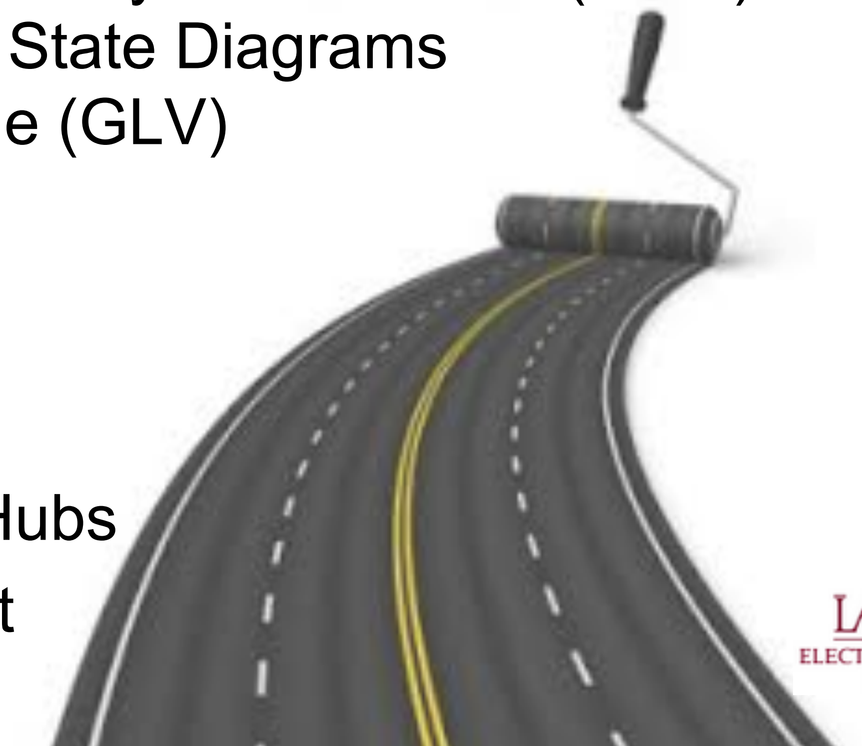
Lafayette Electric Vehicle 2015

ECE 492: Senior Design II
Morning Critical Design Review
March 11, 2015
Hugel 100

Roadmap

1. Meet the Morning Teams
2. Introduction: Motivation
3. Interface Control
    a. System Assemblies Layout/Interfaces (Car)
    b. System Assemblies Layout/Interfaces (Rack)
    c. Interconnects and State Diagrams
4. Grounded Low Voltage (GLV)
    a. Safety Loop
    b. GLV Power
    c. VCI
    d. TSI
5. Panel Drawings and Hubs
6. GLV BOM and Budget



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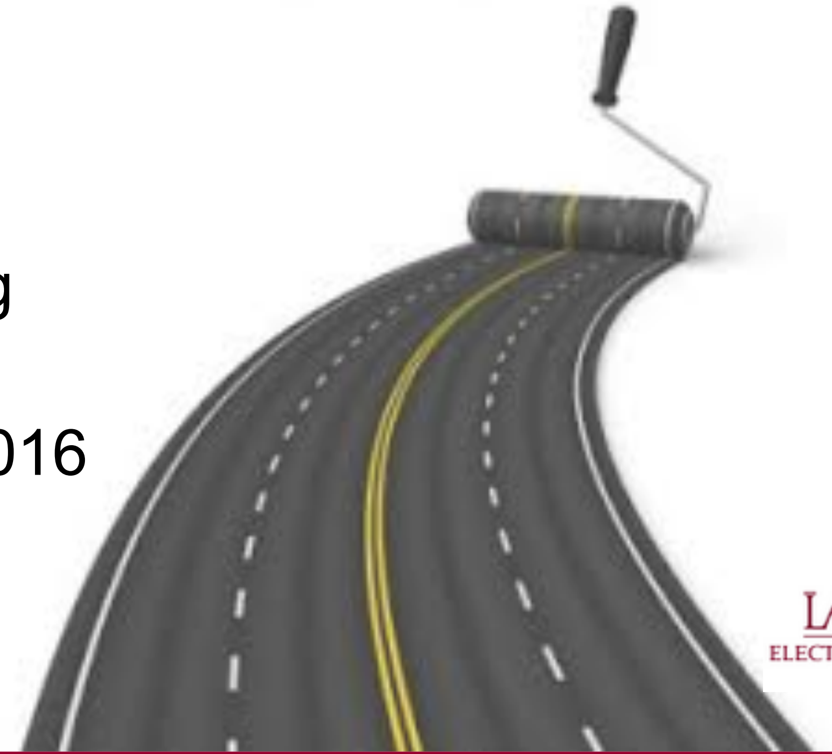
Roadmap Cont.

7. Tractive System Voltage (TSV)
    a. Overview
    b. Safety
    c. Mechanical
    d. PacMan System
    e. Charging
    f. AMS
    g. BoB
    h. Acceptance Testing
    i. Maintenance
8. Out of Scope: LFEV-2016
9. Conclusion



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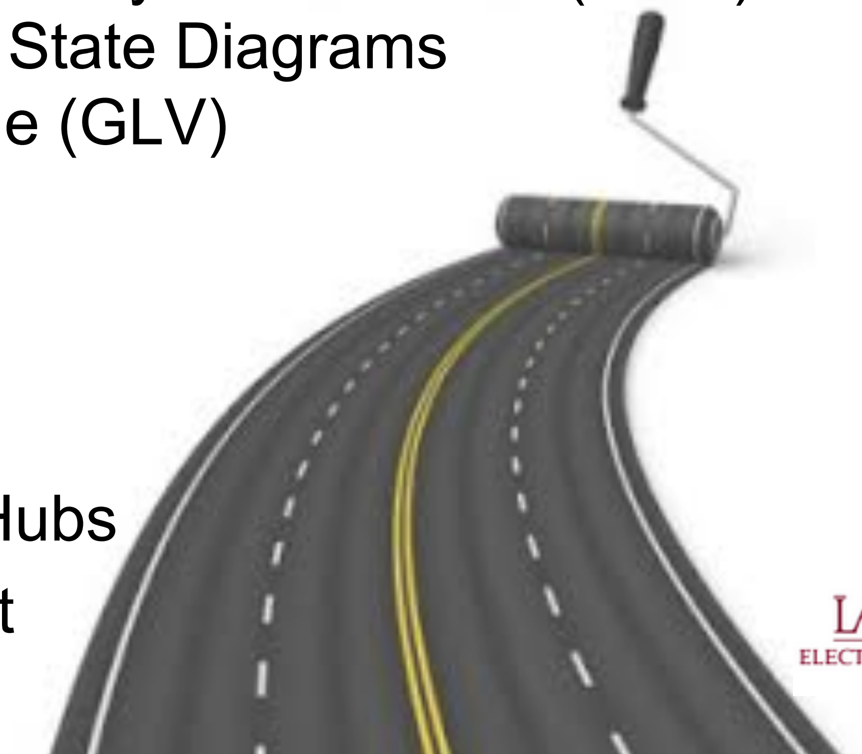

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Meet the Morning Teams

- Grounded Low Voltage (GLV)
  1. Dan Zakzewski
  2. Alo Posillico
  3. Nick DiNino
  4. Jordan Frank
  5. Zach Helwig
- Tractive System Voltage (TSV)
  1. William Stathis
  2. Duhang “Hansen” Liang
  3. Katherine Nellis
  4. Jaejoon Yang
  5. Jordan Blake
- Mechanical Engineering Team
  1. Ben Prevoznak
  2. Kailan Ottaway
  3. A. Freddie Hess

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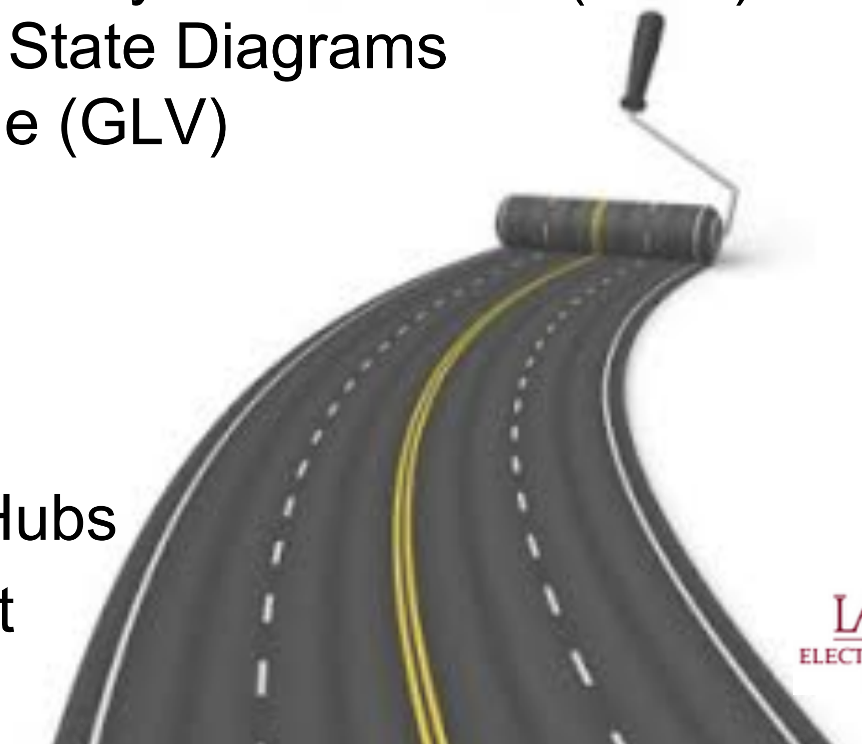

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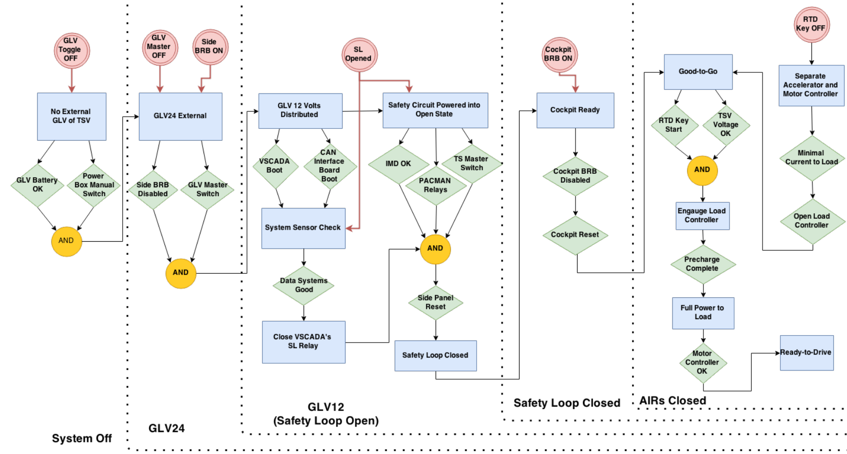
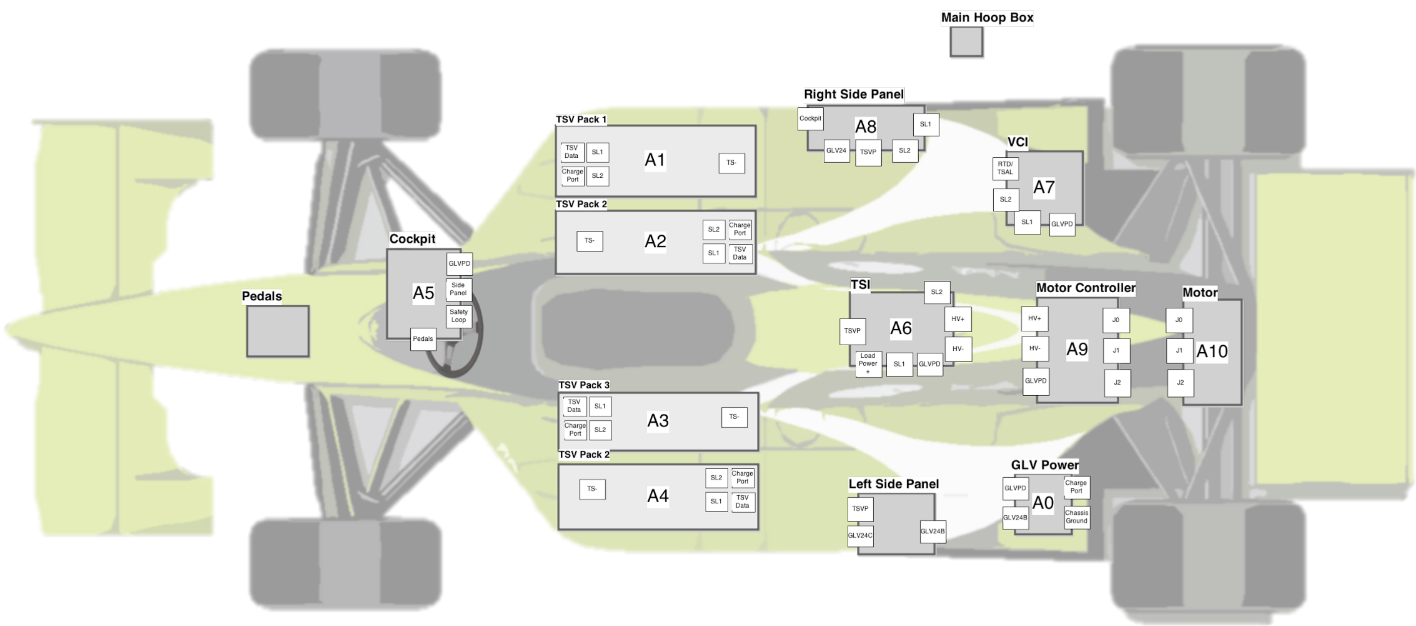
Introduction: Motivation

- IEEE Formula Hybrid Competition Vehicle
    - Electric Car
- 4 Year Project
- Spring 2016





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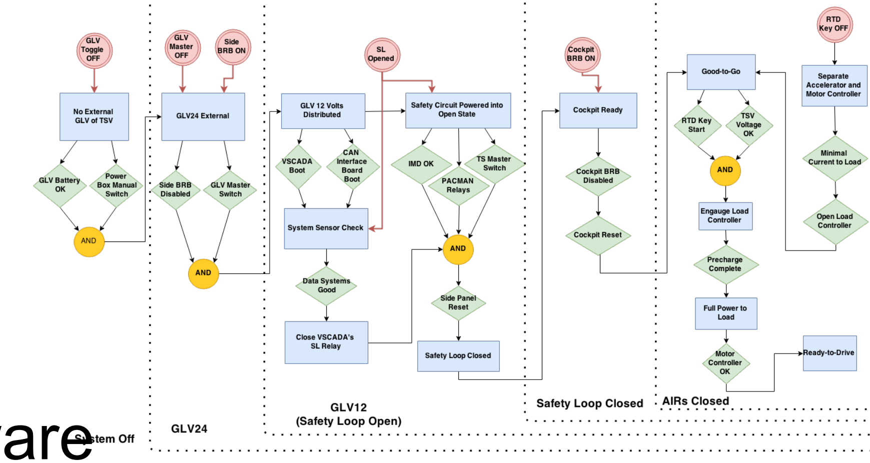
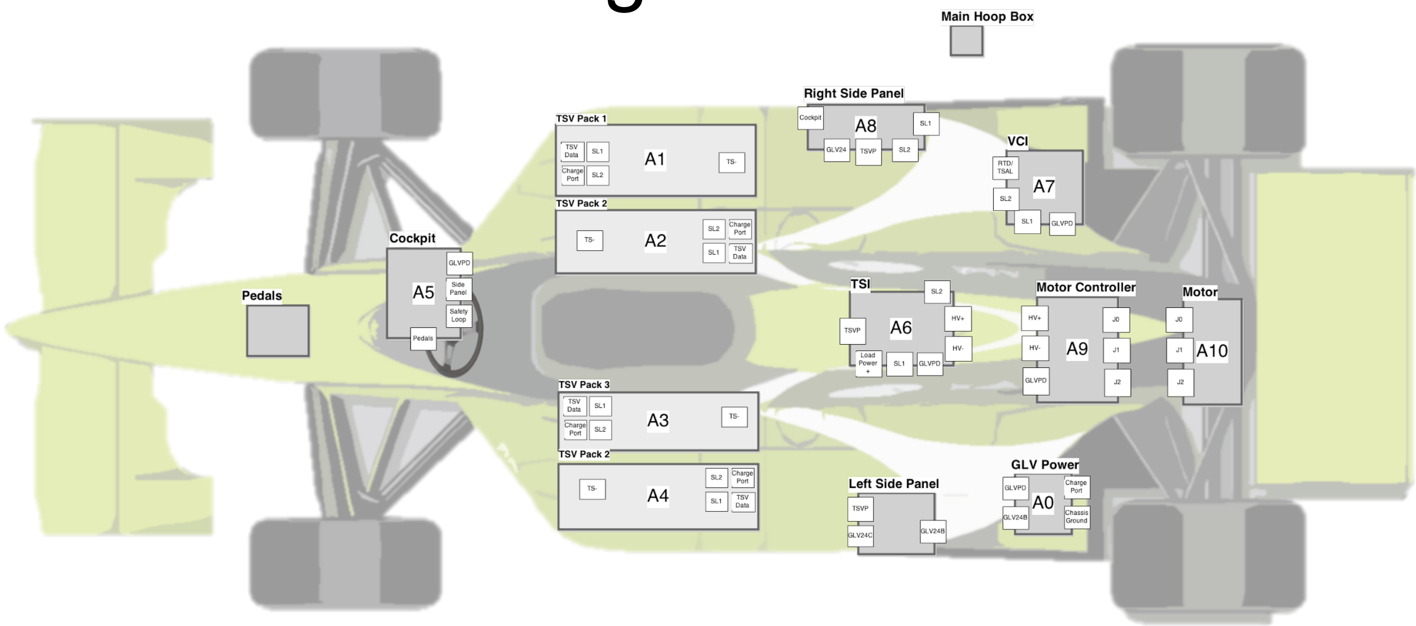
Introduction: Motivation

- Competition Ready:
  - TSV
  - Integrated VSCADA Software
  - GLV Electrical
- Interfaced Dynamometer System
- Mechanical Design on a Chassis





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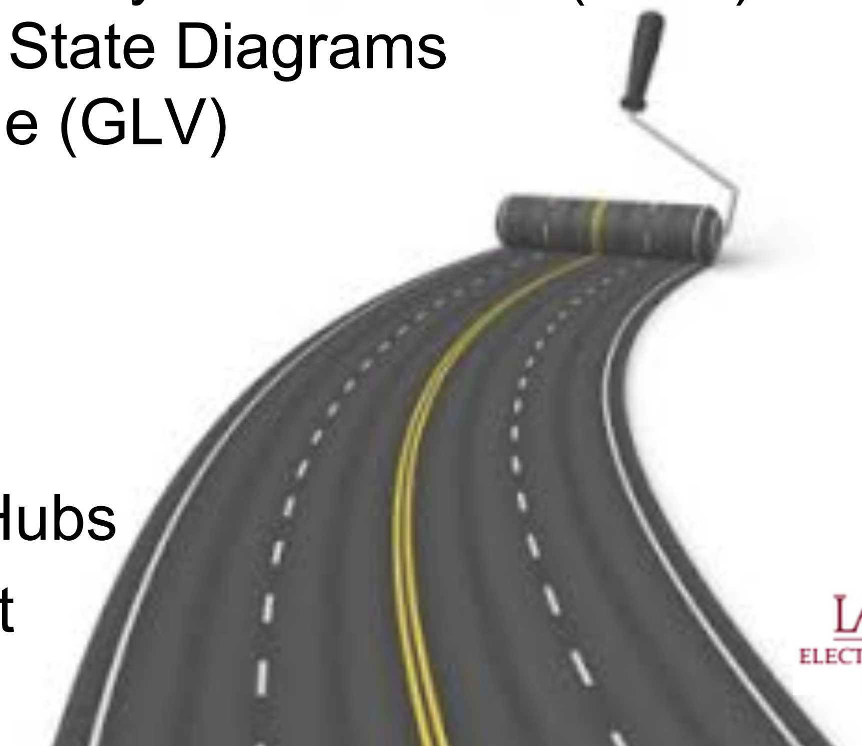

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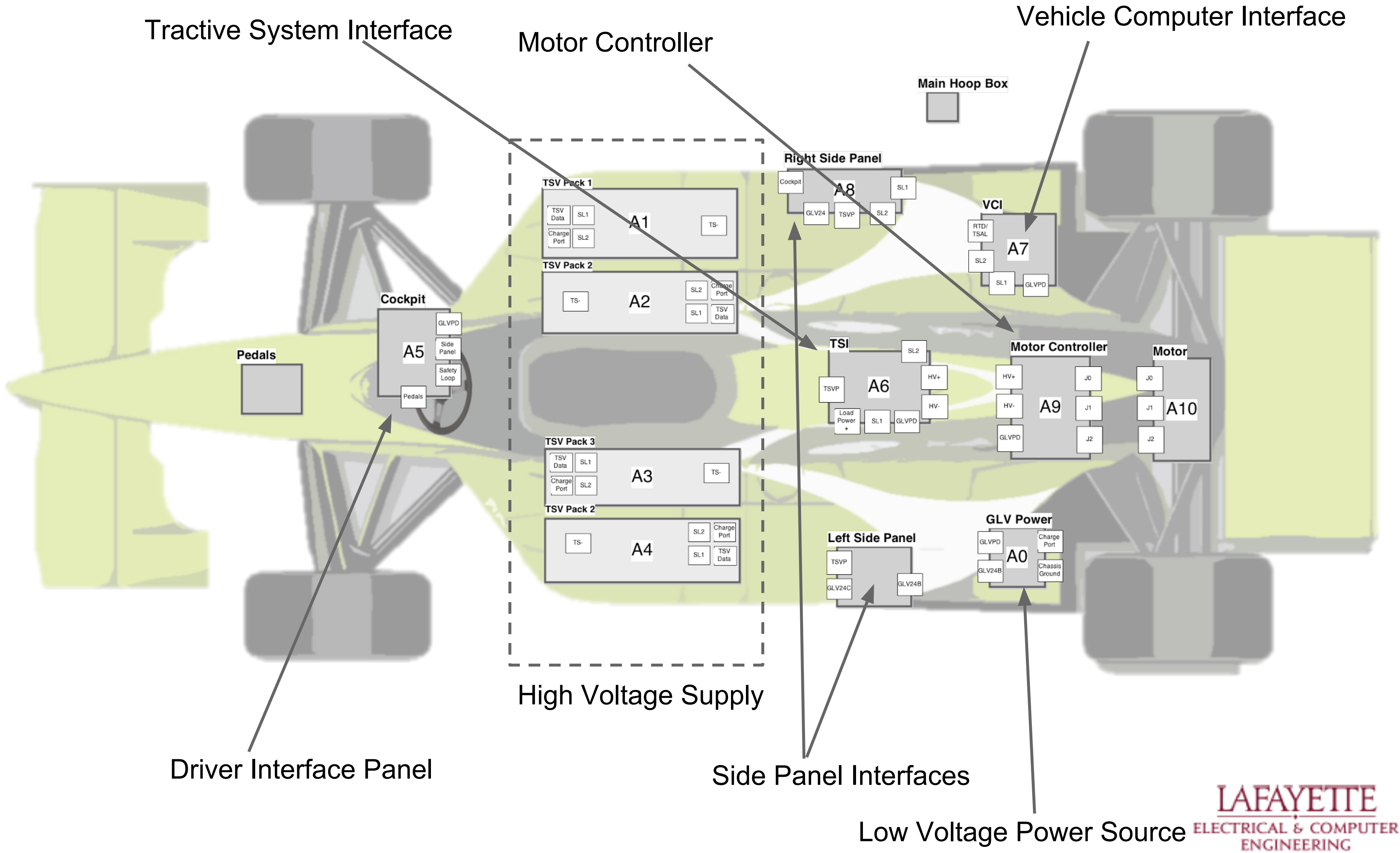
System Assemblies Layout - Top View



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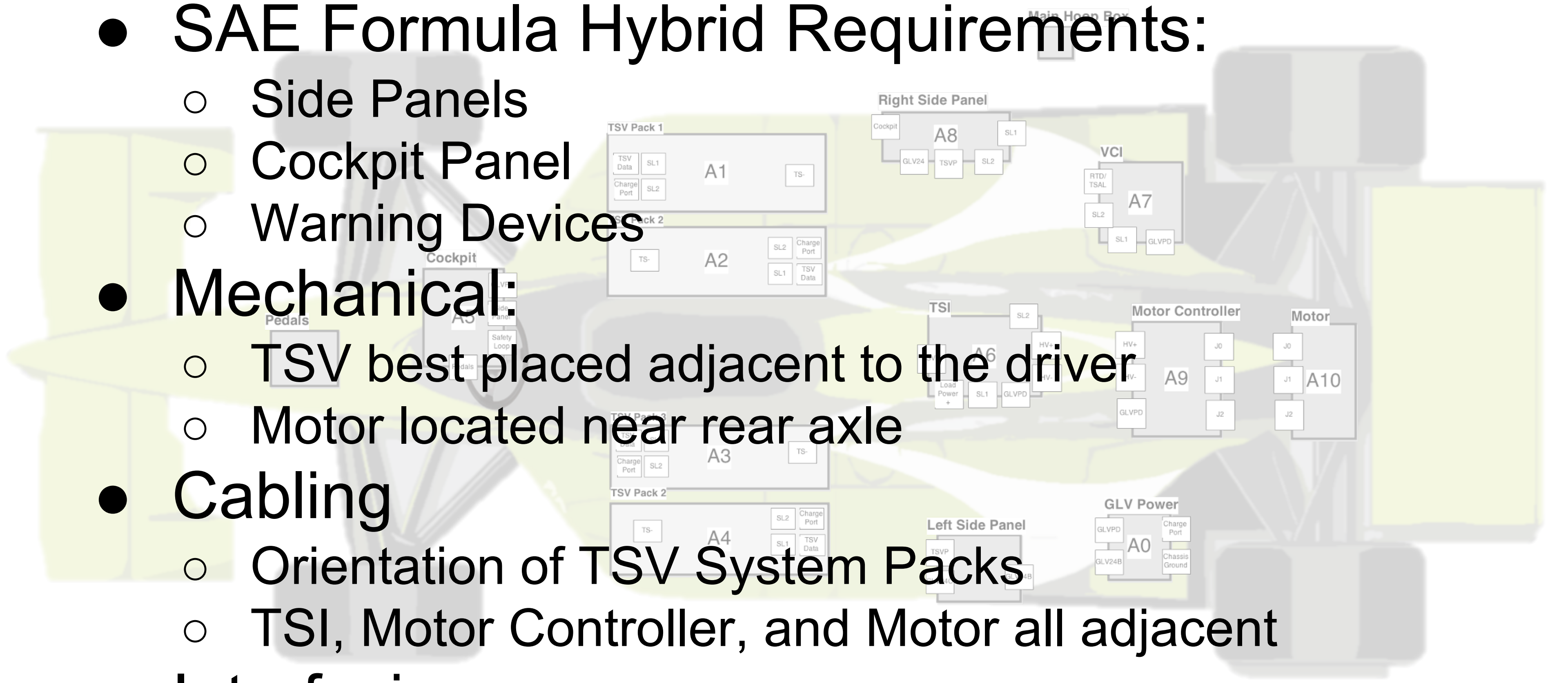
Layout Selection

- SAE Formula Hybrid Requirements:
  - Side Panels
  - Cockpit Panel
  - Warning Devices
- Mechanical:
  - TSV best placed adjacent to the driver
  - Motor located near rear axle
- Cabling
  - Orientation of TSV System Packs
  - TSI, Motor Controller, and Motor all adjacent
- Interfacing
  - VCI accessible by pit station crew



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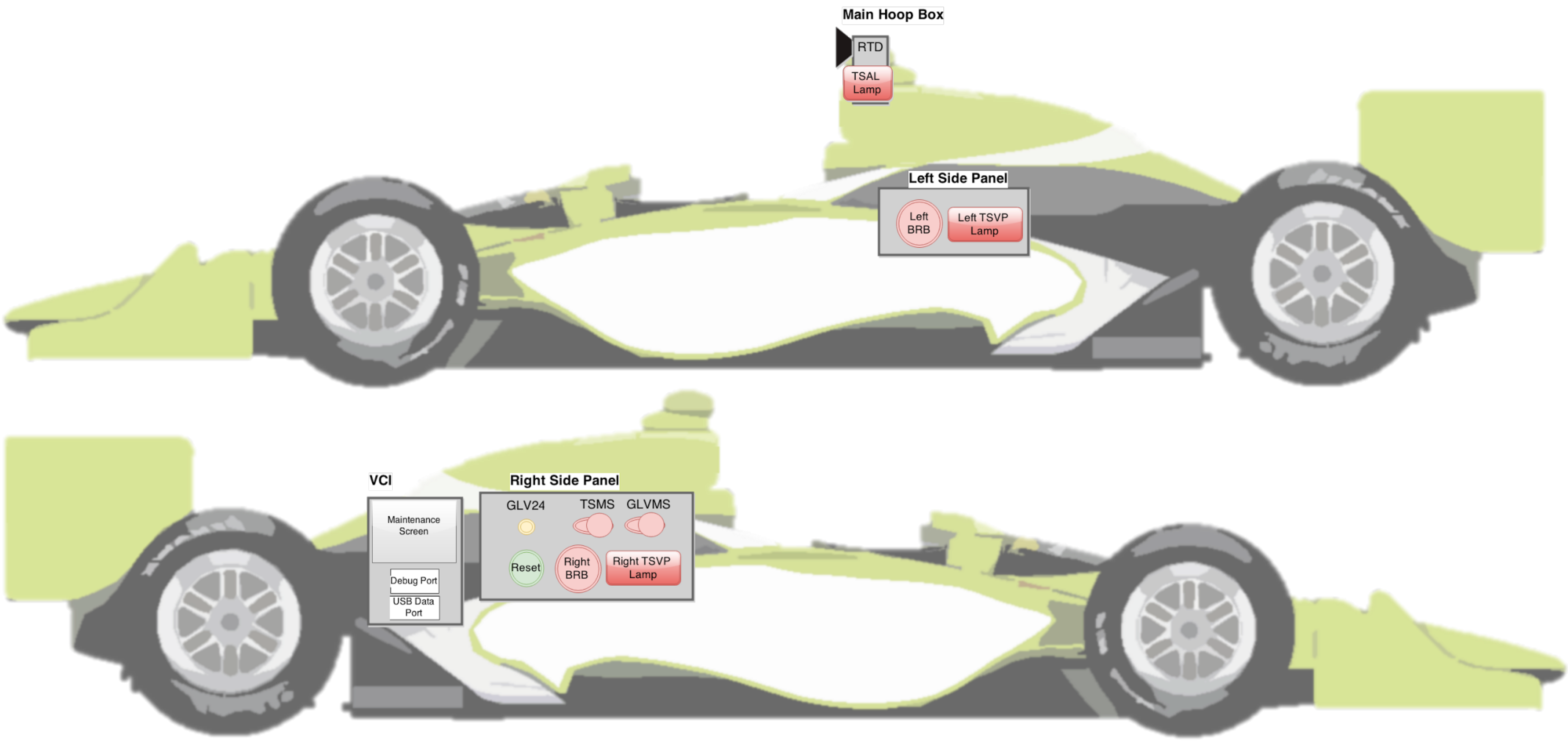
Physical Interfaces Layout - Side View



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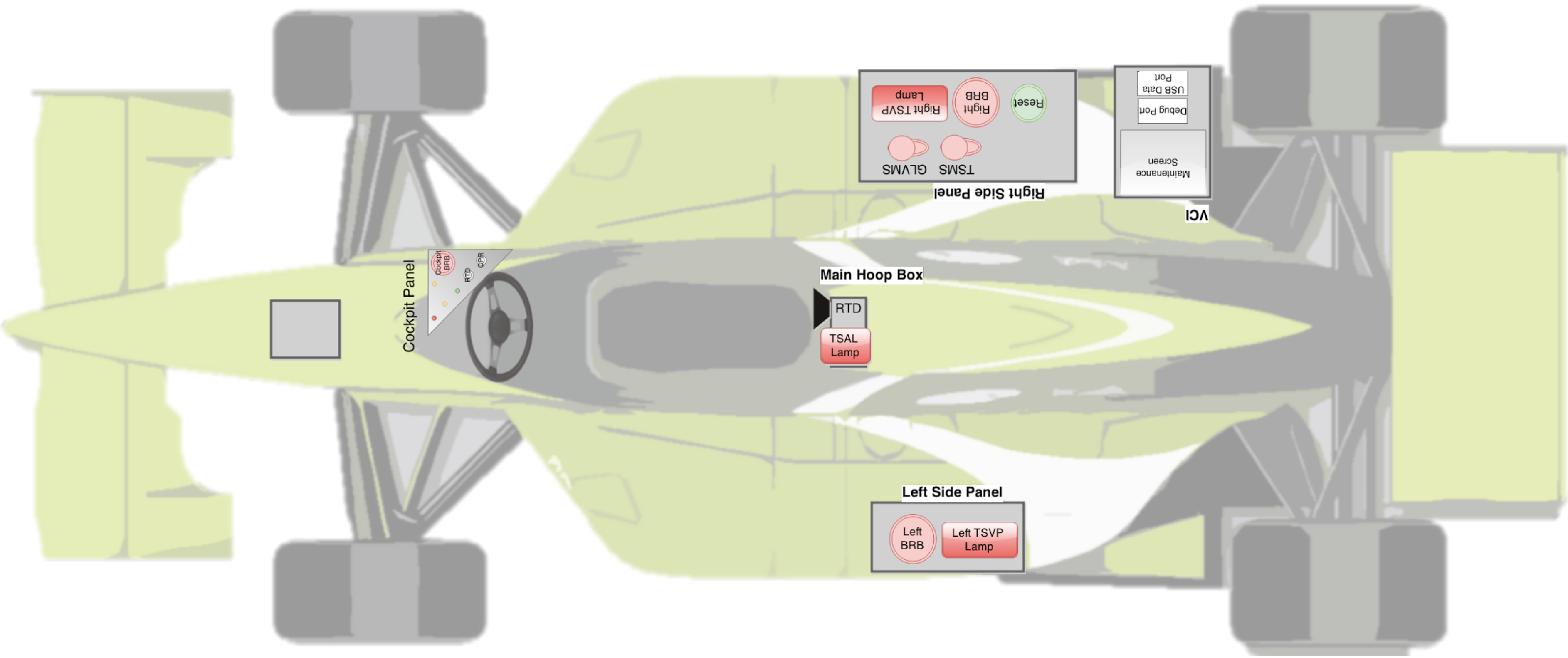
Physical Interfaces Layout - Top View



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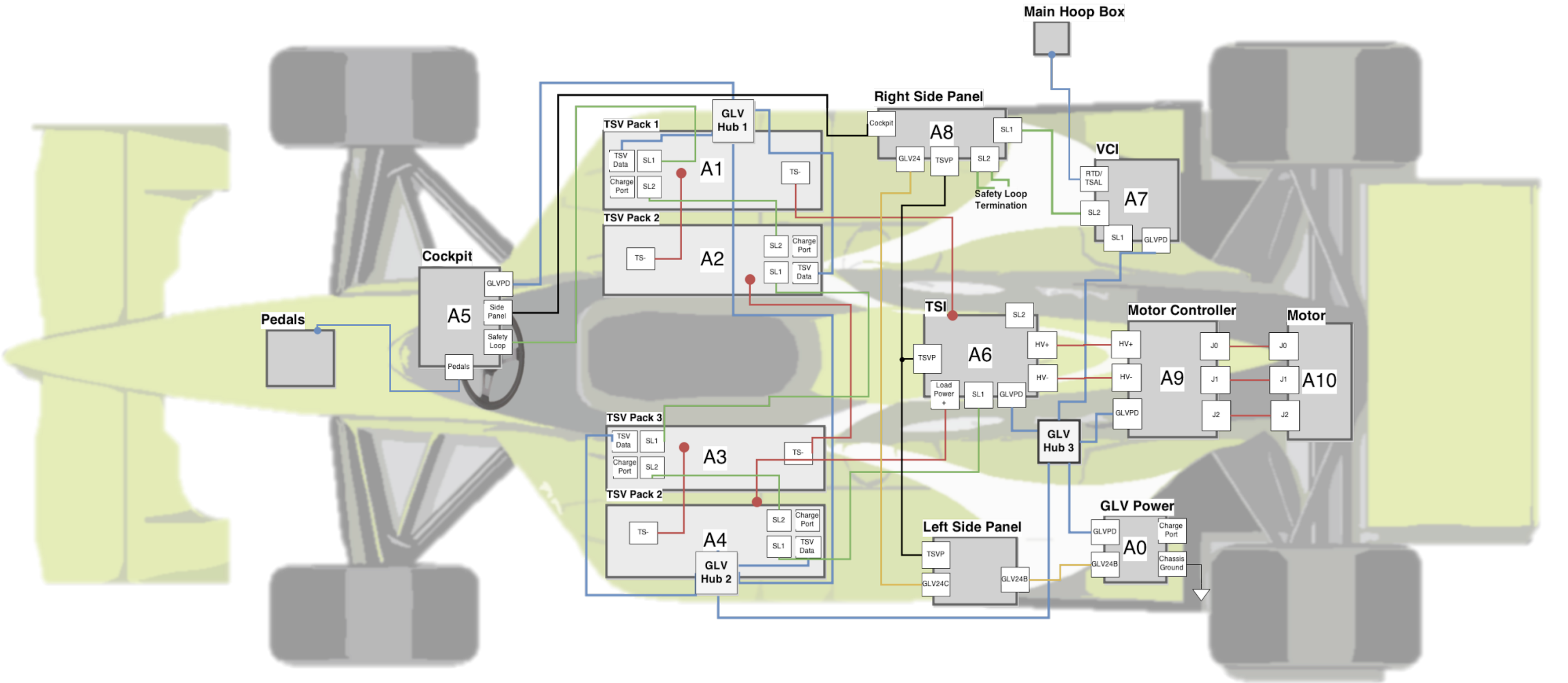

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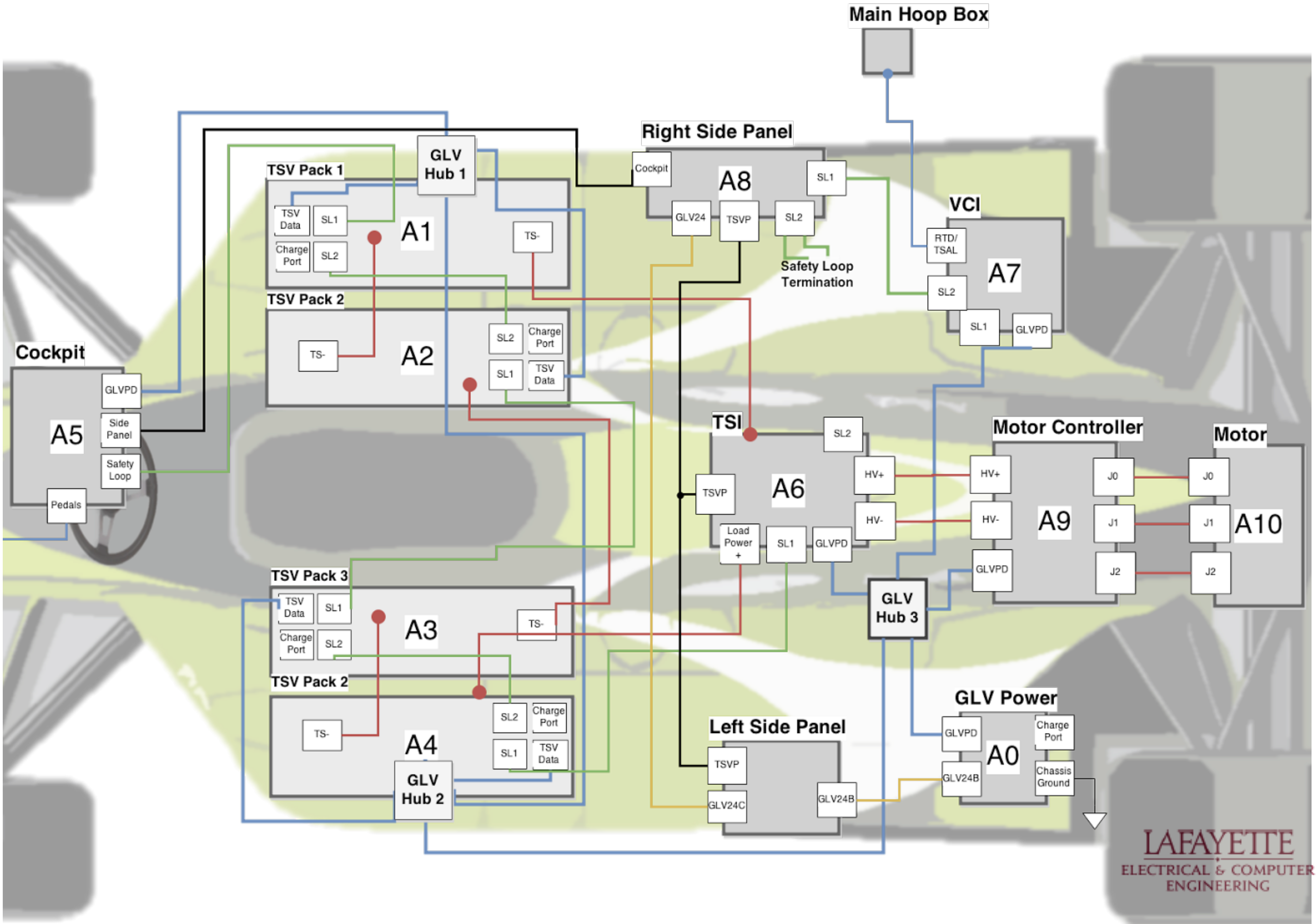

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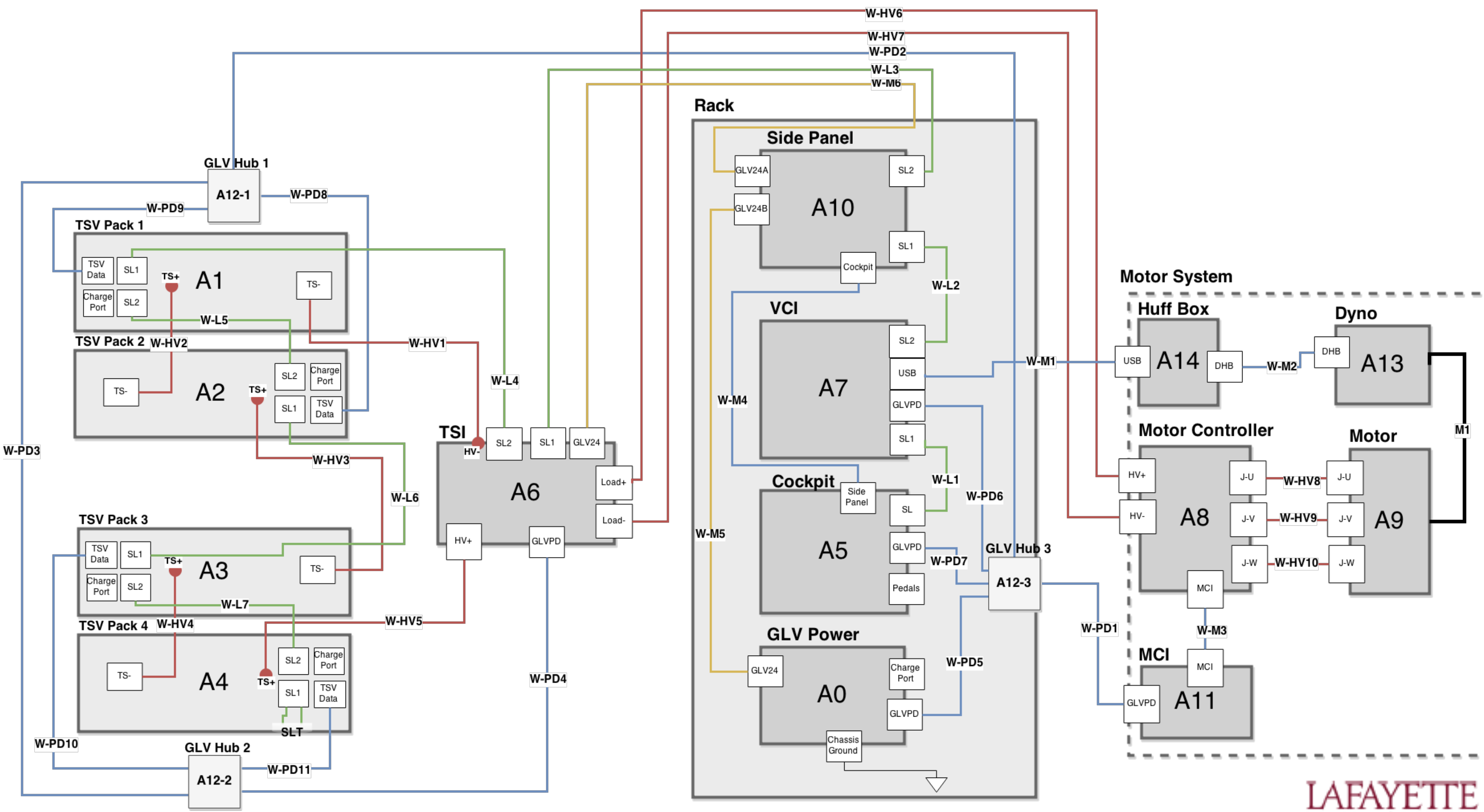
End-of-Term Integration Layout



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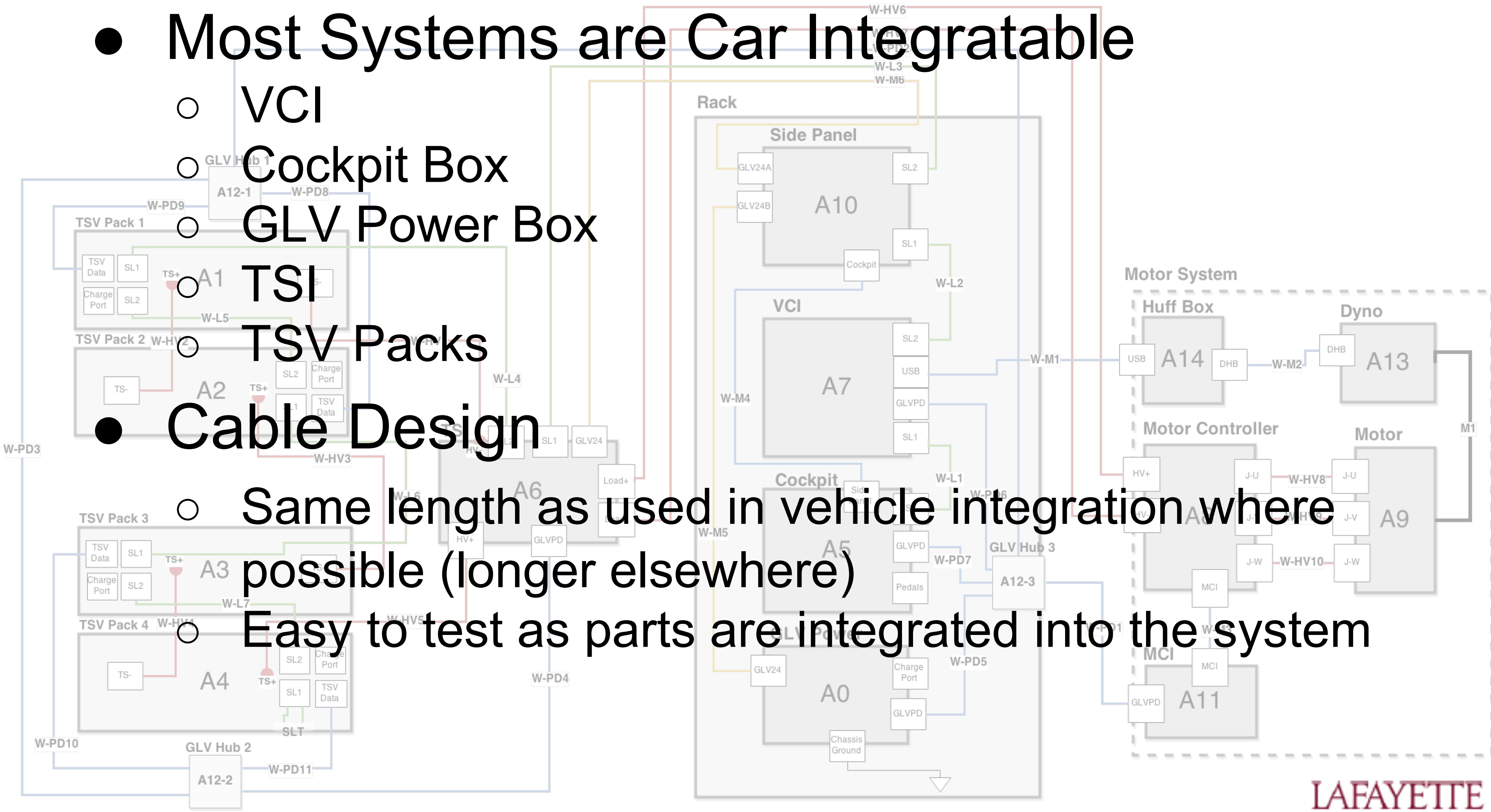
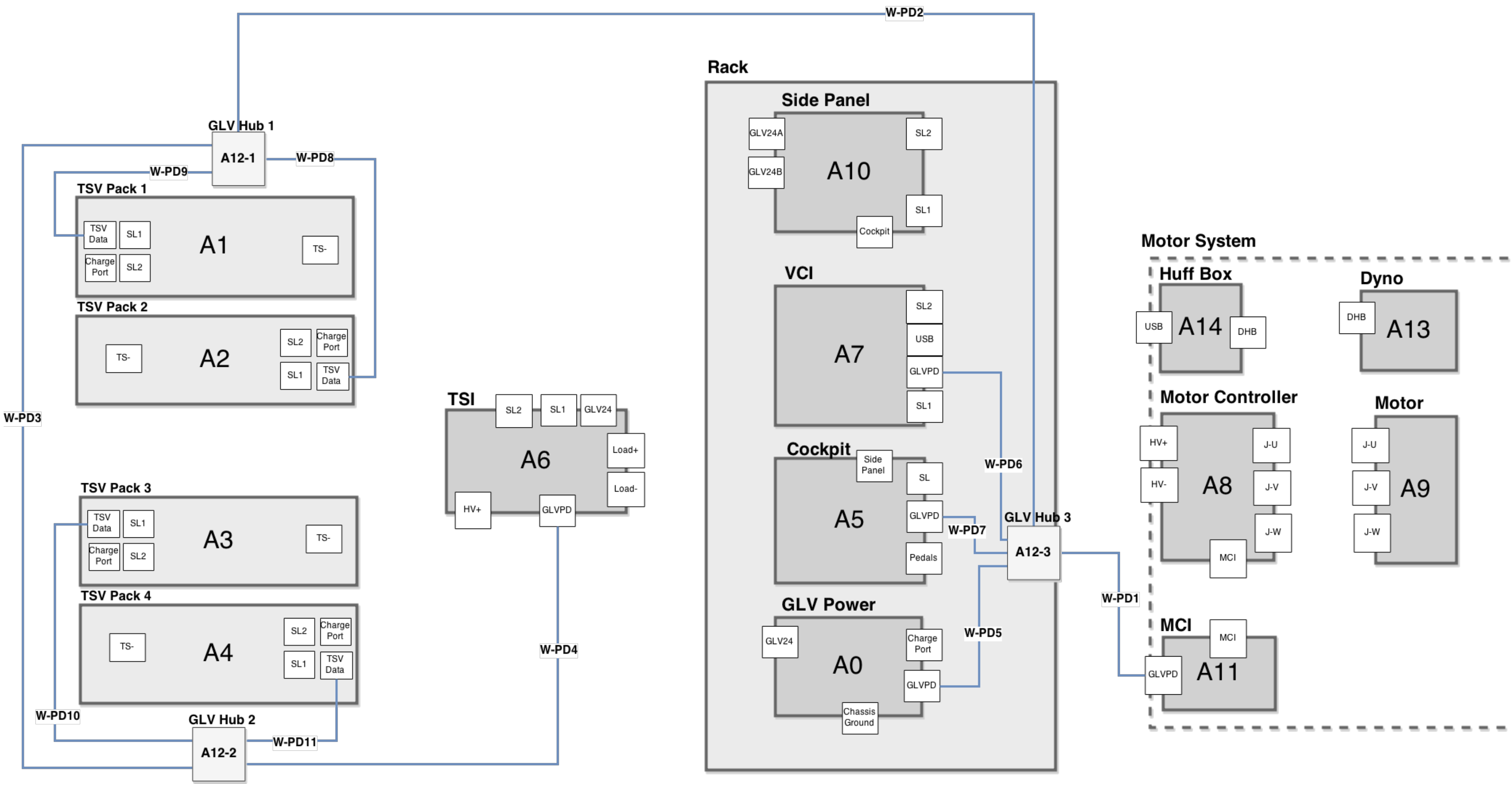
End of Term Integration Layout

- Most Systems are Car Integratable
  - VCI
  - Cockpit Box
  - GLV Power Box
  - TSI
  - TSV Packs
- Cable Design
  - Same length as used in vehicle integration where possible (longer elsewhere)
  - Easy to test as parts are integrated into the system



GLV Power and Data Distribution



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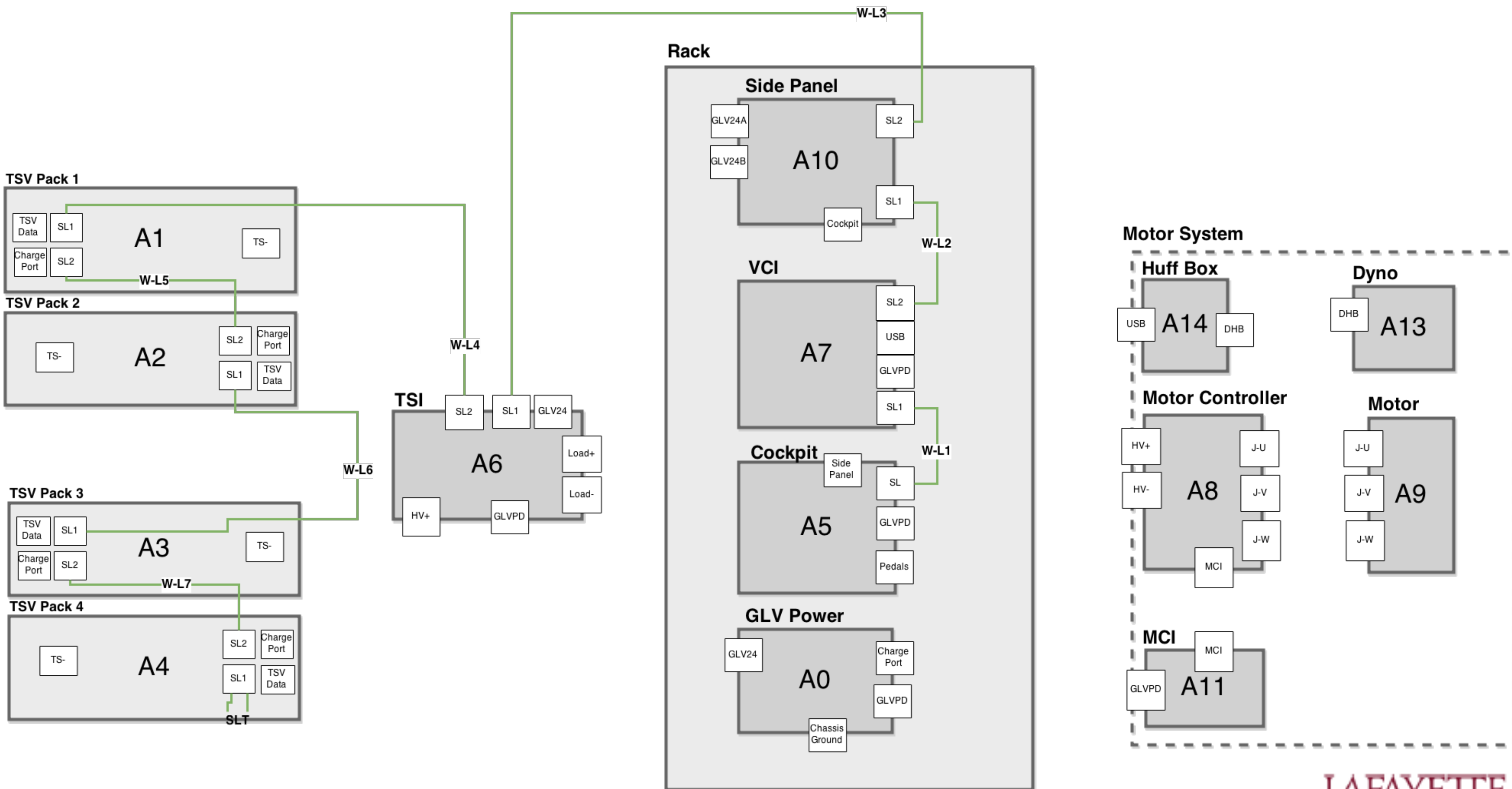
GLV Power and Data Distribution

- 12 Volt Power Supply
  - Needed for VSCADA Computer
  - Easily Regulated to 5V
- CAN Data Line
  - Industry Standard in Automotive Systems
  - Already Implemented inside the Motor Controller
- CAN Consequences
  - CAN Interface Microcontrollers (JGB)
  - Single long bus line
  - Nodes connected via short (<1.0 m) stubs
  - GLV Hub Boxes

Safety Loop Connections



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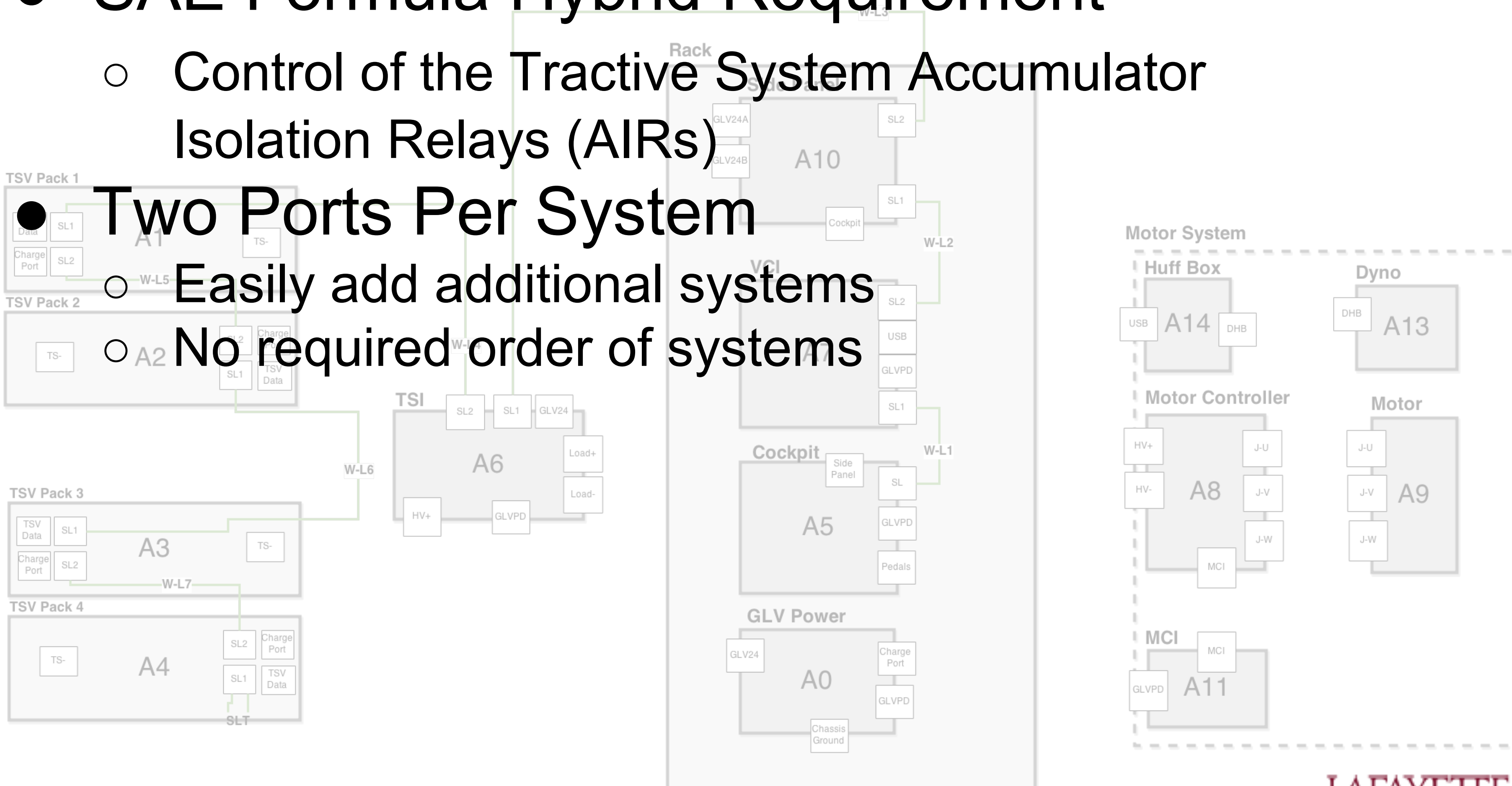
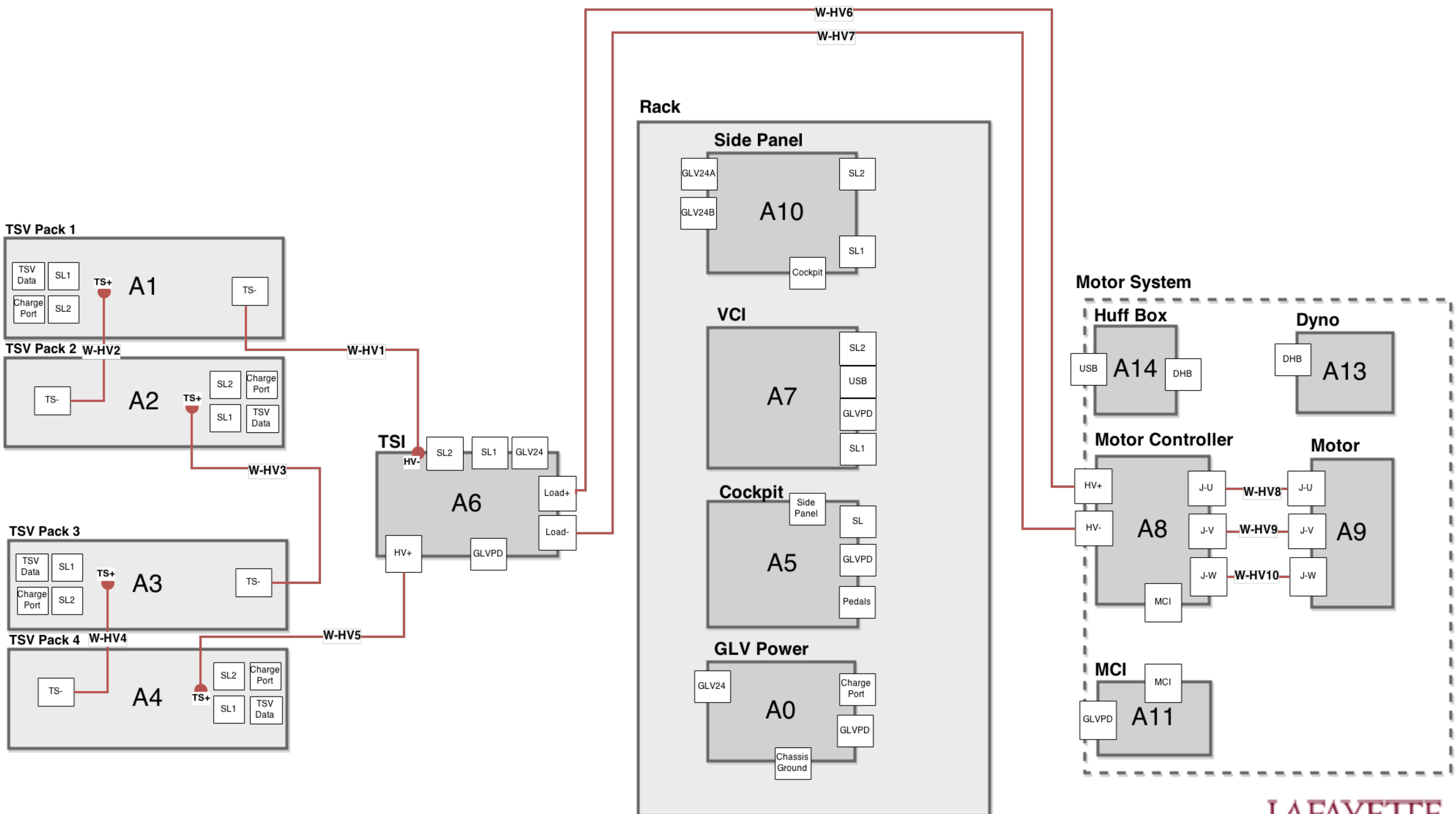
Safety Loop Connections

- SAE Formula Hybrid Requirement
  - Control of the Tractive System Accumulator Isolation Relays (AIRs)
- Two Ports Per System
  - Easily add additional systems
  - No required order of systems



Tractive System High Voltage Path



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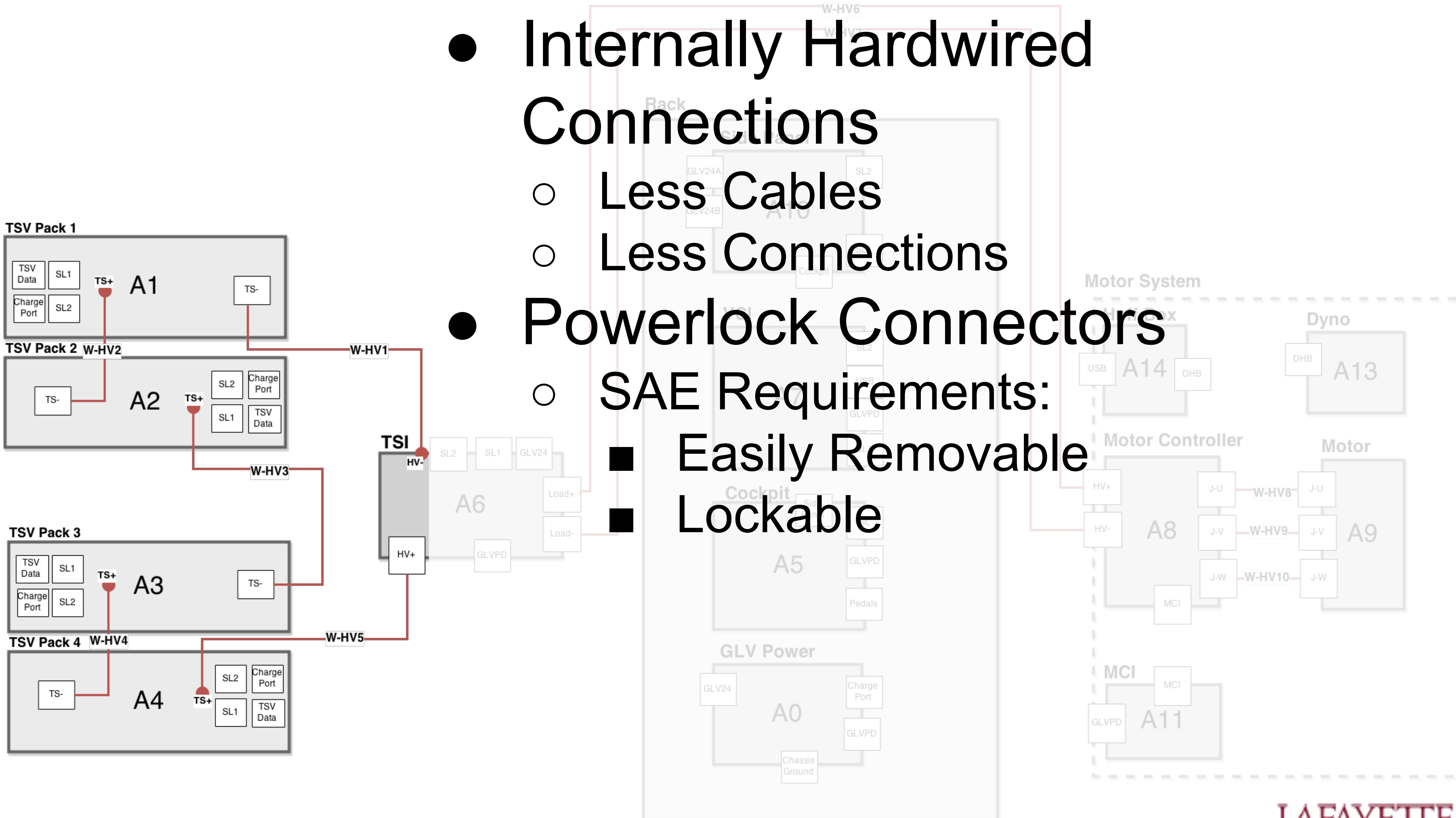
Tractive System High Voltage Path

- Internally Hardwired Connections
  - Less Cables
  - Less Connections
- Powerlock Connectors
  - SAE Requirements:
    - Easily Removable
    - Lockable



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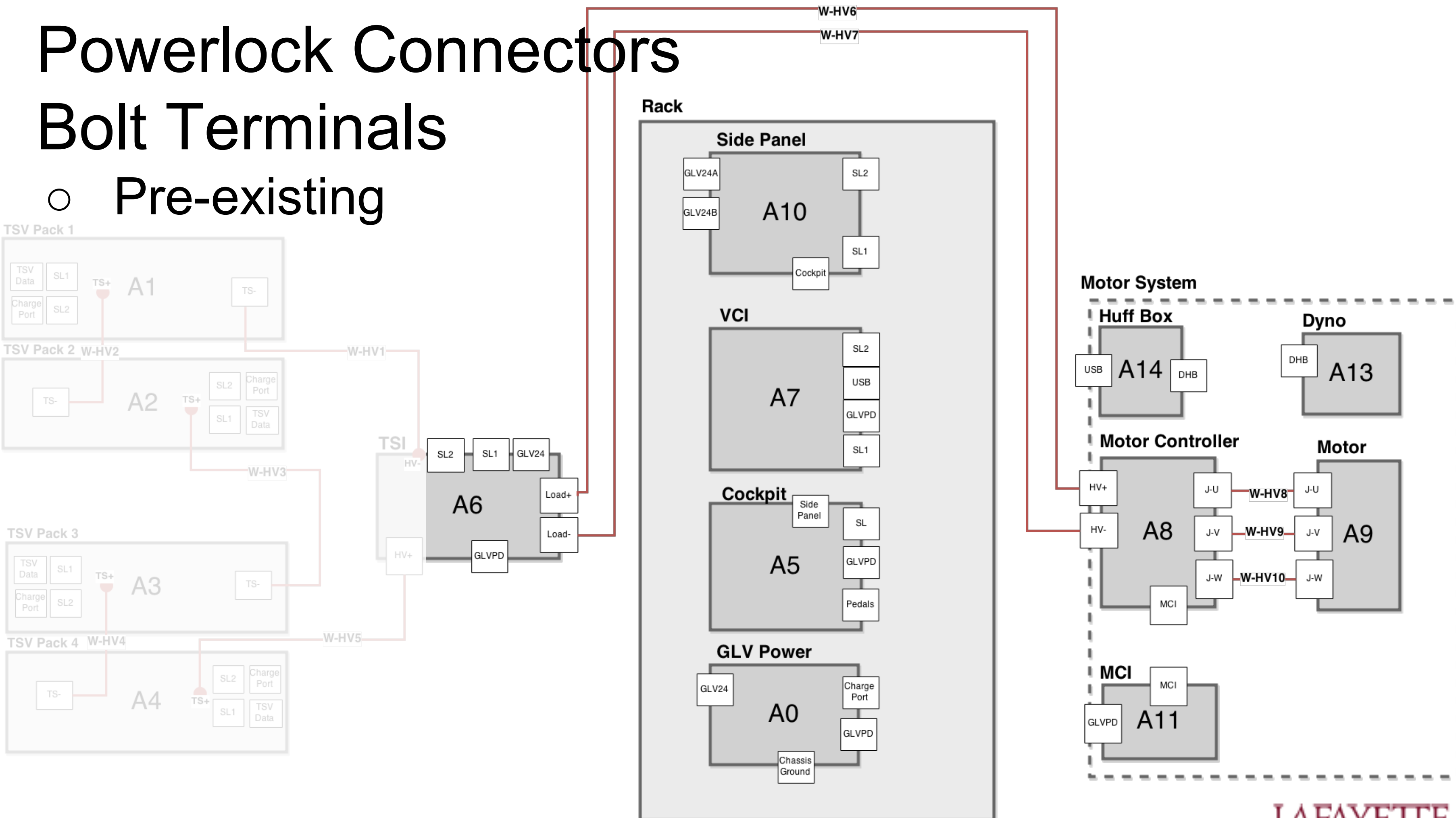
Tractive System High Voltage Path

- Powerlock Connectors
- Bolt Terminals
  - Pre-existing



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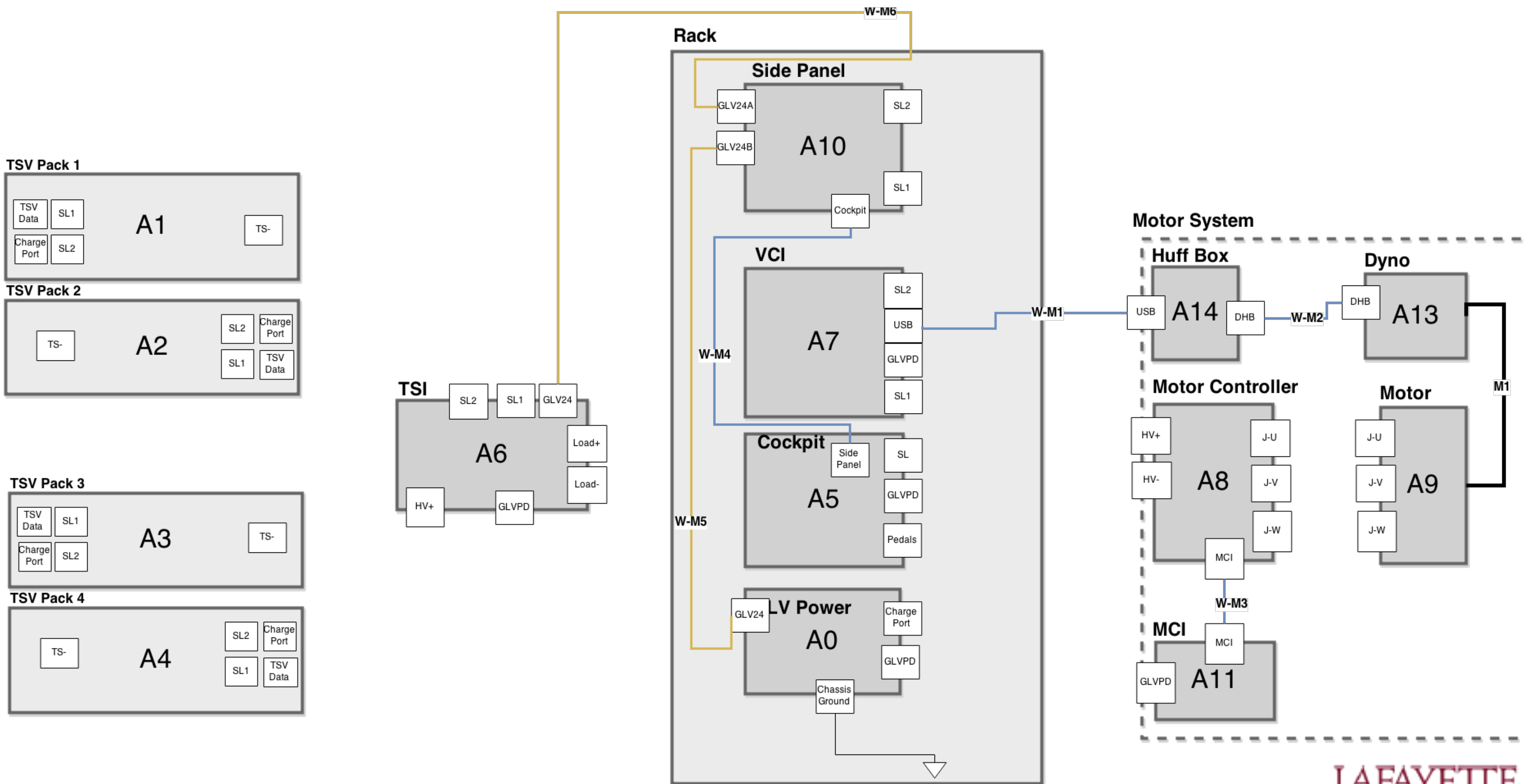
Semester Integration Layout



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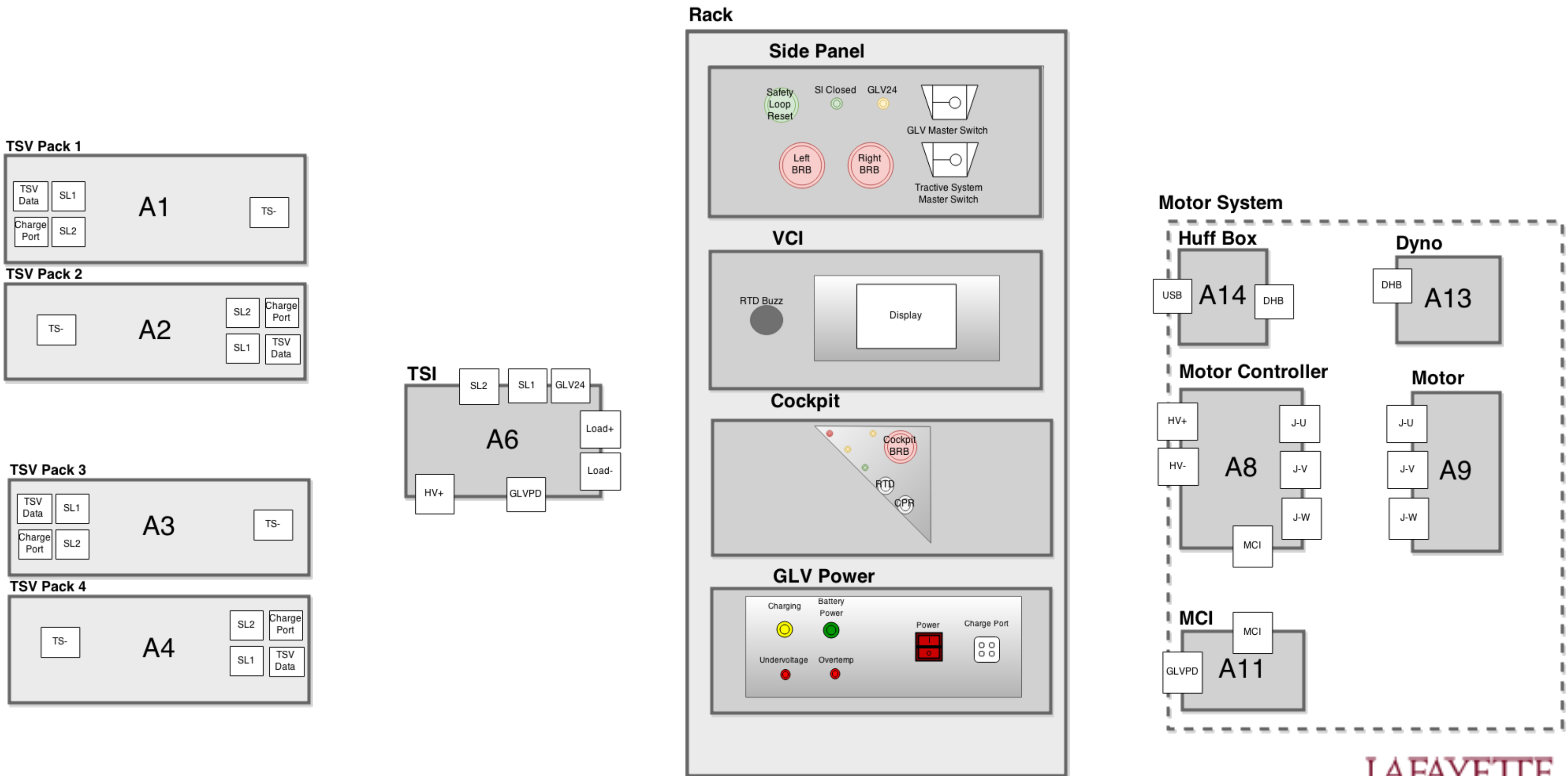
Semester Integration Physical Interfaces



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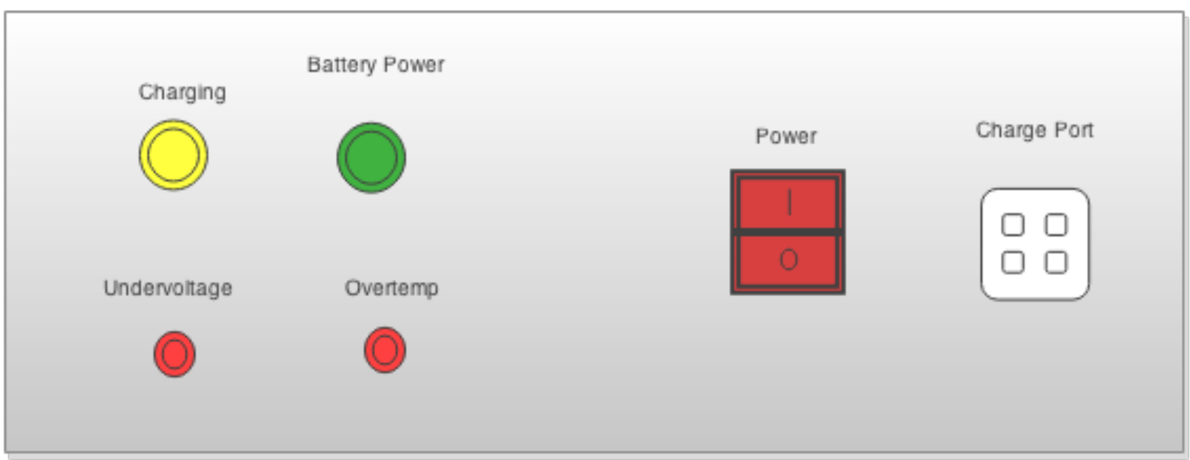
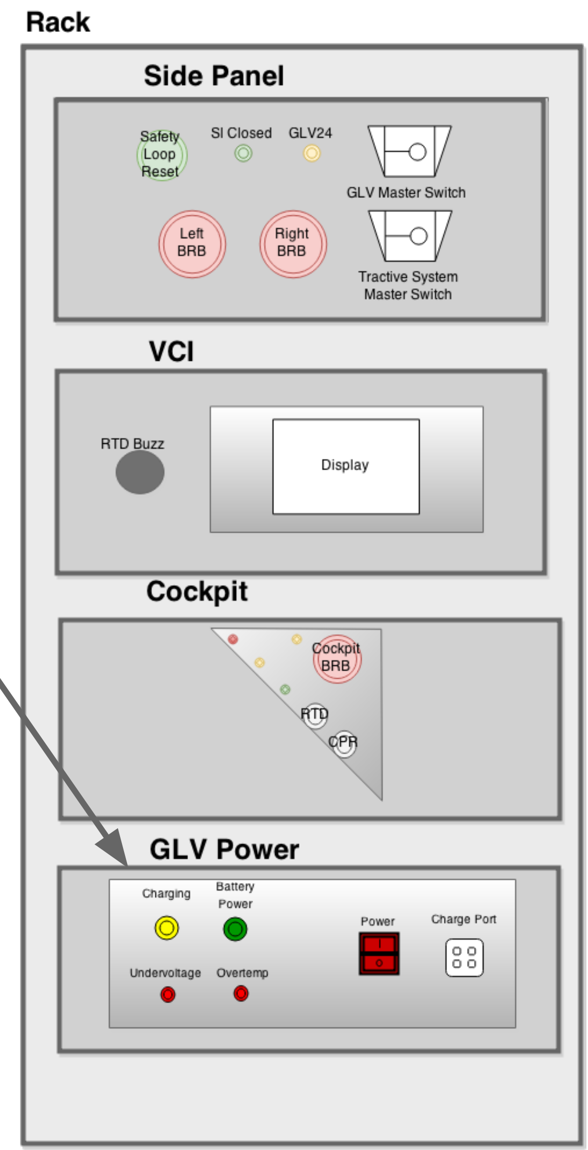
Physical Interfaces

- GLV Power Panel
  - Low Voltage Battery Indicators
  - GLV Power Switch





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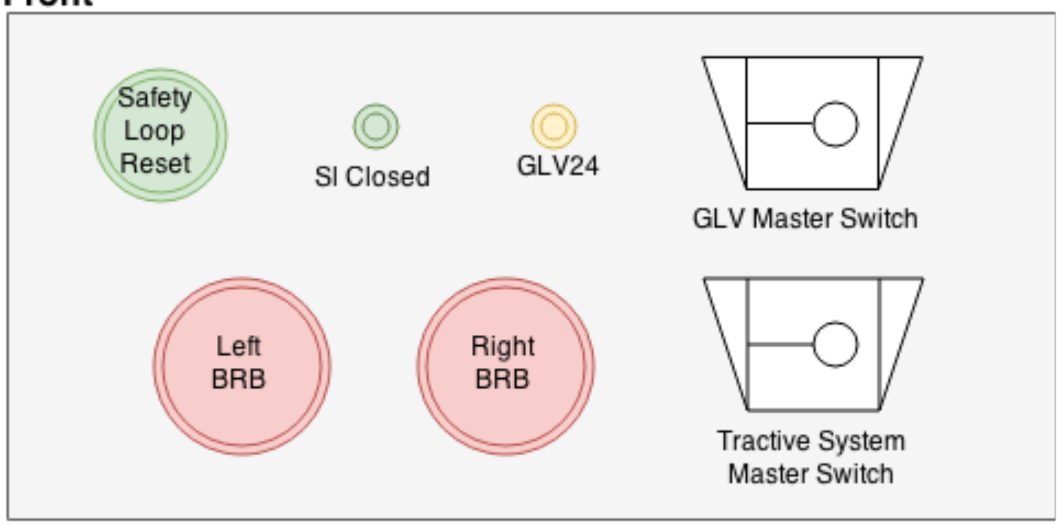
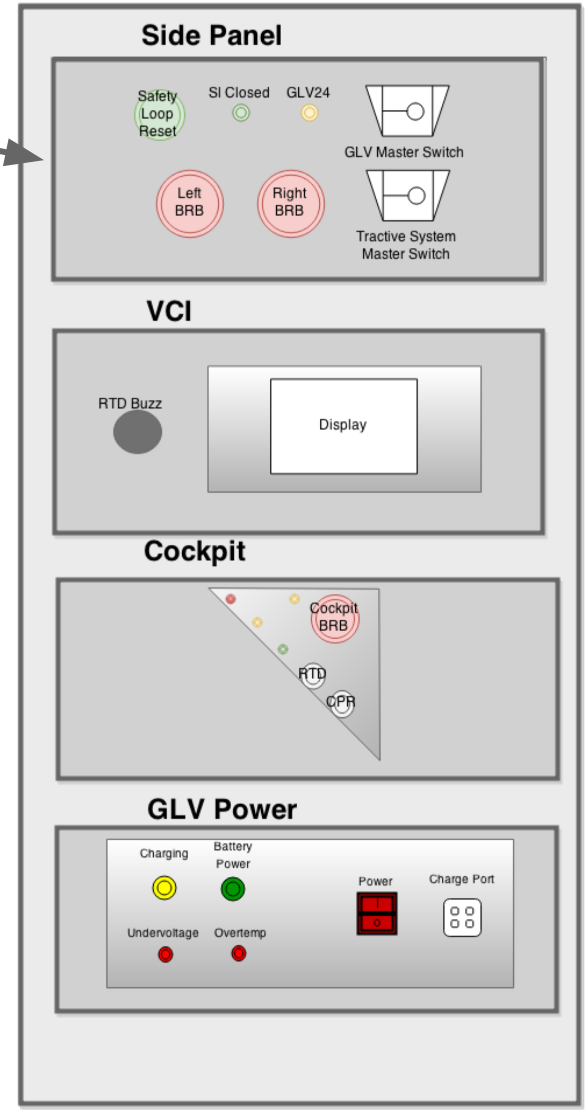
Physical Interfaces

- Side Panel
  - Contains Master Switches
  - Safety Loop Interface
  - Power Indicators

Front



Rack



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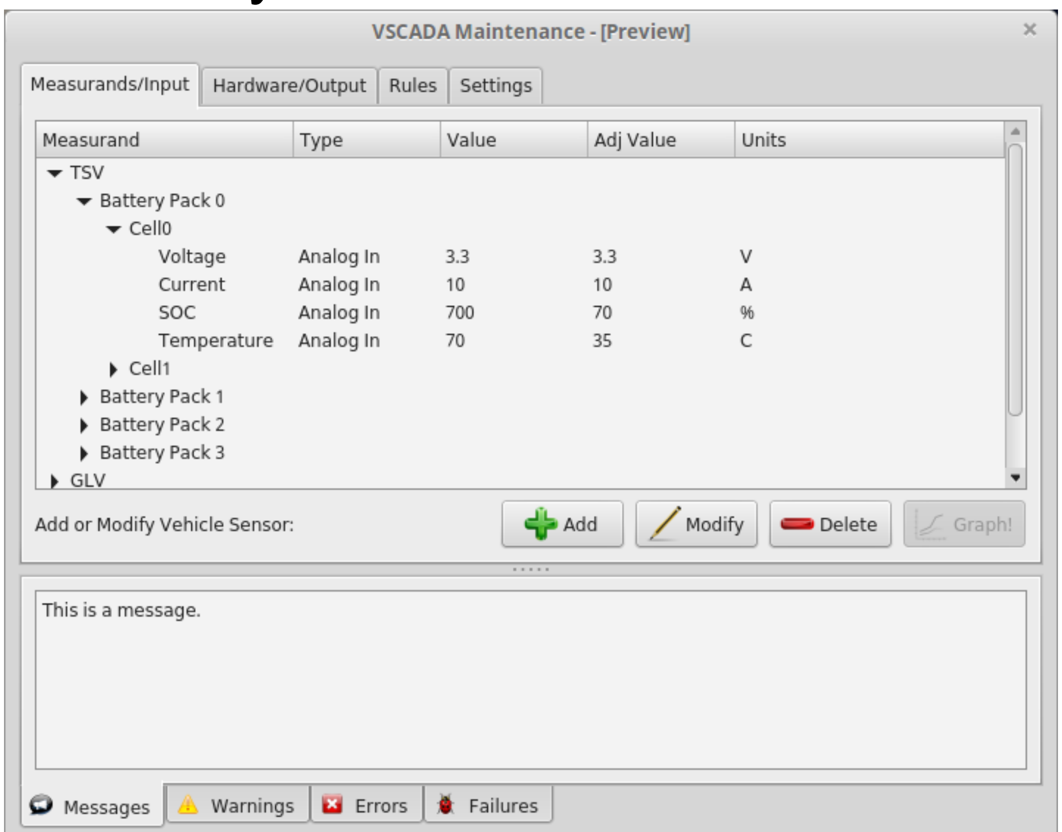
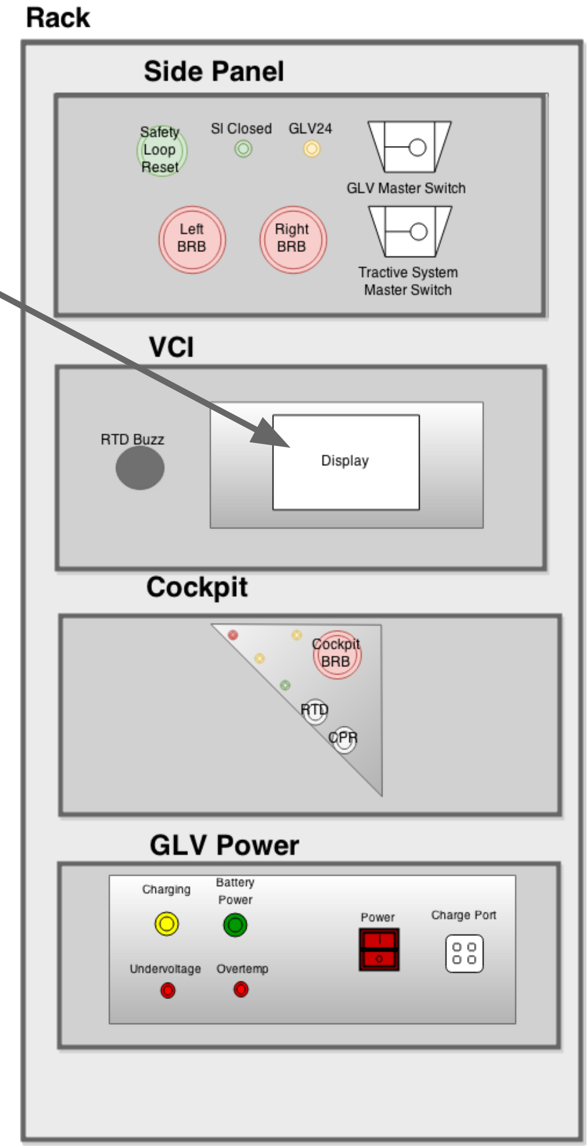
Physical Interfaces

- VCI Display
  - 9 Inch Touchscreen
  - Direct VSCADA Maintenance
  - System Parameter Control





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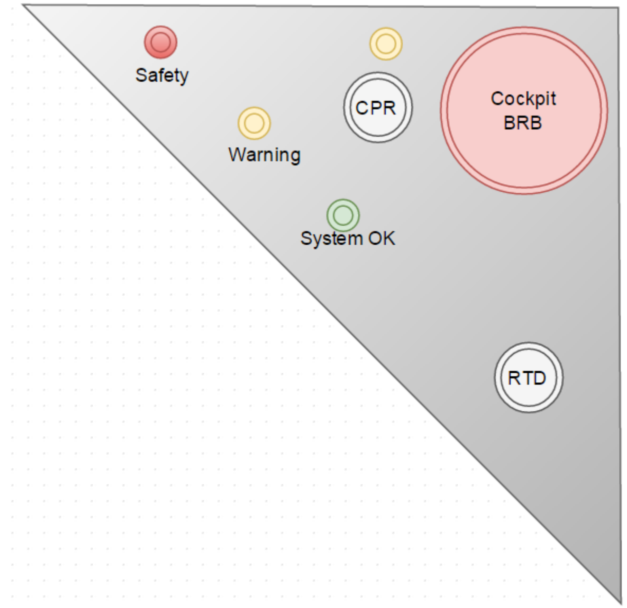
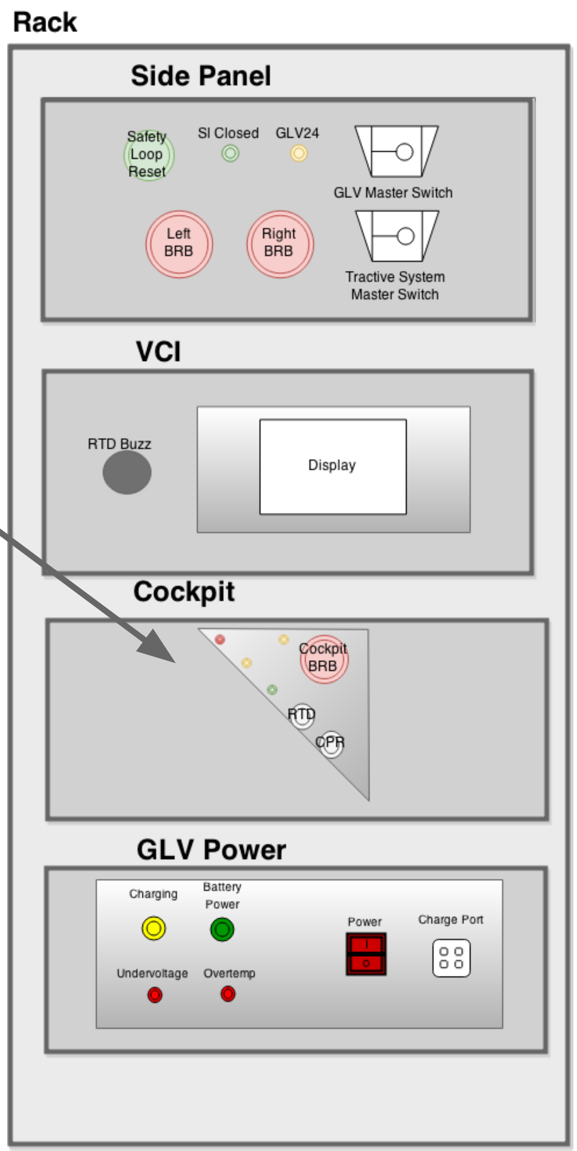
Physical Interfaces

- Cockpit Panel
  - Driver Interface
  - E-Stop (BRB) and Reset (CPR)
  - Indicators
  - Key Start Switch





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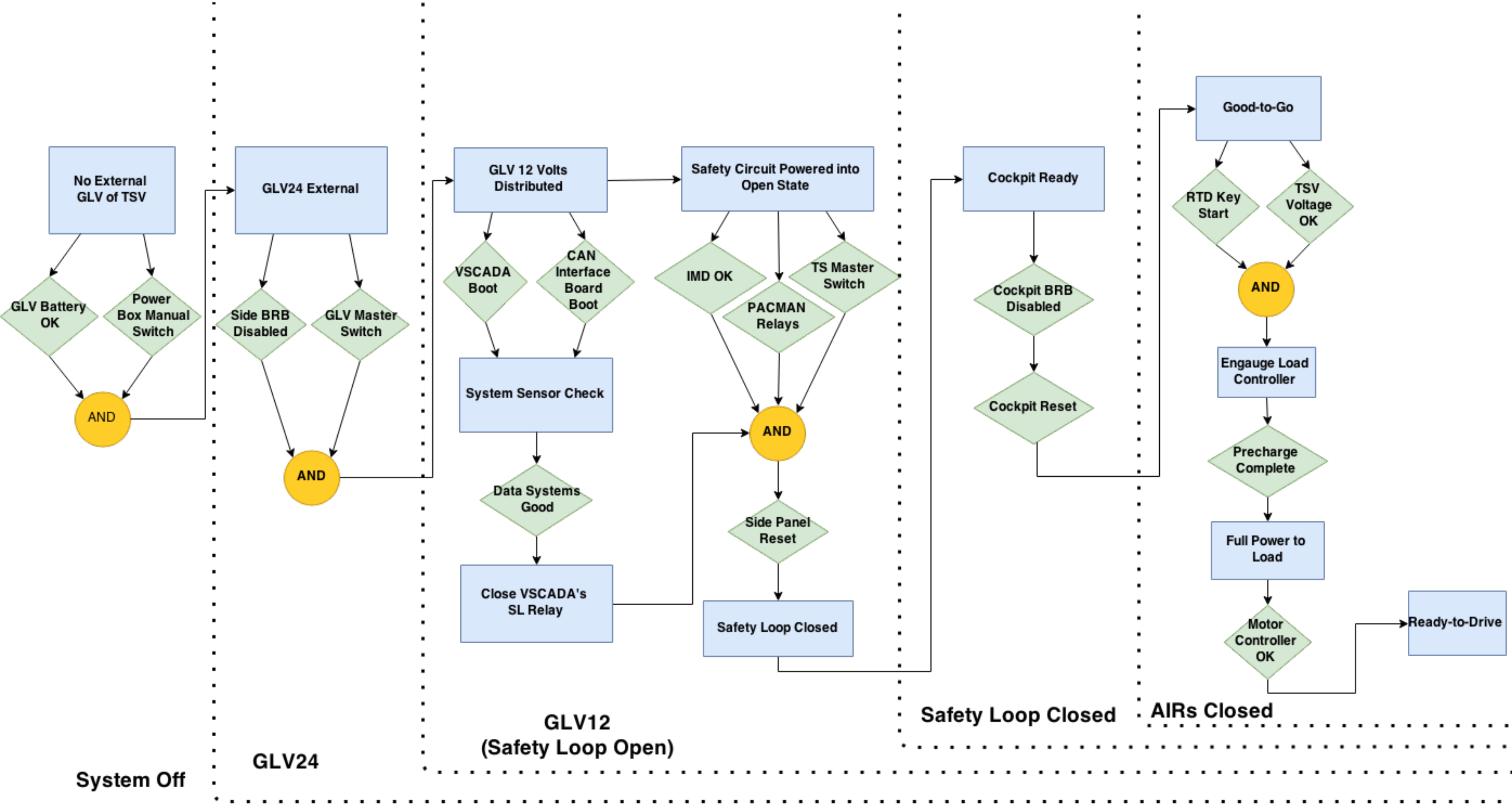
State Transition Diagram



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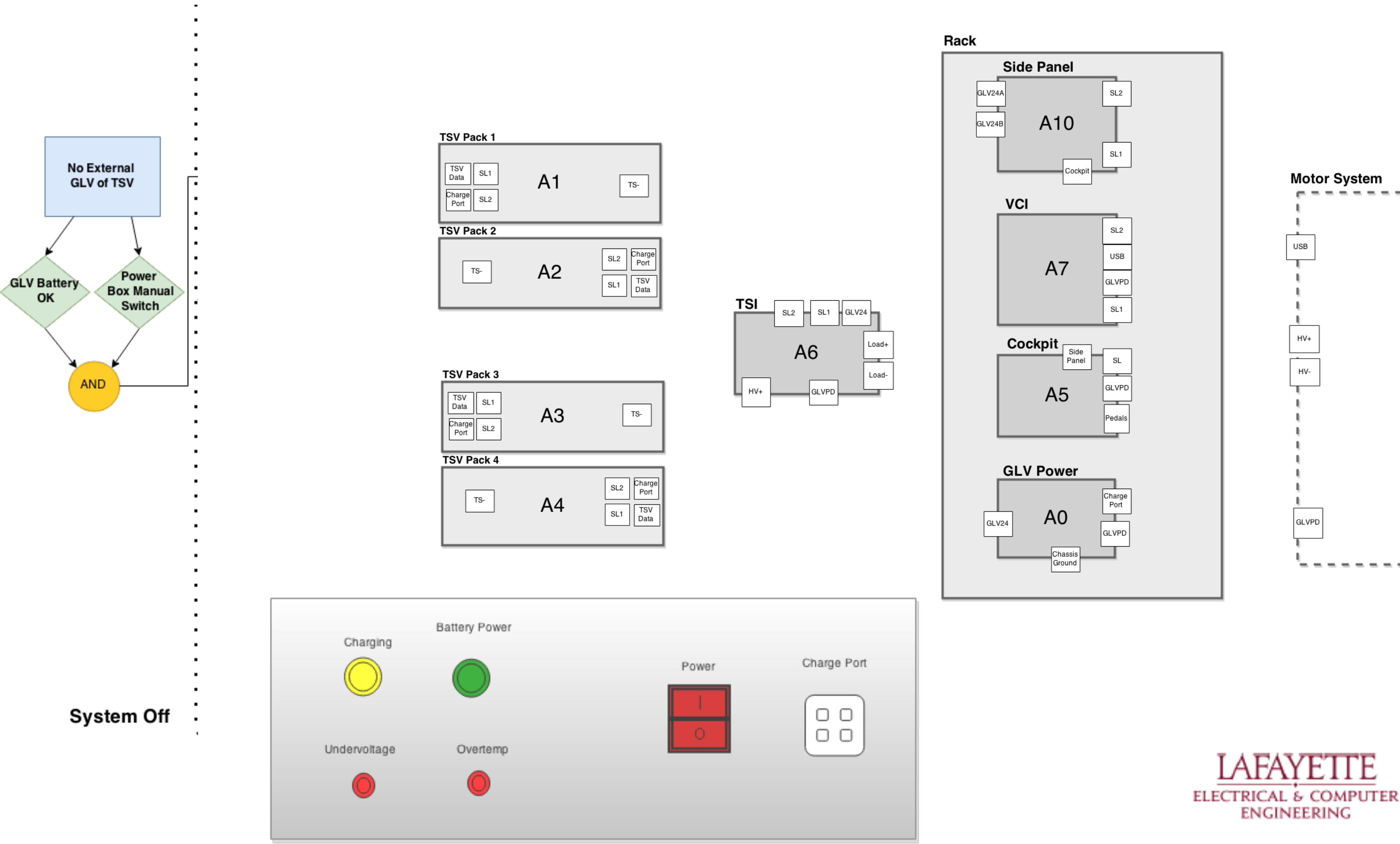
State Transition Diagram - System Off



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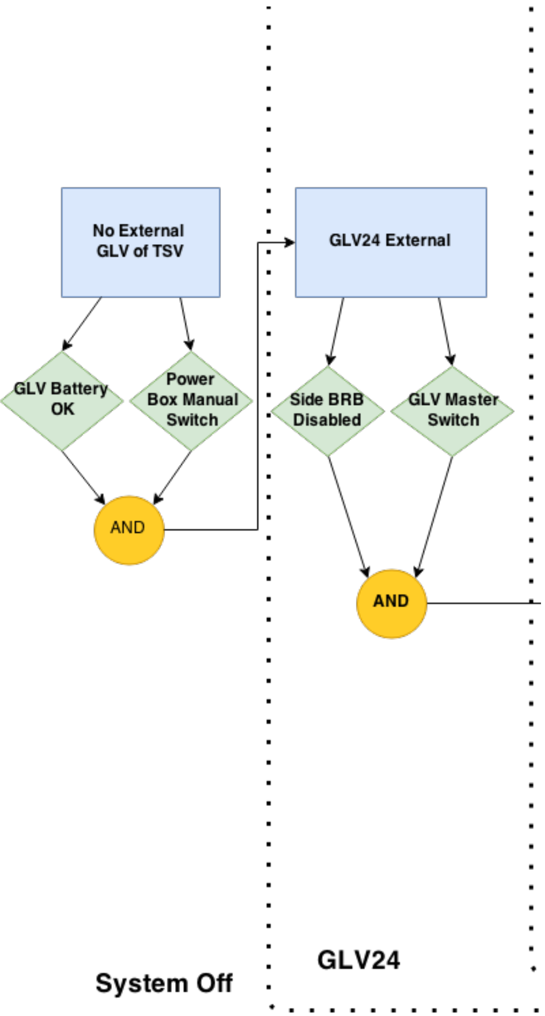
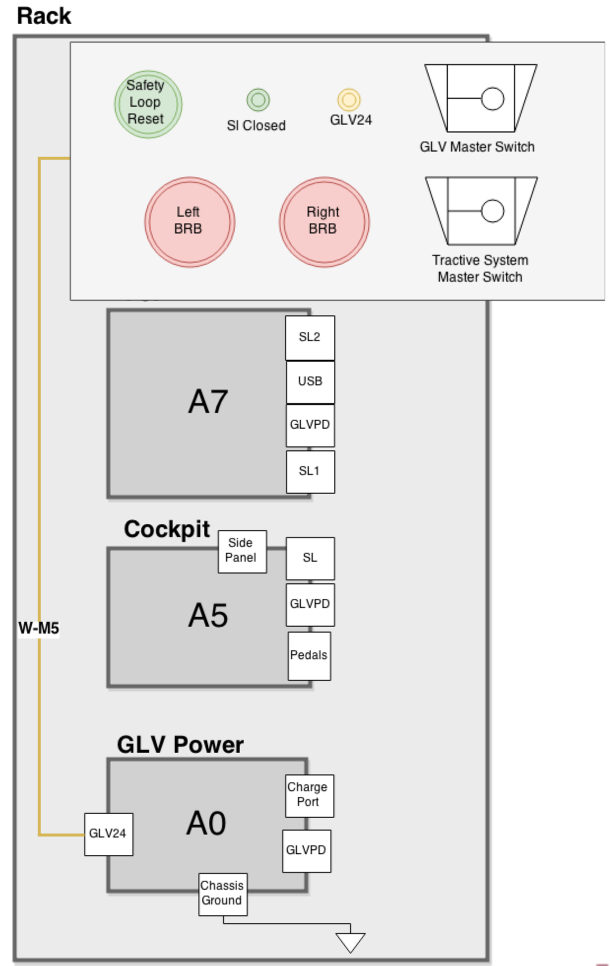
State Transition Diagram - GLV24





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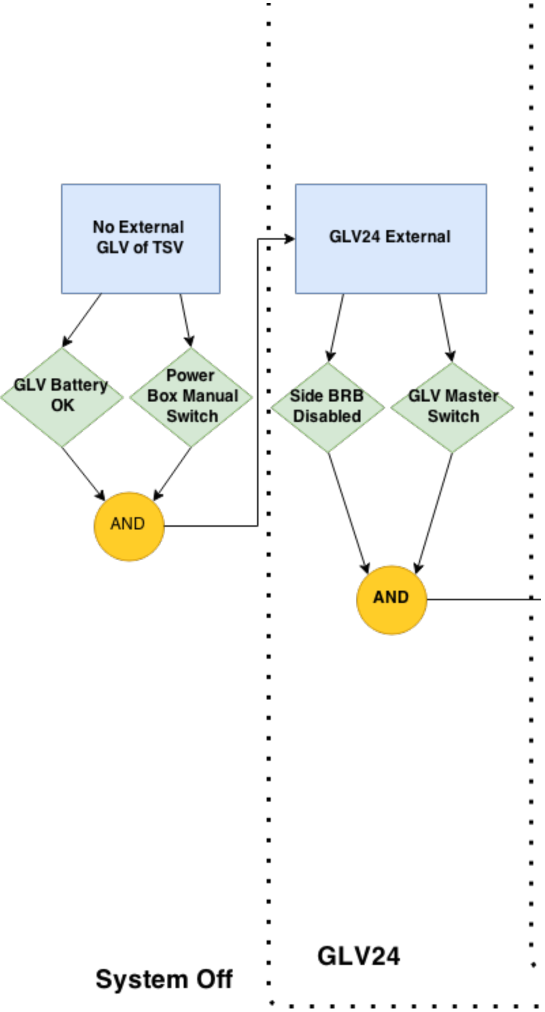
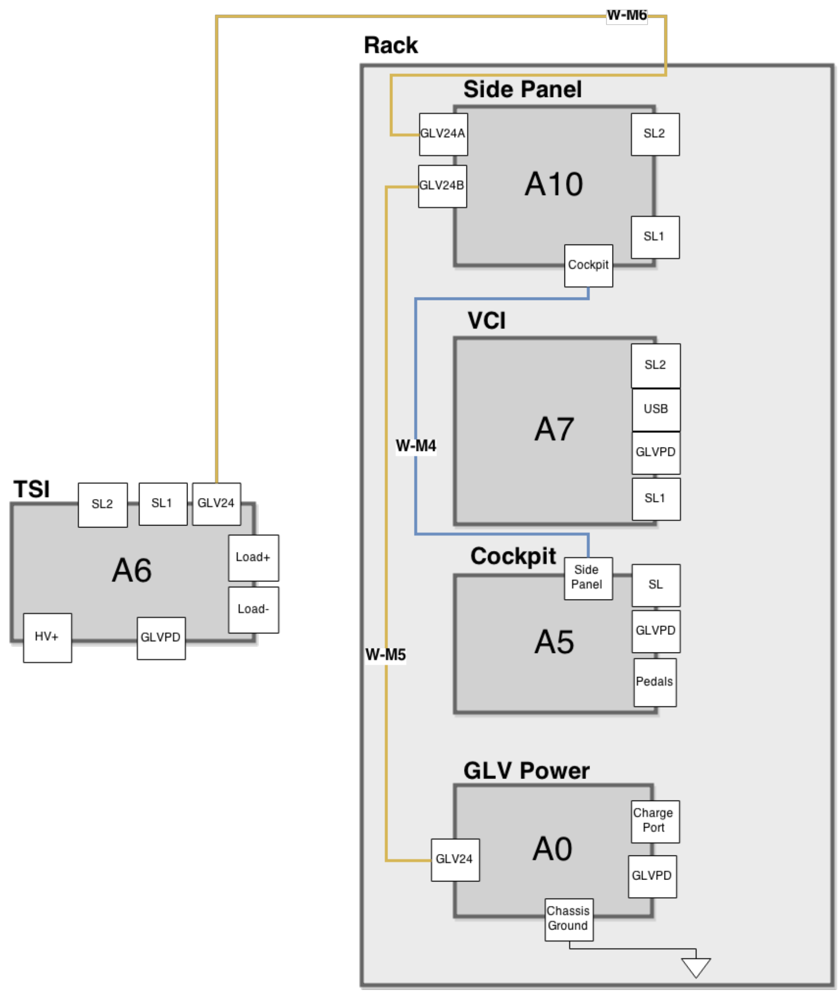
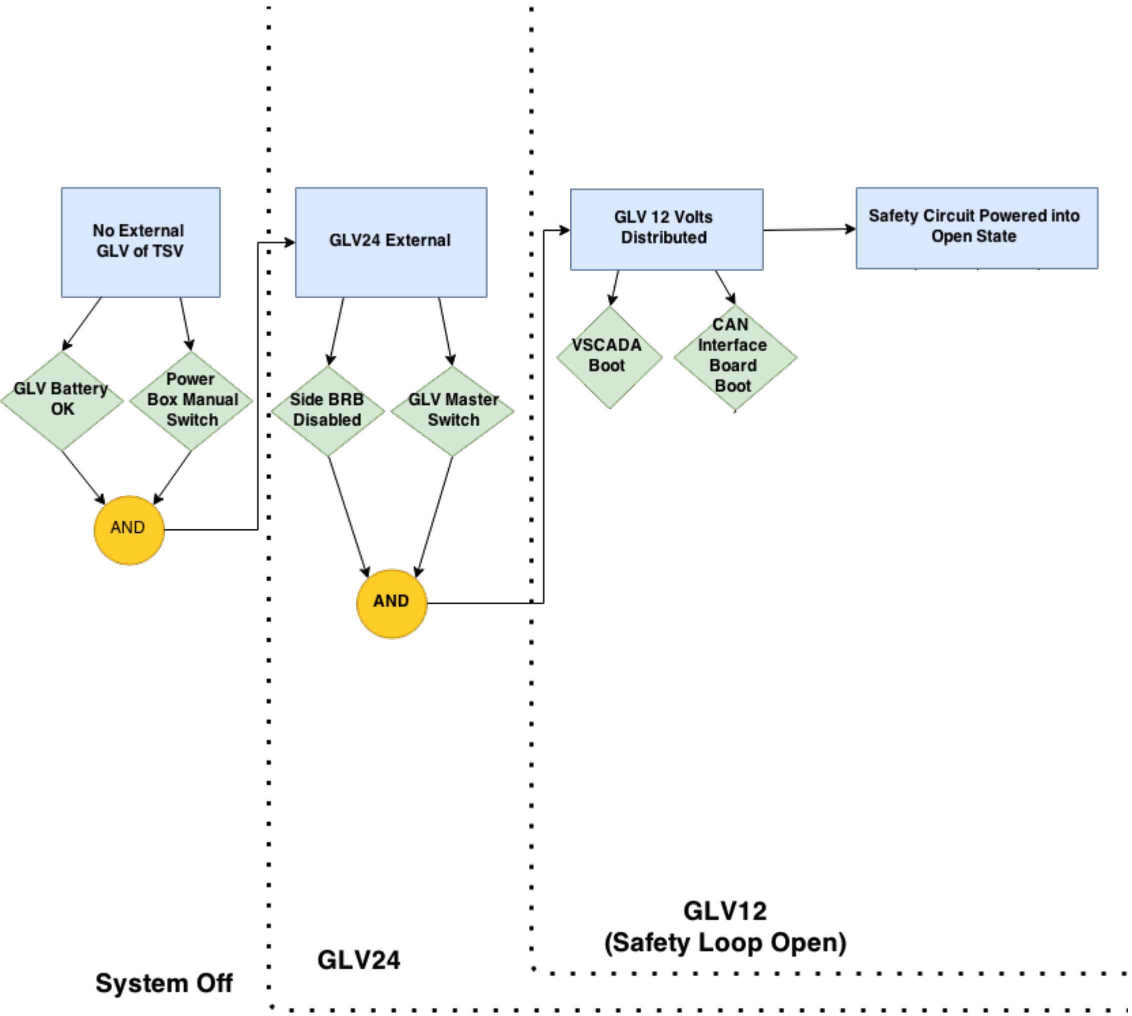




State Transition Diagram - GLV Power and Data



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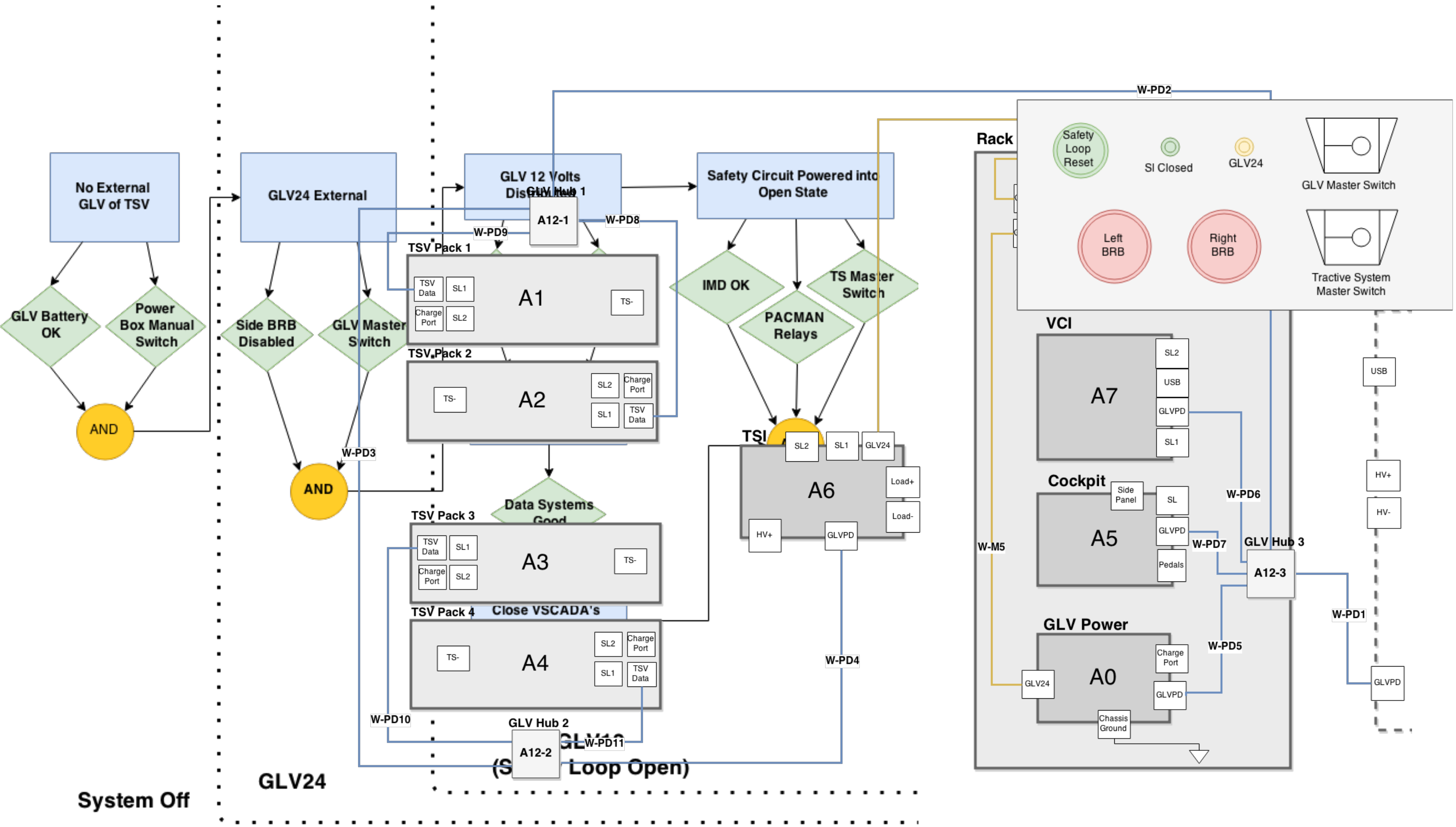
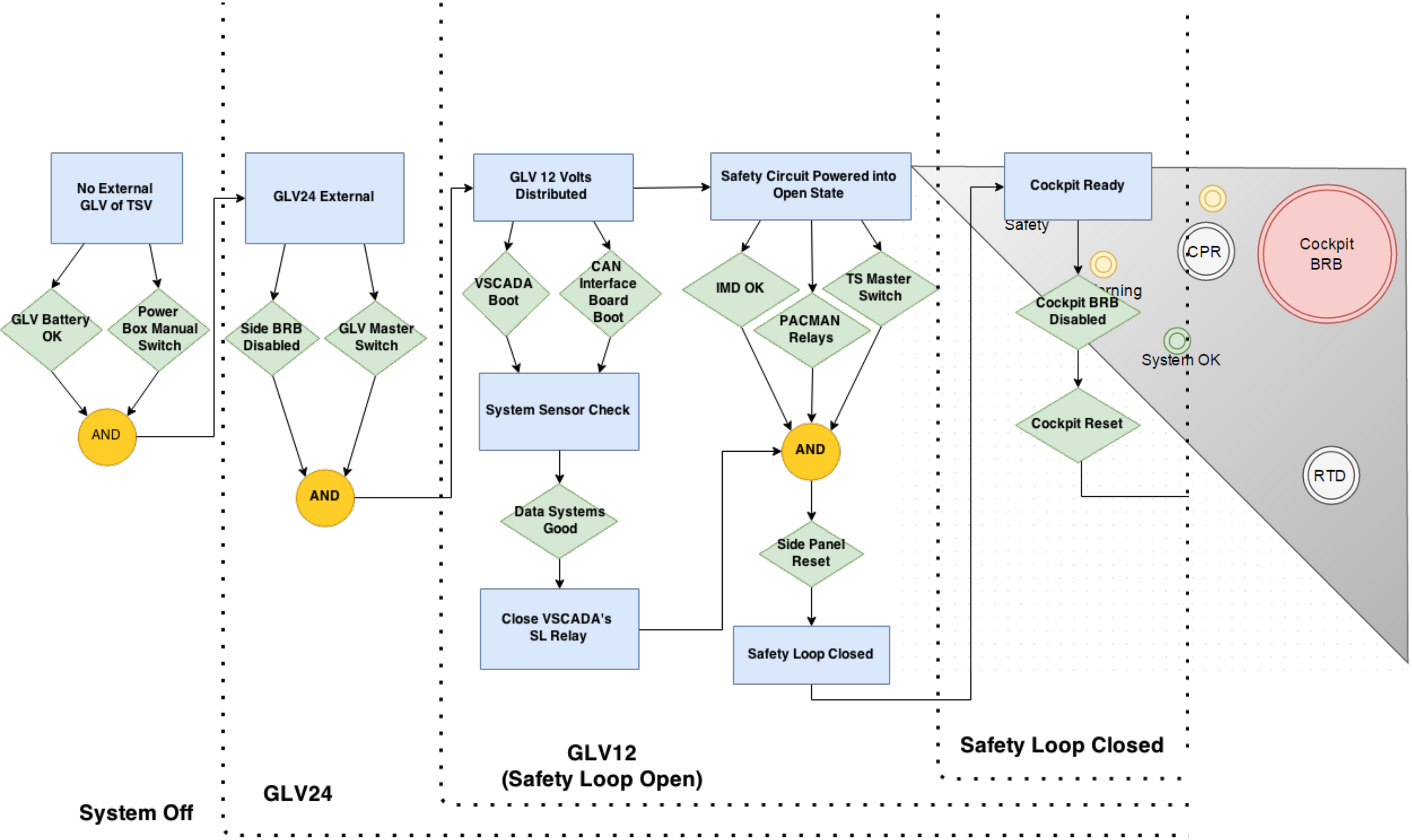


State Transition Diagram - Safety Loop Closing



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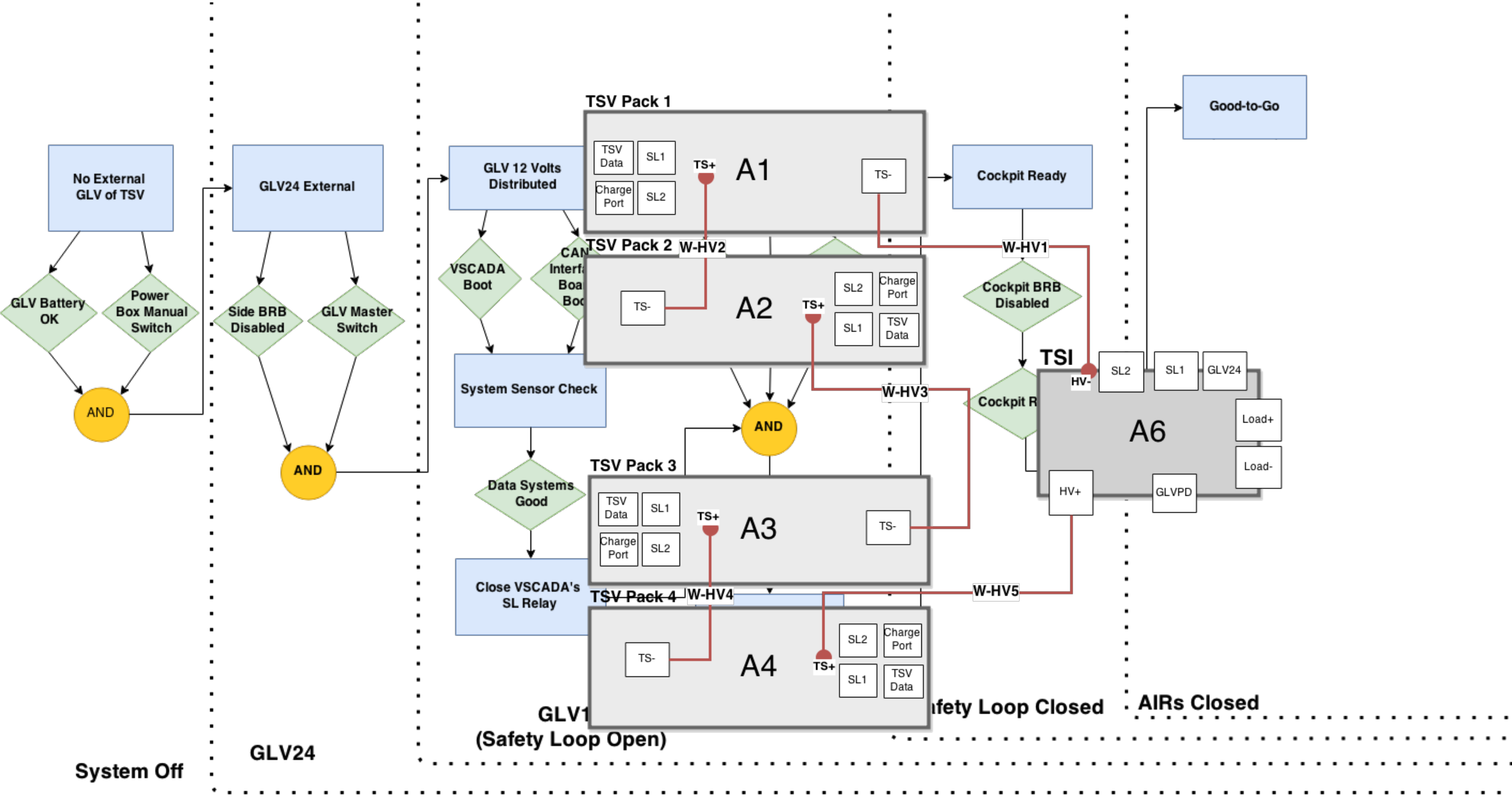
State Transition Diagram - AIRs Closing



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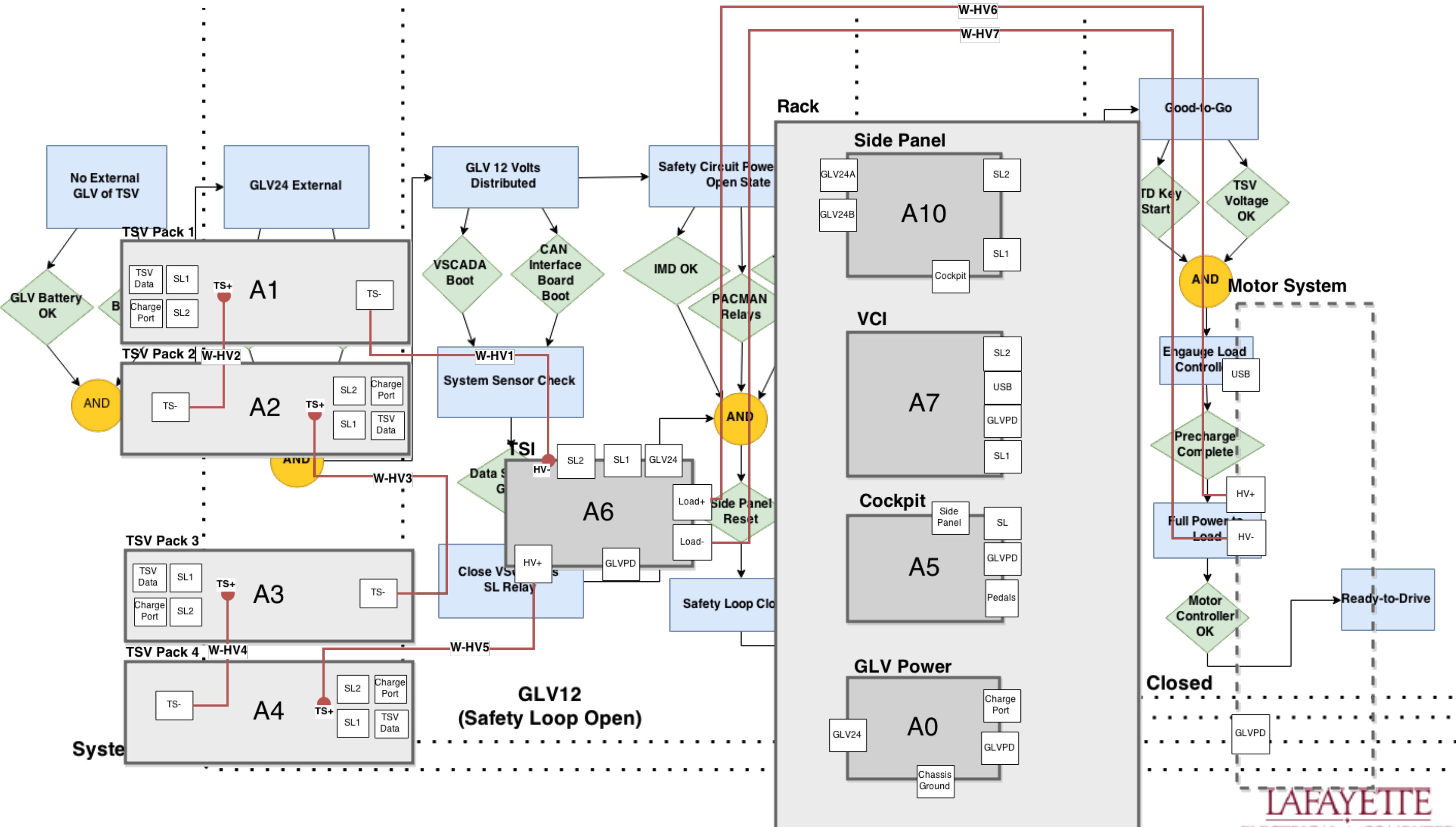
State Transition Diagram - Ready to Drive



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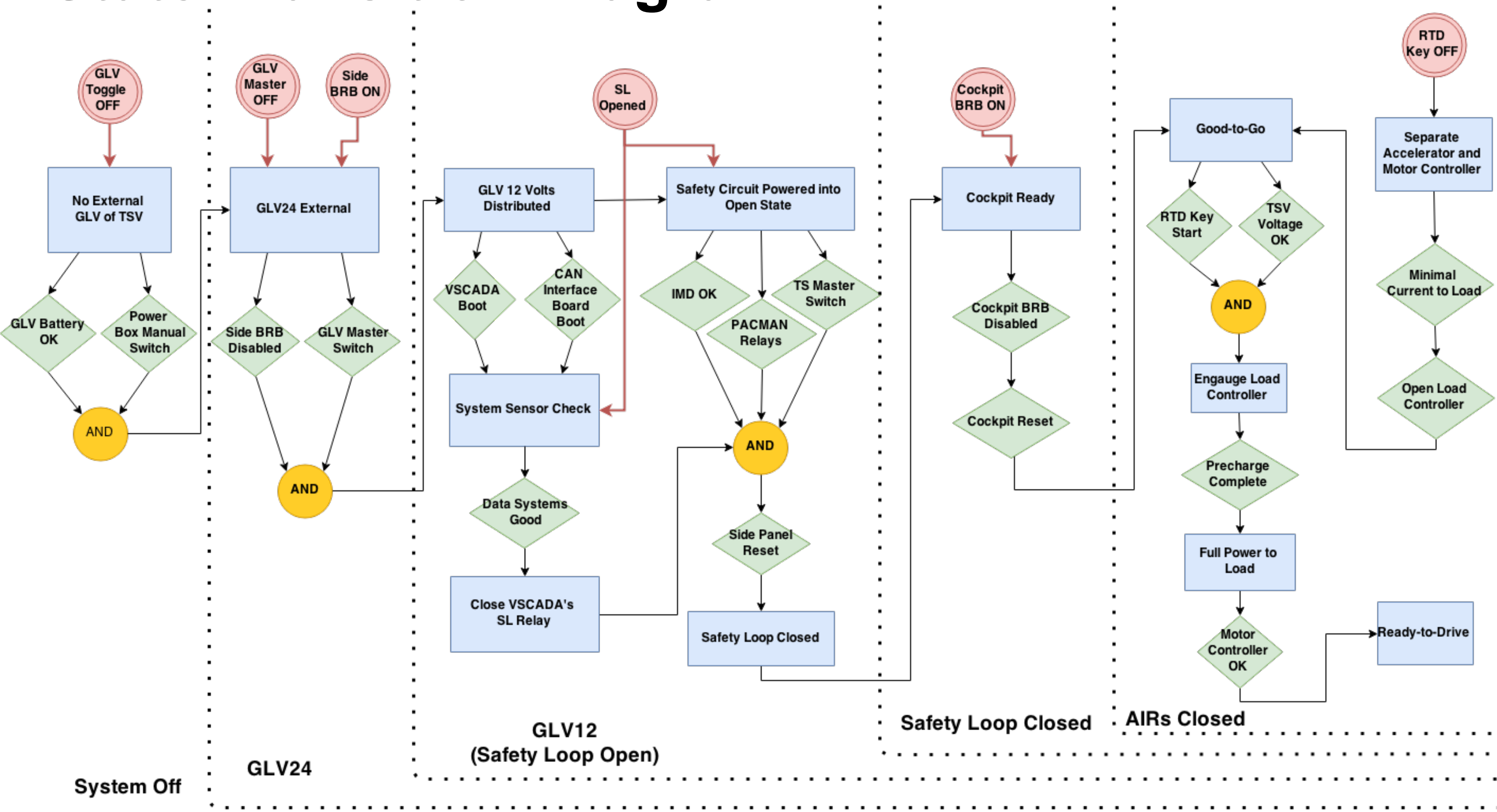
State Transition Diagram



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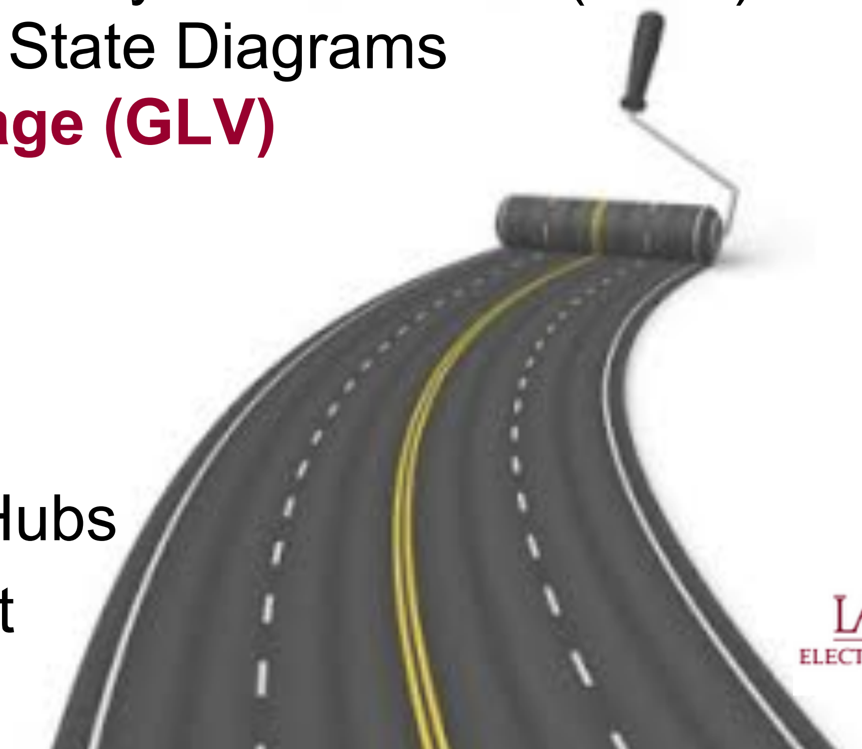

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Grounded Low Voltage

GLV system is responsible for supplying power to all non-tractive devices on the vehicle, interfacing other subsystems together, and operating the safety circuit in accordance to the EV requirements.

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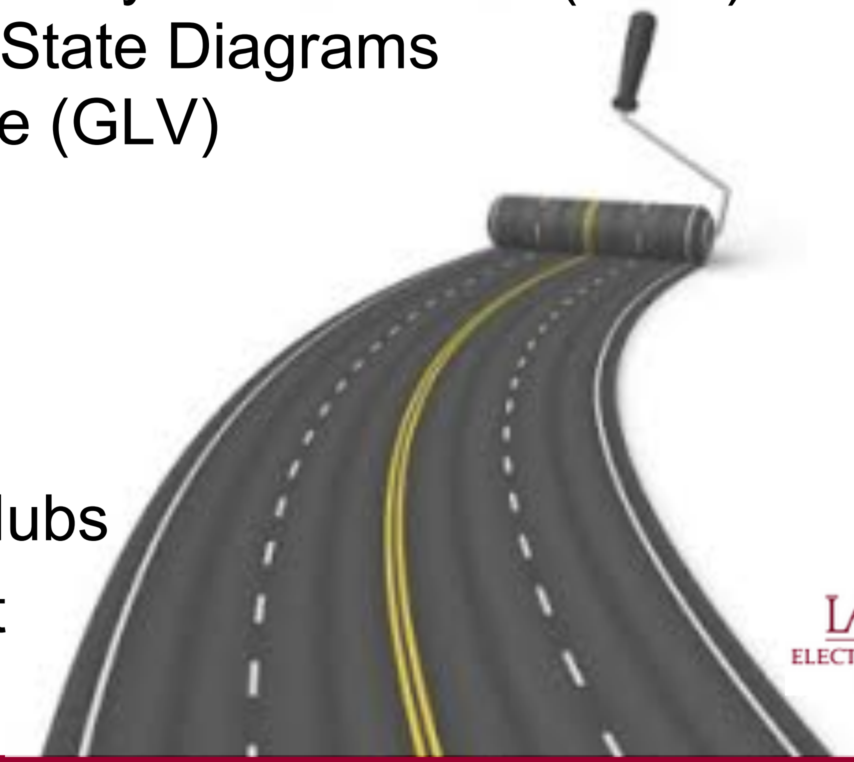

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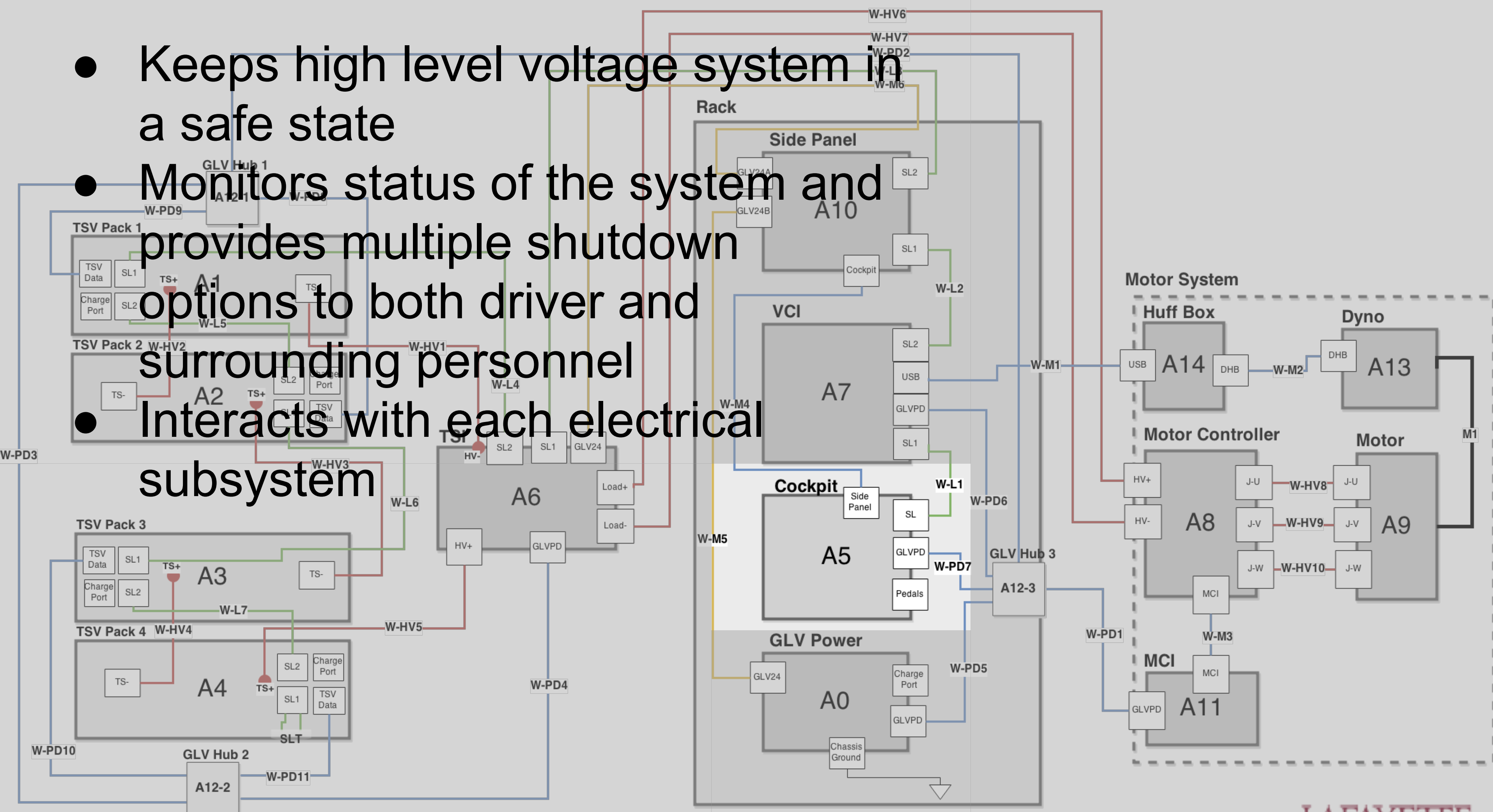
Cockpit and the Safety Loop

- Keeps high level voltage system in a safe state
- Monitors status of the system and provides multiple shutdown options to both driver and surrounding personnel
- Interacts with each electrical subsystem



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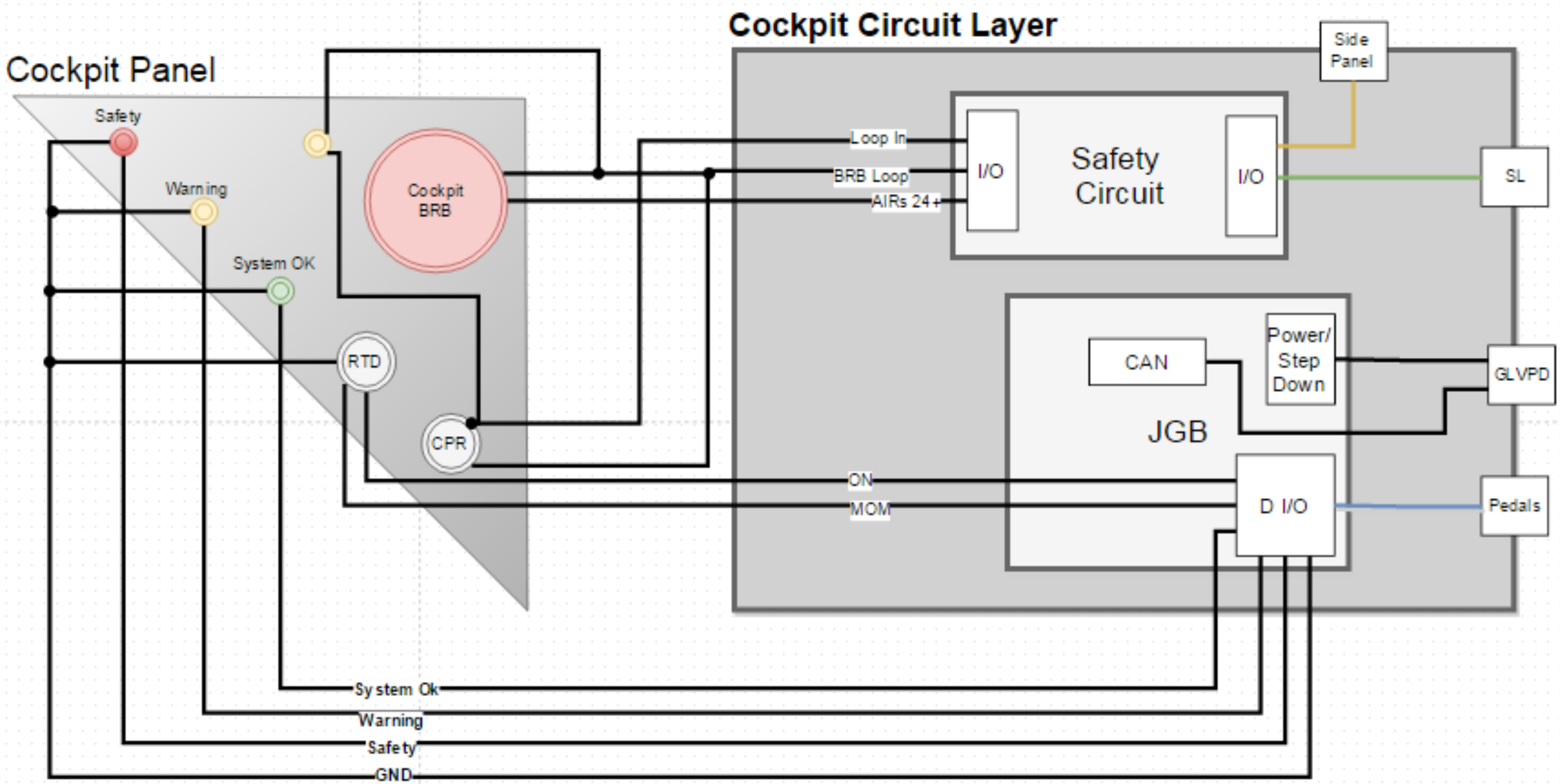
Cockpit Panel and Internals



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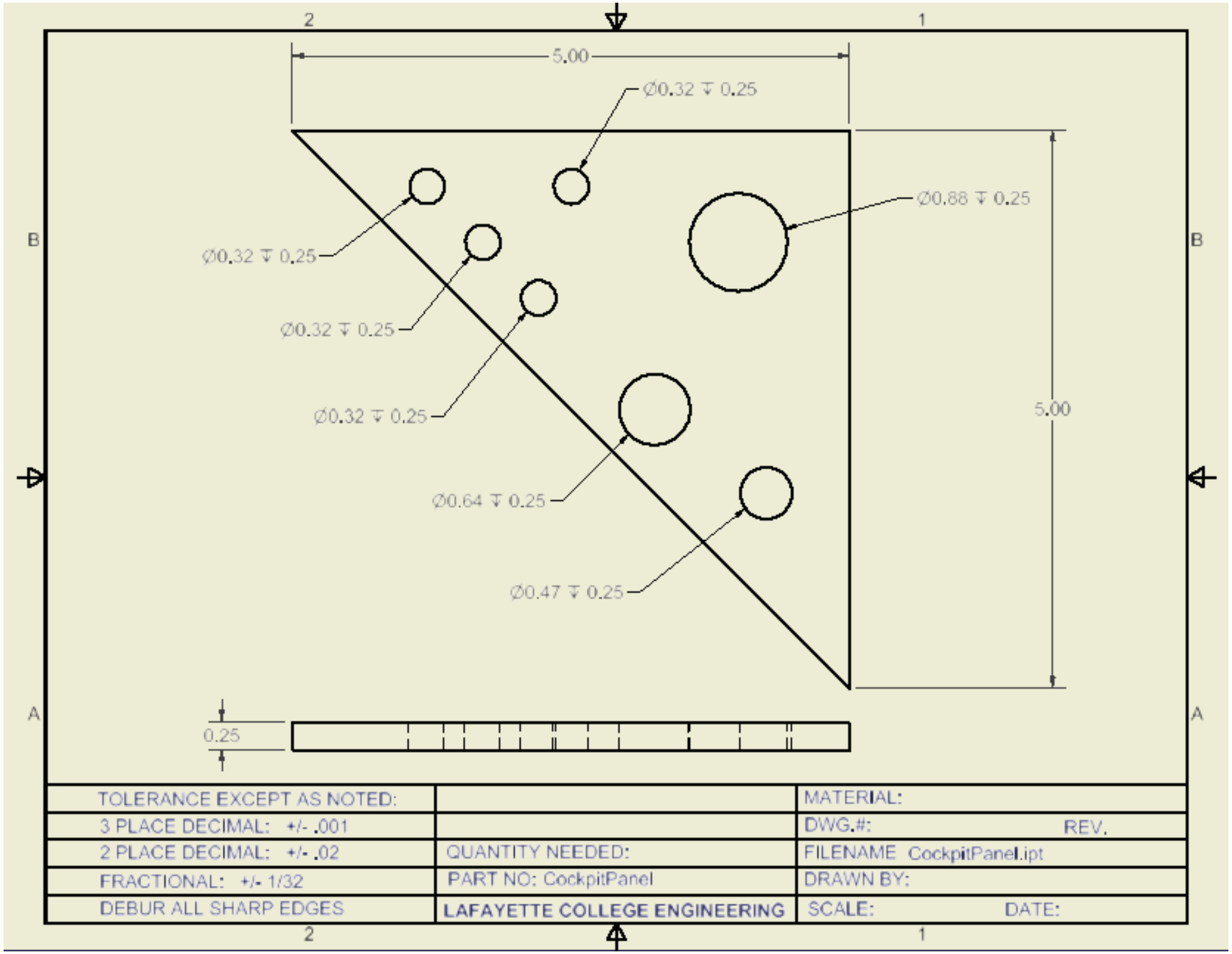
Cockpit Panel Drawing



Materials List:

- Aluminum Panel 5"x5"x1/4"
- CPR - Cockpit Reset Button
- Cockpit BRB
- Red 'Safety' LED
- Amber 'Warning' LED
- Green 'System OK' LED
- Amber Indicator LED
- RTD - Ready To Drive Key

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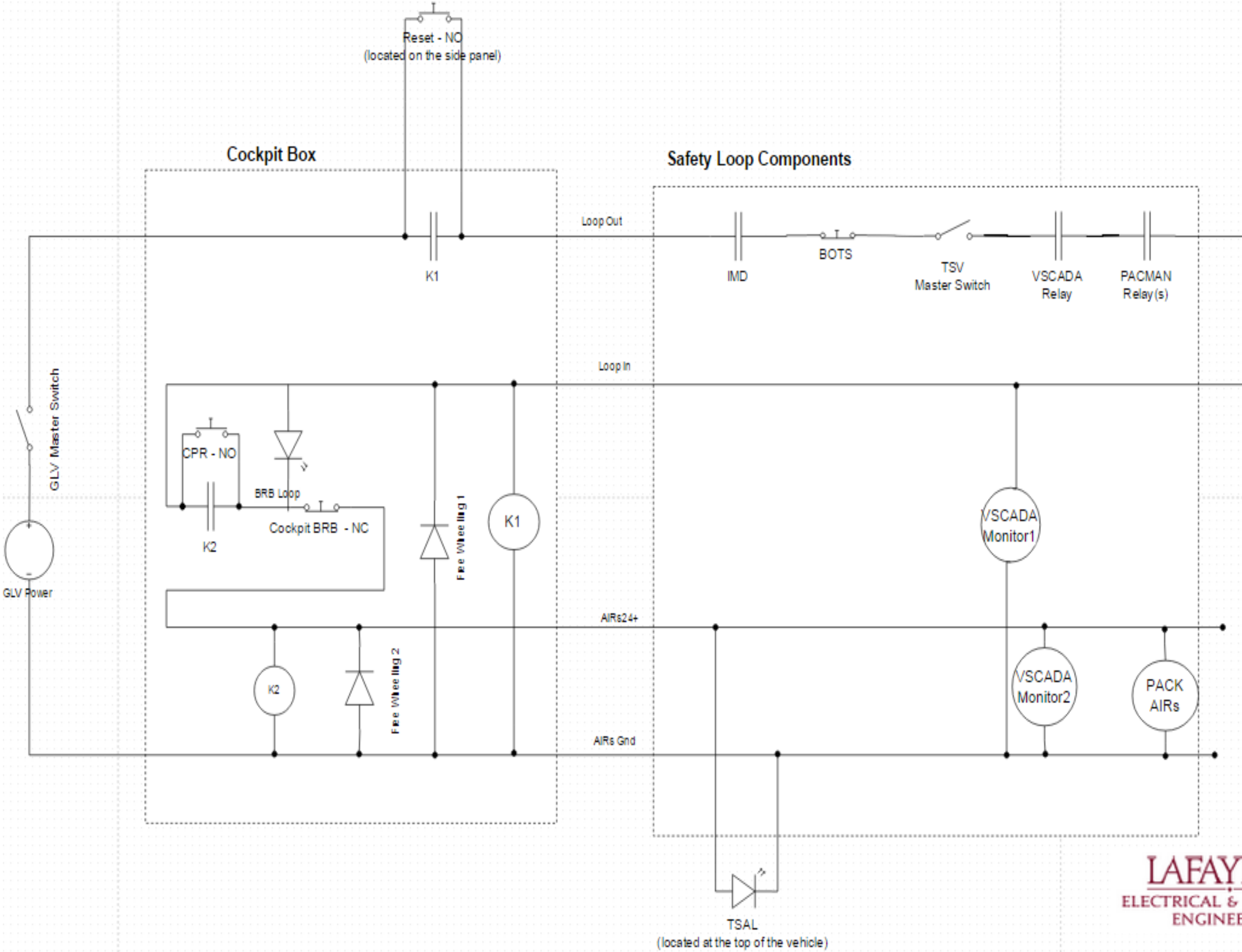

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Safety Circuit PCB

Shutdown Priority Table

Shutdown Sources	GLV Supply to: Instrumentation, Data Acquisition, Computers, Telemetry, Etc.	AIRs (TS Voltage)
TSMS		OFF
Cockpit BRB		OFF
AMS		OFF
IMD		OFF
Brake Over-Travel		OFF
Side-Mounted BRBs	OFF	OFF
GLVMS	OFF	OFF

Controlled Systems

Safety Loop Summary

- Safety Loop accounts for failures/faults in the 4-wire safety loop
- Any failure in the safety loop will be appropriately reacted to within the time constraints provided by the Formula Hybrid Rules
- Appropriate steps must be taken in order to make the car ready-to-drive in each scenario
- The Test Plan for the Safety Loop does not have a threshold for any test; whether it be button/switch functionality or the shutdown circuit itself. The loop will function to the specifications provided.

Roadmap

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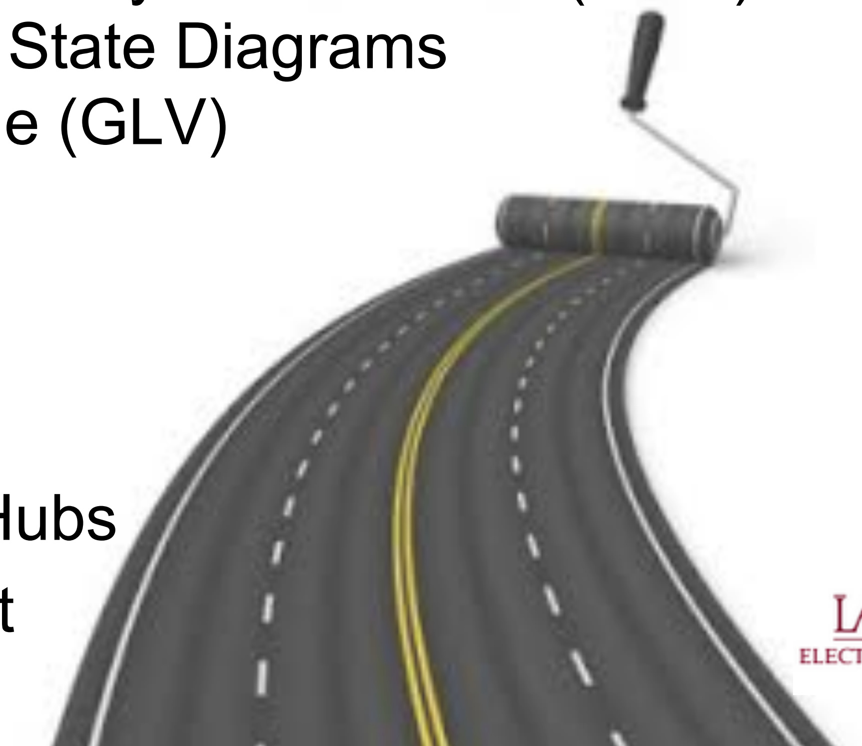
    b. System Assemblies Layout/Interfaces (Rack)
    c. Interconnects and State Diagrams
4. Grounded Low Voltage (GLV)
    a. Safety Loop
    b. **GLV Power**
    c. VCI
    d. TSI
5. Panel Drawings and Hubs
6. GLV BOM and Budget



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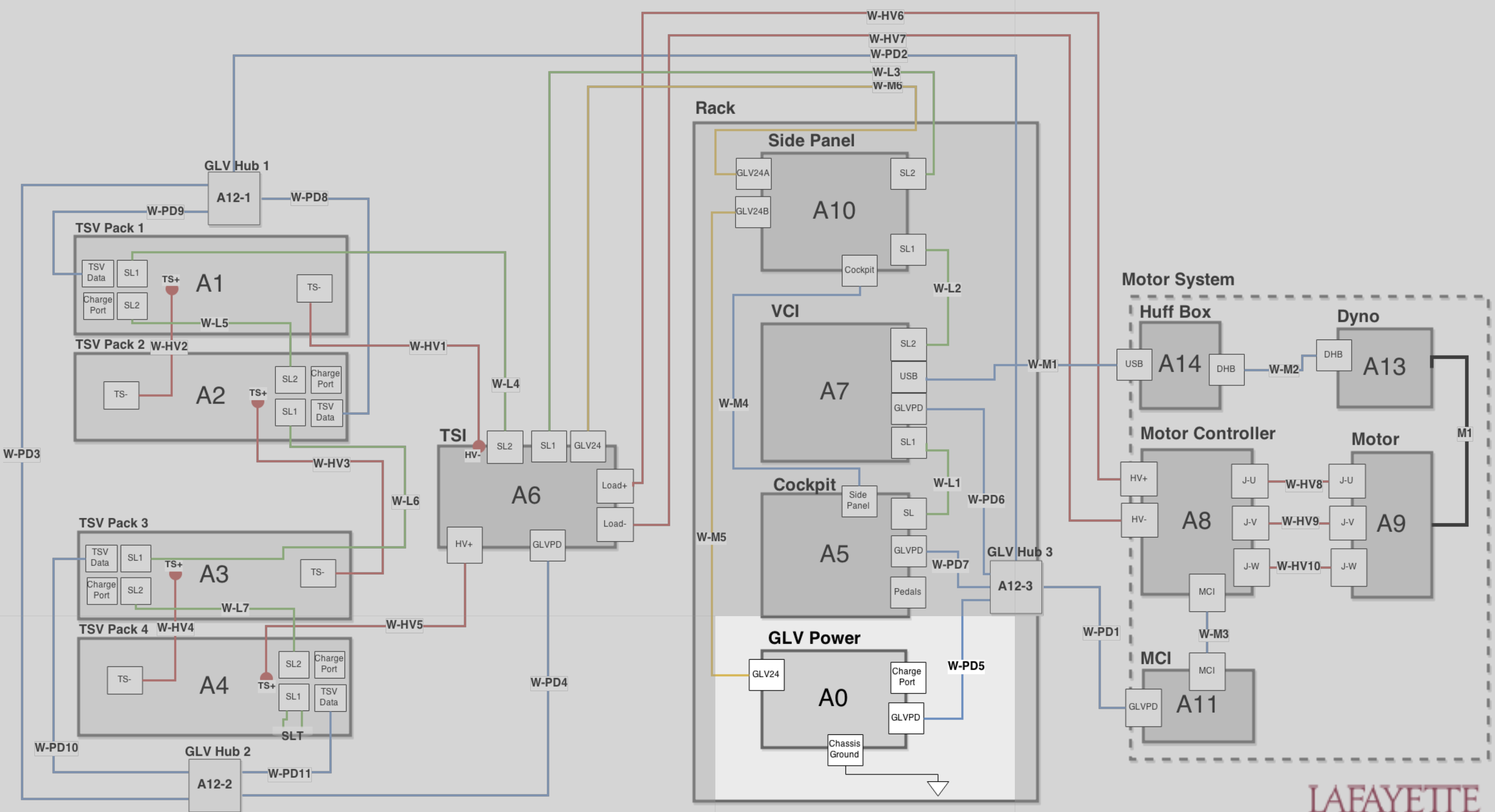
GLV Power



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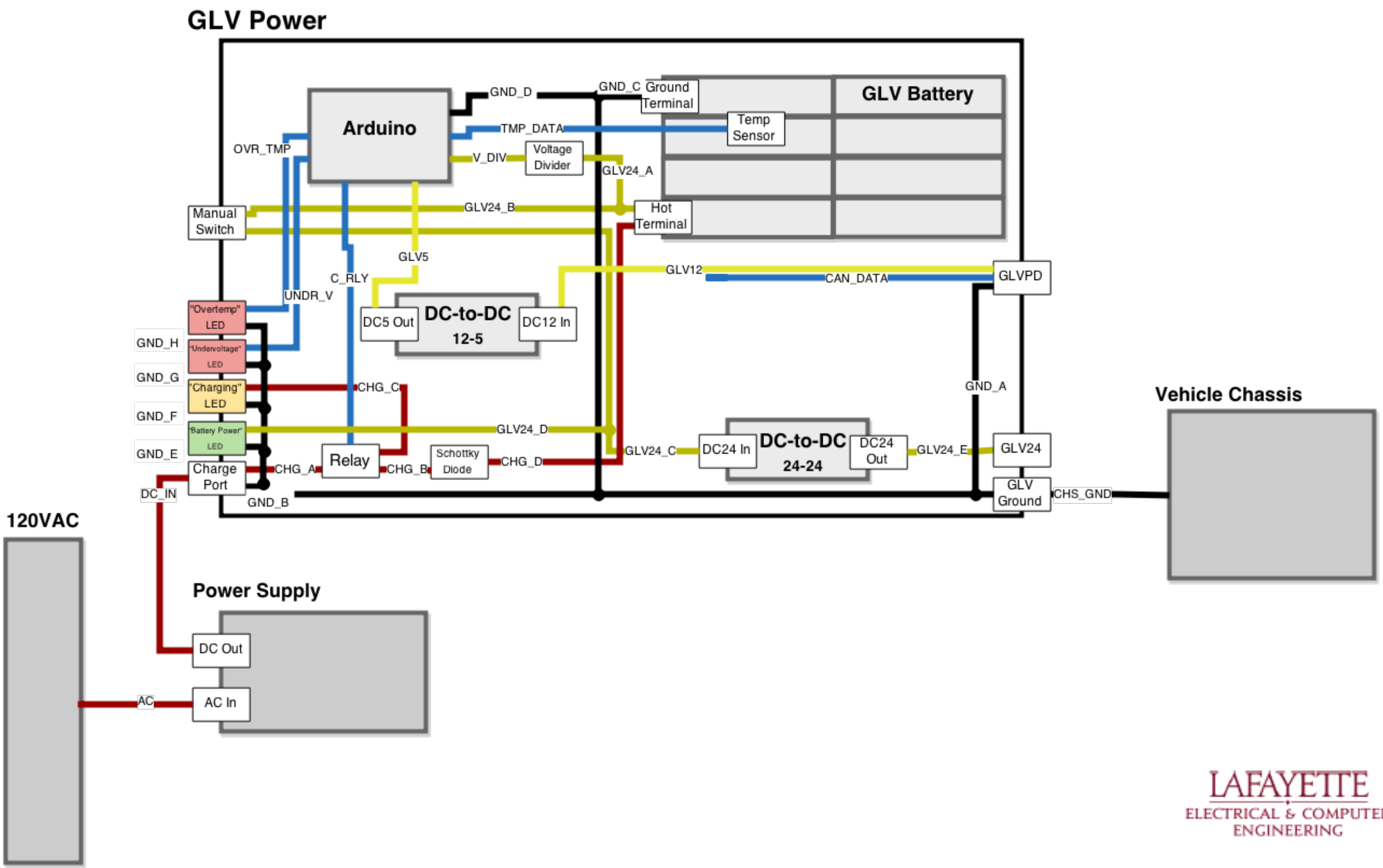
GLV Power Box and Dependents



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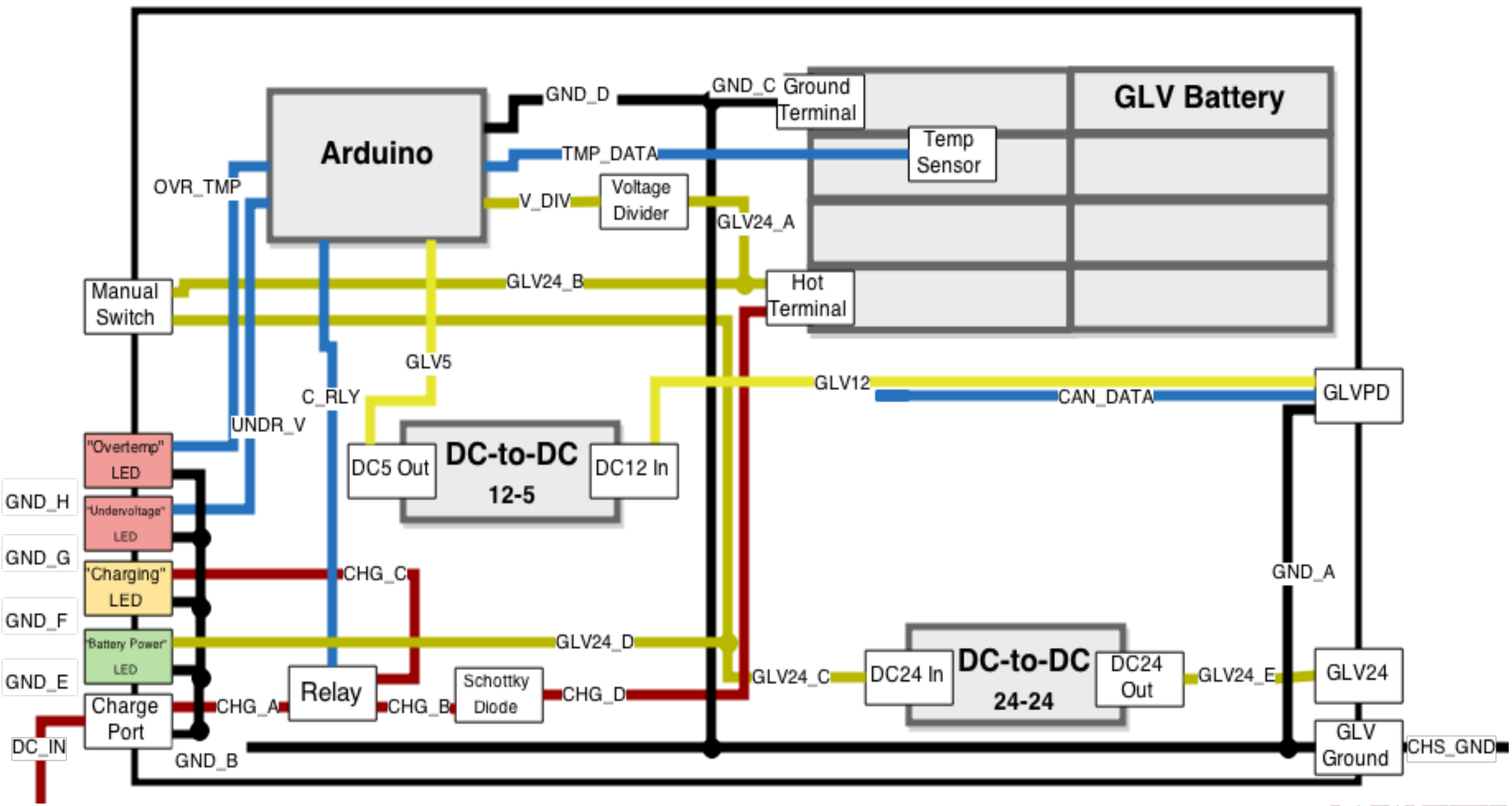
GLV Power Box



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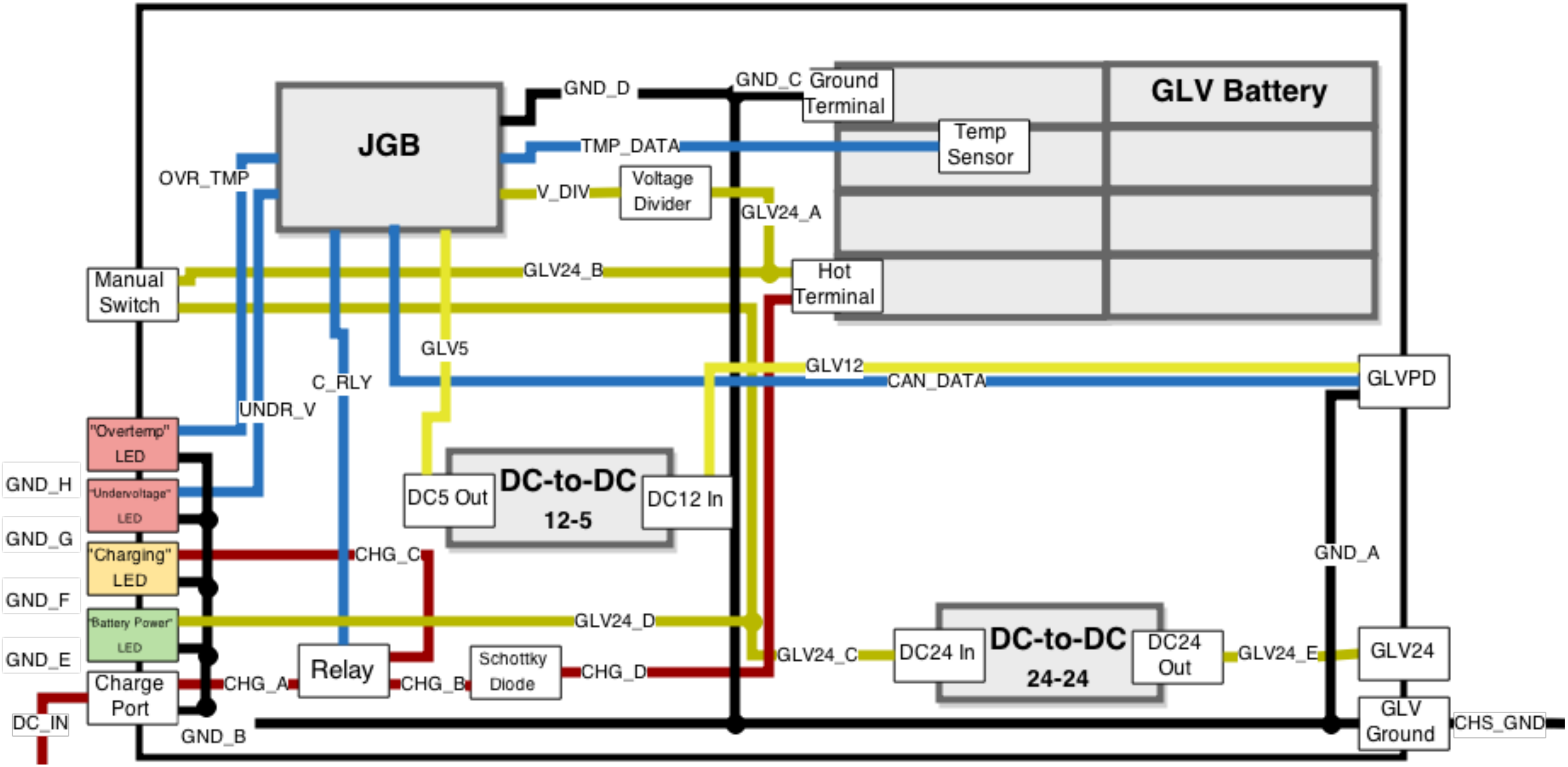
GLV Power Box - End Goal (JGB)



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GLV Battery Cell

3.3V LiFePO4 10Ah

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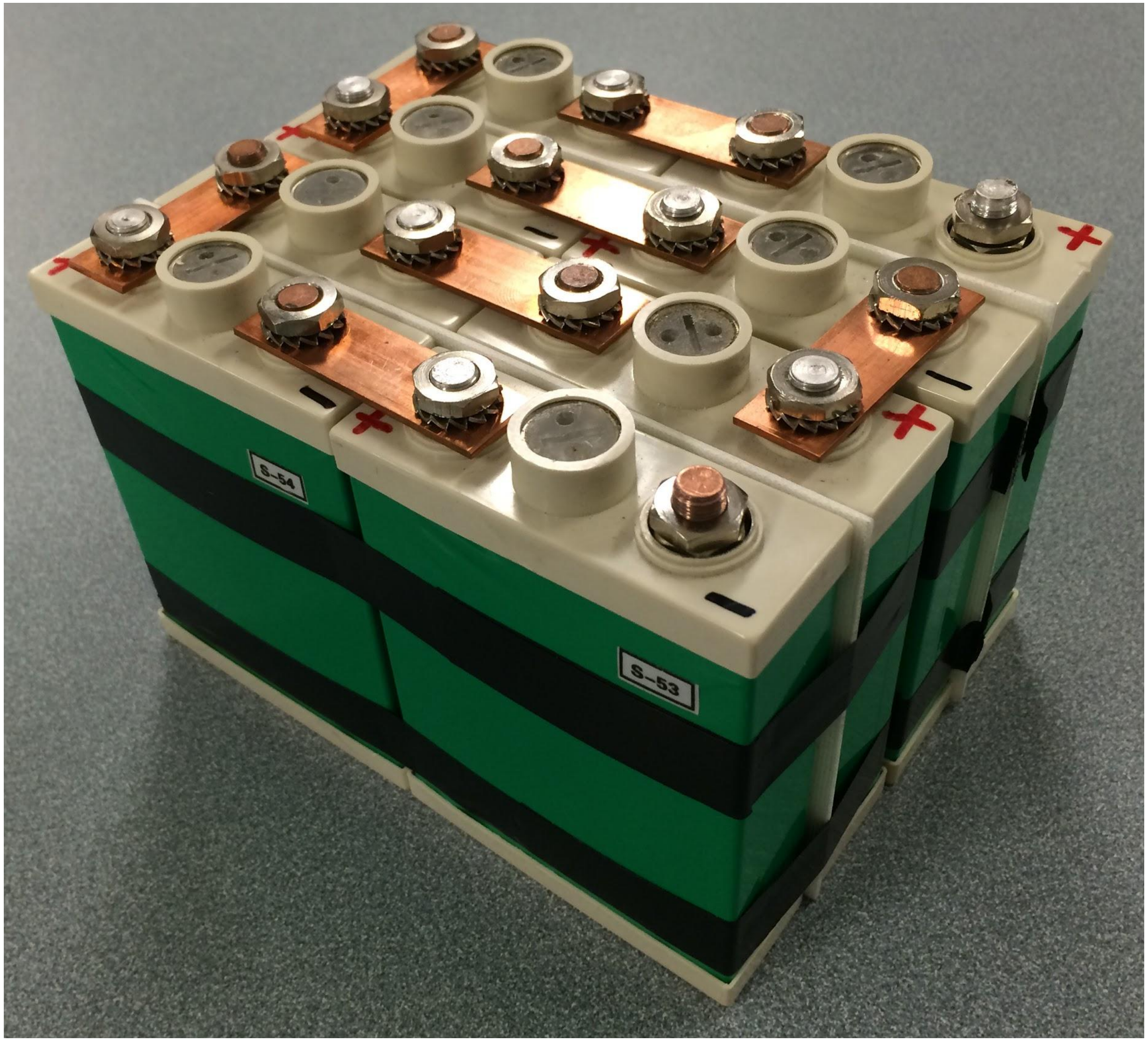
GLV Battery



Eight cells
24V
10Ah

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GLV Battery Connection

Crimped Terminal
(Open Barrel)

Battery Mounting

EV3.7.1- All GLV batteries must be attached securely to the frame.

Battery hold-down will be used for vertical stabilization.

Battery tray pictured is for concept (unavailable in correct size) - MechEs will be asked to create a simple version

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http://www.jegs.com/images/photos/500/555/555-10264.jpg

http://www.ozprodrivers.com.au/shop/images/projecta_battery_tray_PBT100.jpg

GLV Battery Capacity Calculation

R006-1 The GLV system shall contain a rechargeable battery of sufficient capacity to run the car GLV systems for at least three hours.

GLV Relays	**(2.04W x 2) = 4.08W + 1W (for microcontrollers, relays)**		
AIRS	**(2.04W x 4) = 8.16W + ~100mW (CAN transceivers)**		
VSCADA	**2.64W computer + 2W screen**		
Total	**17.88W / 24V = 0.745A x 1.5 =**	**1.1175Ah**	**1hr**
		2.235Ah	**2hr**
		3.3525Ah	**3hr**
		4.47Ah	**4hr**
		5.5875Ah	**5hr**

Utilizes the measured power consumption of the VSCADA computer and a reasonable ceiling estimation for the screen.

GLV Battery Capacity Calculation

R006-1 The GLV system shall contain a rechargeable battery of sufficient capacity to run the car GLV systems for at least three hours.

GLV Relays	**(2.04W x 2) = 4.08W + 1W (for microcontrollers, relays)**		
AIRS	**(2.04W x 4) = 8.16W + ~100mW (CAN transceivers)**		
VSCADA	**5.28W computer + 4W screen**		
Total	**25.52W / 24V = 1.06A x 1.5 =**	**1.595Ah**	**1hr**
		3.19Ah	**2hr**
		4.785Ah	**3hr**
		6.38Ah	**4hr**
		9.57Ah	**5hr**

Utilizes the peak power consumption of the VSCADA computer and a higher ceiling estimation for the screen.

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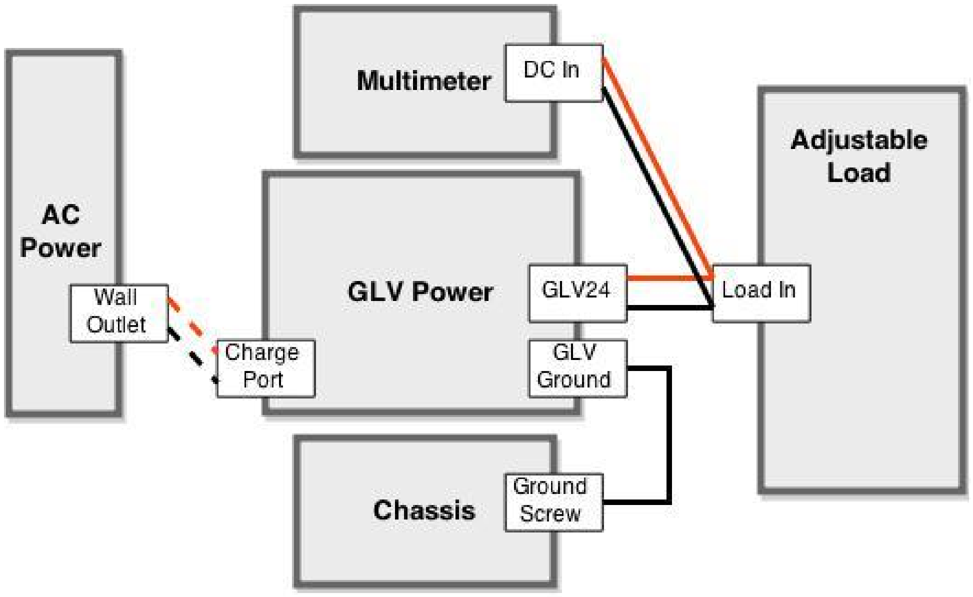
GLV Power and Battery Duration Test

R006-0 The GLV system shall provide DC supply voltage with sufficient current to supply all the power needs of the GLV systems and other non-tractive systems.
R006-1 The GLV system shall contain a rechargeable battery of sufficient capacity to run the car GLV systems for at least three hours.

Simplified Procedure:

1. Fully charge the battery.
2. Attach the Power Box to the adjustable load and set the current to simulate appropriate power consumption.
3. Record voltage at timing intervals.
4. Voltage must remain above designated value (21V) for three hours.



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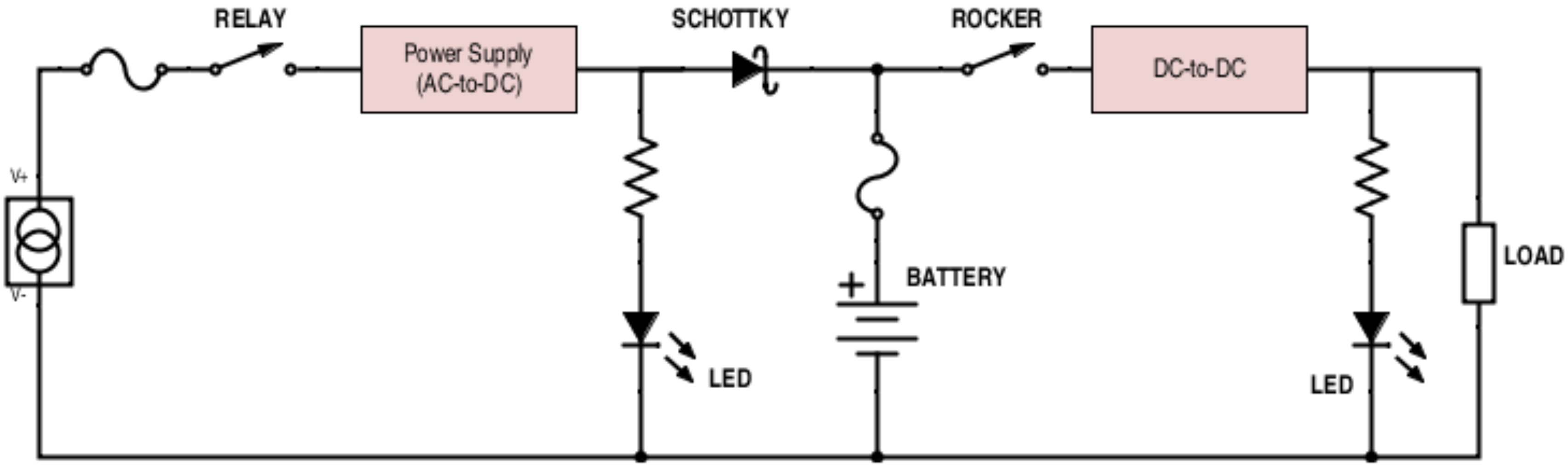
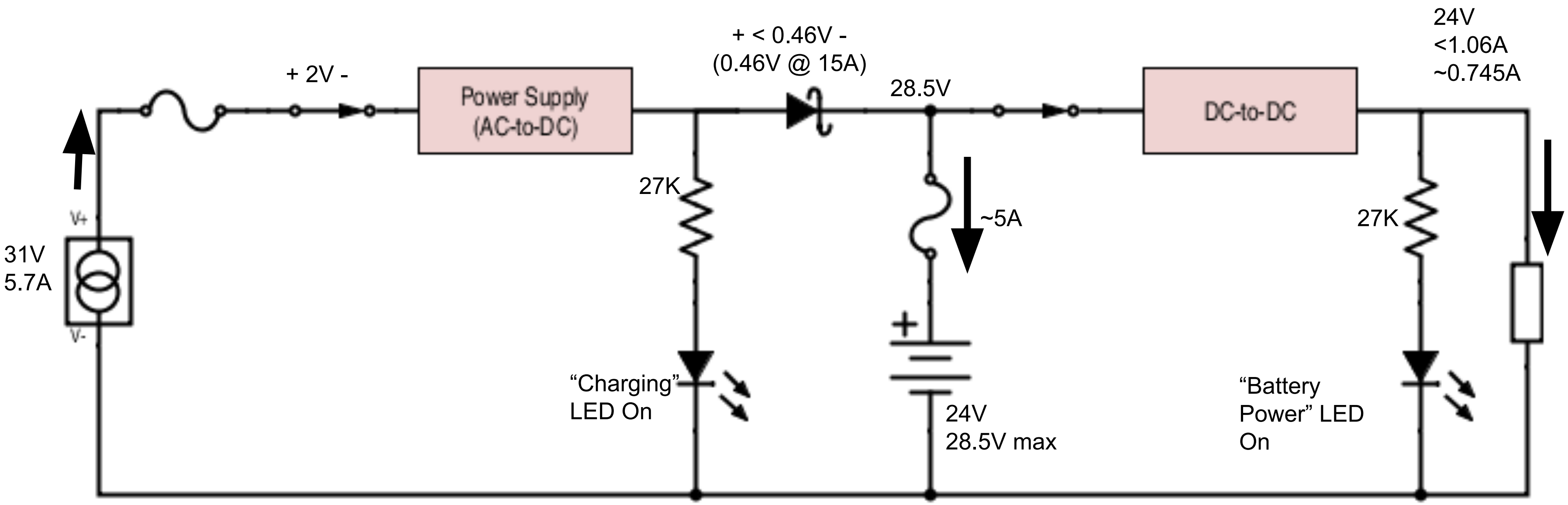
Charging Circuit



Charging Circuit - Charging

R006-2ii The charging system shall be capable of powering the GLV system indefinitely as it simultaneously charges the GLV battery in a *plug and forget* functionality.



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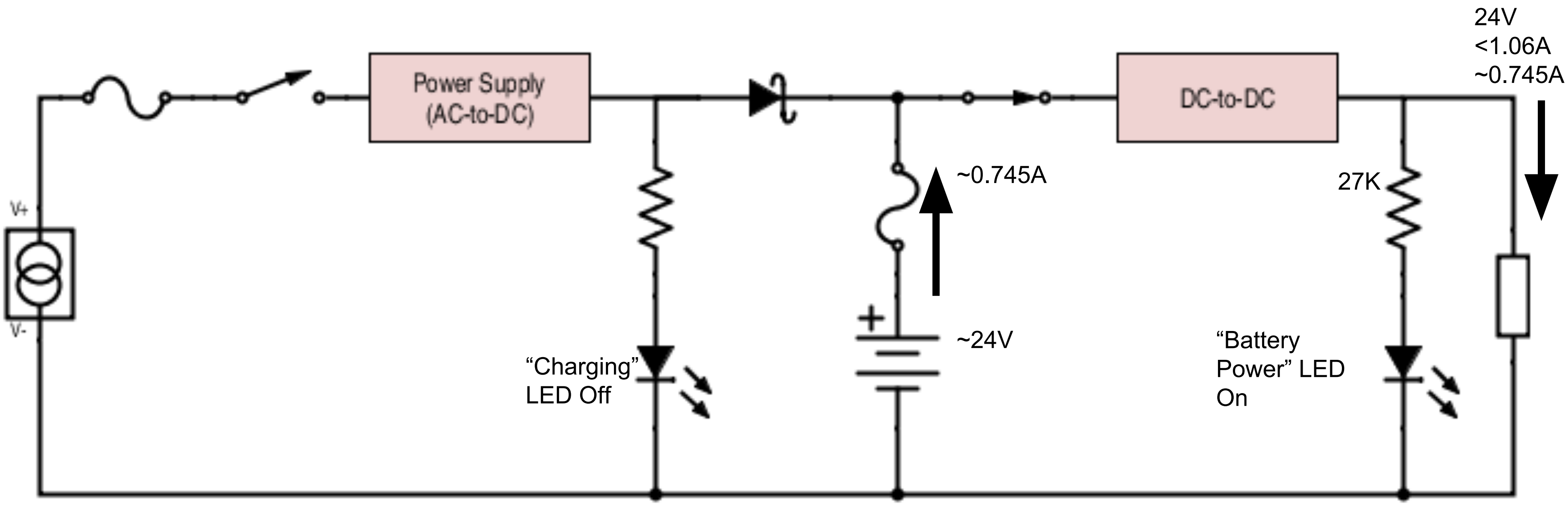
Charging Circuit - Discharging



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GLV Power - Charger

R006-2i The GLV system shall be rechargeable by means of a UL listed charging device that plugs into the 120 VAC mains.

Charge Port will include AC Receptacle, fuse, and switch.

Power Supply can provide 28.8~39.6V at 5.7A.
Constant current limiting protection.
Included in the Power Box.

http://media.digikey.com/Photos/Qualtek%20Photos/761-18%5E003.jpg

www.powergatellc.com

Battery Protection

R006-2iii It shall be possible to charge a fully discharged GLV battery without disassembly or special actions.
R006-2v The GLV battery shall be protected from full discharge, overcharge, overcurrent, and overvoltage.

Full Discharge:

- The 24-24 DC-to-DC Converter has an under voltage shutdown of 15.7 VDC.
- The solid-state relay controlling the charge circuit will be the normally closed type.

Overcharge:

- Discussed on previous slides.

Overcurrent:

- The 24-24 DC-to-DC Converter has a current limitation of 110% its typical, which is 2.5A for this device.
- 2.5A x 1.1 = 2.75A… Well above the expected range and below battery capabilities.

Overvoltage:

- The 24-24 DC-to-DC Converter has an overvoltage protection trigger point of <42V.

uk.farnell.com

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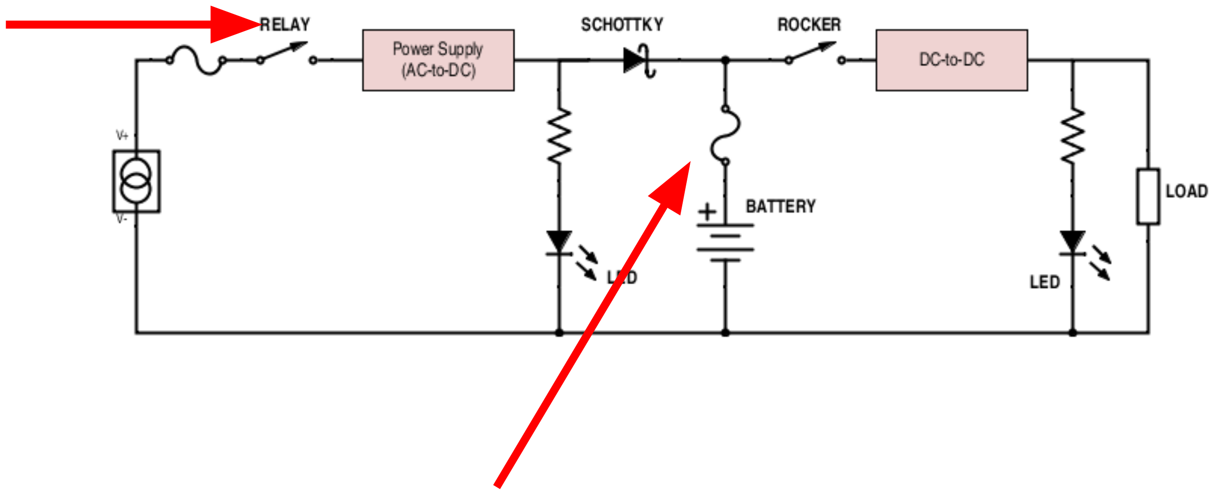
Power Box Fusing

EV6.1.1 All electrical systems must be appropriately fused.

- Strict current upper limit.
- Current limited by power supply.



7A, 35VDC fuse

- A fuse will also be placed before the microprocessor on the 12V line.

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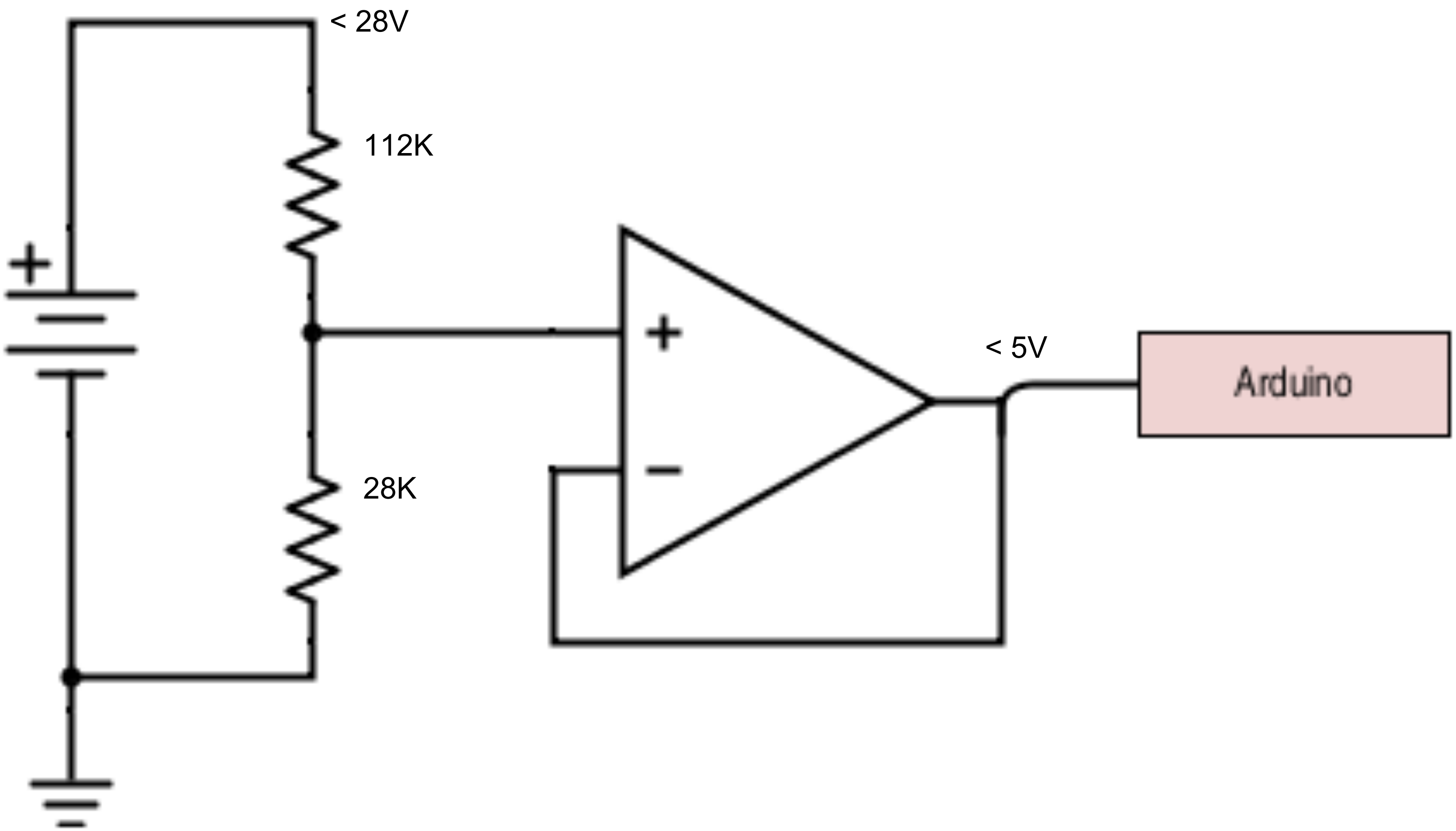
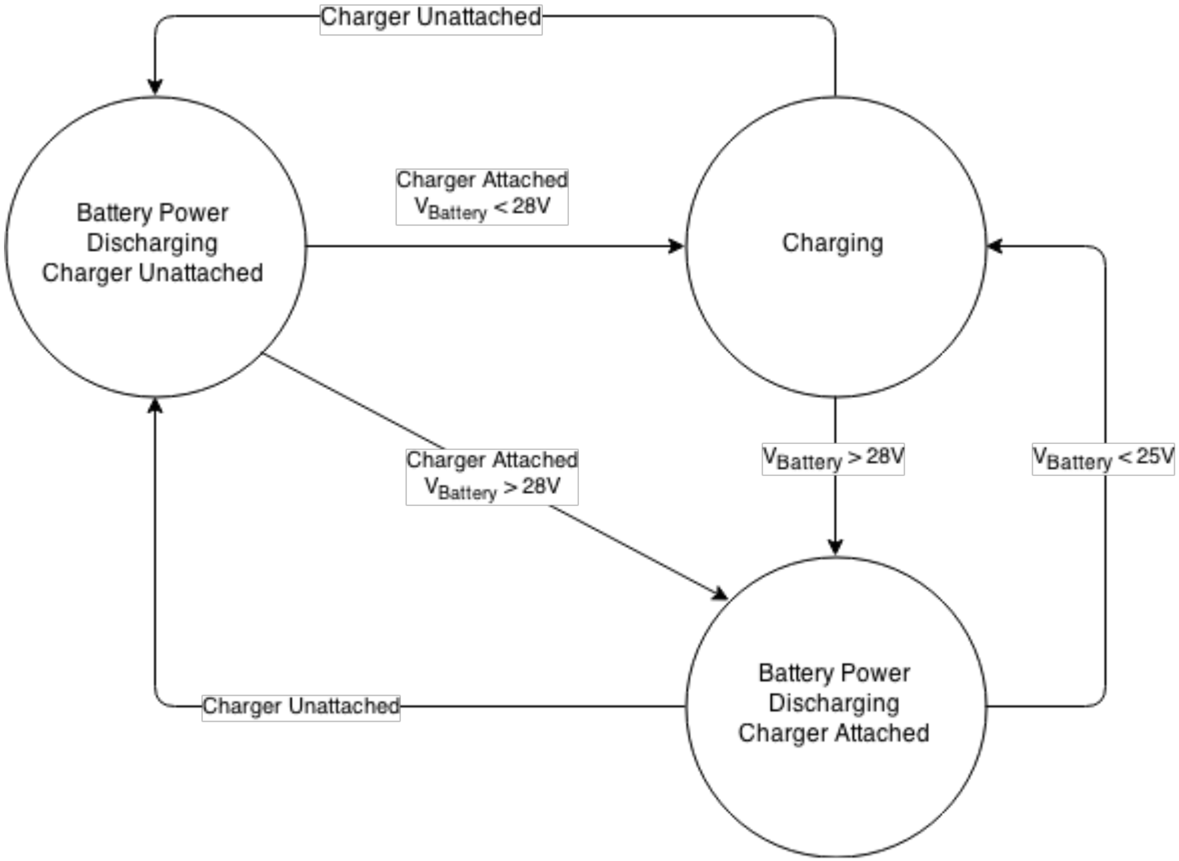
Voltage Sensing

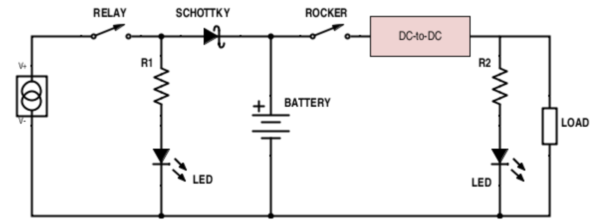
R006-2v The GLV battery shall be protected from overcharge.
R006-4 GLV voltage shall be measured by VSCADA.



GLV Power Charging States

R006-2v The GLV battery shall be protected from full discharge and overcharge.





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GLV Power SOC

R006-4 GLV current and SOC shall be measured by VSCADA.

- Bidirectional current-sensor at battery + terminal, feeds analog output to microprocessor.
- Time duration of each state.
- Use current + time measurement to calculate Ah, compare to battery capacity for SOC.
- If full charge or full discharge is reached, reset SOC value to designated value (0 or 100).

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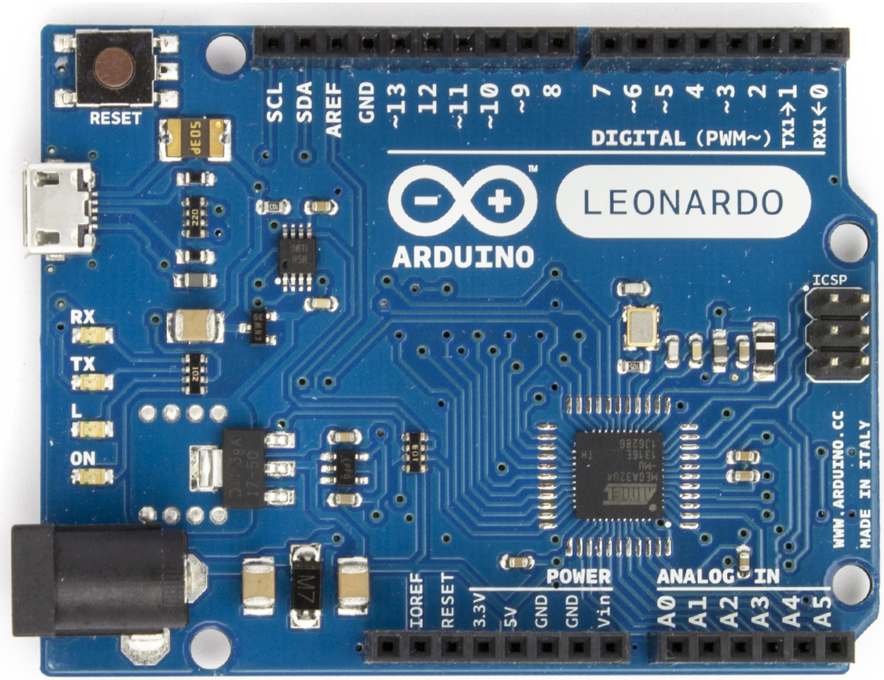
GLV Power Software

R006- GLV voltage, current, temperature, and SOC shall be measured by VSCADA.

GLV Power Arduino
-for use prior to JGB arrival

Maintainability:

- Code will be written in C which is not going extinct in the near future.
- Files will be uploaded to the website containing the source code and Arduino ID.



www.arduino.cc

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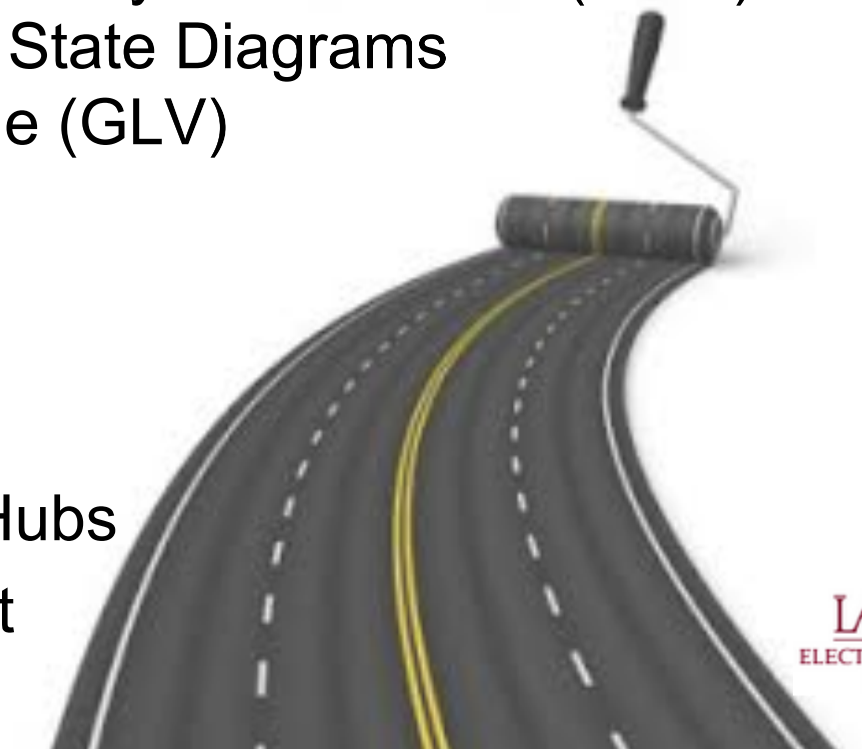

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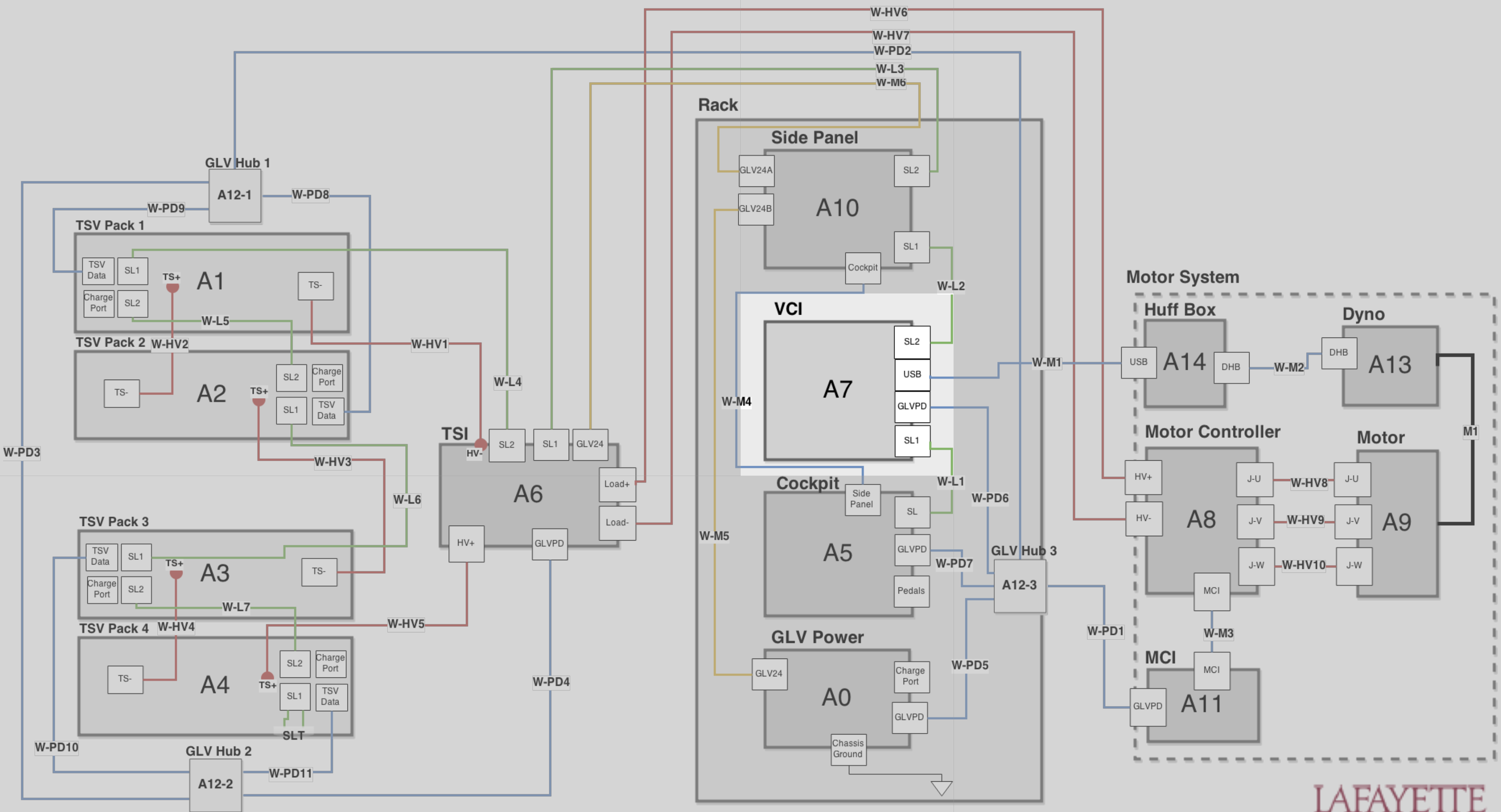
Vehicle Computer Interface



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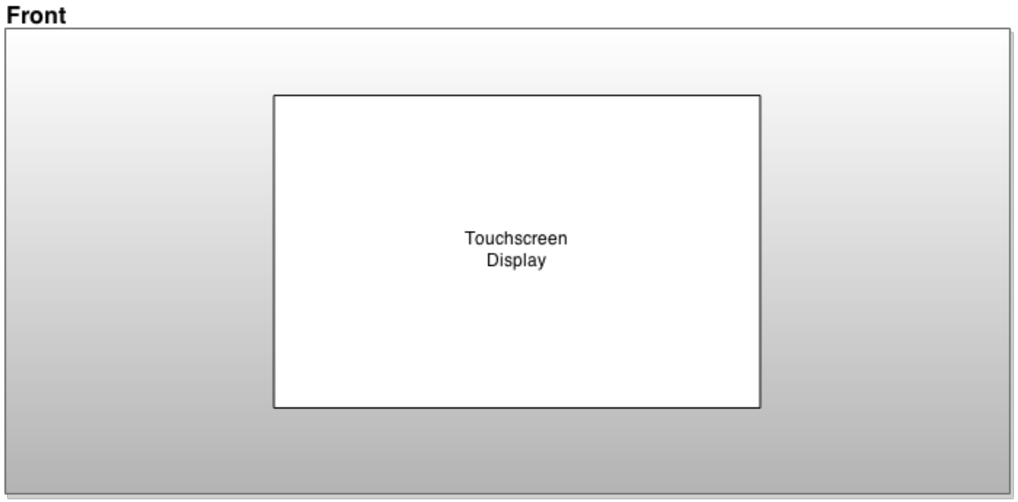
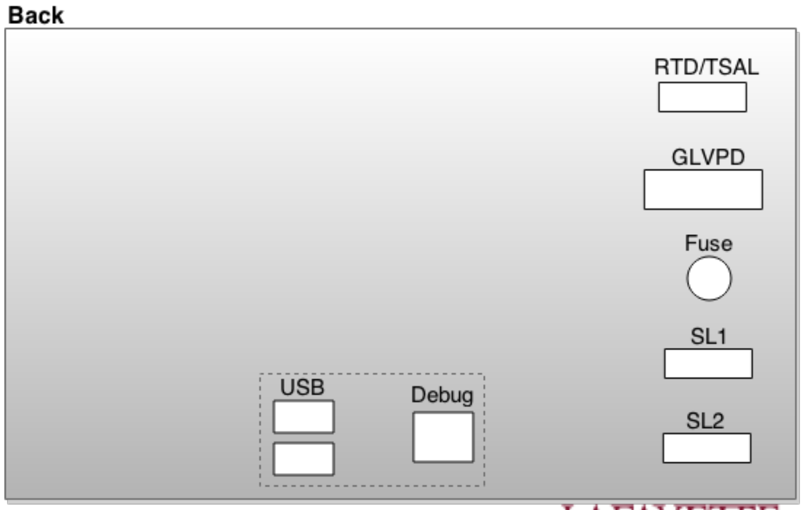
Vehicle Computer Interface (VCI)

- Contains:
  - VSCADA Computer
  - Maintenance Panel Display
  - Safety Loop Control and Monitors
  - TSAL Circuit
  - RTD Sound Control





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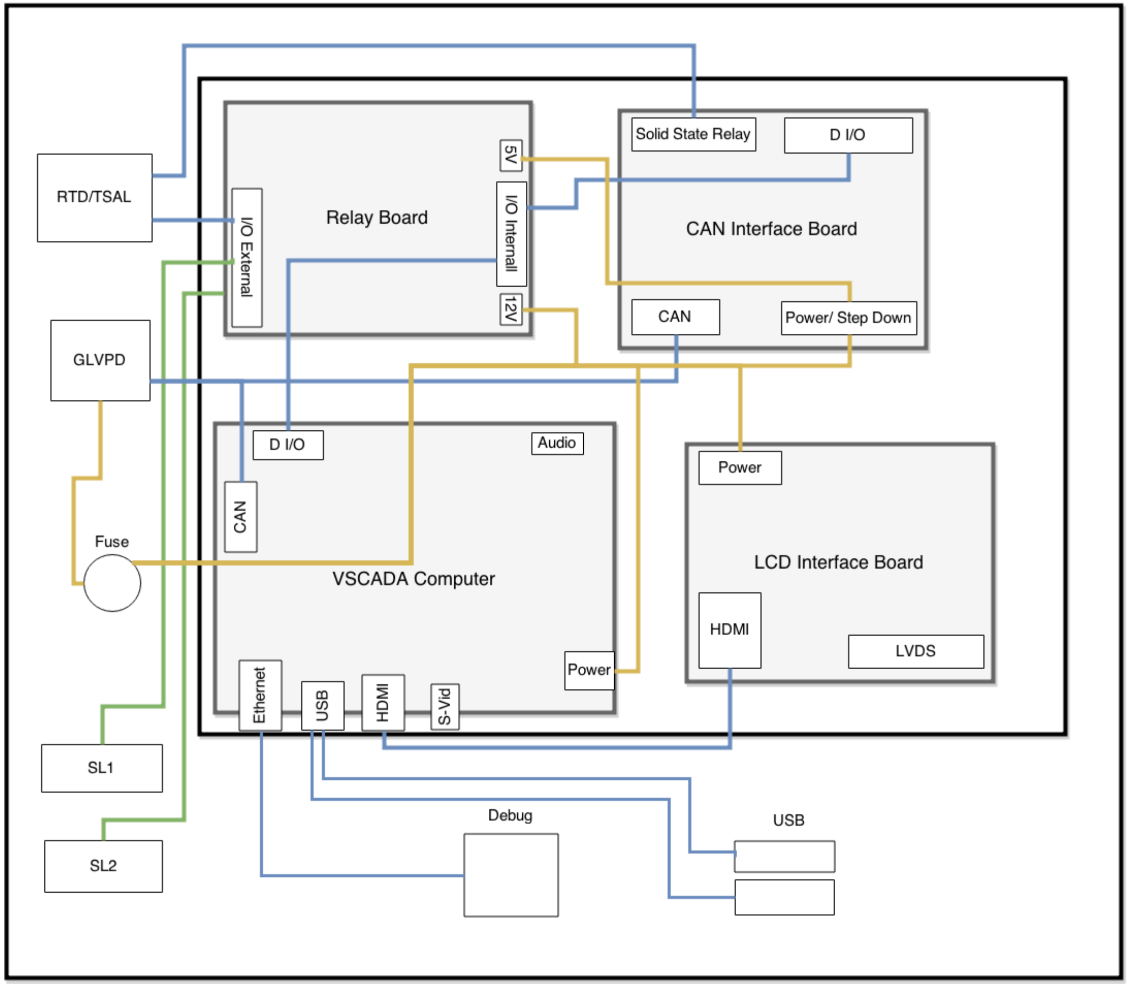
VCI

- Components:
  - VSCADA Computer
  - CAN Interface Board (JGB)
  - Relay/TSAL PCB
  - LCD Interface Board



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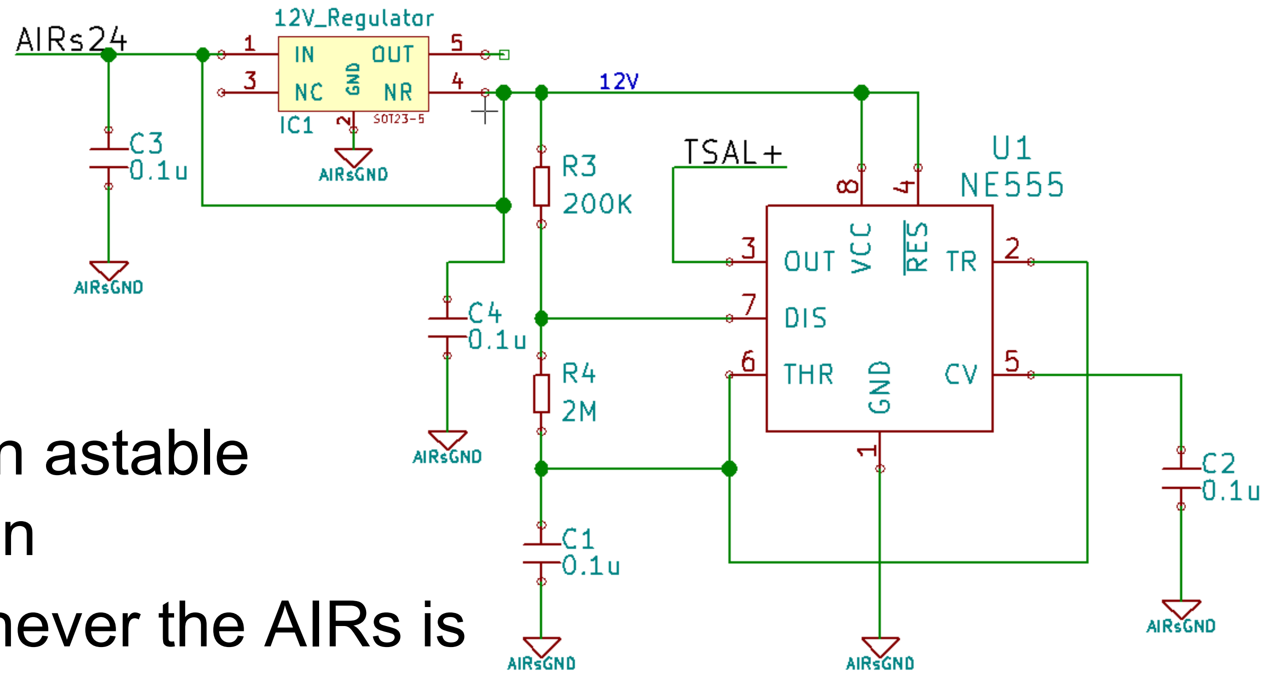
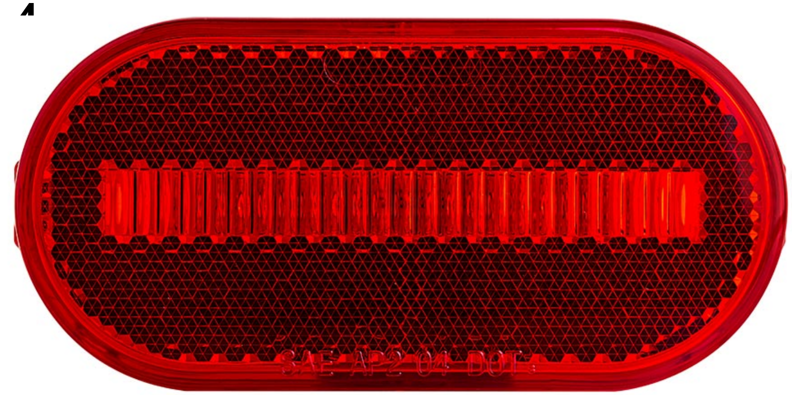
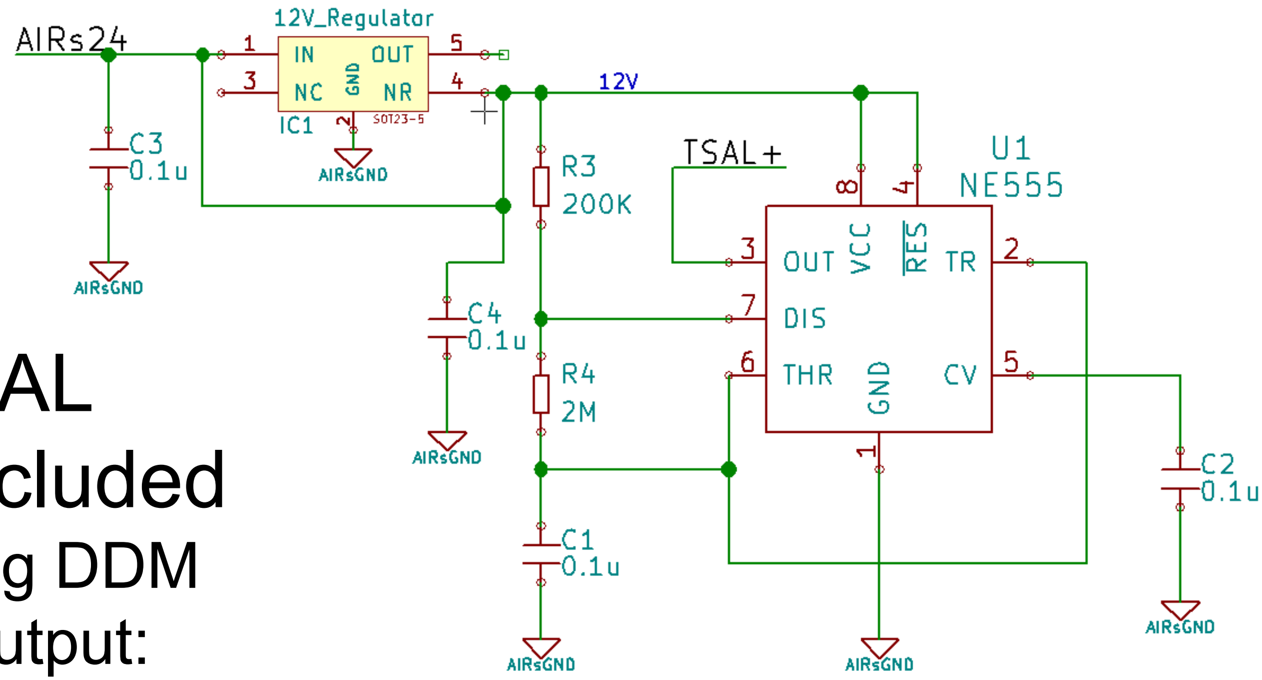
VCI



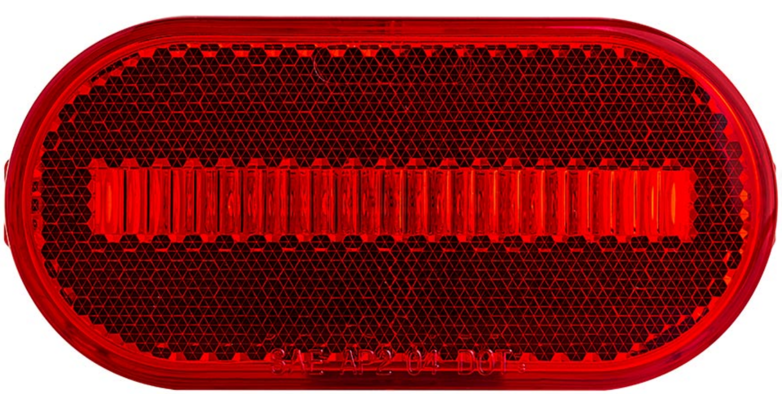
- TSAL
  - 555 Timer in astable configuration
  - Active whenever the AIRs is open
  - Set for a frequency of 3.436 Hz
  - LED Truck Trailer Light M9-x
    - 0.040 Amp draw



VCI



- Physical TSAL
  Lamp not included
  - Tested using DDM
  - Expected output:
    - 12V
    - 52% duty cycle
    - 0.2911 second period



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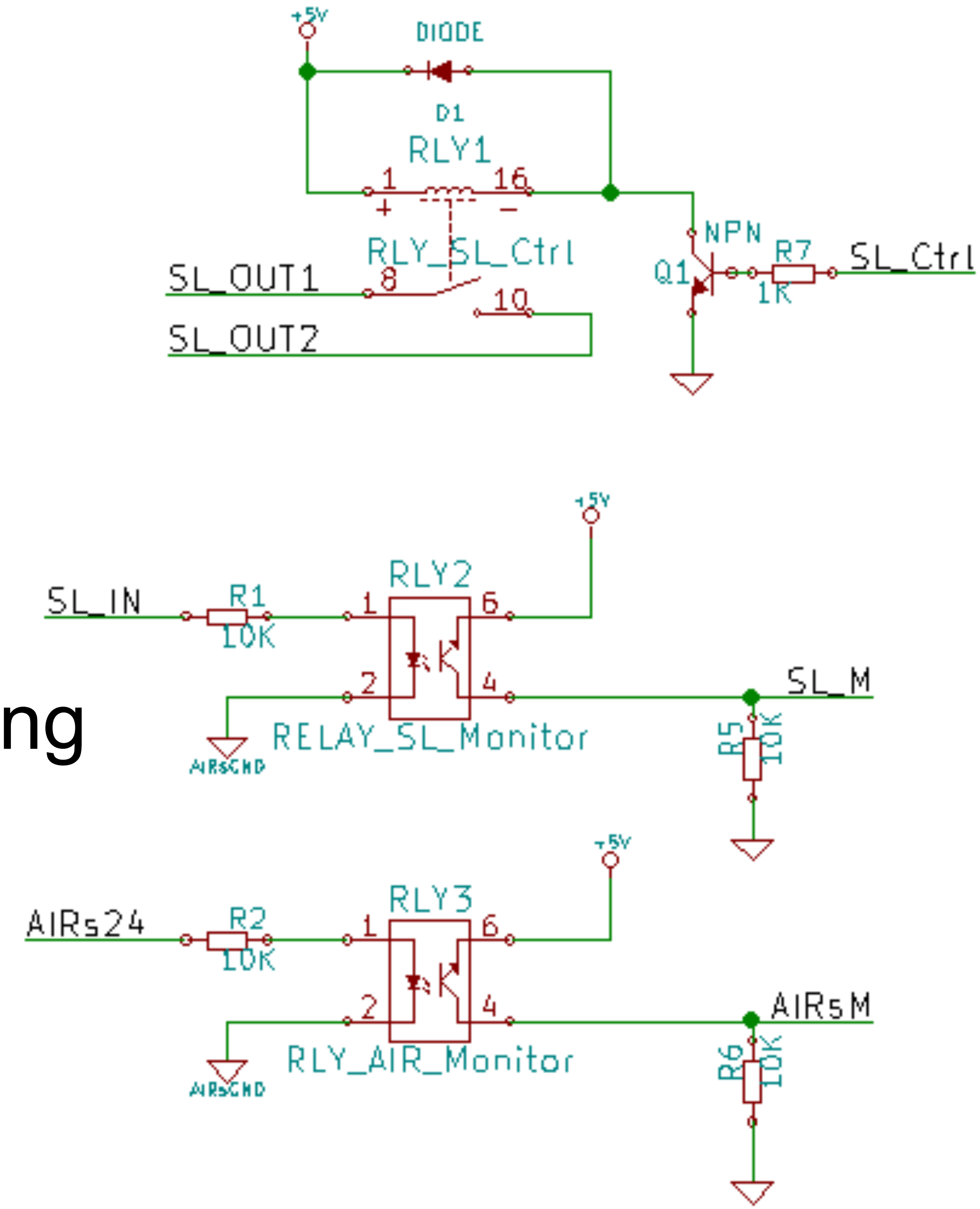
VCI

- Safety Loop Control
  - Controlled by the CAN Interface Board
  - Gives Safety Loop control to system software
- Safety Loop Monitoring
  - Monitored by the CAN Interface Board
  - Safety Loop Monitor
  - AIRs State Monitor



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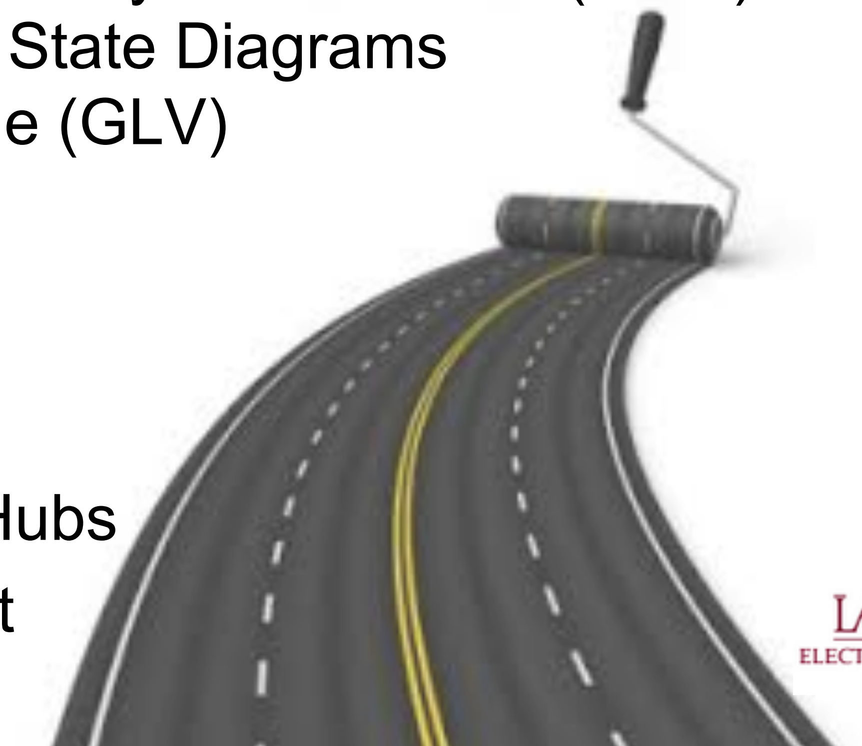

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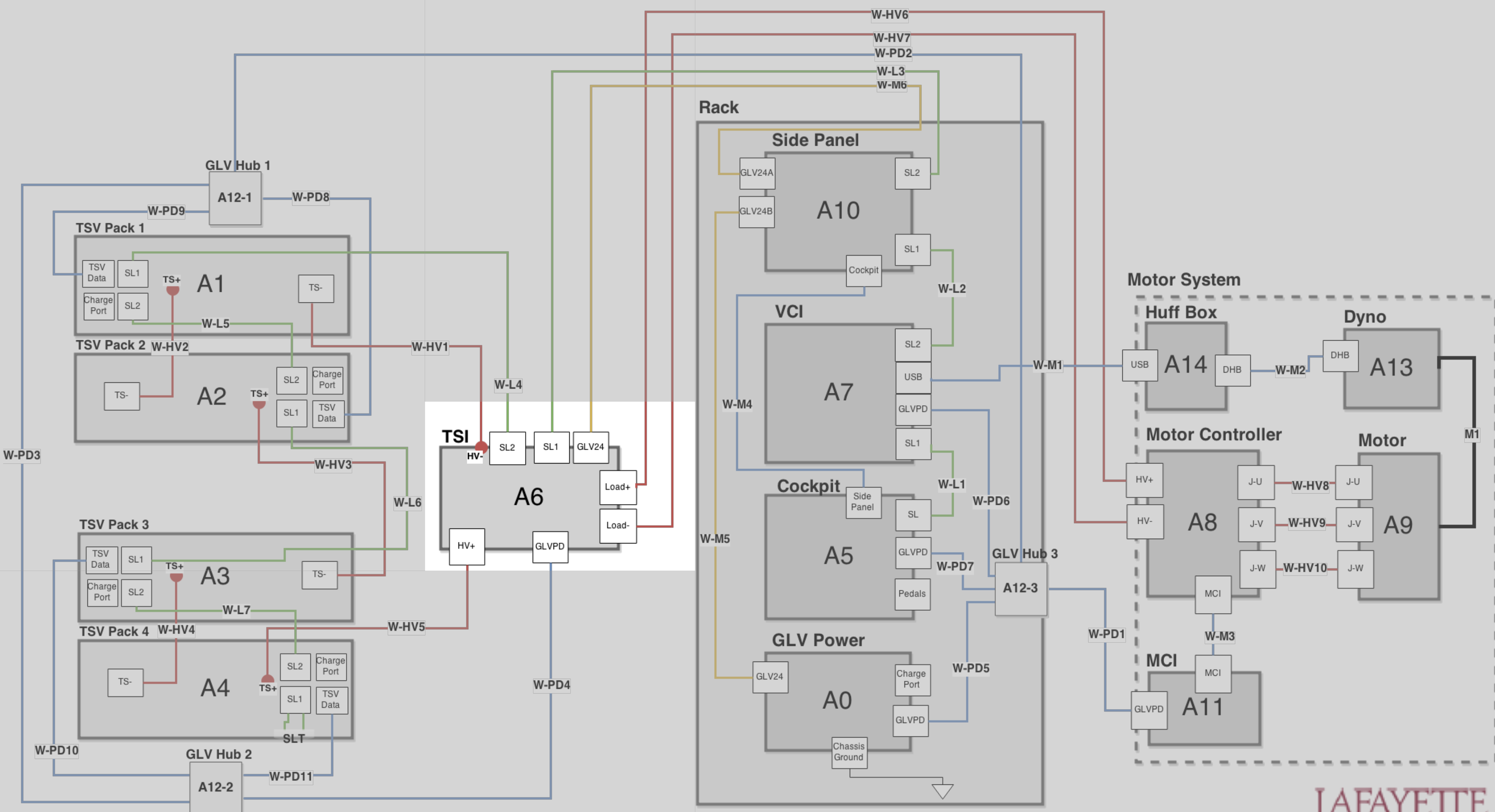
Tractive System Interface (TSI)



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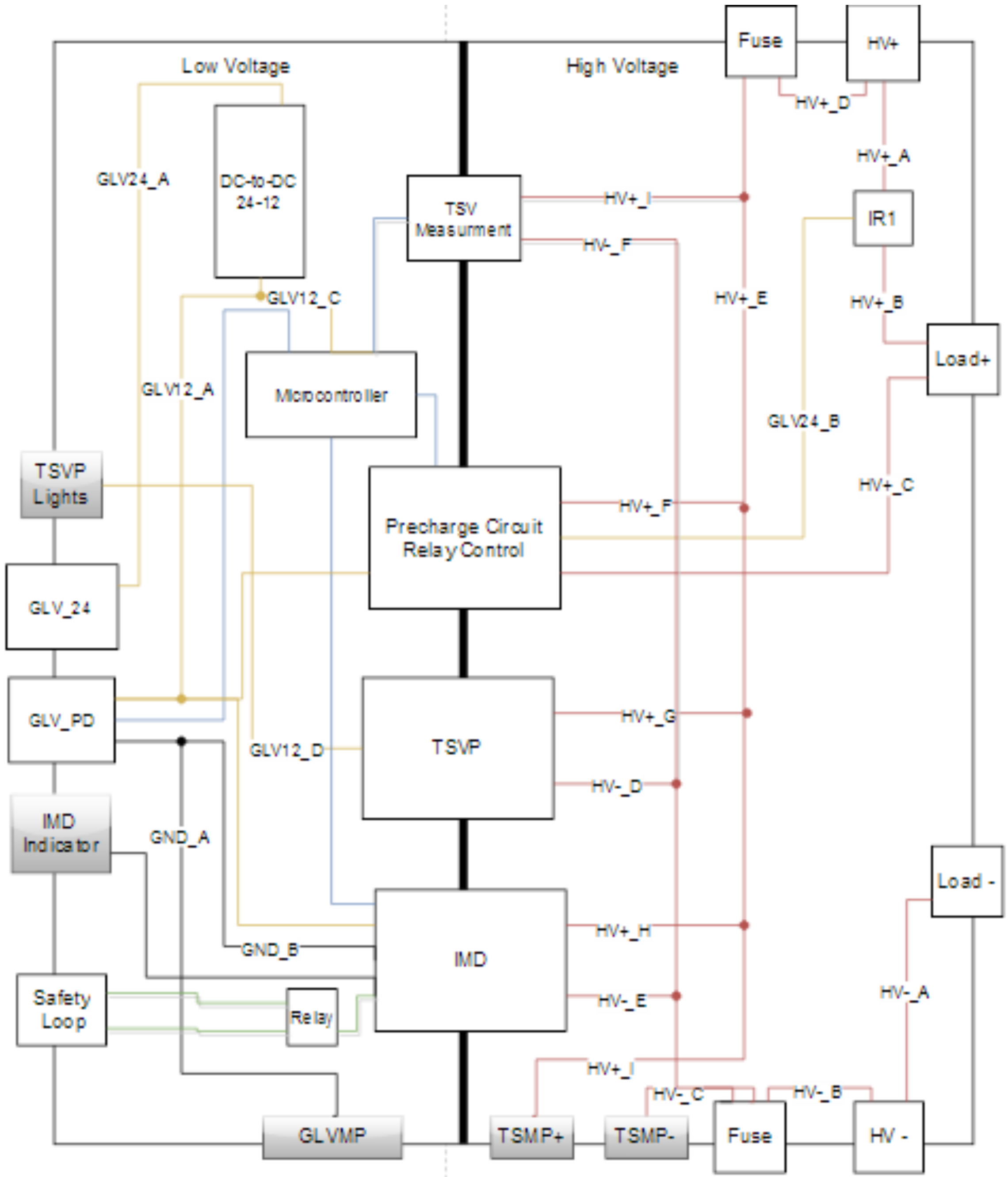
TSI - Overview

- Major Requirements
  - Precharge Protection Circuit
  - VSCADA Relay Control
  - Tractive System Voltage Present Light (TSVP)
  - High Voltage Measurement
  - Insulation Monitoring Device (IMD)
- Other Components
  - GLV PD 24 to 12 step down
  - Tractive System Measuring Points (TSMP)

TSI



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TSI - Precharge/Relay Control

- Precharge circuit prevents inrush current
- Protects relay contacts and internal components of motor controller
- Idea
  - place a resistor between high voltage source and load
  - slows down rate of change of input voltage
  - slowly and controllably charge motor controller
  - switch to a direct connection after motor controller reaches 90% of total voltage

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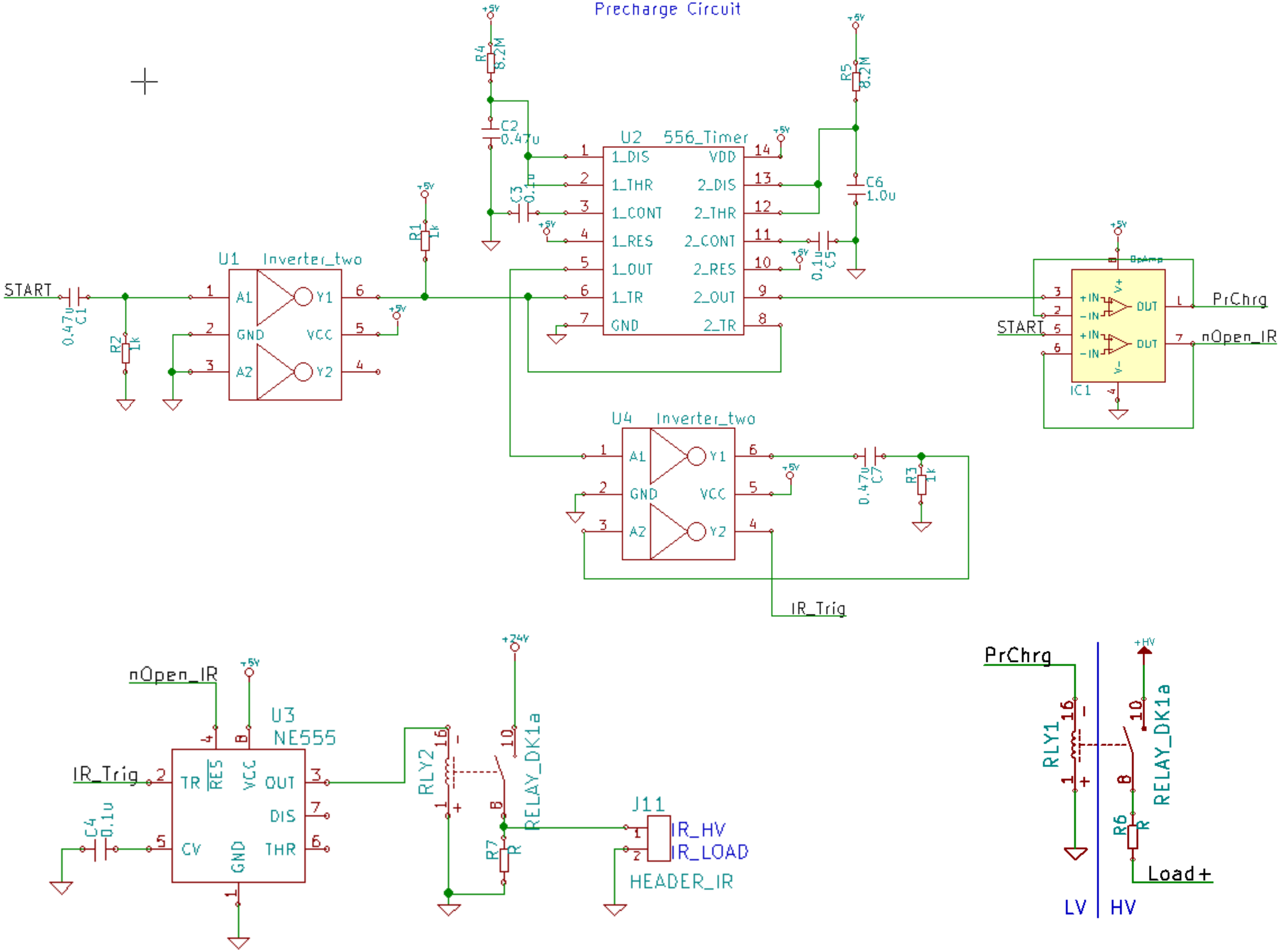
TSI - Precharge/Relay Control



TSI - Precharge/Relay Control

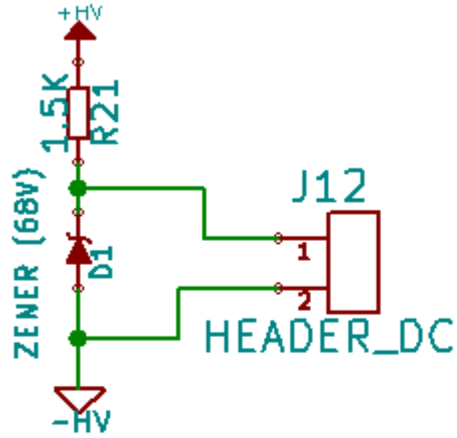
- Pre-charge Resistor = 240 ohm
- Limits input current to 400 mA
- This will take 4.65s to charge the motor controller to 90% and main relay will close
- After 8s, pre-charge relay will open

TSI - TSVP

- TSVP lamps turn on whenever the voltage outside of the accumulator containers exceeds 30 VDC
- Lamps must be powered and controlled tractive system voltage
- Tractive System wiring cannot be present at the lamps themselves
- Lamps must be grounded to GLV system ground
- This could cause isolation problems

TSI - TSVP

- Use an isolated DC-DC converter to step down the battery pack voltage and keep the systems isolated
- Use a zener diode as a voltage regulator to control the input voltage of the DC-DC converter



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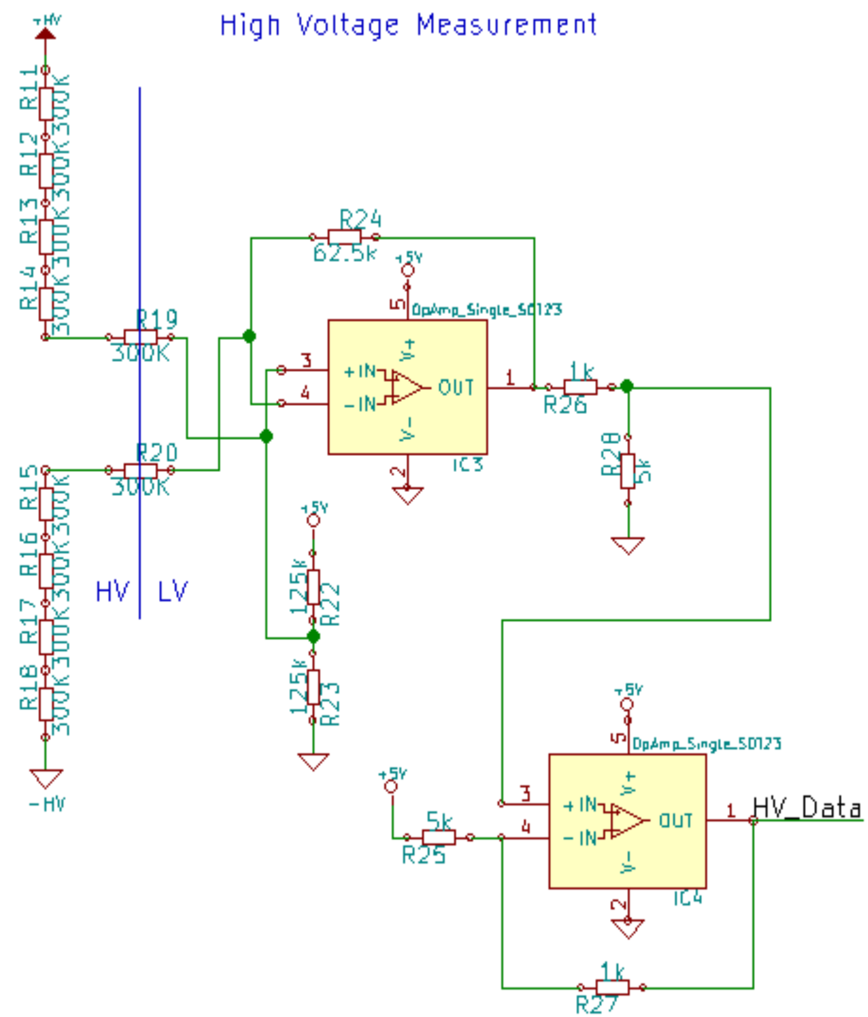
Battery Pack Voltage Measurement

- Voltage divider and buffer to scale down high voltage measurement
- Voltage divider maintains galvanic isolation



Battery Pack Voltage Measurement

- Measures from 30V to 115V
  - High Voltage 85V Range -to- Low Voltage 5V Range
  - Resistor Divider producing A = 5/85 = 0.588235
    - R1 = 1MΩ
    - R2 = 62.5kΩ
    - A = 0.058824
- Resulting Outputs
  - 115V -to- 6.765V
  - 30V -to- 1.76472V
    - (This must be the reference voltage)

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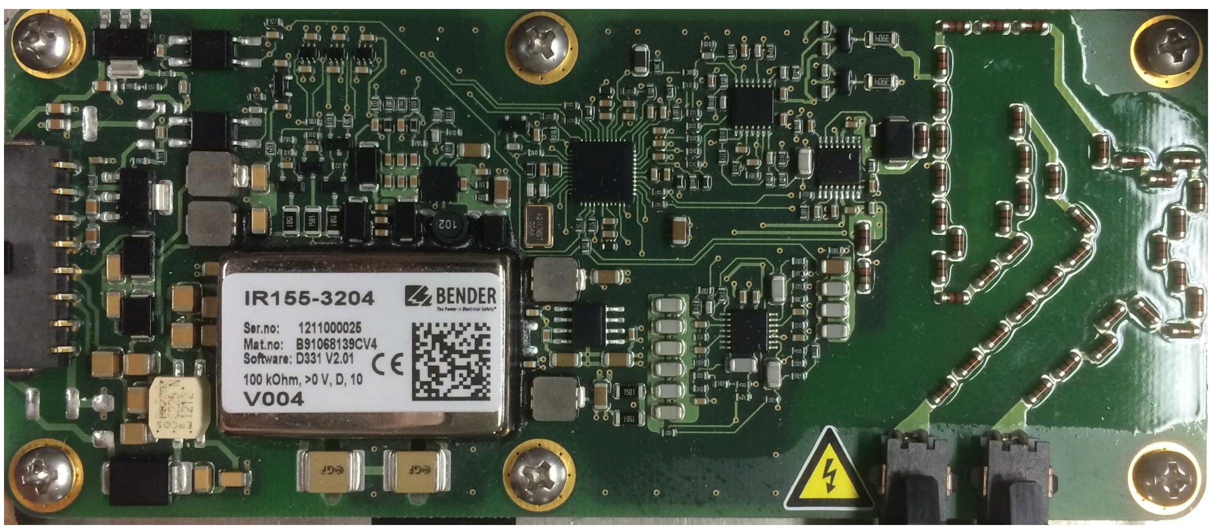
TSI - IMD

- ISOMETER IR155-3203
- Monitors the insulation resistance between the high and low voltage systems
- Provides fault detection



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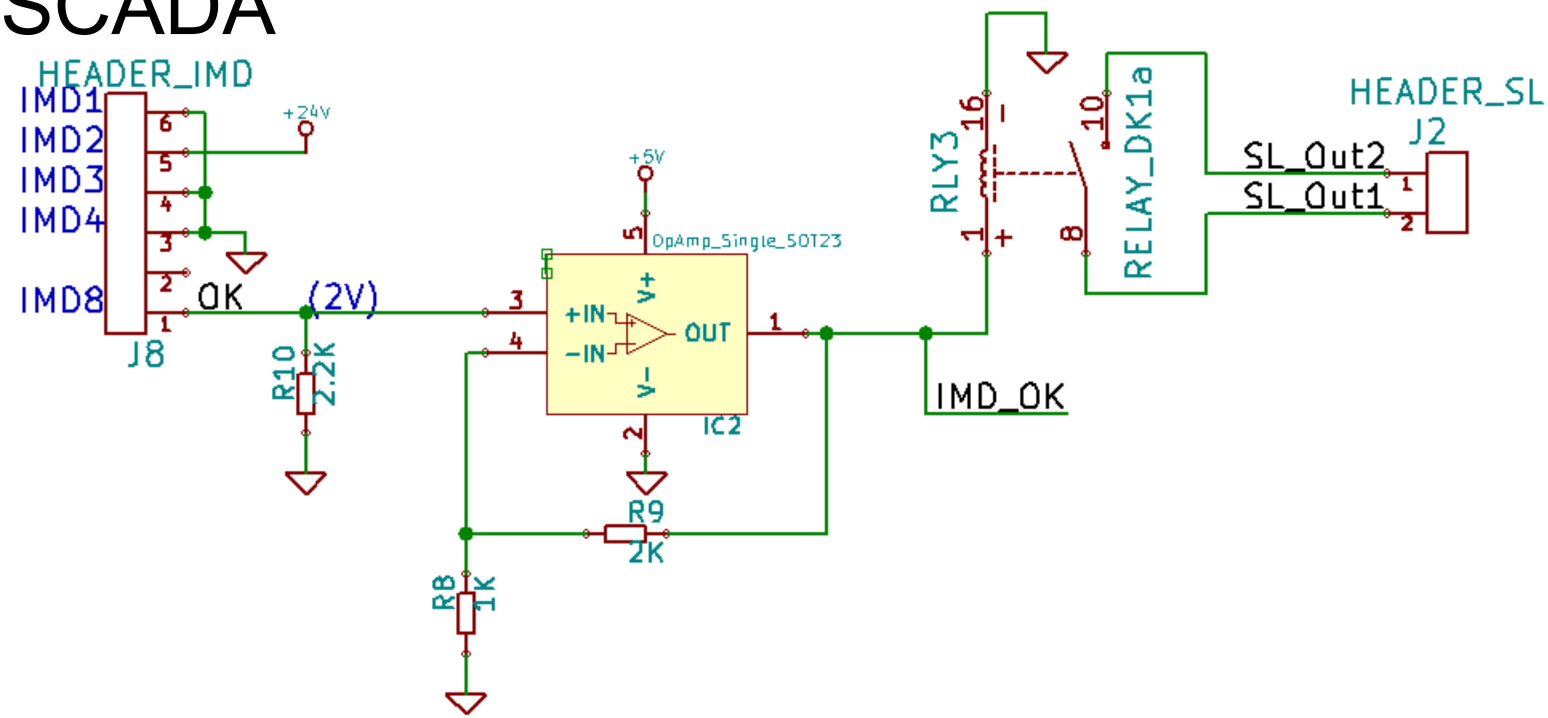
TSI - IMD

- Fault detection status output trips the safety loop relay
- Insulation resistance measurements are sent to VSCADA



TSI - TSMP

- TSMP+
  - Banana jack connected to the positive motor controller supply line
- TSMP-
  - Banana jack connected to the negative motor controller supply line
- GLV GND
  - Banana jack connected to the GLV system ground
- These ports are located directly next to each other to be used to check for isolation

TSI - GLVPD

- TSI receives 24 volts from he GLV24 line from the side panel
- Step down to 12 volts using a DC-DC converter
- 12 volts is connected to other subsystems through the GLVPD connection

http://www.trcelectronics.com/View/Minmax/MKW1033.shtml

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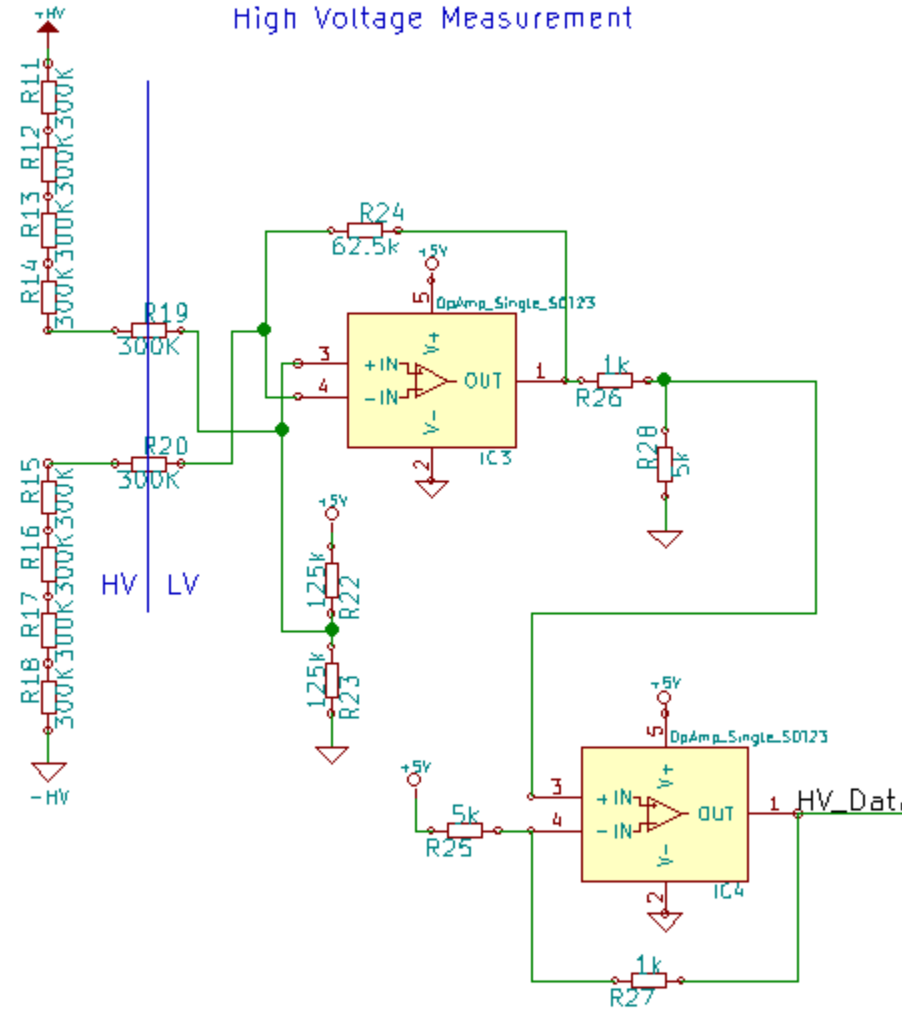
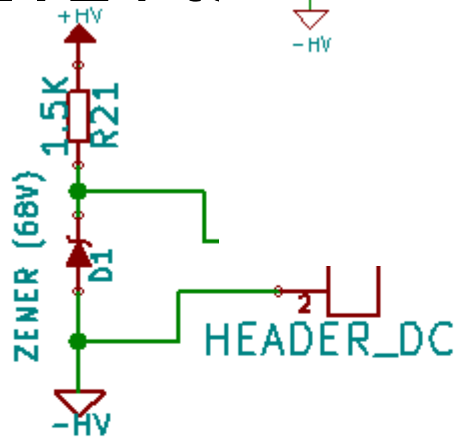
TSI - QA Configura

- Connect high voltage voltage power source
- Connect the high volta the high voltage load
- Connect the GLV24 te power supply





TSI - QA Test Plan

- TSVP Test
  - Slowly increase voltage from the high voltage power supply
  - Observe the voltage at which Lamp turns on
- Pre-charge/Relay Test
  - Use switch to put start signal high
  - Measure the time it takes for relays to switch
- TSMP Test
  - measure voltage at the HV terminals
  - should agree with voltage at banana jacks
- GLVPD Power Test
  - apply 24 volts from low voltage supply
  - output of DC-DC converter should read 12v

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TSI - QA Test Plan

- High Voltage Measurement Test
  - Voltage measurement should be proportional to voltage applied to the HV terminals
- IMD Test
  - Make sure high voltage power supply is off
  - short high voltage and low voltage systems
  - fault should be detected

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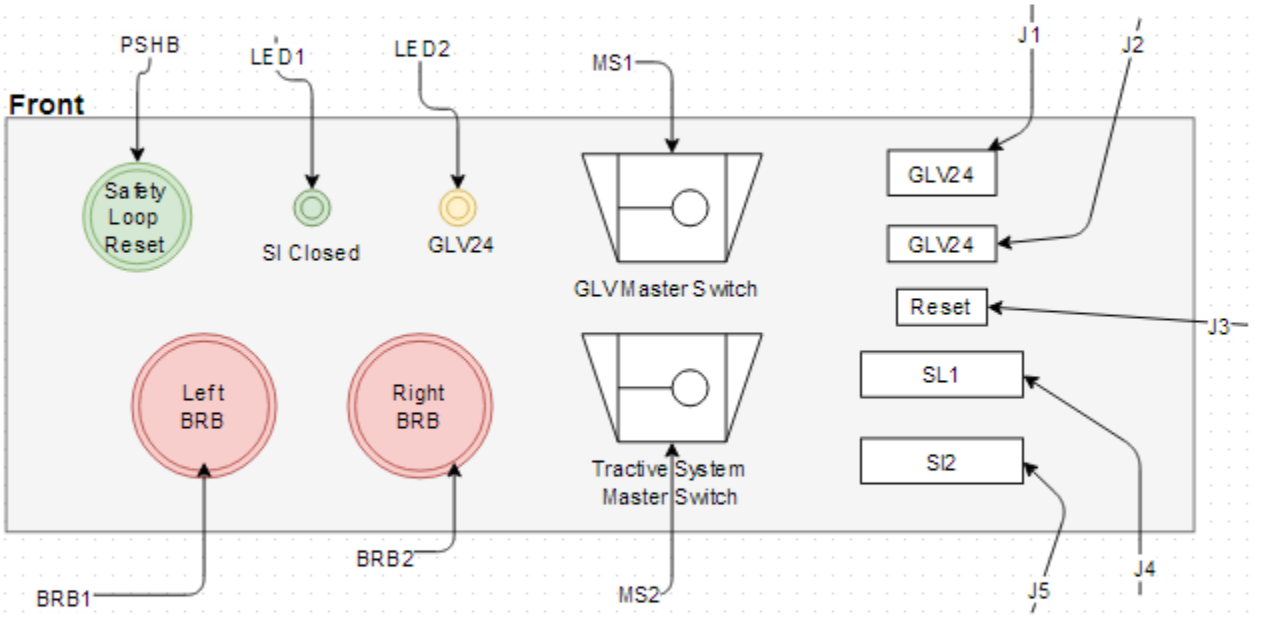
Side Controls Panel

- Designed for testing purposes

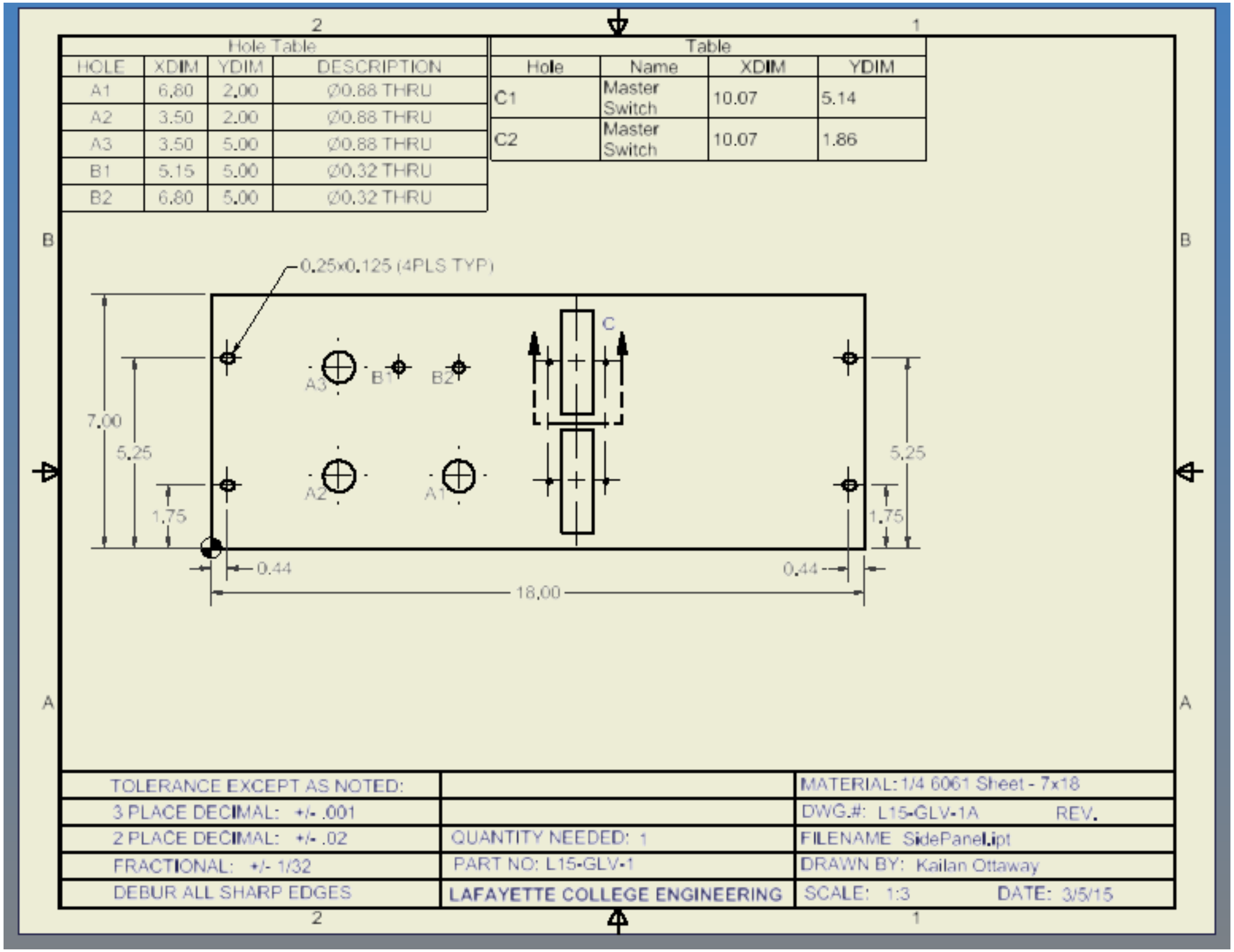


Materials list:

Panel will be aluminum 18"x7"x1/4"

PSHB	Push button
BRB1	Big Red Button
BRB2	Big Red Button
LED1	Green LED
LED2	Amber LED
MS1	Rotary Switch
MS2	Rotary Switch
J1	3-pin TE Connectivity Connectors
J2	3-pin TE Connectivity Connectors
J3	2-pin TE Connectivity Connectors
J4	4-pin TE Connectivity Connectors
J5	4-pin TE Connectivity Connectors

Side Controls Panel Drawing



Hole Table

HOLE	XDIM	YDIM	DESCRIPTION
A1	6.80	2.00	Ø0.88 THRU
A2	3.50	2.00	Ø0.88 THRU
A3	3.50	5.00	Ø0.88 THRU
B1	5.15	5.00	Ø0.32 THRU
B2	6.80	5.00	Ø0.32 THRU

Table

Hole	Name	XDIM	YDIM
C1	Master Switch	10.07	5.14
C2	Master Switch	10.07	1.86

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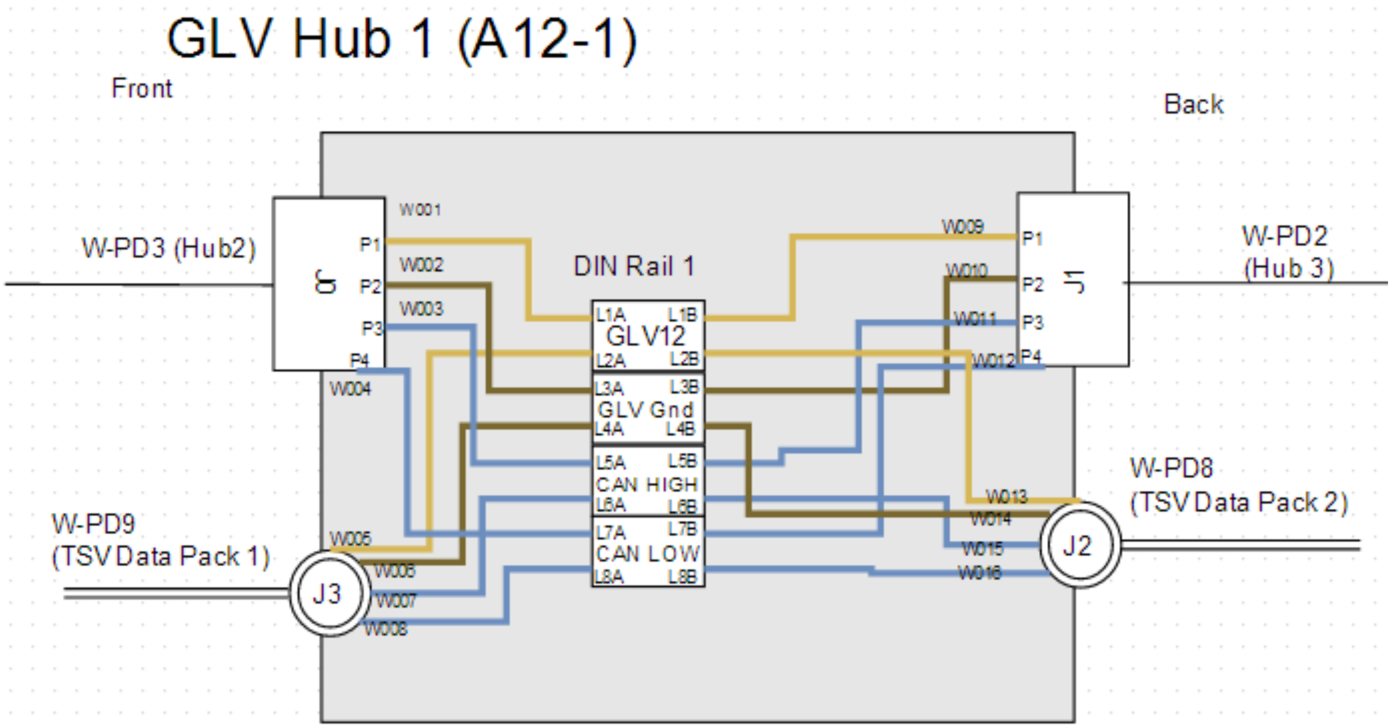
GLV Hub 1

- Connects to GLV Hub 2 and 3
- Dangly that connects to TSV Pack 1 data port
- Dangly that connects to TSV Pack 2 data port



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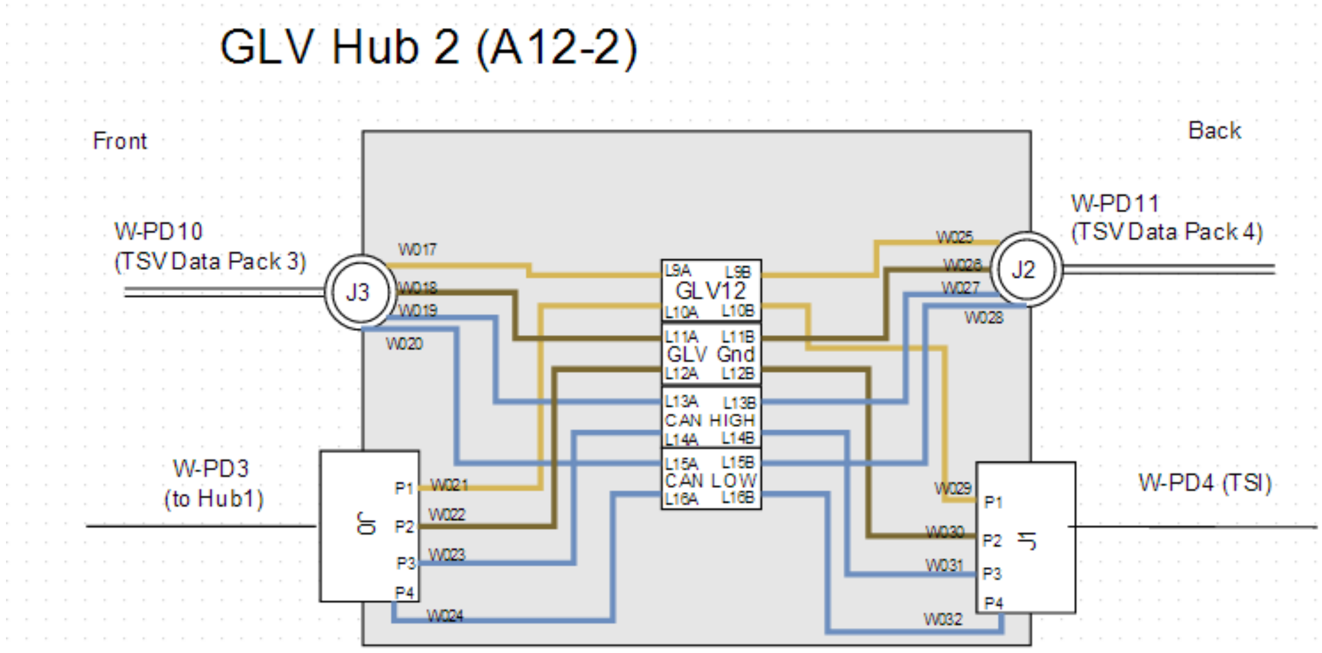
GLV Hub 2

- Connects to GLV Hub 1
- Connects to TSI
- Dangly that connects to TSV Pack 3 data port
- Dangly that connects to TSV Pack 4 data port



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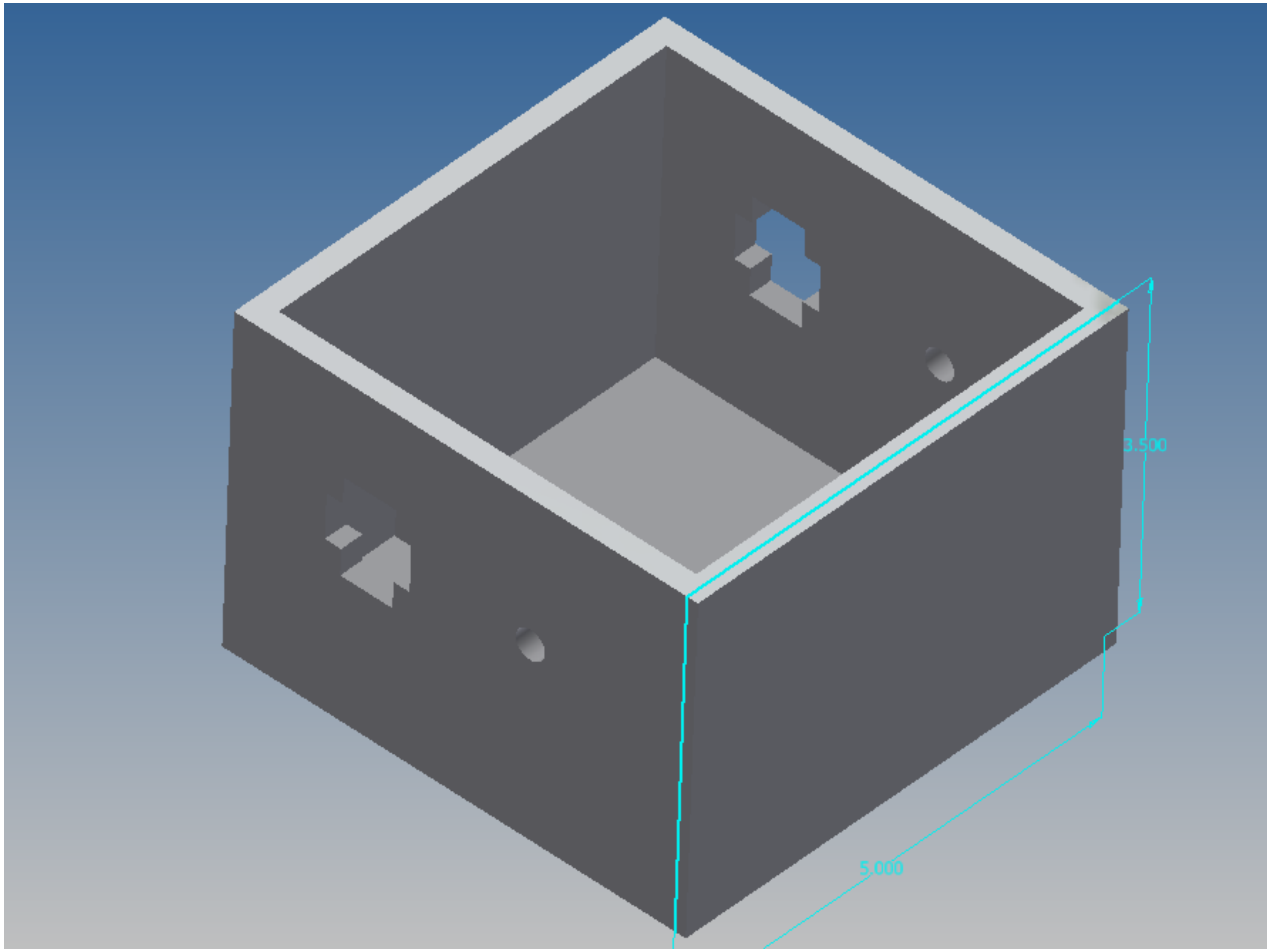
GLV Hub 1 & 2



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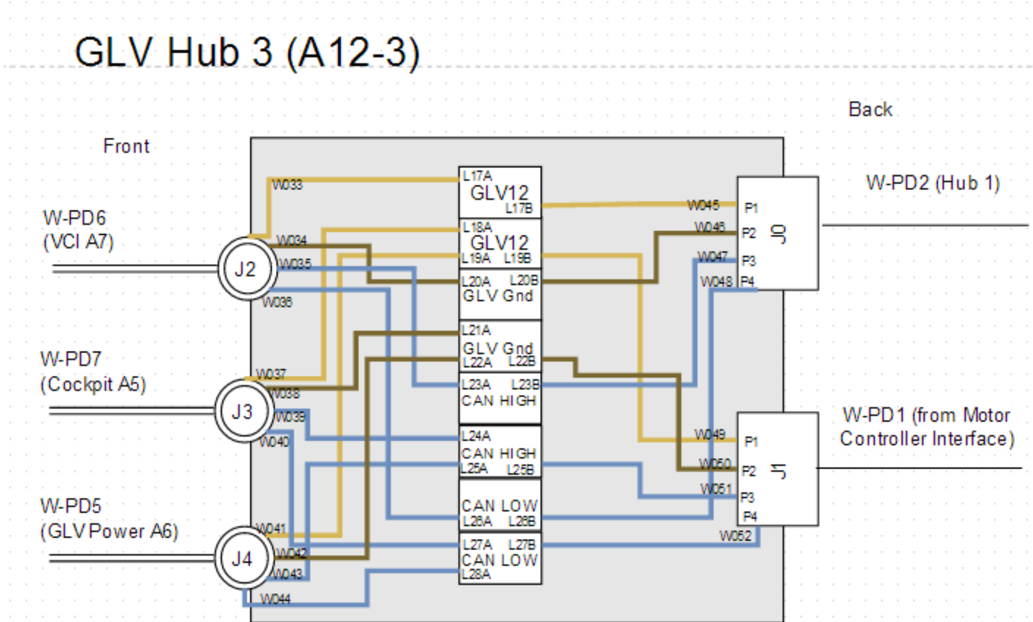
GLV Hub 3

- Connects to GLV Hub 1
- Connects to Motor Controller Interface
- Dangly that connects to the VCI
- Dangly that connects to the Cockpit
- Dangly that connects to GLV Power



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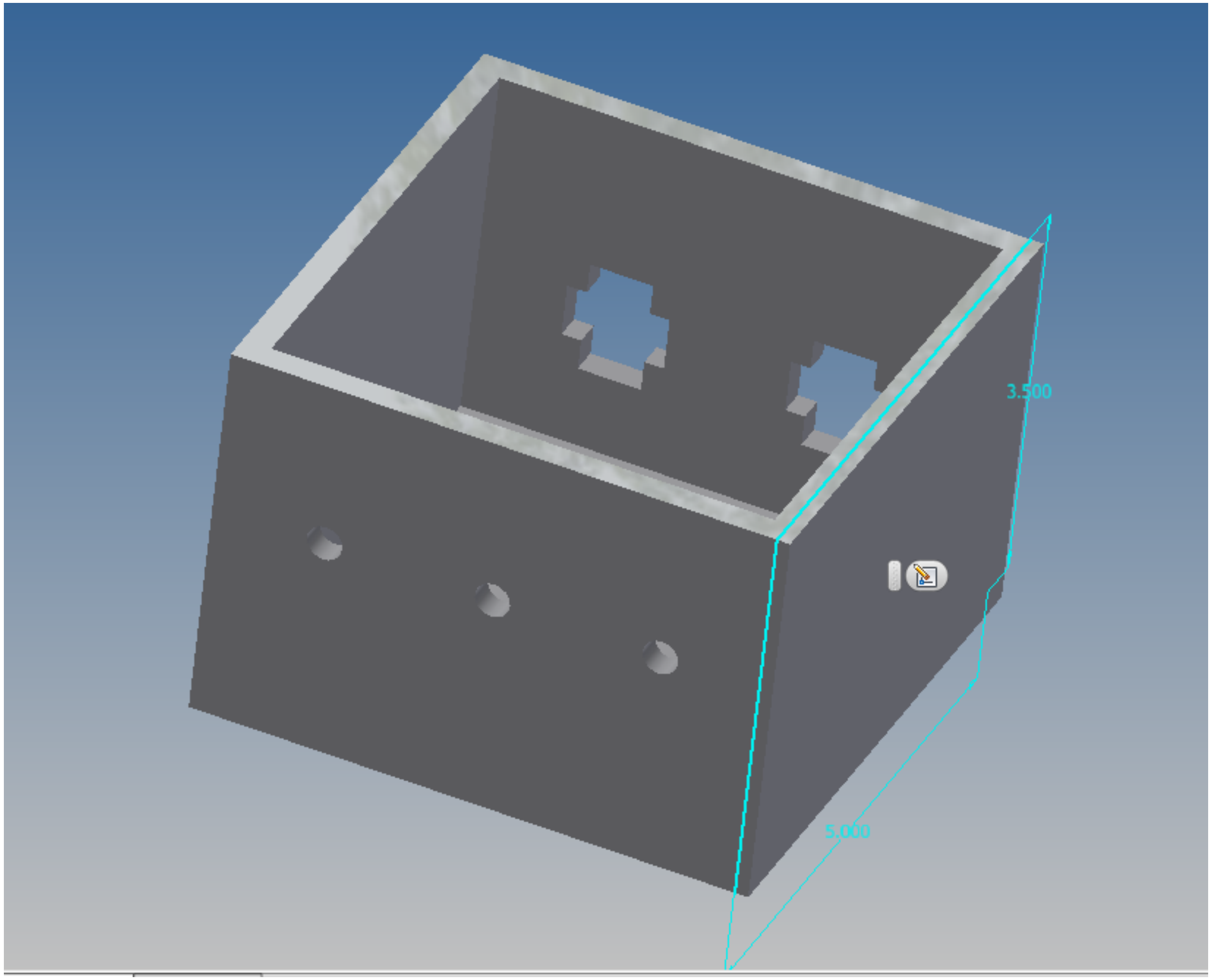
GLV Hub 3



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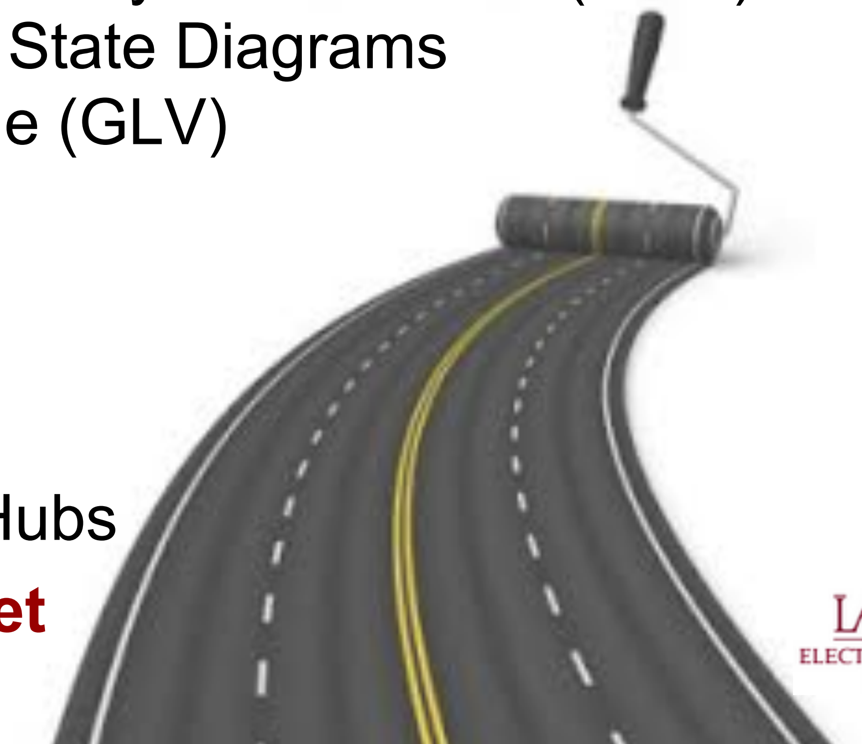
Roadmap

1. Meet the Morning Teams
2. Introduction: Motivation
3. Interface Control
    a. System Assemblies Layout/Interfaces (Car)
    b. System Assemblies Layout/Interfaces (Rack)
    c. Interconnects and State Diagrams
4. Grounded Low Voltage (GLV)
    a. Safety Loop
    b. GLV Power
    c. VCI
    d. TSI
5. Panel Drawings and Hubs
6. **GLV BOM and Budget**



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GLV Purchased Materials

Description	Vendor Part Name	Quantity	Unit Price	Total Price
Te-Connectivity 2 pin/1 row parallel	1-480699-0	4	$0.28	$1.12
Te-Connectivity 2 pin/1 row free	1-480698-0	4	$0.28	$1.12
Te-Connectivity 3 pin/1 row parallel	1-480701-0	6	$0.28	$1.68
Te-Connectivity 3 pin/1 row free	1-480700-0	6	$0.27	$1.62
Te-Connectivity 8 pin/2 row parallel	794954-8	4	$0.25	$1
Te-Connectivity 8 pin/2 row parallel	794953-8	4	$0.25	$1
Te-Connectivity pin	350561-3	10	$0.14	$1.38
Te-Connectivity socket	350570-3	10	$0.13	$1.32
24V DIN Rail DC/DC Converter	TCL 060-124 DC	1	$80.62	$80.62
DIN Rail DC/DC Converter	STMGFS152405-N2	1	$69.05	$69.05
36vdc PFC Power Supply	HRP-200-36	1	$64.80	$64.80
DIN Rail	277-2064-ND	1	$9.82	$9.82
DIN Rail Terminal Blocks	APC1281-ND	50	$1.33	$66.63
SWITCH PUSH SPST-NO	CWI282-ND	1	$4.12	$4.12
SWITCH KEYLOCK SP3T	KO129B606-ND	1	$9.80	$9.80
DIODE SCHOTTKY 45V 7A	SB15H45-E3/73GITB-ND	5	$1.36	$6.80
LED RED 1/4" HOLE 5V	L10021-ND	5	$2.17	$10.85
Relay 5A 5V	Z2774-ND	10	$1.18	$11.78
18-75v dc dc converter	MKW2633	1	$28.92	$28.92
24-12 DC DC converter	MKW1033	1	$30.57	$30.57
Panel Drain, Line 3, Grey	44W4361	2	$49.35	$98.70
Line Source, Line 3, Grey, 400A	44W4352	1	$58.17	$58.17
Panel source, earth, green, 400A	44W4363	1	$49.35	$49.35
Panel Mount Ethernet Extension	909	1	$4.95	$4.95
Panel Mount USB Cable	908	1	$3.95	$3.95
			Grand Total	$619.12

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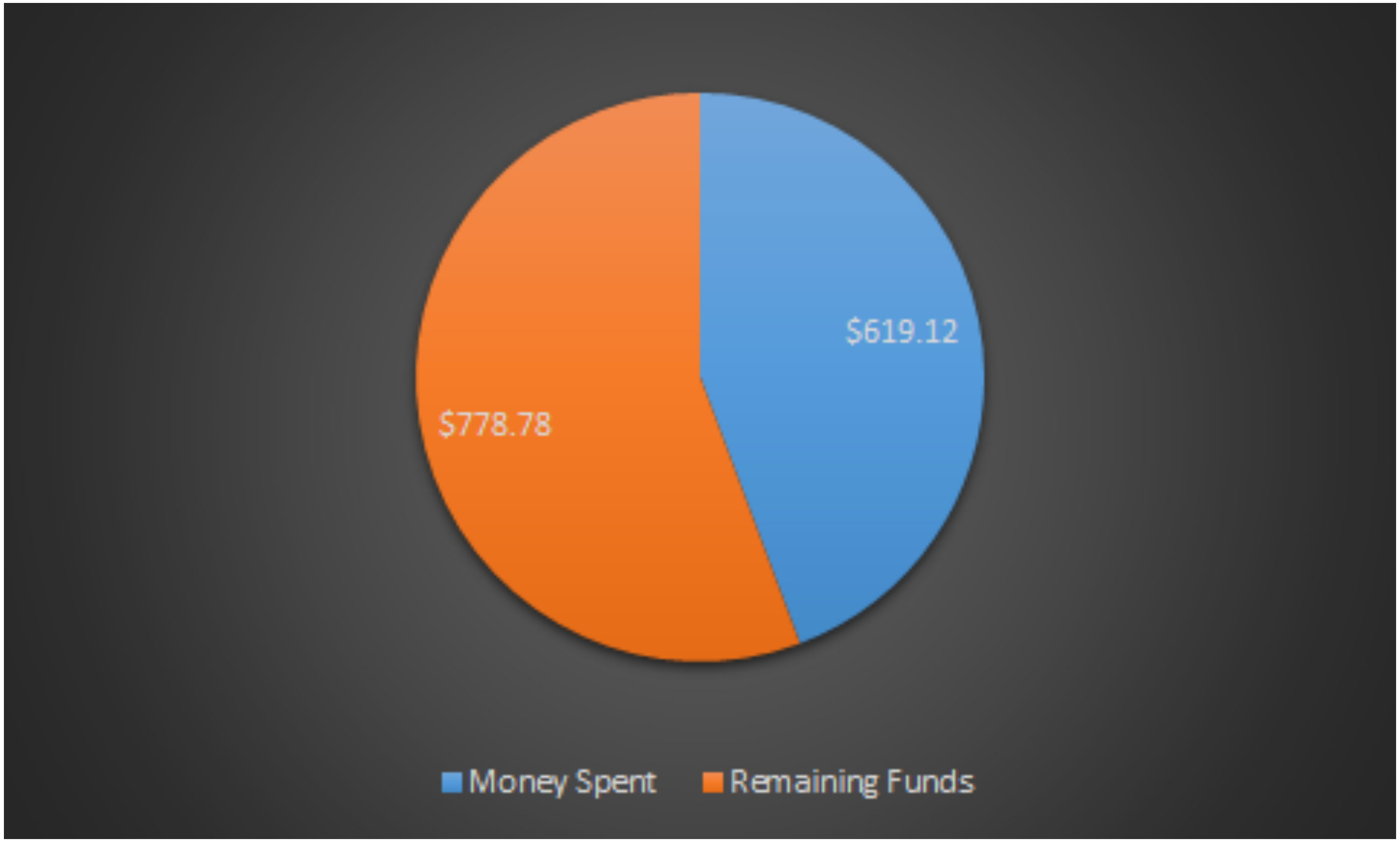
GLV Budget



Total Allocated Funds - $1397.90

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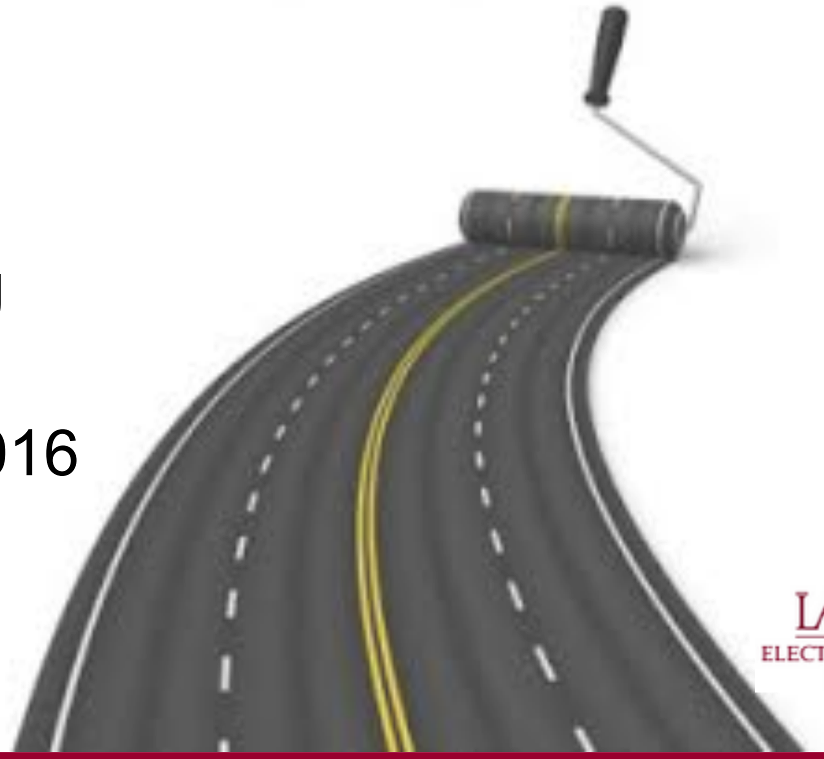
Roadmap Cont.

7. **Tractive System Voltage (TSV)**
   a. **Overview**
   b. Safety
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. Acceptance Testing
   i. Maintenance
8. Out of Scope: LFEV-2016
9. Conclusion



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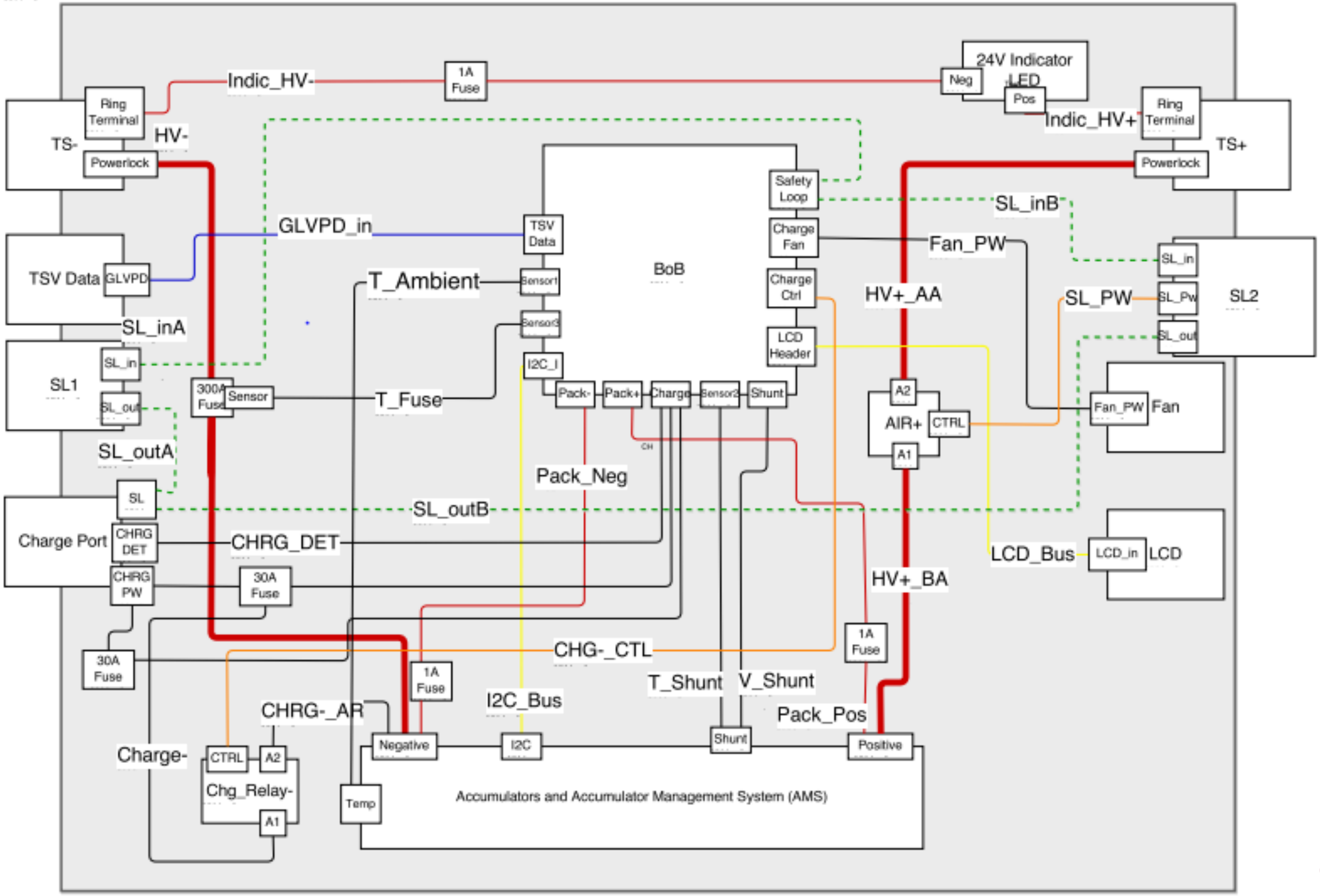
Tractive System Voltage (changed)

TSV Pack



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Main subsystems

- **Accumulator Management System (AMS)**
- **Breakout Board (BoB)**
  - Microcontroller
- **Seven 3.2V 60A-hr LiFePO4 Cells**

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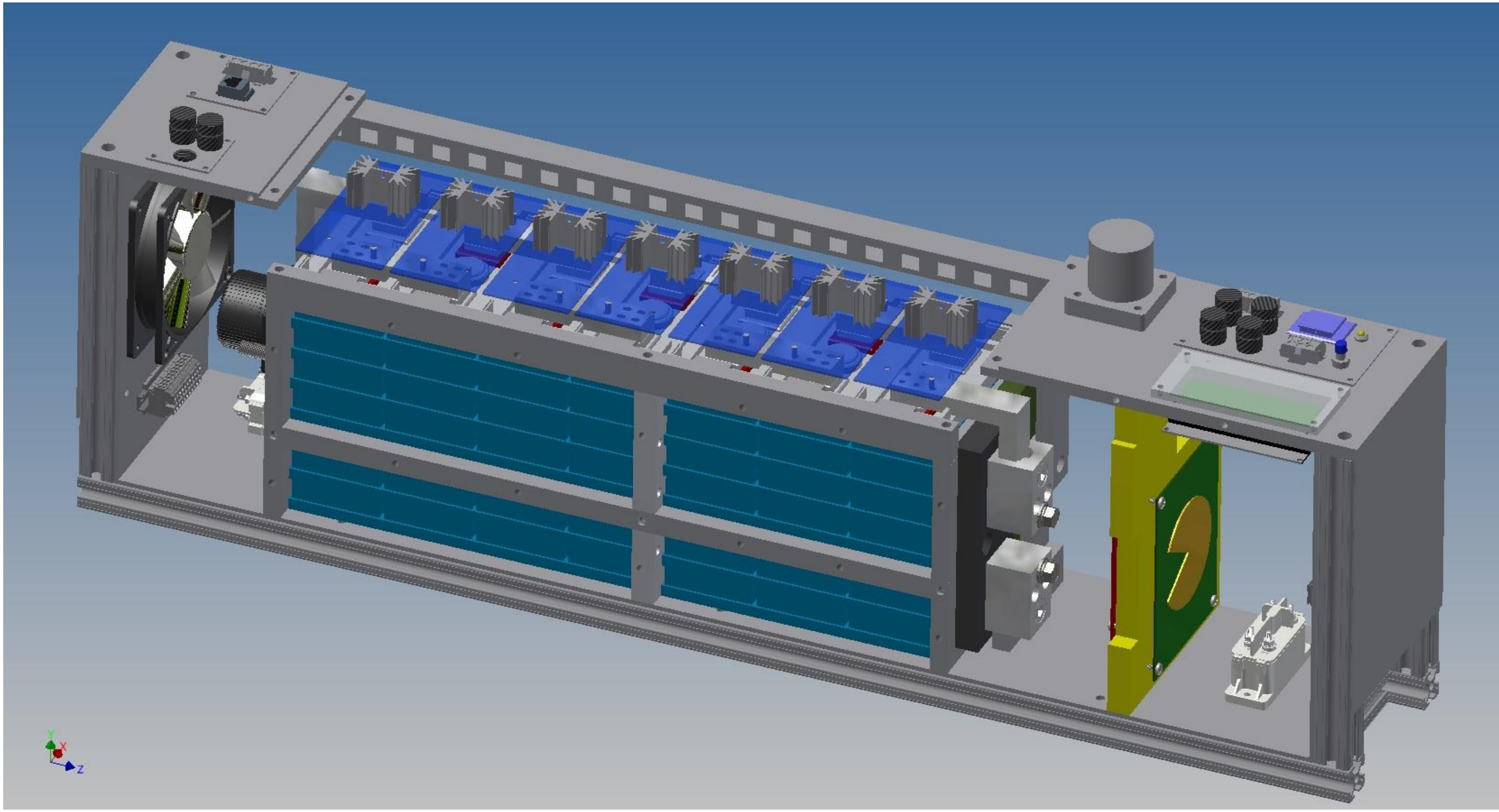

Y
X
Z

Roadmap Cont.

7. Tractive System Voltage (TSV)
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TSV - Safety

- Fusing
  - 2 fuses for BoB
  - 1 large fuse for pack main current path
  - 1 fuse for charge relay
- Voltage present LED
  - turns on when voltage > 20V DC present at poles
  - can sustain voltage up to 96V
  - utilizes resistor to act as fuse
  - works even when a cell fails with all other packs connected
- Safety protocols

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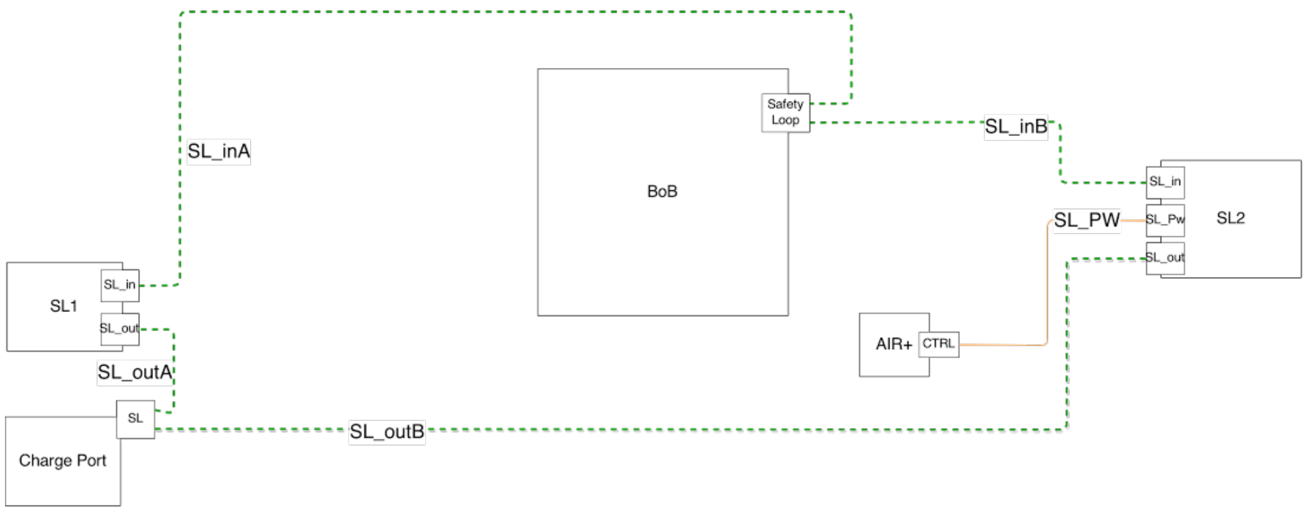
Pack Safety Loop

- One port at each end of the pack
- Each contains safety loop and SL 24V/GND
  - SL 24V/GND used to power AIR
- Safety path:



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High Voltage Interfaces

- 4 “Danglies” one per pack
  - 400A rated Newark 44W4352
  - Source Hangs off of pack with cable to + terminal
- 4 Panel mount female connectors
  - 400A rated Newark 44W4361
  - Connected to - terminal bus bar

http://www.newark.com/itt-cannon/nls-3-gy-s120-m40a/line-source-line-3-grey-400a/dp/44W4352

http://www.newark.com/itt-cannon/npdft-3-gy-l-t4/panel-drain-line-3-grey-400a/dp/44W4361

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Roadmap Cont.

7. Tractive System Voltage (TSV)
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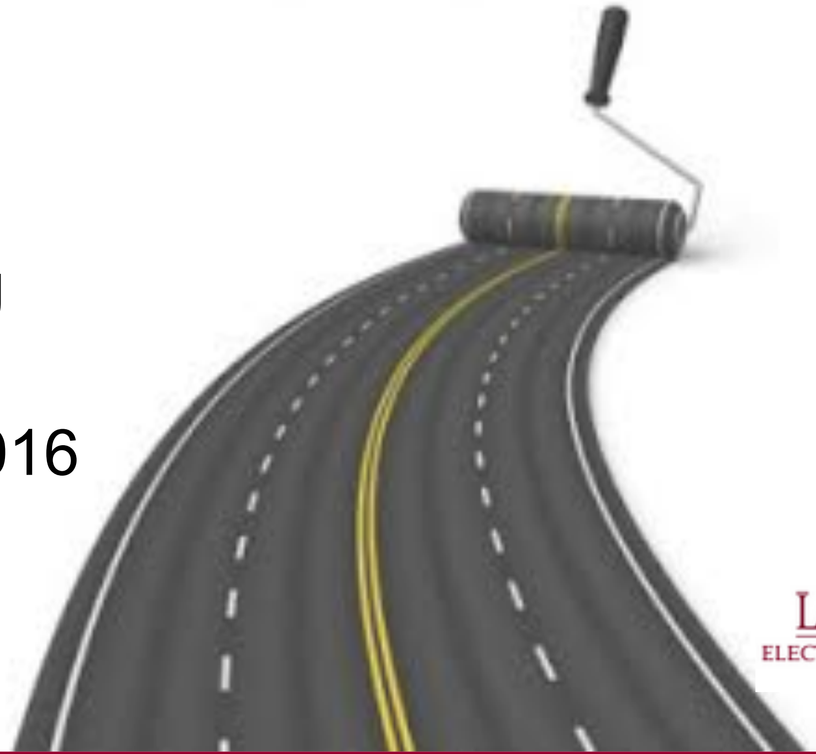

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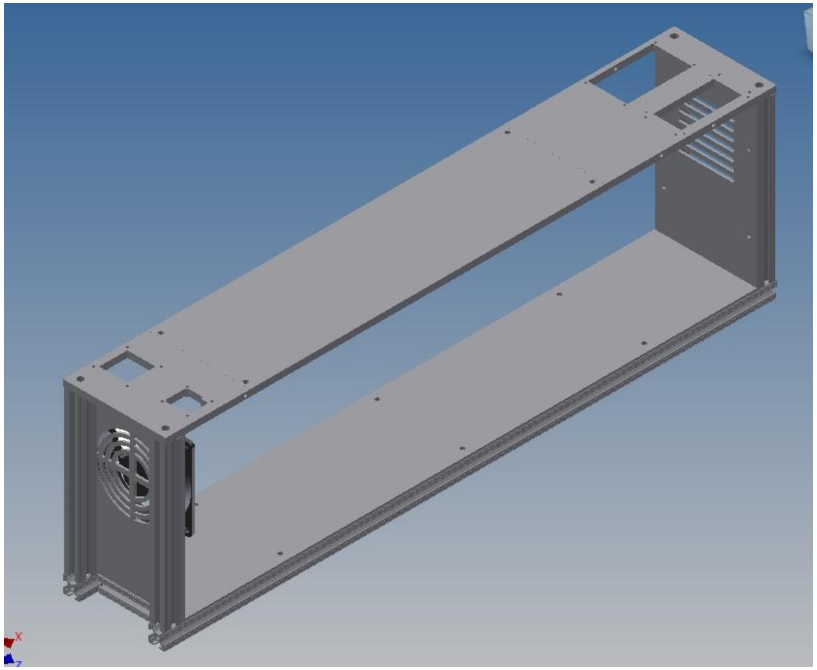
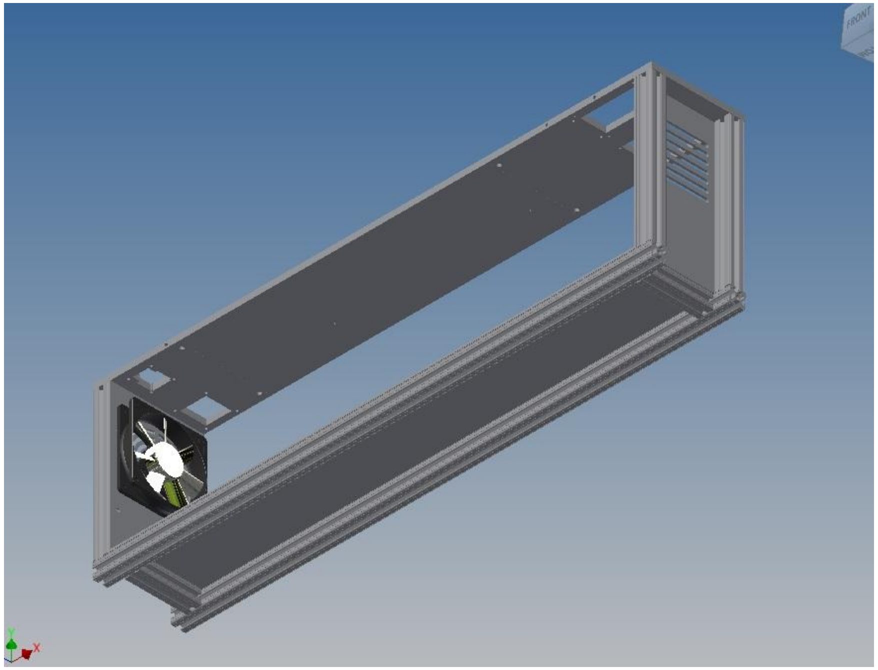
Mechanical Objectives

- acceleration requirements
- splash proof
- internal wall
- vibration
- galvanic isolation

Mechanical- Frame/External Casing

- Rigid 8020 Aluminum External Frame





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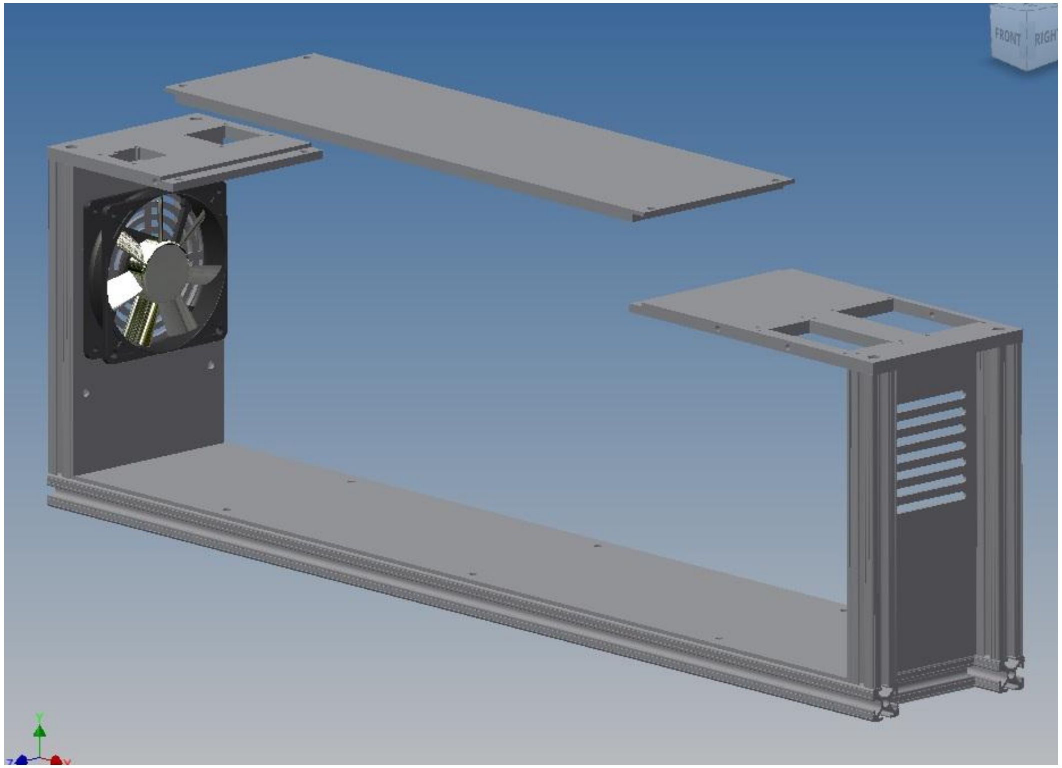
Mechanical- Frame/External Casing

- Removable Top For Quick Battery/BMS Access



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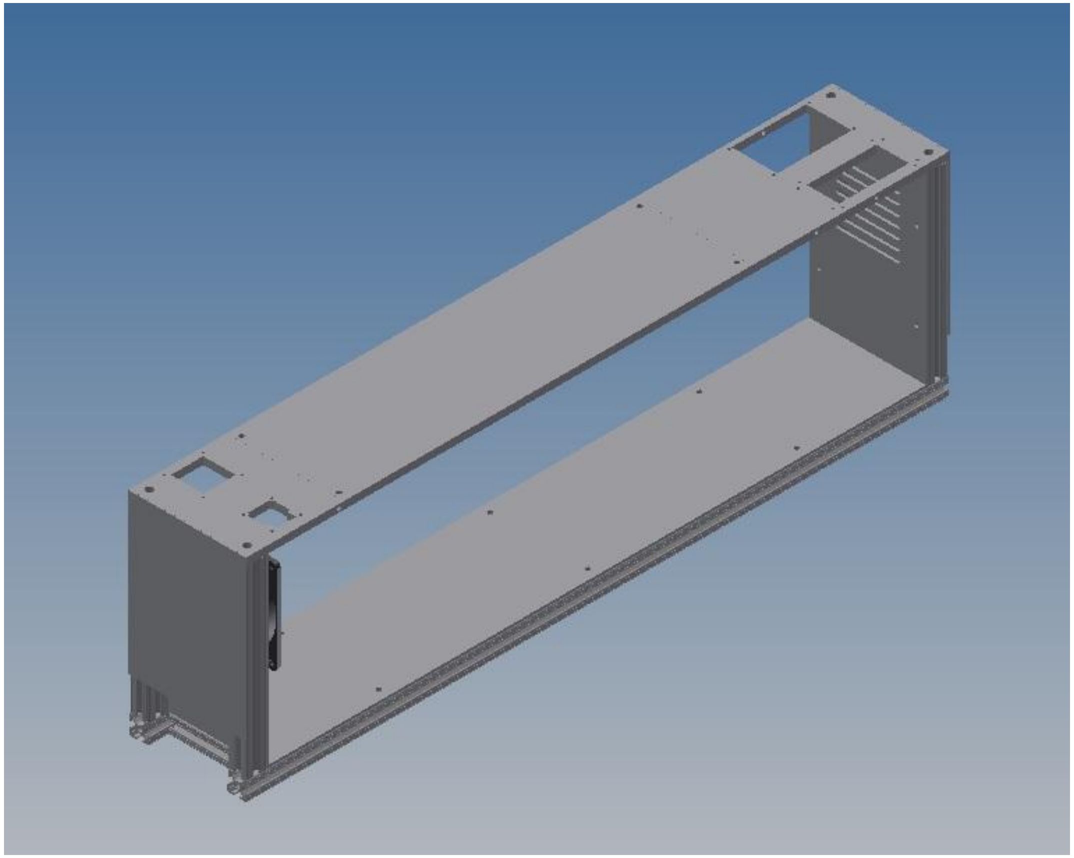
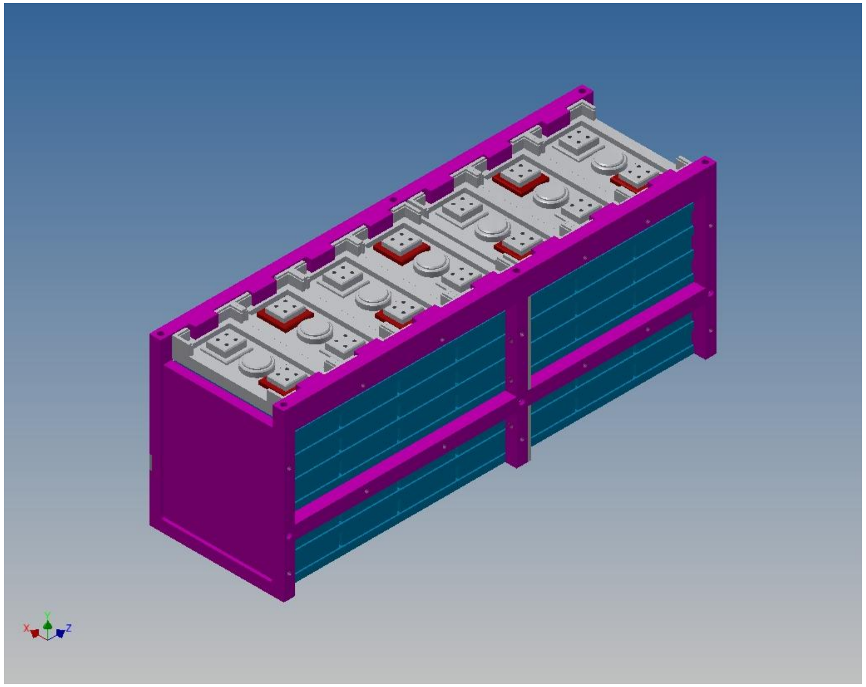
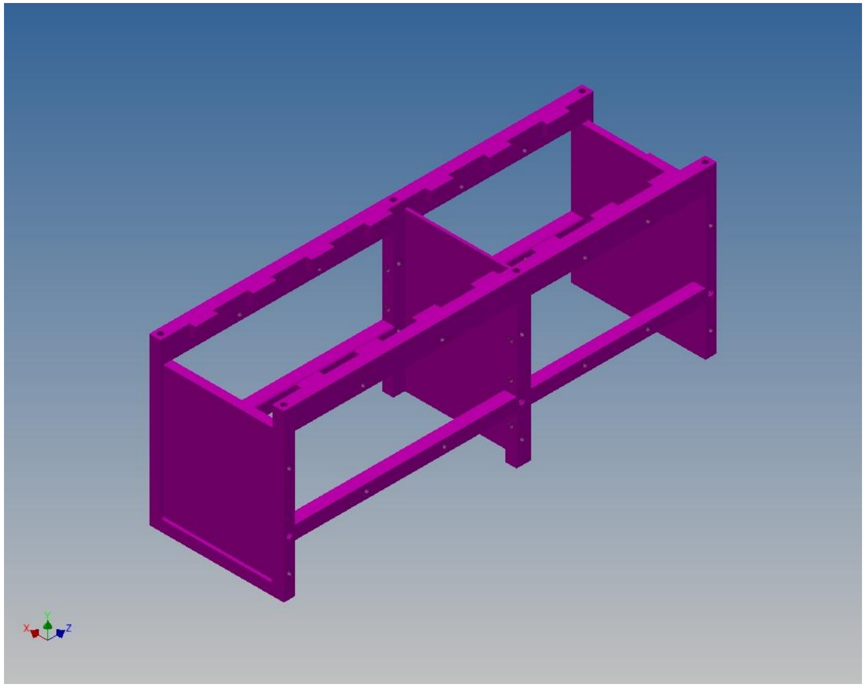
Mechanical- Frame/External Casing

- Splash Resistant Ventilation



Cell Restraint





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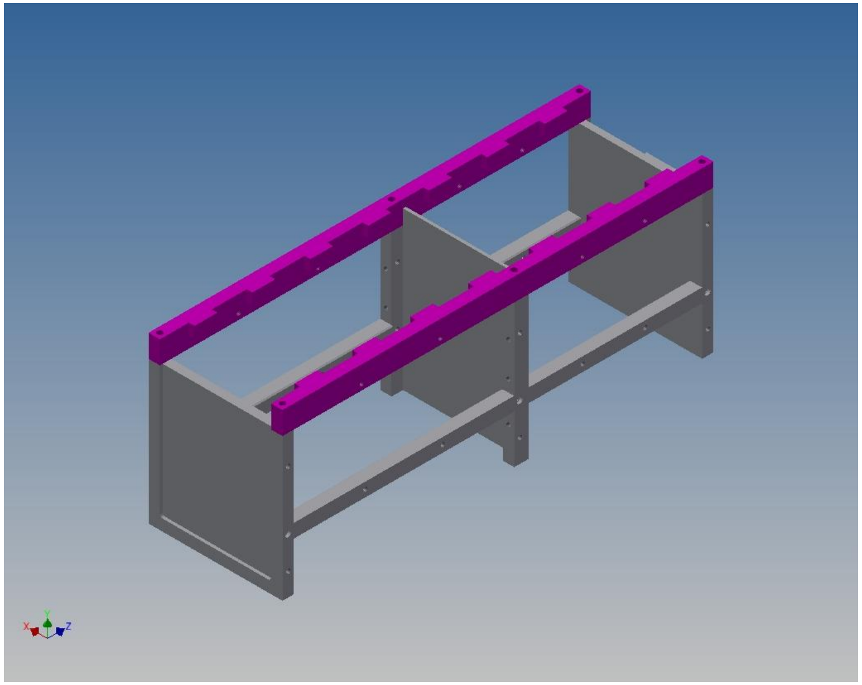
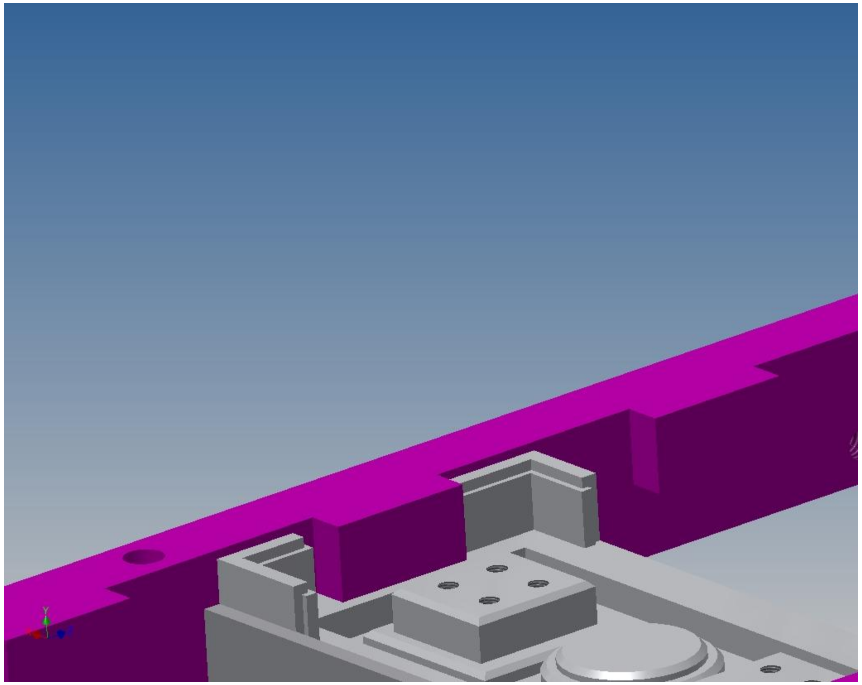
Top Bars





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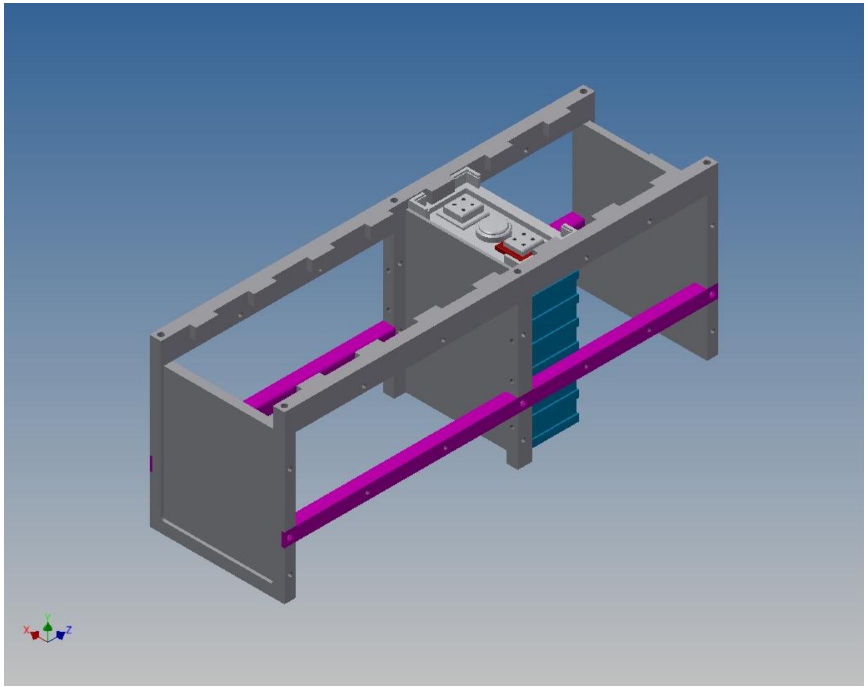
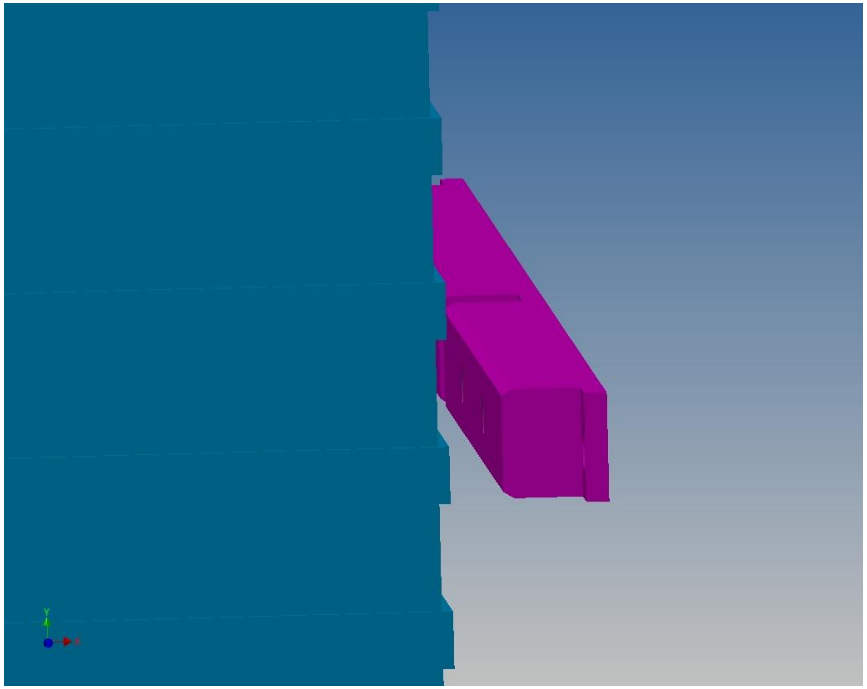
Side Bars





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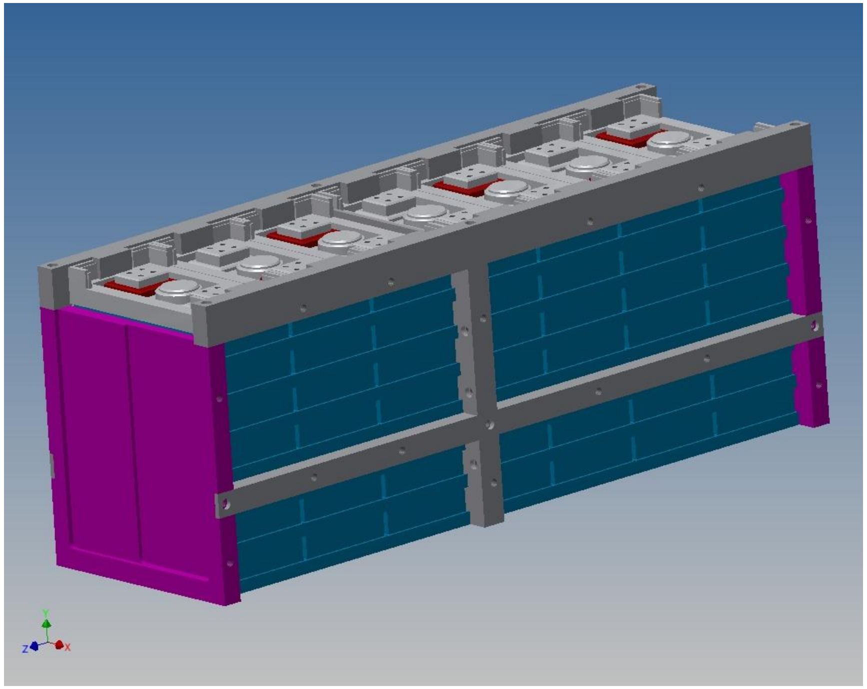
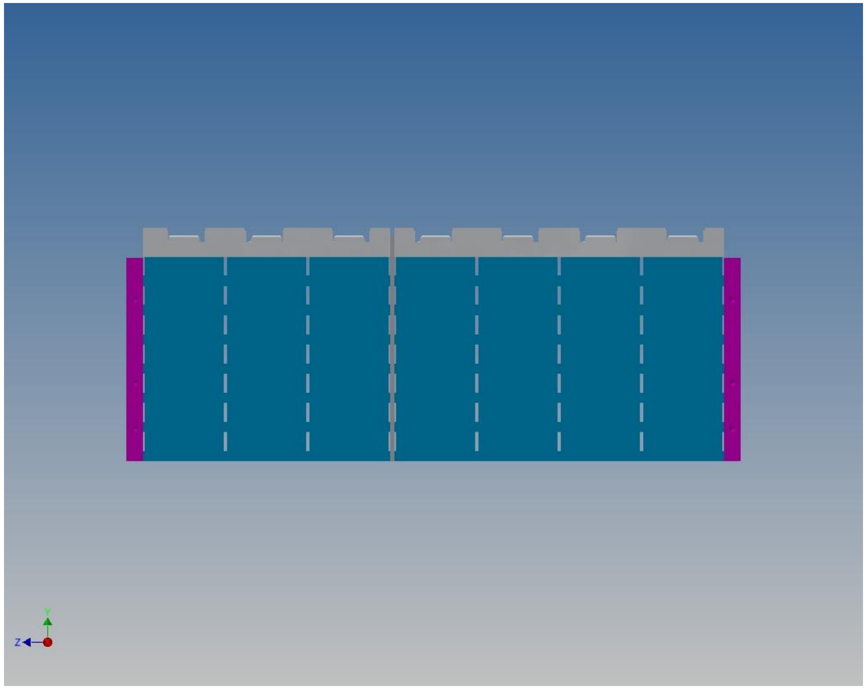
End Plates





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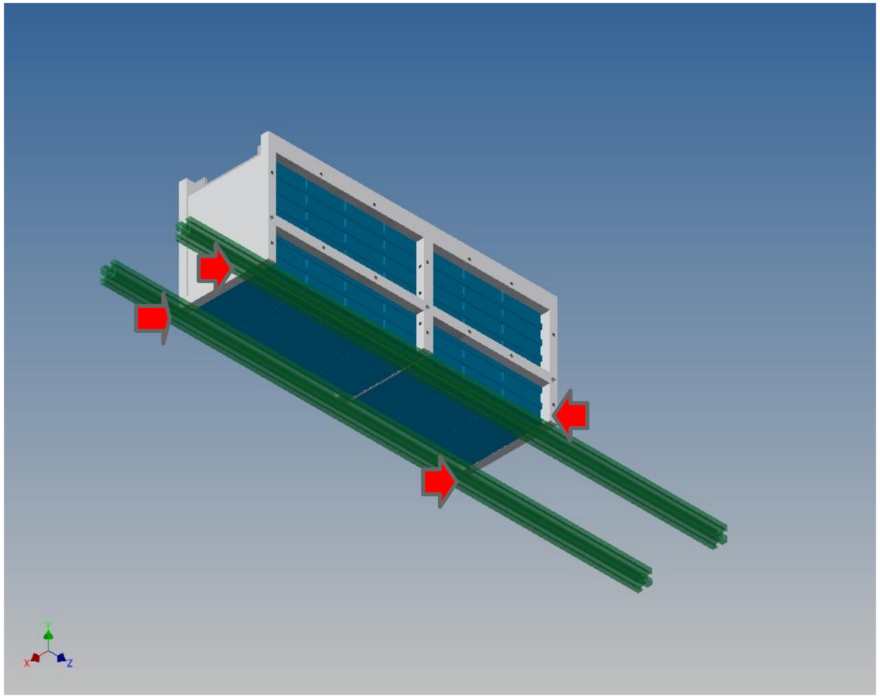
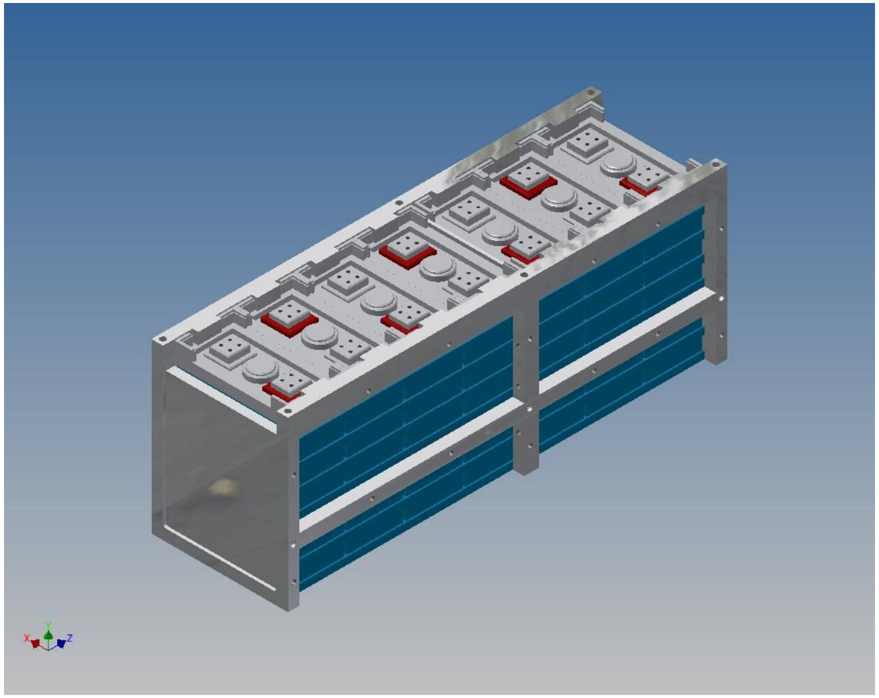
Integration with Container





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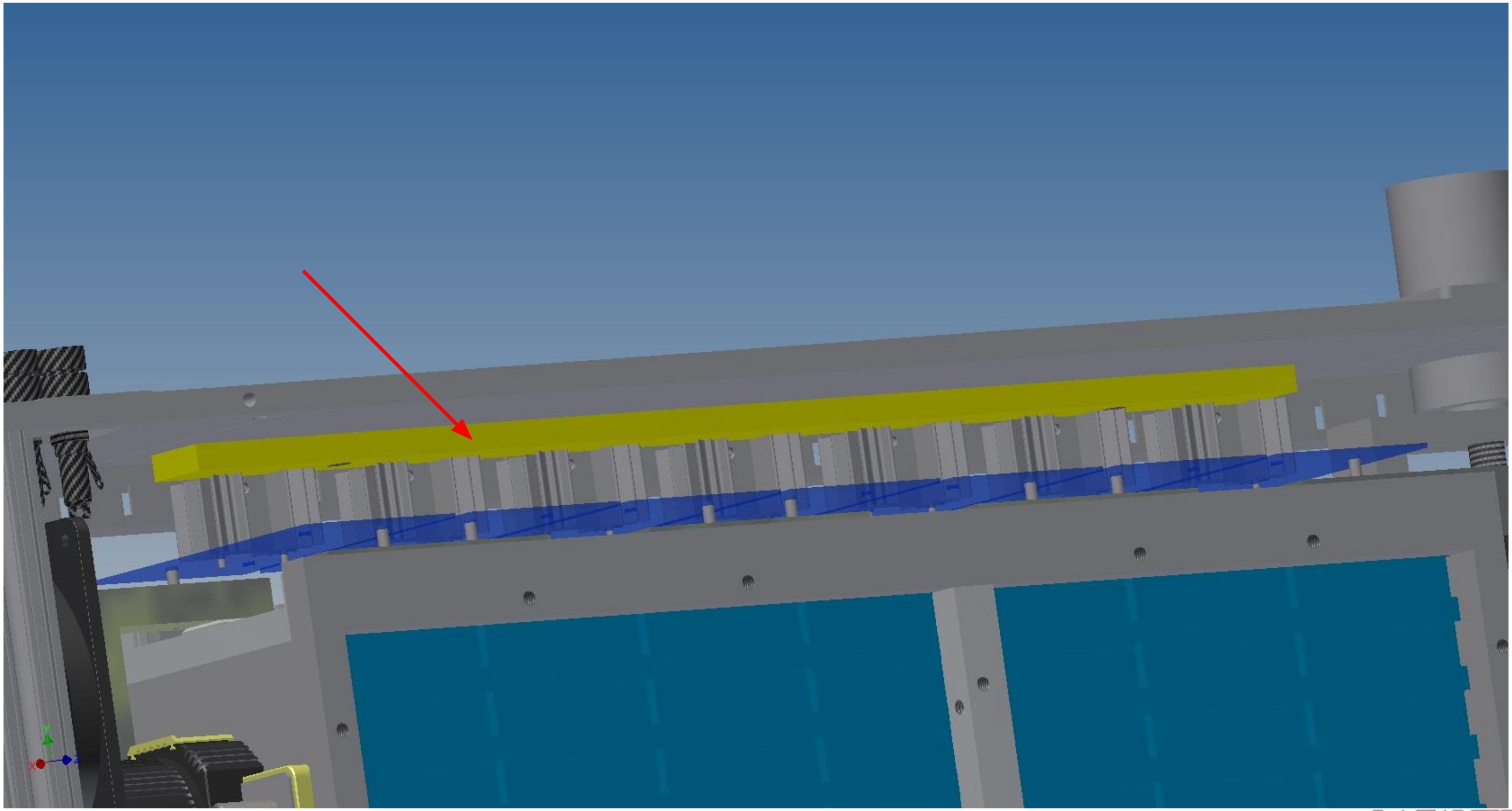
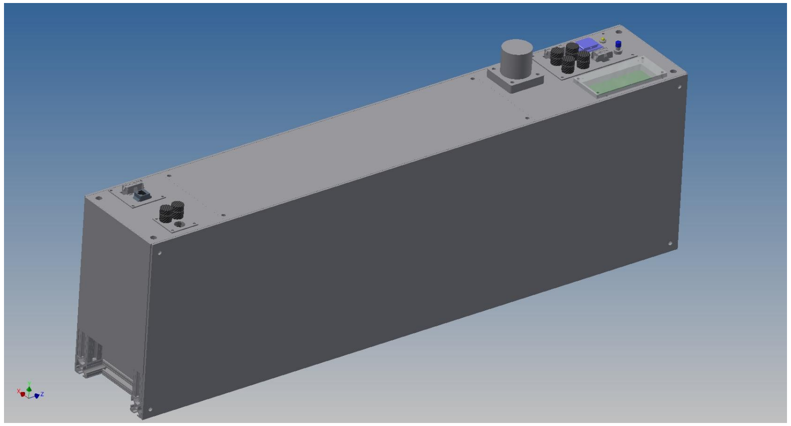
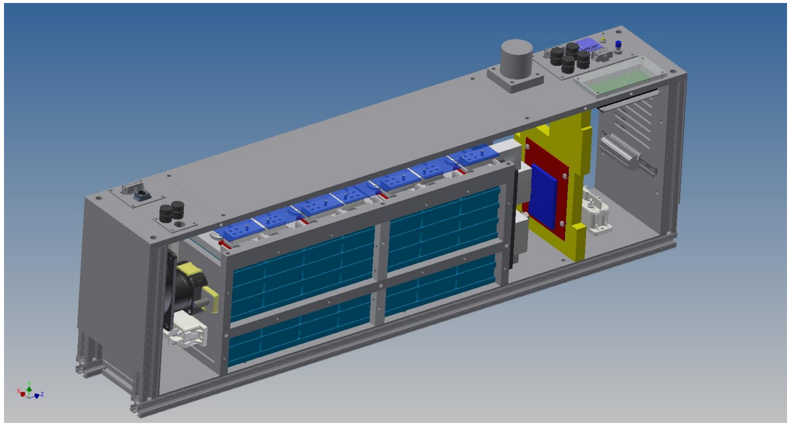
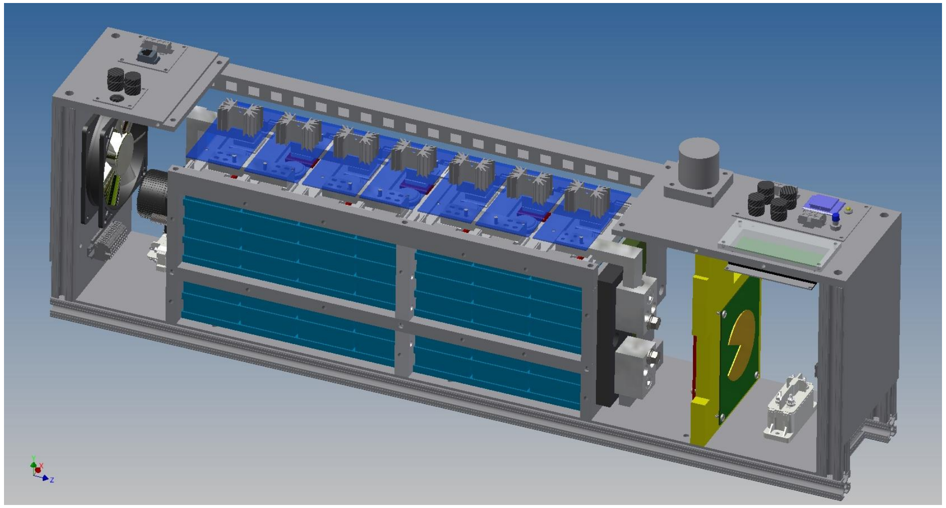
BMS Restraint



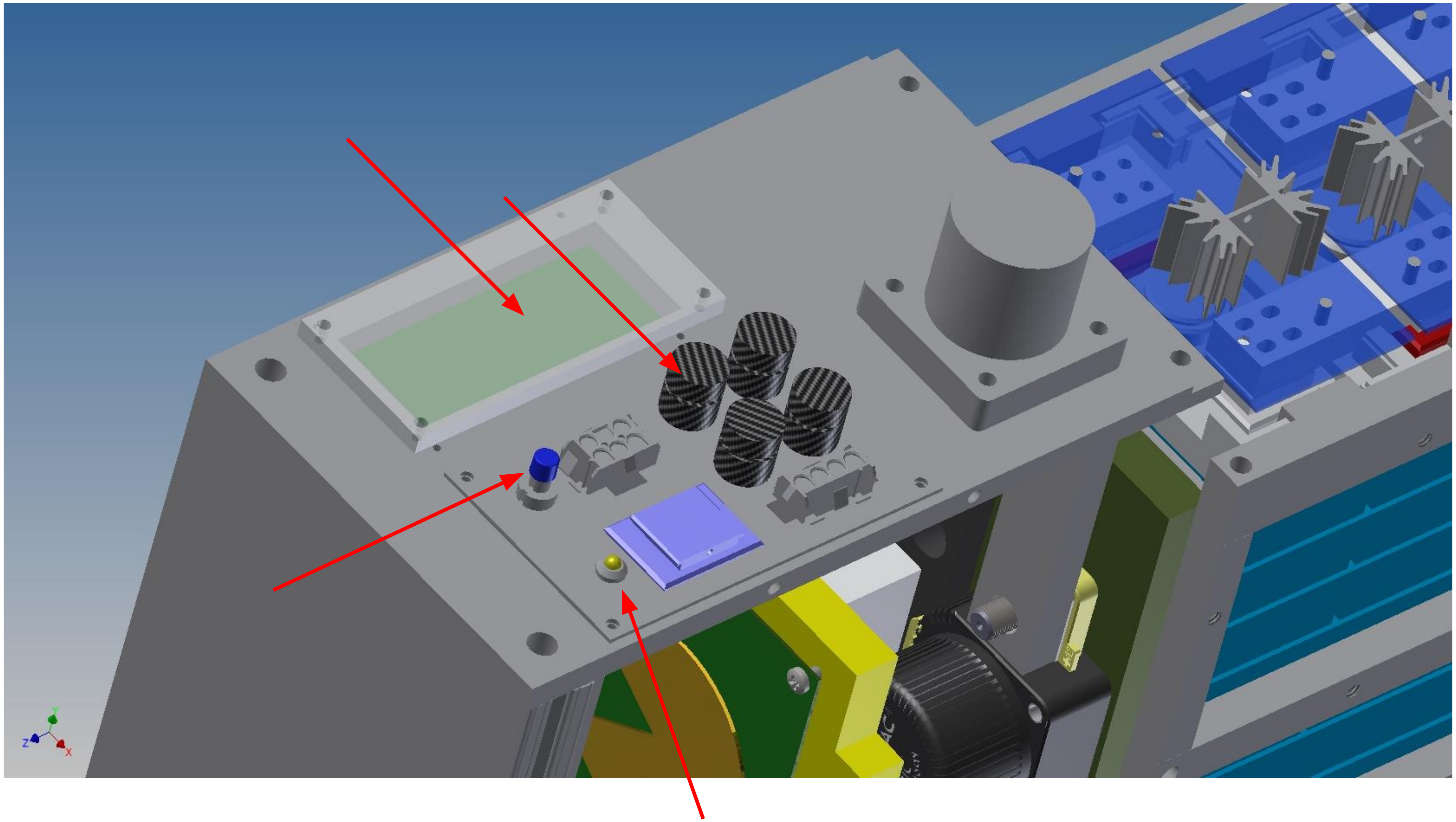
BMS Removal







Added Components



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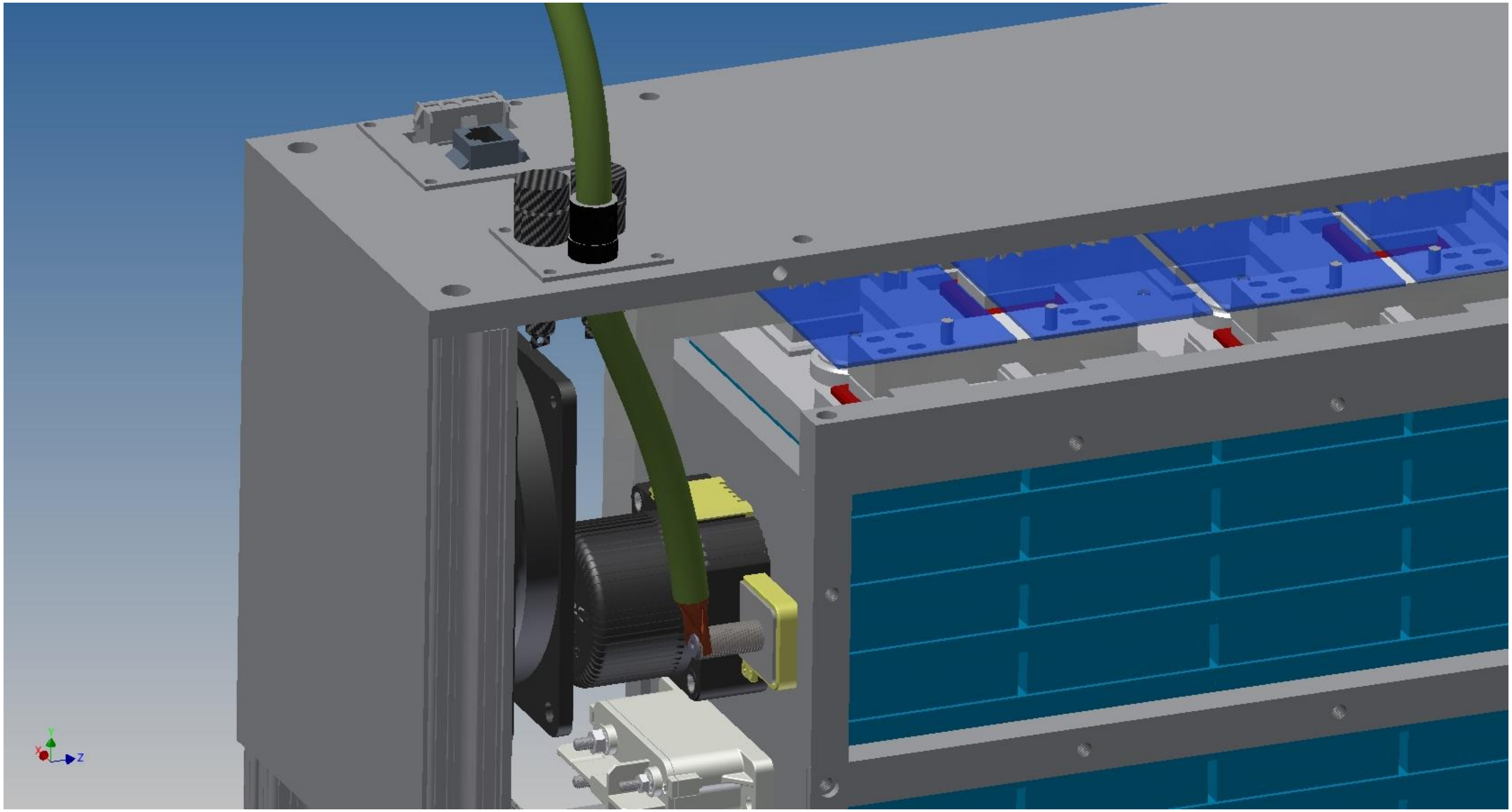
Free Terminal



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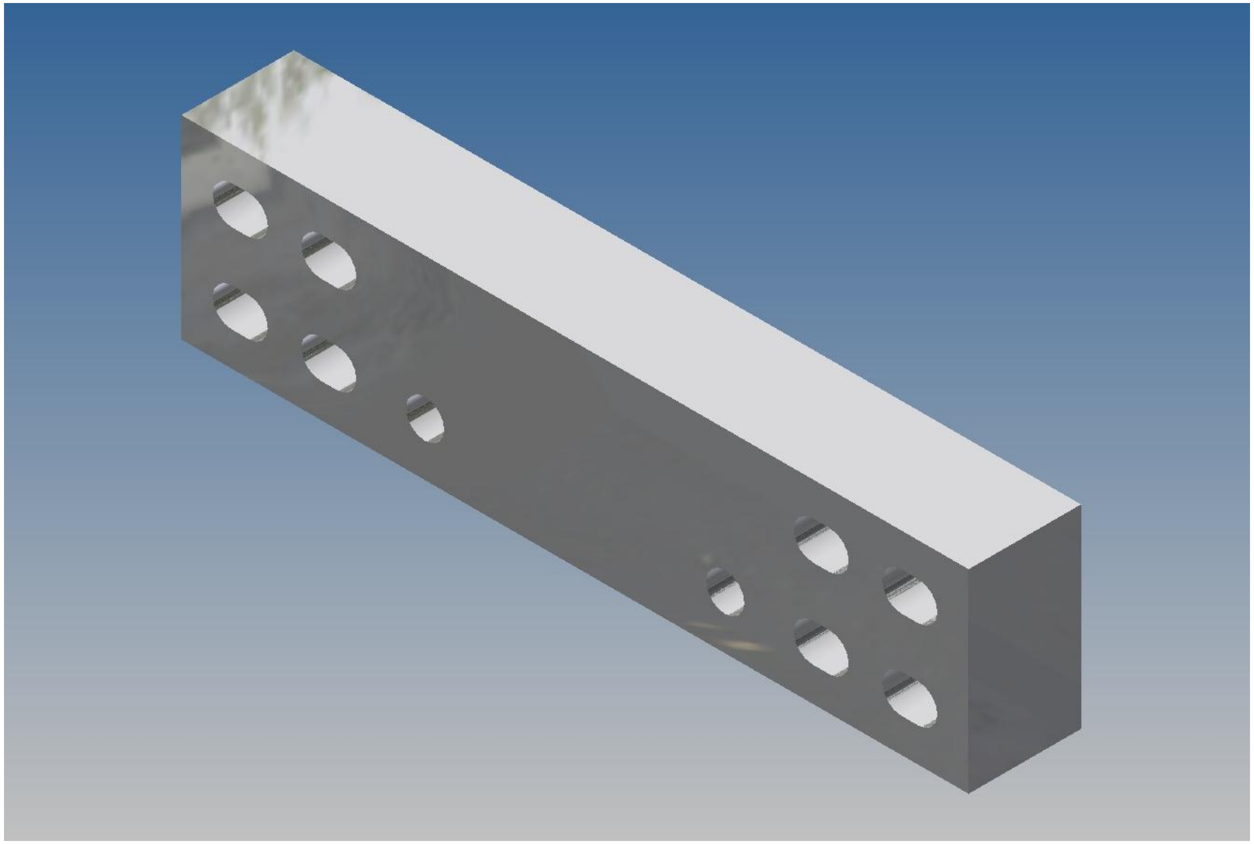
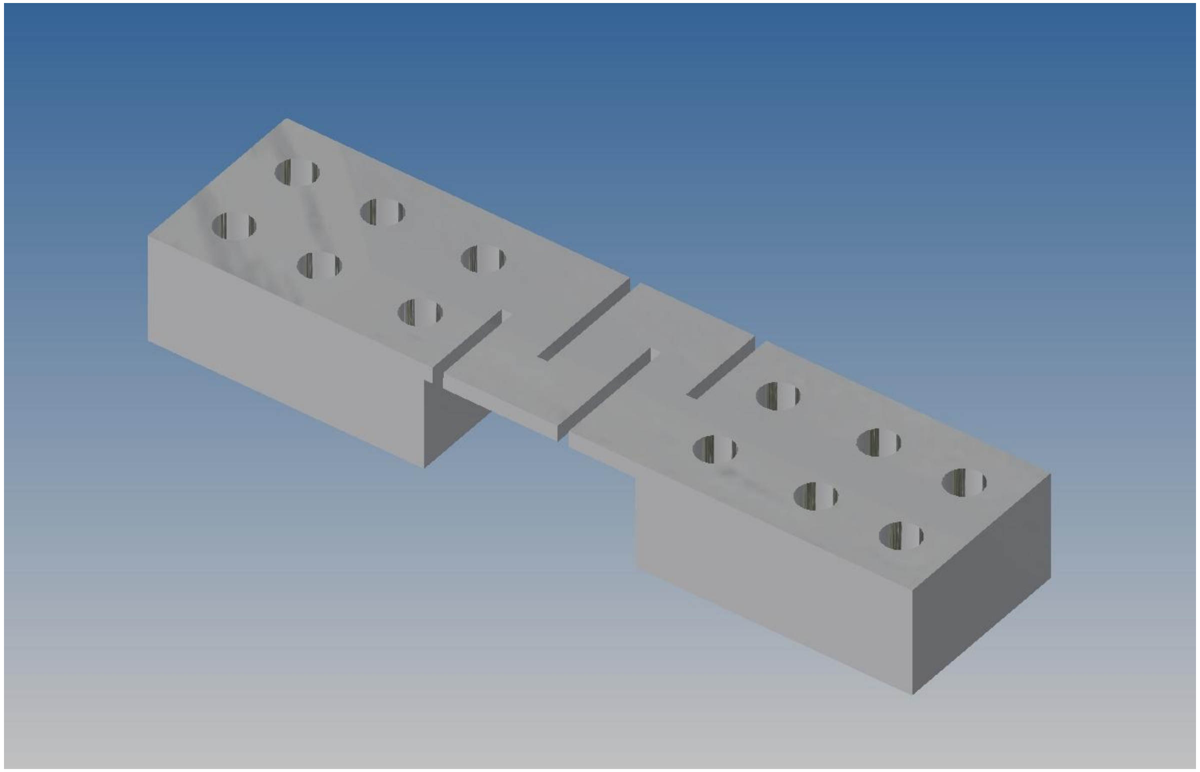
Mechanical - Conductor Bars

- Carries large current
- Low resistance



Mechanical - Current Measuring Shunt

- Special conductor used to measure current
- 118µΩ at STP



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Roadmap Cont.

7. Tractive System Voltage (TSV)
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PacMan System (changed)

- Receives and processes data from AMS
    - I^2C protocol
- Receives and processes pack sensor data
- Opens BoB safety loop
- CAN communication with VSCADA
- Implement charge and forget charging

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Microcontroller (added)

http://au.rs-online.com/web/p/microcontrollers/7153748/

Atmel
AT90CAN32

Microcontroller Hardware Specs (changed)

- 8 ADC channels
- Watchdog
- I^2C bus for AMS and LCD communication
- CAN bus for VSCADA interface
- Datasheet: http://www.atmel.com/Images/7679S.pdf

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PacMan Software (changed)

- AVR architecture
  - Significant refactoring of 2014 team’s code
- Updates from 2014 team’s code
  - Correct State of Charge algorithm
  - Reboot should not invalidate state of charge
  - Temperature adjustment for current-measuring shunt
  - Change charge logic
- CAN communication with VSCADA

LCD Display

- 4 screens on LCD display
  - “PacMan 2015”: name of the program, etc
  - “Pack Status: (Dis)charging. SoC:XX% C: XX, V: XX.XX”
  - “Cell SoC: [1]:XX% [2]:XX% [3]:XX% [4]:XX% [5]: XX% [6]:XX% [7]:XX%”: individual cell state of charge information.
  - “EXX: (error message)”: any error message about the pack or individual cells

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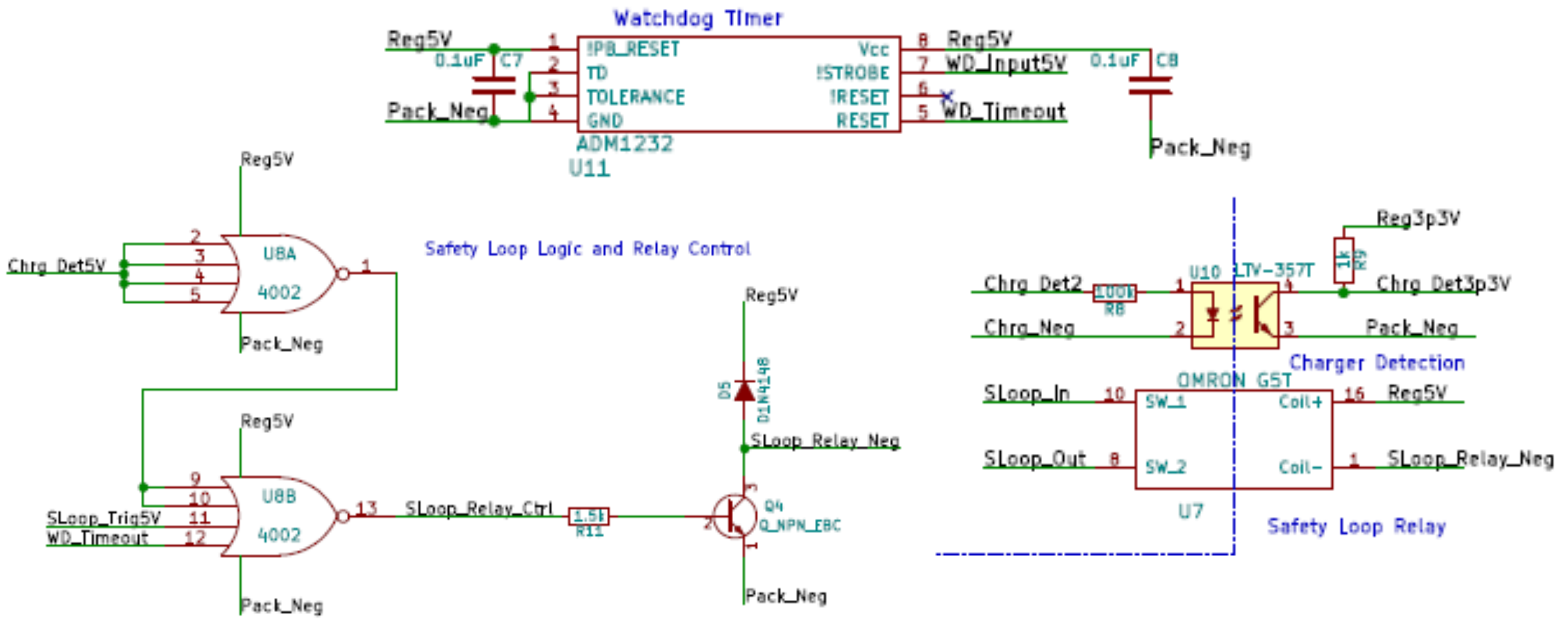
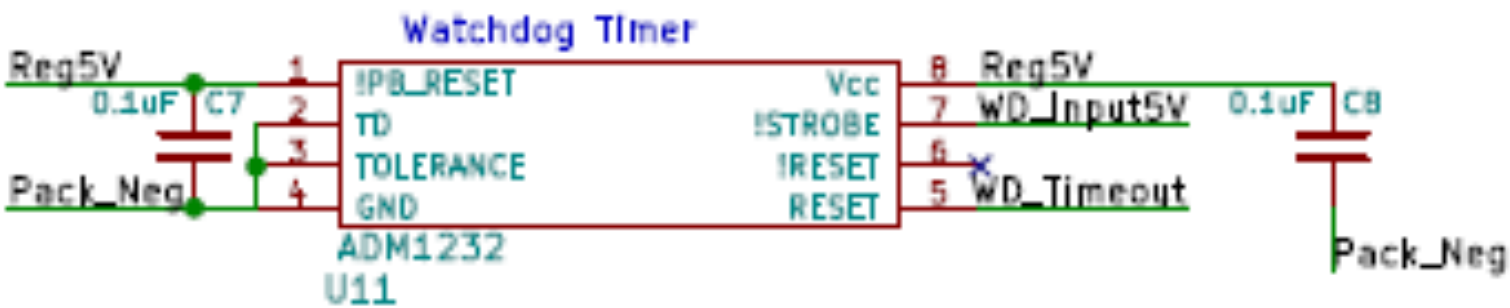
PacMan Safety Loop Control (changed)

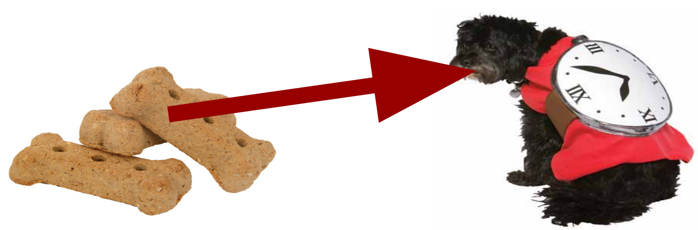
- Safety loop opened in 3 different ways
  - Charger plugged
  - Watchdog timeout
  - Microcontroller software error detection



Watchdog (changed)

- Watchdog fed by microcontroller output
- ADM1232 used
  - Typical timeout of .6s





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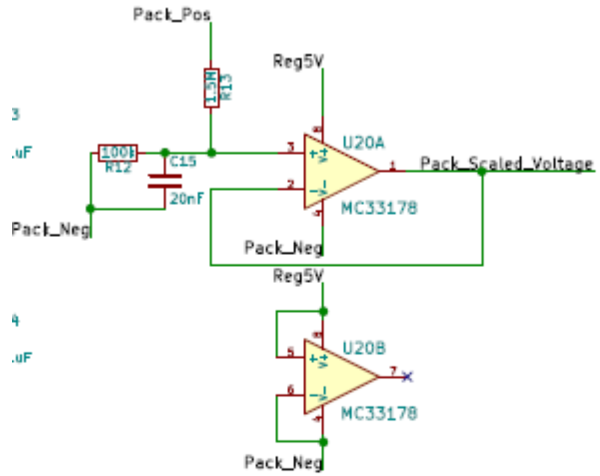
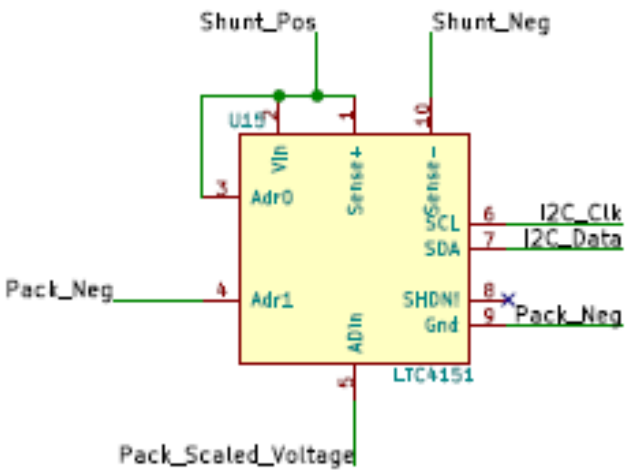
Sensors - Pack Voltage and Current

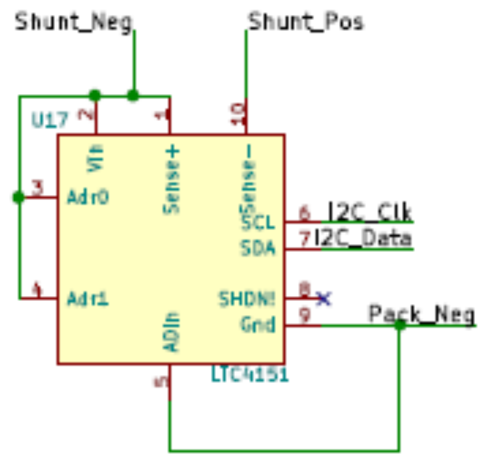
- Scales pack total voltage and uses it as input to ADC pin on LTC4151.
- Senses current through the voltage across current measuring shunt
  - Input to other LTC4151
- Pac man receives the value via I^2C



Pack Voltage Scaler



Pack Voltage Microcontroller



Pack Current Microcontroller

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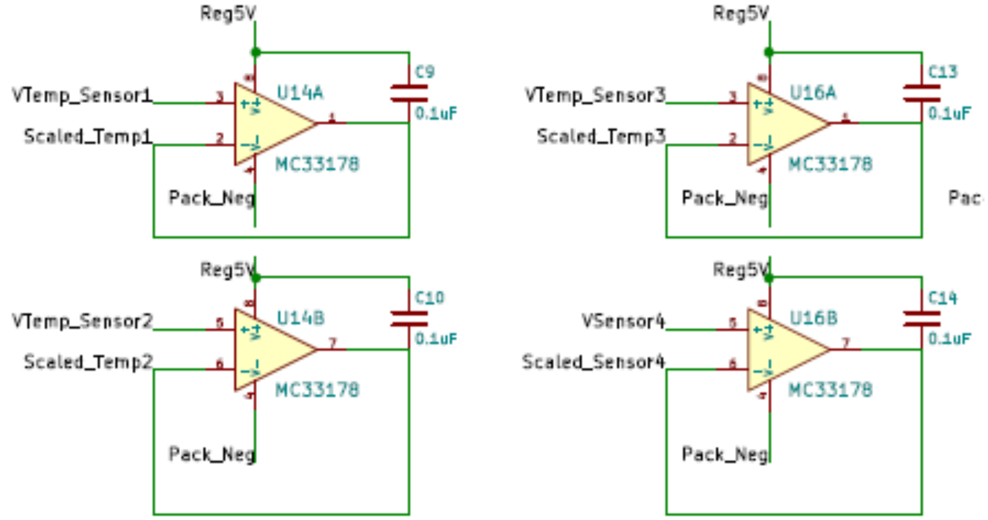
Sensors - Temperature (changed)

- Temp sensors on AMS
- Temp sensor around pack
  - One monitors high current path fuse
  - One monitors shunt
  - Last monitors ambient
- Use shunt temperature to correct resistance



Pack Temperature Sensor Scaling Block

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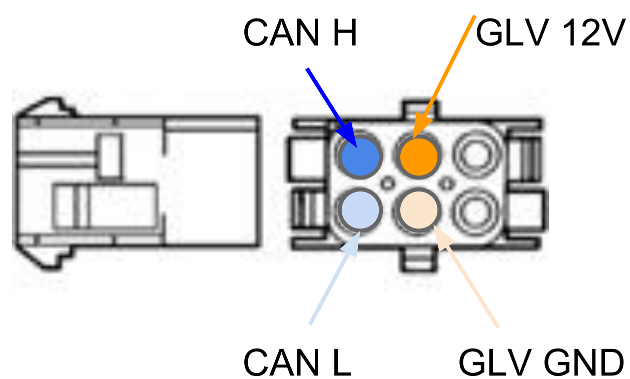
VSCADA CAN Interface

- No longer RS-485, new isolated chip
- All 4 packs on the same main CAN line
- When address prompted, will return all relevant data to VSCADA



http://www.mouser.com/ProductDetail/TE-Connectivity-AMP/1-480705-0/?qs=OSEowtgdlxJxrUuPTLeZpA%3D%3D

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Roadmap Cont.

7. Tractive System Voltage (TSV)
    a. Overview
    b. Safety
    c. Mechanical
    d. PacMan System
    e. **Charging**
    f. AMS
    g. BoB
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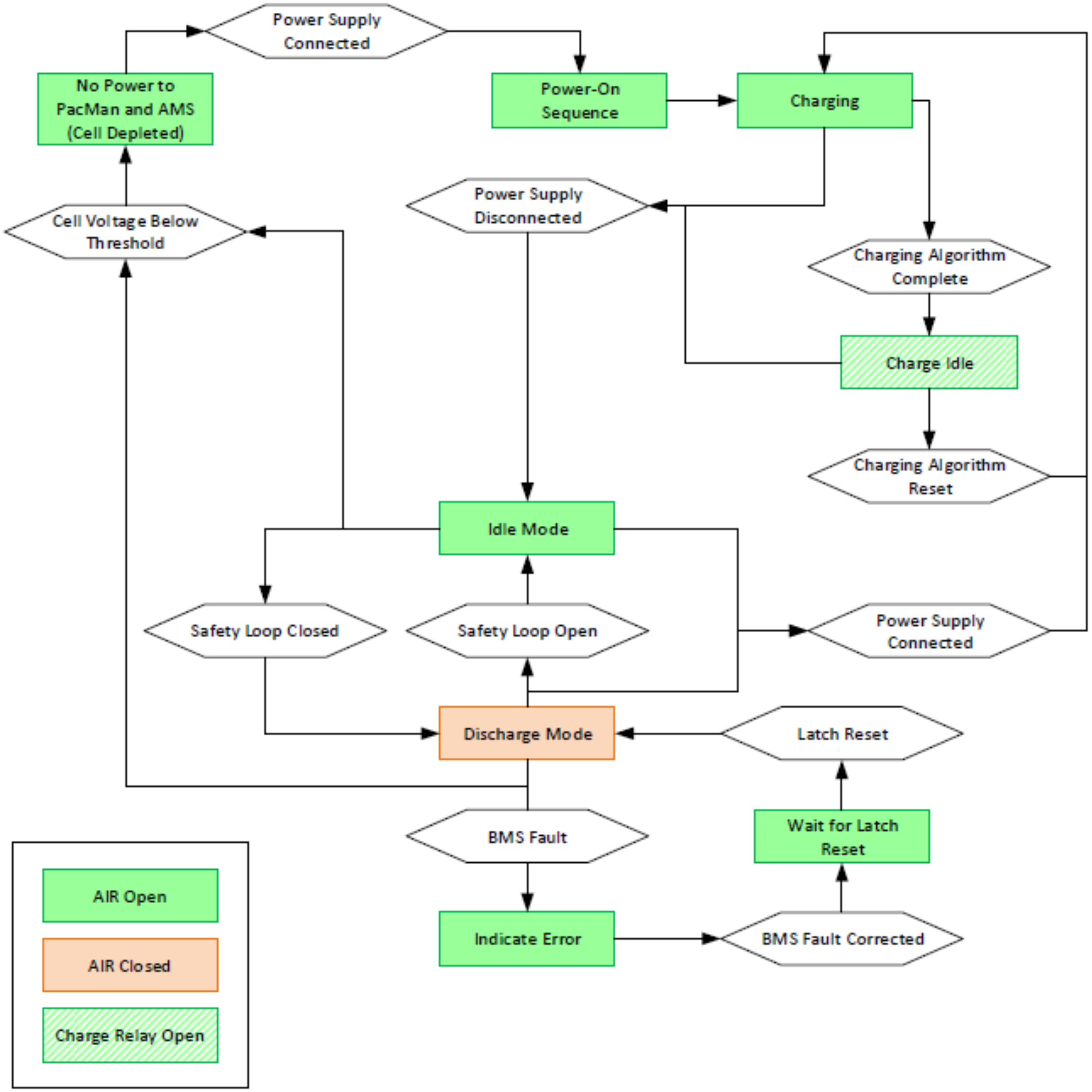
Pack State Diagram



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Charger-GENESYS 750W Half-Rack

http://www.testoon.com/images_produit/009789-full.jpg

http://sites.lafayette.edu/ece492-sp14/files/2014/02/LFEV-ESCM-2014-UsersManual.pdf

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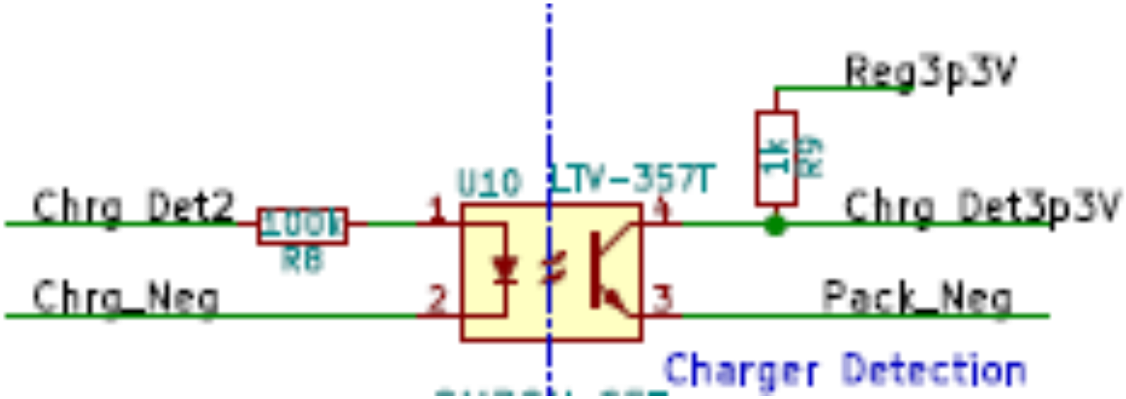
Charging (changed)

- Anderson PowerPole connector used
  - Charge Detect to microcontroller through optoisolator
  - Charge +/-
    - Charge +/- go to charge relays
  - Safety Loop
    - Open when charging plug is plugged in
    - Closed when dummy plug is in charge port

Charge Detect (changed)



- Charger creates electrical connection between CHRG_DET1 and CHRG_DET2
  - Pulls microcontroller pin high through optoisolator

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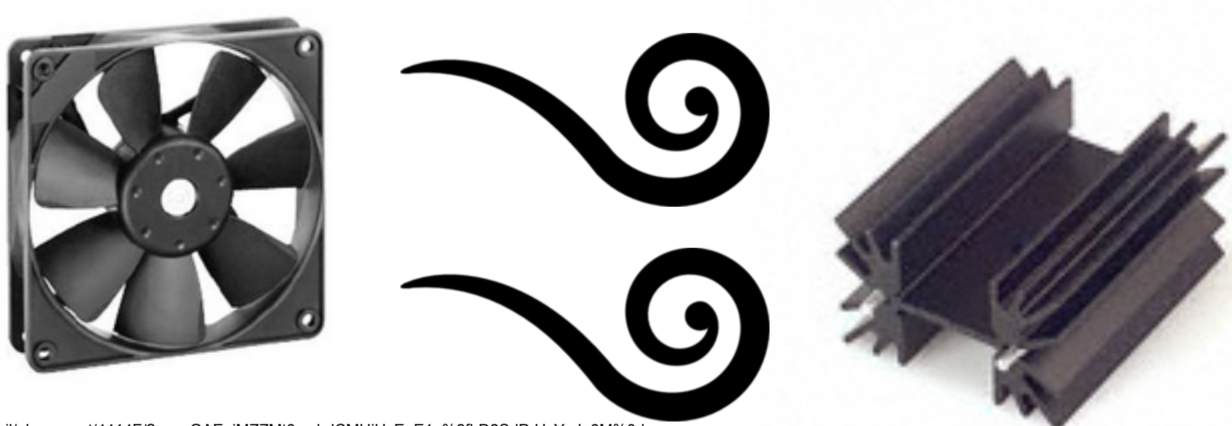
Cooling

- When bypassing cells, they get HOT
- When charger is plugged, fan switches on
  - Fan powered by charger to not deplete batteries
- Reducing heat sink to half height
  - Thermal resistance now 3.7 ℃/W @ 200 LFM
  - With 10.2W power, 37.74 ℃ rise



http://www.mouser.com/ProductDetail/ebm-papst/4414F/?qs=sGAEpiMZZMt8mcbdCMUjUxEnE1a%2fhD2SdPrUzYqJg8M%3d

http://www.digikey.com/product-detail/en/657-20ABP/345-1035-ND/340333?WT.z_cid=ref_octopart_dkc_buynow&site=us

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Charge Relays (changed)

- We will be using a normally closed charge relay
  - This fixes previous error where pack was unchargeable when depleted
  - Allows low-current devices to be powered from charge port
- Charging is finished when all AMS bypass
  - Microcontroller signals CHRG_TRIG to optoisolator for charge relays to open when charging is finished
- Using relay - OMRON MGN1C-DC24
  - SPDT - can wire to be NO or NC
  - 24V DC 30A

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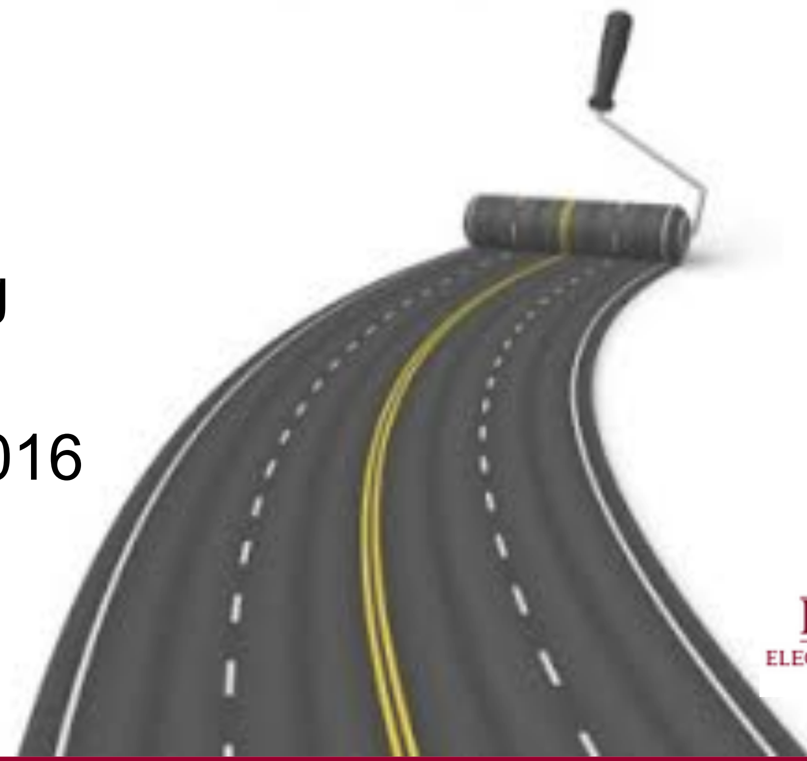
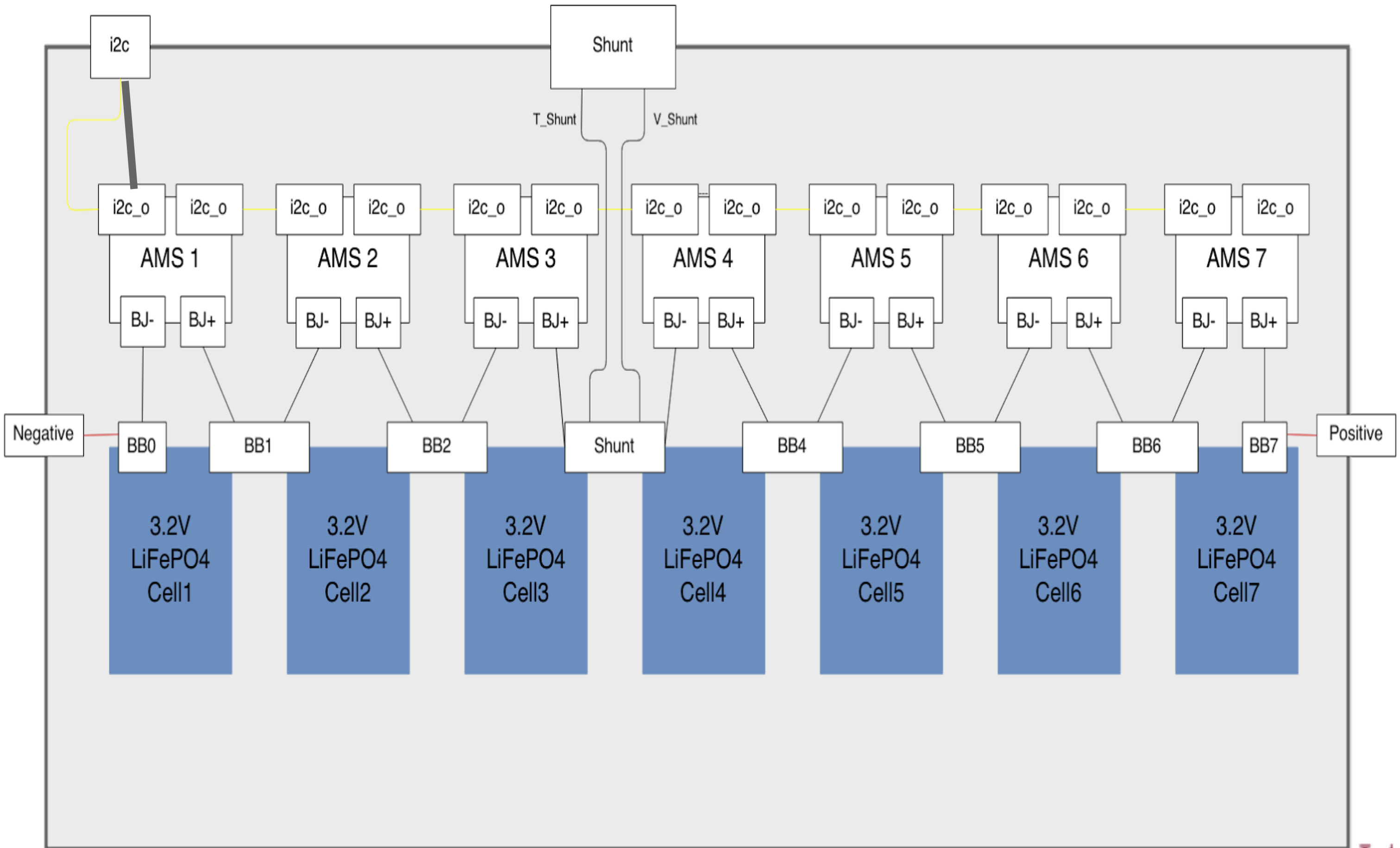


Accumulators and AMS



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Accumulator Management System Board

- Boards monitor attributes of each assigned cell
  - Voltage levels
  - Current levels
- Ability to bypass cell during charging
- Reports back to microcontroller through I^2C
- Board Reset
  - Software
  - Remote/Manual

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AMS Command List

Command #	Description	#Bytes Returned
0x 10	Gets the cell voltage	2
0x 11	Gets the cell temperature	2
0x 12	Gets the pack charging current	2
0x 13	Gets the pack discharging current	2
0x 14	Gets the bypass resistor switch state	2
0x 15	Gets the slave/board address	2
0x 16	Gets the software version	2
0x 17	Gets 0x0042(test command)	2
0x 18	Gets the bypass time in minutes	2
0x 19	Gets charging coulomb count as well as the number of times the charging current was summed	8*
0x 1A	Gets discharging coulomb count, as well as the number of times the discharging current was summed	8*
0x 1B	Gets cell voltage and temperature	4
0x1C	Gets the voltage, temperature and charging current of the cell	6
0x 1D	Gets the voltage, temperature and discharging current of the cell	6
0x 1E	Gets the time elapsed since the bypass switch has been set	6**
0x00	Sets the bypass switch state	n/a
0x 01	Sets the board address	n/a
0x 02	Sets the bypass time in minutes	n/a
0x 03	Calls the function to test the watchdog timer	n/a

Designed by 2013 Team.

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AMS Firmware Bug

- Bugs documented by LFEV-2013
  1. No constraint to force PacMan to wait until the AMS board has processed a request
     - Results: incorrect data readings on the first response
  2. Concurrency issues in memory: read/write collisions
     - Results: possible retrieval of unwanted data

- LFEV-2015 Goals
  1. Manipulate clocks so that no additional requests could be sent by PacMan until original request is processed.
  2. Implement constraints so that data cannot be read and written at the same time

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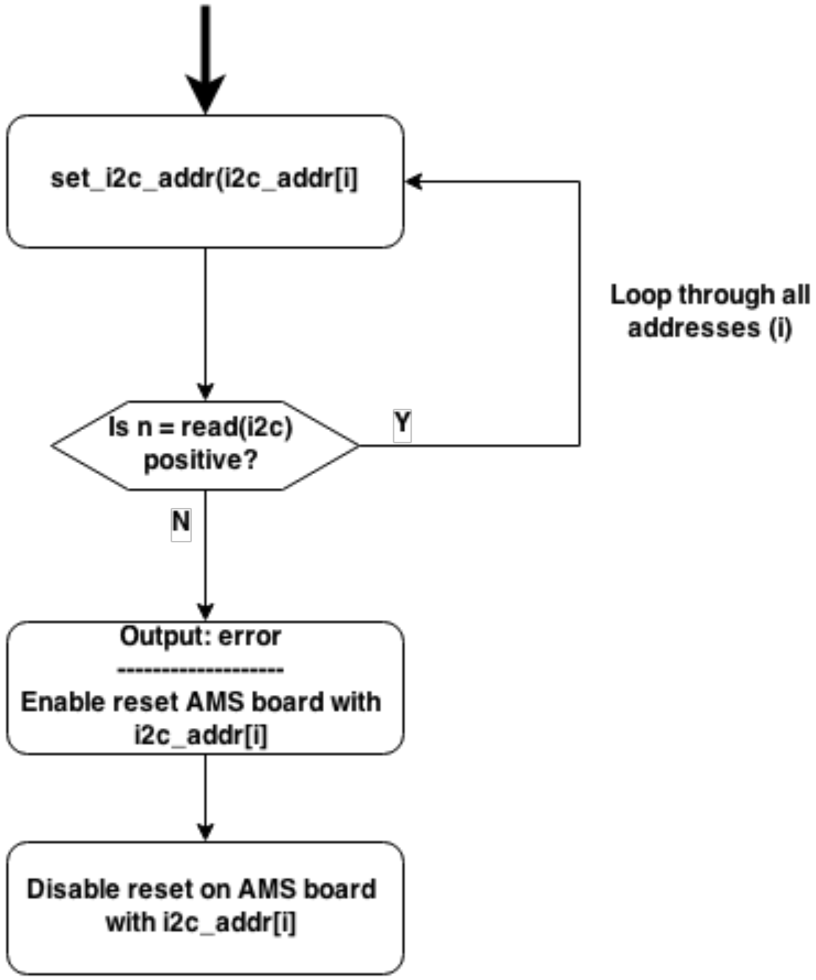
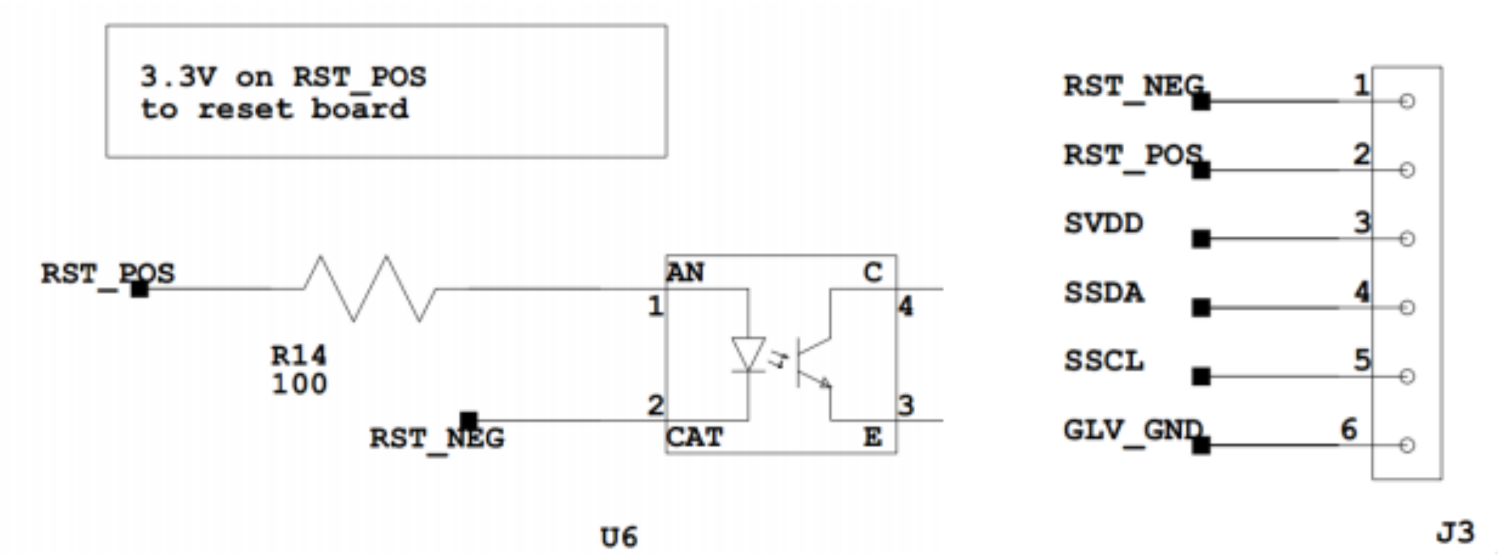
AMS Reset

- Initialization: VSCADA will attempt to communicate with each board
  - Failed attempt → reset of that board
  - Error & Reset will display on Pack LCD



AMS Remote Reset

- LFEV 2014's Design → LFEV 2015 utilizing it
- Asserted by manual reset button through BoB



Roadmap Cont.

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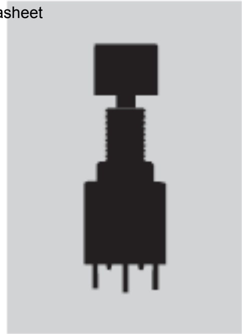
PacMan Breakout Board (changed)

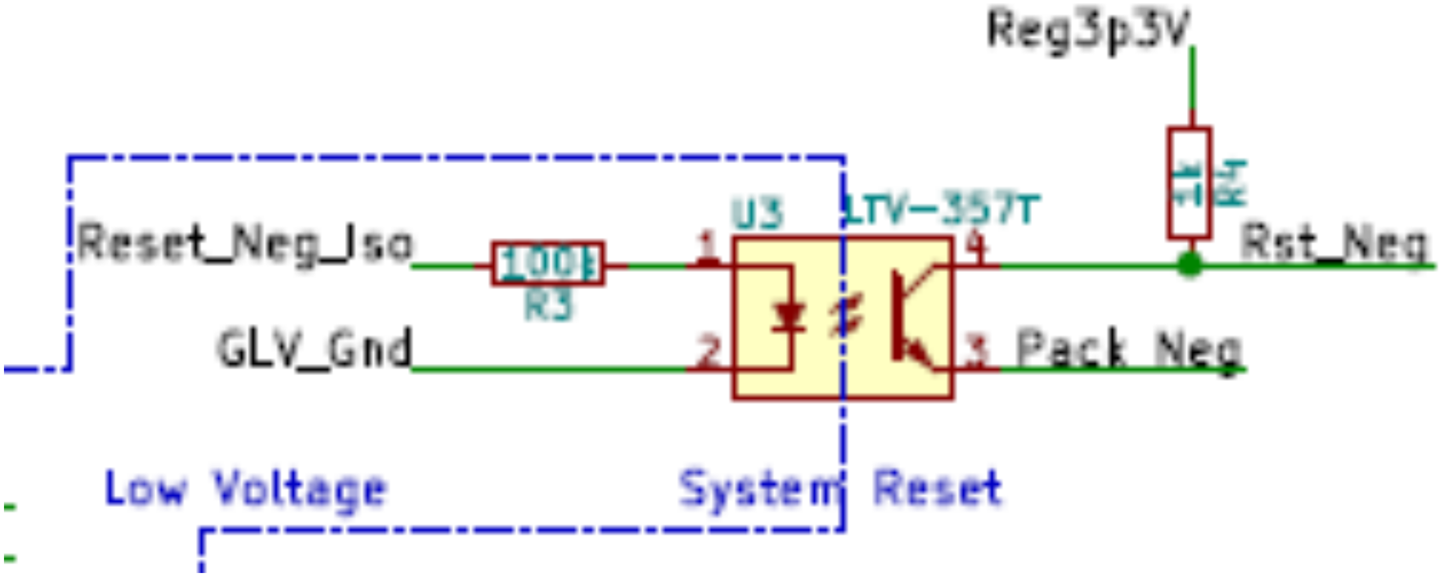
- Contains circuitry used for current, temperature, and pack voltage measurements
- Includes isolation chips to provide galvanic isolation between low and high voltage circuits
- Houses PacMan microcontroller

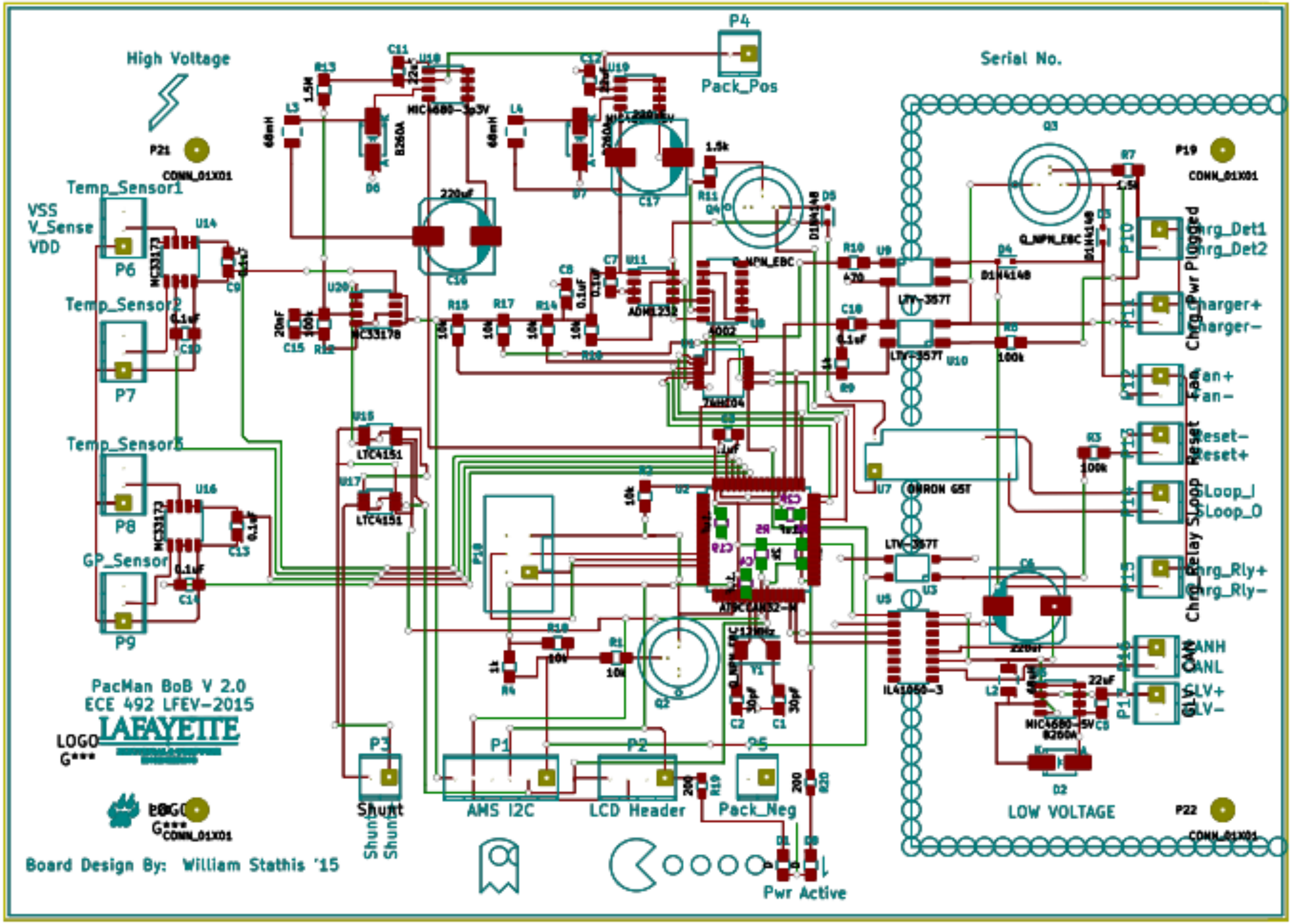
PacMan BoB Manual Reset (changed)

- MB2000 series switch pushbutton (NKK Switches)
  - Shorts RESET_POS and RESET_NEG
  - Activates optoisolator

Photo taken from MB2000 series datasheet







PacMan BoB Layout Errata (changed)

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Roadmap Cont.

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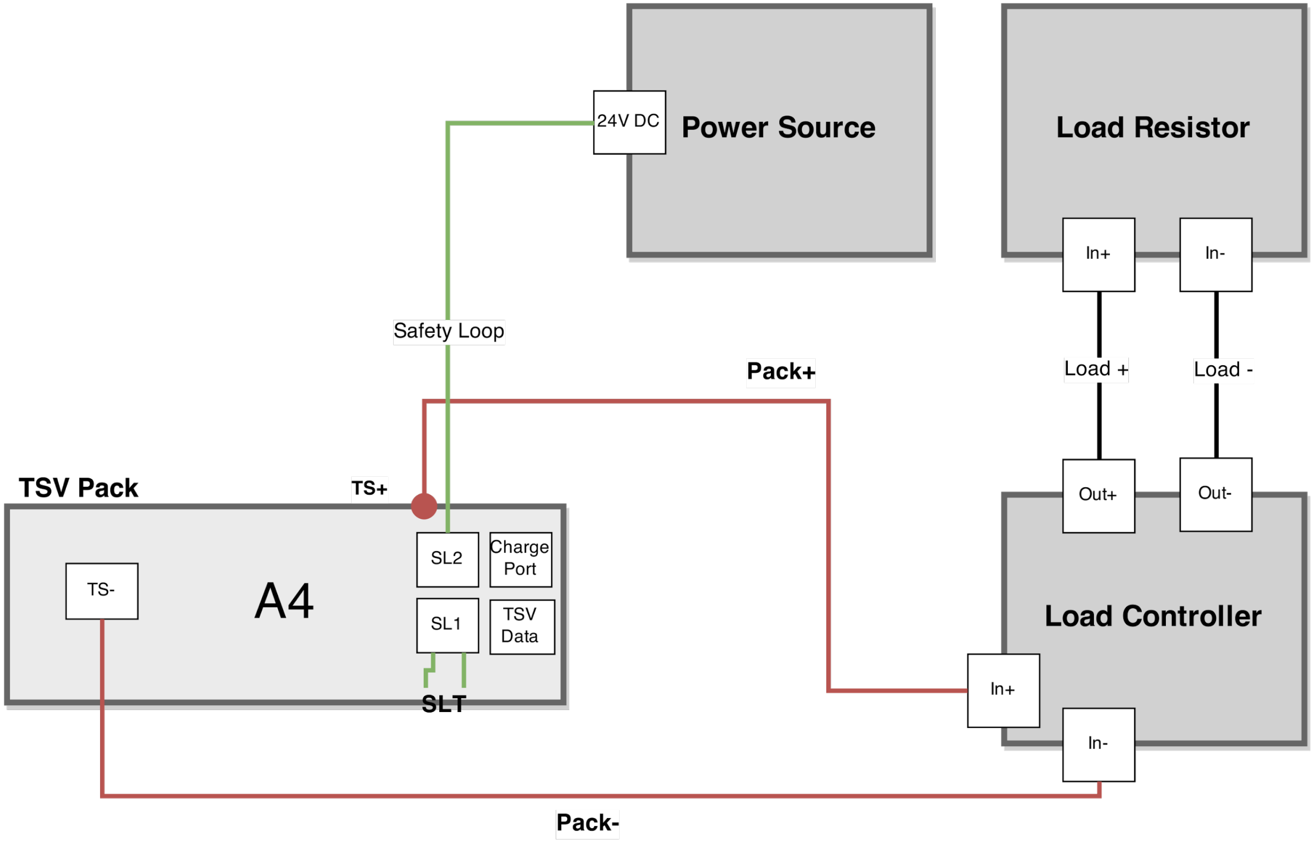
Acceptance Testing

- Overview
    - Designed around requirements
    - Minimizing time and charge cycles needed
    - Repeatable for individual packs
- Focus
    - Safety
    - Plug-and-forget charging
    - Accuracy of measurands
    - New SoC algorithm

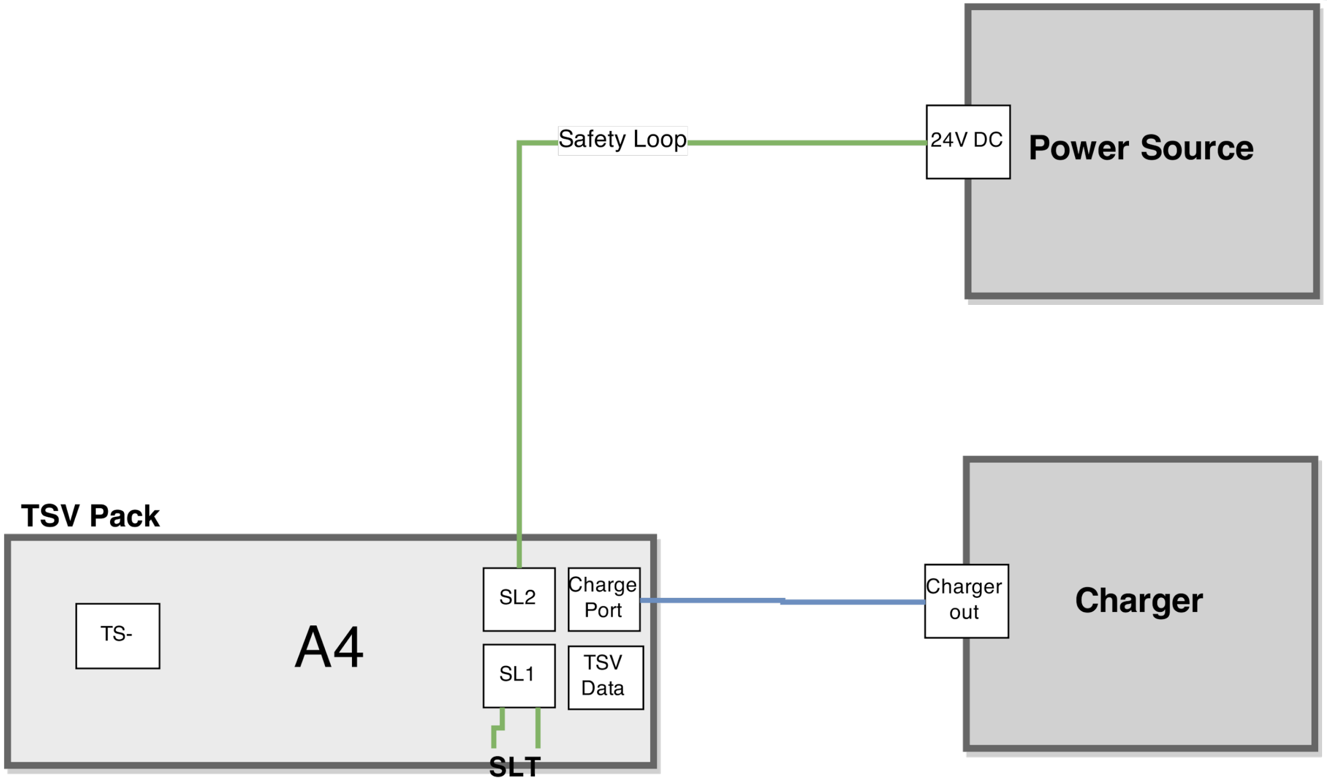
Acceptance Testing Cont.

- Test configuration A



Acceptance Testing Cont.

- Test configuration B



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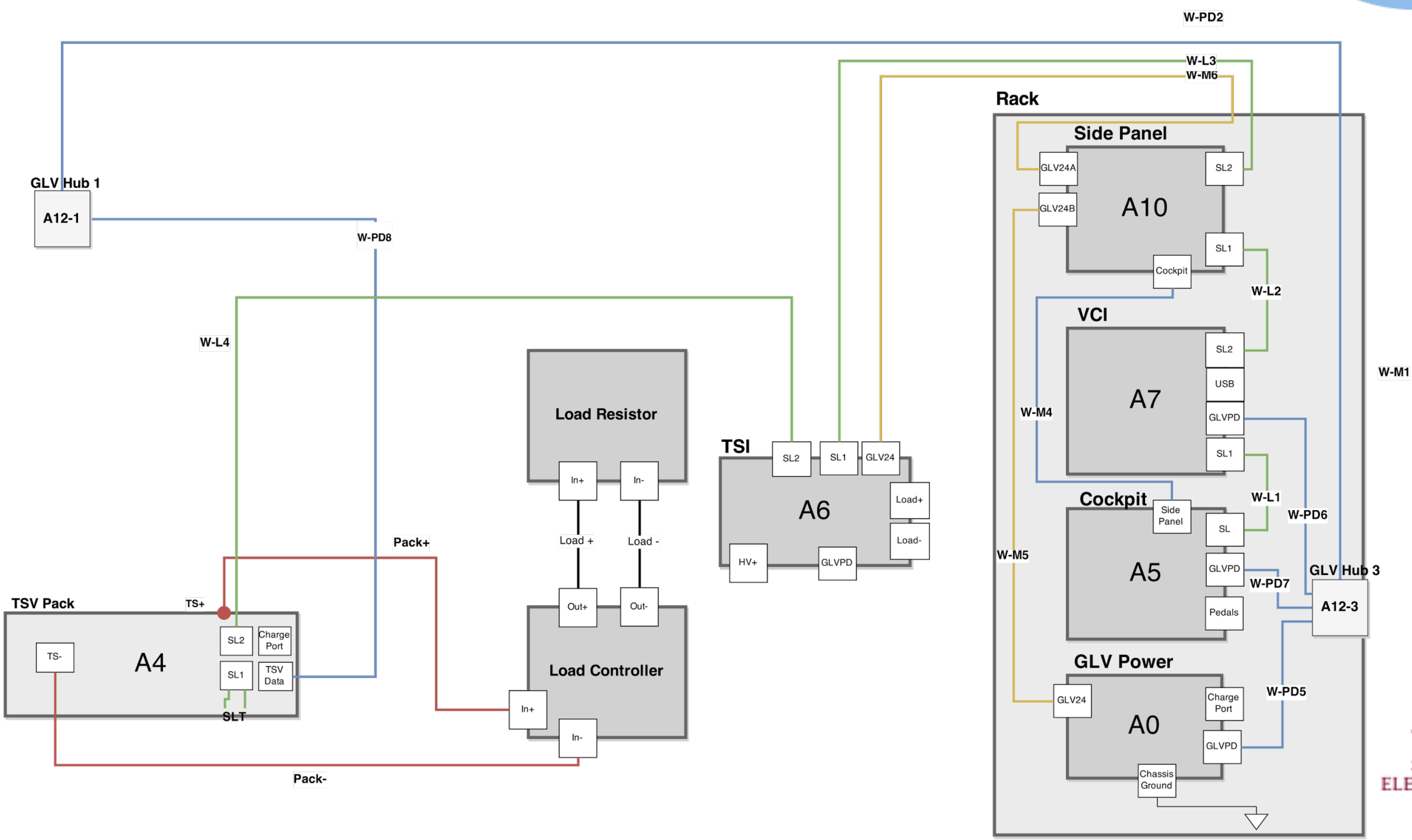
Acceptance Testing Cont.

- Test configuration C



Acceptance Testing Cont.

- T000: Pack Display and Safety Qualification
    - Prerequisite for all other tests
    - Configuration A
    - No active load
    - Measurement accuracy verification
    - Safety checks (isolation, sensor readings)
    - Controls/reset tests

Acceptance Testing Cont.

- T001: Low Current Discharge Test
  - Discharge cycle
  - Configuration A
  - Safety features tested (safety loop, low-voltage protection, temp/voltage sensors)
  - Un-balances cells for subsequent tests
  - Measurement accuracy verification
  - SoC tested

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Acceptance Testing Cont.

- T002: Charge Cycle Test
  - Complete charge cycle
  - Configuration B
  - Charges at two different rates to test SoC
  - Safety loop tested
  - Measurement accuracy verification
  - Cell-balancing tested
  - Plug-and-forget feature tested

Acceptance Testing Cont.

- T003: High/low Current Discharge Test
  - Discharge cycle
  - Configuration C
  - Discharge at 3 different rates (high/low/paused)
  - Max current performance tested
  - Measurement accuracy verification
  - Safety features tested
  - SoC tested
  - Simulates real-life use case

Roadmap Cont.

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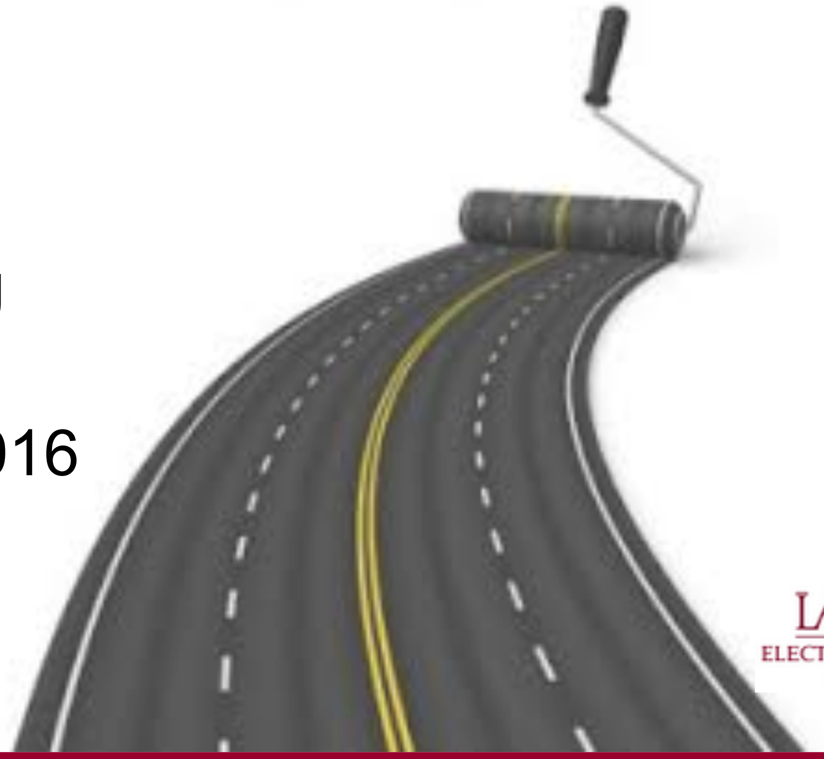

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Maintainability

- Hardware
  - MTTR = 1 day for most parts when spare parts on hand
  - MTTR < 8 days for most parts when no spare parts available
  - Full analysis in maintainability plan

Maintainability Cont.

- Software
  - PacMan software and AMS firmware
  - Source control
  - Backup/restore
  - Instructions for programming
  - Compatibility with VSCADA

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TSV BOM & Budget

Total TSV Budget Required				
AMS	PacMan	BOB Parts	Pack Electrical Parts	Grand Total Budget
$430.38	$674.15	$223.75	$1,263	$2,590.95

Total Given Budget:	$2,739.10
Spent So Far:	$1,026.03
Remaining Budget:	$1,713.07

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AMS

AMS (Accumulator Management System)				
Vendor Part# / Order#	Description	Unit Price	QTY	Total Price
4048778	Advanced Circuits PCB 30 AMS Boards	$8.32	30	$249.45
Mouser				
538-70543-0040	6-PIN SL Locking Header, tin-plate (J2, J3)	$0.74	20	$14.80
538-50-57-9706	6-PIN SL Locking Plug w/TPA (for J2, J3)	$0.75	20	$15.00
538-73838-0006	6-PIN SL TPA Piece (for J2, J3)	$0.26	20	$5.20
538-16-02-0096	SL Socket 24-30 AWG	$0.06	100	$6.00
567-657-15ABPN	TO-220 Vertical Board Mount Heatsink	$1.31	10	$13.10
652-PWR220T-20-R750F	TO-220 Resistor 20watt 0.75ohms 1% (RPOW)	$4.00	10	$40.00
567-173-7-220P	Thermal Interface Pad TO-220 .007" GRAY (for Q1, RPOW)	$0.42	17	$7.14
532-7721-7PPS	Insul Shoulder Washer (for No. 4 screw)	$0.18	15	$2.70
579-PIC16LF1827-I/SO	PIC16LF1827 8-bit Microcontroller (U4)	$1.72	8	$13.76
652-SRN8040-100M	SMD Inductor 10uH 20% (L1)	$0.39	20	$7.80
859-LTV-357T	Transistor Output Isolator (U6)	$0.19	20	$3.80
634-SI8600AB-B-IS	Silicon Labs Dual I2C Isolator Interface (U7)	$3.18	8	$25.44
579-MCP1825S-3302EDB	LDO Voltage Regulators 500 mA 3.3V (U3)	$0.51	9	$4.59
Digikey				
LT1307BCS8#PBF-ND	LT1307B	$2.75	4	$11.00
TIP102TU-ND	TRANS NPN DARL 100V 8A TO-220 (U2)	$0.73	1	$0.73
MCP9700AT-E/TTCT-ND	IC Sensor Thermal 2.3V SOT-23-3 (U5A, U5B)	$0.25	11	$2.75
MBR0520LCT-ND	Diode Schottky 20V 500MA SOD123 (D1)	$0.23	2	$0.46
MCP6242-E/SN	IC Opamp GP 550KHz PRO 8SOIC (U1)	$0.30	5	$1.50
655K-ND	Banana Plug	$1.72	3	$5.16
RMCF0805FT20K0CT-ND	20K 0805 SMD Resistor 1% 1/8W	$0.016	50	$0.81

AMS Total:	$430.38

PacMan & BOB

PacMan (Pack Manager)				
Vendor Part# / Order#	Description	Unit Price	QTY	Total Price
~~TS-7400-V2-256-2048F-I-Dev~~	~~MicroComputer TS-7400-V2~~	~~$158~~	~~4~~	~~$632.00~~
908-MSD04GCS4P-1TM	Micro SD Card 4GB Class 10 Industrial	$10.54	4	$42.15

PacMan Total:	$674.15

BOB (Breakout Board)				
Vendor Part# / Order#	Description	Unit Price	QTY	Total Price
N/A	PCB for BOB boards	$10	6	$60
998-MIC4680-5.0YM	Switching Regulators 1.3A SuperSwitcher in SO-8 (Lead Free)	$4.23	3	$12.69
LTC4151CS-2#PBF-ND	IC CURRENT MONITOR(12BIT) 16SOIC	$5.55	4	$22.20
MCP6242-E/SN	Switching Regulators 1.3A SuperSwitcher in SO-8 (Lead Free) (also in AMS)	$4.23	5	$21.15
859-LTV-357T	Transistor Output Optocouplers (also in AMS)	$0.19	2	$0.38
584-ADM1232ARN	ADM1232 Watchdog Timer SOIC-8	$2.53	2	$5.06
849-LDA210S	LDA210 Dual Optoisolator/Darlington Pair SIP-8	$1.83	2	$3.66
771-HCT4002D118	Single 4 Input NOR/OR Gate SOIC-8	$0.50	2	$1.00
653-G6B-1114P-DC5	SPST 5V PCB Relay	$5.16	2	$10.32
ADM2483BRWZ	Half Duplex RS-485 Isolator	$6.84	2	$13.68
511-74LCX07YMTR	M74HC07 Hex Open-Drain Buffer SOIC-14	$0.52	2	$1.04
652-SRU1028-680Y	SMD Inductor 68uH 30%	$0.75	2	$1.50
P2N2222AGOS-ND	P2N2222A NPN BJT Transistor 600ma	$0.50	2	$1.00
621-B260A-F	B260A Schottky Diodes	$0.47	2	$0.94
512-1N4148	D1N4148 Diode Through Hole	$0.10	6	$0.60
810-C3216X5R1V226M	22uF SM Ceramic Capacitor 1206	$1.26	2	$2.52
598-AVE227M16X16T-F	220uF Electrolytic Capacitor Surface Mount 16V	$0.51	2	$1.02
538-70543-0013	Headers & Wire Housings 14 POS SHROUD HDR	$3.50	5	$17.50
538-50-57-9414	Headers & Wire Housings HSG 14P SINGLE ROW POSITIVE LATCH	$0.87	10	$8.70
517-D3408-6202-AR	16-PIN Shrouded Header	$1.99	3	$5.97
517-3452-6000	16-PIN Plug	$3.23	6	$19.38
517-D3793-6202-AR	10-PIN Shrouded Header	$1.44	2	$2.88
517-3473-6000	10-Pin Plug	$2.64	4	$10.56

BOB Total:	$223.75

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Pack Electrical Parts (page 1)

Pack Electrical Parts				
Vendor Part# / Order#	Description	Unit Price	QTY	Total Price
G3475534	Fuse, 200A, Class T, A3A, 300VAC/160VDC	$28.34	2	$56.68
G1878003	Fuse Holder, 200A AC, 300V, 1 Pole, Molded	$68.99	2	$137.98
504-BK/HKP-R	Cooper Bussmann AGC 30A/250V Fuse Holder	$4.72	6	$28.32
504-C10G0.5	Fuse, Bussman .5A/500V	$13.26	6	$79.56
5912-4414F	Fans 119x25 24DC 100CFM 5W 2900RPM 43dBA BB	$33.58	2	$67.16
562-0945030	Fan Accessories BLK FLTR ASSM 4.65"	$2.08	2	$4.16
562-09123-G	Fan Accessories PLASTIC GUARD 120MM	$1.21	3	$3.63
GX14CB	AIR - 350A Contractor, 24VDC coil, 24-in flying leads, no auxiliary contact	$94.35	1	$94.35
Waytek 124-903 124-11411	POWER RELAY CONTACTOR 24V 100A SPNO WHITE-RODGERS 124-903	$34.96	3	$104.88
Newark 44W4342	Panel Drain, Line 3, Grey	$74.10	2	$148.20
Newark 44W4365	Panel Source, Neutral, Blue	$50.62	2	$101.24
~~DFR0154~~	~~LCD Character Display Module STN Y/G~~	~~$23.00~~	~~4~~	~~$92.00~~
571-14807030	Pin & Socket Connectors CAP HOUSE 4 POS	$0.20	50	$10.00
571-14807050	Pin & Socket Connectors CAP HOUSE 6 POS	$0.32	50	$16.00
571-32950	Insul. Ring Terminal, 18 AWG, #6/M3 stud	$0.29	25	$7.25
538-19070-0121	Insul. Ring Terminal, 10-12 AWG, #8/M4 stud	$0.20	25	$5.00
571-35492	Insul. Ring Terminal, 12-10 AWG #1/4 /M6 stud	$0.56	10	$5.60
579-MCP9700A-E/TO-ND	Board Mount Temperature Sensors Lin Active Therm	$0.37	4	$1.48
517-9602207102AR	Headers & Wire Housings 20P SIDE ENT DR SKT	$3.18	3	$9.54
517-9602406303AR	Headers & Wire Housings 40P STR SR BDMNT SKT 3.5MM TAIL/8.5MM BODY	$4.85	3	$14.55
879-1470G1	Heavy Duty Power Connectors PP PAK 2-4P HSG SNAP-IN RECEPT	$2.10	4	$8.40
879-1327FP	Heavy Duty Power Connectors PP15/45 FINGERPROOF HOUSING ONLY, RED	$0.85	3	$2.55
879-1327G6FP	Heavy Duty Power Connectors PP15/45 FINGERPROOF HOUSING ONLY, BLACK	$0.82	3	$2.46
879-269G1-LPBK	Heavy Duty Power Connectors PP30 HD LOOSE CONT #12-16 AWG	$0.70	3	$2.10
879-4827G6	Heavy Duty Power Connectors PPMX 2-PIECE BLACK HOUSING ONLY	$0.80	3	$2.40
879-261G2	Heavy Duty Power Connectors PP45 REELED CONTACT #10-14 AWG, TIN	$0.16	25	$4.00

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Pack Electrical Parts (page 2)

571-5550521	Ethernet Connectors 8 COUPLER IN-LINE	$7.02	2	$14.04
651-5602099	15mm DIN Rail Perf	$9.64	1	$9.64
651-3100305	MT1.5 Feed-Thru DIN Rail Terminal Block	$2.62	20	$52.40
651-3001682	MT1.5 Twin DIN Rail Terminal Block	$4.62	3	$13.86
651-3100318	MT1.5 PE Ground Din Rail Terminal Block	$8.42	1	$8.42
651-3100321	MT1.5 End Plate	$0.78	3	$2.34
651-3002979	MT1.5 Twin End Plate	$1.34	3	$4.02
651-1402940	MBK5/EZ Feed-Thru DIN Rail Terminal Block	$3.15	6	$18.90
651-1415021	MBK5/EZ End Plate	$0.97	2	$1.94
651-1421659	DIN 15 End Clamp	$1.28	4	$5.12
298-G75X75LG72-ND	Wire Ducting TYPE G .75 X .75 6-FOOT SECTION	$28.56	1	$28.56
651-1725711	Fixed Terminal Blocks 8P 2.54mm 90DEG	$5.40	2	$10.80
651-1725656	Fixed Terminal Blocks 2P 2.54mm 90DEG	$1.42	3	$4.26
651-1725669	Fixed Terminal Blocks 3P 2.54mm 90DEG	$2.16	4	$8.64
571-3506891	Pin & Socket Connectors SOCKET 24-18 AWG	$0.085	100	$8.50
571-3506901	Pin & Socket Connectors PIN 24-18 AWG	$0.088	100	$8.80
538-16-02-0096	SL Socket 24-30 AWG	$0.10	100	$10.00
651-3001624	FBRN 10-4 N Fixed Bridge (10 Position)	$7.90	1	$7.90
298-C75LG72-ND	Wire Ducting COVER 3/4" 6-FOOT SECTION	$8.46	1	$8.46
651-0203250	FBI10-6 Fixed Bridge for 6.2mm DIN blocks	$9.86	1	$9.86
782-ILD755-1X017	Transistor Output Optocouplers Photodarlington	$2.77	4	$11.08
156-1409-E	D-SUB CRIMP FEMALE 9P	$0.56	2	$1.12
156-1401-E	D-SUB CRIMP PIN FM	$0.10	20	$2.00
164-9007-E	IDC SOCKET 14 PIN W/STRAIN RELIEF	$0.65	2	$1.30
164-9008-E	IDC SOCKET 16 PIN W/STRAIN RELIEF	$0.61	2	$1.22

Pack Electrical Total:	**$1,262.67**

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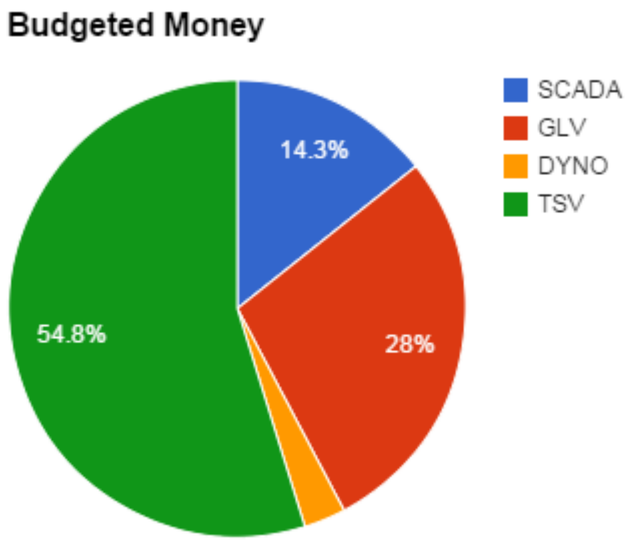
Budget

- Initially Allocated Money:
    - Dyno - $148
    - SCADA - $715
    - GLV - $1397.90
    - TSV - $2739.10



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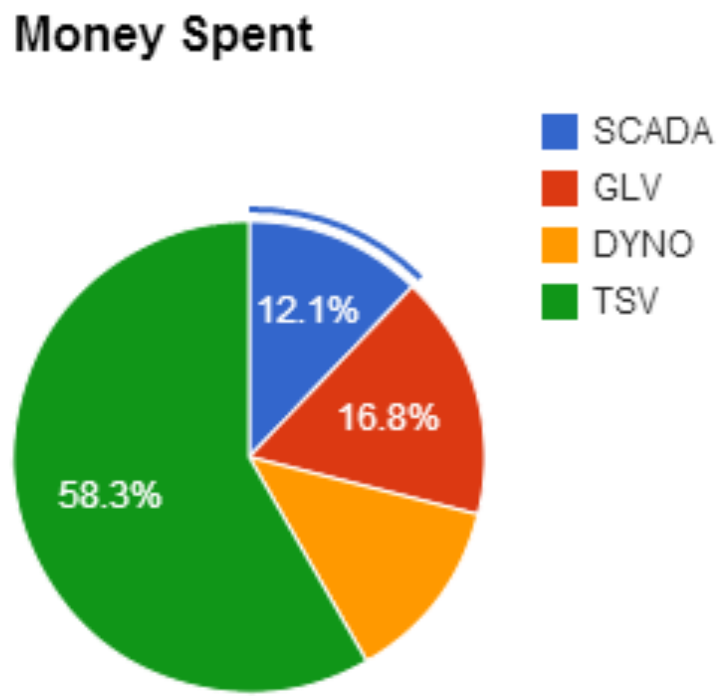
Budget

- Money Spent So Far
  - Dyno - $471.37
  - SCADA - $448.37
  - GLV - $618.99
  - TSV - $2152.08



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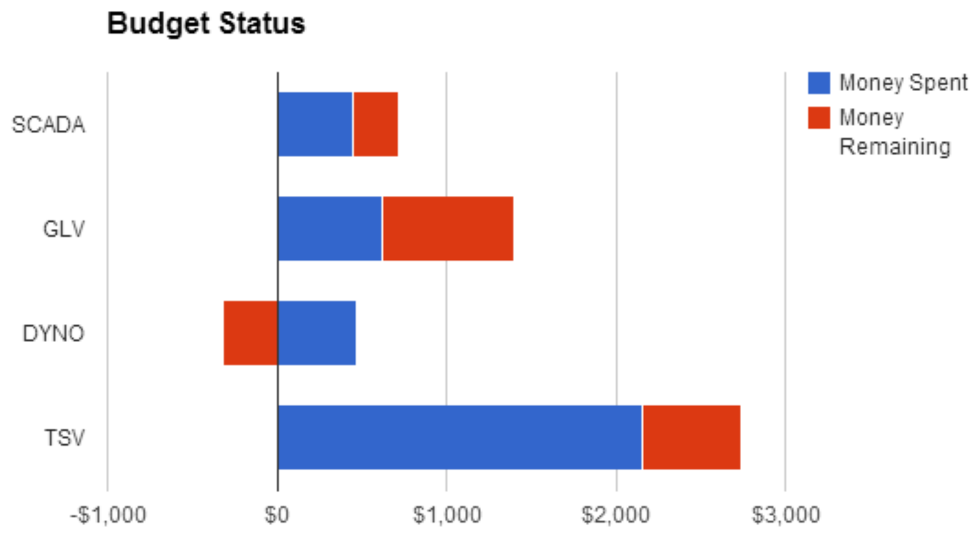
Budget

- Money Remaining:
  - DYNO - $323.37
  - SCADA - $266.63
  - GLV - $778.91
  - TSV - $587.02



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Roadmap Cont.

7. Tractive System Voltage (TSV)
    a. Overview
    b. Safety
    c. Mechanical
    d. PacMan System
    e. Charging
    f. AMS
    g. BoB
    h. Acceptance Testing
    i. Maintenance
8. **Out of Scope: LFEV-2016**
9. Conclusion

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Out of Scope: LFEV-2016

- GLV
  1. Implement AIR failure sensors
  2. Purchase of TSAL
  3. Location/Placement of BOTS

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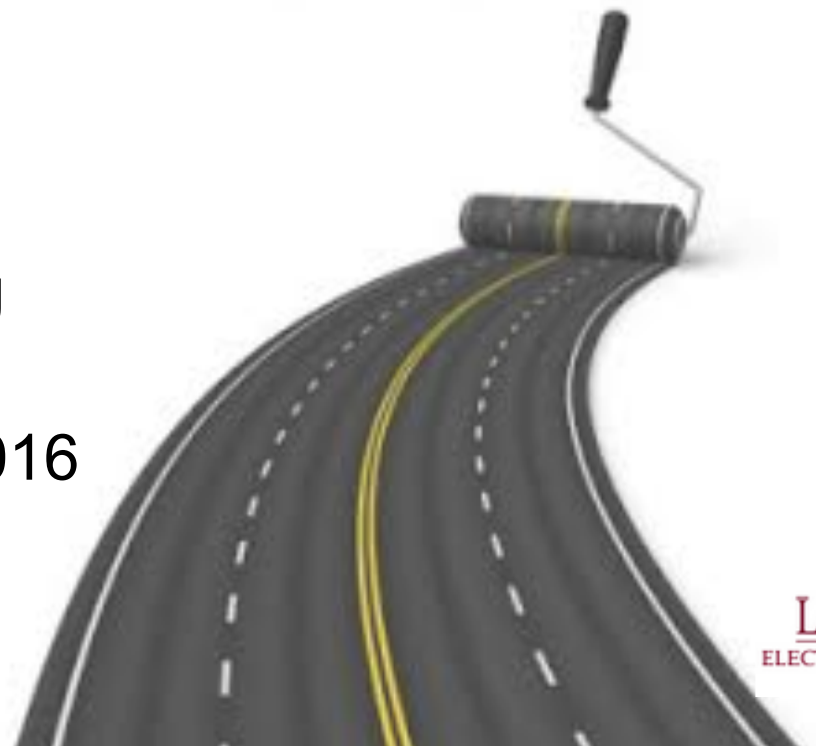
Out of Scope: LFEV-2016 Cont.

- TSV
  1. Implement AIR failure sensors
  2. Low voltage indicator light
  3. Building 4 complete packs

Roadmap Cont.

7. Tractive System Voltage (TSV)
    a. Overview
    b. Safety
    c. Mechanical
    d. PacMan System
    e. Charging
    f. AMS
    g. BoB
    h. Acceptance Testing
    i. Maintenance
8. Out of Scope: LFEV-2016
9. **Conclusion**



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Conclusion

Thanks for listening.

Any (more) questions?