

Battery management by multi-domain digital twins

Title: BATMAX battery management by multi-domain digital twin  
Dr. Prashant Singh, VTT Technical Research Centre of Finland  
highBATTEU Cluster Webinar, 14<sup>th</sup> April 2026

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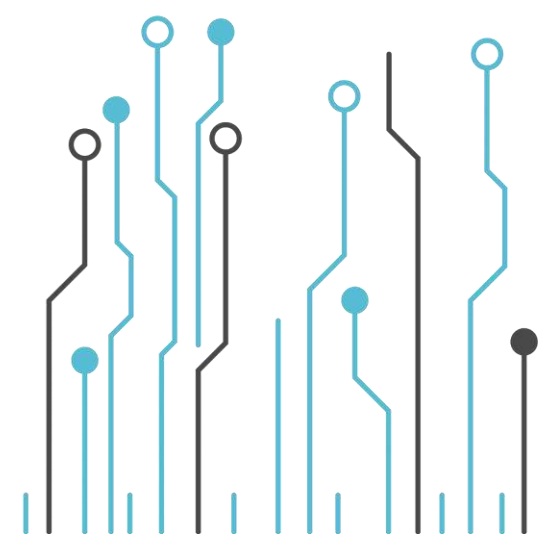
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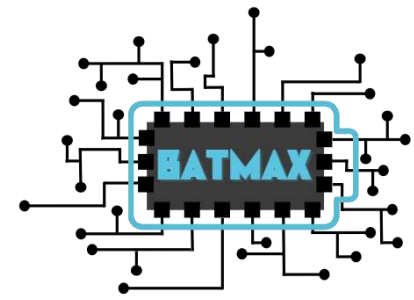
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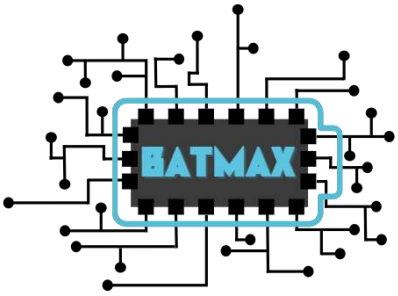
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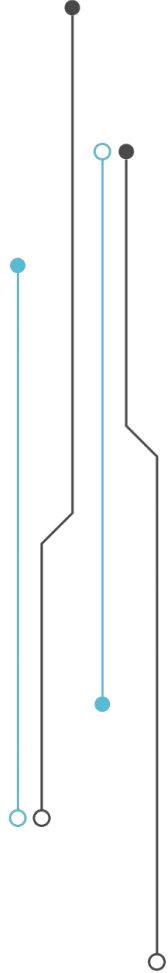
# Outline

- Introduction: objectives and approach
- Digital twin integration
  - Hardware in the Loop Test Bench
  - Driver Basics and Communication setup
  - Monitor foxBMS and Battery Data
  - Cloud-side data flow from HIL
- Conclusion

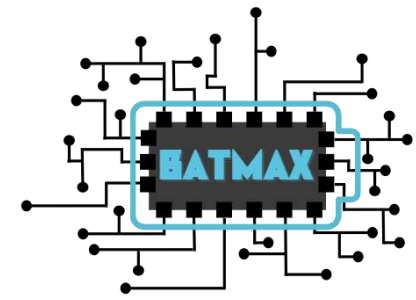




# Introduction

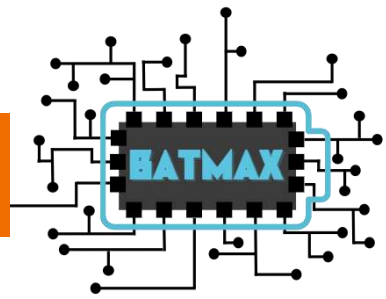


# Objectives of BATMAX



- **The main objective** is to contribute to improving battery system performance, safety, reliability, service life, lifetime cost, and integrating different use applications
- In addition, BATMAX is aiming to
  - develop **framework** for efficient parametrization of physics-based models
  - develop **hardware and sensorisation** on cell and system level for collection and communication of battery measurement data
  - create **hybrid and AI-driven models** to optimise lifetime and management of the battery (BMS)
  - develop **adaptable battery management** with multi-scale battery digital twin framework for dynamic operation

# The conceptual approach of BATMAX



## Efficient Parameterization

Living Parameter Database



Non-Destructive Parameterization

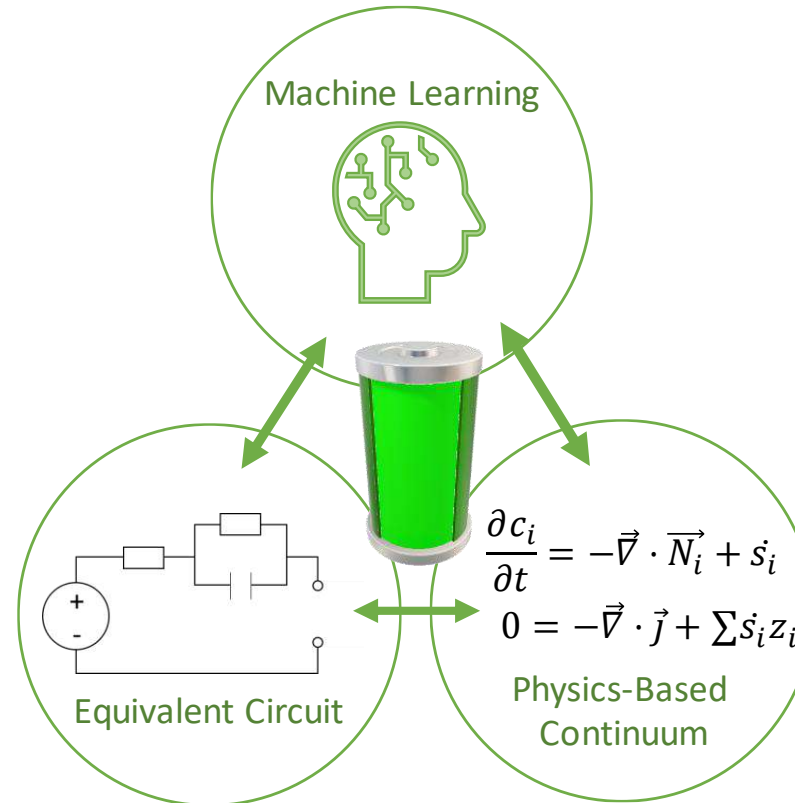


Microscopy and Ex-situ Parameterization



Experimental battery data from laboratory

## Digital Twin of Batteries

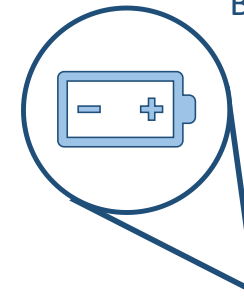


## Real-Time Flow of Field Data



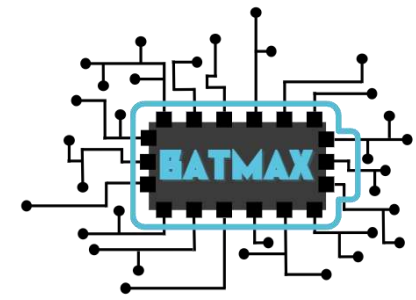
Internet of Things, cloud connectivity with API

Smart Sensing Battery Management

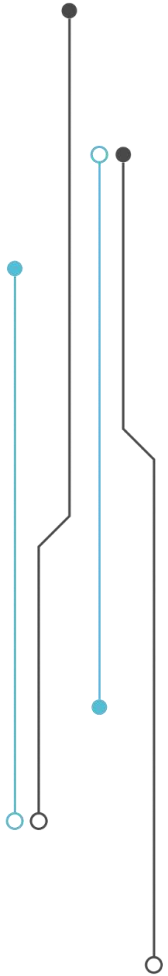


Electric mobility and transport electrification on-road/marine/off-road/stationary

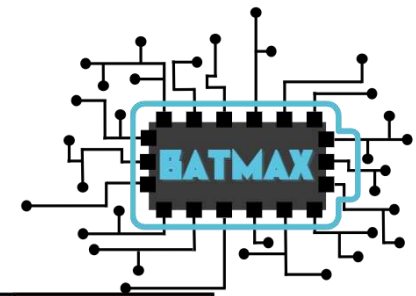




# Digital twin integration



# Utilisation of digital twins for optimal battery management



The digital twin running on a cloud platform will enable

- utilisation of more complex battery models
- an arrangement for **Hardware in the loop (HIL)**, and
- research on several **abnormal situations and fault states**, including also safety-critical operation domains

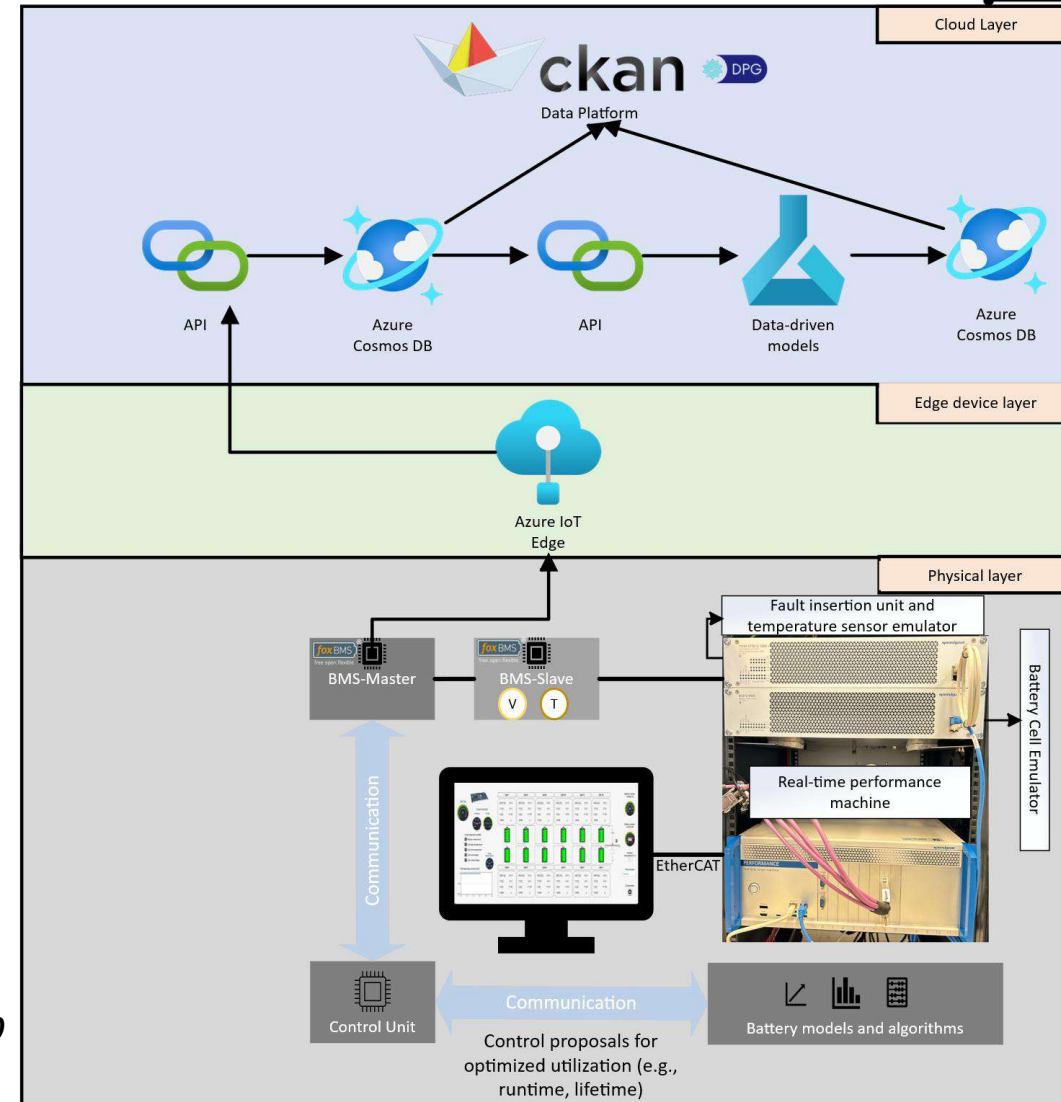
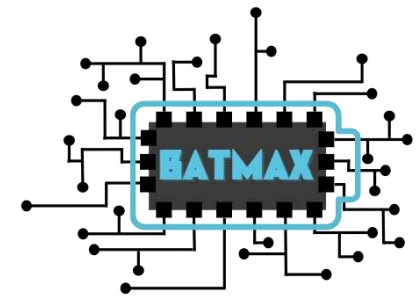


Fig.1: Hardware-in-the-loop with cloud integration.

# Hardware in the Loop Test Bench



- To build a 48 V NMC second-order battery pack model within Simscape Battery, utilising laboratory measurement data.
- Deploy the battery model to a real-time target and set up a complete MIL-to-HIL workflow in Simulink.
- Validate core foxBMS functions cell balancing, SoC estimation, fault detection and communication in a foxBMS master–slave setup.

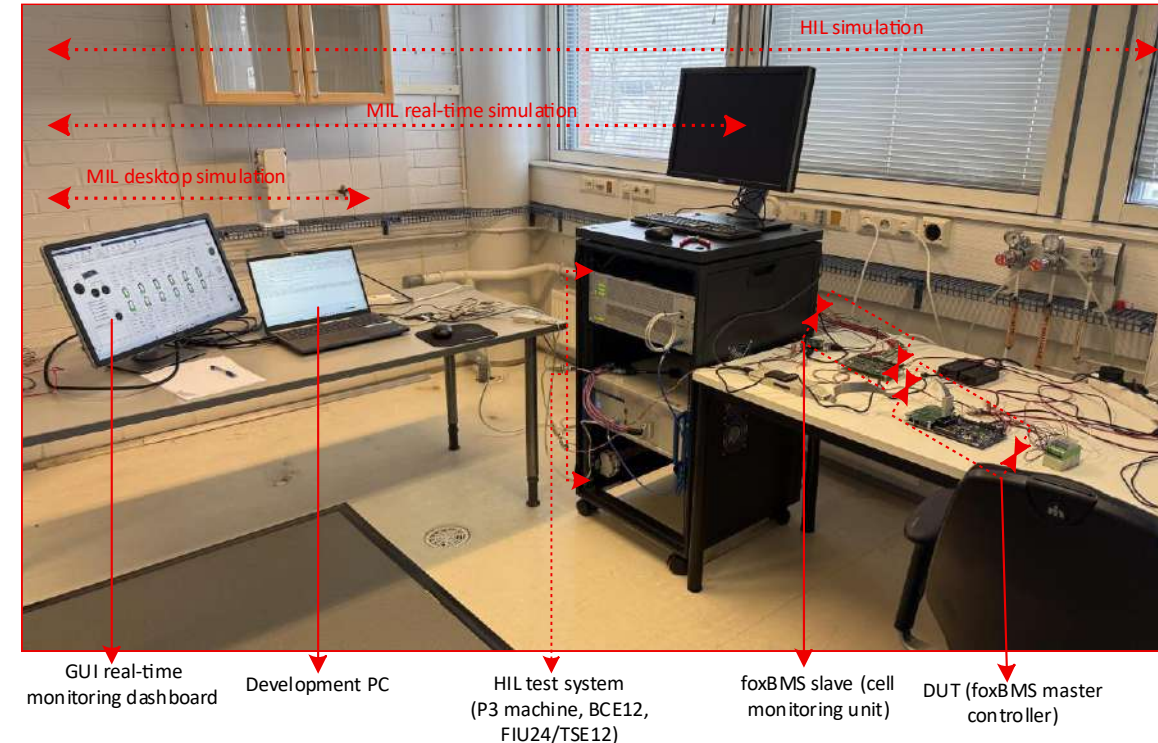
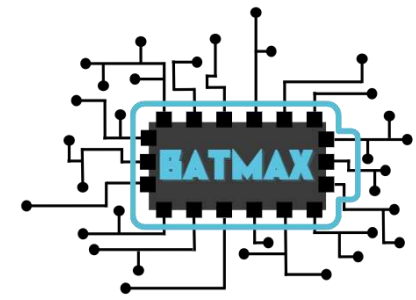


Fig.2: HIL test setup with foxBMS (master and slave)  
SIL-MIL-HIL

# Hardware Components



- The HIL test bench is comprised of essential components, as detailed below.
  - Performance Real-Time Target Machine (P3)
  - Battery Cell Emulator (BCE 12-0505)
  - Fault Insertion Unit and Temperature Sensor Emulator (FIU24/TSE12-1000-1)
  - foxBMS BMS master
  - foxBMS BMS slave
  - IO 603

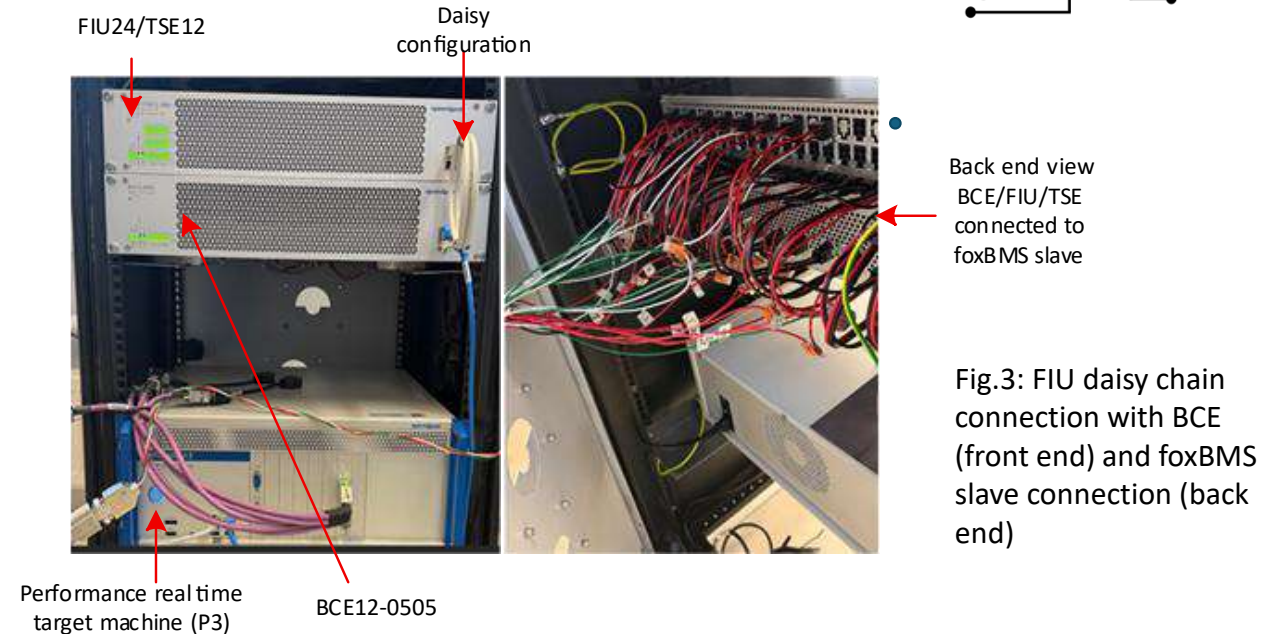
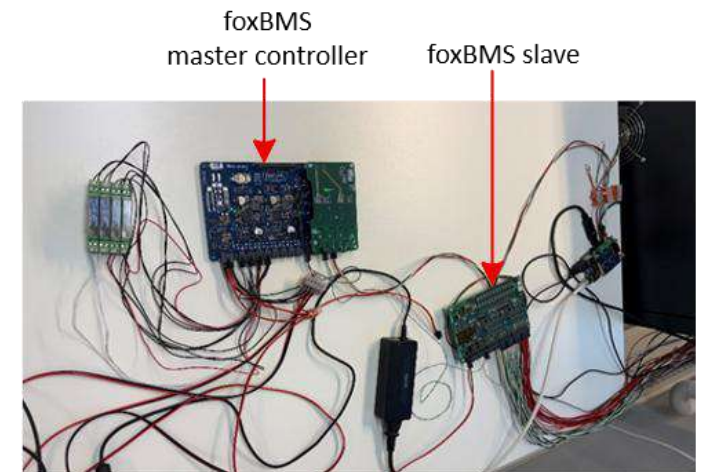
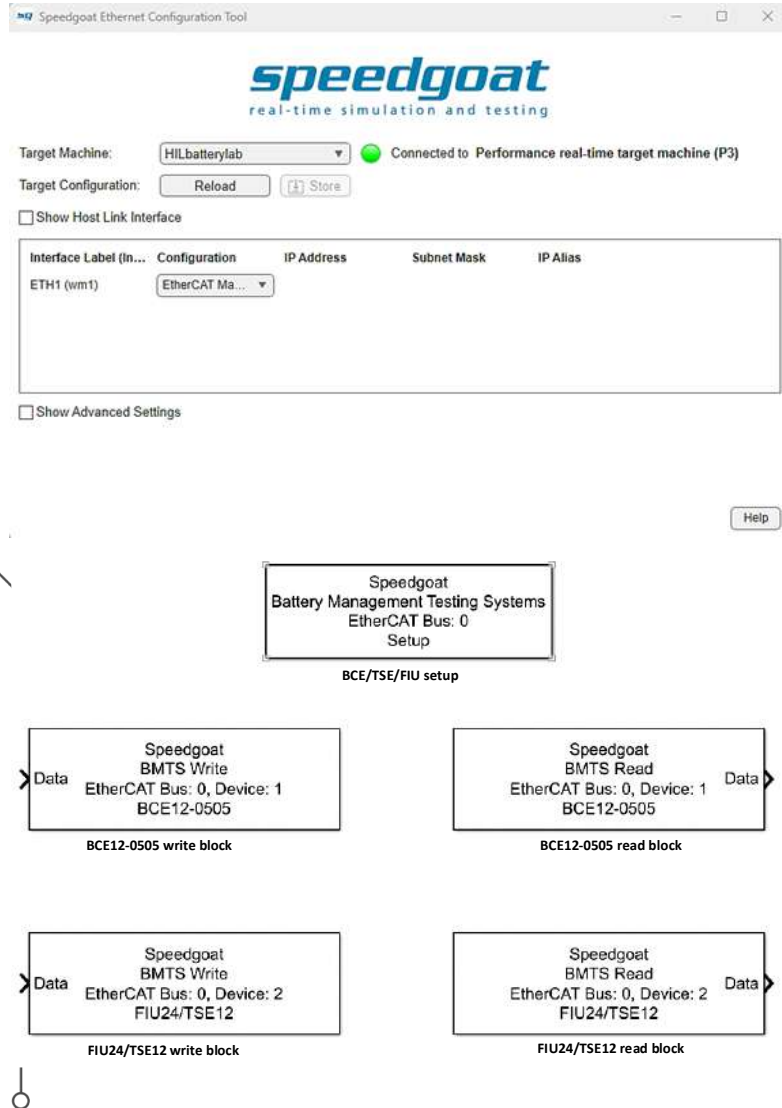
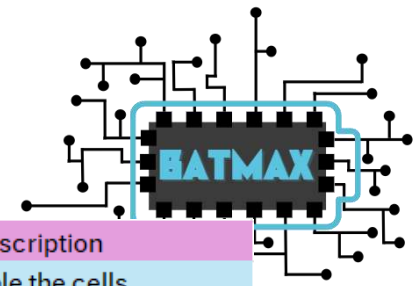


Fig.4: foxBMS BMS master connect via daisy chain to foxBMS slave to BCE+FIU/TSE emulators



# Driver Basics and Communication setup (1/3)

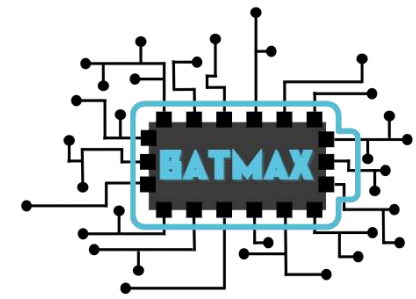


Emulator type	Direction	Bus name	Bus signal	Data type	Description		
BCE12-0505	Write	BCE12-0505_set	Enable	boolean	Enable or disable the cells		
			V	single	Set the cell voltage		
			I	single	Set the cell sink current		
	Read	BCE12-0505_get	Status	unit16	Each bit reports cell status or error		
			V	single	Measured cell voltage		
FIU24	Write	FIU24_set	Fault	unit8	0:No fault		
					1:bat wire broken(+)		
					2:bat wire broken (-)		
					3:bat(+) short		
					4:bat(-) short		
			5:reverse polarity				
			sense wire broken (+)	boolean	control the interruption of the sense (+) line		
			sense wire broken (-)	boolean	control the interruption of the sense (-) line		
			Read	FIU24_get	Status	unit8	0:default state, 1:fault state
			TSE12	Write	TSE12_set	resistance	double
Indicate the resistance set at the channel output							
TSE12	Read	TSE12_get	Status	single	channel output		

Speedgoat GmbH, "Battery cell emulator (BCE12-0505)," 2026. [Online]. Available: <https://www.speedgoat.com/products-services/i-o-connectivity/bms-and-battery-testing/testing-battery-management-systems-battery-cell-emulator>

Speedgoat GmbH, "Fault insertion unit with Temperature sensor emulator (FIU24/TSE12)," 2026. [Online]. Available: <https://www.speedgoat.com/products/temperature-sensor-emulator-with-fault-insertion-unit>

# Driver Basics and Communication setup (2/3)



- Associate setup block to IO 603 module
- Mapping of drive block to PCI slot of the IO 603 module
- Control port baud rate setting
- CAN channel operation mode selection

Indicate CAN messages transmitted to the send buffer

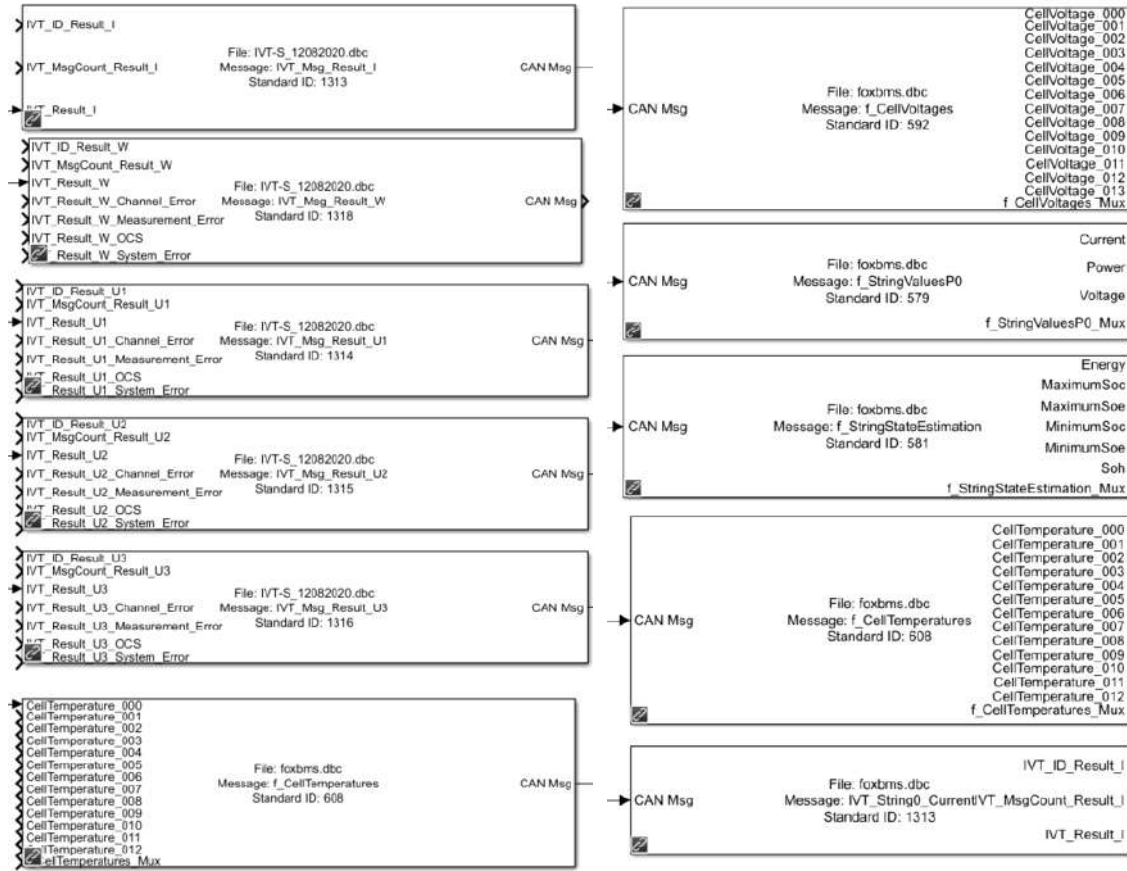
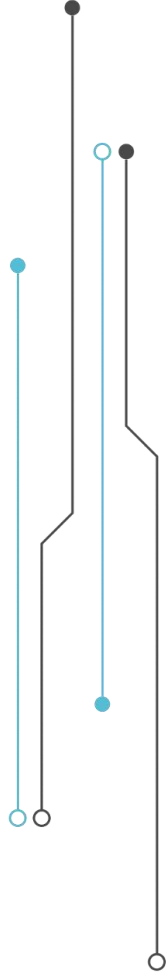
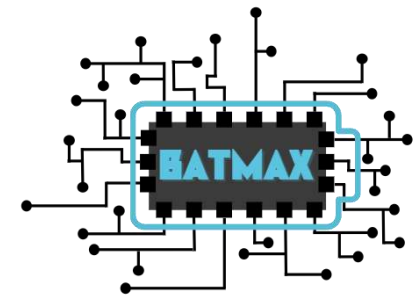
Indicate the ID of the CAN I/O 603 module that this drive block should connect to

Displaying CAN message type

Base sample time

Showing the received message list

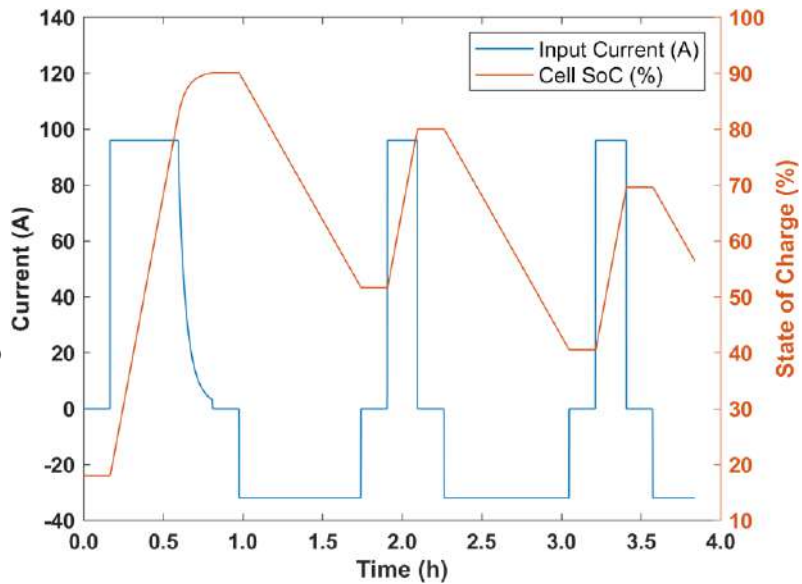
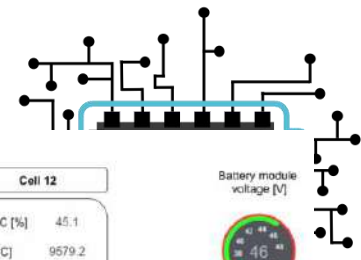
# Driver Basics and Communication setup (3/3)



CAN Pack messages

CAN Unpack messages

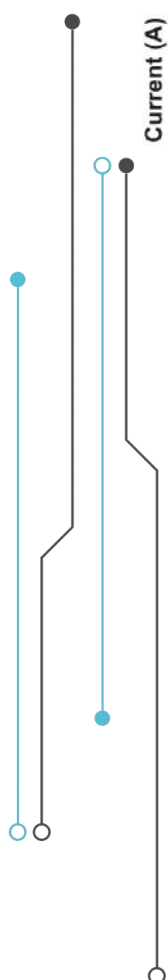
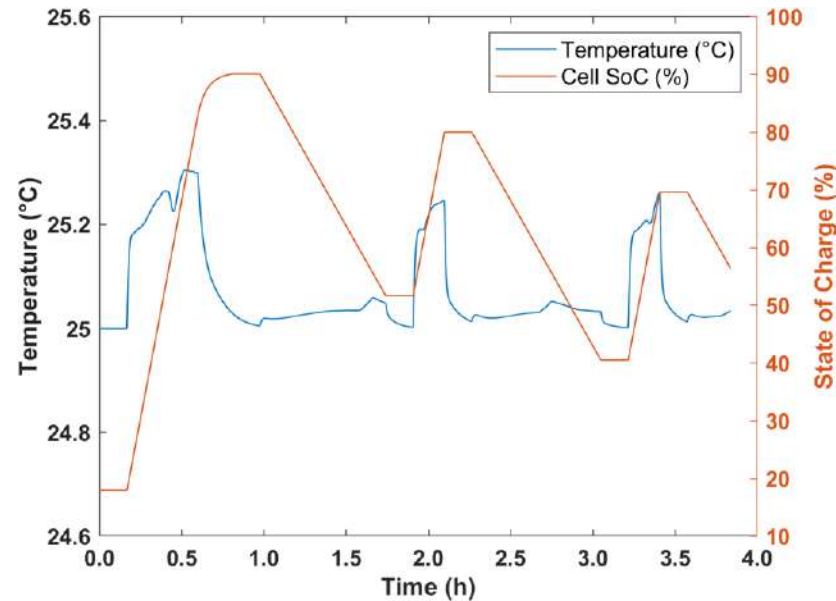
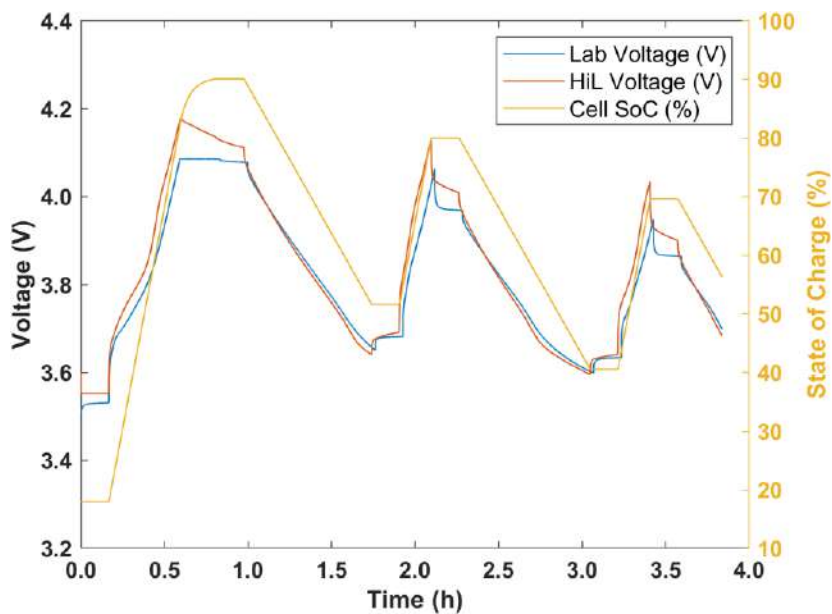
# Monitor foxBMS and Battery Data



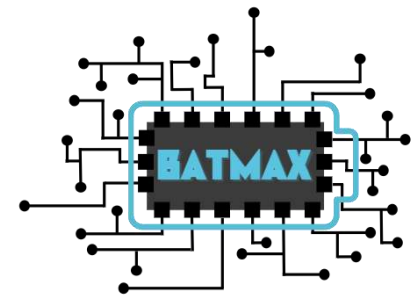
Cell 7	Cell 8	Cell 9	Cell 10	Cell 11	Cell 12
SOC [%] 45.1	SOC [%] 45.1	SOC [%] 45.1	SOC [%] 45.1	SOC [%] 45.1	SOC [%] 45.1
T [°C] 9579.2	T [°C] 9579.0	T [°C] 9579.3	T [°C] 9579.3	T [°C] 9580.3	T [°C] 9579.2
V [V] 3.797	V [V] 3.797	V [V] 3.797	V [V] 3.796	V [V] 3.797	V [V] 3.797
I [mA] -0	I [mA] -0	I [mA] -0	I [mA] -1	I [mA] 0	I [mA] -0

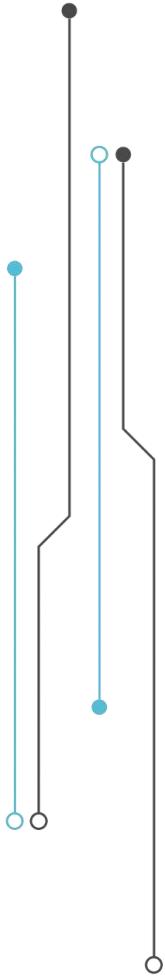
Cell 6	Cell 5	Cell 4	Cell 3	Cell 2	Cell 1
SOC [%] 45.1	SOC [%] 45.1	SOC [%] 45.1	SOC [%] 45.1	SOC [%] 45.1	SOC [%] 45.1
T [°C] 9579.4	T [°C] 9579.9	T [°C] 9579.3	T [°C] 9580.1	T [°C] 9580.6	T [°C] 9579.2
V [V] 3.797	V [V] 3.797	V [V] 3.797	V [V] 3.798	V [V] 3.797	V [V] 3.797
I [mA] 0	I [mA] 0	I [mA] -0	I [mA] -0	I [mA] -1	I [mA] -1



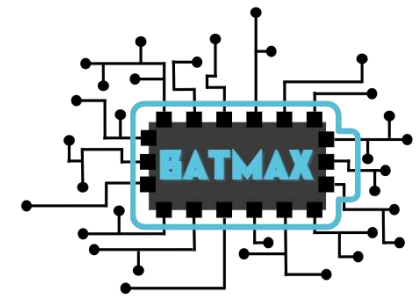
# Cloud-side data flow from HIL



```
File Edit Tabs Help File Edit Tabs Help File Edit Tabs Help
{
  "sender_id": "VTT",
  "data_sink": "bms",
  "data": [
    {
      "cell": 1,
      "parameter": "CellCurrent",
      "timestamp": "2026-03-23T15:08:47.192581+02:00",
      "unit": "mA",
      "value": 96
    },
    {
      "cell": 4,
      "parameter": "CellVoltage",
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    },
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    {
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      "unit": "mV",
      "value": 3740
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      "value": 0
    },
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    {
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      "parameter": "CellTemperature",
      "timestamp": "2026-03-23T15:11:37.776358+02:00",
      "unit": "degC",
      "value": 24
    }
  ]
}
Payload sent
```



# Conclusions



- 2nd order NMC battery built in Simscape employing lab data.
- 2<sup>nd</sup> order battery Model successfully implemented on the P3 real-time target machine, allowing a smooth shift from MIL to HIL without changing the model's design.
- By connecting the real-time simulation to the BCE, FIU, and TSE via EtherCAT, and setting up a master–slave foxBMS system, the we verified essential BMS functions such as passive cell balancing, State-of-Charge calculation, and temperature monitoring.

Battery management by multi-domain digital twins

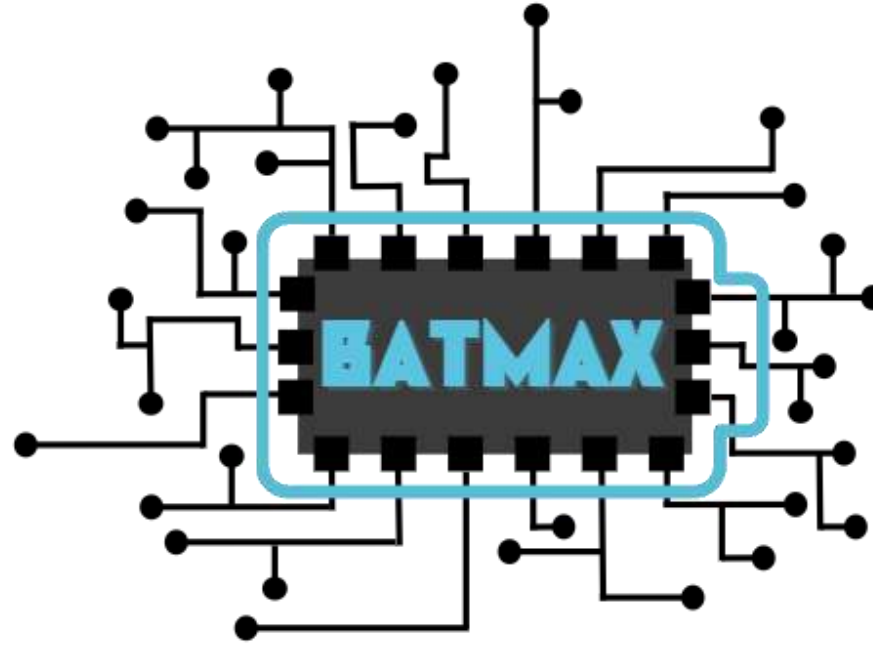
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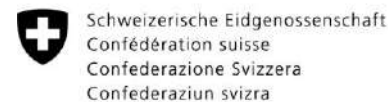
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