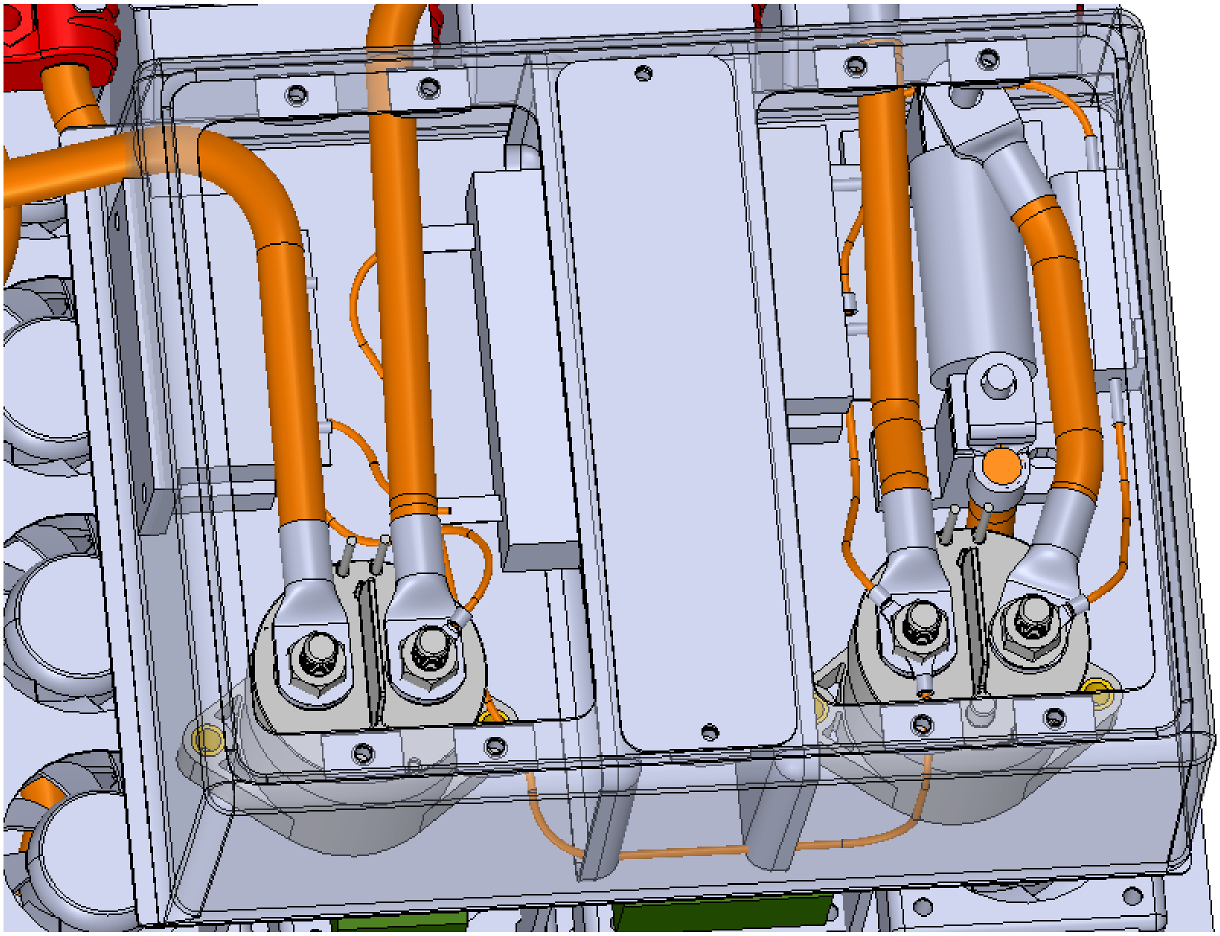

Figure 6-24 - AIR and Fuse Separation

6.9 Charging

6.9.1 Charger Specifications

Make / Model:	TSA400-12/208SP
Power:	5KW
Output Voltage:	400V
Output Current:	12A
Input Voltage:	208V
Input Current:	38A
Datasheet:	Datasheet

Table 6-9 - Charger Specifications

6.9.2 Charging Shutdown Circuit

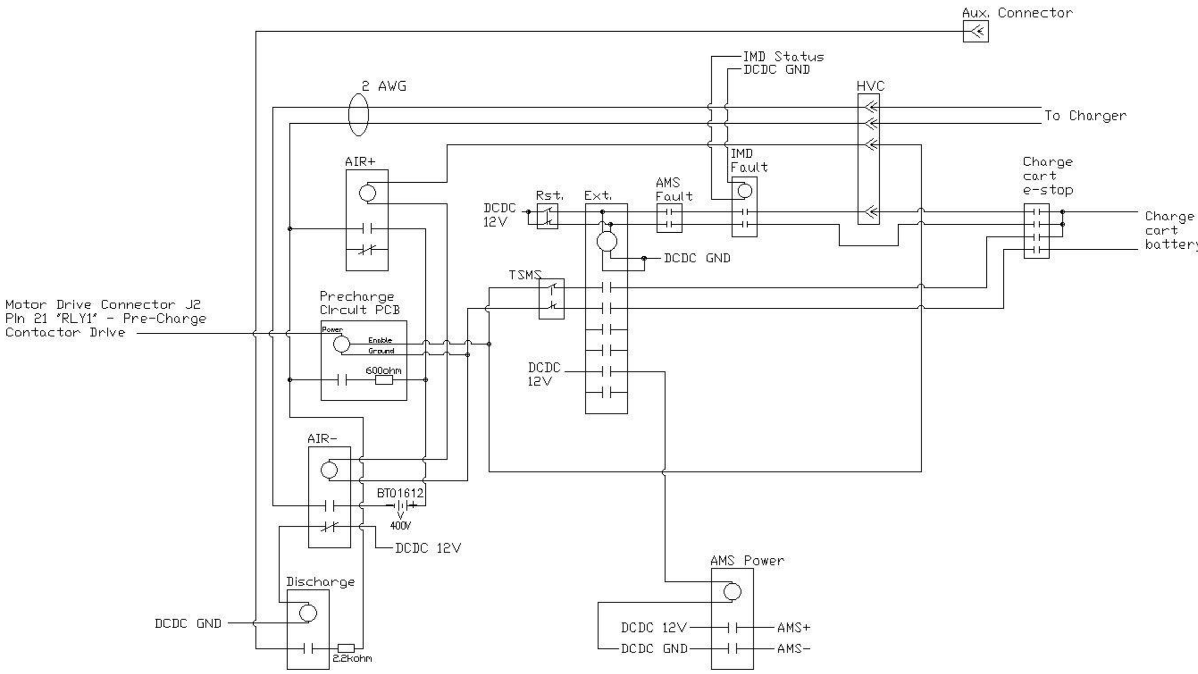

Figure 6-25 - Charging Shutdown Circuit Schematic

6.9.3 Charging TS Circuit

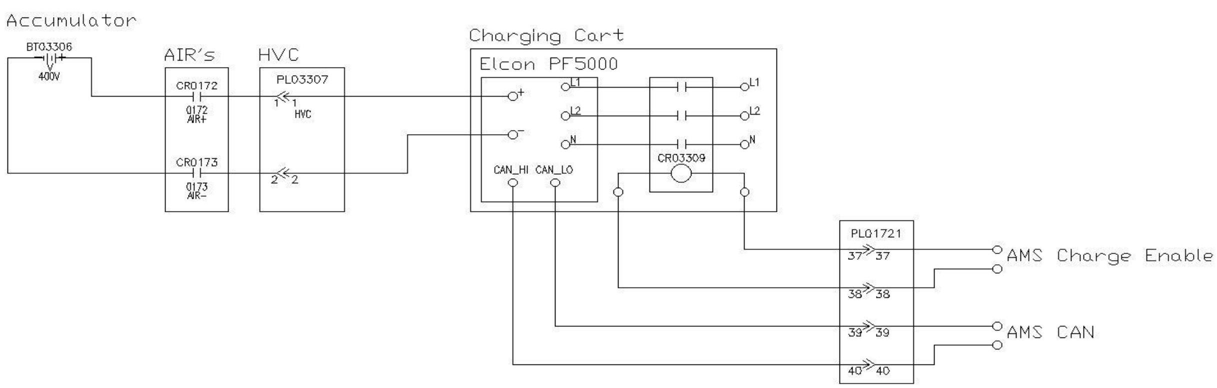

Figure 6-26 - Charging TS Schematic

6.9.4 Charger TS Connection Interlock

The main TS connector for our accumulator has a pilot line interlock integrated into it. If this pilot line is broken or any other safety faults occur, the AIRs are opened.

6.9.5 Charger Control

Once the low voltage connector is plugged into the accumulator from the charging cart, the BMS will boot up in charging mode. While in charging mode the accumulator has an interlock connection the charger, which will shut the charger off in the event of the following conditions:

- Overcurrent
- Over-temperature

- Under-temperature
- Over-voltage
- Under-voltage
- General fault

If the AMS detects any of the previous faults, it will output an unsafe status signal to the charger which will shut it off.

6.9.6 Charger Demonstration

1. Ensure the charger is disconnected from AC power.
2. Ensure service cap is installed on the accumulator's TSMP connector.
3. Connect low voltage connector to the charger harness.
4. Connect high voltage connector to the charger harness.

Ensure that the accumulator indicator light is red to indicate that the AIRs are shut. Once the charger is connected properly it will have output current displayed on an LCD screen located on the front of the charger.

7 Motor Controller

7.1 Controls Architecture/Torque Security

Our apps sensor provides two isolated sensor outputs which are measured by the VCU. The VCU then compares the two signals which are scaled against a chart that is tuned by the team. If the two signals deviate by more than 10% of their scaled values, then the VCU signals an implausibility fault and sets the output torque of the motor controller to 0. If the signal is determined to be plausible then the requested torque is determined based on a scaled value from zero to 125 Nm.

If the vehicle detects wheel slippage than compensation torque is applied to reduce the output torque of the motor. Compensation torque can only be negative, meaning that it can only reduce the requested torque from the motor, not increase it.

The signal path for the torque command is shown in the figure below, highlighted by the red square.

The torque signal from the APPS input is internally pulled up by the VCU, and the CAN-BUS transmission from the VCU to the PM100DXR is verified by a heartbeat signal. If the heartbeat signal is lost between the VCU and the PM100DXR the output torque of the motor is set to zero.

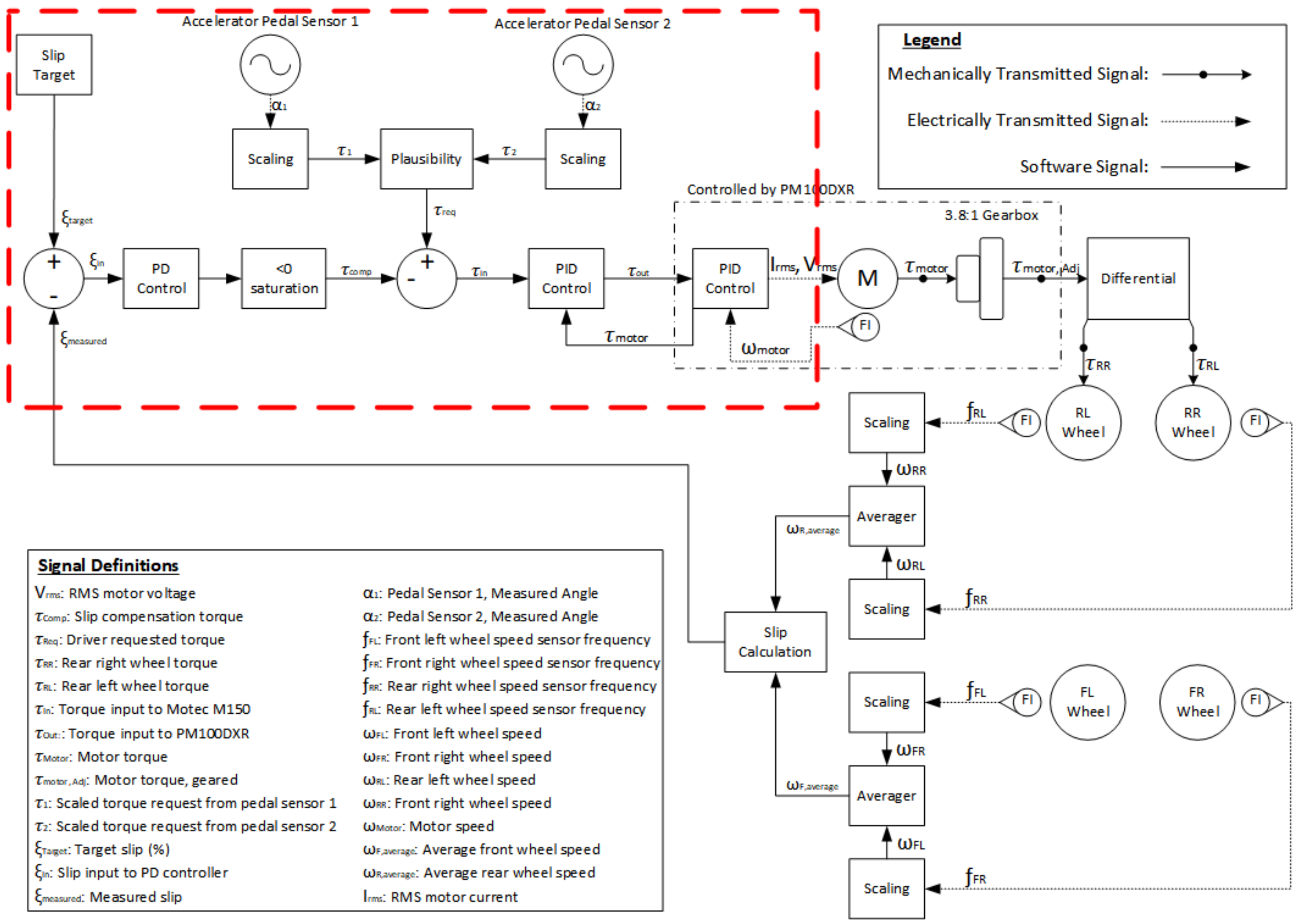

Figure 7-1 - Toque Control Signal Path

7.2 Galvanic Isolation

The RMS PM100DXR HV system is isolated from the 12V power input.

8 Other Items

8.1 Energy Meter

8.1.1 Energy Meter Location

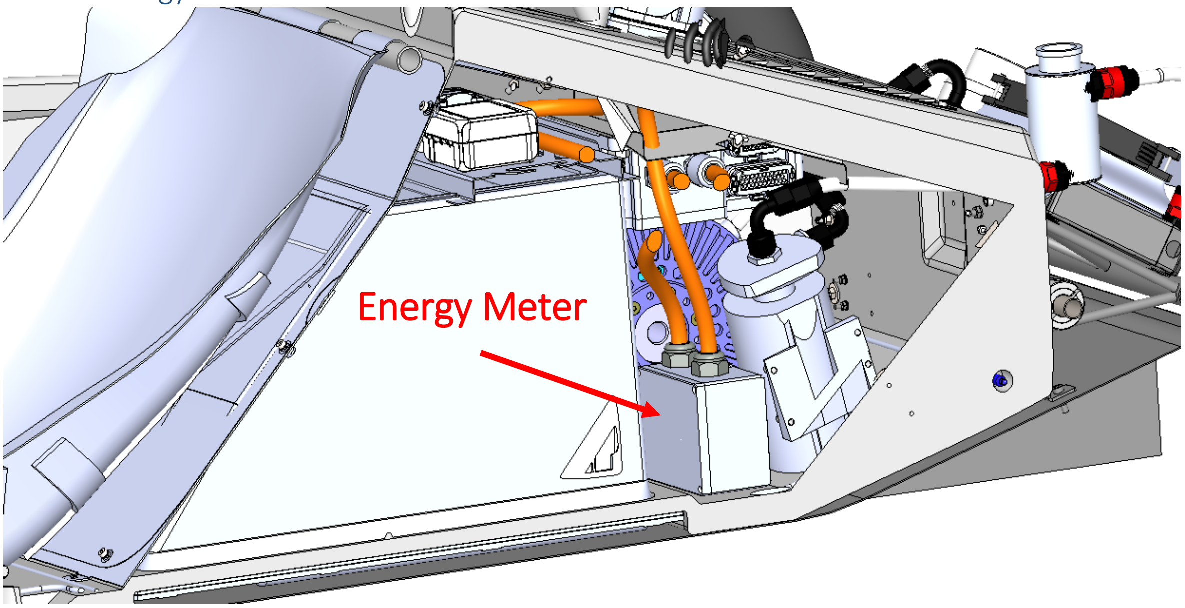

Figure 8-1 - Energy Meter Location

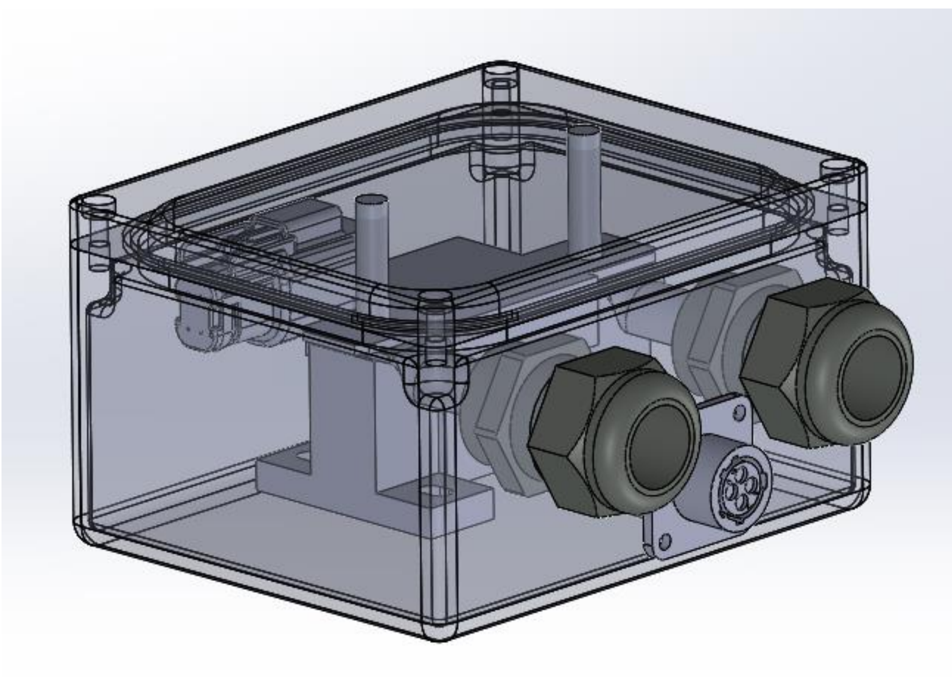

Figure 8-2 - Energy Meter Internal Layout

8.1.2 Energy Meter GLV Supply

Energy meter GLV power is supplied via the LV power distribution module (PDM) located outside of the accumulator.

8.1.3 Energy Meter HV Sense

The accumulator voltage is sensed by the energy meter by using the voltage sense line coming from the auxiliary connector of the accumulator. The voltage sense line exits via the auxiliary connector, and then enters the energy meter enclosure via a wire gland. The line is fused by HVIB terminal 14 located within the accumulator.

8.2 Firewall

8.2.1 Firewall Layer Specifications

Aluminum layer thickness:	0.64mm
Insulating layer thickness:	1mm
Insulating Material Make / Model:	Fiberglass fabric with Phenolic J2027X-1 Cellobond resin.
Insulating Material Datasheet:	Datasheet 1 Datasheet 2 Datasheet 3
Insulating layer side:	Driver Side (as per rules)

Table 8-1 - Firewall Specifications

8.2.2 Firewall Location

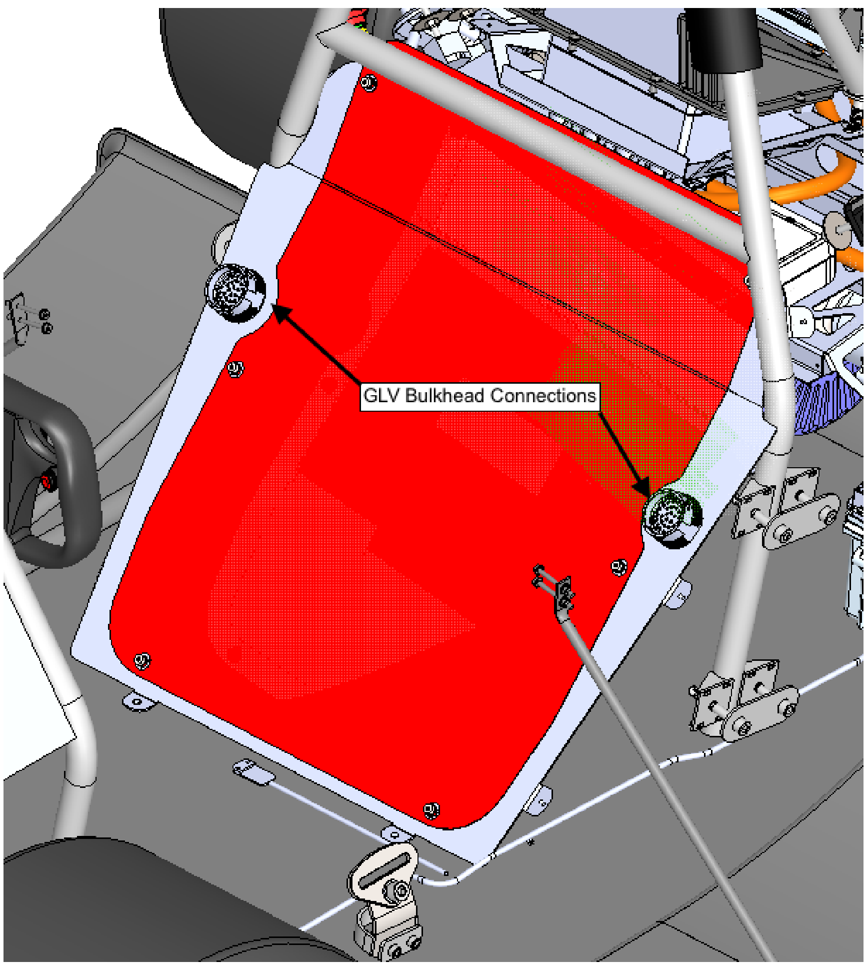

Figure 8-3 - Firewall Location

Firewall shown in red in render above. The plate it is directly resting on, the firewall bracket, can also be considered part of the firewall. Two Grounded Low Voltage (GLV) bulkhead connections are placed on this bracket.

8.3 Grounding

8.3.1 Composite Grounding

All composites will be grounded using a highly conductive spray-on Nickel coating. This coating is offered by MG Chemicals and was tested by the team to confirm conductivity (Datasheet).

8.4 Other Components

8.4.1 DCDC Converter

The DCDC converter is located in the accumulator. It uses normally open thermal switches to disable converters if the board rises above 80 degrees Celsius. A 5V isolated converter and a 2.8V voltage reference IC are used to generate trim voltage. Each converter is fused at 1.6A.

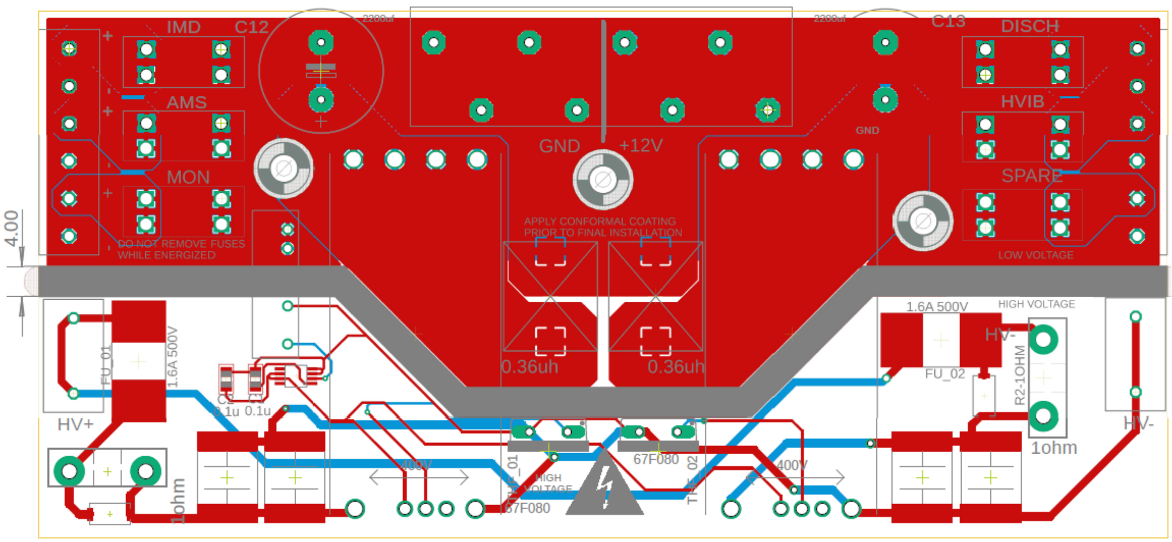

Figure 8-4 - DCDC Converter Board Layout

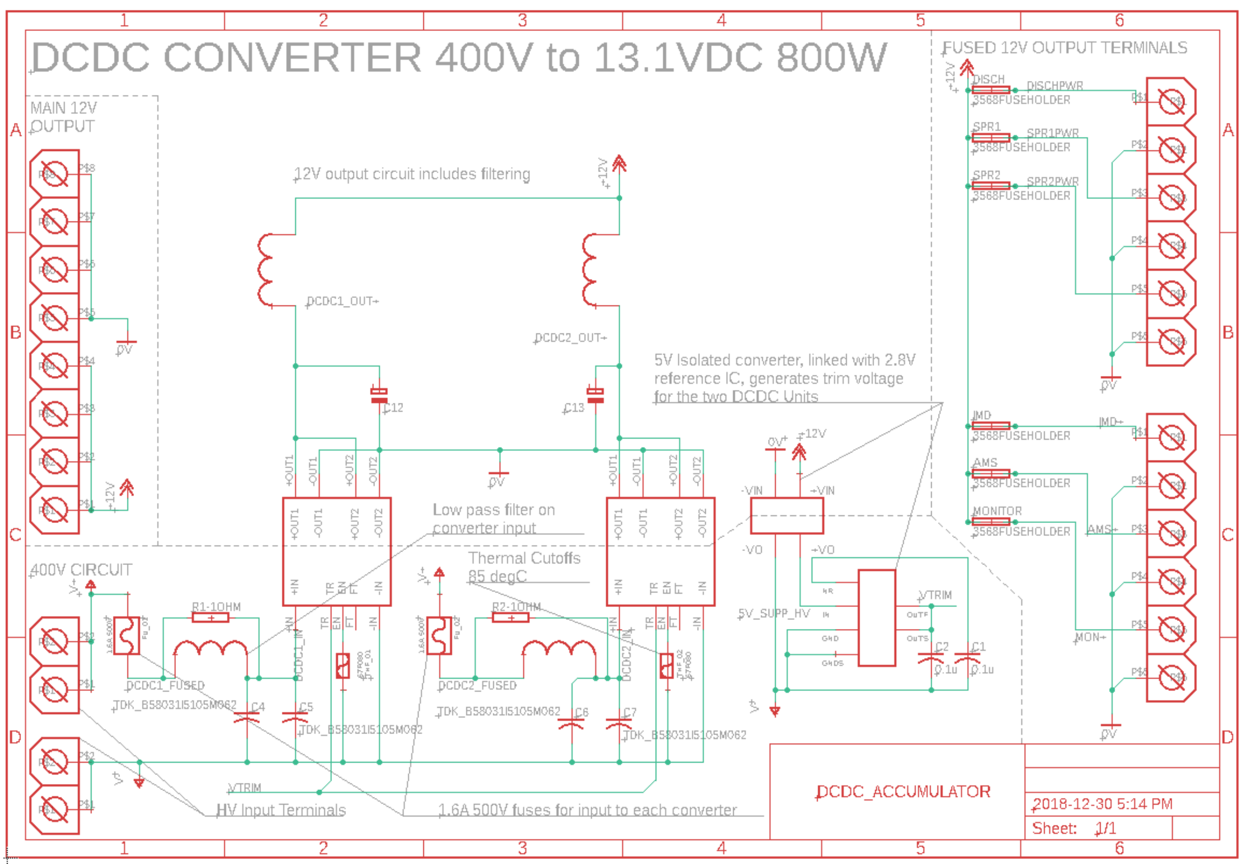

Figure 8-5 - DCDC Converter Schematic

Table 8-2 - DCDC Converter Bill of Materials

Part	Part Number	Qty	Manufacturer	Datasheet	Comments
LV Fuseholder	3568	6	Keystone Electronics	Datasheet	500V 20A
DCDC Converter	DCM4623TD2J13D0T00	2	Vicor	Datasheet	180-420V input, 12V 400W out
Input Resistor	PF2472-1RF1	2	Riedon	Datasheet	TO247, 100W
Input Inductor	P1330-102H	2	API Delevan Inc	Datasheet	1.02uh
Output Inductor	MPC1250LR36C	2	KEMET	Datasheet	0.36uh
Input Capacitor	B58031I5105M062	4	TDK	Datasheet	500V Rating, 1uf
Output Capacitor	UKL1C222KHD	2	Nichicon	Datasheet	16V, 2200uf
Thermal Cutoff	67F080	4	AIRPAX	Datasheet	TO - 220, 85degC
HV Input Terminals	282838-2	2	TE Connectivity	Datasheet	13.5A, 600V
LV Ouptput Terminal	1777600	1	Phoenix	Datasheet	41A, 1000V
LV Fused Terminals	1935200	2	Phoenix	Datasheet	17.5A, 400V
Input Fuse	088501.6DR	2	Littlefuse	Datasheet	1.6A, 600V, 1 per DCDC unit, Solder in
High Voltage Side DCDC	MEV1S1205SC	1	Murata Power Solutions	Datasheet	13.2V to 5V, Isolated
Vtrim Reference	MAX6126A28+	1	Maxim Integrated	Datasheet	2.6 to 12V in, 2.8V out

8.4.3 High Voltage Interlock Board

The High Voltage Interlock Board is designed to accomplish the following tasks:

- House the TSMP resistors
- Fuse the input to the energy meter
- Fuse the input to the IMD
- Sense current across both AIRs or a presence of voltage on the dry poles of the AIRs
- Control the TSAL
- Control the Accumulator Indicator Light
- Provide auxiliary output lights to indicate if either AIR has been closed

The board features detection between three points across the poles of the AIRs to determine if either AIR is shut, or if there is HV present across the AIR poles. Based on that, the circuit provides a switched ground output for the accumulator indicator light, the TSAL green and red lights, and two LEDs located on the dashboard that indicate which AIR is shut. A schematic is included below.

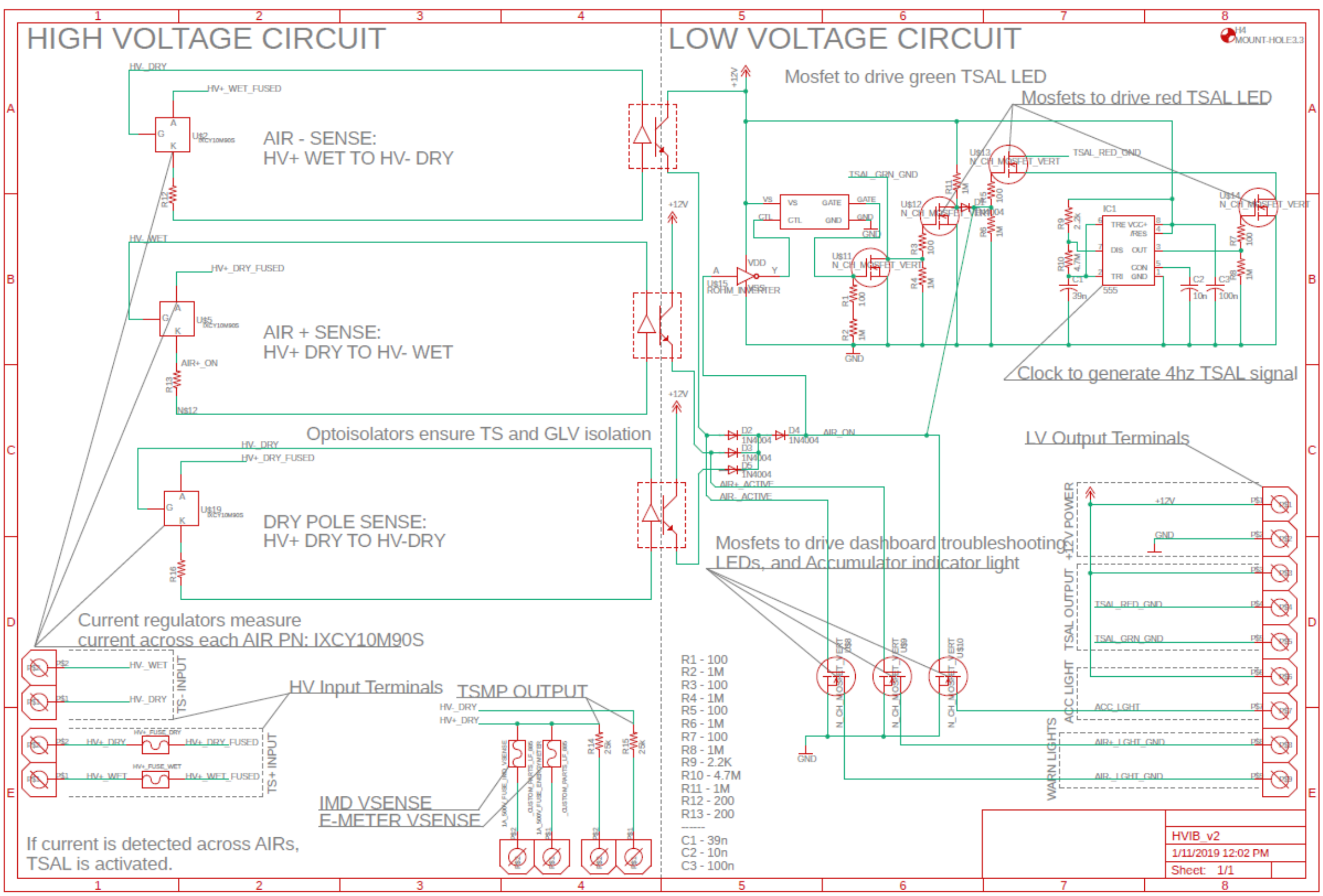

Figure 8-6 - HVIB Circuit Schematic

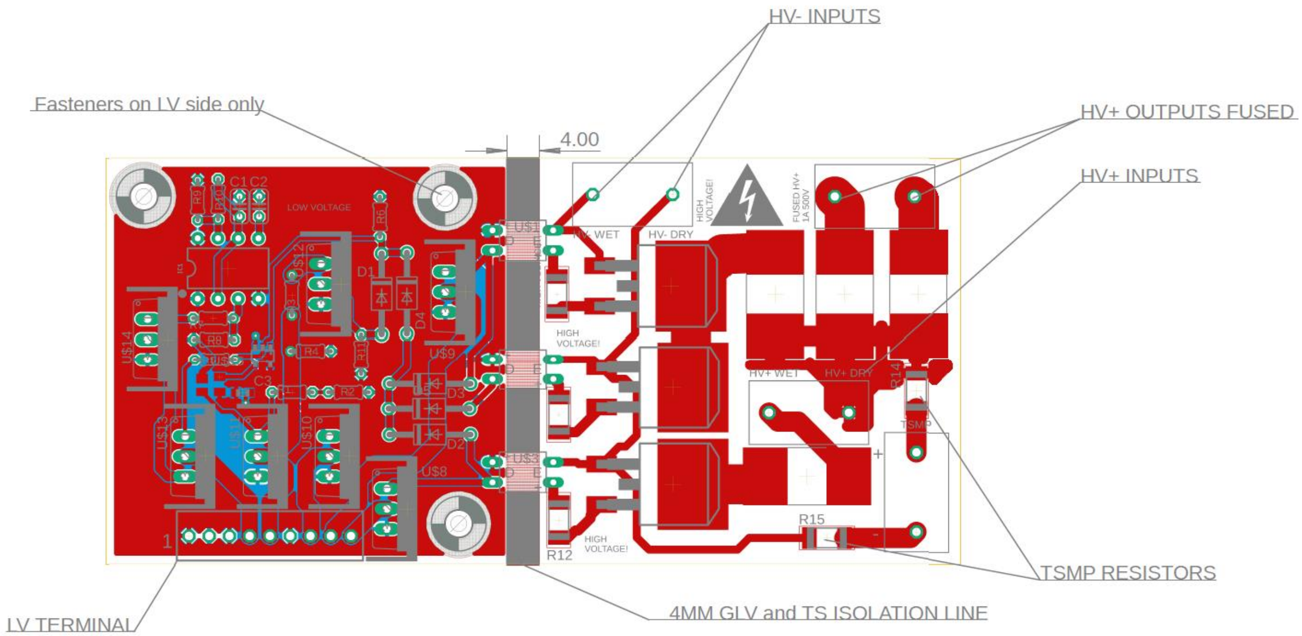

Figure 8-7 - HVIB PCB Layout

Bill of materials listed below:

Name	Part	Manufacturer	Qty	Comments	Link
Opto Isolator	OPI7002	TT Electronics	2	6000VDC Isolation	Datasheet
HV Terminal	282838-2	TE Connectivity	2	13.5A, 600V	Datasheet
TSMP Resistor	CRCW201015K0FKEF	Vishay Dale	2	15kohm, 2010 package	Datasheet
200ohm Resistor	RMCF2010JT200R	Stackpole	3	2010 Package	Datasheet
Current Regulator	IXCY10M90S	IXYS	3	900V, 100mA rating	Datasheet
LV Terminal	1725724	Phoenix	1	9 Posn, 2.54mm Pitch, 6A	Datasheet
NCH Mosfet	PHP18NQ11T,127	Nexperia USA, Inc	7	10A Id, 200V	Datasheet
Mosfet Heatsink	V7236A1	Assmann	7	1.5W Power Dissapation	Datasheet
Thermal Pad	SP400-0.009-00-58	Bergquist	7	TO-220 Thermal Pad	Datasheet
Inverter Gate	BU4SU69G2-TR	Rohm Semiconductor	1	3-16V supply	Datasheet
Timer	SE555P	Texas Instruments	1	555, 4.5 - 18V Supply	Datasheet

9 Appendix

9.1 SDS (MSDS) of accumulator cell

Link