OLIN ELECTRIC
MOTORSPORTS

Electrical System Form FSAE-E 2017
Car E238

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List of Abbreviations

- MSD- Manual Service Disconnect
- CONN- Main accumulator connector
- APPS- Accelerator Pedal Position Sensor
- AMS/BMS- Accumulator Management System / Battery Management System
- TS+ / TS- - High and Low pole of the tractive system

Any other abbreviations used in this document are those used in the 2016 Formula SAE Rules and those used in the FSAE ESF template document.

1 System Overview

The vehicle's electrical system is designed to support all necessary functions of electric vehicle locomotion, while simultaneously ensuring driver and team member safety. The vehicle's electrical system is comprised of two major galvanically isolated subsystems: a 298.8V maximum high power tractive system and a 14V maximum sensing and control system.

The tractive system consists of a custom-designed and fabricated accumulator container which houses 72 LG Chem proprietary pouch cells, as well as a Rinehart Motion Systems PM100DX motor controller driving an Emrax 228 Medium Voltage outrunner motor. Communication to the motor controllers is achieved via the CAN network built into the low voltage system.

The low voltage system consists primarily of a shutdown circuit and a series of peripheral sensors to gather data about vehicle state and performance, all powered by a 12V nominal sealed lead acid battery that is recharged by a DC/DC converter. The Shutdown circuit monitors the vehicle for dangerous conditions such as impacts or isolation faults of the Tractive System, and de-energizes the vehicle in case of emergency. The low voltage system also contains a CAN communication network between Atmel ATmega16m1 microcontrollers that fulfill several rules-required functions like the Ready-to-Drive sound, as well as collecting data and serving as a debugging tool for both high and low power electrical systems.
See figure 1 for a block diagram of the Tractive System and interfacing GLVS parts.

Maximum Tractive system voltage	298.8 VDC
Nominal Tractive system voltage	266.4 VDC
Control-system voltage	12 VDC
Accumulator configuration	72s1p
Total Accumulator capacity	27 Ah
Motor type	permanent magnet synchronous motor
Number of motors	1
Maximum combined motor power in kW	100 kW

Table 1.1: General parameters

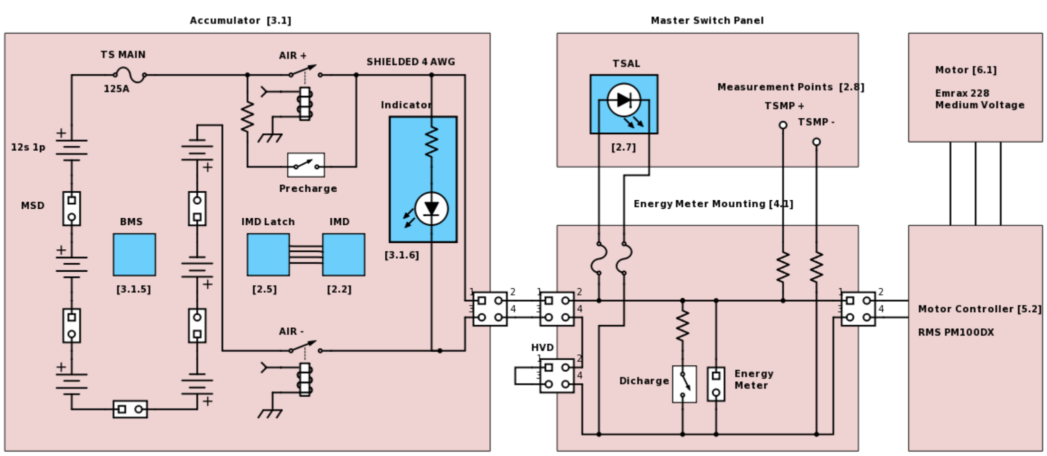


Figure 1: Block diagram of the enclosures of the Tractive System

2 Electrical Systems

2.1 Shutdown Circuit

2.1.1 Description/ concept

The shutdown circuit directly controls the current that closes the AIRs. Since each switch/relay on the shutdown circuit is connected in series, that current must pass through every switch and safety check. If any device on the circuit is triggered by an unsafe condition, the current to the AIRs is cut off and the AIRs open, disconnecting the accumulator from the tractive system. Any capacitive load on the tractive system outside the accumulator is then discharged to ensure that all high voltage is contained inside the accumulator.

- The GLV Master Switch (GLVMS) controls power to the entire low voltage system including the AIRs. As a result, high voltage cannot be present when the low voltage system is not active. The GLVMS has a lockout such that the vehicle can be safely worked on.
- The Left E-Stop is a large red push-rotate button located at approximately the height of the driver's head on the left side of the vehicle.
- The Right E-Stop is identical to the Left E-Stop located on the other side of the vehicle.
- The Brake System Plausibility Device (BSPD) holds a normally open relay closed when it has not detected an implausibility. When it does detect an implausibility, it latches in a low state until the GLV system is power cycled. This shuts down the Tractive System in the event that the brake is pressed while the motors are being significantly driven.
- The Brake Over Travel Switch (BOTS) is a push pull switch located behind the brake pedal. If the pedal over travels, the switch is pushed into an open state and stays that way until it is pulled back into the closed state. This shuts down the Tractive System in the event that brake pressure is lost.
- The Dashboard E-stop functions the same as the other E-stops. It is located such that it can be easily pressed by the driver.
- The Inertia Switch operates as a crash sensor that opens the shutdown circuit in the event that it detects an acceleration indicative of a collision. This ensures that the vehicle is electrically safe in an emergency situation.
- The Battery Management System (BMS) monitors the condition of the accumulator. It holds a normally open relay closed while the lithium cells are operating within safe temperature and electrical conditions.
- The Insulation Monitoring Device (IMD) detects any loss of isolation between the Tractive and GLV systems. It's output is held high while isolation is maintained. This holds a normally open relay closed through a latching circuit that prevents the IMD from re-closing the relay if the output goes low and then returns high. This latches the Tractive System in a shutdown state until the GLV system is power cycled.
- The HVD interlock closes the shutdown circuit whenever the HVD is present. This automatically shuts down the Tractive System whenever the HVD is removed.
- There is an interlock on the Tractive System connector on the accumulator which can be removed without tools. If the connector is removed, the Tractive System automatically shuts down.
- The Tractive System Master Switch (TSMS) is the last switch in the shutdown circuit before the AIRs. It has a lockout such that the vehicle can be safely worked on.
- Both the Pre-charge Relay and positive pole AIR have software controlled MOSFETs in series after them such that the timing of the pre-charge can be controlled by the sensing system.

Part	Function
GLV Main Switch (GLVMS)	Normally open, with lockout
Shutdown buttons (SDB) (Left, right, cockpit)	Normally closed
Brake System Plausibility Device (BSPD)	Normally Open
Brake over travel switch (BOTS)	Push-pull normally closed button
Inertia switch	Normally closed
Battery Management System (AMS)	Normally open
Insulation Monitoring Device (IMD)	Normally open
Interlocks	Closed when TS connections are made
Tractive System Main Switch (SMS)	Normally open, with lockout

Table 2.1: List of switches in the shutdown circuit

2.1.2 Wiring / additional circuitry

Figure 2 on the following page shows the wiring of the shutdown circuit except the interlocks, which are detailed in section 2.6. The AIRs can only be closed and the tractive system energized when all of the elements of the shutdown circuit are closed. The shutdown circuit is expected to handle a maximum peak current of under 8A, so the wire gauge being used is 20AWG, protected by an appropriately-rated circuit breaker that is housed in the master switch panel.

Total Number of AIRs:	2
Current per AIR	3.9A peak while closing, 0.23 A average
Additional parts consumption within the shutdown circuit:	0.067 A (pre-charge and discharge relays)
Total current:	7.867 A peak (everything closing simultaneously)
Cross sectional area of the wiring used:	0.52 mm^2 (20 AWG)

Table 2.2: Wiring- Shutdown Circuit

2.1.3 Position in car

The shutdown circuit passes through five major enclosures on the vehicle. It originates in the master switch panel, then passes through the BSPD in the bulkhead enclosure, then through the cockpit E-stop in the dashboard, and into the IMD and the BMS latches in the accumulator, finally going to the AIRs and out to the discharge circuit in the energy meter enclosure. It also passes through the side E-stop switches along the way.

The shutdown circuit is wired between enclosures through waterproof TE Ampseal automotive connectors, is wrapped in abrasion-resistant mesh, and positively retained to chassis members with zip ties. Low voltage wiring is independently retained from high voltage wiring, and a minimum of 30mm separation is maintained.

2.2 IMD

2.2.1 Description (type, operation parameters)

The IMD used will be a Bender A-ISOMETER IR155-3204. The output is normally high and only low if it detects an isolation fault. The output is then sent to the IMD latch board, where it is powers a SPST-NO relay which

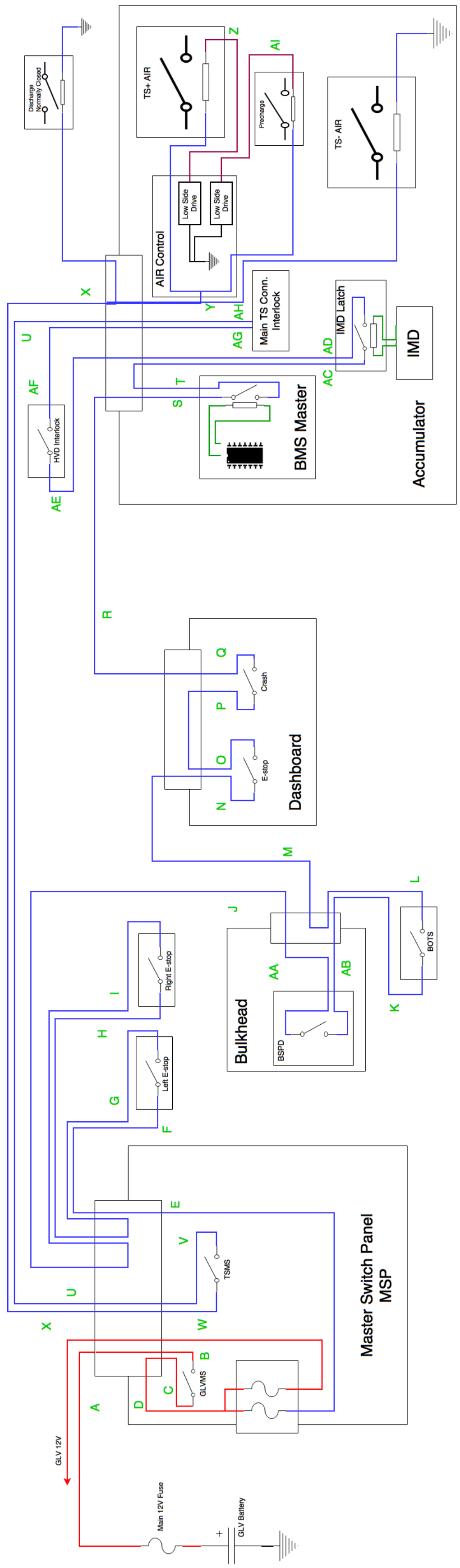


Figure 2: Block Diagram of Shutdown Circuit

closes a switch in the shutdown circuit. The output of the IMD is also monitored directly by an ATmega on the AIR control board. The status of the IMD is also monitored by the BMS master, which sends messages to the dashboard over CAN to toggle the IMD light. The IMD has a start up time of $\leq$ 2s. Further information on the IMD can be found in the appendix, section 11.2.2.

Supply voltage range:	10..36VDC
Supply voltage:	12VDC
Environmental temperature range:	-40..105°C
Selftest interval:	Always at startup, then every 5 minutes
High voltage range:	DC 0..1000V
Set response value:	100kΩ
Max. operation current:	150mA
Approximate time to shut down at 50% of the response value:	$\leq$ 40s

Table 2.3: Parameters of the IMD

2.2.2 Wiring/cables/connectors/

The IMD uses the TYCO-MICRO MATE-N-LOK 1 x 2-1445088-8 connector and it's mate. It connects to the IMD latch using 5-pin Molex LLC 1722861105 connectors. The signal is also sent to the BMS Master. The 18 AWG wire is more than sufficient for 150mA current draw of the IMD. The 18 AWG wire has a cross sectional area of 0.83mm^2, and is rated for at least 90°C, 300 V, and 16 amps. The HV wires to the IMD are protected by 3.15A fuses located on the pre-charge board. These fuses are identical to the fuses used to protect the TSAL, located in the energy meter enclosure documented in section 4. The datasheet can be found in section 11.4. The pre-charge board, seen to the left of the IMD in figure 4, is connected to TS+ and TS- (on the car side of the AIRs), as well as BAT+. It passes fused TS+ and TS- to the IMD.
The IMD latch shown in figure 3 on the next page uses the signal from the IMD to close a relay in the shutdown circuit. In order for the shutdown relay to close a second relay needs to be closed. The second relay is initially powered by a one shot 4 second pulse from the GLV system. After the first four seconds the signal from the IMD is used to keep the secondary relay closed. If the IMD signal goes low the secondary relay will close. This opens the shutdown relay and makes it impossible for the IMD to close the shutdown relay again until the latch has been manually reset. The initial 4 second pulse is necessary to ensure that anomalous start up behavior from the IMD does not cause the secondary relay to open and force a manual reset.

2.2.3 Position in car

The IMD will be located inside the accumulator, as shown in figure 4 on the following page. It is located in the accumulator for continual monitoring of pack isolation while the accumulator is removed for charging.

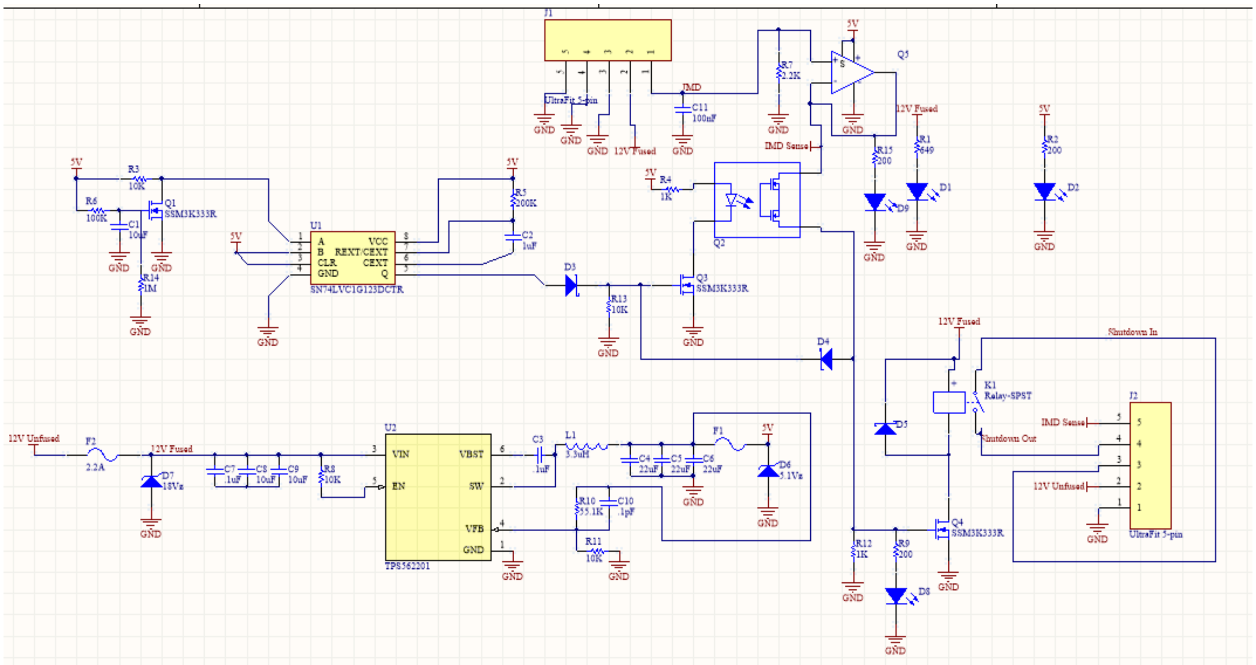


Figure 3: The schematic for the IMD Latch.

Figure 4: View of the top of the accumulator

2.3 Inertia Switch

2.3.1 Description (type, operation parameters)

The Sensata Resettable crash sensor (6-11g version) will trigger due to an impact that decelerates the vehicle between 6-11g.

Inertia switch type	Sensata 6-11g crash sensor
Supply voltage range	12 VDC
Supply voltage	12VDC
Environmental temperature range	-10-120°C
Maximum operational current	20A for max. duration 30sec, 10A max. continuous
Trigger characteristics	Operate above 11g peak, 60ms duration Not operate below 6g peak, 60ms duration

Table 2.4: Parameters of the Inertia Switch

2.3.2 Wiring/cables/connectors/

The Inertia switch will be wired to open the shutdown circuit in the case that there is a crash. The inertia switch is wired in-line with the shutdown circuit to be normally closed. Please see figure 2 on page 4 for the position of the inertia switch relative to the other shutdown system components.

2.3.3 Position in car

The inertia switch will be located on the side of the dashboard enclosure. It is mounted upwards, so the top body panel will have to be temporarily removed to reset it, as seen in figure 5.

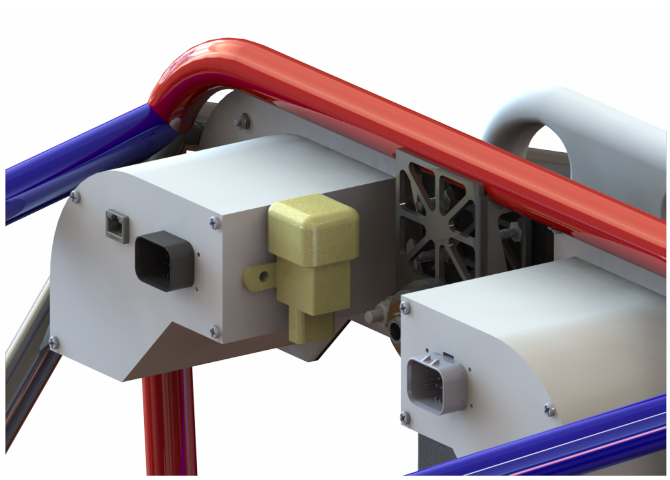


Figure 5: Positioning of the inertia switch alongside the dashboard enclosure

2.4 Brake Plausibility Device (BSPD)

2.4.1 Description/additional circuitry

The Brake System Plausibility Device (BSPD) is a custom circuit designed to open a relay in the shutdown circuit if the brakes are being pressed while there is positive-current being delivered to the motors for more than 0.5 seconds. The custom circuit takes in two digital signals, the brake signal and a boolean yes/no whether or not positive-current is being delivered to the motor. The positive-current will be sensed with our BMS using a hall-effect current sensor and a comparator which will output high when positive-current is being delivered to the motors.

The BMS uses a LEM HO 50-S hall effect current sensor. With our nominal pack voltage of 237.6V, it switches at 21A or 5kW to comply with EV5.6. As can be seen in the datasheet, which can be found in section 11.2.4, the sensor has a sensitivity of 16 mV/A. Figure 7 shows the circuit on the BMS, which amplifies the signal relative to the hall effect reference voltage with a gain of 2. Therefore, the threshold for 5kW of output power is at 672mV. This signal is compared to a voltage divider of a 100k resistor and a 14.3k resistor. With our VCC at 5V, this voltage divider outputs a value of 626mV, which sets the comparator to trigger high at a comfortable margin below the 5kW threshold.

There are two main sections to the circuit: the timing section and the latching section. The timing section consists of a 555-timer in monostable mode which is configured to be powered from the output of an AND-gate which takes in both the brake signal and the positive-current signal. This 555-timer will output a high pulse if the AND gate outputs a high voltage for more than 0.5 seconds.

The latching section of the circuit is a simple SR-latch, which will hold the relay open when tripped by the timing section. The relay is held open until power is reset. Shortly after the circuit is powered, the 1G123 monostable multivibrator outputs a 1ms long pulse to set the latch, and close the shutdown circuit.

The schematic can be seen in figure 6 on the next page.

Brake sensor used:	Pegasus Brake Light switch, part 3601
Torque encoder used:	Active Sensors MHR5621
Supply voltages:	5V
Maximum supply currents:	15 mA
Operating temperature:	-55 to 150°C
Output used to control AIRs:	Opens a relay

Table 2.5: Torque Encoder Data

2.4.2 Wiring

The output of the BSPD circuit will low-side drive a relay in series with the shutdown circuit. This board has not been fully designed, but it will utilize components common across other circuits.

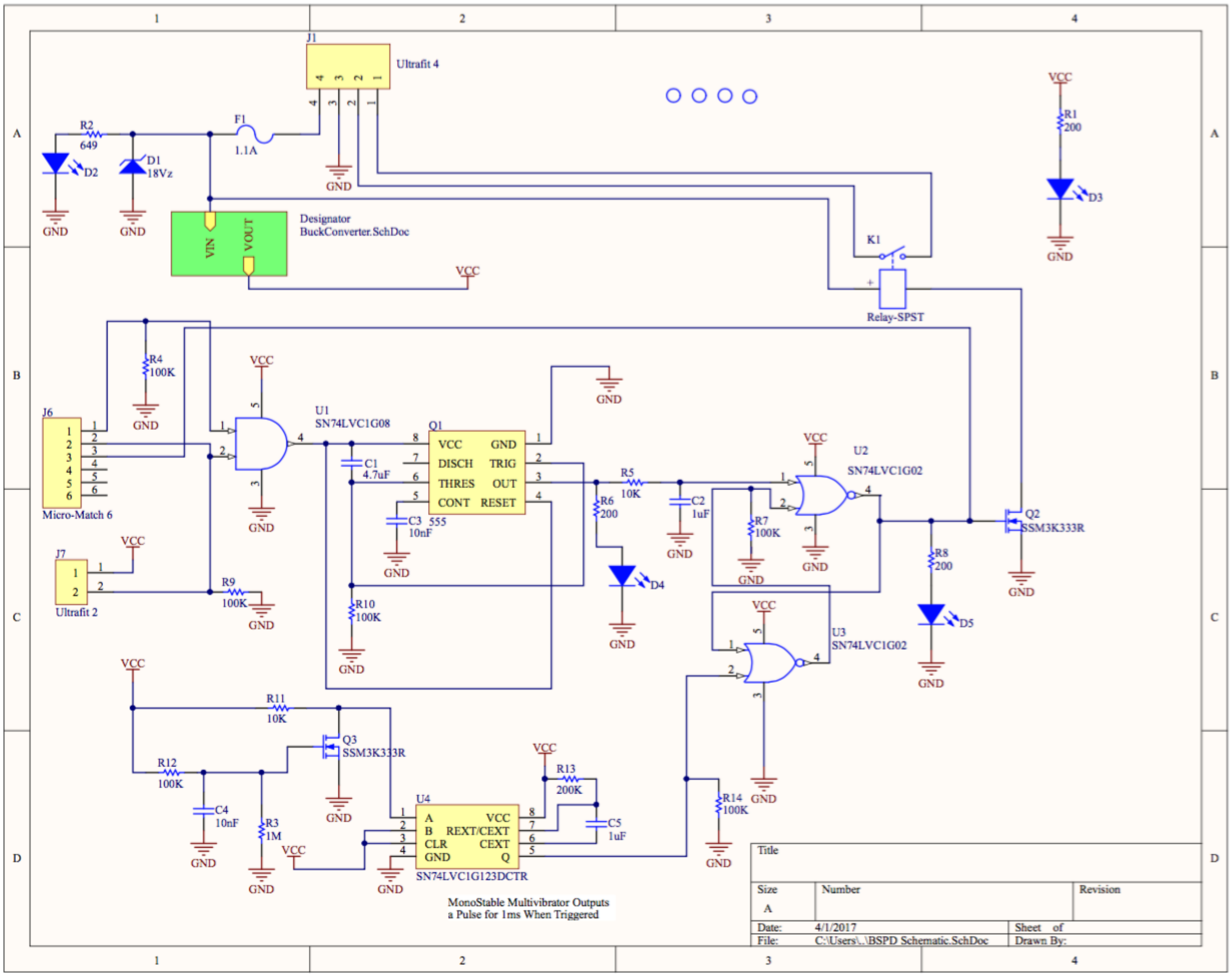


Figure 6: Schematic for BSPD circuit

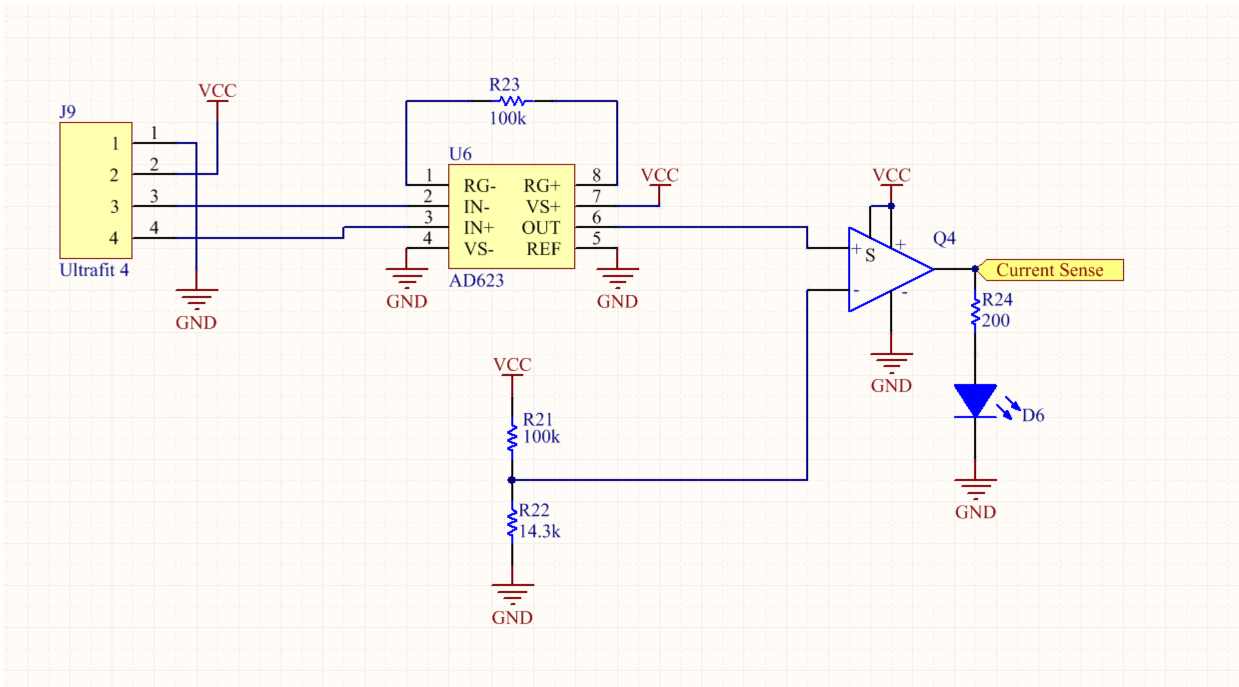


Figure 7: Schematic for BMS current sensing circuit

2.4.3 Position in car/mechanical fastening/mechanical connection

This board is located in the bulkhead enclosure at the front of the car.

2.5 Reset / Latching for IMD and BMS

2.5.1 Description/circuitry

Resetting the IMD latch, which is shown in figure 3 on page 6 , requires restarting the GLV system. Restarting the GLV system will cause the IMD latch to send a pulse. If the output of the IMD is high because there is no ground fault, the pulse from the GLV activation will close the secondary relay, which allows the signal from the IMD to close the shutdown circuit.

The BMS is latched with identical circuitry to the IMD, as shown in figure 3 on page 6, and is also reset by a GLVS power cycle. The BMS latch circuitry, however, will be on the master BMS PCB in the accumulator, and will control a separate on-board relay to open the shutdown circuit. In the case that the BMS detects a fault in cell temperature or voltage that requires a vehicle shutdown, the ATmega16m1 on the board will pull the BMS latch output pin low, latching the BMS latch circuit into a low state and opening the shutdown circuit. The master BMS will also serve as a CAN network monitor, and if another node in the vehicle detects a fault condition that requires vehicle shutdown that is not rules-required to be analog circuity, that node will send a shutdown message to the master BMS that will open the shutdown circuit.

2.5.2 Wiring/cables/connectors

The IMD latch will be connected to the accumulator interface board board via a 5-pin Molex LLC Ultrafit 1722861105 with 18 AWG wire, and the IMD connector using another 5-pin Molex LLC Ultrafit of the same type. The 18 AWG wire has a cross sectional area of .83mm², and is rated for at least 90°C, 300 V, and 16 amps. This provides a considerable safety margin. The ribbon cable carries signals from the IMD. 18 AWG wire is used for the shutdown circuit and to supply power and ground to the IMD latch. The 18 AWG wire has a cross sectional area of .83mm², and is rated for 16 amps for chassis wiring and 2.3 amps for power transmission. The 18 wire will be rated for at least 90°C and 300 V, as required by the rules for wiring in the accumulator (see EV3.3.8 and EV4.5.4).

Similarly to the IMD latch, the BMS latch will be housed in the accumulator, and thus all of the shutdown circuit connections to and from it will be made with 18AWG wire rated to over 300V and 90°C in order to handle the maximum of 8A inrush current to the AIRs and maintain compliance with accumulator wiring regulations. PCB traces will also be appropriately sized to handle 8A peak current.

2.5.3 Position in car

The IMD, IMD latch, and the BMS are in the accumulator, as shown in figure 29 on page 31. BMS is positioned there for ease of access to the battery, and the IMD latch is positioned there in order to be close to the IMD, which is located in the accumulator for continual monitoring of pack isolation while the accumulator is removed for charging.

2.6 Shutdown System Interlocks

2.6.1 Description/circuitry

The vehicle's tractive system connectors are all lever action locking connectors from the TE Connectivity HVP 800 series. Their arrangement in the tractive system can be seen in figure 8 on the next page. These connectors can be removed without tools. In compliance with EV 3.3.6, these connectors all contain an interlock that opens the shutdown circuit when they are not installed.

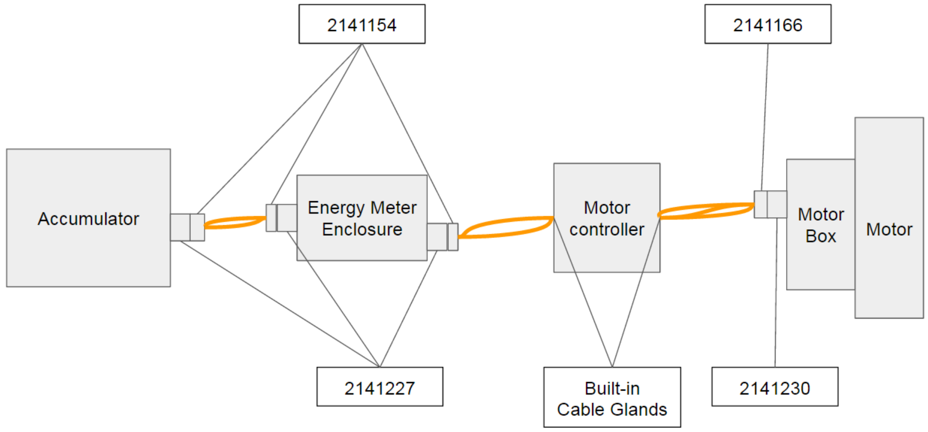


Figure 8: Diagram of HV connectors in the tractive system. They are labelled with TE Connectivity part numbers.

In order to close the shutdown circuit during charging when the accumulator is removed from the vehicle, a connection must be made that overrides the interlocks in the HV connectors that remain with the vehicle. Our solution is a shunt in the LV charging connector that bypasses the circuit that normally connects to the energy meter, HVD, and motor connector interlocks. The main accumulator connector interlock is still required to close the shutdown circuit, so EV 3.3.6 compliance is maintained. A schematic of this interlock circuitry can be seen in figure 9.

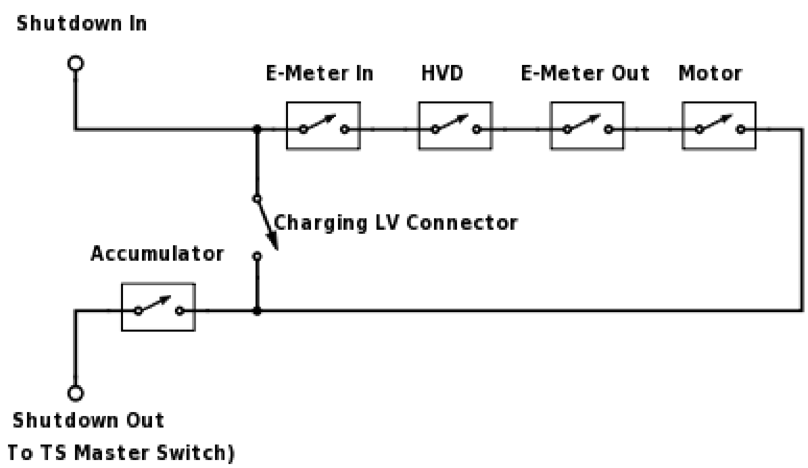


Figure 9: Schematic of the HV interlocks in the vehicle. Note the LV connector that allows the shutdown circuit to close the AIRs when the vehicle is charging.

2.6.2 Wiring/cables/connectors

The shutdown circuit interlock wires will be 20 or 22 AWG and rated to over 300V and 90°C and are protected by the main shutdown circuit breaker as in section 2.1.2 on page 3.

2.6.3 Position in car

Interlocks are built in to each HV connector. The connectors are panel-mounted to the accumulator housing, the energy meter housing, and the motor housing. See the render of the rear of the car in figure 10.

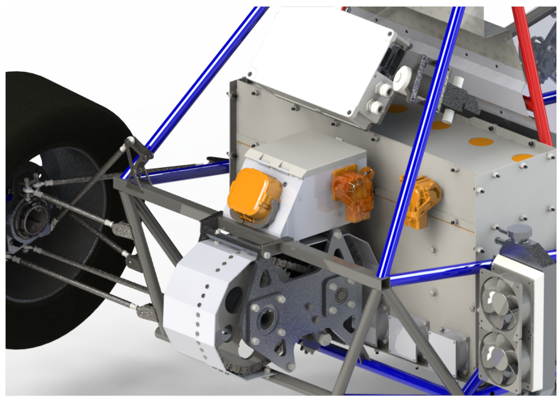


Figure 10: Render of the rear of the vehicle showing location of HV connectors. Connectors are highlighted in orange.

2.7 Tractive system active light

2.7.1 Description/circuitry

The TSAL illuminates when the tractive system is active, which is defined as the tractive system voltage being over 60V.

Supply voltage:	12V
Max. operational current:	1.2A
Lamp type:	LEDs
Power consumption:	14.4W (max)
Brightness:	Unknown
Frequency:	2 Hz
Size (length x height x width):	41x41x32 mm

Table 2.6: Parameters of the TSAL

See the appendix here for a link to the TSAL Datasheet.

2.7.2 Wiring/cables/connectors

The circuitry designed has a TS-controlled digital isolator whose power is supplied by the TS through two linear voltage regulators. When the TS is over 60V, a voltage divider with resistors of 30.1K and 1.91K causes the digital isolator to go logic high which allows the down regulated GLV to switch on the MOSFET allowing current to flow through the TSAL low side drive. The frequency of the TSAL will be controlled by built in settings to flash at 2Hz. See figure 11 for a schematic diagram of the TSAL circuit.

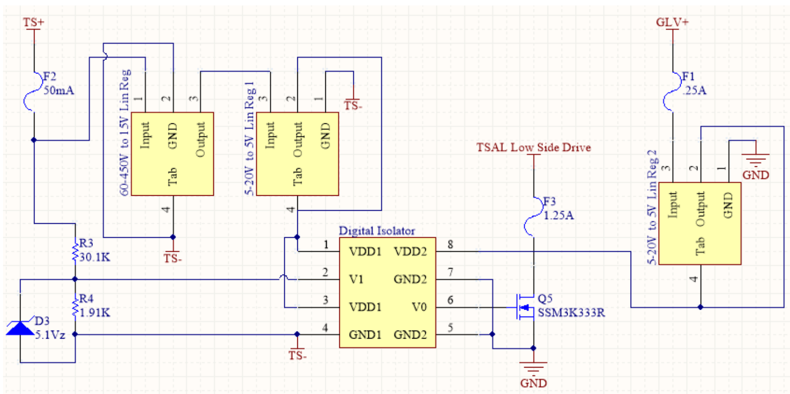


Figure 11: Schematic for the TSAL

All connections made by wires will be 20 AWG rated for 600V, 125°C and 7A, while all PCB traces will be a minimum of 12 mil, but nominally 20 mil in width. The TS voltage will be fused to 50mA. The GLV voltage will be fused to .25A on the supply line for the digital isolator and 1.25A on the power line for the TSAL with traces of at least 60 mil, able to handle 1.5A of current due to the 1.2A max current draw of the TSAL.

2.7.3 Position in car

The TSAL will be mounted to the underside of the highest point of the main roll hoop, per EV 4.12.3 and 4.12.4 using a robust 3D printed (Kevlar reinforced Nylon) bracket integrating the light and necessary wiring. This enclosure has not been designed yet. The PCB will be located in the master switch panel enclosure.

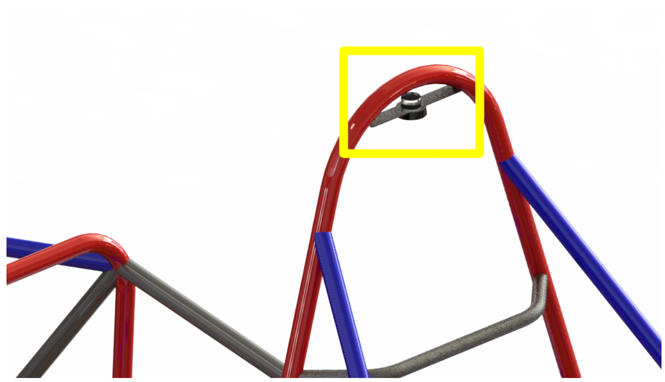


Figure 12: CAD rendering of TSAL position under apex of main roll hoop

2.8 Measurement points

2.8.1 Description

The TSMPs and GLVS ground measurement points are located on the master switch panel on the side of the vehicle, which also houses the TSAL circuitry in section 2.7. They will be a set of three clearly labeled and easily accessible shrouded banana jack connectors with hinged panel-mount covers to prevent any unintentional contact. These are visible in figure 14 on page 17. The measurement points provide a means for safe measurement of the tractive system potential , a secondary manual method for detecting isolation faults, and a reference point for system grounding measurements.

2.8.2 Wiring, connectors, cables

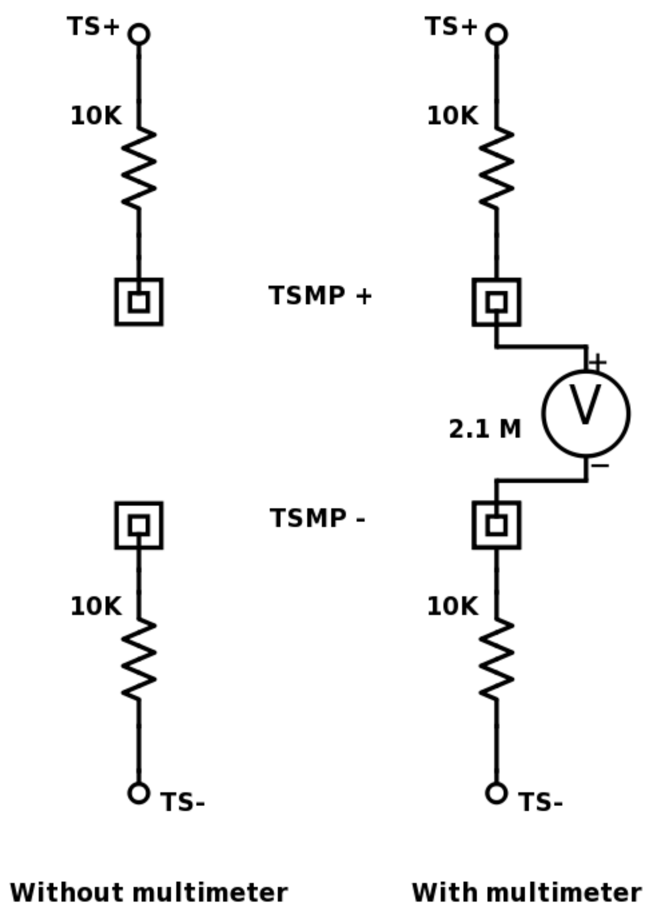


Figure 13: Schematic of TSMP wiring, illustrating the circuit with and without the multimeter, showing the protection resistors and the approximate expected resistance of the multimeter.

There are four measurement points: HV+, HV-, GLVS+, and GLVS chassis ground. The HV TSMP connections will protected with 10kΩ current-limiting resistors. These resistors limit the maximum fault current (a short circuit between the measurement points) in accordance with EV4.4.6.

$$\begin{aligned} V &= I * R \\ 300V &= I * 20,000\Omega \\ I &= 0.015A \end{aligned}$$

$$\begin{aligned} P &= I * V \\ P &= 0.015A * 300V \\ P &= 4.5W \end{aligned}$$

According to the above calculations, the resistors will have to be rated to at least 5W and 300V. We will be using Vishay PAC500001002FAC000 10k 5W resistors. The datasheets for the resistors, the connectors, and an example multimeter can be found in section 11.2.8 on page 59.
The TSMPs are protected with current-limiting resistors because protecting the wires with fuses introduces the failure mode in which one of the fuses has blown, and a measurement across the TSMPs shows an open circuit even though the tractive system is still energized.
In case of gross operator error that results in connecting a multimeter from a TS measurement point to the GLVS ground measurement point, the IMD will detect a loss of isolation and open the shutdown circuit.

2.8.3 Position in car

The TSMPs will be located in the master switch panel enclosure shown in figure 14 on the following page along with TSAL circuitry. The housing will be made of non-conductive material, and proper spacing between TS measurement point wiring and any part of the GLVS of 30mm through air will be maintained in accordance with EV 4.1.5.

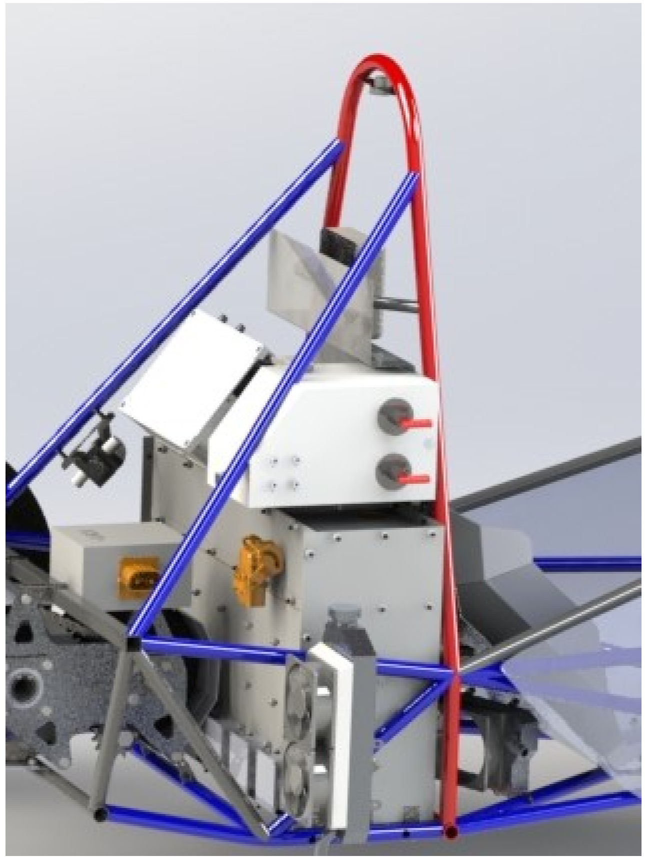


Figure 14: CAD rendering of the master switch panel showing TS and GLVS master switches, and TS and GLVS ground measurement points. This current render has the enclosure protruding from the chassis envelope, but the enclosures team is currently redesigning the face of the master switch panel to be flush with the chassis members.

2.9 Pre-Charge circuitry

2.9.1 Description

In order to prevent inrush current that could damage the motor controller or AIRs, and to comply with EV4.11.1, our pre-charge circuit slowly charges the capacitive load of the motor controller through a power limiting resistor before closing the TS+ AIR. When the shutdown circuit closes, the TS- AIR is immediately closed, but the software controlled MOSFETs seen in figure 15 on the next page will prevent the pre-charge relay and TS+ AIR from closing. After a short delay, the pre-charge relay is allowed to close. This delay is included to allow detection of a welded pre-charge relay. The motor controller tracks its pre-charge state, and signals over the CAN network to allow the TS+ AIR to close when pre-charge is complete.

2.9.2 Wiring, cables, current calculations, connectors

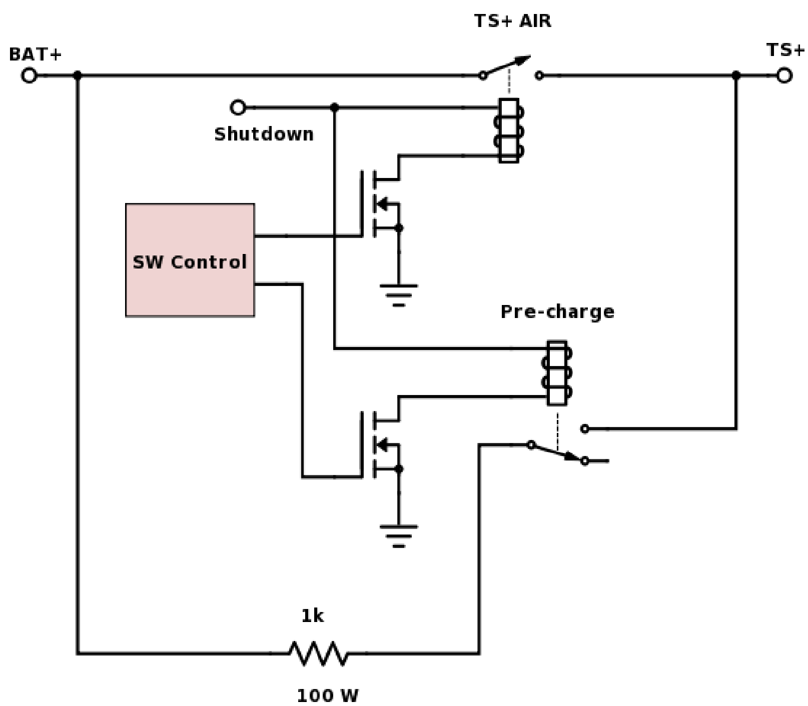


Figure 15: Schematic of the pre-charge circuit. Although the TS+ AIR and pre-charge relay are software controlled, the circuit is designed such that they cannot close if the shutdown circuit is open.

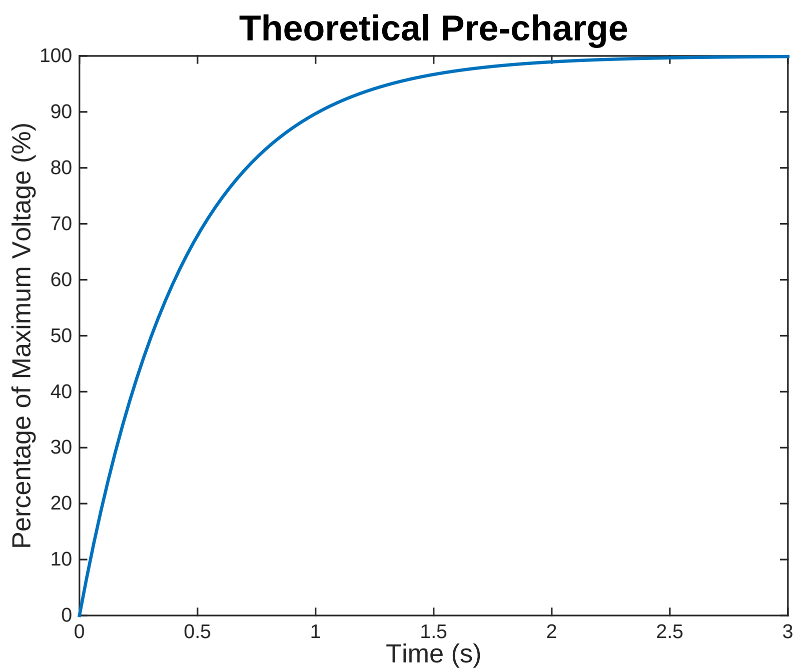


Figure 16: Theoretical pre-charge of the 440μF motor controller capacitance using a 1$k\Omega$ resistor. This plot was created using the equation, $V(t) = V_{BAT}(1 - e^{-t/RC})$ where V_{BAT} is our maximum pack voltage of just under 300VDC. Our motor controller is expecting an approximately 95% pre-charge within 3 seconds, so this circuit covers the needs of our motor controller and is in compliance with EV4.11.1

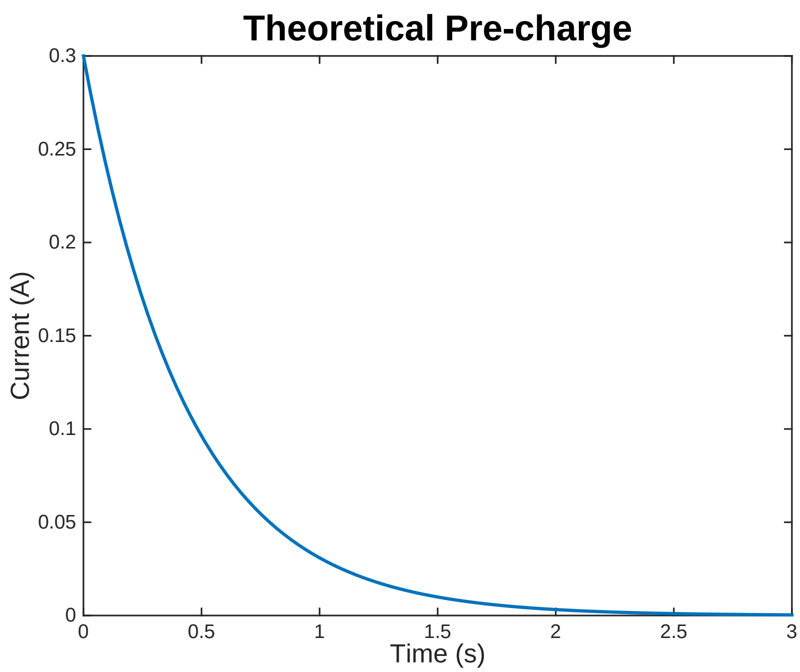


Figure 17: The current of the theoretical pre-charge from figure 16 on the previous page. This plot was created using the equation $I(t) = \frac{V(t)}{R}$ where $V(t)$ is the voltage across the pre-charge resistor found by the equation $V(t) = V_{BAT} * e^{-t/RC}$

Resistor type	Riedon PF2470 Power Film Resistor
Resistance	1 $k\Omega$
Continuous power rating	100 W
Overload power rating	140 W
Voltage rating	700 V
Cross-sectional area of wire used	0.83mm^2 (18 AWG)

Table 2.7: General data of pre-charge resistor

Relay type	Omron G2RL-1-E DC12
Contact arrangement	SPDT
Continuous DC current	16A
Voltage rating	300VDC
Cross-sectional area of wire used	0.83mm^2 (18 AWG)

Table 2.8: General data of the pre-charge relay

2.9.3 Position in car

The pre-charge circuit will be located within the accumulator. The precharge circuitry will be located on the AIR control PCB in the top section of the accumulator, as described in section 3.1.11.

2.10 Discharge circuitry

2.10.1 Description

When the car is shut down, and the AIRs have disconnected the accumulator from the rest of the tractive system, there is still energy stored in the capacitive load of tractive system components like the motor controller that could be harmful to the driver, team members, or first responders. The discharge circuit dissipates the energy found on the vehicle side of the tractive system after a shutdown. The circuit is designed to operate even if the vehicle looses all power. When the shutdown circuit is opened, the normally closed discharge relay connects a power resistor across the two poles of the tractive system.

2.10.2 Wiring, cables, current calculations, connectors

Since the power resistor limits the current on the discharge circuit, a fuse is not needed to protect the wiring. It is also dangerous for the discharge circuit to not operate if a fuse were to blow.

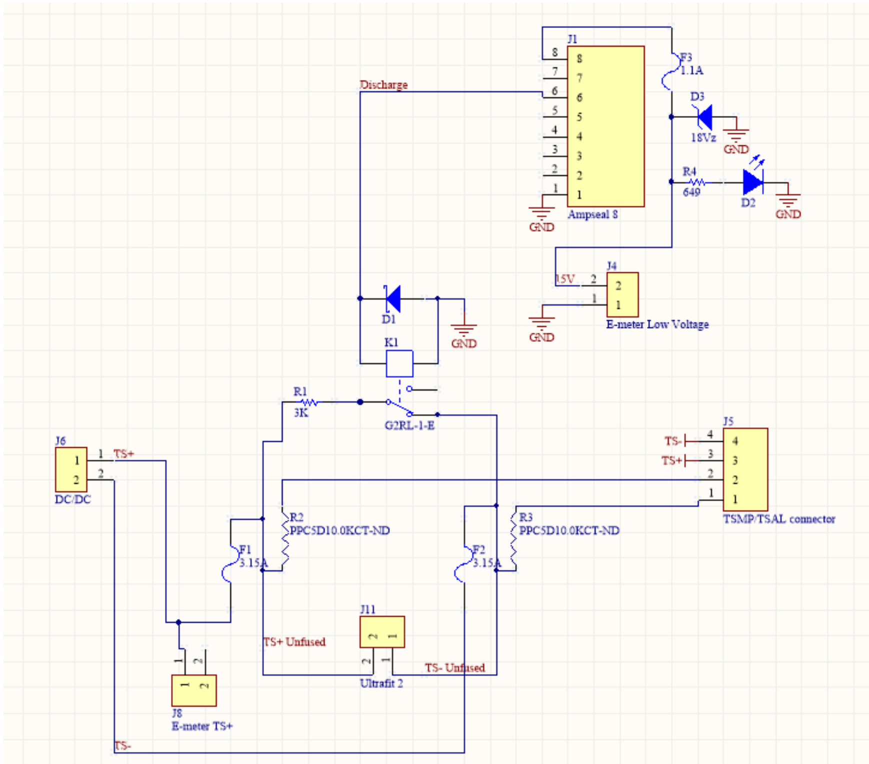


Figure 18: Schematic of the discharge system. The wiring for the TSMPs, TSAL power, and E-meter connections are also visible.

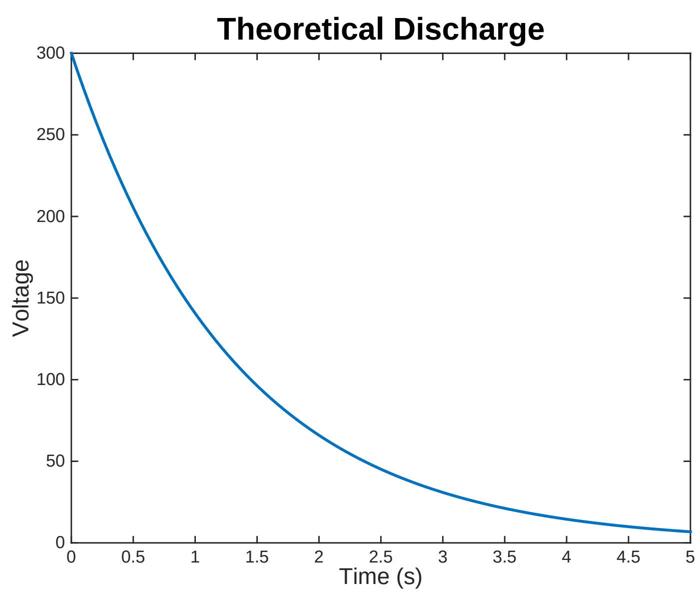


Figure 19: Theoretical discharge of the 440 μF capacitive load of the motor controller across the 3 kΩ resistor. This was calculated using the equation $V(t) = V_0 * e^{-t/RC}$.

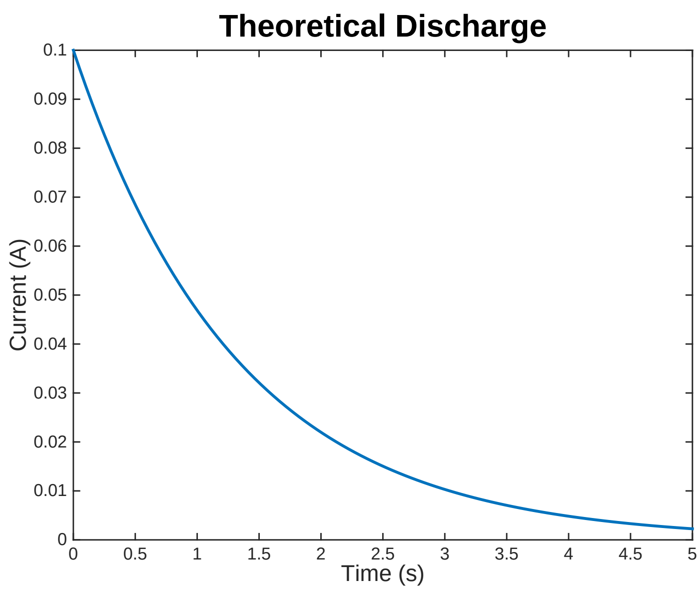


Figure 20: Current of the theoretical discharge from figure 19 on the previous page. This was computed using the voltage exponential and the equation $I = \frac{V}{R}$.

Resistor type	Ohmite AP101 TO-247-2
Resistance	3 kΩ
Continuous power rating	100 W
Overload power rating	1.5 times rated power for 5 seconds
Maximum expected current	0.1 A
Average current	0.0261 A
Cross-sectional area of the wire used	0.83mm^2 (18 AWG)

Table 2.9: General data of the discharge circuit

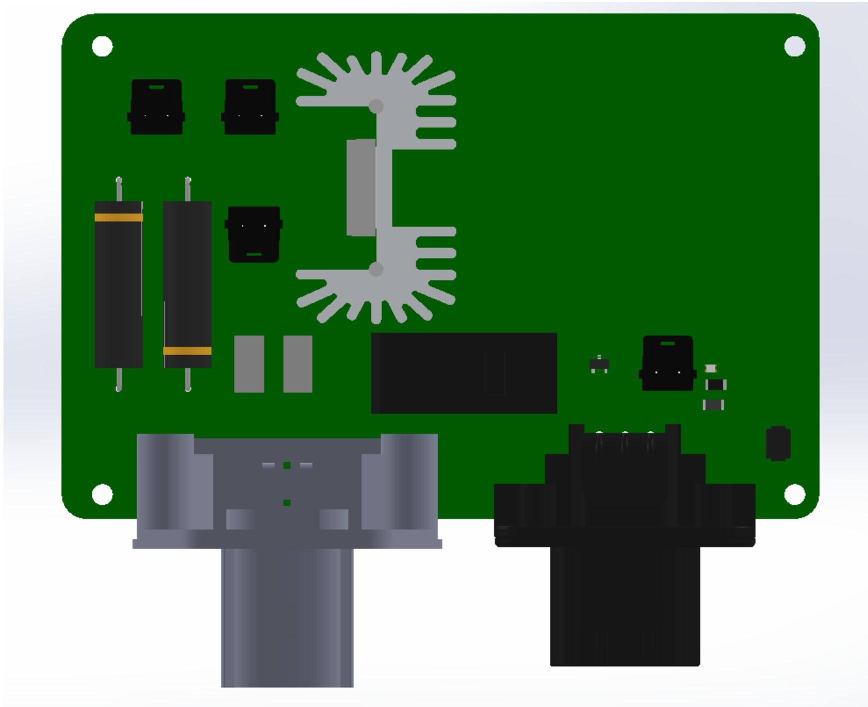


Figure 21: Render of the discharge circuit PCB. The discharge resistor is a TO-247 package mounted to a heatsink.

As shown in figure 21 the discharge resistor is mounted to an Ohmite RA-T2X-25E heatsink. Figure 22 shows the modeled temperature of the discharge resistor under the maximum continuous discharge current for 15 seconds. This temperature curve was computed using the equation,

$$\Delta T = \frac{(P_{in} - P_{out})\Delta t}{m * C_p} \tag{1}$$

Where P_{out} is the power dissapation of the heatsink given by,

$$P_{out} = \frac{1}{R_{therm}}(T - T_{amb}), \tag{2}$$

P_{in} is the power generated by the resistor, Δt is the time step of the simulation, m is the mass of the heatsink in kg, C_p is the specific heat of aluminum, R_{therm} is the thermal resistance of the heatsink under natural convection in $\frac{°C}{W}$, T is the temperature of the heatsink, and T_{amb} is the temperature of the ambient air.

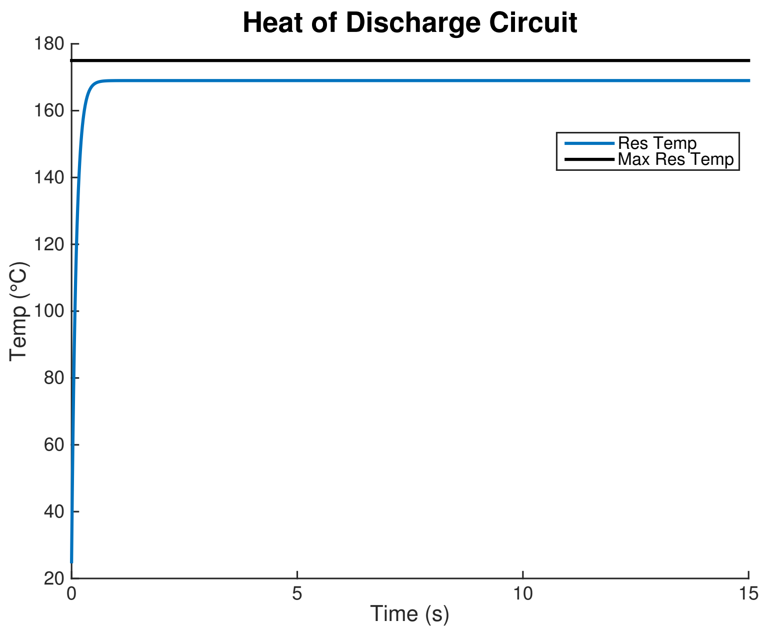


Figure 22: Model of discharge resistor temperature under maximum continuous discharge current for 15 seconds.

2.10.3 Position in car

The discharge circuit is located within the Energy Meter enclosure detailed in section 4, in close proximity to the motor controller which is the main capacitive load in the tractive system.

2.11 HV Disconnect (HVD)

2.11.1 Description

We will be using the shunt version of a TE Connectivity AMP+ Manual Service Disconnect as our HVD. Shown in figure 23 on the following page, it is a sealed, lever operated panel mount device and can be removed without tools. To protect technicians, it has no exposed conductors and provides internal HV interlocking in compliance with EV4.7.5.

Figure 23: The TE Manual Service Disconnect

2.11.2 Wiring, cables, current calculations, connectors

The Manual Service Disconnect is rated for 495V and contains a 630A fuse, which is more than our maximum current of 225A as shown in table 3.1 on page 31. This fuse is superfluous to the TS main fuse, and is simply included as part of the disconnect. It has a dual lever action, which first disconnects the shutdown circuit interlock inside the plug before disconnecting the high power terminals, which causes the AIRs to open and the tractive system to de-energize. The Manual Service Disconnect is a sealed panel mount device, which prevents the ingress of any water or debris.

The datasheet can be found in section 11.2.11.

The HVD is in series with the negative pole of the tractive system, on the vehicle side of the AIRs, as shown in figure 1 on page 1.

2.11.3 Position in car

The HVD is mounted at the rear of the vehicle, on the rear-facing side of the energy meter enclosure, however this enclosure is yet to be designed. It is bright orange, and will be clearly marked and easily accessible from the rear of the vehicle. In accordance with EV 4.7.1, the HVD will be mounted more than 350mm from the ground.

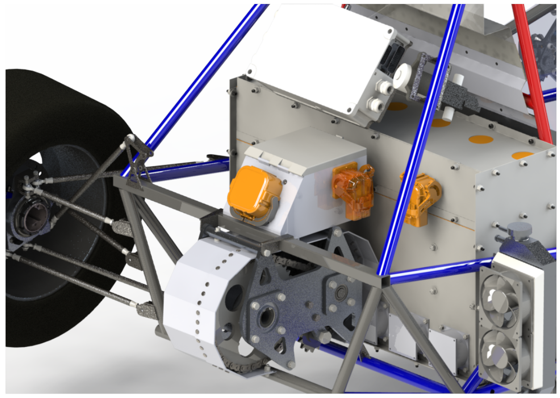


Figure 24: The HVD's location in the car.

As seen in figure 25, the HVD mounting on the energy meter enclosure is currently in violation of EV4.2.1. This is not a final configuration, and the enclosures team is currently redesigning this enclosure and its mounting to move the HVD entirely within the chassis envelope.

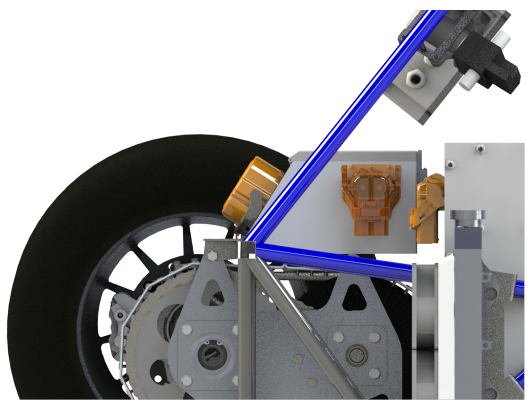


Figure 25: a side view of the HVD mounting, showing protrusion from the chassis envelope. This is a temporary state, and will not be reflected in final design

2.12 Ready-To-Drive-Sound (RTDS)

2.12.1 Description

The Ready to Drive sound is located as a component of the dashboard subsystem, and contains a buzzer (Link: Mallory Sonalert Products Inc. STA20502)11.2.12. The buzzer makes a noise when given a square wave at 1.25kHz, with the loudness proportional to the voltage. When the shutdown sequence is complete, a message will be sent out over the CAN bus. This will then provide the 1.25kHz wave to the gate of an N-FET which will provide a ground path for the buzzer.

2.12.2 Wiring, cables, current calculations, connectors

When the shutdown circuit completes and activates the AIRs, the car is in ready to drive mode. As soon as the car is in this mode, the CAN system will activate the ready to drive sound node to send a positive output that provides voltage to the N-FET for 2 seconds, thus letting the buzzer sound for 2 seconds.

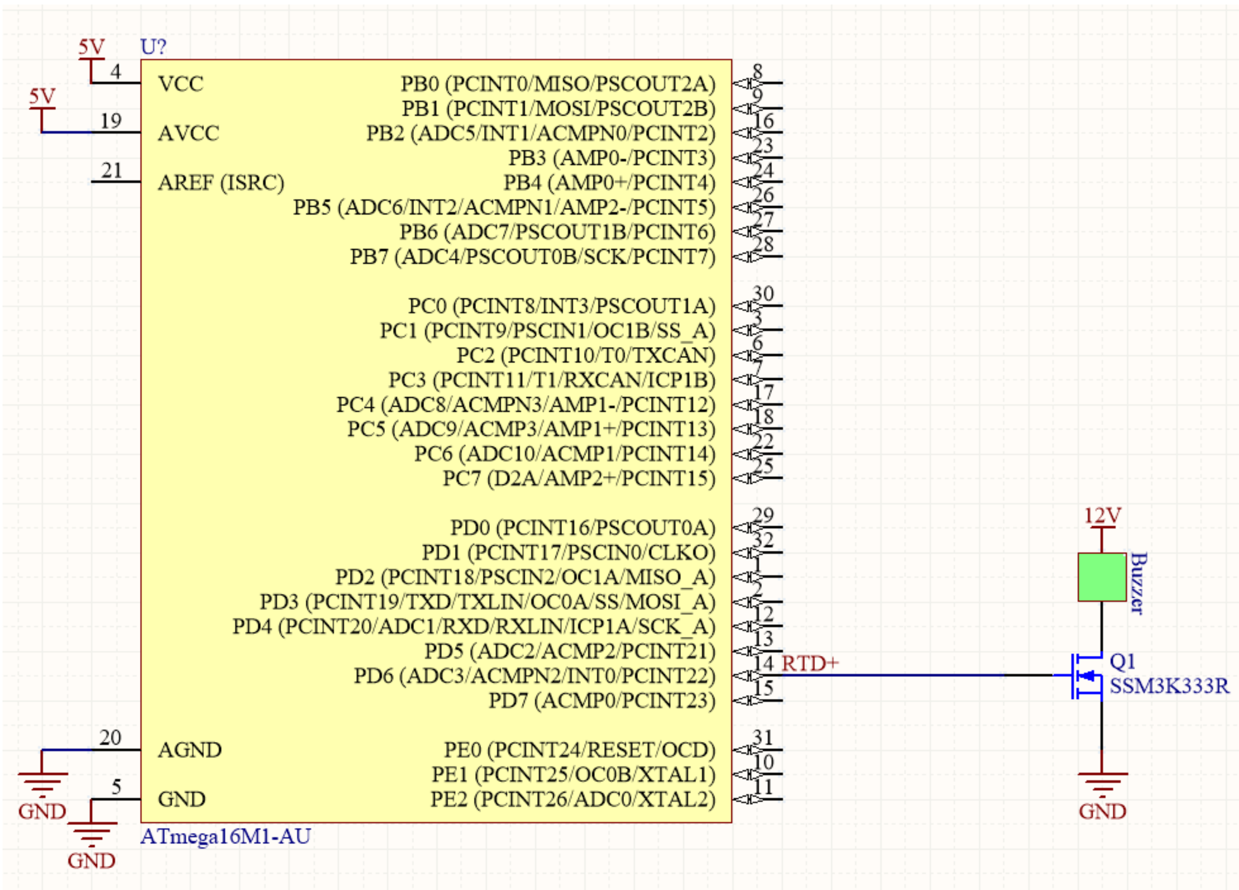


Figure 26: Ready to Drive Sound Schematic as a subsystem of the dashboard's PCB

Sound level L and Distance r

$$L_2 = L_1 - \left|20 \cdot \log\left(\frac{r_1}{r_2}\right)\right| \qquad L_2 = L_1 - \left|10 \cdot \log\left(\frac{r_1}{r_2}\right)^2\right|$$

$$r_2 = r_1 \cdot 10^{\left(\frac{|L_1 - L_2|}{20}\right)} \qquad r_1 = \frac{r_2}{10^{\left(\frac{|L_1 - L_2|}{20}\right)}}$$

Figure 27: Inverse Square Law equations needed to calculate the volume at a certain distance

Using the inverse square law as referenced in the appendix for sound pressure levels 11.2.12, 97db at 122cm will translate to 93db at 2m which is a loud enough volume without inducing harm to the listener.

2.12.3 Position in car

The ready to drive sound will be located in the dashboard enclosure. The buzzer will be mounted to the exterior and front side of this enclosure, facing the front of the car as seen in figure 28. It must be contained outside of the box so that the buzzer is loud enough. The speaker is waterproof, so it doesn't require any extra protection besides using an RTV silicone seal for final instillation.

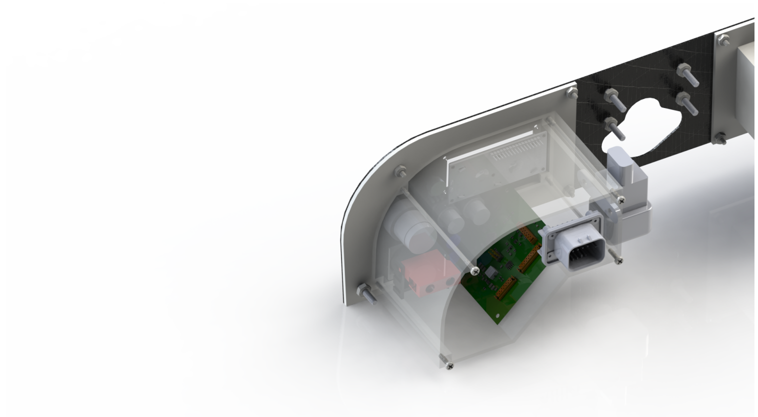


Figure 28: Rendering of Dashboard Right

3 Accumulator

3.1 Accumulator pack 1

3.1.1 Overview/description/parameters

The accumulator pack is based on 72 LG Chem P2.7 $LiNiMnCoO_2$ pouch cells, in a 72s1p configuration. It is divided into six segments of 12 cells each, which each have their own distributed voltage management and temperature management systems that communicate to a master BMS node that interacts with the car's CAN network and can open the shutdown circuit. Each cell has nominal characteristics seen in table 3.2 on page 32, and together they form an accumulator with a max voltage of 298.8A, and a max output current of 225A, with 27.8 MJ total capacity. Details can be found in table 3.1 on the next page.
Since we are using proprietary cells, we are not allowed to publish the complete datasheet for the LG Model P2.7 cells. We have been approved to share the ratings found in table 3.2 on page 32.

Maximum Voltage	298.8 VDC
Nominal Voltage	266.4 VDC
Minimum Voltage	201.6 VDC
Maximum output current	225 A
Maximum nominal current	125 A
Maximum charging current	180 A
Total number of cells	72
Cell configuration	72s1p
Total capacity	27.785 MJ
Number of cell stacks (segments)	6

Table 3.1: Main accumulator parameters

Figure 29: Render of the accumulator with one panel removed to show cell arrangement.

3.1.2 Cell description

The cells we are using are LG Chem Model P2.7, which are lithium nickel manganese cobalt oxide (NMC) pouch cells. The relevant values from the datasheet are shown in table 3.2 on the next page.

Cell Manufacturer and Type	LG Chem Model P2.7
Cell nominal capacity	25.9 Ah
Maximum Voltage	4.15 V
Nominal Voltage	3.7 V
Minimum Voltage	2.8 V
Maximum output current	225 A
Maximum nominal output current	125 A
Maximum charging current	180 A
Maximum Cell Temperature (discharging)	45°C
Maximum Cell Temperature (charging)	45°C
Cell Chemistry	NMC/LMO

Table 3.2: Main cell specification

3.1.3 Cell configuration

The P2.7 pouch cells are connected in six segments of 12 cells in series, for a total configuration of 72s1p, as shown in figure 30.

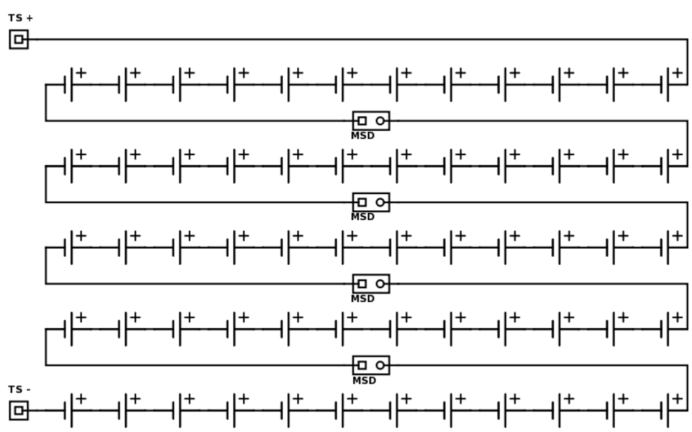


Figure 30: A schematic of the accumulator's cell configuration showing cells in series and manual service disconnects

To connect the cells into segments, they are stacked on one another with 1mm 6061 aluminum heat sinks and neoprene compression foam to distribute load. The cells are alternated in polarity for easy tab connection. Data on the foam can be found in the appendix, in section 11.3.3.
Individual cells are connected by squeezing their tabs together with bolted copper plates. Voltage sensing is done using wires connected to these plates. Each bolted plate assembly is isolated with a 3d-printed cover. This cover protects each terminal from shorts during assembly and maintenance. Each cover is retained with a zip-tie. This is a safer assembly technique than welding the cell tabs together, and allows for replacement of damaged cells if necessary.

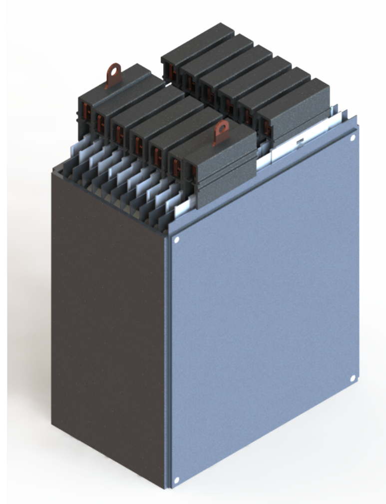


Figure 31: Single segment of 12 cells with 3d-printed covers over clamped cell tabs.

In between the segments, there will be a 4AWG jumper made of the vehicle's HV cable, with a 1-position connector on each end. These will be on the tops of the cell segments, and will be easily removable, so as to act as the manual service disconnects between segments. We are currently in communication with sales representatives from Amphenol about an appropriate connector for our application, and we are considering the Radlok connector system, seen in figure 32.

Figure 32: Radlok connector example. The product page can be found here

3.1.4 Cell temperature monitoring

In compliance with EV3.6.3 and EV3.6.6 the temperature of every cell will be measured within 10mm of the negative terminal. We will achieve this by epoxying an NTC thermistor to the insulated section of the negative terminal of each cell, as close as possible to the body of the cell. The thermistors will be electrically isolated from the terminal by the insulating foil of the cell, and the temperature measurement will most closely approximate the internal temperature of the electrode by being close to the body of the cell.

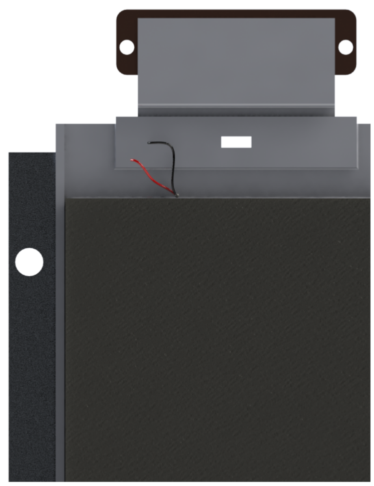


Figure 33: Approximate positioning of the thermistors (seen here with red and black leads) relative to the cells

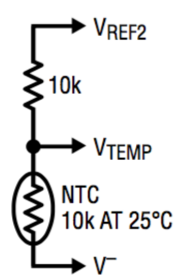


Figure 34: Circuit for sensing NTC thermistors

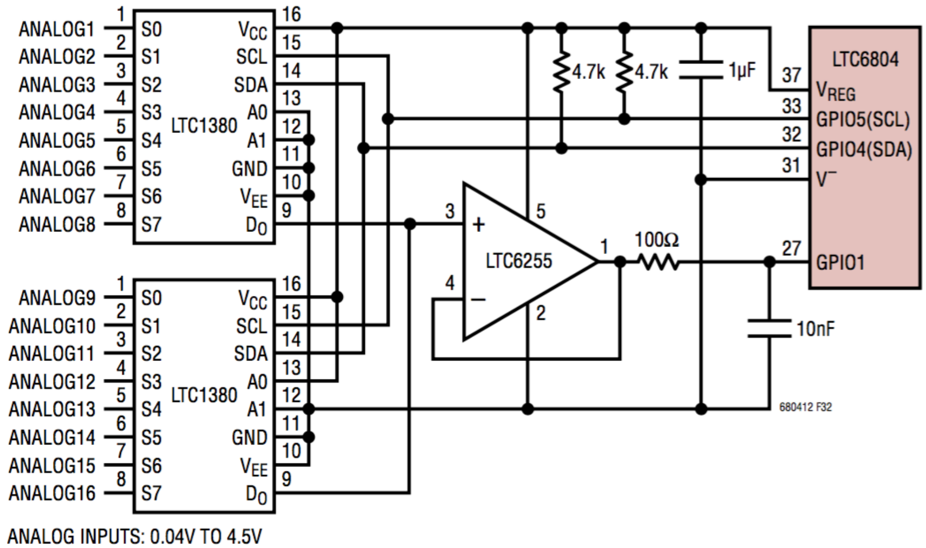


Figure 35: Circuit for multiplexing analog inputs for LTC6804 BMS chip

The NTC thermistors are electrically connected in a voltage divider as shown in figure 34 on the preceding page. Each of the temperature measurement voltages are multiplexed into a single GPIO pin on the LTC6804. See section 3.1.5 for a more detailed description of the implementation of the LTC6804 BMS.

The maximum cell operating temperature is 45 °C. Our thermistors are 1% accurate, and the total measurement error of the ADC is <0.1%, then in the worst case we will be reading 44.5 °C when the temperature is actually over the rating. To give the system a small safety margin, the BMS triggers a shutdown if it ever detects a cell temperature of 44 °C or higher.

3.1.5 Battery management system

Each segment of the accumulator will be monitored and controlled for faults by its own distributed battery management system, which in turn communicates with a central master BMS that calculates state of charge, state of health, and monitors power consumption. In the case of a critical fault, the distributed segment BMS will send error messages over CAN to the master BMS, which has a relay that can open the shutdown circuit. In order to ensure that all segments remain in working order, the master BMS will employ a software watchdog timer, which will shut down the car if it fails to receive communication of nominal operation from each segment after a period of time.

The distributed segment BMS is implemented using the Linear Technology LTC6804-1, which communicates over a daisy-chain-able galvanically-isolated SPI interface called isoSPI. The LTC6804 is capable of measuring the voltages of up to 12 lithium-ion batteries, and is also capable of measuring up to 16 analog inputs with its analog multiplexer. We are using the analog inputs to measure cell temperatures as referenced in section 3.1.4. The LTC6804 datasheet can be found in the appendix under section 11.3.4.

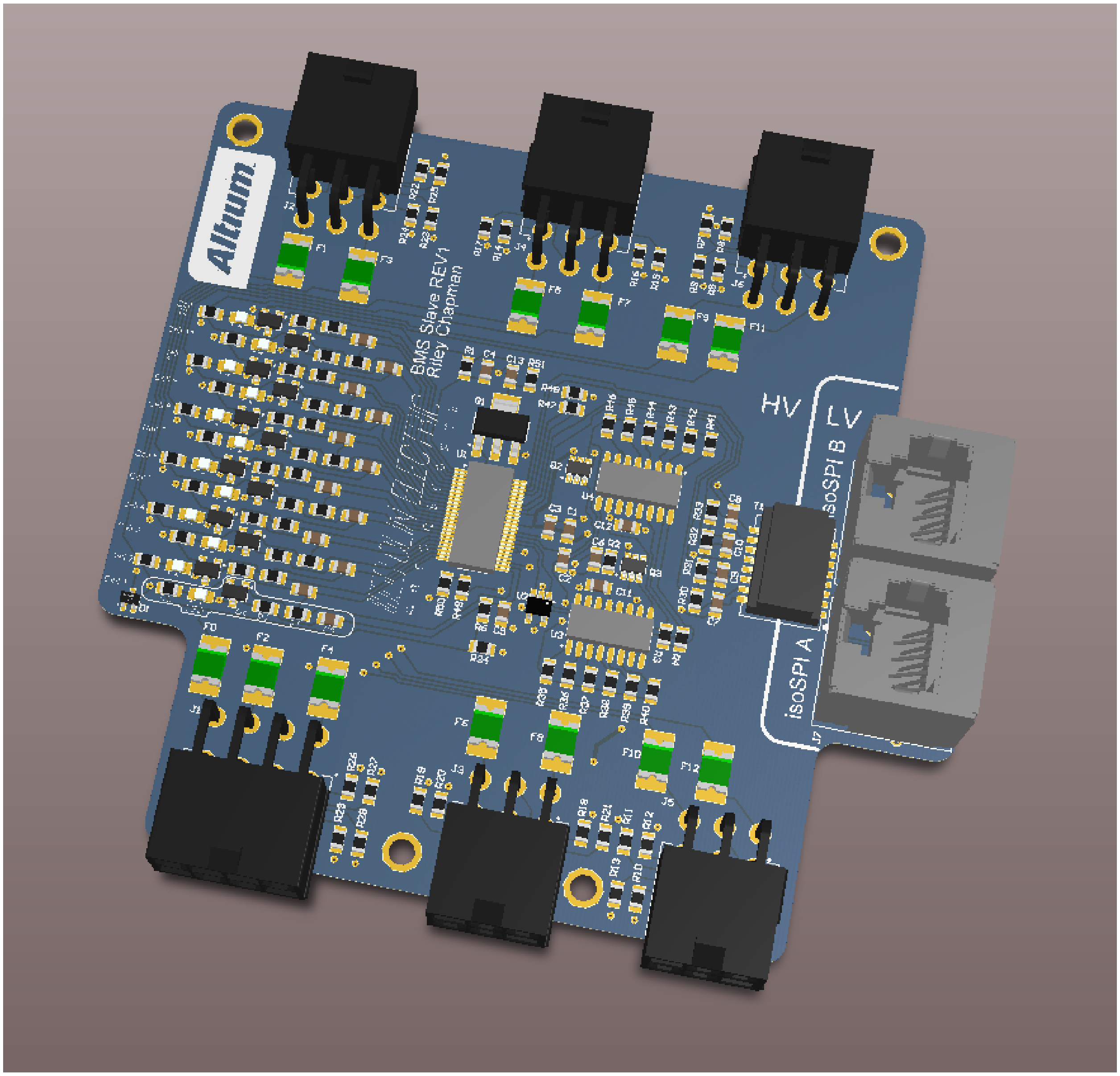


Figure 36: Render of the LTC6804-1 based distributed segment BMS.

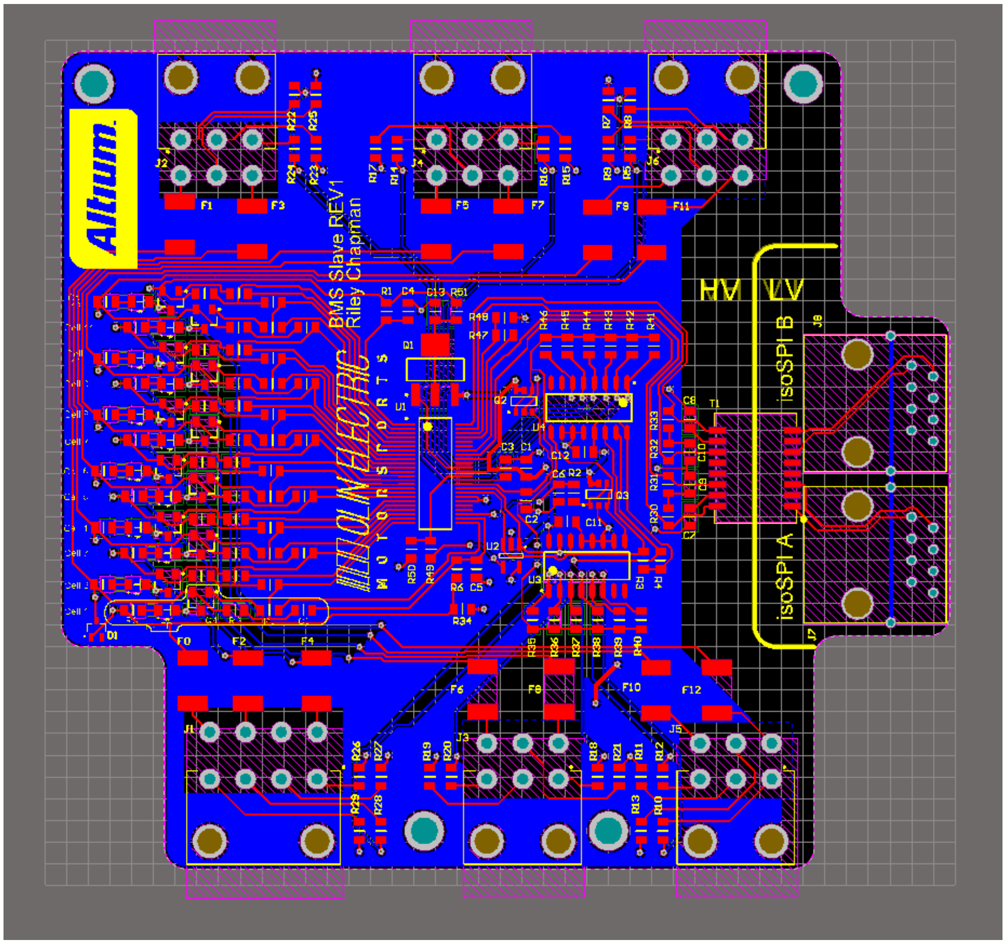


Figure 37: Two dimensional view of distributed segment BMS.

Communication wiring between the distributed segment BMS boards and the master BMS is achieved in a daisy chain via isoSPI, which terminates on the master BMS with an isoSPI interpreting ICs. The communication wiring will be properly retained to maintain spacing of 30mm from any TS voltage.
The master BMS will be a node on the vehicle's CAN system, implemented using an ATmega16m1, a robust CAN-enabled automotive microcontroller. Its primary duties are measuring current leaving the pack via current-sensing coils, estimating state of charge and state of health, and opening the shutdown circuit if the distributed BMS boards sense a fault or fail to report nominal operational parameters.
The maximum Total Measurement Error (TME) of the LTC6804 is 1.2 mV, so in order to account for this error, the max voltage the BMS will react to is 4.1488V, and the minimum voltage is 2.8012V.
The BMS reacts to an upper voltage of 4.100V when charging by shunting excess power from that cell across a discharge resistor. This gives us a 48.8 mV leeway before we approach the max voltage of the cell, corrected for the maximum TME of 1.2 mV. If any cells ever reach 4.1488 V, the BMS will shut down the car by opening the shutdown circuit. This could occur during charging or regeneration in a rare case.
The BMS reacts to critical low voltage of 2.8012V by shutting down the vehicle. This case is harder to remedy, because we can't recharge individual cells on the fly, so to avoid damaging the electrodes inside the cells, the BMS opens the shutdown circuit and de-energizes the vehicle.

3.1.6 Accumulator indicator

The Accumulator Indicator Light (AIL) will be powered directly by the TS voltage using two Zener diodes which will allow enough current to flow through the AIL to turn it on when the supply exceeds 60V. This PCB has not been designed yet but the general schematic can be seen below in figure 38.

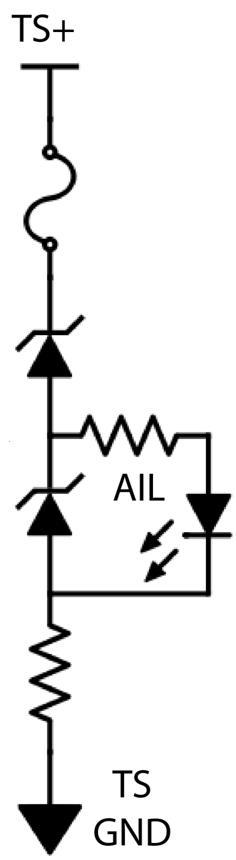


Figure 38: Schematic for the AIL

The AIL will be located on the AIR control board PCB, fused to 1A, and have traces of 20 mil, which are rated for 1.4A. All connections made by wires will be 20 AWG rated for 600V, 125°C and 7A.

3.1.7 Wiring, cables, current calculations, connectors

This wire is used for high power connections in the accumulator. High power connectors are documented in section 2.6.

Wire type	4 AWG Cable
Current rating	190 A
Maximum operating voltage	1 kV
Temperature rating	-55°C to 150°C

Table 3.3: Wire data of the company: Champlain Cable, EXRAD SAE 150 XLE Shielded Cable

3.1.8 Accumulator Insulation Relays (AIRs)

We will use KILOVAC EV200 contactors as our insulation relays. In compliance with EV3.3.5 they are mounted in a compartment separated from the rest of the accumulator by insulating G10/FR4 fiberglass.

Relay Type:	Normally Open
Contact arrangement	SPST-NO-DM
Continuous DC current rating	500A
Overload DC current rating	2000A at 320VDC
Maximum operation voltage	900VDC
Nominal coil voltage	12VDC
Normal Load switching	Make and break up to 650A
Maximum Load switching	3 times at 2,000A

Table 3.4: Basic AIR Data

3.1.9 Fusing

Fuse manufacturer and type:	Bussmann, LPJ type
Continuous current rating	150 A
Maximum operating voltage	600 V
Type of fuse	Time delay
I2t rating	Not Listed
Interrupt Current (max. current at which the fuse can interrupt the circuit)	300 kA

Table 3.5: Tractive system main fuse, LPJ type. Datasheet here.

3.1.10 Charging

Charger Type:	ELCON PFC 2000+ TCCH-288-6
Maximum charging power	24.9 A
Maximum charging voltage	4.15 V (Per Cell) 298.8 V (Overall)
Maximum charging current	5 A
Interface with accumulator	TE Connectivity HVP 800 lever action locking connector
Input voltage	125VAC or 230VAC
Input current	15A @ 125VAC or 8A @ 230VAC

Table 3.6: General Charger data

Figure 39: Elcon PFC 2000+ Battery Charger

The charging system consists of two main components: A charger that connects to the main pack connector and supplies the current needed to charge the accumulator, and a charging circuit that provides power to the AMS, opens the AIRS if the shutdown button is pressed, and displays critical information while charging.

This CE-Listed charger supplies constant current at 6A until cell voltages reach 4.15V. Then, constant voltage is supplied at 4.15V per cell, summing to 298.8 volts, until the cells are fully charged. The charging power lines are protected via the charger's short-circuit protection, which automatically stops charging if a short-circuit condition occurs.

The charger interfaces with the accumulator through a lever action locking connector from TE Connectivity's HVP 800 series (P/Ns 2141227(accumulator side) and 2141154(charger side)). These connectors contain an interlock that opens the shutdown circuit, preventing the AIRS from closing when not engaged to maintain compliance with EV8.3.3. The charger has an interlock function that stops charging when the connector is not engaged, shown in the figure below.

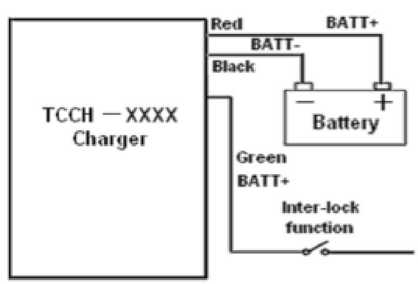


Figure 40: Charger-Side Interlock

The accumulator will only be charged on the charging cart. The cart will be able to support the full weight of the accumulator and only move when a dead man's switch is activated.

The accumulator cart will contain a specialized charging circuit that allows the accumulator to be charged through the main pack connector. The charging circuit mimics the shutdown circuit in the vehicle.The charging circuit will contain a clearly labeled emergency stop push button with a minimum diameter of 25mm which opens the AIRS ands stops charging. It will also communicate with the AMS over CAN and display critical information during charging.

The AMS will be active during charging and have the ability to open the AIRS and stop charging in the event of dangerous battery conditions.The AMS will communicate with the Charger over CAN and turn off the charger in the event of a fault to maintain compliance with EV8.3.5.

3.1.11 Mechanical Configuration/materials

The main structure of the accumulator container is made from .050” 430 stainless steel sheet. The front, left, right, and bottom walls are made from one folded sheet. The rear wall is made from another folded sheet. Inside are six segments of 12 cells. The segments are separated by internal vertical walls. The internal vertical walls are made from 20ga (.0359”) 430 stainless steel sheet. The internal vertical walls are attached to the bottom wall with spot welds. The internal vertical walls are attached to the external vertical walls with spot welds. All walls are internally lined with a sheet of garolite to provide insulation.

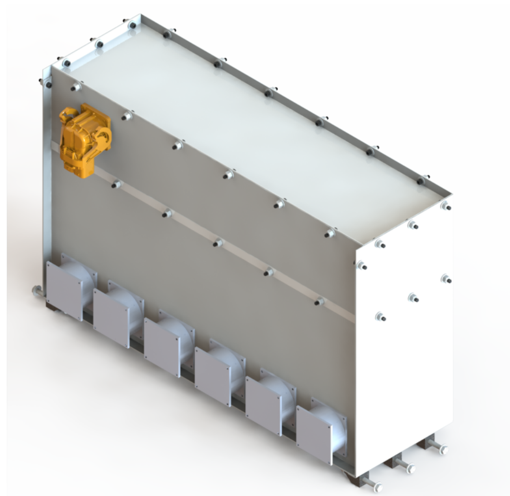


Figure 41: Isometric render of the fully assembled accumulator.

The cells we are using must be compressed on their large face to within the manufacturer recommended range (4-18psi). We are considering two methods of cell compression. In the first, the cells are compressed between two aluminum face sheets by threaded rods. 4 threaded rods are used to compress each segment. In the second method, the threaded rods are replaced by aluminum end caps that set the distance between the aluminum face sheets. In both methods, cell compression pressure will be set by imposing a strain on the stack. The materials will be characterized and the necessary strain will be applied such that the cells remain in the specified pressure range. Each compressed segment is individually installed into the accumulator, then the rear wall is attached.

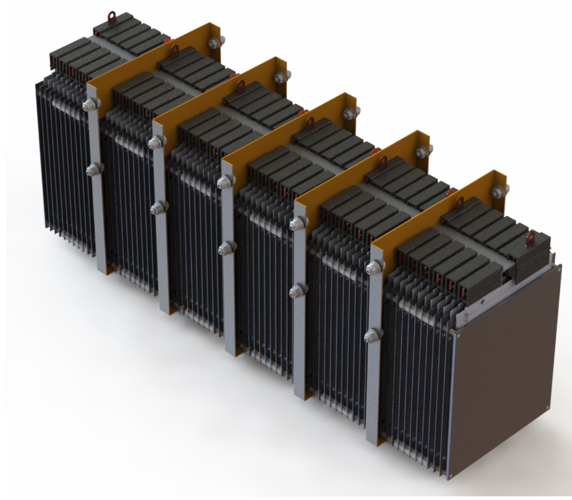


Figure 42: Configuration of cell modules, with dividing walls.

Individual cells are connected by squeezing their tabs together with bolted copper plates. Voltage sensing is done using wires connected to these plates. Each bolted plate assembly is isolated with a 3d-printed cover. This cover protects each terminal from shorts during assembly and maintenance. Each cover is retained with a zip-tie. Thermistors are epoxied to the negative terminal of all cells for temperature monitoring.

The Accumulator Interrupt Relays, Main Pack Fuse, Battery Management System, Service Disconnects, and other related electronics are located in the top section of the accumulator. This section is separated from the lower section by a .050” 430 stainless sheet that is insulated on both sides by 1/32” garolite. The divider is fastened with 18 1/4”-20 grade 5 fasteners. The top section is closed with a lid similar to the divider. It is attached to the side walls with an identical fastener pattern.

All structural fasteners are secured with nylok nuts. The nylok nuts are all located outside the accumulator container. All insulating garolite is epoxied to the surface it insulates.

3.1.12 Position in car

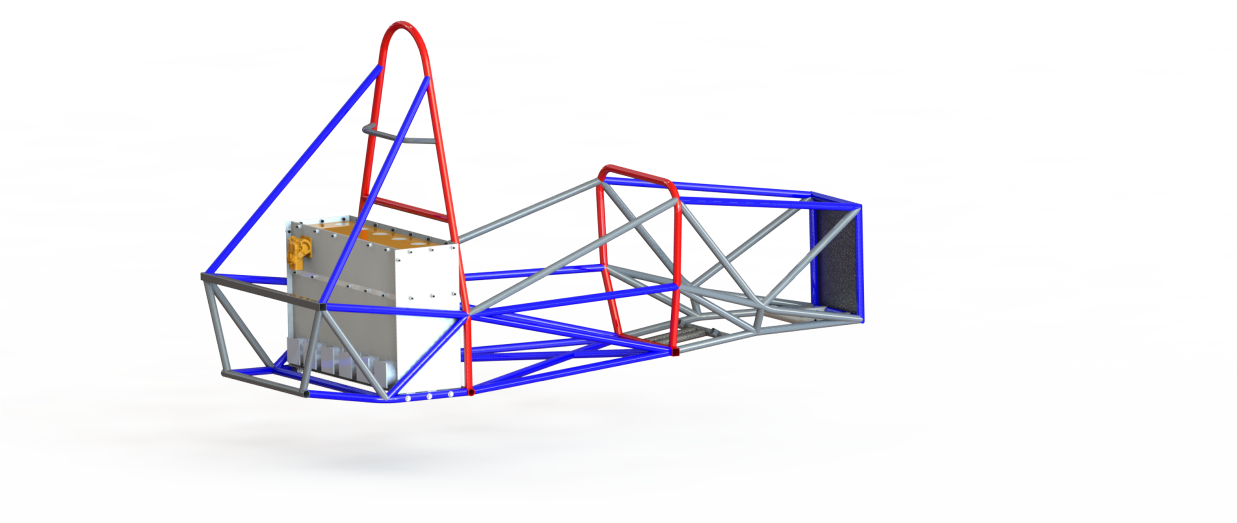


Figure 43: Position of the accumulator in the frame.

3.2 Accumulator pack 2

We only have one accumulator, described in 3.1.

4 Energy meter mounting

4.1 Description

The vehicle's energy meter is mounted in a dedicated tractive system enclosure at the rear of the car that we call the energy meter enclosure. As is visible in figure 1 on page 1, the energy meter enclosure is a pass-through enclosure that connects in series with both poles of the tractive system between the accumulator and the motor controller. Inside are the energy meter, the high-voltage low-current fuses that protect the TSAL (section 2.7), the current-limiting resistors that protect the TSMPs (section 2.8), and the discharge circuit (section 2.10).

4.2 Wiring, cables, current calculations, connectors

The energy meter current calculations require it to be connected in series with the low pole of the tractive system. It is bolted onto custom-made copper bus bars with serrated, distorted-thread locking fasteners to ensure electrical connection, which can be seen in figure 44 on the following page.

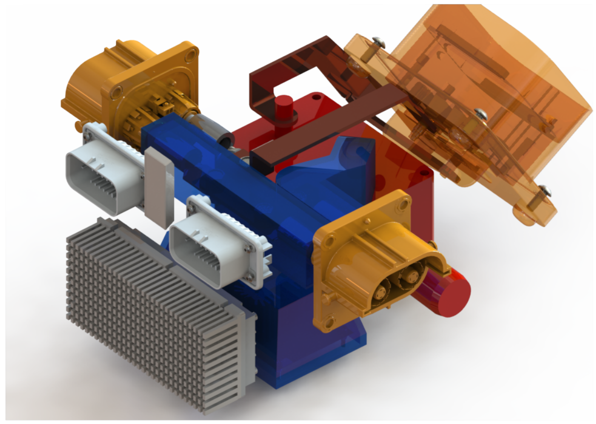


Figure 44: Rendering of the internal geometry of the energy meter enclosure. The energy meter itself is visible in red. The blue solids are insulating covers to separate the individual HV bus bars from one another and to protect the LV energy meter circuitry at the base of the enclosure. See figure 47 on page 46 for a render of the enclosure in the vehicle

Figure 45 shows the internals of the energy meter enclosure from another angle, also including the housing. Internal covers are removed to show bus bar geometry. Bus bars will be wrapped in Kapton polyimide tape with a protective heat-shrink sleeve.

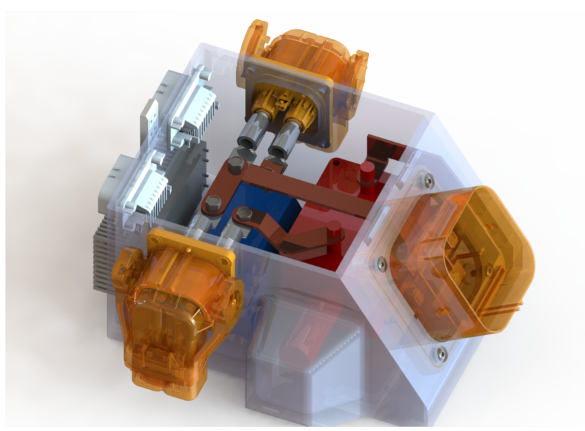


Figure 45: Rendering of the energy meter enclosure showing the housing. Internal bus bar covers have been hidden to show bus bar structure.

Voltage measurement connections to TS+ for the energy meter, and connections for the TSAL fuses and TSMP current-limiting resistors are made via ring terminals to the corresponding bus bars. The wires for the TSMPs, the TSAL, and the energy meter will all be 20AWG rated to 300V and 90°C. The energy meter itself also requires GLVS power, which means that proper HV wire spacing of 30mm will be upheld.

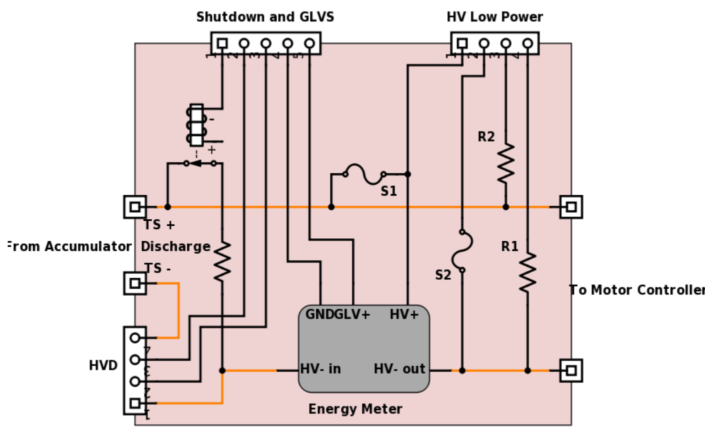


Figure 46: Schematic of the internals of the energy meter. Fuses S1 and S2 are Littelfuse 80812000000s, and resistors R1 and R2 are the TSMP resistors from section 2.8.

Figure 46 shows the internals of the energy meter box in electrical schematic form. The GLVS connector contains the shutdown circuit power for the discharge circuit, the interlock from the HVD, and GLVS power for the energy meter. The high voltage low power connector contains TSMP and TSAL high voltage connections to the master switch panel. High power connections are shown in orange.
The energy meter TS+ connection and the TSAL TS+ measurement wire share the same fused connection, and the TSAL TS- measurement wire has its own fuse. The fuse specifications can be found in table 4.1. The datasheet for the fuse can be found in table 4.1.

Fuse manufacturer and type	Littelfuse 80812000000
Continuous current rating	2.00 A
Maximum operating voltage	450VDC
Type of fuse	Fast-acting
I2T	0.0610 A^2sec
Interrupt current rating	10,000 A

Table 4.1: TS+ fuse for energy meter and TSAL TS+ measurement wire

4.3 Position in car

The energy meter housing is mounted to the chassis at the rear of the vehicle, in close proximity to the motor, motor controller, and accumulator, and with the HVD easily visible and accessible from the rear. See figure 47 on the next page.

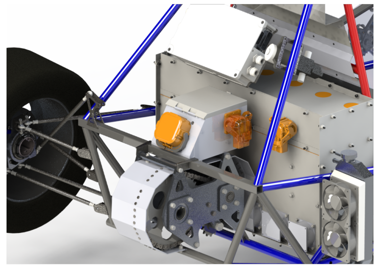


Figure 47: Render of the rear of the vehicle showing the mounting for the energy meter enclosure at the rear of the vehicle

5 Motor controller

5.1 Motor controller 1

5.1.1 Description, type, operation parameters

The motor controller regulates the power delivered to the motor. This motor controller is preferable for its small package and isolated control interface. We will communicate with it using our CAN bus.

Motor Controller type	Rinehart PM100DX
Maximum continuous power	86 kVA
Maximum peak power	100 kVA for 10s
Maximum input voltage	400 VDC
Output voltage	Not listed
Maximum continuous output current	300 A
Maximum peak current	350 A for 10s
Control method	CAN
Cooling method	Water
Auxiliary supply voltage	12 VDC

Table 5.1: General Motor Controller data

5.1.2 Wiring, cables, current calculations, connectors

The PM100DX has five high voltage connections (DC+, DC-, Phase A, Phase B, Phase C) as seen in figure 1 on page 1. Each connection is done with a cable gland that provides strain relief, environmental sealing, and shield termination for the dual insulated shielded 4 AWG cable. The manufacturer recommends this particular cable from Champlain Cable.

Wire type	4 AWG Cable
Current rating	190 A
Maximum operating voltage	1 kV
Temperature rating	-55°C to 150°C

Table 5.2: Wire data of the company: Champlain Cable, EXRAD SAE 150 XLE Shielded Cable

5.1.3 Position in car

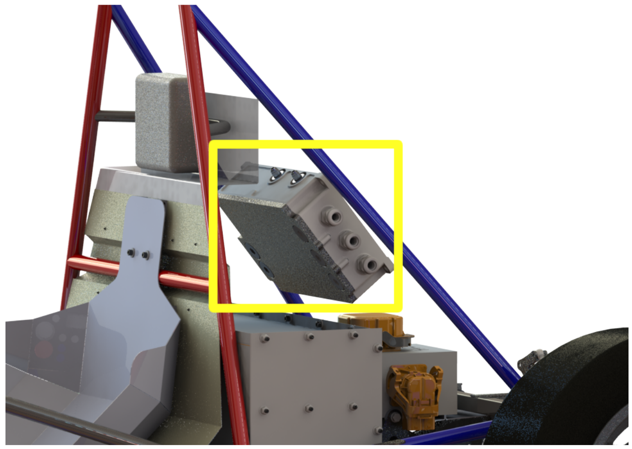


Figure 48: CAD rendering of Motor Controller position

5.2 Motor controller 2

We only have one motor controller, described in 5.1.

6 Motors

6.1 Motor 1

6.1.1 Description, type, operating parameters

Originally designed for aviation use, this out-runner motor delivers remarkable performance for its weight.

Motor Manufacturer and Type:	Make: Enstroj Model: EMRAX 228
Motor principle	Permanent magnet synchronous motor
Maximum continuous power	28 - 42 kW
Peak Power	100 kW
Input voltage	50 – 450 V
Nominal current	160 A
Peak current	340 A
Maximum torque	240 Nm
Nominal torque	125 Nm
Cooling method	Water

Table 6.1: General motor data

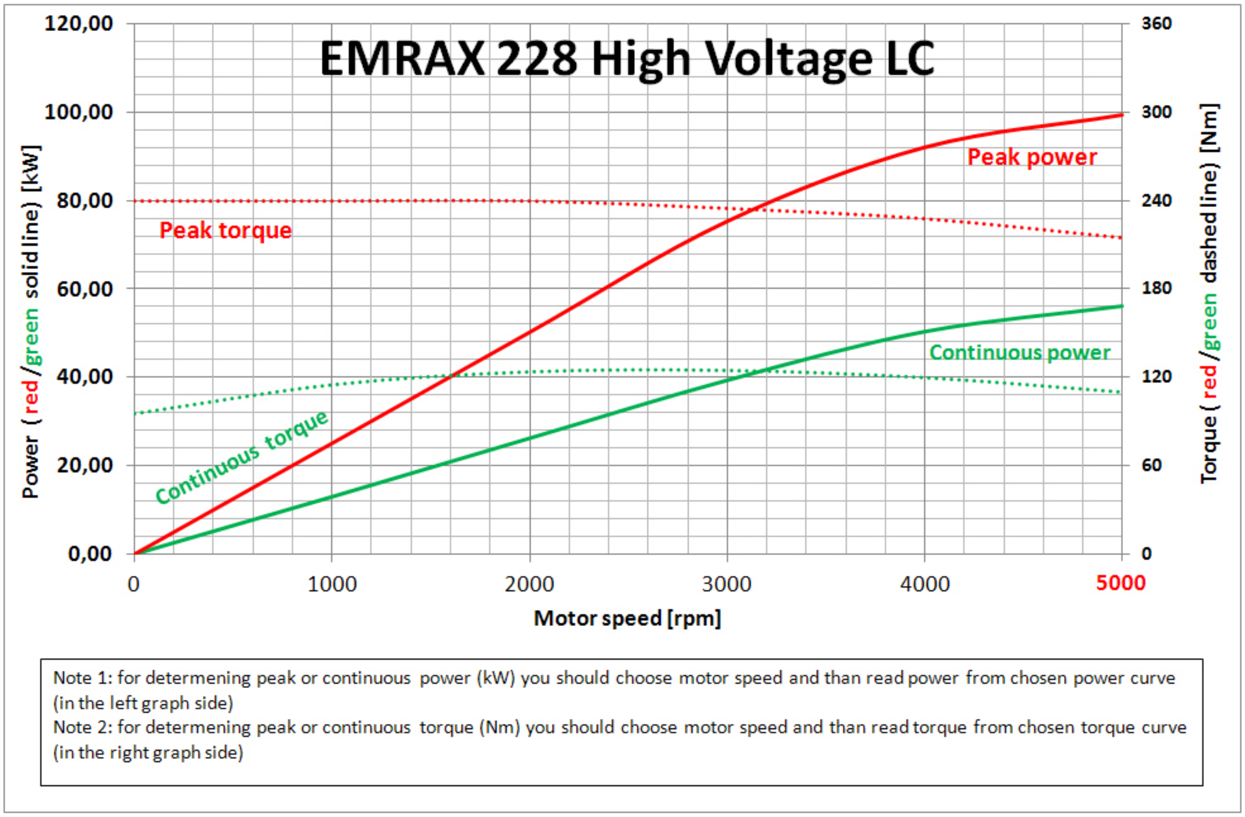


Figure 49: Motor Power and Torque: although we are using the medium voltage version of the motor, the only difference in terms of this plot is the ratio of current and voltage.

6.1.2 Wiring, cables, current calculations, connectors

Wire type	2 AWG Cable
Current rating	255 A
Maximum operating voltage	1 kV
Temperature rating	-55°C to 150°C

Table 6.2: Wire data of the company: Champlain Cable, EXRAD SAE 150 XLE Shielded Cable. Datasheet here

Since the motor leads terminate close to the motor with ring terminals close to the motor as seen in figure 51, the motor will have a 3D printed enclosure around the leads, with a high power connector found here. A CAD render of the motor lead enclosure can be found in figure 50 on the next page. HV and LV segments are separated by a 3D printed wall with an extension designed to protect the LV rotary encoder wires from the motor from HV connections. HV connections will be shielded and double-insulated, so the plastic serves to keep the wires from interfering, not to provide insulation.

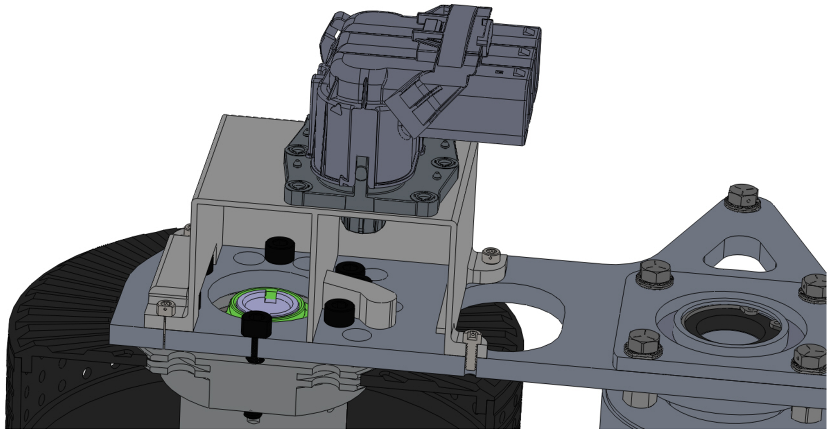


Figure 50: CAD render of 3D printed motor enclosure. HV and LV segments of the enclosure are separated by a PLA wall.

Figure 51: Picture of motor, note ring terminal crimps on leads.

6.1.3 Position in car

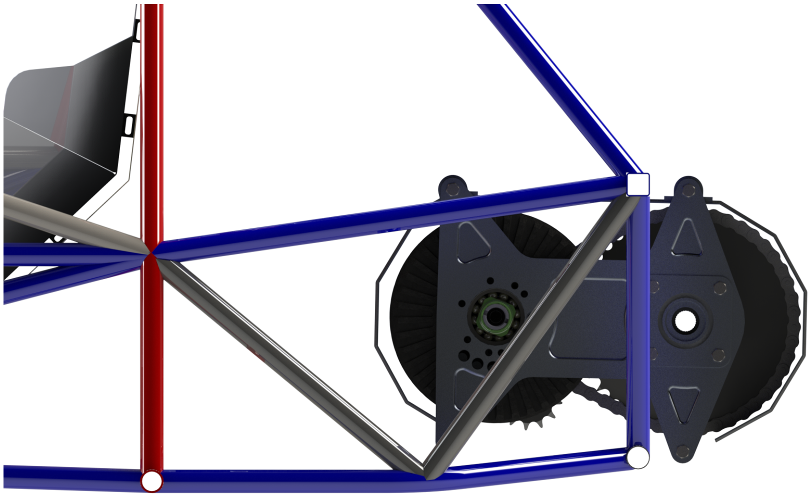


Figure 52: CAD rendering of the motor and transmission in the frame of the vehicle

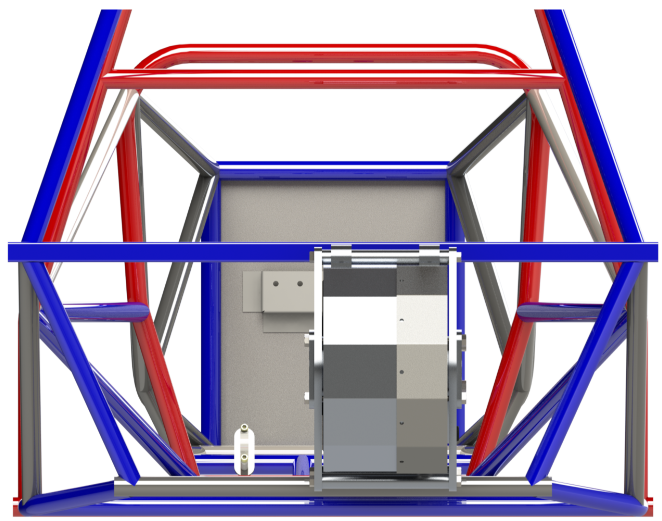


Figure 53: CAD rendering of the motor and transmission in the frame of the vehicle

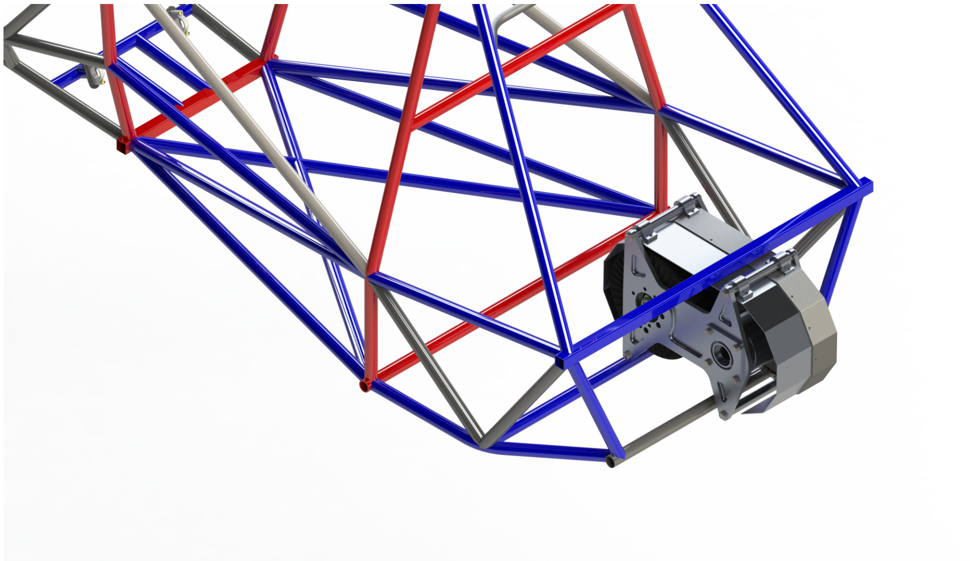


Figure 54: CAD rendering of the motor and transmission in the frame of the vehicle

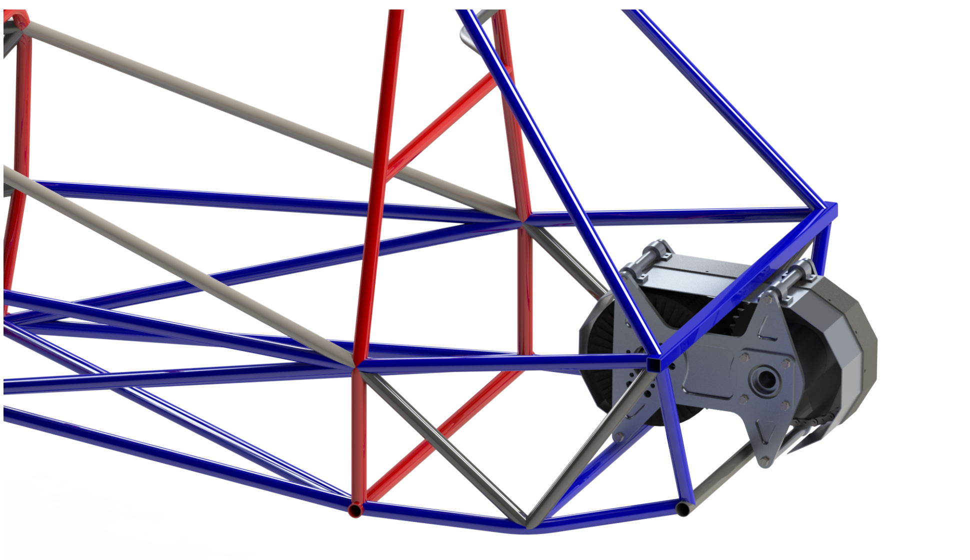


Figure 55: CAD rendering of the motor and transmission in the frame of the vehicle

6.2 Motor 2

We only have one motor, described in 6.1.

7 Torque encoder

7.1 Description/additional circuitry

Two rotary potentiometers are mechanically housed in one unit from Active Sensors (P/N MHR5621) and mounted to the rotating shaft of the throttle pedal assembly. The use of a single housing eliminates concerns regarding mechanical backlash and misalignment. Each output from the potentiometers will go to a CAN connected ATmega16M1, which will compare the two outputs and send a message via CAN bus to the motor controllers with the requested torque.

Torque encoder manufacturer and type:	MHR5621 from Active Sensors
Torque encoder principle	Potentiometer
Supply voltage	5V
Maximum supply current	15 mA
Operating temperature	-55 to 150°C
Used output	0-5V

Table 7.1: Torque Encoder data

7.2 Torque Encoder Plausibility Check

Two potentiometers are mounted on the torque pedal. A CAN node probes the voltage dividers which are amplified in different transfer functions using a Texas Instruments Operational Amplifier, part number LMV341QDCKRQ1. One transfer function amplifies the voltage of one potentiometer by a factor of two and the other amplifies the voltage from the potentiometer by a factor of one half. The ATmega will compare the two independent voltages and if an implausibility occurs, a difference in voltage from the Torque Encoder besides what is expected from the transfer function, and persists for more than 100msec, the power to the motor(s) must be immediately shut down completely. If a short circuit or wiring failure with either potentiometer occurs, the input will be outside the normal operating range, and the power to the motor controllers will be shut down. The normal operating range for the throttle inputs will be from 0.5V to 4.5V on the analog line with a gain of 2, and from 2 to 3 volts on the analog line with a gain of 1/2. Upon detecting an implausibility, the ATmega16m1 ADC will trigger an interrupt that the input voltage is outside the defined range, and a software timer will begin. If the software timer reaches 100 msec before the input voltage triggers a ”return to normal range” interrupt, then the APPS will trigger a motor shutdown over CAN. The node will log the error in the CAN bus. There will also be a Pegasus Brake light pressure switch (part number 3601, recommended by Formula Hybrid) on the brakes, wired to a CAN node with 22 gauge wire. If the pressure switch indicates actuation of the brake and the accelerator pedal position sensor measures more than 25 percent pedal travel, the power to the motors will be completely stopped until the accelerator pedal indicates less than 5 percent pedal travel.

7.3 Wiring

Two potentiometers are wired with their each input wired through an operational amplifier with a specific amplification, one with an amplification of two and one with an amplification of one half, and their output to the CAN analog input pins. The potentiometers are given separate power lines of 5V, parallel, to the supply power of the CAN node itself. The brake switch is positioned to trip at a level of hard braking, and when triggered will deliver 5V to a CAN input pin. The CAN node is wired to send and receive messages to the other nodes.

7.4 Position in car/mechanical fastening/mechanical connection

The torque encoder is bolted to the accelerator pedal assembly with 4x ¼"-20 bolts. The bolts are safetywired to prevent loosening. The torque encoder is manufactured with a D-shaft. This is rotationally fixed to the accelerator pedal axle by a 4-40 set screw. The set screw is bonded with Loctite Purple to prevent loosening. This allows the torque encoder to measure the angular position of the accelerator pedal axle. The accelerator pedal axle is prevented from moving axially by retaining rings. The mounting of the torque encoder does not affect the relative plausibility check. The sensor used contains two independent encoders, each measuring the position of the single shaft

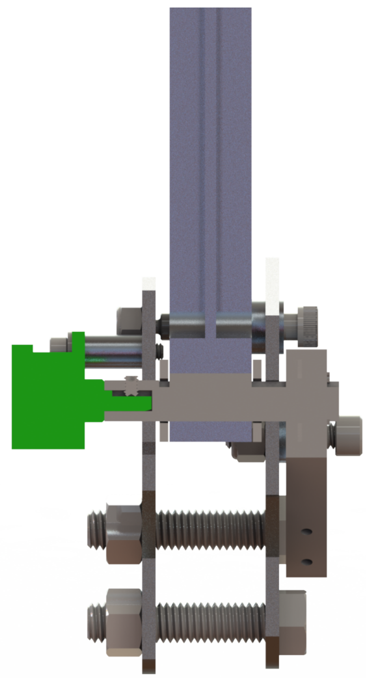


Figure 56: Mechanical fastening and connection to the throttle pedal. Note that the torque encoders are two encoders housed in one package

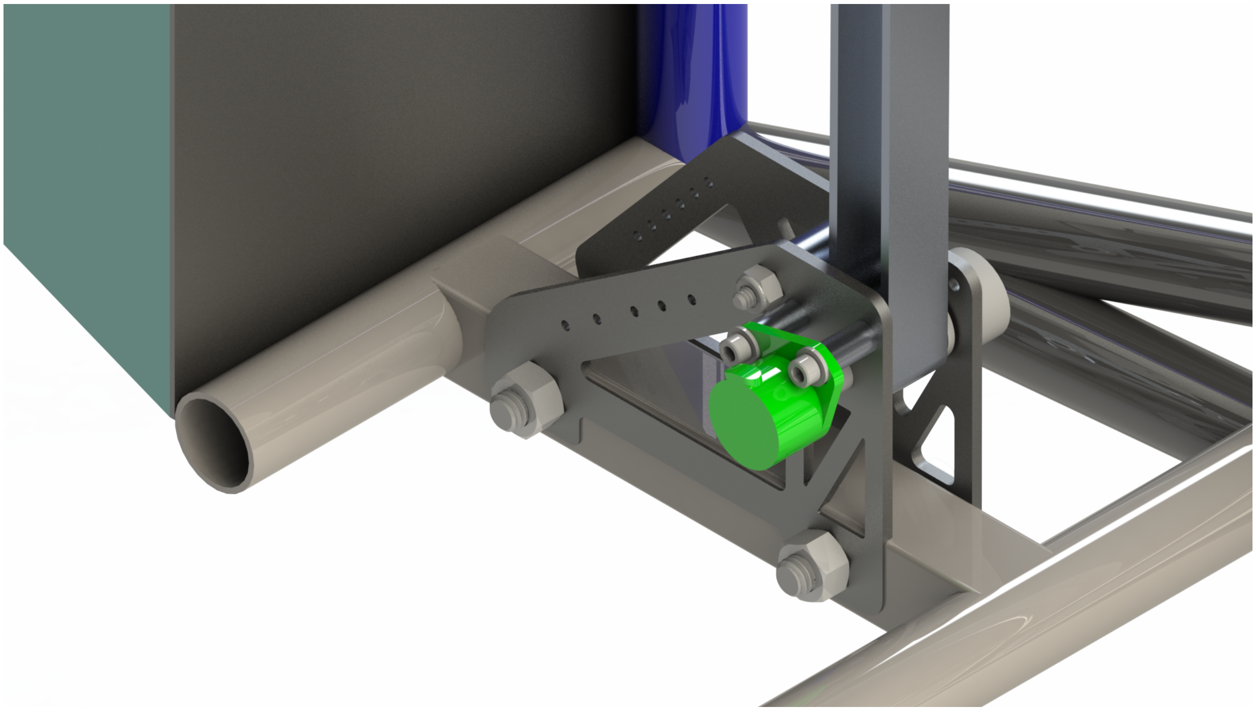


Figure 57: Location of the encoder on the throttle pedal

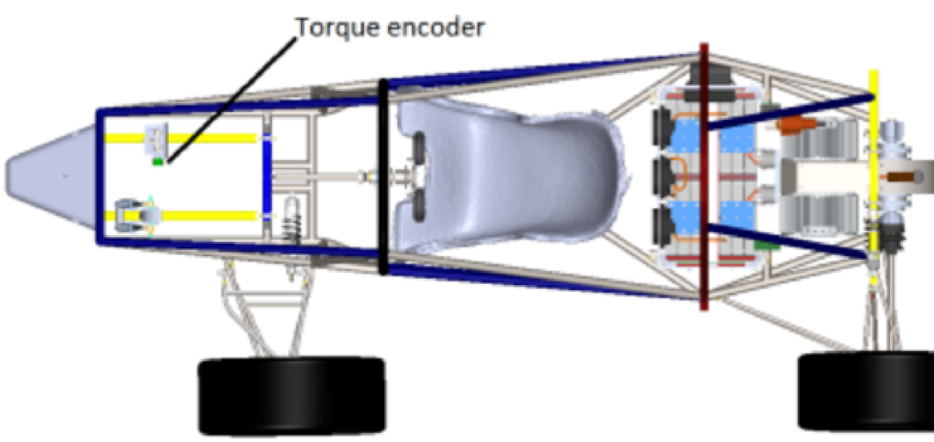


Figure 58: Location of torque encoder in car

8 Additional LV-parts interfering with the tractive system

8.1 LV part 1

There are preliminary design ideas for adding a DC/DC converter into the energy meter enclosure for recharging the GLVS battery, but that design has not yet been considered, and will only appear in a later revision of the ESF if it is included in the vehicle. As of yet all LV parts interfering with the tractive system have been adequately described in other sections.

8.1.1 Description

All LV parts interfering with the tractive system have been adequately described.

Wiring, cables

All LV parts interfering with the tractive system have been adequately described.

8.1.2 Position in car

All LV parts interfering with the tractive system have been adequately described.

8.2 LV part 2

All LV parts interfering with the tractive system have been adequately described.

9 Overall Grounding Concept

9.1 Description of the Grounding Concept

The vehicle's steel chassis is uses as GLVS ground. This ground will be established inside the master switch panel enclosure by attachment to a positively-retained ring terminal on a chassis member that has been locally stripped of paint. All components of the GLVS will be grounded to this point on the chassis through the wiring harness for simplicity of installation and mechanical robustness. All conductive mechanical enclosures are mounted to the chassis with conductive metal fasteners. Electrical connection of the suspension members and knuckles to the main vehicle frame will be achieved by short jumpers with ring terminals on either end in the suspension member bolt stackup on either side of the spherical bearing.

9.2 Grounding Measurements

All conductive components within 100 mm of any Tractive System or GLVS component will be measured by Kelvin ohmmeter to have a resistance of less them 300 mω to chassis ground, measured at the chassis ground measurement point on the master switch panel. All fastened mechanical components and enclosures will be individually measured to ensure proper ground connection. Chassis ground continuity will be tested during and after assembly to ensure complete coverage. Any carbon fiber components will be exhaustively measured to ensure resistance compliance.

10 Firewall(s)

10.1 Firewall 1

10.1.1 Description/materials

The firewall is constructed of two layers. The layer facing the tractive system is 24 gauge Aluminum sheet metal, and the layer facing the cockpit is 24 gauge Flame-Retardant Multipurpose Garolite. The assembly is attached with marine epoxy between the two layers and nylon fasteners. The chassis has welded sheet metal tabs that fasten to the firewall with bolts and lock nuts. Because the firewall is fastened to the chassis using conductive fasteners it is connected to GLV ground. The firewall is attached to the seat through epoxied 3D printed spacers and foam sprayed between the seat and firewall, seen in figure 59. All high voltage and high temperature systems are contained in the rear of the vehicle, so only one firewall will be used. There are GLV systems in the dashboard and pedal box so a small grommet hole will be made in the firewall for GLV wiring.

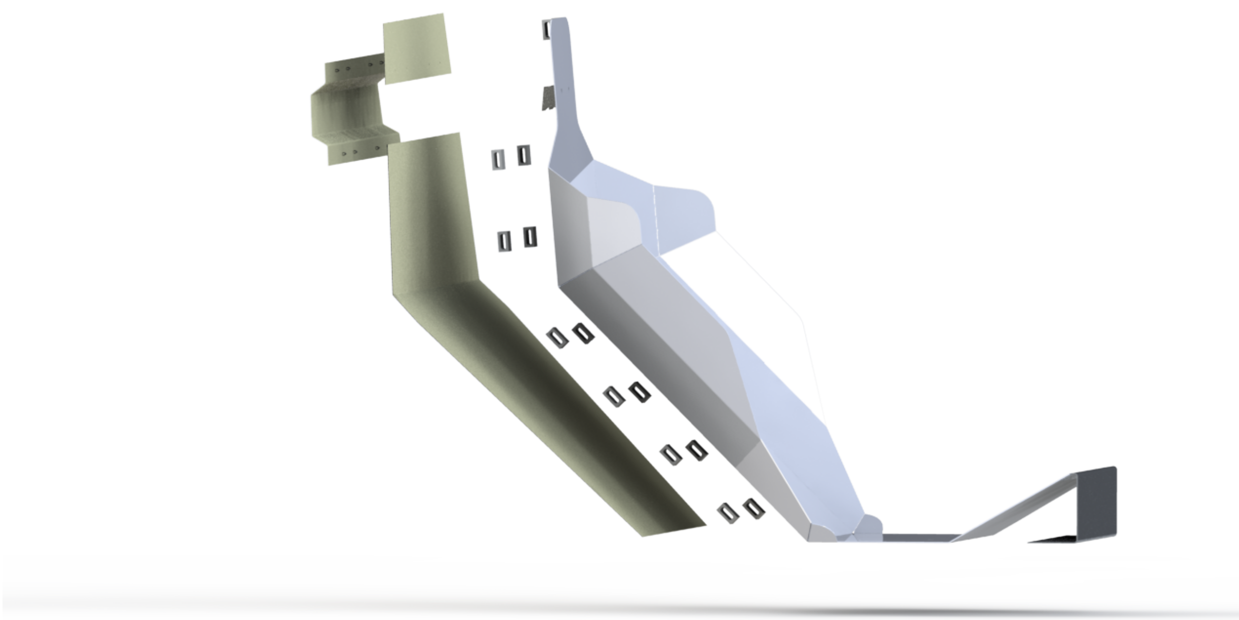


Figure 59: An exploded view of the firewall and seat.

10.1.2 Position in car

The firewall is located between the driver and accumulator, to protect the driver from the tractive system. figure 60 shows the cockpit view without the seat for visual aid. The seat is between the wheel and the firewall, with the firewall cushioning the seat. The firewall is attached to the frame so that its top corners are flush, eliminating a concern of sharp edges.

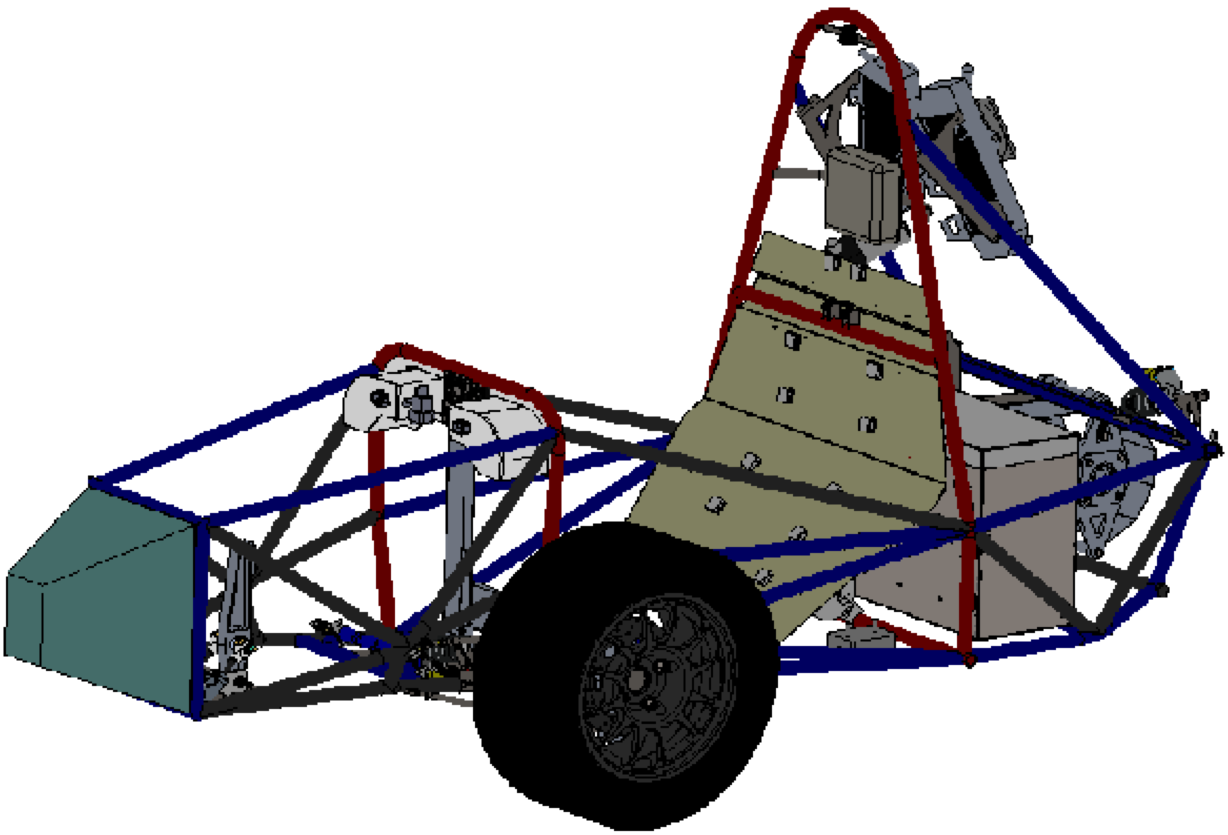


Figure 60: A view of the firewall in the car without the seat.

10.2 Firewall 2

We only have one firewall, described in 10.1.

11 Appendix

11.2 Electrical Systems

11.2.2 IMD Datasheet

Referred from section 2.2.

Insulation coordination acc. to IEC 60664-1	
Protective separation (reinforced insulation)	between (L+/L-) – (Kl. 31, Kl. 15, E, KE, M_{HS}, M_{LS}, OK_{HS})
Voltage test	AC 3500 V/1 min
Supply/IT system being monitored	
Supply voltage U_S	DC 10…36 V
Max. operating current I_S	150 mA
Max. current I_k	2 A 6 A/2 ms inrush current
HV voltage range (L+/L-) U_n	AC 0…1000 V (peak value) 0…660 V r.m.s. (10 Hz…1 kHz) DC 0…1000 V
Power consumption	< 2 W
Response values	
Response value hysteresis (DCP)	25 %
Response value R_{an}	100 kΩ…1 MΩ
Undervoltage detection	0…500 V
Measuring range	
Measuring range	0…10 MΩ
Undervoltage detection	0…500 V default setting: 0 V (inactive)
Relative uncertainty SST (≤ 2 s)	good > 2* R_{an}; bad < 0.5* R_{an}
Relative uncertainty DCP (default setting 100 kΩ)	0…85 kΩ ▸ ±20 kΩ 100 kΩ…10 MΩ ▸ ±15%
Relative uncertainty output M (fundamental frequency)	±5 % at each frequency (10 Hz; 20 Hz; 30 Hz; 40 Hz; 50 Hz)
Relative uncertainty undervoltage detection	$U_n \geq 100$ V ▸ ±10 %; at $U_n \geq 300$ V ▸ ±5 %

Time response	
Response time t_{an} (OK_{HS}; SST)	$t_{an} \leq 2$ s (typ. < 1 s at $U_n > 100$ V)
Response time t_{an} (OK_{HS}; DCP) (when changing over from $R_F = 10$ MΩ to $R_{an}/2$; at $C_e = 1$ µF; $U_n =$ DC 1000 V)	$t_{an} \leq 20$ s (at $F_{ave} = 10$*) $t_{an} \leq 17.5$ s (at $F_{ave} = 9$) $t_{an} \leq 17.5$ s (at $F_{ave} = 8$) $t_{an} \leq 15$ s (at $F_{ave} = 7$) $t_{an} \leq 12.5$ s (at $F_{ave} = 6$) $t_{an} \leq 12.5$ s (at $F_{ave} = 5$) $t_{an} \leq 10$ s (at $F_{ave} = 4$) $t_{an} \leq 7.5$ s (at $F_{ave} = 3$) $t_{an} \leq 7.5$ s (at $F_{ave} = 2$) $t_{an} \leq 5$ s (at $F_{ave} = 1$) during the self test t_{an} + 10 s
Switch-off time t_{ab} (OK_{HS}; DCP) (when changing over from $R_F = 10$ MΩ to $R_{an}/2$; at $C_e = 1$ µF; $U_n =$ DC 1000 V	$t_{ab} \leq 40$ s (at $F_{ave} = 10$) $t_{ab} \leq 40$ s (at $F_{ave} = 9$) $t_{ab} \leq 33$ s (at $F_{ave} = 8$) $t_{ab} \leq 33$ s (at $F_{ave} = 7$) $t_{ab} \leq 33$ s (at $F_{ave} = 6$) $t_{ab} \leq 26$ s (at $F_{ave} = 5$) $t_{ab} \leq 26$ s (at $F_{ave} = 4$) $t_{ab} \leq 26$ s (at $F_{ave} = 3$) $t_{ab} \leq 20$ s (at $F_{ave} = 2$) $t_{ab} \leq 20$ s (at $F_{ave} = 1$) during a self test t_{ab} + 10 s
Duration of the self test	10 s (every five minutes; should be added to t_{an}/t_{ab})

Figure 61: The datasheet for the IMD.

Full IMD datasheet here.

11.2.4 BSPD

Theoretical sensitivity	G_{th}	mV/A		16		800 mV @ I_{PN}

Figure 62: Current sensor sensitivity from datasheet

LEM HO-S series datasheet.
Referred from Section 2.4.

11.2.6 Shutdown System Interlocks

Referred from section 2.6.

APPLICATIONS

- Battery
- Inverter
- E-motor

MECHANICAL

- Terminal: 8mm pin and socket
- Wire range: 16-50mm² discrete shielded wire
- Latching Style: No tool required
- HVIL: Integrated, internal

ELECTRICAL

- Voltage rating: 1000V
- Current rating: Up to 250A
- Temperature range: -40°C to 140°C
- Shielding: 360° from wire to device
- IP rating: Mated: IP67, IP6k9k
Unmated: IP2xb

STANDARDS AND SPECIFICATIONS

- AK 4.3.3
- LV215-1
- RoHS

Figure 63: Ratings and interlock description for TE HVP 800 connectors

TE HVP 800 complete Datasheet

11.2.7 Tractive System Active Light

Referred from section 2.7.
TSAL Datasheet here.

11.2.8 Measurement points (TSMPs)

Referred from section 2.8.

STANDARD ELECTRICAL SPECIFICATIONS				
MODEL	POWER RATING $P_{25\,°C}$ W	LIMITING VOLTAGE $U_{max.}$	RESISTANCE RANGE [2] Ω	TOLERANCE ± %
PAC01	1	$\sqrt{P \times R}$	0.10 to 2.2K	1
PAC02 [1]	2	$\sqrt{P \times R}$	0.10 to 3.6K	1
PAC03	3	$\sqrt{P \times R}$	0.10 to 4.7K	1
PAC04	4	$\sqrt{P \times R}$	0.10 to 8.2K	1
PAC05	5	$\sqrt{P \times R}$	0.10 to 12K	1
PAC06	6	$\sqrt{P \times R}$	0.10 to 12K	1

Notes
- PAC02 WSZ: $P_{25\,°C}$ = 1.8 W
- Resistance value to be selected for ± 1 % tolerance from E24 and E96
- For Pulse Diagrams see AC.. Series (www.vishay.com/doc?28730)

Figure 64: Ratings for Vishay PAC series resistors. The TSMP resistors are PAC05 (PAC500001002FAC000), shown in the fifth row

Example multimeter for TS measurement. Link to datasheet. Complete datasheet for TSMP current limiting resistors. Datasheet for TSMP banana jack connectors here.

11.2.10 Discharge circuitry

Characteristics

Tolerance (Code):	± 1% (F), ± 5% (J), ± 10% (K)
Operating temperature:	-65°C to +175°C
Temperature coefficient:	± 50ppm/°C to ± 300ppm/°C (re to ohmic values), referenced to 25°C, ΔR taken at +105°C
Operating voltage:	700V max
Dielectric strength:	1800Vac 60 seconds, ΔR±0.15%
Insulation resistance:	10G min
Maximum torque:	0.9 Nm
Free air:	25°C, rated at 3.5W
Load Life	ΔR±1.0%, Rated power, 2,000 hours
Solderability	90% min. coverage, 245±5°C for 3 seconds
Momentary Overload	ΔR±0.5%,1.5 times rated power and V (dc) ≤ 1.5VMax. for 5 seconds
Moisture resistance	ΔR±0.5%, -10°C - +65°C, RH>90%, cycle 240 hours
Thermal Shock	ΔR±0.5%, -65°C - 150°C, 100 cycles
Terminal Strength	ΔR±0.2%, (Pull Test) 2.4N
Vibration, High Frequency	ΔR±0.4%, 20g peak

Figure 65: Ratings for Ohmite AP101 series resistors. The discharge resistor is AP101 3K J

SERIES SPECIFICATIONS						
Heatsink Part Number	Height (in. ±.010 / *mm ±.25*)	For Package Type	Ohmite Resistor Series	Surface Area (mm^2)	Weight (g)	Thermal Res.* (°C/W)
RA-T2X-25E	1.0/25.4	TO-220, -218, -247	TBH25,TCH35, TEH70, TEH100	8,901	25	4.8
RA-T2X-38E	1.5/38.1	TO-220, -218, -247	TBH25,TCH35, TEH70, TEH100	12,983	38	3.9
RA-T2X-51E	2.0/50.8	TO-220, -218, -247	TBH25,TCH35, TEH70, TEH100	17,065	51	3.5
RA-T2X-64E	2.5/63.5	TO-220, -218, -247	TBH25,TCH35, TEH70, TEH100	21,148	63	3.1
FA-T220-25E	1.0 / 25.4	TO-220, -218, -247	TBH25,TCH35, TEH70, TEH100	9,285	18	4.7
FA-T220-38E	1.5 / 38.1	TO-220, -218, -247	TBH25,TCH35, TEH70, TEH100	13,756	27	3.8
FA-T220-51E	2.0 / 50.8	TO-220, -218, -247	TBH25,TCH35, TEH70, TEH100	18,222	37	3.4
FA-T220-64E	2.5 / 63.5	TO-220, -218, -247	TBH25,TCH35, TEH70, TEH100	22,814	46	3

*Natural convection

Figure 66: Ratings for Ohmite F and R series heatsinks. The discharge resistor heatsink is RA-T2X-25E, shown in the first row.

Complete datasheet for discharge resistor. Complete datasheet for discharge resistor heatsink.

11.2.11 HV Disconnect (HVD)

Referred from section 2.11.
TE AMP+ Manual Service Disconnect Overview here. TE Manual Service Disconnect Test Parameters datasheet here.

APPLICATIONS

- HV battery pack-to-pack

MECHANICAL

- Latching style: Finger actuated - 2 stage lever assist
- Mating cycles: Tested to 50
- Stud: M6
- IP rating: Mated: IPx7, IP6k9k
  Unmated: IP2xb
- HVIL: 2x integrated, internal

ELECTRICAL

- Fuse rating: Up to 630A
- Voltage rating: 450 VDC
- Operating Temperature: -40°C to 65°C
- Storage Temperature: -40°C to 85°C
- Current rating: Based on fuse selection

STANDARDS AND SPECIFICATIONS

- USCAR-2
- USCAR-37
- IEC 60529
- RoHS

Figure 67: Rating information for the TE AMP+ Manual Service Disconnect

11.2.12 Ready to Drive Sound

Referred from section 2.12.
Ready to drive buzzer datasheet.

Voltage Rating	12 to 24 Vdc
Frequency	1250 Hz ± 20%
Loudness (dB(A) @ 4 ft)	97 ± 8
Current Draw (Amps Max)	0.6
Sound Pulse Rate (pps)	1 to 2
Operating Temperature	-40°C to +85°C
Termination	8-32 UNC Studs
Housing	ABS, Black UL94V-0
Spike Protected	+100 / -400 Volts
Conforms to SAEJ994 (OCT 02) Standards	
Cross Reference	
ECCO	520
PRECO	240

Figure 68: Specification for Mallory Sonalert STA20502 Buzzer

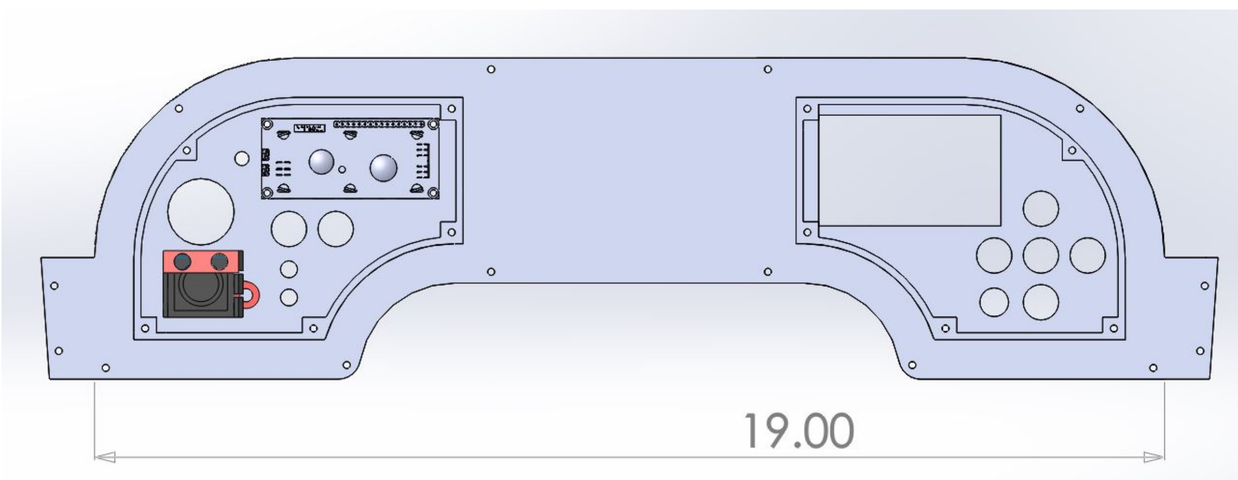


Figure 69: Rendering of the dashboard module as seen from the back

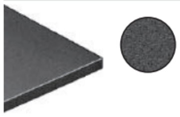
For calculation of sound attenuation over distance, see SengpielAudio Distance Law Equation

11.3 Accumulator

11.3.3 Cell Configuration

Referred from section 3.1.3.

Sheets and Sheeting—Textured Finish



- Temp. Range: –40° to +200° F
- Firmness (25% Deflection): 2-5 psi (extra soft), 5-9 psi (soft), or 9-13 psi (firm)
- Density: Extra soft and soft are 4-8 lbs./cu. ft. and firm is 7-11 lbs./cu. ft.

Foam meets ASTM D1056, UL 94HF1, MIL-C-3133C, and MIL-STD-670B. Material has a fine cell textured finish and does not have a skin. Sheets have a width tolerance of ±1¼″ and a length tolerance of ±2½″. Sheeting has a width tolerance of ±1¼″.

		42″ WD.×72″ LG. SHEETS						42″ WIDE SHEETING						
	Thick.	Extra Soft		Soft		Firm			Extra Soft		Soft		Firm	
Thick.	Tol.		Each		Each		Each	Max. Lg.		Per Ft.		Per Ft.		Per Ft.
1⁄16″	±0.015″	8647K1	$19.38	8647K106	$21.36	8647K109	$16.06	50 ft.	8647K102	$3.80	8647K108	$4.03	8647K12	$2.92
1⁄8″	±0.020″	8647K51	28.63	8647K71	29.62	8647K81	38.96	50 ft.	8647K21	5.49	8647K31	5.57	8647K41	7.77
3⁄16″	±0.026″	8647K52	35.21	8647K72	37.09	8647K82	48.35	50 ft.	8647K22	7.44	8647K32	7.62	8647K42	9.61
1⁄4″	±0.025″	8647K53	41.79	8647K73	44.38	8647K83	56.92	50 ft.	8647K23	8.32	8647K33	8.80	8647K43	11.25
3⁄8″	±0.035″	8647K55	66.90	8647K75	71.03	8647K85	90.66	50 ft.	8647K25	13.26	8647K35	14.69	8647K45	17.99
1⁄2″	±0.040″	8647K56	85.29	8647K76	92.08	8647K86	114.04	50 ft.	8647K26	16.95	8647K36	18.90	8647K46	22.45
3⁄4″	±0.065″	8647K58	99.61	8647K78	104.80	8647K88	127.63	50 ft.	8647K28	19.93	8647K38	21.89	8647K48	25.76
1″	±0.082″	8647K59	133.01	8647K79	140.16	8647K89	177.48	50 ft.	8647K29	26.38	8647K39	28.65	8647K49	33.90
1¼″	±0.095″	8647K61	148.75	8647K64	157.23	8647K67	200.68	6 ft.	8647K501	29.74	8647K601	32.81	8647K701	38.47
1½″	±0.150″	8647K101	167.47	8647K107	178.93	8647K11	265.30	25 ft.	8647K103	42.94	8647K104	43.22	8647K105	52.02
2″	±0.175″	8647K621	216.11	8647K651	235.86	8647K681	286.82	6 ft.	8647K201	41.72	8647K301	46.26	8647K401	56.24

Figure 70: Specifications for the neoprene compression foam that goes in the cell stack.

Complete neoprene information sheet.

11.3.4 Cell Temperature Monitoring

Referred from section 3.1.4.
Link to LTC6804 datasheet used for temperature and voltage measurement

11.3.10 Charging

Referred from section 3.1.10.
Charger datasheet [Note: Per Elcom, a PFC2000+ is a PFC2500 reprogrammed for more power on 115V] Datasheet.
Charger Information Page Information Page.

Specification

Spec Model	Output Voltage -Nominal	Output Voltage -Maximum	Output Current -Maximum 230vac	Output Current -Maximum 115vac
TCCH-36-40	36V	51V	40A	38A
TCCH-48-35	48V	66V	35A	29A
TCCH-60-28	60V	82V	28A	23A
TCCH-72-23	72V	96V	23A	19A
TCCH-84-20	84V	112V	20A	17A
TCCH-96-17	96V	130V	17A	14A
TCCH-120-14	120V	168V	14A	12A
TCCH-144-12	144V	192V	12A	10A
TCCH-168-9	168V	233V	9A	8A
TCCH-216-7.5	216V	289V	7.5A	6.5A
TCCH-288-6	288V	389V	6A	5A

Figure 71: Charger Output Specifications

AC Input

AC Input Voltage - range	90 - 260VAC
AC Input Voltage - nominal	120 VAC / 230 VAC
AC Input Frequency	45 - 65 Hz
AC Input Current - maximum	15A
Current – nominal	12 A rms @ 120 VAC / 12 A rms @ 230 VAC
AC Power Factor - nominal	> 0.98

Mechanical

Dimensions	352mm×195mm×139mm
Weight	< 7 kg Standard output cord
Environmental Enclosure	IP46
Operating Temperature	-30°C to +50°C (-86°F to 122°F)
Storage Temperature	-40°C to +85°C (-104°F to 185°F)

LED Indicator

Red-Green flash (one second interval)	Battery Disconnected
Red flash (three seconds interval)	Repair Battery
Red flash (one second interval)	<80% Charge Indicator
Yellow flash (one second interval)	>80% Charge Indicator
Green flash (one second interval)	100% Charge Indicator

Protection Features

1.Thermal Self-Protection: When the internal temperature of the charger exceeds 80℃, the charging current will reduce automatically. If exceeds 85℃, the charger will shutdown protectively, there is no current output in this case. When the internal temperature drops to 80℃, it will resume charging automatically.

2. Short-circuit Protection: When the charger encounters unexpected short circuit across the output, charging will automatically stop. By cutting AC power for 10 seconds, the charger can be re-set and will start normally(with the output circuit corrected)

3. High and Low Voltage Protection: When the input AC Voltage is higher or lower than the rated input voltage range, the charger will shutdown protectively, but resume working after the voltage is normal again.

Inter-lock Function

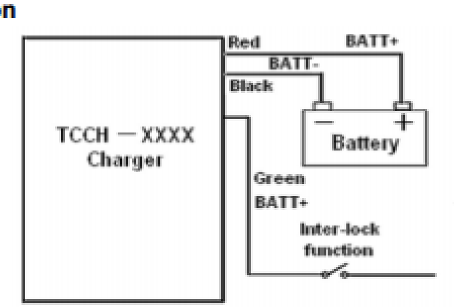


Figure 72: Charger Input and Protection Features

11.4 Energy Meter Mounting

Referred from sections 2.2 and 4.

Electrical Characteristics

Ampere Rating (A)	Amp Code	Max Voltage Rating (V)		Interrupting Rating	Nominal Cold Resistance (Ohms)	Nominal Melting I2t (10In - A^2sec)	Max Voltage Drop (Mv)	Agency Approval cURus
		AC	DC					
2.00	1200	250	450	200A@250VAC 10KA@450VDC	0.069	0.0610	342	x
2.50	1250	250	450		0.054	0.0898	300	x
3.00	1300	250	350	200A@250VAC 10KA@350VDC	0.042	0.2007	276	x
3.15	1315	250	350		0.038	0.2191	270	x
4.00	1400	250	250	200A@250VAC 10KA@250VDC	0.027	0.5445	240	x
5.00	1500	250	250		0.022	1.1584	215	x

Notes:
1. Cold resistance measured at less than 10% of rated current at 23°C.
2. An operating current of 80% or less of rated current is recommended, with further derating required at elevated ambient temperature.
3. Have special electrical characteristic needs? Contact Littelfuse to learn more about application specific options.

Figure 73: Electrical characteristics snapshot for Littelfuse 808 series fast-acting fuses. The high-voltage low-power fuse we use is the 80812000000.

Littelfuse 808 Series datasheet.