High-precision, High-dynamic Emulation of Lithium-Ion Cells for the Entire Life Cycle

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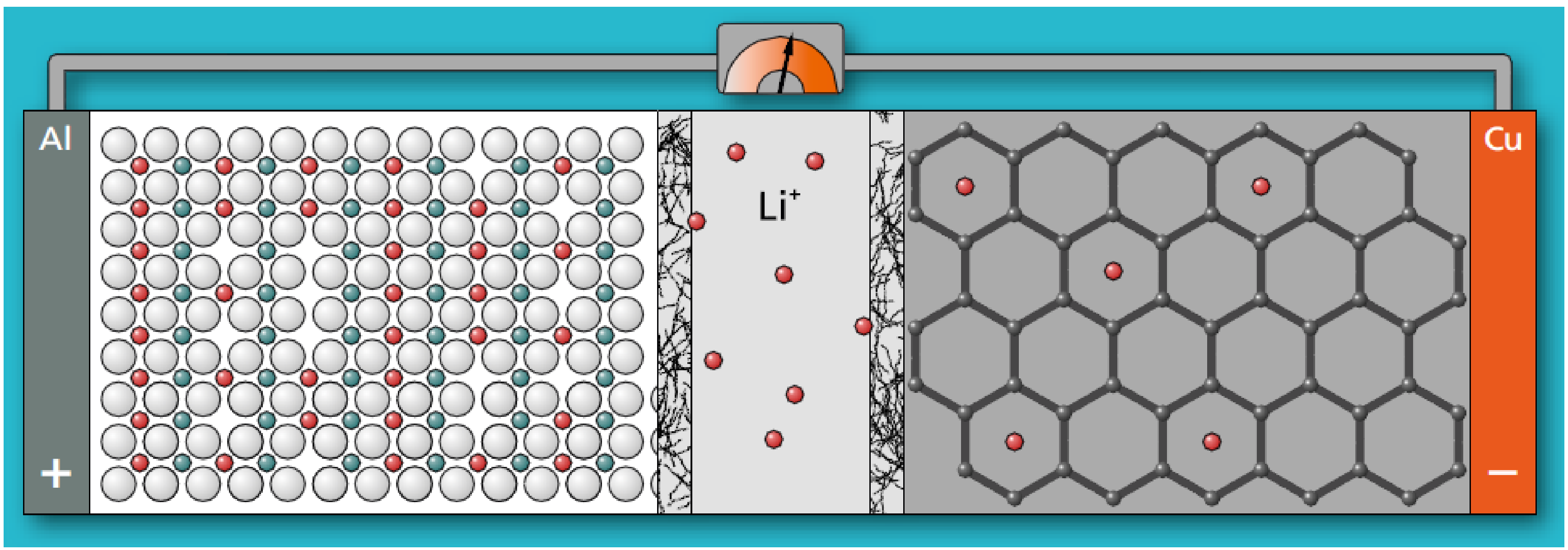
EVS30, Stuttgart 10.10.2017



Source Picture: Fraunhofer IWES

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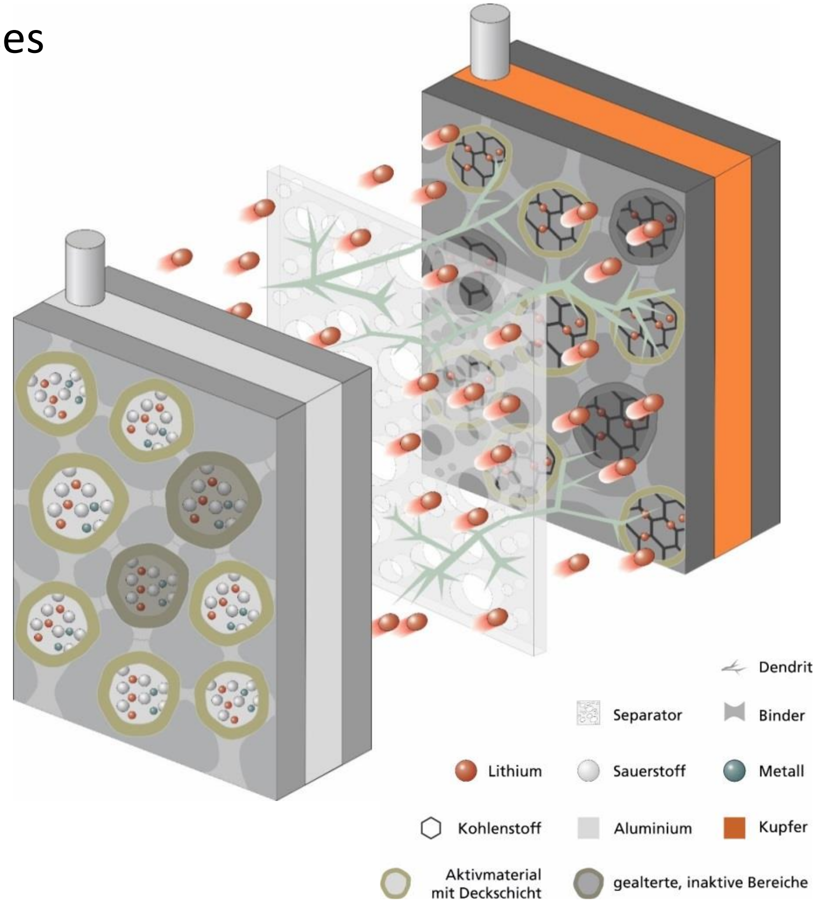
Li-ion Cells | Complex Physical & Electrochemical Processes

- Non-linear physical-electrochemical processes
- Cell voltage influenced by:
  - current
  - temperature
  - state-of-charge
  - cell-chemistry
  - manufacturing tolerances
  - cell construction
  - state-of-health



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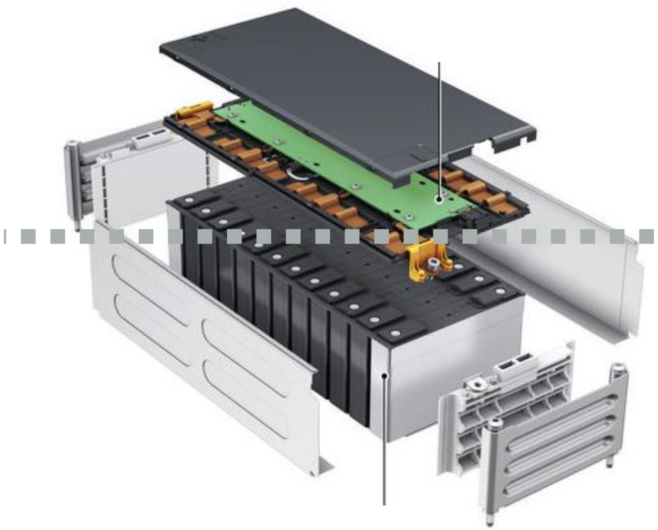
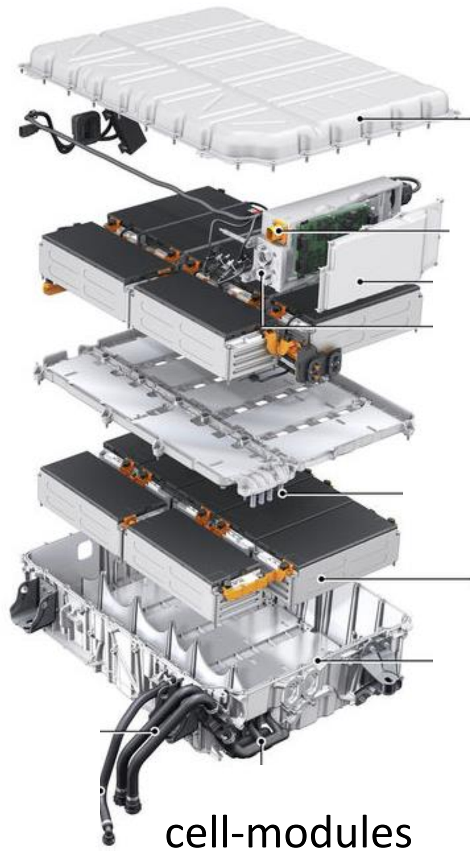
From Cells to Battery Systems

battery management system (BMS)



li-ion cells



cell-modules

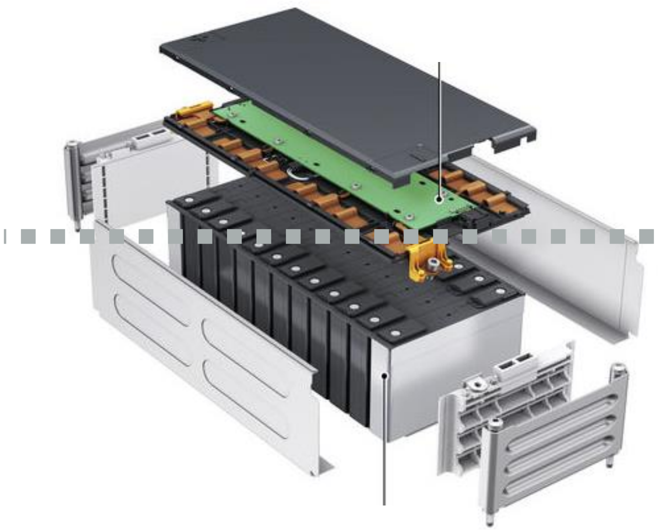
battery system

→ Inhomogeneities require BMS and single-cell observation!

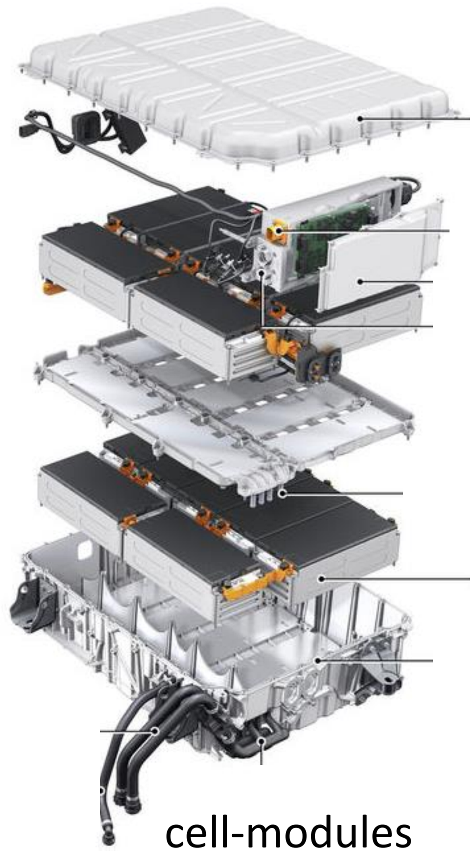
Source Pictures: Audi AG

From Cells to Battery Systems

battery management system (BMS)



li-ion cells



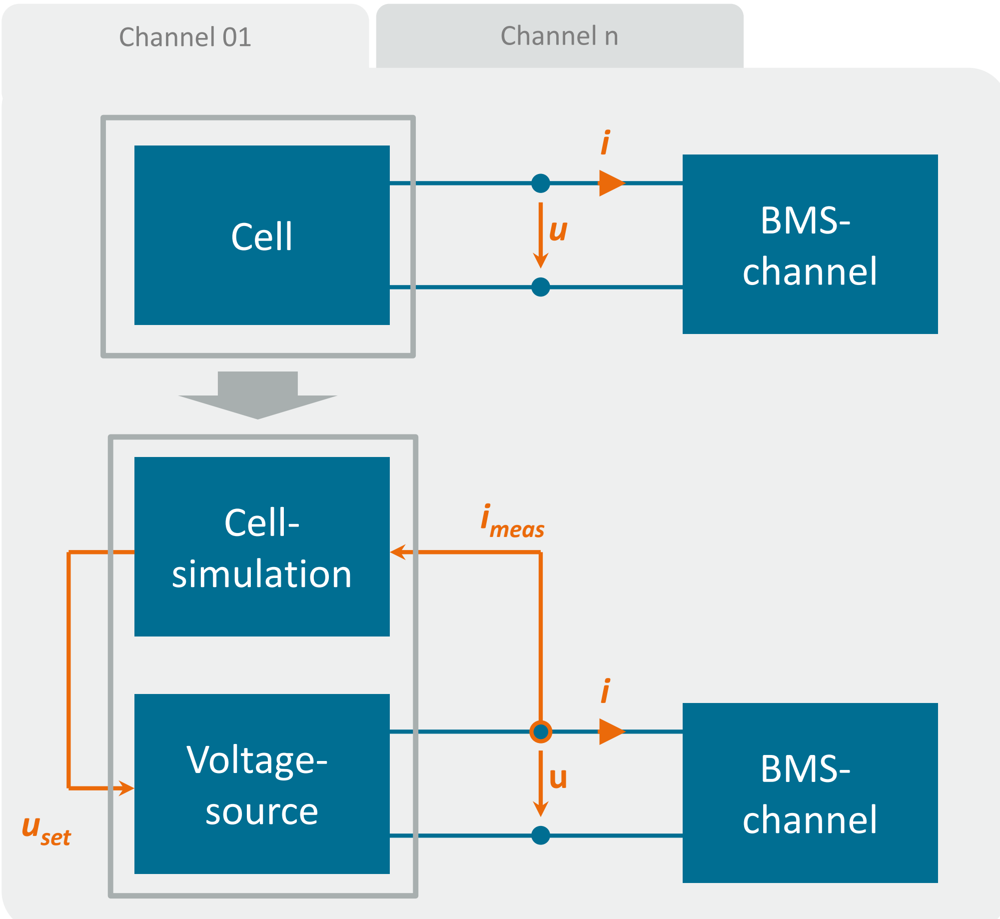
cell-modules

battery system

→ Challenge: reproducible, fast and cost-effective BMS tests!

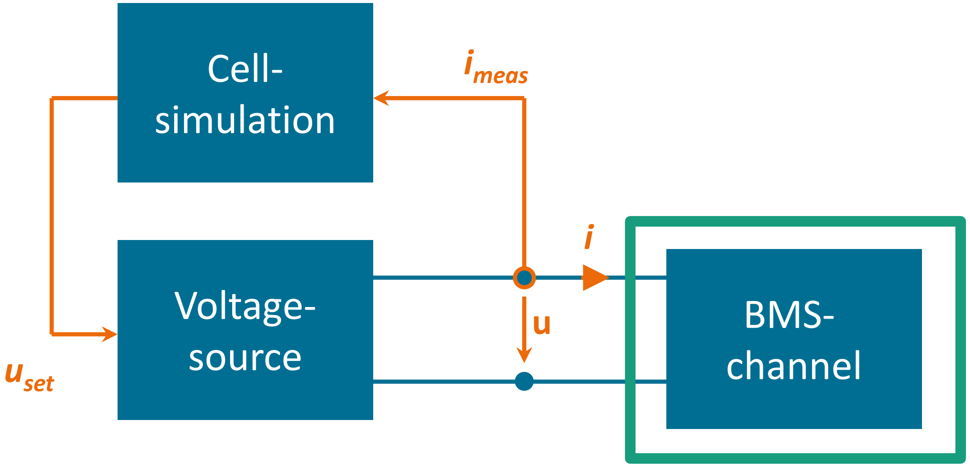
Source Pictures: Audi AG

Li-Ion Cell Emulator | Functional Principle

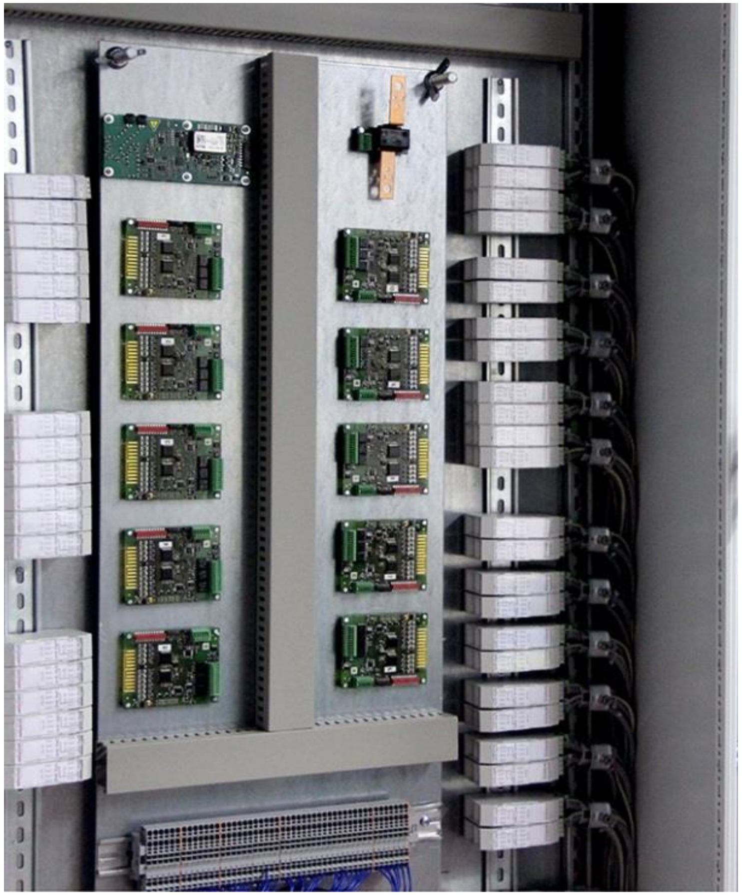


Source: Fraunhofer IWES

Li-Ion Cell Emulator | Requirements from BMS



Device under test



Source: Fraunhofer IWES

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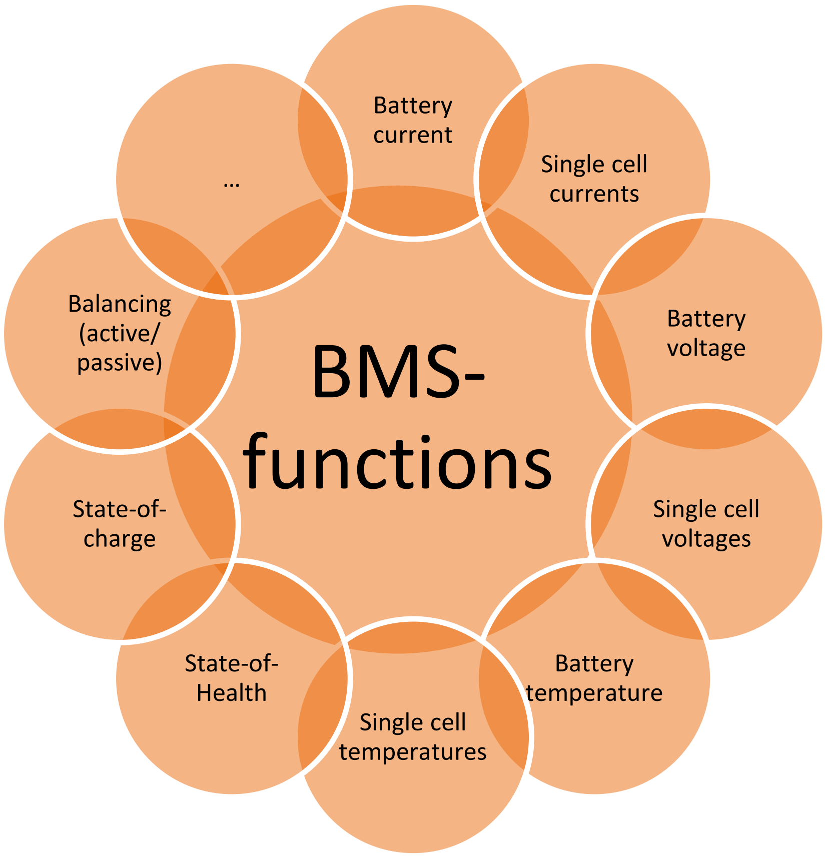
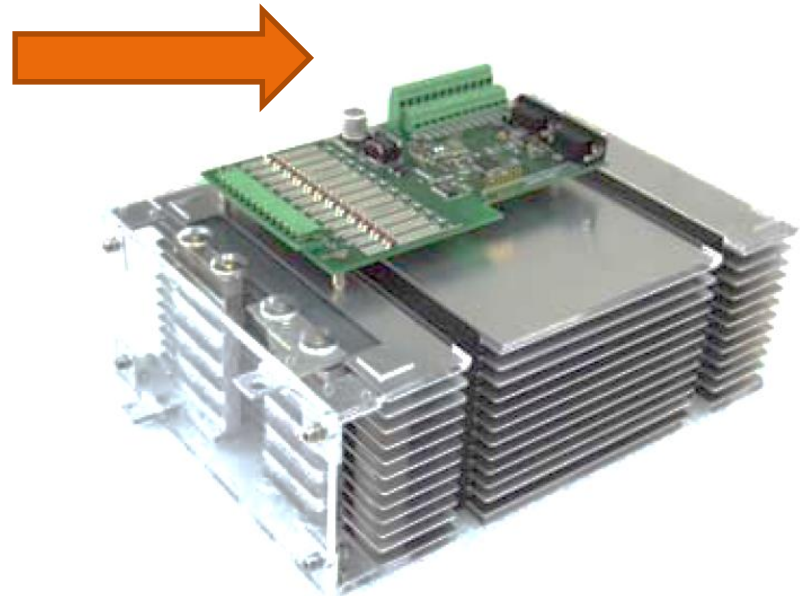
BMS | Functions & Challenges





- →BMS quality determines cars safety, comfort and reliability
- →BMS approval requires comprehensive BMS tests

Source: Fraunhofer IWES, Source Picture right: Fraunhofer Battery Alliance

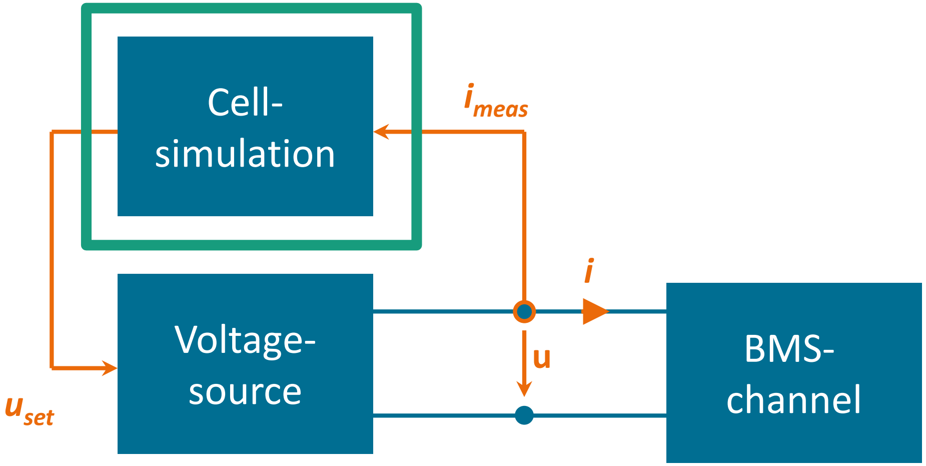
BMS | Industrial Testing Requirements

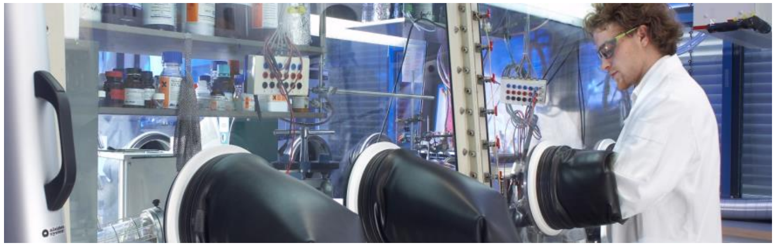
- BMS testing requires reproducible test conditions:
  - voltage
  - SOC
  - SOH
  - temperature
- Testing with real batteries requires days to months for one test!
- HiL-testing and automation speeds up testing time significantly!

→Challenge: Active BMS current pulses < 0.1ms!

→Challenge: Complex simulation models and dynamic hardware!

Li-Ion Cell Emulator | Cell-Simulation





Source Picture left: Fraunhofer IWES, Source Pictures right: Fraunhofer Battery Alliance

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Modelling Approaches | Comparison

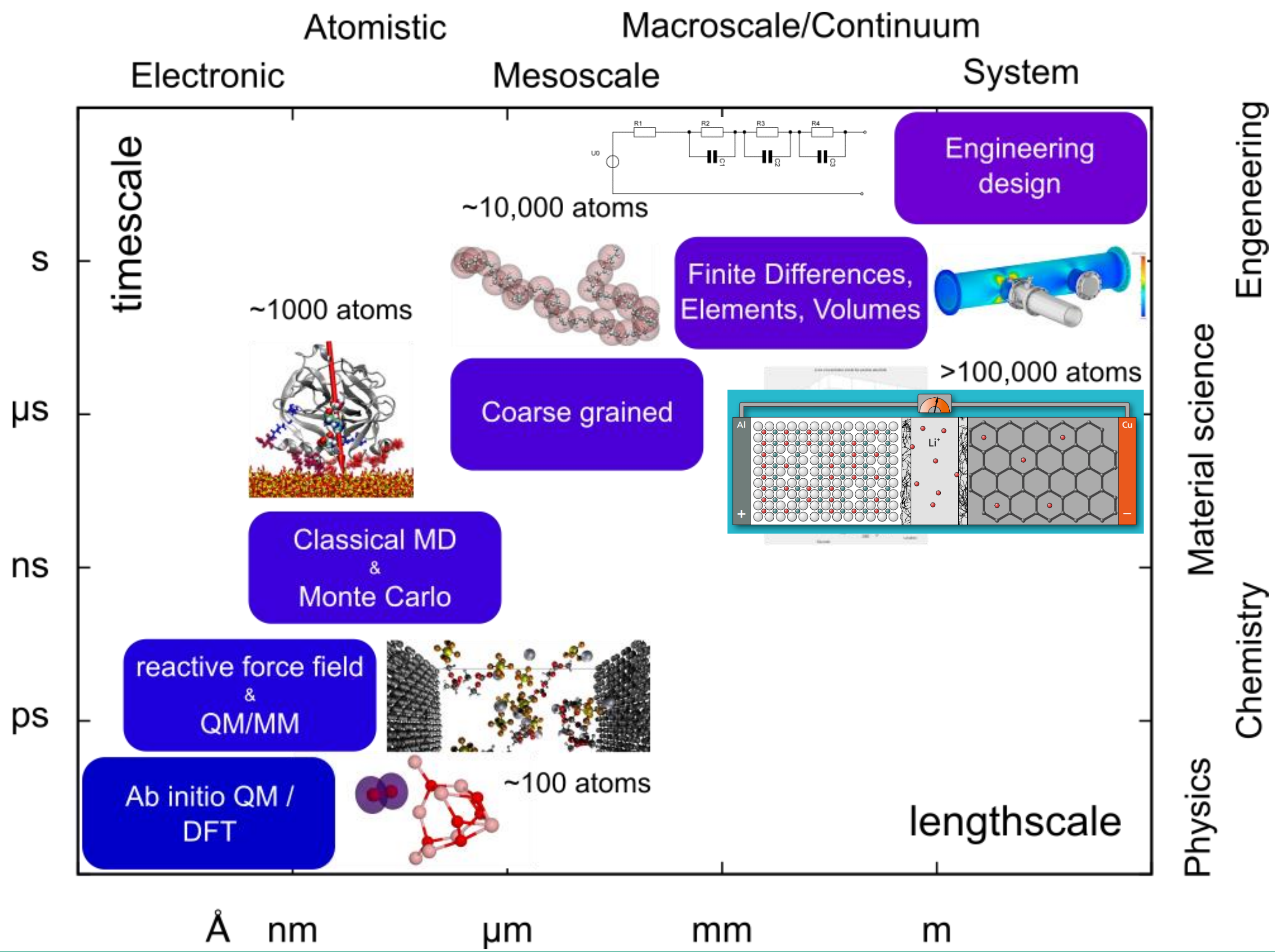

Fig.: T. Dabrowski, L. Colombi Ciacchi, *The Journal of Physical Chemistry C 119*, 25807-25817 (2015); http://www.rxffconsulting.com/; N. Hildebrand, S. Köppen, L. Derr, K. Li, M. Koleini, K. Rezwan, L. Colombi Ciacchi, *Journal of Physical Chemistry C* 119, 7295-7307 (2015); http://compmech.lab.asu.edu/research.php

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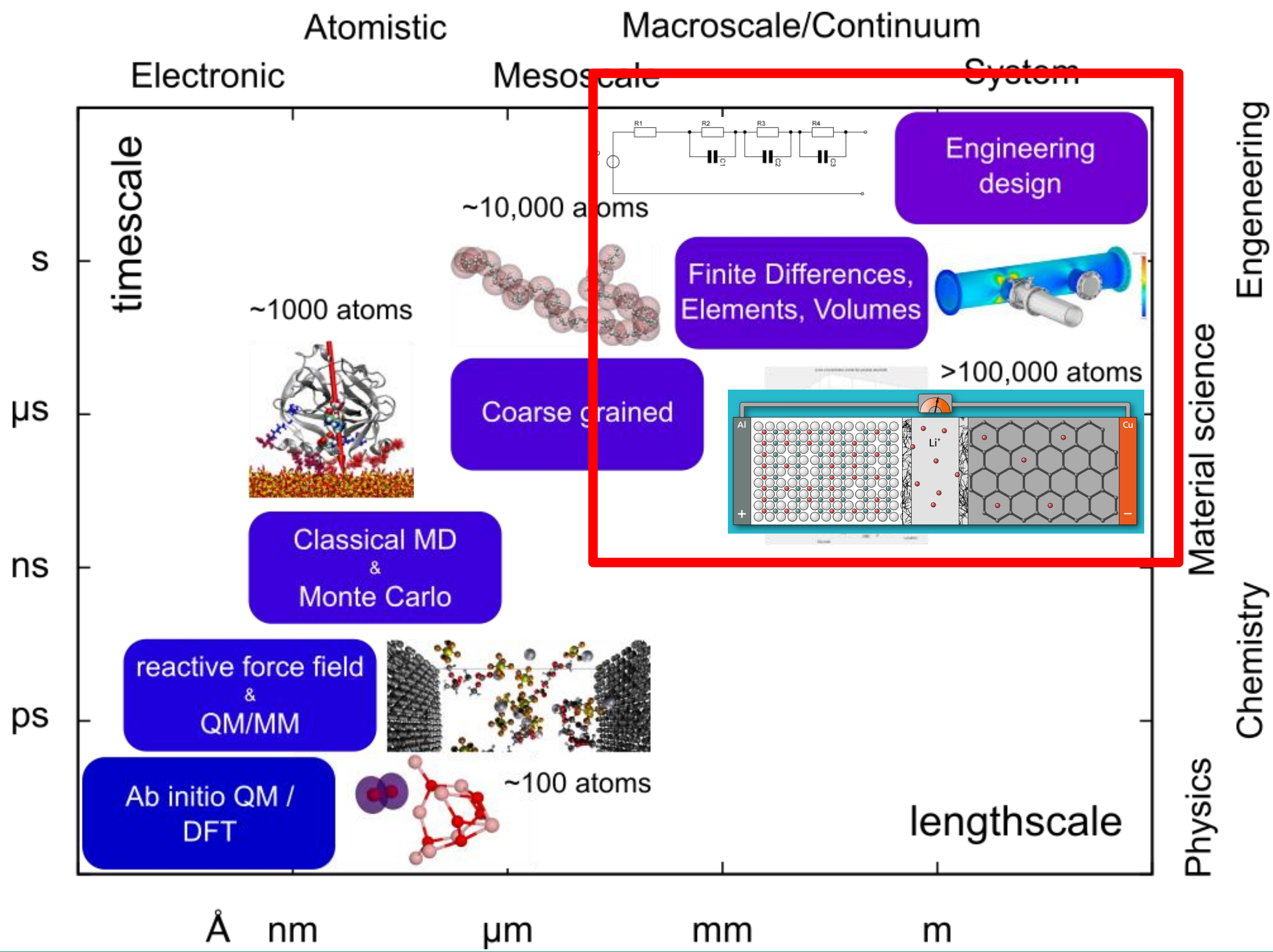
Modelling Approaches | Comparison



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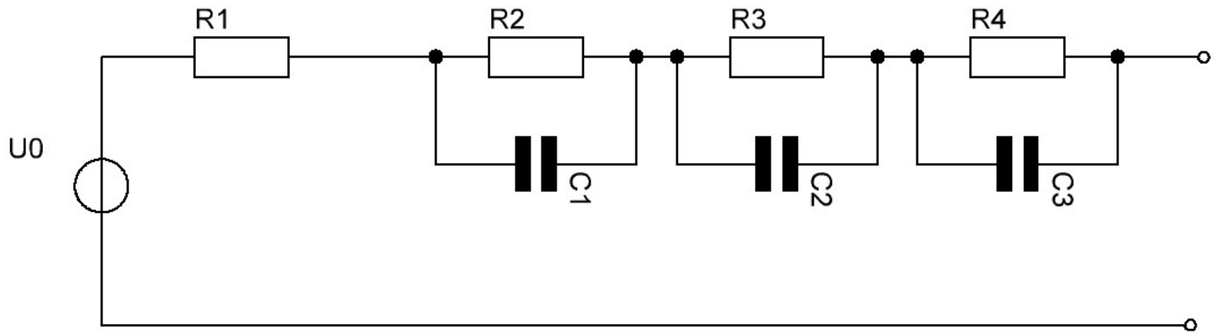
Typical Today | Equivalent Circuit Model



Advantages:

- High computational performance
- Sufficient precision within the range of validity
- Partly physical meaning of parameters (e.g. R1)

Disadvantages:

- Linear Model for non linear system (U = a + b*I)
- Only input/output behavior of a certain battery available
- Comprehensive measurements for parameter identification necessary

Source: Fraunhofer IWES

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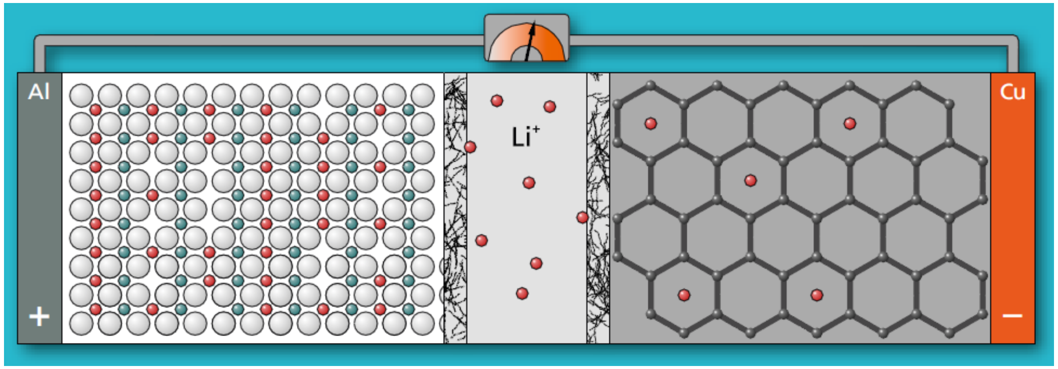
Next Generation | Physical-Electrochemical Model



Advantages:

- Analytical Model (precise theoretical analysis)
- Parameters with physical meaning → insight into system
- High precision over the whole range of operation

Disadvantages:

- Comprehensive knowledge of the system required
- Lower computational performance
- Typically not real-time capable

Source: Fraunhofer IWES

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Real-Time Capable Physical-Electrochemical Model
Fraunhofer Software ISET-LIB

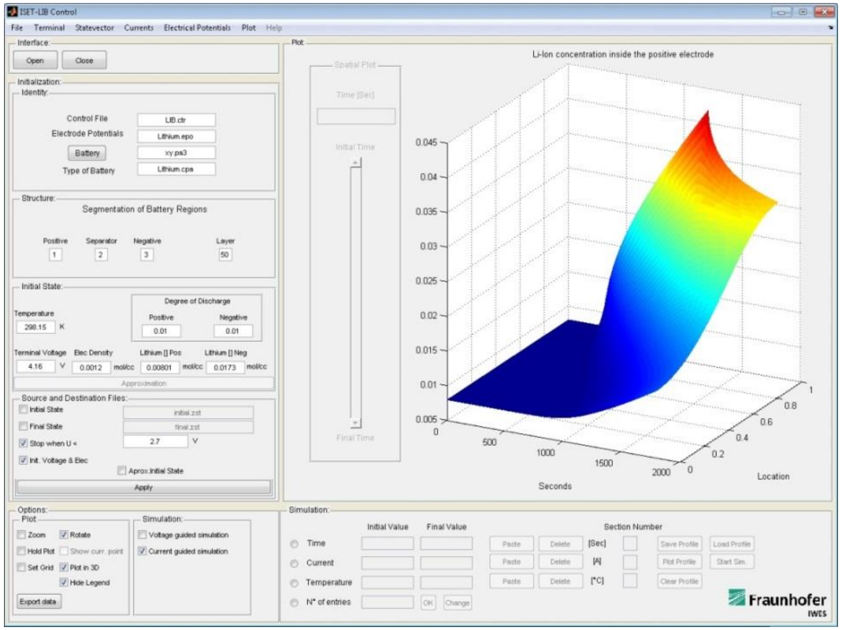
Development goals:

- High precision over the whole range of operation (I,U,SOC,T)
- No measurements by user necessary
- Insight into the system
- Real time capability

Modeling approach:

- Analytical white-box approach
- Non linear
- Accuracy adjustable

→Real-time capable >~0,5ms!



Source: Fraunhofer IWES

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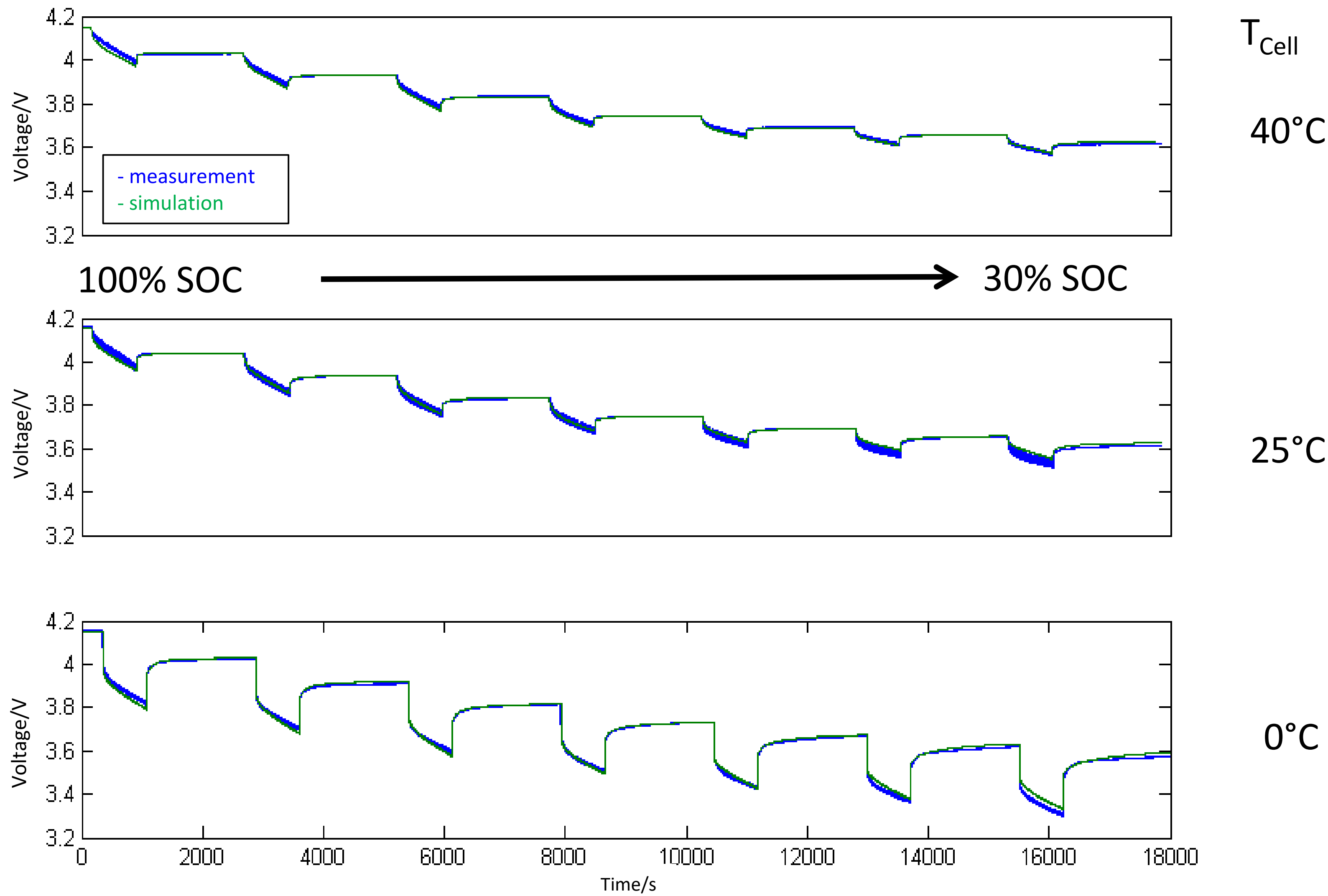
High precision | Simulation of Intermitted Discharge with C_2



Source: Fraunhofer IWES

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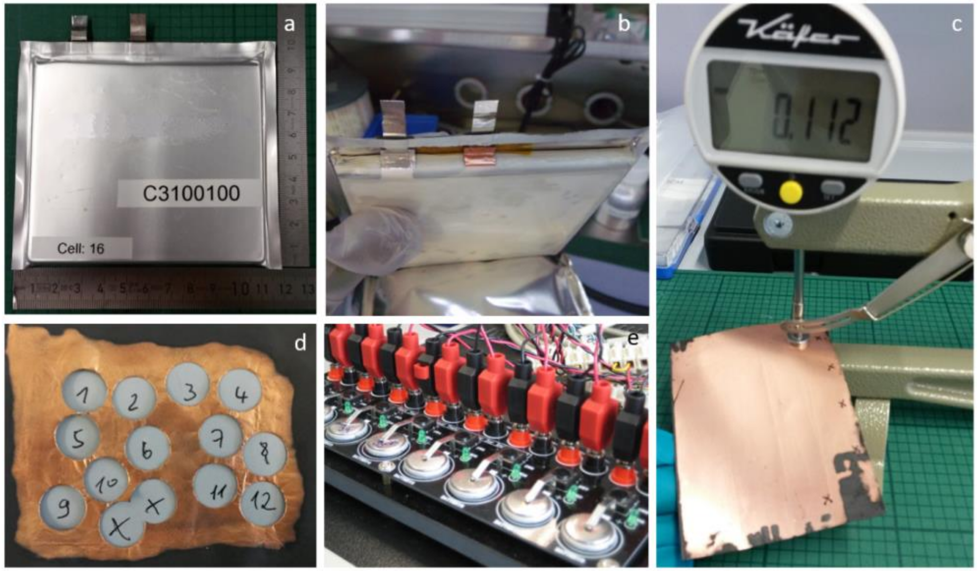
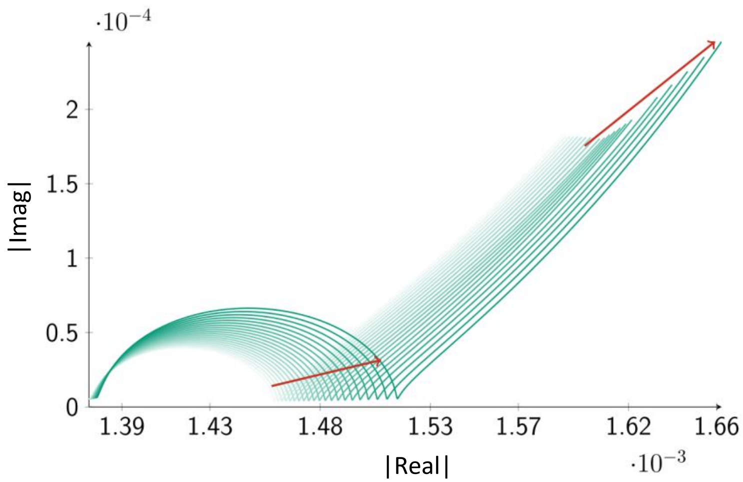
Parameter Determination | ISET-LIB

- Precise simulation model requires precise parameters!
- Typical datasets already determined (NMC, LFP,…)
- Highest precision requires cell specific determination
- Process already developed by Fraunhofer IWES



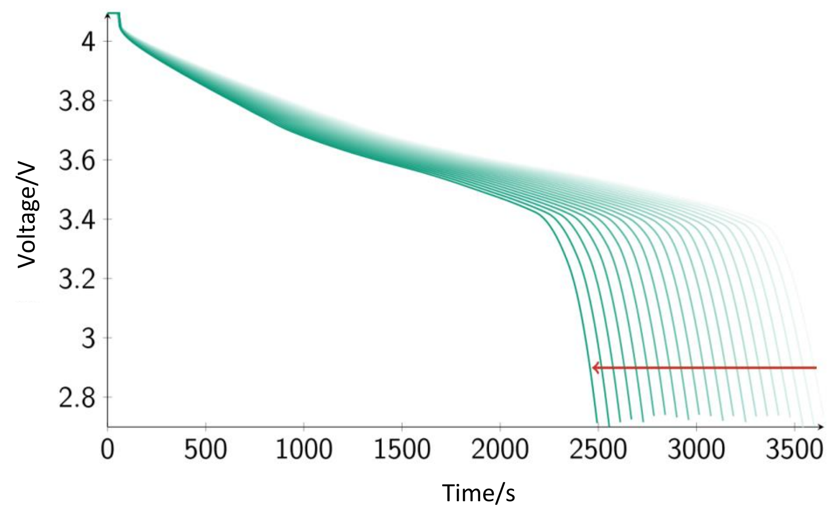
Life Cycle | Simulation of Aged Batteries

- Impedance spectra simulation



100% ——— SOH ——→ 70%

- Time-scale simulation



70% ←—— SOH ——— 100%

→ Only possible with complex physical-electrochemical model!

Source: Fraunhofer IWES

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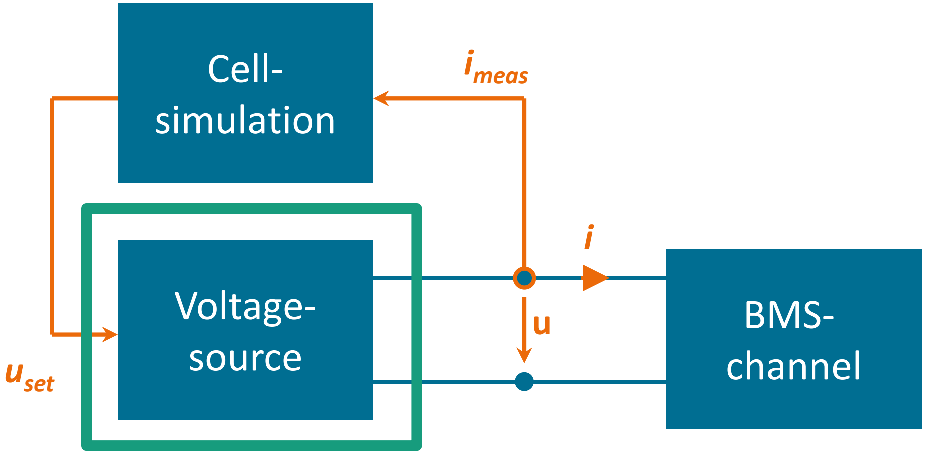
Li-Ion Cell Emulator | Voltage-Source



Source Picture left: Fraunhofer IWES, Source Picture right, Micronova AG

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Voltage Source | High-precision & High-dynamic Micronova Emulation Hardware

Developments achieved:

- Cycle time: <<100 µs
- Series connection of cells up to 1000V
- Fully digital board
- Integrated FPGA-controller
- Dynamic control of:
  - Voltage dips
  - Current pulses

Cell emulation

Source: Micronova AG

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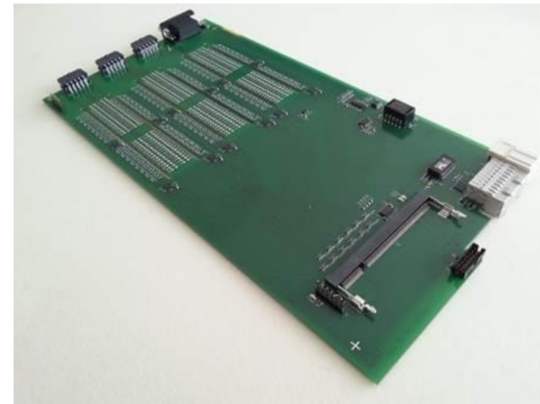
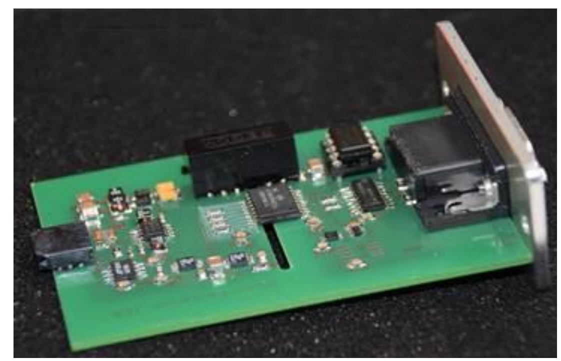
Voltage Source | High-precision & High-dynamic Micronova Emulation Hardware

Developments achieved:

- Resistance simulation
- Shunt simulation



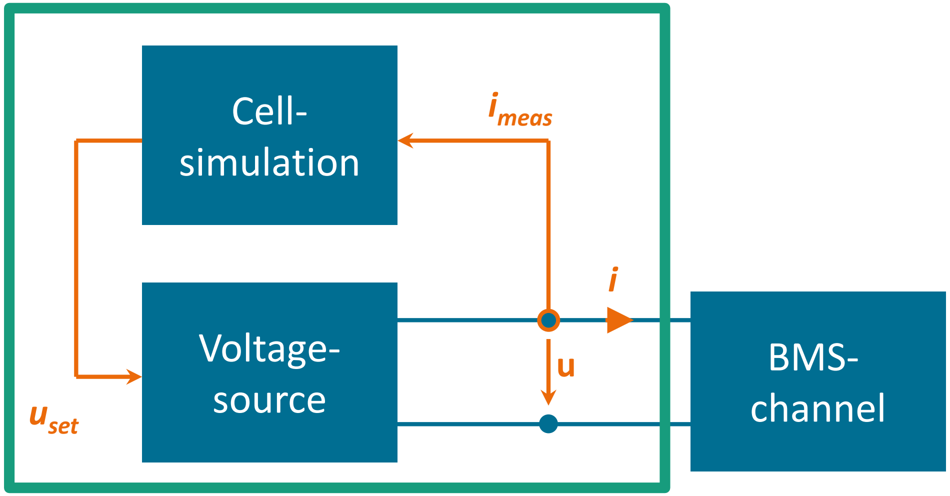
Resistance emulation



Shunt emulation

Source: Micronova AG

Li-Ion Cell Emulator | BMS-Test System



Source Picture right: Marquardt GmbH and MicroNova AG

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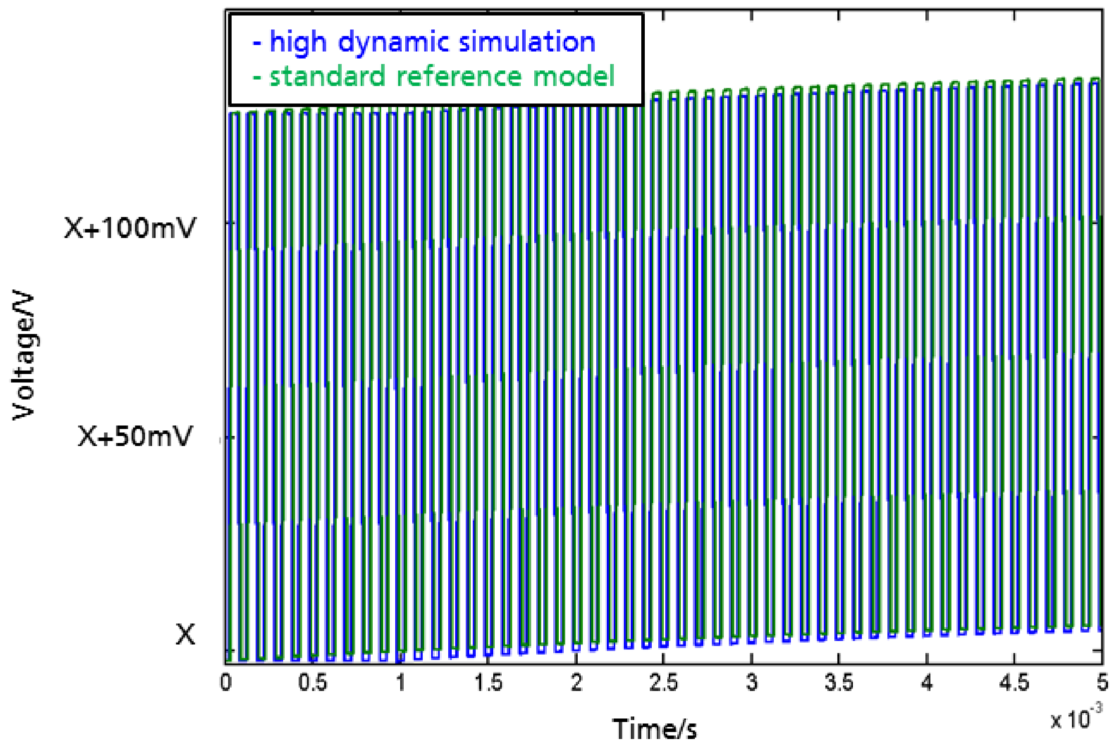
HiL-System Integration | Results

Challenge: How to achieve cycle times below <0,1ms at system level!

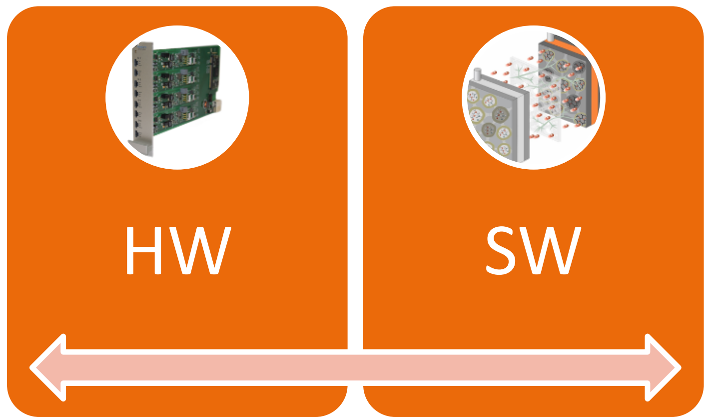
Solution: Split simulation model in slow CPU and fast FPGA part!

Results:

- <~1mV deviation
- Cycle time <100µs



Precise & Dynamic Battery System Emulation…



…is now possible!

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