

Lafayette College | Electrical and Computer Engineering

TSV Accumulator User Manual

ECE 492 Spring 2018

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Overview

This document details the use of, operation of, and technical information for the Tractive System Voltage (TSV) subsystem within the LFEV 2018 Electric Car project. All user interfaces, necessary functions and controls, troubleshooting techniques, calibration, and maintenance of the system over time is described in the respective sections below.

The TSV subsystem delivers the high voltage power in order to power the Formula SAE hybrid electric vehicle. Each pack or accumulator container, numbered 1-4, supplies around 24 V through seven LiFePO₄ battery cells which are all monitored through the accumulator management system (AMS). The AMS consists of a pack manager (PacMAN) computer and seven accumulator management system boards (AMS boards), one per cell. The four containers are wired in series to provide ~96 V in the assembled accumulator system. The subsystem interacts with other subsystems via data acquisition through CAN and via the vehicle's safety loop.

All information regarding the TSV subsystem (schematics, wiring diagrams, memos, firmware/hardware, etc), some of which is linked in this document, can be found on the 2017 LFEV website on the TSV page. See: <http://sites.lafayette.edu/ece492-sp18/subsystems/tsv/>

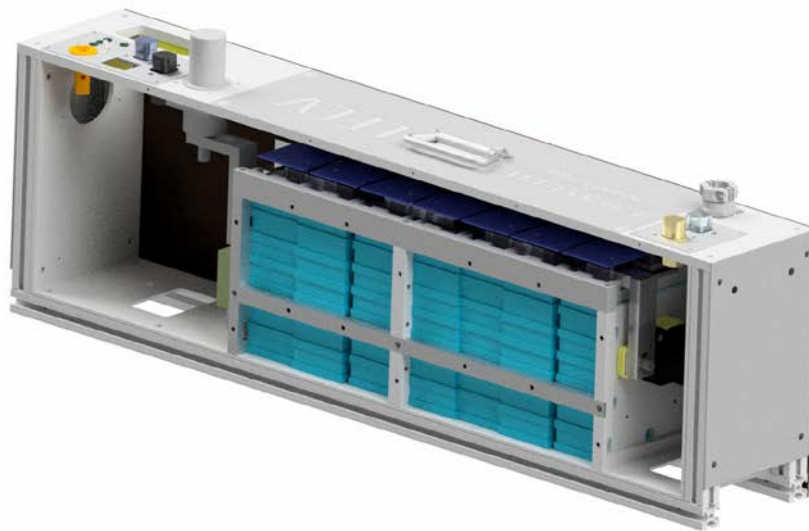


Figure 1. Mechanical rendering of a pack.

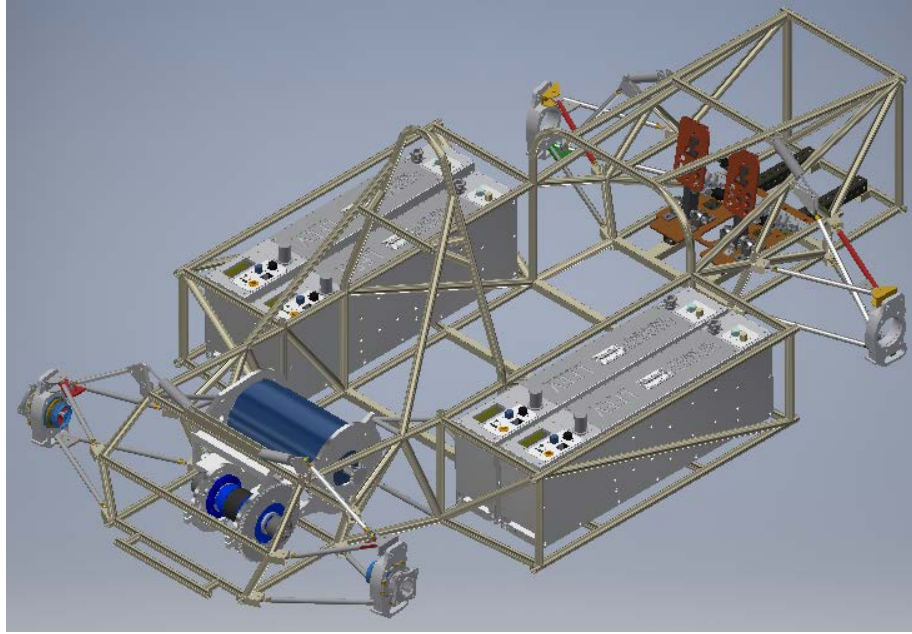


Figure 2. Mechanical rendering of the accumulator in the car.

FAQ

- 1) *What is an accumulator?* An accumulator, in the context of LFEV, is the connection of 4 “packs” to produce a nominal 96V to power the vehicle.
- 2) *What is a pack?* A single pack is $\frac{1}{4}$ of the LFEV-2018 TSV design. It provides 24V, contains 7 cells, 7 AMS boards, and 1 PacMAN. It is contained in an aluminum enclosure with an excessive amount of screws. A synonym for Pack is “Accumulator Container” in Formula hybrid lingo.
- 3) *What is an AMS?* AMS stands for Accumulator Management System. It encompasses the connection of AMS boards to a pack’s PacMAN board. These boards communicate through I2C where the PacMAN is the master and the AMS boards are the slaves.
- 4) *What is a PacMAN?* A PacMAN is the Pack Manager. It is used to aggregate cell data from its corresponding AMS boards. It then sends information such as state, SOC, cell voltage & temp, and safety loop status to the LCD.
- 5) *What is an AMS Board?* An AMS board is used to measure a Cell’s voltage and temperature and send this information to the PacMAN over I2C.
- 6) *What would happen if you dropped a pack off the top of Acopian?* It would break, don’t do this.
- 7) *What would happen if you drop something metal across a cell?* Joking aside, safety with regard to the packs is always a top priority. This would likely result in an arc flash. Only work on the packs utilizing the safety procedures outlined in the relevant documents linked in “Safety” section below. Note that there are two arrangements in which dropping something across the top of the pack. The following figures illustrate these arrangements.

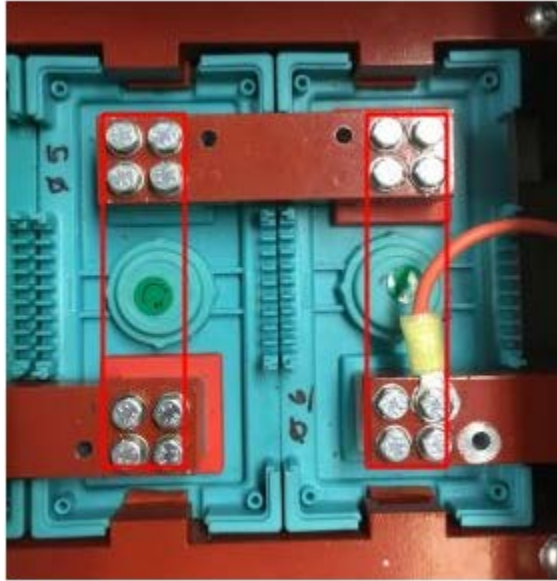


Figure 3. **WARNING DO NOT DO THIS** Short across one cell. Dropping something across the + and - terminals of a single cell, as can be seen with the red rectangles would short a cell.

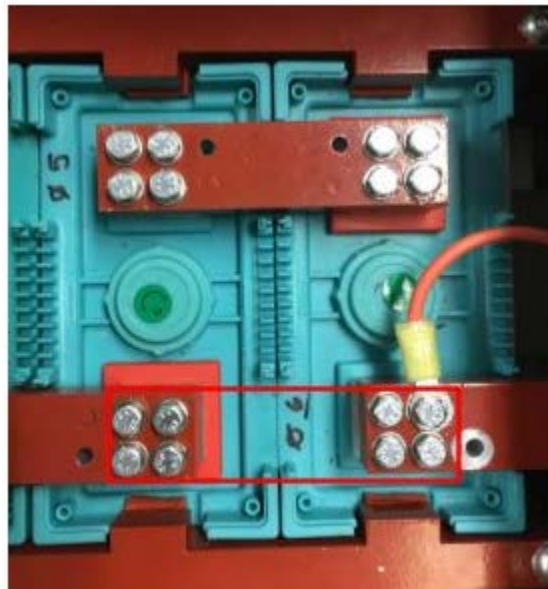


Figure 4. **WARNING DO NOT DO THIS** Short across two cells. Dropping something across the + terminal of one cell and the - terminal of another cell connected by a bus bar would short two cells.

Safety

The 2017 LFEV team utilized the safety procedures and guidelines set forth by previous LFEV teams. In general, personal protective equipment (PPE; consisting of eye protection, cotton clothing, close-toed shoes, etc) was utilized in a designated workspace with a 1 m barrier distance with a safety watch procedure enacted each time a pack was opened.

Safety documents detailing procedures, expectations and guidelines produced by previous LFEV teams and to which the 2017 LFEV team adhered can be found here:

<http://sites.lafayette.edu/ece492-sp15/files/2015/02/SafetyPlan.pdf>

<https://sites.lafayette.edu/ece492-sp16/files/2016/03/2016SafetyPlan.pdf>

Electrical System Components

The accumulator consists of four accumulator containers, which are also known as packs that are wired in series to provide high voltage power (96V nominal) for the vehicle. Each pack contains seven cells to provide approximately 24 V (each cell is 3.3V nominal). Each pack contains an AMS; the AMS consists of a PacMAN board and seven AMS boards. The PacMAN board acts as the “brain” for the AMS, controlling pack state, low current output, charging, pack/cell monitoring (voltage, current, state of charge, etc), safety loop and communication via CAN. The AMS boards monitor each cell’s temperature and voltage which is communicated to the PacMAN via I2C.

PacMAN



Figure 5. PacMAN Board (rev 0.8) that was utilized in the delivered accumulator system in the LFEV 2018 Spring semester. Pulled from Pack 4.

General

The PacMAN turns on around 12V, but should be normally operating between 20-24V. Power rails on the PacMAN consist of HV (the 20-24V), 5V_HV, isolated (GLV) 5V, and isolated (GLV) 3.3V.

Connectors

As the PacMAN implements many connectors in order to maintain its functionality as the brain of the AMS. These connections are described below.

HV

- P1, in the upper left, is used to supply power to the board.
- P2 and P6 in the middle on the left side of the board (both have 2 pins) are used to connect LCO and Charge from the Anderson Port on the top of the Pack. The one closer to the power connector is Charge, the one in the middle is LCO.
- P3 is directly below the LCO port and has 6 pins. This is used for the I2C protocol between the PacMAN and the AMS boards.
- J3 is the ethernet port to the right of P3. The high current sensor on the pack plugs into this port.

LV

- P4 to the right of J3, just above the unplaced reset button, is used to connect the PacMAN to the Control Panel. The pins are GPIOs.
- J2 on the absolute right hand side of the board is a 37 pin, right angle connector that causes problems due to its flakiness. This part will hopefully be replaced in rev 1.0 of the board. It is used in the safety loop and charge circuit.
 - P5 is the JTAG directly above the microcontroller. It is used to program the microcontroller. For more information, read the following https://sites.lafayette.edu/ece492-sp17/files/2017/01/PacMAN-Programming-Manual_2017.pdf

Isolation

The 24V HV must be isolated from the low voltage side of the board. To do this, the following parts are used:

- U7 - DC/DC converter used to step-down HV to an isolated 5V on the right hand side of the board.
- U8 - 12C isolator that steps down 5V_HV to 3.3V.
- Rly2 -Used in the charge circuit.

Functionality

The PacMAN board contains the main functionality within the AMS. This is listed below:

- Control Panel & Display: The PacMAN displays relevant information to the LCD screen in the control panel's display. The communication to the LCD and Control Panel occurs via I2C. Information displayed on the LCD and control panel functionality is described further in the "Control Panel & Display" section below.

- **Cell Monitoring:** The PacMAN communicates to the AMS boards via I2C to collect temperature and voltage information about each cell. This information is verified to be within appropriate cell and voltage limits (<60C, below 3.6V, above 2.7V). If this is not the case, the PacMAN detects a fault.
- **Pack Monitoring:** The PacMAN monitors the pack's current and voltage through sensors on the board and calculates the state of charge from this information. See <https://sites.lafayette.edu/ece492-sp16/files/2016/05/QAR001a.pdf> for further information on the currently implemented charging algorithm.
- **Pack State:** The PacMAN monitors the state of the pack (charging, dead, fault [0,1,2,3,4], low current output, ready, etc). The state machine utilized within the PacMAN firmware is shown within Figure 6 below. The 4 types of fault result for the following cases:
 - Fault 0: Cell temperature is too high
 - Fault 1: Cell voltage is too high
 - Fault 2: Pack voltage is too high
 - Fault 3: The pack cannot locate the correct number of cells / ams boards (configurable)
 - Fault 4: The pack has been locked using the configuration menu

Firmware

The most recent version of PacMAN firmware can be found here:

<https://sites.lafayette.edu/ece492-sp18/tsv/>

It is written in C for the ATMEL AT90CAN32 microcontroller. The documentation for microcontroller can be found here: <http://www.atmel.com/Images/doc7679.pdf>

The programming manual and details on required toolchain can be accessed here:

https://sites.lafayette.edu/ece492-sp17/files/2017/01/PacMAN-Programming-Manual_2017.pdf

The software is built on the AtomThreads RTOS. Atmel TWI and CAN libraries are utilized to achieve communication. All configurations (I2C addresses, CAN addresses, calibration factors) are stored in params.h. The code in main.c sets up tasks listed in tasklist.c and starts the RTOS. Functions that generate LCD screens are detailed in lcd.c. Functions that utilize TWI libraries to perform I2C communication are detailed in i2c.c. The remaining c files detail tasks that run continuously:

- Task_button.c : retrieves button presses on the control panel
- Task_can.c :- transmits CAN messages
- Task_charge.c : performs integration of current and calculates state of charge
- Task_config.c : performs state transitions
- Task_gui.c : calls function in lcd.c to set the display output
- Task_heartbeat.c : blinks an LED on PacMan to indicate the computer is operating
- Task_i2c.c : calls functions to perform I2C communication tasks
- Task_safety.c : opens and closes the safety loop relay
- Task_watchdog.c : resets off chip watchdog

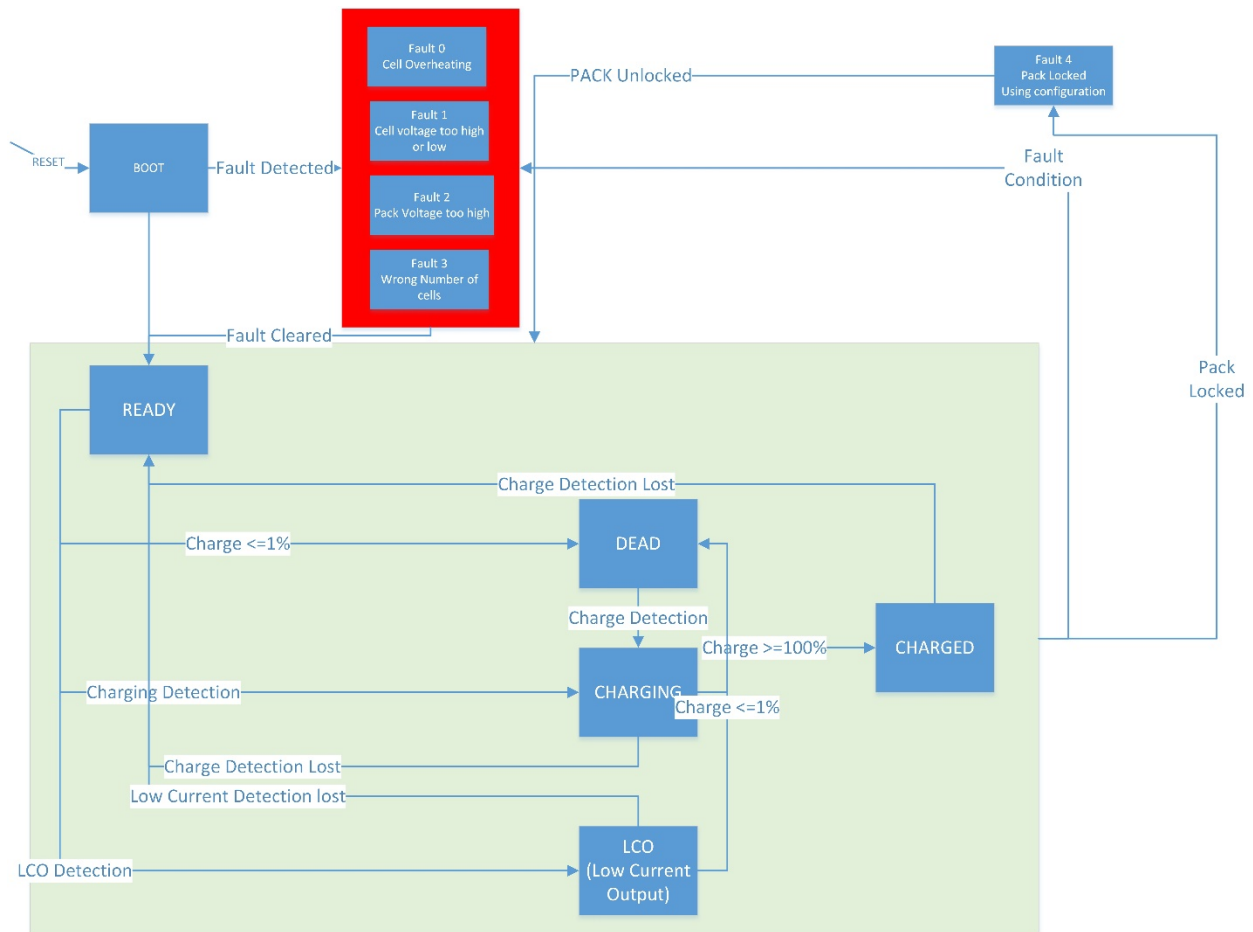


Figure 6. PacMAN State Machine.

AMS Boards

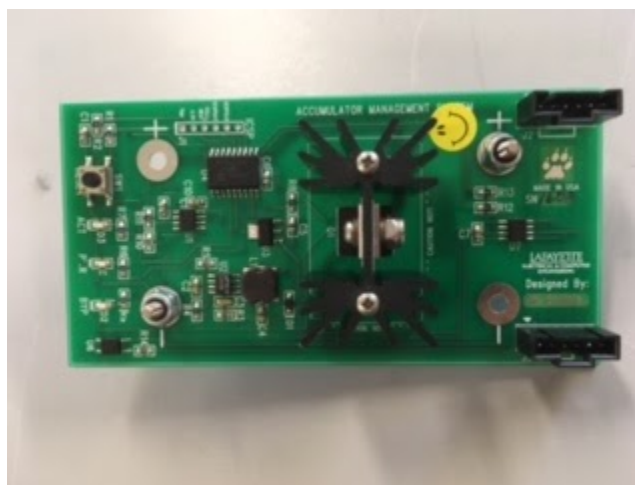


Figure 7. AMS Board (rev 1.1) that was utilized in the delivered accumulator system in the LFEV 2018 Spring semester.



Figure 8. AMS Board installation in a pack.

General

The AMS Boards are powered in the system by cells around 3.2-3.5V during normal operation. The on board power supply has a known bug where U2 will start drawing 500mA, burn up, and drain a cell.

Connectors

- The AMS board is powered by a Cell via cater-cornered banana plug jacks. *Note, if a cell is dead, or undercharged, its corresponding AMS board will not turn on.*
- There are 2 connectors directly across from each other used for implementing the bus used in the I2C protocol between PacMAN and AMS boards. 5V, Gnd, SDA (data), and SCL (clock), are sent through these connectors. AMS boards are connected together as seen in Figure 8.

Functionality

The AMS boards monitor the state of the cell they are attached to. This involves retaining information about cell voltage and cell temperature, monitoring during charging, and communication to the rest of the AMS. This is communicated via I2C to the PacMAN. Each AMS board retains its I2C address, calibration information for voltage, its serial number, among other things.

The AMS boards should be programmed, calibrated, and tested via the AMSVU. The user manual for the AMSVU can be found here: <https://sites.lafayette.edu/ece492-sp17/files/2017/01/AMSVU-User-Manual.pdf>

Firmware

Utilizing the AMS-VU, directly interacting with the AMS firmware should be largely unnecessary as the AMSVU automates the calibration and testing of the AMS boards. The firmware for the AMS boards can be found here: <https://github.com/LafayetteFormulaElectricVehicle/TSV>

Control Panel & Display



Figure 9. Control panel used in LFEV 2017 Spring Packs

General

The control panel on the pack provides the main mode of interaction between the pack, PacMAN, AMS boards and cells. Through the LCD display, buttons, and indicator light, information about the state of the pack can easily be visually acquired. The buttons on the control panel allows interaction with the LCD by paging up or down and “entering” (bottom button) the desired information to calibrate values for the pack such as CAN address, number of cells, etc. The reset button allows for resetting the PacMAN and AMS boards.

From the main screen, the user can either use the down button to scroll through various menus and view information, or press the enter button to set configuration parameters stored in the pacman. Navigation through the menus is illustrated below in figure 10.

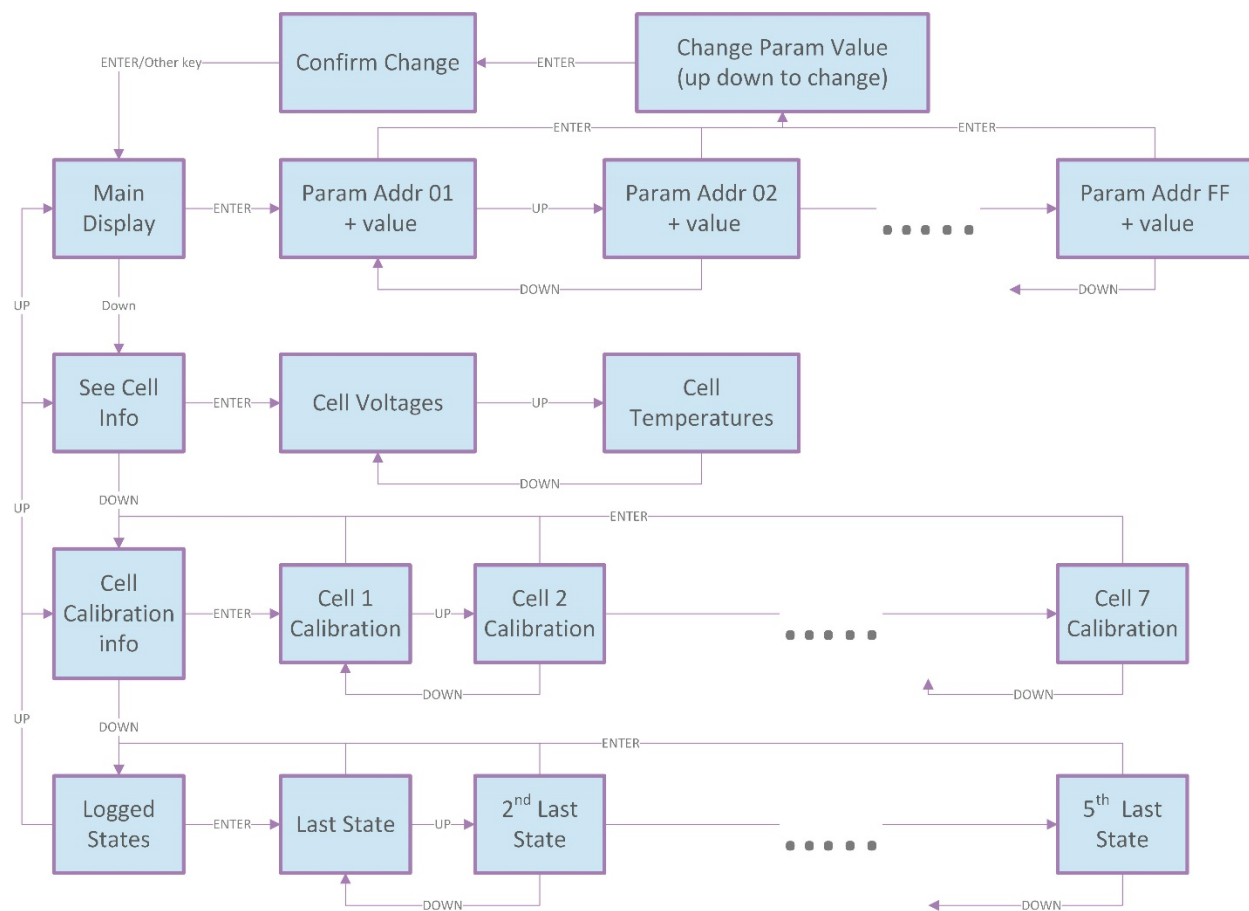


Figure 10. LCD Display navigation

When pressing enter from the main screen, one can enter the configuration parameters menu. In the configuration parameters menu, first enter an address of a parameter to be edited, then edit the parameter itself. The following table is a list of all the parameters and their addresses, as well as other relevant information:

Config Address	Config Parameter	EEPROM addr	Size (Bytes)	Default Value	Units
0x01	pack id	0x08	1	0x01	n/a
0x02	# cells	0x09	1	0x07	cells
0x03	lock state	0x02	1	n/a	bool
0x04	max cell temp	0x03	1	0x3C	degrees C
0x05	max cell voltage	0x04	1	0x28	tenth volts
0x06	screen reset time	0x05	1	0x0F	seconds

0x07	screen sleep time	0x06	1	0x78	seconds
0x08	Min cell voltage	0x0A	1	0x1B	Tenth volts
0x09	Max charge cell voltage	0x0B	1	0x27	Tenth volts
0x0A	Min current	0x0C	1	0x01	Amps
0x0B	Sloop always closed	0x0D	1	0x00	State
0x0C	Default set SOC	NA	1	0x50	%

It is important to note that the parameters can only be edited if the pack is “unlocked.” The lock state is stored at config address 3, and can be toggled by entering the “password” as the value to edit. THE PASSWORD TO TOGGLE THE LOCK STATE IS 0xFF.

Finally, it is important to note that after a set amount of time, the LCD display will turn off. This means it has gone into sleep mode and can be turned back on by pressing up, down or enter.

Connectors

The control panel contains the positive end CAN and Safety Loop connectors in addition to the charging/LCO connector. The CAN in plug connects to the GLV CAN line or the CAN out of another pack depending on the pack number. The Safety loop in plug connects to the GLV safety loop or safety loop out of another pack.

Not pictured in Figure 9 above is the negative end CAN and Safety loop connectors. The safety loop out connector at the negative end of the pack connects to the safety loop in another pack or the safety loop jumper plug depending on pack number. The CAN out plug connects to another pack or the CAN jumper plug depending on pack number.

Functionality

The Control panel enables the ability to navigate between screens on a Pack’s LCD. It is also intended to display when the pack is “Alive” through a red LED. The Reset button will turn the AMS off and on again.

Getting Started & System Operation

StartUp and Shutdown

To bring the PacMan computer online and enable the accumulator, all that is required is to ensure that there are two 25 A blade fuses installed. The fuse holders are located under the lid, one at each end of the pack:



Figure 11. Blade fuse locations boxed in red.

Shutdown for short term storage is accomplished by removing both of these fuses. For long term storage, to prevent any current from being drawn from the cells, all the fuses and all AMS boards may be removed.

Low Current Output

The accumulator may be used to power any device at 23 V and a maximum of 20 A. The device should be connected to the provided Anderson low current output cable. This cable is connected to the same port used for charging.

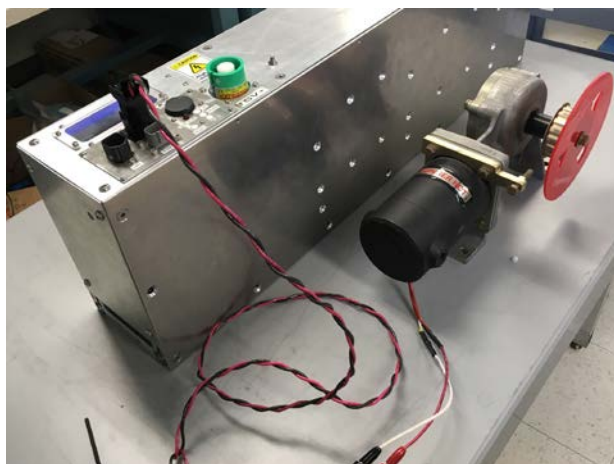


Figure 12. LCO from a pack powering a spinning thing.



Figure 13. LCO State on the Control Panel.

High Current Output

The accumulator is designed to be used in a set of four in series, providing 100 V. The diagram below shows the mating pattern of the TSV+ and TSV-- connectors to achieve 100V. In addition to these connections, the accumulators must be connected to a working safety loop. The 4 wire safety loop cable from the GLV system should be connected the SLOOP plug near the TSV+ connector of accumulator 1. The TSV- SLOOP plug off each accumulator should be connected with a similar 4 wire cable to the TSV+ SLOOP plug of the next pack. The exception is the TSV- SLOOP plug of accumulator 4 should be populated with the provided jumper plug. If the safety loop is working properly the pack alive LED will blink, signifying that high current output is enabled.

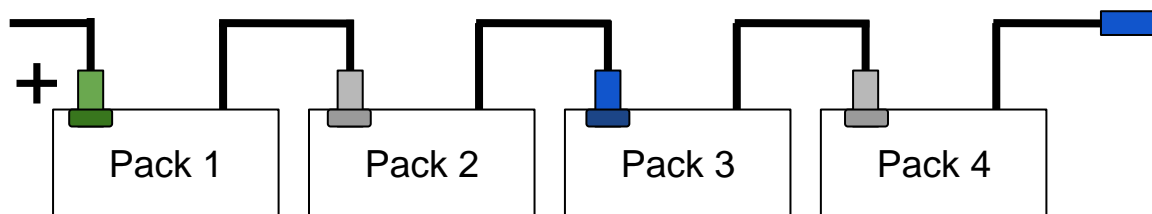


Figure 14. Wiring for 4 Packs.

The packs should be connected to a VSCADA computer during high current output to collect data over CAN. CAN cables should be connected in the same pattern as safety loop cables, and in place of a jumper plug (if a pack is the end of a CAN bus) a plug with a 120 ohm resistor between pin 1 and 2 should be used. **You should have the safety loop running through the packs when working with High Voltage. Remember to use a terminator Deutch connector on the last pack to close the loop.**

Note: High Current Output that requires the any packs in series requires operation by a Professor.

Calibration

In order to ensure that the accumulator will report reasonable data, the AMS boards require calibration. In order to do this, use the AMS verification unit (AMS-VU) designed by John Gehrig. A document outlining the functionality of the AMS-VU can be found here:

<https://sites.lafayette.edu/ece492-sp17/files/2017/01/AMSVU-User-Manual.pdf>

You may additionally calibrate the number of cells a PacMAN should expect and the Pack number (and therefore the CAN address) to which the PacMAN corresponds. In order to do this, navigate to the pack calibration screens as noted in Figure 10 above.

Calibration of sensors on the PacMAN (pack and AMS sensors) is done by adjusting the values in params.h in source code. Slope and offset values are used in all cases. Sensors should be calibrated in the test stand with lab power supplies providing power. To calibrate a sensor, its slope cal factor should be set to 1.0 and offset to 0.0. Output on the LCD screen will then be the raw sensor value. Data points at the high and low end of a sensor should be taken and compared with values measured with a calibrated device to calculate slopes and offsets.

Data collected for calibration (and the calculations of cal factors) can be found in xlsx format at the following address: <https://sites.lafayette.edu/ece492-sp16/files/2016/05/CalData.xlsx>

Troubleshooting

The following section describes recommended techniques for beginner's troubleshooting. See the Maintenance manual for more in-depth troubleshooting.

PacMAN Hardware

Assembling new PacMAN

If building a PacMAN from scratch, follow the build guide. This details step-by-step instructions for which parts to solder in what order and how to debug after each step. We highly recommend this incremental approach! (It will save you pain and heartache later). Note that this guide is intended for rev 0.8. See the build guide here: <https://sites.lafayette.edu/ece492-sp17/files/2017/01/Incremental-PacMAN-Building.pdf>

Power LED

If the Power LED is not on Check to see you are supply 24V. Check to see you are supplying 5V low voltage. Check to see you are supplying 3.3V low voltage. Check that your LED is not placed backwards.

Heartbeat LED

If the heartbeat LED is not blinking, make sure you have programmed your microchip. Make sure your oscillator circuit is soldered properly. Check that your LED is not placed backwards.

Fuse

Make sure you have placed blade fuses into both of the fuse holders!

PacMAN Firmware

Make sure the PacMAN board is programmed with the most up to date firmware located at LFEV 2017 github and linked in the PacMAN firmware section above. A programming guide can be found here: https://sites.lafayette.edu/ece492-sp17/files/2017/01/PacMAN-Programming-Manual-3_2017.pdf

Refer to the maintenance manual for further debugging.

AMS Board

AMSVU Verification

All AMS boards should be calibrated and tested with the AMSVU. See the [AMS - Functionality](#) section above.

AMS Power LED is not on

- 1) Check to make sure the AMS has been properly plugged into the cell (+ goes to the red end of the cell, - goes to the silver end).
- 2) Check to make sure the cell is not dead.
- 3) Check to make sure U2 has not burnt itself. (replace U2, C2, C3, C4 if this is the case ***cell may be dead if U2 breaks and its AMS board is installed***)
- 4) Check to make sure the Power LED is not soldered backwards

Overheating

This is in the case that an AMS board is reporting that a cell is a much higher than normal temperature, (say 40°C) but not yet a Fault 0.

- 1) Remove power from AMS board
- 2) Use heat gun to measure temperature of the cell. If the cell is actually around room temperature, the root cause is the AMS board.
- 3) Plug in AMS board, use heat gun to measure temperature on U2, then remove power **immediately** from AMS board. If U2 was overheating, remove and replace the chip.

Unexpected Voltages Values

Compare the voltage of the cell with a multimeter to the voltages transmitted over I2C via the display on the Control Panel. If this voltage is not the expected multimeter measurement within a very reasonable margin of error, calibrate the AMS board with the AMSVU.

AMS Integration & Communication

Receiving no data

If no cell information is being displayed on the screen,

- 1) Ensure that the ribbon cable between the PacMan and AMS boards is plugged in properly.
- 2) Check that the AMS boards are being powered
- 3) Try resetting the PacMAN board on the control panel
- 4) Reference the LFEV-SP17 Maintenance Manual for information on I2C.

Receiving Incorrect data

If data received about cells indicates they are falsely dead, falsely overheating etc

- 1) Reference the LFEV-SP17 Maintenance Manual for information on I2C.

PacMAN Enters Fault State unexpectedly

- 1) Reference the LFEV-SP17 Maintenance Manual for information on I2C.

Pack and AMS Integration

LCD Power

If the LCD does not turn on,

- 1) Make sure the LCD is not in sleep mode. The LCD falls asleep after a set amount of time (default 2 mins). To turn it back on press up, down or enter.
- 2) Make sure the LCD is connected to the control panel via a ribbon cable.
- 3) Make the control panel is connected to the PacMAN via a ribbon cable.
- 4) Verify the LCD is receiving 5V from the control panel PCB.
- 5) Make sure the PacMAN has been properly installed by reading this document:
<https://sites.lafayette.edu/ece492-sp17/files/2017/01/PacMANInstallationGuide.pdf>

LCD Frozen

- 1) Press the reset button on the control panel.
- 2) Ensure the ribbon cable between the LCD and the control panel is properly connected.
- 3) Ensure the ribbon cable between the control panel and the PacMAN is properly connected.

LCD Cell Data

If you are unable to view any or all desired cell data on the LCD, yet the LCD is powered on.

- 1) Press the reset button on the control panel.
- 2) Ensure the Cell's you wish to observe have an AMS board installed on top of them.
- 3) Ensure every AMS board is connected together with short ribbon cables.
- 4) Ensure the AMS boards are connected to the PacMAN via a long ribbon cable.

Charging

If the Pack won't charge when the charging plug is connected to the charging port

- 1) Refer to the "Charging" section of this document under Maintenance to ensure you are properly using the equipment.
- 2) Check to make sure the Charge cable is properly connected to the PacMAN (LCO and charge aren't swapped by accident).
- 3) Make sure the PacMAN has been programmed
- 4) See the Maintenance Manual for more in depth information.

LCO

If the Pack will not produce Low Current Output when expected

- 1) Make sure that the LCO and Charge cables were not plugged into the PacMAN board backwards as they look similar.
- 2) Make sure the PacMAN has been programmed.

Maintenance

Charging

In order to continue supply 24V, packs must be charged. There are multiple approaches for charging a pack or cell. These are detailed below.

Charging a Pack with AMS

If the AMS is functional, simply plug the anderson charging plug into the charging port on the pack. The charger should be set to 28.00 V and 15.89 A; verify these numbers with the preview option. These numbers should be set no higher than 28 V and 20 A. Before plugging the charger into the pack, turn the output of the charger on. When plugged in, the charger's current should change from 0 A to 15 A. The LCD display on the pack should indicate state as "CHRG" and the amperage should read as a negative 15 amps.

Note: If a pack is at 100% SOC, the pack will not charge. If for some reason SOC indicates 100% after the pack has been discharged, you can manually force the pack's SOC to 50%. To do so, Use the calibration screen.



Figure 15. Charger for the pack.



Figure 16. Charger plugged into pack and pack display indicating charging state. In this case, the pack has been 100% charged; therefore, the state reads “CHRGD”.

Charging a Pack without AMS

If the ASM is not functioning properly, you may charge the packs via banana plugs and a 24V power supply into the bus bar at either end of the pack. Make sure positive goes to TSV+ end of the pack the cell at the end with the red square and ground into the TSV- goes to the cell at the end without the red square; see Figure # below. The AMS boards must be removed for this approach.

NOTE: Only utilize this charging technique if it is known that the cells are a roughly comparable states of charge. (Voltage alone is not an indication of SOC).

NOTE: DOUBLE CHECK POLARITY ON CHARGING SETUP; PLUGGING IN BACKWARDS WILL CAUSE ARCS.



Figure 17. Power supply.

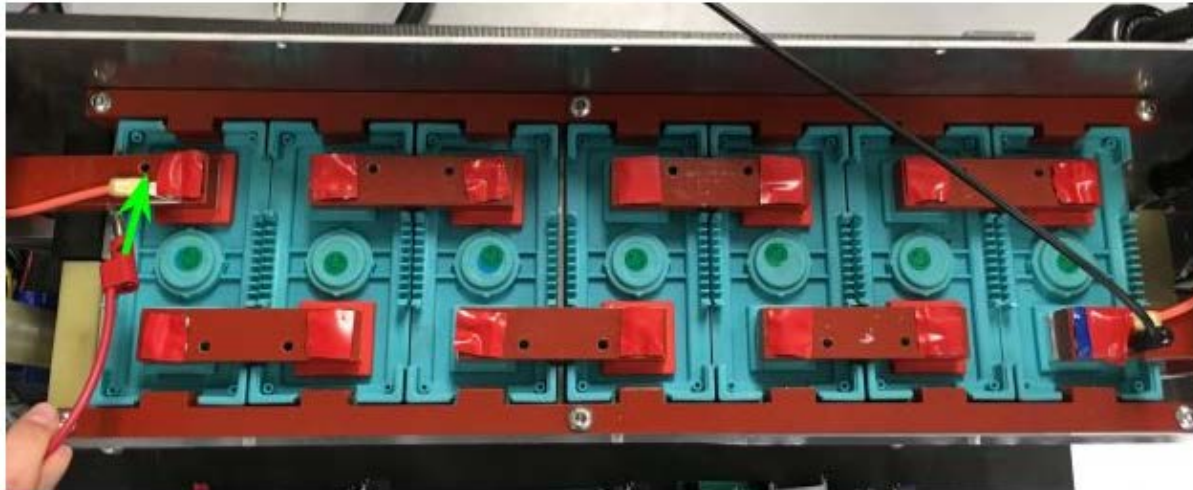


Figure 18. Charging without the AMS.

Charging individual Cells

If the cells were not discharged comparably to each other, you may take the bus bars off the cells, and charge the cells individually. This involves a 3.5V power supply and appropriate cables (See Figures below). Completely charge each cell to ensure they are now at the same amount of charge. This is useful for “precharging” cells before they are installed within a pack.

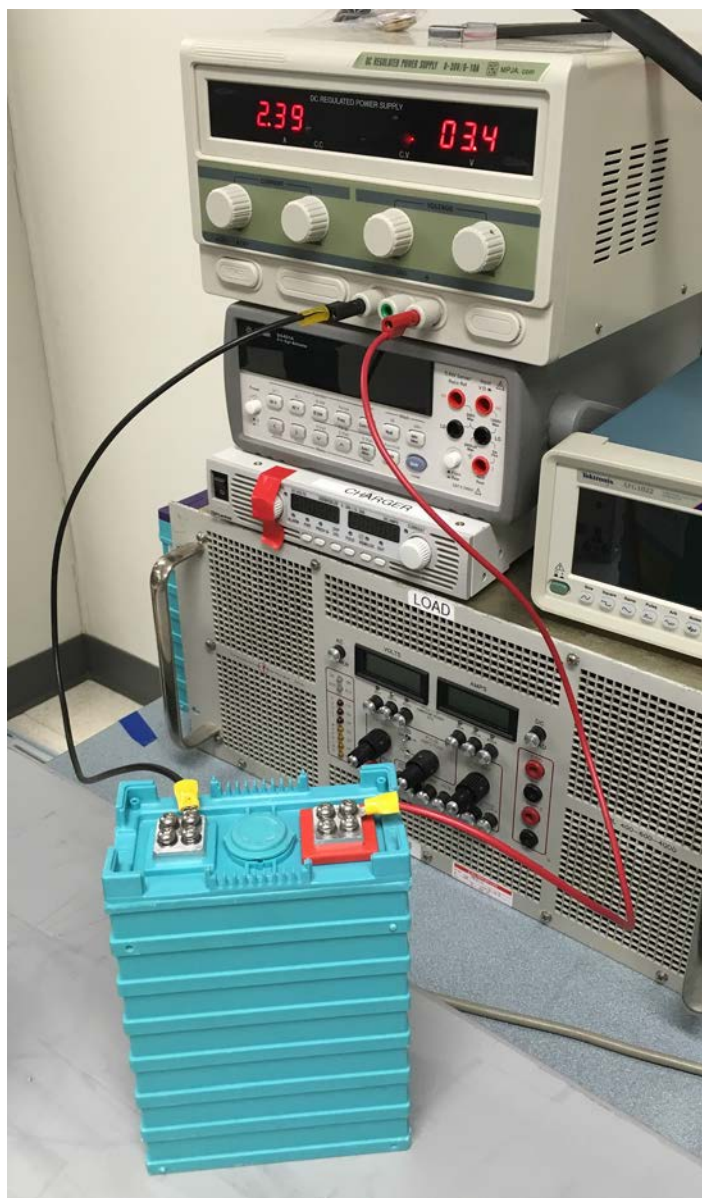


Figure 19. Charging setup for individual cell. This you can see this cell has finished charging due to its low current draw and being voltage limited (red dot on right side)



Figure 20. Charging Cables in Cell.

Charging A segment of Cells with AMS board

After replacing a cell, you would want to charge the remaining cells to full separate from the replaced cell, which can be charged using the above procedure. To charge a set of cells, bypass the cell being replaced. If at one end, move the inline fuse wire to the next cell. If the cell is in the middle, remove the bus bars connecting to that cell and use jumper cables to connect the adjacent -ve and +ve terminals of the cells.

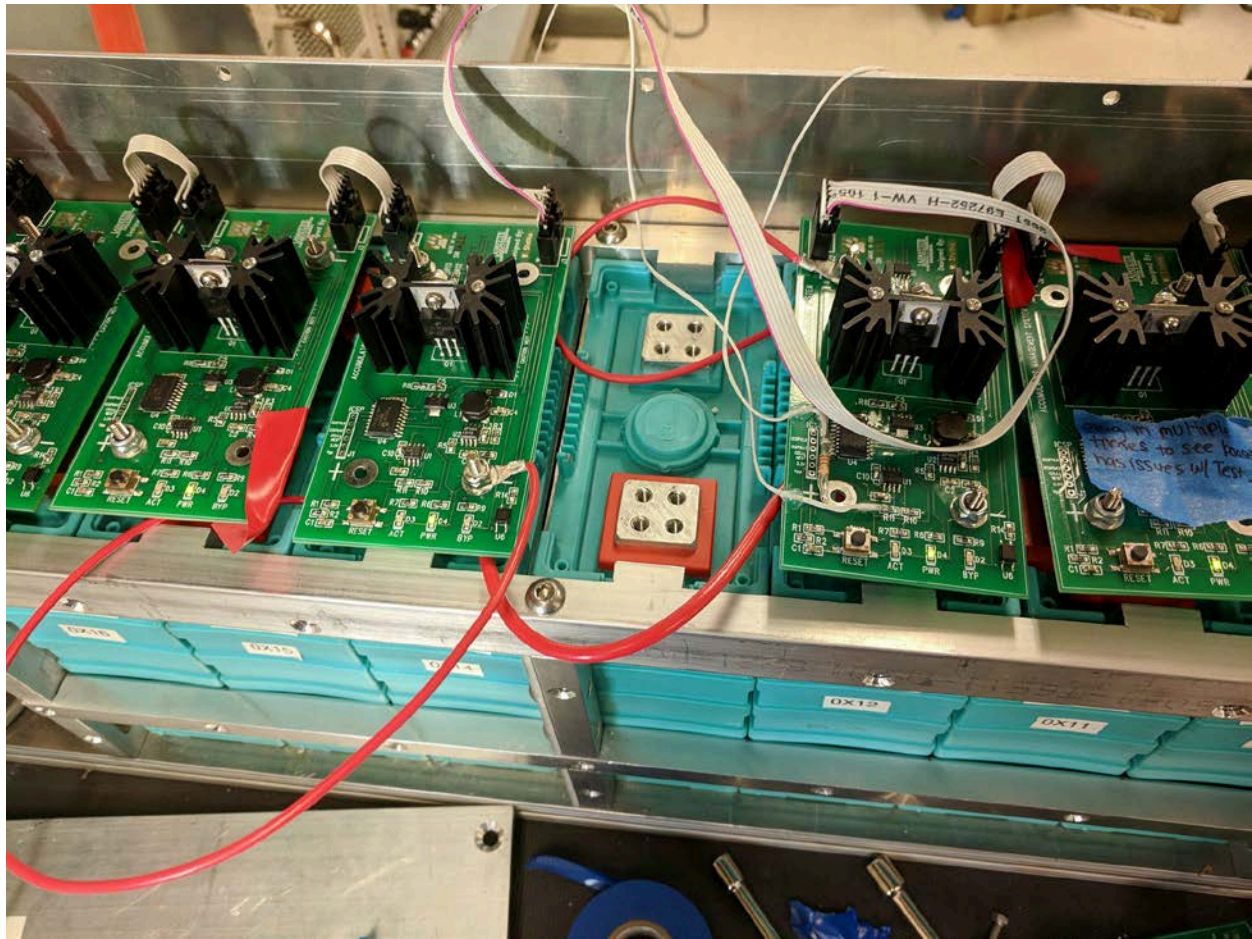


Figure 21 Charging with AMS boards and bypassing middle cell

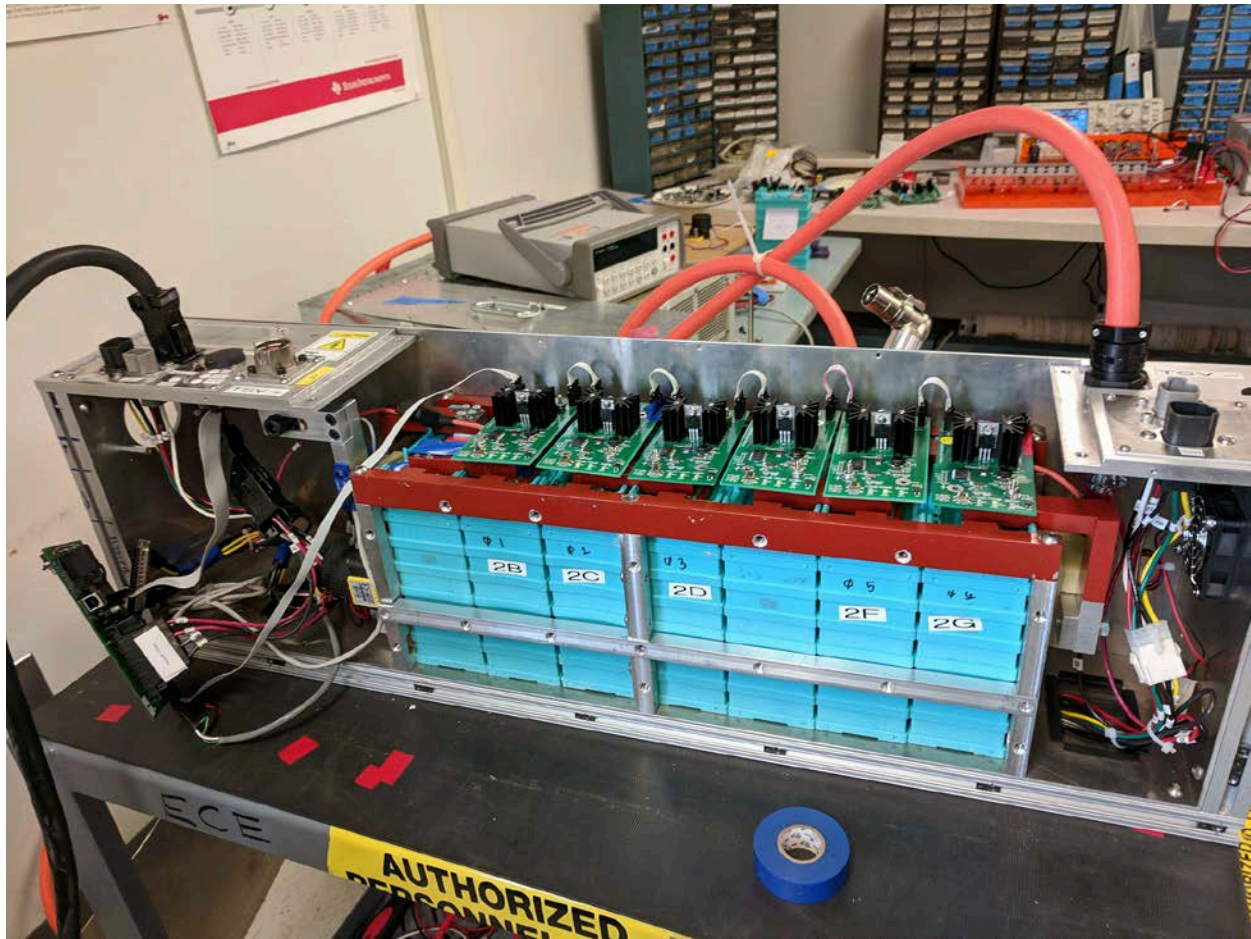


Figure 22 Charging with AMS boards and bypassing first cell

Appendices

A.1 Glossary

AIR - Accumulator Isolation Relay
 AMS - Accumulator Management System
 AMSVU - Accumulator Management System Verification Unit
 BMS - Battery Management System
 GLV - Grounded Low Voltage
 HVD - High Voltage Disconnect
 LCO - Low Current Output
 LFEV - Lafayette Formula Electric Vehicle
 PacMAN - Pack Manager
 PPE - Personal Protective Equipment
 SOC - State of Charge

TS - Tractive System
TSV- Tractive System Voltage
VSCADA - Vehicle Supervisory Control & Data Acquisition

A.2 Bills of Materials

Accumulator Electrical - <https://sites.lafayette.edu/ece492-sp17/files/2017/01/Accumulator-Electrical-BOM.pdf>

AMS Board - <https://sites.lafayette.edu/ece492-sp17/files/2017/01/AMS-BOM.pdf>

Control Panel PCB - <https://sites.lafayette.edu/ece492-sp17/files/2017/01/Control-Panel-PCB-BOM.pdf>

Mechanical Manufacturing - <https://sites.lafayette.edu/ece492-sp17/files/2017/01/Accumulator-Mechanical-BOM-for-Manufacturing.pdf>

Mechanical Assembly - <https://sites.lafayette.edu/ece492-sp17/files/2017/01/Accumulator-Mechanical-BOM.pdf>

PacMAN - <https://sites.lafayette.edu/ece492-sp17/files/2017/01/PacMAN-BOM.pdf>

A.3 Electrical Schematics

AMS Board - https://sites.lafayette.edu/ece492-sp17/files/2017/01/AMS_Schematic_Rev_0_4_2016.pdf

Control Panel - <https://sites.lafayette.edu/ece492-sp17/files/2017/01/panel-pcb.pdf>

PacMAN - https://sites.lafayette.edu/ece492-sp17/files/2017/01/PacMAN_Rev_0_8_Schematic.pdf

A.4 Mechanical Diagrams

<https://sites.lafayette.edu/ece492-sp17/files/2017/01/Mechanical-Drawings.zip>

A.5 Wiring Diagrams

<https://sites.lafayette.edu/ece492-sp17/files/2017/01/Pack-Wiring-Diagrams.zip>

A.6 Data Sheets

PacMAN and AMS Board Data sheets can be found under “Helpful Datasheets”
<http://sites.lafayette.edu/ece492-sp17/subsystems/tsv/>

AIRs - http://www.gigavac.com/sites/default/files/catalog/spec_sheet/gx14.pdf

Anderson Powerpole Connector - <http://www.andersonpower.com/global-assets/downloads/pdf/ds-pp1545.pdf>

Cells - <http://www.batteryspace.com/prod-specs/6334.pdf>

Charger - http://www.us.tdk-lambda.com/hp/pdfs/Product_manuals/835075002.pdf

Mersen Fuse - <http://ep-us.mersen.com/fileadmin/catalog/Products/Fuses-Fusegear-and-Fuse-Systems/Fuse-Holders-Fuse-Bases-and-Supports/UL-CSA-Fuse-Bases/Class-T-300V-Fuseholders-Class-T/ADV-H-Fuse-Blocks-and-Holders-Class-T-300V-600V-Fuse-Blocks.pdf>

PacMAN & AMS Board Connector - http://www.mouser.com/ds/2/276/0738380006_CRIMP_HOUSINGS-173522.pdf