Robert Ratz

BMS System Benchmark and Standardization

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Battery Management System
Agenda

- Ricardo Vehicle Benchmarking and Analysis
- BMS System Overview
- Types of Cell Balancing
- BMS System Benchmark Comparison
  - Architecture Comparison
  - Battery size
  - Cell Balancing
  - Isolation methods
  - Voltage sense & battery balance
  - Microcontrollers
- Motivation for a standardized BMS system specification

Fourteen xEVs have been benchmarked over the last four years by Ricardo

xEVs Benchmarked

(note driveline weights shown)

[1461] - Tesla Model-S (60 kWh)

Model Year: 2013
Teardown year: 2014
Weight: 687.129 kg

[1450] - Ford C-Max Energi SEL 2.0 ATK IVCT

Model Year: 2013
Teardown year: 2013
Weight: 307.496 kg

[1493] - Honda Civic Hybrid (Battery Only)

Model Year: 2014
Teardown year: 2014
Weight: 22.180 kg

[1444] - Ford Fusion Hybrid 2.0

Model Year: 2013
Teardown year: 2013
Weight: 218.370 kg

[1416] - Chevrolet Malibu Eco 2.4L

Model Year: 2013
Teardown year: 2013
Weight: 139.821 kg

[1364] - Chevrolet Volt

Model Year: 2011
Teardown year: 2011
Weight: 417.038 kg

[1417] - Mitsubishi i-MiEV

Model Year: 2011
Teardown year: 2011
Weight: 366.508 kg

[1408] - Toyota Prius Plug-In

Model Year: 2012
Teardown year: 2012
Weight: 213.387 kg

[1409] - Nissan Leaf

Model Year: 2011
Teardown year: 2011
Weight: 475.393 kg

[1489] - Chevrolet Spark EV

Model Year: 2014
Teardown year: 2014
Weight: 380.273 kg

[1499] - BMW i3 eDrive Range Extender

Model Year: 2014
Teardown year: 2014
Weight: 391.840 kg

[1509] - Volkswagen Jetta Hybrid 1.4

Model Year: 2014
Teardown year:
In progress
2014 VW Jetta Hybrid

[1434] - Toyota Highlander Hybrid 3.5

Model Year: 2013
Teardown year: 2013
Weight: 253.664 kg

[1539] - Volkswagen e-Golf VII SEL Premium

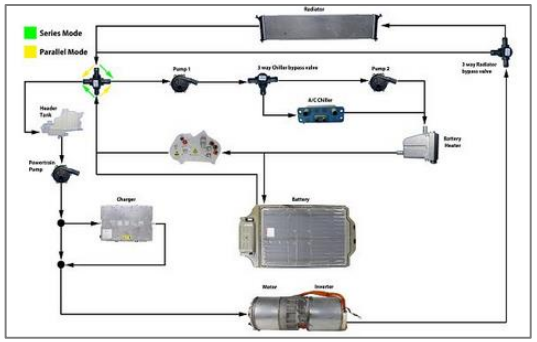
Model Year: 2014
Teardown year:
In progress
2014 VW e Golf EV

- High Voltage Battery Pack
- DC DC Converter
- DC AC Inverter
- Onboard Charger System
- High Voltage Junction Box
- High VoltageHarn Harnes
- HVAC and Cooling Systems
- Transmission / EV Drive System

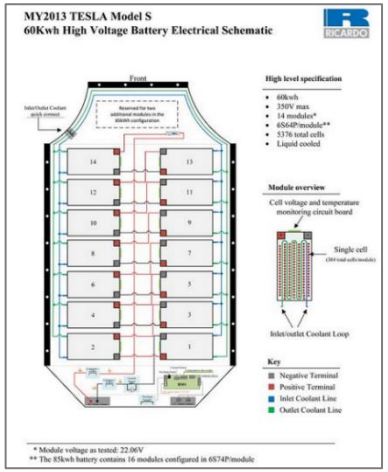
Example Schematics

Battery Pack

Thermal

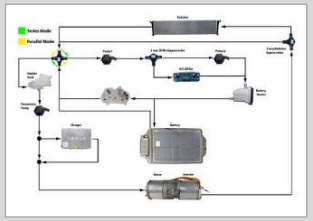


Battery Pack Electrical

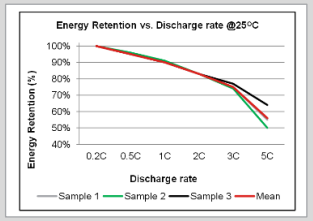


Benchmark activities include in-depth analysis and studies of all major EV systems

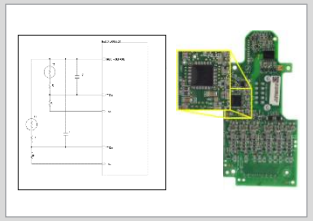
Analyses performed (sample)



Thermal Schematic

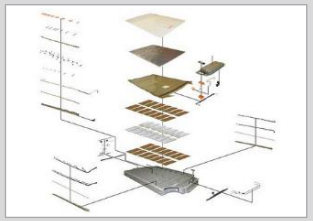


Cell Characterization

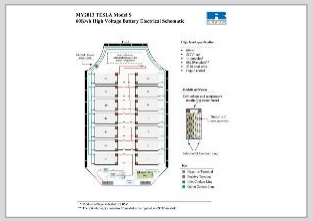


BMS Analysis

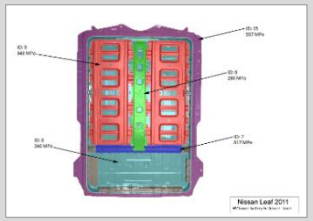
System Schematic



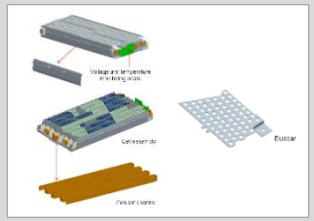
Exploded Views



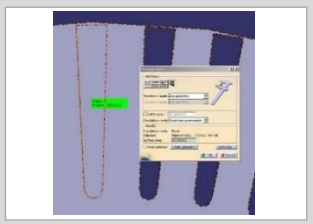
Battery Schematic



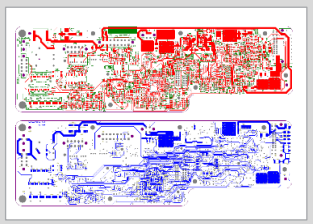
Steel Analysis



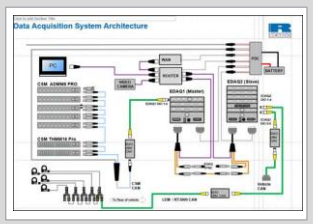
3D CAD Modeling



2D CAD Drawing



Circuit Analysis

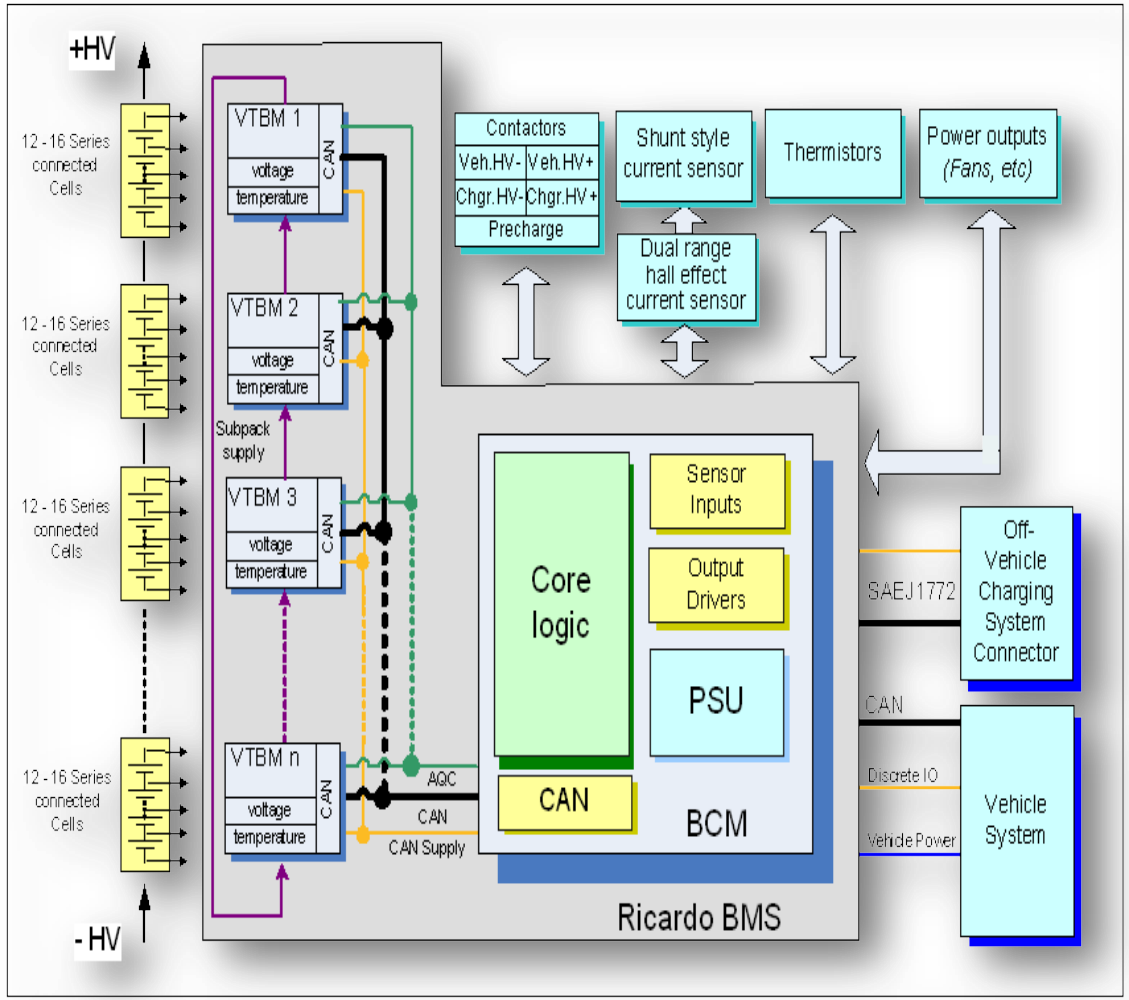


Performance Testing

BMS System Overview

BCM (Battery Controller Module)

- Current Sensing
- Voltage sensing
- Temperature sensing
- CAN Communications
- Battery Charger control
- Output drivers for pumps, fans, and heaters
- Contactor control:
  - Main Contactors
  - pre-charge
  - Charger Contactors
- State of Charge algorithms
- State of health algorithms
- Power capability algorithm
- Safety feature
  - Performs leakage detection and contains ground fault interrupt functionality
  - Self test of all critical functionality on every “key-on” event
  - Diagnostics of key functions



BMS Architectures – Distributed

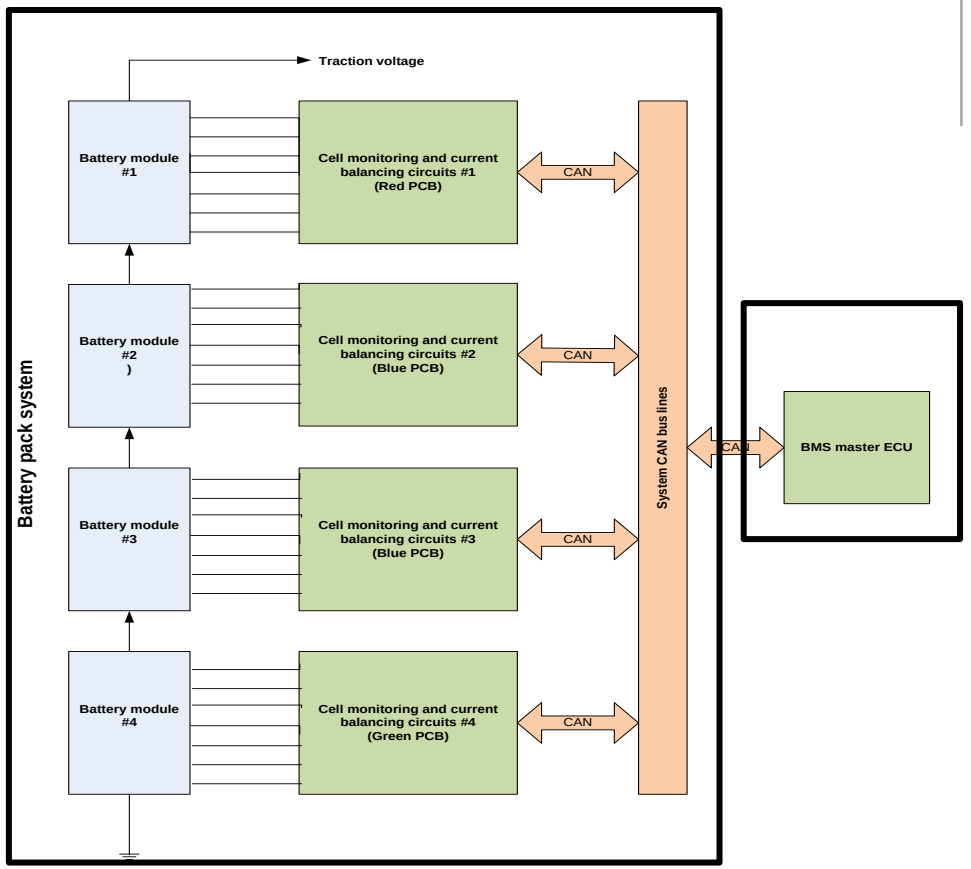
Distributed BMS Architecture is split into one main controller and multiple slave boards

<u>Battery Controller Functions:</u>

- Battery charger control
- Output drivers for pumps, fans, and heaters
- Typically Contactor control
- State of charge algorithms
- State of health algorithms
- Power capability algorithm
- Safety feature

<u>Slave Board (Voltage & Balance PCB)</u>

- Voltage /Temperature
- Cell Balancing
- Communicates to main controller



Pros

- Highly Scalable and modular
- Less wiring

Cons

- Several PCBs

Centralized BMS

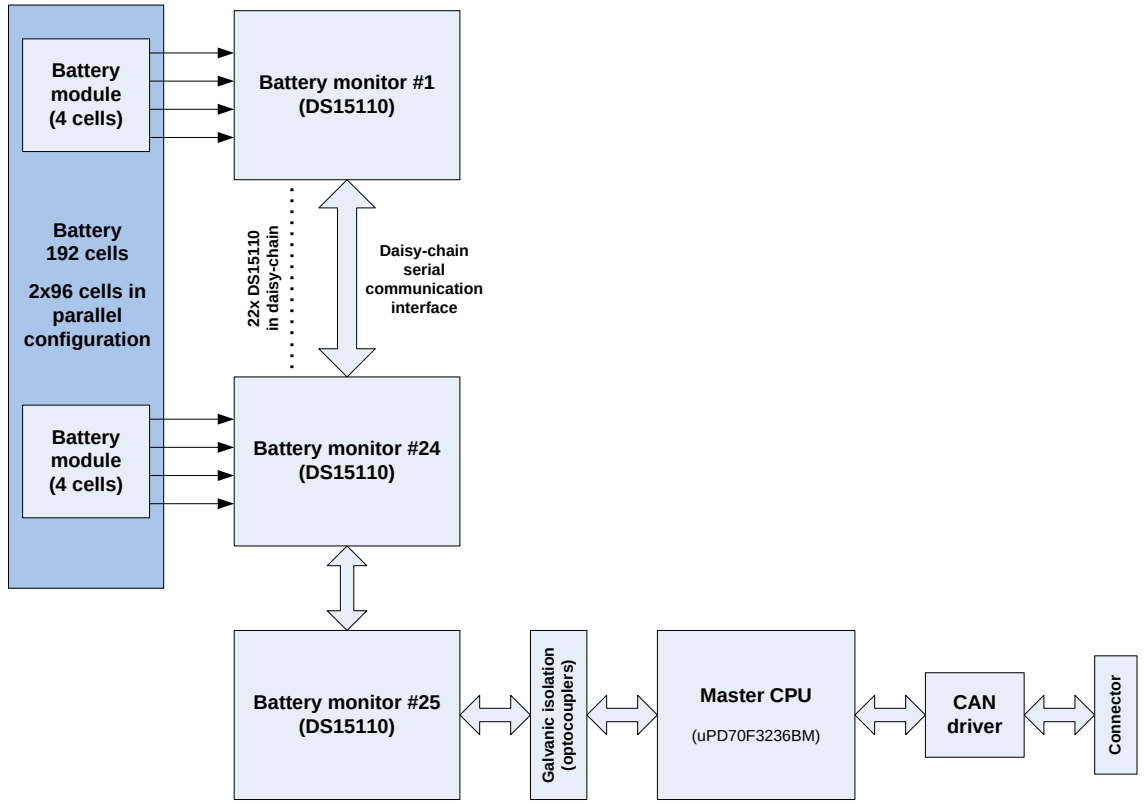
- A Centralized BMS has all of the functions in a single module/PCB.
- Centralized architectures tend to be on smaller packs (exception is the Nissan Leaf)

Pros

- One PCB and reduced electronic costs

Cons

- Wiring intensive
- Not scalable



Cell Balancing

Passive Balancing

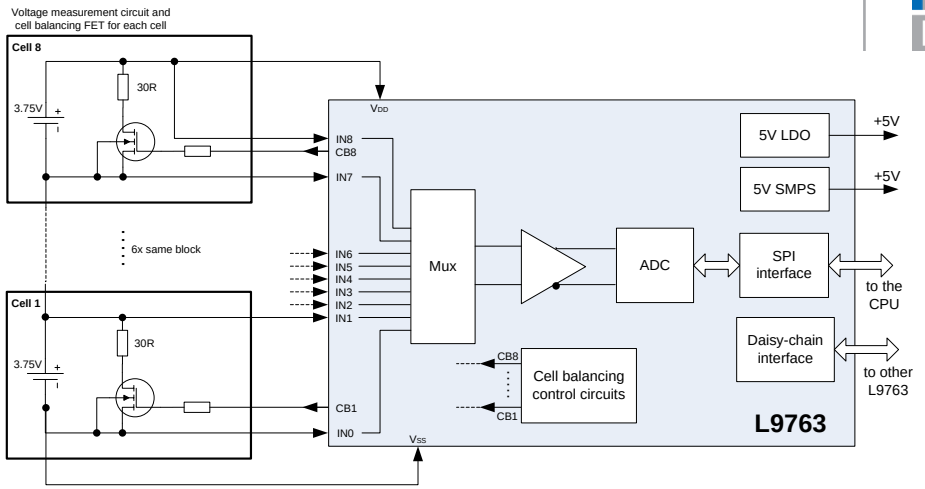
- Resistive discharging of higher voltage cells to the lowest denominator

Pros

- Integrated ASICs
- Least expensive

Cons

- Slower Balancing
- Wastes energy to heat



Active Balancing

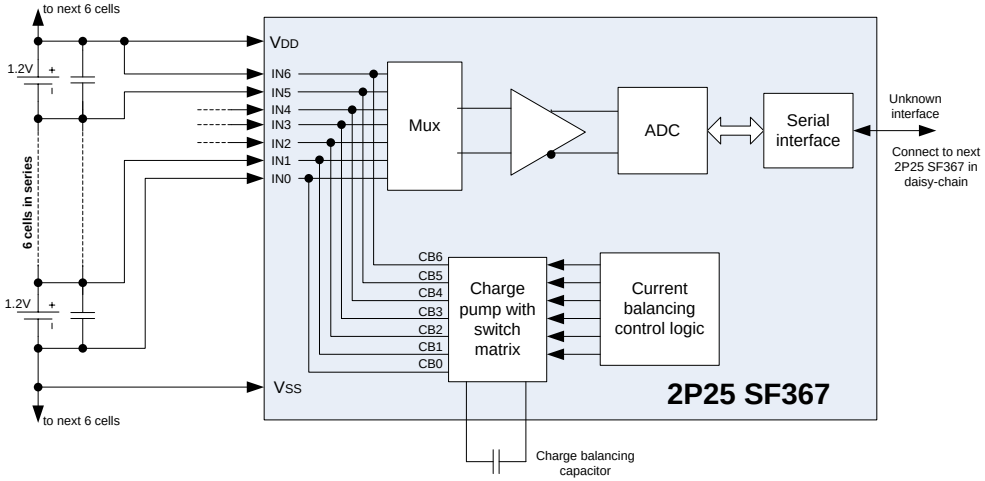
- Charges a low cell from a higher cell

Pros

- Quicker to balance
- Capable of nurturing a weak cell to prolong life
- Recovers energy

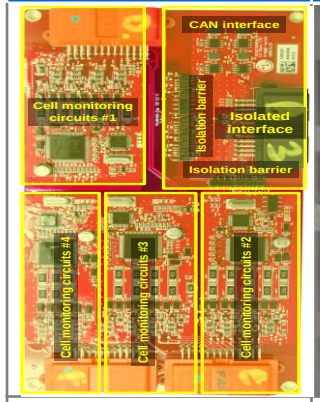
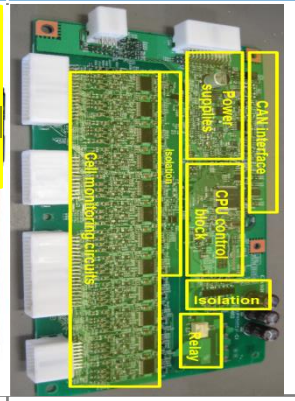
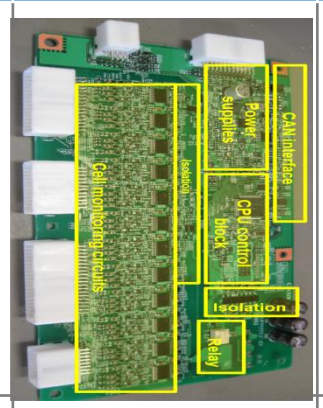
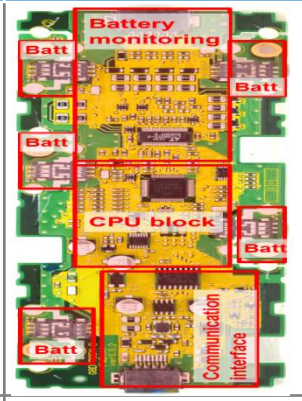
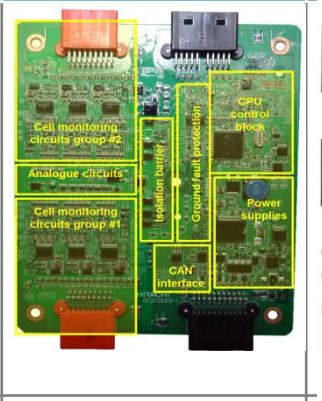
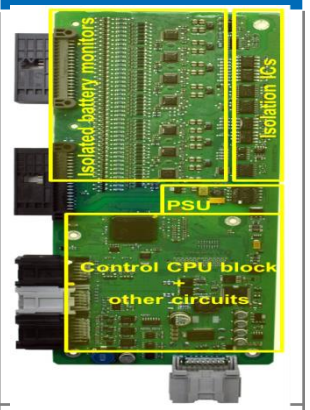
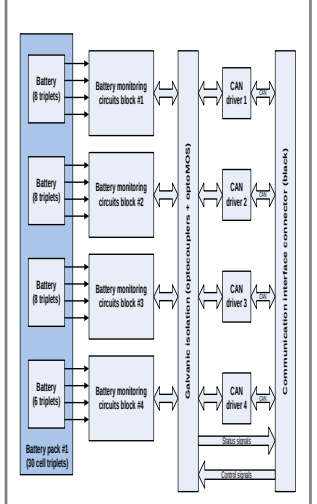
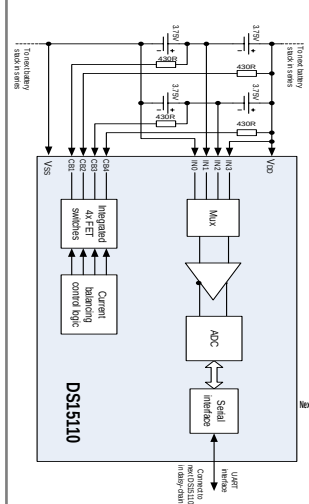
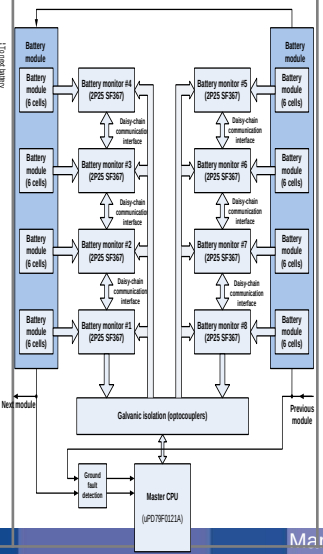
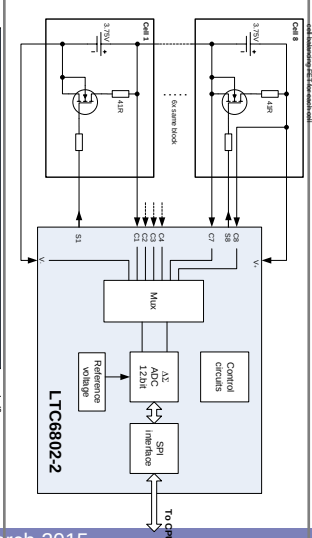
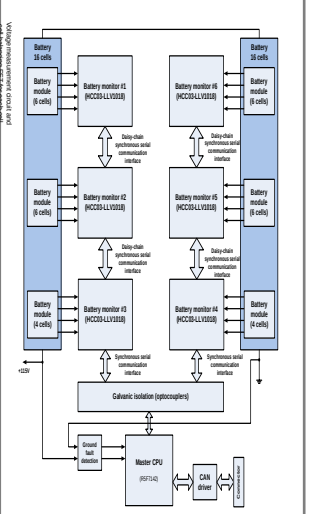
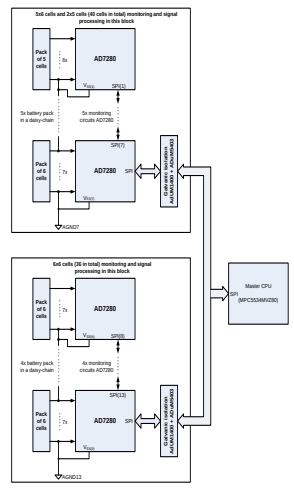
Cons

- More Complex
- More expensive



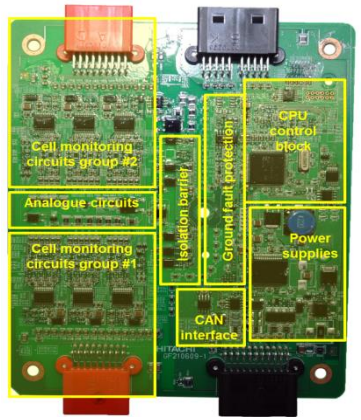
BMS Benchmark and Analysis

- Analyzed BMS PCB
- Determined PCB functional partitioning
- Developed system diagrams
- Analyzed subsystems
- Voltage & Temperature sensing
- Balancing methods & IC's used

2011 Chevrolet Volt	2011 Nissan Leaf	2012 Toyota Prius Plug In	2011 Mitsubishi iMiEV	2013 Chevrolet Malibu Eco	2013 Ford Fusion
					
					

There Are Two Main Architectures

Car model	Year	BMS architecture	kWhr
Ford Fusion Hybrid 2.0	2013	Centralized on the single PCB	1.4
Chevrolet Malibu ECO	2013	Centralized on the single PCB	0.5
Chevrolet Volt	2011	Pseudo-Distributed 4 PCB modules + BMS master ECU	16
Mitsubishi I-MiEV	2012	Distributed 11 PCB modules + BMS master ECU	16
Nissan Leaf	2011	Centralized on the single PCB	24
Toyota Prius	2012	Distributed 4 PCB modules	4.4
Ricardo McLaren P1	2013	Distributed 1 BCM + Several VTBMs	4.8

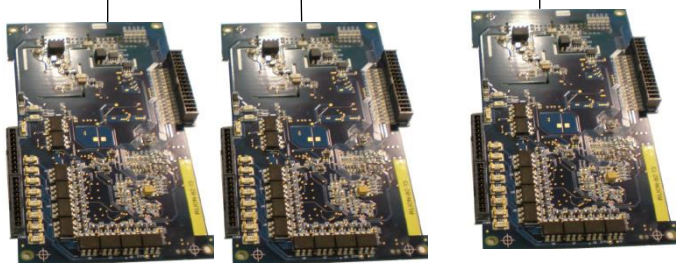


Centralized

Distributed

Master controller

Slave PCBs



Battery Comparison

Car model	Battery voltage	Battery cells
Ricardo McLaren P1	550V	324
BMW i3	360V	96
Tesla Model S60	300V	5,376
Ford Fusion Hybrid	275V	76
Chevrolet Malibu ECO	115V	32
Chevrolet Volt	360V	288
Mitsubishi I-MiEV	330V	88
Nissan Leaf	360V	192
Toyota Prius PlugIn	207V	56

Ford Fusion Hybrid

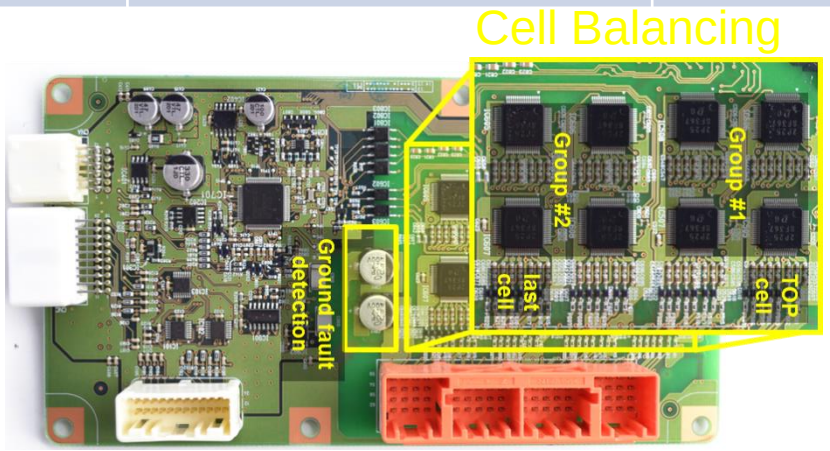
Nissan Leaf

Prius Plug-In Hybrid

Chevy Volt

Battery Cell Balancing Comparison

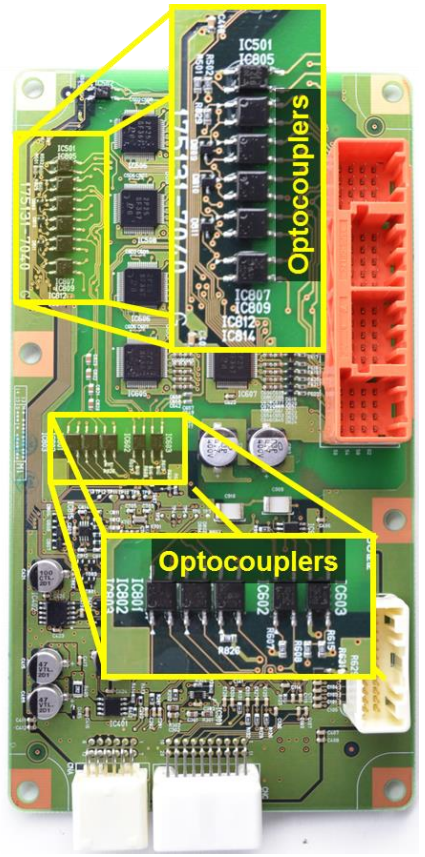
Car model	Cell balancing method	Cell balancing technique	Cell balancing current[1]
Ford Fusion Hybrid	Passive	Resistive	17 mA
Chevrolet Malibu ECO	Passive	Resistive	17 mA
Chevrolet Volt	Passive	Resistive	125 mA[2]
Mitsubishi I-MiEV	Passive	Resistive	92 mA
Nissan Leaf	Passive	Resistive	8.7 mA
Toyota Prius	Active	Charge pump	Unknown
Ricardo McLaren P1	Active & Passive	Charge transfer & resistive	1Amp Active 250 mA Passive



[1] Estimated cell balancing current given at nominal cell voltage
[2] Estimated cell balancing current given at nominal cell voltage for cell triplet

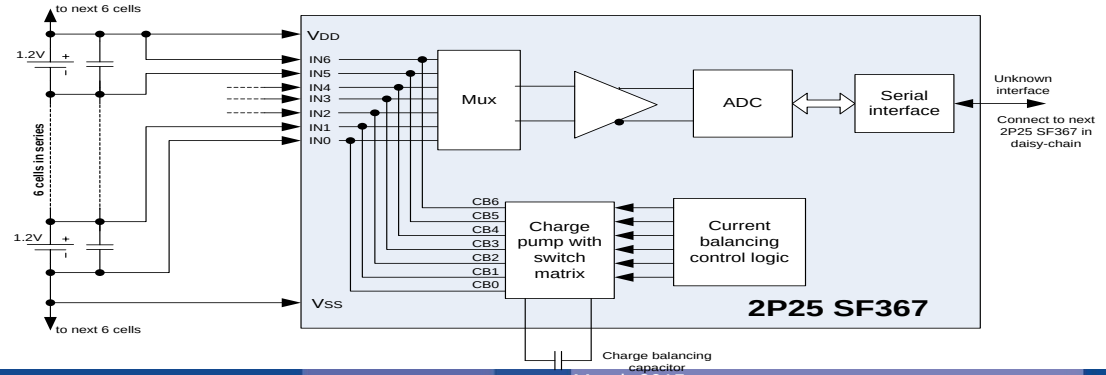
Isolation Method

Car model	Isolation Method	Chip
Ford Fusion Hybrid	Digital isolators	Analog Devices ADuM5403
Chevrolet Malibu ECO	Optocouplers	NEC - PS9121
Chevrolet Volt	Optocouplers	Avago ACPL-M43T Matsushita AQW212S
Mitsubishi I-MiEV	Digital isolators	Analog Device-ADuM1402W
Nissan Leaf	Optocouplers	NEC - PS9114
Toyota Prius	????	Renesas & Matsushita PS9121 216C020
Ricardo McLaren P1	OptoMOSFETs Digital Isolators	NEC PS710E



Voltage & Balance ASICs

Car model	ASIC	# cells	Communications from ASIC to Micro
Ford Fusion Hybrid	Analog Devices AD7280	6 Cells	SPI Daisy Chain
Chevrolet Malibu ECO	Hitachi-HCC03LLV1018	6 Cells	Serial Daisy chain
Chevrolet Volt	STMicro L9763	8 Cells	SPI Daisy Chain
Mitsubishi I-MiEV	Linear-LTC6802G-2	12 Cells	SPI Daisy Chain
Nissan Leaf	NEC DS15110	4 Cells	UART interface
Toyota Prius	???? 2P25 SF367	4 Cells	Serial Daisy chain
Ricardo McLaren P1	Microcontroller	14 Cells	NA



BMS Primary CPU

Car model	BCM CPU	
Ford Fusion Hybrid	Freescale MPC5534MVZ80	32 Bit
Chevrolet Malibu ECO	Renesas R5F714264FPV	32 Bit
Chevrolet Volt	Freescale S9S08DZ32	32 Bit
Mitsubishi I-MiEV	NEC F3612M2	32 Bit
Nissan Leaf	Renesas PD70F3236BM	32 Bit
Toyota Prius	Renesas - PD79F0121A	32 Bit
Ricardo McLaren P1	Freescale MC9512XPE	32 Bit

Architecture Functions Summary

Car model	Voltage Sense	Temperature Sense	Passive Balance	Active Balance	Isolation	Leakage Detection	Contactor Drivers	Accessory Drives	Charger interface	CAN Communication	Voltage < 250V	CPU 32 Bit	Distributed	Centralized
Ford Fusion Hybrid	X	X	X		X	X	X	X	X	X	X	X		X
Chevrolet Malibu ECO	X	X	X		X	X	X	X	X	X		X		X
Chevrolet Volt	X	X	X		X	X	X	X	X	X	X	X	X	
Mitsubishi I-MiEV	X	X	X		X	X	X	X	X	X	X	X	X	
Nissan Leaf	X	X	X		X	X	X	X	X	X	X	X		X
Toyota Prius	X	X		X	X	X	X	X	X	X		X	X	
Ricardo McLaren P1	X	X	X	X	X	X	X	X	X	X	X	X	X	

Rational for a Standardized BMS System

- A global standard for BMS will further reduce high cost energy storage systems
  - BMS electronic cost in the range of $500 to $1500 per battery Target $50
- BMS systems in use today have similar architectures and functions
- A BMS standard will improve safety and image of HEV/EV market
- A single specification can cover the two approaches to the architectures:
  - Distributed
  - Centralized
- BMS's system hardware have 90% of common functions
  - ASICs have common functions of voltage & temperature monitoring and passive balancing
  - Balancing is predominantly Passive with a couple of applications using Active
  - Isolation is predominantly Opto-isolators
  - Microcontroller are 32 bit
- Most of the IP is software related
- A common standard would further enable second life use of battery systems

Car model	Voltage Sense	Temperature Sense	Passive Balance	Active Balance	Isolation	Leakage Detection	Contactor Drives	Accessory Drives	Charger Interface	CAN Communication	Voltage > 60V	CPU 32 Bit	Distributed	Centralized	
Ford Fusion Hybrid	X	X	X		X	X	X	X	X	X	X		X		
Chevrolet Malibu ECO	X	X	X		X	X	X	X	X	X	X		X		
Chevrolet Volt	X	X	X		X	X	X	X	X	X	X	X			
Mitsubishi I-MiEV	X	X	X		X	X	X	X	X	X	X	X			
Nissan Leaf	X	X	X		X	X	X	X	X	X	X		X		
Toyota Prius	X	X	X	X	X	X	X	X	X	X	X	X			
Ricardo	X	X	X	X	X	X	X	X	X	X	X	X			

Questions?

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