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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
Roadmap Cont.

6. Tractive System Voltage (TSV)
   a. Overview
   b. Safety
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. Acceptance Testing
   i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
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
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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
Introduction: Motivation

- Formula Hybrid Competition Vehicle
  - Electric Car
- Capable of Vehicle Integration
- Four Team Integration
- Integrate with Mechanical Engineering Department
- Provide next year’s team with a well-structured Formula Hybrid Vehicle ready for integration
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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
Interface Control

An Interface Control Document was created to accurately and completely define all (electrical, mechanical, semantic) aspects of top-level interfaces to allow different designers to coordinate with each other successfully.

Next, we will discuss these top-level interfaces.
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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
System Assemblies Layout - Top View
Layout Selection

● SAE 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
Physical Interfaces Layout - Side View
Physical Interfaces Layout - Top View
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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
End-of-Term Integration Layout
End of Term Integration Layout

- Most Boxes 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
Semester Integration Physical Interfaces

TSV Pack 1
- TSV Data
- SL1
- SL2
- Charge Port

TSV Pack 2
- TSV Data
- SL1
- SL2
- Charge Port

TSV Pack 3
- TSV Data
- SL1
- SL2

TSV Pack 4
- TSV Data
- SL1
- SL2

Rack

Side Panel
- Safety Loop
- Reset
- SI Closed
- GLV04
- GLV Master Switch
- Left BRB
- Right BRB

VCI
- RTD Buzzer
- Display

Cockpit
- RTD
- CP1

GLV Power
- Charging
- Battery Power
- Power
- Charge Port

Motor System
- Huff Box
- Dyno

Motor Controller

Motor

MCI

LAFFAYETTE ELECTRICAL & COMPUTER ENGINEERING
Physical Interfaces

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

● **VCI Display**
  ○ 9 Inch Touchscreen
  ○ Direct VSCADA Maintenance
  ○ System Parameter Control
Physical Interfaces

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

- GLV Power Panel
  - Low Voltage Battery Indicators
  - GLV Power Switch
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**
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
GLV Power and Data Distribution
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
  ○ Single long bus line
  ○ Nodes connected via short (<1.0 m) stubs
  ○ GLV Hub Boxes
Safety Loop Connections
Safety Loop Connections

● SAE 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
Tractive System High Voltage Path

- Internally Hardwired Connections
  - Less Cables
  - Less Interconnects

- Powerlock Connectors
  - SAE Requirements:
    - Easily Removable
    - Lockable
Tractive System High Voltage Path

- **Powerlock Connectors**
- **Bolt Terminals**
  - Pre-existing
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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
Side Controls Panel

- Designed for testing purposes
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
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
GLV Hub 1 & 2
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
GLV Hub 3
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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
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.
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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
Cockpit and the Safety Loop
Cockpit Panel and Internals
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
Safety Loop and Safety Circuit

- 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
## Shutdown Priority Table

<table>
<thead>
<tr>
<th>Shutdown Sources</th>
<th>Controlled Systems</th>
<th>AIRs (TS Voltage)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GLV Supply to: Instrumentation, Data Acquisition, Computers, Telemetry, Etc.</td>
<td>OFF</td>
</tr>
<tr>
<td>TSMS</td>
<td></td>
<td>OFF</td>
</tr>
<tr>
<td>Cockpit BRB</td>
<td></td>
<td>OFF</td>
</tr>
<tr>
<td>AMS</td>
<td></td>
<td>OFF</td>
</tr>
<tr>
<td>IMD</td>
<td></td>
<td>OFF</td>
</tr>
<tr>
<td>Brake Over-Travel</td>
<td></td>
<td>OFF</td>
</tr>
<tr>
<td>Side-Mounted BRBs</td>
<td></td>
<td>OFF</td>
</tr>
<tr>
<td>GLVMS</td>
<td></td>
<td>OFF</td>
</tr>
</tbody>
</table>
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

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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
     c. VCI
     d. TSI
5. GLV BOM and Budget
GLV Power Box
GLV Power Box - End Goal (JGB)
GLV Battery Cell

3.3V LiFePO4 10Ah
GLV Battery

Eight cells
24V
10Ah
GLV Battery Connection

Crimped Terminal
(Open Barrel)
Battery Mounting
EV3.7.1- All GLV batteries must be attached securely to the frame.
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.

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

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.

<table>
<thead>
<tr>
<th>System</th>
<th>Power Consumption</th>
<th>Capacity Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLV Relays</td>
<td>(2.04W x 2) = 4.08W + 1W</td>
<td>(2.04W x 2) = 4.08W + 1W (for microcontrollers, relays)</td>
</tr>
<tr>
<td>AIRS</td>
<td>(2.04W x 2) = 8.16W + ~100mW</td>
<td>(2.04W x 2) = 8.16W + ~100mW (CAN transceivers)</td>
</tr>
<tr>
<td>VSCADA</td>
<td>5.28W computer + 4W screen</td>
<td>5.28W computer + 4W screen</td>
</tr>
<tr>
<td>Total</td>
<td>25.52W / 24V = 1.06A x 1.5 =</td>
<td>$1.595\text{Ah} \quad 1\text{hr}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$3.19\text{Ah} \quad 3\text{hr}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$4.785\text{Ah} \quad 3\text{hr}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$6.38\text{Ah} \quad 4\text{hr}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$9.57\text{Ah} \quad 5\text{hr}$</td>
</tr>
</tbody>
</table>

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

~24V

"Charging"
LED Off

~0.745A

27K

~0.745A

24V
<1.06A
~0.745A

"Battery Power" LED On

DC-to-DC

LAFAYETTE
ELECTRICAL & COMPUTER ENGINEERING
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.

www.trcelectronics.com

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.
- $2.5A \times 1.1 = 2.75A$… 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.
Voltage Sensing

R006- The GLV battery shall be protected from overcharge. GLV voltage shall be measured by VSCADA.
GLV Power Software

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

GLV Power Arduino

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.
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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
Vehicle Computer Interface
VCI

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

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

- **TSAL**
  - 555 Timer in astable configuration
  - Active whenever the AIRs is open
  - Set for a frequency of 3.2 Hz

- **Physical TSAL Lamp not included**
  - Tested using DDM
  - Expected output:
    - 12V
    - 50% duty cycle
    - 0.3125 second period
VCI

● Safety Loop Monitoring
  ○ Interfaced to the CAN Controller board
  ○ Safety Loop Monitor
  ○ AIRs State Monitor

● Safety Loop Control
  ○ Controlled by VSCADA digital I/O
  ○ Gives Safety Loop control to system software
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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
Tractive System Interface (TSI)
TSI - Overview

- High Voltage Relay Control
- Precharge Protection
- Tractive System Voltage Present Light (TSVP)
- Insulation Monitoring Device (IMD)
- GLV PD 24 to 12 stepdown
- TSMP
TSI - Pre-Charge/Relay Control

- Precharge circuit prevents inrush current and damage to relay contacts
- This configuration will take about 4 seconds for the motor controller to reach 96V
**TSI - TSVP**

- Must be powered by TSV and grounded to GLV ground
- Use a DC DC converter to satisfy this requirement and maintain isolation
Pin 8 - Status Output High
Feeds directly to a relay on Safety Loop
Pin 8 output change opens Safety Loop (High → Low)
TSI - Other Components

● GLV Power
  ○ 24V to 12V DC-DC converter steps down the voltage from GLV24 to power the GLVPD at 12 Volts

● TSMP
  ○ TSMP+ is a direct contact to the HV+ terminal
  ○ TSMP- is a direct contact to the HV- terminal
  ○ GLV GMP provides a reference to GLV ground
TSI - QA Configuration

- Connect high voltage terminals to a high voltage power source
- Connect the high voltage load terminals to the motor controller
- Connect the GLV24 terminal to a low voltage power supply
TSI - QA Test Plan

● TSVP Test
  ○ Apply 30 volts to high voltage power supply and check the TSVP output with a multimeter

● Pre-charge/Relay Test
  ○ Put start signal high and measure time it takes relays to close

● IMD Test
  ○ Using a multimeter, check for connection across the relay after shorting the ground
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
   d. Panel Drawings and Hubs
4. Grounded Low Voltage (GLV)
   a. Safety Loop
   b. GLV Power
   c. VCI
   d. TSI
5. GLV BOM and Budget
# GLV Bill of Materials

<table>
<thead>
<tr>
<th>Description</th>
<th>Vendor Part Name</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Te-Connectivity 2 pin/1 row parallel</td>
<td>1-480699-0</td>
<td>4</td>
<td>$0.28</td>
<td>$1.12</td>
</tr>
<tr>
<td>Te-Connectivity 2 pin/1 row free</td>
<td>1-480698-0</td>
<td>4</td>
<td>$0.28</td>
<td>$1.12</td>
</tr>
<tr>
<td>Te-Connectivity 3 pin/1 row parallel</td>
<td>1-480701-0</td>
<td>6</td>
<td>$0.28</td>
<td>$1.68</td>
</tr>
<tr>
<td>Te-Connectivity 3 pin/1 row free</td>
<td>1-480700-0</td>
<td>6</td>
<td>$0.27</td>
<td>$1.62</td>
</tr>
<tr>
<td>Te-Connectivity 8 pin/2 row parallel</td>
<td>794954-8</td>
<td>4</td>
<td>$0.25</td>
<td>$1</td>
</tr>
<tr>
<td>Te-Connectivity 8 pin/2 row parallel</td>
<td>794953-8</td>
<td>4</td>
<td>$0.25</td>
<td>$1</td>
</tr>
<tr>
<td>Te-Connectivity pin</td>
<td>350561-3</td>
<td>10</td>
<td>$0.14</td>
<td>$1.38</td>
</tr>
<tr>
<td>Te-Connectivity socket</td>
<td>350570-3</td>
<td>10</td>
<td>$0.13</td>
<td>$1.32</td>
</tr>
<tr>
<td>24V DIN Rail DC/DC Converter</td>
<td>TCL 060-124 DC</td>
<td>1</td>
<td>$80.62</td>
<td>$80.62</td>
</tr>
<tr>
<td>DIN Rail DC/DC Converter</td>
<td>STMGFS152405-N2</td>
<td>1</td>
<td>$69.05</td>
<td>$69.05</td>
</tr>
<tr>
<td>36vdc PFC Power Supply</td>
<td>HRP-200-36</td>
<td>1</td>
<td>$64.80</td>
<td>$64.80</td>
</tr>
<tr>
<td>DIN Rail</td>
<td>277-2064-ND</td>
<td>1</td>
<td>$9.82</td>
<td>$9.82</td>
</tr>
<tr>
<td>DIN Rail Terminal Blocks</td>
<td>APC1281-ND</td>
<td>50</td>
<td>$1.33</td>
<td>$66.63</td>
</tr>
<tr>
<td>SWITCH PUSH SPST-NO</td>
<td>CW1282-ND</td>
<td>1</td>
<td>$4.12</td>
<td>$4.12</td>
</tr>
<tr>
<td>SWITCH KEYLOCK SP3T</td>
<td>KO129B606-ND</td>
<td>1</td>
<td>$9.80</td>
<td>$9.80</td>
</tr>
<tr>
<td>DIODE SCHOTTKY 45V 7A</td>
<td>SB15H45-E3/73GITB-ND</td>
<td>5</td>
<td>$0.81</td>
<td>$4.05</td>
</tr>
<tr>
<td>LED RED 1/4&quot; HOLE 5V</td>
<td>L10021-ND</td>
<td>5</td>
<td>$2.17</td>
<td>$10.85</td>
</tr>
<tr>
<td>Relay 5A 5V</td>
<td>Z2774-ND</td>
<td>10</td>
<td>$1.18</td>
<td>$11.78</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$341.76</td>
</tr>
</tbody>
</table>
GLV Budget

Total Allocated Funds - $1397.90
Roadmap Cont.

5. **Tractive System Voltage (TSV)**
   a. **Overview**
   b. Safety
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. Acceptance Testing
   i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
Tractive System Voltage
Main subsystems

- Accumulator Management System (AMS)
- Breakout Board (BoB)
- Pack Manager (PacMan)
- 7 3.2V 60A-hr LiFePO4 Cells
Roadmap Cont.

5. Tractive System Voltage (TSV)
   a. Overview
   b. **Safety**
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. Acceptance Testing
   i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
TSV - Safety

- **Fusing**
  - 2 fuses for BoB
  - 1 fuse for voltage present LED
  - 1 large fuse for pack main current path
  - 2 fuses for charge relay

- **Voltage present LED**
  - turns on when voltage $> 20$V DC present at poles
  - can sustain voltage up to 96V
  - works even when a cell fails with all other packs connected

- **Safety protocols**
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:
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/litt-cannon/nls-3-gy-s120-m40a/line-source-line-3-grey-400a/dp/44W4352
http://www.newark.com/litt-cannon/npdft-3-gy-l-t4/panel-drain-line-3-grey-400a/dp/44W4361
Roadmap Cont.

5. Tractive System Voltage (TSV)
   a. Overview
   b. Safety
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. Acceptance Testing
   i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
Mechanical Objectives

- acceleration requirements
- splash proof
- internal wall
- vibration
- galvanic isolation
Mechanical- Frame/External Casing

- Rigid 8020 Aluminum External Frame
Mechanical- Frame/External Casing

- Removable Top For Quick Battery/BMS Access
Mechanical- Frame/External Casing

-Splash Resistant Ventilation
Cell Restraint
Top Bars
Side Bars
End Plates
Integration with Container
BMS Restraint
BMS Removal
Added Components
Free Terminal
Mechanical - Conductor Bars

- Carries large current
- Low resistance
Mechanical - Current Measuring Shunt

- Special conductor used to measure current
- 118μΩ at STP
Roadmap Cont.

5. Tractive System Voltage (TSV)
   a. Overview
   b. Safety
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. Acceptance Testing
      i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
PacMan System

- Receives and processes data from AMS
- Receives and processes pack sensor data
- Opens BoB safety loop
- CAN communication with VSCADA and LCD
- Implement charge and forget charging
PacMan Computer

Technologic Systems TS-7400-V2

PacMan Computer Hardware Specs

- 1.2W Typical power usage
  - 6.67 Weeks for each pack
- 10mW sleep mode
  - 15.35 years for each pack
- I2C bus for AMS and LCD communication
- CAN bus for VSCADA interface
- 4 ADC inputs for pack sensors
- 39 DIO ports for logic functions
PacMan Computer - Connections

[Image of PacMan Computer board with connections highlighted]

5-28V DC Power

PacMan Computer - Connections

PacMan Computer - Connections

PacMan Software

- Debian 'Wheezy' Linux (Kernel 2.6.36)
- Updates from 2014 team’s code
  - Correct State of Charge algorithm
  - Reboot should not invalidate state of charge
  - Temperature adjustment for current-measuring shunt
- CAN communication with VSCADA
PacMan Safety Loop Control

- Safety loop opened in 3 different ways
  - Charger plugged
  - Watchdog timeout
  - CPU DIO02 pin for software control
- Watchdog fed by CPU DIO03 pin
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=OSeow1gd1xJrUuPTLe2pA%3D%3D
Roadmap Cont.

5. Tractive System Voltage (TSV)
   a. Overview
   b. Safety
   c. Mechanical
   d. PacMan System
   e. **Charging**
   f. AMS
   g. BoB
   h. Acceptance Testing
      i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
Charger-GENESYS 750W Half-Rack

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

Charging

- Anderson PowerPole connector used
  - Charge Detect
    - Charge Detect goes to BoB ends at PacMan
  - 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

- Charger creates electrical connection between CHRG_DET1 and CHRG_DET2
  - Pulls CPU DIO06 pin high through optoisolator
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 °C/W @ 200 LFM
  - With 10.2W power, 37.74 °C rise

http://www.mouser.com/ProductDetail/ebm-papst/4414F/?qs=sGAEpiMZ7M8mcbdCMUJxEnE1sa%2fhD25dPfUzYqJg8M%3d

Charge Relays

● We will be using a normally closed charge relay
  ○ This fixes previous error where pack was unchargeable when depleted

● Charging is finished when all AMS bypass
  ○ CPU DIO00 pin 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
Roadmap Cont.

5. Tractive System Voltage (TSV)
   a. Overview
   b. Safety
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. Acceptance Testing
      i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
Accumulators and AMS

Diagram showing the connection of various accumulators and shunts, labeled with the battery configuration.
Accumulator Management System Board

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

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

Designed by 2013 Team.
AMS Software 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
AMS Software Reset

- Initialization: PacMan 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 PacMan BoB
Roadmap Cont.

5. Tractive System Voltage (TSV)
   a. Overview
   b. Safety
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. Acceptance Testing
      i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
PacMan Breakout Board

● Acts as connector between TS-7400-V2 and the AMS boards and proper sensor relays

● Contains circuitry used for current, temperature, and pack voltage measurements

● Includes isolation chips to provide galvanic isolation between low and high voltage circuits
PacMan BoB Manual Reset

- MB2000 series switch pushbutton (NKK Switches)
  - RESET_POS
  - RESET_NEG
  - J22

- 6N135 high-speed optocoupler (Vishay Semiconductors)
  - U16
PacMan BoB Layout Errata
Roadmap Cont.

5. Tractive System Voltage (TSV)
   a. Overview
   b. Safety
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. **Acceptance Testing**
      i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
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
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
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 A
  - 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.

5. Tractive System Voltage (TSV)
   a. Overview
   b. Safety
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. Acceptance Testing
      i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
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
# TSV BOM & Budget

<table>
<thead>
<tr>
<th></th>
<th>AMS</th>
<th>PacMan</th>
<th>BOB Parts</th>
<th>Pack Electrical Parts</th>
<th>Grand Total Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total TSV Budget Required</strong></td>
<td>$430.38</td>
<td>$674.15</td>
<td>$223.75</td>
<td>$1,263</td>
<td>$2,590.95</td>
</tr>
</tbody>
</table>

- **Total Given Budget:** $2,739.10
- **Spent So Far:** $1,026.03
- **Remaining Budget:** $1,713.07
### AMS (Accumulator Management System)

<table>
<thead>
<tr>
<th>Vendor Part# / Order#</th>
<th>Description</th>
<th>Unit Price</th>
<th>QTY</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>4048772</td>
<td>Advanced Circuit PCB-30 AMS Boards</td>
<td>$0.32</td>
<td>30</td>
<td>$9.60</td>
</tr>
<tr>
<td><strong>Mouser</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>538-70543-0040</td>
<td>6-PIN SL Locking Header, tin-plate (J2, J3)</td>
<td>$0.74</td>
<td>20</td>
<td>$14.80</td>
</tr>
<tr>
<td>538-50-57-9706</td>
<td>6-PIN SL Locking Plug w/TPA (for J2, J3)</td>
<td>$0.75</td>
<td>20</td>
<td>$15.00</td>
</tr>
<tr>
<td>538-73838-0006</td>
<td>6-PIN SL TPA Piece (for J2, J3)</td>
<td>$0.26</td>
<td>20</td>
<td>$5.20</td>
</tr>
<tr>
<td>538-16-02-0096</td>
<td>SL Socket 24-30 AWG</td>
<td>$0.06</td>
<td>100</td>
<td>$6.00</td>
</tr>
<tr>
<td>567-657-15ABPN</td>
<td>TO-220 Vertical Board Mount Heatsink</td>
<td>$1.31</td>
<td>10</td>
<td>$13.10</td>
</tr>
<tr>
<td>652-PWR220T-20-R750F</td>
<td>TO-220 Resistor 20watt 0.75ohms 1% (RPOW)</td>
<td>$4.00</td>
<td>10</td>
<td>$40.00</td>
</tr>
<tr>
<td>567-173-7-220P</td>
<td>Thermal Interface Pad TO-220.007&quot; GRAY (for Q1, RPOW)</td>
<td>$0.42</td>
<td>17</td>
<td>$7.14</td>
</tr>
<tr>
<td>532-7721-7PPS</td>
<td>Insul Shoulder Washer (for No. 4 screw)</td>
<td>$0.18</td>
<td>15</td>
<td>$2.70</td>
</tr>
<tr>
<td>579-PIC16LF1827-I/SO</td>
<td>PIC16LF1827 8-bit Microcontroller (U4)</td>
<td>$1.72</td>
<td>8</td>
<td>$13.76</td>
</tr>
<tr>
<td>652-SRN8040-100M</td>
<td>SMD Inductor 10uH 20% (L1)</td>
<td>$0.39</td>
<td>20</td>
<td>$7.80</td>
</tr>
<tr>
<td>859-LTV-357T</td>
<td>Transistor Output Isolator (U6)</td>
<td>$0.19</td>
<td>20</td>
<td>$3.80</td>
</tr>
<tr>
<td>634-S18600AB-B-IS</td>
<td>Silicon Labs Dual 12C Isolator Interface (U7)</td>
<td>$3.18</td>
<td>8</td>
<td>$25.44</td>
</tr>
<tr>
<td>579-MCP1825S-3302EDB</td>
<td>LDO Voltage Regulators 500 mA 3.3V (U3)</td>
<td>$0.51</td>
<td>9</td>
<td>$4.59</td>
</tr>
<tr>
<td><strong>Digikey</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT1307BCS#PBF-NDB</td>
<td>LT1307B</td>
<td>$2.75</td>
<td>4</td>
<td>$11.00</td>
</tr>
<tr>
<td>TIP102TU-NDD</td>
<td>TRANS NPN DARL 100V 8A TO-220 (U2)</td>
<td>$0.73</td>
<td>1</td>
<td>$0.73</td>
</tr>
<tr>
<td>MCP9700AT-E/TTCT-NDD</td>
<td>IC Sensor Thermal 2.3V SOT-23-3 (U5A, USB)</td>
<td>$0.25</td>
<td>11</td>
<td>$2.75</td>
</tr>
<tr>
<td>MBR0620LTCT-NDD</td>
<td>Diode Schottky 20V 500MA SOD123 (D1)</td>
<td>$0.23</td>
<td>2</td>
<td>$0.46</td>
</tr>
<tr>
<td>MCP6242-E/NSN</td>
<td>IC Opamp GP 550KHz PRO 8SOIC (U1)</td>
<td>$0.30</td>
<td>5</td>
<td>$1.50</td>
</tr>
<tr>
<td>655K-NDD</td>
<td>Banana Plug</td>
<td>$1.72</td>
<td>3</td>
<td>$5.16</td>
</tr>
<tr>
<td>RMCF0805FT20KCT-NDD</td>
<td>20K 0805 SMD Resistor 1% 1/8W</td>
<td>$0.016</td>
<td>50</td>
<td>$0.81</td>
</tr>
</tbody>
</table>

**AMS Total:** $430.38
## PacMan & BOB

### PacMan (Pack Manager)

<table>
<thead>
<tr>
<th>Vendor Part# / Order#</th>
<th>Description</th>
<th>Unit Price</th>
<th>QTY</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS-1498XV2-255-2045R-1Dev</td>
<td>Microcontroller TS-7802-L2</td>
<td>$12.98</td>
<td>4</td>
<td>$51.92</td>
</tr>
<tr>
<td>9GB-MSD04GCS4P-1TM</td>
<td>Micro SD Card 4GB Class 10 Industrial</td>
<td>$10.54</td>
<td>4</td>
<td>$42.15</td>
</tr>
</tbody>
</table>

**PacMan Total: $674.15**

### BOB (Breakout Board)

<table>
<thead>
<tr>
<th>Vendor Part# / Order#</th>
<th>Description</th>
<th>Unit Price</th>
<th>QTY</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>PCB for BOB boards</td>
<td>$10</td>
<td>6</td>
<td>$60</td>
</tr>
<tr>
<td>998-MIC4680-5.0YM</td>
<td>Switching Regulators 1.3A SuperSwitcher in SO-8 (Lead Free)</td>
<td>$4.23</td>
<td>3</td>
<td>$12.69</td>
</tr>
<tr>
<td>LTC4151CS-2#PBF-ND</td>
<td>IC CURRENT MONITOR(12BIT) 16SOIC</td>
<td>$5.55</td>
<td>4</td>
<td>$22.20</td>
</tr>
<tr>
<td>MCP6242-E/JSN</td>
<td>Switching Regulators 1.3A SuperSwitcher in SO-8 (Lead Free) (also in AMS)</td>
<td>$4.23</td>
<td>5</td>
<td>$21.15</td>
</tr>
<tr>
<td>859-LTV-357T</td>
<td>Transistor Output Optocouplers (also in AMS)</td>
<td>$0.19</td>
<td>2</td>
<td>$0.38</td>
</tr>
<tr>
<td>584-ADM1232ARN</td>
<td>ADM1232 Watchdog Timer SOIC-8</td>
<td>$2.53</td>
<td>2</td>
<td>$5.06</td>
</tr>
<tr>
<td>849-LDA210S</td>
<td>LDA210 Dual Optoisolator/Darlington Pair SIP-8</td>
<td>$1.83</td>
<td>2</td>
<td>$3.66</td>
</tr>
<tr>
<td>771-HCT4002D118</td>
<td>Single 4 Input NOR/OR Gate SOIC-8</td>
<td>$0.50</td>
<td>2</td>
<td>$1.00</td>
</tr>
<tr>
<td>653-G6B-1114P-DCS</td>
<td>SPST 5V PCB Relay</td>
<td>$0.16</td>
<td>2</td>
<td>$0.32</td>
</tr>
<tr>
<td>ADM2483BRWZ</td>
<td>Half Duplex RS-485 Isolator</td>
<td>$6.84</td>
<td>2</td>
<td>$13.68</td>
</tr>
<tr>
<td>511-74LCX07YMTT</td>
<td>M74HC07 Hex Open-Drain Buffer SOIC-14</td>
<td>$0.52</td>
<td>2</td>
<td>$1.04</td>
</tr>
<tr>
<td>652-SRU1028-680Y</td>
<td>SMD Inductor 68uH 30%</td>
<td>$0.75</td>
<td>2</td>
<td>$1.50</td>
</tr>
<tr>
<td>P2N2222AG0-ND</td>
<td>P2N2222A NPN BJT Transistor 600ma</td>
<td>$0.50</td>
<td>2</td>
<td>$1.00</td>
</tr>
<tr>
<td>621-B260A-5F</td>
<td>B260A Schottky Diodes</td>
<td>$0.47</td>
<td>2</td>
<td>$0.94</td>
</tr>
<tr>
<td>512-1N4148</td>
<td>D1N4148 Diode Through Hole</td>
<td>$0.10</td>
<td>6</td>
<td>$0.60</td>
</tr>
<tr>
<td>810-C3216X5R1V226M</td>
<td>22uF SM Ceramic Capacitor 1206</td>
<td>$1.26</td>
<td>2</td>
<td>$2.52</td>
</tr>
<tr>
<td>598-AVE227M16X16F-5</td>
<td>220uF Electrolytic Capacitor Surface Mount 16V</td>
<td>$0.51</td>
<td>2</td>
<td>$1.02</td>
</tr>
<tr>
<td>538-70543-0013</td>
<td>Headers &amp; Wire Housings 14 POS SHROUD HDR</td>
<td>$3.50</td>
<td>5</td>
<td>$17.50</td>
</tr>
<tr>
<td>538-50-57-9414</td>
<td>Headers &amp; Wire Housings HSG 14P SINGLE ROW POSITIVE LATCH</td>
<td>$0.87</td>
<td>10</td>
<td>$8.70</td>
</tr>
<tr>
<td>517-D3408-6202-AR</td>
<td>16-PIN Shrouded Header</td>
<td>$1.99</td>
<td>3</td>
<td>$5.97</td>
</tr>
<tr>
<td>517-3452-6000</td>
<td>16-PIN Plug</td>
<td>$3.23</td>
<td>6</td>
<td>$19.38</td>
</tr>
<tr>
<td>517-D3793-6202-AR</td>
<td>10-PIN Shrouded Header</td>
<td>$1.44</td>
<td>2</td>
<td>$2.88</td>
</tr>
<tr>
<td>517-3473-6000</td>
<td>10-PIN Plug</td>
<td>$2.64</td>
<td>4</td>
<td>$10.56</td>
</tr>
</tbody>
</table>

**BOB Total: $223.75**
<table>
<thead>
<tr>
<th>Vendor Part#/ Order#</th>
<th>Description</th>
<th>Unit Price</th>
<th>QTY</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>G3475534</td>
<td>Fuse, 200A, Class T, A3A, 300VAC/160VDC</td>
<td>$28.34</td>
<td>2</td>
<td>$56.68</td>
</tr>
<tr>
<td>G1878003</td>
<td>Fuse Holder, 200A AC, 300V, 1 Pole, Molded</td>
<td>$68.99</td>
<td>2</td>
<td>$137.98</td>
</tr>
<tr>
<td>504-BK/HKP-R</td>
<td>Cooper Bussmann AGC 30A/250V Fuse Holder</td>
<td>$4.72</td>
<td>6</td>
<td>$28.32</td>
</tr>
<tr>
<td>504-C10G0.5</td>
<td>Fuse, Bussman .5A/500V</td>
<td>$13.26</td>
<td>6</td>
<td>$79.56</td>
</tr>
<tr>
<td>5912-4414F</td>
<td>Fans 119x25 24DC 100CFM 5W 2900RPM 43 dBA BB</td>
<td>$33.58</td>
<td>2</td>
<td>$67.16</td>
</tr>
<tr>
<td>562-0945030</td>
<td>Fan Accessories BLK FLTR ASSM 4.65”</td>
<td>$2.08</td>
<td>2</td>
<td>$4.16</td>
</tr>
<tr>
<td>562-09123-G</td>
<td>Fan Accessories PLASTIC GUARD 120MM</td>
<td>$1.21</td>
<td>3</td>
<td>$3.63</td>
</tr>
<tr>
<td>GX14CB</td>
<td>AIR - 350A Contractor, 24VDC coil, 24-in flying leads, no auxiliary contact</td>
<td>$94.35</td>
<td>1</td>
<td>$94.35</td>
</tr>
<tr>
<td>Waytek 124-903 124-11411</td>
<td>POWER RELAY CONTACOR 24V 100A SPNO WHITE-RODGERS 124-903</td>
<td>$34.96</td>
<td>3</td>
<td>$104.88</td>
</tr>
<tr>
<td>Newark 44W4342</td>
<td>Panel Drain, Line 3, Grey</td>
<td>$74.10</td>
<td>2</td>
<td>$148.20</td>
</tr>
<tr>
<td>Newark 44W4365</td>
<td>Panel Source, Neutral, Blue</td>
<td>$50.62</td>
<td>2</td>
<td>$101.24</td>
</tr>
<tr>
<td>0FR0189</td>
<td>LCD Character Display Module STM786</td>
<td>$25.00</td>
<td>3</td>
<td>$75.00</td>
</tr>
<tr>
<td>571-14807030</td>
<td>Pin &amp; Socket Connectors CAP HOUSE 4 POS</td>
<td>$0.20</td>
<td>50</td>
<td>$10.00</td>
</tr>
<tr>
<td>571-14807050</td>
<td>Pin &amp; Socket Connectors CAP HOUSE 6 POS</td>
<td>$0.32</td>
<td>50</td>
<td>$16.00</td>
</tr>
<tr>
<td>571-32950</td>
<td>Insul. Ring Terminal, 18 AWG, #6/M3 stud</td>
<td>$0.29</td>
<td>25</td>
<td>$7.25</td>
</tr>
<tr>
<td>538-19070-0121</td>
<td>Insul. Ring Terminal, 10-12 AWG, #8/M4 stud</td>
<td>$0.20</td>
<td>25</td>
<td>$5.00</td>
</tr>
<tr>
<td>571-35492</td>
<td>Insul. Ring Terminal, 12-10 AWG #1/4 /M6 stud</td>
<td>$0.56</td>
<td>10</td>
<td>$5.60</td>
</tr>
<tr>
<td>579-MCP9700A-E/TO-ND</td>
<td>Board Mount Temperature Sensors Lin Active Therm</td>
<td>$0.37</td>
<td>4</td>
<td>$1.48</td>
</tr>
<tr>
<td>517-9602207102AR</td>
<td>Headers &amp; Wire Housings 20P SIDE ENT DR SKT</td>
<td>$3.18</td>
<td>3</td>
<td>$9.54</td>
</tr>
<tr>
<td>517-9602406303AR</td>
<td>Headers &amp; Wire Housings 40P STR SR BDMNT SKT 3.5MM TAIL/8.5MM BODY</td>
<td>$4.85</td>
<td>3</td>
<td>$14.55</td>
</tr>
<tr>
<td>879-1470G1</td>
<td>Heavy Duty Power Connectors PP PAK 2-4P HSG SNAP-IN RECEPT</td>
<td>$2.10</td>
<td>4</td>
<td>$8.40</td>
</tr>
<tr>
<td>879-1327FF</td>
<td>Heavy Duty Power Connectors PP15/45 FINGERPROOF HOUSING ONLY, RED</td>
<td>$0.85</td>
<td>3</td>
<td>$2.55</td>
</tr>
<tr>
<td>879-1327G6FP</td>
<td>Heavy Duty Power Connectors PP15/45 FINGERPROOF HOUSING ONLY, BLACK</td>
<td>$0.82</td>
<td>3</td>
<td>$2.46</td>
</tr>
<tr>
<td>879-269G1-1LBP        Heavy Duty Power Connectors PP30 HD LOOSE CONF #12-16 AWG</td>
<td>$0.70</td>
<td>3</td>
<td>$2.10</td>
<td></td>
</tr>
<tr>
<td>879-4827G6</td>
<td>Heavy Duty Power Connectors PPMX 2-PIECE BLACK HOUSING ONLY</td>
<td>$0.80</td>
<td>3</td>
<td>$2.40</td>
</tr>
<tr>
<td>879-261G2</td>
<td>Heavy Duty Power Connectors PP45 REELED CONTACT #10-14 AWG, TIN</td>
<td>$0.16</td>
<td>25</td>
<td>$4.00</td>
</tr>
<tr>
<td>Part Number</td>
<td>Description</td>
<td>Quantity</td>
<td>Unit Price</td>
<td>Total</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------------------------------------------------</td>
<td>----------</td>
<td>------------</td>
<td>---------</td>
</tr>
<tr>
<td>571-5550521</td>
<td>Ethernet Connectors 8 COUPLER IN-LINE</td>
<td></td>
<td>$7.02</td>
<td>$14.04</td>
</tr>
<tr>
<td>651-5602099</td>
<td>15mm DIN Rail Perf</td>
<td></td>
<td>$9.64</td>
<td>$9.64</td>
</tr>
<tr>
<td>651-3100305</td>
<td>MT1.5 Feed-Thru DIN Rail Terminal Block</td>
<td></td>
<td>$2.62</td>
<td>$52.40</td>
</tr>
<tr>
<td>651-3001682</td>
<td>MT1.5 Twin DIN Rail Terminal Block</td>
<td></td>
<td>$4.62</td>
<td>$13.86</td>
</tr>
<tr>
<td>651-3100318</td>
<td>MT1.5 PE Ground Din Rail Terminal Block</td>
<td></td>
<td>$8.42</td>
<td>$8.42</td>
</tr>
<tr>
<td>651-3100321</td>
<td>MT1.5 End Plate</td>
<td></td>
<td>$0.78</td>
<td>$2.34</td>
</tr>
<tr>
<td>651-3002979</td>
<td>MT1.5 Twin End Plate</td>
<td></td>
<td>$1.34</td>
<td>$4.02</td>
</tr>
<tr>
<td>651-1402940</td>
<td>MBKS/EZ Feed-Thru DIN Rail Terminal Block</td>
<td></td>
<td>$3.15</td>
<td>$18.90</td>
</tr>
<tr>
<td>651-1415021</td>
<td>MBKS/EZ End Plate</td>
<td></td>
<td>$0.97</td>
<td>$1.94</td>
</tr>
<tr>
<td>651-1421659</td>
<td>DIN 15 End Clamp</td>
<td></td>
<td>$1.28</td>
<td>$5.12</td>
</tr>
<tr>
<td>298-G75X75LG72-ND</td>
<td>Wire Ducting TYPE G .75 X .75 6-FOOT SECTION</td>
<td></td>
<td>$28.56</td>
<td>$28.56</td>
</tr>
<tr>
<td>651-1725711</td>
<td>Fixed Terminal Blocks 8P 2.54mm 90DEG</td>
<td></td>
<td>$5.40</td>
<td>$10.80</td>
</tr>
<tr>
<td>651-1725656</td>
<td>Fixed Terminal Blocks 2P 2.54mm 90DEG</td>
<td></td>
<td>$1.42</td>
<td>$4.26</td>
</tr>
<tr>
<td>651-1725669</td>
<td>Fixed Terminal Blocks 3P 2.54mm 90DEG</td>
<td></td>
<td>$2.16</td>
<td>$8.64</td>
</tr>
<tr>
<td>571-3506891</td>
<td>Pin &amp; Socket Connectors SOCKET 24-18 AWG</td>
<td></td>
<td>$0.085</td>
<td>$8.50</td>
</tr>
<tr>
<td>571-3506901</td>
<td>Pin &amp; Socket Connectors PIN 24-18 AWG</td>
<td></td>
<td>$0.088</td>
<td>$8.80</td>
</tr>
<tr>
<td>538-16-02-0096</td>
<td>SL Socket 24-30 AWG</td>
<td></td>
<td>$0.10</td>
<td>$10.00</td>
</tr>
<tr>
<td>651-3001624</td>
<td>FB RN 10-4 N Fixed Bridge (10 Position)</td>
<td></td>
<td>$7.90</td>
<td>$7.90</td>
</tr>
<tr>
<td>298-C75LG72-ND</td>
<td>Wire Ducting COVER 3/4&quot; 6-FOOT SECTION</td>
<td></td>
<td>$8.46</td>
<td>$8.46</td>
</tr>
<tr>
<td>651-0203250</td>
<td>FBI10-6 Fixed Bridge for 6.2mm DIN blocks</td>
<td></td>
<td>$9.86</td>
<td>$9.86</td>
</tr>
<tr>
<td>782-ILD755-1X017</td>
<td>Transistor Output Optocouplers Photodarlington</td>
<td></td>
<td>$2.77</td>
<td>$11.08</td>
</tr>
<tr>
<td>156-1409-E</td>
<td>D-SUB CRIMP FEMALE 9P</td>
<td></td>
<td>$0.56</td>
<td>$1.12</td>
</tr>
<tr>
<td>156-1401-E</td>
<td>D-SUB CRIMP PIN FM</td>
<td></td>
<td>$0.10</td>
<td>$2.00</td>
</tr>
<tr>
<td>164-9007-E</td>
<td>IDC SOCKET 14 PIN W/STRAIN RELIEF</td>
<td></td>
<td>$0.65</td>
<td>$1.30</td>
</tr>
<tr>
<td>164-9008-E</td>
<td>IDC SOCKET 16 PIN W/STRAIN RELIEF</td>
<td></td>
<td>$0.61</td>
<td>$1.22</td>
</tr>
</tbody>
</table>

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

- Initially allocated money:
  - Dyno - $148
  - SCADA - $715
  - GLV - $1397.90
  - TSV - $2739.10
Budget

- Money Spent so far
  - Dyno - $362
  - TSV - $1026.03
  - SCADA - $304.26
  - GLV - $10.24
Budget

Current status of money:
Roadmap Cont.

5. Tractive System Voltage (TSV)
   a. Overview
   b. Safety
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. Acceptance Testing
   i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
Out of Scope: LFEV-2016

- GLV
  1. Implement AIR failure sensors
  2.
Out of Scope: LFEV-2016 Cont.

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

6. Tractive System Voltage (TSV)
   a. Overview
   b. Safety
   c. Mechanical
   d. PacMan System
   e. Charging
   f. AMS
   g. BoB
   h. Acceptance Testing
   i. Maintenance

6. Out of Scope: LFEV-2016

7. Conclusion
Conclusion