# Electrical System Form FSAE-E2015

The University of Akron

Akron Electric

Car E217

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# III List of Abbreviations

- HV: High Voltage
- GLVS: Grounded Low Voltage System
- BMS: Battery Management System
- BMM: Battery Management System Master
- BMSS: Battery Management System Slave (S)
- SAS: Sensor Acquision System
- MCS: Motor Controller System
- SS: Safety System
- DDS: Dasboard Display System

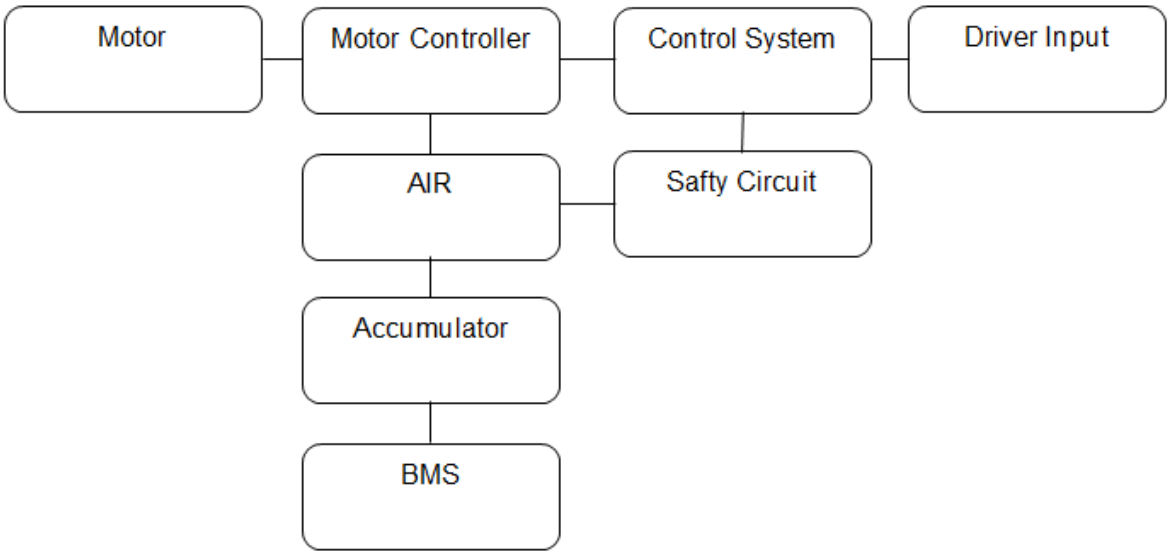
# 1 System Overview

The University of Akron's electrical system concept splits the electrical system into the Tractive HV system, and the GLV control system. The tractive system includes the motors, motor controllers, batteries, AIR's, main fuse, and part of the BMS. The GLV control system includes the control section of the BMS, sensors.

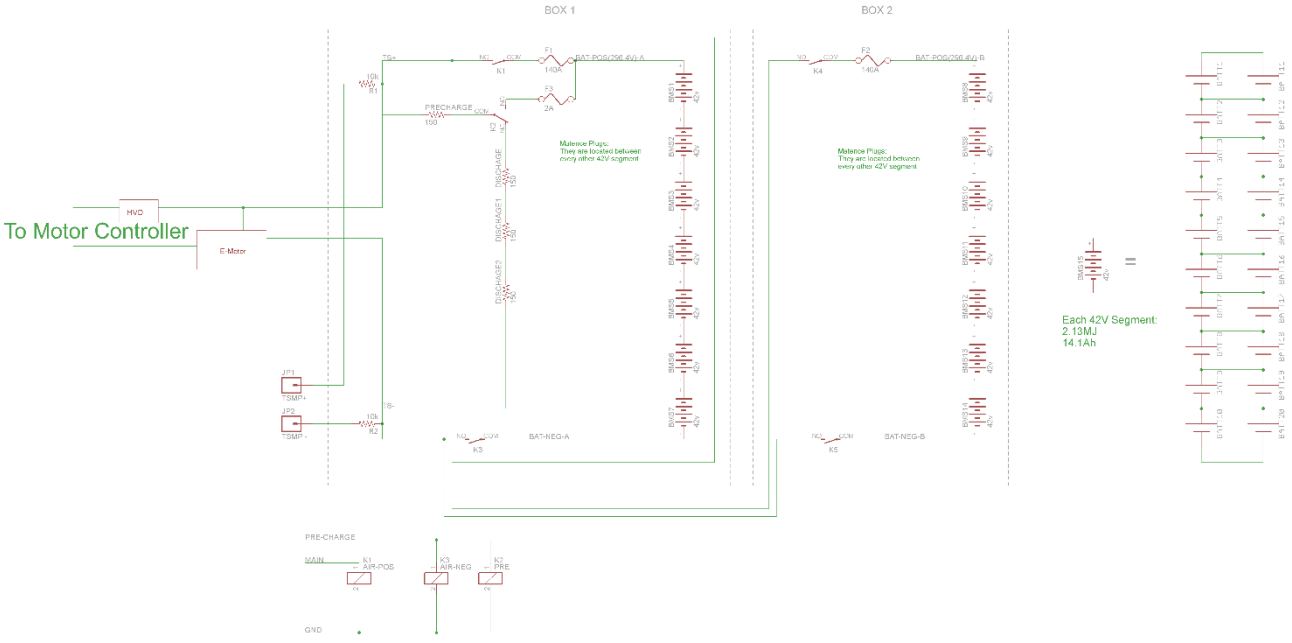
The vehicle is a single motor, rear wheel drive electric car. The motor is a79kW peak output power with a 3.5:1 gear ratio and a mechanical differential. Traction control is required to keep wheel slip to a minimum. The accumulator system consists of 280LiPo battery cells. They are connected in two accumulators that holds two 70 series sets.

| | |
|---|---|
| Maximum Tractive-system voltage: | 294VDC |
| Nominal Tractive-system voltage: | 231VDC |
| Control-system voltage: | 24VDC |
| Accumulator configuration: | 70s4p |
| Total Accumulator capacity: | 28.2Ah6.46 kWatt-hours; 29.68MJ |
| Motor type: | Permanent Magnet Brushless AC |
| Number of motors: | One |
| Maximum combined motor power in kW | 79kW |

*Table 1.1 General parameters*




University of Akron 2015 Battery Layout



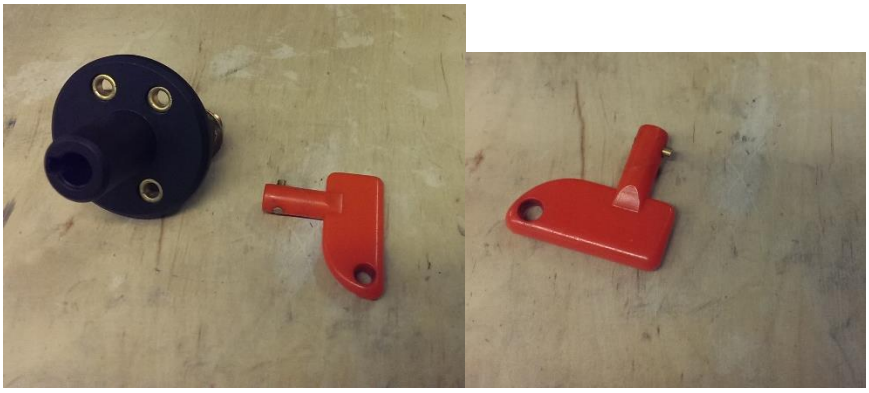
# 2 Electrical Systems

## 2.1 Shutdown Circuit

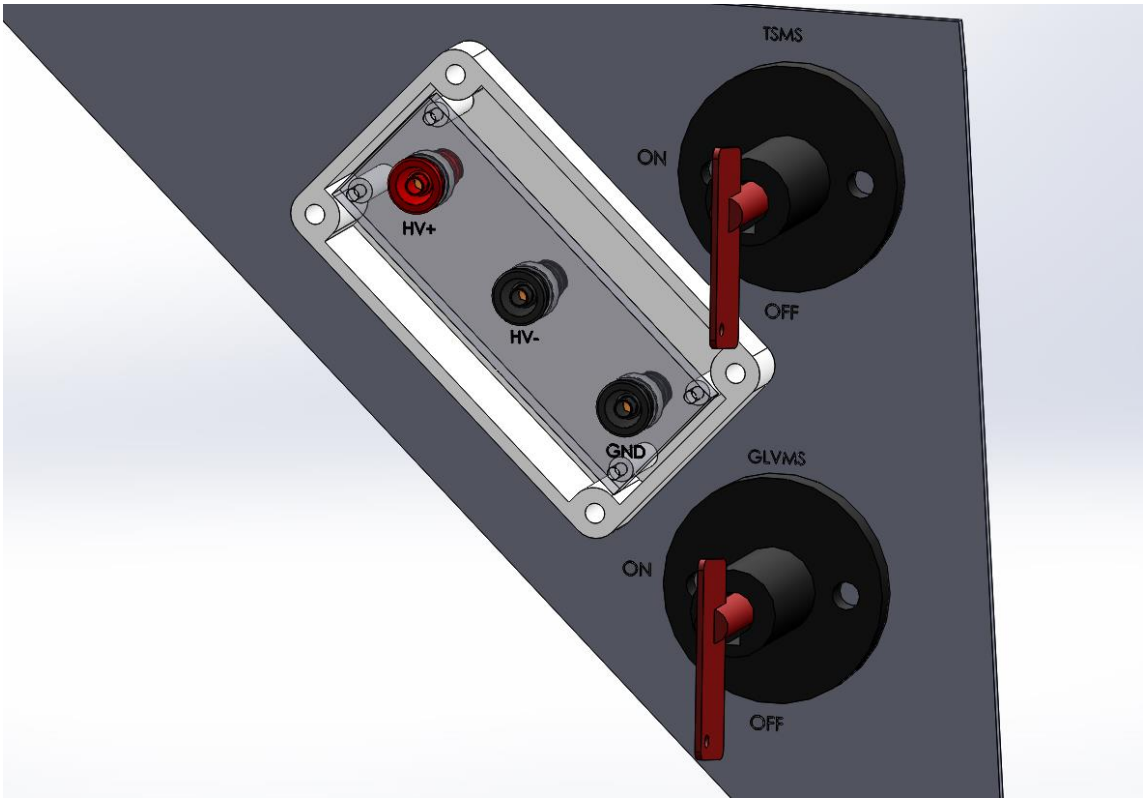
### 2.1.1 Description/concept

The shutdown circuit carries the current to open or close the Accumulator Isolation Relays, providing several methods for shutting down the high voltage parts of the car in emergencies. All the emergency switches are connected in series so if one switch opens, the power is removed to the AIR's. The safety system gets its power from the GLVMS. The power supplied to the GLVMS is from our custom battery pack. The power after the GLVMS flows through the E-Stops and then to the safety circuits. These are controlled by digital hardware monitoring IMD, Brake pressure, current, and BMS issues. The ECU relay is to stop the car from precharging until the start button is hit and brake pedal is depressed. We do this to add hardware and software lockouts. The safety system faults that are AMS, IMD, or BSPD are only cleared with a car power down. That would require driver to have access to GLVMS and they do not. The shutdown system also examines where the fault is to alert the team what faulted. (10.14 E-Stop datasheet)

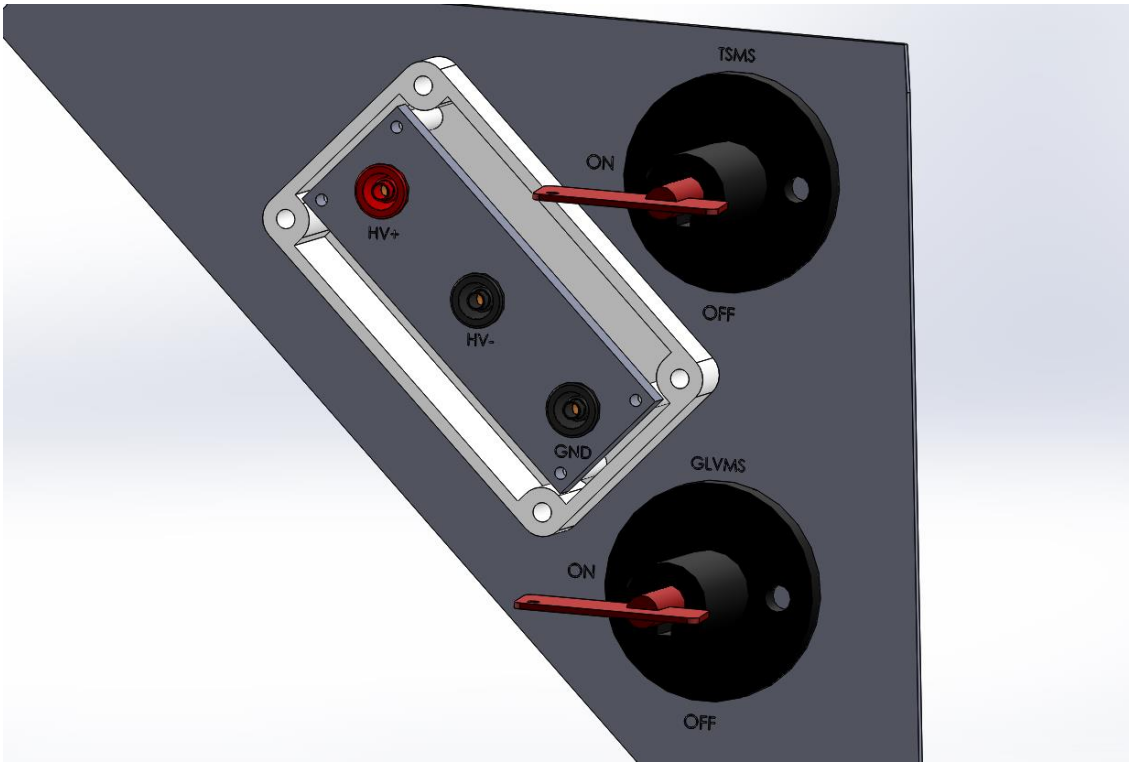
We are able to perform lockout at the TSMS by removing the red key. The safety officer keeps the one key on themselves. This prevents the car from being energized when in an unsafe condition. The key is unique enough that it would be hard to activate without it. This is demonstrated bellow:



TSMS and GLVMS in the OFF position:



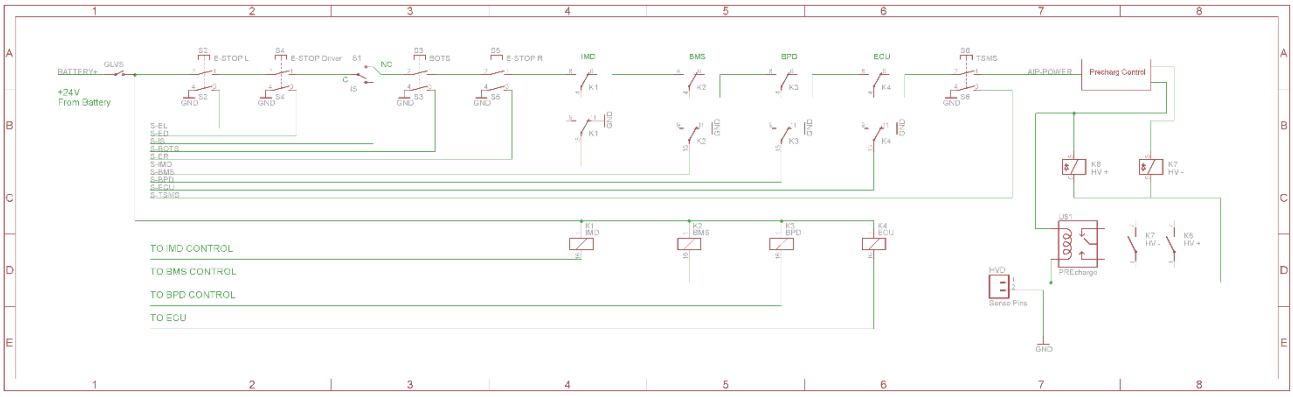

TSMS and GLVMS in the ON position:


TSMS
ON
OFF
HV+
HV-
GND
GLVMS
ON
OFF

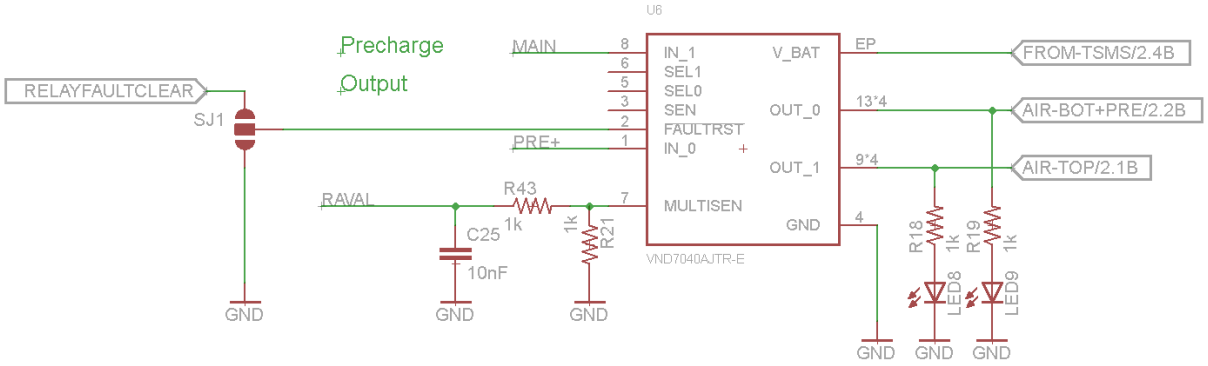
| Part | Function |
|---|---|
| Main Switch (for control and tractive-system; CSMS, TSMS) | Normally open |
| Brake over travel switch (BOTS) | Normally closed |
| Shutdown buttons (SDB) | Normally closed |
| Insulation Monitoring Device (IMD) | Normally closed |
| Battery Management System (BMS) | Normally closed |
| Inertia Switch | Normally closed |
| Interlocks | Closed when circuits are connected |
| Brake System Plausibility Device | Normally Closed |
| Software system (ECU) | Normally Closed |

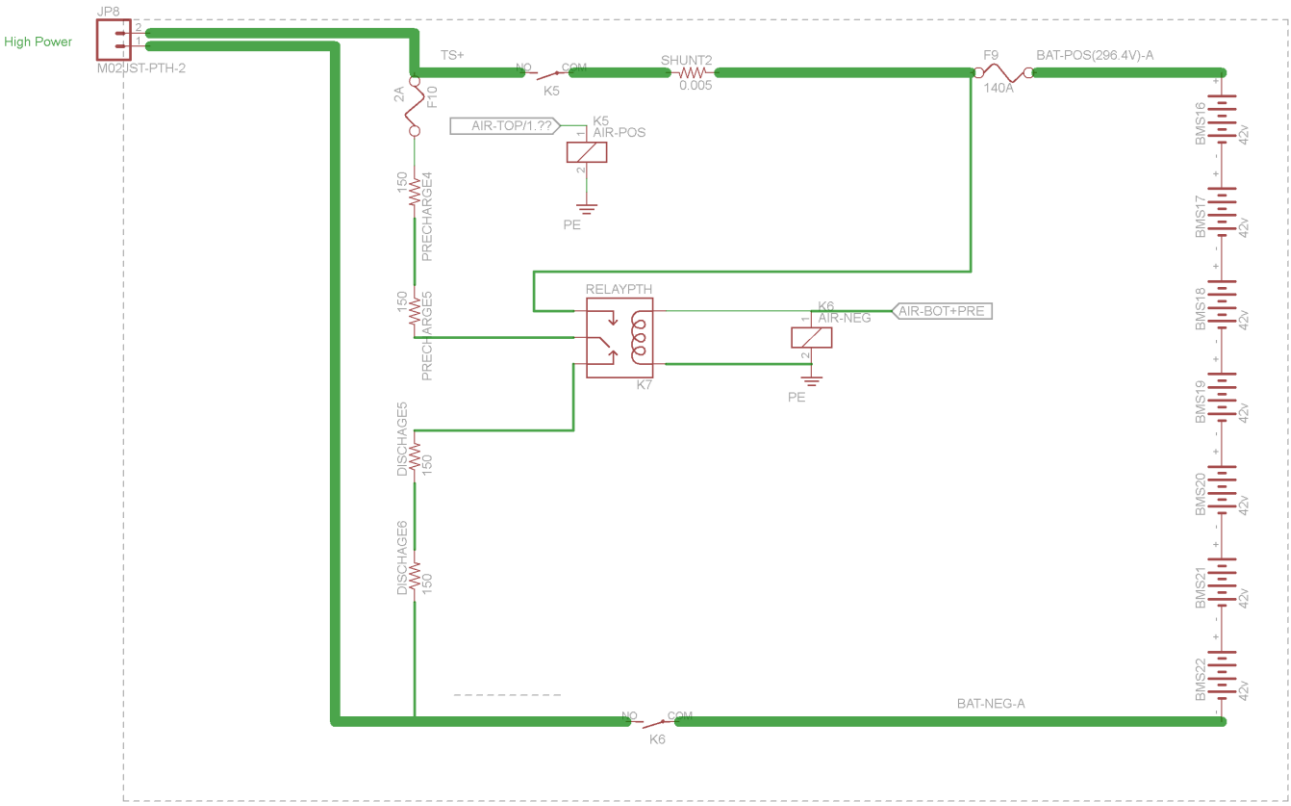
*Table 2.1 List of switches in the shutdown circuit*

### 2.1.2 Wiring / additional circuitry



# Relay Control



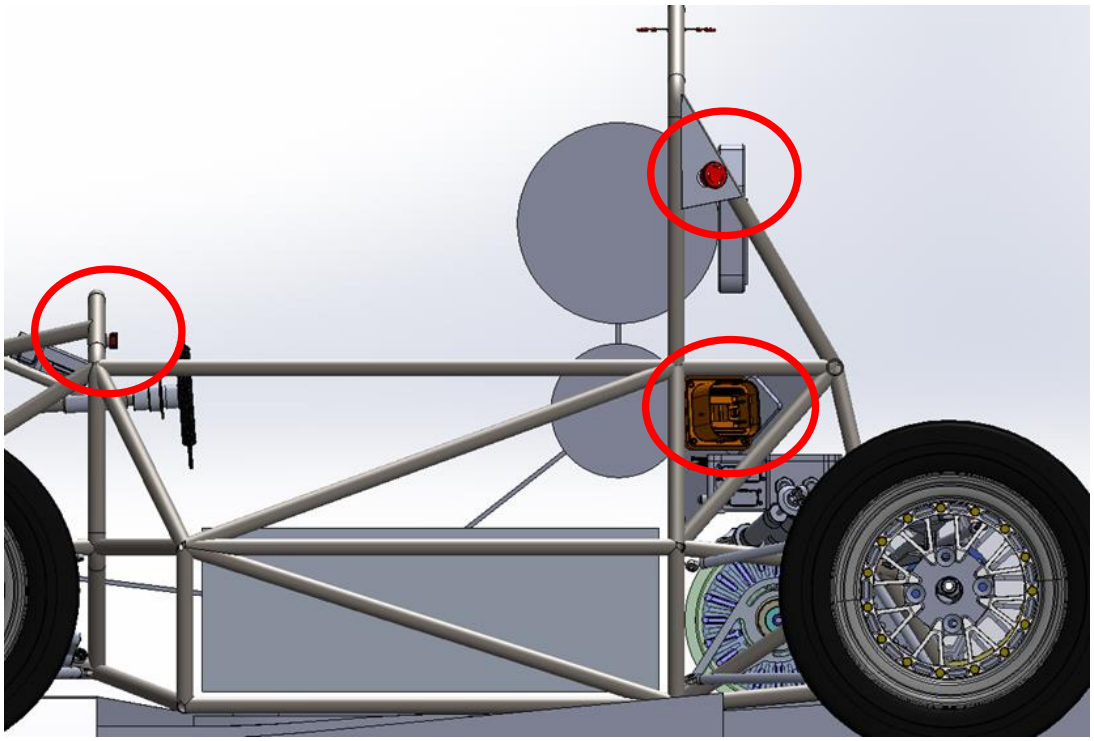



| | |
|---|---|
| Total Number of AIRs: | 4 |
| Current per AIR: | 0.25A |
| Additional parts consumption within the shutdown circuit: | 1A |
| Total current: | 2A |
| Cross sectional area of the wiring used: | 2.1mm² |

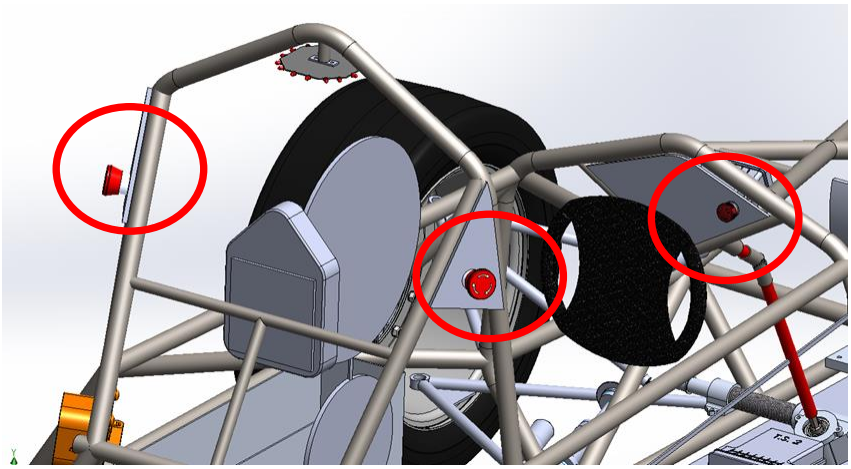
*Table 2.2 Wiring – Shutdown circuit*

### 2.1.3 Position in car

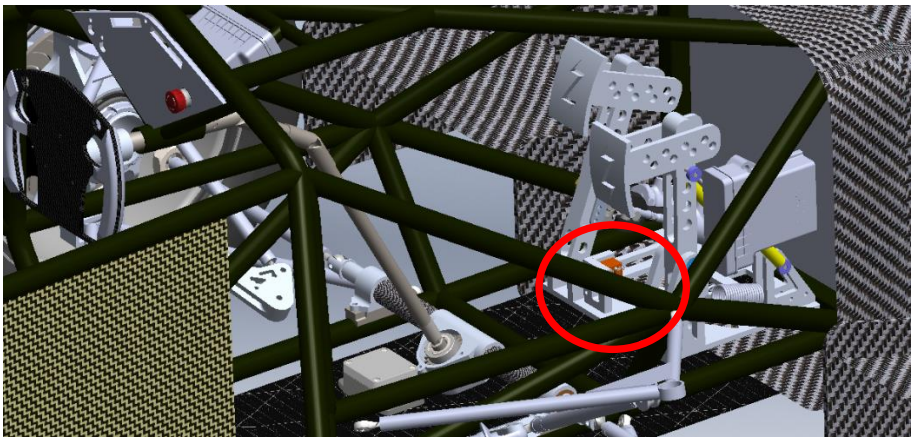
Disconnect, driver e-stop, and left e-stop:



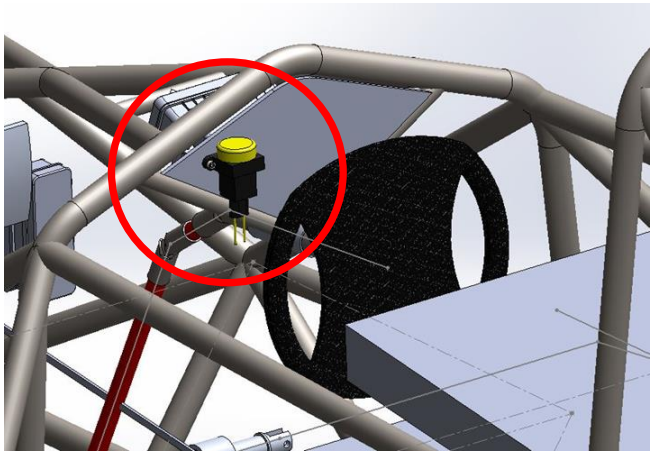
Driver e-stop, right e-stop and left e-stop:



BOTS:



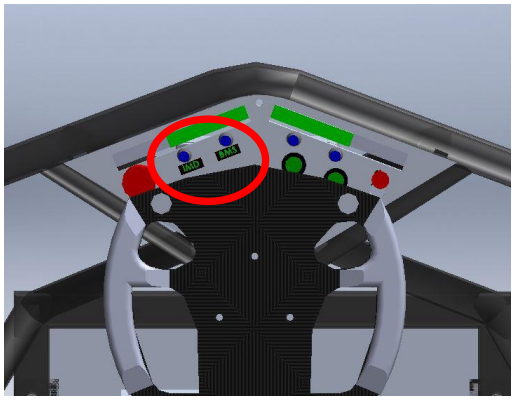
IS:



## 2.2 IMD

### 2.2.1 Description (type, operation parameters)

Bender A-Isometer IR-155-3203, Automatic Device Self-test and Continuous measurement of insulation resistance. The indicator is wired to the front dash. The LED is lit by software cue from the safety system (SS) to the Dashboard Display System DDS controller warning the driver. The system is not able to be reset unless there is a GLVMS power cycle.



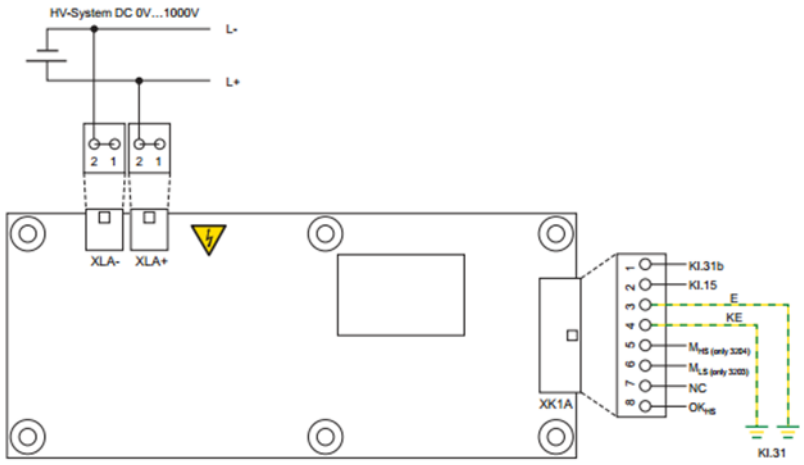

| | |
|---|---|
| Supply voltage range: | 10..36VDC |
| Supply voltage | 24VDC |
| Environmental temperature range: | -40..105°C |
| Selftest interval: | Always at startup, then every 20 minutes |
| High voltage range: | DC 0..1000V |
| Set response value: | 300kΩ (500Ω/Volt) |
| Max. operation current: | 500mA |
| Approximate time to shut down at 50% of the response value: | 27s |

*Table 2.3 Parameters of the IMD*

### 2.2.2 Wiring/cables/connectors

The IMD requires 24 Gauge PVC wire with a 300v and 105C rating.

**Wiring diagrams**




**Connector XLA+**

| | | |
|---|---|---|
| Pin 1+2 | L+ | Line voltage |

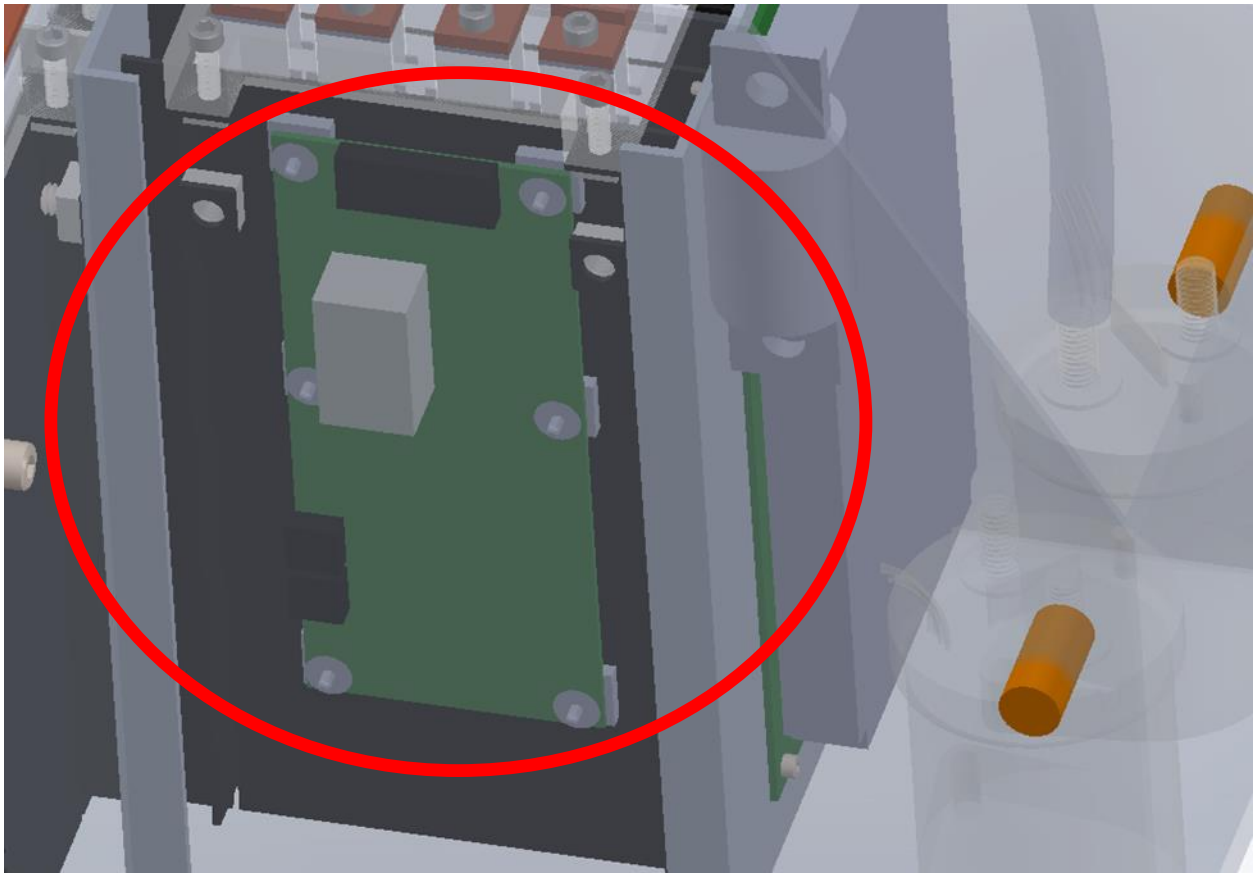
**Connector XLA-**

| | | |
|---|---|---|
| Pin 1+2 | L- | Line voltage |

**Connector XK1A**

| | | |
|---|---|---|
| Pin 1 | Kl. 31b | Electronic ground |
| Pin 2 | Kl. 15 | Supply voltage |
| Pin 3 | Kl. 31 | Chassis ground |
| Pin 4 | Kl. 31 | Chassis ground (sep. line) |
| Pin 5 | $M_{HS}$ | Data Out, PWM (high side) |
| Pin 6 | $M_{LS}$ | Data Out, PWM (low side) |
| Pin 7 | n.c. | |
| Pin 8 | $OK_{HS}$ | Status Output (high side) |

### 2.2.3 Position in car



## 2.3 Inertia Switch

### 2.3.1 Description (type, operation parameters)

The inertia switch will be normally closed and will open to shut down the tractive system in the event of a crash. This is hooked up in series with the other safety switches that control the AIR's so if it went off the tractive system would become unpowered. The driver will have the ability to depress the Sensata crash sensor to reset it. The crash sensor is removable off the dashboard with two screws and an electrical connector to test the device at competition. 10.5 Datasheet

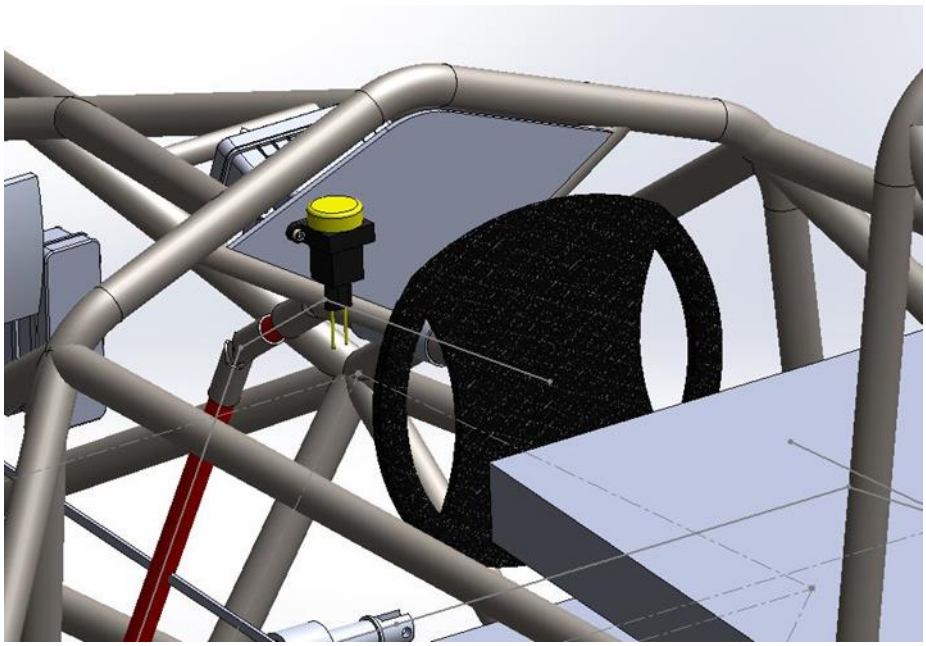
| | |
|---|---|
| Inertia Switch type: | Sensata Resettable crash sensor |
| Supply voltage range: | 10..36VDC |
| Supply voltage: | 24VDC |
| Environmental temperature range: | -40..105°C |
| Max. operation current: | 10A |
| Trigger characteristics: | 6g for 50ms / 11g for 15ms |

*Table 2.4 Parameters of the Inertia Switch*

### 2.3.2 Wiring/cables/connectors/

The crash sensor will be rigidly mounted to the frame of the car near the bottom to ensure that it receives the full force of any vibration or impact using a mating connector and 18 AWG, PVC, 105 C, 300v wire will be used for the electrical connections.

### 2.3.3 Position in car



## 2.4 Brake Plausibility Device

### 2.4.1 Description/additional circuitry

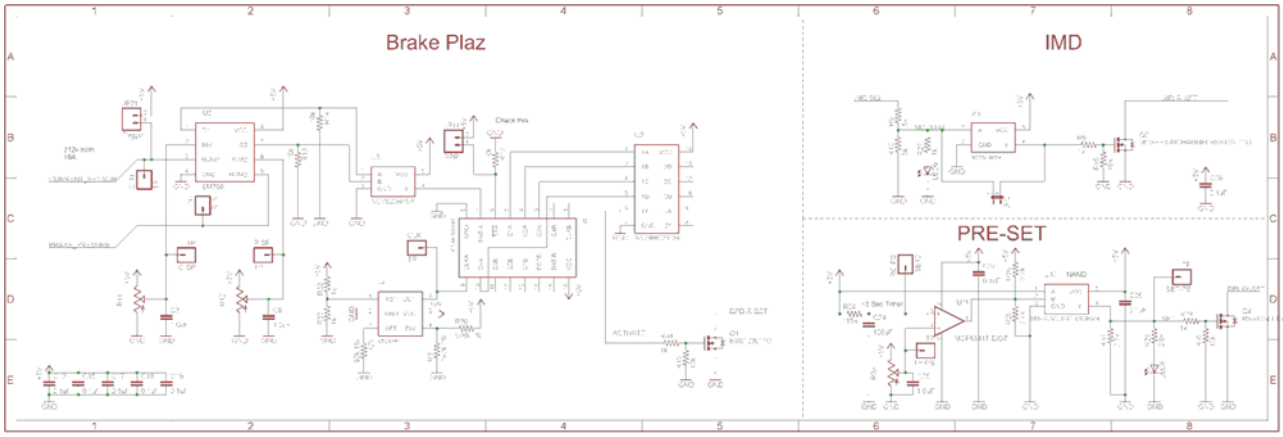
The purpose of the brake plausibility system is to ensure that the brake pedal does not pass a certain threshold if the motors are being driven. It will work by using brake pressure on the brake pedal to measure braking and a current sensor on the connection between the accumulator and motor controllers to measure the current. These measured values will be compared to pre-calculated constant threshold values. The current set point is at 16.6A. To reset this system, it requires a GLVMS power cycle.

| | |
|---|---|
| Brake sensor used: | PX2AF1XX500PAAAX |
| Torque encoder (current sensor) used: | MLX91205 |
| Supply voltages: | 5V |
| Maximum supply currents: | 20mA |
| Operating temperature: | -40..100 °C |
| Output used to control AIRs: | Open a relay |

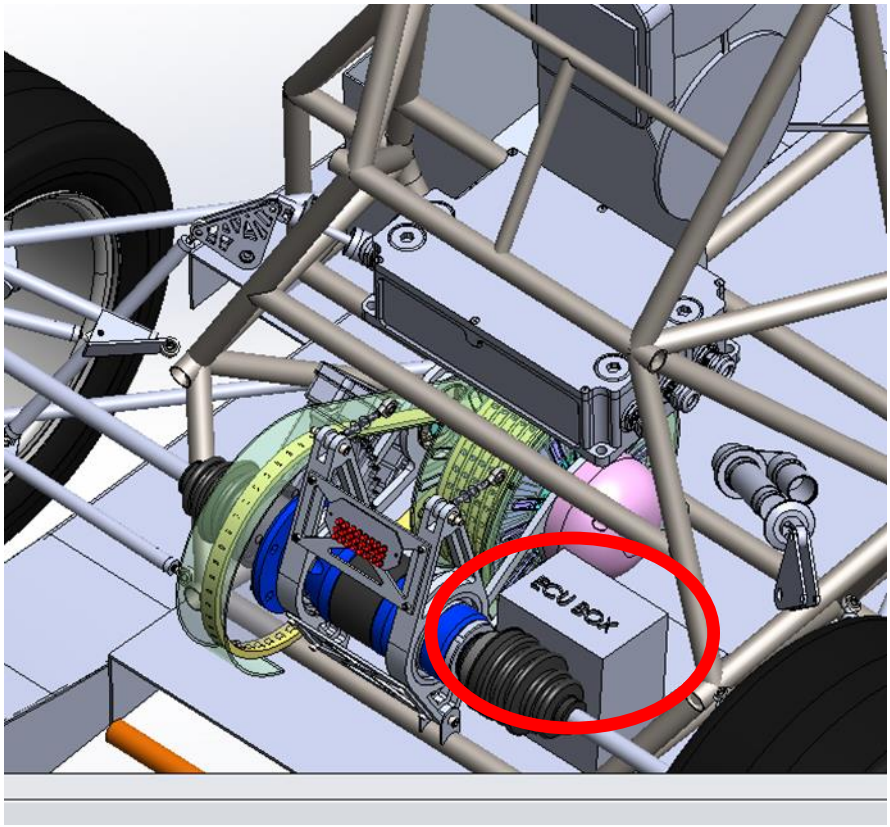
*Table 2.5 Torque encoder data*

### 2.4.2 Wiring

The brake plausibility system takes a 9V power input from the LV power system, along with 0-5Vdigital sensor input from the brake pedal sensor and the current sensor on the motor supply. The only output is the on or off 24v relay power that goes to the shutdown circuit. The reset of this system is done by power cycling the GLVS or hitting the reset button. The TSAL uses 24 Gauge PVC wire with a 300v and 105C rating.  10.16 datasheet



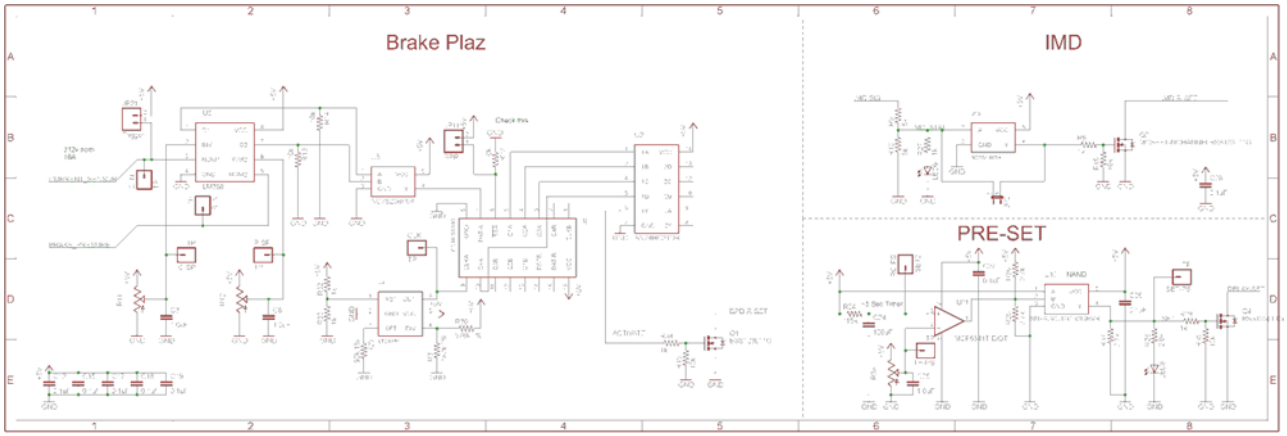

### 2.4.3 Position in car/mechanical fastening/mechanical connection



## 2.5 Reset / Latching for IMD and BMS

### 2.5.1 Description/circuitry

If the IMD or BMS becomes tripped, the latching relays will open. A GLVS power cycle will reset these systems or pushing the reset button. The latching relays are set by the PRE-SET circuit. Below is the IMD hardware Safety System. The BMS is done in software but is only reset (turned on) during startup.

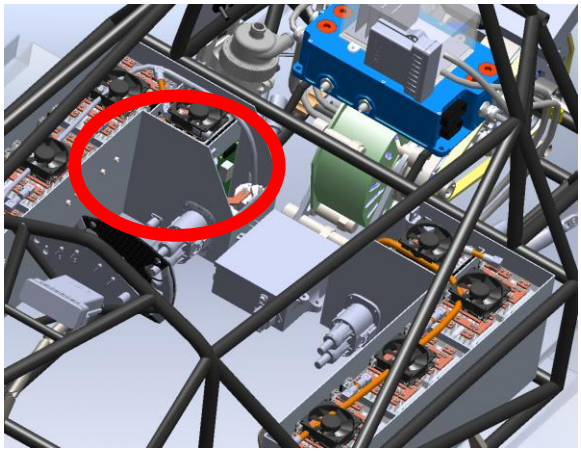



### 2.5.2 Wiring/cables/connectors

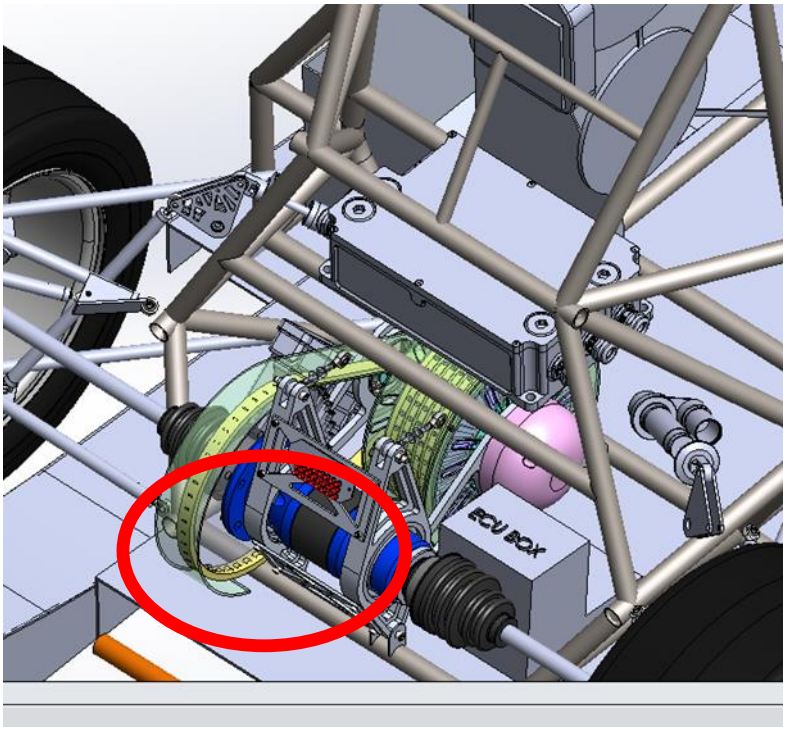
The BMS and IMD relay is wired into the shutdown system in series with other safety systems. This is wired with The TSAL uses 24 Gauge PVC wire with a 300v and 105C rating. The BMS has a relay on the PCB that it can trip to open the shutdown circuit. 10.16 wire datasheet

### 2.5.3 Position in car

IMD:



Control circuitry:



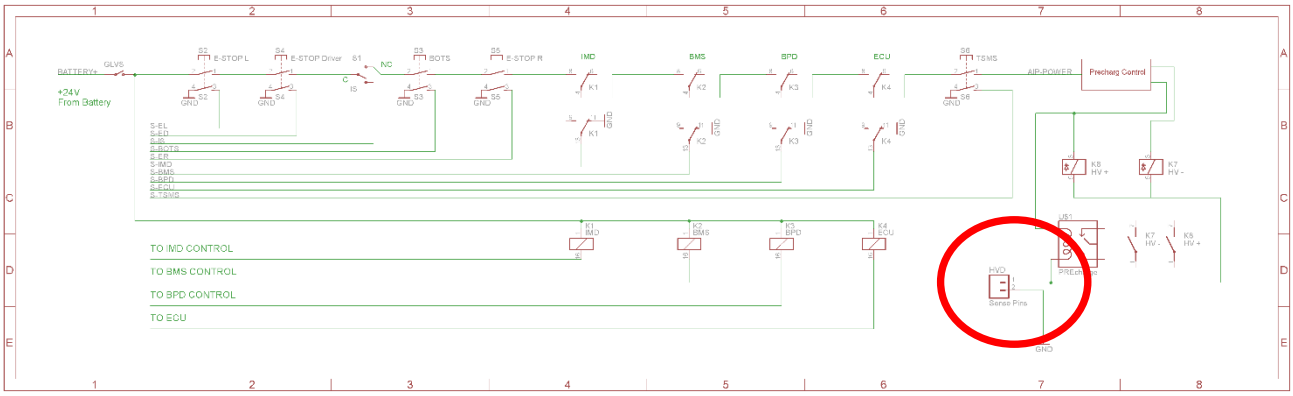

## 2.6 Shutdown System Interlocks

### 2.6.1 Description/circuitry

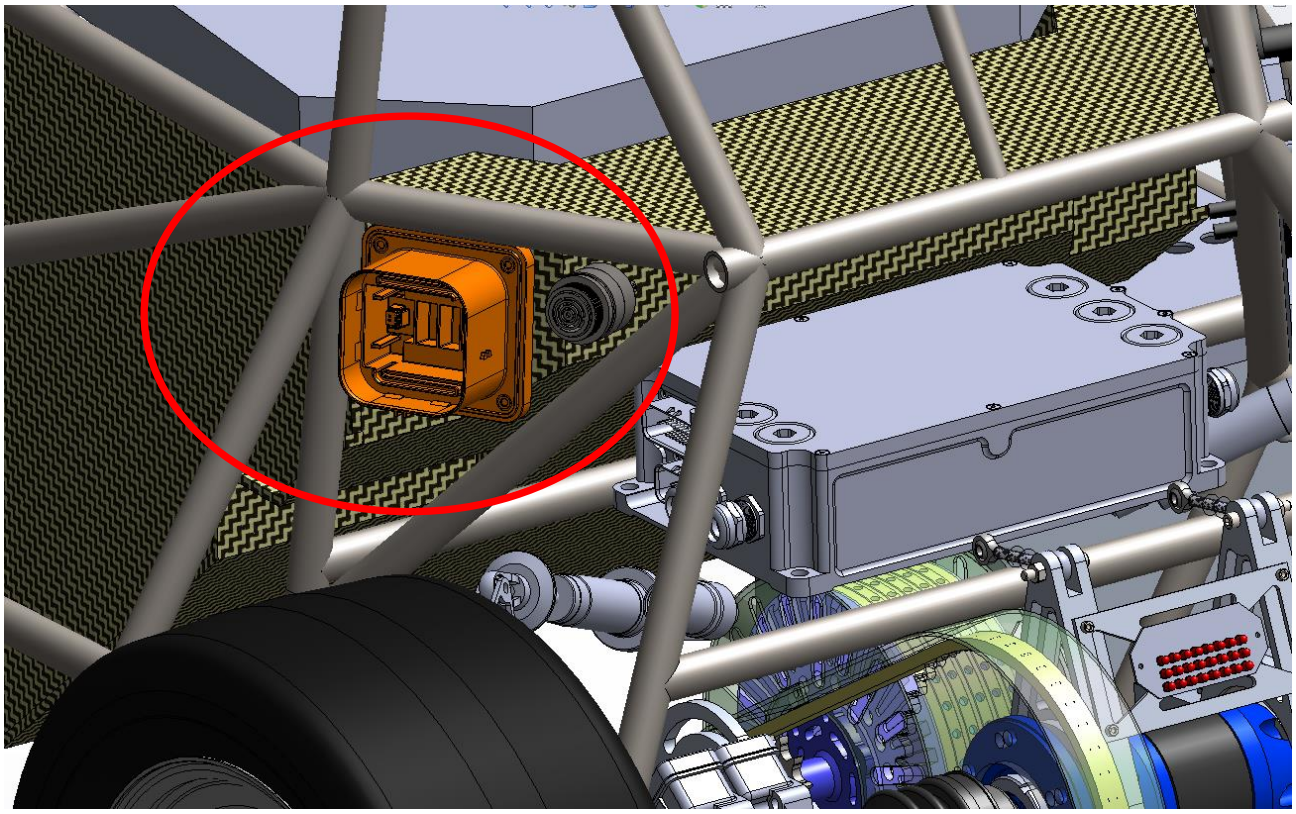
The interlocks are achieved by using sense low voltage isolated pins in the connectors to detect open or closed connections. The AIR's power travel threw them. We have interlocks between the HVD. All other connectors will require tools to open.

### 2.6.2 Wiring/cables/connectors

The HVD requires 18 Gauge PVC wire with a 300v and 105C rating.



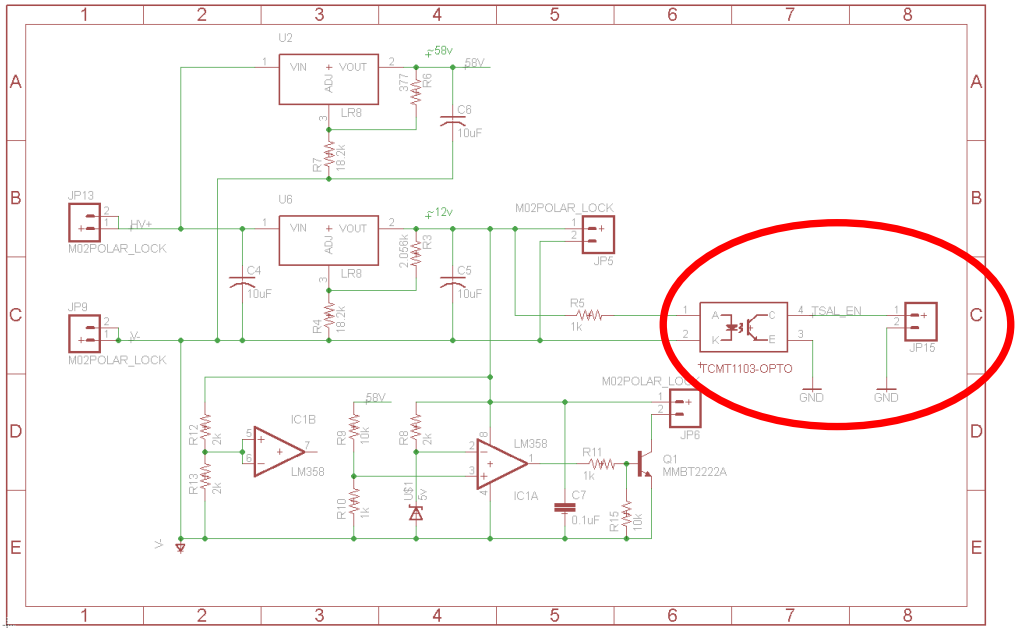
### 2.6.3 Position in car



## 2.7 Tractive system active light

### 2.7.1 Description/circuitry

The TSAL consists of 16 LED's mounted every 45 deg. to form an octagon with 2 LED's on each side. The 3 Hz flashing frequency is driven by a 555 timer. This is turned on by a high voltage sensor after the AIR's in the battery pack. (shown below)

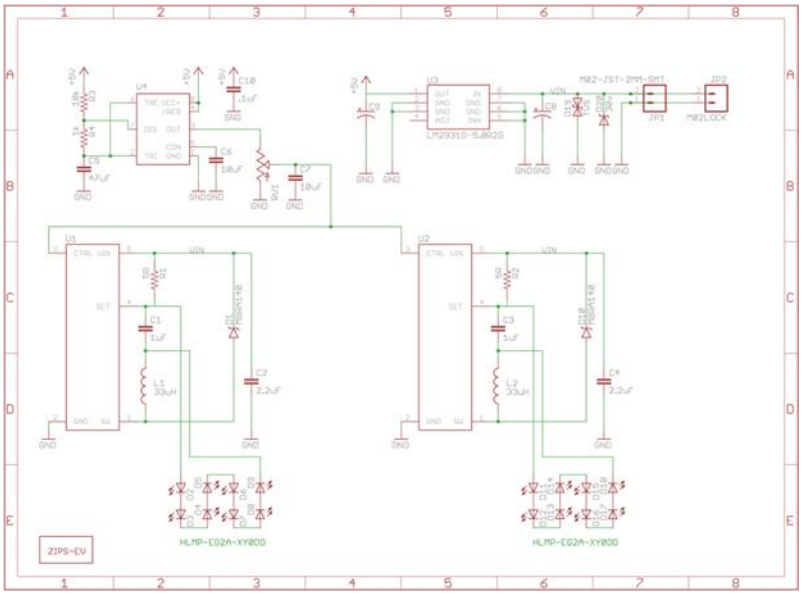



| | |
|---|---|
| Supply voltage: | 24VDC |
| Max. operational current: | 40mA |
| Lamp type | LED |
| Power consumption: | 1 W |
| Brightness | 100 Lumen |
| Frequency: | 1.5Hz |
| Size (length x height x width): | 20mm x 10mm x 50mm |

*Table 2.6 Parameters of the TSAL*

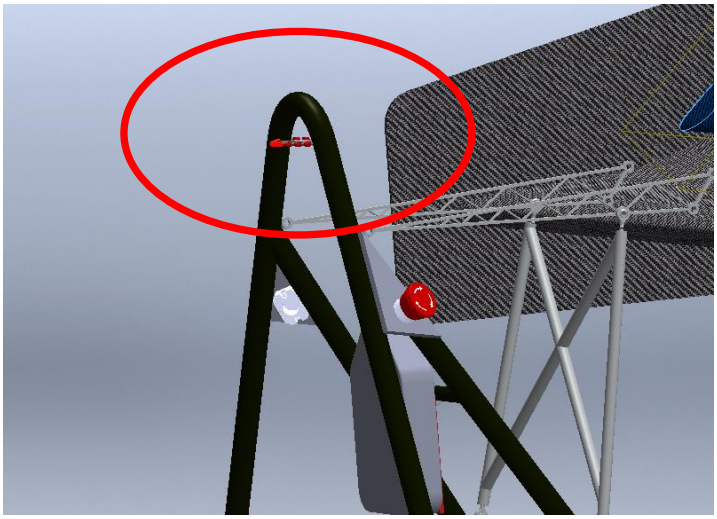
### 2.7.2 Wiring/cables/connectors

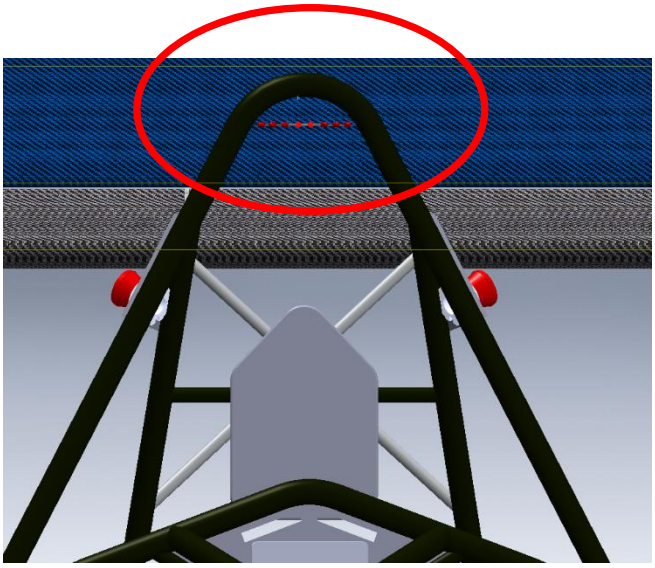
The TSAL uses 24 Gauge PVC wire with a 300v and 105C rating. 10.16 datasheet



### 2.7.3 Position in car

The TSAL is mounted to the bottom of the main roll hoop as required by the rules. It will be mounted with a metal bracket if necessary.

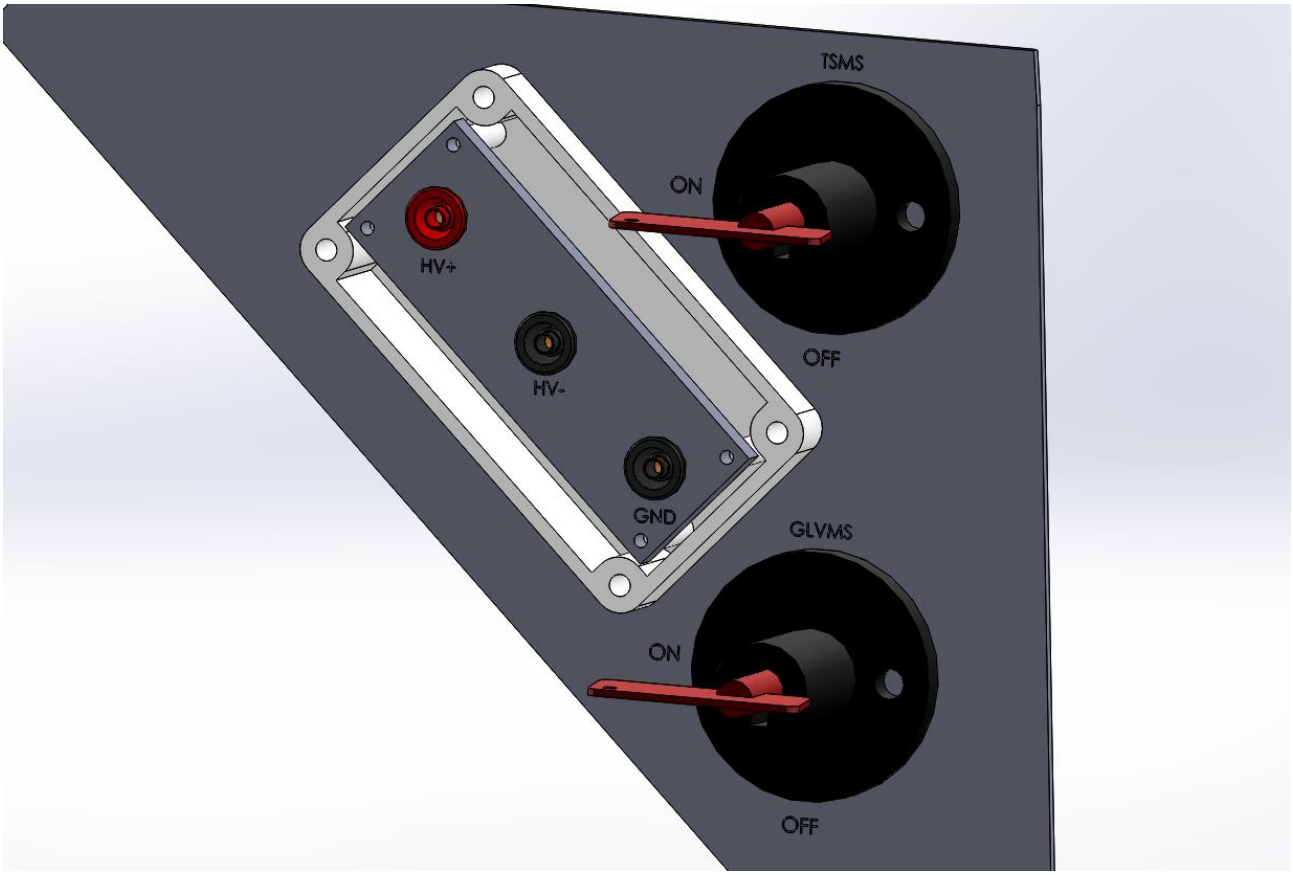




## 2.8 Measurement points

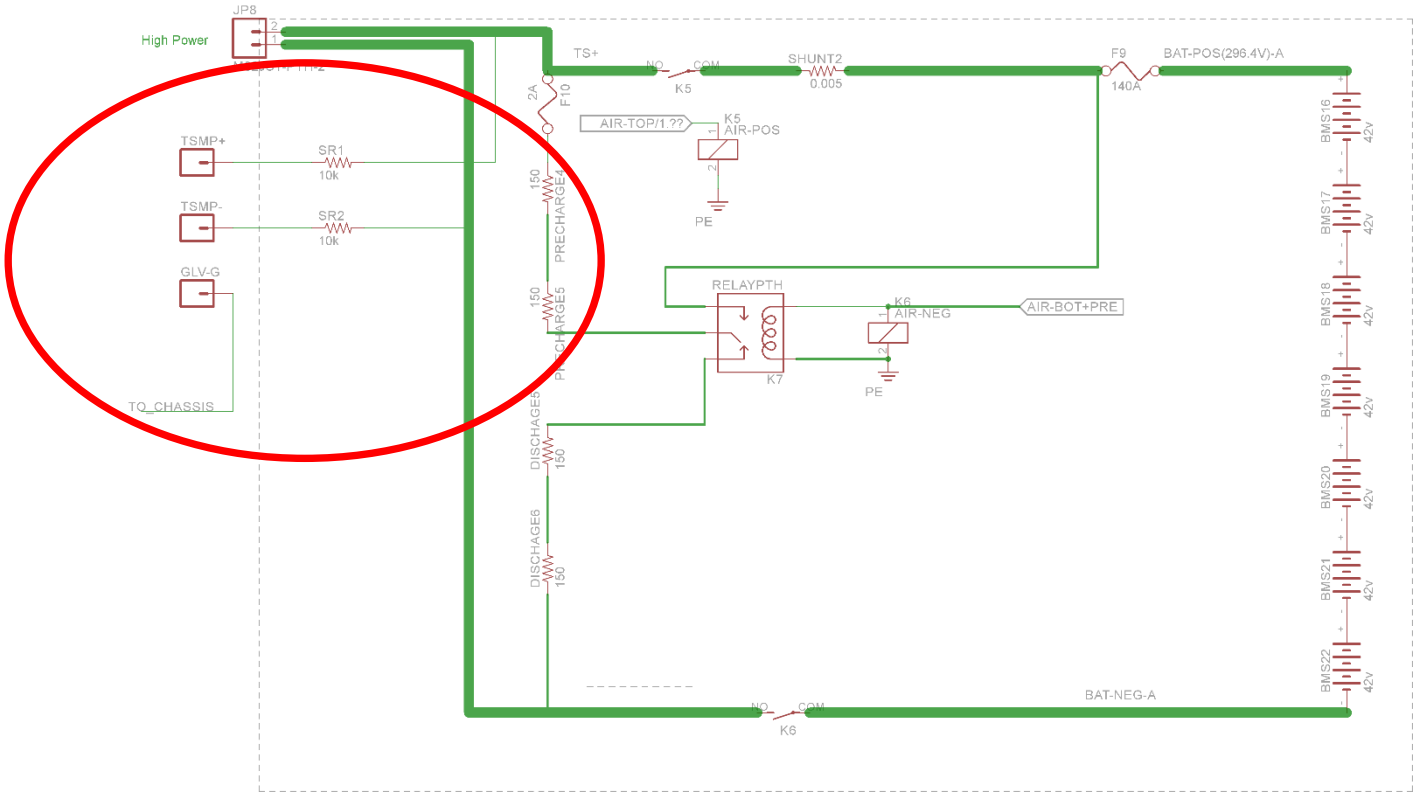
### 2.8.1 Description

4mm red and black banana jacks will be used to allow tractive system voltage measurement. They sit in an IP67 plastic box that has thumb screws holding on the cover. The box is UL Listed to UL508-4x, 12, & 13 specifications. 10.11 Jack Datasheet  10.12 Resistor Datasheet 10.15 Wire Info

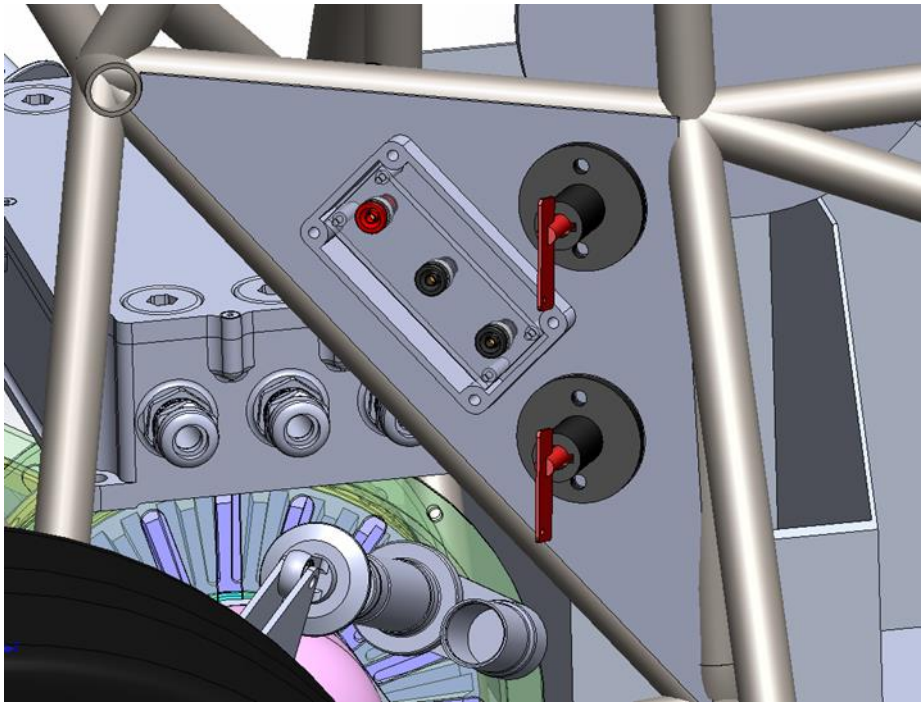



### 2.8.2 Wiring, connectors, cables

The TSMP 24 Gauge PVC wire with a 300v and 105C rating wire will connect the banana jacks in line with a 10kOhm resistor to the HV+ and HV- connections after the AIR's.




### 2.8.3 Position in car

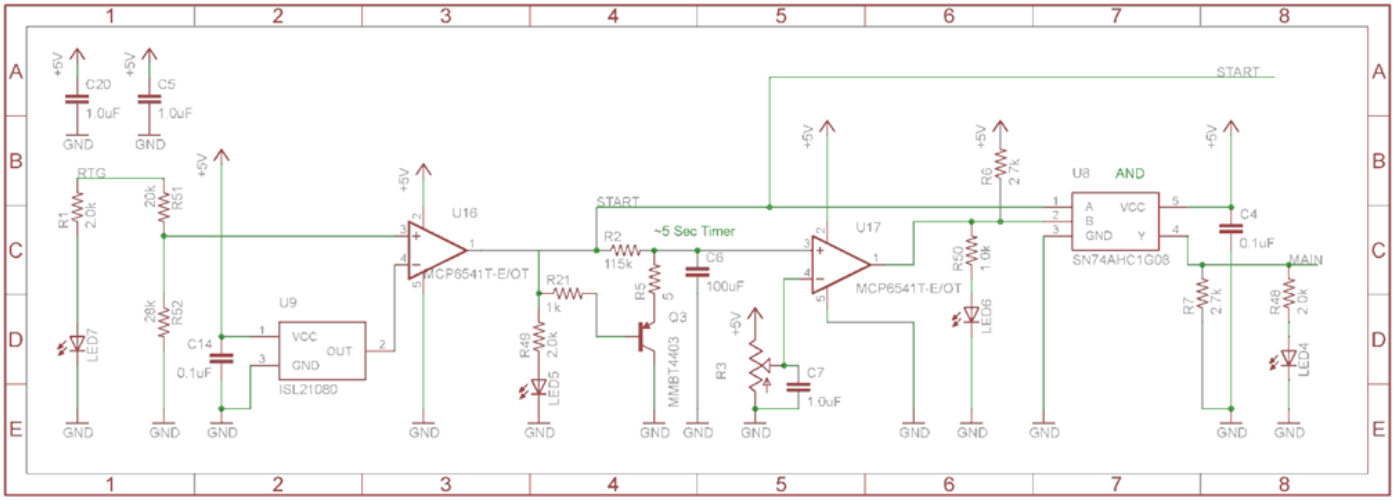


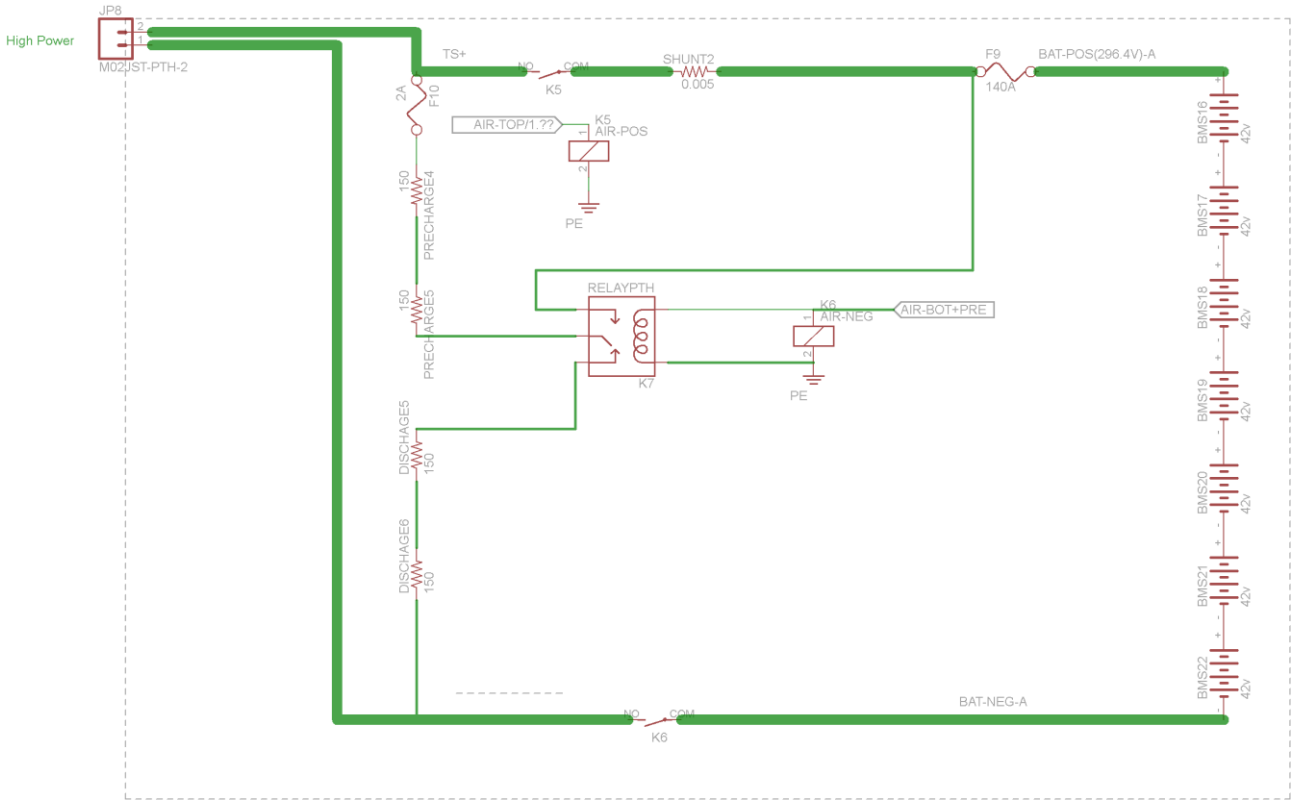
## 2.9 Pre-Charge circuitry

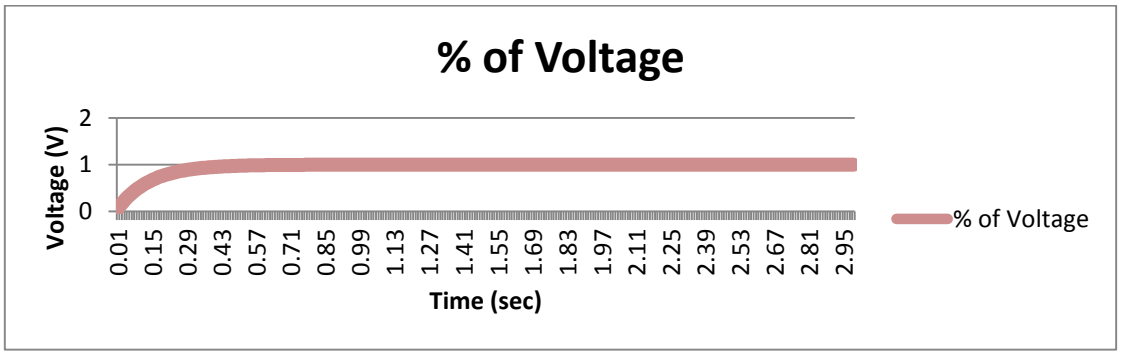
### 2.9.1 Description

The Pre-Charge system of the car is used to equalize the potential of the across the AIR switch and both battery packs. Pre-Charge started when the safety system is all clear of faults. This includes the ECU clearing its fault and setting the ready to drive relay. Bottom or negative relay turns on with the Pre-Charge relay in series with two 150 ohm resistors. The hardware then waits 2.5 seconds. This 2.5 second delay originates from the safety system board. This is set by an RC timer. After the 2.5 seconds are up, the Pre-Charge relay stays on and the AIR's turn on shorting out the Pre-Charge resistor. During Pre-Charge, the car is acquiring data from the motor controller to verify voltage is present and increasing on the battery input to the device. If this doesn't happen, the car will trip ECU safety stop and report an error code. The Control circuitry is not near the high voltage.

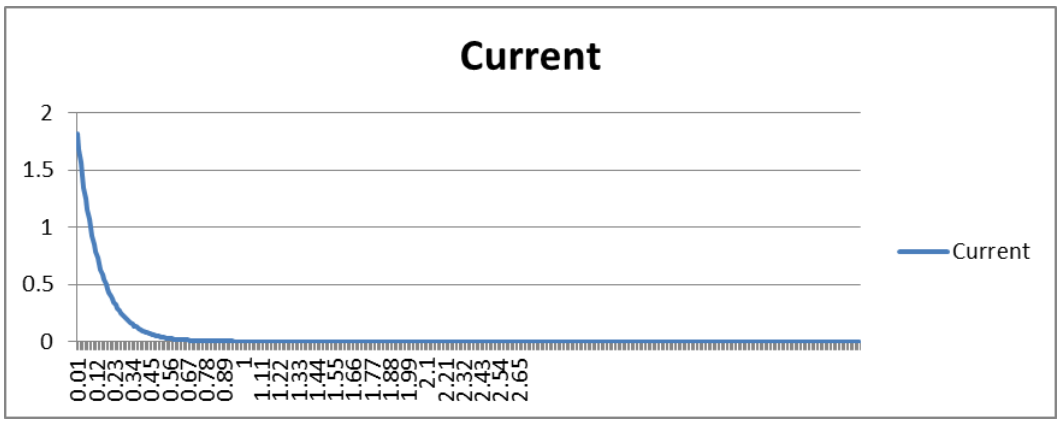
### 2.9.2 Wiring, cables, current calculations, connectors






Formula = $1 - 294.2^{\frac{-t}{150*0.00088}}$




Formula = $294.2 * 2.7182^{\frac{-t}{150*0.00088}}$

| | |
|---|---|
| Resistor Type: | WFH160L150JE - Wirewound |
| Resistance: | 150Ω |
| Continuous power rating: | 160W |
| Overload power rating: | 160W |
| Voltage rating: | 600V |
| Cross-sectional area of the wire used: | 1.31mm² |

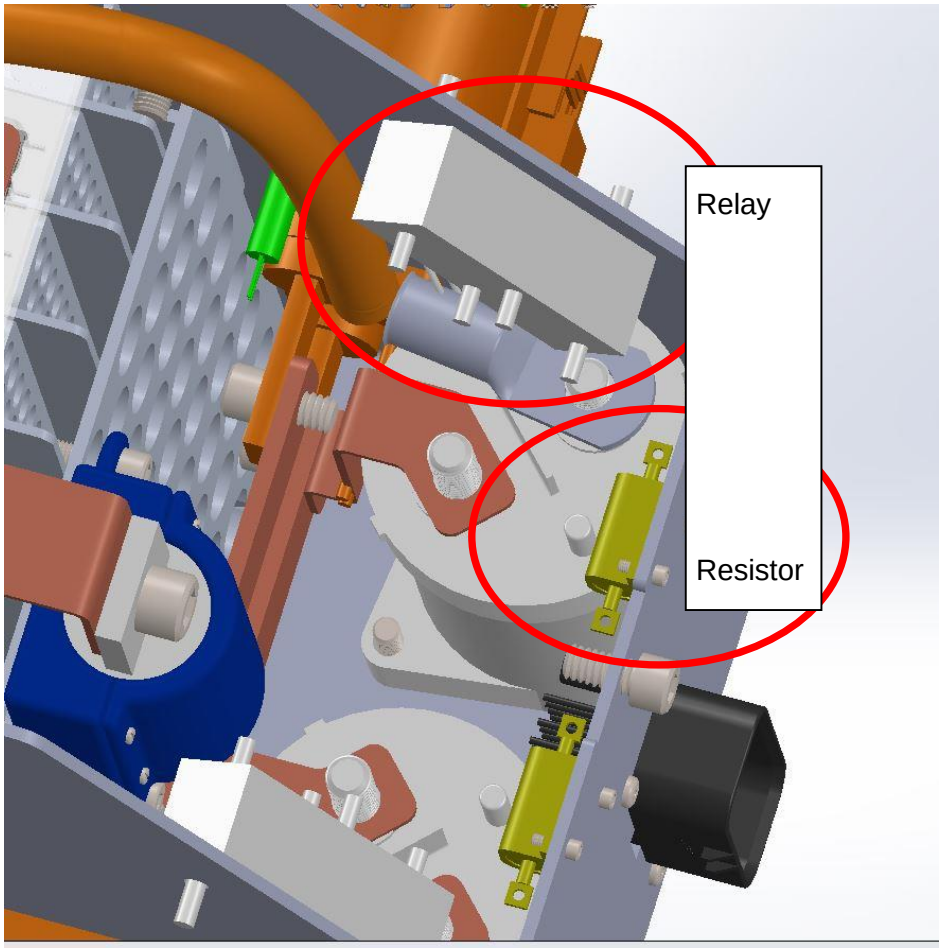
*Table 2.7 General data of the pre-charge resistor*

| | |
|---|---|
| Relay Type: | 5501-24-1 |
| Contact arrangment: | SPST-NO |
| Continuous DC current: | 3A |
| Voltage rating | 7500VDC |
| Cross-sectional area of the wire used: | 1.31mm² |

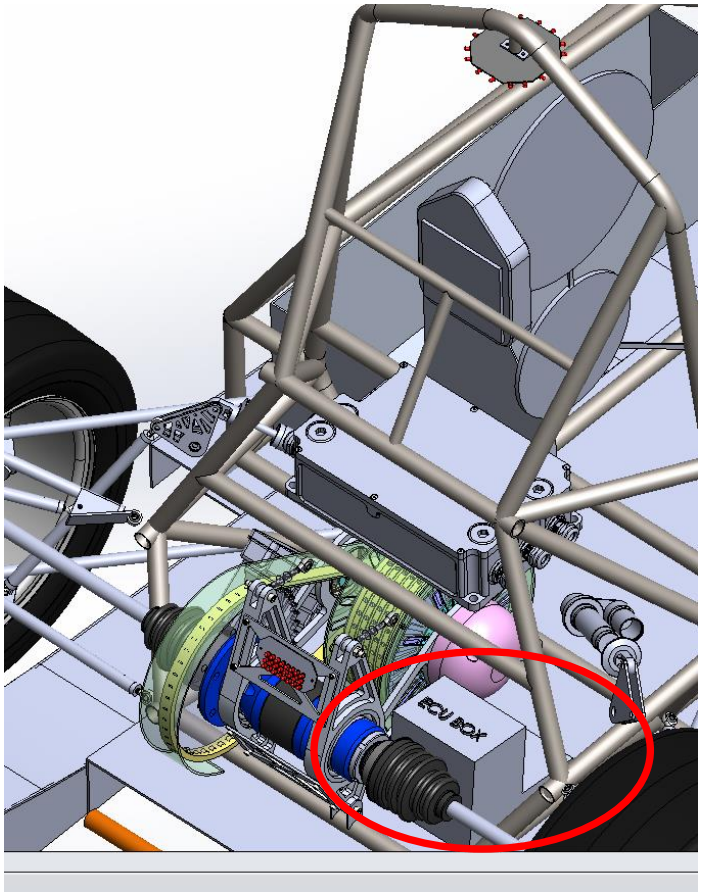
*Table 2.8 General data of the pre-charge relay*

### 2.9.3 Position in car

Relay and resistor (in accumulator)



Control system:

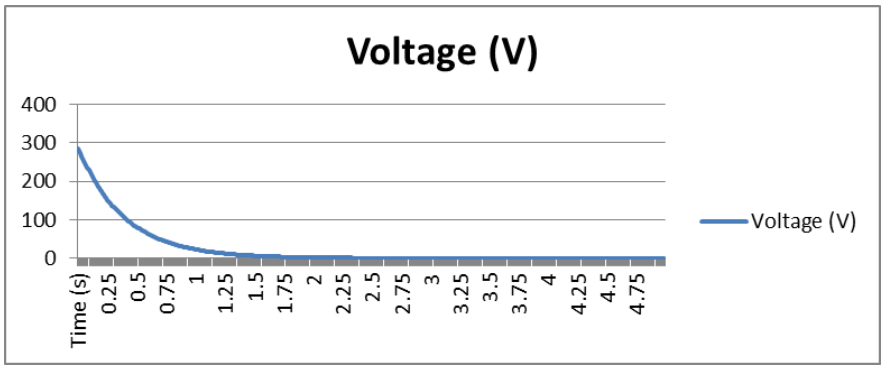



## 2.10 Discharge circuitry

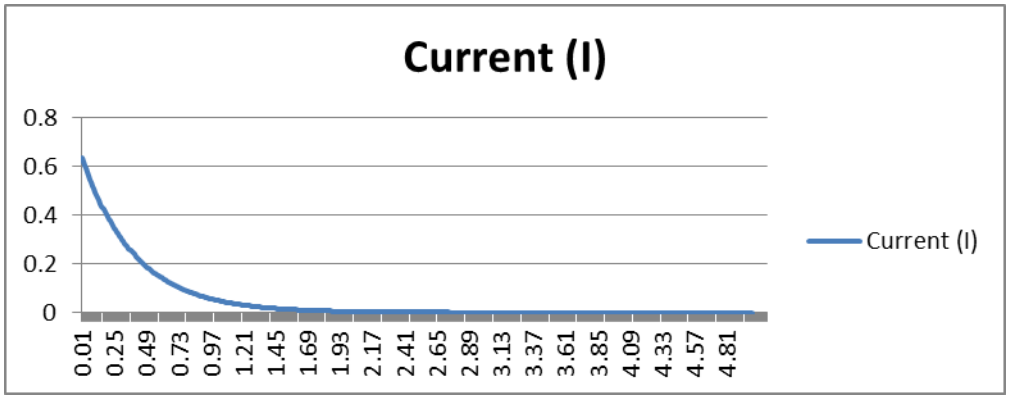
### 2.10.1 Description

Our system requires a discharge system to get the capacitive energy out of the motor controller. Our system uses a resistor to drop the energy. We are able to discharge the energy in about 1.8 seconds. This circuit works off of the inverted precharge system relay output. It works by being a normally closed relay shorting the output of the accumulators and only opens when the precharge system activates and main AIRs open.

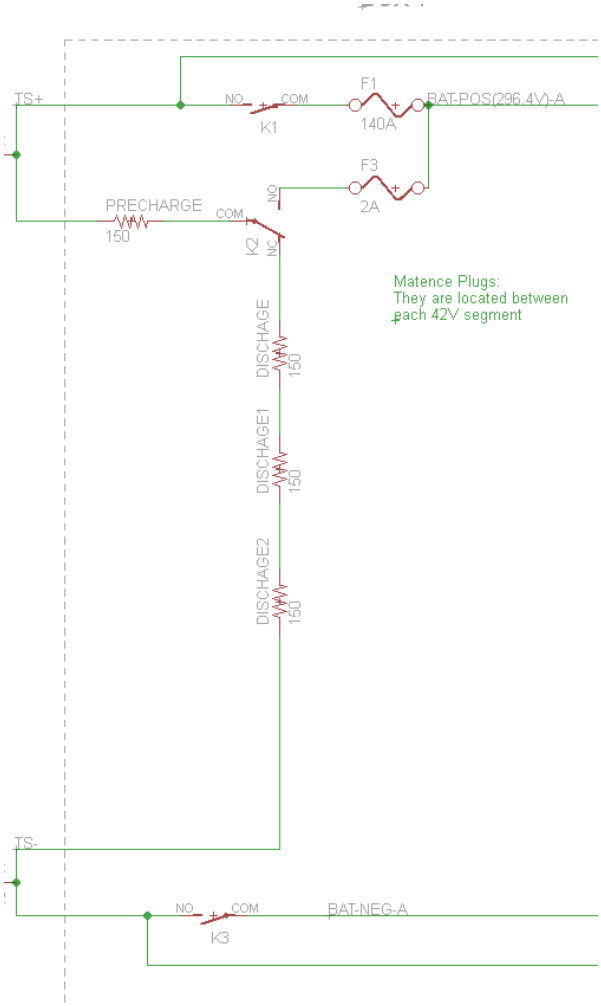
### 2.10.2 Wiring, cables, current calculations, connectors




Formula = $\frac{294.2}{450} 2.7182^{\frac{-t}{150*0.00088}}$




Formula = $294.2 * 2.7182^{\frac{-t}{150*0.00088}}$


TS+
NO
COM
K1
F1
140A
BAT-POS(296.4V)-A
F3
2A
PRECHARGE
150
COM
NO
K2
NC
Matence Plugs:
They are located between
each 42V segment
DISCHAGE
150
DISCHAGE1
150
DISCHAGE2
150
TS-
NO
COM
K3
BAT-NEG-A

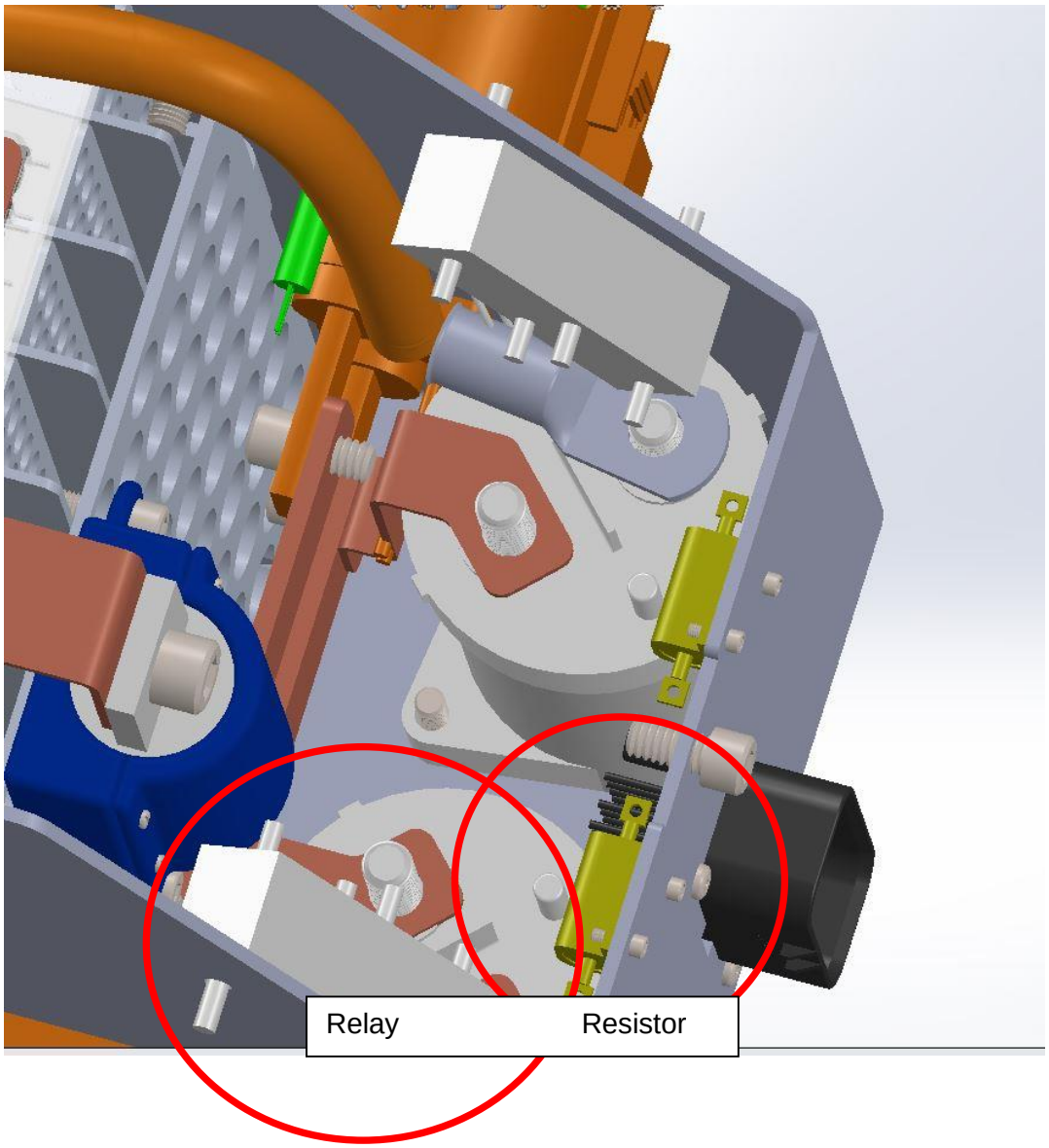
| | |
|---|---|
| Resistor Type: | WFH160L150JE - Wirewound |
| Resistance: | 450Ω |
| Continuous power rating: | 160W |
| Overload power rating: | 160W |
| Voltage rating: | 600V |
| Maximum expected current: | 0.7A |
| Average current: | 0.4A |
| Cross-sectional area of the wire used: | 1.31 mm² |

*Table 2.9 General data of the discharge circuit*

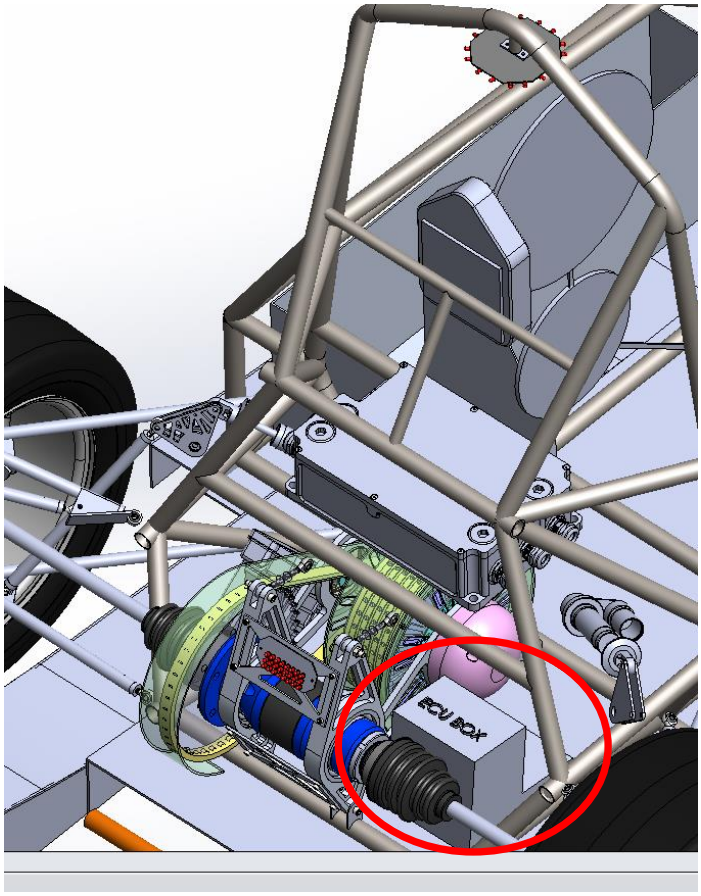
| | |
|---|---|
| Relay Type: | 5502-24-1 |
| Contact arrangment: | SPST-NC |
| Continuous DC current: | 3A |
| Voltage rating | 7500VDC |
| Cross-sectional area of the wire used: | 1.31 $mm^2$ |

*Table 2.10 General data of the dis-charge relay*

### 2.10.3 Position in car



Control system:




## 2.11 HV Disconnect (HVD)

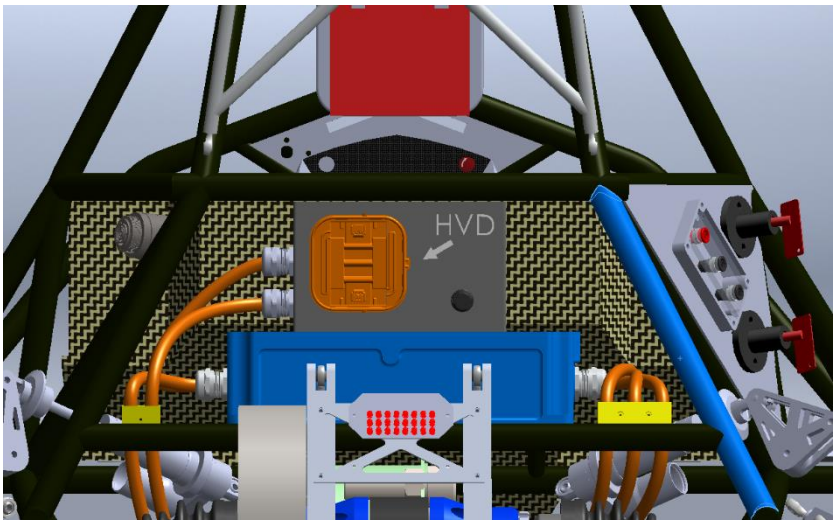
### 2.11.1 Description

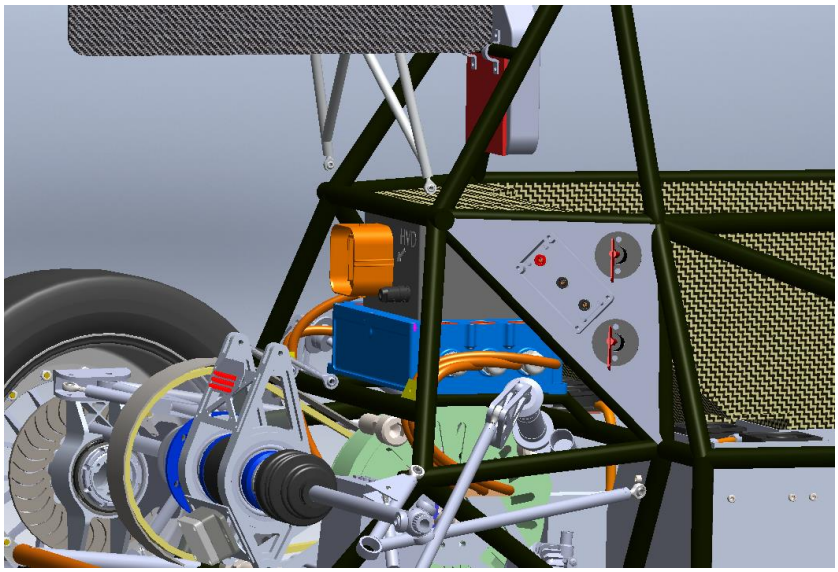
The HVD is a 1-1587987-7 (10.13 Datasheet for HVD) model from TE connectivity. It is a member of their Series B connector family and is capable of 630Amps and 450V. It is disconnected by a pull handle.

### 2.11.2 Wiring, cables, current calculations, connectors

Wire - EXRAD-FSX1X 1 couple.

### 2.11.3 Position in car



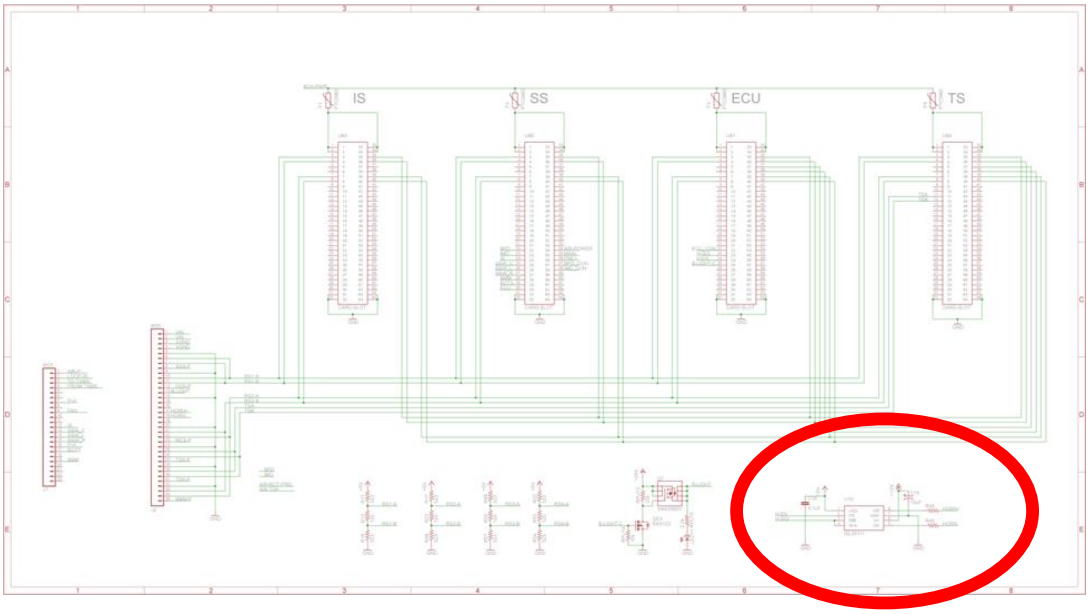



## 2.12 Ready-To-Drive-Sound (RTDS)

### 2.12.1 Description

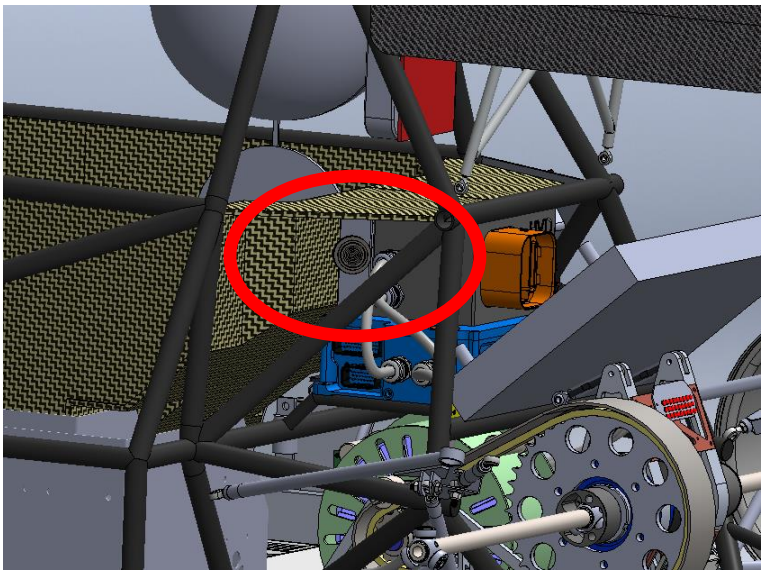
Upon the Accumulator Isolation Relays closing, and the motor controllers turning on, a 24V car horn will turn on for more than one second and less than three to notify all that the vehicle is ready to drive. The horn (Piezzo) is driven by a mosfet driver. The signal that drives the buzzer is from the ECU with software. We are using a Mallory PT-4532PLQ. The horn is capable of generating 83bBA at 2 meters.

### 2.12.2 Wiring, cables, current calculations, connectors




The Horn uses 24 Gauge PVC wire with a 300v and 105C rating. (10.16 Wire Datasheet) There are no connectors for the Horn. 10.16 datasheet

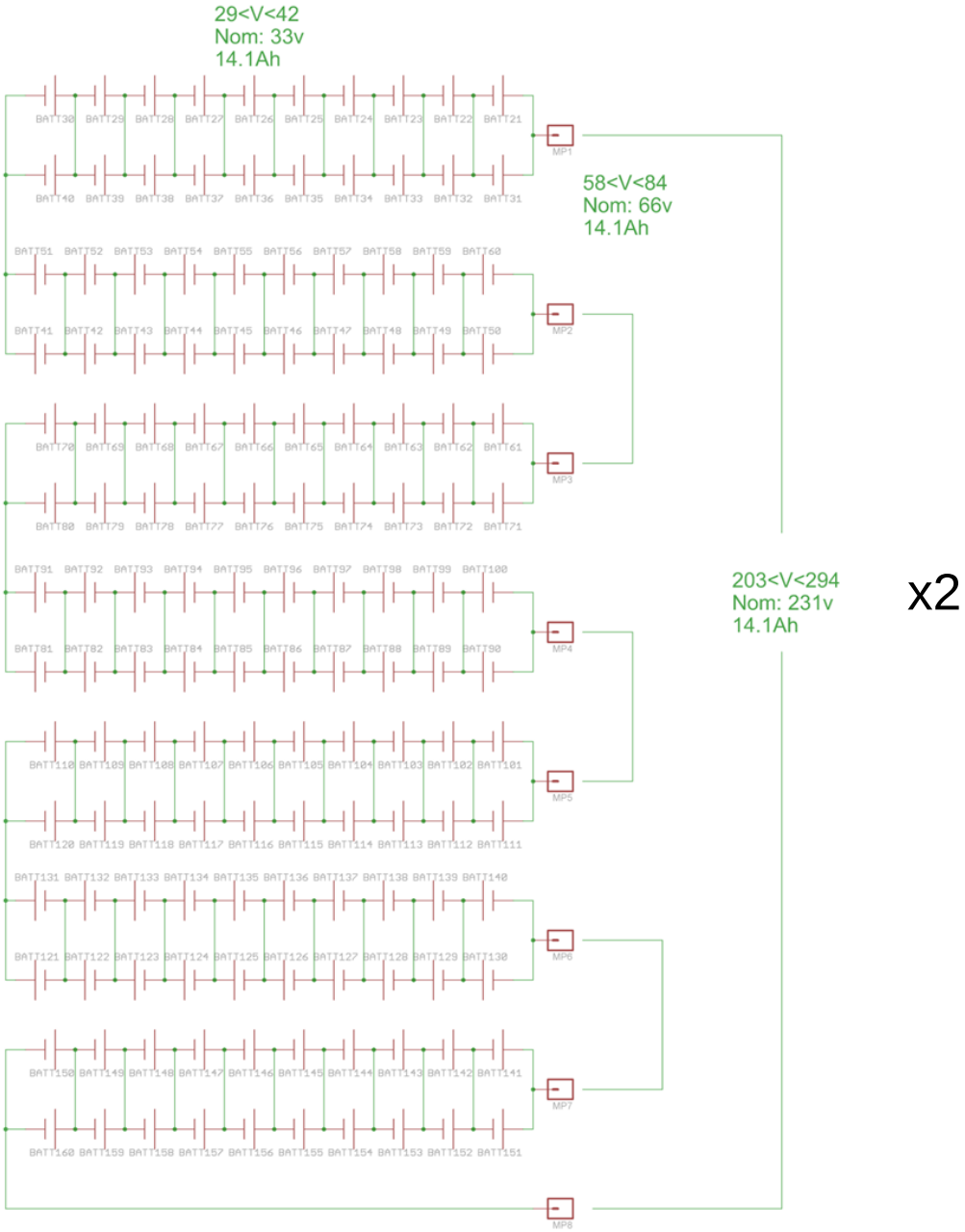
### 2.12.3 Position in car

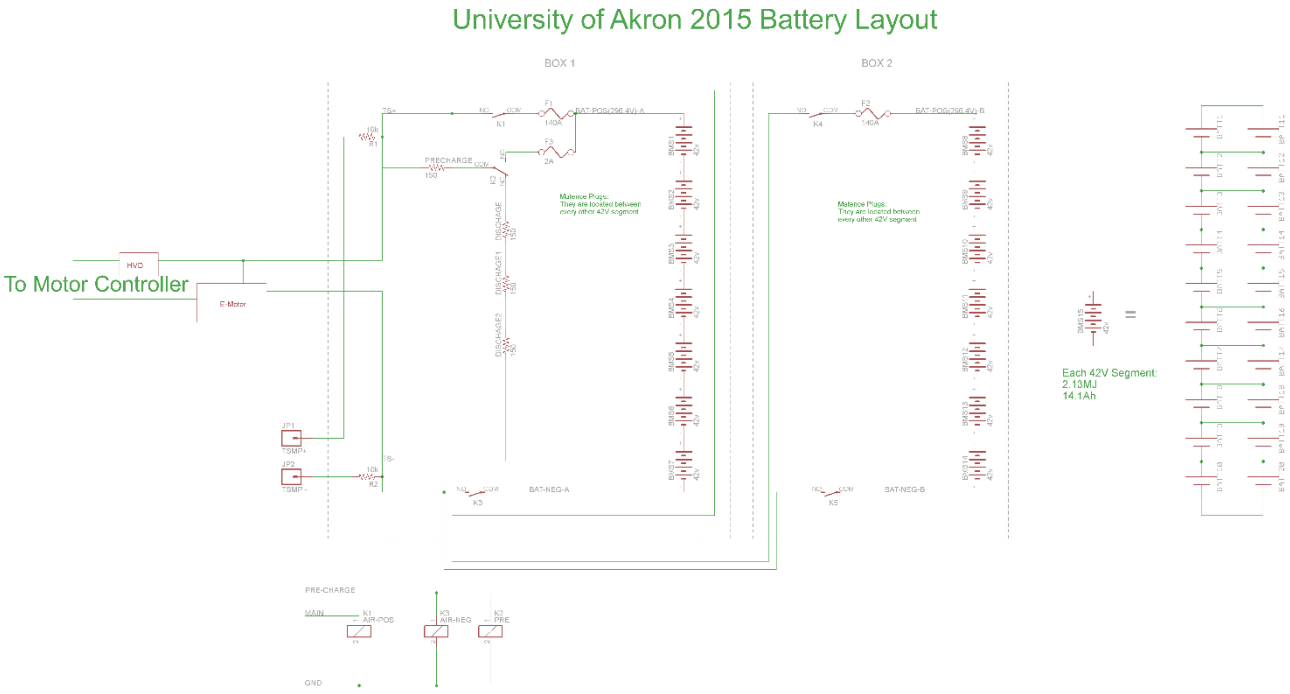


# 3 Accumulator

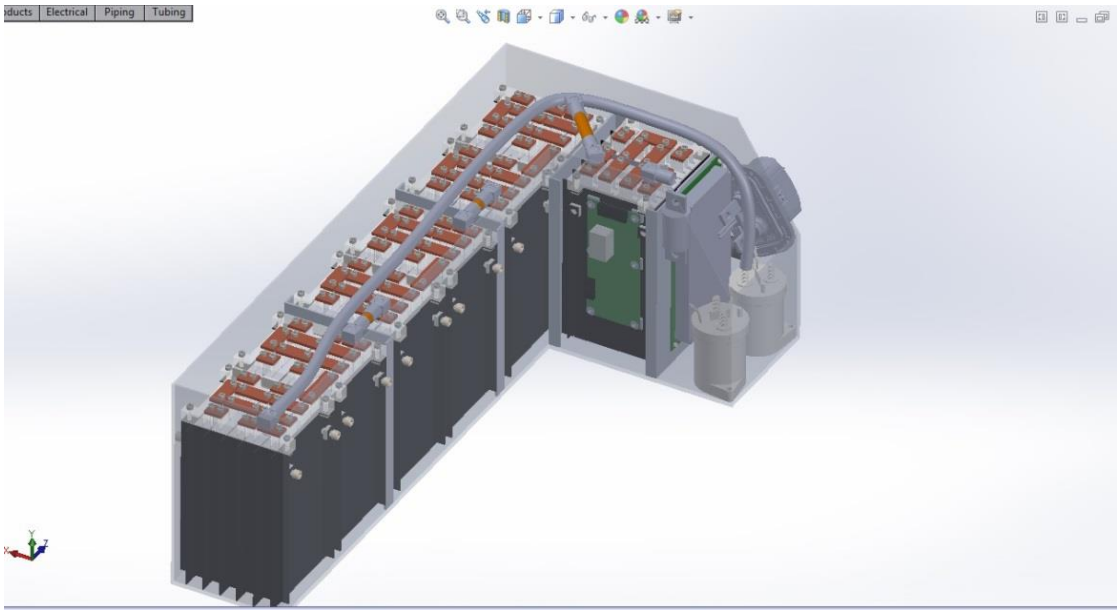
## 3.1 Accumulator pack 1

### 3.1.1 Overview/description/parameters

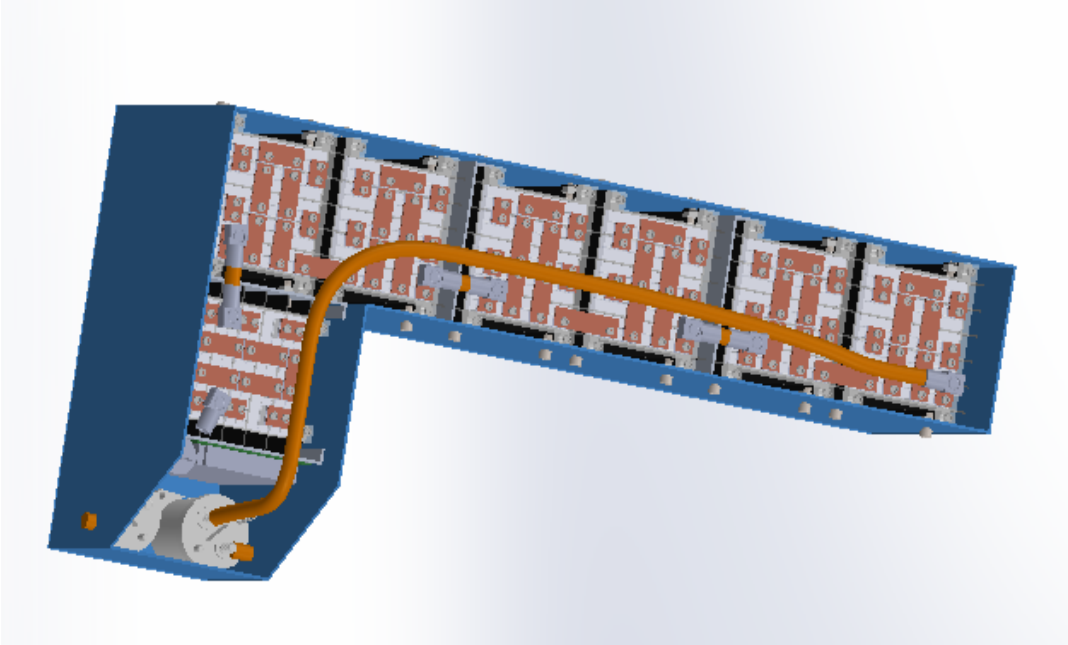




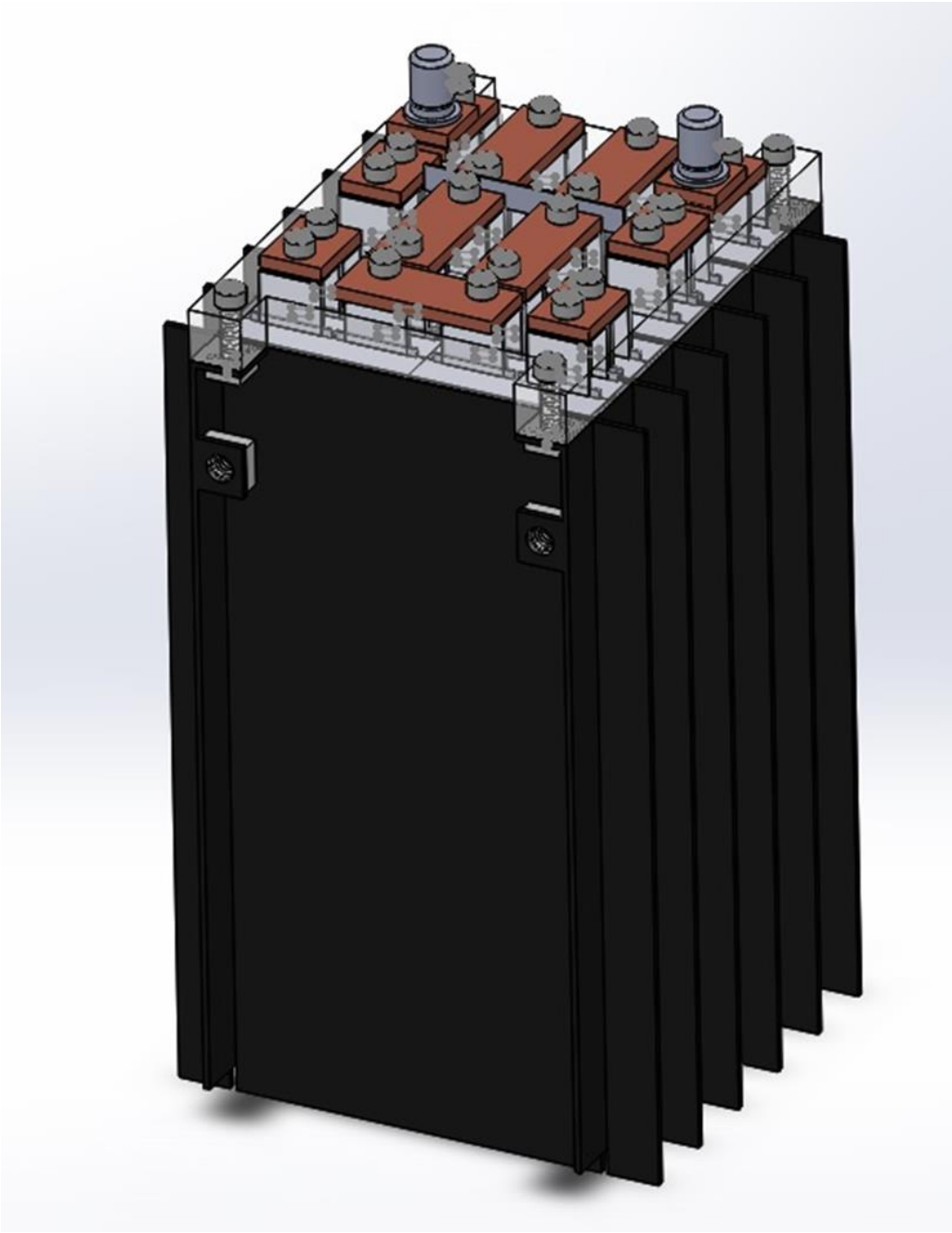

Right (Box1-70s2p)




Left (Box2-70s2p)



Modules (10s2p) x7 per container ~42v



| | |
|---|---|
| Maximum Voltage: | 294VDC |
| Nominal Voltage: | 231VDC |
| Minimum Voltage: | 203VDC |
| Maximum output current: | 580A for 2s |
| Maximum nominal current: | 280A |
| Maximum charging current: | 28A |
| Total numbers of cells: | 280 |
| Cell configuration: | 70s4p |
| Total Capacity: | (7.05Ah)(3.3V)(3600j/Wh)(280cells)x10^-6=23.45MJ<br><br>(7.05Ah)(3.3V)(280cells)=6,514.2 Watt-hours |
| Number of cell stacks < 120VDC | 7 |

*Table 3.1 Main accumulator parameters*

### 3.1.2 Cell description

| | |
|---|---|
| Cell Manufacturer and Type | Melasta SLPB9145180 |
| Cell nominal capacity: | 7.05 Ah |
| Maximum Voltage: | 4.2 V |
| Nominal Voltage: | 3.3V |
| Minimum Voltage: | 3.0V |
| Maximum output current: | 25C for 10s |
| Maximum nominal output current: | 20C |
| Maximum charging current: | 2C |
| Maximum Cell Temperature (discharging) | 60°C |
| Maximum Cell Temperature (charging) | 45°C |
| Cell chemistry: | LiPo |

*Table 3.2 Main cell specification*

HV Battery Cell Datasheet

### 3.1.3 Cell configuration

Each accumulator contains 140 cells. The cells are separated in 7 segments containing 20 cells each. The segments are in a 10s2p arrangement. Each parallel cell in the segment is back to back. The cells are connected together by clamping custom copper bus bar on top of the tabs. This is shown in above figure.

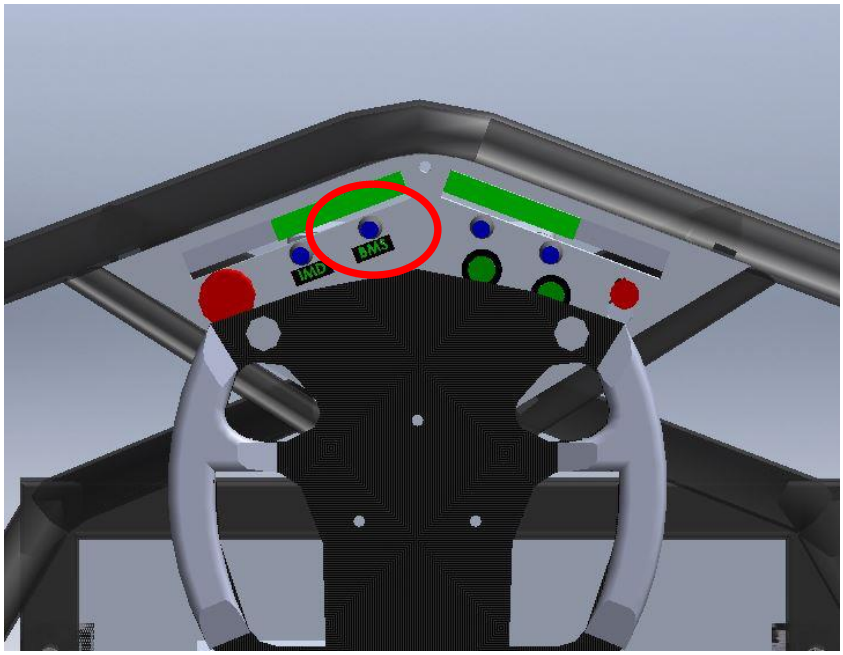
### 3.1.4 Cell temperature monitoring

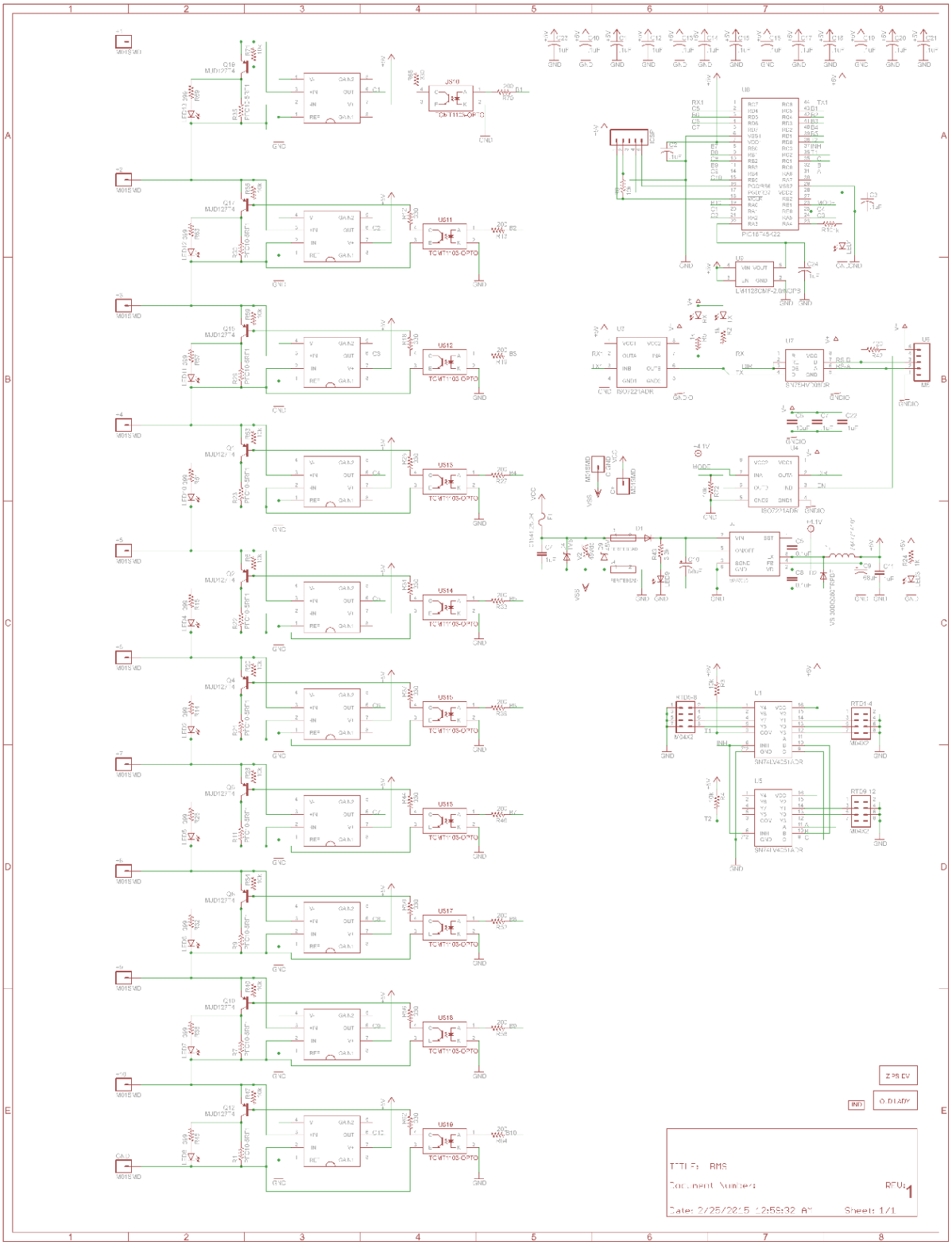
Every cell will be monitored for temperature. We do this by putting an NTC resistor between the cells. Each battery segment PIC will monitor the cell temperature.

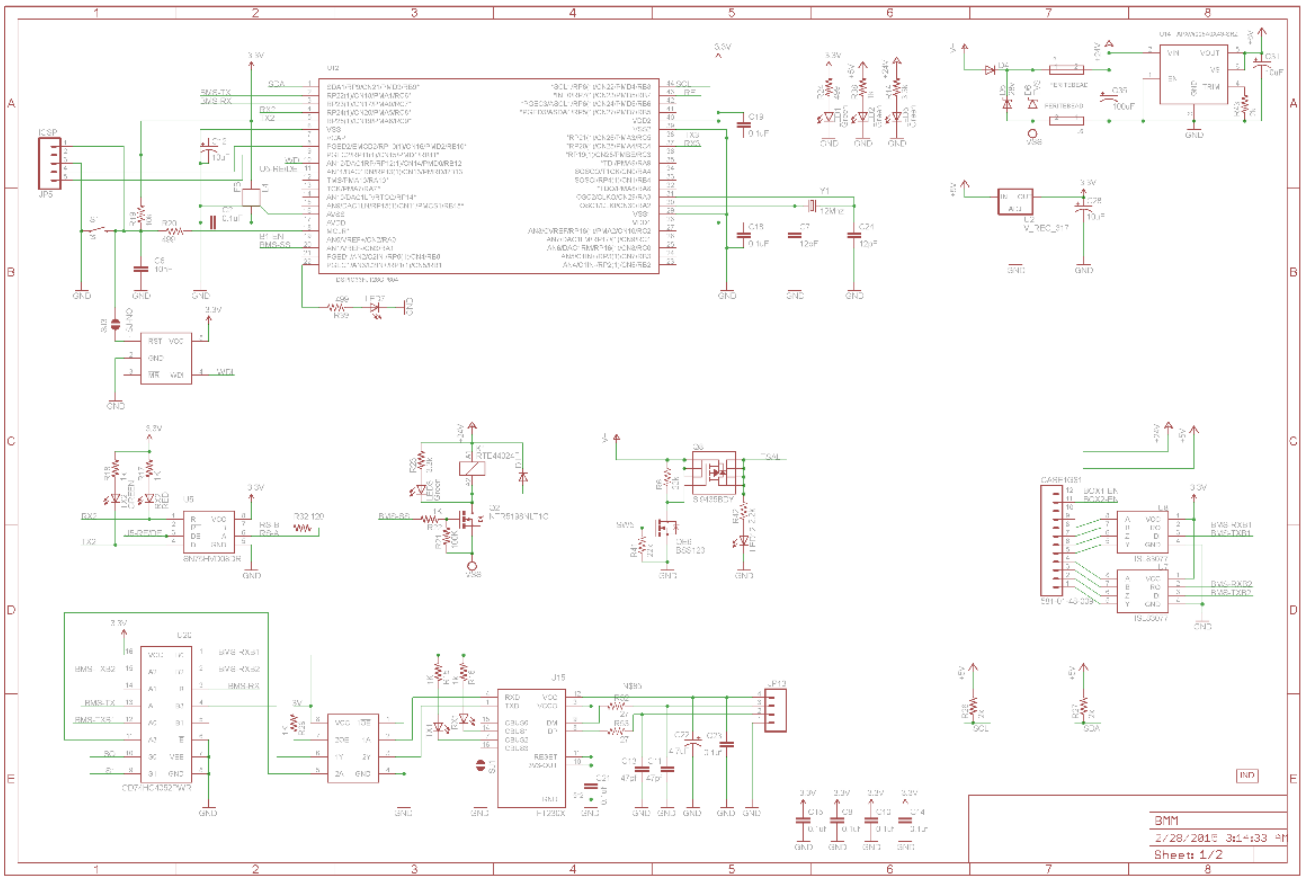
### 3.1.5 Battery management system

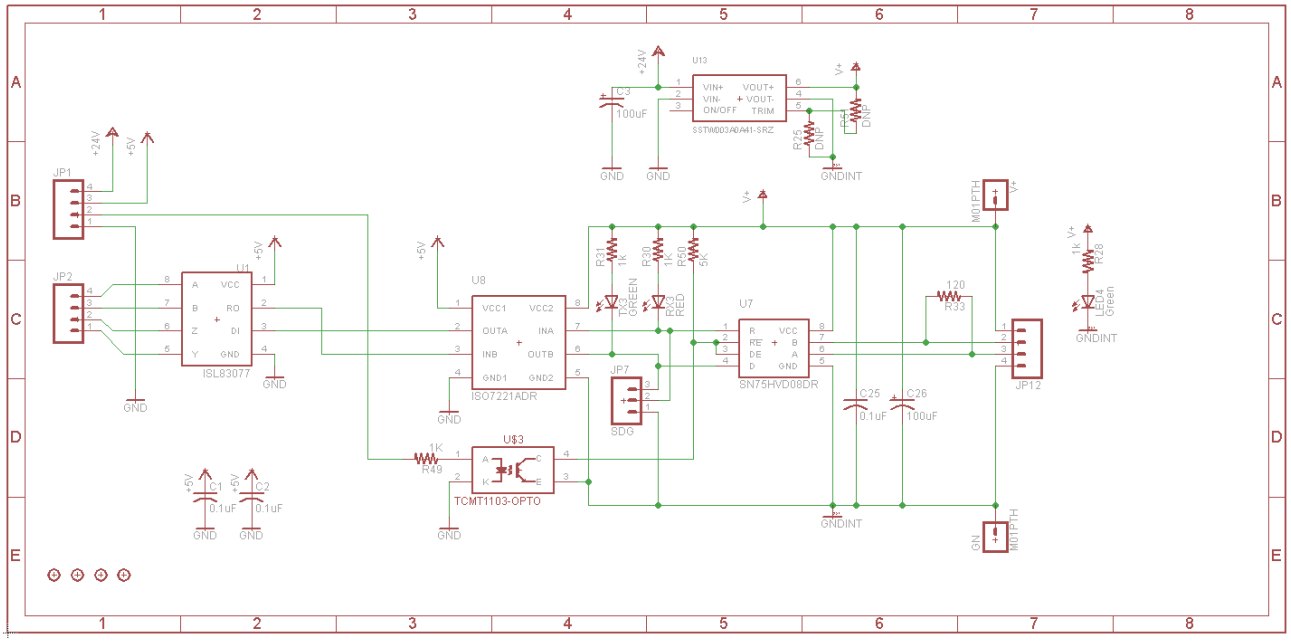
280 cells will be monitored by the BMS that we made ourselves. 14 Slave devices with microcontrollers will communicate with one Master. This communication is done over RS485 and is isolated at each cell and master. The BMS is capable of opening a relay in the shutdown circuit to open the AIRs in the case of an error. At a minimum cell voltage of 3.8 and a maximum of 4.2, the

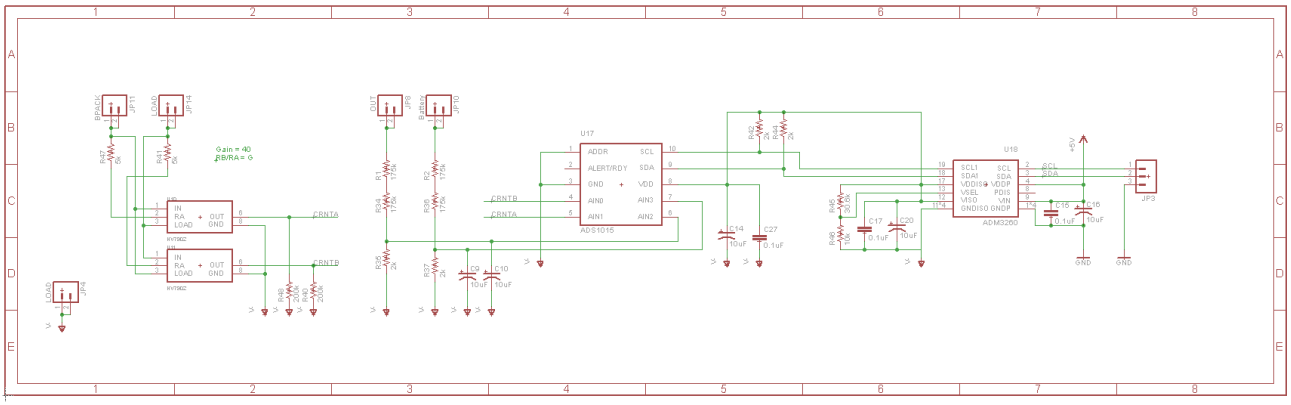
BMS will take actions to bypass the affected cell(s) and shutdown the tractive system if necessary. The BMS also reacts to temperature problems at 60°C. The BMS can also measures current with a high side current shunt and trigger the safety system. The BMS shuts down the tractive system via a relay that is tied into the safety loop. If shut down, it would trip the safety system and the car would shut down. These boards are linked with locking Molex connectors. This allows for hot swapping boards. The slave boards are mounted to the sides of the modules. There is wire going between the BMS PCB and the Battery pack. We have PCB inline fuses to protect the wires.





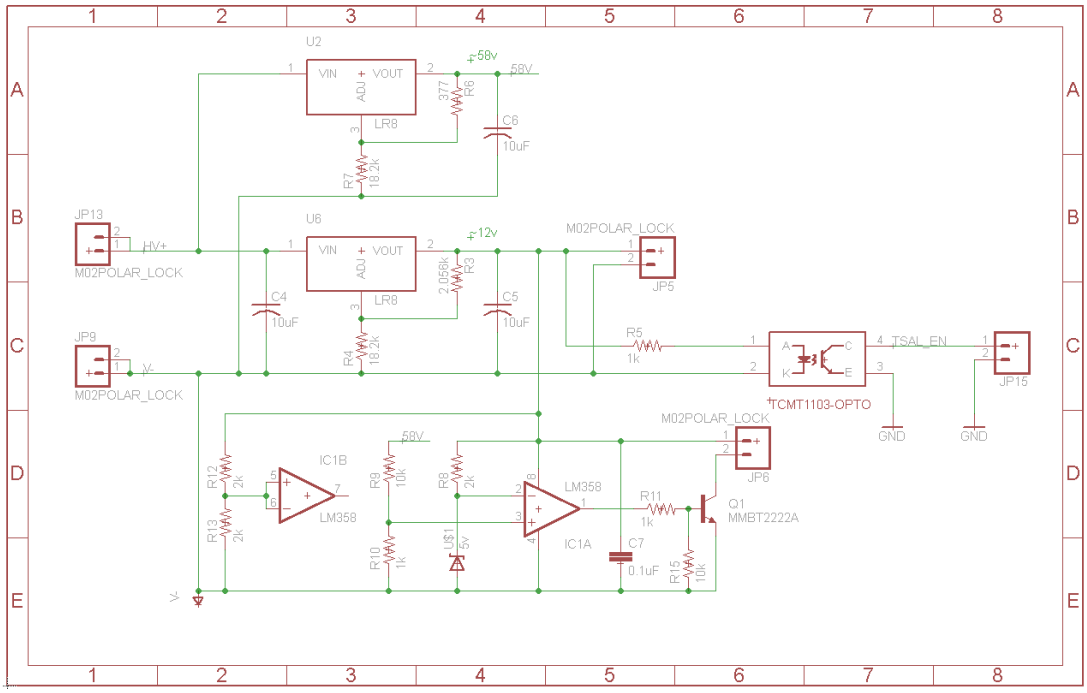

BMM
2/28/2013 3:14:33 PM
Sheet: 1/2


ISL83077
ISO7221ADR
SN75HVD08DR
TCMT1103-OPTO
SSTW003A0A41-SRZ



### 3.1.6 Accumulator indicator

The accumulator indicator is an LED that will be attached to the battery enclosure to indicate that the pack is active. This indicator will be wired across the first and last AIR's, so that it is powered when there is voltage on the vehicle side of the accumulator container. It therefore the circuit below is only powered from tractive system voltage. It does not run off of the GLVS and therefore work outside of the car. The wire used for this AWG 22.



### 3.1.7 Wiring, cables, current calculations, connectors

| | |
|---|---|
| Wire type | Alpha Wire 1855 |
| Continuous current rating: | 7A |
| Cross-sectional area | 0.030 in |
| Maximum operating voltage: | 600V |
| Temperature rating: | 105 °C |
| Wire connects the following components: | Cell and BMS |

*Table 3.3*

### 3.1.8 Accumulator insulation relays

| | |
|---|---|
| Relay Type: | EV200AAANA |
| Contact arragment: | SPST |
| Continous DC current rating: | 500A |
| Overload DC current rating: | N/A |
| Maximum operation voltage: | 900VDC |
| Nominal coil voltage: | 24VDC |
| Normal Load switching: | Make and break up to 500A |
| Maximum Load switching | 10 times at 1500A |

*Table 3.4 Basic AIR data*

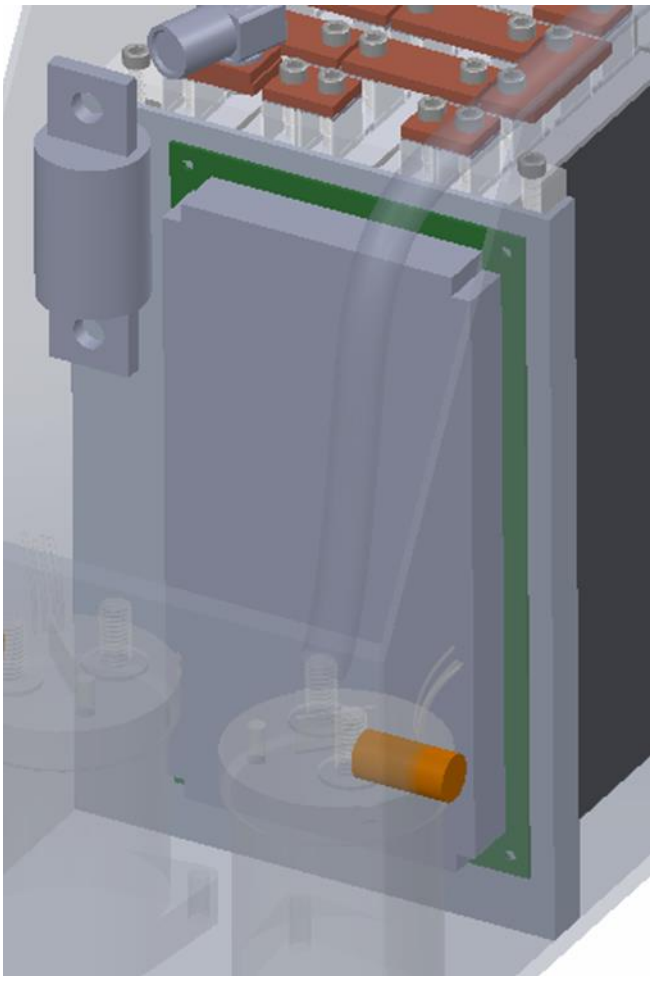
AIR Data sheet

### 3.1.9 Fusing

We use two main fuses in the car. One in each bank that fuses the outputs of each individual box. The fuse holders we are using are the LSCR001 from little fuse. They are 600v, 400A rated fuse holder.

| | |
|---|---|
| Fuse manufacturer and type: | Littelfuse,  Class T |
| Continous current rating: | 150A |
| Maximum operating voltage | 300VDC |
| Type of fuse: | High speed |
| I2t rating: | 1500A2s at 450VDC |
| Interrupt Current (maximum current at which the fuse can interrupt the current) | 20000A |

*Table 3.5 Basic fuse data*



| Location | Wire Size | Wire Ampacity | Fuse type | Fuse rating |
|---|---|---|---|---|
| Cells to AIRs | 2 AWG | 255 | 2xMNO Fuse | 145 |
| AIR to Motor controller | 2 AWG | 255 | N/A | N/A |
| AIR to TSAL | 24 AWG | 3.5 | EFG Fuse | XXX |
| Accumulator output connector | 2 AWG | 300 | | |
| Cells to BMS | 22 | 7 | | |

*Table 3.6 Fuse Protection Table*

### 3.1.10 Charging

The battery charging will use the battery management system to control the charger. The BMS-master by default is not able to talk to the charger directly and control the AIR's.. We designed a charging control adapter board that hosts the interfaces and isolation necessary to follow the rules of the competition. This board also hosts the safety system for the IMD, control relays, lights and LCD display.

| | |
|---|---|
| Charger Type: | SmartCharge-12000 |
| Maximum charging power: | 12kW |
| Maximum charging voltage: | 350V |
| Maximum charging current: | 70A |
| Interface with accumulator | serial communication |
| Input voltage: | 120-230 VAC |
| Input current: | Up to 50A |

*Table 3.7 General charger data*

### 3.1.11 Mechanical Configuration/materials

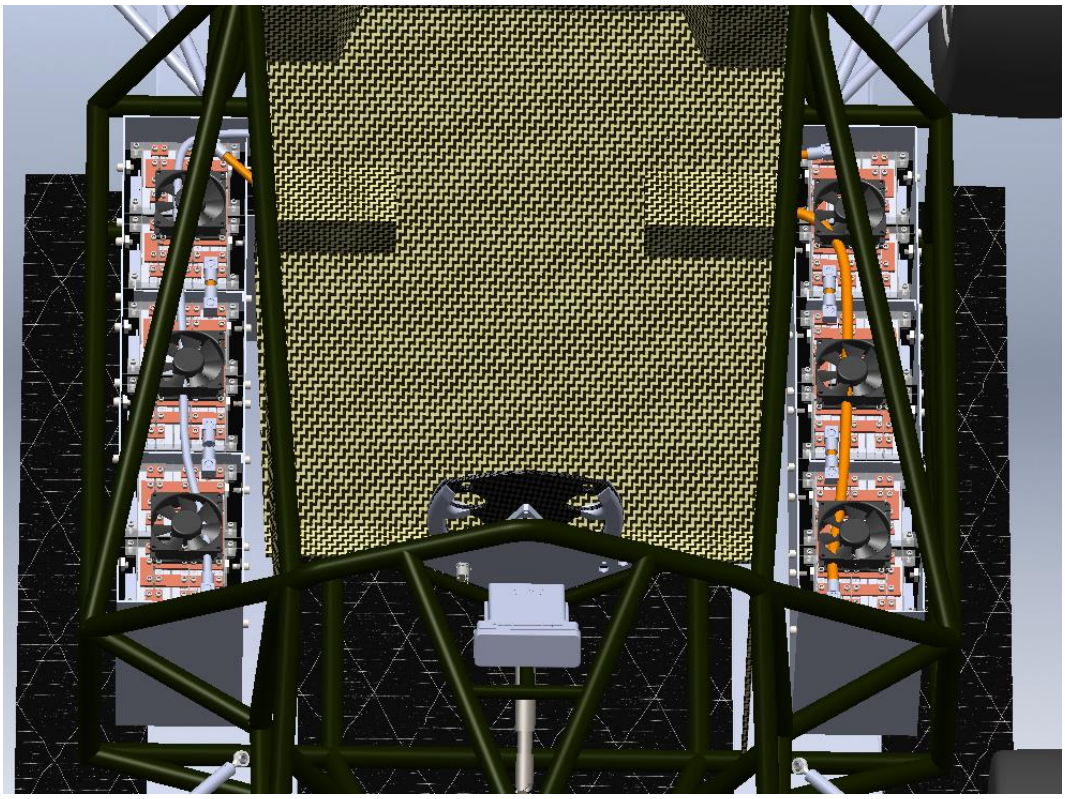
The accumulator design features two separate contains each housing 140 cells along with accompanying components and PCBs. These containers are designed to be easily removable for charging and servicing. The HV warning sticker for these accumulators will be positioned on the exterior walls near the HV connector. The connectors being used in the design incorporate an interlock, however additionally these connectors will be zip tied to ensure full connection with the port. The housing of the container is made up of 5 components; 3 side panels, 1 floor plate, and 1 lid. To minimize the number of fasteners used in the overall assembly, bending of the side walls was utilized. Where the 3 side walls mate are 3 bolted joints where 3 ¼" bolts are used to secure them. Flanges were also designed to mate with the floor plate and the corresponding jointed connection rules were followed. The lid of the housing is secured via 6 bolts to ensure the lid is secure to the rest of the housing. The accumulator will also have holes/ports for cooling aspects. Holes are included in both the lid and the bottom plate, these holes enable for an even flow of air through the cell segment walls. The holes on the lid mate with 24 volt PC fans that use filters and tubing to the front intake to ensure water is not leaked into the container. The holes on the bottom exit to an area that does not experience water and therefore not necessary to seal.

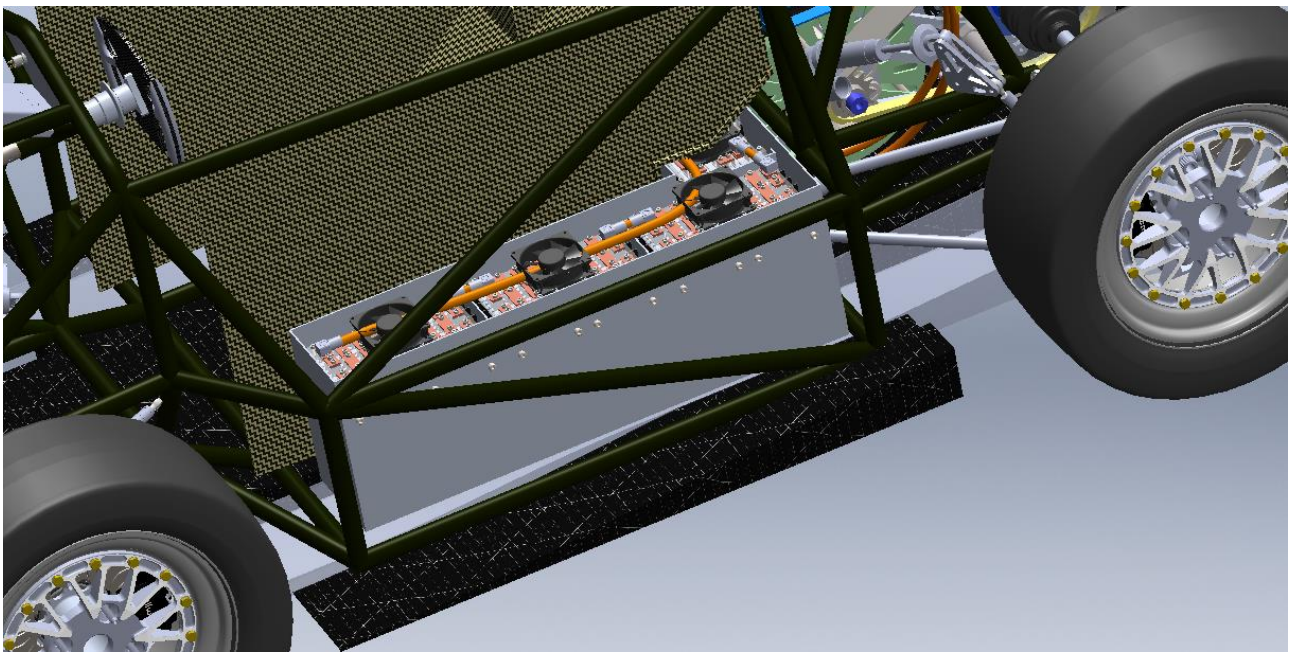
The design of the battery segments incorporates an array of aluminum partitions. These partitions interlock with each other and are fastened into the accumulator via bolts to the sidewalls. The partitions are designed and assembled in such a way so that cells are compressed to an allowable pressure and thus ensuring that they are securely in place inside the segment wall assembly. The electrical tabs of the cells are connected using a series of copper busbars. The busbar width (0.600") and thicknesses (0.0625" and 0.125") were determined using formulas from the current that will be witnessed in through the cells. The busbars themselves are secured via a bolted method that incorporates a steel mounting plate with a threaded hole to accept the bolt that runs through the busbar and the cell tabs. The bolts are locked to the busbar with a Belleville Washer to increase the distribution of pressure to the busbar and to ensure loosening doesn't occur over time. The busbars are oriented to the cell segments via an acrylic pattern that is mechanically attached to the top of the segment wall assembly. These acrylic patterns create electrical separation/insulation between the busbars and thus prevents arching. Terminal rings will be used to route the current sense from the cells to the BMS and these will be secured underneath the bolt used to secure the busbar. The BMS boards for each electrical segment are located along the vertical sides of the segment wall assembly. To connect the electrical segments together in accordance to the rules quick disconnects were designed in. This quick disconnects satisfy the need for maintenance plugs because the electrical segments are under the 6MJ and 120V limit. We are using the 6648223-1 from TE with a boot to cover up the connector. Maintenance Plugs

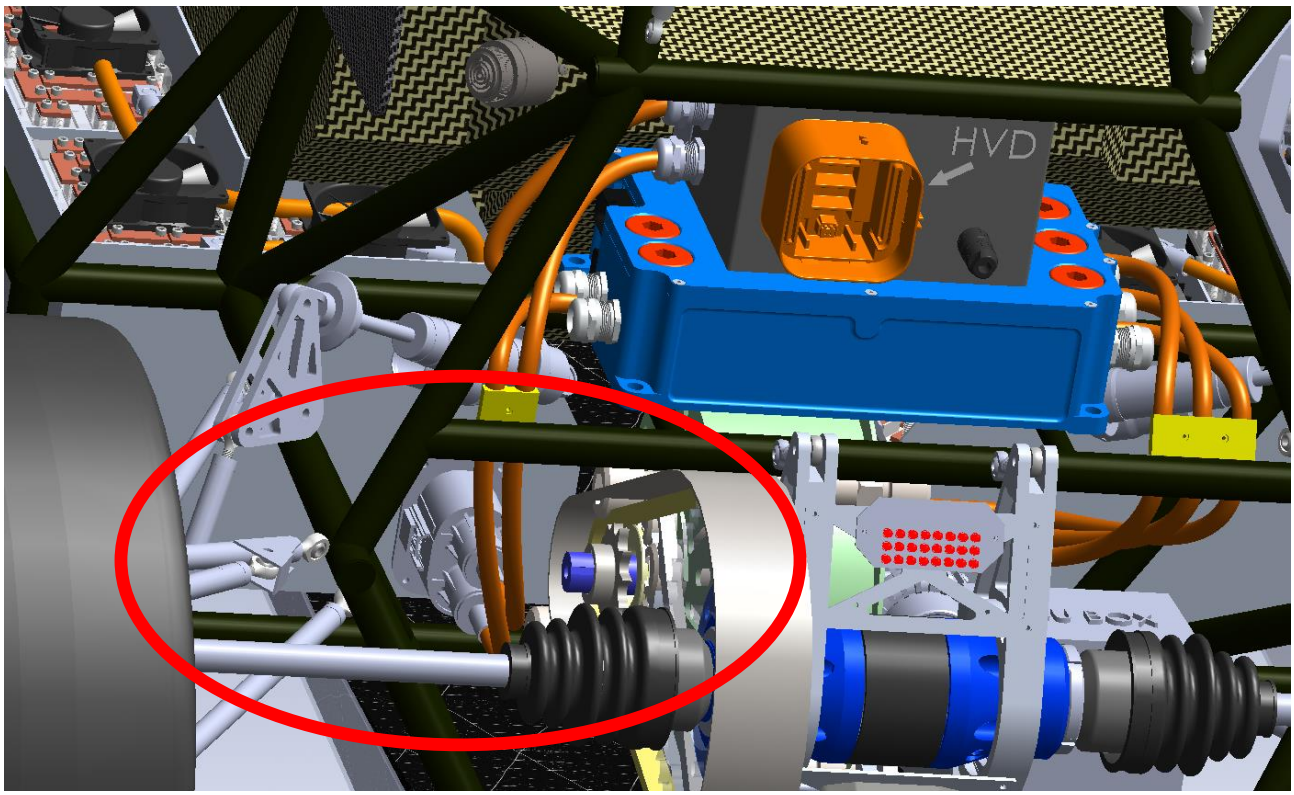
The accumulator features a separate compartment for components of the accumulator that need to be electrically isolated. Each compartment inside the accumulator is electrically isolated by aluminum dividers wrapped in Kapton tape. Inside this component compartment AIRs, fuses, connectors, relays, current sense, resistors among other are located. These components are arranged in a way to prevent low voltage wiring from violating the 1.2" electrical insulation requirement. Also included in this compartment is the Indicator Light, which is positioned directly

above connector. This indicator light is of the panel mounted variation, therefore it can simply secure against the side of the accumulator wall.

### 3.1.12 Position in car








## 3.2 Accumulator pack 2

We don't have two separate packs

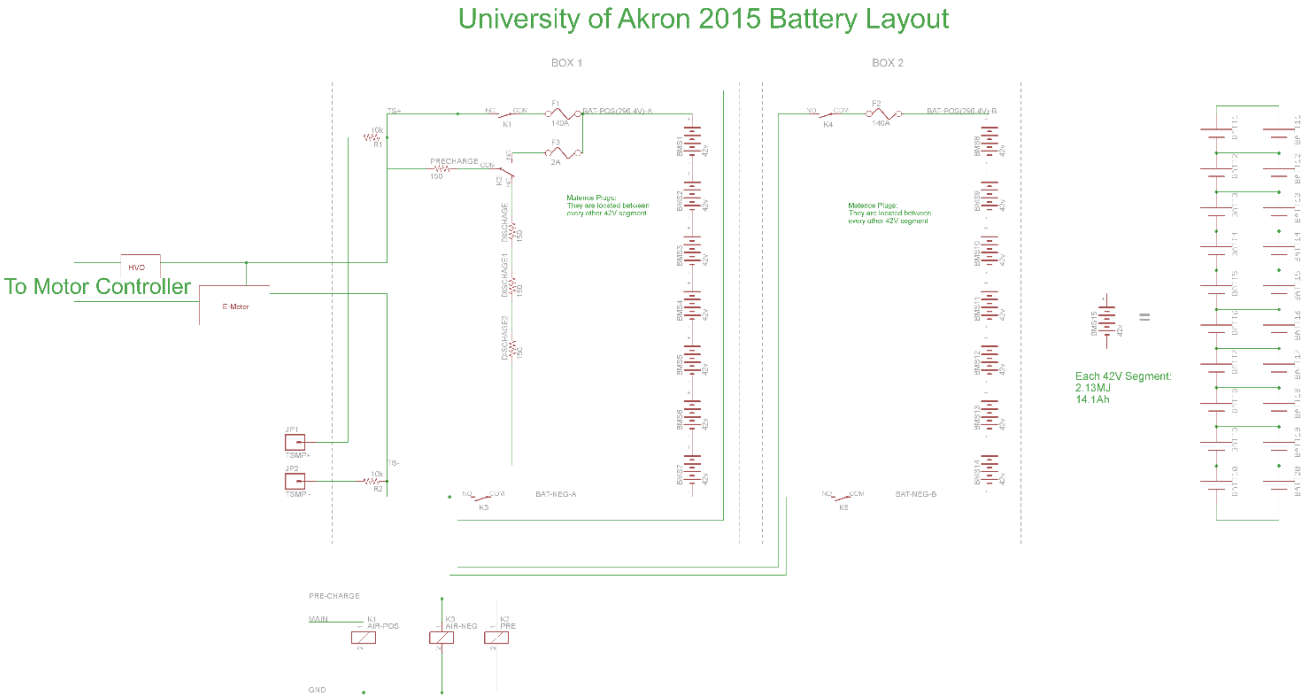
# Energy meter mounting

## 3.3 Description

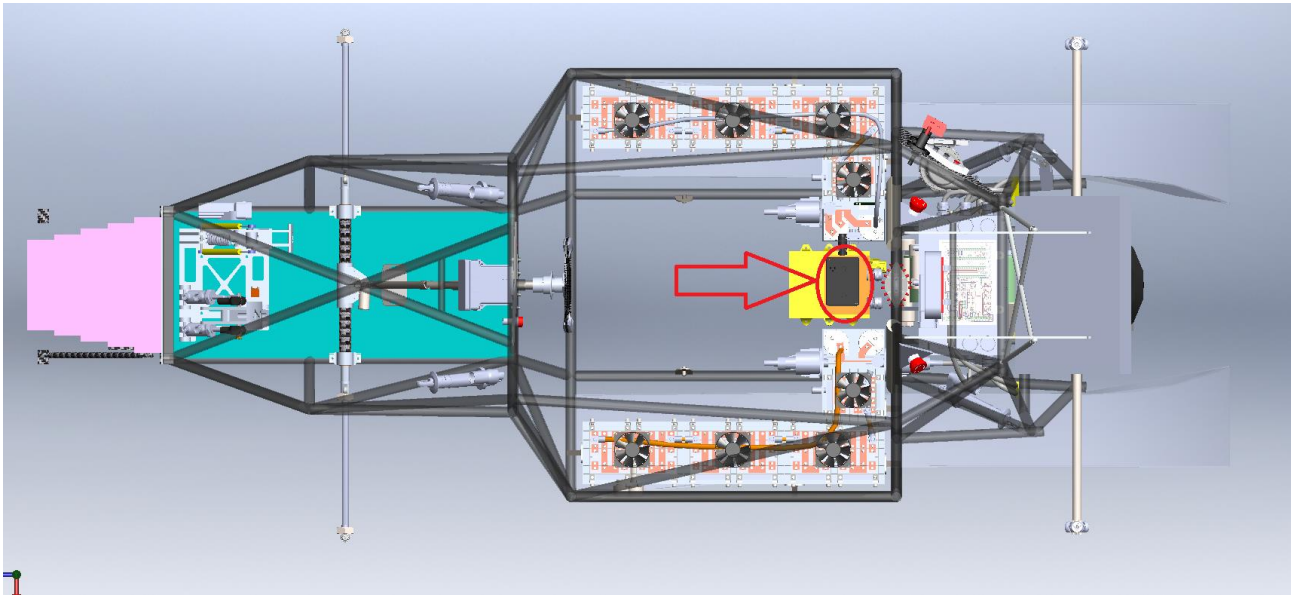
Energy Meter will be connected between the ground of the accumulator and motor controller. It will measure the total energy used and calculate the efficiency.

## 3.4 Wiring, cables, current calculations, connectors

All connections to the accumulator, the motors, and the energy meter are all Exrad XLE 2 cable.
We have a 1A fuse between the TS+ and the HV sense input on the box.



## 3.5 Position in car



# 4 Motor controller

## 4.1 Motor controller 1

### 4.1.1 Description, type, operation parameters

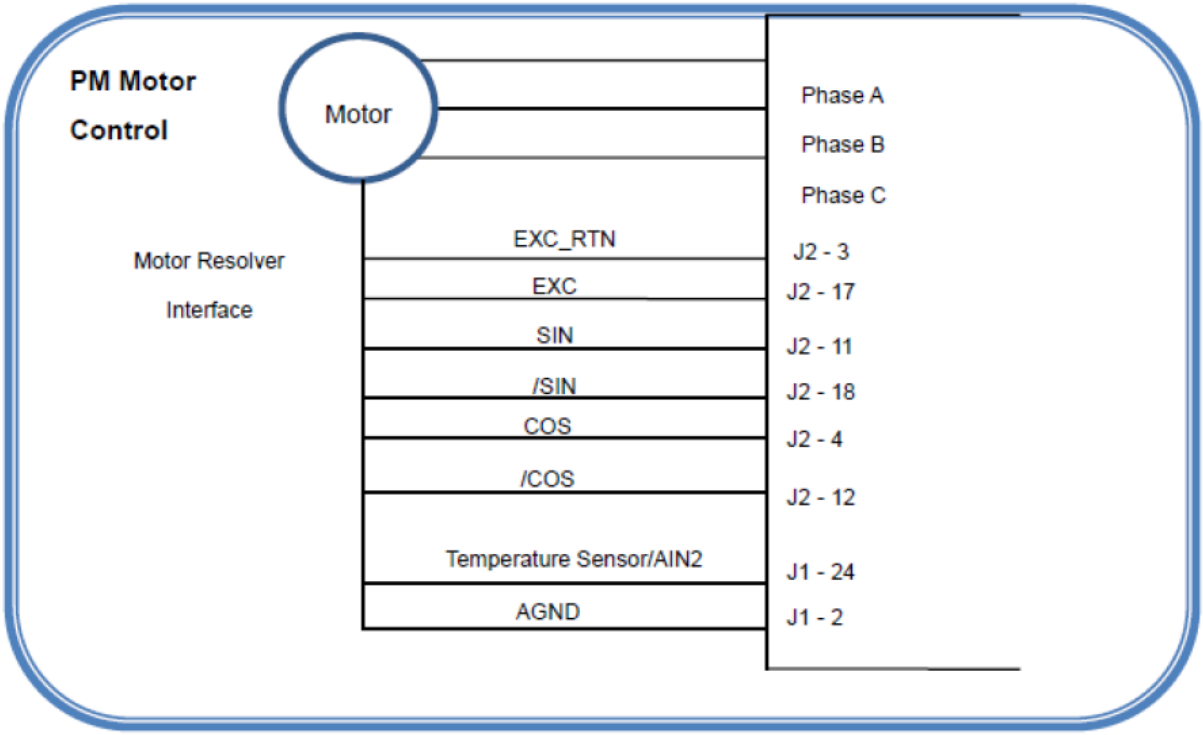
The PM100DX from Rinehart Motion Systems we are using are permanent magnet brushless AC motor controllers. They are capable of 0-360V and 300Arms. The motor controllers are commanded via analog signals sent by our self-designed motor controller PCB (MCS). It communicates over a RS485 communication bus from the ECU. The motor controllers also control the regenerative braking of the car. This is set from hardware controlled by our software. The controllers are isolated. Because of that, nothing connecting to them needs isolated from chassis ground.

| | |
|---|---|
| Motor controller type: | RMS PM100DX brushless AC |
| Maximum continous power: | 108kW |
| Maximum peak power: | 126kW for 30s |
| Maximum Input voltage: | 360VDC |
| Output voltage: | 250VAC |
| Maximum continuous output current: | 300Arms |
| Maximum peak current: | 350Arms for 30s |
| Control method: | analog signal |
| Cooling method: | water |
| Auxiliary supply voltage: | 12VDC |

*Table 4.1 General motor controller data*

### 4.1.2 Wiring, cables, current calculations, connectors

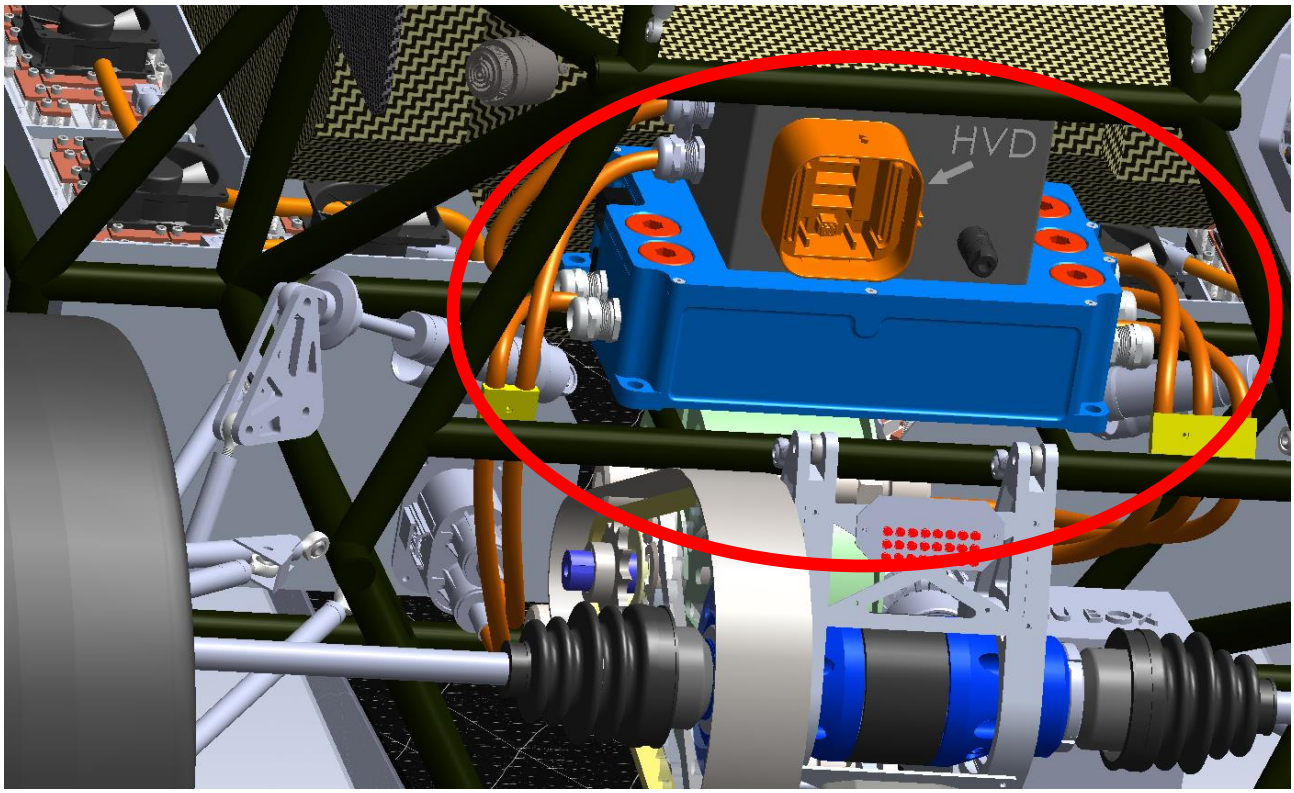
All connections to the accumulator, the motors, and the energy meter are all Exrad XLE 2 cable. The motor controller will do all of our shield grounding for us on the High power cable. They go through grounding cable glands. This makes a sealed connection. The conductor is clampe in a bus bar in the motor controller.




| | |
|---|---|
| Wire type: | Champlain Exrad xlx2x |
| Current rating: | 255A |
| Maximum operating voltage: | 1000V |
| Temperature rating: | 240 °C |

*Table 4.2 Wire data of company A, 0.205 mm²*

### 4.1.3 Position in car




## 4.2 Motor controller 2

There is only one motor controller.

.

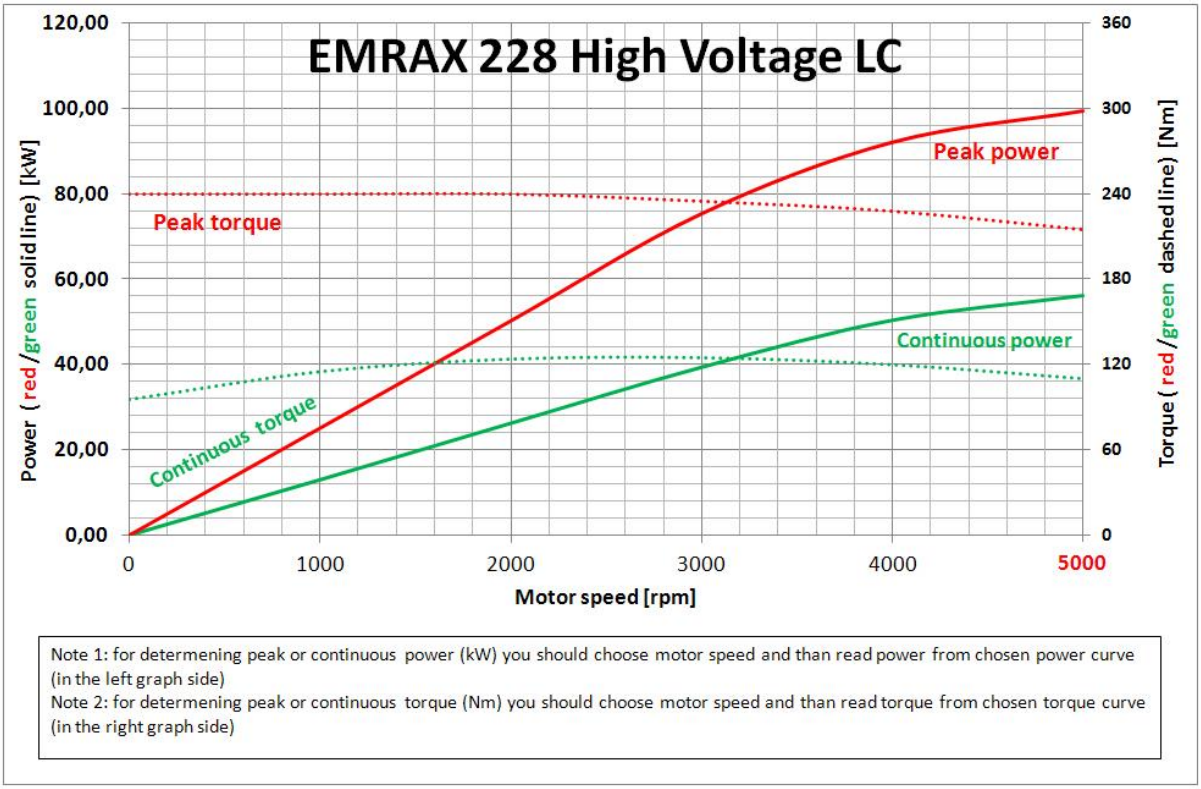
# 5 Motors

## 5.1 Motor 1

### 5.1.1 Description, type, operating parameters

| | |
|---|---|
| Motor Manufacturer and Type: | Enstroj EMRAX228 HV |
| Motor principle | Brushless Synchronus Three Phase AC |
| Maximum continuous power: | 45kW |
| Peak power: | 100kW for 3s |
| Input voltage: | 50-600Vdc |
| Nominal current: | 115A |
| Peak current: | 240A |
| Maximum torque: | 240Nm |
| Nominal torque: | 125Nm |
| Cooling method: | Water |

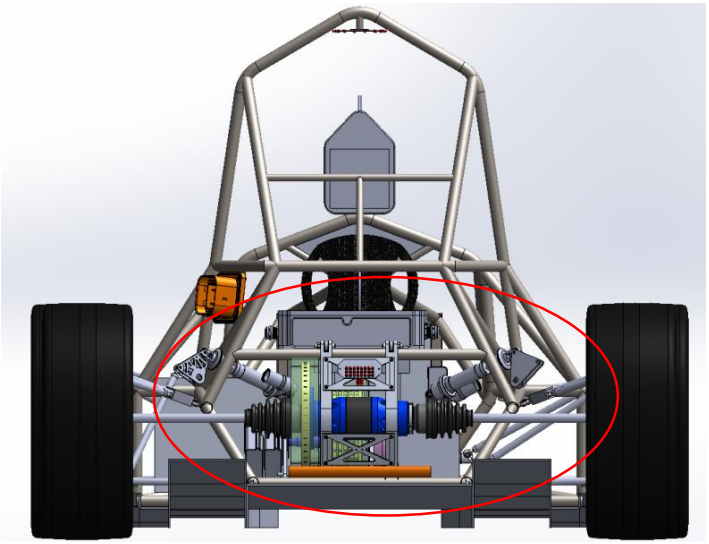
*Table 5.1 General motor data*

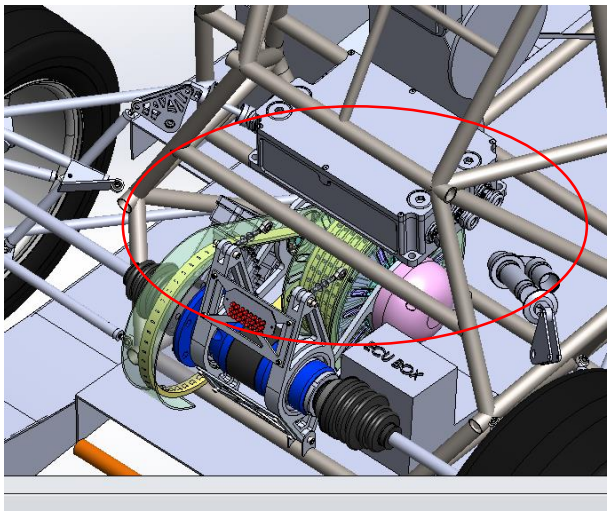



### 5.1.2 Wiring, cables, current calculations, connectors

The three shielded wires coming to the motor have 90 degree crimp terminals and then bolted on to the connections to the motor. We are adding locking nuts to prevent looseness of the connection. We are 3D printing a cover that goes over these terminals to provide isolation spacing and protect people.

### 5.1.3 Position in car





## 5.2 Motor 2

We only have one motor in the car.

# 6 Torque encoder

## 6.1 Description/additional circuitry

The two CLS1322-075 sensors are linear displacement sensor. They will be connected to the throttle pedals of the vehicle. As the pedal moves the sensor will slide with the pedal and provide an analog output to the system. That output will be sent as an input to a conditioning circuit. Once conditioned, the signal will be sent to the main controller.

| | |
|---|---|
| Torque encoder manufacturer and type: | CLS1322-075 |
| Torque encoder principle: | potentiometer |
| Supply voltage: | 3.3V |
| Maximum supply current: | 20mA |
| Operating temperature: | -20..180 °C |
| Used output: | 150mV-3.2V |

*Table 6.1 Torque encoder data*

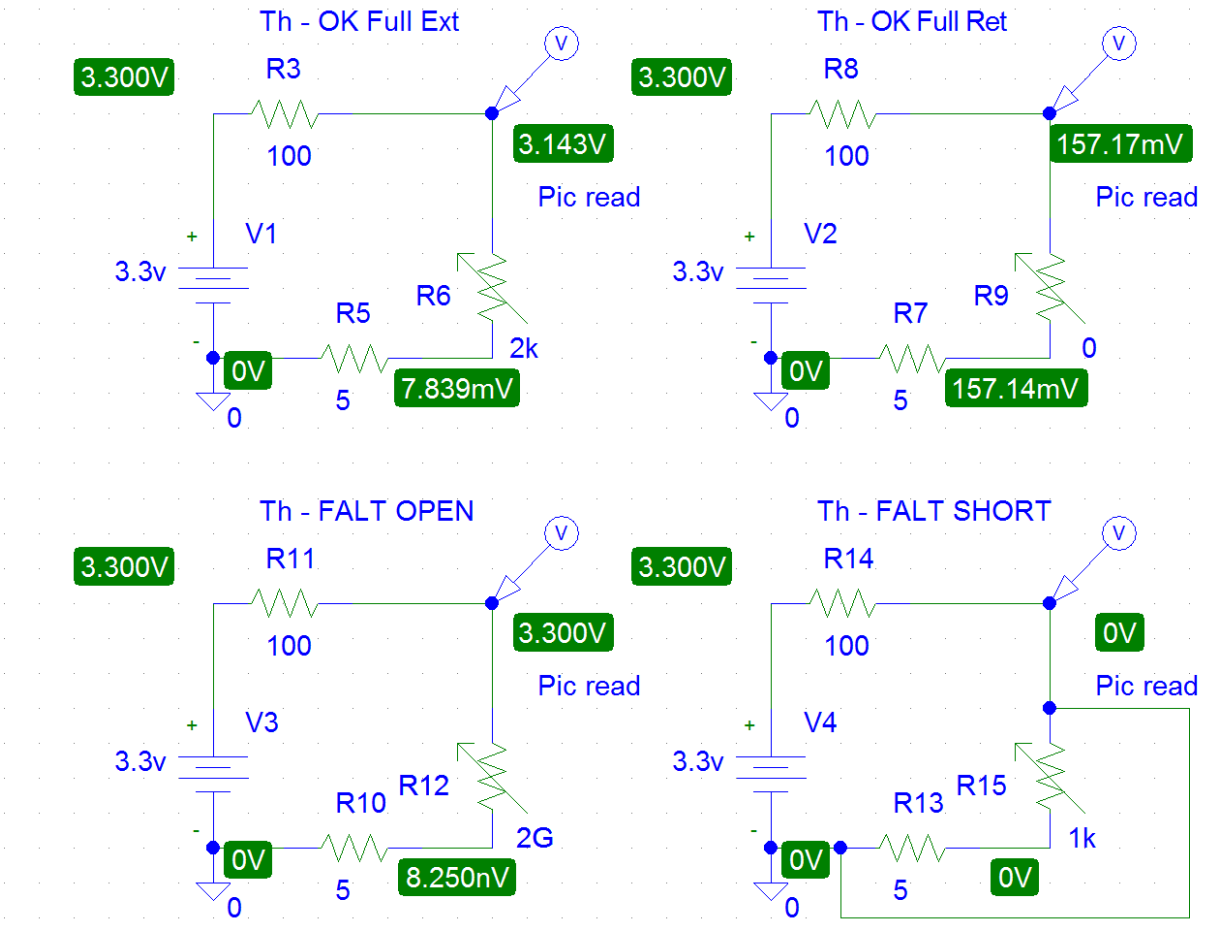
## 6.2 Torque Encoder Plausibility Check

If an error occurs in the measuring requested torque from the throttle pedal the main controller will shut the vehicle down. A number of errors could occur. If the communication is lost between the SAS (Where the analog signal is measured) and ECU the car will be shutdown (AIR's opened). If at any time the conditioning circuit is shorted or becomes open the controller will see the loss of signal and shut the car down. If the outputs of the two potentiometers differ by more than 10% the vehicle will be shut down as stated in the rules.

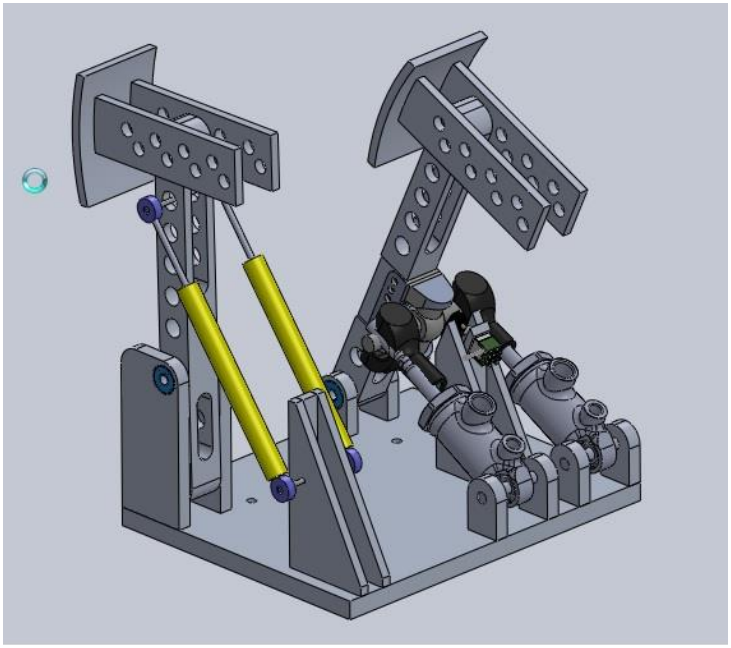
We check for above failures by first, monitoring data integrity by using check sums in serial data and in code. We monitor position sensors integrity by using the sensors as rheostats and adding a 5 ohm resistor in series with the sensor. We added a 100 ohm pull up on the ADC pin. With the sensor connected to the ADC pin to ground we can measure all fault modes.

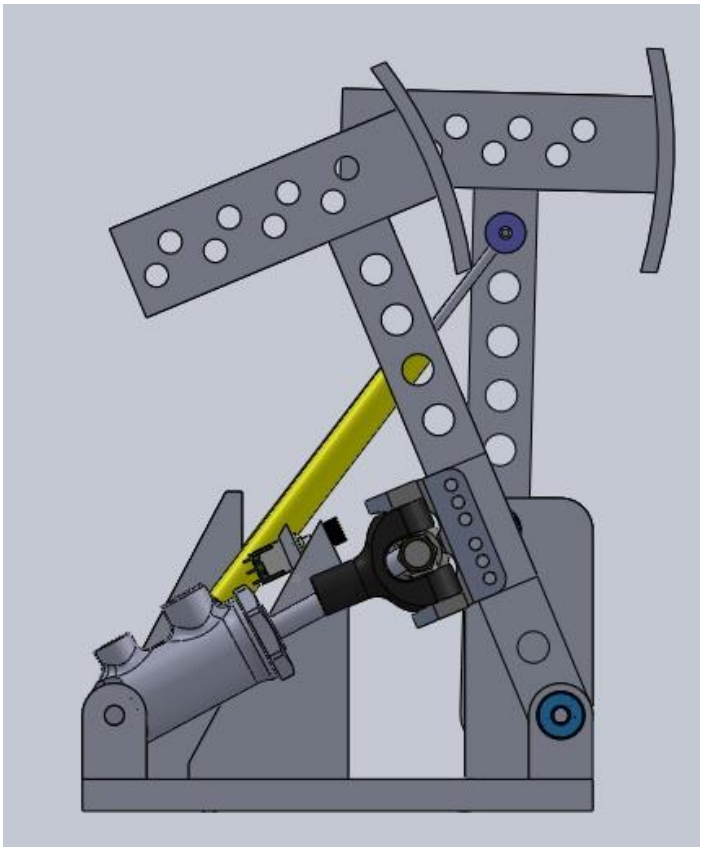
The analog output to the motor controller is made created by an I2C DAC. It is buffered by an op-amp. That signal goes to a SPDT relay. The output to the motor controller is on the common pin. The DAC is connected to the NO pin. The NC pin is pulled to ground. The uC reads the DAC to verify output matched set point. If they match, the relay opens and stays open as long as the car is on and output matches set point.

## 6.3 Wiring


Th - OK Full Ext
3.300V
R3
100
3.143V
Pic read
V1
3.3v
R5
R6
2k
0V
7.839mV
5
0
Th - OK Full Ret
3.300V
R8
100
157.17mV
Pic read
V2
3.3v
R7
R9
0
0V
157.14mV
5
0
Th - FALT OPEN
3.300V
R11
100
3.300V
Pic read
V3
3.3v
R10
R12
2G
0V
8.250nV
5
0
Th - FALT SHORT
3.300V
R14
100
0V
Pic read
V4
3.3v
R13
R15
1k
0V
0V
5
0

## 6.4 Position in car/mechanical fastening/mechanical connection





# 7 Additional LV-parts interfering with the tractive system

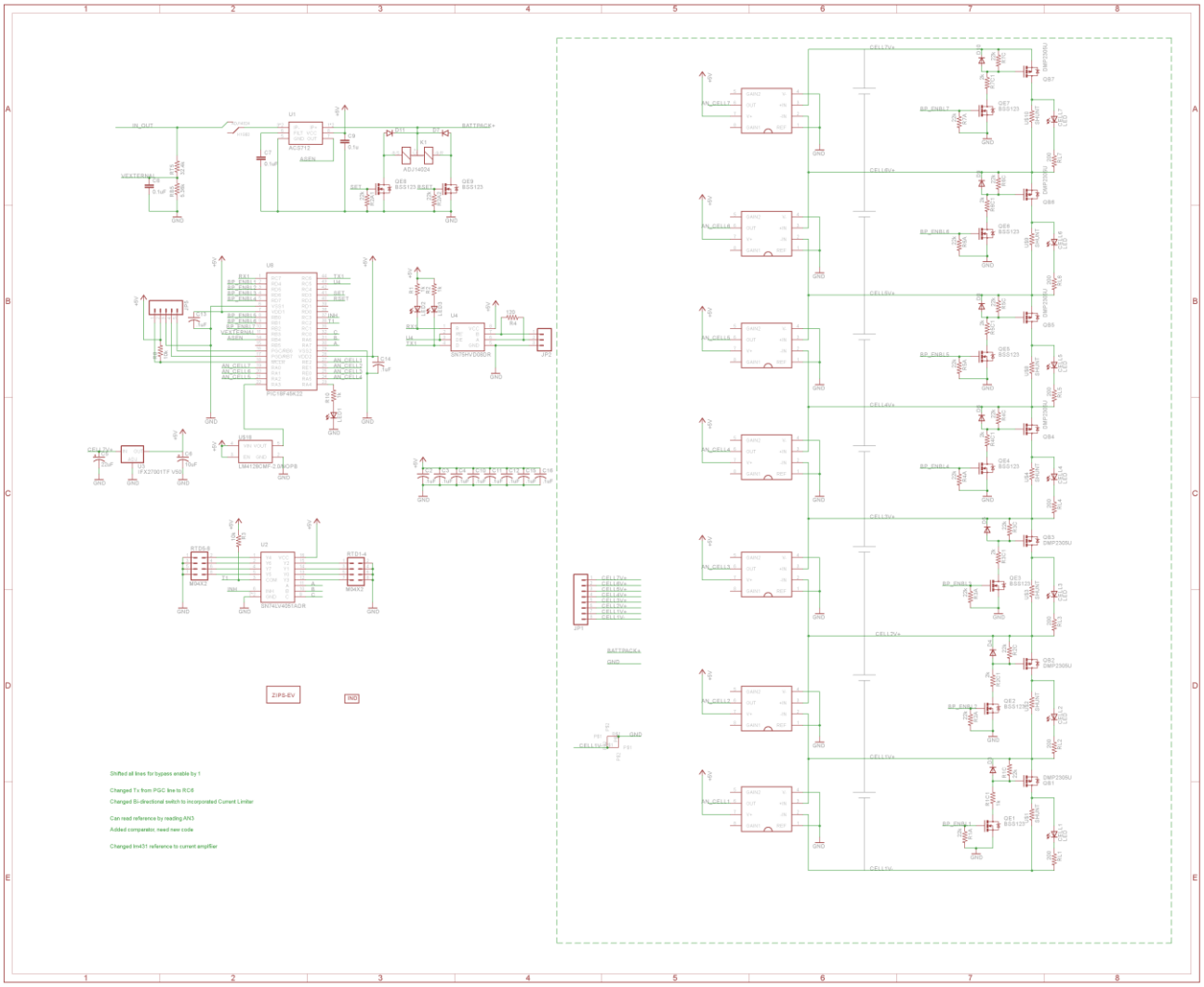
## 7.1 LV part 1 – GLVS

Our GLVS is powered by a custom battery pack. This pack is protected by a student designed battery management system that is from a reference design from Design Flux Technologies.

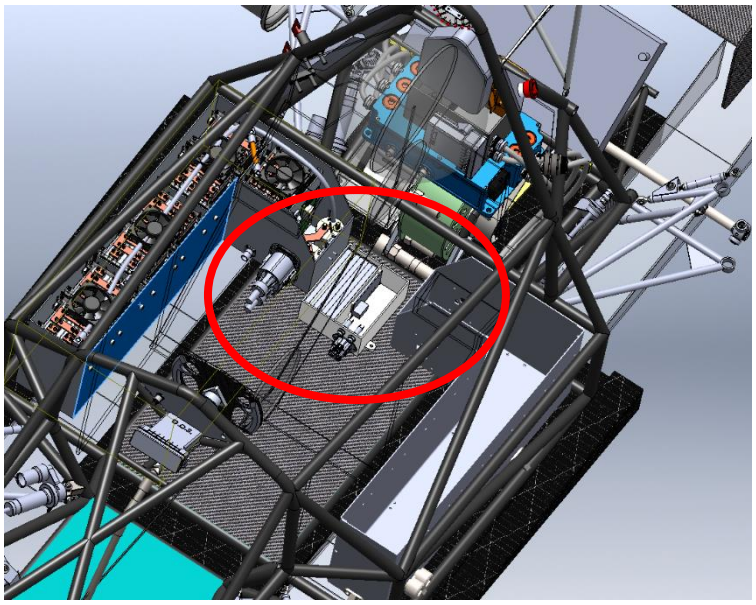
### 7.1.1 Description

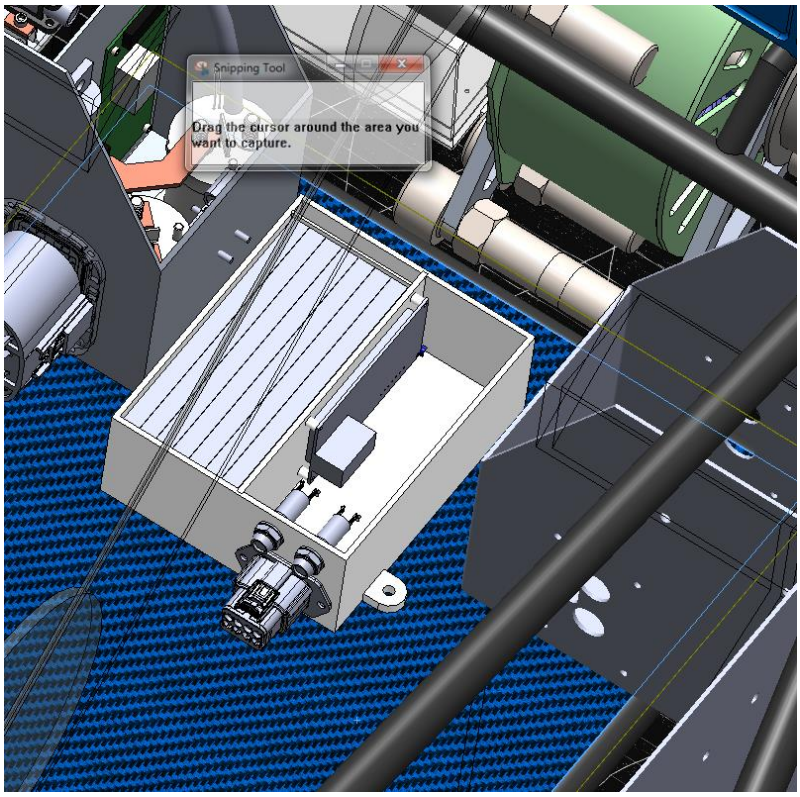
7cells will be monitored by the BMS that we made ourselves. The BMS is capable of opening a relay to disconnect the pack. The BMS will monitor cells for minimum voltage of 2.75v and a maximum of 4.2. Our BMS will take actions to bypass the affected cell(s) of higher voltage and shutdown the GLVS system if necessary. The BMS also reacts to temperature problems at 60°C. The BMS can also measure current and trigger the safety system. There is a wire going between the BMS PCB and the Battery pack.

### 7.1.2 Wiring, cables,



### 7.1.3 Position in car





## 7.2 LV part 2

N/A

# 8 Overall Grounding Concept

## 8.1 Description of the Grounding Concept

The chassis is made from conductive chrome-moly and will provide low resistance paths through the frame. The steering wheel will have a ground wire thru the disconnect to insure low resistance. Firewalls will be mounted to the car with tabs welded to the frame. The tabs will have paint removed to make a solid electrical connection to the firewall

## 8.2 Grounding Measurements

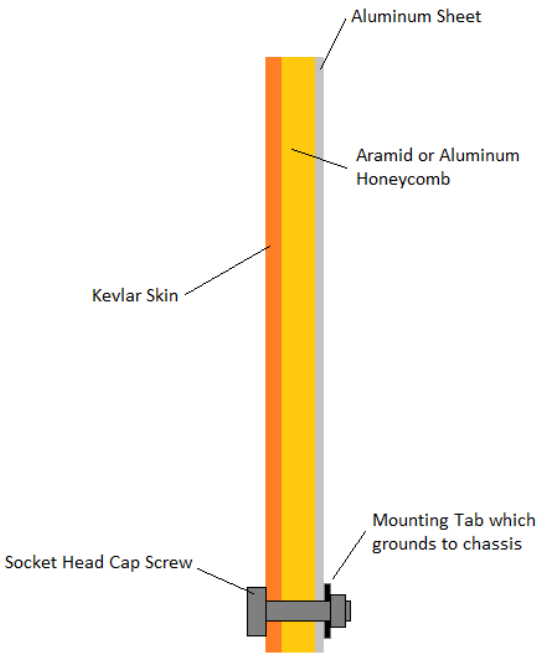
GLVMP location. GLV battery lead comes out and lands on a frame bolt.

# 9 Firewall(s)

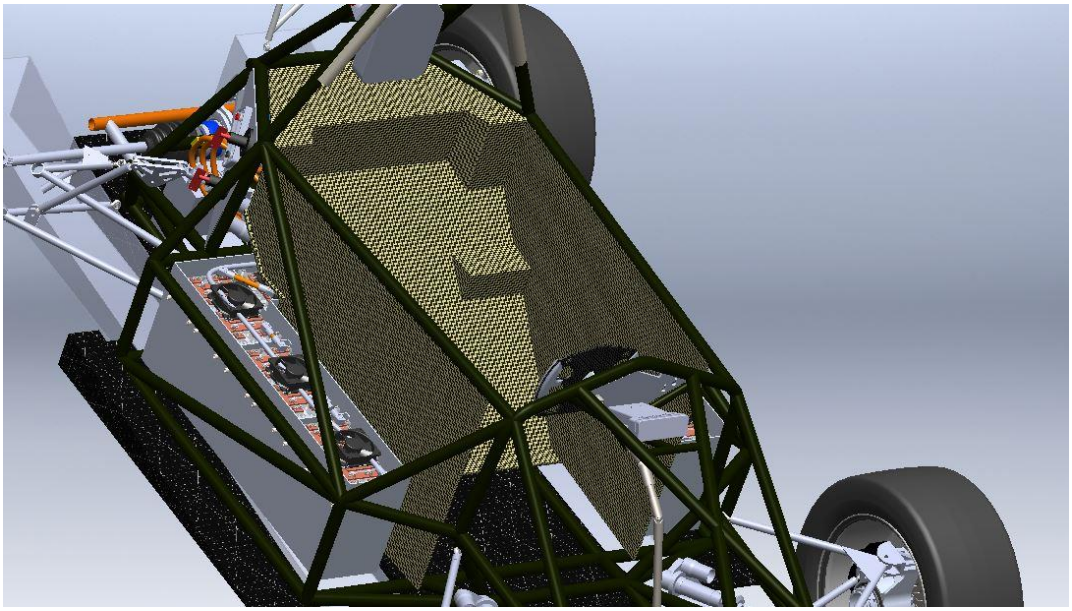
## 9.1 Firewall 1

### 9.1.1 Description/materials

The Tractive System Firewall serves purpose of not only protecting the driver from potential hazard, but also supporting the driver in the car. Because the seat is molded foam and not rigidly mounted to the chassis, the firewall must be capable of supporting the driver's torso and seat throughout the dynamic events. The proposed firewall is a composite structure consisting of fire retardant materials. This allows us to make a stiff panel that is also fire resistant. The concept, attached below, consists of an aluminum skin (0.5 mm thick) facing the HV components (per the required firewall rules) and fire resistant core materials, followed by a Kevlar skin. A thick kevlar skin will be sufficient in preventing piercing of the firewall, and the honeycomb structure will give the panel enough stiffness to support the loads required. The firewall is grounded to the chassis via the mounting system used to secure it to the chassis. This consists of Socket head cap screws through the firewall and tabs welded directly to the chassis. In the event that this grounding method is not sufficient, a properly sized grounding strap will be added to the aluminum skin to which travels to the chassis.



### 9.1.2 Position in car



## 9.2 Firewall 2

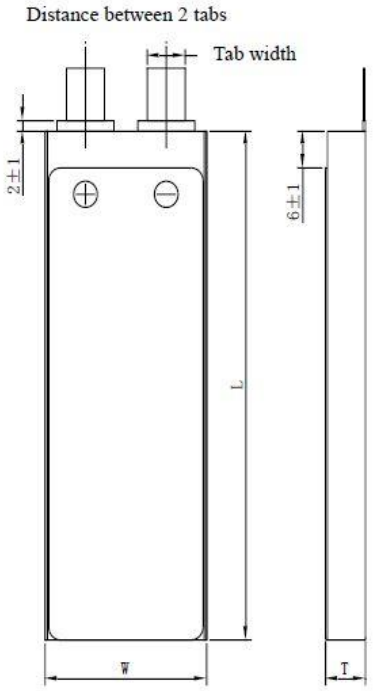
We only have one firewall in the car.

# 10 Appendix

## 10.1 HV Battery Cell Datasheet

**3. 产品规格 SPECIFICATION**

单颗电池规格 Specifications of single cell




| | | |
|---|---|---|
| ◆标称容量 Typical Capacity① | | 7.05Ah |
| ◆标称电压 Nominal Voltage | | 3.7V |
| ◆ 充电条件 Charge Condition | 最大持续电流充电 Max. Continuous charge Current | 14.1A |
| | 峰值充电 Peak Charge current | 28.2A(≤1sec) |
| | 电压 Voltage | 4.2V±0.03V |
| ◆ 放电条件 Discharge Condition | Max Continuous Discharge Current | 141A |
| | Peak Discharge Current | 176.25A |
| | Cut-off Voltage | 3.0V |
| ◆交流内阻 AC Impedance(mOHM) | | <2.0 |
| ◆循环寿命【充电:1.0C,放电:20C】 Cycle Life【CHA:1.0C,DCH:20C】 | | >100cycles |
| ◆使用温度 Operating Temp. | 充电 Charge | 0℃~45℃ |
| | 放电 Discharge | -20℃~60℃ |
| ◆ 电芯尺寸 Cell Dimensions | 厚度 Thickness(T) | 8.8±0.3mm |
| | 宽度 Width(W) | 45±0.5mm |
| | 长度 Length(L) | 181.5±0.5mm |
| | 极耳间距 Distance between 2 tabs | 21±1mm |
| ◆ 极耳尺寸 Dimensions of Cell tabs | 极耳宽度 Tab Width | 15mm |
| | 极耳厚度 Tab Thickness | 0.2mm |
| | 极耳长度 Tab Length | Max 30mm |
| ◆重量 Weight(g) | | 157.5±2 |
| ①标称容量：0.5CmA,4.2V~3.0V@23℃±2℃ Typical Capacity:0.5CmA,4.2V~3.0V@23℃±2℃ | | |

http://www.melasta.com/product.asp?lie=Lithium%20polymer%20battery

## 10.2 AIR

### Product Facts

- **Designed to be the smallest, lightest weight, lowest cost sealed contactor in the industry with its current rating (500+A carry, 2000A interrupt at 320VDC).**
- **Built-in coil economizer – only 1.7W hold power @ 12VDC and it limits back EMF to 0V. Models requiring extenal economizer also available.**
- **Optional auxiliary contact for easy monitoring of power contact position.**
- **Hermetically sealed – intrinsically safe, operates in explosive/harsh environments with no oxidation or contamination of coils or contacts, including long periods of non-operation.**
- **Versatile coil/power connections.**
- **CE marked for EC applications.**
- **AIAG QS9000 designed, built and approved**

CE

c UL us File E208033


**EV200 Series Contactor (CZONKA® Relay, Type III)**

**Typical EV200 applications include battery switching and back-up, DC voltage power control, circuit protection and safety.**

For factory-direct application assistance, dial 800-253-4560, ext. 2055, or 805-220-2055.

### 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<br>*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. | A | 2A @ 30VDC / 3A @ 125VAC |
| Aux. Contact Current, Min. | mA | 100mA @ 8V |
| Aux. Contact Resistance, Max. | ohms | 0.417 @ 30VDC / .150 @ 125VAC |
| Operate Time @ 25°C | | |
| Close (includes bounce), Typ. | ms | 15 |
| Bounce (after close only), Max. | ms | 7 |
| Release (includes arcing), Max @ 2000A | ms | 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) |

| 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)

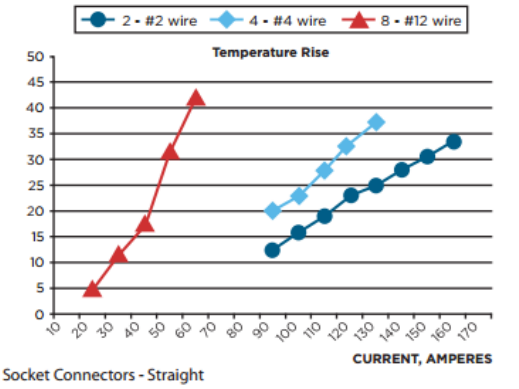
**Coil Terminal Connector:**
N = None

http://www.te.com/catalog/pn/en/1618002-7

## 10.3 Maintenance Plugs

RAPID LOCK Quick Connect/Disconnect Bus Bar Connectors

- Replacement for threaded studs
- No loose nuts = no fretting/heat rise
- Quick connect/disconnect
- Safety locking feature
- Currents from 50A to 250A
- Wire sizes from 2.5 to 95mm²
- Color coding available
- Straight and right angle versions




Pin Connectors Swage

| Type | Type | Size | Current Rating | Part No |
|---|---|---|---|---|
| Pin Contact | Swage | #8 | 50A | 6648221-1 |
| Pin Contact | Swage | #4 | 120A | 6648222-1* |
| Pin Contact | Swage | #2 | 150A | 5648223-1 |
| Pin Contact | Swage | 12mm | 250A | 1857523-3 |

Pin Connectors Screw and Washer

| Type | Type | Size | Current Rating | Part No |
|---|---|---|---|---|
| Pin Contact | Screw & Washer | 2085957-1* | #4 | 120A |
| Pin Contact | Screw & Washer | 6648226-1 | #2 | 150A |

Insulation Boots

| Part No | Size | Color |
|---|---|---|
| 1651003-1 | #4 #8 | Black |
| 1651003-2 | #4 #8 | Red |
| 1651003-3 | #4 #8 | Grey |
| 1651003-4 | #4 #8 | Blue |
| 1766600-1 | #2 | Black |
| 1766600-2 | #2 | Red |
| 1766600-3 | #2 | Grey |
| 1766600-4 | #2 | Blue |

Socket Connectors - Straight

| Type | Size | Wire Size | Current Rating | Color | Part No |
|---|---|---|---|---|---|
| Straight housing | #8 | | | Black | 1643279-1 |
| Straight housing | #8 | | | Red | 1643279-2 |
| Straight housing | #8 | | | Blue | 1643279-3 |
| Straight receptacle contact | #8 | #8 | 50A | | 6648317-1 |
| Straight housing | #4 | | | Black | 1651766-1 |
| Straight receptacle contact | #4 | #4 | 120A | | 6648434-1 |

Socket Connectors - Right Angle

| Type | Part No | Size | Wire Size | Current Rating | Color |
|---|---|---|---|---|---|
| Right Angle Socket | 6648228-1 | #8 | #8 | 50A | Black |
| Right Angle Socket | 6648228-2 | #8 | #8 | 50A | Red |
| Right Angle Socket | 6648237-1 | #8 | #12 | | Black |
| Right Angle Socket | 6648235-1 | #4 | #4 | 120A | Black |
| Right Angle Socket | 6648235-2 | #4 | #4 | 120A | Red |
| Right Angle Socket | 6648239-1 | #4 | #6 | | Black |
| Right Angle Socket | 6648239-2 | #4 | #6 | | Red |
| Right Angle Socket | 6648236-1 | #4 | #8 | | Black |
| Right Angle Socket | 6648236-2 | #4 | #8 | | Red |

*Part numbers listed are examples of some available samples, please visit website for additional and mating part numbers

More info at :
http://www.te.com/catalog/bin/TE.Connect?C=24079&M=PPROP&P=&BML=10576,17560,17685,17694&LG=1&PG=1&IDS=471845,471847,471618,471851,471619,471623,434075,434076,471634,434073,471631,434071,471620,471621,471622,471624,434074,434059,434061,434072&N=5

## 10.4 HV cable


Ampacity 150°C rated single-insulated conductor in free air at 40°C ambient air temperature.

| Product Number | Standard Conductor Bare Copper | Nom. Dia Cond. in. | Nom. Dia Cond. mm. | Nom. Dia. Primary insulation in. | Nom. Dia. Primary insulation mm. | Nom. Dia Shield in. | Nom. Dia Shield mm. | Nom. Dia. Outside in. | Nom. Dia. Outside mm. | Shield Coverage | Min. Static Bend Radius | Finished Weight (lbs/mft) | Ampa -city |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EXRAD-XLX10X | 10 (105/30) | .112 | 2.84 | .162 | 4.11 | .184 | 4.67 | .234 | 5.94 | 95% | 30mm | 59.0 | 80 |
| EXRAD-XLX8X | 8 (133/29) | .166 | 4.22 | .236 | 5.99 | .254 | 6.45 | .304 | 7.72 | 95% | 39mm | 92.0 | 106 |
| EXRAD-XLX6X | 6 (133/27) | .195 | 4.95 | .265 | 6.73 | .283 | 7.19 | .333 | 8.46 | 95% | 42mm | 126.0 | 155 |
| EXRAD-XLX4X | 4 (133/25) | .242 | 6.15 | .312 | 7.92 | .330 | 8.37 | .390 | 9.91 | 95% | 50mm | 187.0 | 190 |
| EXRAD-XLX2X | 2 (665/30) | .318 | 8.08 | .388 | 9.86 | .410 | 10.41 | .490 | 12.45 | 95% | 60mm | 295.0 | 255 |
| EXRAD-XLX1X | 1 (779/30) | .346 | 8.79 | .446 | 11.33 | .469 | 11.91 | .529 | 13.44 | 95% | 95mm | 335.0 | 293 |
| EXRAD-XLX1/0X | 1/0 (1007/30) | .390 | 9.91 | .500 | 12.70 | .528 | 13.41 | .588 | 14.91 | 95% | 105mm | 412.0 | 339 |
| EXRAD-XLX2/0X | 2/0 (1254/30) | .438 | 11.13 | .558 | 14.17 | .586 | 14.83 | .666 | 16.92 | 95% | 115mm | 534.0 | 390 |
| EXRAD-XLX3/0X | 3/0 (1615/30) | .475 | 12.07 | .595 | 15.11 | .623 | 15.82 | .703 | 17.86 | 95% | 125mm | 620.0 | 451 |
| EXRAD-XLX4/0X | 4/0 (2107/30) | .602 | 15.29 | .722 | 18.34 | .750 | 19.05 | .830 | 21.08 | 95% | 150mm | 876.0 | 529 |

CHAMPLAIN CABLE
Colchester, Vermont www.champcable.com

**Manufacturing Locations:**
**Colchester, Vermont**
**El Paso, TX**
**Leeds, Massachusetts**

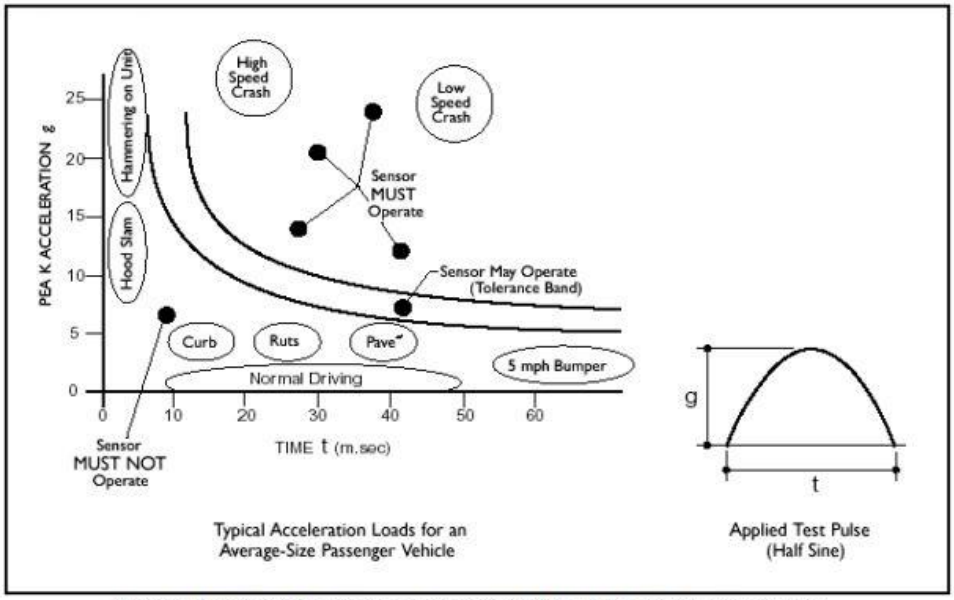
More information at
http://www.champcable.com/product_pdfs/14_SAE_XLE_Shielded_High_Voltage.pdf

## 10.5 Crash Sensor

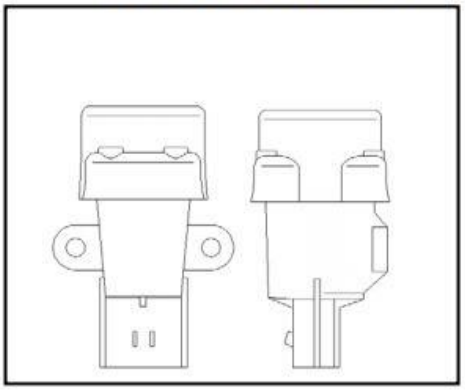
**Features:**

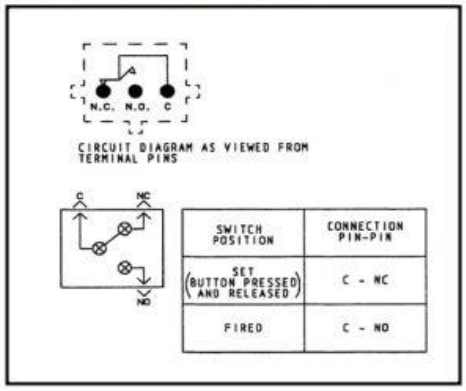
- Unique magnet restrained mass inertia mechanism
- Rated at 10 Amps electrical load
- Manually resettable

www.sensata.com Printed in U.S.A., December 2010




Above are the typical performance characteristics of resettable crash sensors






http://www.sensata.com/download/resettable-crash.pdf

## 10.6 IMD

Referred from 2.1.1.

**Technical data**

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

Complete data sheet located at: [http://www.bender-de.com/fileadmin/products/doc/IR155-32xx-V004_DB_en.pdf](http://www.bender-de.com/fileadmin/products/doc/IR155-32xx-V004_DB_en.pdf)

## 10.7 HV Fuse

# POWR-GARD® Fuse Datasheet

Littelfuse
Expertise Applied | Answers Delivered

## CLASS T – JLLN / JLLS SERIES FUSES

300/600 VAC • Fast-Acting • 1-1200 A

### Description

JLLN / JLLS fuses are less than ⅓ the size of comparable Class R fuses and are typically used for short circuit protection of drives and surge sensitive components. When rated in accordance with the NEC®, JLLN / JLLS fuses provide fast-acting overload and short circuit protection for non-inductive circuits and equipment.

### Features/Benefits

- Extremely current-limiting
- Compact design
- 200 kA Interrupting Rating

### Applications

- Variable speed drive protection
- Compact mains switches

### Specifications

**Voltage Ratings**
AC: 300 V (JLLN)
600 V (JLLS)
DC: 160 V (JLLN 1 – 60 A)
125 V (JLLN 70 – 1200 A)
300 V (JLLS)

**Interrupting Ratings**
AC: 200 kA rms symmetrical
DC: 20 kA (JLLN 35-1200 A only)

**Ampere Range**
1 – 1200 A

**Approvals**
AC: Standard 248-15, Class T
UL Listed (File: E81895):
JLLN (1 – 1200 A)
JLLS (1 – 800 A)
UL Recognized (File: E71611)
JLLN PCB Mount (35 – 60 A)
JLLS (900 – 1200 A)
CSA Certified (File: LR29862)
JLLN/JLLS (1 – 600 A)
DC: UL Listed (File: E81895):
JLLN (35 – 1200 A)
Littelfuse self-certified
JLLN (1 – 30 A)
JLLS (1 – 1200 A)

**Environmental**
RoHS Compliant
(Note: Not all amperages are RoHS compliant. Contact the factory for additional details.)

### Ordering Information

| AMPERE RATINGS | | | | | |
|---|---|---|---|---|---|
| 1 | 25 | 70 | 175 | 450 | 1100 |
| 2 | 30 | 80 | 200 | 500 | 1200 |
| 3 | 35 | 90 | 225 | 600 | |
| 6 | 40 | 100 | 250 | 700 | |
| 10 | 45 | 110 | 300 | 800 | |
| 15 | 50 | 125 | 350 | 900* | |
| 20 | 60 | 150 | 400 | 1000 | |

*JLLS only

### Part Numbering System

JLLN xxxx V –

- JLLN: Series
- xxxx: Amperage
- V: Package Quantity
  - T = 10 (1-60 A)
  - V = 5 (70-100 A)
  - X = 1 (110-1200 A)
- –: Options
  - Blank = Standard Non-Plated
  - XP = Premium Plated
  - XL = Leaded[1]
  - XV = Vertical Mount[1]
  - XLS = Solder Lead[1]

| SERIES | AMP | PACK SIZE | PLATING SUFFIX | MOUNT SUFFIX | CATALOG NUMBER | ORDERING NUMBER |
|---|---|---|---|---|---|---|
| JLLS | 6 | T | – | – | JLLS006 | JLLS006T |
| JLLN | 35 | V | – | XL[1] | JLLN035L | JLLN035VXL |
| JLLN | 100 | V | XP | – | JLLN100P | JLLN100VXP |

[1]Option is available for JLLN 35-60 A only. Premium plating is standard

### Web Resources

Download TC Curves, CAD drawings and other technical information: **littelfuse.com/jlln**
**littelfuse.com/jlls**

### Recommended Fuse Holders

LFT30 Series
LFT60 Series
LSCR Series for 700-800 A

### Dimensions

Please refer to the Class T dimensions on page 4

## 10.8 Motor Controller

RINEHART MOTION SYSTEMS LLC
7929 SW Burns Way, Suite B, Wilsonville, OR 97070 503.344.5085

**AC Motor Controller for Electric and Hybrid Vehicles**

**Product Summary**

The Rinehart Motion Systems LLC (RMS) PM Family of AC Motor Controllers are designed for on- and off-road Electric (EV) or Hybrid Electric (HEV) applications. The motor controller converts the DC power from the vehicle ESS (Energy Storage System / Battery) to the 3-phase AC required by the motor. These Traction drives are fabricated using a patented high heat flux thermal design approach that dramatically reduces the size and weight of the finished drive, and improves its life in the automotive environment. With extensive experience in automotive and military vehicle traction and power electronics applications, RMS has achieved a major breakthrough in integrating Motor Control into a vehicle.

RMS offers several different models within the PM Family of motor controllers to suit the DC bus voltage and motor current requirements of your specific vehicle. The PM Family has been designed to operate with many types of motors, including Induction Motors (IM) and Permanent Magnet motors (PMSM or IPM). Contact RMS for the latest list of motors supported by our controllers. The Drive can also be tuned to your new motor - contact the factory for more information.

The primary difference between models in the PM Family is the rated voltage and current (ultimate power output):

| Controller Model | PM100DX | PM100DZ | PM100DXR * | PM150DX | PM150DZ |
|---|---|---|---|---|---|
| Maximum DC Voltage – operating | 360 V | 720 V | 400 V | 360 V | 720 V |
| Maximum DC Voltage – non-operating | 500 V | 900 V | 500 V | 500 V | 900 V |
| Motor Current Continuous | 300 Arms | 150 Arms | 300 Arms | 450 Arms | 225 Arms |
| Motor Current Peak ** | 350 Arms | 200 Arms | 450 Arms | 450 Arms | 300 Arms |
| DC Bus Capacitance | 440 µF | 280 µF | 440 µF | 880 µF | 560 µF |
| Size | See drawing | See drawing | See drawing | See drawing | See drawing |
| Weight | 7.5 kg | 7.5 kg | 7.5 kg | 10.7 kg | 10.7 kg |
| Minimum Conductor Size | 4 AWG | | | 2 AWG | 4 AWG*** |
| Maximum Conductor Size | 1 AWG | | | 3/0 AWG | 1 AWG |
| Minimum Cable O.D. | 9.0 mm | | | 11.0 mm | |
| Maximum Cable O.D. | 16.5 mm | | | 21.0 mm | |

* The PM100DXR is only available for special applications (i.e. racing), use must be approved by RMS.

** Peak current is defined as a maximum of 30 seconds.

*** Depending on cable, it may be necessary to add additional sleeve to cable to meet the minimum Cable O.D. of the cable gland.

http://www.rinehartmotion.com/files/Download/PM_Datasheet_01052012.pdf

## 10.9 Motor

**EMRAX 228 Technical Data Table**

| Type / Technical data | EMRAX 228 High Voltage | | | EMRAX 228 Medium Voltage | | | EMRAX 228 Low Voltage | | |
|---|---|---|---|---|---|---|---|---|---|
| Air cooling = AC<br>Liquid cooling = LC<br>Combined cooling = Air + Liquid cooling = CC | AC | LC | CC | AC | LC | CC | AC | LC | CC |
| Ingress protection | IP21 | IP65 | IP21 | IP21 | IP65 | IP21 | IP21 | IP65 | IP21 |
| Cooling medium specification (Air Flow = AF; Water Flow = WF – if inlet water temperature and/or ambient temperature are lower, then continuous power is higher) | AF speed 25 m/s; 25°C | inlet WF 8 l/min - 40°C; ambient air 25°C | inlet WF 8 l/min - 40°C; ambient air 25°C | AF speed 25 m/s; 25°C | inlet WF 8 l/min - 40°C; ambient air 25°C | inlet WF 8 l/min - 40°C; ambient air 25°C | AF speed 25 m/s; 25°C | inlet WF 8 l/min - 40°C; ambient air 25°C | inlet WF 8 l/min - 40°C; ambient air 25°C |
| Weight [kg] | 12,0 | 12,3 | 12,3 | 12,0 | 12,3 | 12,3 | 12,0 | 12,3 | 12,3 |
| Diameter ø / width [mm] | 228 / 86 | | | | | | | | |
| Battery voltage range [Vdc] | 50 – 600 (*700 – to get 6500 RPMp) | | | 50 – 450 (*540 – to get 6500 RPMp) | | | 24 – 150 (*180 – to get 6500 RPMp) | | |
| Peak motor power (few min at cold start / few seconds at hot start) [kW] | **100** | | | | | | | | |
| Continuous motor power (depends on the motor RPM 3000 - 5000) [kW] | 28 - 42 | 28 - 42 | 35 - 55 | 28 - 42 | 28 - 42 | 35 - 55 | 28 - 42 | 28 - 42 | 35 - 55 |
| Maximal rotation speed [RPM] | 5500 (*6500 RPM peak) | | | | | | | | |
| Maximal motor current (for 2 min if cooled as described in Manual for EMRAX) [Arms] | 240 | | | 340 | | | 900 | | |
| Continuous motor current [Arms] | 115 | | | 160 | | | 450 | | |
| Maximal motor torque (for a few seconds) [Nm] | 240 | | | | | | | | |
| Continuous motor torque [Nm] | 125 | | | | | | | | |
| Torque / motor current [Nm/1Aph rms] | **1,1** | | | **0,75** | | | **0,27** | | |
| Maximal temperature of the copper windings in the stator and also max. temp. of the magnets [°C] | 120 | | | | | | | | |
| Motor efficiency [%] | 93 – 98 | | | | | | | | |
| Internal phase resistance at 25 °C [mΩ] | 18 | | | 8,0 | | | 1,12 | | |
| Input phase wire cross-section [$mm^2$] | 10,2 | | | 15,2 | | | 38 | | |
| Induction in Ld/Lq [µH] | 175/180 | | | 75/80 | | | 10,6/11,2 | | |
| Controller / motor signal | sine wave | | | | | | | | |
| Specific idle speed (no load RPM) [RPM/1Vdc] | 9,8 | | | 14 | | | 40 | | |
| Specific load speed (depends on the controller settings) [RPM/1Vdc] | 8 – 9,8 | | | 11 – 14 | | | 34 – 40 | | |
| Magnetic field weakening (for higher RPM at low torque) [%] | up to 100 | | | | | | | | |
| Magnetic flux – axial [Vs] | 0,0542 | | | 0,0355 | | | 0,0131 | | |
| Temperature sensor in the motor | kty 81/210 | | | | | | | | |
| Number of pole pairs | 10 | | | | | | | | |
| Rotor inertia (mass dia=175mm, m=5,5kg) [kg*$cm^2$] | 421 | | | | | | | | |
| Bearings SKF _ FAG | R/R 6206/6206 or R/AR 6206/7206 or AR/AR 7206/7206 (»O« orientation) | | | | | | | | |

*For a few seconds.

Maximal battery voltage is 700 Vdc (EMRAX 228 High Voltage). Maximal RPM must not be exceeded.

It is possible to weaken the magnetic field (up to 100%) to get higher RPM at existing battery voltage. Maximal RPM must not be exceeded.

These data are valid for the motors, which were sold after January 2014.

EMRAX motors that had been made before May 2012 have 30% lower power/torque and RPM than new generation of EMRAX motors.

http://www.enstroj.si/Electric-products/emrax-228-motorsgen.html

## 10.10 Lov Voltage Battery

| Polymer Lithium-ion battery Product Specification | Doc. No. | Q/WMDCJ06011-2007 |
|---|---|---|
| | Edition No. | 1.0 |
| | Sheet | 1/6 |

**1、Scope:**

This product specification describes Wanma polymer lithium-ion battery. Please using the test methods that recommend in this specification. If you have any opinions or advices about the test items and methods, please contact us. Please read the cautions recommended in the specifications first, take the credibility measure of the cell's using.

If the cells should be using at the environment that not preferred in this document, please connect with our first and get our authorization.

It is claimed that we should have no any responsibility with the contingency and loss due to the cells' wrong usage (not preferred in the product specification).

**2、Product Type, Model and Dimension:**

2.1 Type: Polymer lithium-ion battery

2.2 Model: PL-9759156-5C( Cell or adding Cu tabs)

2.3 Cell Dimension with Torelence +/- 0.5mm (Thickness×Width×Length, $mm^3$): 9.8×59.5×157.0

Pack Dimension(Max, Thickness×Width×Length, $mm^3$): _____

**3、Specification:**

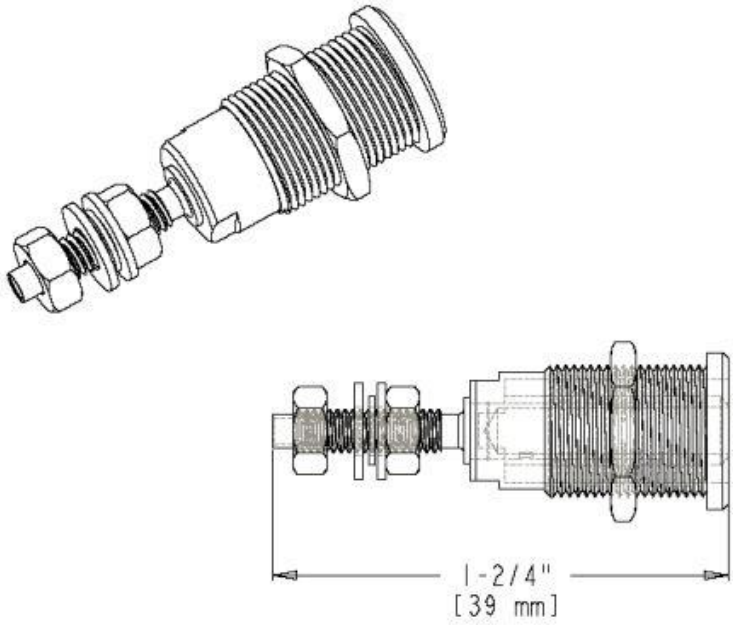
| Item | | Specifications | Remark |
|---|---|---|---|
| Nominal Capacity | | 10100 mAh | 0.2$C_5$A discharge |
| Typial Capacity | | 10000 mAh | 0.2$C_5$A discharge |
| Nominal Voltage | | 3.7V | Average Voltage at 0.2$C_5$A discharge |
| Charge Current | | Standard: 0.2 $C_5$A; Max: 1$C_5$A | Working temperature: 0~45℃ |
| Charge cut-off Voltage | | 4.200±0.05V | |
| Discharge Current | | Continuously:5$C_5$A; Max: 10$C_5$A | Working temperature: 0~60℃ |
| Discharge cut-off Voltage | | 2.75V | |
| Cell Voltage | | 3.7~3.9V | When leave factory |
| Impedance | | ≤15mΩ | AC 1KHz after 50% charge |
| Weight | | Approx210g | |
| Storage temperature | ≤1month | -20~45℃ | Best 20±5℃ for long-time storage |
| | ≤3month | 0~30℃ | |
| | ≤6month | 20±5℃ | |
| Storage humidity | | 65±20% RH | |

http://www.batteryspace.com/prod-specs/3.7V10Ah.pdf

## 10.11 TSMP

MUELLER

**Part Number:** BU-31607- *
**Description:** Screw-in Safety Socket with Stud and Metal Nut
1308




- Screw-in Safety Socket with Stud and Metal Nut
- Material: Hardware: nickel-plated brass; Insulator: ABS-nylon composite
- Length: 1.53" (39 mm)
- *Std. Colors: -0 Black, -2 Red
- Rating: 600Volts, category III, 1000Volts, category II, 45 Amps, IEC 1010 Compliant
- RoHS Compliant

*Mueller Electric Company*
*1625 E. 31st Street*
*Cleveland, Ohio 44114*

*ISO 9001:2000*
*Over 95 Years Of Innovation*
*www.muellerelectric.com*

*TEL. 800-955-2629*
*TEL. 216-771-5225*
*FAX. 216-771-3068*

Full datasheet: http://muellerelectric.com/wp-content/uploads/DS-BU-31607-0.pdf

## 10.12 TSMP-Resistors

High Power Resistor

### Type SBC (Square Ceramic) Series

**Key Features**

- Up to 17 Watts
- Fusible Styles
- Vertical or Axial
- Non Flammable
- Special Solvent Resistance
- Customer Specials Invited
- Widely Available from Distribution

This range of Power Wirewound Resistors are wound on continuous glass fibre elements or have a ceramic core depending on resistance value. The element is housed in a ceramic case and sealed with an inorganic silica filler. Their construction gives a resistor with high insulation resistance and low surface temperature, capable of withstanding high overload currents. These resistors are ideally suited to a variety of applications within industrial and commercial environments, where performance and reliability are of prime importance. Applications include fan force ovens, cooker hoods, power supplies and triac based speed controls. Custom Design Variants in value and style are welcomed.

**Characteristics - Electrical**

| | |
|---|---|
| Resistance Values: | Series E24 5% E12 10% (see tables for value limits per style) |
| Resistance Tolerance: | ±5% ±10% |
| Maximum Continuous Voltage: | $\sqrt{P \times R}$ |
| Load Life: | ΔR <±3% 1000 hours at 70°C |
| Power Rating: | See Surface Temperature Curve (below) |

**Characteristics - Environmental and Mechanical**

| | |
|---|---|
| Temperature Coefficient of Resistance: | 200ppm/°C (400ppm/°C below 18R) |
| Resistance to Solder Heat: | ΔR < 0.2% (350°C for 2.5 seconds) |
| Voltage Coefficient of Resistance: | Negligible |
| Operating Temperature Range: | -55°C to +350°C |
| Load Stability: | ΔR < 5% (full load at 70°C for 1000 hours) |
| Long Term Damp Heat: | ΔR < 0.2% (21 days at 40°C for 93% humidity) |
| Shelf Life: | ΔR < 1.0% (per 12 months) |
| Insulation Resistance: | > 10000M |
| Dielectric Strength: | 2000V RMS |
| Lead Material: | Steel - Solder coat |
| Marking: | Legend mark, Manufacturer name, type, ohmic value and tolerance. |

Full datasheet:
http://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocNm=1773278&DocType=DS&DocLang=English

## 10.13 HVD

**AMP+ Manual Service Disconnect Fused Version**

**KEY FEATURES**

- Finger proof, touch safe
- Finger actuated - 2 stage lever assist latching
- No tool required to unmate
- 2x integrated internal HVIL
- Scalable design
- Current rating determined by fuse rating or shunt
- Available with integrated fuse up to 630A or with shunt
- USCAR-2, USCAR-37, IEC 60529, RoHS compliant
- Tested to 50 mating cycles
- Sealed

**TE Technical Support Center**

| | |
|---|---|
| Canada: | +1.905.470.4425 |
| C. America: | +52.0.55.1106.0814 |
| China: | +86.0.400.820.6015 |
| France: | +33.0.1.3420.8686 |
| Germany: | +49.0.6251.133.1999 |
| Great Britain: | +44.0.8706.080208 |
| India: | +91.80.285.40800 |
| Japan: | +81.44.844.8111 |
| Korea: | +82.2.3415.4500 |
| Mexico: | +52.0.55.1106.0814 |
| Netherlands: | +31.0.73.6246.999 |
| South America: | +55.0.11.2103.6000 |
| USA: | +1.800.522.6752 |

**te.com**



**APPLICATIONS**

- HV battery pack or remote location
- Energy storage systems (ESS)

**MECHANICAL**

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

**ELECTRICAL**

- Fuse rating: Up to 630A
- Voltage rating for fused version: 450 VDC
- Shunted version for higher voltages
- Operating temperature: -40 °C to 65 °C
- Storage temperature: -40 °C to 85 °C
- Current rating: Based on fuse selection

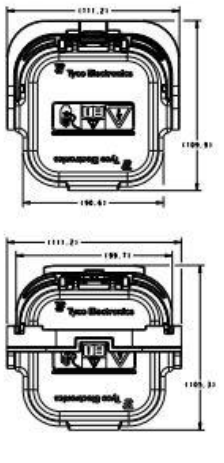
**STANDARDS AND SPECIFICATIONS**

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

**PRODUCT OFFERING**

| | |
|---|---|
| 1587987-8 | Receptacle Assembly, 200A, MSD |
| 2103172-8 | Plug Assembly, 200A, MSD, Market label |
| 1587987-9 | Receptacle Assembly, 250A, MSD |
| 2103172-9 | Plug Assembly, 250A, MSD, Market label |
| 1-1587987-1 | Receptacle Assembly, 350A, MSD |
| 1-2103172-1 | Plug Assembly, 350A, MSD, Market label |
| 1-1587987-7 | Receptacle Assembly, Shunt (No fuse), MSD |
| 1-2103172-7 | Plug Assembly, Shunt (No fuse), MSD, Market label |

**PRODUCT DIMENSIONS**



TE connectivity

Full Datasheet: [http://www.te.com/content/dam/te/global/english/industries/hybrid-electric-mobility-solutions/amp-msd-tech-sheet.pdf](http://www.te.com/content/dam/te/global/english/industries/hybrid-electric-mobility-solutions/amp-msd-tech-sheet.pdf)

## 10.14 E-Stop

### SSA-EB Series Emergency Stop Buttons

BANNER
more sensors, more solutions

**Datasheet**

Figure 1. SSA-EBM-xxE Series with Enclosure

Figure 2. SSA-EBP-xxE Series with Enclosure

- Push-to-stop, twist-to-release operation
- Rugged, modular design; easy assembly and installation
- Kits available for easy selection
- Choice of metal or plastic button base with or without enclosure; all kits include disc label with "Emergency Stop" legend
- Choice of normally closed (safety) or combination normally closed/normally open (non safety) contacts
- Latching design complies with ISO 13850; direct (positive) opening operation per IEC 60947-5-1

| Models | | Button Base Material | Contacts | Enclosure Included |
|---|---|---|---|---|
| SSA-EBM-02L |  | Metal | 2 normally closed | No |
| SSA-EBM-11L | | | 1 normally closed and 1 normally open | |
| SSA-EBM-12L | | | 2 normally closed and 1 normally open | |
| SSA-EBP-02L |  | Plastic | 2 normally closed | |
| SSA-EBP-11L | | | 1 normally closed and 1 normally open | |
| SSA-EBP-12L | | | 2 normally closed and 1 normally open | |
| SSA-EBM-02E |  | Metal | 2 normally closed | Yes |
| SSA-EBM-11E | | | 1 normally closed and 1 normally open | |
| SSA-EBM-12E | | | 2 normally closed and 1 normally open | |
| SSA-EBP-02E |  | Plastic | 2 normally closed | |
| SSA-EBP-11E | | | 1 normally closed and 1 normally open | |
| SSA-EBP-12E | | | 2 normally closed and 1 normally open | |

**Dimensions**

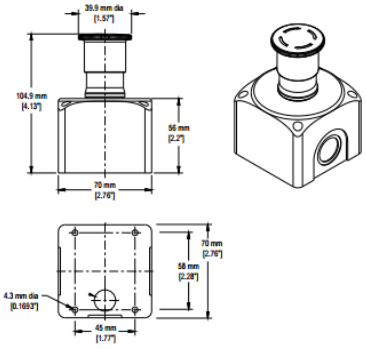



Figure 4. SSA-EBM-xxE and EBP-xxE Series E-Stop Buttons

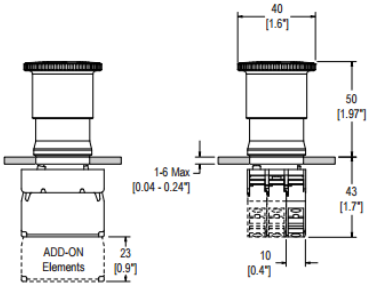



Figure 5. SSA-EBM-xxL and EBP-xxL Series E-Stop Buttons

Full Datasheet: http://info.bannersalesforce.com/cs/groups/public/documents/literature/111880.pdf

## 10.15 TSMS / HV sense wire

Enlarge

Images are for reference only
See Product Specifications

| | |
|---|---|
| **Mouser Part #:** | 602-6460-100-04 |
| **Manufacturer Part #:** | 6460 OR005 |
| **Manufacturer:** | Alpha Wire |
| **Description:** | Multi-Paired Cables 22AWG 2C SHIELD 100ft SPOOL ORANGE |

Add to Compare List

Share | 8+1 0

**Specifications** | **My Notes**

| | | |
|---|---|---|
| **Manufacturer:** | Alpha Wire | ☑ |
| **Product Category:** | Multi-Paired Cables | ☑ |
| **RoHS:** | RoHS Details | |
| **Number of Pairs:** | 1 | ☐ |
| **Wire Gauge - AWG:** | 22 AWG | ☐ |
| **Stranding:** | 7 x 0.0096 | ☐ |
| **Shielding:** | Shielded | ☐ |
| **Length:** | 100 ft | ☐ |
| **Voltage Rating:** | 300 V | ☐ |
| **Jacket Material:** | Polyvinyl Chloride (PVC) | ☐ |
| **Insulation Material:** | Polypropylene (PP) | ☐ |
| **Type:** | Industrial Automation | ☐ |
| **Jacket Color:** | Orange | ☐ |
| **Brand:** | Alpha Wire | |
| **Conductor Material:** | Tinned Copper | |

Full datasheet: http://www.mouser.com/ProductDetail/Alpha-Wire/6460-OR005/?qs=sGAEpiMZZMv1%2f%252b2kKkGMBdDOvp5WNg%252bt9emRXpKWYqs%3d

## 10.16 Hookup wire

Alpha Wire | 711 Lidgerwood Avenue, Elizabeth, NJ 07207
Tel: 1-800-52 ALPHA (25742), Web: www.alphawire.com

Request a Sample

# Customer Specification

# PART NO. 3050

### Construction

| | | Diameters (In) |
|---|---|---|
| 1) Component 1 | 1 X 1 HOOKUP | |
| a) Conductor | 24 (7/32) AWG Tinned Copper | 0.024 |
| b) Insulation | 0.016" Wall, Nom. PVC | 0.056+/- 0.002 |
| (1) Print | ALPHA WIRE E163869-* RU AWM STYLES 1569 105C<br>OR 1007 80C VW-1 300V 24 AWG ---- LXXXX CSA<br>TR-64 90C FT1 ROHS<br>{0} * = Factory Code<br>*[Note: Product may have c(UL) or CSA markings depending upon plant of manufacture.]* | |
| (2) Color(s) | WHITE, BLACK, RED, GREEN, YELLOW, BLUE, BROWN<br>ORANGE, SLATE, VIOLET, WHITE/BLACK, WHITE/RED<br>WHITE/GREEN, WHITE/YELLOW, WHITE/BLUE<br>WHITE/BROWN, WHITE/ORANGE, WHITE/SLATE<br>WHITE/VIOLET, GREEN/YELLOW, PINK | |

### Applicable Specifications

| | | |
|---|---|---|
| 1) UL | AWM/STYLE 1007 | 80°C / 300 $V_{RMS}$ |
| | AWM/STYLE 1569 | 105°C / 300 $V_{RMS}$ |
| | VW-1 | |
| 2) CSA International | TR-64 | 90°C |
| | FT1 | |

### Environmental

Full Datasheet: [http://www.alphawire.com/Home/Products/Wire/Hook-Up-Wire/Premium/3050?device=pdf](http://www.alphawire.com/Home/Products/Wire/Hook-Up-Wire/Premium/3050?device=pdf)