ESS Preliminary Design Review

May 20, 2015

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TABLE OF ACRONYMS

Table 1 Acronyms

Acronym	Meaning
BEV	Battery Electric Vehicle
BCM	Battery Control Module
CSM	Current Sense Module
CAD	Computer-aided Design

CD	Charge Depleting
CS	Charge Sustaining
DC	Direct Current
EDS	Emergency Disconnect Switch
EDM	Electronic Distribution Module
EMI	Electromagnetic Interference
ESS	Energy Storage System
EREV	Extended Range Electric Vehicle
EV	Electric Vehicle
Ft	Feet
FMEA	Failure Mode & Effects Analysis
G	Gravitational Constant
HV	High Voltage
HVAC	Heating, ventilation, and air conditioning
HVIL	High Voltage Interlock Loop
ICE	Internal Combustion Engine
IVM	Initial Vehicle Movement
Km	Kilometer
L	Liter
MSD	Manual Service Disconnect
MVEC	Multiplexed Vehicle Electric Center
NYSR	Non-Year Specific Rules
PHEV	Plug-in Hybrid Electric Vehicle
Sec	Second
RPN	Risk Priority Number
SOC	State of Charge
VTS	Vehicle Technical Specifications
UW	University of Washington
Wh	Watt-hour

PROJECT PLAN

ESS Timing Plan

Error! Reference source not found. shows the Energy Storage System (ESS) GANTT chart, which displays a time schedule of key activities

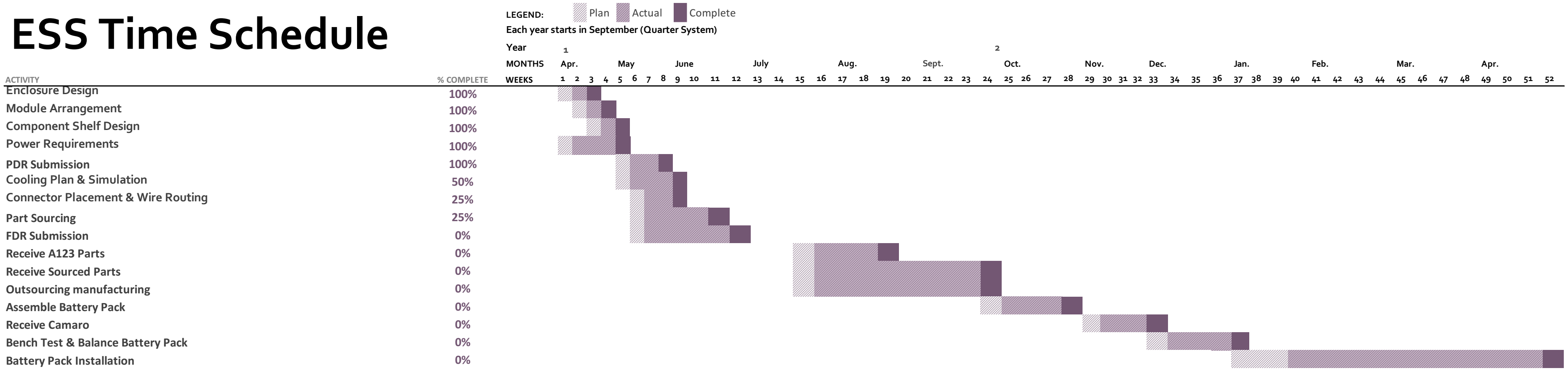


Figure 1 ESS GANTT chart

and tasks integral to the ESS design and integration process from year 1 through year 2. The legend at the top of each chart shows color-marked squares defining planning, actual, and complete stages of the project. The planning stage of a project defines setting up a procedure and deadline, which typically only takes a week depending on the activity. The actual stage of the project is when the team starts fulfilling the plan and implementing tasks. And the complete stage of the project marks the expected project deadline.

The design process begins in April of year 1 and finishes the battery pack integration process near the end of April of Year 2. Key battery pack design activities such as the enclosure design, module arrangement, component-shelf design, and power requirements are staggered across April all before Preliminary Design Review (PDR) Submission begins in early May. Once PDR and FDR Submission are complete, we plan to order these key components through A123 and various other sources in mid-July. At the beginning of Year 2 Fall Quarter, the electrical team will assemble, test, and adjust the Battery Pack until we receive the Chevrolet 2016 Camaro in late November or early December. Finally, the Battery Pack Installation is planned to begin in January and stretch through the end of April before Year 2 Competition.

ESS Design Management Process

The electrical lead, Jake Garrison, is primarily responsible for overseeing the battery pack design and integration in the Chevrolet 2016 Camaro that the UW EcoCAR will receive at the end of this year. The above GANTT chart broadly outlines the timing plan for the ESS battery pack design and integration over the course of this year and next year's EcoCAR 3 competition. The work on the design and integration of the battery pack is split into two sub-teams: mechanical and electrical. Matthew Palmer is in charge of the mechanical team working on this project, and directly reports his progress to Jake Garrison. Matthew has full power over making decisions on material design. All decisions, however, must be approved by Jake Garrison. While Jake Garrison has executive power and authority over this project, his work on the design and integration will be reviewed by the engineering team leads and our faculty adviser Professor Brian Fabien. Open issues such as component sourcing will be handled with a weekly meeting of electrical team members who are present for the summer. The electrical team members in the lab will also send a weekly report to Jake Garrison to update him on key activities/tasks as well as to ask any questions in light of uncertainty. In times of uncertainty, Jake Garrison will reach out to one of the organizer advisers, Jesse Alley, for advice and guidance.

Risks and Risk Mitigation Plans

UW EcoCAR uses Failure Mode and Effects Analysis (FMEA) to conduct, organize, and assess risk analysis. The FMEA table shown in Figure 2 calculates a Risk Priority Number (RPN) by multiplying the risks' severity by its chance of occurrence by its difficulty of detection. Each of the above categories are quantifiably ranked from a scale of 0-10, meaning the higher the RPN the higher risk-level it represents. Below is a list of battery pack design risks with their effects and root causes as well as respective contingency plans in the event of the risks' occurrence. The highest-level risk with the battery pack design is the potential issue with an inadequate cooling system, which can result in the overheating of the battery pack. This represents a significant risk in its severity and difficulty of detection. Through careful planning and design efforts, the team has managed to reduce all risks chance of occurrence to a relatively low number (1-3 range), thus proactively lessening RPNs of ESS risks.

FAILURE MODE AND EFFECTS ANALYSIS

Item: Battery Pack Design

Involved Teams: All engineering teams

Process Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Detec	RPN	Contingency Plan	Contingency Plan Triggers
Enclosure Design	Wrong Dimensions	Unable to mount, set back in cost and time, and requires redesign	7	Incorrect processing of CAD to design	3	2	42	More intensive CAD processing and redesign	Unable to implement due to size constraint
	Not Meet Force Constraints	Pack design does not pass the efficient design review, set back in time	5	Lack of training and foresight in choosing materials	2	1	10	Redesign material selection	Identified either by design review panel or our simulations
Cooling System	Inadequate Cooling Sytem	Overheat	7	Lack of air flow from poor design	3	8	168	Add fans and vents internally	Testing on the vehicle
High Voltage	Safety	Shock and team member injury	10	Poor training and design is a safety risk	1	1	10	Training tutorials and mandatory testing on rules outlined in safety	Quarterly training for new members
Packaging	Not fit size constraint	Not servicable and not safe	4	Poor design and foresight	5	1	20	Explore alternative options for consumer acceptability	suitcases in car, and not being able to service pack as needed
	Conflict with rules	Set back from getting pack certified by competition	6	Miscommunications between organizers and team	2	1	12	Thorough communications with organizers to confirm compliance with rules	Periodic emails and calls to organizers

Figure 2: FMEA Table

VEHICLE ARCHITECTURE OVERVIEW

Powerflow Diagram

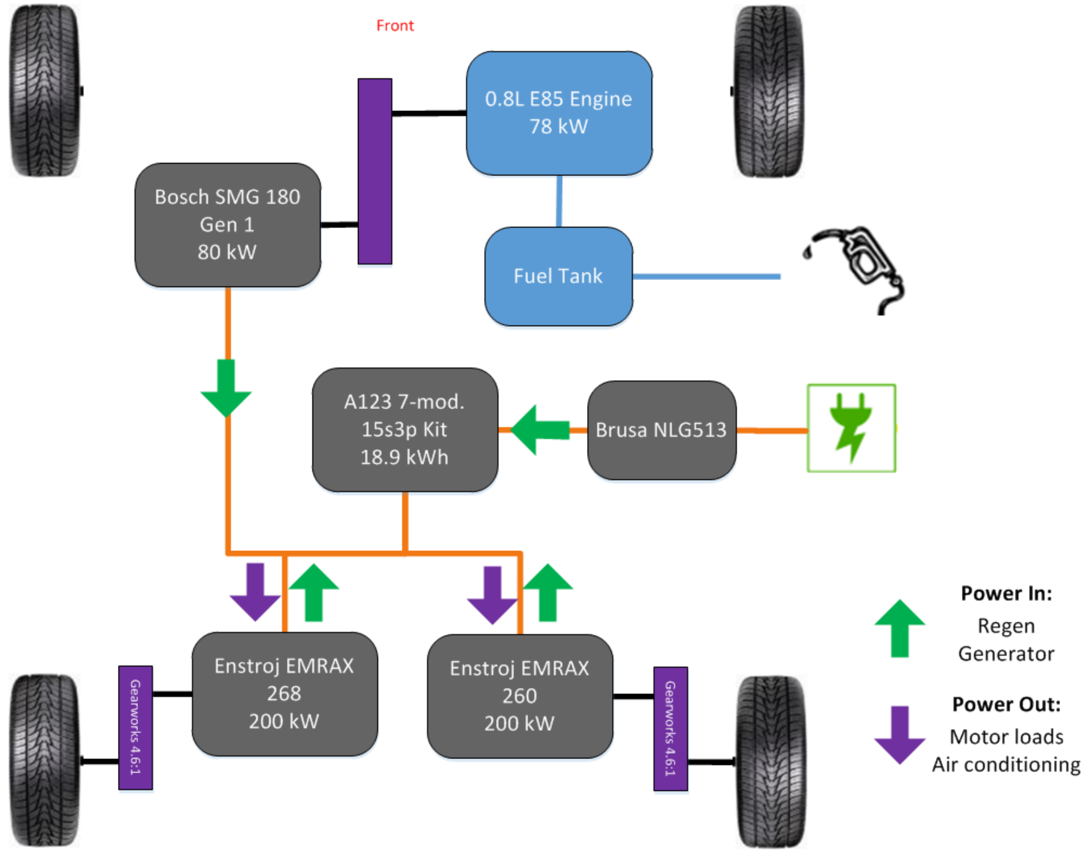


Figure 3: Power Flow Diagram

Vehicle-Level Requirements

In order to achieve the performance desired, UW EcoCAR has chosen to use an A123 battery pack with 7x15s3p configuration. This pack gives the highest power output and it is also the most packageable setup available for the team's application. This pack is rated at 58.8 Ah in capacity and 18.9 kWh in energy, which provides around 50 miles of EV-range. In addition, this setup provides a peak pack voltage of 375 V and peak current of 612 A for 10 seconds, which is desired for an acceleration of 5.3 seconds from IVM-60mph, 2.9 seconds from 50-70mph and a top speed of 85mph.

ENCLOSURE / MECHANICAL PACKAGING

Packaging of Battery Hardware

At the beginning of this project, the team established specific goals to optimize the integration with the existing structure, the practicality of assembly, and the ease of serviceability. These three themes governed the decision making for all sections of the ESS pack.

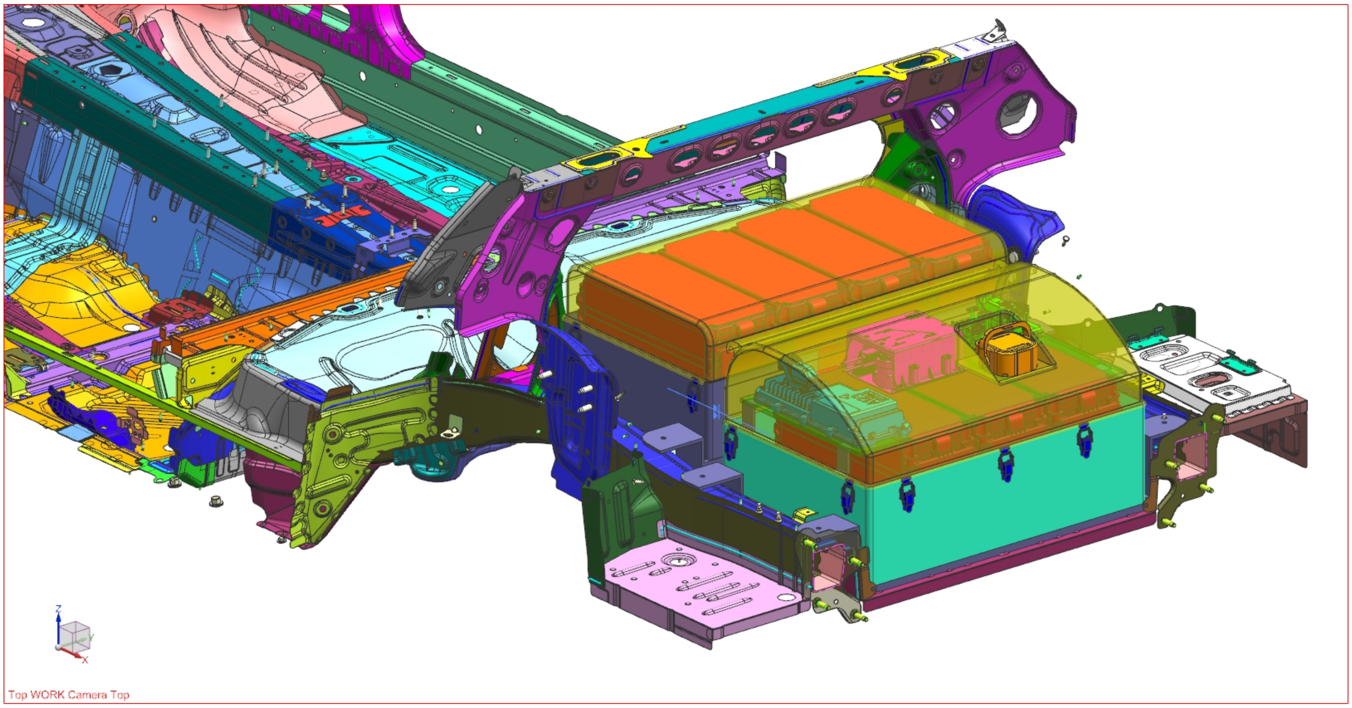


Figure 4: Complete ESS assembled in vehicle

The pack will fit within the vehicle structure by utilizing a tiered design to conform to the shape of the vehicle’s tiered trunk (See Figure 4). It will consist of front and rear halves that will be rigidly connected to form the enclosure. The pack will be sealed and covered with a two-piece lid. The pack itself will be attached to four support rails, stretching between the frame rails on each side of the vehicle (See Figure 5). Tabs will be welded to the existing vehicle frame that will allow the support rails to be attached to the vehicle. These welded tabs and rails will be designed and analyzed to ensure they meet the structural requirements of the 8G vertical and 20G lateral static load conditions when the ESS pack is fully installed.

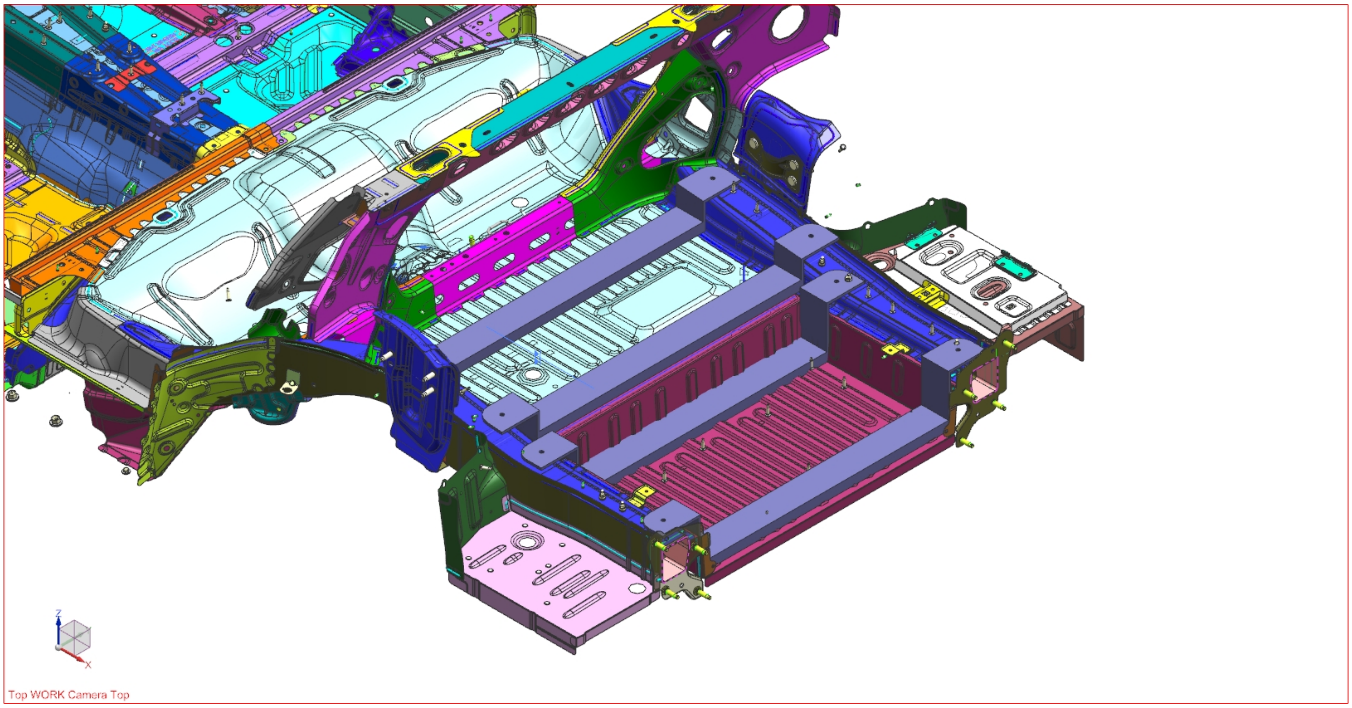


Figure 5: Structural support rails attached to vehicle frame

The enclosure will be constructed from aluminum sheet and the two lids will be constructed from Boltaron™. Aluminum is chosen for its strength and ease of manufacturing, and Boltaron™ is chosen for its ability to be formed into complex surfaces and its low electrical and thermal conductivity.
Inside the pack, the battery modules will be oriented in two rows. The upper half of the pack will house a row of 4 modules while the lower half will house a row of three modules. Each of these two rows will be mounted to a secondary structure inside the enclosure designed to fix the modules to the structural support rails and provide even spacing between the modules. See the Component Mounting section for further details on this subsystem.
The other ESS components including the BSM, CSM, EDM, and MSD receptacle will be mounted on a removable shelf within the enclosure. This shelf will mount directly above the battery modules in the lower enclosure (See Figure 11). It will allow for easy assembly, effective use of space, and simple servicing.
Service and installation of the battery modules in the enclosure can be performed from either the trunk or through the rear passenger seat opening (see Appendix: **Supplementary ESS Design CAD Images**). The two-piece lid secured by draw latches will allow for easy access to the inside of the enclosure.
Clearances between the enclosure and the surrounding trunk structure are relatively small, but the enclosure is capable of fitting within the acceptable locations defined by the NYSR and no portion of the ESS components are located in the designated crush zones (see images in Appendix: **Supplementary ESS Design CAD Images**).

Sealing and Venting

The battery pack will be sealed to prevent both the ingress and exit of vapors, moisture, and contaminants. The interface between the enclosure and the lid will be sealed by silicon rubber edge trim. The lid will be clamped down with spring draw latches that will maintain clamping force on the lid and thus guarantee that the lid remains sealed even in the case of positive pressure inside the pack (see Figure 6). All holes through the enclosure will have gaskets or other sealants.

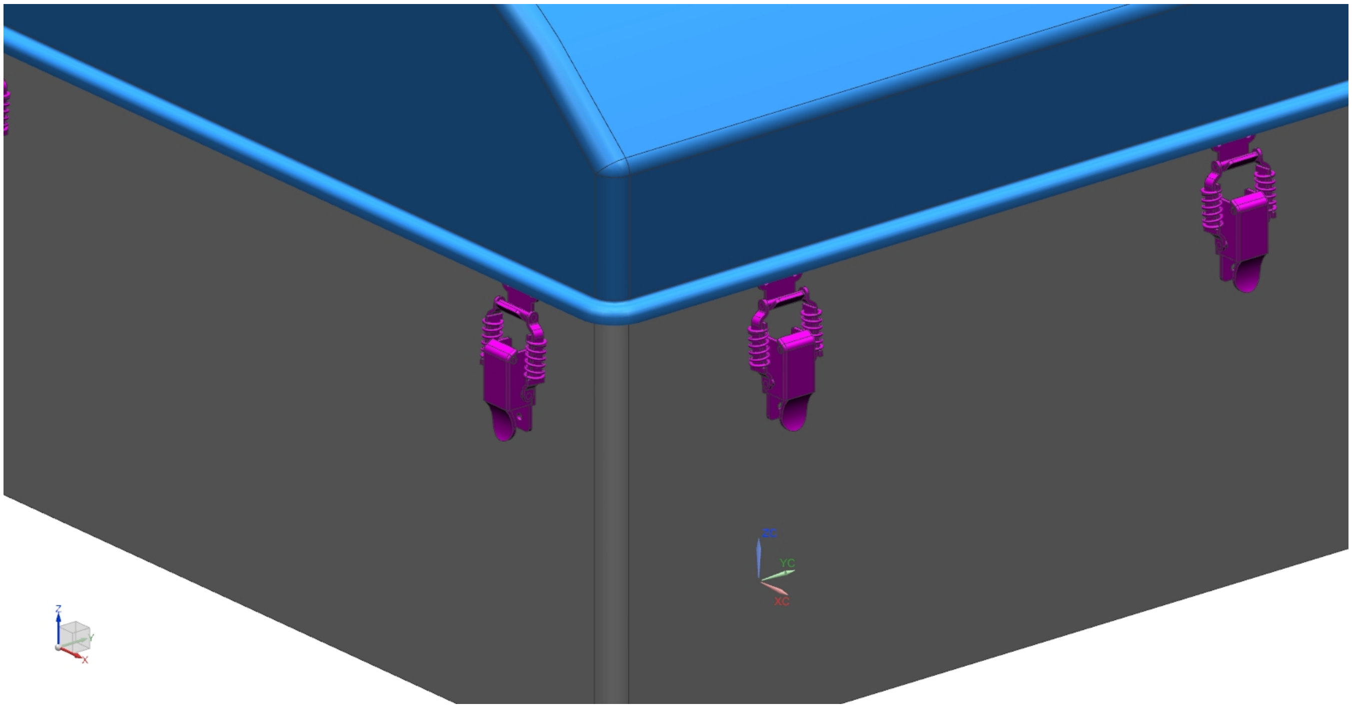


Figure 6: Detail view of sealing interface and latches

The ESS design also utilizes an inline pressure relief valve located adjacent to the pack side-HV connector (see Figure 7), that will maintain the pack seal but allow internal pressure and off-gassing to be routed outside of the passenger compartment.

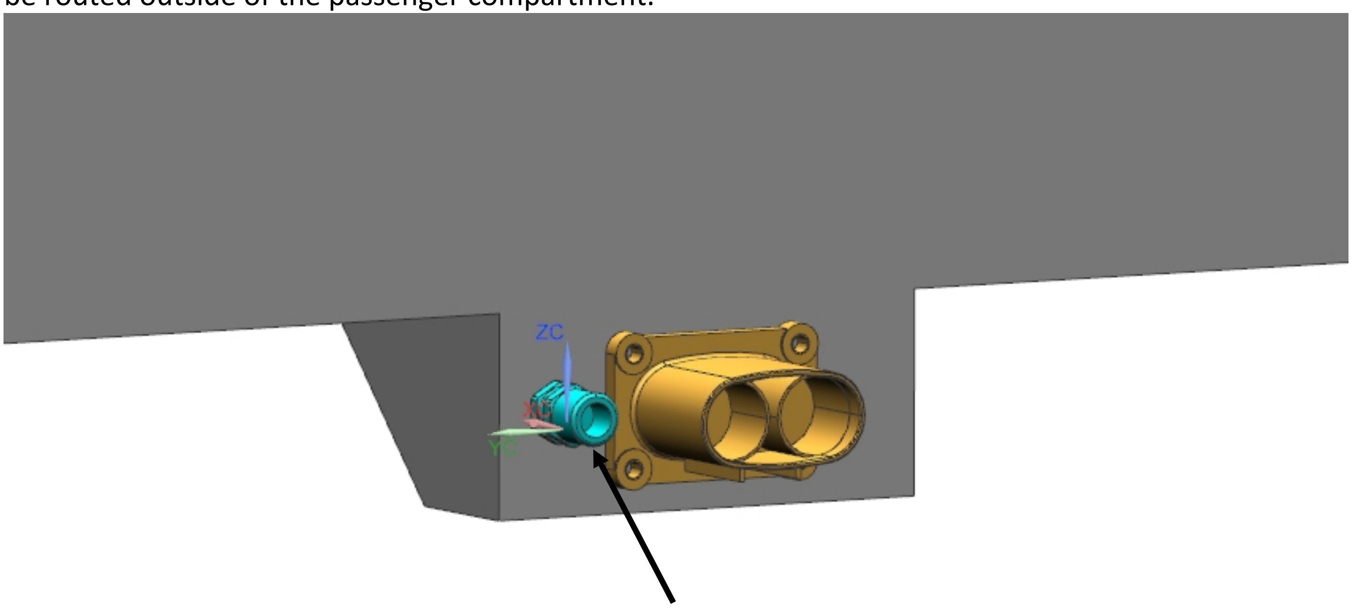


Figure 7: Pressure relief valve location

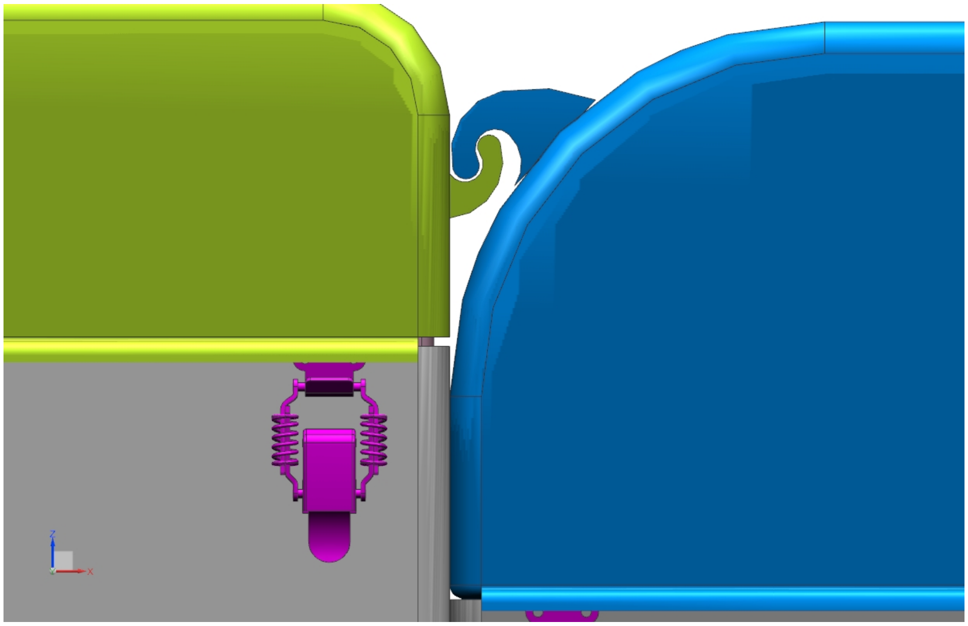


Figure 8: Lid interface at center of the battery pack, clamp and lid seal visible

LV and HV Wire Routing

The wire routing within the ESS is to be implemented with safety, serviceability, and protection of components in mind. Specifically, the physical design of spans of cable, connections and terminals, and wire intersections shall adhere to the relevant sections of the NYSR, while also serving the team's purpose and modular ESS design. The following guidelines and ideas are influenced by the relevant sections within the NYSR **(I-3 Design Rules for High Voltage Systems, I-4 Design Rules for Energy Storage Systems),** and are adapted to the team's specific pack construction. As wire routing within the ESS is still in the conceptual stage and no designs have been made concrete, many of these guidelines will require further analysis and perhaps revision. The team's next task is to include wire routing in CAD model to solidify the final strategy.

HV Exterior Connection: The modular design of the ESS allows for optimal positioning of the HV terminal. The terminal is placed such that the internal positive and negative cables are under low bend stress when accommodating the connection. The exterior terminal faces toward the front of the vehicle and is centered along the vehicle, which allows for optimal connecting to the rear junction box. The cable shielding is also fed through this connector (See Figure 9).

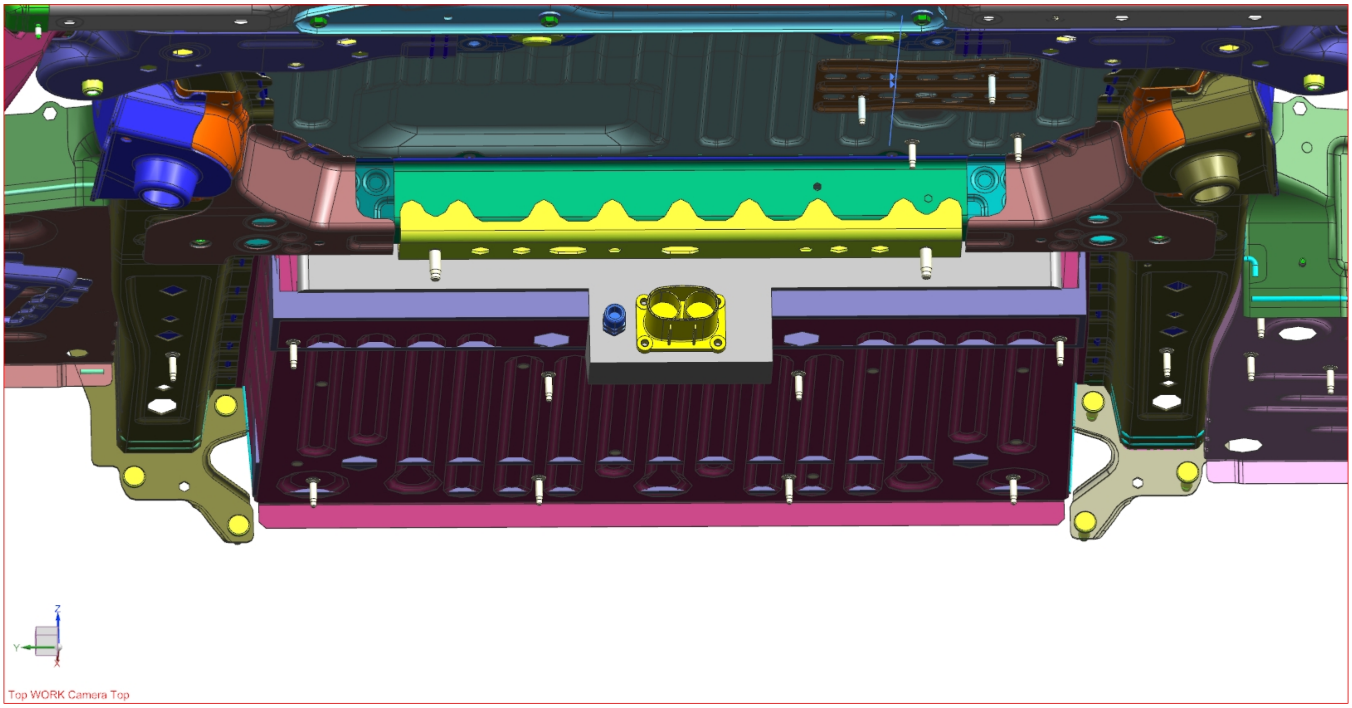


Figure 9: Location of HV pack side connector allowing simple wire routing to junction box

LV Exterior Connection (Not yet in CAD model): Design considerations for this connection include mitigation of EMI on LV communications signals, and external routing optimization. The LV connector is likely to be placed on the rear portion of the enclosure, on either the left or right side. Internally, this allows LV communication lines to have optimal distance from HV cables to mitigate EMI (See EMI Section). Externally, the connector routes the LV through the passenger compartment towards the supervisory controller in the front of the vehicle.

Possible Shelf Configurations: In order to reduce the amount and complexity of HV lines around the shelf area of the ESS (where the CSM, MSD, BCM, and EDM are located), the team is considering a few different options in terms of interfacing shelf components with connections from the battery modules. In order to connect the shelf to the modules, the design will either have connections around the edge of the shelf up from the modules, or coming through the shelf.

With either of these options, the team still has the issue of connecting each shelf component. Power distribution (bus bars) that sits on the shelf may be one solution. This would involve having custom laminated/insulated bus bars instead of cable routing that could be custom-built by Mersen for the team's application.

Other solutions may include simply keeping separate cables, or re-arranging shelf components to optimize space usage and ensure the team is not compromising on minimum bend radius of 1/0 cable. For reference, the Champlain EXRAD 1/0 has a minimum-bending radius of 105 mm, or approximately 4 inches.

Coolant Line Routing

UW ESS will utilize passive cooling. Refer to Thermal System section for additional description.

Component Mounting

Inside the pack, the battery modules will be mounted to an internal structure that will allow for even spacing and sturdy attachment of the modules (See Figure 10). This structure will be constructed from aluminum and will be mounted through the enclosure directly to the support rails. The mounting structure will also utilize a polycarbonate indexing structure that will aid in aligning the modules during assembly and maintaining module spacing. Each module will be spaced a minimum of **10 mm** from adjacent modules or enclosure walls on either side, allowing for thermal expansion and cooling of the modules. This secondary battery module mounting structure and connections will also be designed and analyzed to ensure structural requirements specified by the NYSR are met. Additionally, all the hardware used to attach the rails, enclosure, and modules will be class 12.9 and locking hardware will be used where applicable.

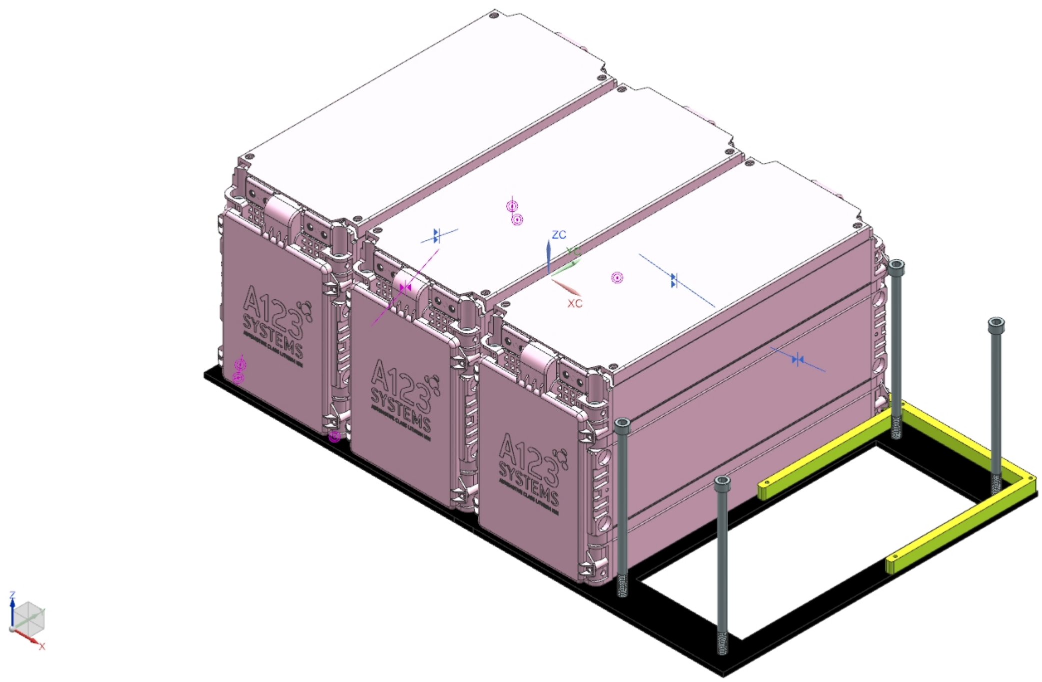


Figure 10: Battery Module mounting with indexing structure visible in yellow

The BCM, CSM, EDM, and MSD receptacle will be fixed to a removable polycarbonate shelf (See **Figure 11**: Removable control hardware shelf with components attached) and will be assembled outside of the enclosure for convenient, safe assembly. After each component is attached, the shelf is mounted in the enclosure above the lower row of batteries and is supported at the corners by four mounting brackets. Further discussion of the MSD mounting can be found in the Safety section.

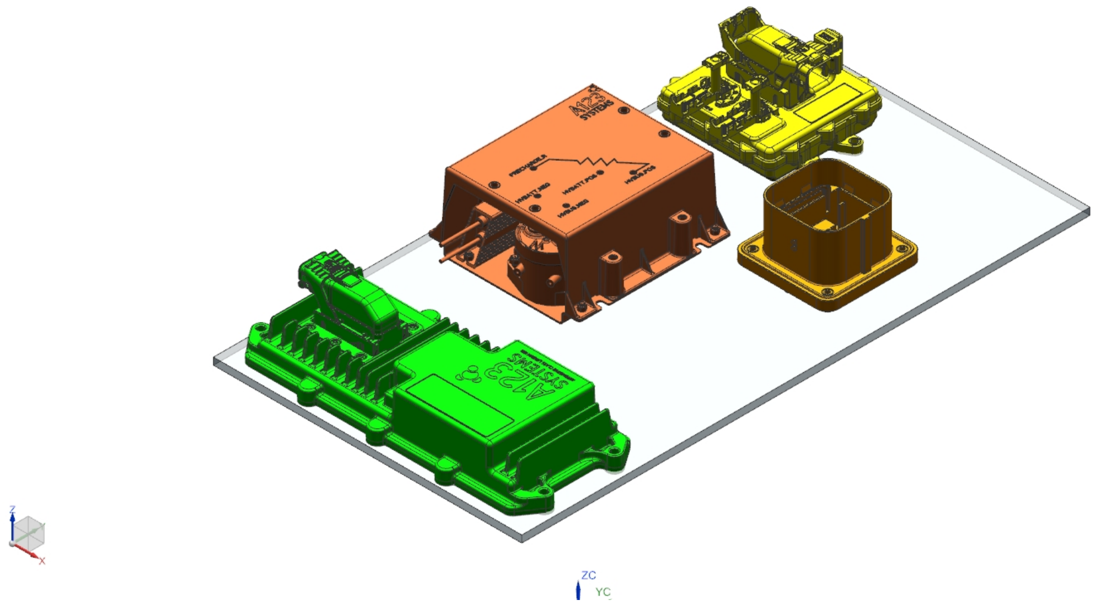


Figure 11: Removable control hardware shelf with components attached

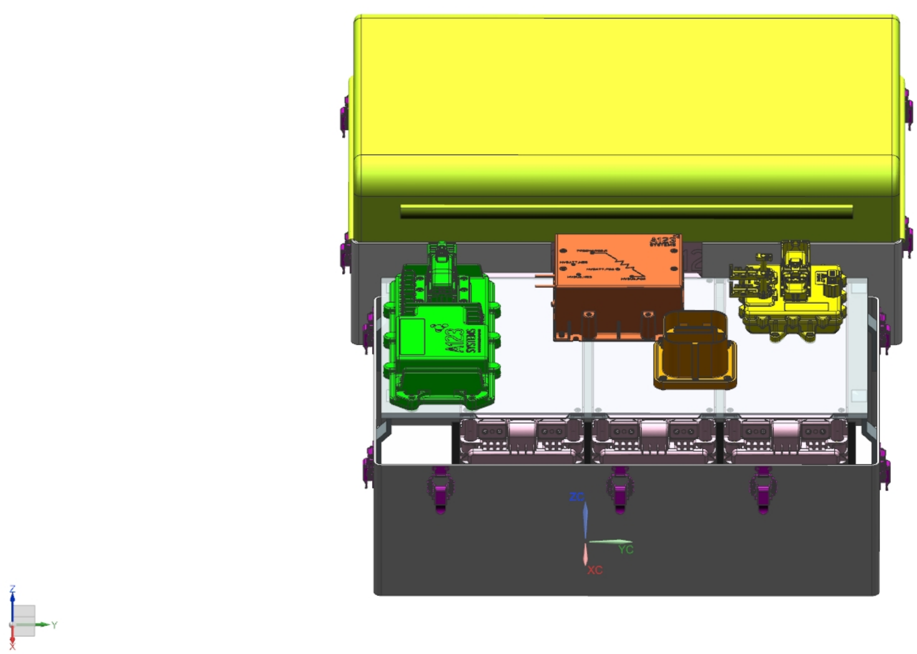
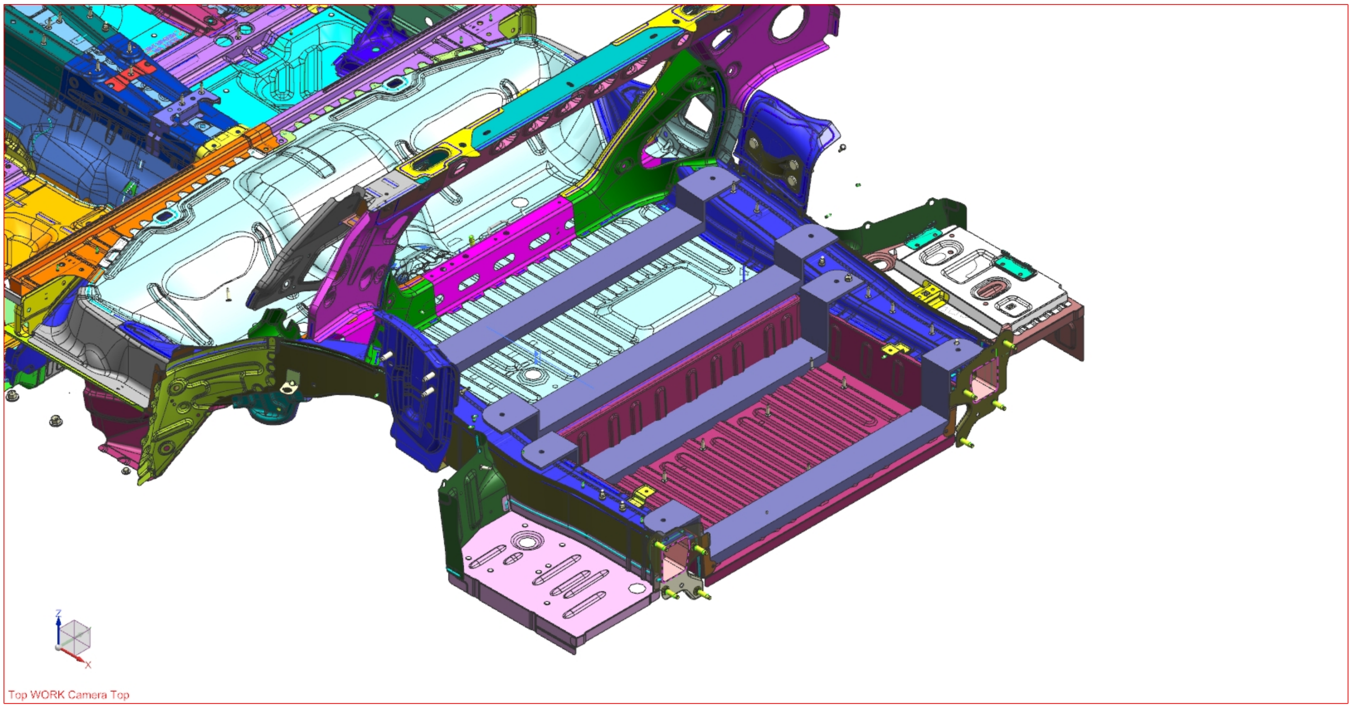


Figure 12: View of control hardware shelf installed in pack

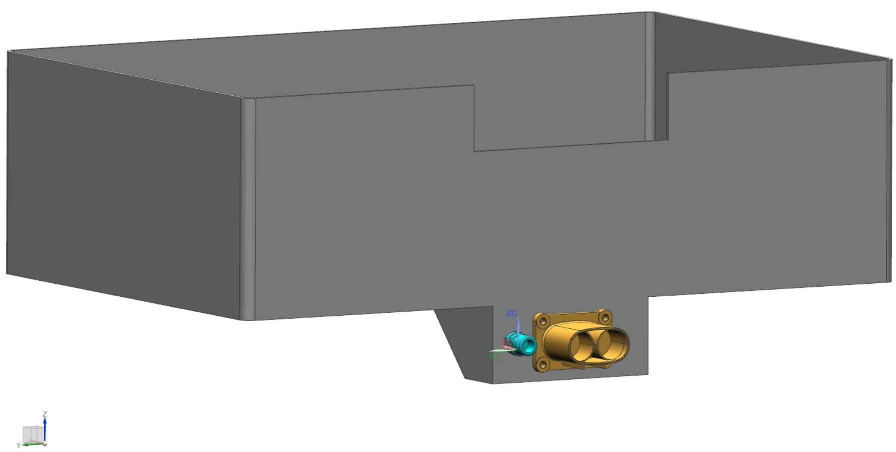
The placement of the shelf will be above the lower assembly of batteries for ease of servicing (See **Figure 12**). Additionally, all lower batteries can be accessed by simply disconnecting and removing the shelf from the enclosure. This assembly gives the best balance of space conservation and accessibility.

ESS Assembly

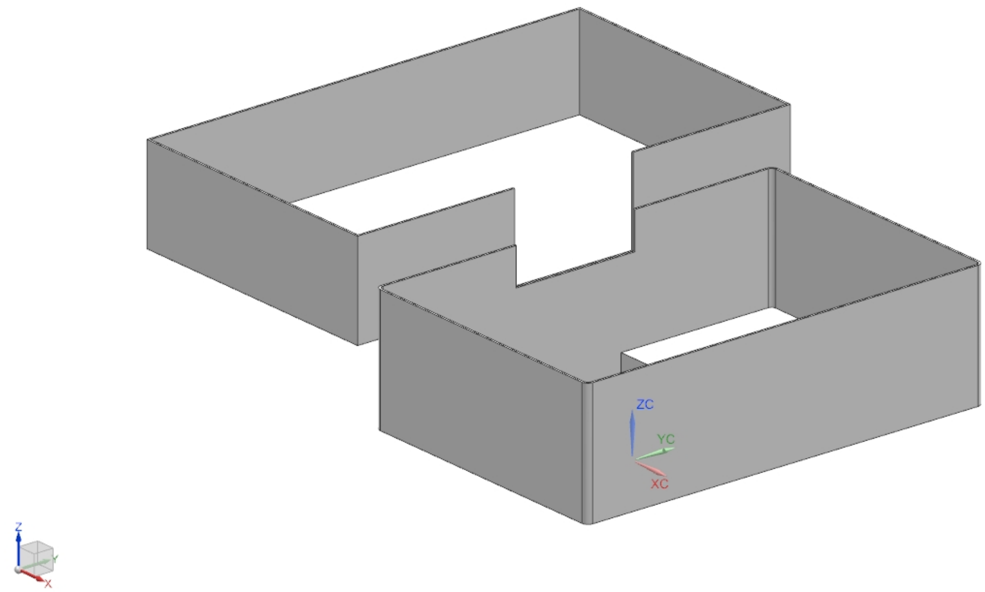
1. Weld structural attachment tabs on top of vehicle frame rails. Install support rails in Camaro, two in the front of the trunk right behind the rear seat and two in the spare tire well. Bolt the rails to the tabs.



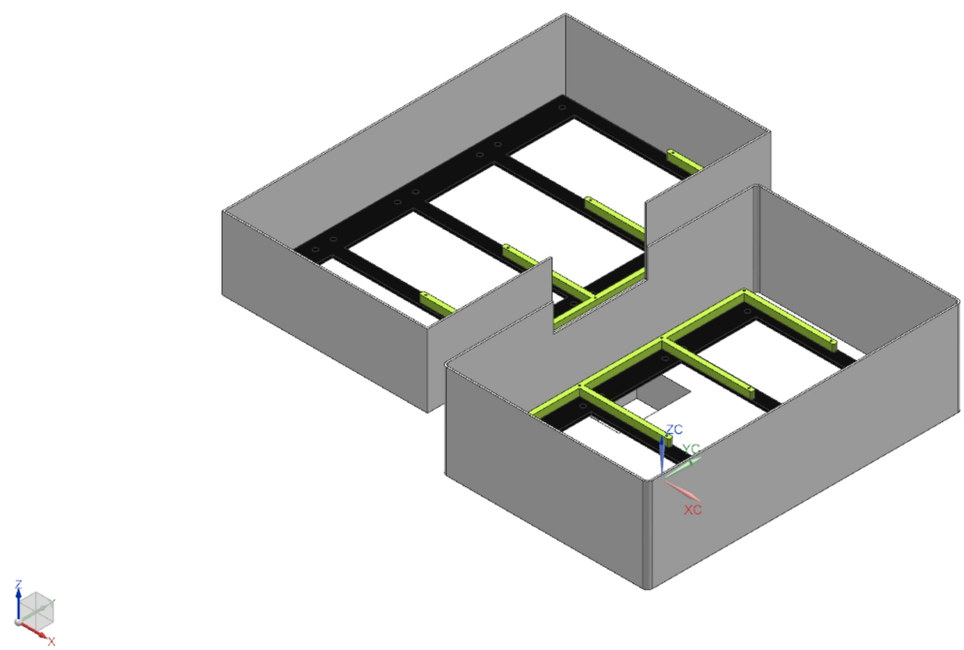
2. Install the HV connector and pressure relief valve on the front of the lower aluminum enclosure. Line interior of both enclosures with electrically insulating material. (See section on Electrical Isolation)



3. Install both aluminum enclosures in the vehicle trunk on top of the support rails. Bolt halves together.

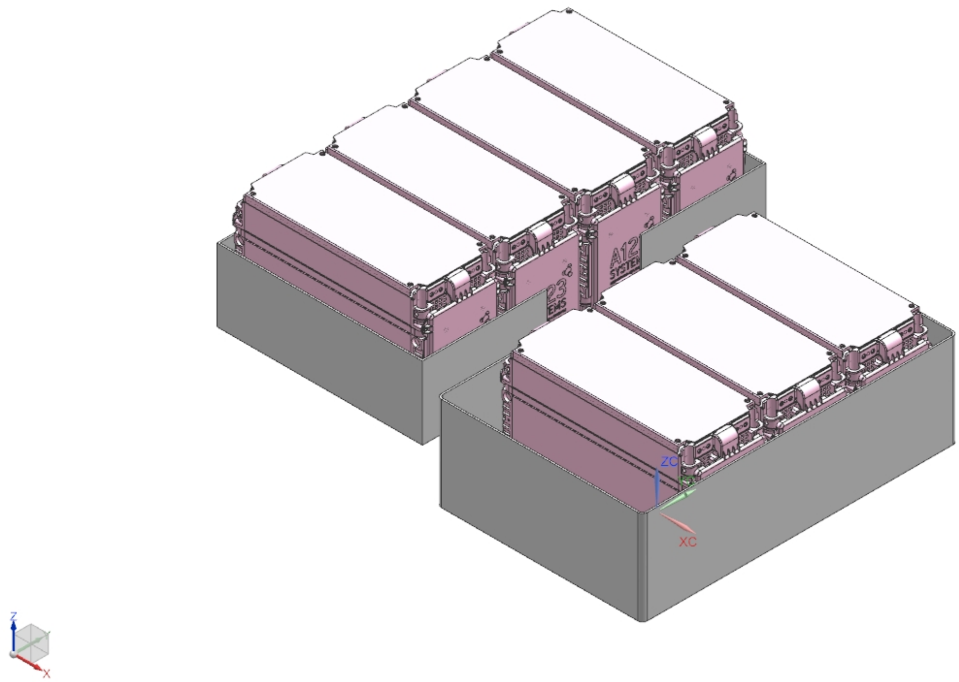


4. Insert battery secondary structure into enclosures. Attach structure to support rails by installing bolts through enclosure to underlying rails.

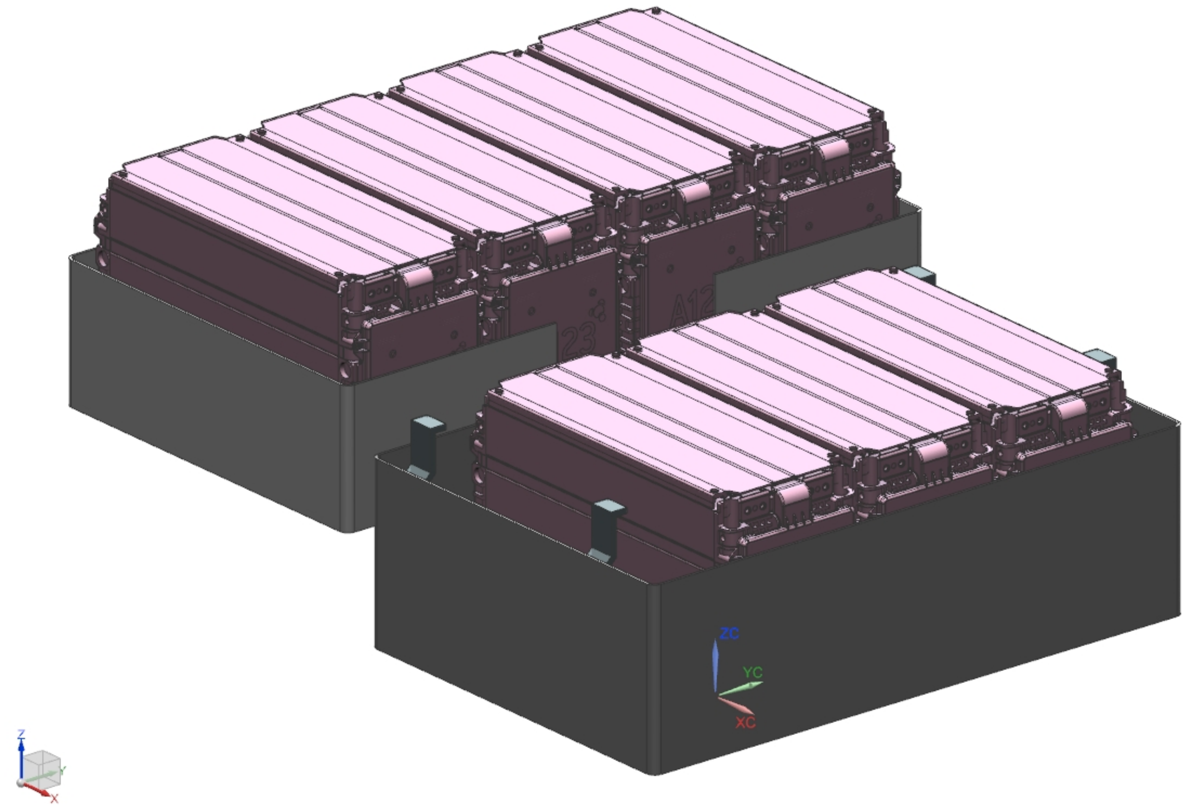


5. Mount the battery modules to the secondary structure within slots designated by the index. Install four modules in the front enclosure and three in the rear enclosure. Once the modules are in place,

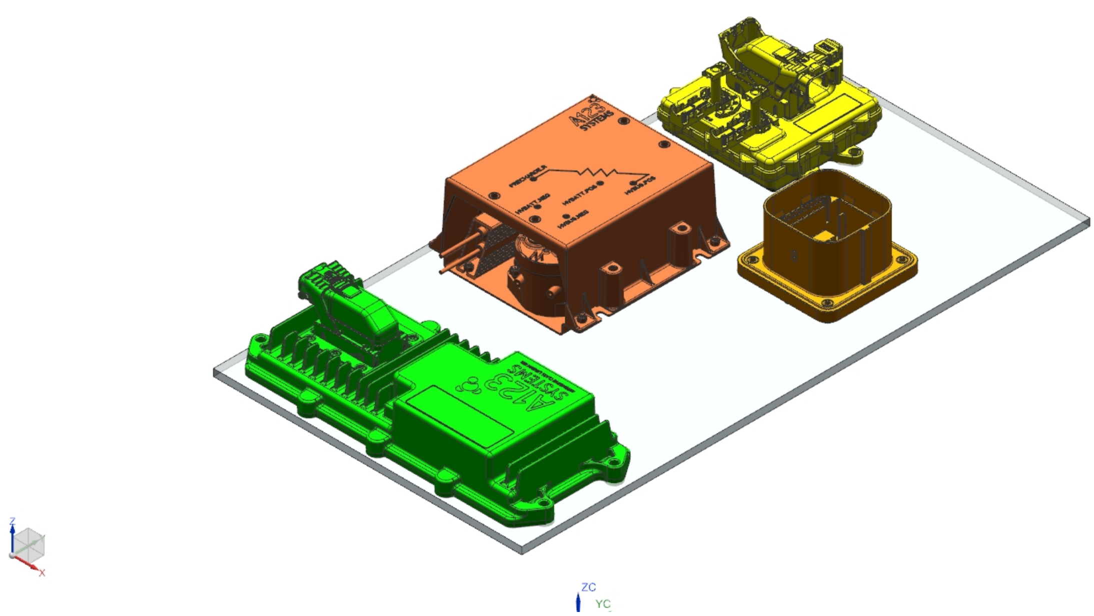
install bolts through modules into the secondary structure. Install wiring between modules according to schematic.



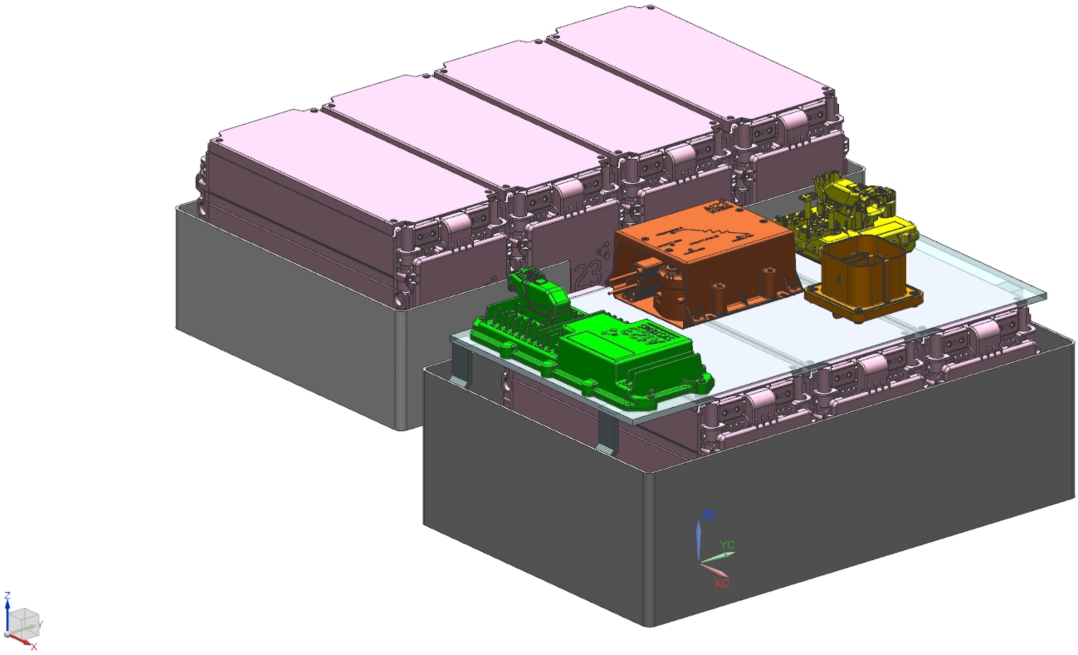
6. Install shelf mounts flush against the sidewalls of the lower enclosure.

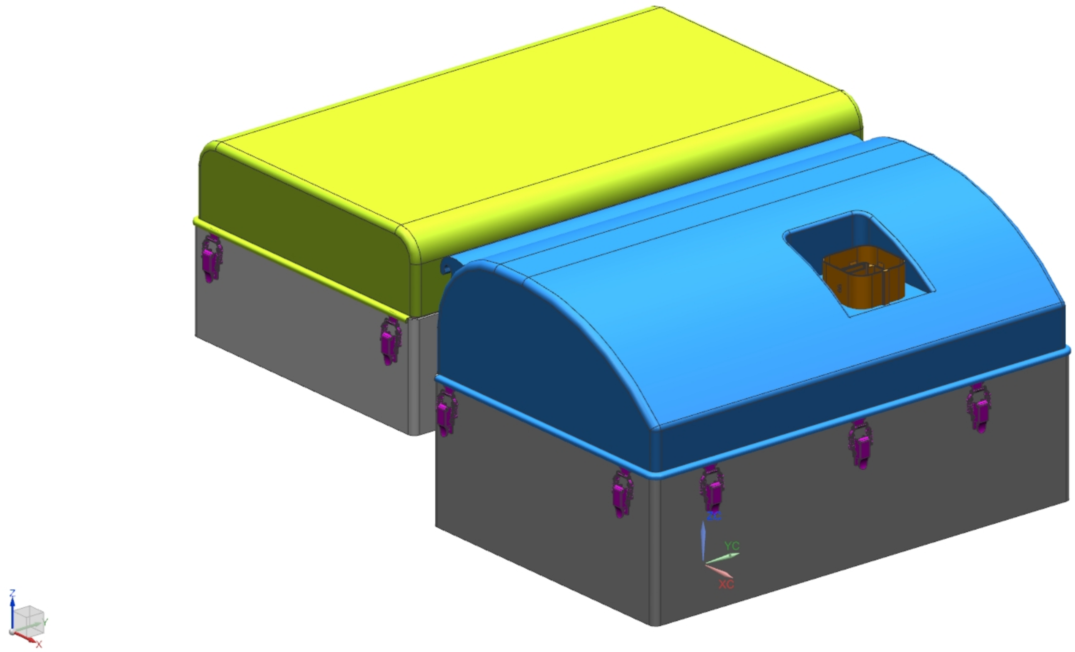


7. Attach the CSM, BCM, EDM, and MSD receptacle to the control hardware shelf. Install wiring according to schematic.

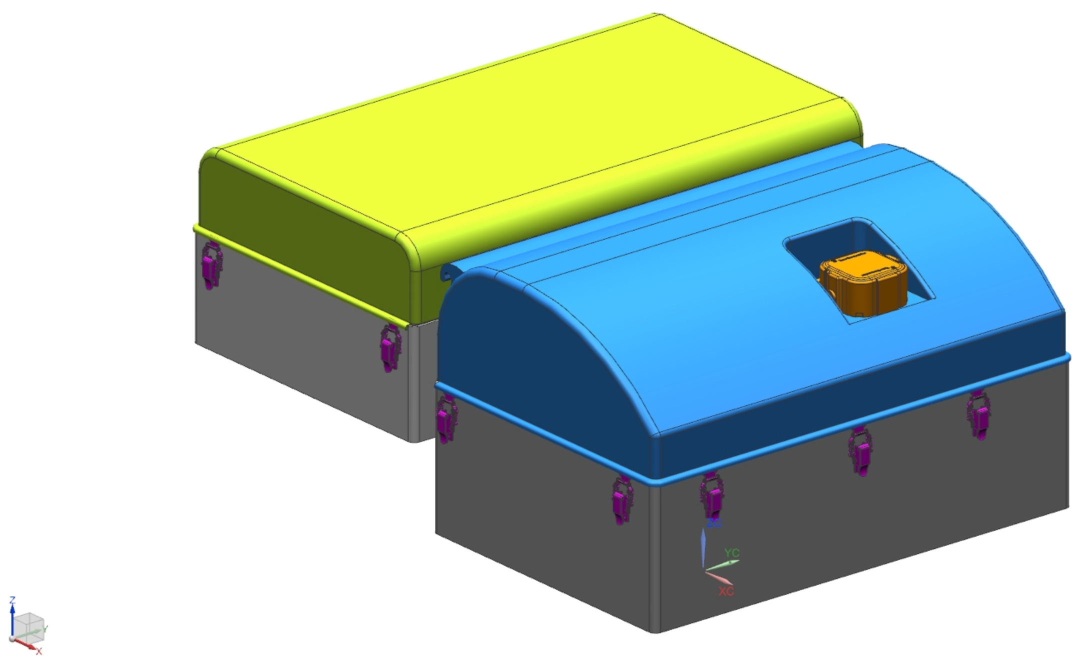


8. Install the assembled control hardware shelf in the rear enclosure and bolt to the four support brackets. Complete all necessary electrical wiring and connections.


ZC
YC
XC
Z
Y
X



11. Install the MSD plug on the rear lid.



ELECTRICAL DESIGN

HV Schematic

HV schematic of ESS (See **Figure 13**) shows high voltage connections between the components and some of the low voltage BCM and HVIL wiring. The general layout of the components in the figure is similar to the physical model. Notice the MSD splits the pack. For a schematic of our HV system, see the respective section in the Appendix.

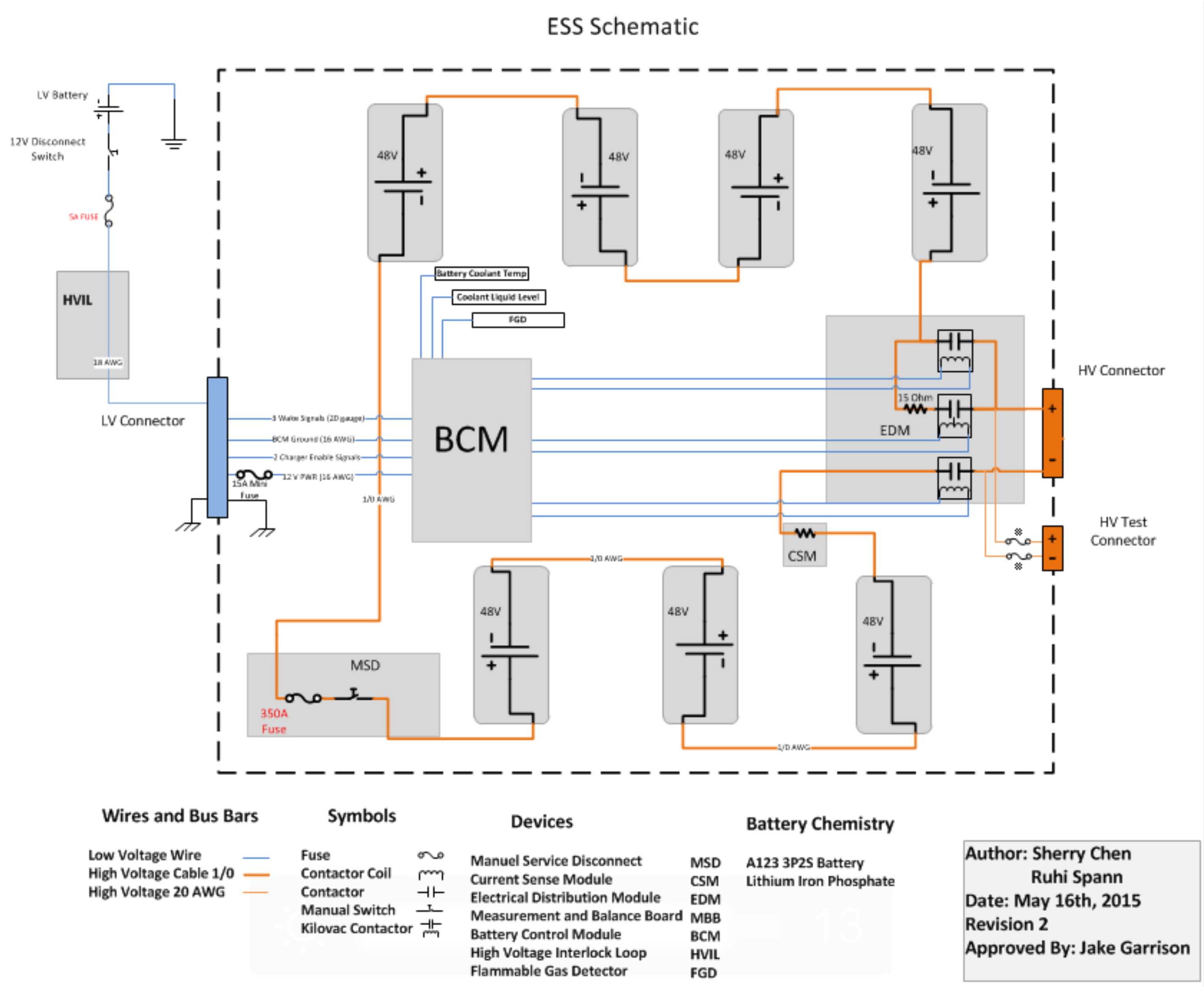


Figure 13: ESS HV Schematic

HV Interlock Loop

The purpose of HVIL is to disconnect the high-voltage DC battery from the electric system to avoid damage and danger to the driver. The battery will be disconnected in the following situations:

- Inertia sensor is triggered when the car has acceleration greater than 8G's, which is typical in a crash
- Emergency Disconnect Switches (EDS) in the front and back of the car are pressed
- LV connector, HV connector or MSD is disconnected
- 12 V battery fails or is disconnected

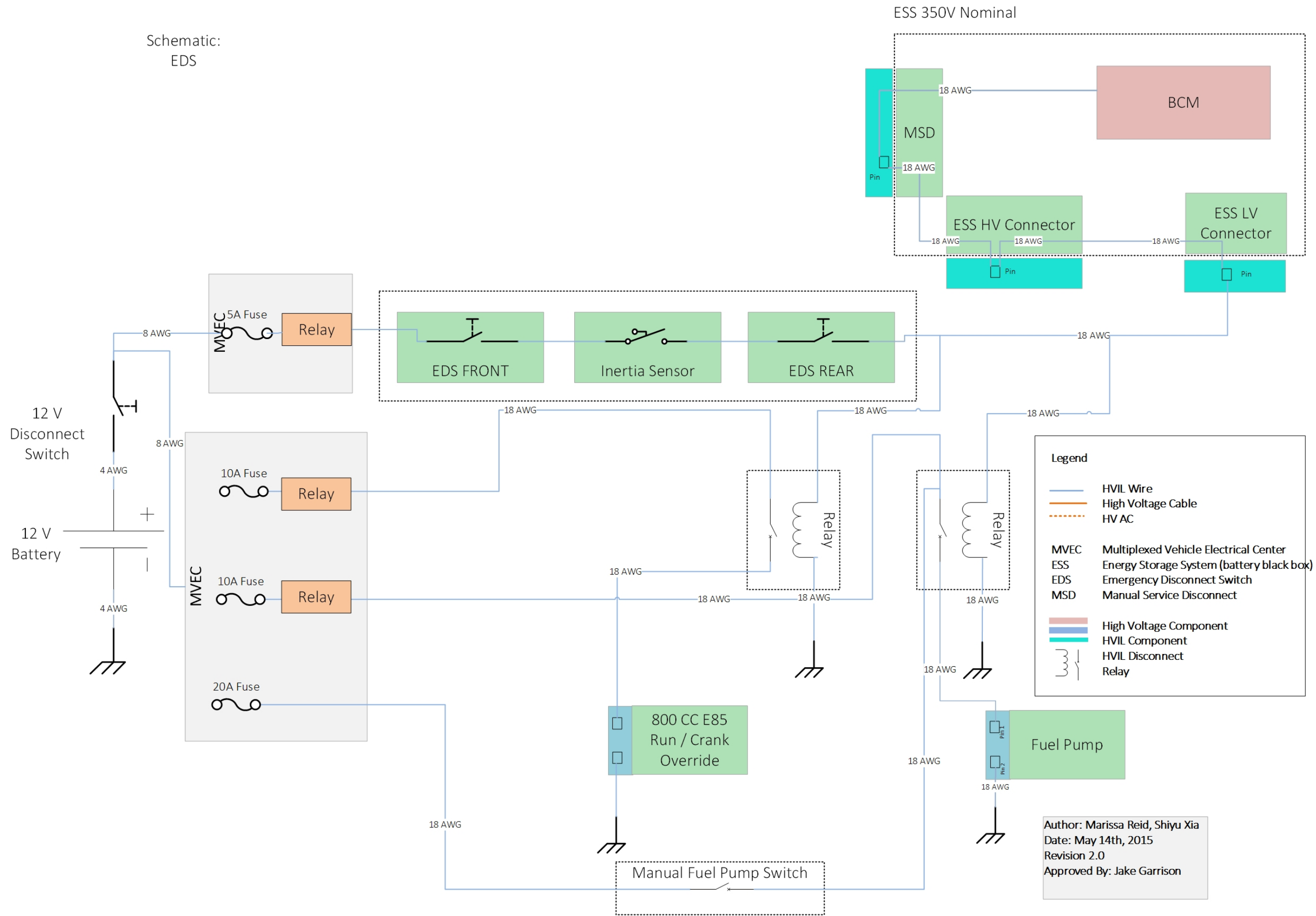


Figure 14: HVIL Schematic

Electrical Isolation

To ensure that the exterior of the battery pack is electrically isolated, the team has chosen to use a lid constructed from Boltaron™ with proper lid sealing described in the Sealing and Venting section. In addition, the interior of the aluminum enclosure will be covered up with Nomex® electrical isolation foam which prevents the enclosure from having contact with the components within. In addition, the high voltage connector and the MSD are designed to be finger proof and acrylic inserts near the battery terminals will be used to better protect them as well (See the section on Finger Proofing and Secondary Cover section for more information). Finally, all the wires and bus bars used in ESS are covered with high dielectric insulating material.

SAFETY

Preliminary Failure Mode

The ESS status is continuously monitored by the supervisory control system to detect onset of any failure modes such as overheating, ground fault, communication failure, fault current etc. The DFMEA prepared for the ESS (See **Figure 15**) describing failure modes and subsequent response action required for avoiding any further damage to the system serves as the basis for the failure diagnostic signals from the supervisory control to the components and the driver.

DFMEA									
Component	**Potential Failure Mode**	**Potential Effect(s) of Failure**	**SEV[1]**	**Potential Cause(s)**	**OCC[2]**	**Current Process Controls**	**DET[3]**	**RPN[4]**	**Recommended Action(s)**
ESS	Overheating	Fire	9	Temperature above flammability limits	1	Cell Temperature Sensor	1	9	ESS Offline
		Permanent battery damage	8	Ineffective cooling system	5	Cell Temperature Sensor	1	40	ESS Offline
		HV system inoperable	8	ESS electronics unresponsive	6	ESS Status Signal	3	144	ESS Offline
	Ground Fault	Electric shock	5	ESS not grounded	8	Ground Fault Sensor	1	40	ESS Offline
		HV system inoperable	8	Stray current in the system	7	ESS Status Signal	3	168	ESS Offline
	Fault Current	Permanent battery damage	8	Excessive Charging and Discharging	5	Current Sensor	2	80	ESS Offline
	Communication Failure	HV system inoperable	8	No CAN communcation	3	ESS Status Signal	2	48	ESS Offline

Key:
1. **Severity:** Severity of impact of failure event. Scored on a scale of 1 to 10. High score assigned to high - impact events and low score to low - impact events.
2. **Occurrence:** Frequency of occurrence of failure event. Scored on a scale of 1 to 10. High score assigned to frequently occurring events and low score to less frequent events.
3. **Detection:** Ability of process control to detect the occurrence of failure events. Scored on a scale of 1 to 10. High score assigned to easily detected and low score to inconspicuous event.
4. **Risk Priority Number:** The overall risk score of an event. RPN = SEV*OCC*DET. High RPN value events demand immediate attention, low RPN values are less risky.

Figure 15: ESS DFMEA Chart

MSD Placement

To ensure that the ESS is safe to service, a MSD will be incorporated into the design. Great care is taken in the consideration of the placement of the MSD, as it needs to be easily accessible for servicing and must also prevent access to the ESS without being disconnected. For this reason, the MSD plug is located on top of the lid of the enclosure and is easily accessible from the opening of the vehicle trunk. The pack is designed to have two sections, taking advantage of the Camaro's tiered trunk design. To fit into this space, the battery enclosure will have a two-piece lid. The back lid will interlock into the front lid, making its removal impossible without first removing the front lid and the MSD.

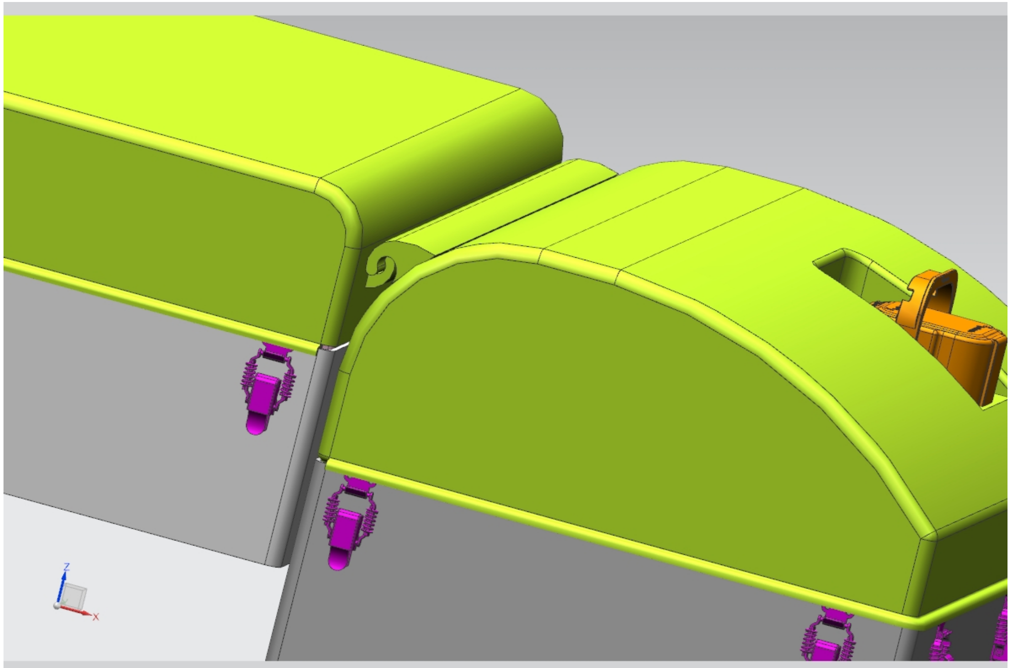


Figure 16: Interlocking two lid design

In turn, the MSD will prevent the front lid from being removed. This is to ensure that no part of the ESS can be accessed while fully energized. To accomplish this, the receptacle portion of the MSD will be mounted to the shelf directly below the front lid. The plug portion of the MSD will pin the front lid to the internal shelf preventing the front lid's removal without disconnecting the MSD plug.

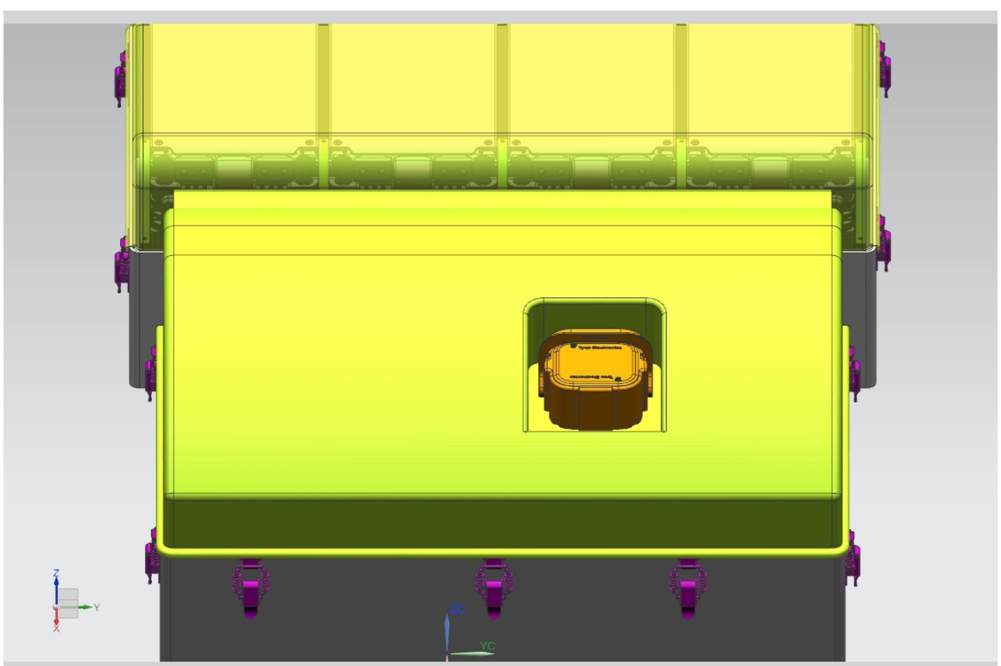


Figure 17: MSD location front view

Finger Proofing and Secondary Cover

Exterior finger proofing is satisfied through the two Boltaron™ lids and the two base enclosures. They will be sealed together tightly with spring latches to prevent access (in purple, **Figure 17**). All HV exterior receptacles (MSD, HV connector and Test Connector) are designed to be finger proof as well. Within the enclosure, all battery module terminals and component terminals will be covered by insulating acrylic covers secured by Velcro. All wires will also be covered by insulating material. Finally, as stated in the Electrical Isolation section, the pack will be lined in high dielectric Nomex® material to prevent electrical shorts through the aluminum enclosure.

THERMAL SYSTEM

Requirements for Battery Thermal Performance

According to documentation supplied by A123, the optimal performance of the 7 module 15s3p pack occurs at cell temperatures from 20 to 50 °C. This can be validated through the information on **Table 2** and **Table 3**.

Table 2: Charge Current Limits

3p (6x15s3p and 7x15s3p) Pack Charge Current Limits

Vehicle Continuous Charge Current (Amps)

Cell Temperature (degC) \ SOC(%)	0	10	20	30	40	50	60	70	80	90	100
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	0.0
40	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	0.0
30	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	0.0
20	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	0.0
10	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	0.0
0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	0.0
-10	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	0.0
-20	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0
-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Vehicle 10-sec Charge Current (Amps)

Cell Temperature (degC) \ SOC(%)	0	10	20	30	40	50	60	70	80	90	100
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	0.0
40	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	0.0
30	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	0.0
20	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	294.8	0.0
10	300.0	300.0	300.0	300.0	296.8	283.0	271.6	260.5	250.2	240.7	0.0
0	300.0	300.0	286.0	266.1	251.7	239.9	230.1	220.6	211.9	204.4	0.0
-10	234.6	188.3	168.1	160.5	156.3	148.0	140.9	136.6	132.8	126.6	0.0
-20	30.0	30.0	30.0	30.0	60.0	65.2	61.8	59.9	58.2	55.1	0.0
-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

For charging current, the maximum continuous current (60A) can occur for temperatures ranging from 10 to 50 °C at all SOC and drops at approximately 2A/degree C outside that range. Also the maximum 10-sec charge current (300A) occurs for temperatures between 20 and 50 °C for all SOC with an almost immediate drop outside that range.

Table 3: Discharge Current Limits

3p (6x15s3p and 7x15s3p) Pack Discharge Current Limits

Vehicle Continuous Discharge Current (Amps)

Cell Temperature (degC) \ SOC(%)	0	10	20	30	40	50	60	70	80	90	100
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
40	0.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
30	0.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
20	0.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
10	0.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
0	0.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
-10	0.0	164.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0	180.0
-20	0.0	37.7	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3
-30	0.0	30.0	55.3	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0

Vehicle 10-sec Discharge Current (Amps)

Cell Temperature (degC) \ SOC(%)	0	10	20	30	40	50	60	70	80	90	100
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0
40	0.0	540.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0
30	0.0	540.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0
20	0.0	540.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0
10	0.0	432.6	578.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0	612.0
0	0.0	300.5	456.0	489.6	509.9	521.8	532.1	544.9	557.2	585.1	612.0
-10	0.0	184.4	250.9	275.2	293.6	302.6	310.8	316.4	321.7	339.9	391.9
-20	0.0	113.5	130.5	144.5	155.7	163.4	170.8	173.9	176.8	186.9	216.7
-30	0.0	42.4	59.7	65.4	69.6	75.6	81.8	83.9	86.0	91.8	115.8

For discharge currents, the maximum continuous current (180A) occurs for temperatures between 0 and 50 °C at all SOC and drops almost immediately outside that range. Also the maximum 10-sec discharge current (612A) occurs for temperatures between 20 and 50 °C and has less of a temperature effect as state of charge is increased. In all cases cells have a maximum operable temperature of 50 °C. Based on these results it can be shown that the battery pack performs close to ideal at temperatures between 20 and 50°C, with less effects from SOC when at temperatures above 30 °C.

Cooling Method

The UW ESS will utilize passive cooling. The team learned through EcoCAR 2, the provided A123 docs, and simulations outlined in this section that the batteries operate most effectively between 20 and 50 °C, with slightly better performances above 30 °C and through passive air cooling the approximate maximum temperature rise is less than 20 °C.

Initial Thermal System Analysis

The team began the analysis with data from A123, which was derived from testing logs without active cooling relying on heat transfer through the pack to ambient. The first test had an ambient temperature of 25 °C, with current of approximately 48 A and 51.5% capacity used. Based on these conditions only a 5 °C increase of cell temperature was seen over a period of 44 minutes.

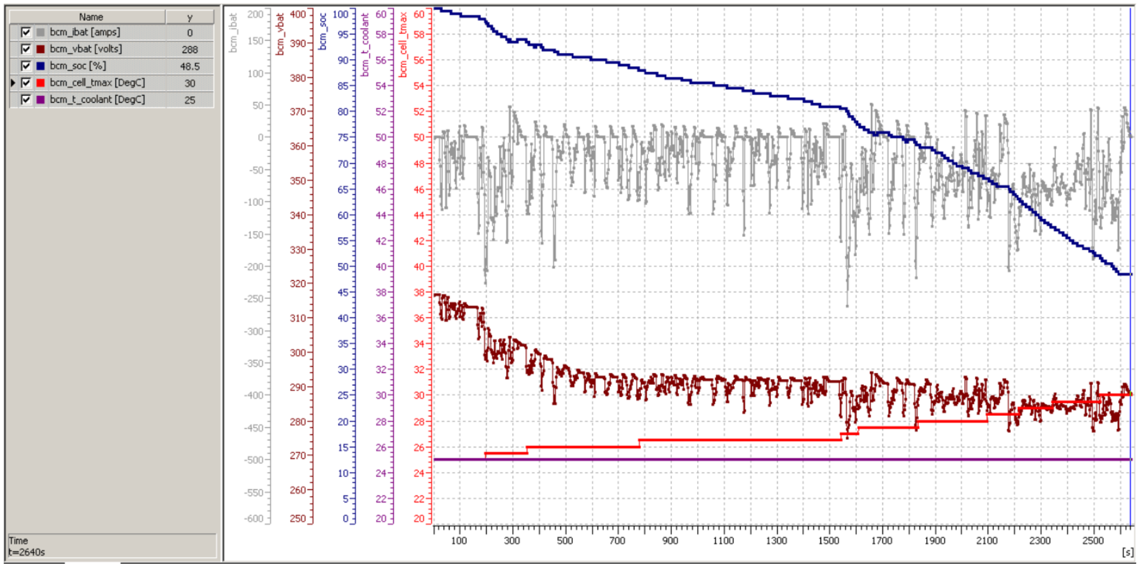


Figure 18: Temp rise at 50% SOC

The second test had an ambient temperature of 25 °C, with current of approximately 165 A and 90% capacity used. Based on these conditions 15.5°C increase of cell temperature was seen over a period of 17.7 minutes.

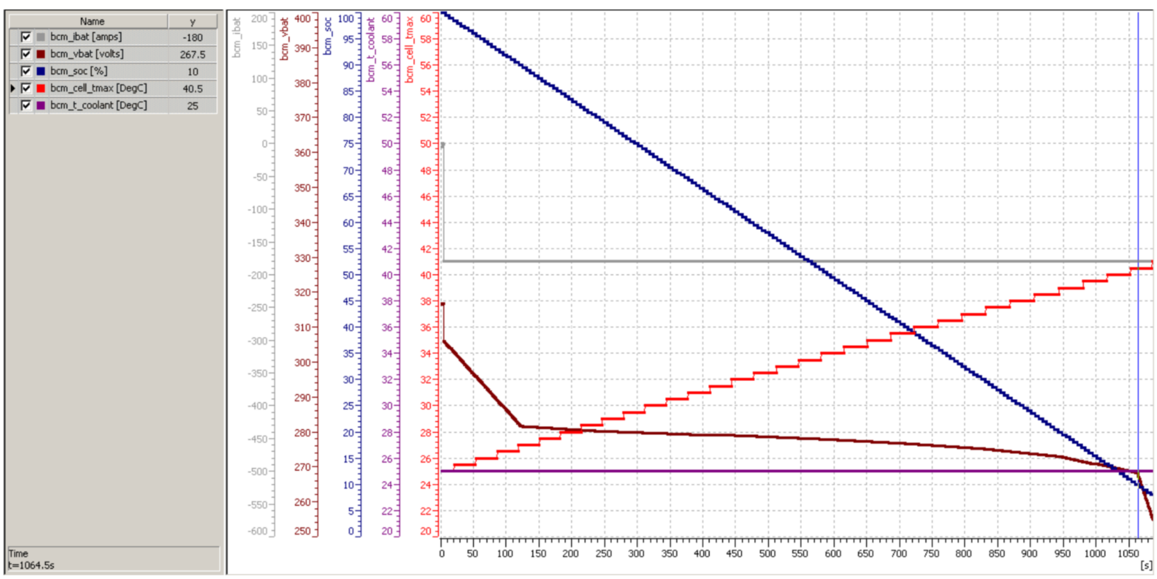


Figure 19: Temp Rise at 10% SOC

These tests show that in both normal continuous operation and maximum discharge that the pack remains below the safe maximum cell temperature increase limit of 20 °C as stated on the 15s3p module specification sheet provided by A123.

According to the specifications provided by A123 the packs cells must remain within 8 °C of each other for proper operation and to prevent damage. The proposed pack design has a uniform distribution of models which allows for even heat convection between them.

The next step of analysis is through modeling of the system. The model consists of a dual parallel RC combinational representation of a lithium ion cell with values derived from charge and discharge characteristics provided by A123. Heat generation is directly derived from power dissipated through internal resistance in each cell. These cells are connected in a 15s3p modular orientation with thermal convection between each directly proportional to surface area and convection heat transfer coefficient for each cell. Seven of these modules are connected in series with thermal convection between each proportional to surface area and convection heat transfer coefficient for each module.

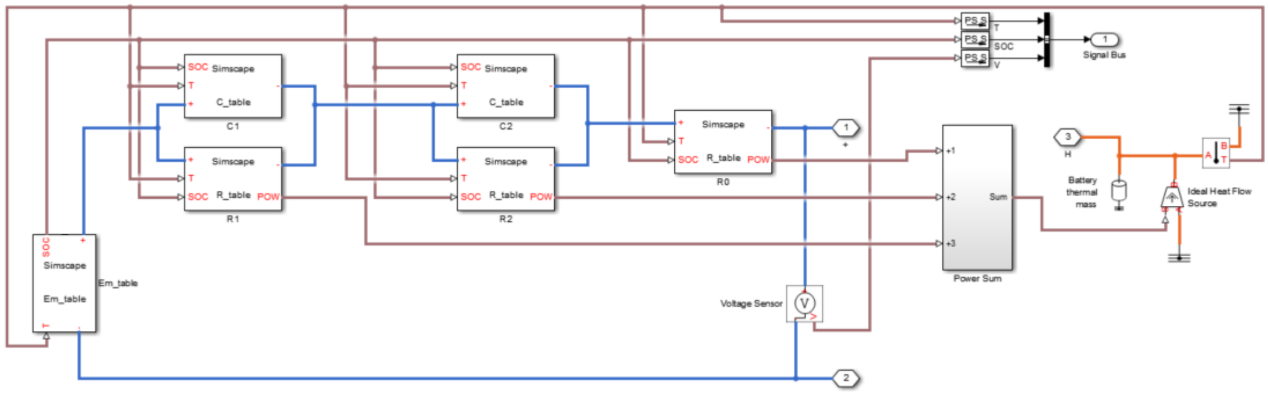


Figure 20: Simscape model of ESS

Currently this model is missing the necessary coefficients for thermal convection between cells and modules based on air cooling. The team is in the process of obtaining values from A123 and estimating parameters based on the UW design. Currently the models electrical characteristics and power generation is very accurate and matches real logs quite close. This model will be used to test conditions not supplied by A123 and add realistic factors related to pack conditions.

CHARGER

Compatibility with Battery Hardware

The UW design uses a water cooled Brusa NLG513 3.7 kW on board charger. The charger has an input voltage range of 100-264 V (48-62 Hz) which is perfect for practically any standard home plug in. The 7 module 15s3p battery pack has a voltage range of 263-378 V and the charger has an output range of 200-520 V thus the voltages are compatible. Additionally, the pack has a maximum charge current of 60A and the Brusa charger has an output charging current of 12.5A which meets current requirements. Brusa also has the option of preprogramming the charger for the A123 7 module 15s3p battery management system and communicates via CAN, which makes it an ideal integration. The charger is also lightweight at only 6.2 kg and 93% efficient and directly designed for automotive applications.

EMI

Design Features to Mitigate EMI Impacts

In designing the ESS, appropriate steps will be taken to ensure that the following competition rules are adhered to in order to reduce unwanted EMI both within and outside of the pack. Once preliminary designs are accepted, we will be able to simulate our system and conduct an analysis of the EMI effects on our system.

NYSR I-3.6: Exposed High Voltage and High Voltage Connections

- Exposing HV systems must not be a prerequisite for accessing non-HV systems
- All shielded connectors must follow proper grounding practices and must be checked for loss of isolation through the shielding.

Note: The team has chosen to use 1/0 Shielded EXRAD HV cable in the interior of the ESS.

ESS Enclosure

For the ESS enclosure, the team has chosen to use aluminum casing and Boltaron™ lid. In addition, a layer of Nomex® electrical insulation foam will be used in the interior of the aluminum casing (as outlined in our Electrical Isolation section). With this setup, we can mitigate the EMI from ESS to the other components outside the ESS.

Wire routing Strategy

The team is following the rules outlined below for wire routing. When circuits cannot be appropriately segregated, they will be crossed perpendicularly in order to minimize inter-circuit noise transmission.

NYSR I-3.10: Segregation of HV and LV Circuits

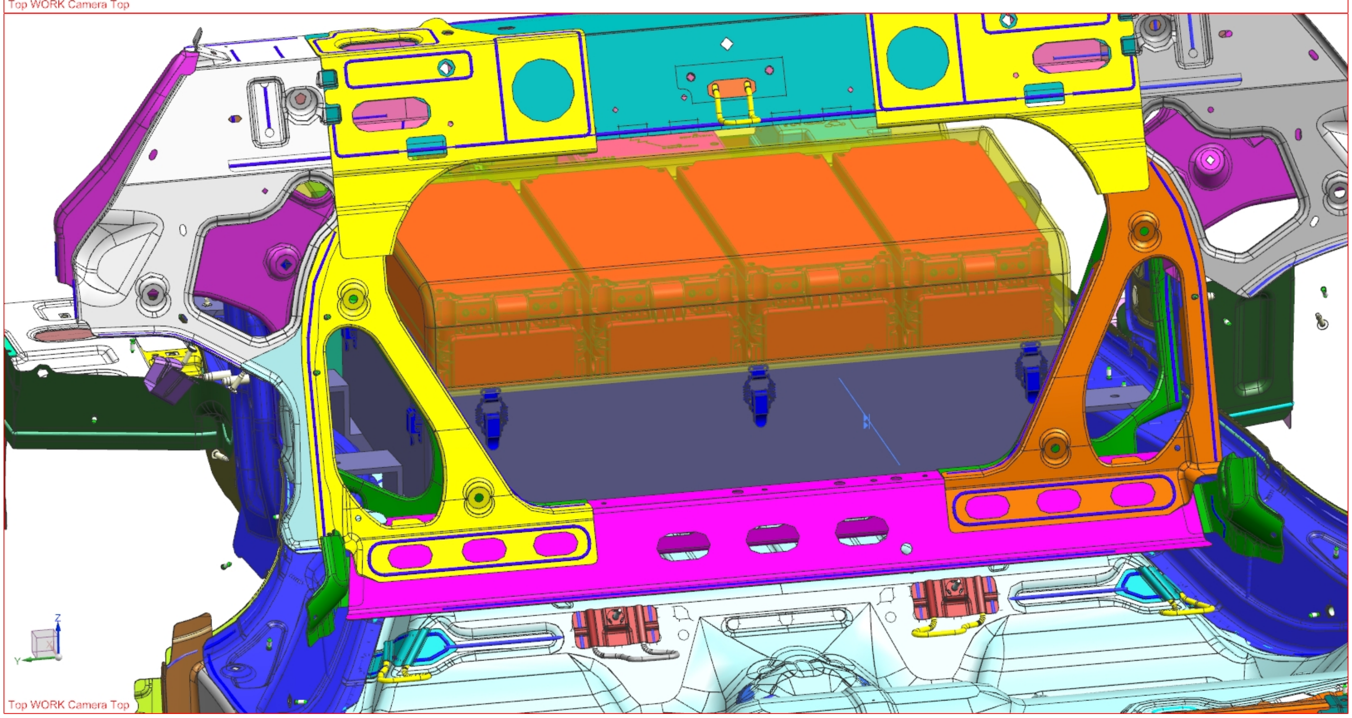
- If HV line is <100V, spacing must be 1 cm (0.4 in.)
- If HV line is ≥100 and ≤200 V, spacing must be 2cm (0.75 in.)
- If HV line is >200V, spacing must be 3 cm (1.2 in.)

Shield Termination Strategy

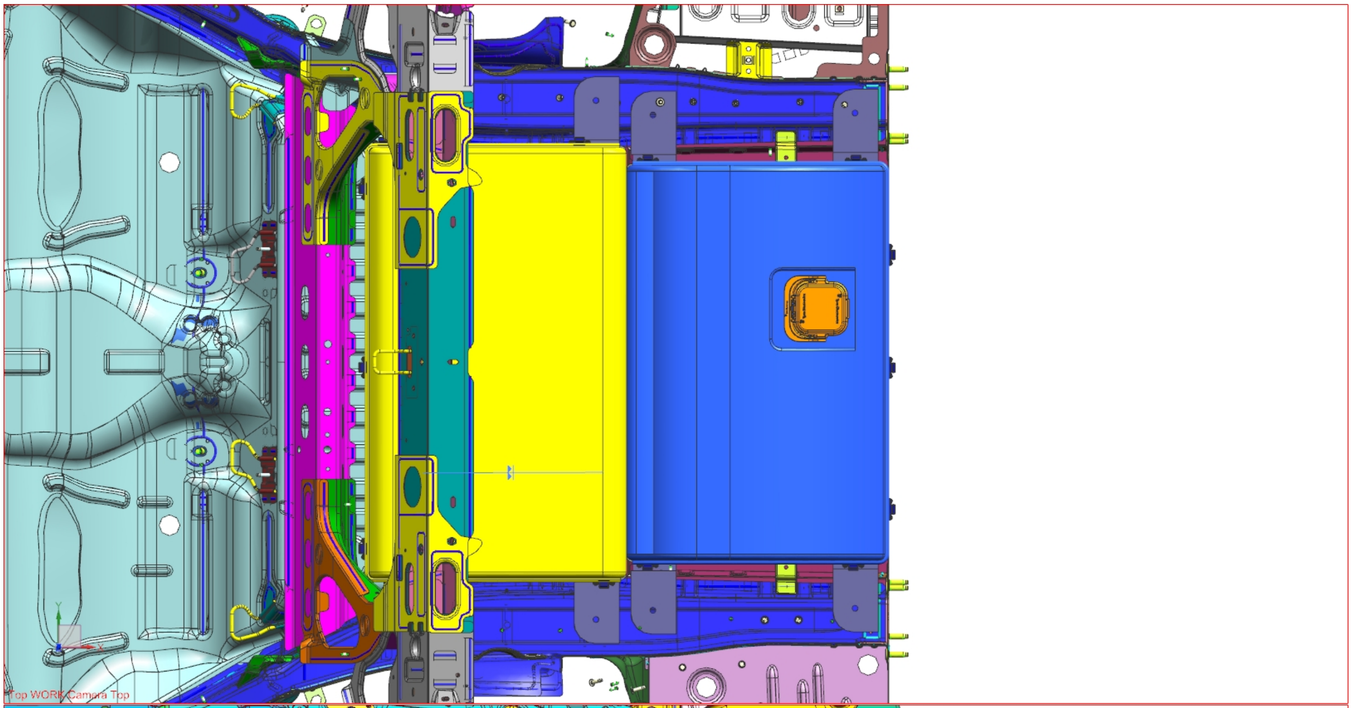
To avoid terminating cable shields in a location an inconvenient location, the cable shielding will all be grounded within the junction box of the ESS.

APPENDIX

Supplementary ESS Design CAD Images



Link back: **Packaging of Battery Hardware**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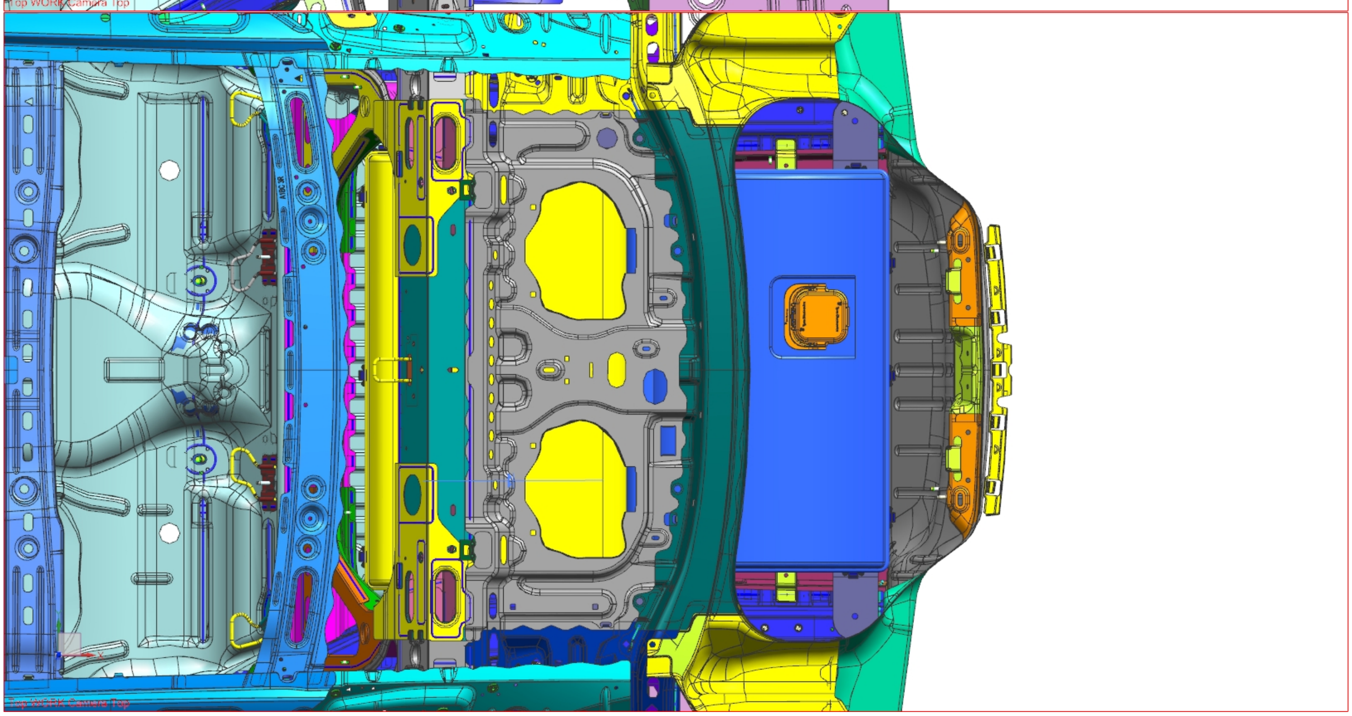

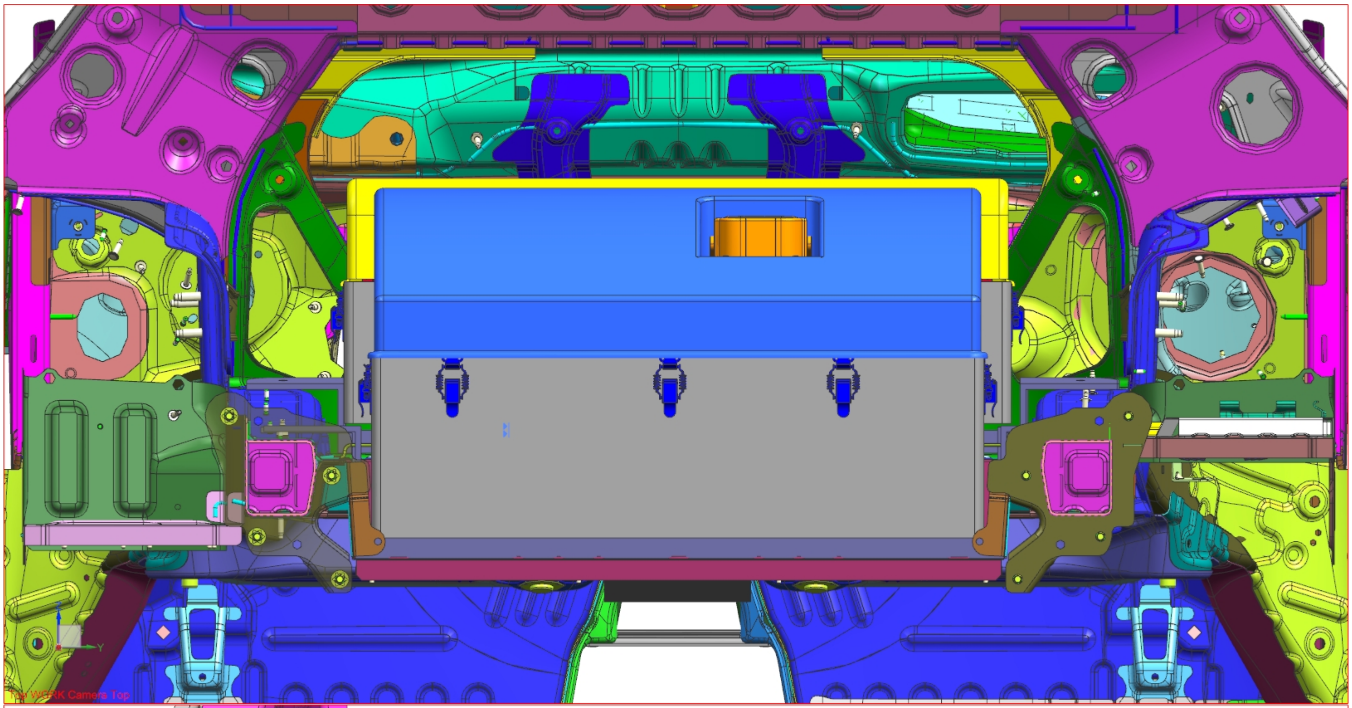
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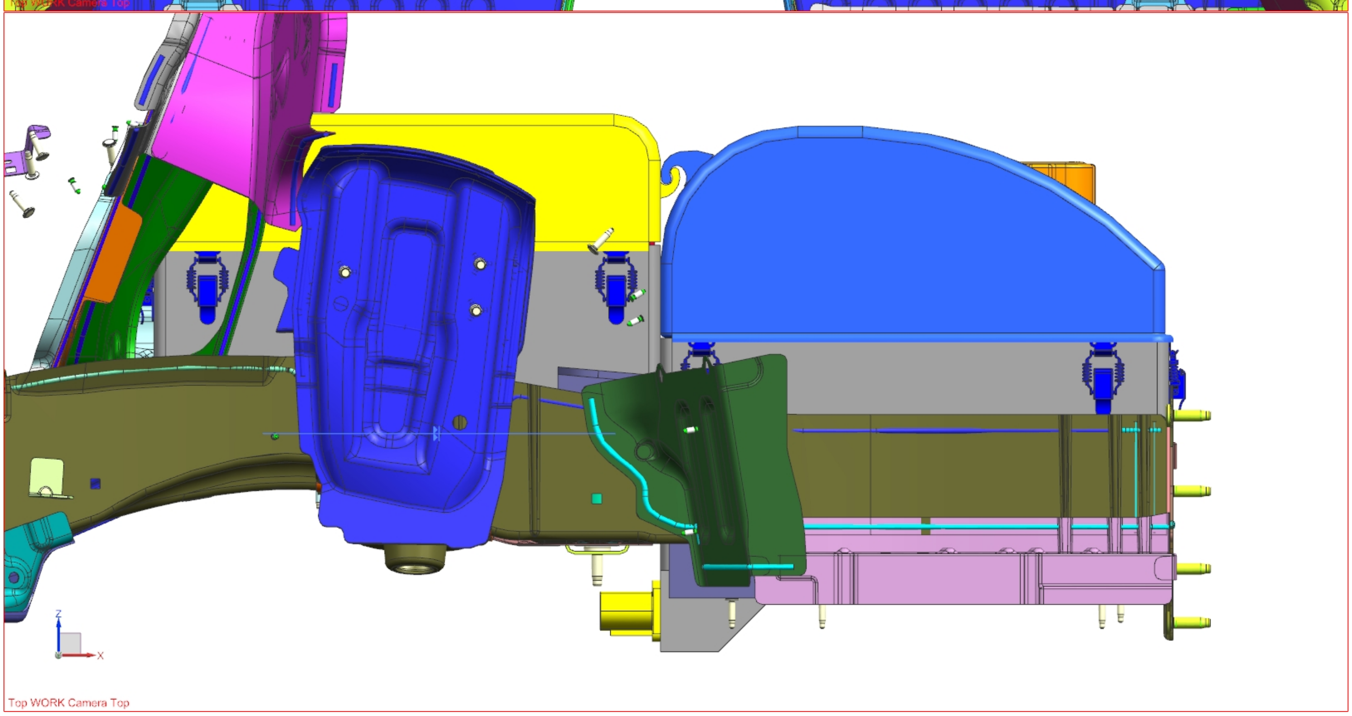
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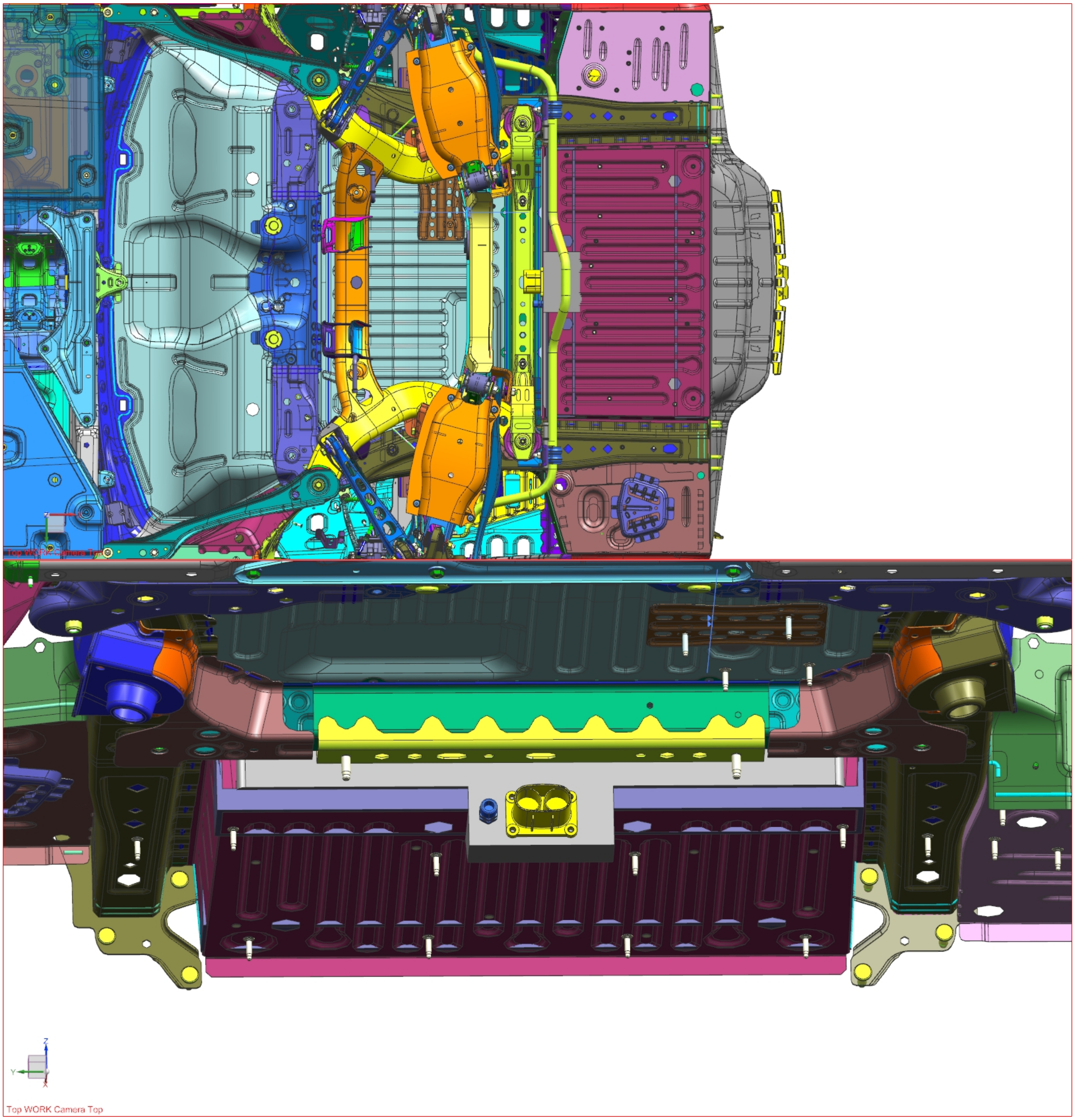
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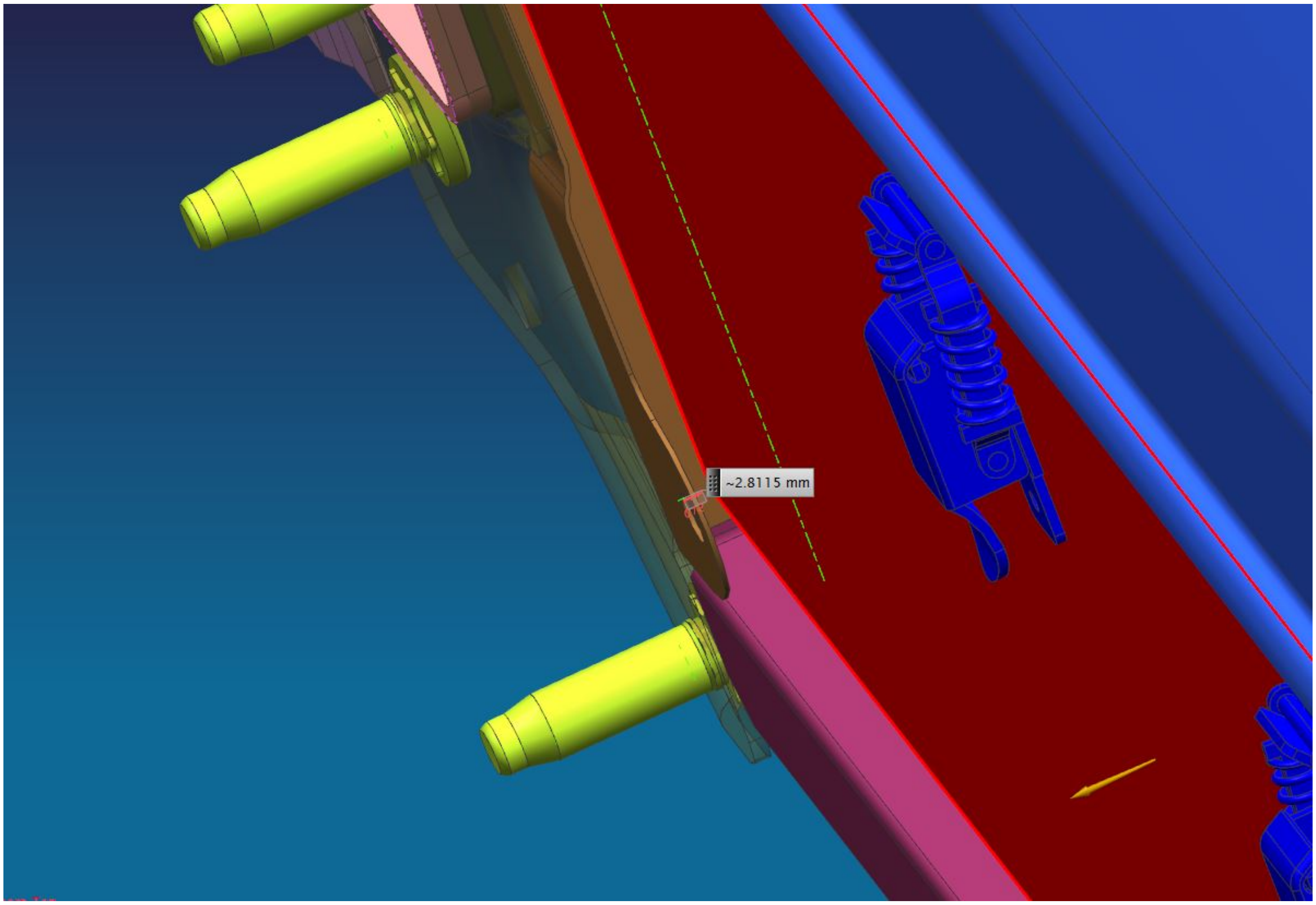

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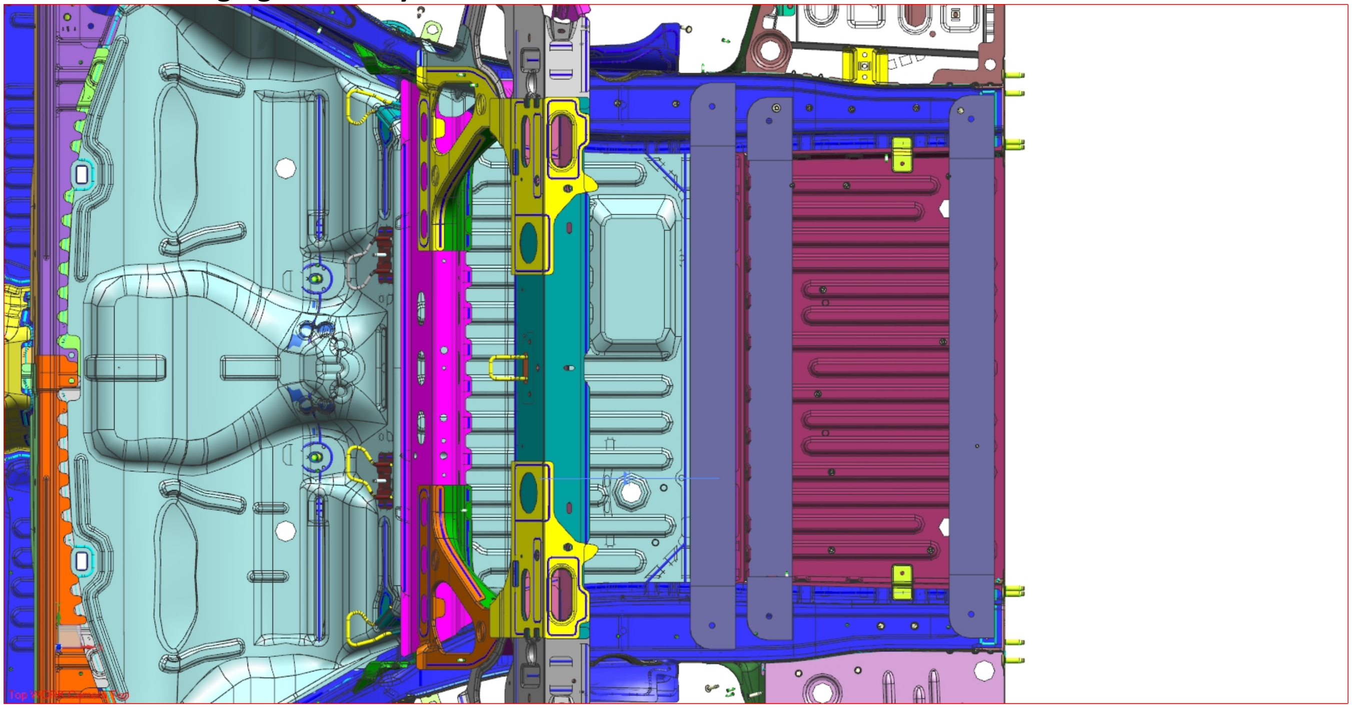

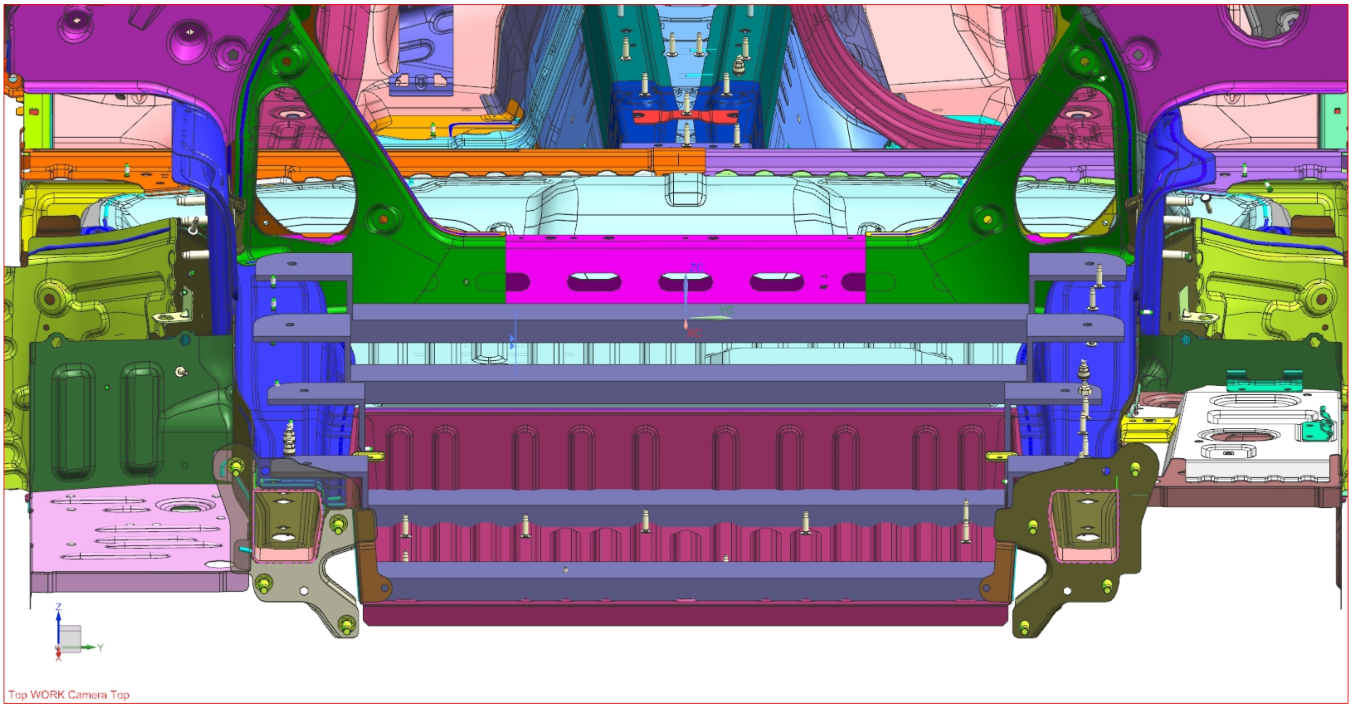
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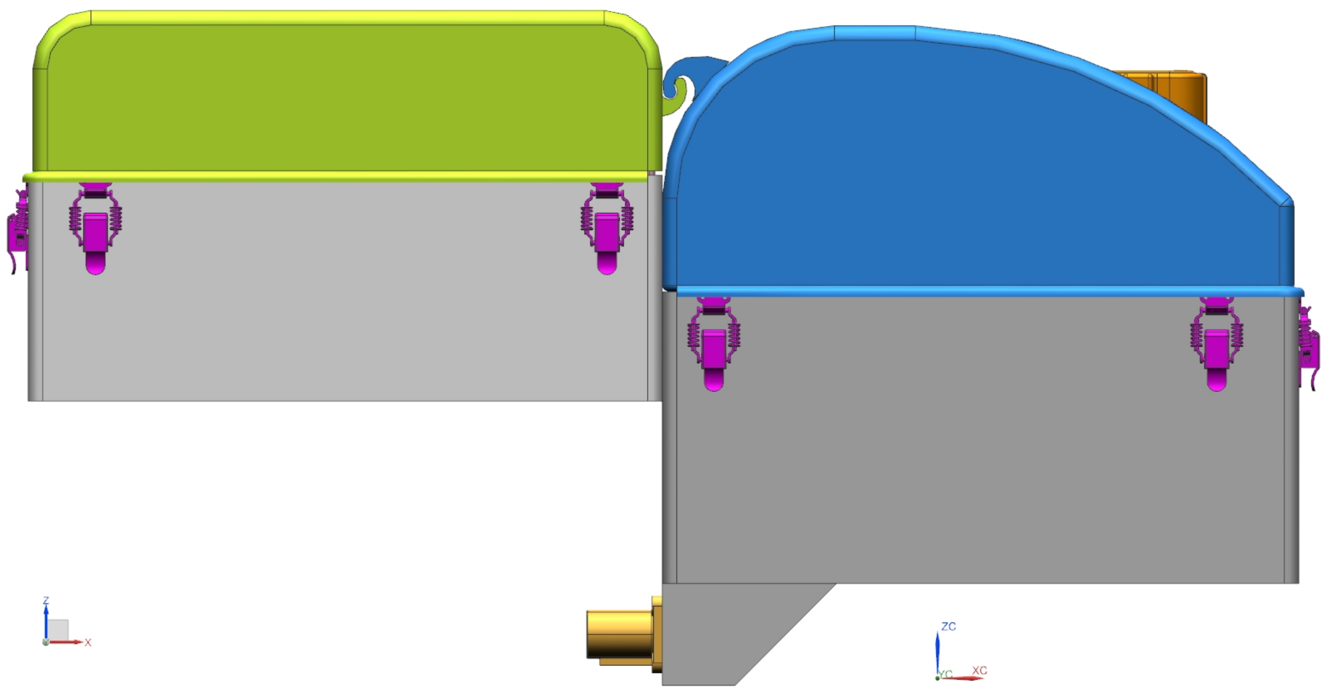
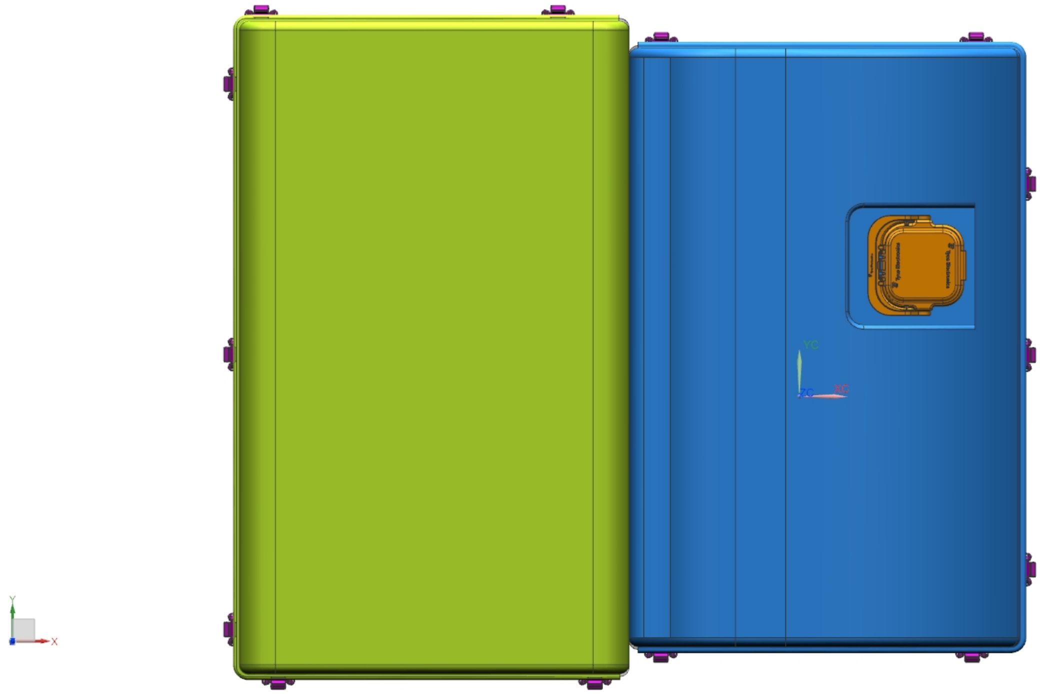
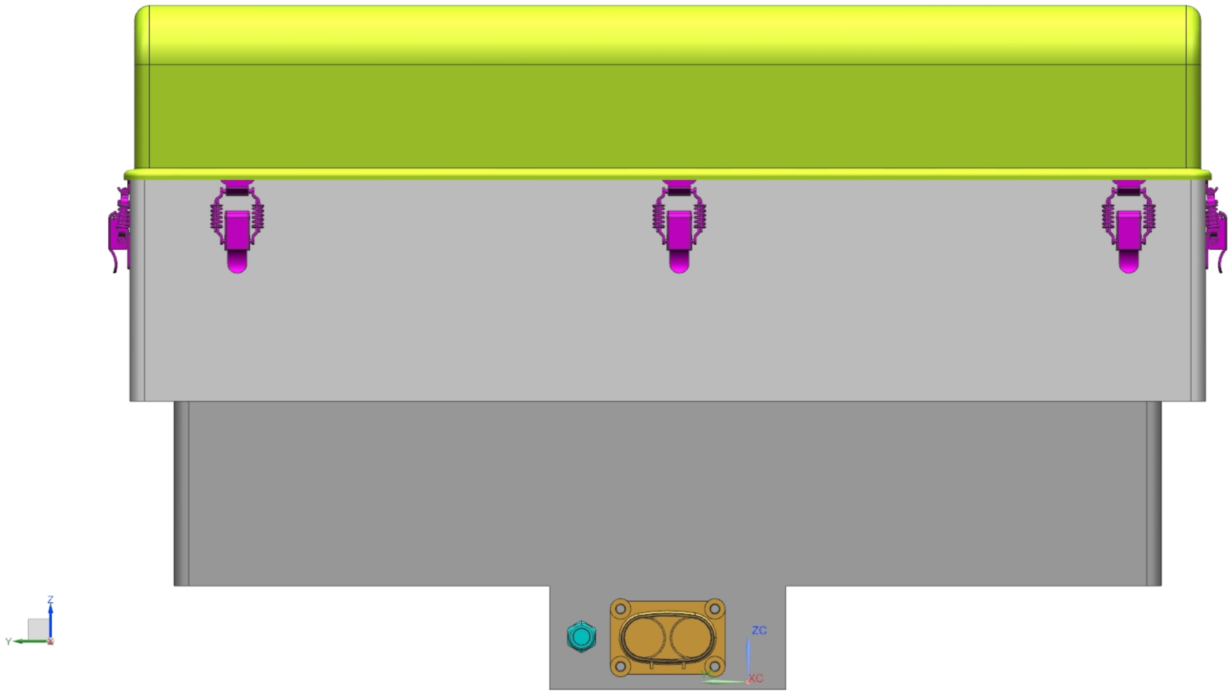
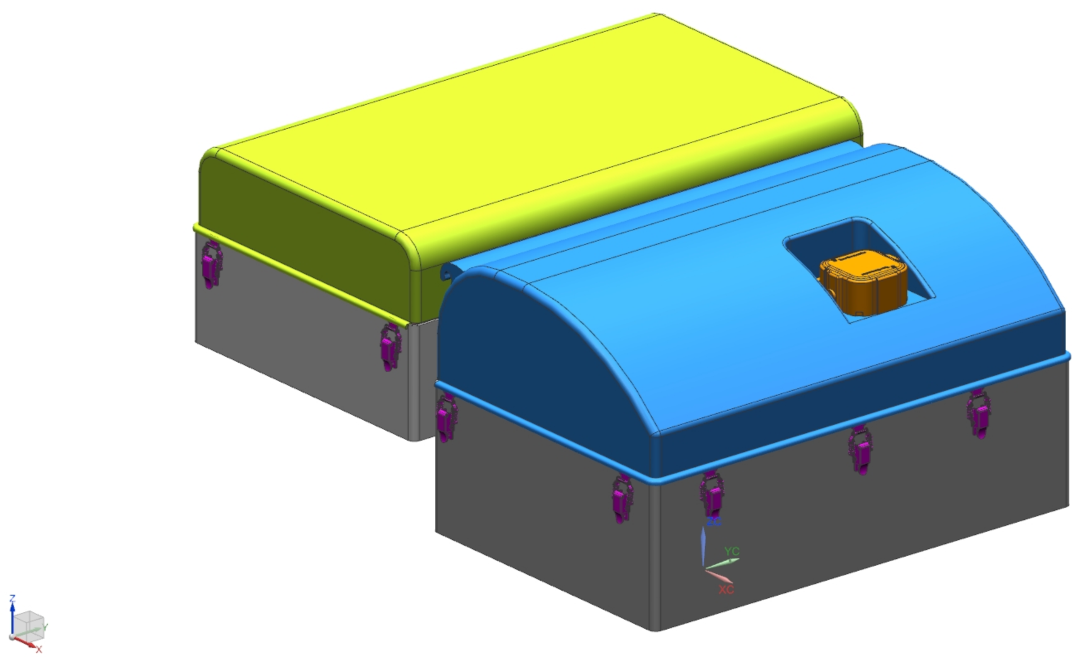
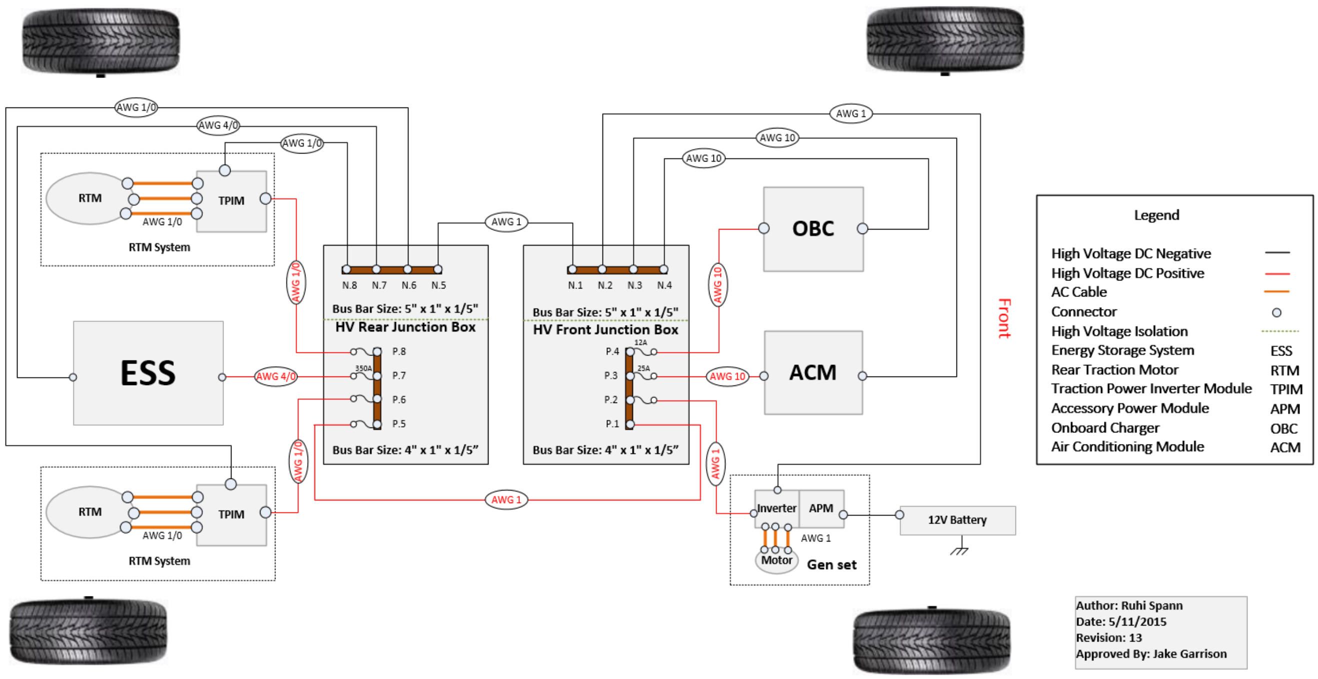








Supplementary Schematics



Link back: **HV Schematic**