Tests and Cell Monitoring for Lithium Vehicle Batteries

Günter Müller, Karl-Ragmar Riemschneider

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

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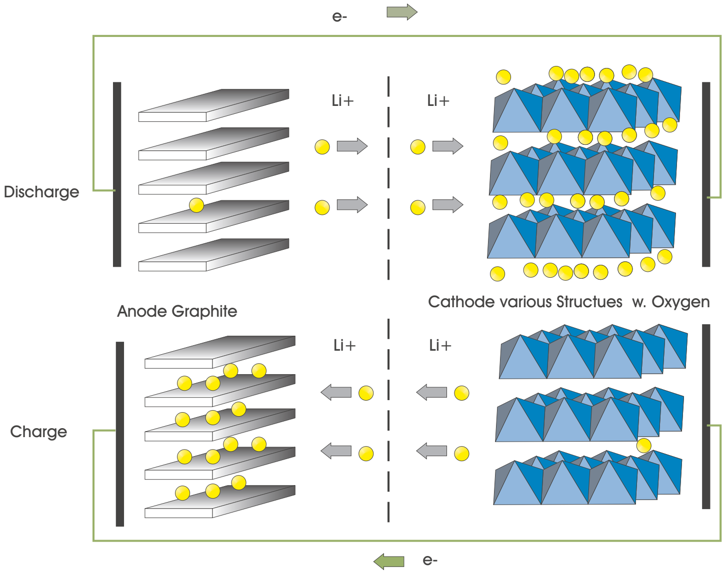
Hamburg University of Applied Sciences

Interreg IVB North Sea project
e-mobility NSR
www.e-mobility-nsr.eu

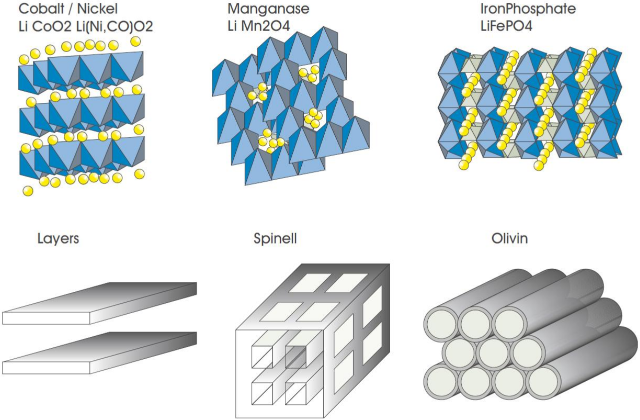
The Interreg IVB North Sea Region Programme

This project is part-financed by the EU

Lithium Battery Principle: Intercalation



Different Cathodes



Cathodes stores Li-Ions in nano-scaled structures, anodes are recently graphite/graphene structures

EV Battery Chemistry

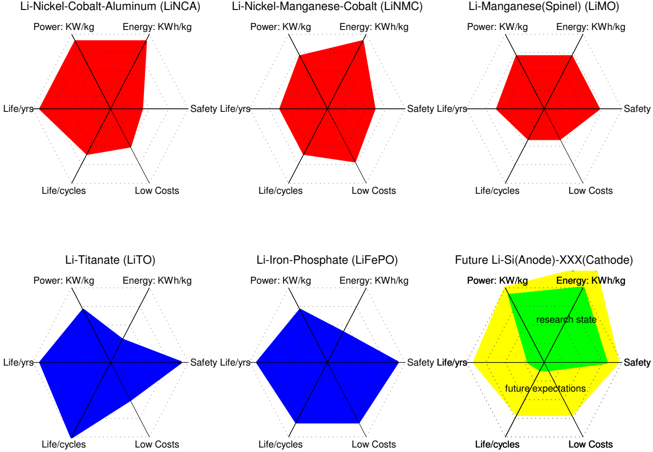
Examples of current Li-Ion battery chemistry

Developer	Chemistry	Vehicle	MY
EnerDel	Lithium manganese titanate	Think	2009
A123	Doped lithium nanophosphate	Volt-EV Vue-PHEV Think	2010 2009 2009
Compact (LG) NEC	Manganese spinel	Volt-EV Nissan-EV	2010 2010
Panasonic JCI-Saft	Lithium nickel cobalt aluminium oxide	Toyota-PHEV S400-HEV Vue-PHEV	2010 2009 2009
Hitachi	Lithium cobalt oxide	GM-HEV	2010
Available Cells	Lithium manganese oxide	Tesla-EV	2008
Altair Nanotechnologies	Lithium titanate spinel	Phoenix Electric	2008

Duleep G. , van Essen H., Kampman B., Grünig M. Assessment of electric vehicle and battery technology, ICF Report, Delft 2011

Battery chemistries in use - various combinations of anode and cathode materials

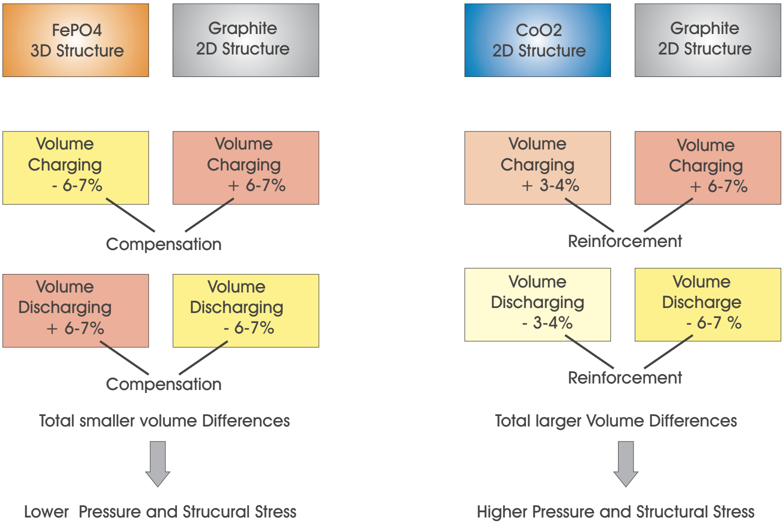
Advantages and Disadvantages of Chemistries



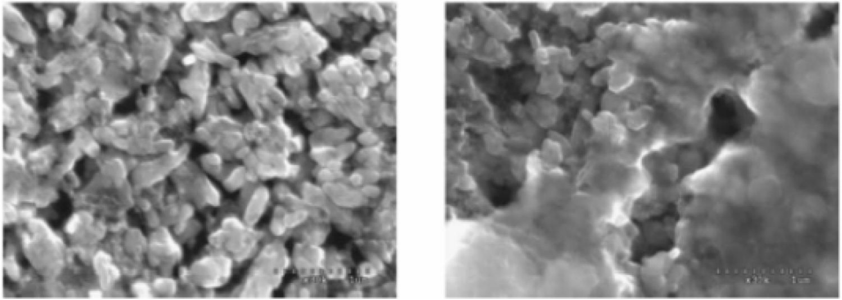
simplified features (thermal safety w.o. external thermal system monitoring), modified / extended orig. source: Boston Consulting Group

Distinct features in terms of performance, cost, safety and lifetime

Example of different Cyclic Ageing Effects



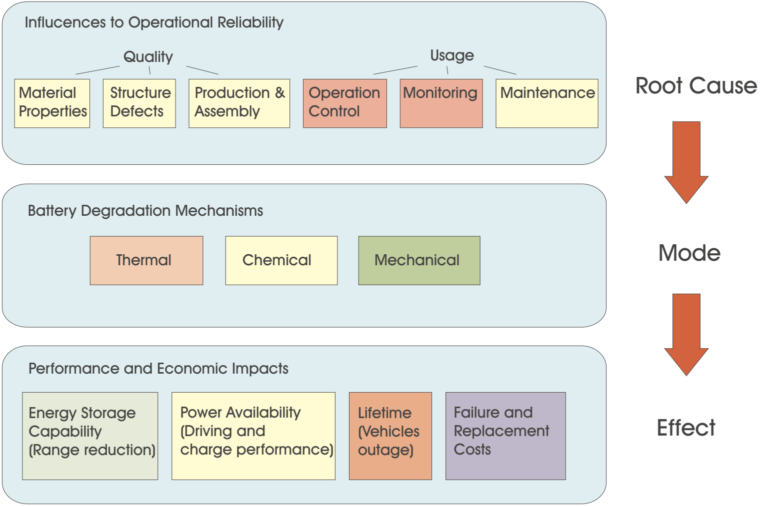
Fresh and Aged Cathode Material



Marie Kerlau, Robert Kostecki: *Interfacial Impedance Study of Li-Ion Composite Cathodes during Aging at Elevated Temperatures.* In: *Journal of The Electrochemical Society, Vol. 153 (2006), Nr. 9, S. 1644 - 1648*

Electron-microscopic shown Ironphosphate Surface (Production (left) and artifical aged (right))

Quality and Usage Influences



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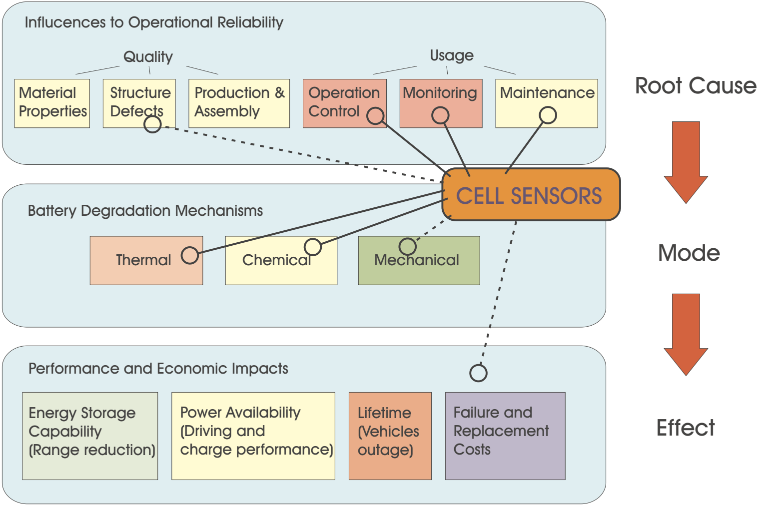
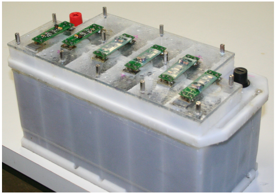
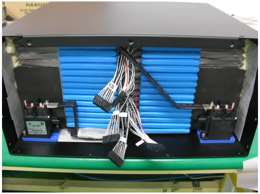


Battery Management in Vehicle Batteries



Starter Battery w. Sensor Prototypes

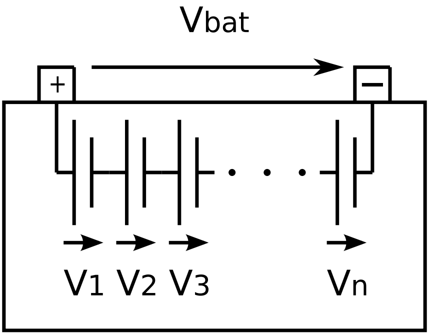
Traction Battery for Forklifts



Electric Car Battery

- Starter & buffer batteries in conventional vehicles (~50 €) 0.5 kWh, 15 kg
- Objective: Early warning of end of life, in future safety related
- Traction batteries in forklifts (~2000-4000 €) 7-40 kWh, 300-2000 kg
- Objective: Optimized battery usability and economics
- Batteries in electric vehicles (~20000 €) ~ 20 kWh, 200 kg
- Objective: Safety of use, guaranted high lifetime

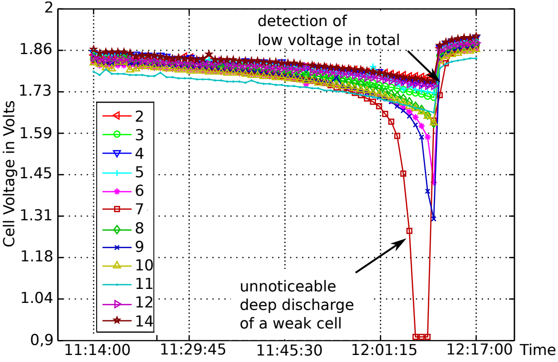
Multi Cell Battery



Batteries are structured up to several hundred cells

- Cells in Serial Connection: $U_{ges} = \sum_{i=1}^{n} U_i, \; I_{ges} = I_1 = ... = I_n$
- Capacity and Lifetime are given from EVERY part of this chain

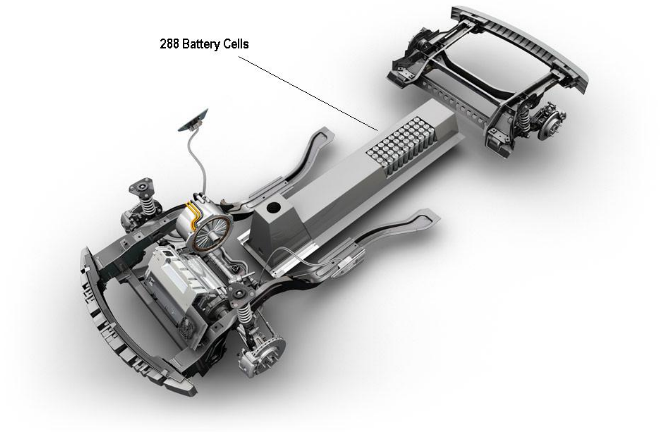
Cell State Differences - a Lifetime Issue



Cell voltages in a forklift battery discharge [10]

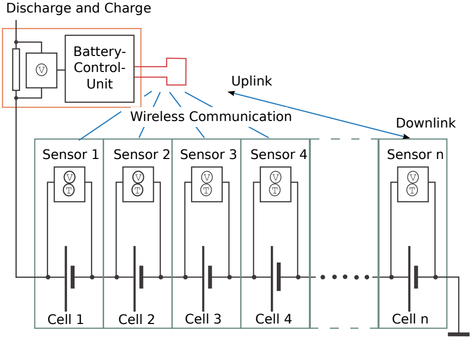
- Differences in the State of Charge (SoC)
- Weaker Cells reach the discharge/charge limits earlier
- Faster ageing of weaker cells, reduced state of health (SOH)

How to Handle Hundreds of Cell Sensors ?



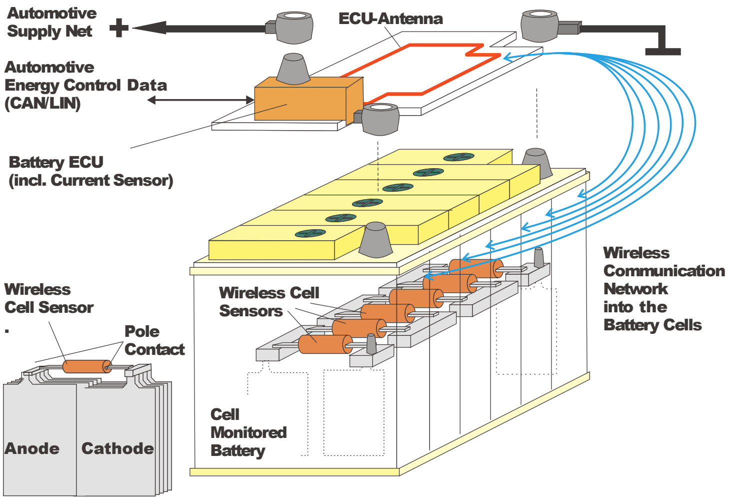
288 Battery Cells in a Chevrolet Volt / Opel Ampera Source: General Motors

Our Approach



- Voltage and temperature sensors located in every cell
- Wireless sensor data transmission
- Battery Control Unit:
  central current measurement, data fusion, state of charge and state of health estimation, battery model, communication to vehicle electronics ...

Communication: Robust and Galvanic Decoupled



Cell Sensor Implementation

Sensor Hardware:

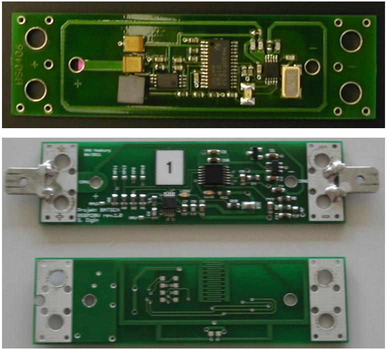
- Ultra-Low-Power Controller measures voltage and temperature
- Uplink Transmitter-Chip ISM Band 433 MHz

Controller software:

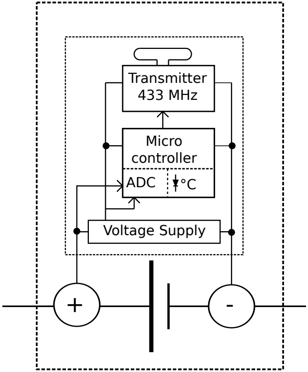
- Measurement and communication protocol

Sensors Class	Class 1	Class 2	Class 3
Communication sensors and control Unit	Uplink, no Down-link	Uplink and Downlink w. Broad-cast-Wake-up	Uplink a. Down-link w. Multi-cast or addressed commands
Receiver in the sensor	no receiver	passive frontend of receiver	active receiver
Measurement and communication function in the sensor	autonomous	semi-autonomous	central given commands

Sensor Class 1



Above: Early Version with Quartz[11], [10], [3], [2];
Down: Recent Version w./o. Quartz [4]



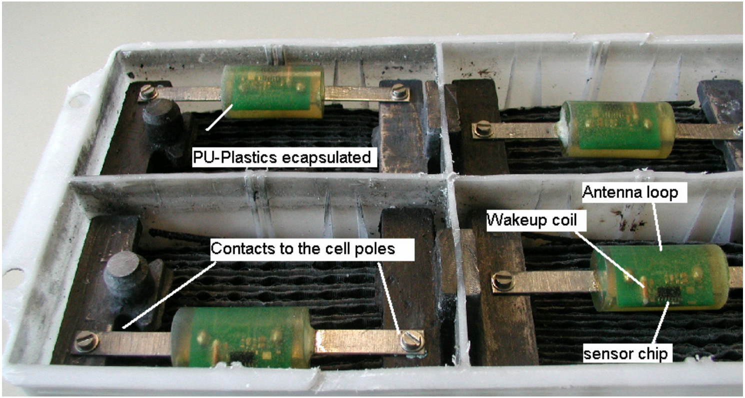
Schematic of Sensor Class 1

- Simplified Sensor-Hardware, Costs Target: 1 € per sensor
- No Receiver, Transmitter w./o. quartz
- Design Objective: High Volume Application like Starter Batteries

Cell Sensors - Complete Encapsulated for Integration in the Cells

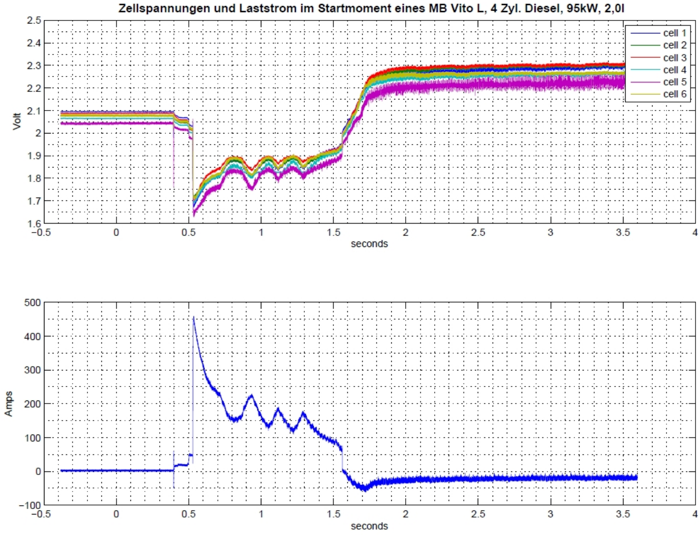
Mock up for construction and material tests

Cell Sensors mounted inside the Cells



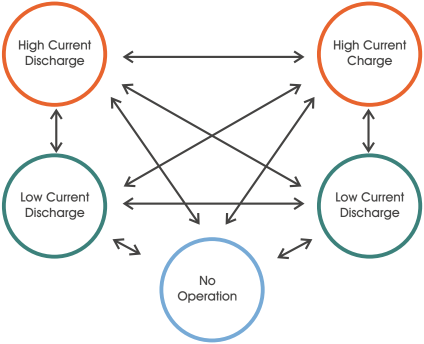
Mock up in a conventional starter battery

Handling Fast and High Current Events



High Current Example Mercedes Benz Vito - 2.4 TDI Engine Start - 4 sec. plotted cell voltages and current

Operation Mode and Transmission Capacity

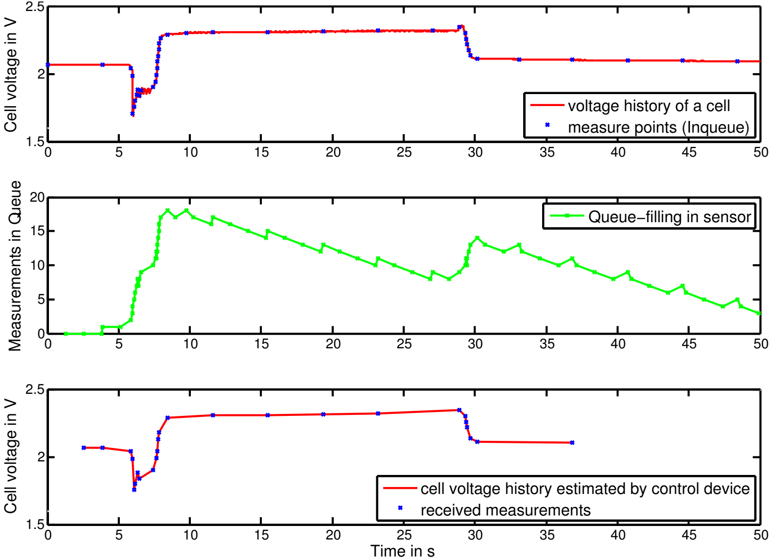


Measurement Rate > Transmission Rate

Measurement Rate < Transmission Rate

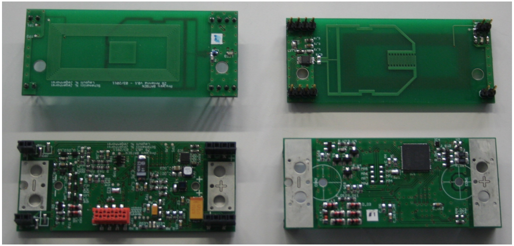
Measurement and Transmission Rate low

Capturing & Data Queues & Central Recovering

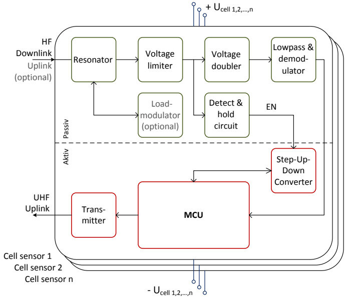


Value Capturing on Demand (Density Gradient Dependent)+ Data Queues for Transmission + Central Data Recovering

Sensor Class 2



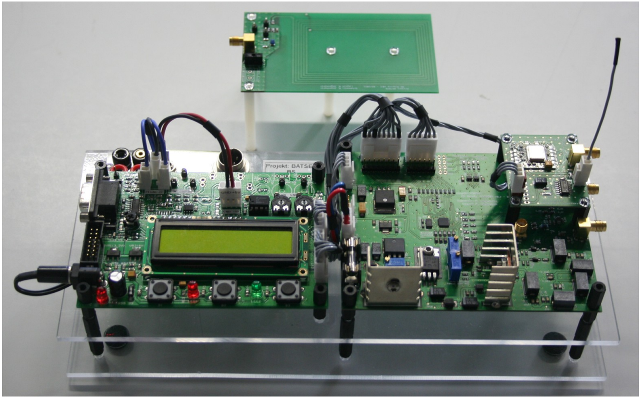
Sensor Class 2 with Antennas (Up- and Downlink) [6]



Block Schematic Sensors Class 2 [6]

- Passive frontend-circuit as receivers 13,56 MHz Downlink
- 'Quartzfree' transmitter-chip 433 MHz Uplink
- Wake-up function with the downlink signal
- Central synchronized measurements and transmissions
- ready for cell balancing

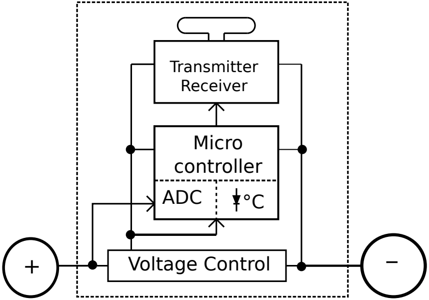
Battery Control Unit for Sensors Class 2



Prototyp Battery Control Unit for Class 2 Sensors [6]

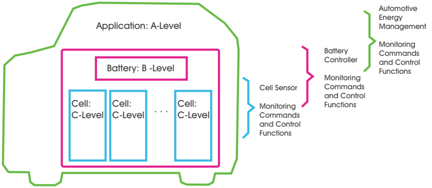
- Uplink Receiver 433 MHz Hybrid-Chip similar Class 1
- Chipset of a RFID-Reader in the downlink transmitter
- Very short time booster amplifier up to 4 watts wake-up signal
- Printed board coils sufficient as low-cost-antennas

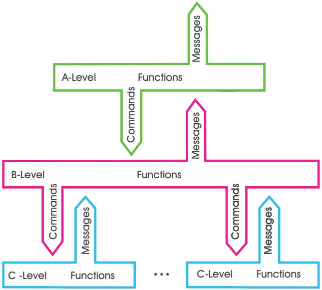
Planned Sensor Class 3



- Protocols like ZigBee or Bluetooth or similar
- Individual communication from / to each sensor
- Central control of cell balancing possible
- Costs are critical

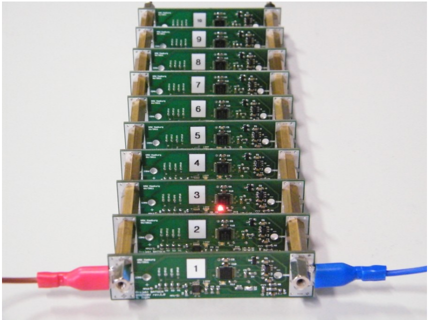
Battery Management and Control Language (BMCL)





- Monitoring and control language abstracts the control parameters, battery modells, battery module and cell structure and technology
- Our approach to preserve flexibility for various battery chemistries and system types
- Well leveled structure of distributed functions and communication of battery management system components

Calibration & Precision - a Sensor Issue



Parallel working sensors for calibration [4]

- Calibration tests done in Temperature Chambers
- Dense datafield in two dimensions voltage and temperature (-40 to 85 ^{o}C)
- Statistics in software, individual calibration values loaded into Sensors
- Two-dimensional compensation calculation in sensor-controller

Tests in Automotive Electric Board Net

Combined tests with conventional and wireless measurements

Roadmap of our Research Group

- Sensors Class 1 in versions available and under field test
- Implemented dynamic measurement- und transmission rates promising
- Sensors Class 2 first prototypes successfully tested
- Implementation sensor Class 3 prepared
- First BMCL commands implemented

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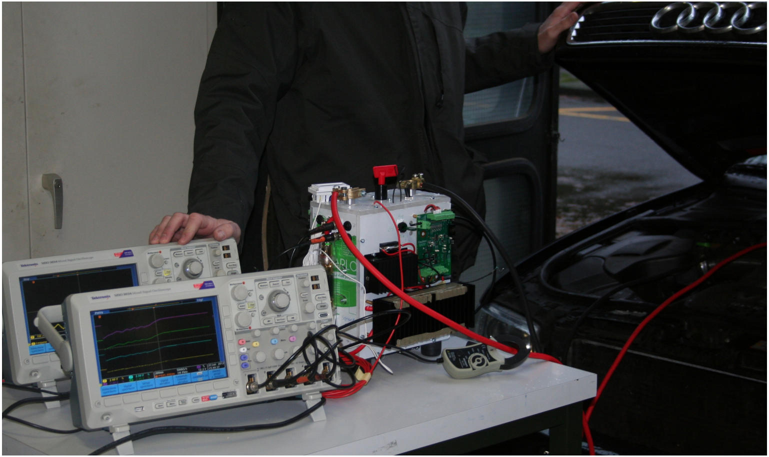
Next Steps:

- Introduce wireless sensors different Li-Technologies
- Advanced battery monitoring for long life lithium-titanium forklift batteries
- Establish tests procedures in the planned Battery-Lab at HAW
- Contribue to a "Graduate School Key Technologies for Sustainable Energy Systems in Smart Grids" at Universities of Hamburg

Just under Construction - Lithium Iron Phosphate Starter Battery



Electronically monitored Lithium Iron Phosphate Starter Battery - Prototype HAW Hamburg

Conclusion

Major Challenges for E-Mobility:

- Driving Down the Cost
- Improving the Performance of EV Batteries
- Ensure Lifetime and Safety

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- Driving Down the Cost
- Improving the Performance of EV Batteries
- Ensure Lifetime and Safety
- and somewhat to contribute with suitable cell sensors

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- Still GmbH Hamburg (Forklifts)
- OMT/ECC GmbH Lübeck, Geesthacht (Battery Producer & Lithium Technology)
- Fey Electronic GmbH Seevetal (Battery Systems & Importer)
- Coilcraft Ltd. Cary US/Cumbernauld UK (Electronic Components)

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