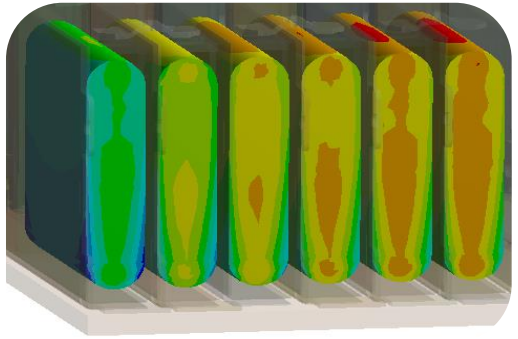
foxBMS

The open source BMS development and research platform

free.open.flexible



Fraunhofer IISB – Who we are

Fraunhofer Society

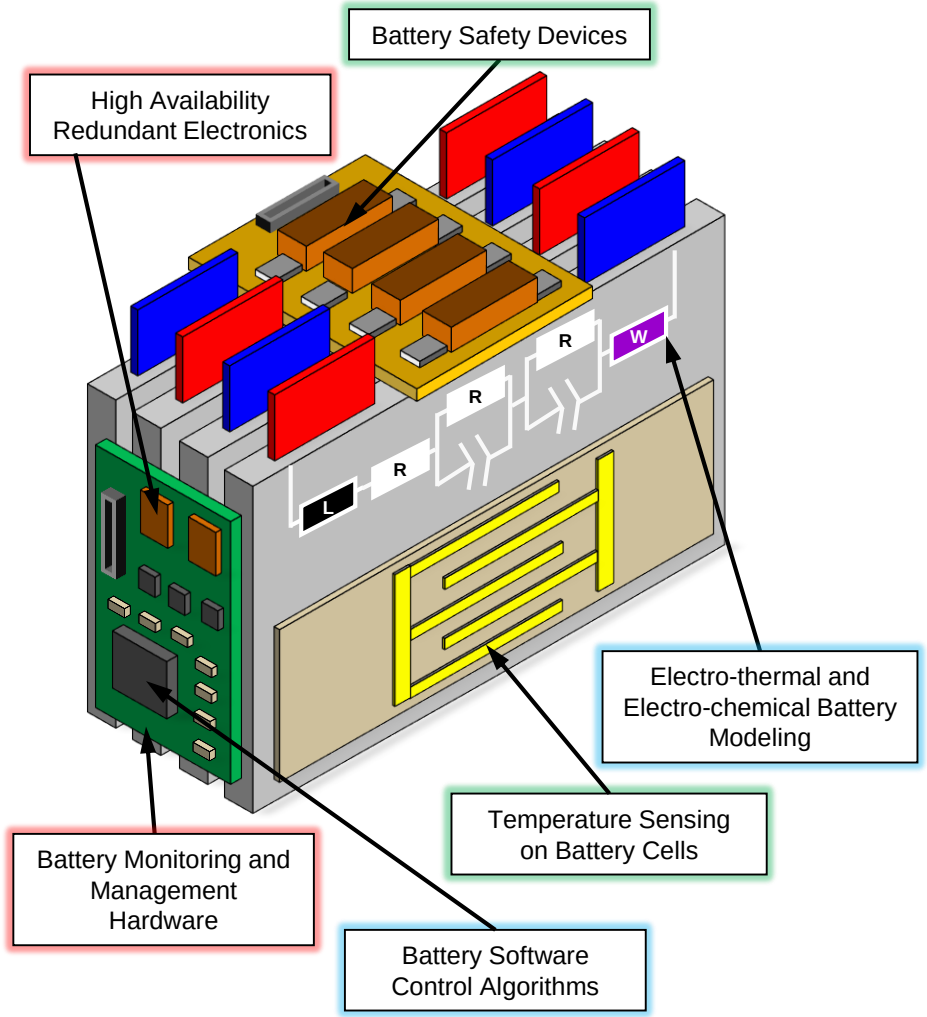
- Applied Research
- Around 28,000 Employees
- 74 Research Institutes
- Annual Budget: € 2.8 billion

Fraunhofer IISB

- Director: Prof. Martin MÄRZ (acting)
- R&D Fields:
  - **Semiconductor Technologies** (Si & SiC) (1000m² clean room Class 10)
  - **Power Electronic Systems**
- Cooperation with the FAU (Friedrich-Alexander-University Erlangen-Nürnberg)
- Staff: 280 (about 210 Engineers)
- Budget: ca. 25 M€/year
  - 30% Public Funding
  - 70% Project Revenues
- www.iisb.fraunhofer.de

Fraunhofer IISB – Battery Systems Group

- The group Battery Systems at Fraunhofer IISB develops innovative solutions in the field of:
  - Prototyping of complete battery systems and mechatronic integration
  - Battery Management Systems (BMS Hardware and Software) with high availability concepts
  - Passive and active safety concepts for high functional safety integrity levels (ASIL-D / SIL-3 / DAL-C)
  - Battery Junction Boxes (BJB)
  - Thermal management for non-propagation in case of thermal runaway and temperature homogenization concepts for ultra-fast charging (>3C-rate)
  - Modelling and simulation methods for battery system design

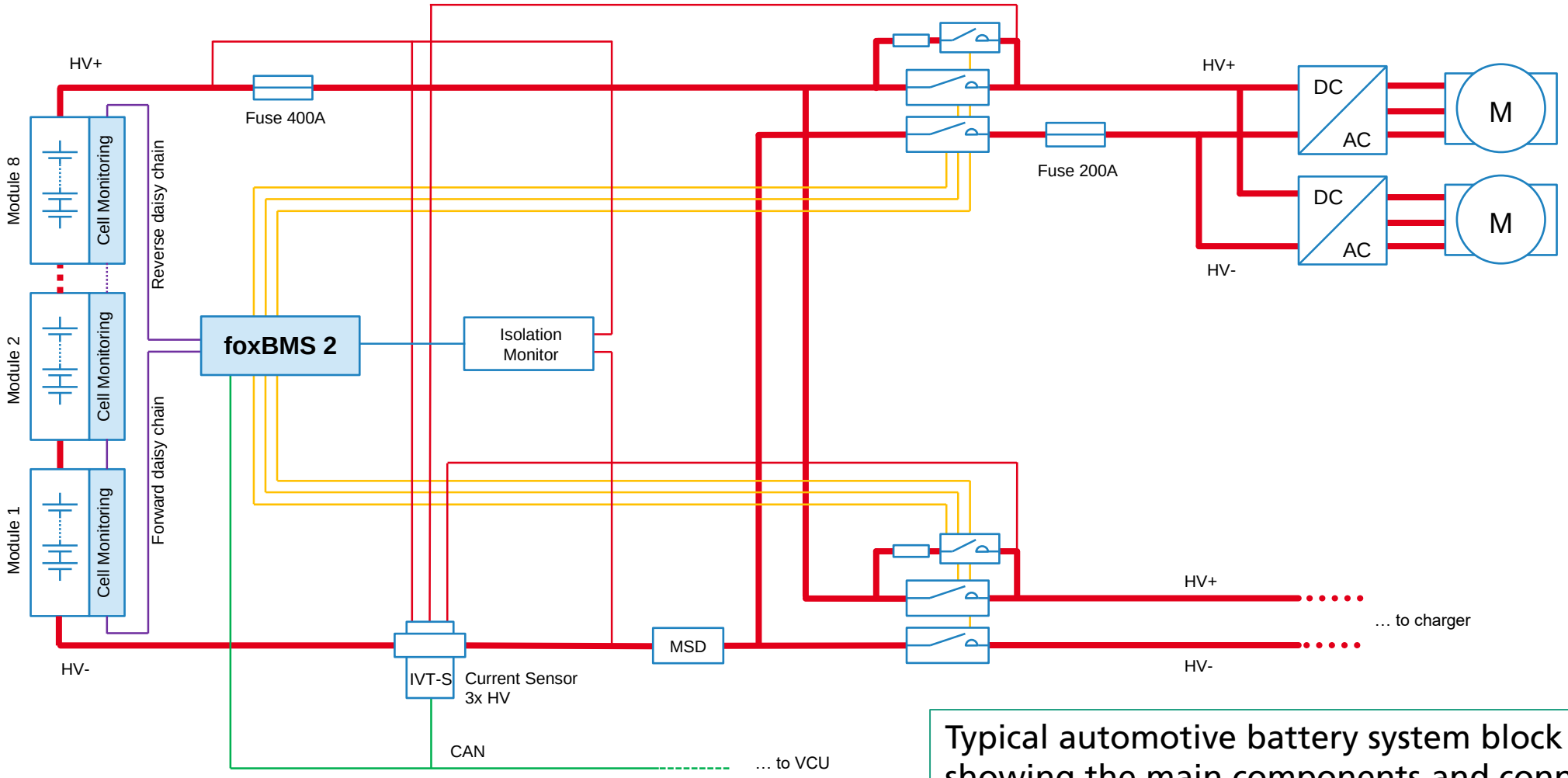


Why do we need a Battery Management System (BMS)?

The BMS has to ensure a **safe**, **reliable** and **economic** operation of its battery system

- Safety
  - Keep harm from humans, living beings, the environment and surrounding equipment that might be caused by the battery system
- Reliability
  - Maximize the availability of the battery system, i.e., ensuring that the battery can function as intended for the application
- Economy
  - Maximize the life time of the battery system, e.g., by preventing premature ageing

Battery System Block Diagram – BMS Architecture



Typical automotive battery system block diagram showing the main components and connections

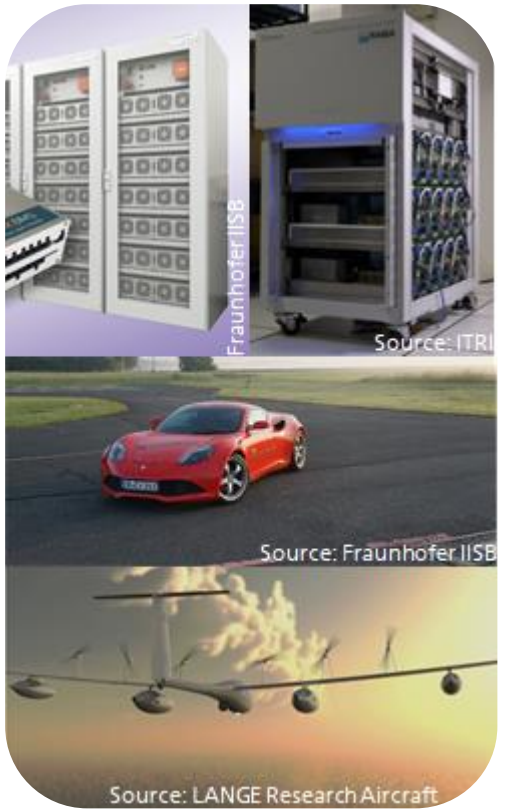
foxBMS – the Free, Open And Flexible Battery Management Development Platform

- foxBMS – free, open and flexible development platform for BMS
  - Initiated in 2015 and online since 2016 (foxbms.org, github.com/foxBMS)
  - Royalty free license (BSD 3-Clause and Creative Commons Attribution 4.0)
  - More than 200 development kits (master + slave units) delivered to a wide array of industrial and academic users, partners and customers
  - Currently in application in electric (sports-)vehicles and trucks, airships and gliders and submersible unpiloted vehicles.
  - Continuous maintenance, improvement and enhancement
- foxBMS focused on
  - Safe development and testing environment for developers and researchers
  - Fully open source and freely accessible (no NDA or similar required)
  - Gaining experience through user feedback

foxBMS Gen 1

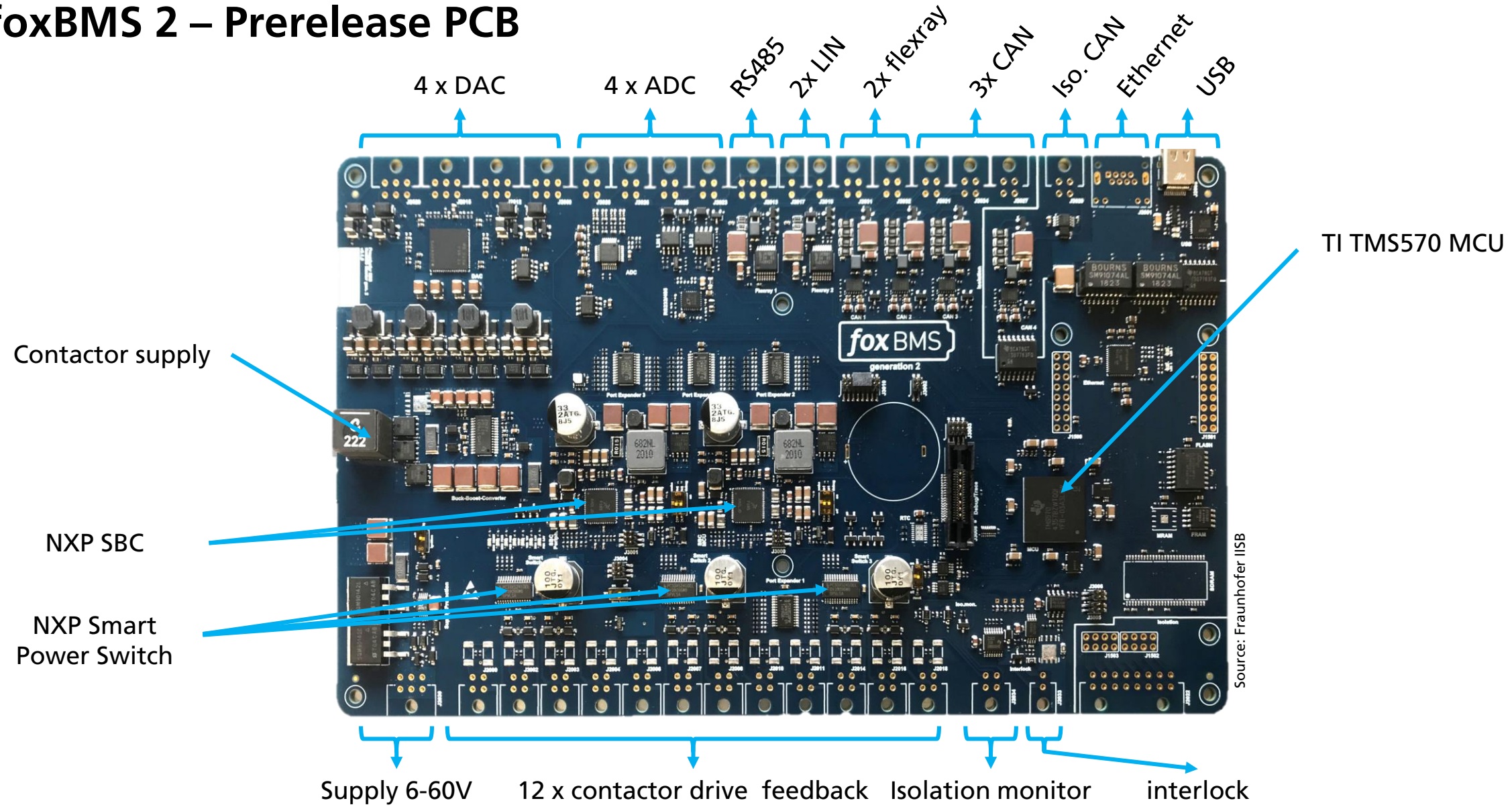
foxBMS 2 – what's new?

- Fraunhofer IISB presented foxBMS 2 at PCIM 2020
- foxBMS 2 will be the first research and development BMS platform featuring a multi-domain functional safety architecture by:
  - **Multi-applications**: automotive, aviation, industrial, rail, marine, military
  - **Safety**: certification ready functional safety hardware and software parts
  - **Components**: cutting-edge components from our partners (NXP, Maxim, ADI, Cypress, Intel)
  - **Edge-Cloud & AI**: developed to support data processing on the edge and in the cloud (IIoT, NB-IoT/LTE-M)
  - **Interfaces**: wider connectivity with additional interfaces (e.g., Industrial Ethernet, Modbus, LIN)
  - **Robust memories**: memory diversification and data integrity (Semper Flash, FRAM, MRAM)

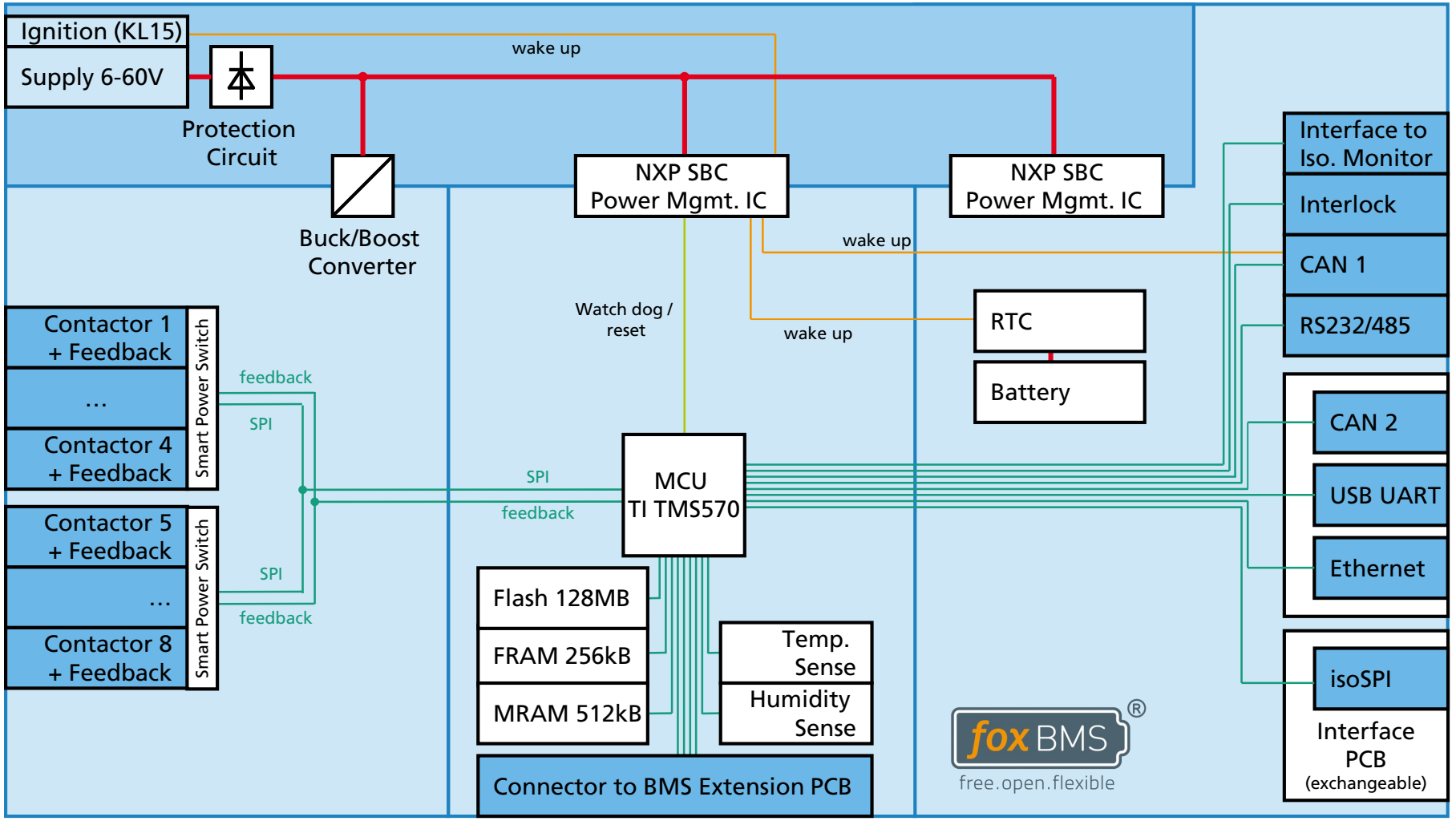


foxBMS Applications

foxBMS 2 – Prerelease PCB



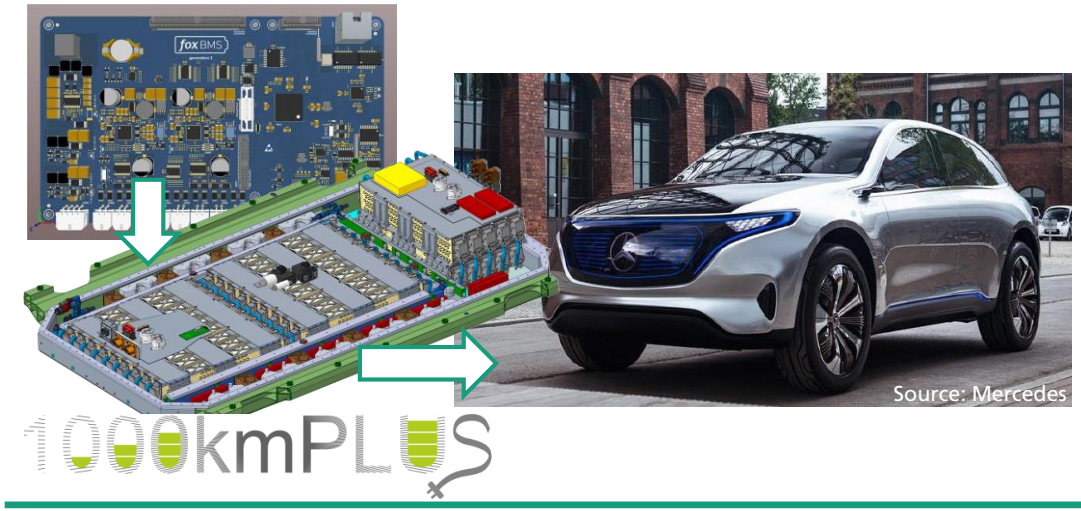
foxBMS 2 – Master Block Diagram



foxBMS 2 – Examples

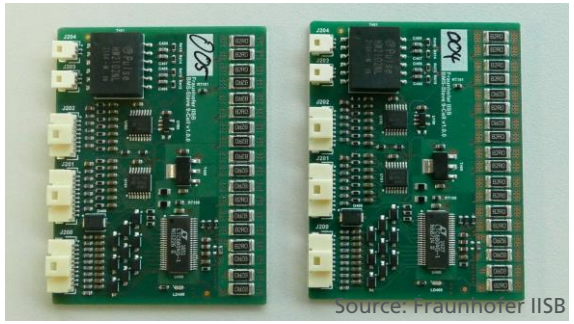
Retrofit Mercedes EQC Battery

- EU-funded Research Project 1000kmPLUS: Development of a retro-fit battery system for a Mercedes EQC
- Several driving challenges on public roads in Europe (e.g., 1000km in 12h with 3 charging stops, 90 min total → up to 350kW fast charging)



4-seater electric airplane

- The e-Sling is based on the Sling TSi, which has been adapted for electrification
- A modular battery system offers the e-Sling 250km range for 4 passengers
- With optional range extender e-Sling travels up to 350 km
- Customer specific BMS solution based on foxBMS 2 approved by Swiss BAZL (Swiss Aviation Authority)



Customized foxBMS Slave Units

Electrified Sling TSi

foxBMS 2 – Q&A 1

- Any questions so far on e.g.,
  - Licenses and licensing
  - Hardware and hardware customization
  - Target applications and examples
  - Safety
  - …

foxBMS 2 – Software Outline

- foxBMS 2 uses a safety-certified MCU
- Getting started with foxBMS 2
- A glance on the software architecture
- Configuration and customization of hard- and software
- Algorithms on the foxBMS platform and Application examples

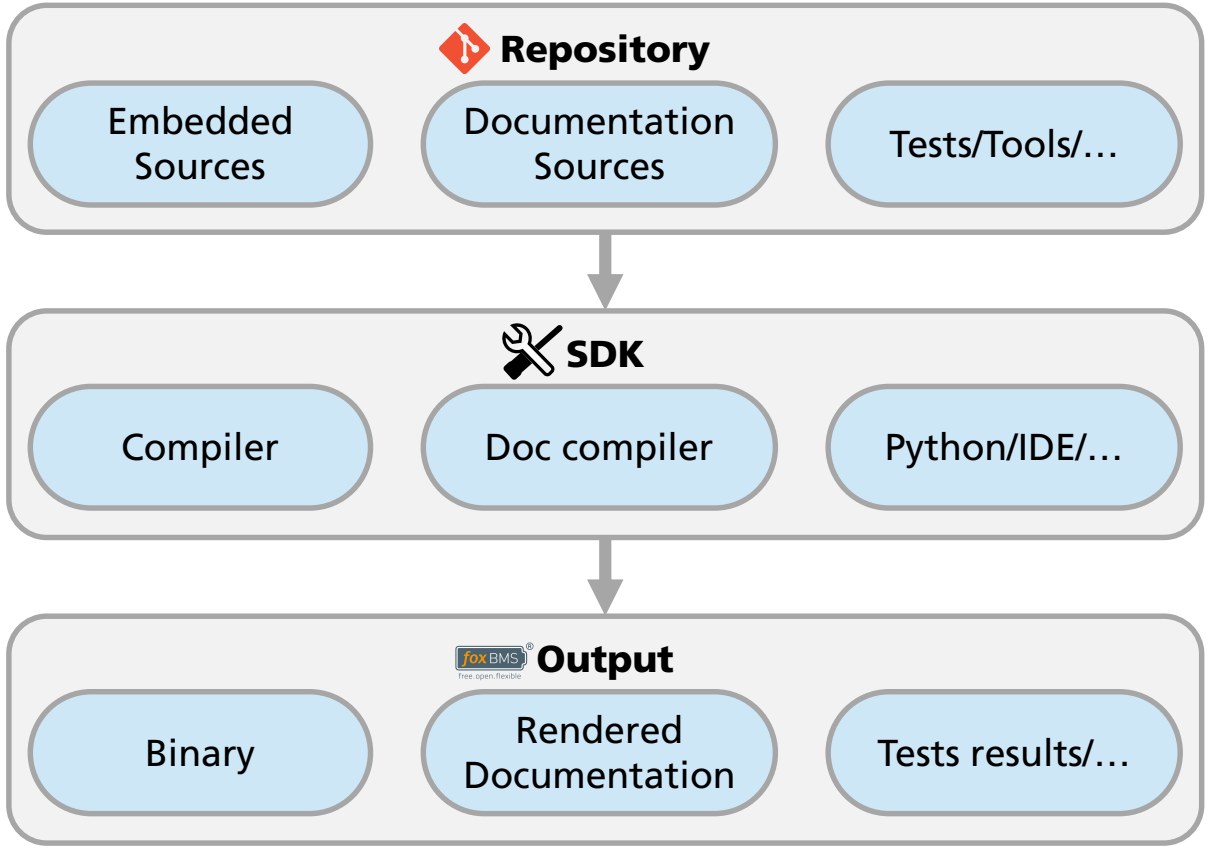
foxBMS 2 – Function Safety Qualified ARM® Cortex®-R-based MCU

- foxBMS 2 uses an Texas Instrument TMS570LC4357 MCU qualified for safety-critical applications
  - Qualified for ISO 26262 and IEC 61508 applications
  - 32 Bit RISC Flash MCU (ARM Cortex-R5F)
  - Up to 300-MHz CPU clock frequency
  - Dual-Core lockstep CPUs with ECC-protected caches
  - ECC for flash and RAM interfaces
  - Single- and double-precision FPU
  - Multiple communication interfaces: Ethernet, FlexRay, 4x CAN, 2x I^2C, 5x SPI, 4x UART
  - 2x 12bit multi-buffered ADCs (32 and 25 channels)
  - 16-Region Memory Protection Unit (MPU)
  - Built-In Self-Test (BIST) for CPU and on-chip RAMs
  - Integrated Memory (all with ECC)
    - 4MB of program flash
    - 512KB of RAM
    - 128KB of data flash for emulated EEPROM
  - 16-Bit External Memory Interface (EMIF)

foxBMS 2 – Repository and Software Development Kit

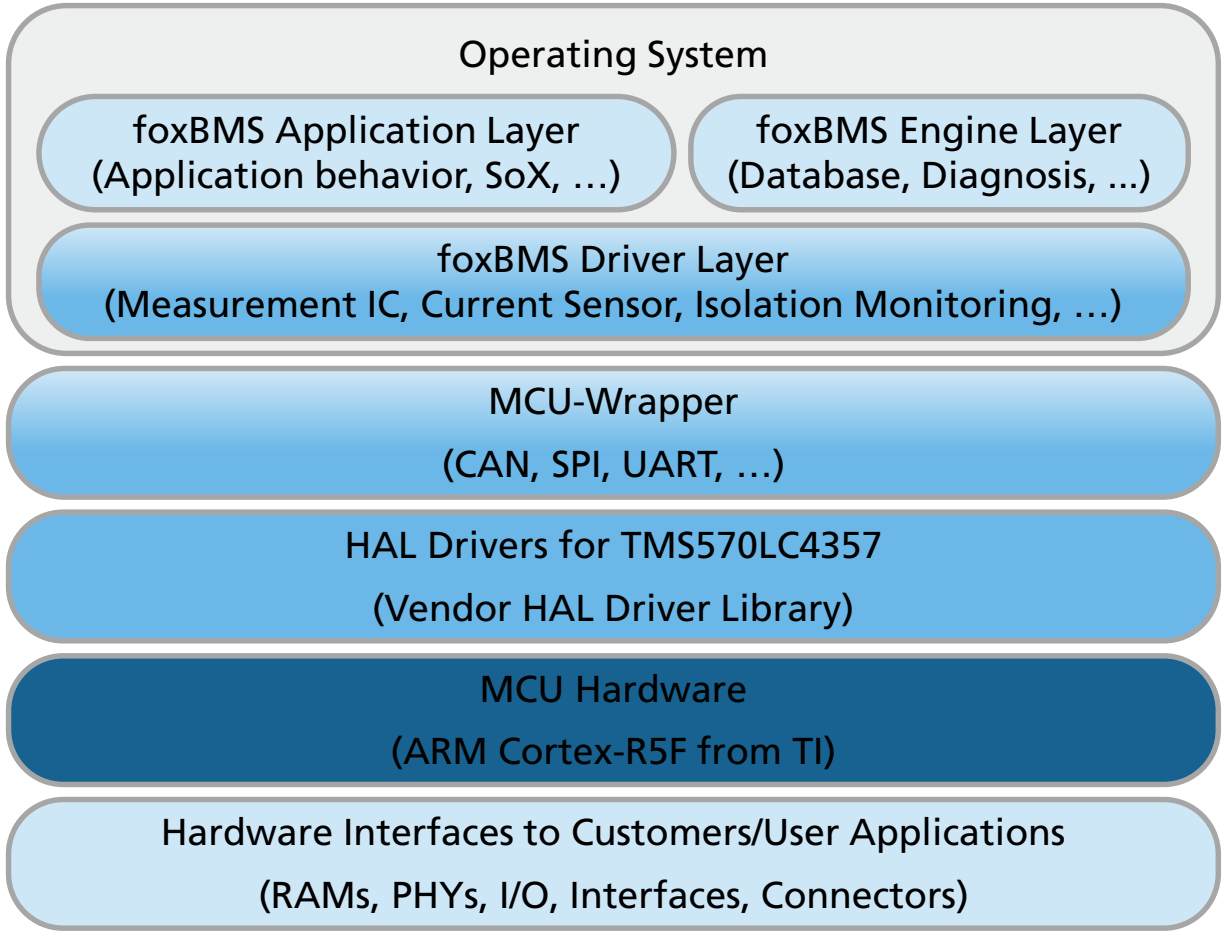
- Working on an embedded software project often requires a time-consuming project setup with expensive software – but not for foxBMS:
  - Tools are freely available, many of them open source (for details see licenses in docs.foxbms.org)
  - Simple setup process, fully documented at docs.foxbms.org
  - Compiler, build tool, documentation tool, pre-configured IDE, …

  → Total setup time: **less than 15 minutes**

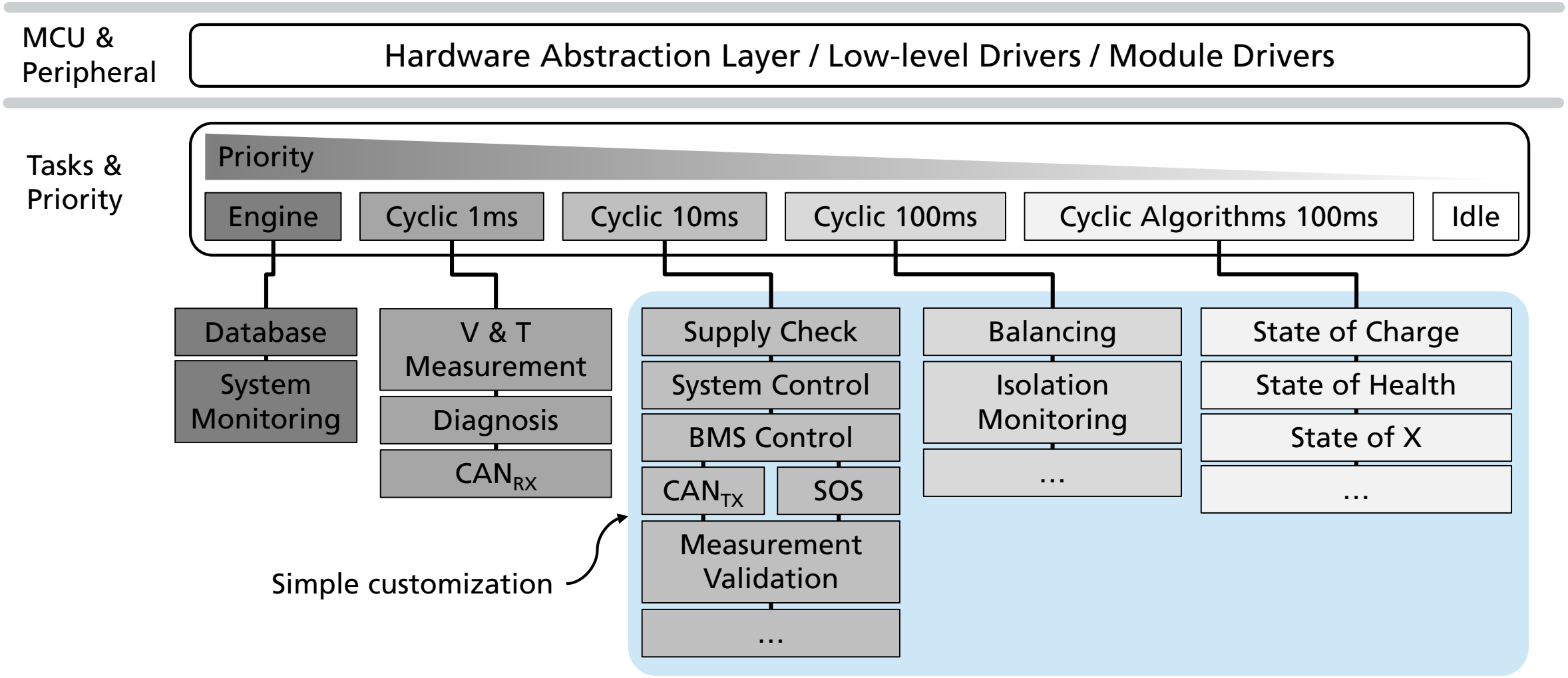


foxBMS 2 – Software Architecture: Basics

- The foxBMS architecture facilitates hardware and operating system independent BMS implementations
  - All application code runs in an simple operating system context
  - MCU and external hardware dependent drivers are abstracted by the provided wrappers/abstraction layers.
- foxBMS-based developed BMS solution is
  - **hardware independent** and
  - **OS independent.**

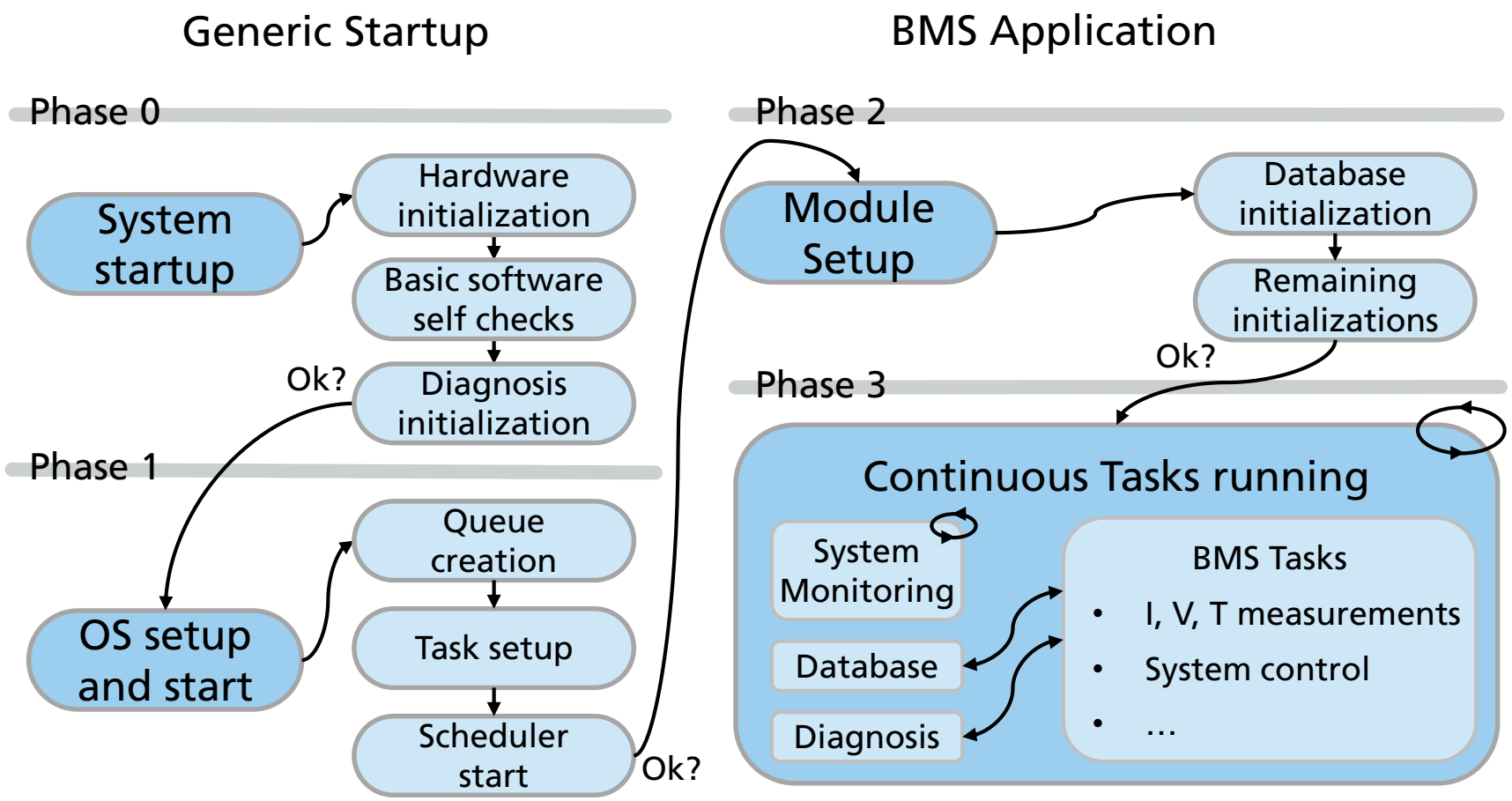


foxBMS 2 – Software Architecture: Task Model



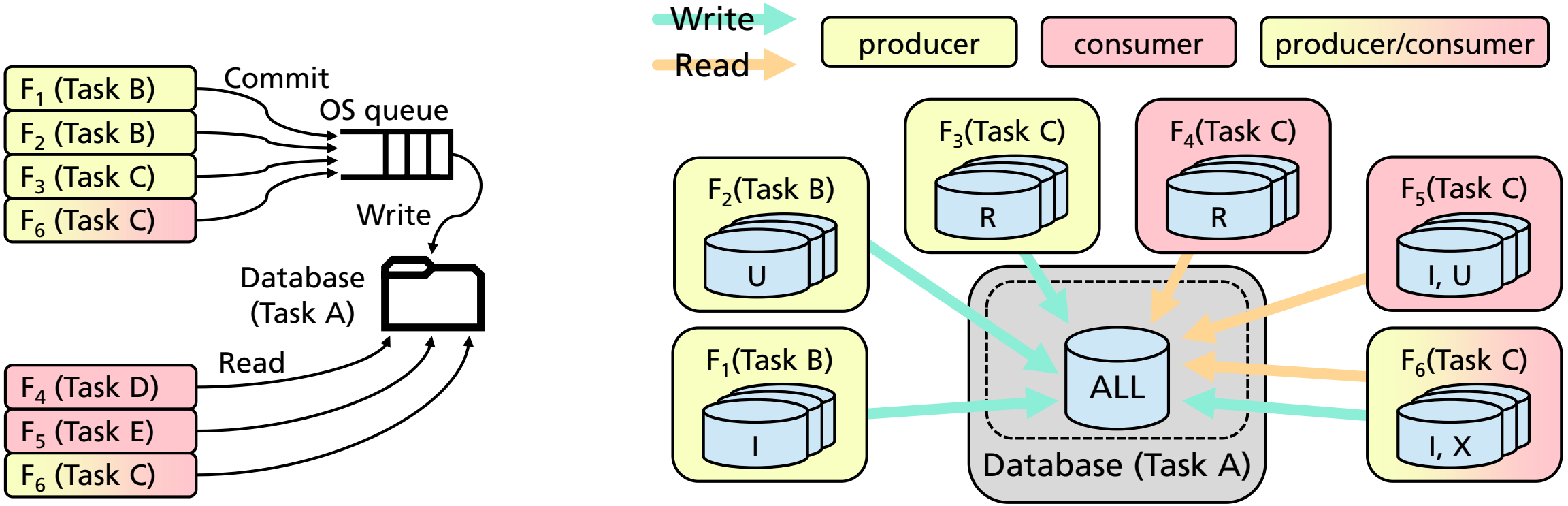
foxBMS 2 – Software Architecture: Setup & Monitoring, Database, Diagnosis

- System startup phases:
  1. PWR: Initialize MCU, peripherals and basic self checks
  2. Initialize operating system and start the scheduler
  3. Initialize BMS specific soft- and hardware
  4. “Normal operation”



foxBMS 2 – Software Architecture: Database for Asynchronous Data Exchange

- Asynchronous data exchange between tasks is done thread-safe through a database module
- Database works based on producer/consumer pattern



foxBMS 2 – Configuration Overview

System Control
- Configurable CAN
- Configurable Ethernet
- Configurable Modbus

MCU
TI TSM57LC4357

Operating System
- FreeRTOS
- SafeRTOS

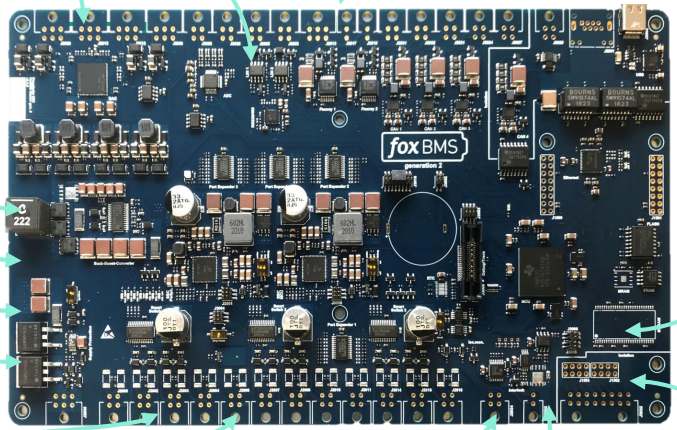
Number of power paths

Number of strings

Number of modules

Number of cells

Number of contactors



BMS Slave

Measurement IC
- ADI LTC6804-1
- ADI LTC6806
- ADI LTC681x-1
- MAXIM MAX17841B
- NXP MC33775A

Temperature Sensor
- EPCOS B57251v5103j060
- EPCOS B57861s0103f045
- Vishay ntcalug01a103g

Balancing (Passive/Active)
- No balancing
- Voltage based balancing
- History based balancing

Cell Parameters
- Any cell type by data sheet
- Easy extendable parameters

IMD
- Bender iso165c
- Bender IR155

Current Sensor
- Isabellenhütte IVT-S

IMD: Insulation Measurement Device

foxBMS 2 – Simpler Testing for Better Software and Customer Satisfaction

- The foxBMS SDK supports the complete test range from unit tests through integration tests to verification and validation (beta).

Unit Tests

- Testing at module (i.e. basically source file) level
- Can be run without hardware on a desktop PC to find bugs early in the development cycle

Integration Tests

- Testing of a (combined) group of software modules, in order to see that the interaction works as intended.
- Some tests require the real hardware

Verification and Validation

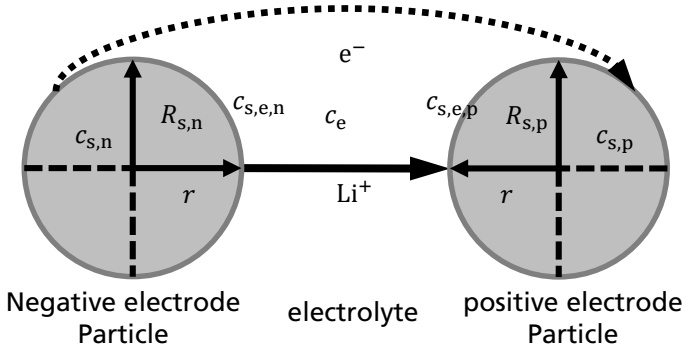
- Testing the software behavior against the initially provided requirements
- Some tests require the real hardware

We have BMS hardware and an SDK – What's next?

- Having a BMS development solution available, the "interesting work" starts
  - Implementation of the application specific BMS behavior
  - Development/porting advanced algorithms to the embedded system
- API for embedding models that supports initialization and continuous prediction exists
- Only requirements are: the model must
  - be implement in C and compile as C99 (ISO/IEC 9899:1999) or C11 (ISO/IEC 9899:2011)
  - fit into 4MB of program flash and work with 512KB of RAM (if EMIF is not used)

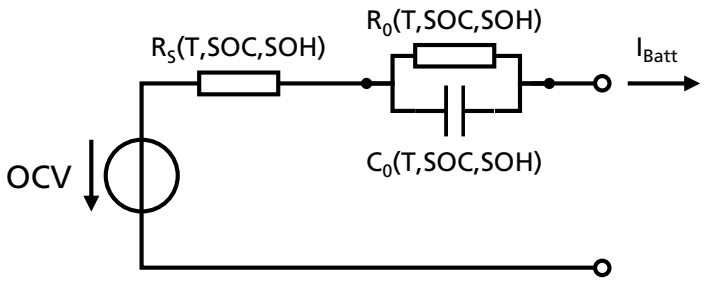
Lithium-Ion Battery Model Classification

Doyle-Fuller-Newman Model



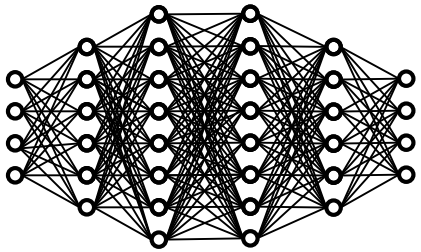
White Box Model

Equivalent Circuit Model



Grey Box Model

Neural Networks



Black Box Model

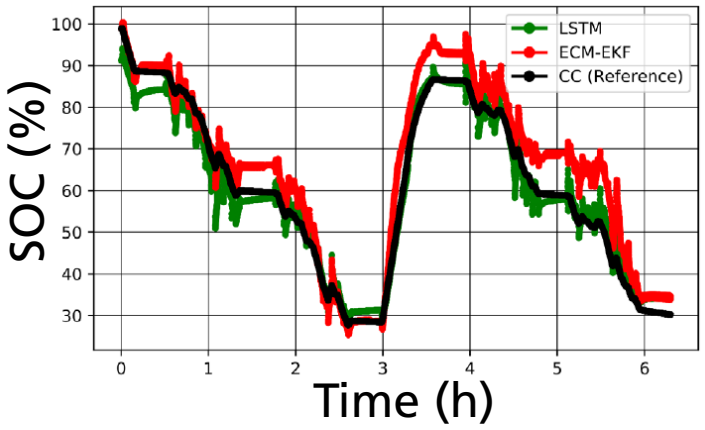
Physical interpretability

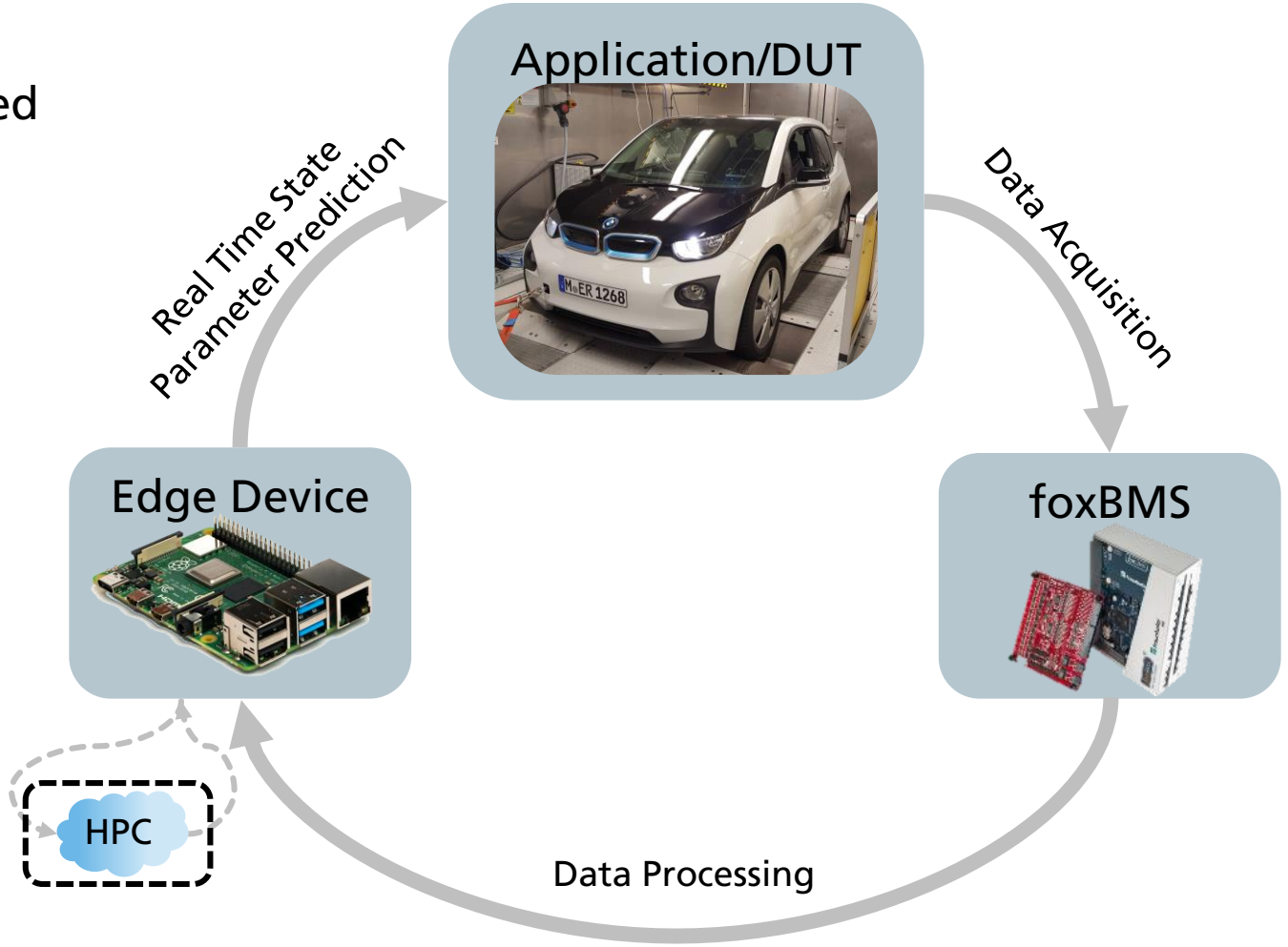
Adaptability and self-learning ability

Implementation complexity and resource usage

foxBMS 2 – Application Example – Electric Vehicle

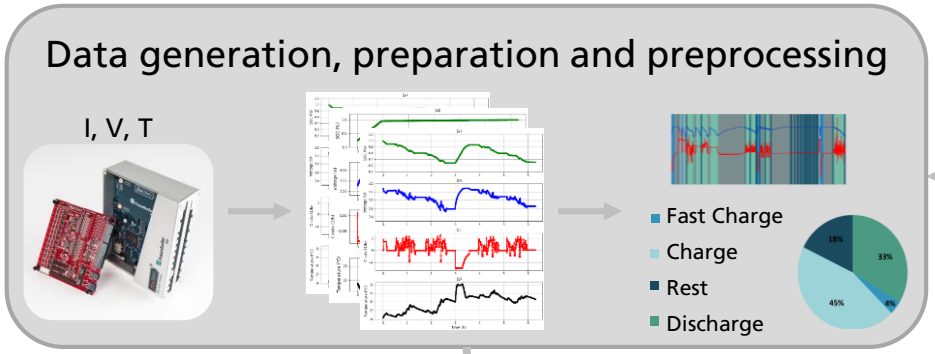
- Common BMW i3 (60Ah version) equipped with foxBMS for I, V and T measurement
- Data acquisition during initial test bench drives (model calibration) and normal driving cycles on public roads to validate the model performance and accuracy
- SOC prediction using a LSTM

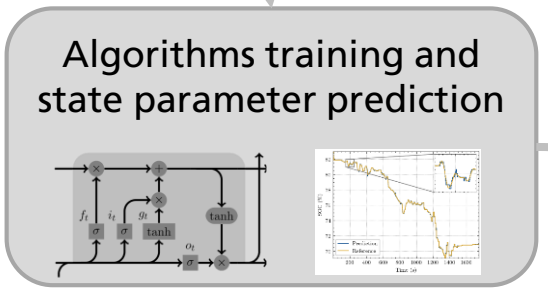


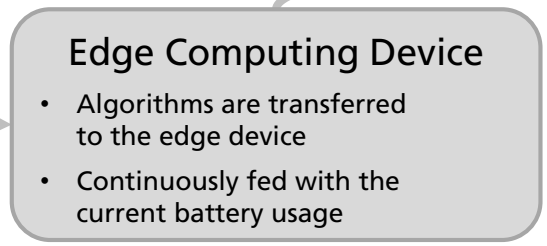


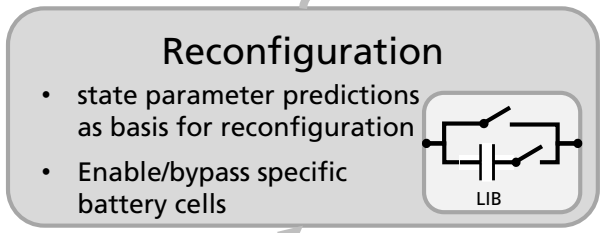
foxBMS 2 – Application Example – Reconfigurable Battery Storage

- Development of an autonomous reconfigurable battery system
- Storage efficiently uses heterogeneously used second life batteries









Dynamically reconfigurable battery storage with 25 modules

foxBMS 2 – Community Participation – It's about FOSS

- foxBMS is a FOSS project - free and open-source software
- Community participation is desired and warmly welcomed → Contact us if you want to contribute!
  - Contributions should be under a permissive license (e.g., BSD-3Clause, MIT or similar)
  - Generally any bug fix to source code, documentation, tools, …
  - Additional hardware support (additional measurement ICs, insulation measurement devices, new sensors, …)
  - Algorithms and models
- Contact us for joint projects

The foxBMS Project – Links

🌐 https://foxbms.org

🕮 https://docs.foxbms.org

https://github.com/foxBMS

✉ info@foxbms.org

The foxBMS Project

Thanks for your attention

We are happy to hear your feedback and answer your questions ☺

Sources

[1] https://git-scm.com/downloads/logos, Git Logo by Jason Long is licensed under the Creative Commons Attribution 3.0 Unported License.

[2] https://commons.wikimedia.org/wiki/File:Raspberry_Pi_4_Model_B_-_Side.jpg, Raspberry Pi 4, Michael Henzler / Wikimedia Commons / CC BY-SA 4.0

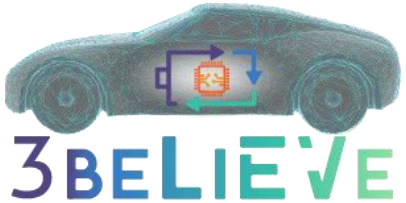
[3] Texas Instruments MCU mockup, https://www.ti.com/graphics/folders/partimages/TMS570LS3137.jpg

[4] Python logo, https://www.python.org/community/logos/

[5] Texas Instruments TMS5704357BZWTQQ1, https://www.ti.com/store/ti/en/p/product/?p=TMS5704357BZWTQQ1

[6] S. Bockrath, A. Rosskopf, S. Koffel, S. Waldhör, K. Srivastava and V. R. H. Lorentz, "State of Charge Estimation using Recurrent Neural Networks with Long Short-Term Memory for Lithium-Ion Batteries," IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society, 2019, pp. 2507-2511, doi: 10.1109/IECON.2019.8926815

Acknowledgement



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