Improved Functional Safety with Advanced Real Time Embedded Battery Diagnostics

ENERGY STORAGE EVENT

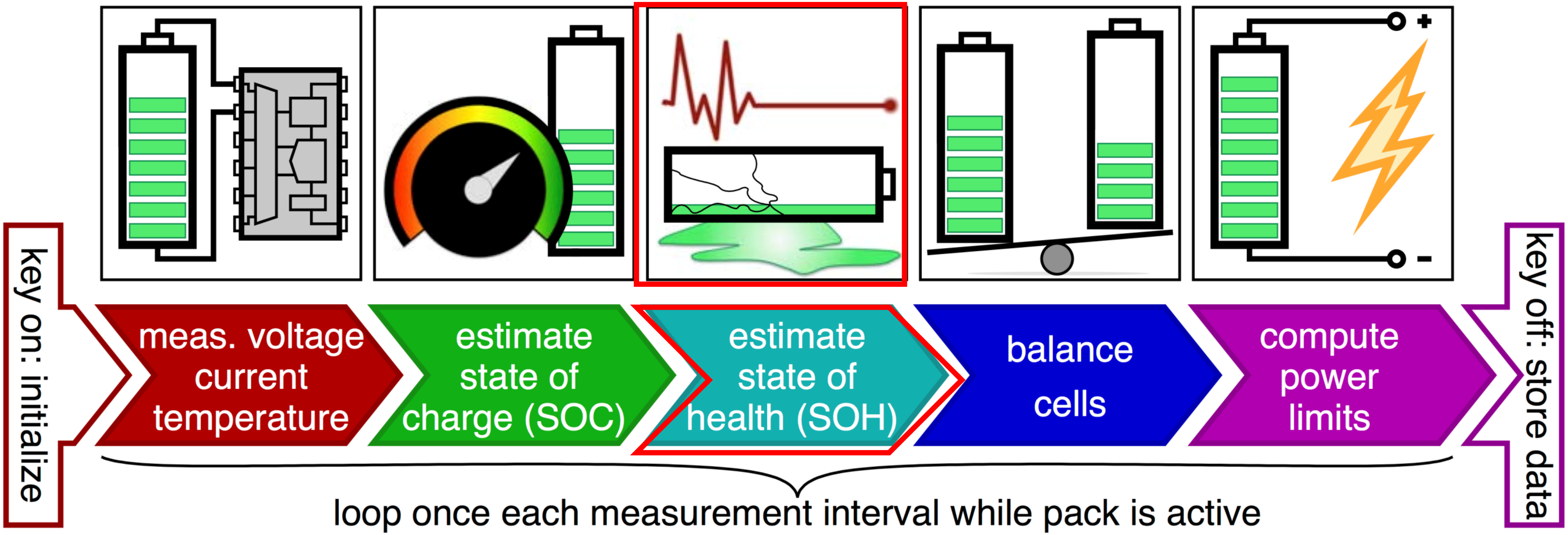
12 februari 2019 | NH Conference Centre Koningshof

Content

- Motivation – EV Battery Management
- Thermal Runaway
- Thermal Model Behavior and Thermal Management
- New Advanced Diagnostics Features
- System Structure and Implementation
- Results and Conclusion

High Voltage Battery System based on Stack Structure

Requirements and Challenges

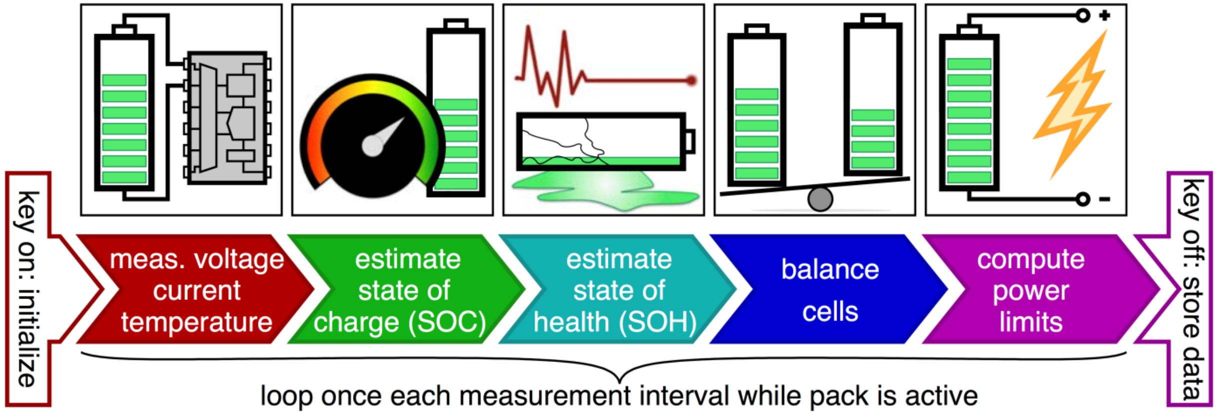


Source Figure UCCS University of Colorado Colorado Springs

High Voltage Battery System based on Stack Structure

Challenges

- Functions of a battery management system
- Battery models and simulation of battery packs
- Battery state estimation
- Battery health estimation
- Cell balancing
- Voltage-based power limit estimation
- Aging mechanisms and degradation models
- Optimized controls for power estimation



Source Figure UCCS University of Colorado Colorado Springs

ENERGY STORAGE EVENT
12 februari 2019
NH Conference Centre Koningshof

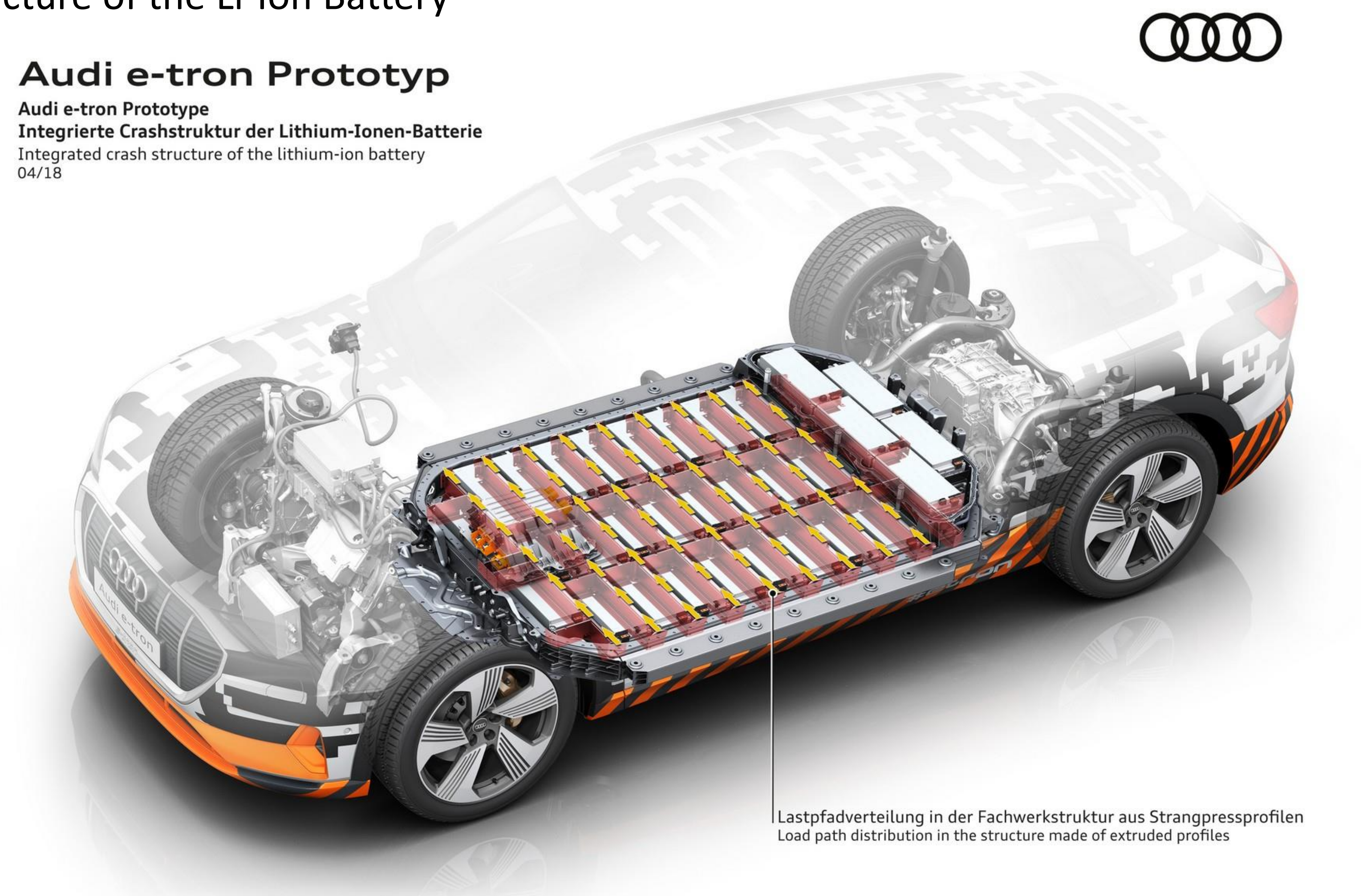
How to Improve Functional Safety ?

Requirements for Advanced Battery Diagnostics

- State-of-Health SoH Analysis
- State-of-Function SoF Analysis
- Smart Battery Management
- Remaining Useful Life Calculation
- Battery 2nd Life Qualification
- Non Invasive Temperature Measurement
- State-of Charge Analysis
- Prediction of Battery Life without Big Data

Battery System Audi e-tron 2018

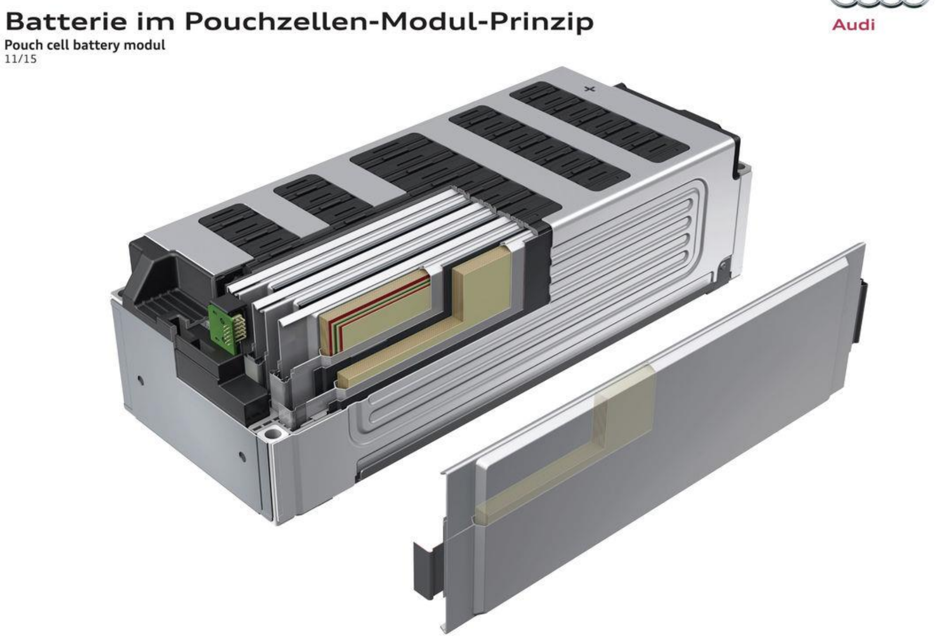
Integrated Crash Structure of the Li-Ion Battery

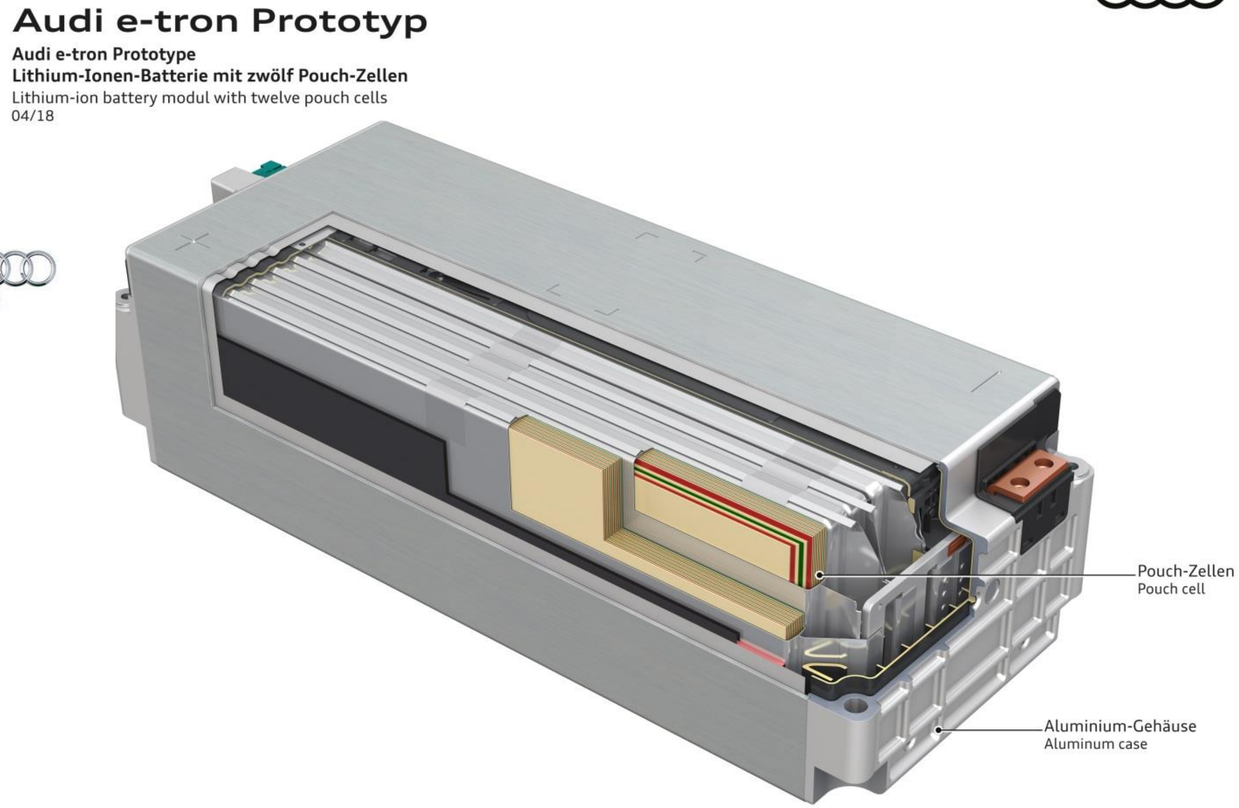


Source: Audi Media Center, Automobil Produktion

Battery System Audi e-tron 2018

Li-Ion Battery Module with 12 Pouch Cells

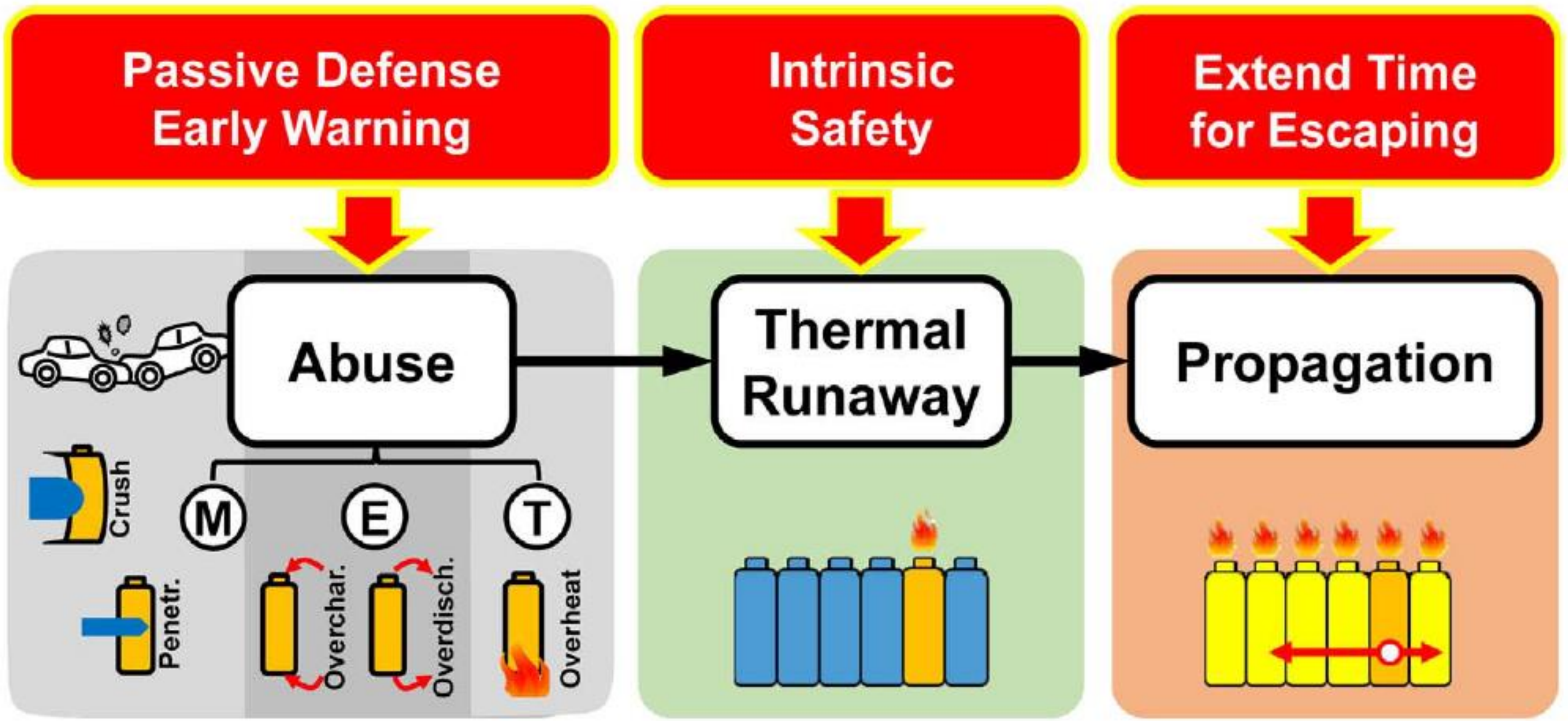




Source: Audi Media Center, Automobil Produktion

Thermal Runaway

The three-level strategy of reducing the hazard caused by thermal runaway.

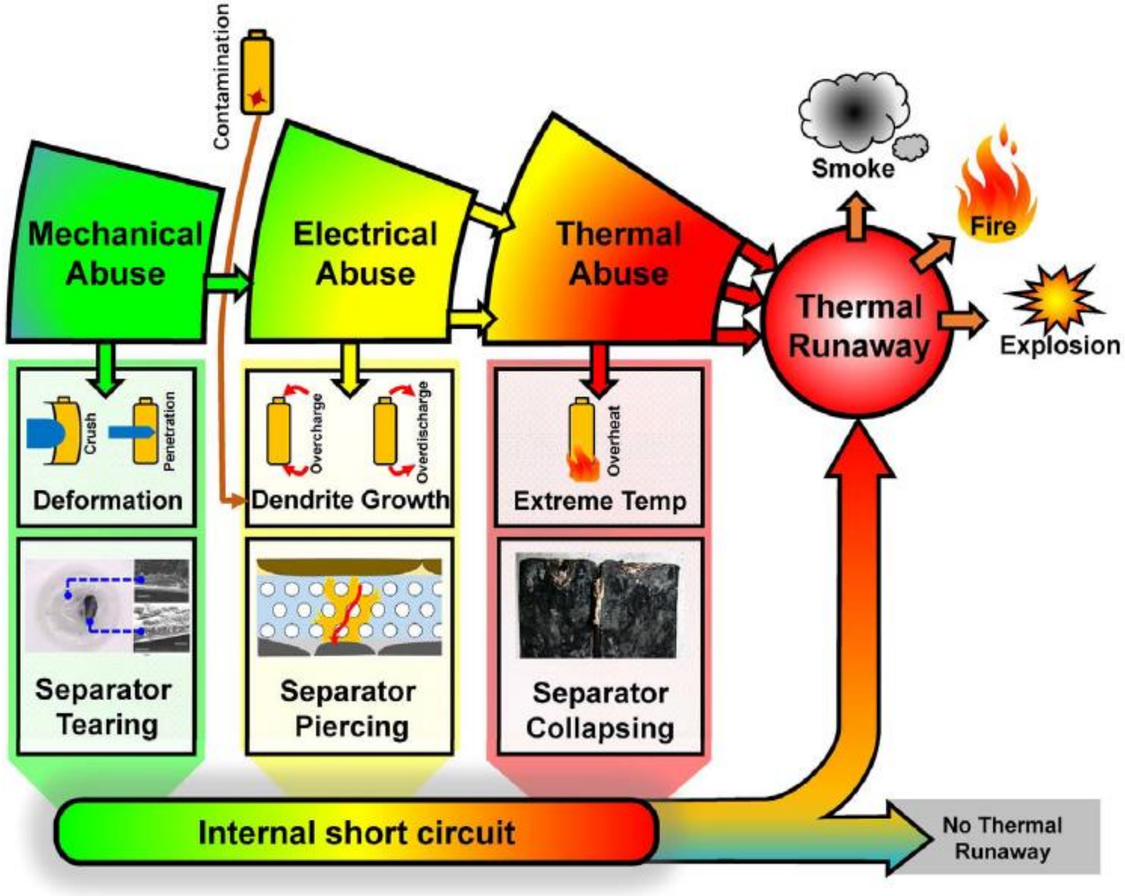


Source: [1] Thermal runaway mechanism of lithium ion battery for electric vehicles: A review; Xuning Fenga,b, Minggao Ouyanga,⁎, Xiang Liua, Languang Lua, Yong Xiaa, Xiangming Hea,b a State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
b Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing, 100084, China; http://dx.doi.org/10.1016/j.ensm.2017.05.013

ENERGY STORAGE EVENT
12 februari 2019
NH Conference Centre Koningshof

Thermal Runaway

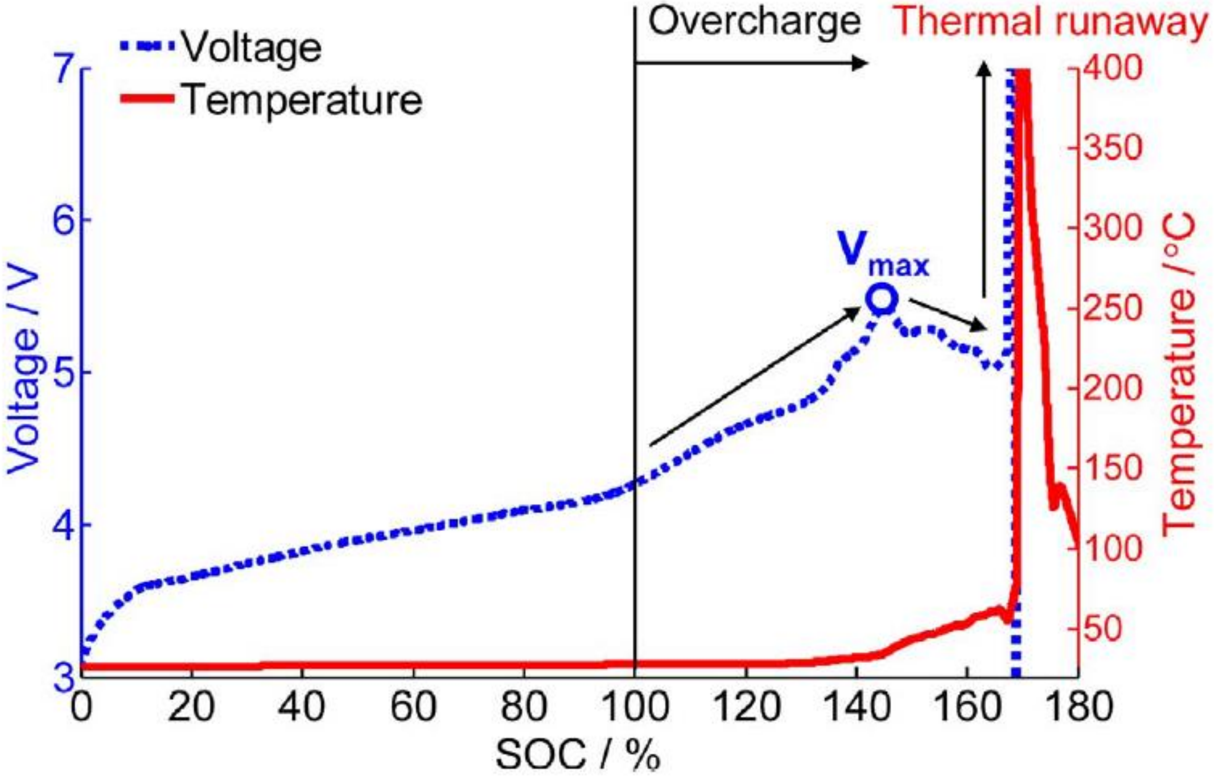
Internal short circuit: the most common feature of TR.



Source: [1] Thermal runaway mechanism of lithium ion battery for electric vehicles: A review; Xuning Fenga,b, Minggao Ouyanga,⁎, Xiang Liua, Languang Lua, Yong Xiaa, Xiangming Hea,b a State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
b Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing, 100084, China; http://dx.doi.org/10.1016/j.ensm.2017.05.013

Thermal Runaway

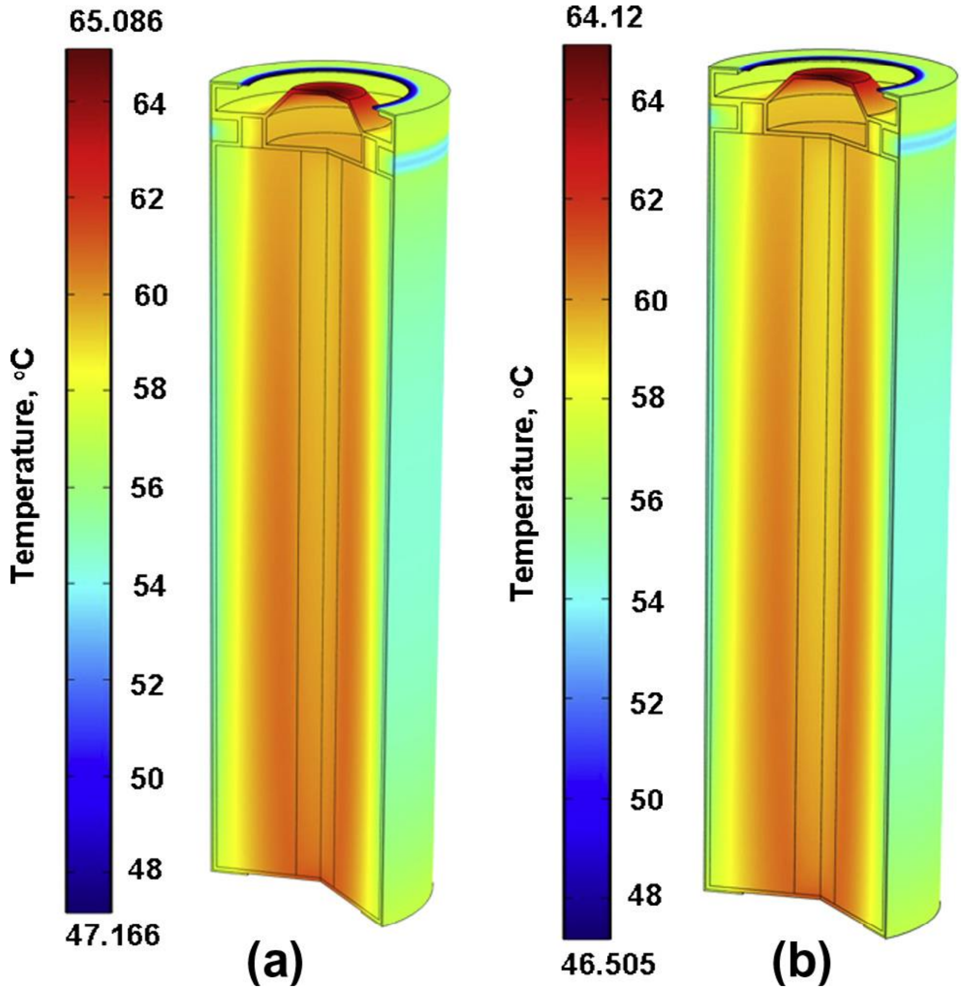
The results of overcharge induced TR for a commercial lithium ion battery



Source: [1] Thermal runaway mechanism of lithium ion battery for electric vehicles: A review; Xuning Fenga,b, Minggao Ouyanga,⁎, Xiang Liua, Languang Lua, Yong Xiaa, Xiangming Hea,b a State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
b Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing, 100084, China; http://dx.doi.org/10.1016/j.ensm.2017.05.013

ENERGY STORAGE EVENT
12 februari 2019
NH Conference Centre Koningshof

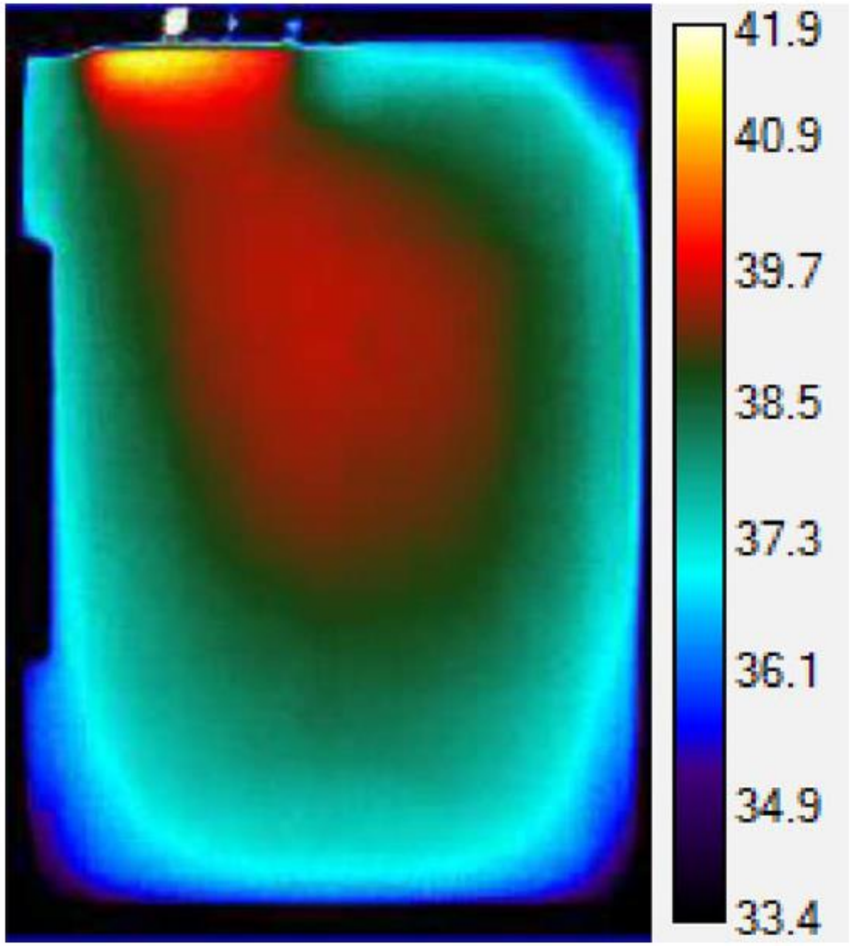
Contour of temperature distribution in the cell @ 5C:



Charging Discharging

Source: [1] Electrochemical–thermal analysis of 18650 Lithium Iron Phosphate cell; L.H. Saw, Yonghuang Ye, A.A.O. Tay; Department of Mechanical Engineering, Faculty of Engineering, National University of Singapore, 117576 Singapore, Singapore; Energy Conversion and Management 75 (2013) 162–174

Contour of temperature distribution in the pouch cell @ 5C:

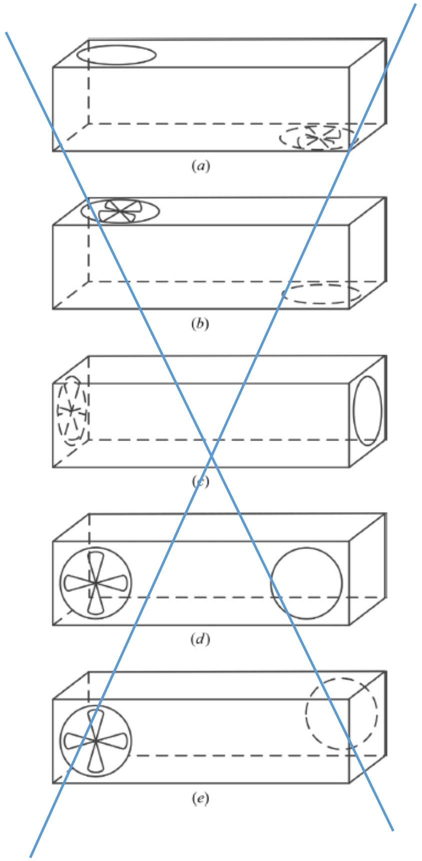


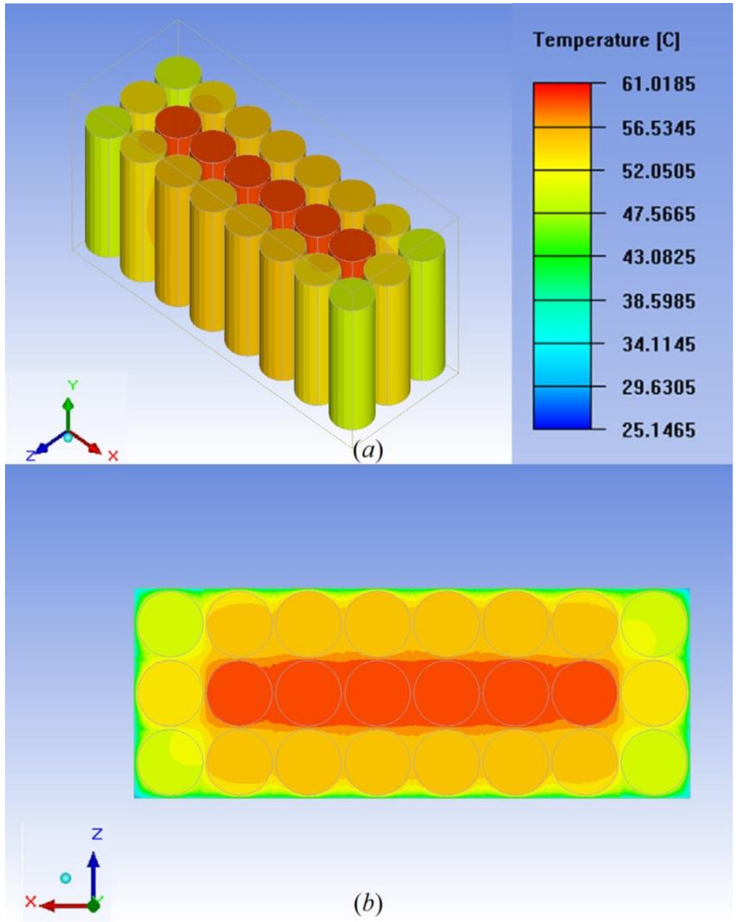
Thermal image of a lithium-ion pouch cell discharging at a 5C rate in ambient air. Cathode terminal is in the upper left corner of pouch cell.

Source: [1] Journal of The Electrochemical Society, 161 (14) A2168-A2174 (2014); Thermal Effect of Cooling the Cathode Grid Tabs of a Lithium-Ion Pouch Cell; Stephen J. Bazinski and Xia Wang; Department of Mechanical Engineering, Oakland University, Rochester, Michigan 48309, USA

Battery Design and Cooling Strategies w/o Fan

Explanation of fan and opening locations





Temperature of 3 x 8 battery module without airflow.

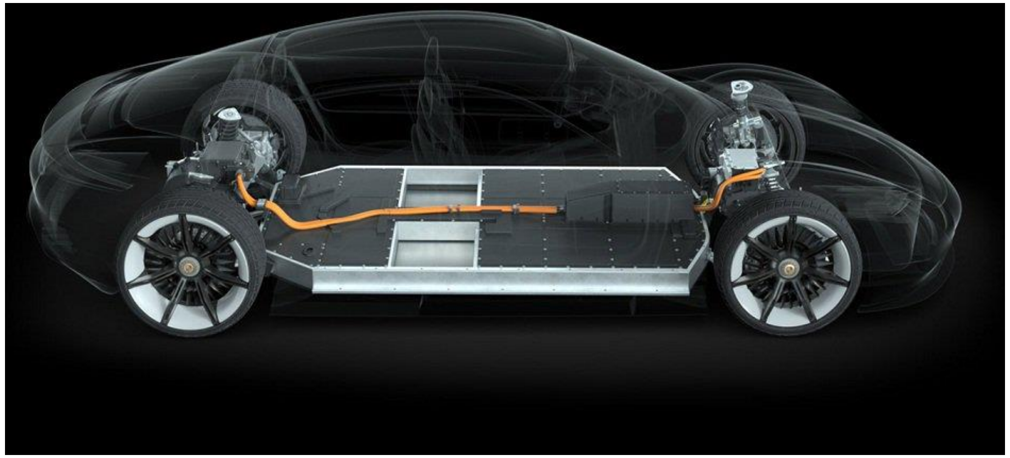
Conditions:

- Airflow speed of different module patterns to be 1 m/s
- Area of the fan and opening is 0.002828 m2
- Radius of fan is 0.03 m when the air inlet is round
- Outer cells are 1 mm away from the module case,
- There is 5 mm between the cell bottom and case bottom and 15 mm on the top.

Source: [2] Thermal investigation of lithium-ion battery module with different cell arrangement structures and forced air-cooling strategies; Tao Wang, K.J. Tseng, Jiyun Zhao ⇑, Zhongbao Wei; EXQUISITUS, Centre for E-City, School of Electrical and Electronics Engineering, Nanyang Technological University, Singapore 639798, Singapore; http://dx.doi.org/10.1016/j.apenergy.2014.08.013

High Voltage Battery System based on Stack Structure

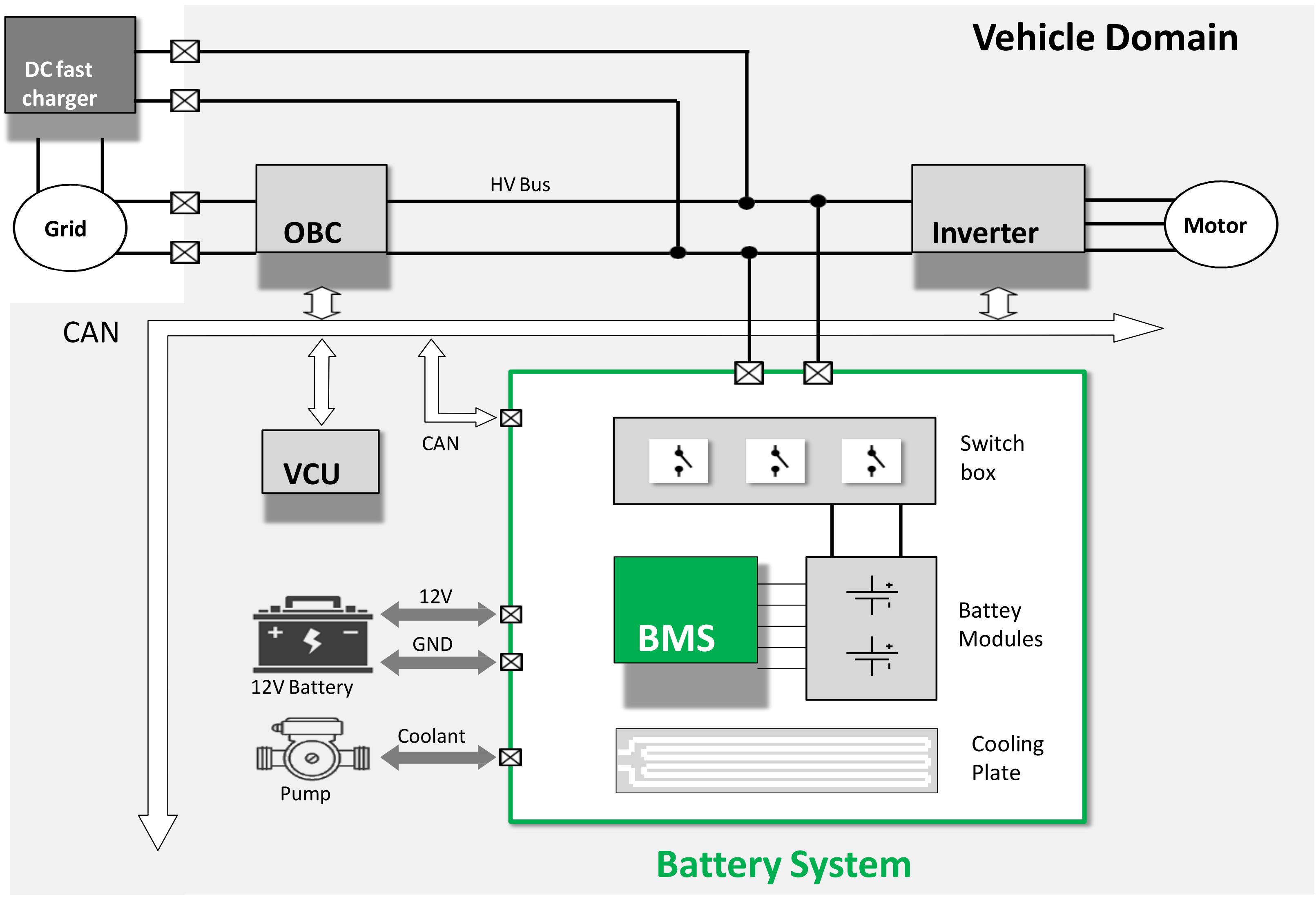
Challenges



- Monitoring and analyzing on cell level
  and / or stack level
- High voltage power net up to 800V
- Fast charging mode based on higher voltages
- Temperature Measurement and Analysis
- Thermal management during charge and discharge cycles , Pressure Measurement
- Load current limitations without limiting the driving performance
- Real time battery analyzing procedure during traffic light stop
- Battery analyzing based on functional safety without big data or cloud connectivity

Source : Photo Porsche AG

Introduction – Simplified xEV Powertrain

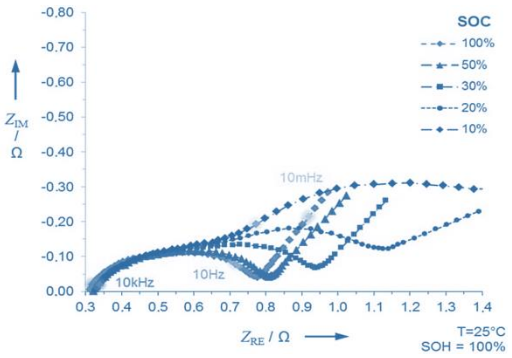


The Approach

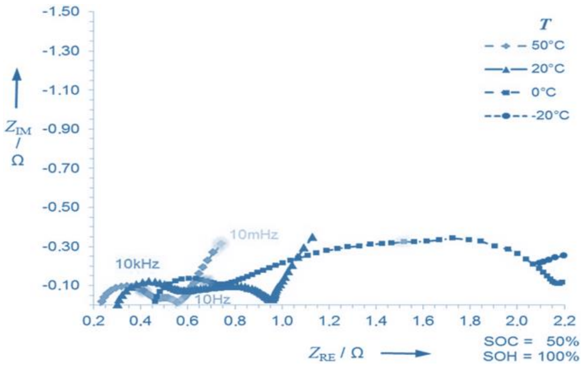
Measure, analyze and characterize a battery without knowing anything about the life of the battery before !!!!

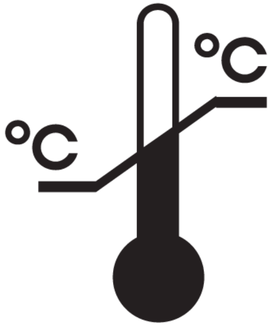
Key Requirements in BMS

SOC Analysis and Monitoring

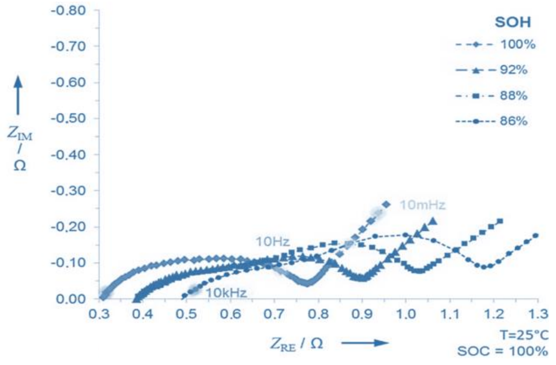


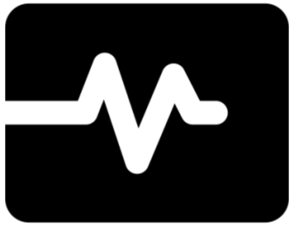
Temperature Analysis and Monitoring





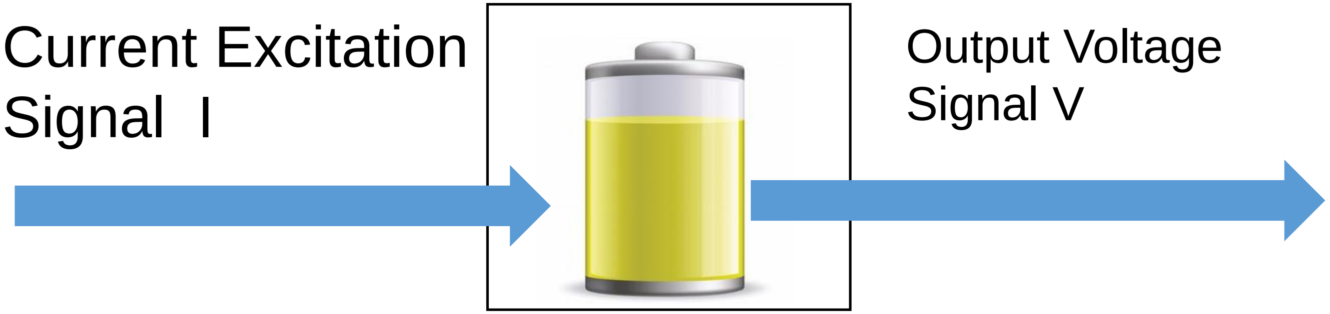
SoH Analysis and Monitoring



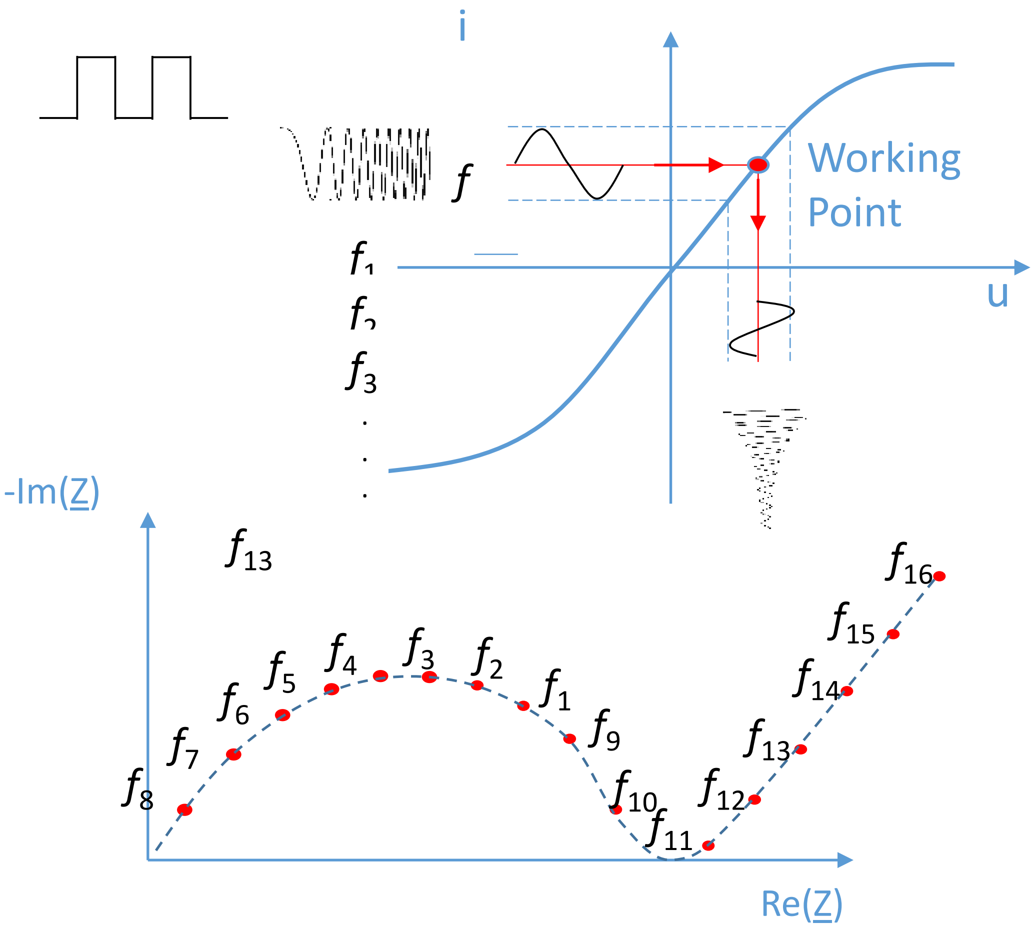


Why Electro Impedance Spectroscopy (EIS) is so important in BMS?

Impedance Spectroscopy - Method



$$\underline{Z}(\omega) = \left|\underline{Z}(\omega)\right| \cdot e^{j\varphi(\omega)}$$

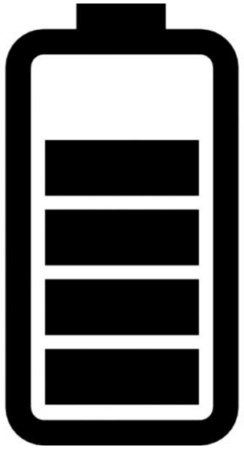


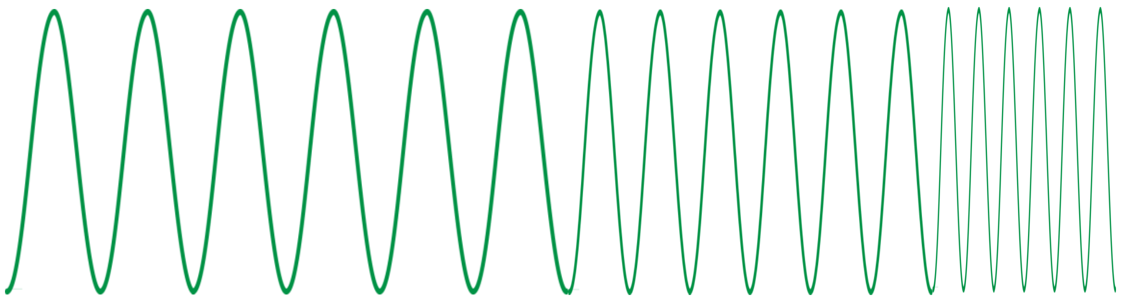
- Experimental **efficiency and non-invasiveness**
- More **information** than only by resistive, capacitive or inductive measurement
- Possibility to **separate effects** dominating in different frequency ranges

EIS Data for Li-Ion Battery Analysis

Typical Parameters for a EIS data analysis

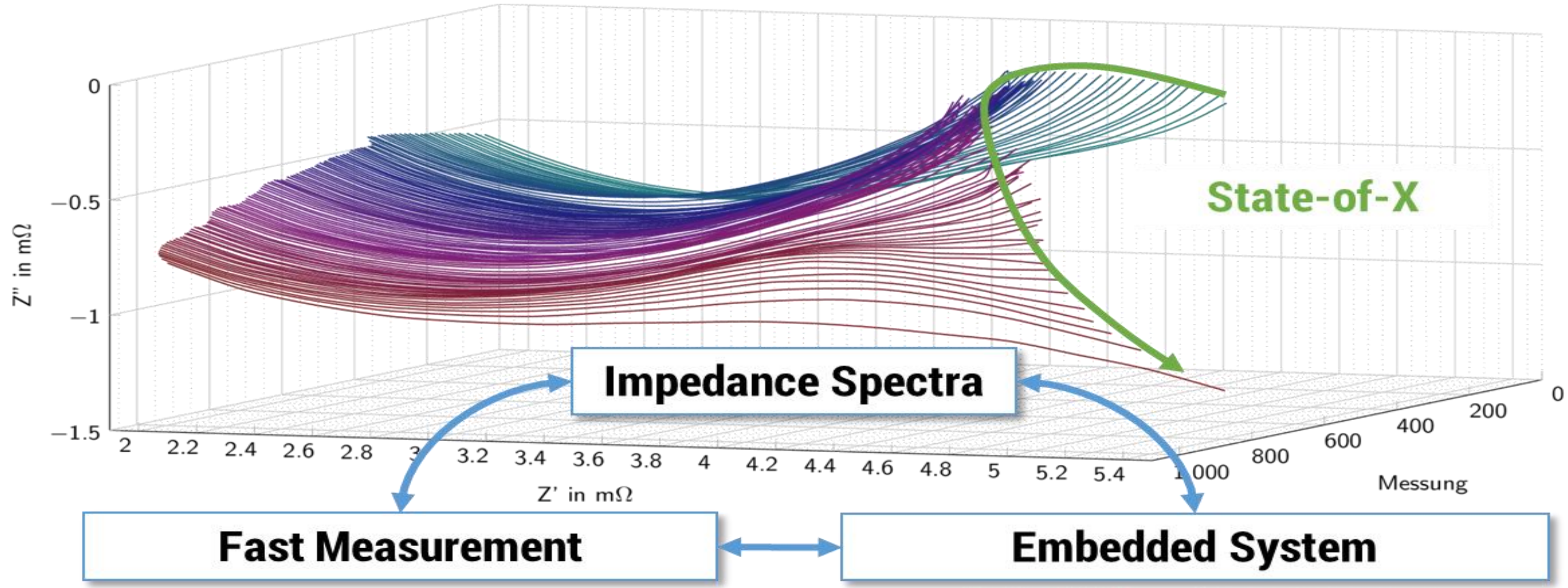
- State-of-Charge SOC from 0% to 100%
- Temperature Range from -20°C to +60°C
- Frequency Range Analysis 10mHz to 1kHz for Electro Impedance Spectroscopy





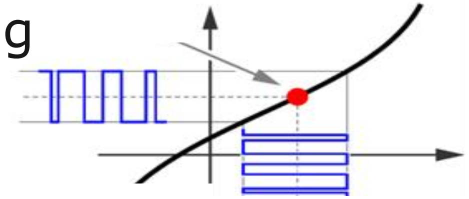
ENERGY STORAGE EVENT
12 februari 2019
NH Conference Centre Koningshof

Overview – Battery Diagnosis and Challenges



Working

Excitation



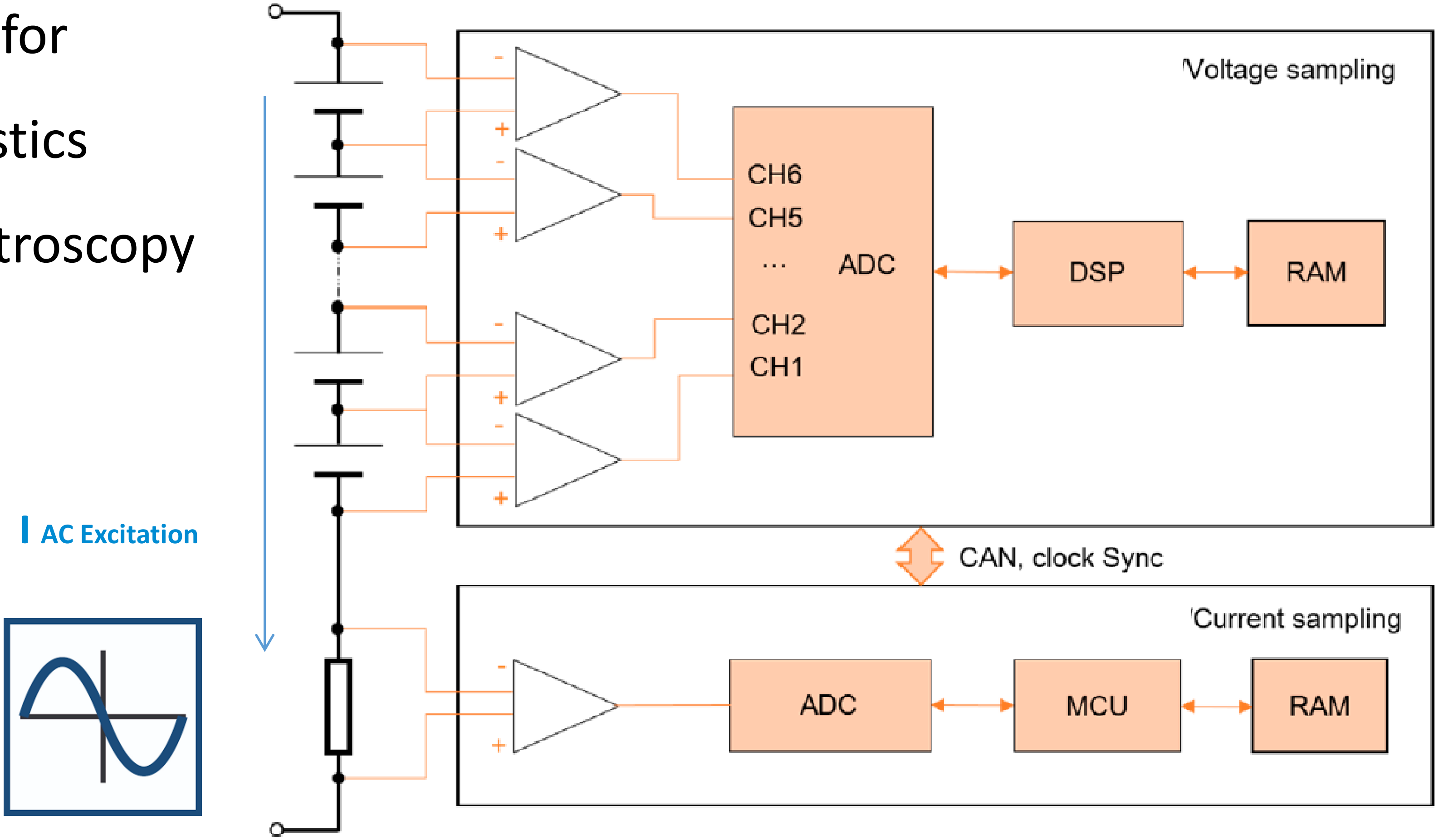
Characteristic

Response

Source: TU-Chemnitz – Professorship Sensor and Measurement Technology – Olfa Kanoun

EIS - Voltage and current sampling circuits.

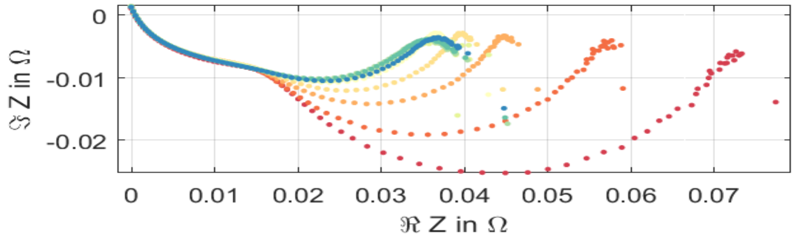
- Simplified Block Diagram for Advanced Battery Diagnostics based on Impedance Spectroscopy

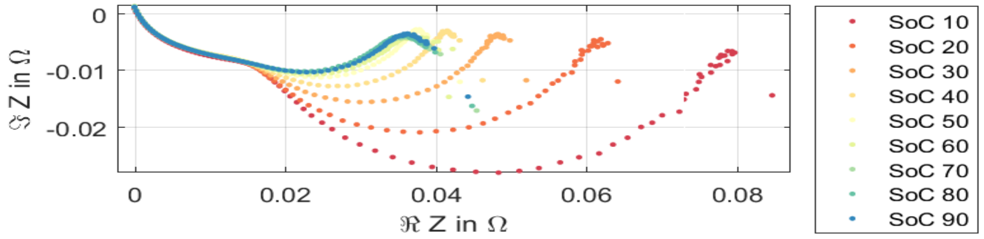


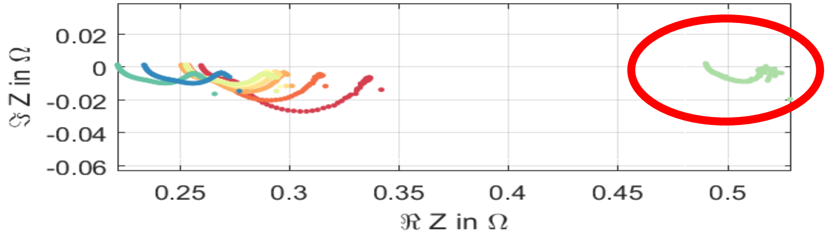
Source: Energuies MDPI; Practical On-Board Measurement of Lithium Ion Battery Im edance Based on Distributed Voltage and Current Sampling; XuezheWei 1,2, Xueyuan Wang 1,2 ID and Haifeng Dai 1,2,* 1 Clean Energy Automotive Engineering Center, Tongji University, Shanghai 201804, China; weixzh@tongji.edu.cn (X.We.); 7wangxueyuan@tongji.edu.cn (X.Wa.) 2 School of Automotive Studies, Tongji University, Shanghai 201804, China * Correspondence: tongjidai@tongji.edu.cn; Received: 4 December 2017; Accepted: 26 December 2017; Published: 1 January 2018

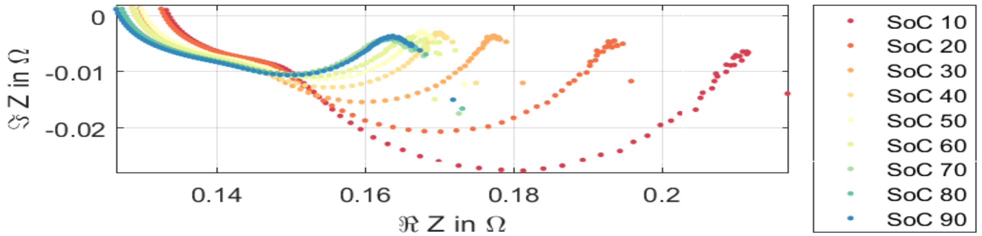
Application Example: Intelligent BMS

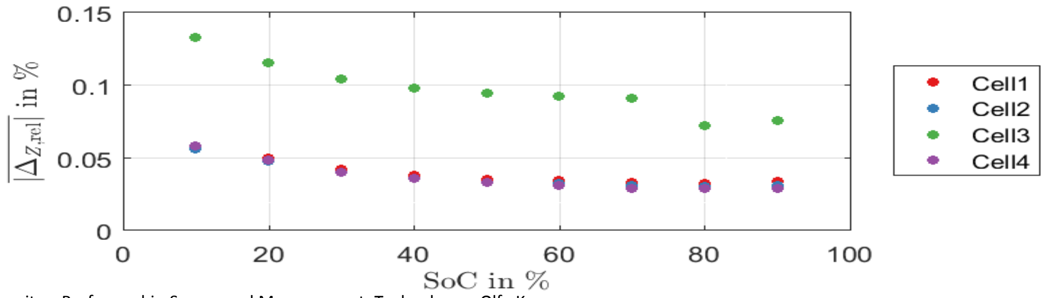
→ Impedance Spectra @ different SOC (10-90%) of 4 equivalent cells









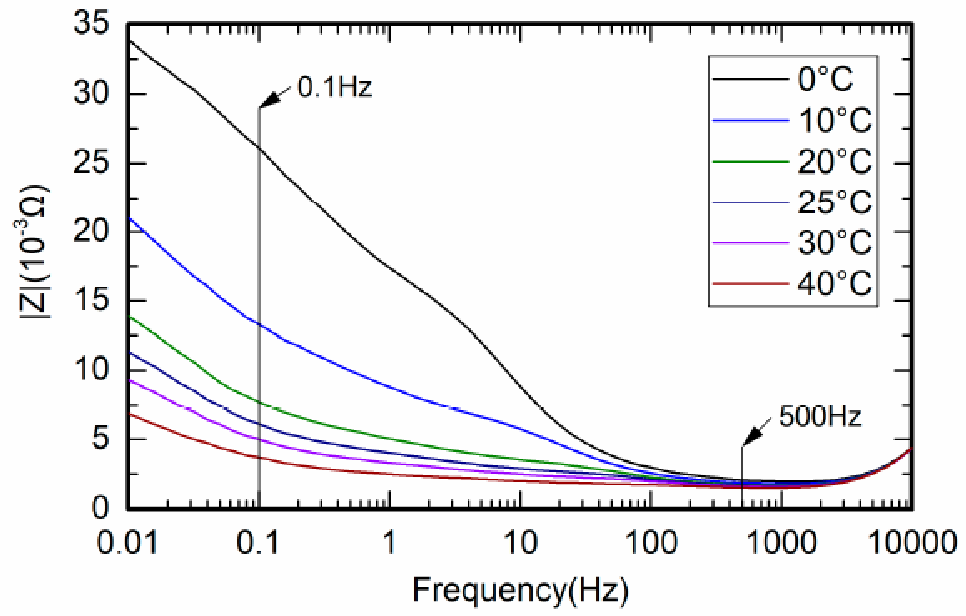


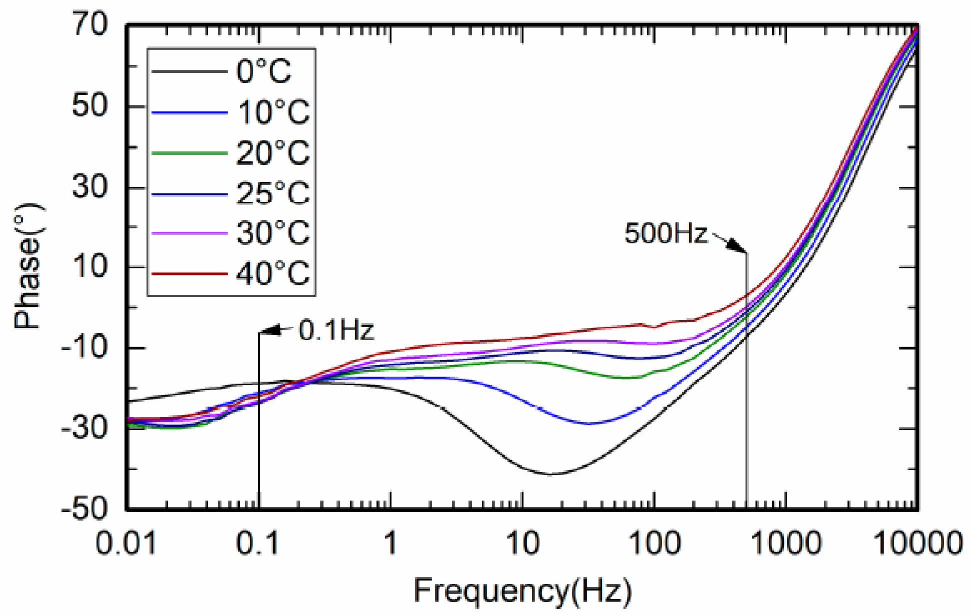
→ Incorrect cells are detectable by impedance spectroscopy

Source: TU-Chemnitz – Professorship Sensor and Measurement Technology – Olfa Kanoun

Application Example: Intelligent BMS

Impedance Analysis for Cell Temperature Diagnostics

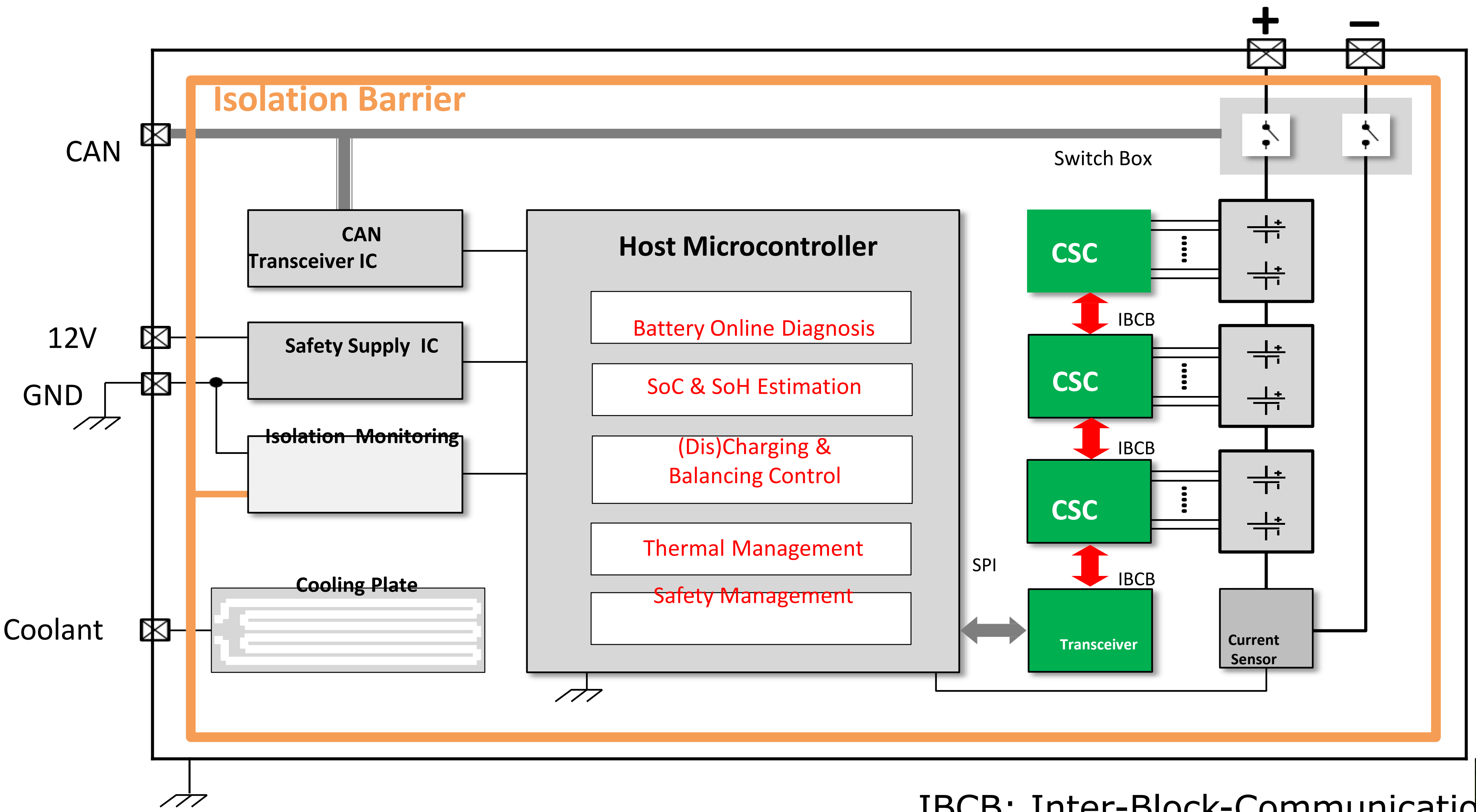




→ Hot Spots are detectable by impedance spectroscopy

Source: Practical On-Board Measurement of Lithium Ion Battery Impedance Based on Distributed Voltage and Current Sampling XuezheWei 1,2, Xueyuan Wang 1,2 ID and Haifeng Dai 1,2,* 1 Clean Energy Automotive Engineering Center, Tongji University, Shanghai 201804, China; weixzh@tongji.edu.cn (X.We.); 7wangxueyuan@tongji.edu.cn (X.Wa.) 2 School of Automotive Studies, Tongji University, Shanghai 201804, China

Battery System

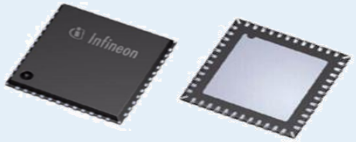


IBCB: Inter-Block-Communication Bus

CSC: Cell Supervisory Chip

Our BMS Chipset Solution

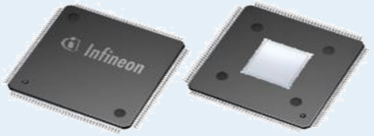
TLF35584
Safety power supply



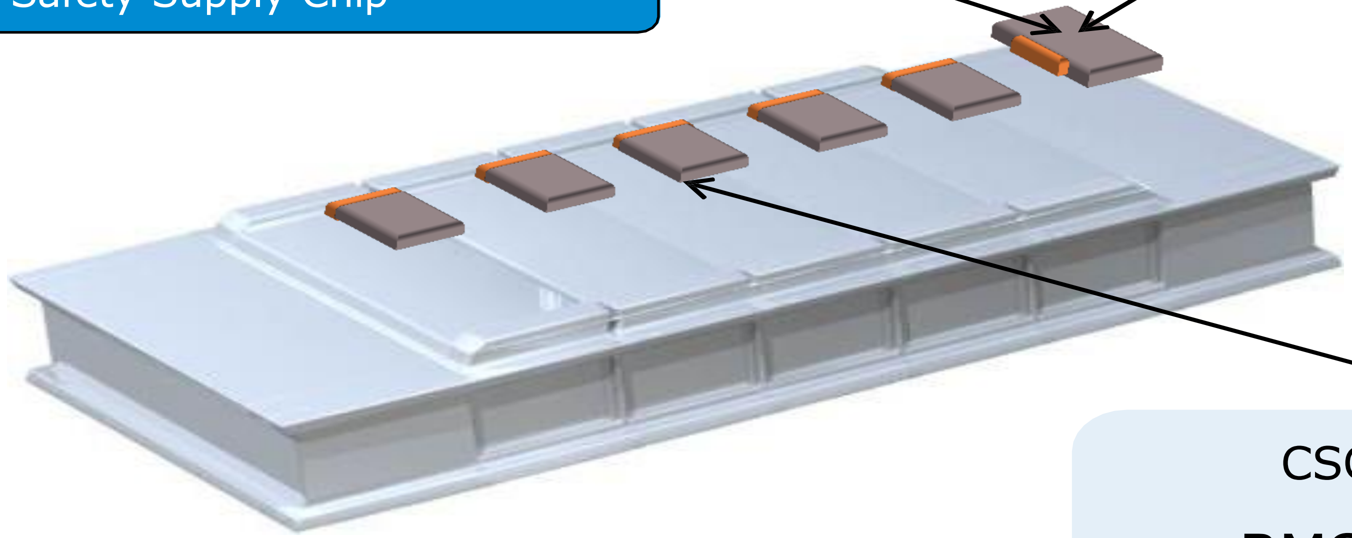
Safety Supply Chip

Host Controller

Aurix™



Main Microcontroller



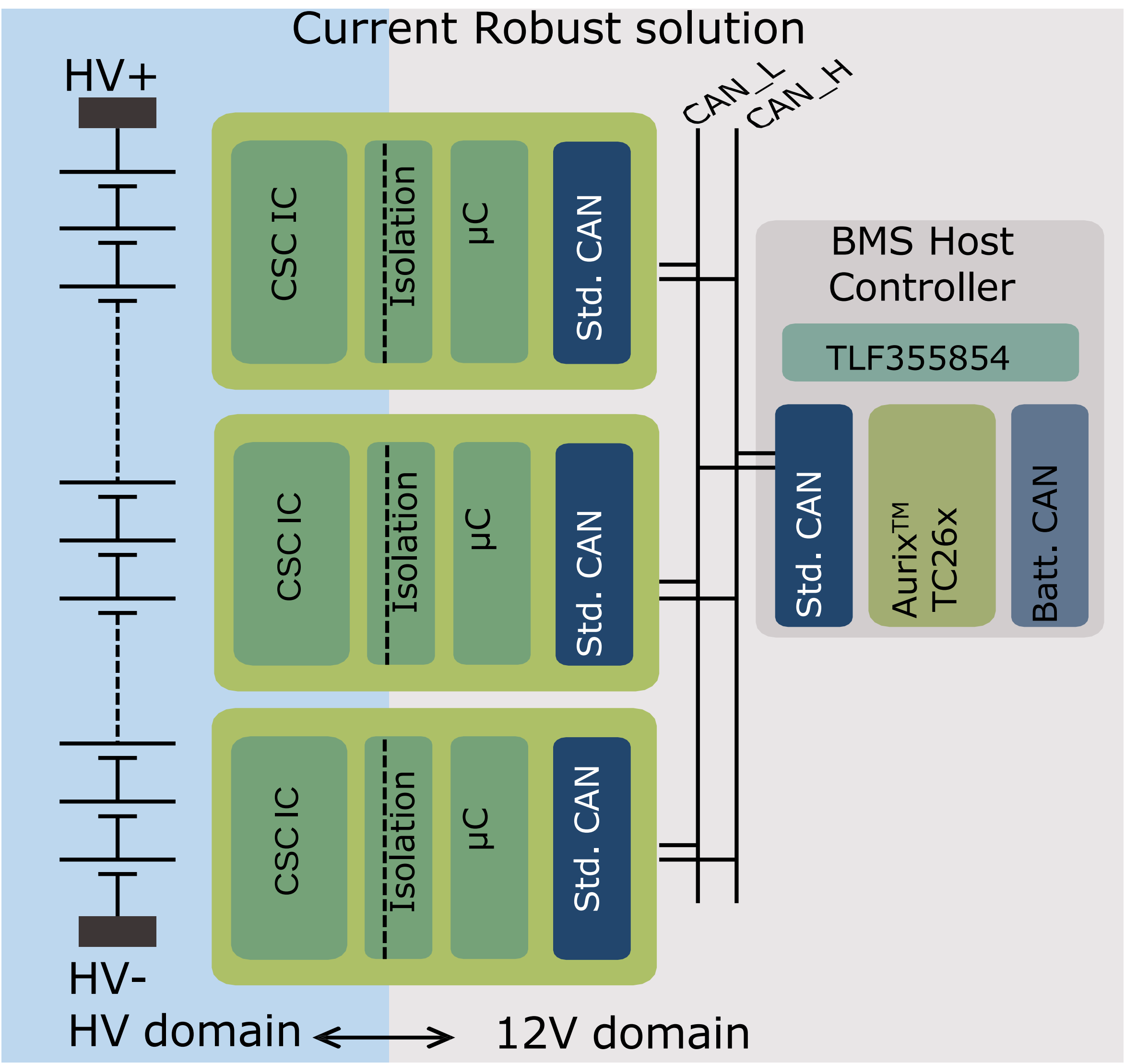
CSC Controller

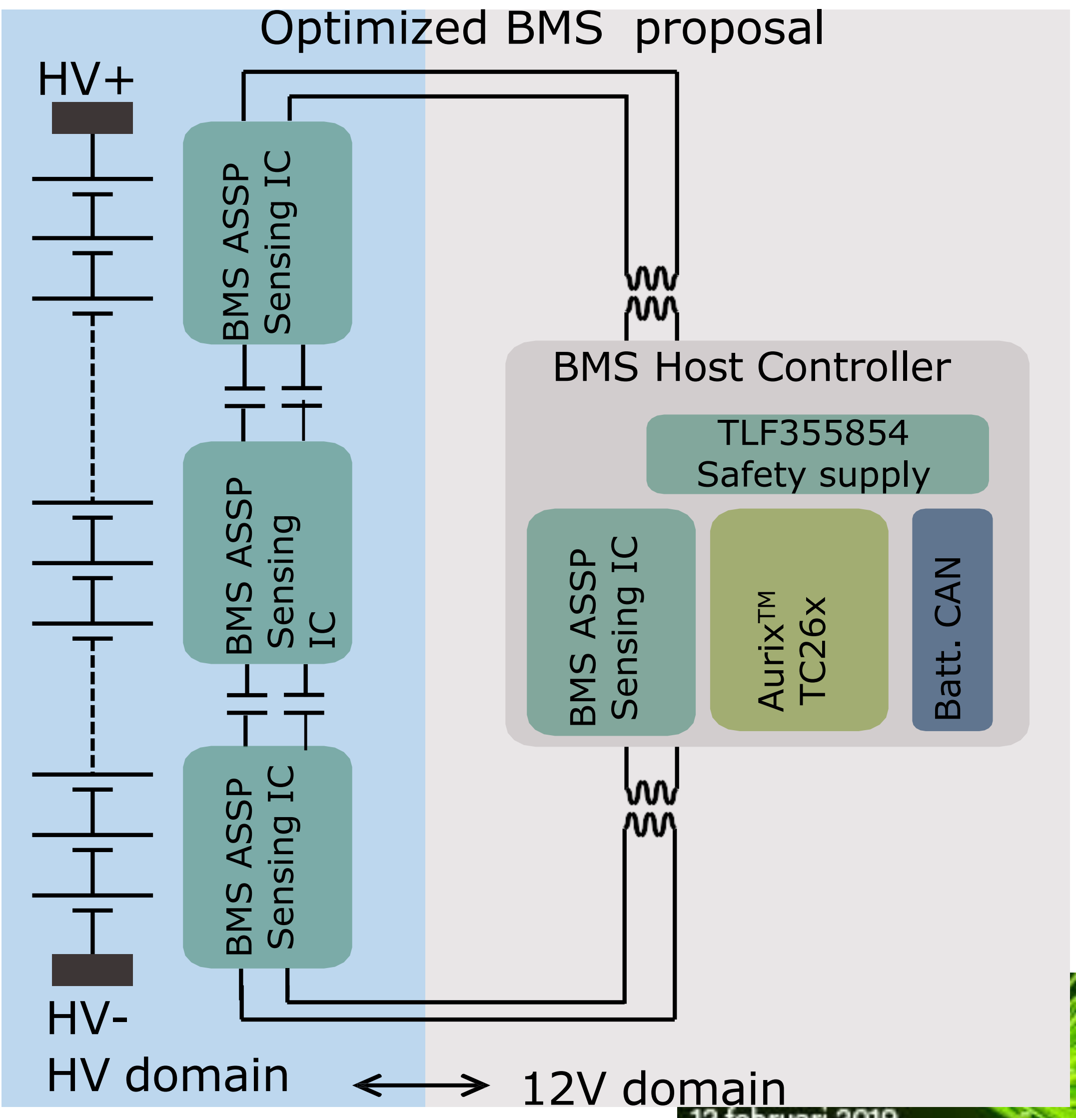
BMS ASSP
12ch Sensing IC

Sensing IC

ENERGY STORAGE EVENT
12 februari 2019
NH Conference Centre Koningshof

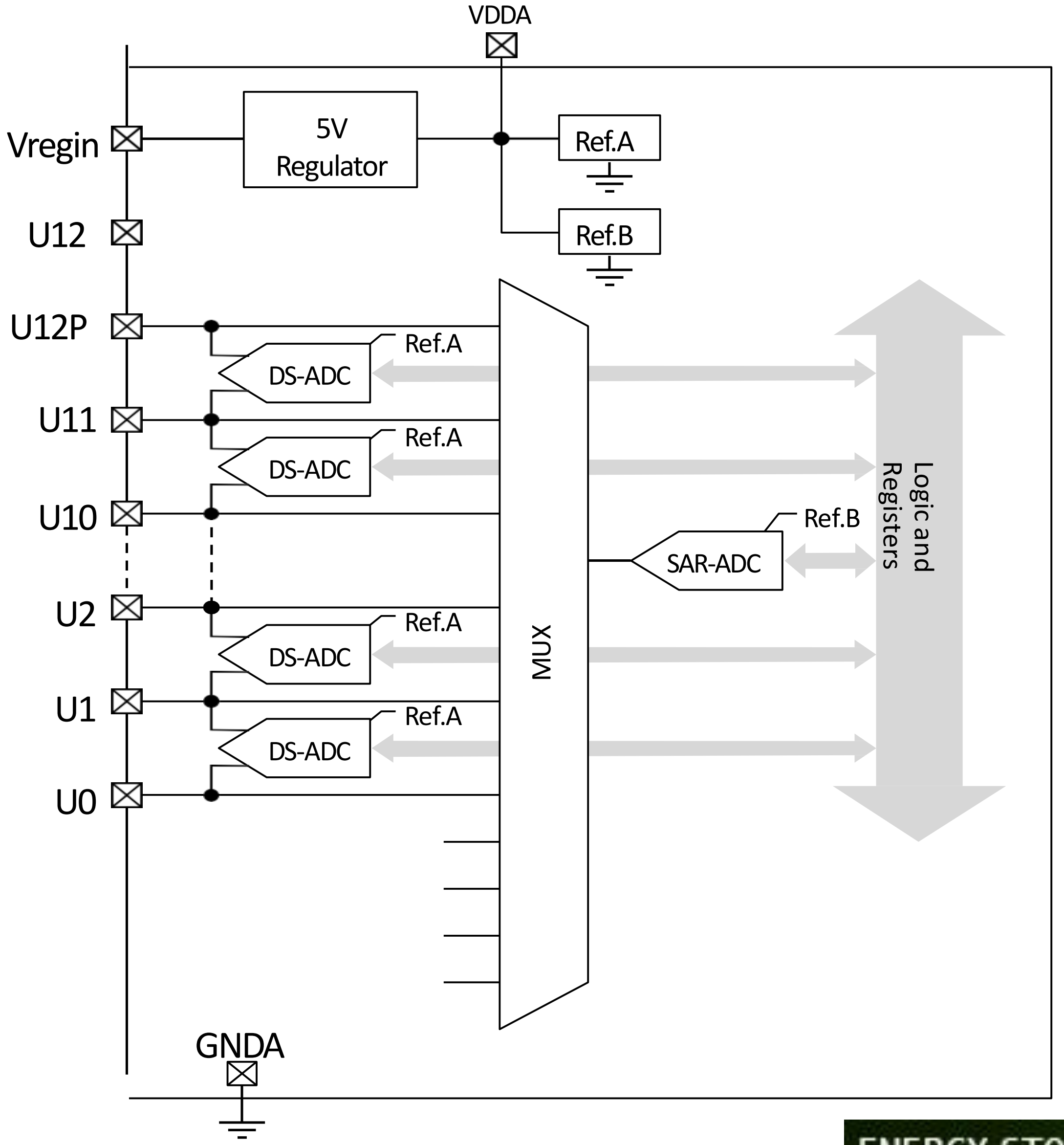
Traditional System Architecture vs. Advanced System Architecture





Cell Voltage Measurement

- **Redundancy:**
  - 13 bits Delta-Sigma ADC **for each channel**
  - 10 bits SAR-ADC + MUX **for all channels**
  - Separate power supply for both ADCs
- **Synchronous Measurement**
- **Accuracy:**
  - ± 1.5 mV @ 4.6V Cell and 25°C
  - ± 3 mV @ 4.6V Cell and -40°C~125°C



Summary and Conclusions

As a CSC chip, is eye and hand of the BMS host MCU

- Benefits at a glance:
  - Redundant and Synchronous Cell Voltage Measurement
  - RealTime Robust Inter-Block Communication
  - Unique Active Balancing methods
  - Rich Diagnosis Features
  - Possible to support ASIL-C systems
  - Modeling for state estimation
  - Measurement of inner cell temperature, State-of Health SoH, State-of-Function SoF
  - Usage for all Cell Chemistries

Significant Improvement of Functional Safety

Contact

RUTRONIK
ELECTRONICS WORLDWIDE

Andreas Mangler
IEEE Member
Director Strategic Marketing
Member of the Extended Management Board
Rutronik Elektronische Bauelemente GmbH
andreas.mangler@rutronik.com

Kazim Akyar

Regional Sales Manager Netherlands
Tel. +31 76 572 4008
Mobile +31 6 46 14 32 32
kazim.akyar@rutronik.com
Rutronik Elektronische Bauelemente GmbH
NL-Breda

Committed to excellence