BATTERY PROTECTION SYSTEM (BPS)

Dan Bohachick
Feb 20, 2021
dan_Bohachick@americansolarchallenge.org
danb #2348

OBJECTIVE

Cover important safety considerations, regulations, and requirements to:

- Protect your batteries to manufacture limits during normal operations
- Speed your team through the scrutineering test process
- Improve your VDR documentation to communicate proper design
- Clear up common questions or confusions with regulations
- Get your design to Rayce!

SAFETY

At the heart of our regulations, scrutineering, inspectors, and this conference.

States

- Safe Startup
- Safe Operation
- Safe Shutdown
- Fail Safe

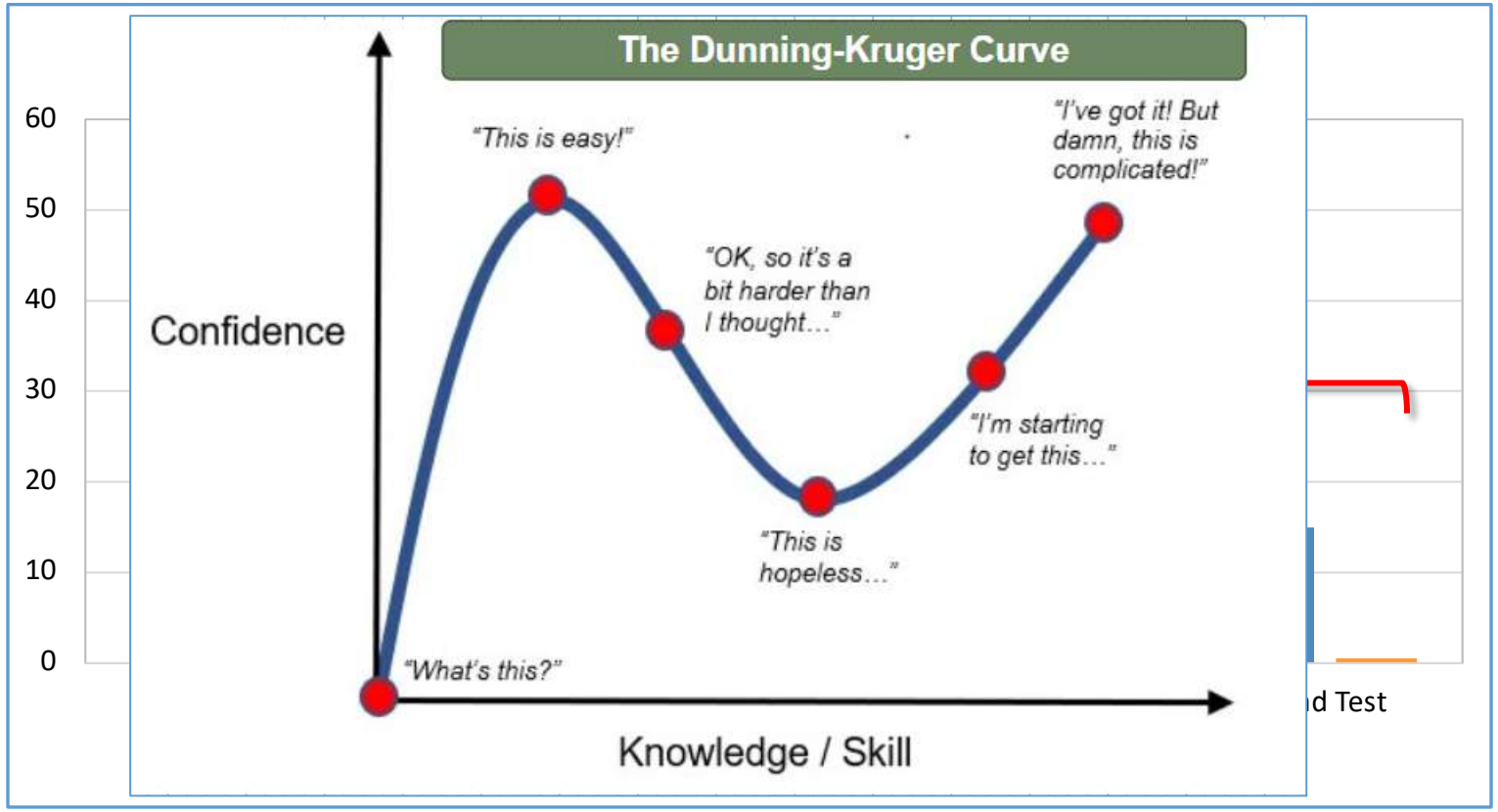
WHAT IS A BPS

- **B**attery **P**rotection **S**ystem
- Required for all Lithium Battery Types
- “Smart Circuit Breaker”
- Active or Automatic protection for battery pack
- Only regulatory function is to protect batteries for manufacture specified limits
- Not the same a BMS (Battery Management System) *
- Required when racing, charging, or any time batteries are part of electrical circuits
- It function to detect fault conditions and isolate batteries from ALL sources and sinks

HOW ARE WE GOING TO GET THERE?

Project Management

With a timeline, milestones, and strategies to stay on schedule

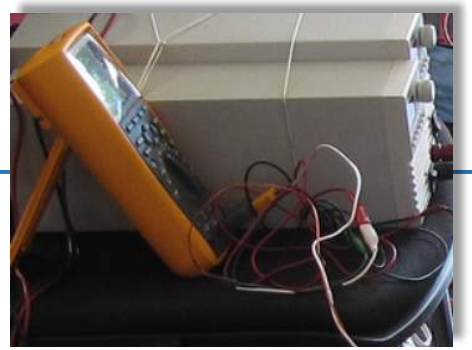


ON THE ROAD

The “Ideal” BPS:

- No faults or required reset at any point along race.
- Will be protected from getting fault conditions by a separate BMS w/ coordination
  - Array limits shuts off before creating excess Over Voltage or Over Current Charge
  - Motor limits current and regen based on state of charge
  - Secondary alarming levels set prevent reaching BPS limits
- Vehicle has proper telemetry, data logging, and driver display for team to know state of charge and operating parameters
- Design is robust to electrical noise, vibration, elements, and users
- System has been tested and calibrated to have accurate measurement values over the entire operating ranges as a total system
- Clear indication of faults with the driver dash indicator(internal) and BPS Fault Indicator(exterior)

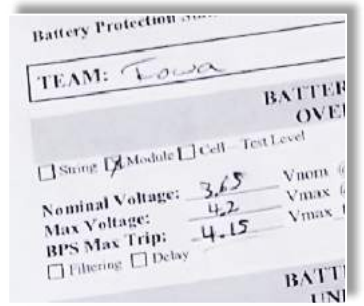
SCRUTINEERING



- **What will you need:**
  - Working and tested system with the car chassis minus the canopy
  - Scrutineering sheet filled out
  - Provide any harness and special tools to access sense leads, thermistor, and current sensor for test
  - Read the posted testing procedure
    - UV
    - OV
    - OC charge/discharge
    - OT charge/discharge
  - Demonstrate a latching fault with manual clearing
  - Have a means for locking firmware settings by covering programming or IC's
  - Working Dash indicator for fault and method to see external indicator

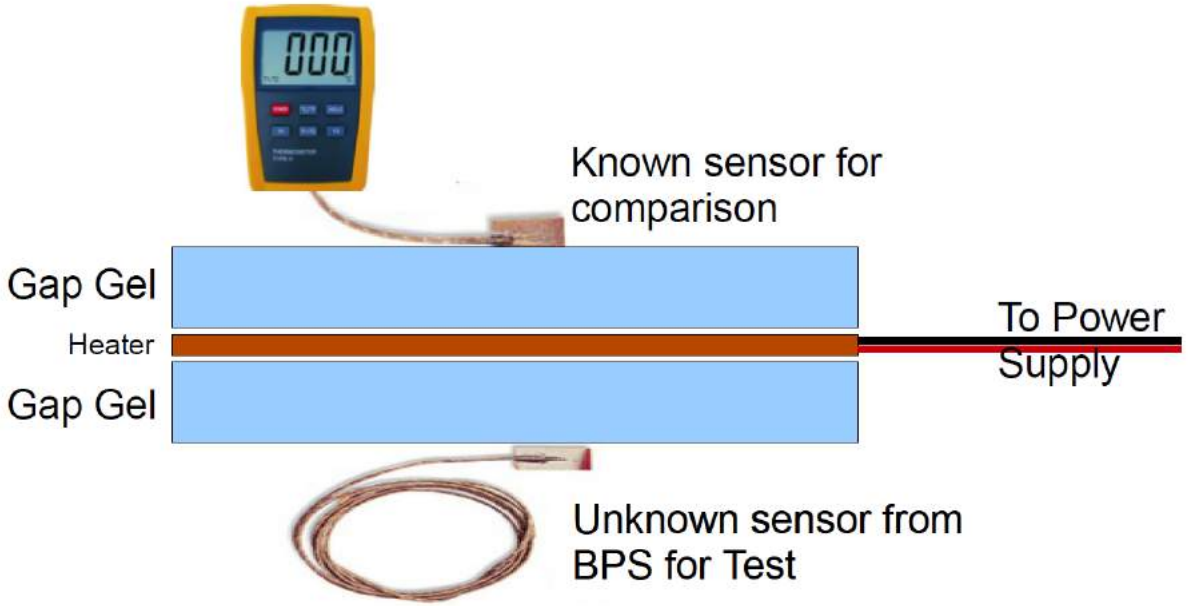
SCRUTINEERING CONT.

Common Problems:



- Showing up at appointed time
- Having scrutineering sheet completed with all values
- Bringing the required connectors or tools
- Having the correct team members with expertise to describe and operate
- Having telemetry or displays to verify readings
- Documents to show specs and configuration
- Correct measurement coding to:
  - Latching fault so as not to reset if value brought back to operating range
  - Two tier measurement values for charge and discharge temperature ranges
- Having not planned how to test setting (No test points, leads, or harness)

SCRUTINEERING TESTING



https://www.minco.com/products/heat

http://www.bergquistcompany.com/thermal_materials/gap-pad.htm

Test	Lithium
Voltage	O.01 VDC ± O.01V cell or module(<5VDC) ≈ +10 Bit precision
Current	1 ADC ± 0.2A cell or module ≈ 2%
Temperature	± 2-degree Celsius

REPORT

5.1.E Battery Protection Tech Report:

All batteries must be protected with technology appropriate to the chemistry used. The battery protection test report must be submitted to Event Headquarters as part of the Vehicle Design Report by the date indicated in Reg. 4.3.A.2. The tech report must document the design approach used with respect to Reg. 8.3 including the following information:

5.1.E.1 Battery Approval Forms for each battery type

5.1.E.2 Battery pack configuration including cells per module, modules per strings, strings in parallel, and total cell count

5.1.E.3 Over temperature set points (charge and discharge if different) for each battery type

5.1.E.4 Under voltage set point for each battery type

5.1.E.5 Over voltage set point for each battery type

5.1.E.6 Over current set point for each (charge and discharge if different) battery type

5.1.E.7 Block diagram for BPS and component within battery enclosures for each battery type

5.1.E.8 Description of how the BPS will operate for start-up and fault conditions for each battery type.

5.1.E.9 How firmware or settings will be rendered static and un-modifiable after inspection (i.e. sealed in battery enclosure)

5.1.E.10 Describe function of driver dash and BPS fault indicator strobe for External Cutoff switch, ref. Reg. 8.6.C

DESIGN REPORT

How they are reviewed

- Read Electrical System Technical Report (Reg. 5.1.C)
- Read Battery Tech Report (Reg. 5.1.D)
- Read Battery Protection Tech Report (Reg. 5.1.E)

Event	ASC/FSGP 2018
College	Southern Illinois Univ. Edwardsville
Team	SIUE
#	57
Car	
Email	siue.solarcarteam@gmail.com

Status	Rule	Notes
Green	**5.2.E** All batteries must be protected with technology appropriate to the chemistry used. Battery protection test report must be submitted to ASC Headquarters as part of the Vehicle Design Report by the date indicated in Reg. 4.3.A.2. The tech report must document the design approach used with respect to Reg. 8.3 including the following information:	Document Received
Green	**5.2.E.1** Battery Approval Forms for each battery type	Electrical Review Complete
Green	**5.2.E.2** Battery pack configuration including cells per module, modules per strings, strings in parallel, and total cell count	Electrical Review Complete
Green	**5.2.E.3** Over temperature set points (charge and discharge if different) for each battery type	Battery allows Chrg(45) | DisChrg(60) > Chrg_Set(45) | Discharg_Set(60).
Green	**5.2.E.4** Under voltage set point for each battery type	2.5 = Set(2.5)
Green	**5.2.E.5** Over voltage set point for each battery type	4.2 = Set(4.2)
Yellow	**5.2.E.6** Over current set point for each (charge and discharge if different) battery type	25.5 = ChrgSet(25.5) | 120>DisChrgSet(95).
Green	**5.2.E.7** Block diagram for BPS and component within battery enclosures for each battery type	
Green	**5.2.E.8** Description of how the BPS will operate for start-up and fault conditions for each battery type.	Explained start. Missing details on rolling restart prevention. Would like to know more about aux batt.
Green	**5.2.E.9** How firmware or settings will be rendered static and un-modifiable after inspection (i.e. sealed in battery enclosure)	password
Green	**5.2.E.10** Describe function of driver dash and BPS fault indicator strobe for External Cutoff switch, ref.Reg. 8.6.C	missing

DESIGN REPORT CONT. 1

Top Feedback Points on VDRs

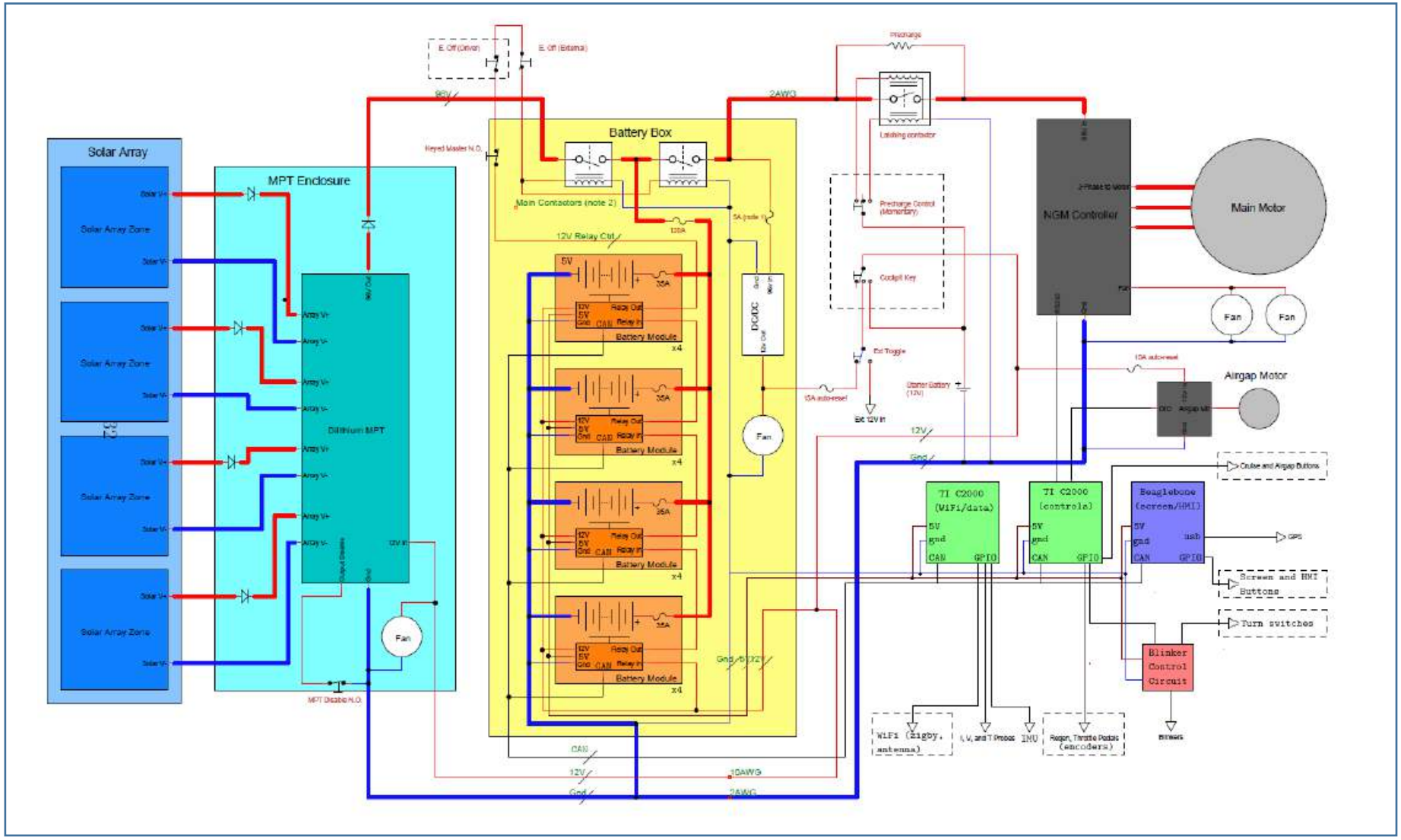
- Primary function of BPS (Don’t call it a BMS)
- Current Team Name, Number, and Team Contact in PDF Format
  - We will respond back to the team’s email, not individuals.
- Inconsistencies between battery approval and tech reports
- Set point margins at absolute value of manufacturing spec
- Two tier temperature and current for charging and discharge
- Component location (outside the battery box)

DESIGN REPORT CONT. 2

Top Feedback Points

- Communication dependencies(CAN Bus)
- Layers of protection
- Manufactured spec sheets for components or sub-systems are not a substitute for the system design report.
- How system starts
- Car must come to a complete stop before re-engaging the BPS
- After Isolation what steps are required to restart car
- Locking out changes (Firmware / Setpoints)

BPS “DETAILED” BLOCK DIAGRAM



REGULATIONS (8.3)

8.3 Protection Circuitry

All batteries must have protection circuitry appropriate for the battery technology used.

Proof is required at Scrutineering that the protection system is functional and meets manufacturer's specifications.

Testing procedures will be provided, and the protection system design should allow for such testing.

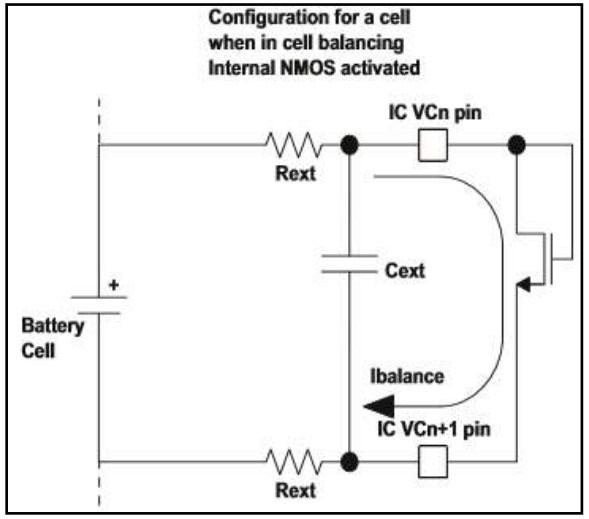
All measurement leads should be **fused or current limited to less than 1 mA** for non-isolatable sinks in the measurement circuitry.

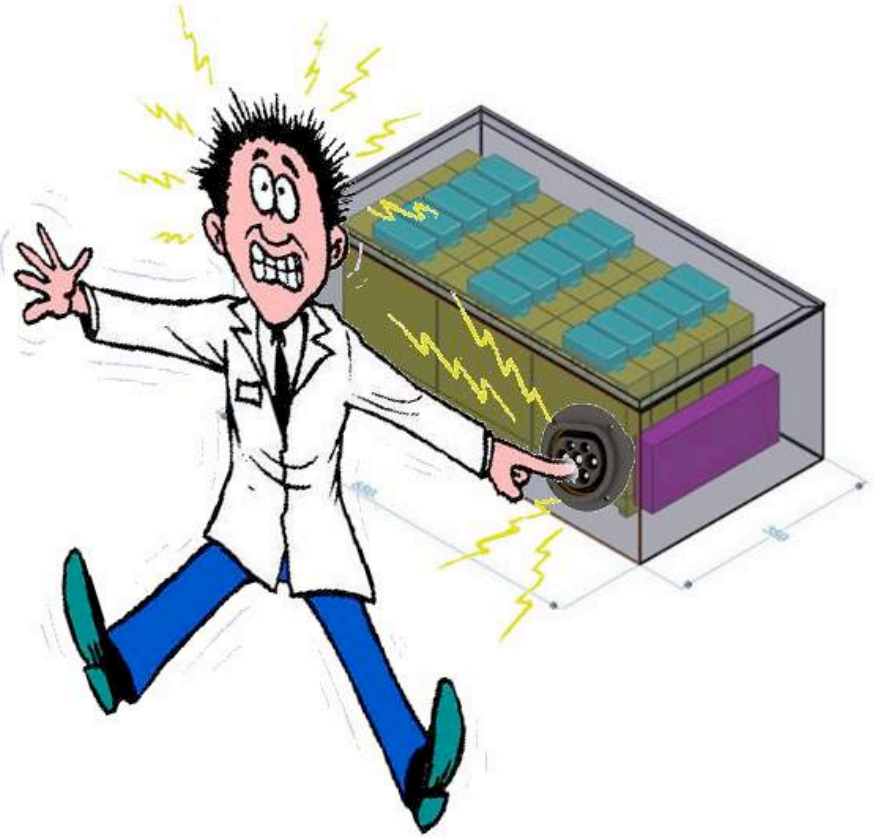
All protection circuitry should be contained in the battery enclosures per Reg. 5.5.

WHY A MILLIAMPERE

- All measurement leads should be fused or current limited to less than 1 mA for non-isolatable sinks in the measurement circuitry. All protection circuitry should be contained in the battery enclosures per Reg. 8.5.C.

Pack Voltage



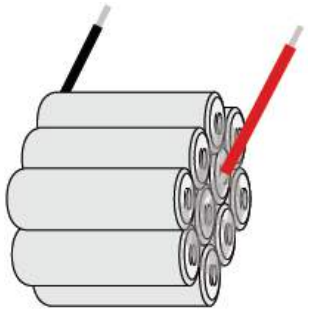


REGULATIONS (8.3)

- **8.3.A.1 Cell:** The smallest available source of energy in the battery pack as purchased from a manufacturer. A single electrochemical cell.
- **8.3.A.2 Module:** The smallest easily removable group in a battery pack.
- **8.3.A.3 String:** The smallest group of cells needed in a battery pack to provide the required voltage.
- **8.3.A.4 Protection Limit:** The measured level determined to be adequate to protect from an event.
- **8.3.A.5 Active Protection:** System in which measurements are constantly monitored and where actions are taken immediately without operator intervention. Any protection faults will latch such that a **manual clearing process is required by the diver with the vehicle not in motion and only after faults have been verified clear by the protection system**.
- **8.3.A.6 Passive Protection:** System in which measurements are monitored by the driver and where action is driver controlled.

REGULATIONS (8.3.B)

- **8.3.B Li-Based:** All lithium based battery packs must have **active** protection such that
  - **over-voltage**,
  - **over-temperature** (for charge and discharge rating),
  - **over-current** and
  - **under-voltage**



- causes the pack to electrically **isolate the source or sink** from the battery pack.
- The level of protection measurement is required down to the **module** level at a minimum and may be required at a **cell** level depending on the cell manufacturer.

- **Fuses** are not acceptable for over-current protection, but are required as per Reg. 5.6.

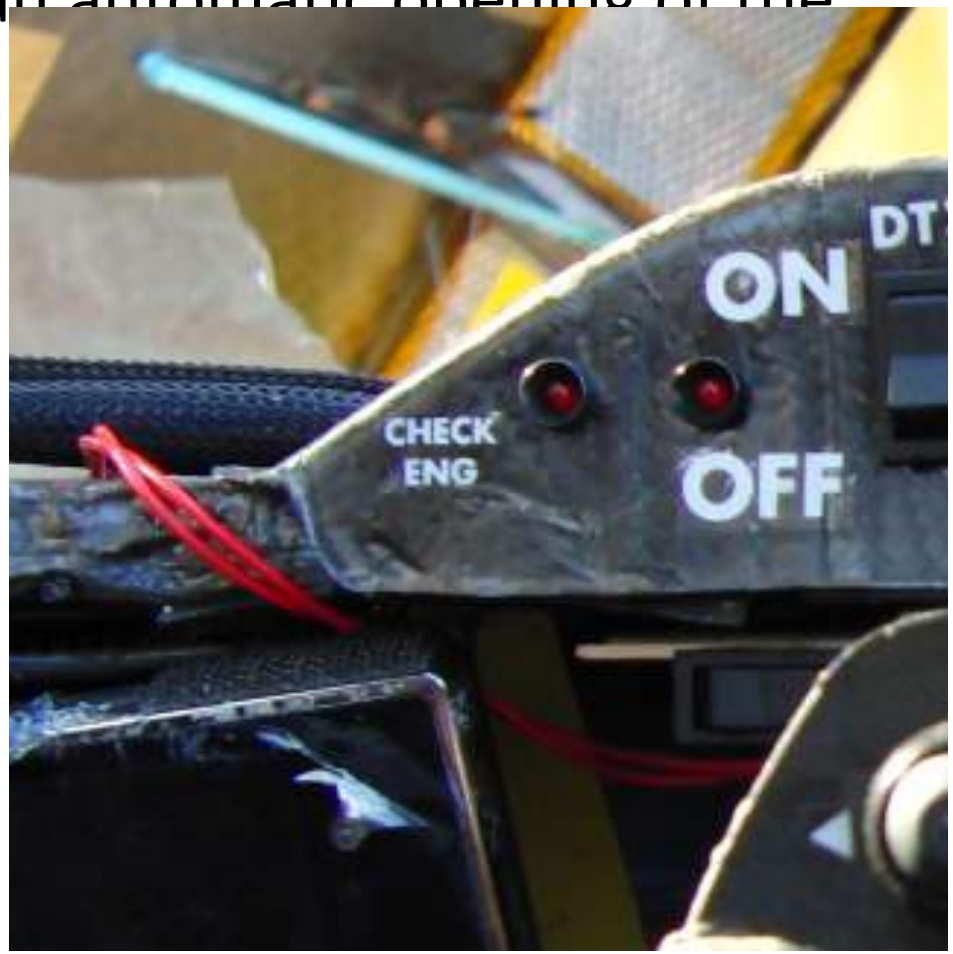
RELATED REGULATIONS

- **8.2.C.1 Supplemental Batteries:** Supplemental, replaceable batteries carried in the solar car may be used to power: main power switch, radios, commercially available electronic panel meters with internal batteries, cell phones, driver ventilation fans (if solely used for driver ventilation), and the horn. Supplemental battery power may be used to momentarily power the battery protection system (BPS) as defined by Reg. 8.3 to verify safe battery parameters before energizing the main power switch. During a battery fault, in which the BPS has automatically opened the main power switch, the supplemental battery power may be used to power the battery fans per Reg. 8.4.D.
- **8.2.C.2** The supplemental battery used during start-up must also be used to power the BPS, BPS Strobe, and BPS Fault Driver Indication under fault conditions. This supplemental battery must be located in the battery enclosure.
- **8.5.C Voltage Taps:** Voltage Taps All battery protection circuitry (BPS) measurement leads or voltage taps off the battery must be fused or current limited to less than 1 mA for non-isolatable sinks in the Battery Protection or measurement circuitry.
- **8.6.A Main Power Switch:** A DC-rated fuse (not a circuit breaker) must be placed first in series with the battery starting at the positive connection within each battery enclosure. Both leads to the fuse must be mechanically constrained to battery enclosure using a fuse block. The fuse rating must not exceed 200% of the maximum expected current draw or 75% of the rated wire current capacity. It must be rated to break the Fault Current due to a shorted pack and protect the relay or switch. (High Speed or Fast Acting Semiconductor Type Fuse) ** Removed the MOSFET

DRIVER FAULT INDICATION

- **8.6.B** BPS Fault Dash Indication The driver is to have an illuminated dash indication of a BPS fault to provide warning of an automatic opening of the Main Power Switch.

- Needs to come **<u>on and persist</u>** until cleared



FAULT LIGHT

9.4.G BPS Fault Indicator

9.4.G.1 Position: at the rear of the vehicle canopy at an elevation of not less than 700 mm above ground.

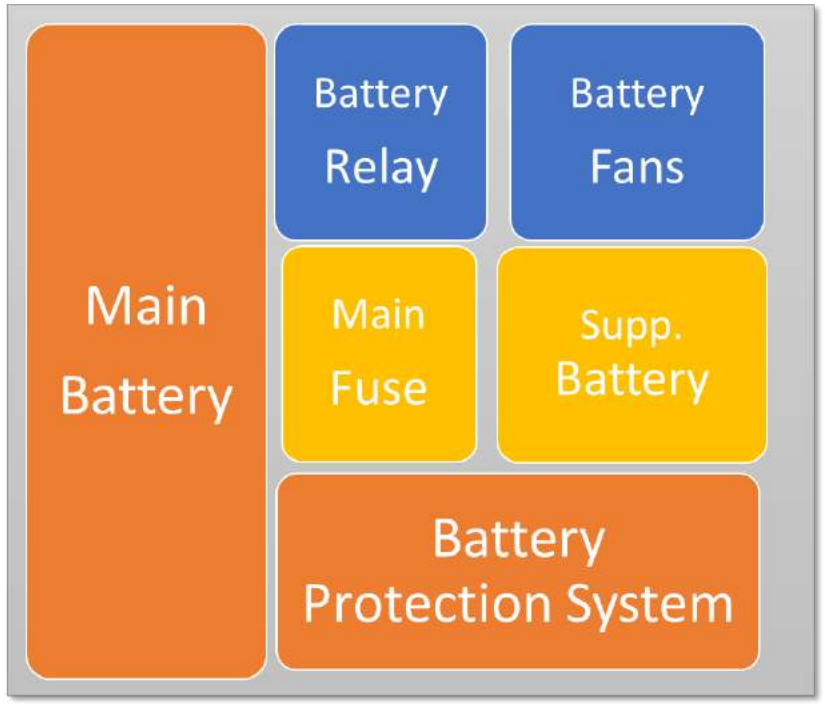
9.4.G.2 Activation: it is to activate any time the Battery Protection System (BPS) actuates to automatically open the Main Power Switch and **remain active** while the BPS fault is present.

9.4.G.3 Must flash between 60 and 120 pulses per minute

9.4.G.4 Color: white strobe

9.4.G.5 Viewing Angle: 30° from center in both directions and 15° up from horizontal.

BPS PHYSICAL LAYOUT



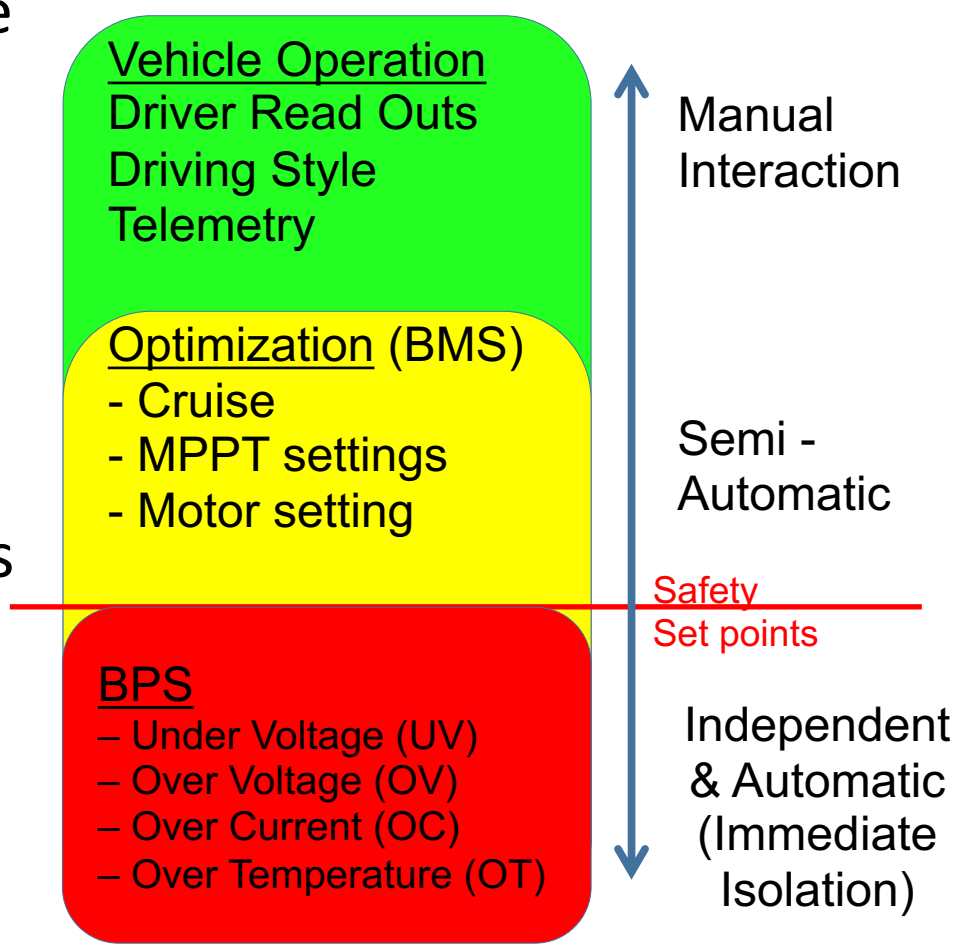
[In the Box]	Why?
Cells	Protection and ventilation
Battery Relay	Electrical Isolation (wet hand test)
Fans	Sealing and ducting
Main Fuse	Electrical Isolation
Supplemental Battery	• Temporary power for BPS • Power for Relay • Monitor it with BPS
Batt. Protection System (BPS)	No connectors No HV wire leads Sealed from damage / elements

BPS FAIL SAFE AND RELIABILITY

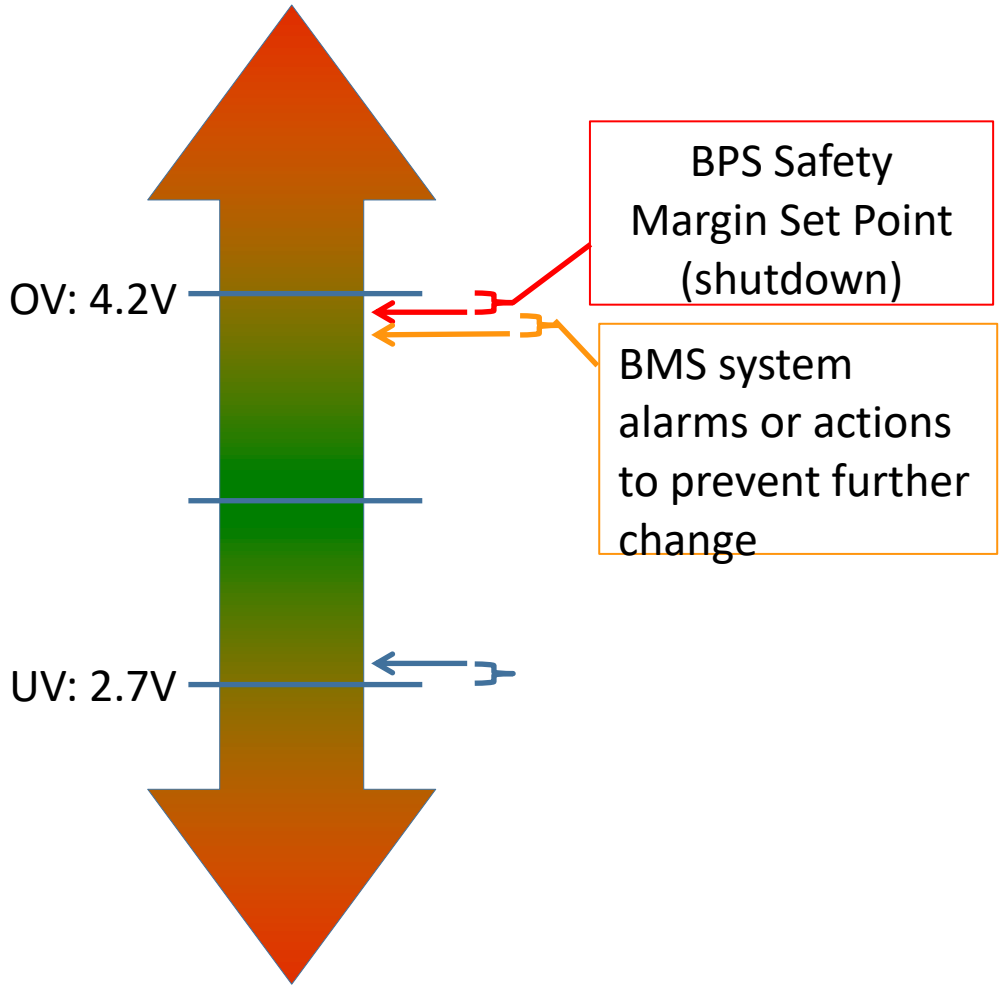
- Fault Condition
  - Cell failure
  - Harsh Environmental Conditions
  - BPS Self Diagnostics (watchdog, communications error)
- User Error
  - Coding Set Points
  - Incorrect setting on power trackers or motor controller
  - Lack of active monitoring(telemetry or driver readouts)
  - Regen Braking
- Reliability
  - Loose Wire or Connectors
  - Bad Sensor or Measurement
  - Sensitivity to noise (EMI/RFI)
  - Hysteresis, Delay, Calibration
  - Sense Voltage Isolation(Galvanic, Optocouplers)

WHOLE SYSTEM PROTECTION

- Disconnecting Motor Controller, DC/DC, or MPPT under load can cause secondary damage.
- Braking Resistor, Clamping Diode, or Transient Stability on Main Bus
- Integrate Protection System to soft shut down all sources (BMS)
- Provide telemetry to detect and prevent conditions that result in faults
- When a fault occurs determine root cause before continuing
- Understand effects on system when an abrupt shut down occurs



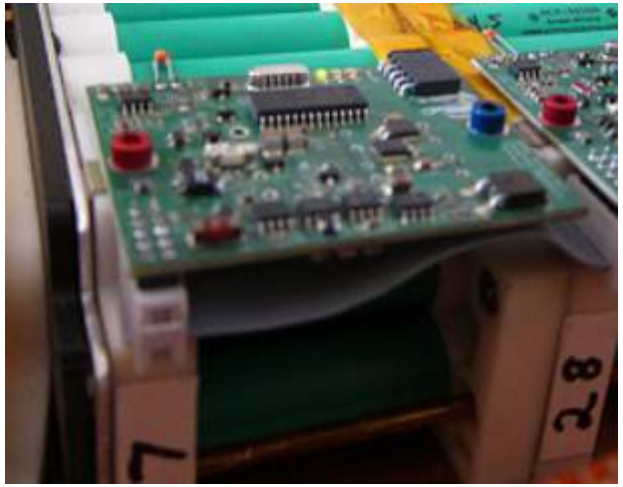
BPS SET POINTS

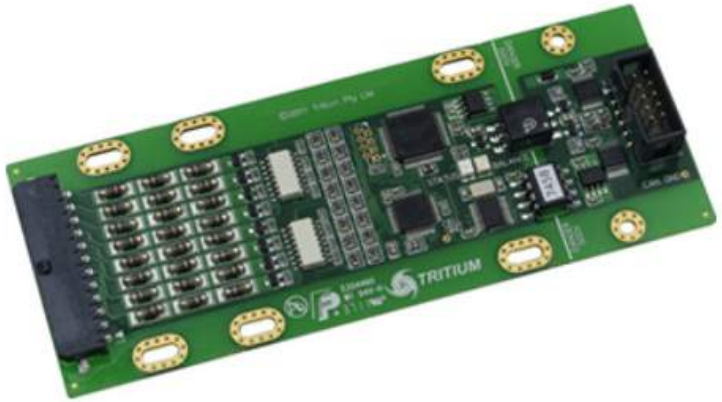


Battery Voltage Range
(Example Only)

- Careful choice of BPS set point
- Must be equal or under manufactures limit
- Accuracy
- Noise
- Bias
- Calibration
- Manufacture tolerance
  - (Ex. 4.2V ±0.03 V)
- Series / Parallel

TO BUILD OR BUY



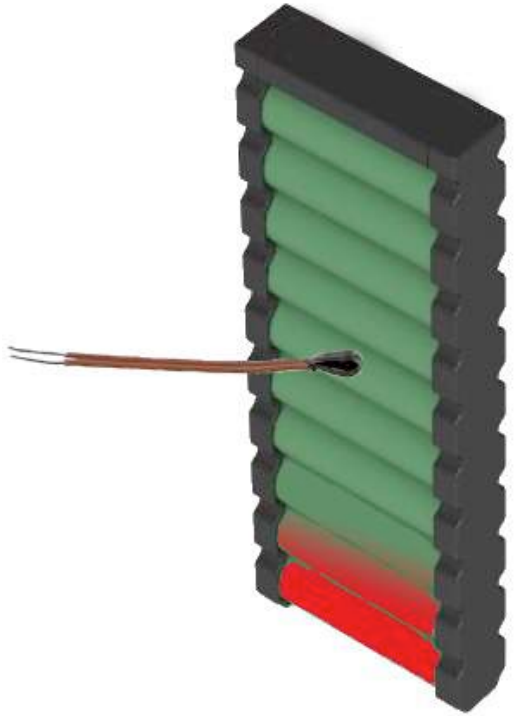


- Time
- Experience
- Cost
- Testing
- Customization
- Pre-Charge Integration

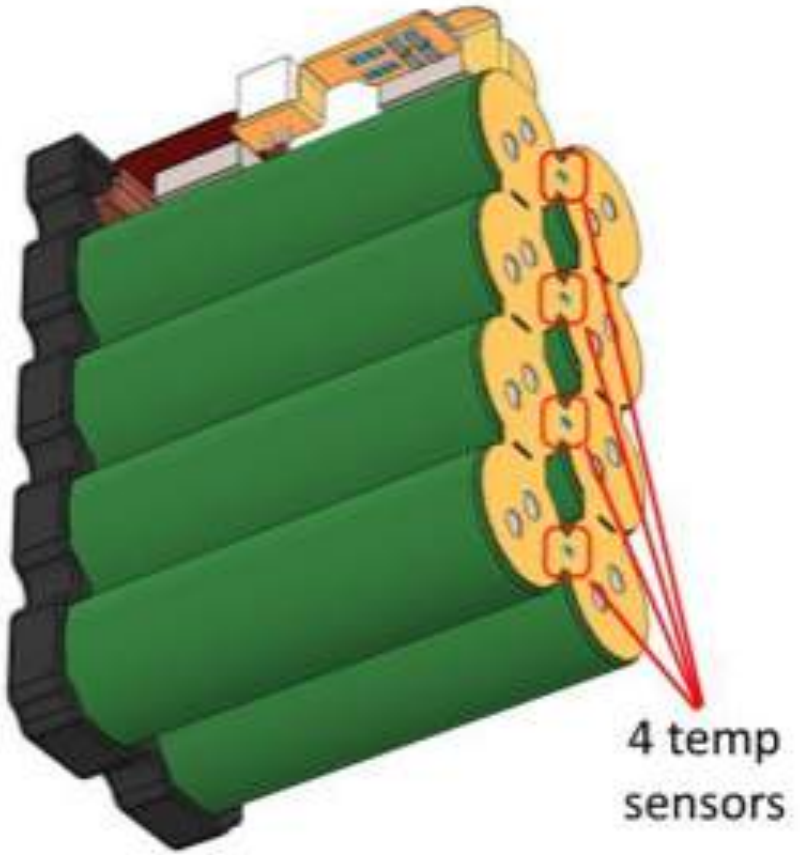
- Documentation
- Support
- Firmware
- Tested
- Integration
- Safer Balancing

SENSOR PLACEMENT

- Wrong



Right



TIPS

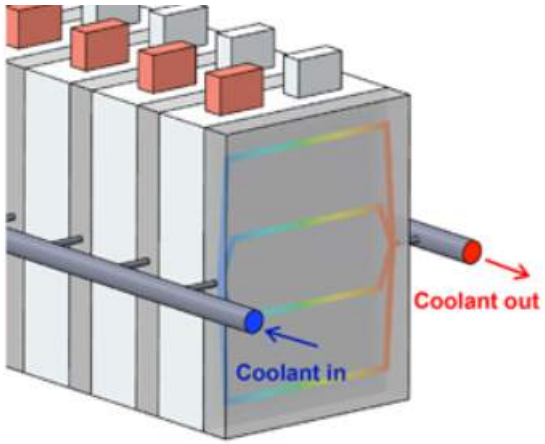
- BPS can be powered temporarily on startup or after fault from supplemental
- Fans can be powered after fault from supplemental
- Avoid long leads or leads with the same ¼ wave as radio and telemetry
- Twist leads reduce noise
- Ducting airflow pulled through battery box is important
- Key, align, and label all connectors
- Relays/Contactor have inductive kickback so use a flyback diode
- Keep a 3-ring binder with all documentation for system
- Have a SD OpenLog device as backup to telemetry
- Keep source code and compiler backups on multiple systems or online(github)

COOL IDEAS

Resettable Inertia Switch Crash Sensor

Battery Outgassing Sensor

Active Temperature Regulation



REGULATION CLARIFICATIONS

- **No Paralleled Strings of Batteries are to be used in solar vehicles**

- Require addition measurement(voltage and current)
- Can cause cascade shutdown
- Creates un-controlled current path

- Benefit to Teams: Safer battery design because the strings each need protection of their own.

SAFETY

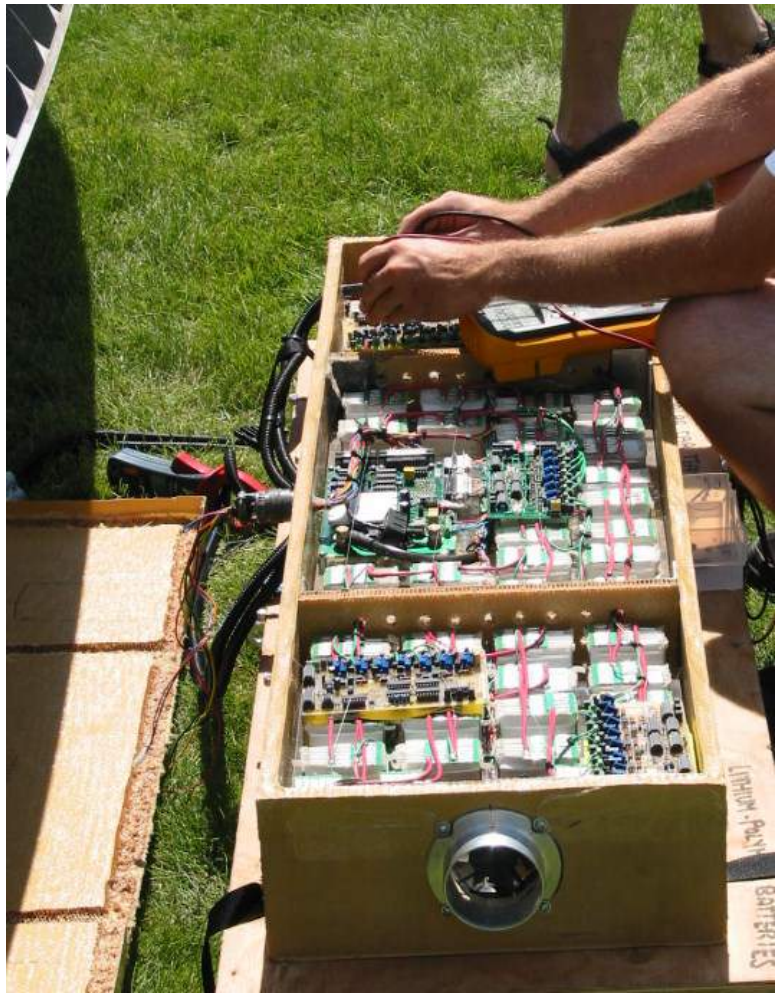
- The batteries are an electro-chemical process
- **Risk compensation** : Feeling protected = Taking more risk
- Don’t underestimate the complexity of the engineering design necessary to not only meet, but exceed the regulation for the safest system you can produce.

Boeing, Tesla, Samsung, and other companies still have difficulty taming all issues with larger resources of headcount, research, and testing.

The BPS is a critical safety component to your operating car! It is there to stop abuse to the batteries.

- There is no performance gain to not fully implementing to your manufactures specifications or not following the intent of the regulations
- **Never** charge or operate batteries without protection or supervision

QUESTIONS?



HOMEWORK

- **Read the Regulations**
- **Present your designs to others for review**
- **Run your own mock scrutineering**
- **Get Road Miles (+1000)**
- **Have backups and emergency plans**

WHAT TEAMS MISS!

- Delivering the VDR with all the required Points covered
- Not having a means to test their BPS function and Calibrations with against test procedure
- Visibility to live measurements or code to see what is going on during the test
- Calibration of all separate sensor with a good source(not heat guns, open flames)
- Test harness for easy connection to test point on board
- Datasheet on sensor specification or ratings
- Experience team members that have design, build, coded, calibrated, and debugged problem on their system in the field.
- Correct setpoints for their batteries data sheet and approved values from Steve.
- Ability to show BPS fault indicator on body while testing