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
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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6. 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
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Introduction: Motivation

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

- **Competition Ready:**
  - TSV
  - Integrated VSCADA Software
  - GLV Electrical

- **Interfaced Dynamometer System**

- **Mechanical Design on a Chassis**
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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
Physical Interfaces Layout - Side View
Physical Interfaces Layout - Top View
End-of-Term Integration Layout
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

- **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
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

- Internally Hardwired Connections
  - Less Cables
  - Less Connections

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

- Powerlock Connectors
- Bolt Terminals
  - Pre-existing
Semester Integration Layout
Semester Integration Physical Interfaces
Physical Interfaces

- GLV Power Panel
  - Low Voltage Battery Indicators
  - GLV Power Switch
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
State Transition Diagram

- No External GLV of TSV
  - GLV Battery OK
  - Power Box Manual Switch
    - GLV24 External
    - GLV Master Switch
    - Side BRB Disabled
  - AND

- GLV 12 Volts Distributed
  - VSCADA Boot
  - CAN Interface Board Boot
  - System Sensor Check
    - Data Systems Good
    - Close VSCADA’s SL Relay
    - Safety Loop Closed
    - AND

- Safety Circuit Powered into Open State
  - IMD OK
  - TS Master Switch
  - PACMAN Relays
    - Side Panel Reset

- Cockpit Ready
  - Cockpit BRB Disabled
  - Cockpit Reset
  - AND

- Good-to-Go
  - RTD Key Start
  - TSV Voltage OK

- AND
  - Engage Load Controller
  - Precharge Complete
  - Full Power to Load
    - Motor Controller OK
    - Ready-to-Drive

System Off

GLV24 (Safety Loop Open)

Safety Loop Closed

AIRs Closed
State Transition Diagram - System Off
State Transition Diagram - GLV24

- No External GLV of TSV
- GLV24 External
  - GLV Battery OK
  - Power Box Manual Switch
  - Side BRB Disabled
  - GLV Master Switch

- System Off

- GLV24

- Rack
  - Safety Loop Reset
  - SL Closed
  - GLV24
  - GLV Master Switch
  - Left BRB
  - Right BRB

- Cockpit
  - Side Panel
  - SL
  - GLVPO
  - Pedals

- GLV Power
  - Charge Port
  - GLVPO
  - Chassis Ground
State Transition Diagram - GLV24
State Transition Diagram - GLV Power and Data

- No External GLV of TSV
  - GLV Battery OK
  - Power Box Manual Switch

- GLV24 External
  - Side BRB Disabled
  - GLV Master Switch

- GLV 12 Volts Distributed
  - VSCADA Boot
  - CAN Interface Board Boot

- Safety Circuit Powered Into Open State

- System Off

- GLV24

- GLV12 (Safety Loop Open)
State Transition Diagram - GLV Power and Data
State Transition Diagram - Safety Loop Closing

No External GLV of TSV
- GLV Battery OK
- Power Box Manual Switch
- Side BRB Disabled
- GLV Master Switch

GLV24 External
- GLV 12 Volts Distributed
- CAN Interface Board Boot
- VSCADA Boot
- System Sensor Check
- Data Systems Good
- Close VSCADA's SL Relay

GLV12 (Safety Loop Open)
- Safety Circuit Powered into Open State
- IMD OK
- PACMAN Relays
- TS Master Switch
- Side Panel Reset
- Safety Loop Closed

Cockpit Ready
- Cockpit BRB Disabled
- Cockpit Reset
- System OK
- RTD
- CPR

Safety Loop Closed

System Off

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State Transition Diagram - Ready to Drive
State Transition Diagram

No External GLV of TSV

GLV24 External

GLV 12 Volts Distributed

Safety Circuit Powered into Open State

Cockpit Ready

System Sensor Check

AND

Data Systems Good

IMD OK

PACMAN Relays

TS Master Switch

Cockpit Ready

Cockpit Reset

Safety Loop Closed

Close VSCADA’s SL Relay

Side Panel Reset

Side BRB Disables

GLV Master Switch

Power Box Manual Switch

AND

AND

GLV24

GLV12 (Safety Loop Open)

Safety Loop Closed

AIRs Closed

Good-to-Go

RTD Key Start

TSB Voltage OK

Engage Load Controller

Precharge Complete

Full Power to Load

Ready-to-Drive

Separate Accelerator and Motor Controller

Mineral Current to Load

Open Load Controller

RTD Key OFF

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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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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
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

TOLERANCE EXCEPT AS NOTED:
- 3 PLACE DECIMAL: +/- .001
- 2 PLACE DECIMAL: +/- .02
- FRACTIONAL: +/- 1/32
- DEBUR ALL SHARP EDGES

MATERIAL:
- DWG.#
- REV.
- QUANTITY NEEDED:
- FILENAME: CockpitPanel.tmp
- PART NO: CockpitPanel
- DRAWN BY:
- SCALE:
- DATE:

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Safety Circuit PCB
## Shutdown Priority Table

### Controlled Systems

<table>
<thead>
<tr>
<th>Shutdown Sources</th>
<th>GLV Supply to: Instrumentation, Data Acquisition, Computers, Telemetry, Etc.</th>
<th>AIRs (TS Voltage)</th>
</tr>
</thead>
<tbody>
<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>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>GLVMS</td>
<td>OFF</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.
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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.

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.
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 4) = 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><strong>3.3525Ah 3hr</strong></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>Component</th>
<th>Power Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLV Relays</td>
<td>(2.04W x 2) = 4.08W + 1W</td>
</tr>
<tr>
<td>AIRS</td>
<td>(2.04W x 4) = 8.16W + ~100mW (CAN transceivers)</td>
</tr>
<tr>
<td>VSCADA</td>
<td>5.28W computer + 4W screen</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>25.52W / 24V = 1.06A x 1.5 =</strong></td>
</tr>
</tbody>
</table>

- **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.
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

- Power Supply (AC-to-DC)
- DC-to-DC
- "Charging" LED Off
- "Battery Power" LED On
- 24V
  - <1.06A
  - ~0.745A
- ~24V
- 27K
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.
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 $<42V$. 
Power Box Fusing

EV6.1.1 All electrical systems must be appropriately fused.

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

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

7A, 35VDC fuse
Voltage Sensing

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

< 28V

112K

< 5V

28K

Arduino

< 28V

< 5V
GLV Power Charging States

R006-2v The GLV battery shall be protected from full discharge and overcharge.
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).
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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Vehicle Computer Interface
Vehicle Computer Interface (VCI)

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

- Components:
  - VSCADA Computer
  - CAN Interface Board (JGB)
  - Relay/TSAL PCB
  - LCD Interface Board
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
- Physical TSAL
  Lamp not included
  ○ Tested using DDM
  ○ Expected output:
    ■ 12V
    ■ 52% duty cycle
    ■ 0.2911 second period
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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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 - 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
TSI - Precharge/Relay Control

Precharge Circuit

**Component Diagram**

- **U1**: Inverter_two
- **U2**: 555_Timer
- **U4**: Inverter_two
- **U3**: NE555
- **J11**: R_HV, R_LOAD
- **RELAY_DK1a**: RLY2, RELAY_DK1a
- **HEADER_IR**: IR_Trig, nOpen_IR
- **IC1**: PrChrg

**Connections**

- START
- OUT
- GND
- VCC
- DIS, THR
- CY, GND
- LV, HV
- PrChrg
- nOpen_IR
- IR_Trig
- R_HV, R_LOAD
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
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 $A = \frac{5}{85} = 0.588235$
    - $R1 = 1\,\Omega$
    - $R2 = 62.5\,k\Omega$
    - $A = 0.058824$

- Resulting Outputs
  - 115V -to- 6.765V
  - 30V -to- 1.76472V
    - (This must be the reference voltage)
TSI - IMD

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

- Connect high voltage terminals to the high voltage power source
- Connect the high voltage load terminals to the high voltage load
- Connect the GLV24 terminal to a low voltage 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
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
Side Controls Panel

- Designed for testing purposes
Side Controls Panel Drawing

<table>
<thead>
<tr>
<th>HOLE</th>
<th>XDIM</th>
<th>YDIM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>6.06</td>
<td>2.00</td>
<td>20.88 THRU</td>
</tr>
<tr>
<td>A2</td>
<td>3.56</td>
<td>2.00</td>
<td>20.88 THRU</td>
</tr>
<tr>
<td>A3</td>
<td>3.56</td>
<td>5.00</td>
<td>20.88 THRU</td>
</tr>
<tr>
<td>B1</td>
<td>5.15</td>
<td>5.00</td>
<td>20.32 THRU</td>
</tr>
<tr>
<td>B2</td>
<td>6.80</td>
<td>5.00</td>
<td>20.32 THRU</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hole</th>
<th>Name</th>
<th>XDIM</th>
<th>YDIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Master Switch</td>
<td>10.07</td>
<td>5.14</td>
</tr>
<tr>
<td>C2</td>
<td>Master Switch</td>
<td>10.07</td>
<td>1.86</td>
</tr>
</tbody>
</table>

TOLERANCE EXCEPT AS NOTED:
3 PLACE DECIMAL: +/- .001
2 PLACE DECIMAL: +/- .02
FRACTIONAL: +/- 1/32
DEBUR ALL SHARP EDGES

MATERIAL: 1/4 6061 Sheet - 7x18
DWG.#: L15-GLV-1A
QUANTITY NEEDED: 1
PART NO: L15-GLV-1
FILENAME: SidePanel.png
DRAWN BY: Kaitan Ottaway
SCALE: 1:3
DATE: 3/5/15

LAFAYETTE COLLEGE ENGINEERING
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 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
## GLV Purchased 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>
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<td>$1.12</td>
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<tr>
<td>Te-Connectivity 3 pin/1 row parallel</td>
<td>1-480701-0</td>
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<td>$1.68</td>
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<td>1-480700-0</td>
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<td>Te-Connectivity 8 pin/2 row parallel</td>
<td>794954-8</td>
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<td>$1</td>
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<td>Te-Connectivity 8 pin/2 row free</td>
<td>794953-8</td>
<td>4</td>
<td>$0.25</td>
<td>$1</td>
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<tr>
<td>Te-Connectivity pin</td>
<td>350561-3</td>
<td>10</td>
<td>$0.14</td>
<td>$1.38</td>
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<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>
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<tr>
<td>DIN Rail DC/DC Converter</td>
<td>STMGFS152405-N2</td>
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<td>HRP-200-36</td>
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<td>DIN Rail</td>
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<td>DIN Rail Terminal Blocks</td>
<td>APC1281-ND</td>
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<td>$66.63</td>
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<td>SWITCH PUSH SPST-NO</td>
<td>CWI282-ND</td>
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<td>SWITCH KEYLOCK SP3T</td>
<td>KO129B606-ND</td>
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<td>$9.80</td>
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<tr>
<td>DIODE SCHOTTKY 45V 7A</td>
<td>SB15H45-E3/73GITB-ND</td>
<td>5</td>
<td>$1.36</td>
<td>$6.80</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>
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<tr>
<td>Relay 5A 5V</td>
<td>Z2774-ND</td>
<td>10</td>
<td>$1.18</td>
<td>$11.78</td>
</tr>
<tr>
<td>18-75v dc dc converter</td>
<td>MKW2633</td>
<td>1</td>
<td>$28.92</td>
<td>$28.92</td>
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<tr>
<td>24-12 DC DC converter</td>
<td>MKW1033</td>
<td>1</td>
<td>$30.57</td>
<td>$30.57</td>
</tr>
<tr>
<td>Panel Drain, Line 3, Grey</td>
<td>44W4361</td>
<td>2</td>
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<td>$98.70</td>
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<tr>
<td>Line Source, Line 3, Grey, 400A</td>
<td>44W4352</td>
<td>1</td>
<td>$58.17</td>
<td>$58.17</td>
</tr>
<tr>
<td>Panel source, earth, green, 400A</td>
<td>44W4363</td>
<td>1</td>
<td>$49.35</td>
<td>$49.35</td>
</tr>
<tr>
<td>Panel Mount Ethernet Extension</td>
<td>909</td>
<td>1</td>
<td>$4.95</td>
<td>$4.95</td>
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<tr>
<td>Panel Mount USB Cable</td>
<td>908</td>
<td>1</td>
<td>$3.95</td>
<td>$3.95</td>
</tr>
</tbody>
</table>

**Grand Total** $619.12
GLV Budget

Total Allocated Funds - $1397.90
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
Tractive System Voltage (changed)
Main subsystems

- Accumulator Management System (AMS)
- Breakout Board (BoB)
  - Microcontroller
- Seven 3.2V 60A-hr LiFePO4 Cells
7. Tractive System Voltage (TSV)
   a. Overview
   b. **Safety**
   c. Mechanical
   d. PacMan System
   e. Charging
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   g. BoB
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      i. Maintenance

8. Out of Scope: LFEV-2016

9. Conclusion
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**
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
Roadmap Cont.

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8. Out of Scope: LFEV-2016

9. 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
- $118\mu\Omega$ at STP
Roadmap Cont.

7. Tractive System Voltage (TSV)
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8. Out of Scope: LFEV-2016

9. Conclusion
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
Microcontroller (added)

Atmel

AT90CAN32

http://au.rs-online.com/web/p/microcontrollers/7153748/
Microcontroller Hardware Specs (changed)

- 8 ADC channels
- Watchdog
- I\(^2\)C bus for AMS and LCD communication
- CAN bus for VSCADA interface
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
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
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
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
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
Roadmap Cont.

7. Tractive System Voltage (TSV)
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8. Out of Scope: LFEV-2016

9. Conclusion
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
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
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
Roadmap Cont.

7. Tractive System Voltage (TSV)
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8. Out of Scope: LFEV-2016

9. Conclusion
Accumulators and AMS
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 I²C

- 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 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
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 $\rightarrow$ LFEV 2015 utilizing it
- Asserted by manual reset button through BoB
Roadmap Cont.

7. Tractive System Voltage (TSV)
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      i. Maintenance

8. Out of Scope: LFEV-2016

9. Conclusion
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)
Roadmap Cont.

7. Tractive System Voltage (TSV)
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8. Out of Scope: LFEV-2016

9. 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

[Diagram showing connectivity between Power Source, Load Resistor, Load Controller, and TSV Pack with labels such as 24V DC, Safety Loop, Pack+, Pack-]
Acceptance Testing Cont.

- Test configuration B
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
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.

7. Tractive System Voltage (TSV)
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8. Out of Scope: LFEV-2016

9. 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>
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<tbody>
<tr>
<td>Total TSV Budget Required</td>
<td>$430.38</td>
<td>$674.15</td>
<td>$223.75</td>
<td>$1,263</td>
<td>$2,590.95</td>
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</tbody>
</table>

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

### 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>4043772</td>
<td>Advanced Circuit PIC30 AMS Boards</td>
<td>$0.32</td>
<td>50</td>
<td>$16.00</td>
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<tr>
<td>Mouser</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>
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<td>20</td>
<td>$15.00</td>
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<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/0SO</td>
<td>PIC16LF1827 8-bit Microcontroller (U4)</td>
<td>$1.72</td>
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<td>$13.76</td>
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<tr>
<td>652-SRN8040-100M</td>
<td>SMD Inductor 10uH 20% (L1)</td>
<td>$0.39</td>
<td>20</td>
<td>$7.80</td>
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<tr>
<td>859-LTV-357T</td>
<td>Transistor Output Isolator (U6)</td>
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<td>634-SL600AAB-1S</td>
<td>Silicon Labs Dual I2C Isolator Interface (U7)</td>
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<td>579-MCP1825S-3302EDB</td>
<td>LDO Voltage Regulators 500 mA 3.3V (U3)</td>
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<td>Digikey</td>
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<td>LT1307BCS#PBF-NDD</td>
<td>LT1307B</td>
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<td>TIP102TU-NDD</td>
<td>TRANS NPN DARL 100V 8A TO-220 (U2)</td>
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<tr>
<td>MCP9700AT-E/TTCND</td>
<td>IC Sensor Thermal 2.3V SOT-23-3 (USA, USB)</td>
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<td>Diode Schottky 20V 500MA SOD123 (D1)</td>
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<td>MCP6242-E/SN</td>
<td>IC Opamp GP 550KHz PRO 8SOIC (U1)</td>
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<td>655K-NDD</td>
<td>Banana Plug</td>
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**AMS Total:** $430.38
# PacMan & BOB

## PacMan (Pack Manager)

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<td>TC-400E2-20E-304TV1-C2</td>
<td>Microcontroller TC7B02-E2</td>
<td>$29.90</td>
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<td>90B-MSD04GCS4P-1TM</td>
<td>Micro SD Card 4GB Class 10 Industrial</td>
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**PacMan Total:** $674.15

## BOB (Breakout Board)

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<td>N/A</td>
<td>PCB for BOB boards</td>
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<td>$60</td>
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<tr>
<td>998-MIC4680-5.0YM</td>
<td>Switching Regulators 1.3A SuperSwitcher in SO-8 (Lead Free)</td>
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<td>LTC4151CS-2#PBF-ND</td>
<td>IC CURRENT MONITOR(12BIT) 16SOIC</td>
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<td>MCP6242-E/SN</td>
<td>Switching Regulators 1.3A SuperSwitcher in SO-8 (Lead Free) (also in AMS)</td>
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<td>584-ADM1232ARN</td>
<td>ADM1232 Watchdog Timer SOIC-8</td>
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<td>849-LDA210S</td>
<td>LDA210 Dual Optoisolator/Darlington Pair SIP-8</td>
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<td>771-HCT4002D118</td>
<td>Single 4 Input NOR/OR Gate SOIC-8</td>
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<td>653-G6B-1114P-DCS</td>
<td>SPST 5V PCB Relay</td>
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<td>ADL2483BRWZ</td>
<td>Half Duplex RS-485 Isolator</td>
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<td>511-74LCX07YMT-R</td>
<td>M74HC07 Hex Open-Drain Buffer SOIC-14</td>
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<td>652-SRU1028-680Y</td>
<td>SMD Inductor 68uH 30%</td>
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<td>P2N2222AGOS-ND</td>
<td>P2N2222A NPN BJT Transistor 600ma</td>
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<td>621-B260A-F</td>
<td>B260A Schottky Diodes</td>
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<td>512-1N4148</td>
<td>D1N4148 Diode Through Hole</td>
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<td>810-C3216X5R1V226M</td>
<td>22uF SM Ceramic Capacitor 1206</td>
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<td>598-AVE227M16X16T-F</td>
<td>220uF Electrolytic Capacitor Surface Mount 16V</td>
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<td>538-70543-0013</td>
<td>Headers &amp; Wire Housings 14 POS SHROUD HDR</td>
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<td>538-50-57-9414</td>
<td>Headers &amp; Wire Housings HSG 14P SINGLE ROW POSITIVE LATCH</td>
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<td>517-D3408-6202-AR</td>
<td>16-PIN Shrouded Header</td>
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<td>517-3452-6000</td>
<td>16-PIN Plug</td>
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<td>517-D3793-6202-AR</td>
<td>10-PIN Shrouded Header</td>
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<td>517-3473-6000</td>
<td>10-PIN Plug</td>
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**BOB Total:** $223.75
# Pack Electrical Parts

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<th>Vendor Part# / Order#</th>
<th>Description</th>
<th>Unit Price</th>
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<tbody>
<tr>
<td>G3475 5534</td>
<td>Fuse, 200A, Class T, A3A, 300VAC/160VDC</td>
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<td>$56.68</td>
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<td>G1878003</td>
<td>Fuse Holder, 200A AC, 300V, 1 Pole, Molded</td>
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<td>504-BK/HKP-R</td>
<td>Cooper Bussmann AGC 30A/250V Fuse Holder</td>
<td>$4.72</td>
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<td>504-C10G0.5</td>
<td>Fuse, Bussman .5A/500V</td>
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<td>5912-4414F</td>
<td>Fans 119x25 24DC 100CFM SW 2900RPM 43dBA BB</td>
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<tr>
<td>562-0945030</td>
<td>Fan Accessories BLK FLTR ASSM 4.65&quot;</td>
<td>$2.08</td>
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<td>562-09123-G</td>
<td>Fan Accessories PLASTIC GUARD 120MM</td>
<td>$1.21</td>
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<td>$3.63</td>
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<tr>
<td>GX14CB</td>
<td>AIR - 350A Contractor, 24VDC coil, 24-in flying leads, no auxiliary contact</td>
<td>$94.35</td>
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<tr>
<td>Waytek 124-903 124-11411</td>
<td>POWER RELAY CONTACTOR 24V 100A SPNO WHITE-RODGERS 124-903</td>
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<td>Newark 44W4365</td>
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<td>OFR504-9040</td>
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<td>571-14807030</td>
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<td>879-1327FP</td>
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<td>879-1327G6FP</td>
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<td>879-269G1-LPBK</td>
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<td>879-4827G6</td>
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<td>879-261G2</td>
<td>Heavy Duty Power Connectors PP45 REELED CONTACT #10-14 AWG, TIN</td>
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### Pack Electrical Parts

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Quantity</th>
<th>Unit Price</th>
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<td>571-5550521</td>
<td>Ethernet Connectors 8 COUPLER IN-LINE</td>
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<td>651-5602099</td>
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<td>651-3001682</td>
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<td>651-3100318</td>
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**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 - $471.37
  ○ SCADA - $448.37
  ○ GLV - $618.99
  ○ TSV - $2152.08
Budget

- **Money Remaining:**
  - DYNO - $323.37
  - SCADA - $266.63
  - GLV - $778.91
  - TSV - $587.02
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
Out of Scope: LFEV-2016

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

Thanks for listening.

Any (more) questions?