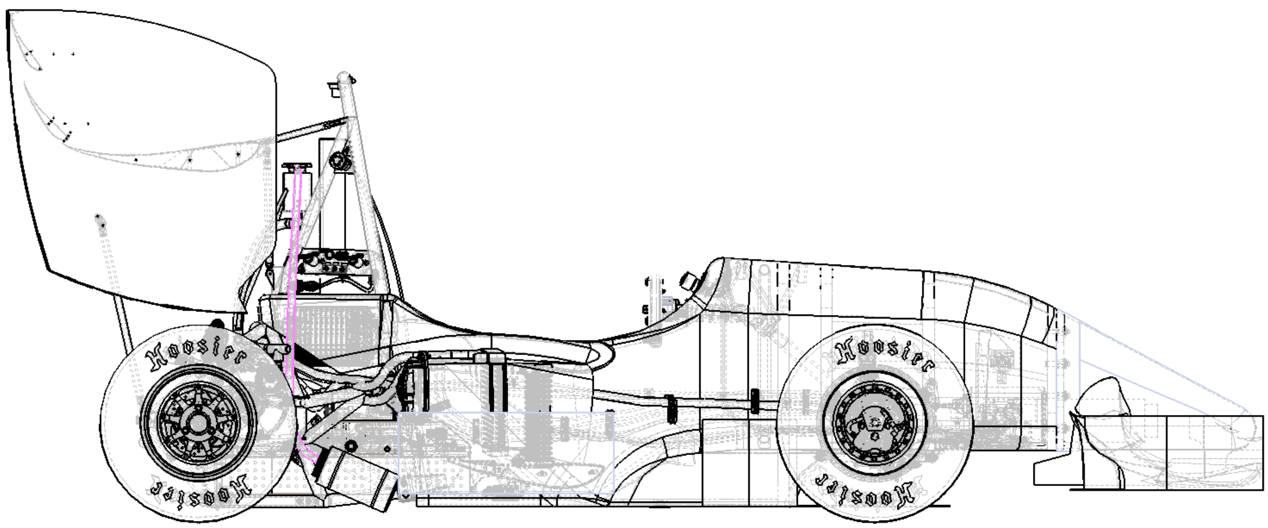
Electrical System Form FSAE-E2017

University of Wisconsin-Madison



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List of Abbreviations

ADC – Analog to Digital Converter

AIR – Accumulator Isolation Relay(s)

AEU – Accumulator Electronics Unit

AWG – American Wire Gage

BMS – Battery Management System

BOTS – Brake OverTravel Switch

BPD – Brake Plausibility Device

CAN – Controller Area Network

DPDT- Double Pole, Double Throw

ECU – Electronic Control Unit

FEU – Front Electronics Unit

GLV – Grounded Low Voltage

GLVMS – Grounded Low Voltage Master Switch

GLVMP – Grounded Low Voltage Measuring Point

HV – High Voltage

HVD – High Voltage Disconnect

IMD – Insulation Monitoring Device

LV – Low Voltage

PCB – Printed Circuit Board

RTDS – Ready To Drive Sound

REU – Rear Electronics Unit

SDB – Shutdown Button

SDC – Shutdown Circuit

SPDT – Single Pole, Double Throw

SPST – Single Pole, Single Throw

TSAL – Tractive System Active Light

TSMP – Tractive System Measuring Point

TSMS – Tractive System Master Switch

VDC – Voltage in Direct Current

1 System Overview

This electric vehicle is designed for a race environment where it must have high acceleration, good stability, and the ability to run for 30 minutes continuously with safety as the highest priority. The vehicle is driven by four synchronous permanent magnet motors where each wheel is controlled independently through a torque vectoring algorithm run on our ECU. Our battery pack is in 30s24p configuration with a total available energy of 6.48 kWh and nominal voltage of 108V.

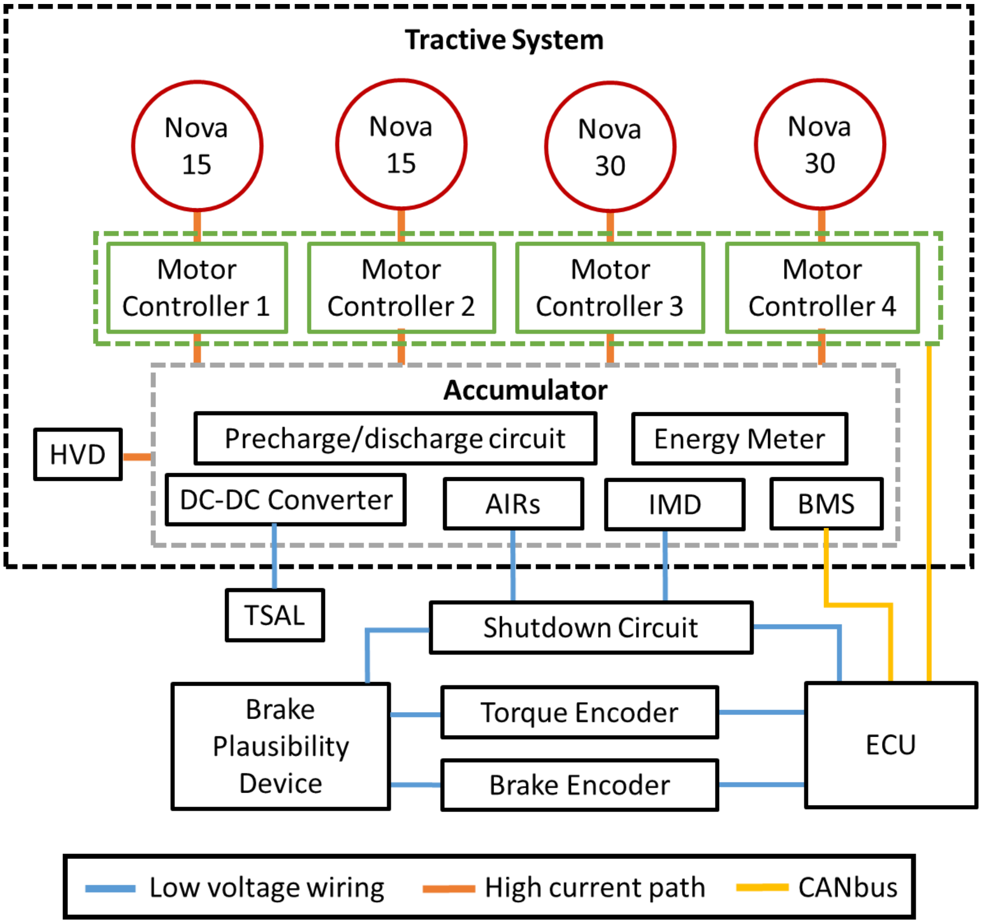


Figure 1: Top level schematic of vehicle electrical systems

Maximum Tractive-system voltage:	126VDC
Nominal Tractive-system voltage:	108VDC
Control-system voltage:	5VDC, 12VDC
Accumulator configuration:	30s24p
Total Accumulator capacity:	60Ah, 6.48kWhr
Motor type:	synchronous permanent magnet brushless DC motor
Number of motors:	Total 4, two outboard motors in front wheels and two inboard in the rear
Maximum combined motor power in kW	90

Table 1.1 General parameters

2 Electrical Systems

2.1 Shutdown Circuit

2.1.1 Description/concept

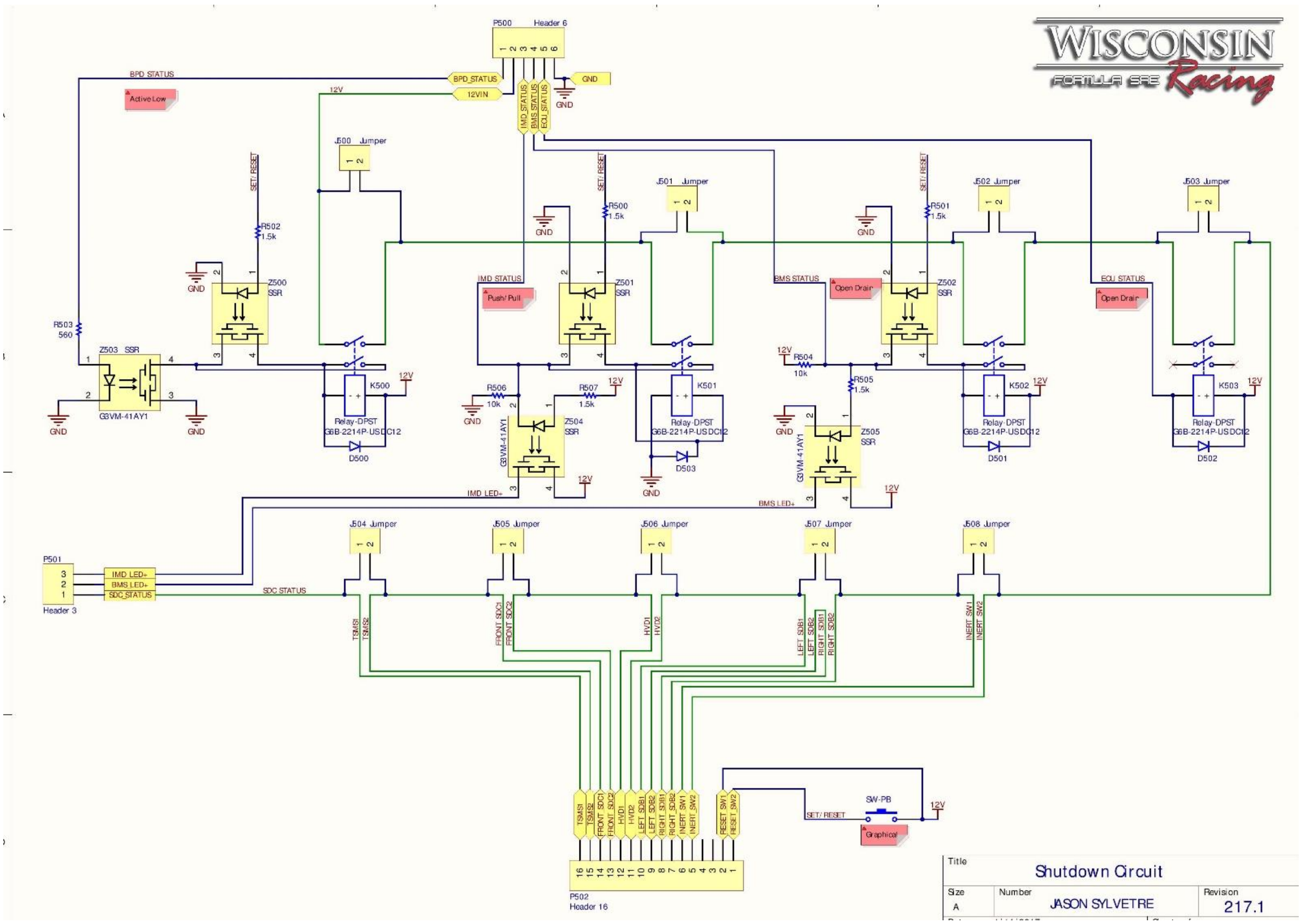


Figure 2: Shutdown circuit schematic

The shutdown circuit is composed of several switching elements connected in series that drive the AIR coils with a 12V signal. The main series path that drives the coils is shown above in green. If any one of these elements is triggered by a fault, the power stage corresponding to that system input will open, thus opening the main path that drives the AIRs coils, which will isolate the accumulator from the rest of the tractive system.

Tractive System Master Switch: This is a SPST red key switch that is the last switching element in the shutdown circuit. Deactivating this switch will disconnect the path carrying the control current to the AIR, which will disable the tractive system.

Grounded Low Voltage Master Switch: This is a SPST red key switch that switches power to the LV circuitry. Deactivating this switch will disconnect the low voltage supply from all the circuits in the vehicle. This will cause all systems in the vehicle to shut down including the high voltage tractive system.

Shutdown Buttons: There are 3 shutdown buttons: one on the left side of the car, one on the right side of the car, and one in the cockpit. All three buttons are normally closed and will open the AIRs upon being pressed. They feature an LED that indicates if the shutdown circuit is active.

Inertia Switch: This is a SPST switch that will open the AIRs upon impact in a crash.

Brake over travel switch: This is a SPST switch that will open the AIRs in case over travel of the brake pedal is detected.

Brake Plausibility Device: This circuit will open the AIRs through a power stage relay if brake pedal is depressed while the motor controllers are supplying 5kW of power to the motors for more than half a second.

Isolation Monitoring Device: This device will open the AIRs through a power stage relay if a leakage is detected between the high voltage tractive system and the grounded low voltage system.

Battery Management System: The BMS will open the AIRs through a power stage relay if any fault is detected in the accumulator.

Electronic Control Unit: The ECU will open the AIRs through a power stage relay if a critical fault is detected with any of the systems on the CAN network.

Safety interlocks: There are two wheel interlocks and one HVD interlock that will open the AIRs if there one of the front corners is blown off the car or the HVD is activated.

Part	Function
Main Switch (for control and tractive-system; CSMS, TSMS)	single pole single throw switch, normally open
Brake over travel switch (BOTS)	single pole single throw switch, normally closed
Shutdown buttons (SDB)	single pole single throw switch, normally closed
Insulation Monitoring Device (IMD)	powerstage relay, normally open
Battery Management System (BMS)	powerstage relay, normally open
Electronic Control Unit (ECU)	powerstage relay, normally open
Inertia Switch	single pole single throw switch, normally closed
Interlocks	closed when HVD is connected and A-arms are intact
Brake System Plausibility Device	powerstage relay, normally closed

Table 2.1 List of switches in the shutdown circuit

2.1.2 Wiring / additional circuitry

The shutdown circuit is a daughter board that connects to our Rear Electronics Unit (schematic shown below) via header pins. The Rear Electronics Unit uses a Molex CMC connector. Binder M5 connectors with pre-crimped cabling are used for inline connections. Each cable consists of four separate conductors that are each 24AWG with a voltage rating of 60V.This circuit is protected by a 32VDC 7.5A MINI fuse. The fuse must be able withstand the inrush current of 7.8A for less than 1 second. Based on this inrush current, we selected the fuse using the time-current characteristic curve given for that line of products.

Total Number of AIRs:	2 (+4 non-SDC contactors for separating the battery into four segments)
Current per AIR:	0.13A
Additional parts consumption within the shutdown circuit:	0.10A
Total current:	0.36A
Cross sectional area of the wiring used:	0.205 mm²

Table 2.2 Wiring – Shutdown circuit

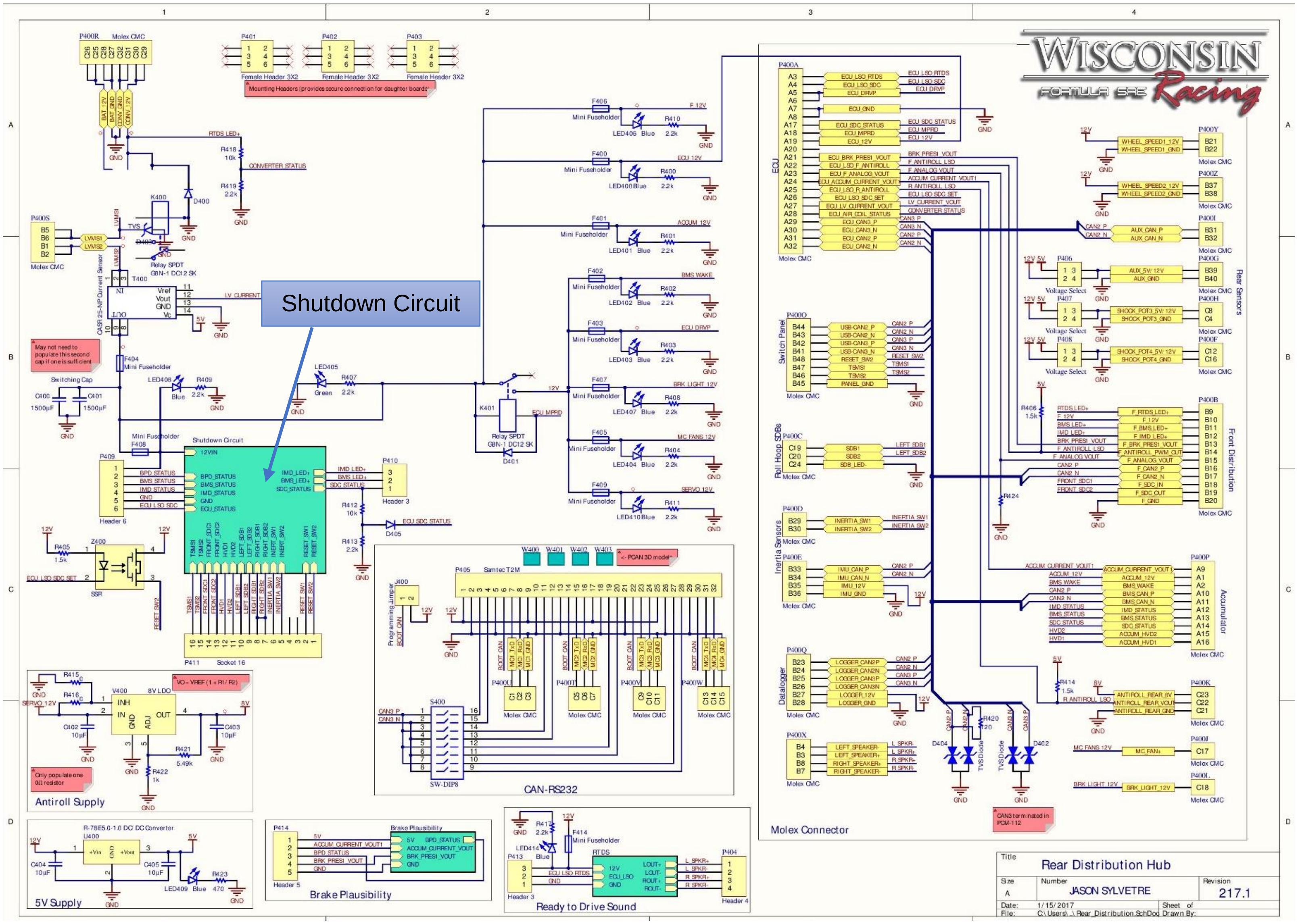


Figure 3: Rear Electronics Unit Schematic

2.1.3 Position in car

The shutdown circuit is housed inside the rear electronics unit.

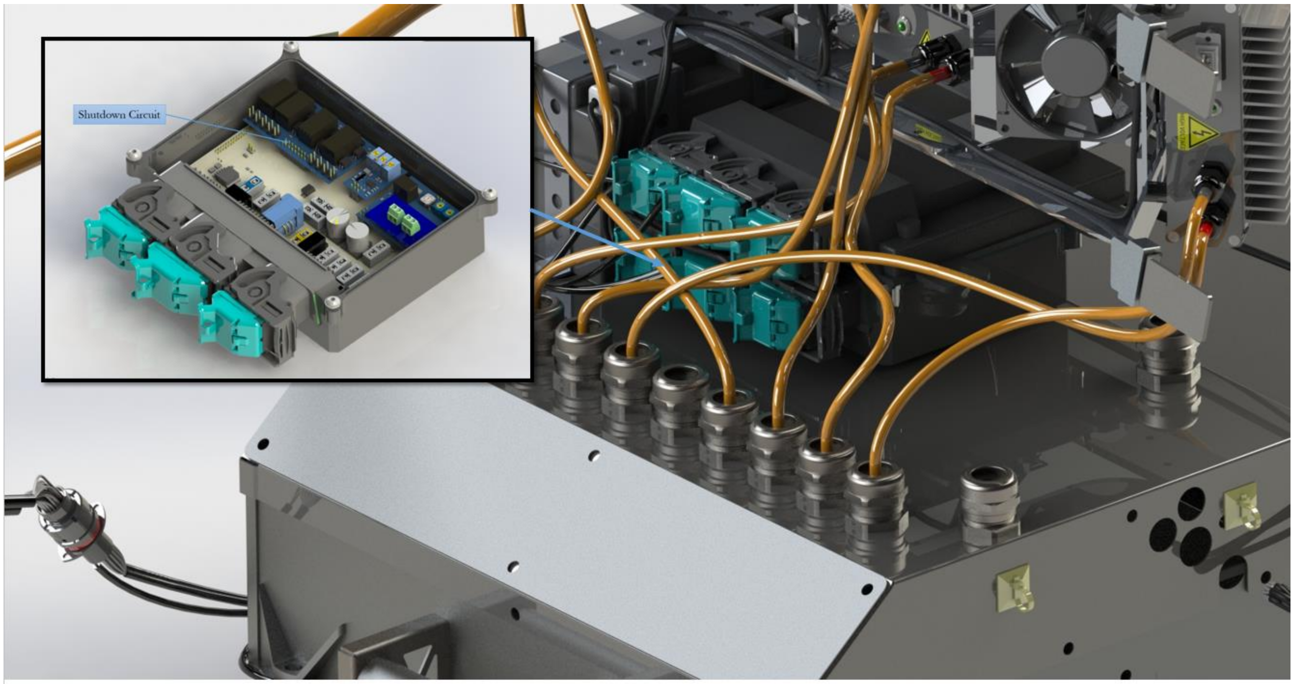


Figure 4: Shutdown circuit location

2.2 IMD

2.2.1 Description (type, operation parameters)

The IMD device used is the Bender IR155-3204. The IMD measures the insulation resistance between the GLV and HV system. If the resistance measurement drops below this threshold (63kOhms), under-voltage is detected, or the IMD is the off, the IMD will pull its status output to LOW and will open the shutdown circuit. Multiple GND lines run to different parts of the chassis for redundancy. The IMD has an automatic self-test with the ability to detect lost ground, power and HV connections. Also, our BMS also offers redundant protection by monitoring insulation resistance as well and will open the shutdown circuit if it detects a breakdown in insulation.

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:	0 - 1000VDC
Set response value:	63kΩ (500Ω/Volt)
Max. operation current:	150mA
Approximate time to shut down at 50% of the response value:	10s

Table 2.3 Parameters of the IMD

2.2.2 Wiring/cables/connectors/

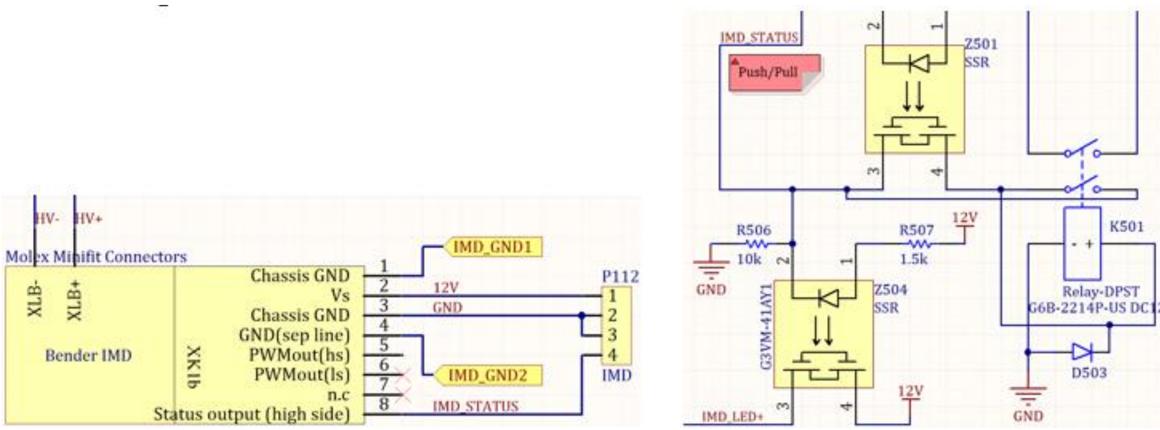


Figure 5: Wiring of IMD inside accumulator and its corresponding circuitry in SDC

In the shutdown circuit, the IMD status uses pulldown resistors in such a way where the SDC will be triggered in case an IMD cable is disconnected or any wire in the cable (Power, Ground or Signal) is damaged.

It is connected to the HV bus using Molex Minifit connectors and ring terminals. A 2A 400VDC inline fuse is connected between HV+ and the HV bus for protection. It is connected to the GLV system using Samtec connectors.

2.2.3 Position in car

The IMD is housed inside the accumulator so the device will be active when we pull the accumulator out of the car for charging.

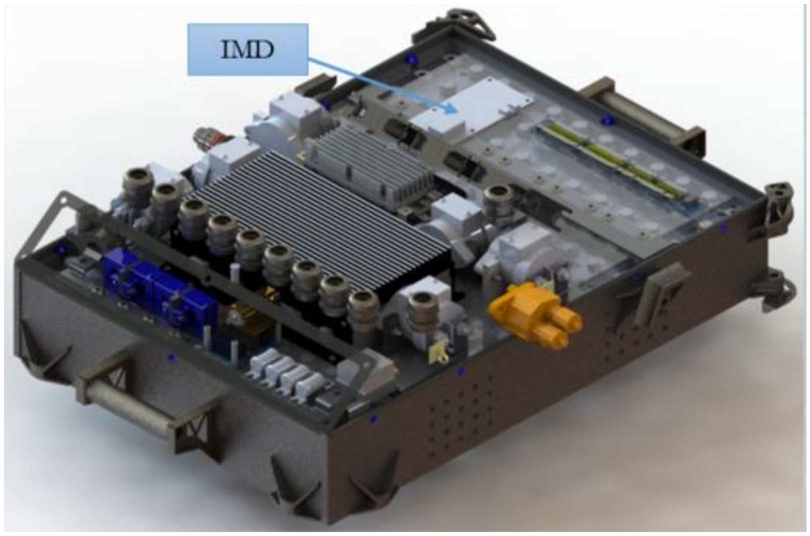


Figure 6: IMD location

2.3 Inertia Switch

2.3.1 Description (type, operation parameters)

The crash sensor used is a [Sensata Technologies 360° Resettable Crash Sensor]. This sensor is responsive to 360° impact. It is a normally-closed switch with a 10A rating that is in series with all the other switching elements in the shutdown circuit. It can be reset manually by pressing and releasing a button. In event of an impact, the sensor will open the AIRs and isolate the tractive system from the accumulator.

Inertia Switch type:	Sensata Technologies 360° Resettable Crash Sensor
Supply voltage range:	10 - 36VDC
Supply voltage:	12VDC
Environmental temperature range:	-40 - 105°C
Max. operation current:	10A
Trigger characteristics:	8g to 30g

Table 2.4 Parameters of the Inertia Switch

2.3.2 Wiring/cables/connectors/

Binder M5 connectors with pre-crimped 24AWG cabling are used for inline connections. It is connected to the rear electronics unit (houses shutdown circuit) through an automotive Molex CMC connector. Crash sensor is connected in line with AIRs power supply and therefore is fail-safe.

2.3.3 Position in car

The inertia switch is located next to the IMUs under the driver seat.

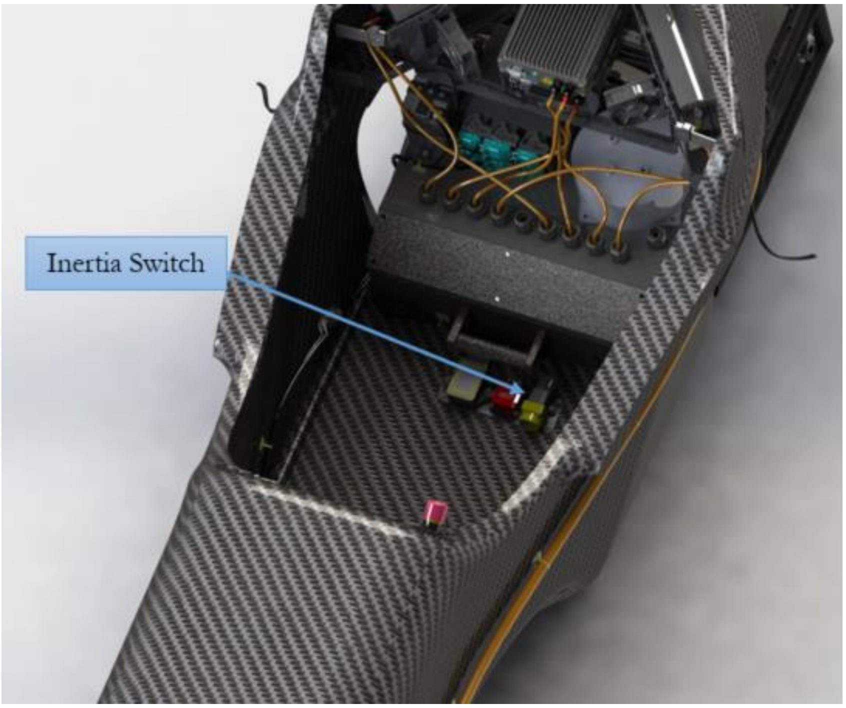


Figure 7: Inertia switch location

2.4 Brake Plausibility Device

2.4.1 Description/additional circuitry

The purpose of the brake plausibility system is to ensure that the driver is not on the accelerator position pedal sensor (>5kW) and the brake pedal simultaneously. To do this, the circuit takes input from the main accumulator current sensor and one of the brake pressure transducers. The circuit uses a dual comparator (U600) to compare the input signals to threshold voltages set by potentiometers. The threshold voltage for the main accumulator current sensor corresponds to when 5kW is being delivered to the motors. The threshold voltage for the brake pressure corresponds to when the brake pedal is being depressed. A NOR gate (U601) will check if both inputs are above the threshold voltages and if they are, both inputs to the NOR gate will be low (dual comparator is active low), and the NOR gate will output a 5V signal. If the signal persists for more than 0.5 seconds, the RC network will reach a voltage above the threshold voltage set by a potentiometer. The comparator (U602) will then pull the output of the BSPD circuit LOW, which then opens its respective power stage relay in the shutdown circuit. When there is no BSPD fault, BPD_STATUS will be 5V, which is influenced by the pull-up resistor R604.

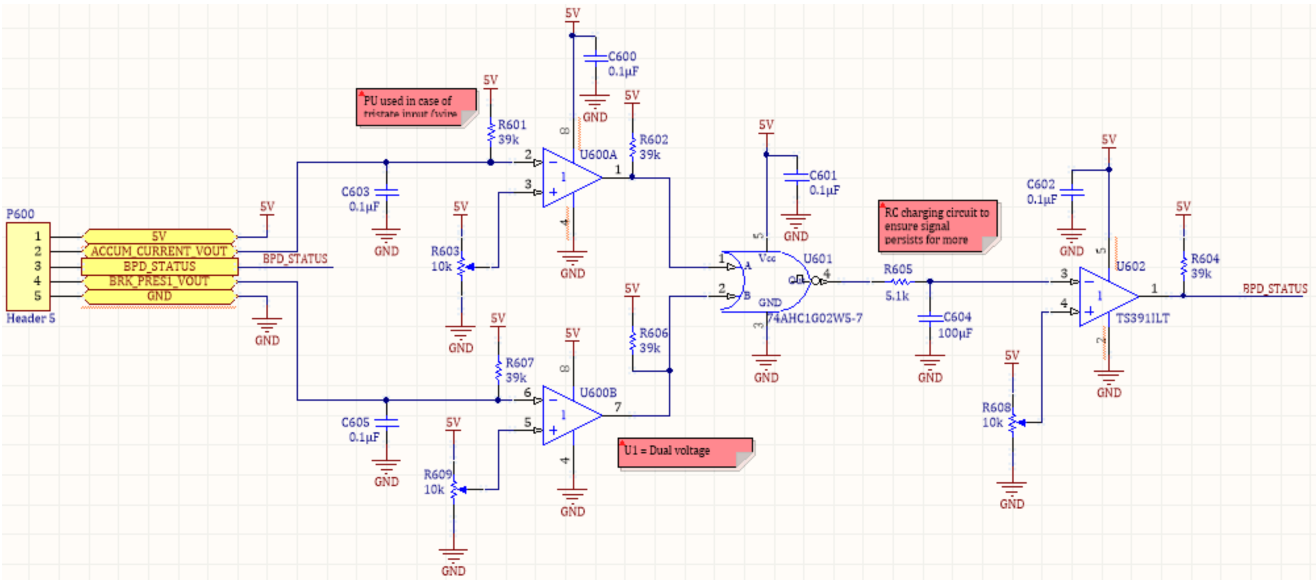


Figure 8: Brake Plausibility Device schematic

The brake plausibility status signal comes from the output of the circuit above. If it is high (status OK) and the set/reset button is being depressed, the solid-state relay will connect the hi-Z side of the DPST relay coil to ground and will close the contacts. The set/reset button only needs to be pressed initially or if a fault has been thrown to set/reset the circuit on. If the signal output from the brake plausibility system device is low (fault), then Z503 will open and then K500 will open. K500 will stay latched off until the status of the brake plausibility device changes and the set/reset button is pressed.

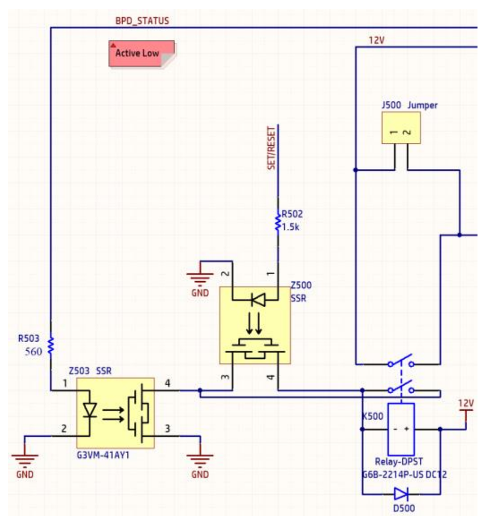


Figure 9: BPD section in SDC

Brake sensor used:	TE US300 Pressure Transducer, 5000PSI
Torque encoder used:	Bosch RP-100 Twin Rotary Position Sensor
Supply voltages:	5V, 5V
Maximum supply currents:	10mA, 20mA
Operating temperature:	-40 to 125 °C
Output used to control AIRs:	Opens a power stage relay

Table 2.5 Torque encoder data

2.4.2 Wiring

The brake pressure transducer analog output is connected to the front electronics unit through Souriau 8STA Autosport circular connector. The signal then goes back to the rear electronics unit (houses BSPD) and connects to it through a Molex CMC connector. The main accumulator current sensor exits the accumulator through an 8STA connector and connects to the rear electronics unit through the CMC connector. The BPD can be considered failsafe because it is wired using pulldown resistors in such a way where the SDC will be triggered if the inputs to the brake plausibility device are in a high impedance state.

Binder M5 connectors with pre-crimped 24AWG cables are used for inline connections. The devices are connected to the rear electronics unit through an automotive Molex CMC connector.

2.4.3 Position in car/mechanical fastening/mechanical connection

The APPS is bolted to the pedal assembly. The brake pressure transducers are connected in parallel with the brake line circuit and are mechanically restrained using zip ties.

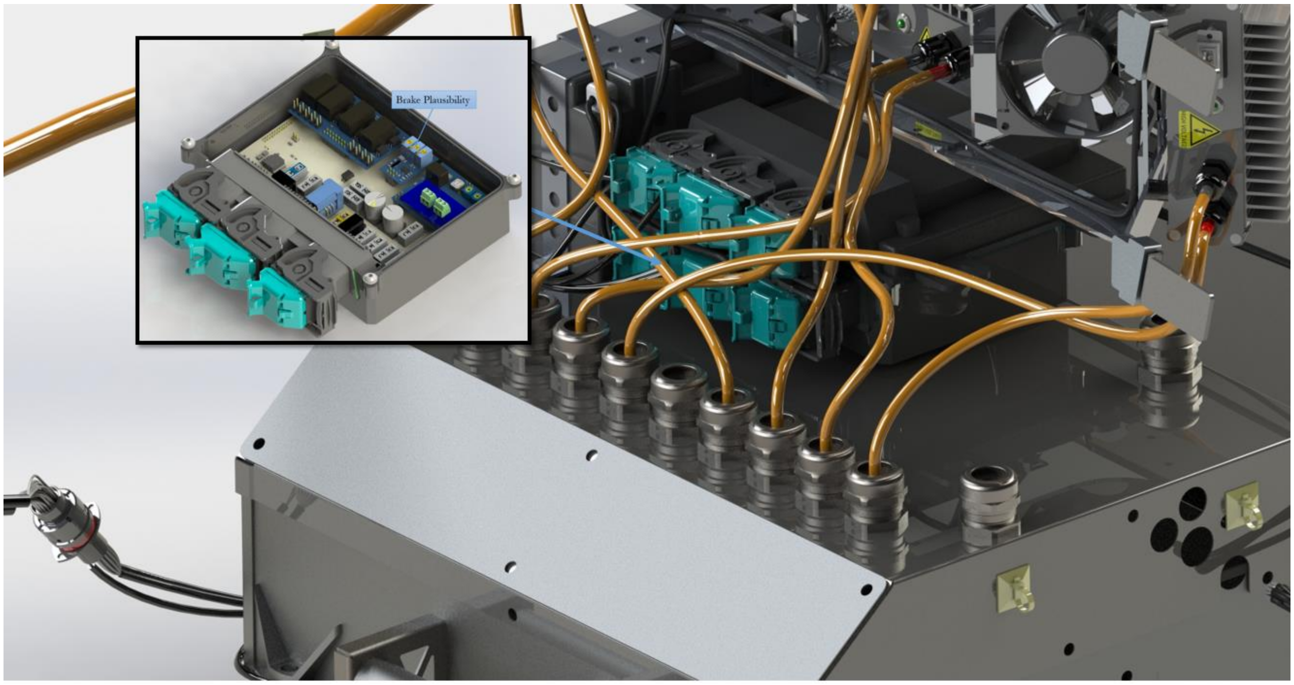


Figure 10: Brake Plausibility Device location

2.5 Reset / Latching for IMD and BMS

2.5.1 Description/circuitry

If the BMS or IMD throws a fault, the shutdown circuit latches off until the reset button is pressed. The BMS LED or IMD LED will illuminate if that system detects an error. You will also know the shutdown circuit has been tripped by observing that the reset switch LED will be off.

When BMS_STATUS goes to a hi-Z state, K502 will open and stay open until the fault is resolved and SET/RESET is then asserted (Z502 closes).

2.5.2 Wiring/cables/connectors

The IMD and BMS LED share a Binder M5 for its inline connector with 4 conductor cabling that uses 24AWG cable rated for 60V. They connect to the Front Electronics Unit (FEU) through a 8STA connector, which connects to the Rear Electronics Unit (REU) through a Molex CMC connector.

The reset switch connects directly to the REU through a 10-conductor cable harness with 24AWG wire that is rated for 600V.

2.5.3 Position in car

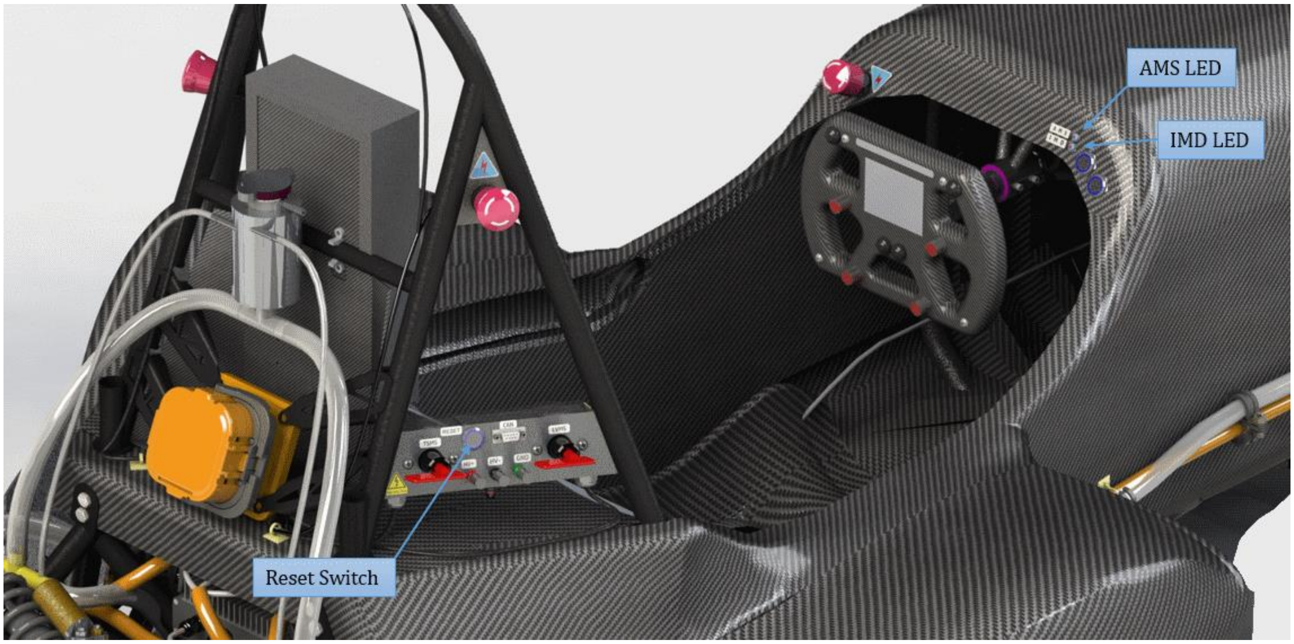


Figure 11: Reset switch, AMS LED, and IMD LED locations

2.6 Shutdown System Interlocks

2.6.1 Description/circuitry

Our shutdown circuit features three interlocks – one on the HVD and then one for each of the front corners. If the HVD is pulled, this will open the HV path as well as the shutdown circuit. The front corner interlocks are opened in the event where one of the front corners is blown off the car.

2.6.2 Wiring/cables/connectors

The HVD interlock uses [Binder M5] with 24AWG wire for its inline connectors. The wheel interlocks use 18AWG cable with bullet connectors.

2.6.3 Position in car

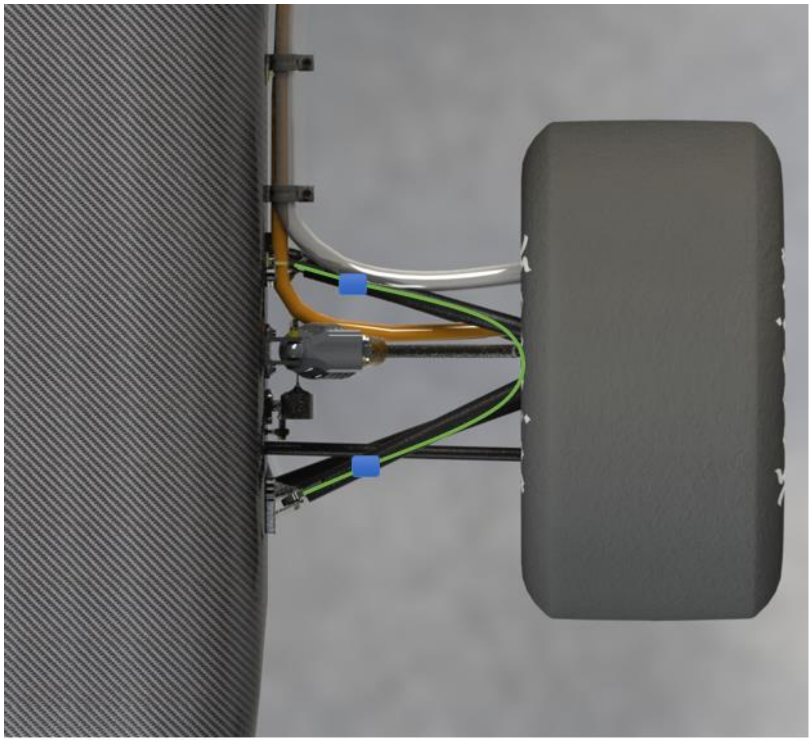


Figure 12: A-arm interlock circuit

Figure 13: High Voltage Disconnect location

2.7 Tractive system active light

2.7.1 Description/circuitry

The tractive system active light flashes red at a rate of 5Hz whenever the AIRs are closed and the tractive system is active. We use a DC-DC converter to reduce our HV bus to 12V, which is then used to power the TSAL. This DC-DC converter is enabled (pin 'PC' goes low) whenever the AIRs are closed and thus can be directly driven from the HV bus. The TSAL will only illuminate when tractive system bus voltage is >66V. This is the minimum input voltage for the DC-DC converter.

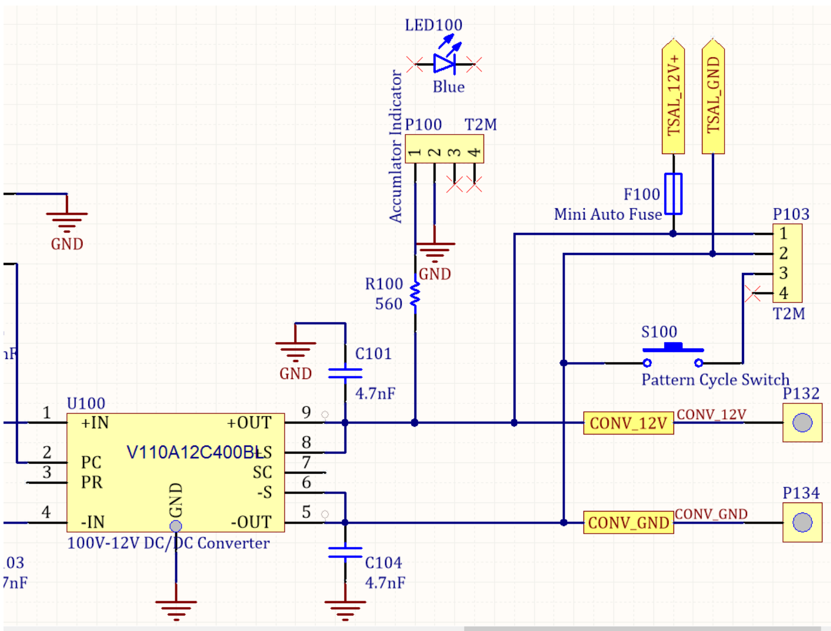


Figure 14: TSAL driving circuit

Supply voltage:	12VDC
Max. operational current:	1200mA
Lamp type	LED
Power consumption:	14.4 W
Brightness	100 Lumen
Frequency:	5Hz
Size (length x height x width):	40mm x 30mm x 40mm

Table 2.6 Parameters of the TSAL

2.7.2 Wiring/cables/connectors

The TSAL is wired using a Binder M5 connector with 24AWG cable for its inline connections and connects to the accumulator through an 8STA connector. Four 24AWG cables are wired to the TSAL so we have two redundant 12V connections and two redundant GND connections.

The TSAL is protected from overcurrent by a 2A 400VDC fuse.

2.7.3 Position in car

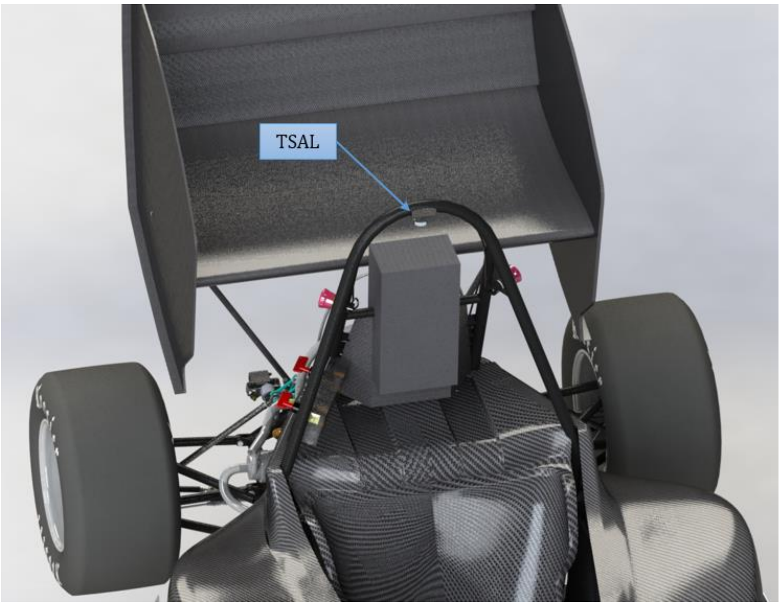


Figure 15: TSAL location

2.8 Measurement points

2.8.1 Description

There are three measurement points on the side of the driver's right shoulder – one for HV+, one for HV-, and one for GND. These are mounted on a chromoly plate that is welded to our roll hoop. The backside (driver's head) is protected by a 3D printed ABS enclosure. When not in use, blind plugs are used to ensure that there is no HV that can be touched accidentally by a bystander.

2.8.2 Wiring, connectors, cables

The two HV measurement points use four conductor 24AWG cable and a 4 pin 8STA connector with redundant connections for HV+ and HV-. The GND measuring point is connected directly to the frame

Each measurement point has a 5.1k through-hole resistor in series with its connection to the HV bus. These resistors are located inside the switch panel housing and are rated for 3W so they can dissipate the power in case of a tractive system bus voltage short.

2.8.3 Position in car

Figure 16: TSMPs location

2.9 Pre-Charge circuitry

2.9.1 Description

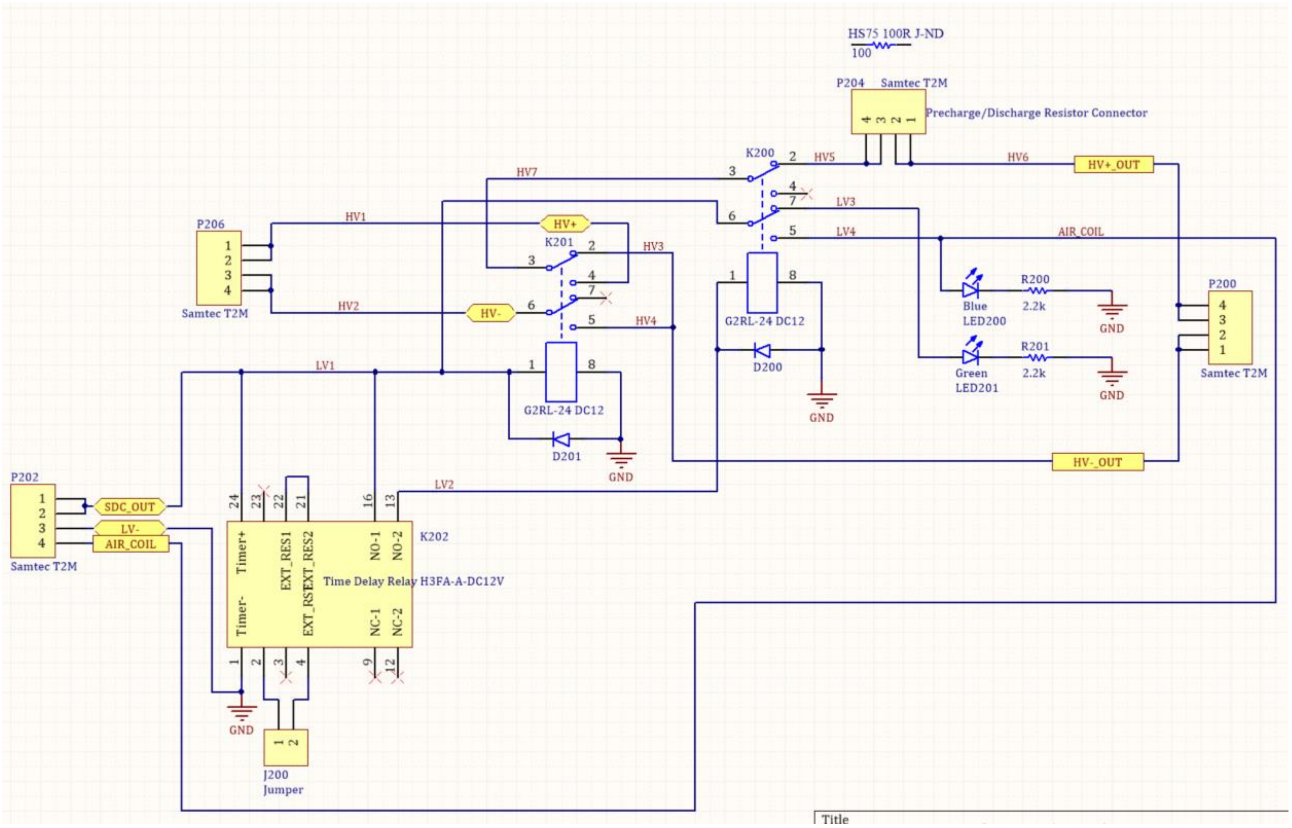


Figure 17: Precharge/Discharge Schematic

Pre-charging of internal capacitors in motor controllers input circuits to 90-95% of battery voltage is important to avoid inrush current and pitting of contactors. Discharge of internal capacitors in motor controllers input circuits is important for avoiding electric shock after deactivation of the tractive system. In our car, those two systems are combined and will use the same resistor for both pre-charging and discharging of motor controller's internal capacitors

2.9.2 Wiring, cables, current calculations, connectors

Precharge/discharge circuit is wired to both high and low voltage circuits using 22AWG wire and Samtec T2M connectors.

To calculate the value needed, we created a MATLAB script.

```
%% Precharge / Discharge Resistor Calculator by timec and Jason

% User inputs
C = 0.01166;        % motor controller capacitance [Farads]
V = 126;            % bus voltage [Volts]
target_precharge_time = 2;  % time to 3 tau (95%) [Seconds]


target_R = target_precharge_time /(3*C);    % in Ohms
fprintf('\n Target Resistor: %i ohms', round(target_R));

actual_R = input('\n Input standard resistor value, Look here
http://tinyurl.com/hhaghfv \n')
fprintf('\n Actual Resistor: %i ohms', actual_R);

actual_I = V / actual_R;
fprintf('\n Current: %g amps', actual_I);

actual_precharge_time = 3 * actual_R * C;
fprintf('\n Actual Precharge Time: %g seconds', actual_precharge_time);

% time to discharge to 60V
% make sure less than 5 seconds as per EV5.1.3
discharge_time = actual_R * C * log(V/60);
fprintf('\n Discharge time to drop below 60V: %g seconds', discharge_time);

% actual energy dissipated over the precharging event
E = (1/2) *C * V^2;
power = E / actual_precharge_time;
fprintf('\n Power dissipated during precharging event: %g watts', ceil(power));

% maximum power dissipated by resistor
max_power = V^2 / actual_R;
fprintf('\n Peak Power: %g watts', ceil(max_power));

% TE power overload curve says resistor can handle 2x its power rating for 15
seconds
fprintf('\n \n Recommended resistor based on overload curve: %i watts \n',
round(max_power/2.2));
```

Each motor controller has 2615µF of capacitance (from electrolytics) and then we had to add an [additional 1200uF film capacitor] to satisfy the ripple current needed for the system.

Based on our MATLAB script, we got the following results when using a 100 ohm resistor.

- Max Current: 1.26 amps
- Actual Precharge Time: 3.50 seconds
- Discharge time to drop below 60V: 0.865 seconds
- Power dissipated during precharging event: 27 watts
- Peak Power: 159 watts

Voltage vs time $V_{bus} = V_{bus} * e^{-t/RC}$

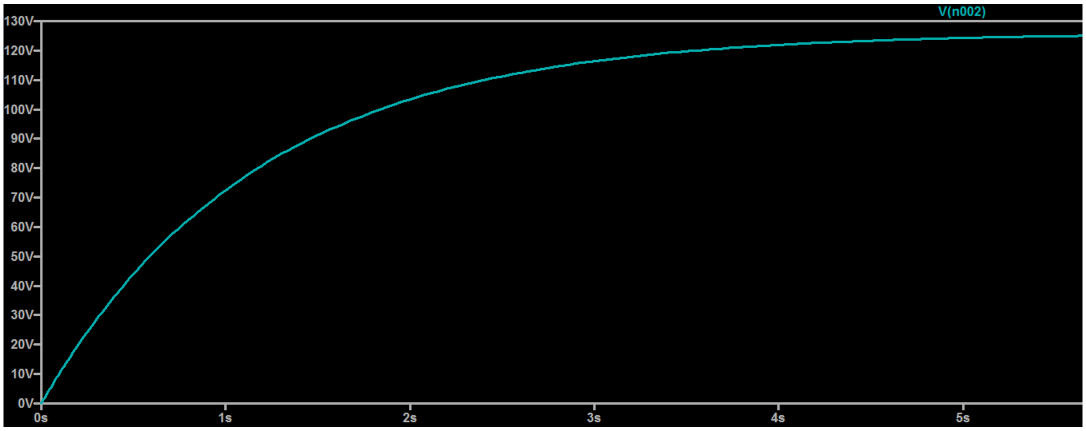


Figure 18: Plot showing voltage vs time during charging event

Current vs Time $I = (V_{bus} / R) * e^{-t/RC}$

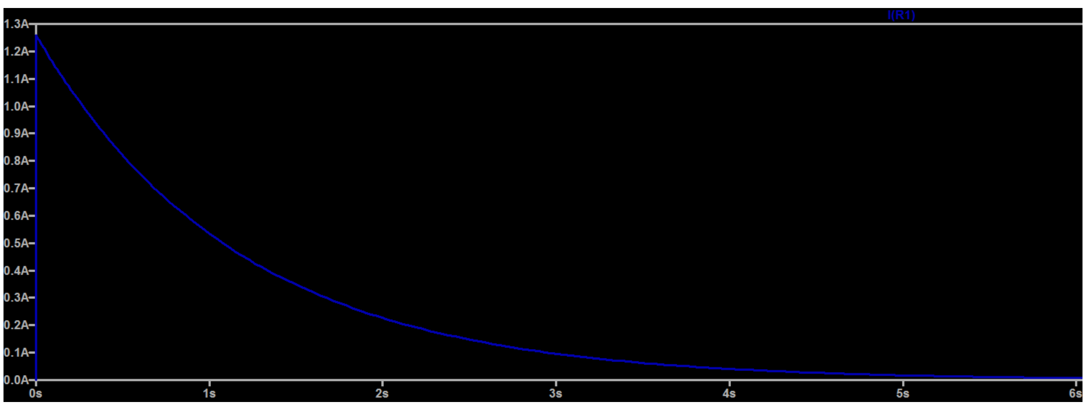


Figure 19: Plot showing current vs time during charging event

Resistor Type:	[Chassis Mount Wirewound Resistor]()
Resistance:	100Ω
Continuous power rating:	75W
Overload power rating:	375W for 5 seconds, 150W for 20 seconds
Voltage rating:	1400V
Cross-sectional area of the wire used:	0.326 mm² (22AWG)

Table 2.7 General data of the pre-charge resistor

Relay Type:	[Omron G2RL-24 DC12]
Contact arrangement:	DPDT
Continuous DC current:	8A
Voltage rating	300VDC
Cross-sectional area of the wire used:	0.326 mm² (22AWG)

Table 2.8 General data of the pre-charge relay

2.9.3 Position in car

The precharge/discharge resistor is located inside the accumulator and shown in Figure 20.

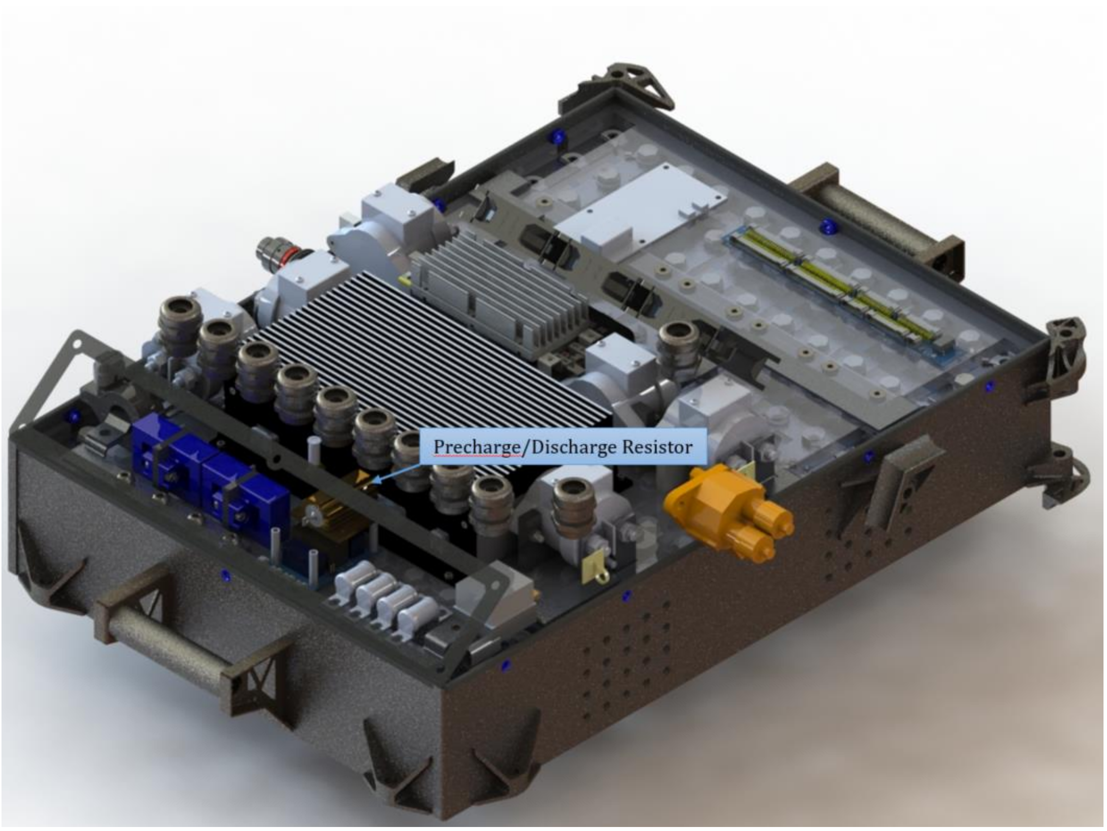


Figure 20: Precharge/Discharge Resistor location in accumulator

2.10 Discharge circuitry

2.10.1 Description
See 2.9.1

2.10.2 Wiring, cables, current calculations, connectors
See 2.9.2

2.10.3 Position in car
See 2.9.3

2.11 HV Disconnect (HVD)

2.11.1 Description
The HVD and interlock consists of a Manual Service Disconnect from TE Connectivity that has both power and signal connections. The main HV connector will be mounted on the rear of the car behind the headrest with a non-conductive handle attached directly to the plug. Pulling on the handle will disconnect one pole of the battery from the rest of the circuit. The signal wires on the connector will be part of the Shutdown Circuit and will also open the AIRs when the plug is disconnected. Because the HVD is only intended for use in emergency situations, the motor controllers will not be able to discharge. If the HVD is activated, a dummy connector will be put in place to maintain HV insulation operated.

2.11.2 Wiring, cables, current calculations, connectors
The HVD uses 50mm^2 shielded Coroplast cable with double wall insulation. 24AWG wire with Binder M5 connectors are used for the interlock inline connectors.

2.11.3 Position in car

Figure 21: High Voltage Disconnect location

2.12 Ready-To-Drive-Sound (RTDS)

2.12.1 Description

When the car can be put into ready-to-drive-mode, a blue LED on the RTDS button will illuminate. To switch the car to Ready-to-Drive mode driver should push a start button on the dash while pressing the brake pedal. At that moment, the ECU is switched to drive mode and triggers an LSO which causes the speakers to play a sound that is 2-3 seconds long. The audio board stores a WAV file and when it receives its trigger signal, it outputs an audio signal which is then amplified and sent to the RTDS speakers. The RTDS will not be able to function when shut down circuit has been activated.

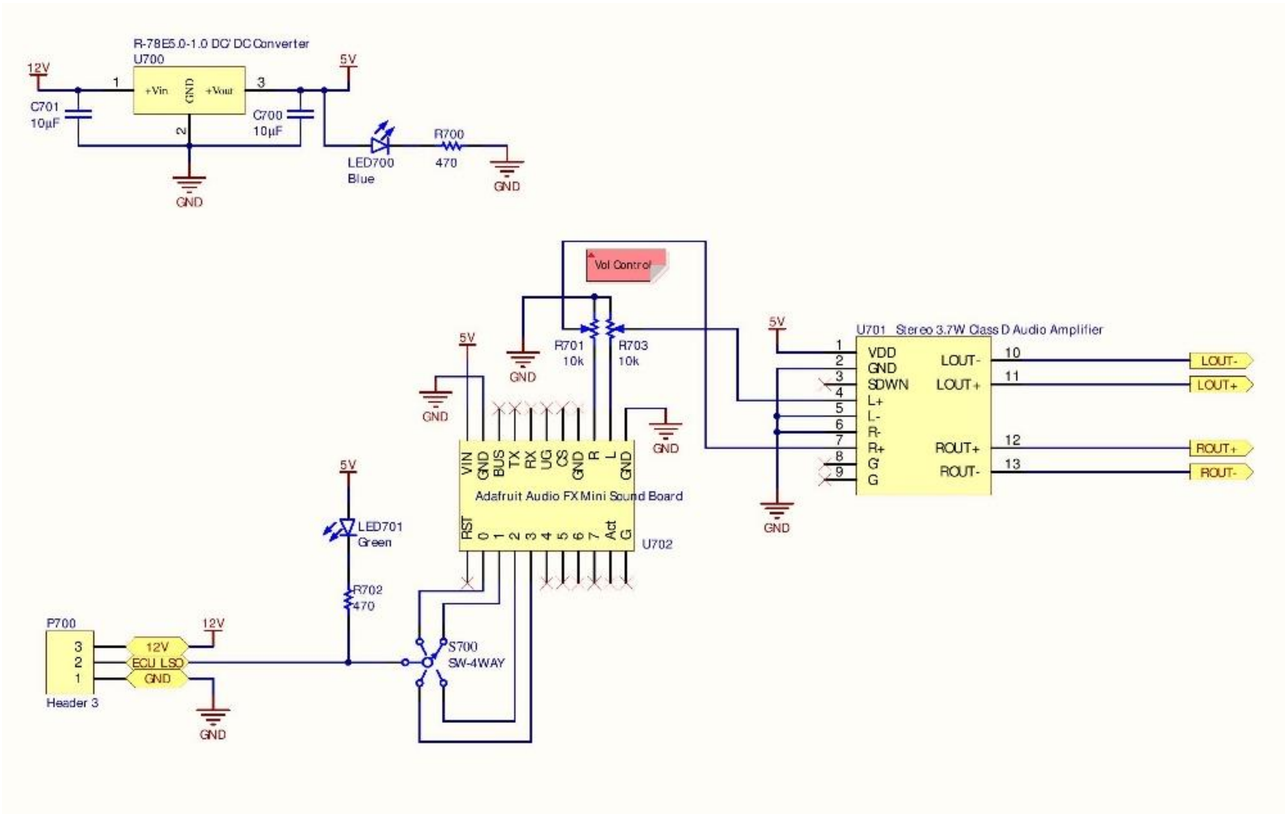


Figure 22: Ready to drive sound schematic

2.12.2 Wiring, cables, current calculations, connectors

Binder M5 connectors with 24AWG cables are used for all inline connectors. The RTDS speakers are connected to the REU through a Molex CMC connector.

2.12.3 Position in car

The ready-to-drive sound circuit board is located inside the Rear Electronics Unit and the speakers are located within our headrest.

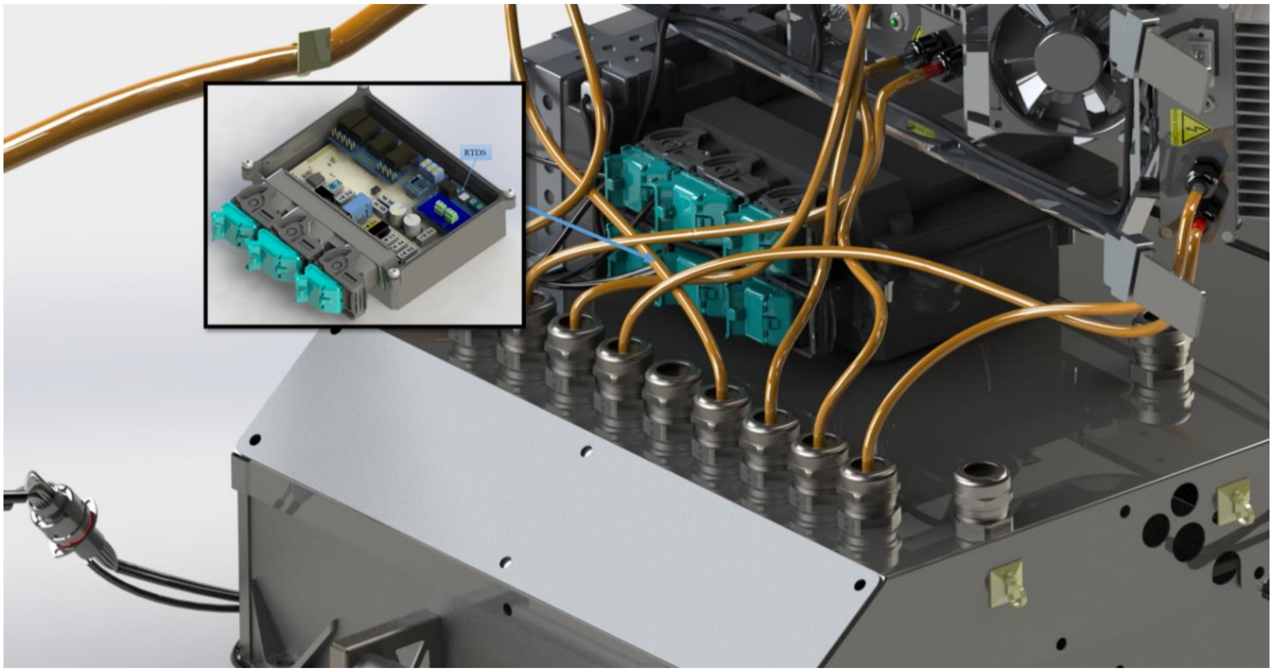


Figure 23: RTDS PCB location

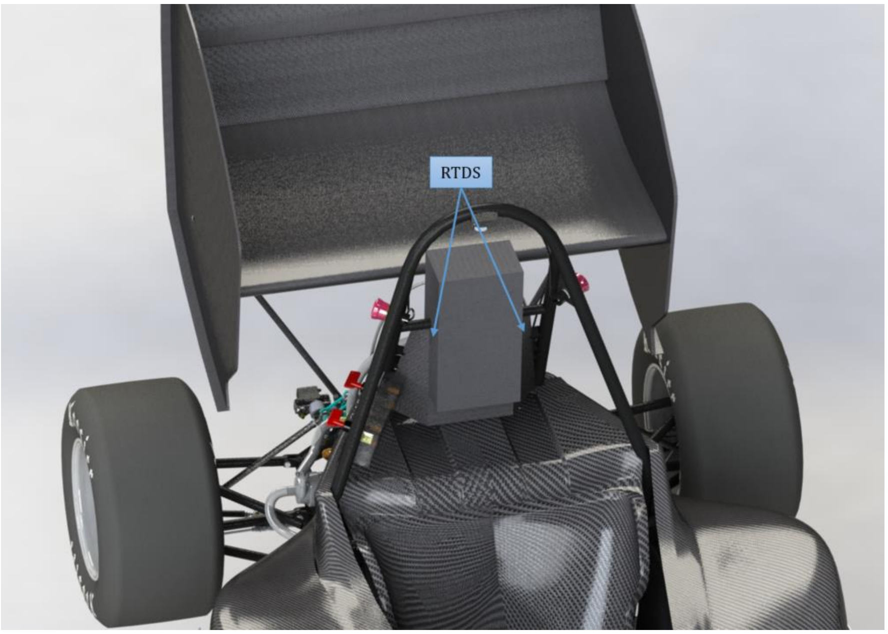


Figure 24: RTDS speakers location in headrest

3 Accumulator

3.1 Accumulator pack 1

3.1.1 Overview/description/parameters

The accumulator pack consists of 720 lithium polymer battery cells, arranged in a parallel-series configuration. Twenty-four cells are connected directly in parallel, and thirty of these sets are then connected in series. Each module of the accumulator contains 6 series connections, and is separated from the others by high voltage contactors.

Maximum Voltage:	126VDC
Nominal Voltage:	108VDC
Minimum Voltage:	75VDC
Maximum output current:	1080A for 10 sec
Maximum nominal current:	480A
Maximum charging current:	96A
Total numbers of cells:	720
Cell configuration:	30s24p
Total Capacity:	23.3 MJ, 6.48 kWh
Number of cell stacks < 120VDC	5

Table 3.1 Main accumulator parameters

3.1.2 Cell description

The battery cells used are a cylindrical, 2.5 Ah lithium polymer battery in a standard 18650 form factor from Samsung. These Samsung INR18650-25R cells were purchased and assembled into a 1s8p configuration submodule from Energus Power Solutions for easier monitoring, packaging and assembly.

Cell Manufacturer and Type	Samsung INR18650-25R
Cell nominal capacity:	2.5Ah
Maximum Voltage:	4.2V
Nominal Voltage:	3.6V
Minimum Voltage:	2.5V
Maximum output current:	100A for less than 1 second
Maximum nominal output current:	20A
Maximum charging current:	4A
Maximum Cell Temperature (discharging)	60°C
Maximum Cell Temperature (charging)	45°C
Cell chemistry:	LiNiCoAlO2 [NCA]

Table 3.2 Main cell specification

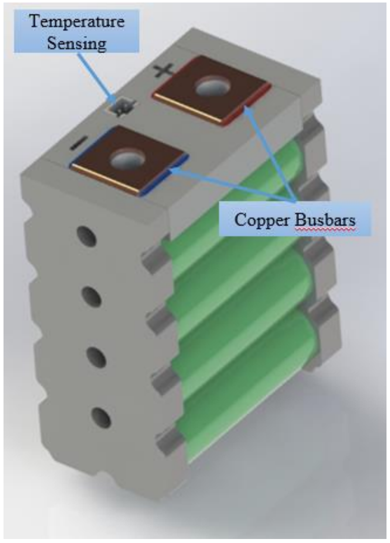


Figure 25: 1s8p Energus Power Solutions Submodule

3.1.3 Cell configuration

The accumulator system consists of 720 battery cells with 30 series groups of 24 cells connected in parallel. Within those parallel groupings of cells, sets of 8 are packaged in what we call "submodules" in a 1s8p configuration from Energus Power Solutions (part number Li8P25RT). This packaging consists of a UL 94 V-0 rated plastic encasement, internal fusing, built-in temperature sensing, and 8mm threaded high voltage path connections. Three of these submodules are then connected in parallel via aluminum busbars. This leads us to a full accumulator with a 30s3p configuration of submodules.

The busbars connecting the submodules will be attached via the 8mm bolts threaded into the internal threads that come attached to the copper within. To ensure positive locking a tab washer will be installed between the busbar and the bolt head, bending around each to prevent rotation.

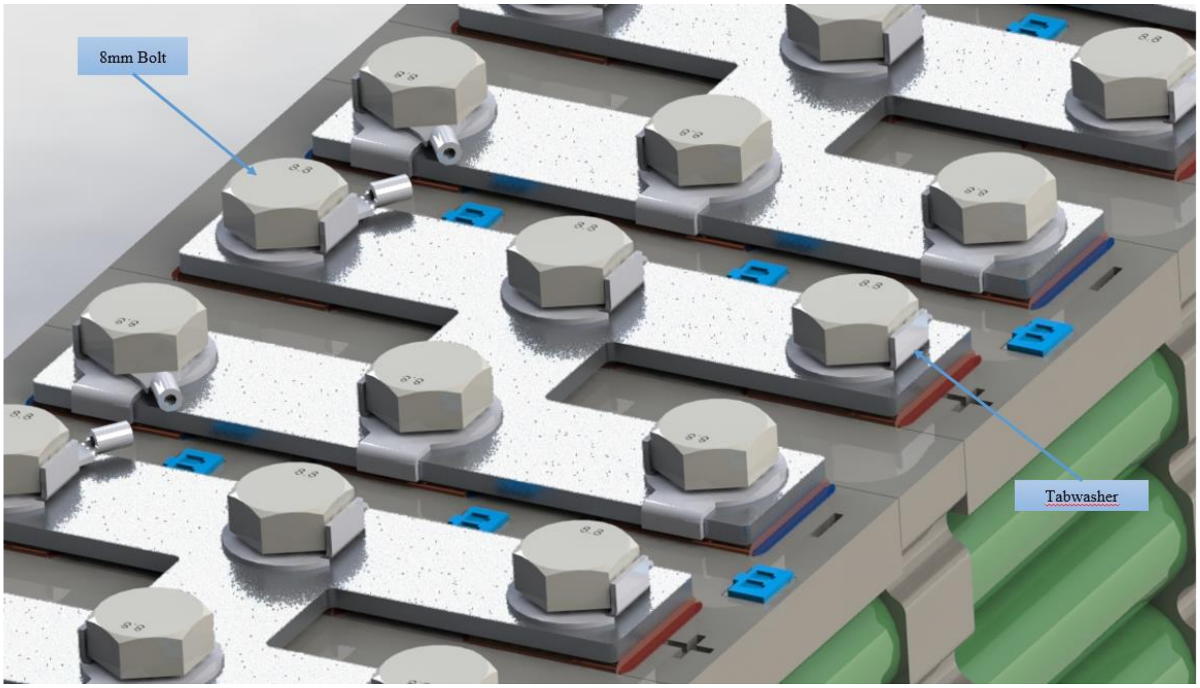


Figure 26: Close up of module

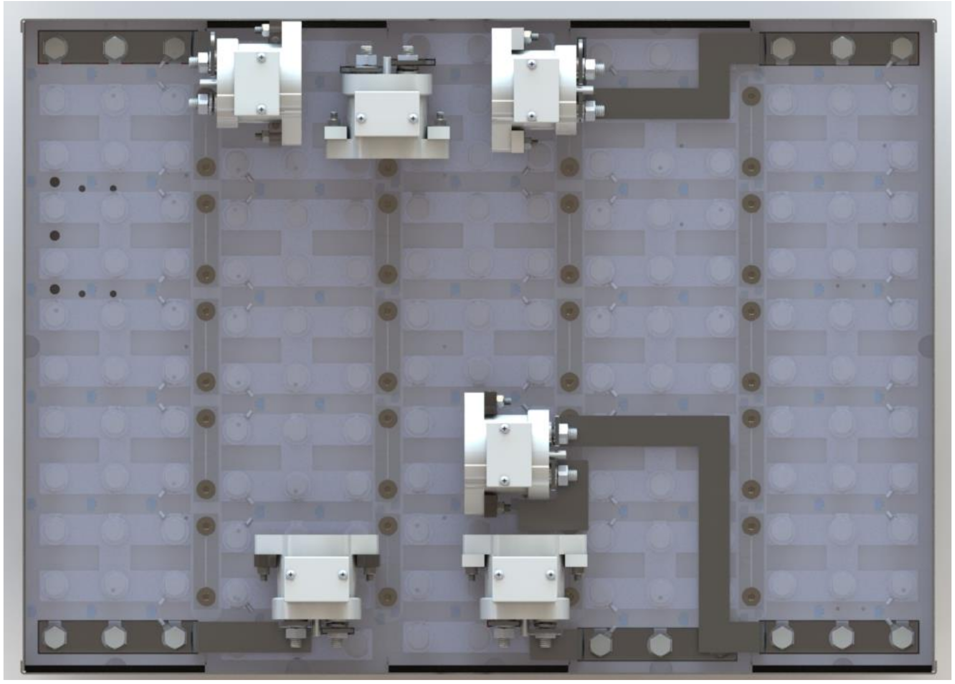


Figure 27: Overhead of accumulator showing layout of cell and connections

The accumulator is separated into 5 isolated battery sections, each containing 6 series connections. Each battery section has a peak voltage and energy capacity of 25.2 V and 5.8 MJ, respectively. The sections of the accumulator are physically separated by the steel internal walls, and the batteries themselves are physically separated by the non-conductive, UL 94 V-0 rated plastic enclosures.

Internal cell fusing is included in the Energus Power Solutions package, with 32 fuses included in each 1s8p package (2 fuses on each cell end). The fuses are made of nickel wire and are welded straight to the cells and copper conductor, deeming them non-resettable. The fuse blow curve is shown in Figure 28, which depicts the amount of time the fuse will take to blow versus the percent of maximum continuous current of the individual INR18650-25R cells (20 A). The physical location and relative size of the fuses are depicted in Figure 29.

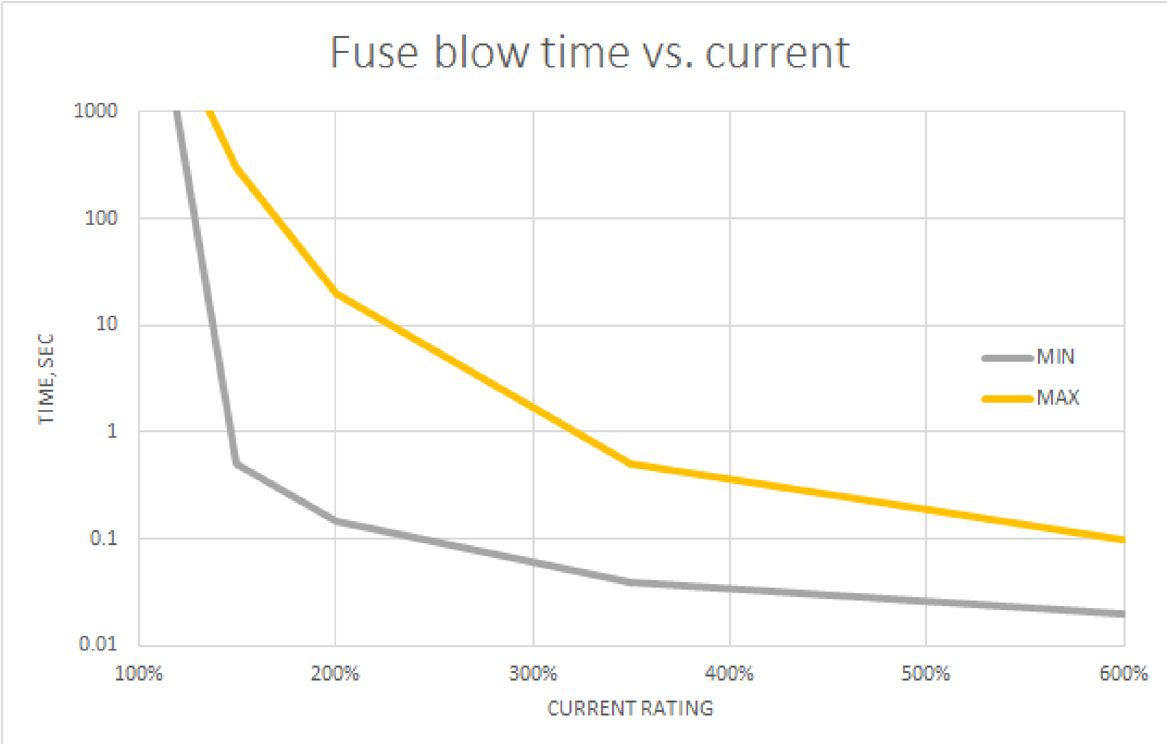


Figure 28: Graph of current rating for the internal fuses inside the Energus package

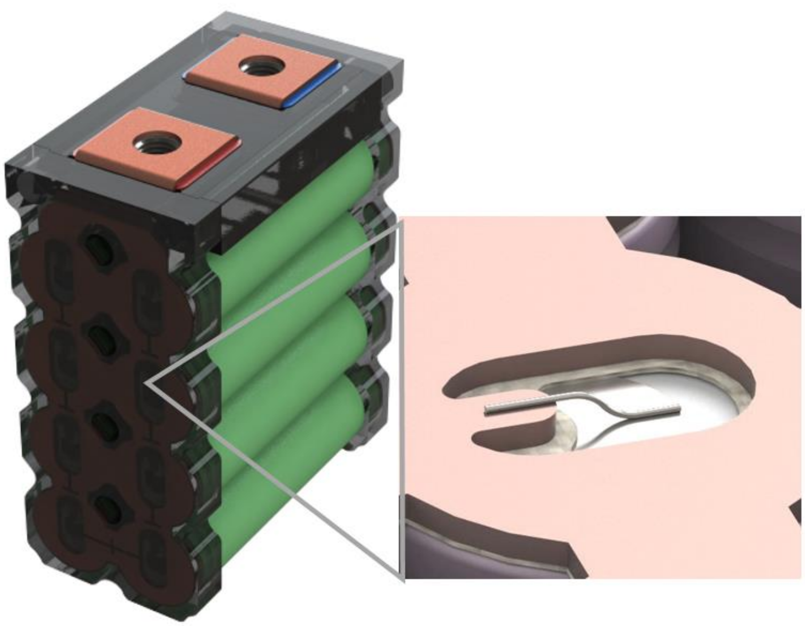


Figure 29: Simplified render of welded nickel wire fuse connecting cell to copper busbar

3.1.4 Cell temperature monitoring

Each grouping of 8 cells in the Energus submodule has a 4-point temperature sensor built in, which sit on the negative pole of the 2 adjacent cells. The output of all 4 temperature sensors gets fed into a 2-wire system as the maximum temperature reading between them. This allows us to sense the temperature of all the cells in each submodule without quadrupling the amount of wires. All these outputs are connected to the Orion BMS through a Thermistor Expansion Module, which limits the number of submodules being sensed to 80. Although this will leave 10 submodules without temperature sensing, over 80% of the submodules will be monitored.

The sensor is a temperature-variable voltage shunt reference, acting as a Zener diode whose voltage depends on temperature. By taking the voltage drop measured across and referencing that against the temperature-voltage response curve in Figure 31, we will know the highest temperature sensed in the module.

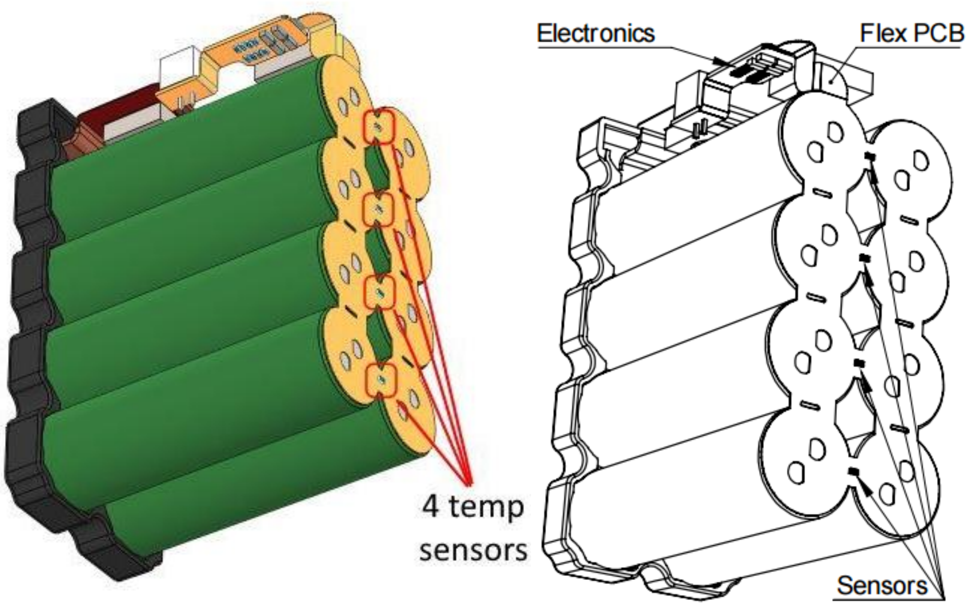


Figure 30: Placement of the 4 temperature sensors within the Energus submodule

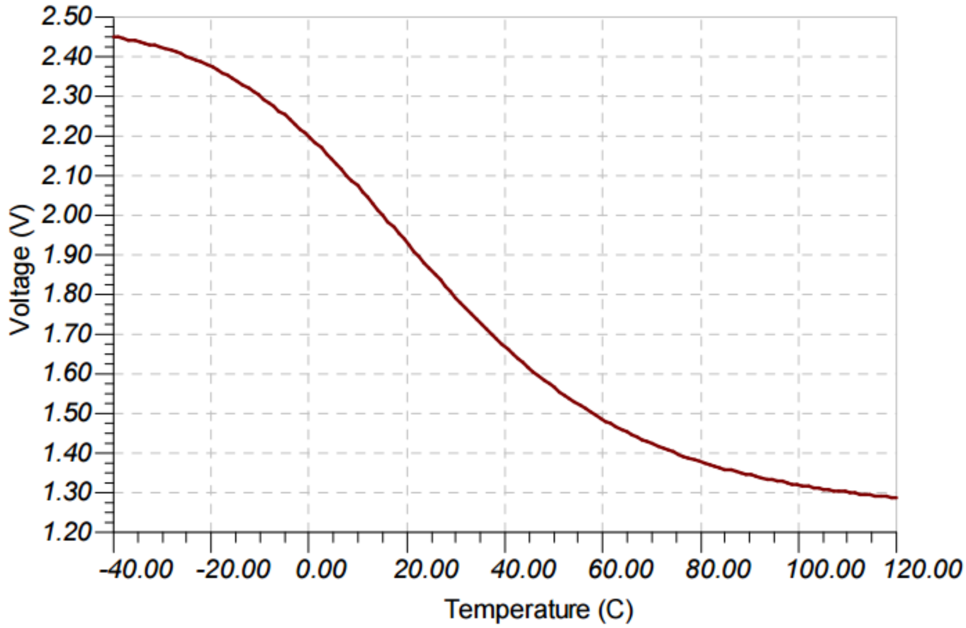


Figure 31: Temperature-Voltage response of internal Energus submodule sensors

3.1.5 Battery management system

The BMS utilized in our design is the [Orion BMS](#) from Ewert Energy Systems. This BMS is commercially available and designed specifically for electric and hybrid vehicles. It supports sets of 12 cells up to 108 battery cells or a variety of different battery chemistries. Since we have 30 series groups to monitor, we had to acquire a BMS with a 36 cell or above configuration. It is designed to work in high noise environments and in harsh temperatures ranging from -40 to 80 degrees Celsius. The BMS can read cell voltages from .5 to 5 volts. The accumulator pack consists of lithium ion cells, the maximum cell open circuit voltage limit is set to 4.2 volt and minimum open circuit voltage limit set to 3 volts. Measurement resolution is 1.5mV. The ADC within the AMS has a 12 bit resolution with a ±10mV accuracy rating. If the voltages get near the limits it opens the AIRs. The temperature limit is set to be 60 C and if this temperature is exceeded it opens the AIRs. All the sense wires are electrically and magnetically isolated by the BMS. In the case that an error is detected and the BMS needs to open AIR's, it switches the internal relay which connects to the internal shutdown circuit. Galvanic isolation between the tractive system and the grounded low voltage system connections occurs within the BMS.

Electrical Specification Item	Min.	Typ.	Max	Units
Nominal Supply Voltage	10	12	16	Vdc
Supply Current – Active		250		mA
Supply Current – Sleep		650		uA

Operating Temperature	-40		80	C
Cell Voltage Measuring Range	0.5		5.0	V
Number of Cells Supported in Series	4		108	cells

Table 3.3 BMS Parameters

3.1.6 Accumulator indicator

The accumulator indicator is a Q Series Panel Mount blue LED. that is directly mounted to our accumulator and indicates when there is HV in the tractive system. It is driven off the same circuitry that the TSAL uses.

3.1.7 Wiring, cables, current calculations, connectors

Knowing the size of our battery pack, the expected aerodynamics and kinematics of the vehicle, we used our student developed lap simulator to get an accurate estimate of our nominal current draw and how long each maximum current draw would occur. The maximum current from the accumulator occurs during heavy acceleration and high speed when the total vehicle power output is just below the 80 kW limit.

The maximum and nominal current draw from the accumulator at 50% state of charge (108 VDC) with a 20 kW regeneration and an 80 kW power limit are 950 A and 240 A rms, respectively. Current draws of over 800 A only occur for a maximum of 0.5 seconds.

Wire type	Coroplast, Silicone-insulated single-core high-voltage automotive cables, screened - Copper
Continuous current rating:	400 A @ 60°C
Cross-sectional area	50 mm²
Maximum operating voltage:	900VDC
Temperature rating:	180 °C
Wire connects the following components:	Accumulator to HVD

Table 3.4 Wire data of Coroplast, 50 mm²

Wire type	Coroplast, Silicone-insulated single-core high-voltage automotive cables, screened - Copper
Continuous current rating:	200 A @ 60°C

Cross-sectional area	16 mm²
Maximum operating voltage:	800VDC
Temperature rating:	180 °C
Wire connects the following components:	Accumulator to Motor Controller

Table 3.5 Wire data of Coroplast, 16 mm²

Wire type	TE Raychem, 55A0111-22-9
Continuous current rating:	7A
Cross-sectional area	0.326 mm², 22 AWG
Maximum operating voltage:	600VDC
Temperature rating:	150 °C
Wire connects the following components:	Cell to BMS, Contactors, and Pre-charge/discharge circuit

Table 3.6 Wire data of Raychem, 0.326 mm²

To ensure that the shield of the high voltage cable cannot potentially come into contact with the copper core, we will be utilizing a cable specific treatment process. First, we begin stripping away the outer insulation about three inches from the end of the cable. We then cut the shield halfway between the outer insulation and cable end (~1.5" from end). Next, we cut the inner insulation halfway between the shield and the end of the cable, exposing the copper high voltage conductor. Finally, before crimping any ring terminals on the copper, we ensure that there is heat shrink added to cable so that after the crimp has been performed, that the barrel of the crimp can be covered, further preventing any contact. The shield will be terminated by securing a copper braid to ground with solder or with copper internal brushes such as with the Lapp cable glands (*P/N #53112676*).

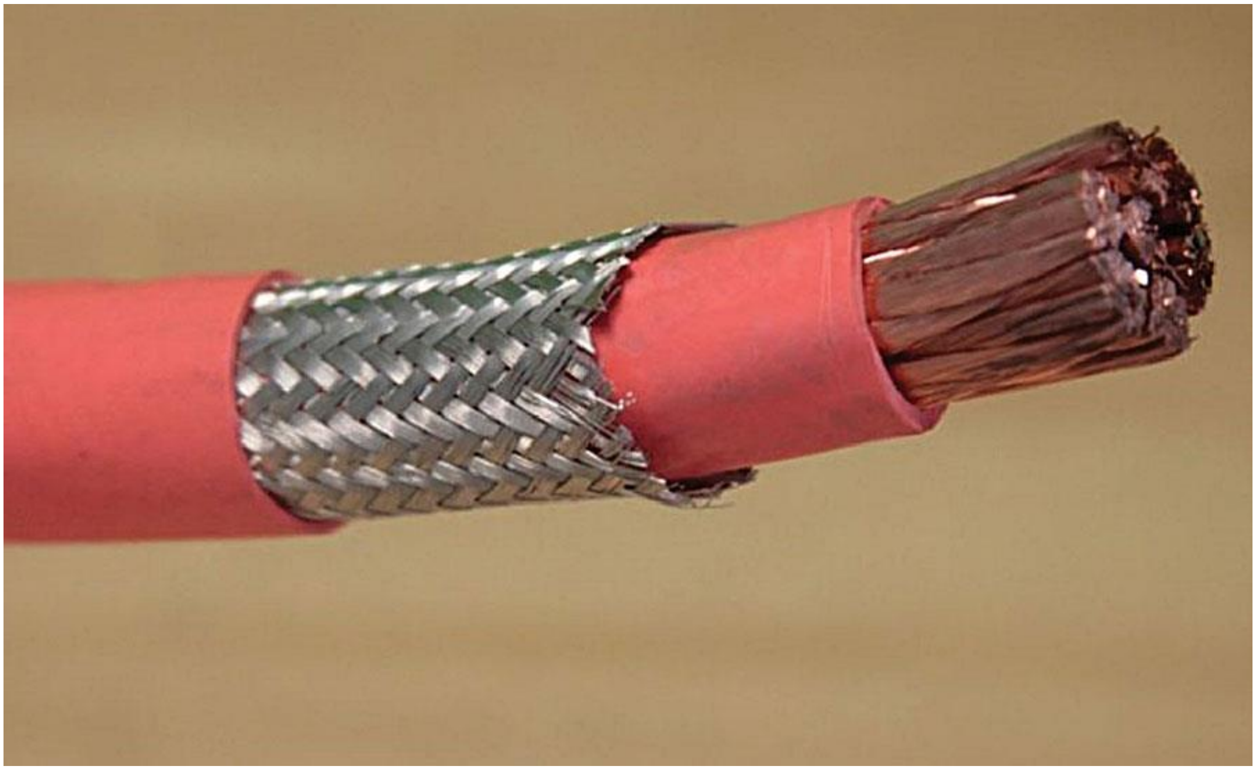


Figure 32: Image showing proper lengths of the separate shielded cable parts

Instead of maintenance plugs our design utilized normal open contactors to separate the different battery sections. The contactors are the same as those used for the AIRs. Inside the Accumulator, all connections are made by aluminum 6061 busbars, positive locking tab washers and head bolts. There is no high voltage cabling internally, just connecting external components (i.e. HVD, motor controllers) to the accumulator.

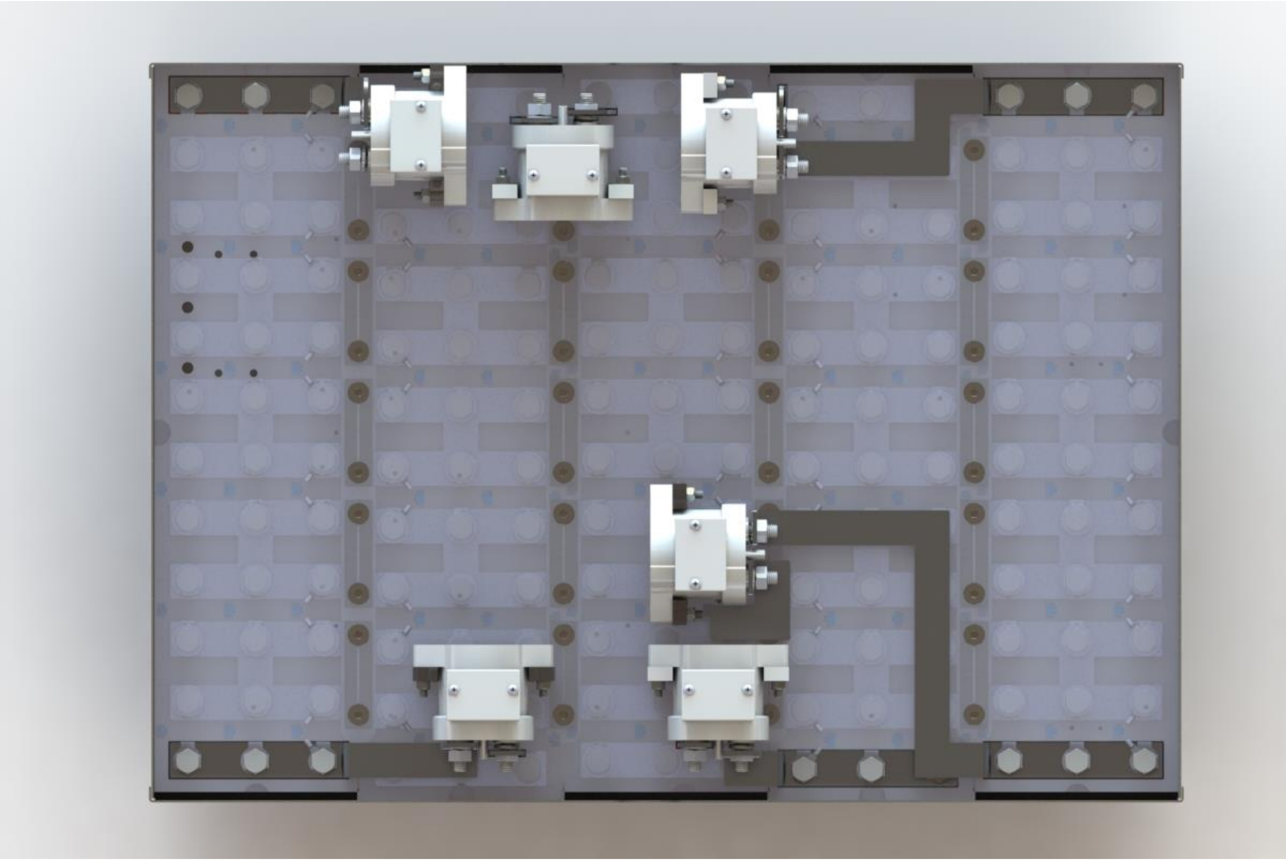


Figure 33: Render of contactor placement as well as high voltage busbar layout

3.1.8 Accumulator insulation relays

The AIRs used are normally open [KILOVAC EV200AAANA] Contactors rated for 500 amps continuous current from Tyco Electronics. These insulation relays are used between each of the modules and between the negative and positive most battery terminals before the high voltage motor controller distribution busbars.

Relay Type:	KILOVAC EV200
Contact arrangement:	1 Form A (SPST-NO)
Continuous DC current rating:	500A
Overload DC current rating:	2000A for 10sec
Maximum operation voltage:	900VDC
Nominal coil voltage:	12VDC
Normal Load switching:	Make and break up to 300A
Maximum Load switching	10 times at 1500A

Table 3.7 Basic AIR data

3.1.9 Fusing

The main high voltage tractive system current path is protected by one main fuse, a 170M3418 fuse from Bussmann, within the High Voltage Disconnect. Additionally, four smaller, stud-mount 160LET fuses from Bussmann (an Eaton company) protect each of the motor controllers. These smaller fuses connect the negative terminal of each motor controller to the negative terminal distribution busbar of the accumulator.

Fuse manufacturer and type:	Bussmann, 170M3418
Continuous current rating:	350A
Maximum operating voltage	550VDC
Type of fuse:	High speed
I2t rating:	68500A2s at 660VDC
Interrupt Current (maximum current at which the fuse can interrupt the current)	200kA

Table 3.8 Basic main tractive system fuse data

Fuse manufacturer and type:	Bussmann, 160LET Fuse
Continuous current rating:	160A
Maximum operating voltage	150VDC
Type of fuse:	High speed
I2t rating:	16000A2s at 240VDC
Interrupt Current (maximum current at which the fuse can interrupt the current)	200kA

Table 3.9 Basic motor controller fuse data

Location	*Wire Size*	*Wire Ampacity*	*Fuse type*	*Fuse rating*
Aluminum Busbars connecting Cells	*50mm^2*	*350 A*	*170M3418 Fuse*	*350 A*
Shielded Copper Cable Accumulator to Motor controller	*16mm^2*	*200 A*	*160LET Fuse*	*160 A*
Shielded Copper Cable AIR to HVD	*50mm^2*	*400 A*	*170M3418 Fuse*	*350 A*
TE KILOVAC EV200 Contactor	-	*500 A*	*170M3418 Fuse*	*350 A*
Cell Voltage Taps to BMS	*22 AWG*	*7 A*	*SSQ500* *Redundant Orion BMS Internal Fuse*	*500mA* *5 A*

Table 3.10 Fuse Protection Table

3.1.10 Charging

The accumulator will be charged with a PFC 5000 Battery Charger from ElCon, part number TCCH-96-44. This charger has been manufactured to a high standard, with conformance to SAEJ1378 for mechanical shock and vibration resistance, and IP46 for enclosure ingress protection. During charging, the BMS passively balances the cells. The charger will be connected to the accumulator and BMS through an external charge plug that connects the positive and negative terminals of the accumulator before the AIR’s. To ensure the safety of the vehicle and everyone around it, a dummy plug will be mated to the charging port to cover the charging terminals during traction event.

When the AIRS open, the ECU will send a message over CAN to the BMS stop all cell balancing.

Overvoltage protection is provided by the CAN communication between the charger and the BMS and the BMS disabling the contactors separating the modules. The IMD will be active during charging to ensure that high voltage and low voltage continue to be galvanically isolated. The charger will only become live when connected to the accumulator due to a low voltage interlock loop within the connector. There will also be an emergency shutdown button on the charging cart as a manual failsafe.

Charger Type:	ElCon PFC 5000 TCCH-96-44
Maximum charging power:	5kW
Maximum charging voltage:	130V
Maximum charging current:	44A @ 230 VAC, 20 @ 115VAC
Interface with accumulator	CAN-Bus
Input voltage:	230 VAC, 115 VAC
Input current:	20A rms @ 120 VAC / 23 A rms @ 230 VAC

Table 3.11 General charger data

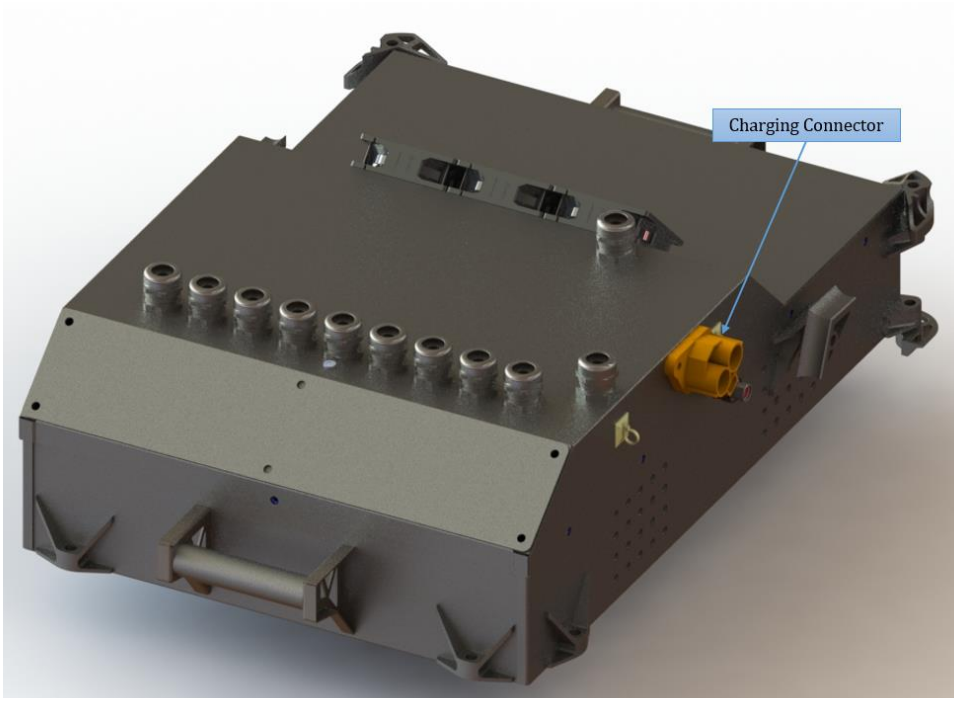


Figure 34: Charging port that will connect the accumulator to the ElCon charger

3.1.11 Mechanical Configuration/materials

The accumulator container consists of a welded, bent 4130 sheet steel lower chassis (0.05” thick) with welded internal walls (0.04” thick) that break it up into 5 equal compartments. The cover is also made of welded, bent 4130 sheet steel (0.04” thick). The accumulator is internally broken up into the lower section, where the cells are housed, and an upper section, which houses the low voltage components that interact with the accumulator (contactors, BMS, AIR’s, etc.).

All conductive paths within the accumulator, including the poles of the battery, are insulated from the conductive internal walls and outer case by the structural plastic of the Energus package, a machined polycarbonate sheet, and 3D printed busbar covers where necessary. The polycarbonate is 0.5” thick and functions as a separation between the cells and the rest of the battery, as well as the mounting structure for the low voltage components.

In the upper section, there is a portion that is dedicated to power distribution, which is protected from the rest of the low voltage components by a polycarbonate wall. All aforementioned materials meet UL94 V-0 standards.

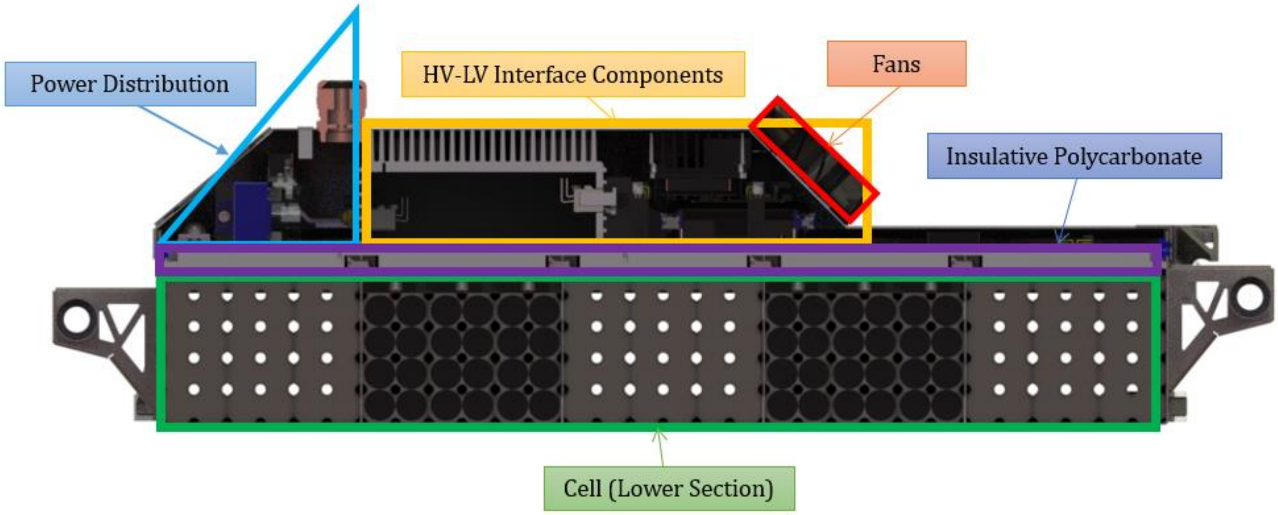


Figure 35: Cross-section of accumulator showing compartmentalization

To ensure adequate cooling, holes in the sides of the lower chassis are laser-cut to align with the cooling holes on the Energus submodules. Air will be forced in through the lower chassis and up through and out of the upper section of the accumulator by 3 92mmx92mm fans.

3.1.12 Position in car

In the vehicle, the accumulator is mounted directly behind the driver and firewall. The driver side impact structure extends all the way to the rear of the monocoque to protect the accumulator. The accumulator is rigidly attached to the monocoque and rear tubular spaceframe by welded on mounts. In all there are 10 mounts, each with 5/16-24 steel bolts going through them. These mounts are capable of withstanding 20 kN of force in all directions, which are detailed in the SES.

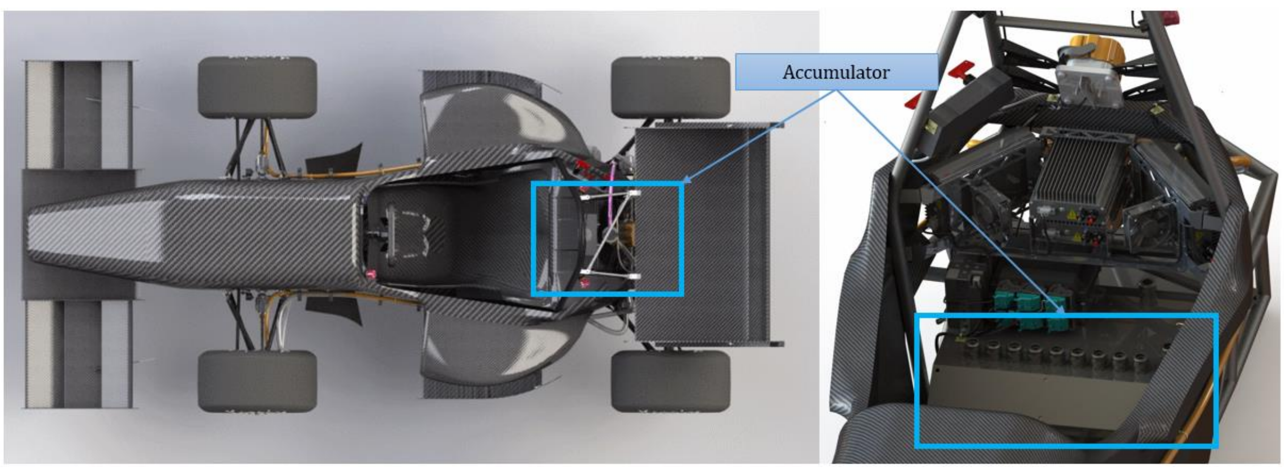


Figure 36: Accumulator container position

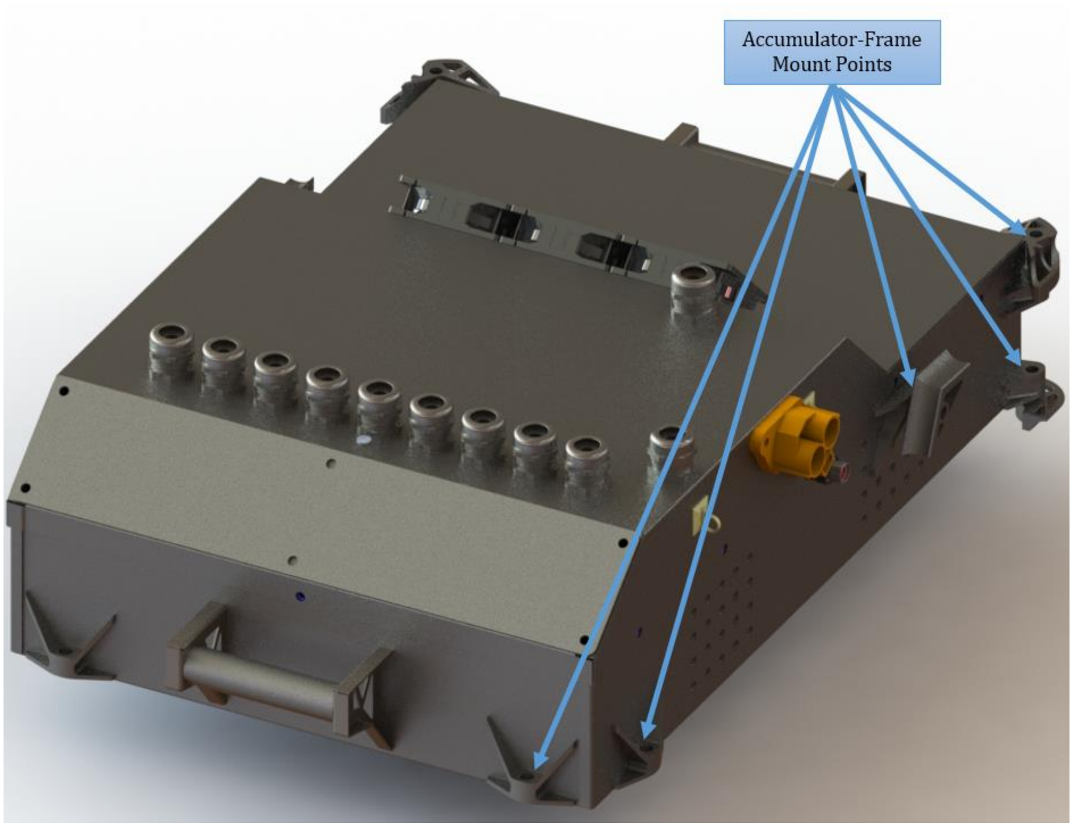


Figure 37: Accumulator mount point locations

3.2 Accumulator pack 2

There is no second accumulator container in our car.

4 Energy meter mounting

4.1 Description

The energy meter is mounted inside the accumulator upper section via 6 mm bolts through its two conductive pads into polycarbonate blocks attached to the insulating polycarbonate layer. The energy meter is connected in series on the negative side of the tractive system and is connected to HV+ through a fused connection (3 amp). The 4 GLV connections exit the accumulator through an Autosport 8STA connector.

4.2 Wiring, cables, current calculations, connectors

22 AWG wire is used to connect the energy meter to the LV system. Aluminum 6061 busbars and 50mm^2 Coroplast shielded cabling will connect the energy meter to the high voltage system. The Energy Meter is located on the negative leg of the accumulator between the HVD and the motor controller high voltage negative power distribution busbar.

4.3 Position in car

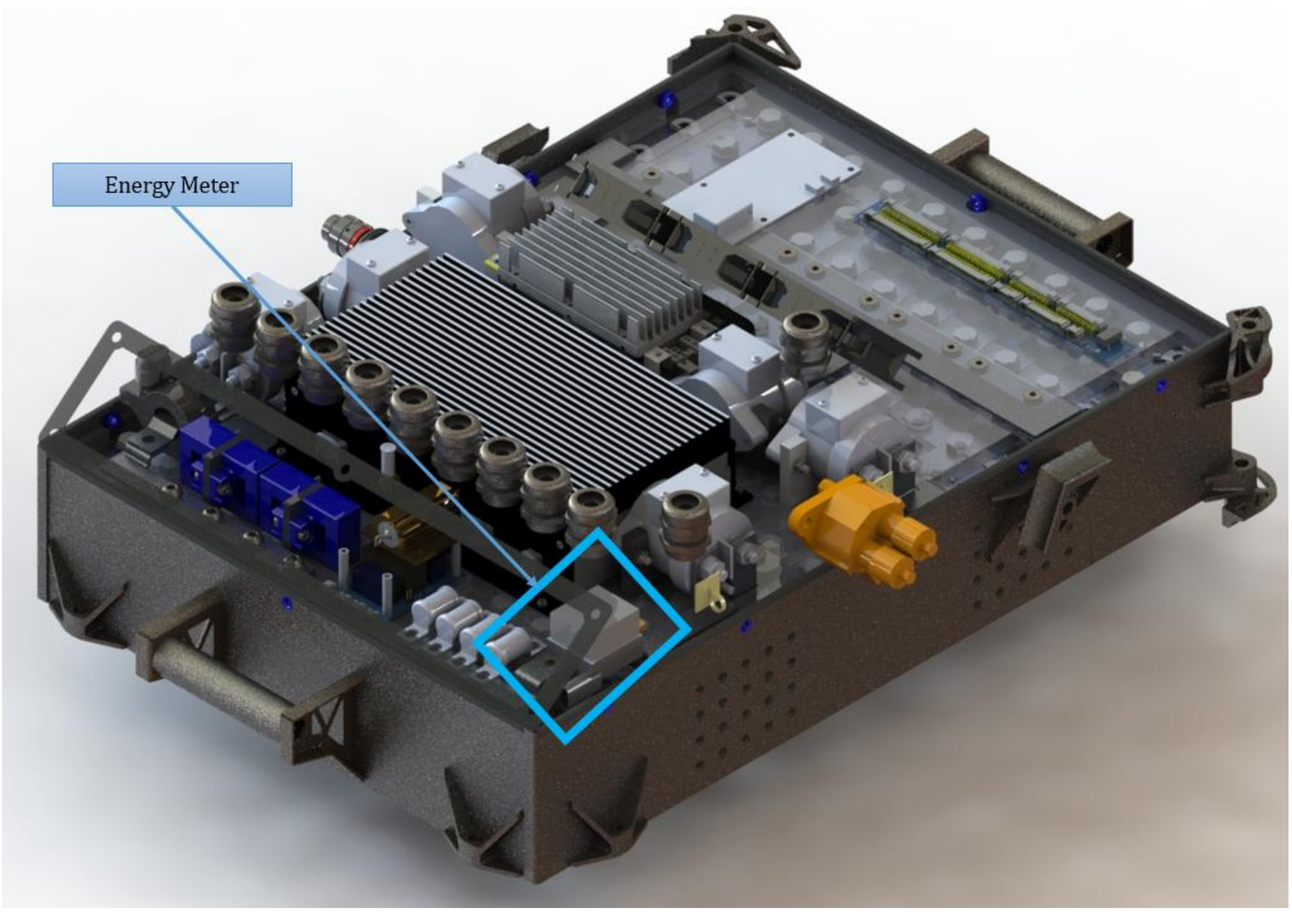


Figure 38: Energy meter position

5 Motor controllers

5.1 Plettenberg MST-140-200 V2

5.1.1 Description, type, operation parameters

Four Plettenberg MST-140-200 V2 motor controllers are used as the motor controller for all four motors on the vehicle. The PWM request to the motor is controlled over RS-232, and the motor controller sends phase current, bus voltage, motor and controller temperature, and motor speed back to the central control unit over RS-232.

The motor controller has built in protections for internal sensor error, over-current, over-voltage, under-voltage, and high-temperature conditions and will shut down the motors during these events. These safety functions are detailed in Section 11.5.1.

Motor controller type:	Plettenberg MST-140-200 V2
Maximum continuous power:	30kW
Maximum peak power:	39kW
Maximum Input voltage:	140VDC
Output voltage:	126VDC
Maximum continuous output current:	220A
Maximum peak current:	280A
Control method:	RS-232 Serial
Cooling method:	Forced air
Auxiliary supply voltage:	N/A

Table 5.1 Plettenberg MST-140-200 technical data

5.1.2 Wiring, cables, current calculations, connectors

16mm^2 HV shielded Coroplast cable and is used for both the DC and the phase cables on our motor controllers. This selection is based the continuous current draw based on our student designed Lap Simulator which gave us the following results.

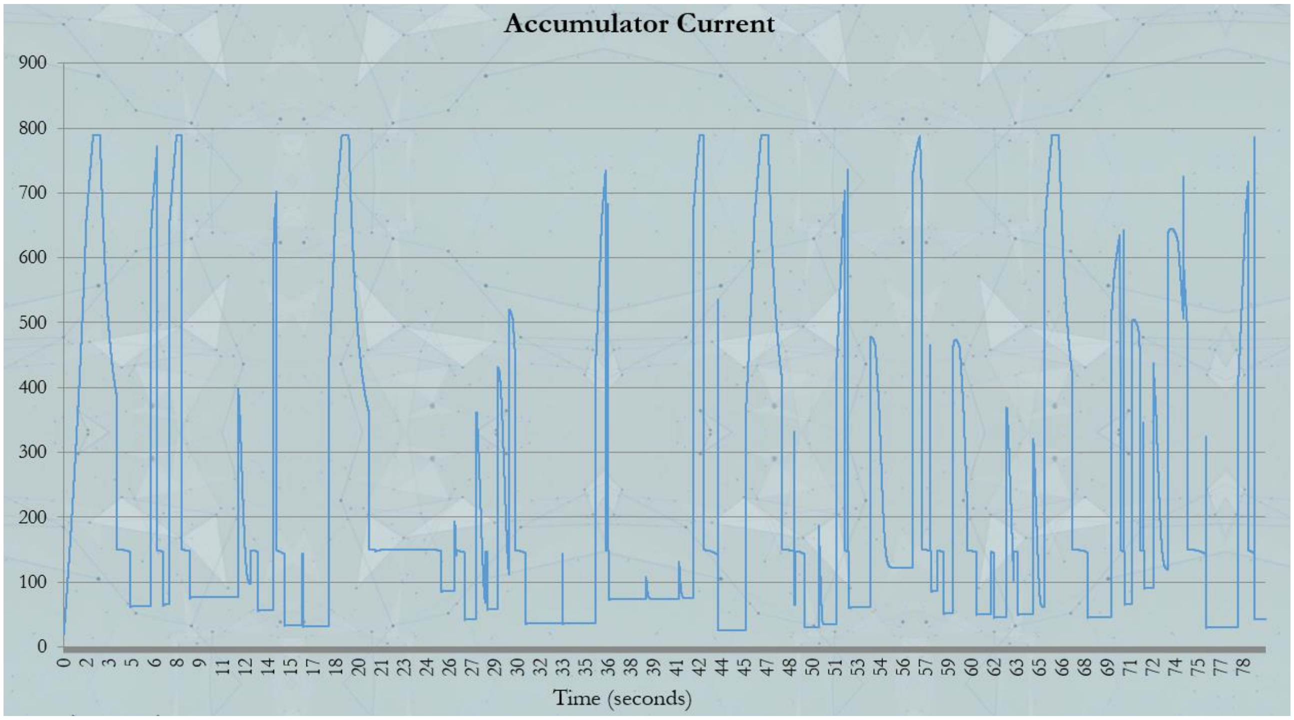


Figure 39: Accumulator Current vs Time (Endurance Lap)

- Rear Motors
  - Average Draw: 70A
  - Peak Draw: 280A
- Front Motors
  - Average Draw: 50A
  - Peak Draw: 190A

Based on these plots, we selected the 16mm^2 cable which have the following temperature-current curve.

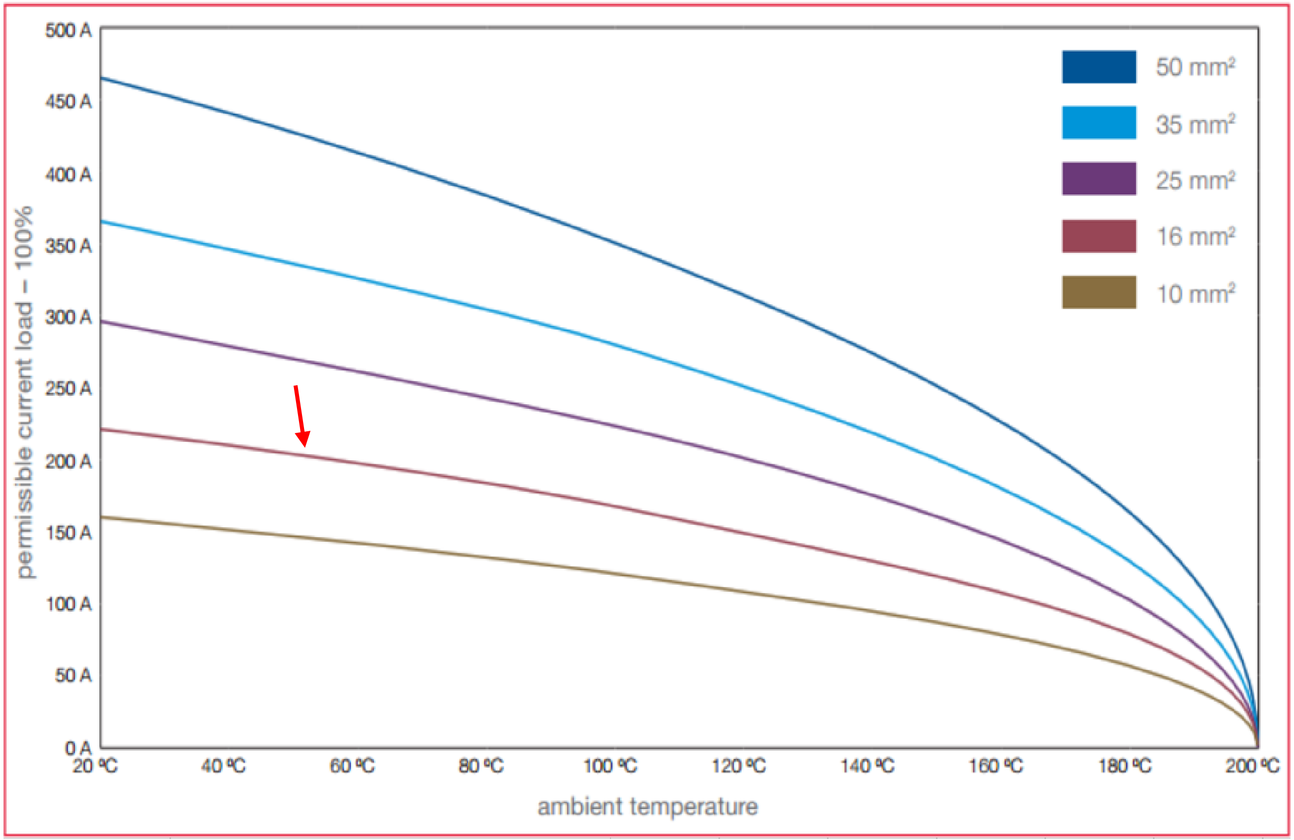


Figure 40: Threshold curves of permissible current vs ambient temperature

Wire type:	Coroplast HV Shielded Cable, 16 mm²
Current rating:	~210A continuous at 40C ambient
Maximum operating voltage:	1000V
Temperature rating:	180 °C

Table 5.2 Coroplast, 16 mm²

The cables entering motor controllers are strain-relieved by cable glands. For inline phase connections between the motor controllers and motors, we use *two-hole cable lugs* that are fastened together with positive locking hardware and are then insulated with double-layered heatshrink. The cables then go into the motors and are strain-relieved by cable glands.

5.1.3 Position in car

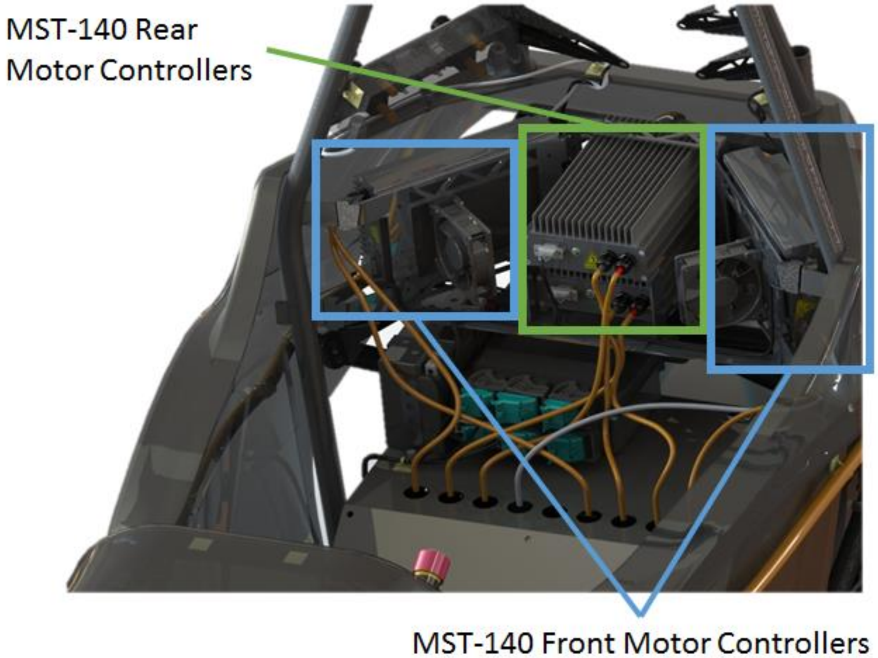


Figure 41: Motor controller locations in rear frame.

5.2 Motor controller 2

Four MST-140-200-V2 controllers are used on the vehicle. See Section 5.1.

5.3 Motor controller 3

Four MST-140-200-V2 controllers are used on the vehicle. See Section 5.1.

5.4 Motor controller 4

Four MST-140-200-V2 controllers are used on the vehicle. See Section 5.1.

6 Motors

6.1 Plettenberg Nova 30

6.1.1 Description, type, operating parameters

The motors driving the rear wheels are brushless DC permanent magnet motors by Plettenberg Electric Motors, the Nova 30. The Nova 30 features a lightweight design and an integrated water jacket.

Motor Manufacturer and Type:	Plettenberg Nova 30
Motor principle	Brushless permanent magnet
Maximum continuous power:	20kW
Peak power:	30kW
Input voltage:	126VDC
Nominal current:	80A
Peak current:	280A
Maximum torque:	60Nm
Nominal torque:	17Nm
Cooling method:	Water cooled

Table 6.1 Plettenberg Nova 30 specifications

- *The Plettenberg Nova 30 is being custom wound for our 126VDC tractive system. While we will be dyno testing our motors to implement torque control, dyno data for these motors is unavailable.*

6.1.2 Wiring, cables, current calculations, connectors

See Section 5.1.2

6.1.3 Position in car

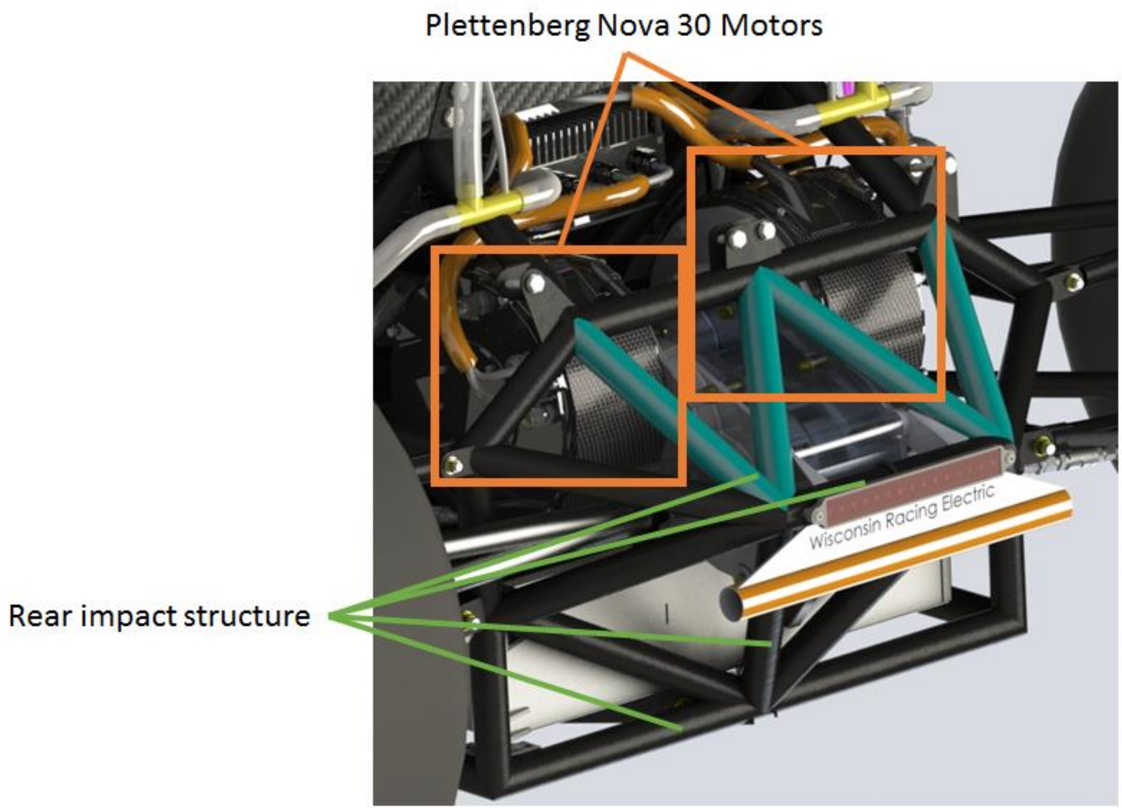


Figure 42: Rear motor locations in vehicle with impact structure shown.

6.2 Plettenberg Nova 15

6.2.1 Description, type, operating parameters

The in-hub front motors are the [Nova 15 series] produced by Plettenberg Electric Motors and are being custom wound for the 126V tractive system. The Nova 15 is an extremely compact design, allowing for in-hub packaging and includes an integrated water jacket.

Motor Manufacturer and Type:	Plettenberg Nova 15
Motor principle	Brushless permanent magnet
Maximum continuous power:	10kW
Peak power:	15kW
Input voltage:	126VDC

Nominal current:	100A
Peak current:	280A
Maximum torque:	30Nm
Nominal torque:	11Nm
Cooling method:	Water cooled

Table 6.2 Plettenberg Nova 15 specifications

- *The Plettenberg Nova 15 is being custom wound for our 126VDC tractive system. While we will be dyno testing our motors to implement torque control, dyno data for these motors is unavailable.*

6.2.2 Wiring, cables, current calculations, connectors

See Section 5.1.2

6.2.3 Position in car

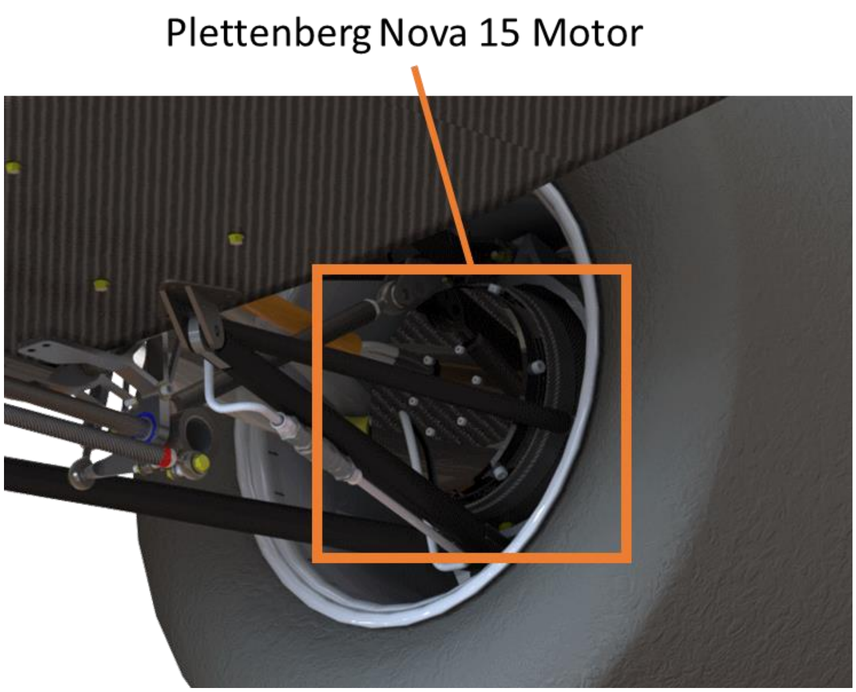


Figure 43: Location of in-wheel Nova 15 motor in front wheels

7 Torque encoder

7.1 Pedal Position Sensor

The dual redundant Bosch RP-100 Twin rotary position potentiometer is used as the accelerator pedal positon sensor. The RP-100 has two independent resistive sliders that are read as two separate analog voltages through the ECU's 10-bit analog-to-digital converter.

Torque encoder manufacturer and type:	Bosch RP-100 Twin
Torque encoder principle:	Potentiometer
Supply voltage:	5V
Maximum supply current:	10mA
Operating temperature:	-40 to 150 °C
Used output:	1V to 4V (sensor 1), 0.5V to 2V (sensor 2)

Table 7.1 Torque encoder data

7.1.1 Brake pressure sensor (brake encoder)

Two TE Connectivity US300 brake pressure sensors are used to measure driver braking input. Since the front and rear brakes have separate lines, two sensors are required to measure the braking pressure. The average of these two signals is then used as the brake encoder to activate regenerative braking.

Torque encoder manufacturer and type:	TE Connectivity US300 Pressure Sensor
Torque encoder principle:	Pressure transducer
Supply voltage:	5V
Maximum supply current:	5mA
Operating temperature:	-40 to 105 °C
Used output:	0.5V to 4.5V

Table 7.2 Brake encoder data

7.2 Torque Encoder Plausibility Check

The central PCM-112 ECU reads the voltage output of the two sensors within the Bosch RP-100 twin and determines plausibility between the two readings. No less than 20° travel is used, giving a minimum full-scale ADC count of 102 for the 2.5V sensor and 204 for the 5V senor with the 10-bit ADC's on the PCM-112. If greater than 10% difference is detected between the torque encoder sensors (with a floor of 1 ADC count for small values), an implausibility is detected and zero tractive current is requested by the ECU. Because the sensor transfer functions only agree at the zero torque position, if a short circuit or open circuit occurs in either of the torque encoder sensors then an implausibility is detected and zero tractive current is requested.

Because the brake encoder is used in the tractive system shutdown circuit and used to control regenerative braking, implausibility detection is implemented as well. If an implausibility between the brake encoders of greater than 10% is detected, then zero tractive system current is requested. Because the brake encoder output voltage is 0.5-4.5V, a short circuit or open circuit is detected by a signal outside of this range and zero tractive system current is requested.

The ECU transmits motor current requests over CANbus to an off-the-shelf PCAN-RS-232 converter that then transmits the control signals over RS-232 to the motor controller.

The PCAN-RS-232 modules implement several checks. First, if the periodic CAN message being sent from the ECU is not received by the PCAN-RS-232 modules in more than five times its expected period, then the CAN communication is determined to be faulty and the PCAN-RS-232 modules will request zero current in the motors.

Similarly, if the PCAN-RS-232 modules detect a loss of RS-232 communication with the motor controllers, then a fault CAN message will be sent to the ECU to initialize the shutdown circuit.

7.3 Wiring

Our torque encoder has two separate Binder M5 connectors with separate power, ground, and analog output signal connections. Each Binder M5 connector has precrimped 24AWG cables.

7.4 Position in car/mechanical fastening/mechanical connection

The torque encoder is connected to the brake pedal by a direct mechanical connection. A single shaft provides the input for the two internal potentiometers in the RP-100 twin. Both the pedal mount and the RP-100 twin have return springs.

The brake over-travel switch is a simple toggle switch that is mounted to the pedal rack and is designed to be tripped in the event that the brake pedal breaks through its mechanical stops.

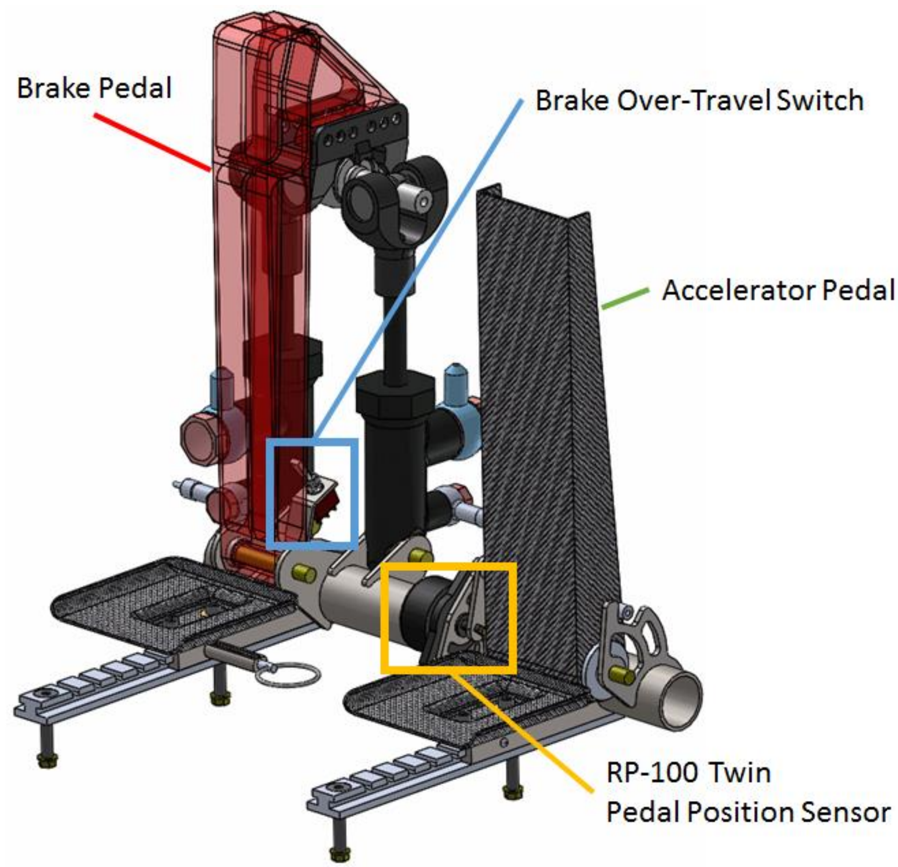


Figure 44: Torque encoder, brake over-travel switch, and driver pedals

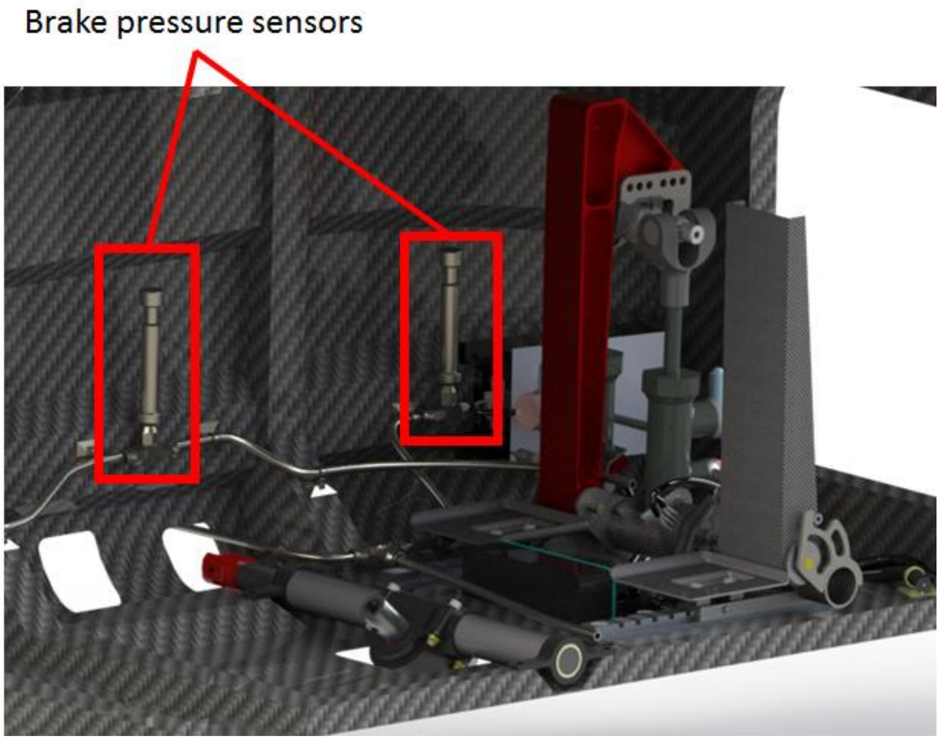


Figure 45: Brake pressure sensor locations

8 Additional LV-parts interfering with the tractive system

8.1 Woodward PCM-112-14 Electronic Control Unit

8.1.1 Description

The Woodward PCM-112-14 Electronic Control Unit (ECU) is the primary control unit used on the vehicle. The ECU receives data from sensors by analog signals or CAN. CAN is used to communicate with the motor controllers, BMS, the electronic steering wheel, and the data acquisition system. The ECU monitors the status of the tractive system shutdown circuit and requests zero current in the motors in order to safely shut them down before the AIRs close.

All vehicle dynamics control is managed by the ECU. This includes traction control, torque vectoring, and power limiter. The tractive force available at the contact patch is calculated from measured longitudinal and lateral acceleration, vehicle velocity, and yaw acceleration. The ECU limits each tire based on its individual torque limit and the estimated traction limit.

Torque vectoring is implemented as a yaw moment PID controller based on measured yaw rate and estimated target yaw from steering angle input and vehicle speed. The ECU decreases torque on one side of the car and increases torque on the opposite side (such that net torque is equal to driver requested value or is otherwise traction limited) in order to create the PID requested yaw moment.

Because the motors possess the capability to exceed 80kW total power draw, a software power limiter must be implemented to ensure this does not occur. In addition, the power limiter is used to increase range for the endurance event. The power limiter reduces torque at the wheels to maintain the set power limit while maintaining the desired yaw moment request and minimizing power draw by optimally splitting the torque requested from the front and rear motors.

8.1.2 Wiring, cables,

Our ECU uses a Molex CMC 112 connector, the same one that is on the Rear Electronics Unit. 22 and 24AWG cable is used for all low current connections to the ECU. 16AWG cable is used for the connections made to our fans and pumps in our cooling system.

8.1.3 Position in car

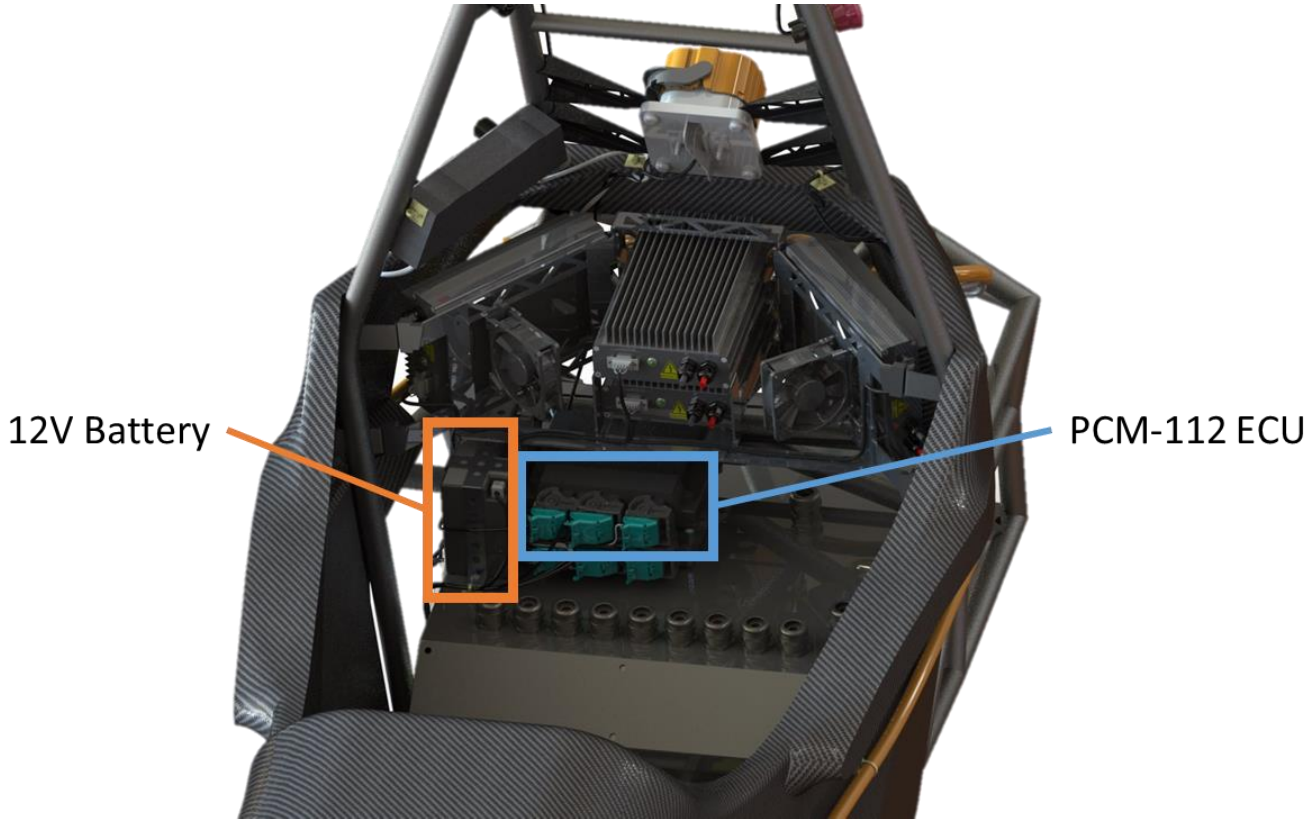


Figure 46: ECU and 12V battery locations.

8.2 Low Voltage Battery

A Shorai 12V lithium iron phosphate battery is used as the power source for the low voltage system when the tractive system is not active. The 18Ah size was chosen such that it could be used for an entire competition event without recharging and have sufficient capacity to power the fans and pumps as necessary when the tractive system is disabled.

Battery Model:	Shorai LFX18L1-BS12
Supply voltage:	12V
Maximum supply current:	270A
Capacity:	18Ah

Table 8.1 Low voltage battery data

8.3 126V to 12V DC-DC Converter

The Vicor Maxi DC-DC converter is used to step down the tractive system voltage of 126V for use on the 12V low voltage system. A switching relay is used to transition between the low voltage system source being the 12V to the DC-DC converter upon activation of the tractive system. The DC-DC converter and associated switching electronics are housed inside of the accumulator.

DC-DC Converter Model:	Vicor V110A12C500BL
Input voltage range:	66-154V
Output voltage:	12V
Maximum output power:	500W
Operating temperature:	-55 to 100 °C

Table 8.2 DC-DC Converter data

9 Overall Grounding Concept

9.1 Description of the Grounding Concept

All areas of the monocoque within 100 mm of any tractive system or GLV component will have 0.5 mm aluminum sheeting placed between it and the monocoque ensuring resistance of 300 mOhm (measured with a current of 1A) to GLV system ground. The rear half of the vehicle is a fully conductive steel space frame.

9.2 Grounding Measurements

We will measure resistance between every grounded component and GLV measurement point to be <300 mOhm. We will have measurement points on the outer layer of the monocoque in various locations near the tractive system or areas that may become electrically conductive to measure resistance to GLV to be < 5 Ohm.

10 Firewall(s)

10.1 Firewall 1

10.1.1 Description/materials

The vehicle utilizes firewalls in three areas, behind the seat to isolate the driver from the battery and tractive system, behind the headrest to isolate the driver from the HVD and along the size of the vehicle to isolate the driver from the front motor wires and motor.

Each of the firewalls consists of three layers. One layer, facing the tractive system side, made of aluminum with a thickness of .5 mm. The aluminum is bonded to the structural center, carbon fiber, and then to the insulating layer made of Nomex type 410 sheeting. The Nomex sheeting is 0.38 mm thick and directly bonded to the center structure on the driver side. The Nomex sheeting sufficiently prevents penetration with a 4mm wide screwdriver with 250N of force applied.

The firewall is rigidly mounted to the main roll hoop providing a conductive path the LV ground to meet EV 4.3. A sample firewall will be presented at technical inspection.

10.1.2 Position in car

The three firewall locations are highlighted in the two following images. Locations 2 & 3 make up the driver isolation from battery and tractive system while areas 1 & 4 isolate the driver from the front motor cables and HVD, respectively

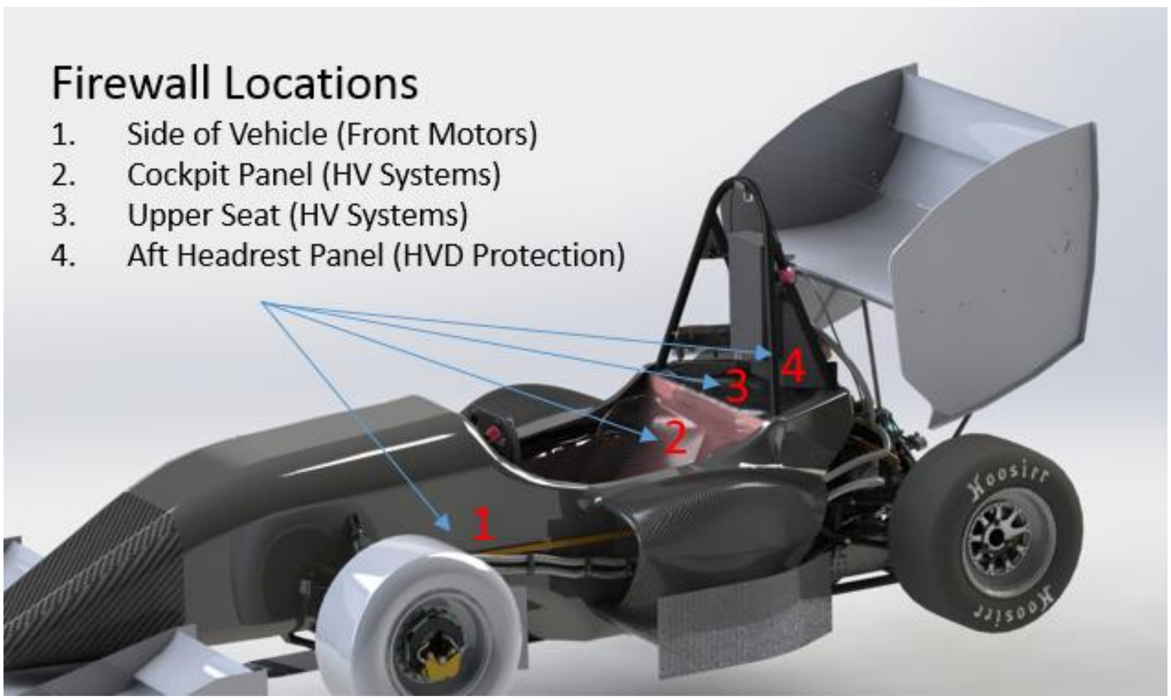


Figure 47. Firewall locations

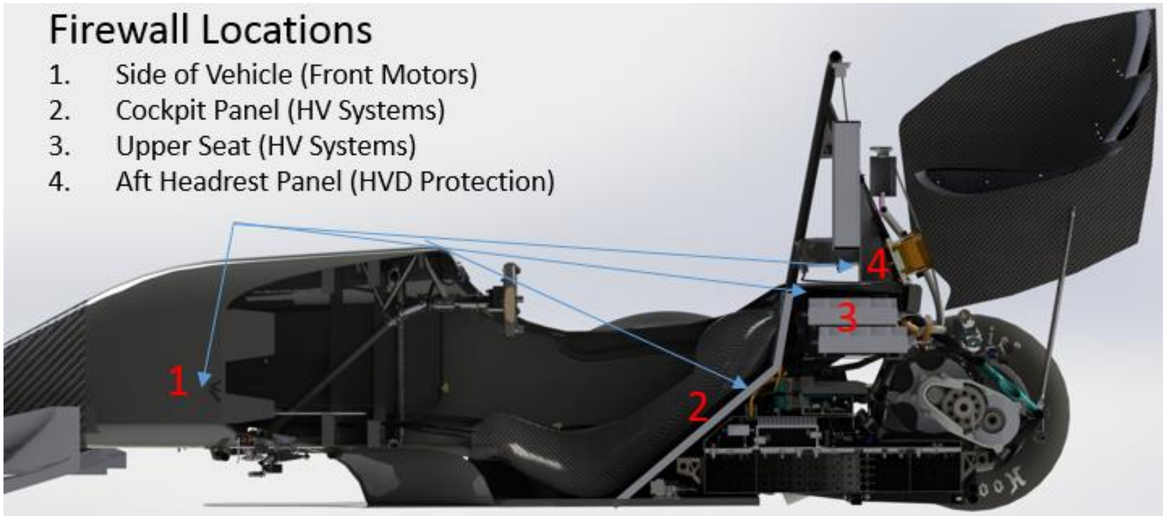


Figure 48. Firewall locations vehicle cross section

Location one, shown below, consist of a .5mm aluminum sheet bonded to the exterior monocoque surface. The aluminum sheet extends 3" above and below the cables and 9" fore and aft of the motor, as well as above the motor in the view shown. The aluminum sheet is then covered by the vinyl wrap for the vehicle with 0.5" circular sections visible for technical inspection. Nomex 410 sheeting is placed on the interior side of the monocoque, inside the cockpit, in the corresponding location to isolate the driver.

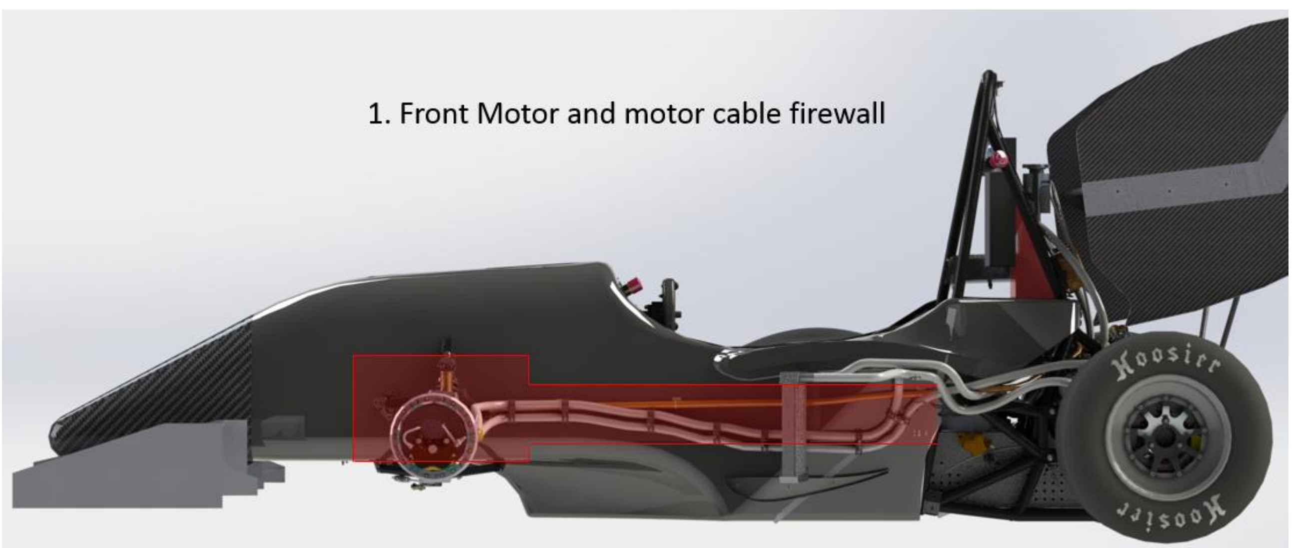


Figure 49. Motor and cable firewall

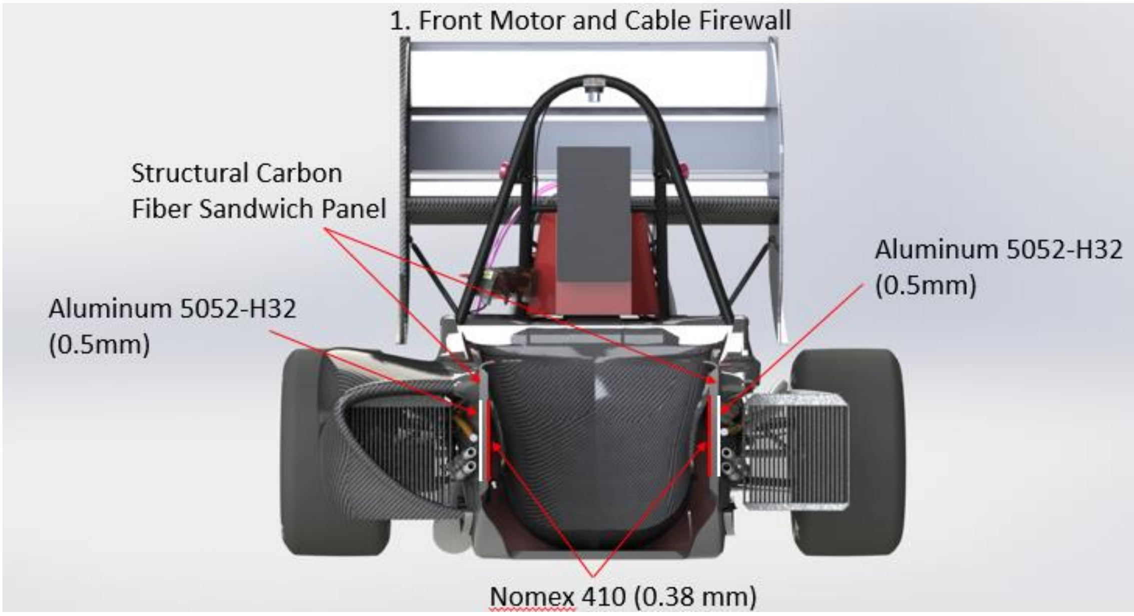


Figure 50. Front cross-section of motor and cable firewall

10.2 Firewall 2

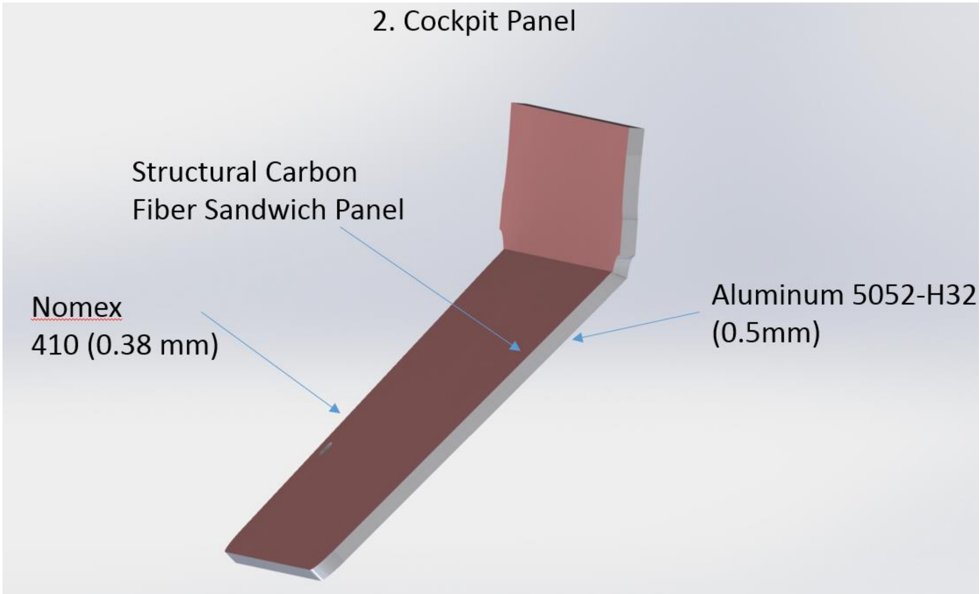


Figure 51. Construction of cockpit firewall panel

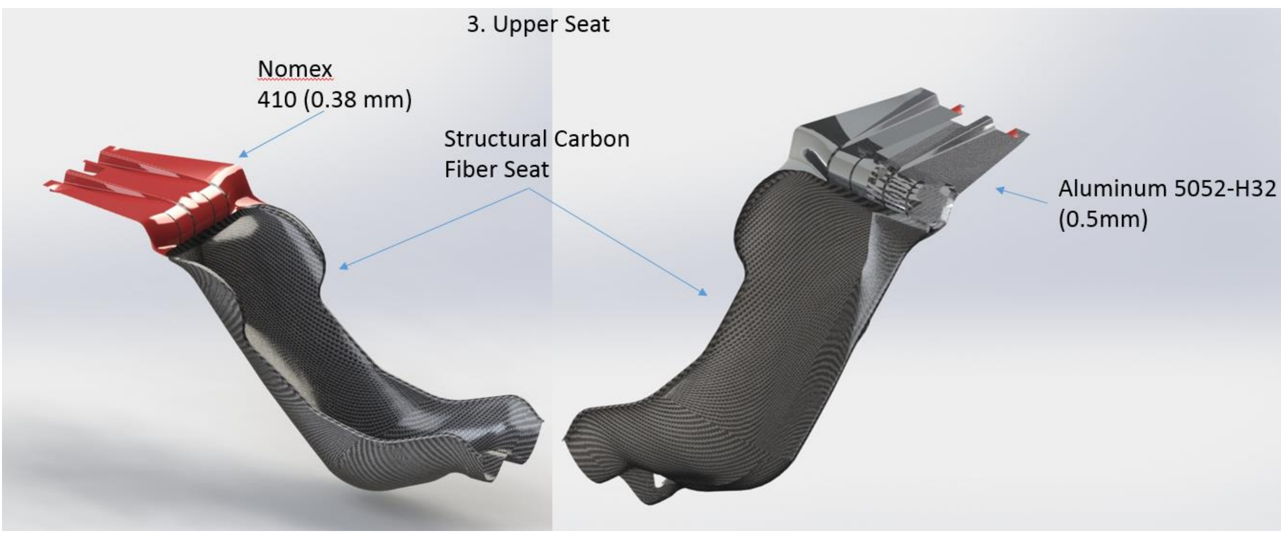


Figure 52. Construction upper seat firewall

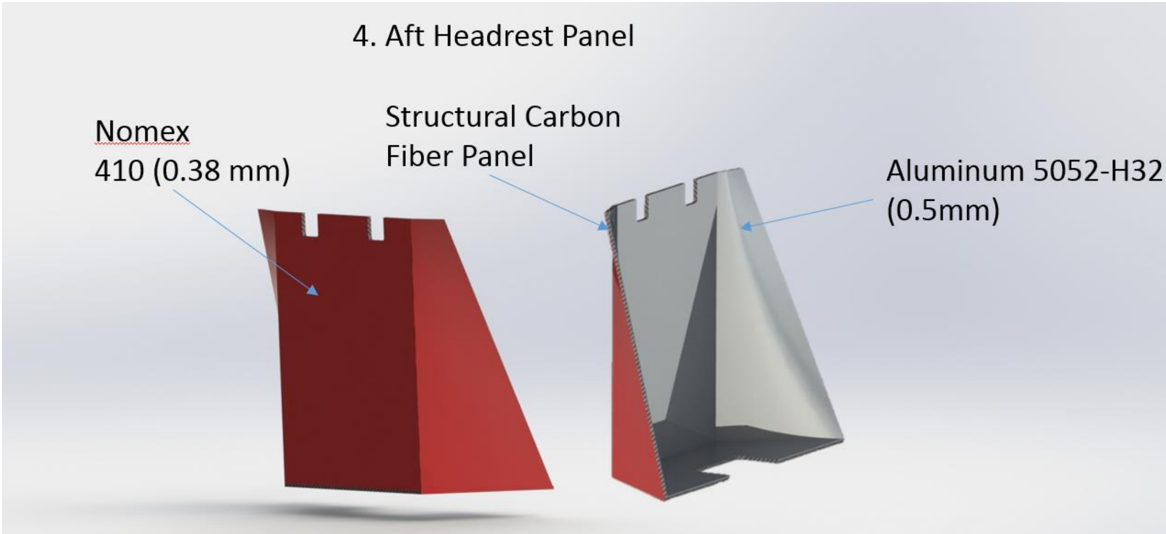


Figure 53. Construction of aft headrest firewall panel

11 Appendix

11.2.1.2 Molex CMC 112 Connector data

The Molex CMC 112 connector is covered in Section 2.1.2, Section 2.3.2, Section 2.4.2, and Section 2.12.2.

2.54mm (.100")
3.70mm (.146") Pitch
Wire-to-Board
3 pocket
CMC Header

64333
112-circuit

Features and Benefits

- 112-circuit, three-pocket, right-angle header
- Terminals mate with CP 0.635mm (.025") and CP 1.50mm (.059") solder-mount terminals
- Housing made out of high flammability V0 plastic material
- Plastic material is suitable for epoxy adhesion
- Plastic material is hydrolyticallly stable
- Headers are off shelf available
- Mates with CMC receptacle 32-circuit grey+48-circuit brown+32-circuit black coding
- For low- and medium-current applications
- Achieves OEM specification requirements
- Allows glueing process at Engine Control Unit manufacturer
- Suitable for sealed applications
- No custom tooling costs

Reference Information

Product Specification:
please refer to product specification of the relevant mating CMC connector

Reference Information
Packaging: Trays in carton box

Mates With: 64319-3211 and
64320-3319 and
64319-1218

Use With:
On Connector side: 64325-1010 Blind Plug 0.635mm
64325-1023 Blind Plug 1.50mm

64319-1201 32ckt Wire Cap
64320-1301 48ckt Wire Cap

64322 series
CP Terminals 0.60mm (.025")
64323 series
CP Terminals 1.50mm (.059")

Designed In: mm
RoHS: Yes
Halogen Free: Yes

Electrical

Voltage: 250V AC

Current: *
CP 0.635mm (.025") terminals – max 6.0A ($0.75mm^2$ wire)*
CP 1.50mm (.059") terminals – max 12.0A ($2.00mm^2$ wire)*

** current tested on a 5 terminals loaded connector, current for temperature increase of 40°C*

Contact Resistance:
0.635mm (.025") terminals: 8 milliohms max.
1.50mm (.059") terminals: 4 milliohms max.

Dielectric Withstanding Voltage:
1000V AC for 1 minute

Insulation Resistance:
100 Megohms min.

Mechanical

Contact Insertion Force:
0.635mm (.025") terminal: 12.00N max
1.50mm (.059") terminal: 25.00N max

Contact Retention to Housing:
0.635mm (.025") terminal: 60.00N min.
1.50mm (.059") terminal: 100.00N min

Wire Pull-Out Force:
min 100.00N

Mating Force: 70.00N max.
Unmating Force: 70.00N max.
Durability: 20 mating cycles

Physical

Housing: PBT, Glass-filled
Lead-Free: Yes
Operating Temperature: -40 to +125°C

Full datasheet can be found here

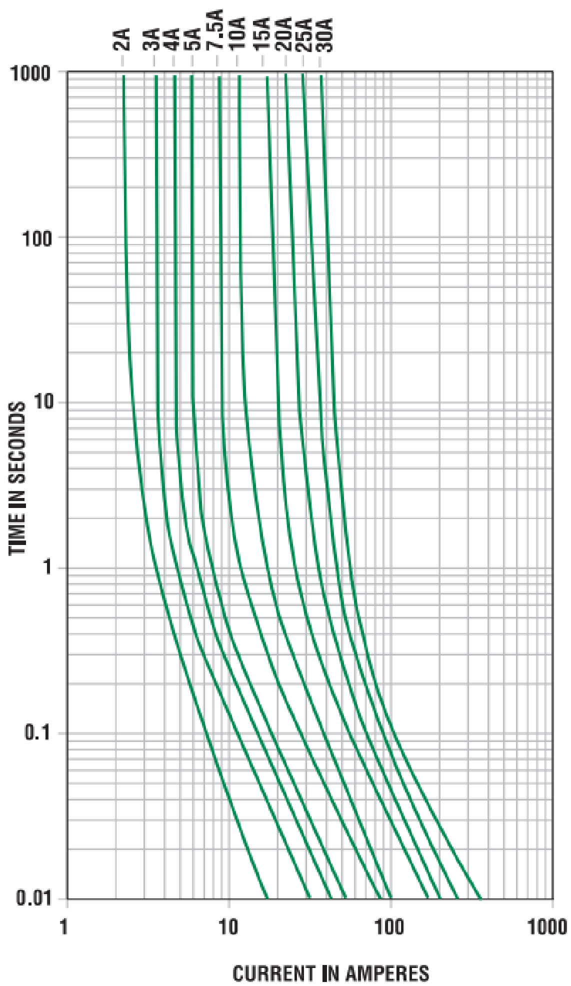
11.2.1.2 LittleFuse Mini Fuse Data

The Mini fuses are covered in Section 2.1.2.

Specification	MINI (Silver Plated)
Interrupting Rating:	1000A @ 32 VDC
Voltage Rating:	32 VDC
*Component Level Temperature Range:	-40°C to +125°C
**System Level Temperature Range:	-40°C to +105°C

105°C and 85°C are typical system level temperature requirements.

Terminals:	Ag plated zinc alloy
Housing Material:	PA66
Complies with:	SAE J2077, ISO 8820-3,



Full datasheets can be found here.

11.2.2.1 IMD Specs

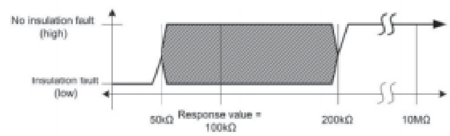
The IMD is covered in Section 2.2.

Technical data

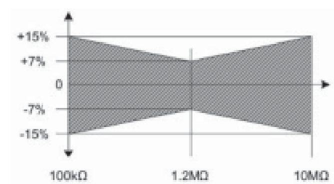
Supply voltage U_S	DC 10…36 V
Nominal supply voltage	DC 12 V / 24 V
Voltage range	10 V…36 V
Max. operational current I_S	150 mA
Max. current I_k	2 A
	6 A / 2 ms Rush-In current
Power dissipation P_S	< 2 W
Line L+ / L- Voltage U_n	AC 0 V…1000 V peak; 0 V…660 V rms (10 Hz…1 kHz) DC 0 V…1000 V
Protective separation (reinforced insulation) between	(L+ / L-) – (Kl.31b, Kl.15, E, KE, M_{HS}, M_{LS}, OK_{HS})
Voltage test	AC 3500 V / 1 min
Under voltage detection	0 V…500 V; Default: 0 V (inactive)
System leakage capacity C_e	≤ 1 µF
Measuring voltage U_m	+/- 40 V
Measuring current I_m at $R_F = 0$	+/- 33 µA
Impedance Z_i at 50 Hz	≥ 1.2 MΩ
Internal resistance R_i	≥ 1.2 MΩ
Measurement range	0…10 MΩ
Measurement method	Bender DCP technologie
Factor averaging F_{ave} (Output M)	1…10 (default: 10; EOL Bender)
Relative error at SST (≤ 2s)	Good > 2 * R_{an}; Bad < 0.5 * R_{an}
Relative error at DCP	0…85 kΩ ▶ +/-20 kΩ 100 kΩ…10 MΩ ▶ +/-15 %
Relative error Output – M (base frequencies)	+/- 5 % at each frequency (10 Hz; 20 Hz; 30 Hz; 40 Hz; 50 Hz)
Relative error under voltage detection	U_n ≥100 V ▶ +/-10 %; at U_n ≥300 V ▶ +/-5 %
Response value hysteresis (DCP)	25 %
Response value R_{an}	100 kΩ…1 MΩ ▶ higher tolerances at R_{an} < 85 kΩ; (Default: 100 kΩ)
Response time t_{an} (OK_{HS}; SST)	t_{an} ≤ 2 s (typ. < 1 s at U_n > 100 V)
Response time t_{an} (OK_{HS}; DCP) (Changeover R_F: 10 MΩ ▶ R_{an}/2; at C_e = 1 µF; U_n = 1000 V DC)	t_{an} ≤ 20 s (at F_{ave} = 10*) t_{an} ≤ 17.5 s (at F_{ave} = 9) t_{an} ≤ 17.5 s (at F_{ave} = 8) t_{an} ≤ 15 s (at F_{ave} = 7) t_{an} ≤ 12.5 s (at F_{ave} = 6) t_{an} ≤ 12.5 s (at F_{ave} = 5) t_{an} ≤ 10 s (at F_{ave} = 4) t_{an} ≤ 7.5 s (at F_{ave} = 3) t_{an} ≤ 7.5 s (at F_{ave} = 2) t_{an} ≤ 5 s (at F_{ave} = 1) during self test ▶ t_{an} + 10 s

* F_{ave} = 10 is recommended for electric vehicles

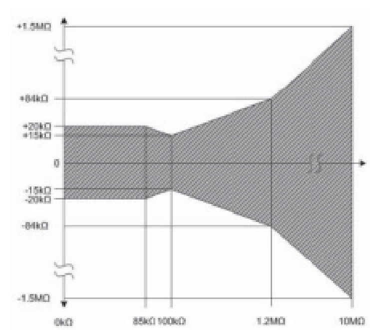
Switch-off time t_{ab} (OK_{HS}; DCP) (Changeover R_F: $R_{an/2}$ ▶ 10 MΩ; at C_e = 1 µF; U_n = 1000V DC)	t_{ab} ≤ 40 s (at F_{ave} = 10) t_{ab} ≤ 40 s (at F_{ave} = 9) t_{ab} ≤ 33 s (at F_{ave} = 8) t_{ab} ≤ 33 s (at F_{ave} = 7) t_{ab} ≤ 33 s (at F_{ave} = 6) t_{ab} ≤ 26 s (at F_{ave} = 5) t_{ab} ≤ 26 s (at F_{ave} = 4) t_{ab} ≤ 26 s (at F_{ave} = 3) t_{ab} ≤ 20 s (at F_{ave} = 2) t_{ab} ≤ 20 s (at F_{ave} = 1) during self test ▶ t_{ab} + 10 s
Self test time	10 s (every 5 minutes; has to be added to t_{an} / t_{ab})
Relative error (SST)	"Good-Value" ≥ 2 * R_{an} "Bad-Value" ≤ 0.5 * R_{an}



Relative error (DCP)	100 kΩ ▶ +/-15 % 100 kΩ…1.2 MΩ ▶ +/-15 % to +/-7 % 1.2 MΩ ▶ +/-7 % 1.2 MΩ…10 MΩ ▶ +/-7 % to +/-15 % 10 MΩ ▶ +/-15 %



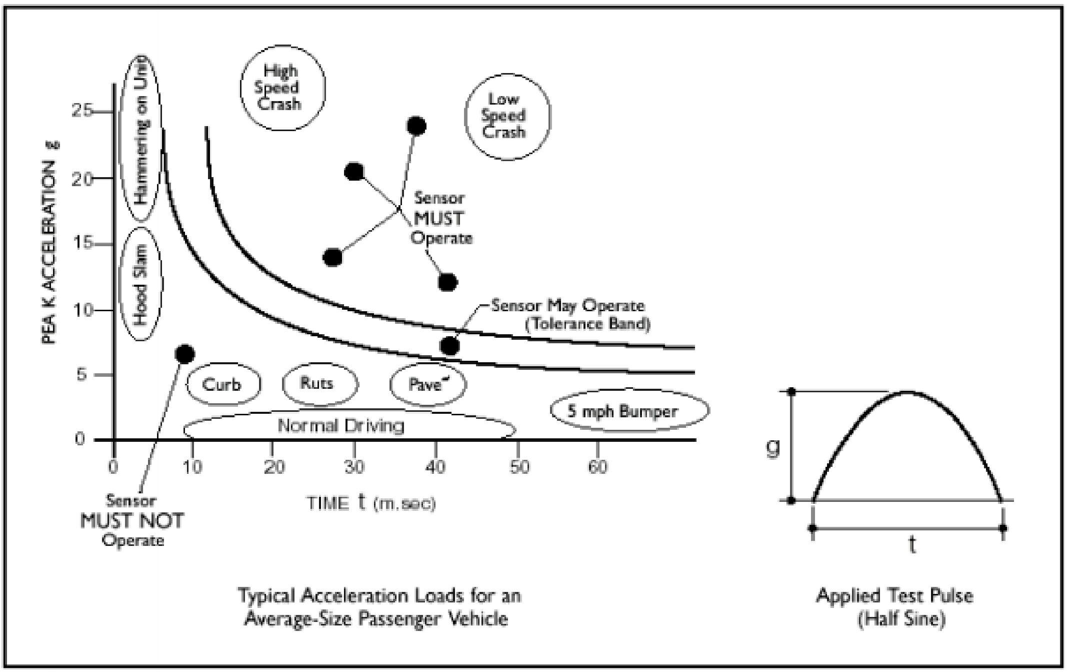
Absolute error (DCP)	0 Ω…85 kΩ ▶ +/-20 kΩ



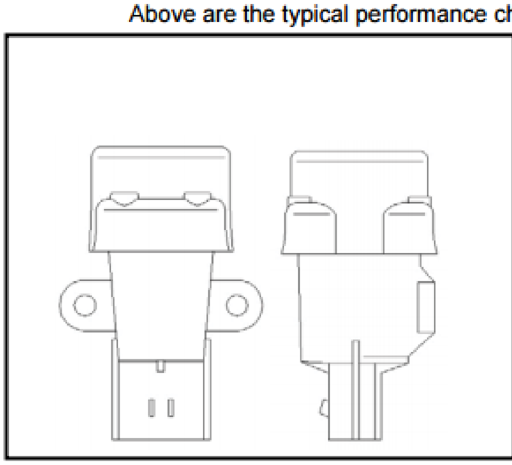
Full datasheet can be found here

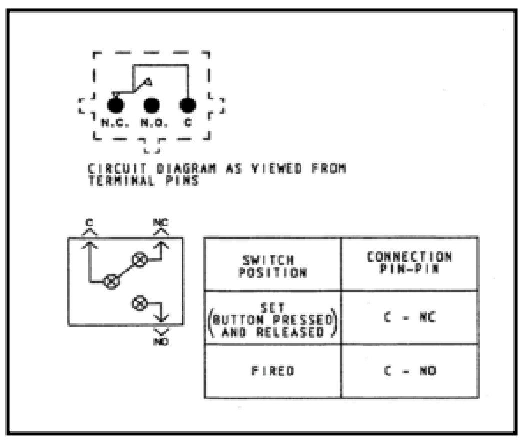
11.2.2.2 Sensata Resettable Crash Sensor Data

The Sensata Crash Sensor is covered in Section 2.3.



Above are the typical performance characteristics of resettable crash sensors





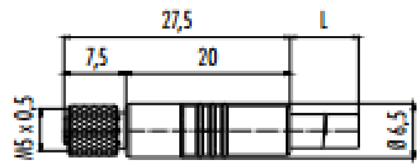
Full datasheets can be found here

11.2.3.2 Binder M5 connectors data

Binder M5 connectors are covered in Section 2.1.2, Section 2.3.2, Section 2.4.2, Section 2.6.2, Section 2.7.2, Section 2.11.2, and Section 2.12.2.

Male cable connector, moulded, M5 x 0,5

Female cable connector, moulded, M5 x 0,5



Wire gauge	0,14 mm² (AWG 26), 0,25 mm² (AWG 24)
Mechanical operation	> 100 Mating cycles
Temperature range	– 25 °C / + 80 °C
Rated voltage	60 V
Pollution degree	3
Rated current (40°C)	1 A
Contact plating	Au (Gold)
Material of housing	PUR

[Full datasheet can be found here]

11.2.4.1 DHAB S/137 Main accumulator current sensor data

The main accumulator current sensor is covered in Section 2.4.

Operating characteristics in nominal range (I_{PN})

Parameter	Symbol	Unit	Specification Min	Specification Typical	Specification Max	Conditions
Electrical Data						
Supply voltage [1]	U_C	V	4.75	5	5.25	
Current consumption	I_C	mA		15	20	
Maximum output current	I_{out}	mA	−1		1	
Load resistance	R_L	KΩ	10			
Capacitive loading	C_L	nF	1		100	
Ambient operating temperature	T_A	°C	−10		65	High accuracy
			−40		125	Reduced accuracy
Performance Data channel 1						
Primary current, measuring range	$I_{PM\ channel\ 1}$	A	−75		75	
Primary nominal DC or rms current	$I_{PN\ channel\ 1}$	A	−75		75	@ T_A = 25 °C
Offset voltage	V_O	V		2.5		@ U_C = 5 V
Sensitivity	G	mV/A		26.67		@ U_C = 5 V
Resolution		mV		2.5		@ U_C = 5 V
Output clamping voltage min [1]	V_{sz}	V	0.2	0.25	0.3	@ U_C = 5 V
Output clamping voltage max [1]		V	4.7	4.75	4.8	@ U_C = 5 V
Output internal resistance	R_{out}	Ω		1	10	
Frequency bandwidth [2]	BW	Hz		70		@ −3 dB
Power up time		ms			1	
Setting time after overload		ms			10	
Ratiometricity error	ε_r	%	−0.6		0.6	
Output voltage noise peak-peak	$V_{no\ pp}$	mV	−10		10	
Performance Data channel 2						
Primary current, measuring range	$I_{PM\ channel\ 2}$	A	−1000		1000	
Primary nominal DC or rms current	$I_{PN\ channel\ 2}$	A	−1000		1000	@ T_A = 25 °C
Offset voltage	V_O	V		2.5		@ U_C = 5 V
Sensitivity	G	mV/A		2		@ U_C = 5 V
Resolution		mV		2.5		@ U_C = 5 V
Output clamping voltage min [1]	V_{sz}	V	0.2	0.25	0.3	@ U_C = 5 V
Output clamping voltage max [1]		V	4.7	4.75	4.8	@ U_C = 5 V
Output internal resistance	R_{out}	Ω		1	10	
Frequency bandwidth [2]	BW	Hz		70		@ −3 dB
Power up time		ms			1	
Setting time after overload		ms			10	
Ratiometricity error	ε_r	%	−0.6		0.6	
Output voltage noise peak-peak	$V_{no\ pp}$	mV	−10		10	

Channel 1

Parameter	Symbol	Unit	Specification Min	Specification Typical	Specification Max	Conditions
Electrical Data						
Electrical offset current	I_{OE}	A		±0.07		@ T_A = 25 °C
Magnetic offset current	I_{OM}	A		±0.03		@ T_A = 25 °C
Offset current	I_O	A	−0.15		0.15	@ T_A = 25 °C
			−0.23		0.23	@ −10 °C < T° < 65 °C
			−0.35		0.35	@ −40 °C < T° < 125 °C
Sensitiviy error	ε_G	%		±0.4		@ T_A = 25 °C
				±1.0		@ −10 °C < T° < 65 °C
				±1.5		@ −40 °C < T° < 125 °C
Linearity error	ε_L	%		±0.5		@ T_A = 25 °C, @ U_C = 5 V, of full range

Channel 2

Parameter	Symbol	Unit	Specification Min	Typical	Max	Conditions
Electrical Data						
Electrical offset current	I_{OE}	A		±0.6		@ T_A = 25 °C
Magnetic offset current	I_{OM}	A		±0.25		@ T_A = 25 °C
Offset current	I_O	A	−3		3	@ T_A = 25 °C
			−3.6		3.6	@ −10 °C < T^o < 65 °C
			−4.5		4.5	@ −40 °C < T^o < 125 °C
Sensitiviy error	ε_G	%		±0.4		@ T_A = 25 °C
				±0.8		@ −10 °C < T^o < 65 °C
				±1.2		@ −40 °C < T^o < 125 °C
Linearity error	ε_L	%		±0.5		@ T_A = 25 °C, @ U_c = 5 V, of full range

[Full datasheets can be found here]

11.2.4.2 8STA Series connectors

The 8STA series connectors are covered in Section 2.4.2, Section 2.5.2, Section 2.7.2, Section 2.8.2,

Technical features

Mechanical

- **Shell:** Aluminium alloy
- **Shell plating:**
  Conductive black zinc
  Nickel (F)
- **Insulator:** Thermoplastic
- **Grommet & seal:** Liquid silicone rubber
- **Contact:** Copper alloy
- **Contact plating:** Gold
- **Endurance:** 500 mating cycles
- **Shock:** 300g for 3ms and EIA-364-27
- **Vibration:** 147m/s², 10 to 2000Hz
- **Contact retention:**
  Size 22D: 45 N
  Size 20: 60N
  Size 16: 100 N
  Size 12: 100 N
  Size 8: 110 N
  Size 4: 200 N

Electrical

- **Test voltage:**

Service	M	N	I	II
Sea level	1,300	1,000	1,800	2,300

- **Contact resistance:**
  Size 22D: 14.6 mΩ
  Size 20: 7.3 mΩ
  Size 16: 3.8 mΩ
  Size 12: 3.5 mΩ
  Size 8: 3 mΩ
  Size 4: 2 mΩ
- **Insultation resitance:**
  ≥ 5000 MΩ (at 500 Vdc)
- **Contact rating:**
  Size 22D: 5 A
  Size 20: 7.5 A
  Size 16: 13 A
  Size 12: 23 A
  Size 8: 45 A
  Size 4: 80 A
- **Shell continuity:** ≤10 mΩ

Environmental

- **Operating temperature:**
  -55°C to +175°C
- **Sealing mated connectors:**
  IP67 (1 metre for 30 min minimum)
- **Salt spray:**
  Aluminum: 48 hours

[Full datasheets can be found here]

11.2.7.1 LED Hideaway Strobe Light specs

The LED Hideway Strobe Light is covered in Section 2.7.

Specifications

Connector Type	Pigtail	**Current Draw**	1200mA
Finish	Black	**IP Rating**	Waterproof IP67
LED Type	High Power	**Mount Type**	Surface
PC Rated	No	**Special Features**	Alternating Flash Patterns/Multiple Flash Patterns
Standards And Certifications	RoHS Compliant	**Submersible**	Yes
Volts	10~30 VDC	**Wire Length**	7in(17.8cm)

Package Dimensions: 2.6" (7cm) x 2.1" (5cm) x 2.1" (5cm)

Package Weight: 1.90oz (0.05kg)

Full datasheets can be found here

11.2.7.2 400VDC Fuse data

Electrical Characteristic

Amp Code	Amp Rating	Max Voltage Rating (V)		Interrupting Rating				Nominal Cold Resistance (Milli-ohms)	Nominal Melting I^2t (A^2 sec.)	Agency Approvals				
				Voltage (V)		Current (A)				PSE	cURus	S	Δ	VDE
		AC	DC	AC	DC	AC	DC							
.500*	0.5*	500	400	500	400	100	1500	1055.900	0.300		x	x**		
.800*	0.8*	500	400	500	400	100	1500	430.000	0.909		x	x**		
001.*	1*	500	400	500	400	100	1500	139.400	1.800	x	x	x**		x
002.*	2*	500	400	500	400	100	1500	55.200	9.120	x	x	x**		
3.15*	3.15*	500	400	500	400	100	1500	27.700	50.109	x	x	x**		x
004.*	4*	500	400	500	400	100	500	17.200	52.480	x	x	x**		
005.*	5*	500	400	500	400	100	500	13.700	76.500	x	x	x**		
06.3	6.3	500	400	500	400	100	500	10.970	121.451	x	x	x		
008.	8	500	400	500	400	100	500	8.305	203.520	x	x	x		
010.	10	500	400	500	400	100	500	4.950	509.000	x	x		x	
012.	12	500	400	500	400	100	500	4.730	576.000	x	x		x	
016.	16	500	400	500	400	100	400	3.100	1331.200	x	x		x***	

*100A@600Vac interrupting rating witnessed by UL available for 0.5A to 5A with 600Vac markings. Add suffix "MXE6P" Example: 0477004.MXE6P

**Semko approval for 500Vac type only.

I^2t test at 10x rated current.

***100A@ 500Vac and 300A@400Vdc for 16A

Full datasheets can be found here

11.2.8.1 Pomona Electronics 4mm Banana jack data

The insulated banana jack test point is covered in Section 2.8.1.

Features

- Panel mount IEC61010 4mm (0.16in) banana jack for sheathed banana plugs, with threaded stud.
- Hexagonal nut.

Specifications

Max Current	36A
Max Voltage	1000 V CAT III

Full datasheet can be found here

11.2.9.1 HS75 100R F Precharge/Discharge Resistor Data

The Precharge/Discharge resistor is covered in Section 2.9.1.

Electrical Specifications

Size	Style MIL-R 18546	Power rating on std. heatsink @25°C	Watts with no heatsink @25°C	Resis-tance range	Limiting element voltage	Voltage proof AC Peak	Voltage proof AC rms.	Approx weight gms	Typical surface rise HS mounted	Standard heatsink	
										cm²	Thickness mm
HS10	RE 60	10	5	R005-10K	160	1400	1000	4	5.8	415	1
HS15	RE 65	15	7	R005-10K	265	1400	1000	7	5.1	415	1
HS25	RE 70	25	9	R005-36K	550	3500	2500	14	4.2	535	1
HS50	RE 75	50	14	R01-86K	1250	3500	2500	32	3.0	535	1
HS75		75	24	R01-50K	1400	6363	4500	85	1.1	995	3
HS100		100	30	R01-70K	1900	6363	4500	115	1.0	995	3
HS150		150	45	R01-100K	2500	6363	4500	175	1.0	995	3
HS200		200	50	R01-50K	1900	7070	5000	475	0.7	3750	3
HS250		250	55	R01-50K	2200	7070	5000	600	0.6	4765	3
HS300		300	60	R01-68K	2500	7070	5000	700	0.6	5780	3

Full datasheet can be found here

11.2.9.2 LH30BA507 Capacitor Data

The DC-link capacitor is covered in Section 2.9.2.

PART NUMBER	VOLTAGE	CAP	"H"	ESR	Rth	ESL	dv/dt	I pk	Fres	WEIGHT	Rms Current (10kHz			
	VDC	µF	mm	(Milliohms)	°C/W	(nH)	(v/us)	(AMPS)	(kHz)	(kg)	25°C	55°C	85°C	105°
LH30BA507	500	500	50	0.20	2.2	8	42	21110	79.6	0.9	408	315	209	50

Full datasheet can be found here

11.2.9.2 G2RL DPDT Relay Data

The Precharge/Discharge relay is covered in Section 2.9.2.

■Ratings

●Coil

	Item / Rated voltage	Rated current (mA)	Coil resistance (Ω)	Must operate voltage (V)	Must release voltage (V)	Max. voltage (V)	Power consumption (mW)
				% of rated voltage			
Standard	5 VDC	80.0	62.5	70% max.	10% min.	130% (at 85°C)	Approx. 400
	12 VDC	33.3	360				
	24 VDC	16.7	1,440				
	48 VDC	8.96	5,358				Approx. 430
High-sensitivity	12 VDC	20.8	576	75% max.			Approx. 250
	24 VDC	10.42	2,304				

Note 1. The rated current and coil resistance are measured at a coil temperature of 23°C with a tolerance of ±10%.
Note 2. The operating characteristics are measured at a coil temperature of 23°C.
Note 3. The "Max. voltage" is the maximum voltage that can be applied to the relay coil.

●Contacts

Classification	Standard type (resistive load)				High-capacity type (resistive load)		High-sensitivity type (resistive load)	
Item / Model	G2RL-1A	G2RL-1	G2RL-2A	G2RL-2	G2RL-1A-E (-CV, -ASI)	G2RL-1-E	G2RL-1A-H	G2RL-1-H
Contact type	Single							
Contact material	Ag-alloy (Cd free)							
Rated load	12 A at 250 VAC 12 A at 24 VDC (See note)		8 A at 250 VAC 8 A at 30 VDC (See note)		16 A at 250 VAC 16 A at 24 VDC (See note)		10 A at 250 VAC (See note)	
Rated carry current	12 A (See note)		8 A (70°C)/5 A (85°C) (See note)		16 A (See note)		10 A (See note)	
Max. switching voltage	440 VAC, 300 VDC							
Max. switching current	12 A		8 A		16 A		10 A	
Failure rate (P level) (reference value*)	40 mA at 24 VDC							

* This value was measured at a switching frequency of 120 operations/min.
Note: Contact your OMRON representative for the ratings on sealed models.

■Characteristics

Classification		Standard type		High-capacity type	High-sensitivity type
Item	Number of poles	1-pole	2-pole	1-pole	
Contact resistance *1		100 mΩ max.			
Operate (set) time		15 ms max.			
Release (reset) time		5 ms max.			
Insulation resistance *2		1,000 MΩ min.			
Dielectric strength	Between coil and contacts	5,000 VAC, 50/60 Hz for 1min			
	Between contacts of the same polarity	1,000 VAC, 50/60 Hz for 1min			
	Between contacts of different polarity	–	2,500 VAC, 50/60 Hz for 1min	–	
Impulse withstand voltage		10 kV (1.2 x 50 μs)			
Vibration resistance	Destruction	10 to 55 to 10 Hz, 0.75 mm single amplitude (1.5 mm double amplitude)			
	Malfunction	10 to 55 to 10 Hz, 0.75 mm single amplitude (1.5 mm double amplitude)			
Shock resistance	Destruction	1,000 m/s²			
	Malfunction	Energized: 100 m/s², De-energized: 100 m/s²			
Durability	Mechanical	20,000,000 operations (at 18,000 operations/hr)			
	Electrical *3 (resistive load)	G2RL-1(A): 50,000 operations at 250 VAC, 12 A 30,000 operations at 24 VDC, 12 A	G2RL-2(A): 30,000 operations at 250 VAC, 8 A 30,000 operations at 30 VDC, 8 A	G2RL-1(A)-E, G2RL-1A-E-ASI: 30,000 operations at 250 VAC, 16 A 30,000 operations at 24 VDC, 16 A G2RL-1A-E-CV: 50,000 operations at 250 VAC, 16 A at 105 C	G2RL-1(A)-H: 50,000 operations at 250 VAC, 10 A
Ambient operating temperature		-40°C to 85°C (with no icing or condensation) -40°C to 105°C (with no icing or condensation) by G2RL-1A-E-CV			
Ambient operating humidity		5% to 85% (with no icing or condensation)			
Weight		Approx. 12 g			

Note. Values in the above table are the initial values at 23 C.
*1. Measurement conditions: 5 VDC, 1 A, voltage drop method
*2. Measurement conditions: Measured at the same points as the dielectric strength using a 500 VDC ohmmeter.
*3. 1,800 operations per hour.

Full datasheet can be found here

11.2.11.1 TE Manual Service Disconnect Data

The high voltage disconnect is covered in Section 2.11.

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
- Shunt (no fuse) version available
- Voltage rating: 495 VDC (fused version) 1000 VDC (shunt version)
- 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

Full datasheet can be found here

11.2.11.2 Coroplast 50mm² Cable Data

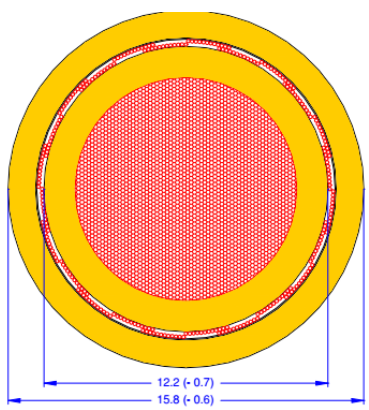
The Coroplast 50mm² is covered in Section 2.11.2 and Section 3.1.7. Also see Section 11.3.1.7.

Automotive Leitung geschirmt für elektrische Fahrzeugantriebe

FHLR2GCB2G
50 mm² / 0,21 T180 0,6/1,0 kV

Shielded cable for automotive electric powertrain

FHLR2GCB2G
50 mm² / 0.21 T180 0.6/1.0 kV



Electrical properties

Conductor resistance: (DC, 20°C)	*max. 0.368 mΩ/m* *max. 3.7 mΩ/m*	*50 mm²* *Shielding*
Test voltage:	*eff. 8.0 kVolt* *eff. 5.0 kVolt*	*spark test* *5 minutes*
Nominal voltage: (AC / DC)	*max. 600 / 1000 Volt*	
Capacitance:	*nom. 670 pF/m*	*core-screen*
Inductance:	*nom. 105 nH/m*	
Impedance:	*nom. 10 Ohm*	

Thermal properties

Operating temperature:	*-40 °C to +180 °C*
Short term ageing	*up to +205 °C*

Full datasheet may be found here.

11.2.12.2 RTDS Adafruit 3W Speakers specs

The RTDS speakers are covered in Section 2.12.2.

TECHNICAL DETAILS

- Weight: 25g per speaker
- Dimensions: 30mm x 70mm x 17mm / 1.2" x 2.8" x .7"
- Cable is 30" long total, 15" from each speaker to SPK plug
- 3.1mm diameter mounting holes
- 24mm x 64mm mounting rectangle

Product page here

11.3.1.2 Samsung INR18650-25R Technical Data

The Samsung INR18650-25R cells are covered in Section 3.1.2.

Type		Spec.	Typical INR18650-25R
Chemistry		NCA	NCA
Dimension (mm)	Diameter	18.33 ± 0.07	18.33 ± 0.07
	Height	64.85 ± 0.15	64.85 ± 0.15
Weight (g)		Max. 45.0	43.8
Initial IR (mΩ AC 1kHz)		≤ 18	13.20 ± 2
Initial IR (mΩ DC (10A-1A))		≤ 30	22.15 ± 2
Nominal Voltage (V)		3.6	3.64
Charge Method (100mA cut-off)		CC-CV (4.2±0.05V)	CC-CV (4.2±0.05V)
Charge Time	Standard (min), 0.5C	180min	134min
	Rapid (min), 4A	60min	55min
Charge Current	Standard current (A)	1.25	1.25
	Max. current (A)	4.0	4.0
Discharge	End voltage (V)	2.5	2.5
	Max. cont. current (A)	20	20
	Max. momentary pulse (A, <1sec)	100	100
Rated discharge Capacity	Standard (mAh) (0.2C)	2,500	2.560
	rated (mAh) (10A)	2,450	2.539

Full datasheet may be found here.

11.3.1.3 Energus Power Solutions Li8P25RT Technical Data

The Energus Power Solutions Li8P25RT is covered in Section 3.1.3 and Section 3.1.4.

Parameter	Comment	Min.	Typ.	Max.	Unit
Battery voltage	Allowed range	2.50	3.60	4.20	V
Battery capacity	20A discharge to 2.5 V	19.5	20.4	-	Ah
	20A discharge to 2.5 V	70.2	73.4	-	Wh
	200A discharge to 2.5 V	18.5	19.5	-	Ah
Fast charge current	Forced air cooling	-	-	40	A
	No cooling, in a pack	-	-	30	A
	10 sec. pulse, 50% SOC	-	-	240	A
Discharge current	Forced air cooling	-	-	240	A
	No cooling, in a pack	-	-	120	A
	10 sec. pulse, fuse limited	-	-	360	A
Initial internal impedance	1kHz after rated charge	-	2.7	3.0	mΩ
Internal fuse rating	Holding current	-	-	360	A
Working temperature	Discharge	-20	25	60	°C
	Charge	0	25	45	°C
Dimensions	±0.5 mm	-	39×69.5×87	-	mm
Weight	Without fasteners	-	0.427	0.429	kg

Full datasheet may be found here.

11.3.1.5 Orion Battery Management System Technical Data

The Orion BMS is covered in Section 3.1.5.

Specification Item	Min	Typ	Max	Units
Supply Voltage	8		16	Vdc
Supply Current—Active		250		mA
Supply Current—Sleep (Rev. D & E)				uA
Operating Temperature	-40		80	C
Sampling Rate for Current Sensor		8		mS
Sampling Rate for Cell Voltages		30	50	mS
Isolation Between Cell Taps and Chassis / 12v Supply	2.5			kVrms
Isolation Between Cells 36-37, 72-73, 108-109, & 144-145	2.5			kVrms
Digital Output Voltage (Open Drain)			30	V
Digital Output Sink Current (Rev. D & newer)			175	mA
Cell Voltage Measurement Range	0.5		5	V
Cell Voltage Measurement Error (over 1-5v range)			0.25	%
Cell Balancing Current			200	mA
Cell Current (Operating)		5		mA
Cell Current (Sleep)				
Thermistor Accuracy				C
Cell Voltage Reporting Resolution		1.5		mV

Full datasheet may be found here.

11.3.1.6 Q Series Panel Mound LED Accumulator Indicator Technical Data

The accumulator LED indicator is covered in Section 3.1.6.

Features

- 8mm panel mounting LED indicator
- 5mm colored diffused epoxy lens or 5mm water clear super bright LEDs
- Plated brass bezel finished in bright chrome, black chrome or satin grey and moulded polycarbonate rear body
- Prominent, recessed and flush bezel styles
- 2VDC – 220VAC
- (2.8 x 0.8) solder lug/faston terminals, pins or (200mm long) wire terminations (2.0 x 0.5) solder lug/faston terminals on tricolor versions
- IP67 sealing option (EN60529)
- Supplied with fixing nut and spring washer

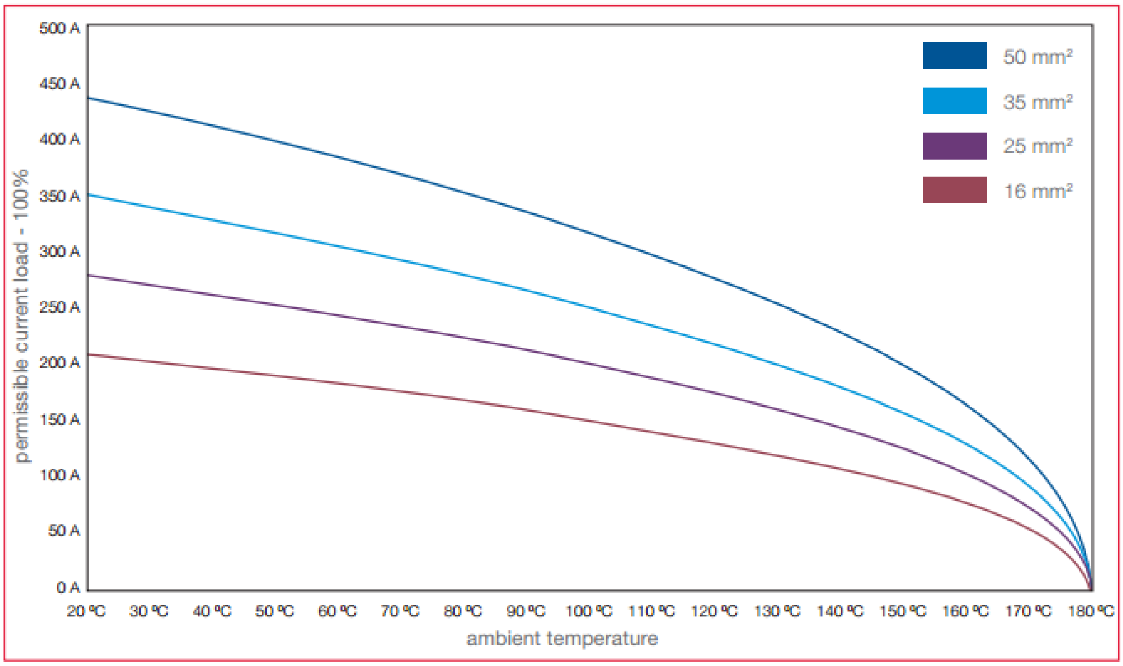
NB: UL Recognized Component

Full datasheet may be found here.

11.3.1.7 Coroplast High Voltage Wiring Technical Data

The Coroplast 50mm^2 and 16mm^2 cable is covered in Section 3.1.7 and Section 5.1.2. Also see Section 3.2.11.2.

Derating: Threshold value curves of screened copper high-voltage cables



Full datasheet may be found here.

11.3.1.7.2 TE Raychem 22 AWG Accumulator Low Voltage Wiring Technical Data

The Raychem 22 AWG low voltage wiring is covered in Section 3.1.7.2.

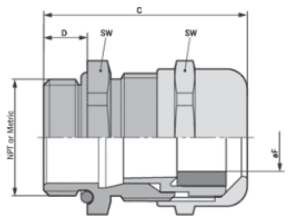
TABLE I. CONSTRUCTION DETAILS

PART NUMBER 1/	WIRE SIZE (AWG)	CONDUCTOR STRANDING (number x AWG)	DIAMETER OF STRANDED CONDUCTOR (in.)		FINISHED WIRE		
			MINIMUM	MAXIMUM	MAXIMUM RESISTANCE AT 20°C (ohms/1000 ft.)	DIAMETER (in.)	MAXIMUM WEIGHT (lbs/1000 ft.)
55A0111-30-*	30	7 x 38	.011	.013	108.4	.024 ± .002	.66
55A0111-28-*	28	7 x 36	.014	.016	68.6	.027 ± .002	.91
55A0111-26-*	26	19 x 38	.018	.020	41.3	.032 ± .002	1.4
55A0111-24-*	24	19 x 36	.023	.025	26.2	.037 ± .002	2.0
55A0111-22-*	22	19 x 34	.029	.031	16.2	.043 ± .002	2.8
55A0111-20-*	20	19 x 32	.037	.039	9.88	.050 ± .002	4.3
55A0111-18-*	18	19 x 30	.046	.049	6.23	.060 ± .002	6.5
55A0111-16-*	16	19 x 29	.052	.055	4.81	.068 ± .002	8.3
55A0111-14-*	14	19 x 27	.065	.069	3.06	.085 ± .003	13.0
55A0111-12-*	12	37 x 28	.084	.089	2.02	.103 ± .003	19.7
55A0111-10-*	10	37 x 26	.106	.113	1.26	.128 ± .006	31.8
55A0111- 8-*	8	133 x 29	.158	.173	.701	.188 ± .008	58.8

Full datasheet may be found here.

11.3.1.7.2 Lapp Skintop MS-M Brush M25 x 1.5 (P/N #53112676)

The Lapp Skintop MS-M Brush are covered in Section 3.1.7.2.



Part Number	Thread Type & Size	ØF Clamping Range (in)	ØF Clamping Range (mm)	SW Wrenching Flats (in)	C Overall Length (in)	D Thread Length (in)	Min Ø Above Braiding (in)	Standard Pack Size
SKINTOP® MS-NPT BRUSH								
53112037	NPT 3/4"	0.354 - 0.669	9 - 17	1.142	1.694	0.591	0.236	10
53112047	NPT 1"	0.433 - 0.827	11 - 21	1.418	1.891	0.591	0.315	1
53112057	NPT 1-1/4"	0.748 - 1.103	19 - 28	1.773	2.265	0.669	0.394	1
53112067	NPT 1-1/2"	1.063 - 1.379	27 - 35	2.127	2.323	0.669	0.551	0.1
53112077	NPT 2"	1.339 - 1.773	34 - 45	2.639	2.482	0.669	0.787	0.1
53112087	NPT 2", plus	1.733 - 2.167	44 - 55	2.955	2.836	0.669	0.984	0.1
SKINTOP® MS-M BRUSH								
53112676	M25 x 1.5	0.354 - 0.669	9 - 17	1.142	1.418	0.315	0.236	10
53112677	M32 x 1.5	0.433 - 0.827	11 - 21	1.418	1.663	0.354	0.315	1
53112678	M40 x 1.5	0.748 - 1.103	19 - 28	1.773	2.344	0.354	0.394	1
53112679	M50 x 1.5	1.063 - 1.379	27 - 35	2.127	2.049	0.394	0.551	1
53112680	M63 x 1.5	1.339 - 1.773	34 - 45	2.639	2.415	0.591	0.788	1
53112681	M63 x 1.5, plus	1.733 - 2.167	44 - 55	2.955	2.719	0.591	0.985	1
53112501	M75 x 1.5	2.088 - 2.482	53 - 63	3.743	4.137	0.591	1.379	1
53112500	M75 x 1.5, plus	2.285 - 2.679	58 - 68	3.743	4.137	0.591	1.379	1
53112503	M90 x 2.0	2.600 - 3.073	66 - 78	4.531	5.339	0.788	1.773	1
53112505	M110 x 2.0	2.994 - 3.467	76 - 88	5.319	6.068	0.985	2.167	1
53112504	M110 x 2.0, plus	3.388 - 3.861	86 - 98	5.319	6.068	0.985	2.167	1

Full datasheet may be found here.

11.3.1.8 TE EV200AAANA Accumulator Insulation Relay Technical Data

The accumulator isolation relays are covered in Section 3.1.8.

Performance Data

Parameter	Units	Value for EV200 Series
Contact Arrangement, power contacts		1 Form X (SPST-NO-DM)
Rated Operating Voltage	VDC	12 - 900
Continuous (Carry) Current, Typical *Consult Factory for required conductors for higher (500+ A) currents*	A	500 @ 85°C, 400 mcm conductors
Make/Break Current at Various Voltages [1]	A	See next page
Break Current at 320VDC [1]	A	2,000, 1 cycle [3]
Contact Resistance, Typ. (@200A)	mohms	0.2
Load Life	Cycles	See next page
Mechanical Life	Cycles	1 million
Contact Arrangement, auxiliary contacts		1 Form A (SPST-NO)
Aux. Contact Current, Max. Aux. Contact Current, Min.	A mA	2A @ 30VDC / 3A @ 125VAC 100mA @ 8V
Aux. Contact Resistance, Max.	ohms	0.417 @ 30VDC / .150 @ 125VAC
Operate Time @ 25°C Close (includes bounce), Typ. Bounce (after close only), Max. Release (includes arcing), Max @ 2000A	 ms ms ms	 15 7 12
Dielectric Withstanding Voltage	Vrms	2,200 @ sea level (leakage <1mA)
Insulation Resistance @ 500VDC	megohms	100 [2]
Shock, 11ms 1/2 sine, peak, operating	G	20
Vibration, sine, 80-2000Hz., peak	G	20
Operating Ambient Temperature	°C	-40 to +85
Weight, Nominal	lb.(kg)	.95 (.43)

[1] Main power contacts
[2] 50 at end of life
[3] Does not meet dielectric & IR after test, 1700 amp for unit with Aux. Contacts

Coil Operating Voltage (valid over temperature range)			
Voltage (will operate)	9-36VDC	32-95VDC	48-95VDC
Voltage (Max.)	36VDC	95VDC	95VDC
Pickup (close) Voltage Max.	9VDC	32VDC	48VDC
Hold Voltage (Min.)	7.5VDC	22VDC	34VDC
Dropout (open) Voltage (Min.)	6VDC	18VDC	27VDC
Inrush Current (Max.)	3.8A	1.3A	0.7A
Holding Current (Avg.)	0.13A@12V, 0.07A@24V	0.03A@48V	0.02A@72V
Inrush Time (Max.)	130ms	130ms	130ms

Part Numbering System

Typical Part Number EV200 A A A N A

Series:
EV200 = 500+ Amp, 12-900VDC Contactor

Contact Form:
A = Normally Open H = Normally Open with Aux. Contacts

Coil Voltage:
A = 9-36VDC (1 = requires external coil economizer)
D = 32-95VDC (2 = requires external coil economizer)
J = 48-95VDC (3 = requires external coil economizer)
R = 28VDC with Mechanical Economizer

Coil Wire Length:
A = 15.3 in (390 mm) B = 6.0 in (152 mm)

Coil Terminal Connector:
N = None
B = Yazaki 7282-5558-10 male, 7114-4102-02, 7158-3030-50 +red is pin 2 (B length only)
C = Molex Mini-fit Jr, 2 Ckt, Female 18-24, P/N 39-01-2020 & 39-00-0060 +red is pin 1 (A length only)

Mounting & Power Terminals:
A = Bottom Mount & Male 10mm x M8 Terminals

Full datasheet may be found here.

11.3.1.9 Eaton Bussman 170M3418 Main Tractive System Fuse Technical Data

The Bussman 170M3418 tractive system fuse is covered in Section 3.1.9.

Bussmann

Square Body – Flush End Contact

690V/700V (IEC/U.L.) 40-2000A

Electrical Characteristics					Ordering Information						Curves
Size	Rated Current RMS-Amps	I²t (A²S) Pre-arc	I²t (A²S) Clearing at 660V	Losses at Rated Current	-B/- Visual Indicator	-BKN/- Type K Indicator for Micro	-G/- Visual Indicator	-GKN/- Type K Indicator for Micro	Carton Qty.	Carton Weight (kg)	BIF #
1*	40	40	270	9	170M3408	170M3458	170M3508	170M3558			
	50	77	515	11	170M3409	170M3459	170M3509	170M3559	10		
	63	115	770	14	170M3410	170M3460	170M3510	170M3560	(-B/-)	2.40	
	80	185	1250	18	170M3411	170M3461	170M3511	170M3561			
	100	360	2450	21	170M3412	170M3462	170M3512	170M3562			
	125	550	3700	26	170M3413	170M3463	170M3513	170M3563	10		
	160	1100	7500	30	170M3414	170M3464	170M3514	170M3564	(-G/-)	2.40	
	200	2200	15000	35	170M3415	170M3465	170M3515	170M3565			
	250	4200	28500	40	170M3416	170M3466	170M3516	170M3566			17056314
	315	7000	46500	50	170M3417	170M3467	170M3517	170M3567	6		
	350	10000	68500	55	170M3418	170M3468	170M3518	170M3568	(-BKN/-)	1.62	
	400	15000	105000	60	170M3419	170M3469	170M3519	170M3569			
	450	21000	140000	65	170M3420	170M3470	170M3520	170M3570			
	500	27000	180000	70	170M3421	170M3471	170M3521	170M3571	6		
	550	34000	230000	75	170M3422	170M3472	170M3522	170M3572	(-GKN/-)	1.62	
	630	48500	325000	80	170M3423	170M3473	170M3523	170M3573			

Full datasheet may be found here.

11.3.1.9 Eaton Bussmann 160LET Motor Controller Fuse Technical Data

The Bussman 160LET motor controller fuses are covered in Section 3.1.9.

Electrical characteristics

Catalog numbers	Type	Rated current RMS-amps	I²t (A² sec) Pre-arc	I²t (A² sec) Clearing at 120V	I²t (A² sec) Clearing at 240V	Watts loss
6LCT	LCT	6	2	6	9	1.0
10LCT		10	3.8	12	22	2.5
12LCT		12	7	22	32	2.5
16LCT		16	20	50	100	2.5
20LCT		20	25	80	160	4.0
25LET	LET	25	18	120	250	4.0
32LET		32	32	200	450	5.0
35LET		35	50	320	600	5.0
50LET		50	100	500	1400	7.0
63LET		63	180	1100	2200	9.0
80LET		80	300	1900	3800	10.0
100LET		100	600	3800	7500	10.0
125LET		125	600	3800	7500	16.0
160LET		160	1100	7000	16000	20.0

Full datasheet may be found here.

11.3.1.10 ElCon PFC 5000 5kW 96V 44A Battery Charger Technical Data

The Elcon PFC 5000 charger is covered in Section 3.1.10.

Specifications

Spec Model	Output Voltage -Nominal	Output Voltage -Maximum	Output Current -Maximum 230vac	Output Current -Maximum 115vac
TCCH-48-80	48V	66V	80A	38A
TCCH-60-70	60V	82V	70A	30A
TCCH-72-56	72V	96V	56A	26A
TCCH-84-50	84V	112V	50A	22A
TCCH-96-44	96V	130V	44A	20A
TCCH-120-36	120V	168V	36A	15A
TCCH-144-30	144V	192V	30A	13A
TCCH-168-24	168V	233V	24A	12A
TCCH-216-20	216V	289V	20A	8A
TCCH-288-15	288V	389V	15A	7.5A
TCCH-312-14	312V	417V	14A	7A

Note: red = in stock, black = special order.

Technical Features

AC Input Voltage Range	AC85V~AC265V
AC Input Frequency	45~65 Hz
AC Power Factor	≥0.98
Full Load Efficiency	≥93
Mechanical Shock & Vibration Resistance Level	Conformance to SAEJ1378 Standard
EnvironmentalEnclosure	IP46
Operating Temperature	-40℃ +55℃
Storage Temperature	-40℃ +100℃
Mechanical Dimensions	365mm×352mm×139mm
Net Weight	13.80kg

Full datasheet may be found here.

11.5.1 Motor Controller Plettenberg MST-140-200 V2 Technical Data

The Plettenberg MST-140-200 V2 motor controller is covered in Section 5.1.

Over voltage protection: At over 140V input voltage the MST controller switches off. If the input voltage rises over 150V the controller can be damaged.

Under voltage protection: Below 30V input voltage the MST controller switches of to protect the internal power supply voltages.

Motor temperature protection: If the motor temperature is exceed the motor temperature limit the MST controller switches off to protect the motor.

Controller temperature protection: If the controller temperature is exceed the controller temperature limit the MST controller switches off to protect the motor.

High pedal protection: To avoid that the controller went to full throttle in case the minus wire to the throttle potentiometer is broken, the MST controller switches off, if the voltage at the analog input exceed 4.95V for safety.

Sensor error: If the positions sensors gives faulty signals the MST controller switches oft o protect the motor and the controller.

Protection class: IP53

Maximum Speed: 240000rpm electrical

Maximum continuous power 30kW

Maximum short term power 39kW

Battery voltage range 36V to 122V nominal
Permissible supply voltage 30 to 140V

Maximum current 280A / 220A continuous current (at 25 ° C ambient temperature)
At 50 ° C ambient temperature, the continuous current is 180A.
At 75 ° C ambient temperature, the continuous current is 125A.
The continuous current data refer to standard atmosphere (1013 mbar 25 ° C) and vertically aligned fins (eg control lies with the base plate horizontally with the ribs upwards on the table).

By forced cooling (forced ventilation with a fan or air flow), the allowable continuous current can be increased.

Full datasheet may be found here.

11.5.1.2 Panduit Two Stud Ring Terminals Inline Phase Connectors

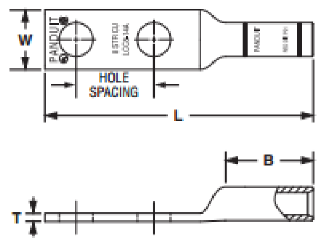
The terminals used for inline phase connections are covered in Section 5.1.2.

Code Conductor, Two-Hole, Long Barrel Lug

For Use with Stranded Copper Conductors

Type LCC

- Long barrel maximizes number of crimps and provides premium wire pull-out strength and electrical performance
- Color-coded barrels marked with Panduit and specified competitor die index numbers for proper crimp die selection
- Enclosed barrel prevents corrosive material from entering barrel when used in harsh environments
- Tin-plated to inhibit corrosion
- UL Listed and CSA Certified to 35 KV** and temperature rated to 90°C when crimped with Panduit and specified competitor crimping tools and dies
- UL Listed and CSA Certified for wide wire range-taking capability when crimped with Panduit® Uni-Die™ Dieless Crimping Tools‡
- **Tested by Telcordia – meets NEBS Level 3**
- American Bureau of Shipping approved
- Available with NEMA hole sizes and spacing



[Full datasheet may be found here.]

11.6.1 Plettenberg Nova 30 Technical Data

The Plettenberg Nova 30 is covered in [Section 6.1].

[Full datasheet may be found here.]

11.6.2 Plettenberg Nova 15 Technical Data

The Plettenberg Nova 15 is covered in [Section 6.2].

[Full datasheet may be found here.]

11.7.1 Torque Encoder Technical Data

The RP-100 twin accelerator pedal position sensor is covered in [Section 7.1].

Application

Application	0 to 100°
Operating temperature range	-40 to 150°C
Max. vibration	200 m/s² at 5 to 2,000 Hz

Technical Specifications

Mechanical Data

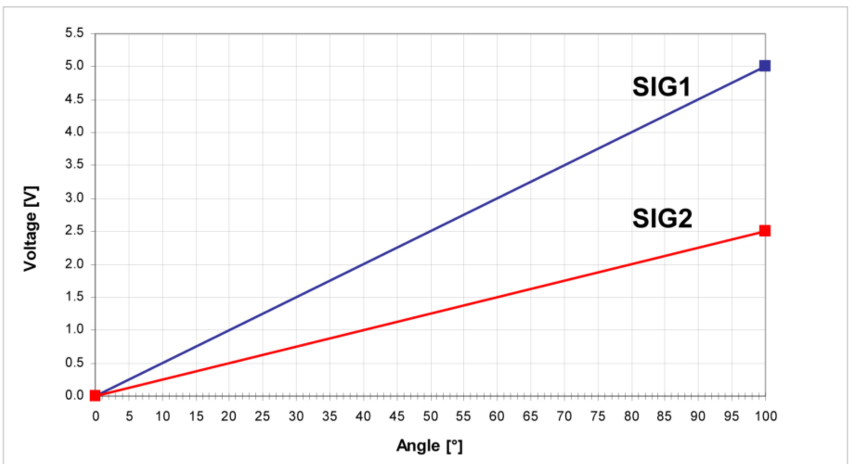
Weight w/o wire	32 g
Protection class	IP65
Mounting	2 x M4
Lifetime	50 x 10^6 rotations
Housing	Synthetic material

Electrical Data

Power supply U_S	5 V
Max. power supply	42 V
Total resistance	3 kΩ ±20 %
Current IS	1 µA
Max. allowable contact current	10 mA

Characteristic

Max. rotation speed	120 min-1
Temp. coefficient	5 ppm/°K
Direction of rotation	Clockwise
Both rotation directions are available on request	
Redundancy	



[Full datasheet may be found here.]

11.7.2.1 Brake Encoder Technical Data

The brake encoder is covered in Section 2.4.1 and Section 7.2.1.

Ambient Temperature: 25°C (unless otherwise specified)

PARAMETERS	MIN	TYP	MAX	UNITS	NOTES
Accuracy (combined non linearity, hysteresis, and repeatability)	-0.15	±0.1	0.15	%Span	FS<1kpsi @25°C
	-0.25	±0.2	0.25	%Span	FS≥1kpsi @25°C
Span Tolerance	-1.0	±0.5	1.0	%Span	@25°C
Zero Offset	-1.0	±0.5	1.0	%Span	@25°C
Temperature Error – Span	-1.5	±0.75	1.5	%Span	
Temperature Error – Offset	-1.5	±0.75	1.5	%Span	
Thermal Hysteresis – Span		±0.05		%Span	
Thermal Hysteresis – Offset		±0.05		%Span	
Long Term Stability – Span		±0.10		%Span/year	
Long Term Stability – Offset		±0.10		%Span/year	
Insulation Resistance (50Vdc)	50			MΩ	
Response Time	1		1	Ms	
Proof Pressure			3X	Rated	
Burst Pressure			4X	Rated	
Compensated Temperature	-20		+85	°C	Except cable -20~80°C
Operating Temperature	-40		+105	°C	Except cable -20~80°C
Storage Temperature	-40		+125	°C	Except cable -20~80°C
Media Compatibility	Liquids and gases compatible with 316/316L Stainless Steel				
Vibration	±20g MIL-STD-810C, Procedure 514.2, Figure 514-2, Curve L				
Shock (11ms)	100g 11mS				
Pressure Cycles (Zero to Full Scale)	1 million cycles 0 to full scale				
Environmental Protection	IP67 (Cable Version)				

Full datasheet may be found here.

11.8.1 PCM-112 Electronic Control Unit Technical Data

The PCM-112 ECU is covered in Section 8.1.

Environmental Capabilities

The following is a summary list of the environmental limits used for ECM design validation.

Operating Voltage	9–16 V (dc)
Minimum Cranking Voltage	4.5 V
Operating Temperature	(–40 to +85) °C (105 °C capable)
Storage Temperature	(–40 to +125) °C
Mechanical Vibration	3.53 Grms for 250 hours
Mechanical Shock	50 g, 11 ms, half-sine wave, 4 shocks in each direction (24 total shocks)
Ingress Protection	IP67 & IP69K (equivalent)
EMI/RFI Specification	SAE J1113-41 (Radiated & Conducted Emissions) SAE J1113-13 (ESD) SAE J1113-21 (Radiated RF Immunity) SAE J1113-11 (Transient Testing)

Full datasheet may be found here.

11.8.2 Low Voltage Battery Technical Data

The low voltage battery is covered in Section 8.2.

Full datasheet may be found here.

11.8.3 DC-DC Converter Technical Data

The DC-DC converter is covered in Section 2.7.1 and Section 8.3.

MODULE INPUT SPECIFICATIONS

Parameter	Min	Typ	Max	Unit	Notes
Operating input voltage	66	110	154	V_{DC}	Per EN50155 and GBT-25119
Input surge withstand			250	V_{DC}	<100ms
Undervoltage turn-on		64	65.4	V_{DC}	
Undervoltage turn-off	54	56		V_{DC}	
Overvoltage turn-off/on	155.5	161.7	169.4	V_{DC}	
Disabled input current			1.3	mA	PC pin low

MODULE OUTPUT SPECIFICATIONS

Parameter	Min	Typ	Max	Unit	Notes
Output voltage setpoint			±1	%	Of nominal output voltage. Nominal input; full load; 25°C
Line regulation		±0.02	±0.20	%	Low line to high line; full load
Temperature regulation		±0.002	±0.005	% / °C	Over operating temperature range
Power sharing accuracy		±2	±5	%	10 to 100% of full load
Programming range	10		110	%	Of nominal output voltage. For trimming below 90% of nominal, a minimum load of 10% of maximum rated power may be required.

$12V_{OUT}$, 400W (e.g. S110A12C400BL, V110A12C400BL)

Parameter	Min	Typ	Max	Unit	Notes
Efficiency					
S110A12C400BL (enhanced efficiency)	86.7	88.5		%	Nominal input; full load; 25°C
V110A12C400BL (standard efficiency)	85.0	86.2			
Ripple and noise		240	300	mV	p-p; Nominal input; full load; 20MHz bandwidth
Output OVP setpoint	13.7	14.3	14.9	Volts	25°C; recycle input voltage or PC to restart (>100ms off)
Dissipation, standby		12.7	13.5	Watts	No load
Load regulation		±0.02	±0.2	%	No load to full load; nominal input
Load current	0		33.33	Amps	
Current limit	33.9	38.3	45	Amps	Output voltage 95% of nominal
Short circuit current	23.3	38.3	45	Amps	Output voltage <250mV

Full datasheet may be found here.

11.10.1 Firewall Material Technical Data

The firewall is covered in Section 10.1.

DUPONT™ NOMEX® PAPER TYPE 410

DuPont™ Nomex® paper Type 410 is an insulation paper which offers high inherent dielectric strength, mechanical toughness, flexibility and resilience. Nomex® paper Type 410 is the original form of Nomex® paper, and is widely used in a majority of electrical equipment applications. Available in 11 thicknesses (0.05 to 0.76 mm) (2 to 30 mil), Nomex® paper Type 410 is used in almost every known electrical sheet insulation application.

Electrical Properties

The typical electrical property values for Nomex® paper Type 410 are shown in Table 1. The AC Rapid Rise dielectric strength data of Table 1, representing voltage stress levels, withstood 10 to 20 seconds at a frequency of 60 Hz. These values differ from long-term strength potential. DuPont recommends that continuous stresses in transformers not exceed 1.6 kV/mm (40 V/mil) to help minimize the risk of partial discharges (corona). The full wave impulse dielectric strength data shown in Table 1 are based on multiple sheets. These values are appropriate for the applications which employ these materials in such configurations. Data based on single sheets of material are available upon request.

The geometry of the system has an effect on the actual impulse strength values of the material. The dielectric strength data are typical values and not recommended for design purposes. Design values can be supplied upon request.

Table 1— Typical Electrical Properties

Nominal Thickness (mil) (mm)	2 0.05	3 0.08	4 0.10	5 0.13	7 0.18	10 0.25	12 0.30	15 0.38	20 0.51	24 0.61	29 0.73	30 0.76
Dielectric strength AC rapid rise[1] (V/mil) (kV/mm)	460 18	565 22	527 21	715 28	865 34	845 33	870 34	850 33	810 32	810 32	760 30	680 27
Full wave impulse[2] (V/mil) (kV/mm)	1000 39	1000 39	864 34	1400 55	1400 55	1600 63	N/A N/A	1400 55	1400 55	N/A N/A	N/A N/A	1250 49
Dielectric Constant[3] at 60 Hz	1.6	1.6	1.8	2.4	2.7	2.7	2.9	3.2	3.4	3.7	3.7	3.7
Dissipation Factor[3] at 60 Hz (x 10^{-3})	4	5	6	6	6	6	7	7	7	7	7	7

[1] ASTM D-149 using 50 mm (2 inches) electrodes, rapid rise; corresponds with IEC 60243-1 subclause 9.1 except for electrode set-up of 50 mm (2 inches)
[2] ASTM D-3426
[3] ASTM D-150

Full datasheet can be found here.