Wireless Sensor BMS for ARPA-E AMPED

AMPED Annual Review

Spring 2015 Meeting

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Multi-discipline, multi-institutional collaboration

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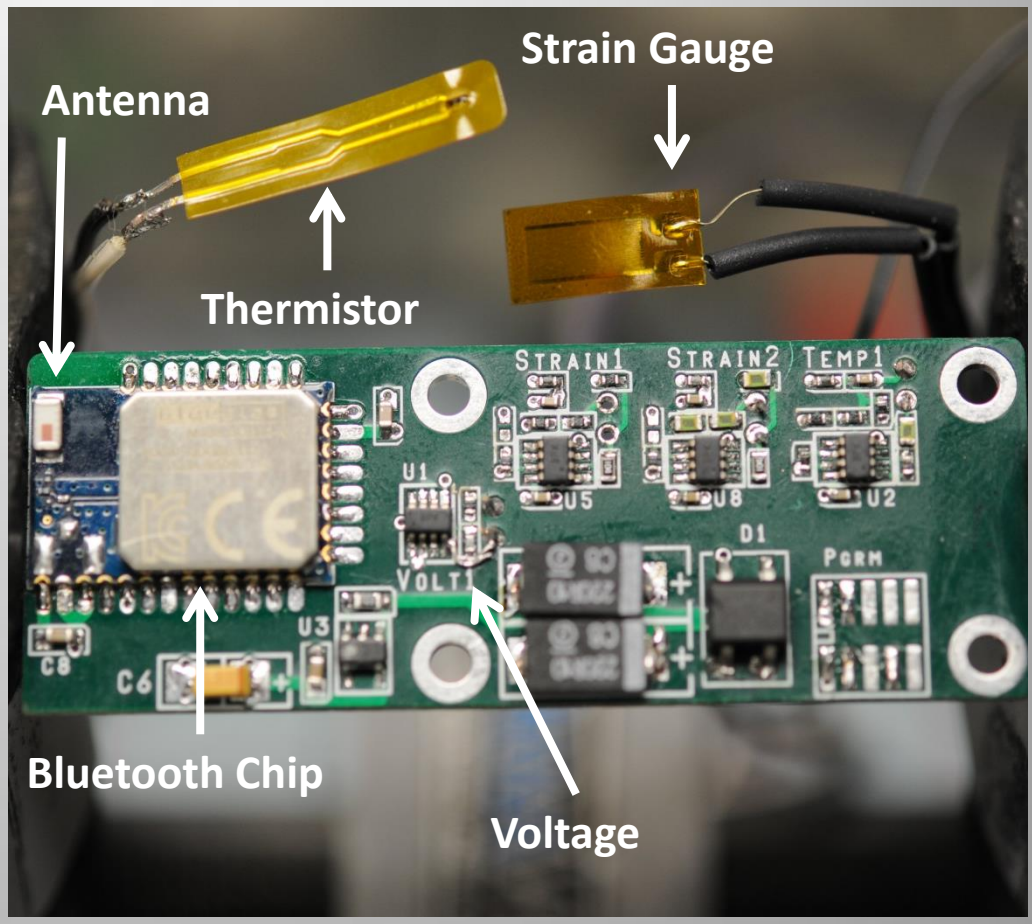
- Naval Post Graduate School: Sebastian Osswald
- Naval Facilities Engineering & Expeditionary Warfare Center: Kevin Wolf
- Polystor Energy Corporation: Jim Kaschmitter
- Eaves Devices: Steve Eaves
- eNow: Steve Lasher, Bob Doane

The World is Going Wireless

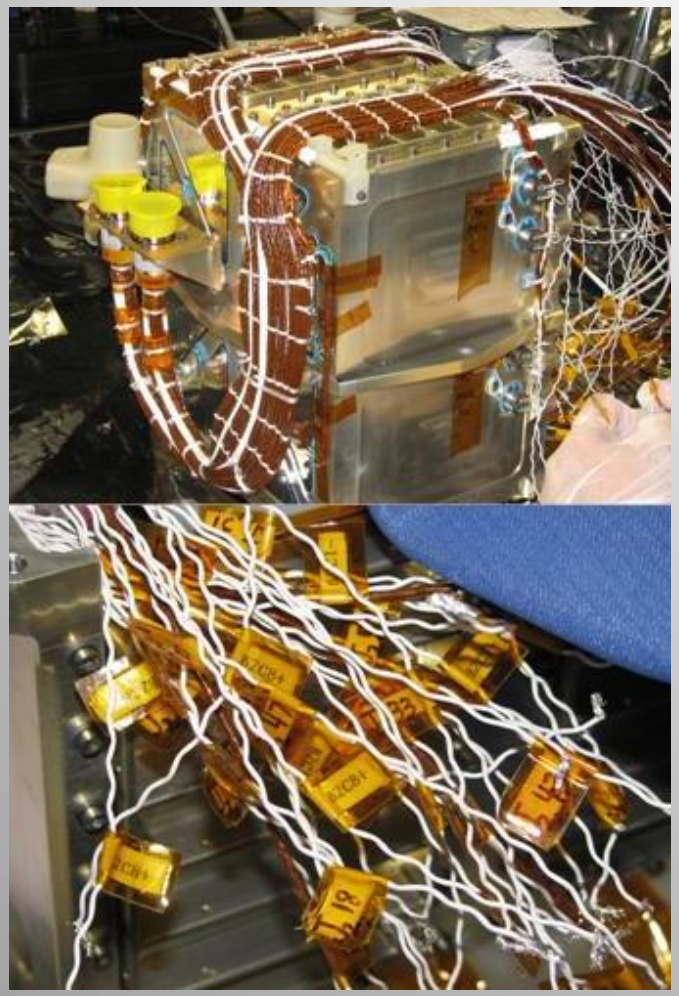
- This ARPA-e Team believes that the only essential use of massive wiring harnesses in a battery pack is for the transmission of stored energy.
- Why not create an entirely new wireless approach to BMS technology?
- Such innovation could enable cell-level monitoring and communication from manufacturing … to battery packs and grid storage … to recovery and recycle!
- Wireless can provide unprecedented capability to emplace unencumbered distributed wireless sensing for 'cradle-to-grave' state of health monitoring that will extend service life, prevent catastrophic failure, and reduce cost.

AMPED Enabled Wireless BMS Sensing Capability

- Wireless sensor suite
- Monitors Energetic devices
- Increases safety and lifetime
- Demonstrated on batteries (voltage, temp, strain, more available)

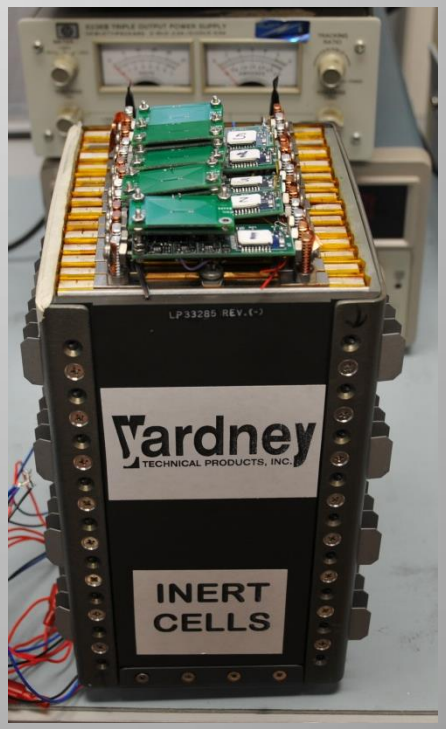


Advantages of Wireless Sensors

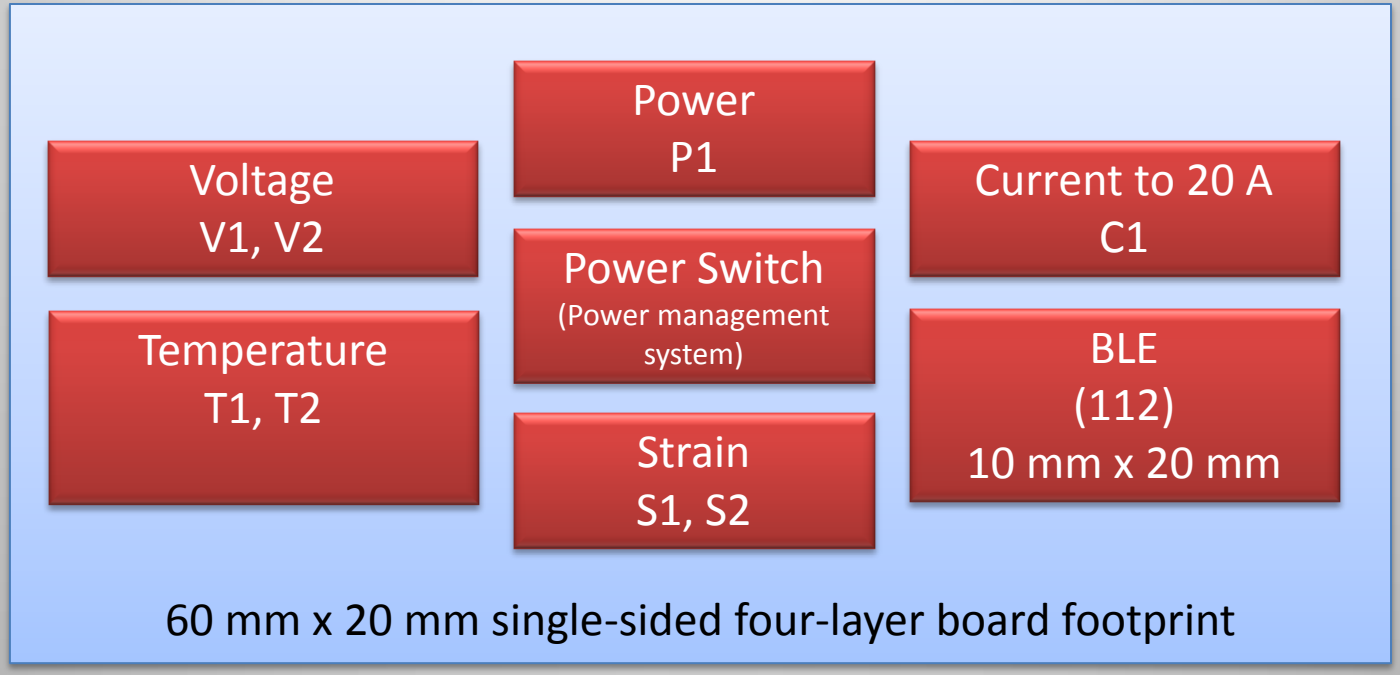


<u>State of the art</u>: Li-Ion Battery Pack Requires Massive Wiring Harness

<u>New Technology</u>: Wireless sensor boards greatly reduce wiring, and increase sensor numbers



Product Development Plan:
Current form factor = 60 mm x 20 mm



TRL 4: low volume production, tailored solution, no modification from current solution

NRE: $250K (done)

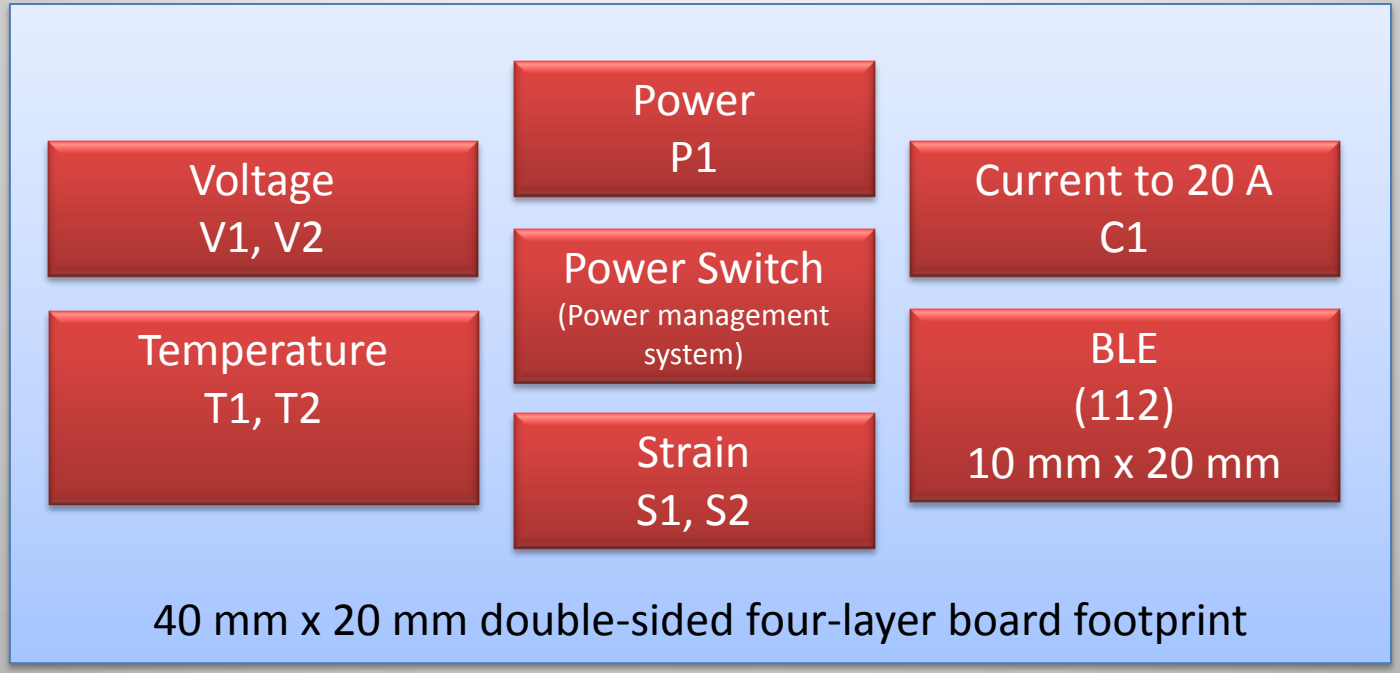
For 16 est. $6K build, program, test

For 160 est. $60K build, program, test **$375 per PCB system**

Product Development Plan: Current form factor = 60 mm x 20 mm

- Analog plus digital in one package requires more development efforts
- Specifications to be finalized:
  - Number of sensors (maximum is 8 per BLE)
    - Currently allocated 7 (V1,V2, T1, T2, S1, S2, C1)
  - Resolution
    - Currently 12-bit over 3-V dynamic range
  - Processing speed
    - Currently 10-Hz for all 8 channels, limited by BLE script language
  - Accuracy requirements for sensors needs to be decided upon
  - Power source is either DC (active) or coil (passive)
  - Current monitoring limited by precision/size of drop in resistor

Product Development Plan: Intermediate Form Factor #1 = 40 mm x 20 mm



TRL 3: low volume production, tailored solution, mod from existing solution on previous graph

NRE: $40K

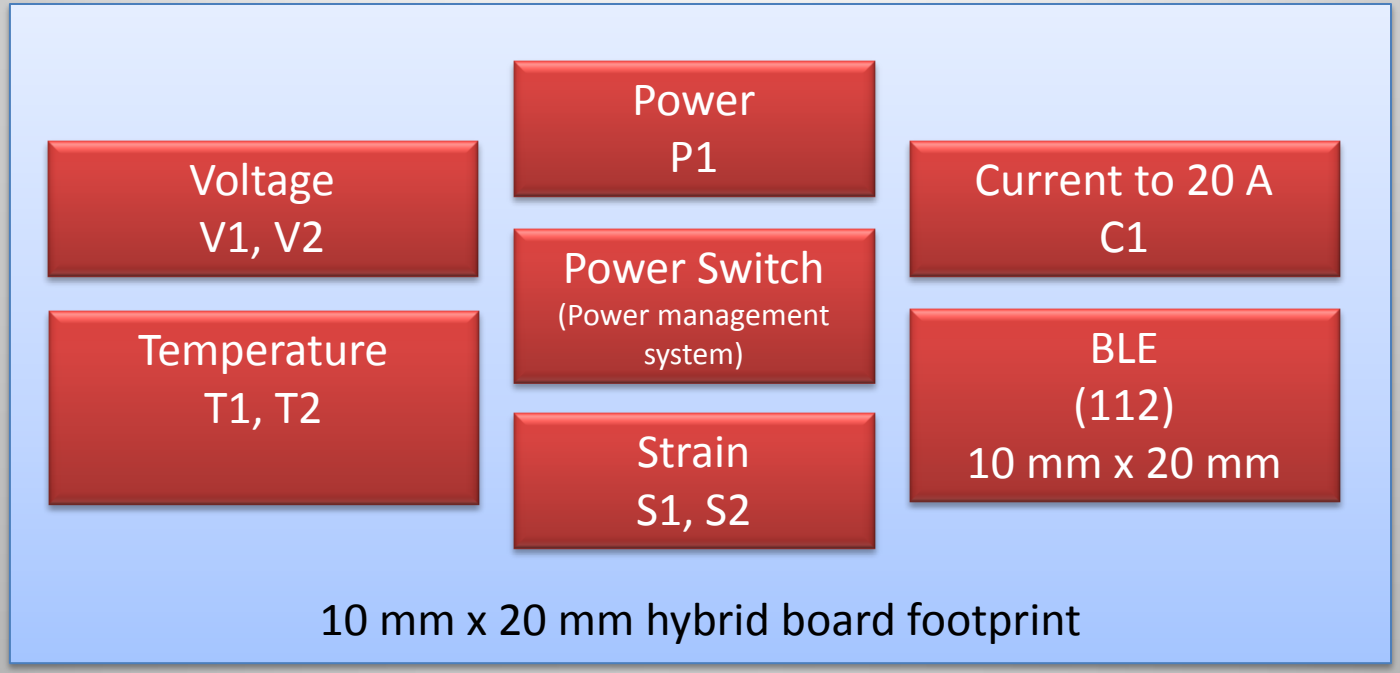
For 16 est. $6K build, program, test

For 160 est. $60K build, program, test **$375 per PCB system**

Product Development Plan: Intermediate Form Factor #1 = 40 mm x 20 mm

- Analog plus digital in one package requires more development efforts
- Uncertainties:
  - Number of sensors (maximum is 8 per BLE)
    - Currently allocated 7 (V1,V2, T1, T2, S1, S2, C1)
  - Resolution
    - Currently 12-bit over 3-V dynamic range
  - Processing speed
    - Currently 10-Hz for all 8 channels (limited by BLE script language)
  - Unknown accuracy requirements for sensors
  - Power source is either DC (active) or coil (passive)
  - Current monitoring limited by precision/size of drop in resistor

Product Development Plan: Intermediate Form Factor #2 = 10 mm x 20 mm



TRL 1: low volume production, tailored solution, significant modification from existing solution

NRE: $100K

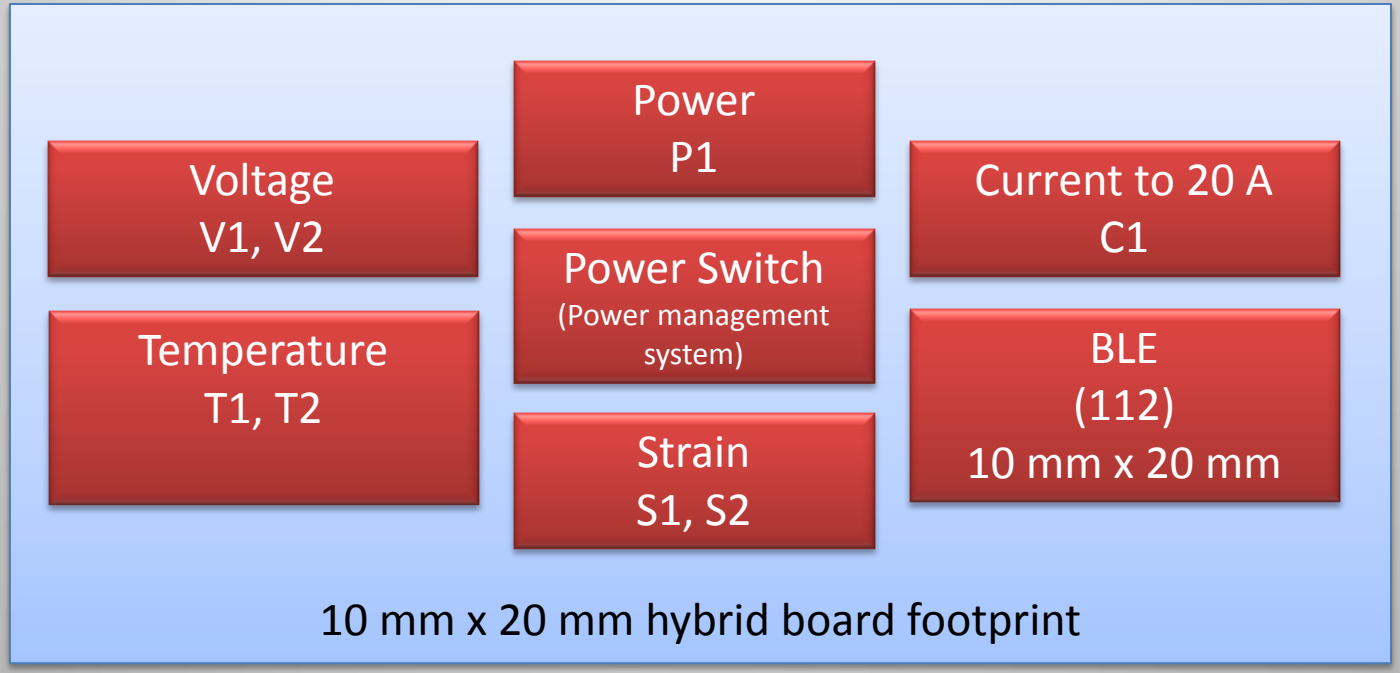
For 16 est. $150K for 6 months for build, program, test

For 160 est. $200K build 6 months for program, test **$1250 per PCB system**

Product Development Plan: Intermediate Form Factor 2 = 10 mm x 20 mm

- Analog plus digital in one package requires more development efforts, with lots of unknowns, buying bare die and wire bonding onto substrate
- Uncertainties:
  - Number of sensors (maximum is 8 per BLE)
    - Currently allocated 7 (V1,V2, T1, T2, S1, S2, C1)
  - Resolution
    - Currently 12-bit over 3-V dynamic range
  - Processing speed
    - Currently 10-Hz for all 8 channels (limited by BLE script language)
  - Unknown accuracy requirements for sensors
  - Power source is either DC (active) or coil (passive)
  - Current monitoring limited by precision/size of drop in resistor

Product Development Plan:
Single-Die Form Factor (low volume production)



TRL 1: low volume production , tailored solution, significant modification from existing solution

NRE: $1.5M and 12 months

For > 160 est. $50K build, 3 months for program, test $375 per system to <$1's

Product Development Plan: Single-Die Form Factor

- Analog plus digital in one package requires more development efforts, lots of unknowns, buying bare die and wire bonding onto substrate
- Uncertainties:
  - Number of sensors (maximum is 8 per BLE)
    - Currently allocated 7 (V1,V2, T1, T2, S1, S2, C1)
  - Resolution
    - Currently 12-bit over 3-V dynamic range
  - Processing speed
    - Currently 10-Hz for all 8 channels (limited by BLE script language)
  - Unknown accuracy requirements for sensors
  - Power source is either DC (active) or coil (passive)
  - Current monitoring limited by precision/size of drop in resistor

Wireless Overview

Bluetooth 4.0 wireless tags and sensors free of wiring harnesses

- Integrated Bluetooth 4.0 transceiver, 8051 microcontroller and software stack
- Seven 12-bit ADC sensor channels (2 voltage; 2 strain; 2 temperature; 1 current)
- Data throughput greater than 100 kbps
- Enables relatively fast time-to-market and low development risks
- Possible cost reduction from $387 per unit to less than $10 per unit with ASIC

Available memory (128kB flash & 8kB RAM)

- System settings & application data can be stored in flash memory
- Stored field-upgradeable software

Software programmable power requirement

- Bluetooth chip drain of 0.4 microamperes in lowest power sleep model
- System can awaken within a few hundred microseconds

International standards for adoption and integration

- USB-compatible; plug-and-play with PCs, tablets & smart phones
- Bluetooth, CE, FCC, IC, Japan, and South Korea qualified
- SIG with > 1,900 members

T2M Involves Early Adopter Applications

Our vision for Next-Generation

Today's Wireless Sensors

- Cell potential
  - Terminal
  - Internal reference electrode
- Cell temperature
  - External
  - Internal temperature sensor
- Cell strain
  - Infer internal pressure
- Emission sensors
  - Acoustic
  - Optical

Tomorrow's Wireless Control

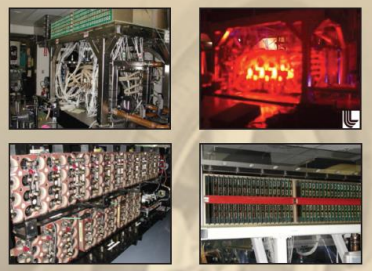
- Enable high-fidelity balancing of individual cells
- Distributed wireless low-drain switches for control of current flow to each cell based upon sensed voltage
- Distributed wireless low-drain operational amplifier circuits to charge each cell with potential control

Wireless BMS tech-to-market plan: Possible early adopter applications

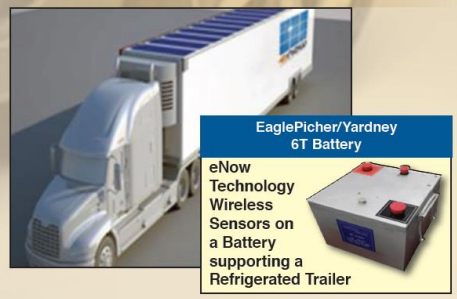
- Early adopters in Aerospace & Defense
- Advanced applications in civilian aviation
- UPS, grid & test equipment applications
- Automotive applications (EV, HEV & SLI)

Curiosity Rover on Mars

Early adopters in defense

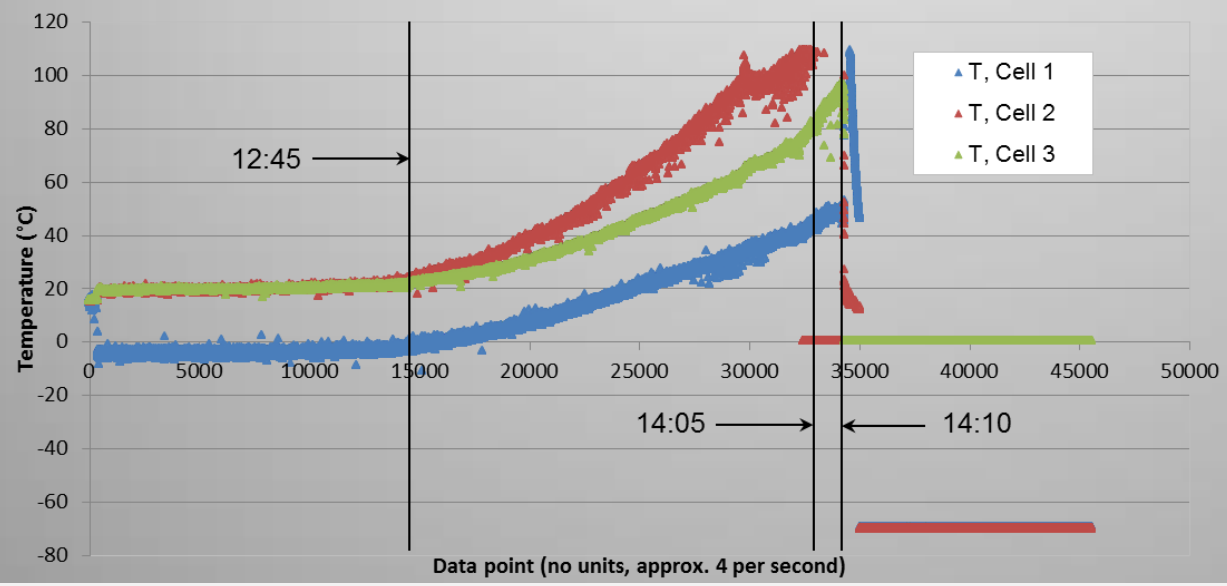


Early adopters in transportation



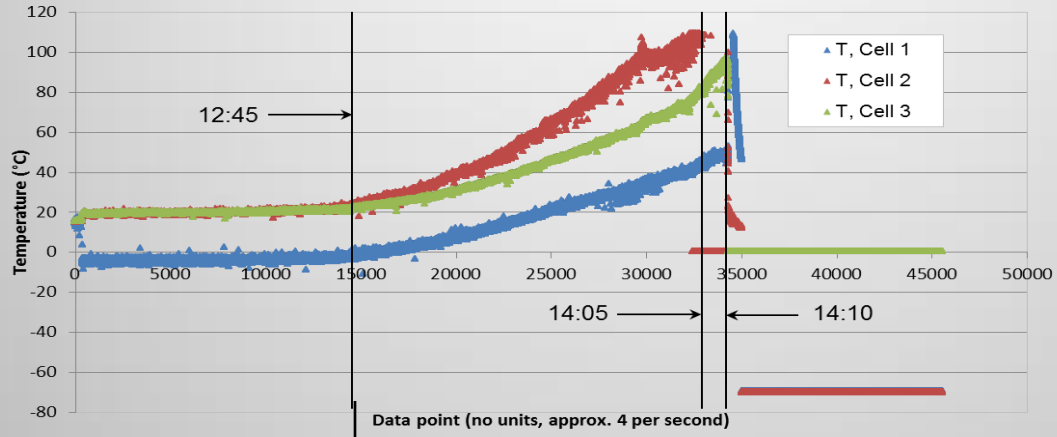
Monitoring Cells to Thermal Run-away

- Wireless monitoring of cells under failure
- Sensors show approaching failure
- Failure can be prevented
- Also prevent degradation

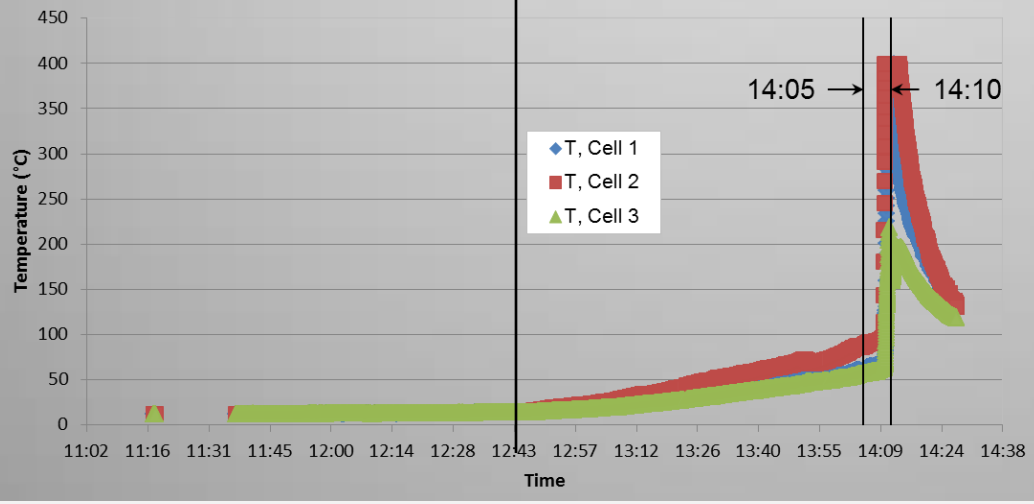


Preliminary Wireless vs. Wired Comparison

Wireless

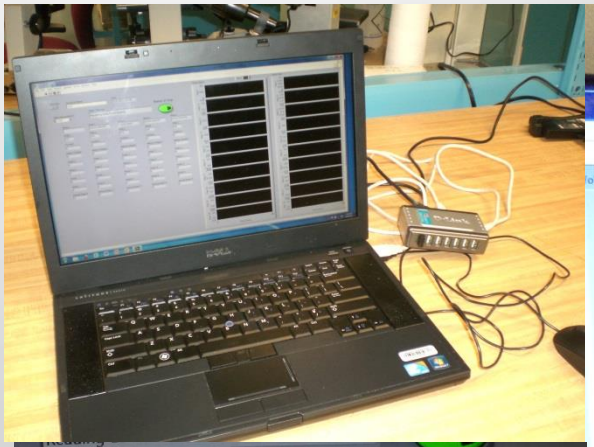


Wired



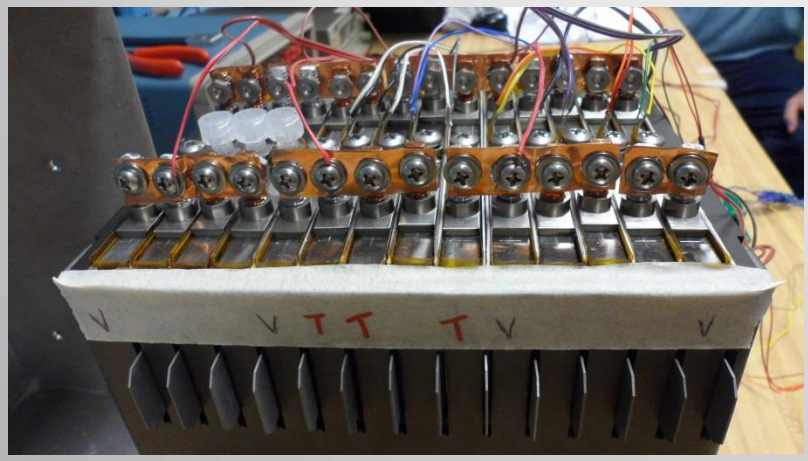
Accuracy of Monitoring

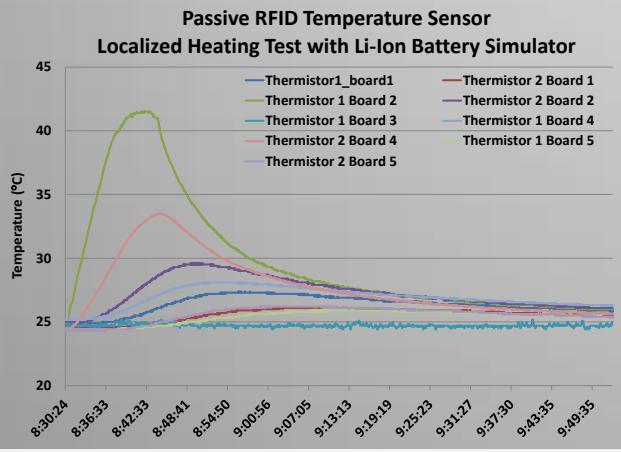
- Live monitoring of cells or energy storage device
- Data can be stored, sent to control system
- Voltage, temp & strain (others available)

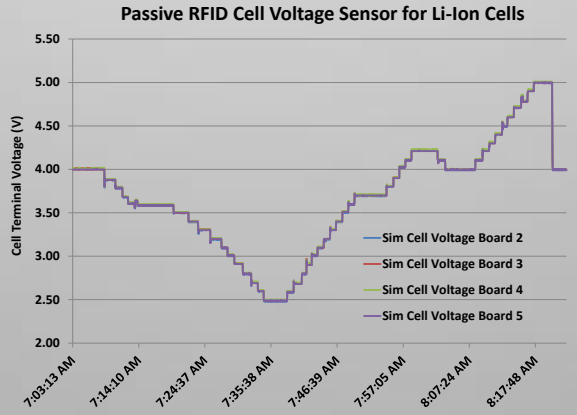


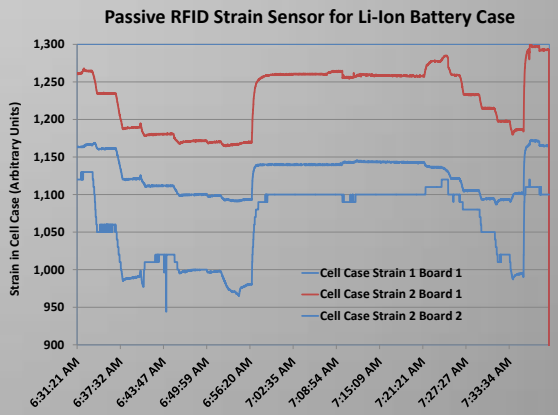
Simulated Data Acquisition

Battery simulator & real battery used to prove in sensors and wireless board



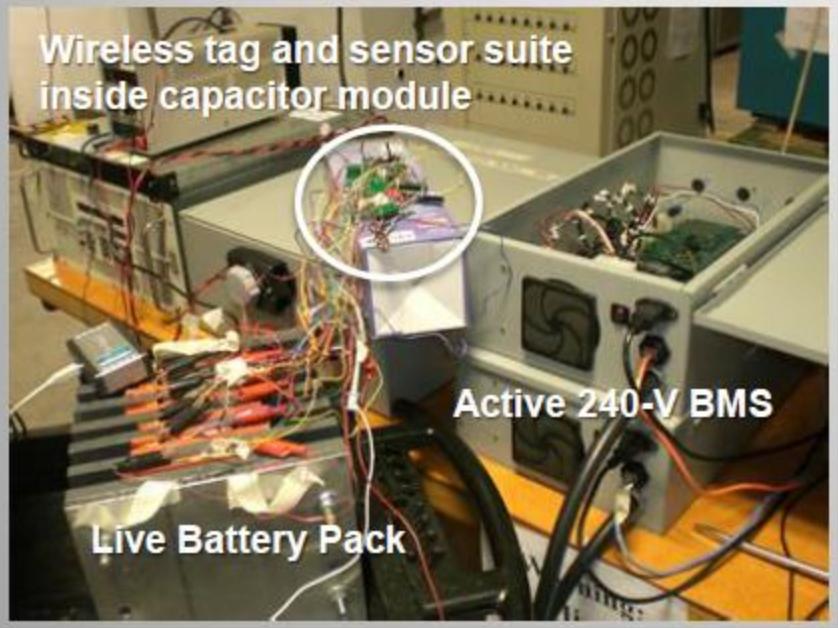






Demonstration in High EMI Environment

Successful testing of wireless tags and sensors with active 240-volt BMS demonstrating no significant interference



Successful testing of wireless tags and sensors inside active 22-kV capacitor module successfully transmitting data to monitoring station during charge and discharge

Trailer….

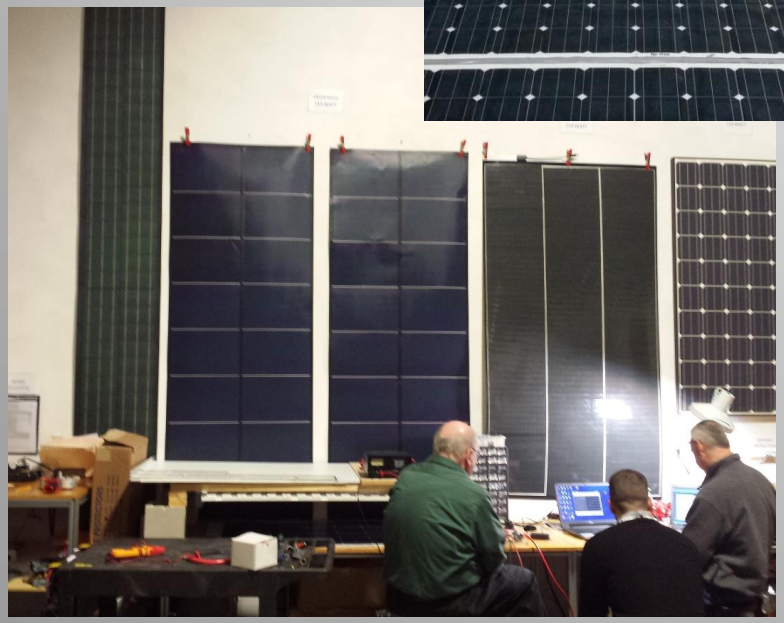
- After much anticipation, the eNOW test trailer is here

Some re-analysis is being done as the air circulators are much more powerful than specified. But the batteries are high power and should still be able to handle the loads. Checking cables and contactors and fuse design.

On the Road Demonstration Trailer….

- Solar Panels and Batteries with Wireless Sensors….

53’



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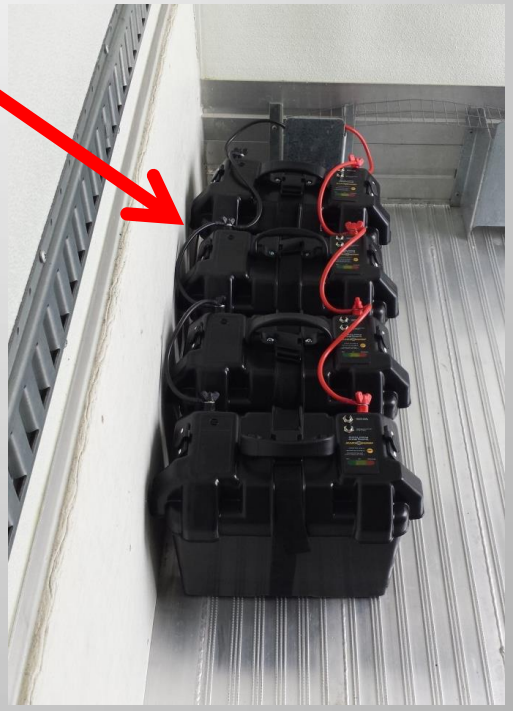
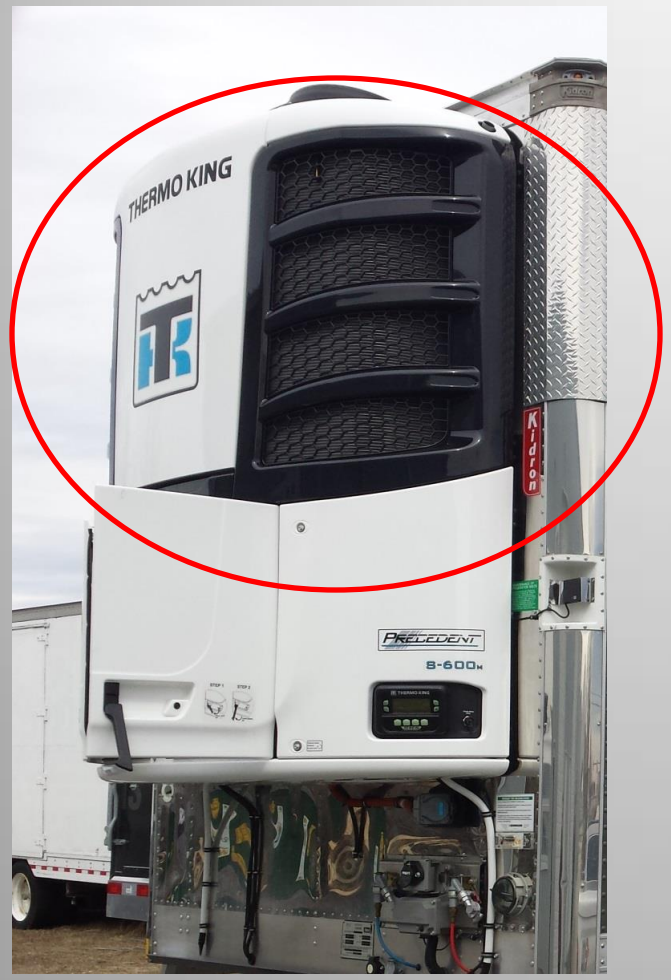


On the Road Demonstration Trailer….

- Will help power this and these



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Back of Trailer, Near Doors

Compressor and batteries are in the front of the trailer, evaporators and fans in back of trailer.

On the Road Demonstration Trailer….

- Without This or This

Diesel Engine….

+

Diesel Fuel

Validation Plan & Performance Targets

- Developed & proved sensors and wireless board
- Board tested on simulator and real battery
- Tested board on battery in high EMI area
- Wireless system worked with LIB safety tests
- Technology to market plan
- IP protected and IP agreements
- Built wireless system on battery unit for truck

AMPED off ramping plans

HESM 1 & 3:

- ONR Sponsored Hybrid Energy Storage Modules
- Jointly written to leverage off AMPED progress
- “Yardney” and LLNL are currently working on both 1 & 3
- HESM 1: Hybrid Technology
- HESM 3: Safety
- Wireless sensors to provide more points of data collection while eliminating the massive harnesses

Summary

- Wireless sensor boards work (even with EMI)
- These boards can be adapted to LIBs
- Batteries can be monitored to prevent failures
- Also monitoring for battery health
- Wireless system with LIB created for commercial truck for hybrid energy system

Steps Forward

Marketing Efforts:

- Finding an OEM to adopt the wireless technology
- Demonstrate value of technology to DOD as being done currently with HESM projects
- Continue to validate technology and work on a Gen II of the technology that is hardened and addresses any shortcomings in last leg of validation

Thanks to ARPA-E for the
Funding and Opportunity to develop the
Wireless BMS Sensor Technology
and Exploring Future Opportunities

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