speedgoat
real-time simulation and testing

# Validation of Desktop Simulation – The Path Towards Real-Time Simulation

VEHICLE Webinar n°3

Janosch Marquart
November 17th, 2021

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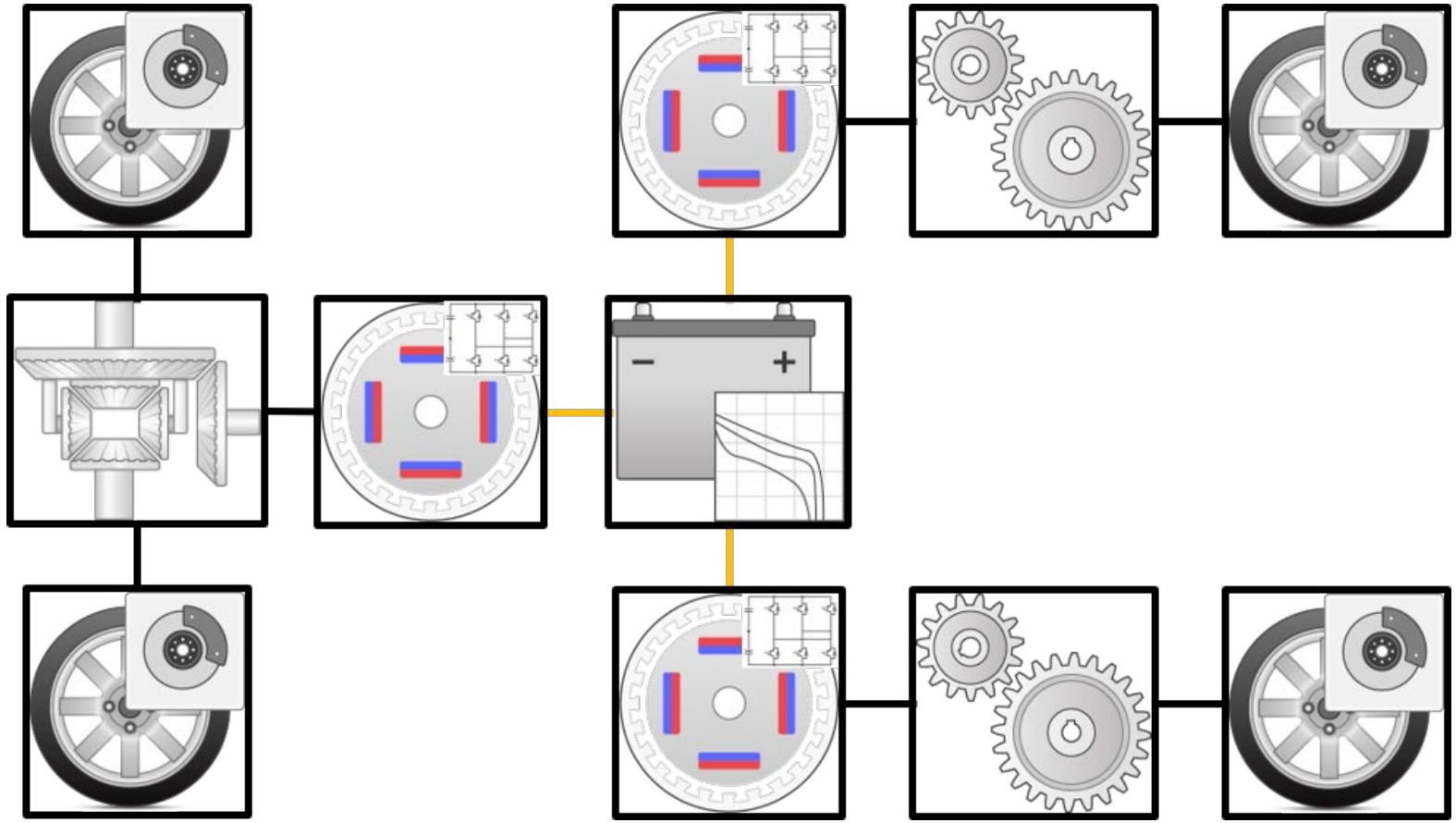
VEHICLE Webinar n°3 – Hochschule Karlsruhe

*Vehicle battery technology : from desktop-simulation to real-time simulation*

Janosch Marquart
Technical Sales / Academia

# Energy Management Systems

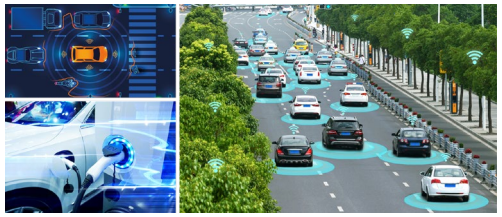


Where is it used?

# Industries Relying on Real-Time Simulation and Testing

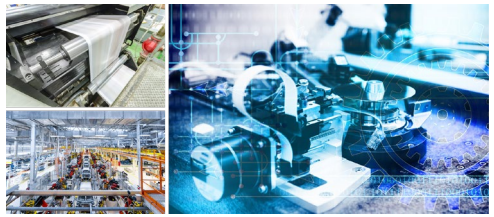
## Electrification

## Automotive



## Aerospace

## Automation & Controls



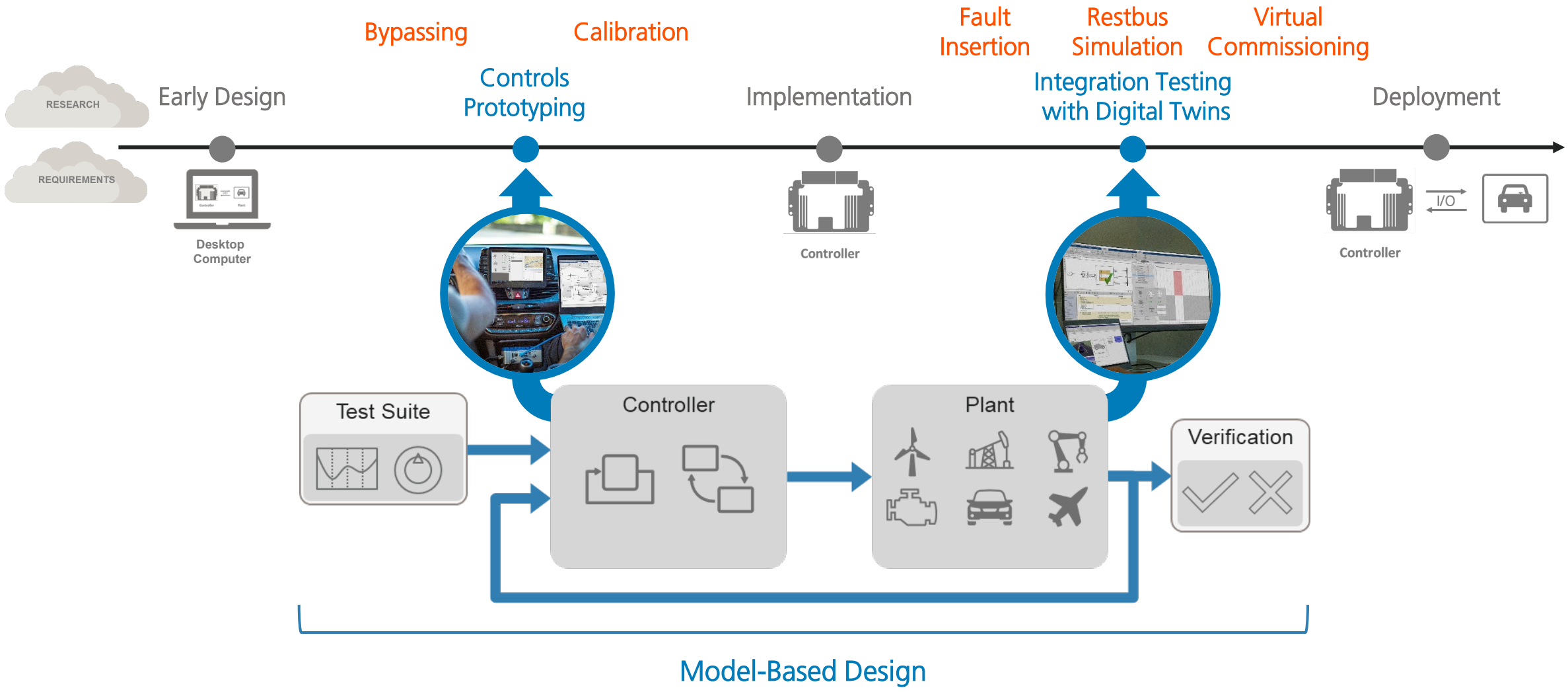
## Medical

# Key Takeaways

1. Easily Re-Use Desktop Simulations for RTS
2. Detect Design Flaws at the Earliest Possible Stage
3. Automate your Extensive Testing and Validation

## Why Real-Time Simulation and Testing?

# Real-Time Enabled Model-Based Design



## Simplify Your Workflow

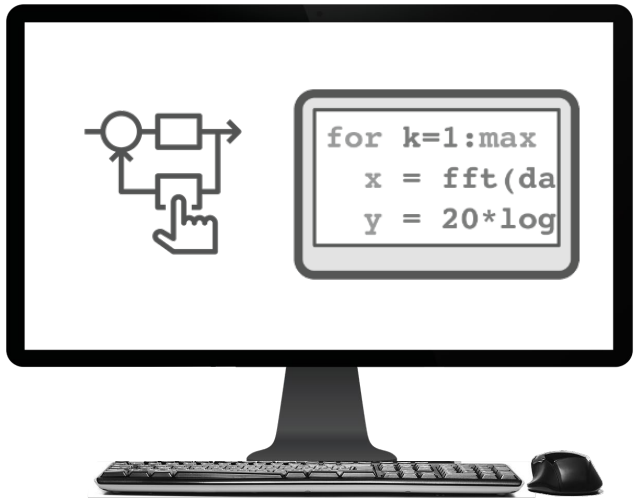
# Deliver Better Through Full Integration

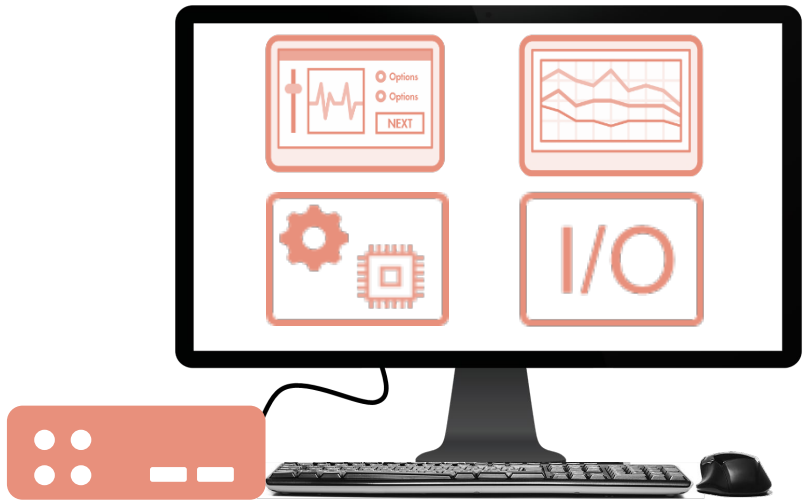
**Desktop Design, Simulation & Test**

- Test & Measurement
- Plant Simulation
- Supervisory Logic
- Control Algorithms

**Real-Time Simulation & Testing**

- RTOS & Hardware
- I/O Connectivity
- Instrumentation
- Automated Testing




I/O, protocols, scheduling, multi-thread, ...

# Unify Desktop and Real-Time Simulation and Testing

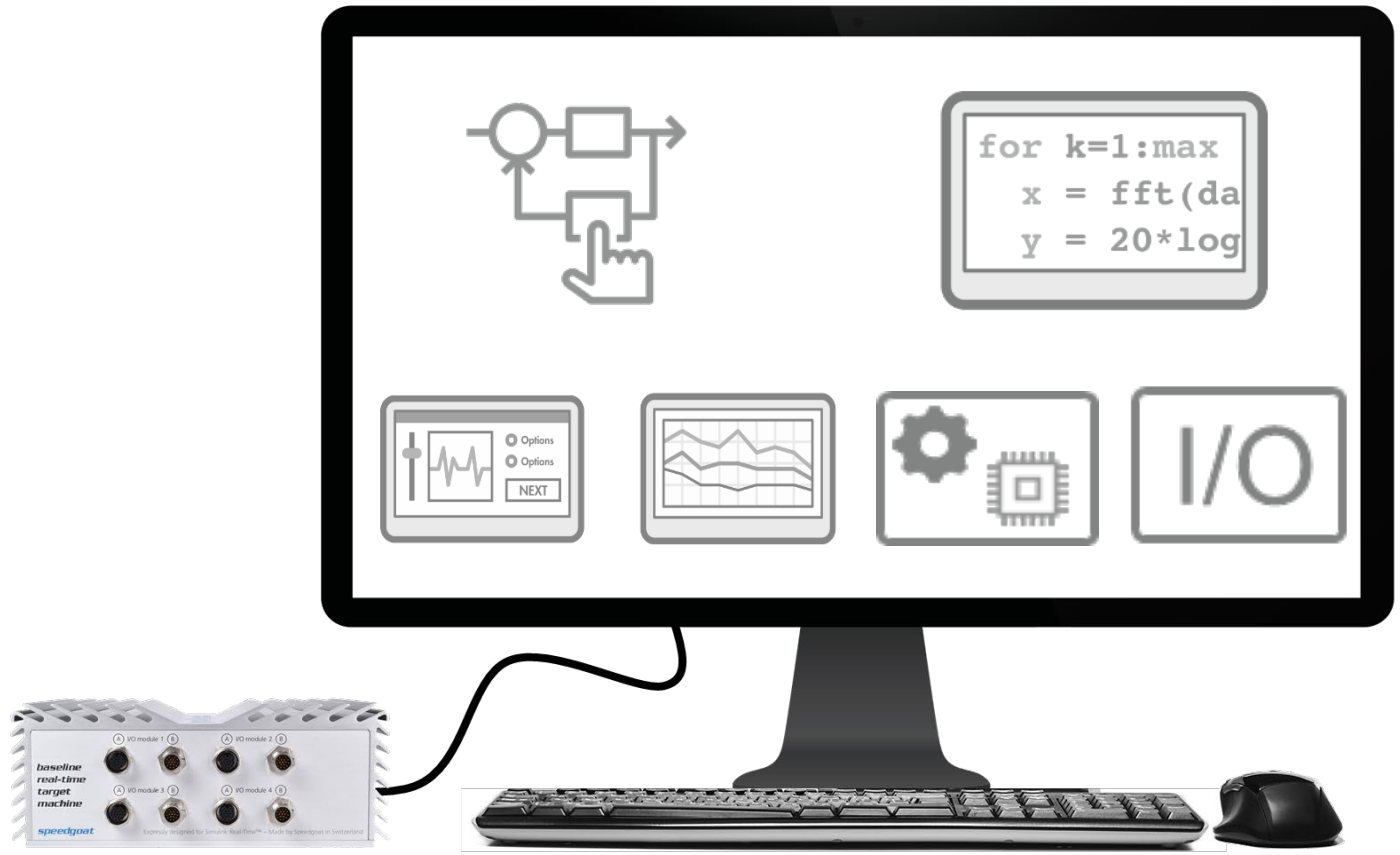
**Simulation & Testing**

**Desktop**

- Test & Measurement
- Plant Simulation
- Supervisory Logic
- Control Algorithms

**Real-Time**

- RTOS & Hardware
- I/O Connectivity
- Instrumentation
- Automated Testing



# With Simulink Real-Time™ by MathWorks

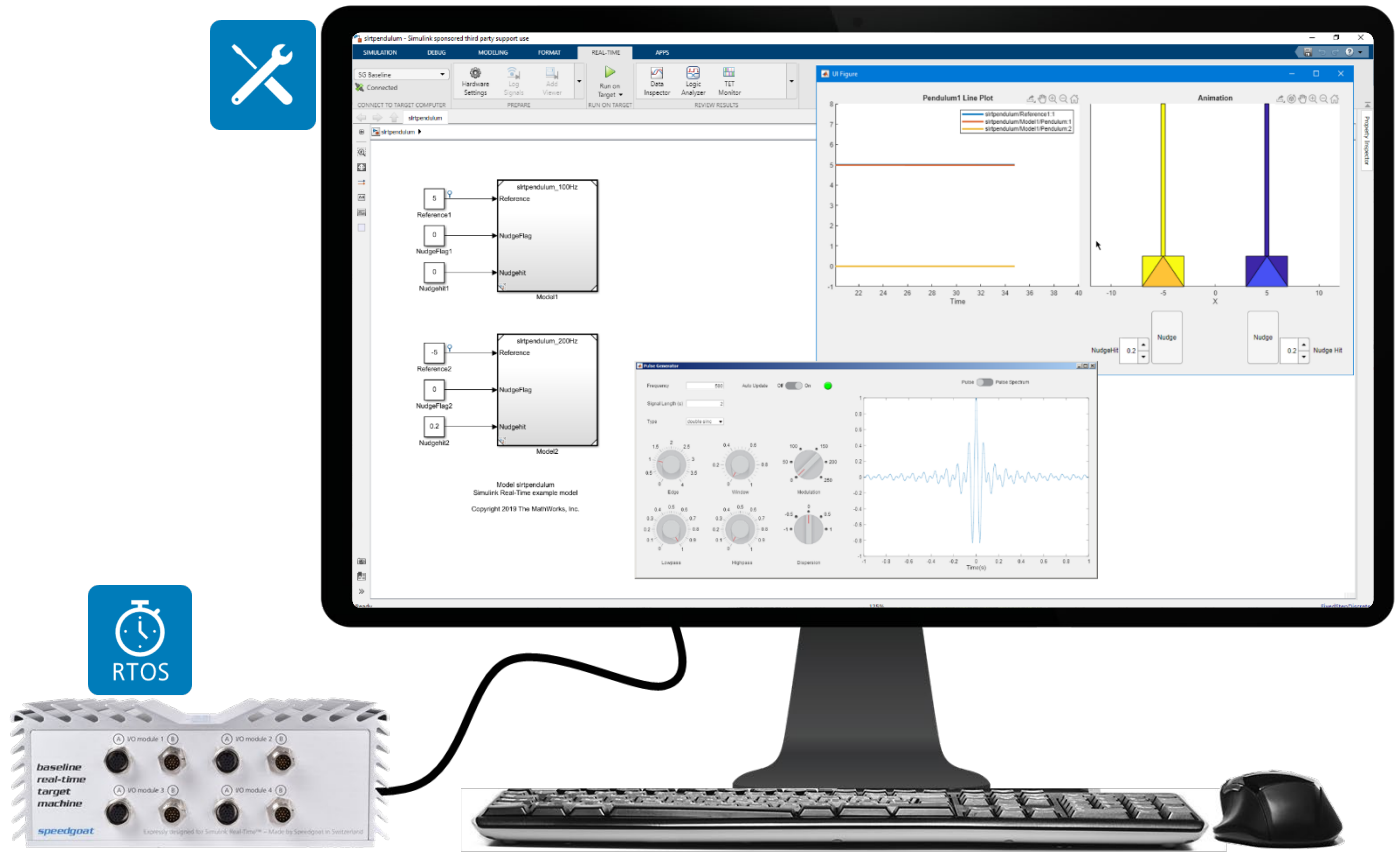
**Simulation & Testing**

**Desktop**

- Test & Measurement
- Plant Simulation
- Supervisory Logic
- Control Algorithms

**Real-Time**

- RTOS & Hardware
- I/O Connectivity
- Instrumentation
- Automated Testing



# and Versatile Speedgoat Hardware

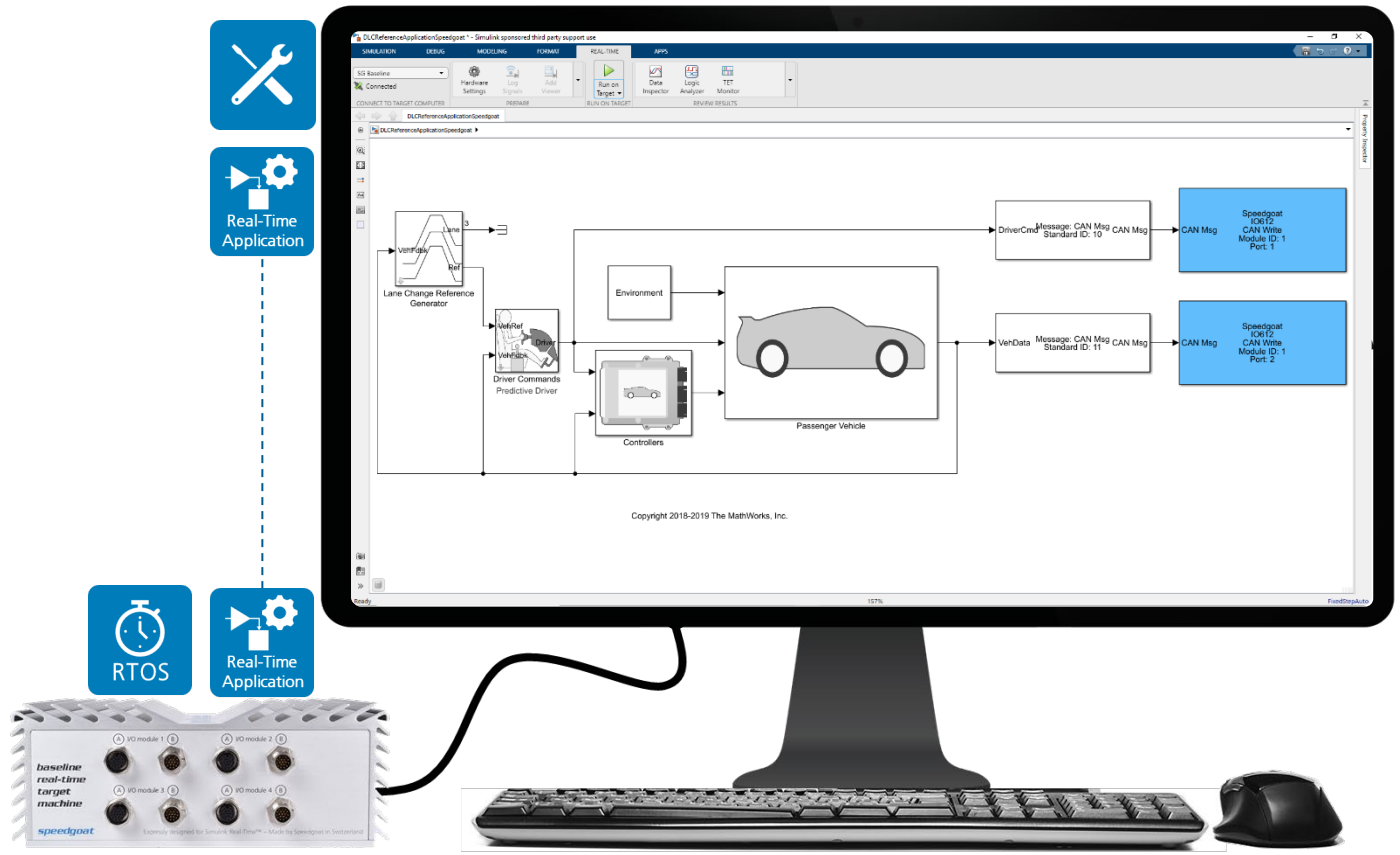
**Simulation & Testing**

**Desktop**

- Test & Measurement
- Plant Simulation
- Supervisory Logic
- Control Algorithms

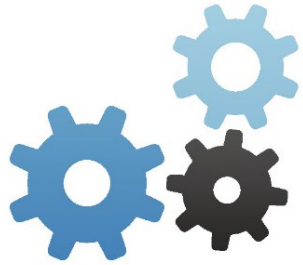
**Real-Time**

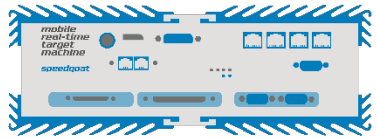
- RTOS & Hardware
- I/O Connectivity
- Instrumentation
- Automated Testing



# Two Companies Form a Turnkey Solution

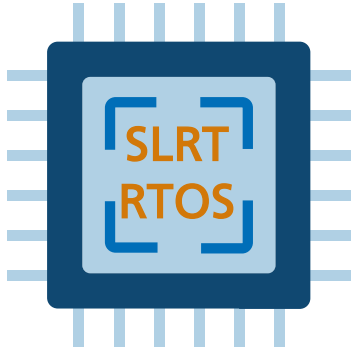
**MathWorks**
**Simulink Real-Time**





**Speedgoat**
**Real-time Target Machines**

- RT - instrumentation
- Code Gen (C/VHDL)
- Toolboxes / Blocksets
- Simscape
- Simulink Test




- I/O protocol support
- FPGA-based solutions
- Speedgoat driver library
- Complete HIL-Rigs

Success Story: Leclanché

# Next-Gen Li-Ion Battery Packs for Autonomous Vehicles

## Challenge

- Unable to test and verify new BMS algorithms in realistic operating conditions before connecting to actual battery packs.
- Late bug discovery and no preliminary testing can damage batteries
- Poor development tool compatibility leading to manual testing

## Solution

- Use Simulink and Speedgoat products for HIL testing of BMS
- Test platform with fault insertion, CAN communication, and Speedgoat battery cell emulators
- Use Simulink Test to thoroughly validate BMS and battery state estimation algorithms (SoC, SoH, etc.)

## Results

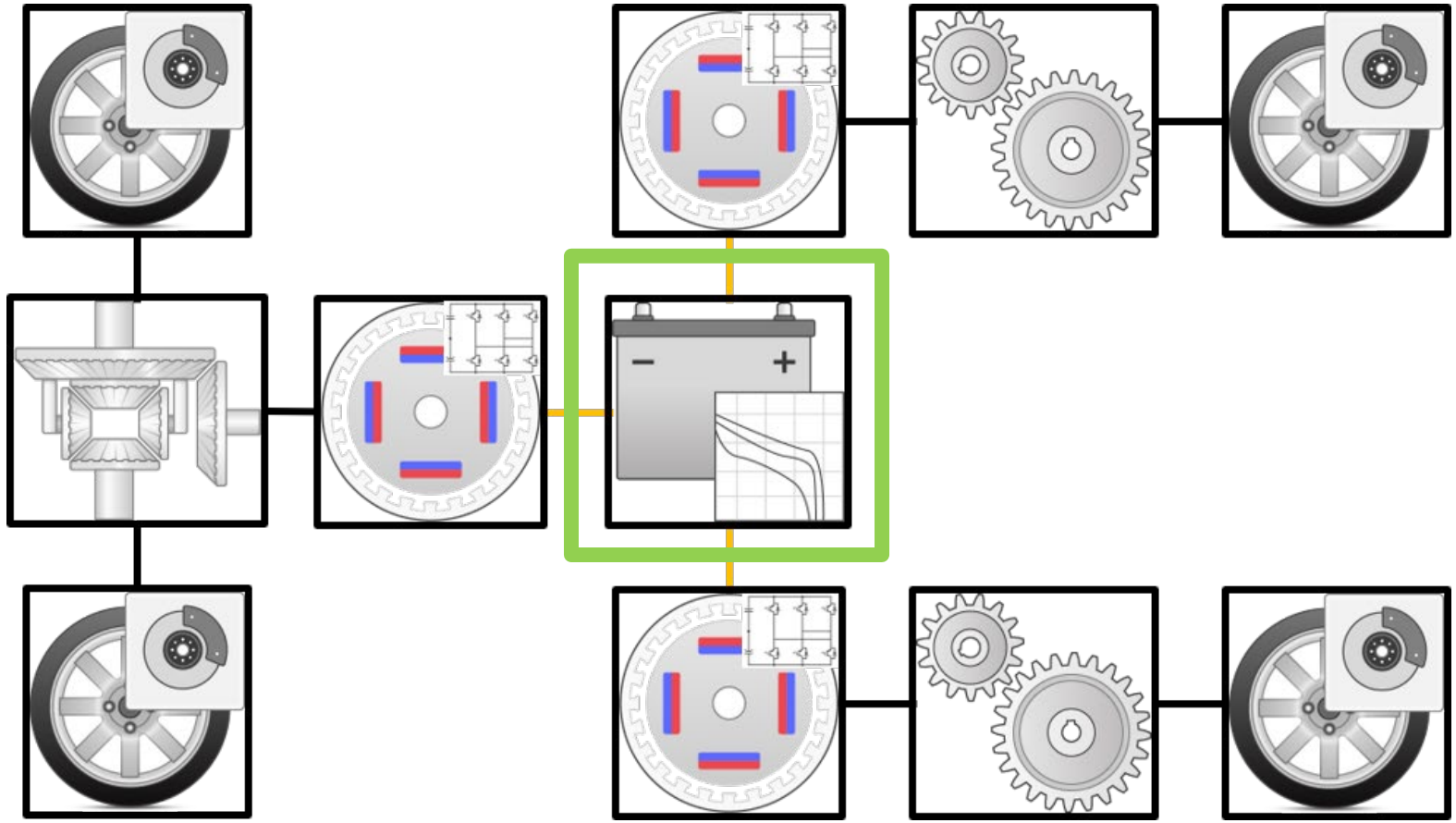
- Reduced testing time with automated testing by 50%
- Increased test coverage for safety features by 40%
- Faster development with early bug detection

Leclanché Energy Storage Solutions

***"Speedgoat together with MathWorks products offer a very efficient workflow to design, test and validate algorithms for Battery Management Systems"***

- Marc Lucea, Senior Application SW Engineer

# Energy Management Systems



# Real-Time Testing for Energy Management System

## Typical Challenges

- Develop energy management algorithms
  - Controlling energy storage systems
  - Battery Management Systems (BMS) or fuel cell controls development
  - State estimation like SoC or SoH
- Test controls and front-ends
  - Thoroughly test BMS or fuel cell control firmware
  - Test faults and cell balancing for battery modules
  - Having validated battery models

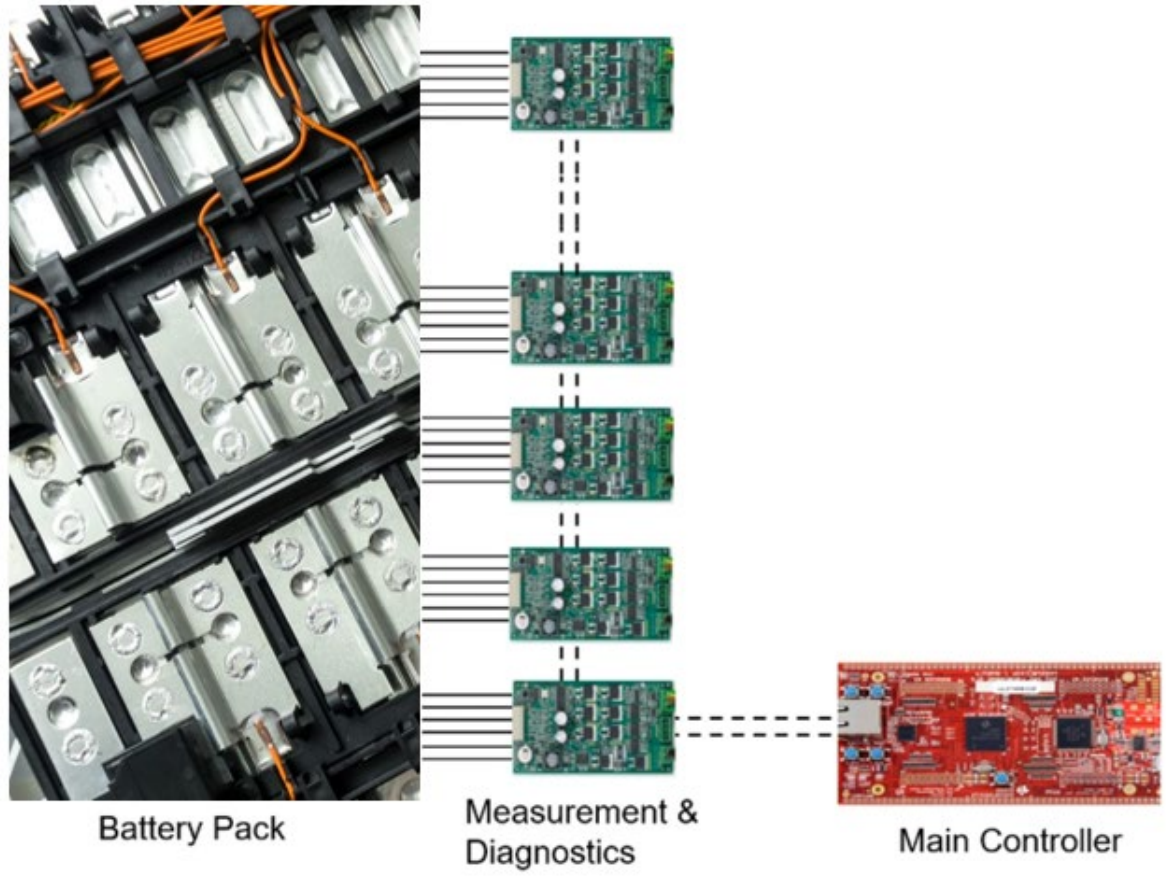
## Solutions

- Rapid controls prototyping
  - Control interfaces
  - I/O emulation and signal conditioning
  - Using communication protocols like CAN bus
- HIL simulation e.g. Battery Cell Emulation
  - Emulate hundreds of cells in series
  - Fault insertion for each cell
  - Thermal tests via temperature sensors
  - Battery model validation

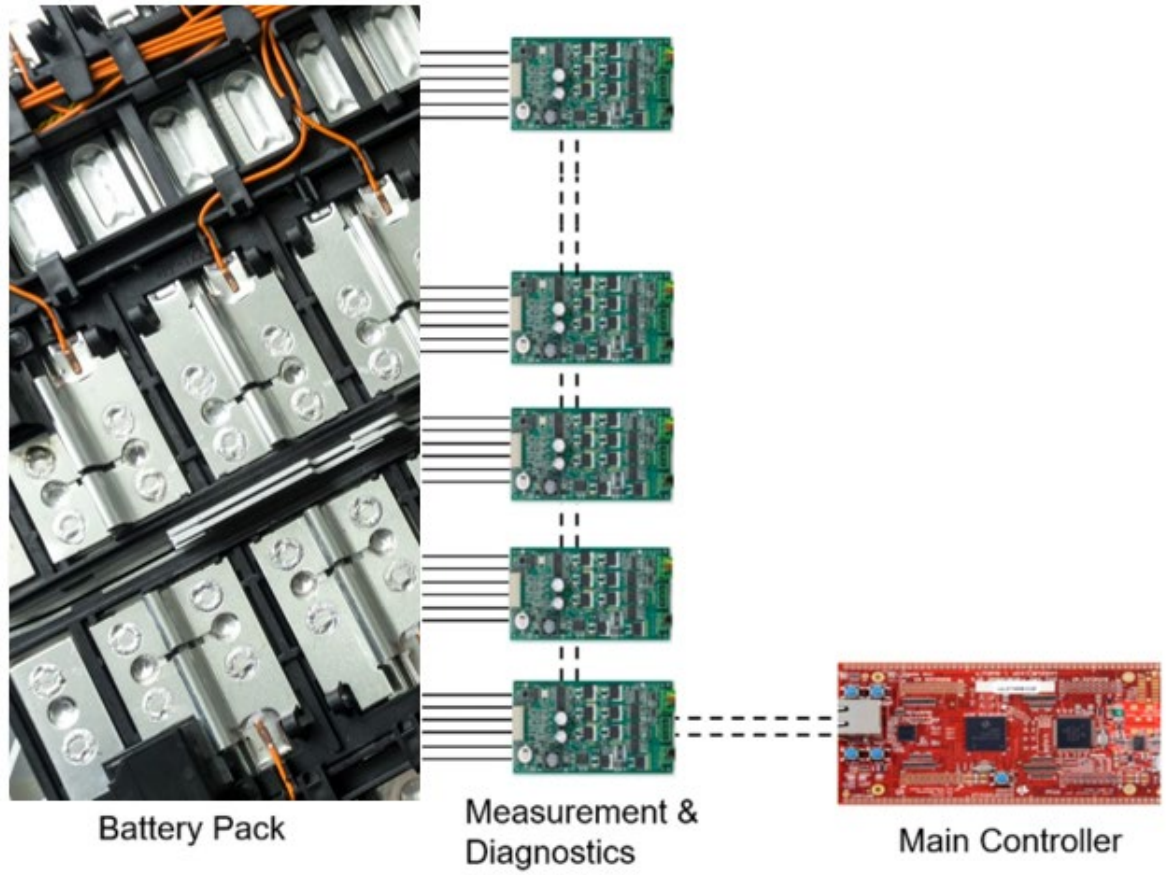
# Hardware-in-the-Loop Testing of Battery Management Systems

## WHY?

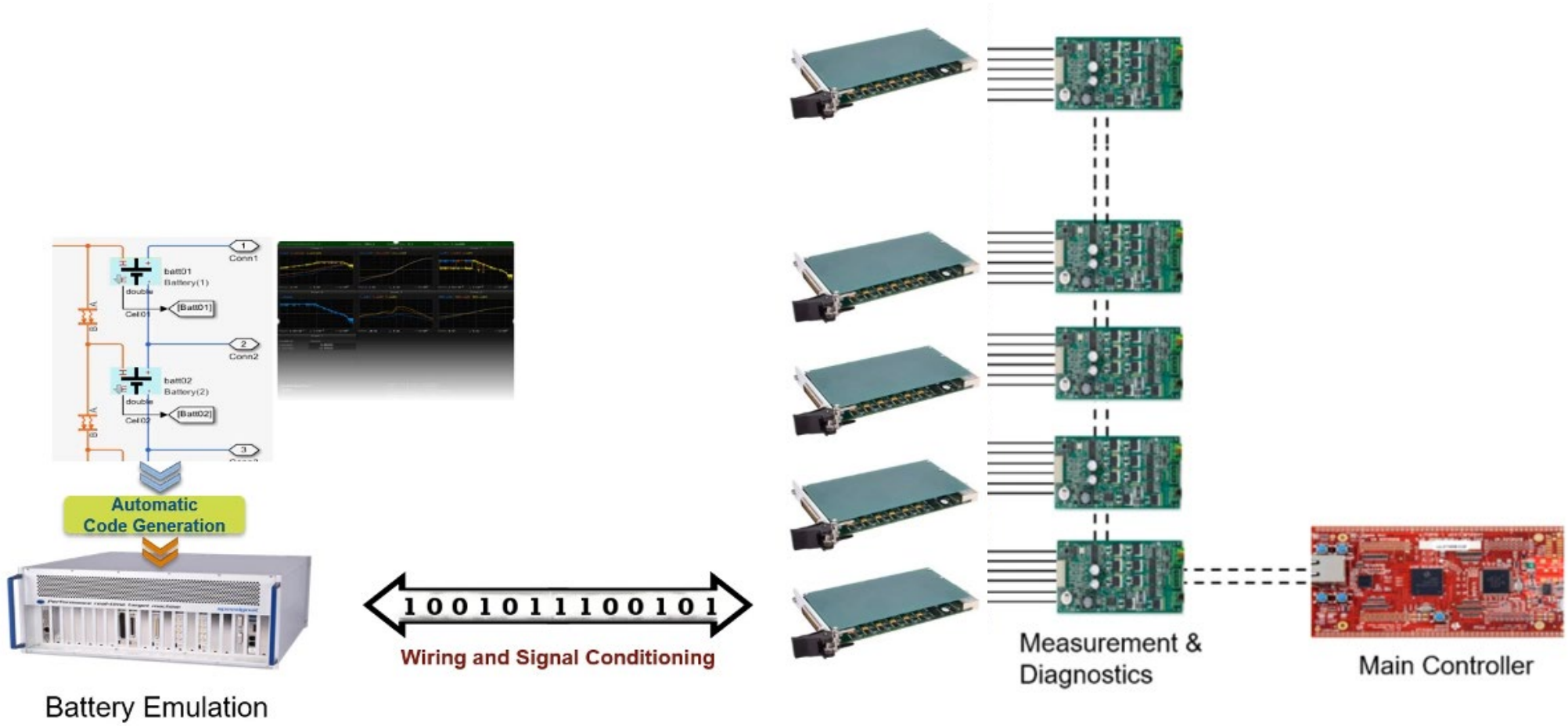
- Charge-discharge cycles may take hours
- Fault-testing: Reproducibility and Safety
- Testing software revision or design iteration



# Hardware-in-the-Loop Testing of Battery Management Systems

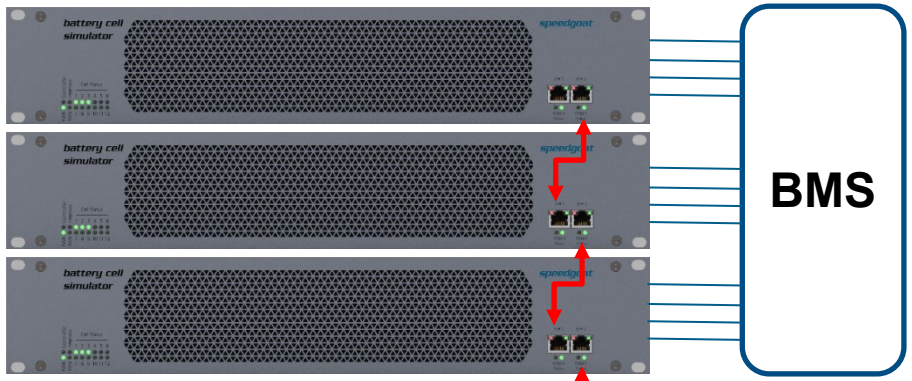


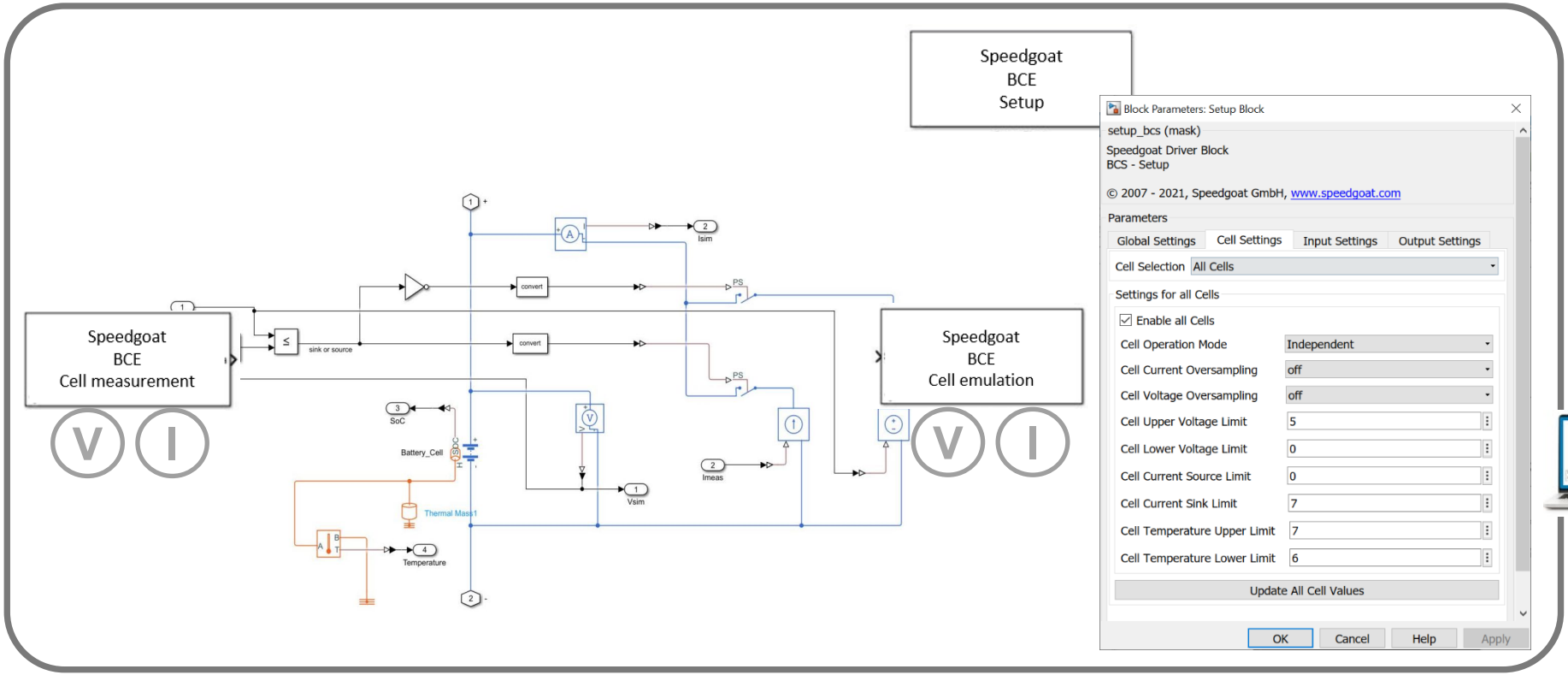
# Hardware-in-the-Loop Testing of Battery Management Systems



# Setup

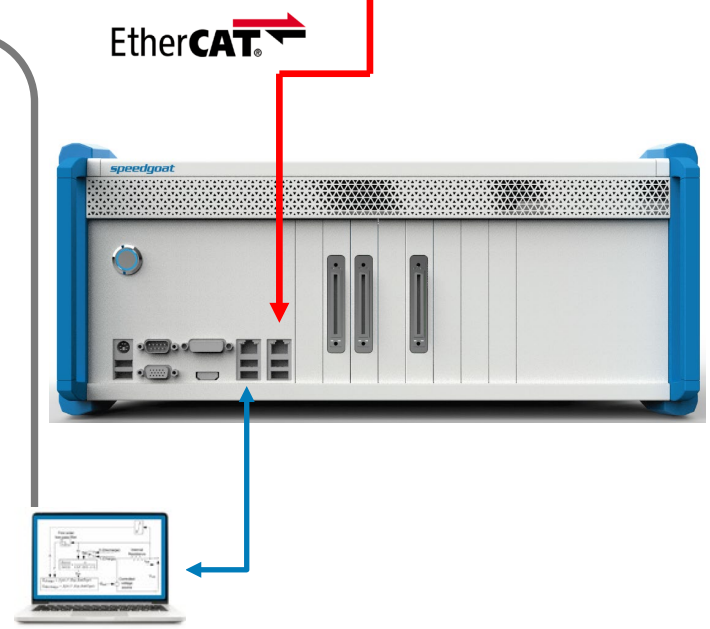
- Fast, deterministic, available onboard on Speedgoat real-time target machines
- Directly set and read voltages and currents to/from battery cell emulator
- Model battery behaviours using Simulink real-time and Simscape Electrical



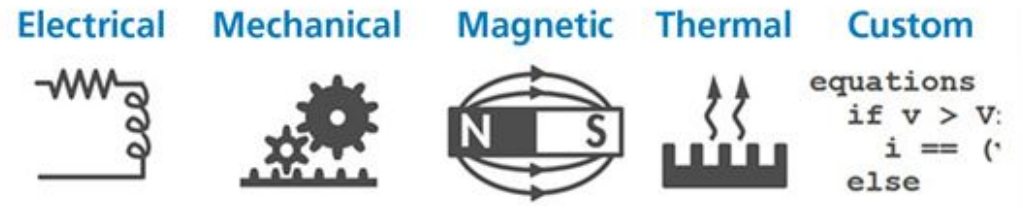


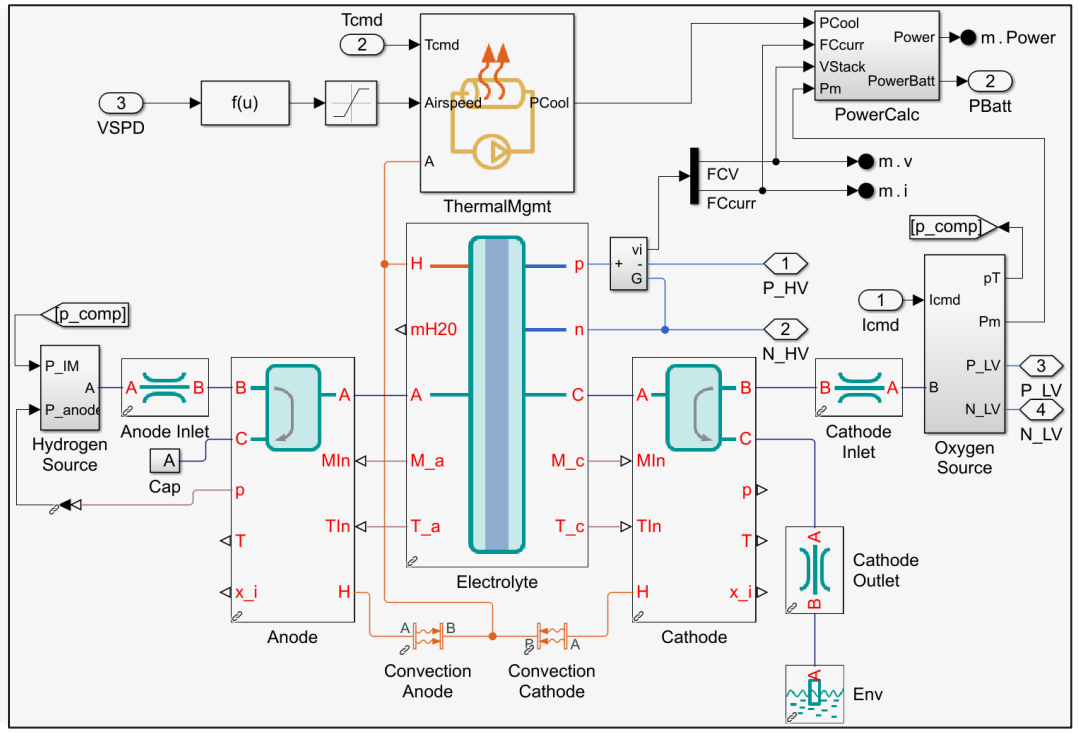




# Model Physical Systems with Simscape™

- Seamless multi-domain modelling
- Code generation support
- Highest fidelity for e.g.
  - Electric powertrain
  - Batteries
  - Liquid cooling system
  - Fuel Cells
  - Hydraulics
  - And more



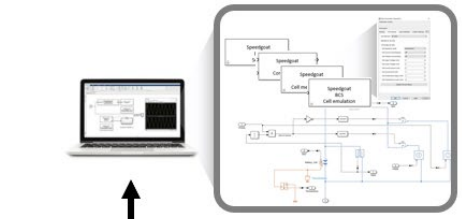




[HIL for Battery Testing MathWorks File Exchange]

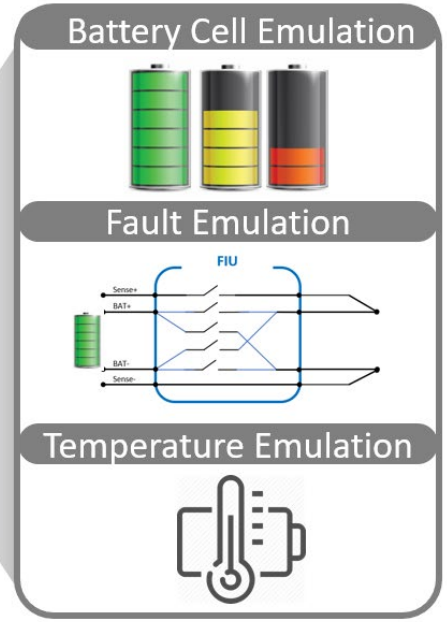
# New Speedgoat Product Portfolio for Battery Cell Emulation

BMS Challenges:
- Cell Monitoring
- Cell Balancing
- State control (SOC, SOH)
- Thermal management
- Safety control (out of range, fault condition)

Battery Cell Validation
- Active Charge and Discharge
- Isolated Measurement
- Active- and passive Balancing
- Cell-stack behaviour analysis

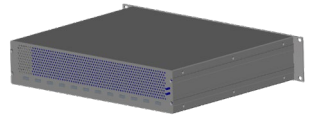


Simulink Real-Time and Simscape Electrical




Speedgoat Battery Emulator

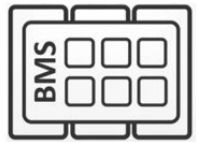
Battery Cell Emulator



Fault Insertion Unit

Temperature Emulation

V,I,T

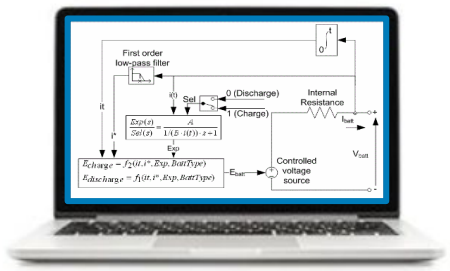



Battery Management System (DUT)

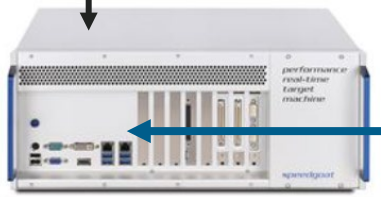
## Battery Cell Emulator

# Temperature Emulation and Fault Insertion

Simulink & Simscape




Ethernet



Ethercat

Cell emulation

Current Sink

Voltage Source

Current read

Voltage read

A

V

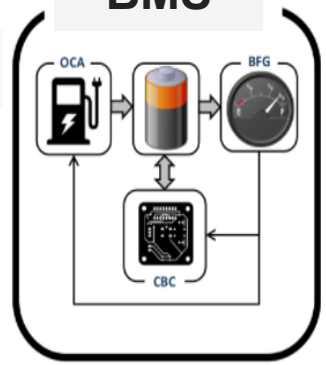
Temperature emulation

Fault Insertion

Sense+

Sens e-

BMS




Power cables
0 – 6 V output,
-5 A … +5 A

# Modular Rack Solutions

- Integrate battery cell emulators, fault insertion and temperature emulation channels into full rack solutions
- Expand systems with custom equipment and signal conditioning units

# Technical Specifications

| | |
|---|---|
| General | ▪ Number of cells per unit: 12<br>▪ Number of cells in series: Up to 312, depending on voltage configuration<br>▪ Cell-to-Cell isolation: 96V<br>▪ Cell-to-Ground isolation: 1.6kV<br>▪ Communication Interface: EtherCAT<br>▪ Update rate: up to 1kHz (in validation) |
| Cell Emulation | ▪ Voltage ranges: 0.01 –8V with 18-bit resolution (different options)<br>▪ Voltage accuracy: ±0.5mV (in validation)<br>▪ Current range sink/source: ±5A (current derating above 5V), 18-bit resolution<br>▪ Current accuracy: ±2mA (in validation) |
| Cell Measurement | ▪ Voltage range: 0-10V, 18-bit resolution<br>▪ Voltage accuracy: ±0.5mV<br>▪ Current range: ±5A, 18-bit resolution<br>▪ Current accuracy: ±2mA |

# EV & HEV Full Vehicle Simulation

## High Fidelity Simulation with Simscape Templates

- Real-time capable, fully customizable templates
- High-fidelity & multidomain physical models
- Tailor models for your electrification tasks
- Easily adapt system fidelity
- Real-time execution and HW connectivity with just a few clicks

Success Story: Nuvera

# Electrifying Commercial Vehicles with Hydrogen Fuel Cells

- Developing fuel cell technology for commercial vehicles
- Hybrid fuel cells with lithium-ion batteries
- Fuel cells and batteries modeled in Simulink


## Using real-time testing

- Nuvera uses real-time simulation for quick iterations on their designs
- HIL testing avoids putting a real engine at risk.

## Reducing CO2 emissions

- Application for forklifts
- Reducing 128 metric tons of $CO_2$ can be avoided annually.
- Possible to integrate with buses, trains, and special vehicles


One of Nuvera's E-Series Fuel Cell Engines.
Image credit: Nuvera Fuel Cells

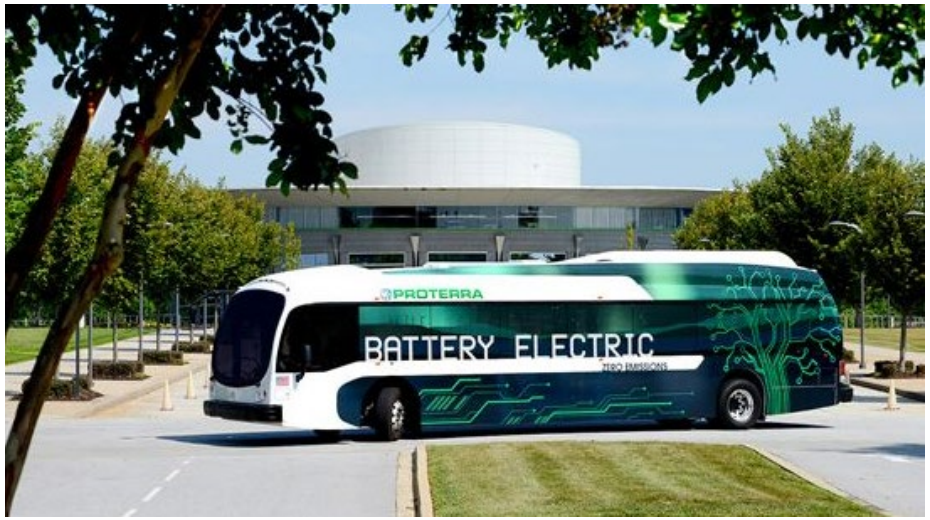
# Wrap-Up

1. Stay in the same modeling environment
2. No extra knowledge required
3. Connect to hardware with a few clicks and experiment in real-time
4. Rapidly switch between desktop and real-time
5. Fully automate your testing and validation

# Addendum for Discussion

User Story: Proterra

# Zero-Emission Battery Electric Bus Charges On-Route




## Application

- Proterra decided to leverage a hardware-in-the-loop (HIL) development approach to aid the testing and development of the control systems for the new transit bus
- Temperature, CAN network, pressure, speed emulation
- Seamless integration into MathWorks Tools
- Faster time to market

*"I feel that Speedgoat has certainly developed a plug-and-play real-time platform for Simulink. For us, that translates into more time testing our control systems and less time developing a HIL bench."*

*- Joaquin Reyes, Controls Engineer, Proterra*


PROTERRA

Simulink Real-Time is designed for Speedgoat real-time systems

# Real-Time Hardware-Software Solution

- Real-Time Target Computers
- I/O and Communication Protocols

Simulink Real-Time is designed for Speedgoat real-time systems

# Real-Time Hardware-Software Solution

- Real-Time Target Computers
  - Performance real-time target
  - Mobile real-time target
  - Baseline real-time target
  - Unit real-time target
- I/O and Communication Protocols

Simulink Real-Time is designed for Speedgoat real-time systems

# Real-Time Hardware-Software Solution

- Real-Time Target Computers
  - Performance real-time target
  - Mobile real-time target
  - Baseline real-time target
  - Unit real-time target
- I/O and Communication Protocols



Ideal for labs, rack installation or desktop use

Latest Intel CPUs (9th Gen Core i7 and Xeon)

Install up to 50 I/O modules with expansion chassis

[More information]

Hardware-in-the-Loop

Rapid Controls Prototyping

Simulink Real-Time is designed for Speedgoat real-time systems

# Real-Time Hardware-Software Solution

- Real-Time Target Computers
  - Performance real-time target
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  - Baseline real-time target
  - Unit real-time target
- I/O and Communication Protocols

More information


For desk, field, and in-vehicle use, DIN Rail Mountable

Latest Intel CPUs (9th Gen Core i7)

Install up to 14 I/O modules

Hardware-in-the-Loop

Rapid Controls Prototyping

Simulink Real-Time is designed for Speedgoat real-time systems

# Real-Time Hardware-Software Solution

- Real-Time Target Computers
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  - Unit real-time target
- I/O and Communication Protocols

More information



For desk, field, and in-vehicle use

Flexible for applications required small set of diverse I/O

Over 100 I/O compact miniPCIe, PMC, and XMC modules

Hardware-in-the-Loop

Rapid Controls Prototyping

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- Real-Time Target Computers
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- I/O and Communication Protocols

More information


Ideal for small scale Rapid Controls Prototyping

Suitable for size/weight constrained projects

Intel Atom Quad-Core CPU

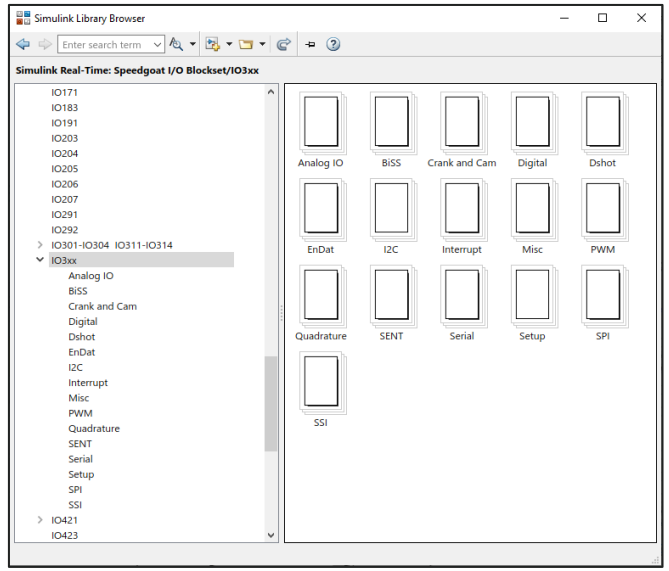
Hardware-in-the-Loop

Rapid Controls Prototyping

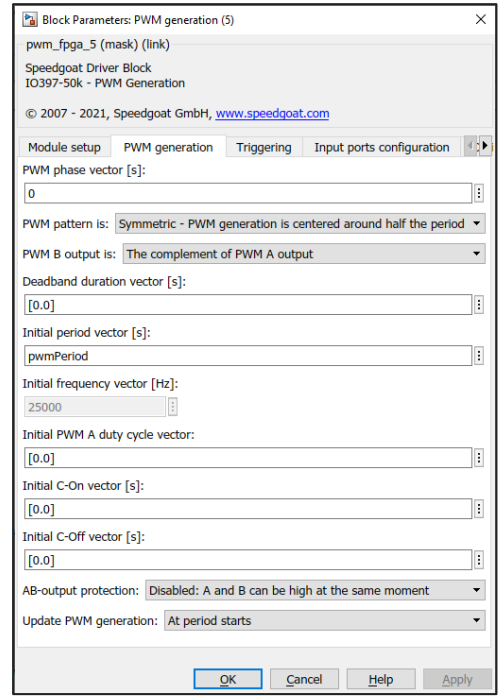
## Simulink Real-Time is designed for Speedgoat real-time systems

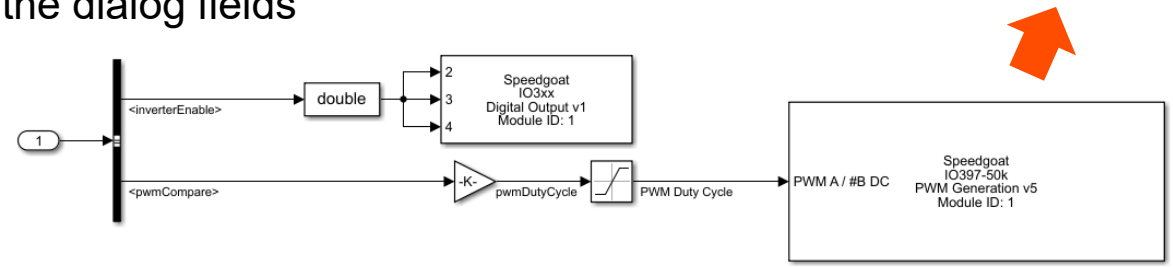
# Real-Time Hardware-Software Solution

- Real-Time Target Computers
- I/O and Communication Protocols
  - I/O Connectivity
  - Communication Protocols
  - Plant Emulation
  - Timing & Synchronization




Drag and drop Speedgoat driver blocks into the Simulink model, connect and configure in the dialog fields



## Simulink Real-Time is designed for Speedgoat real-time systems

# Real-Time Hardware-Software Solution

- Real-Time Target Computers
- I/O and Communication Protocols
  - I/O Connectivity
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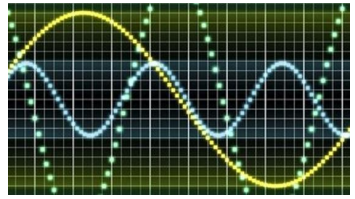
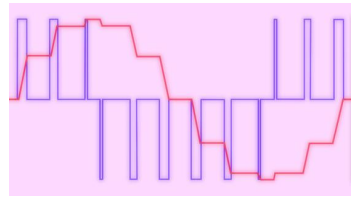


Analog
A/D D/A
16-24 bit

Digital
TTL, RS-422
LVDS

Audio & Speech



PWM
Generation & Capture

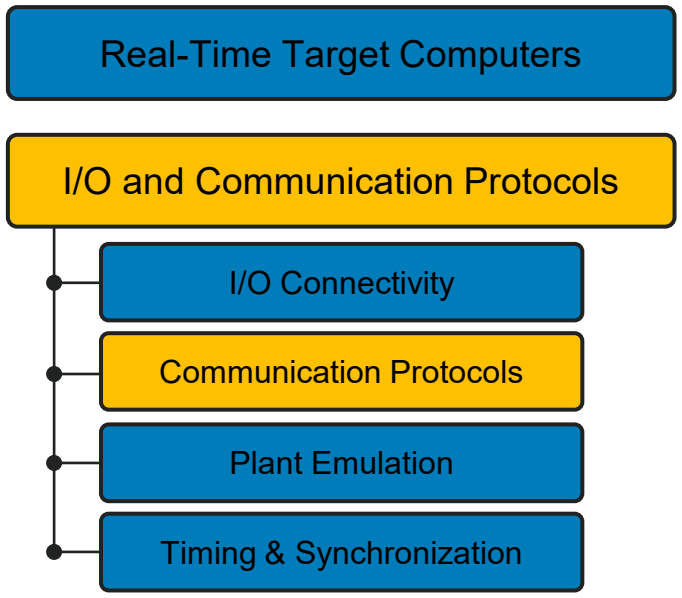
Encoders
BiSS, EnDat, Quadrature…

LVDT
RVDT
Synchro
Resolver

Vibration

Simulink Real-Time is designed for Speedgoat real-time systems

# Real-Time Hardware-Software Solution




More information

## Aerospace

ARINC 429
ARINC 629
ARINC 825
AFDX
MIL-STD-1553
SDLC/HDLC
D-SHOT

## Automotive

CAN
CAN-FD
LIN
FlexRay
J1939
XCP
SENT
MVB/WTB

## Industrial Automation

PROFIBUS
PROFINET
EtherCAT
Modbus
EtherNet/IP
POWERLINK

## Multi-Industry

Aurora
UDP, TCP
Ethernet
PTP
IRIG w/ GPS
RS-422
RS-485
RS-232

Simulink Real-Time is designed for Speedgoat real-time systems

# Real-Time Hardware-Software Solution

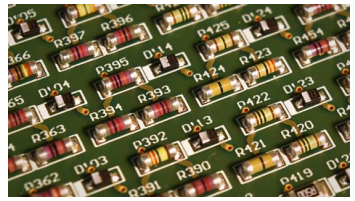
- Real-Time Target Computers
- I/O and Communication Protocols
  - I/O Connectivity
  - Communication Protocols
  - Plant Emulation
  - Timing & Synchronization

Battery Cell Emulation

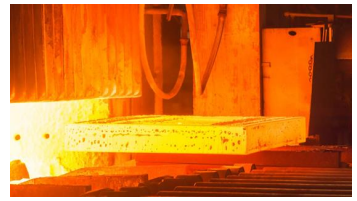
Multi-Node Simulator

Fault Insertion

Relays
SPST
DPST
SPDT



Resistors



Temperature & Strain
Thermocouples

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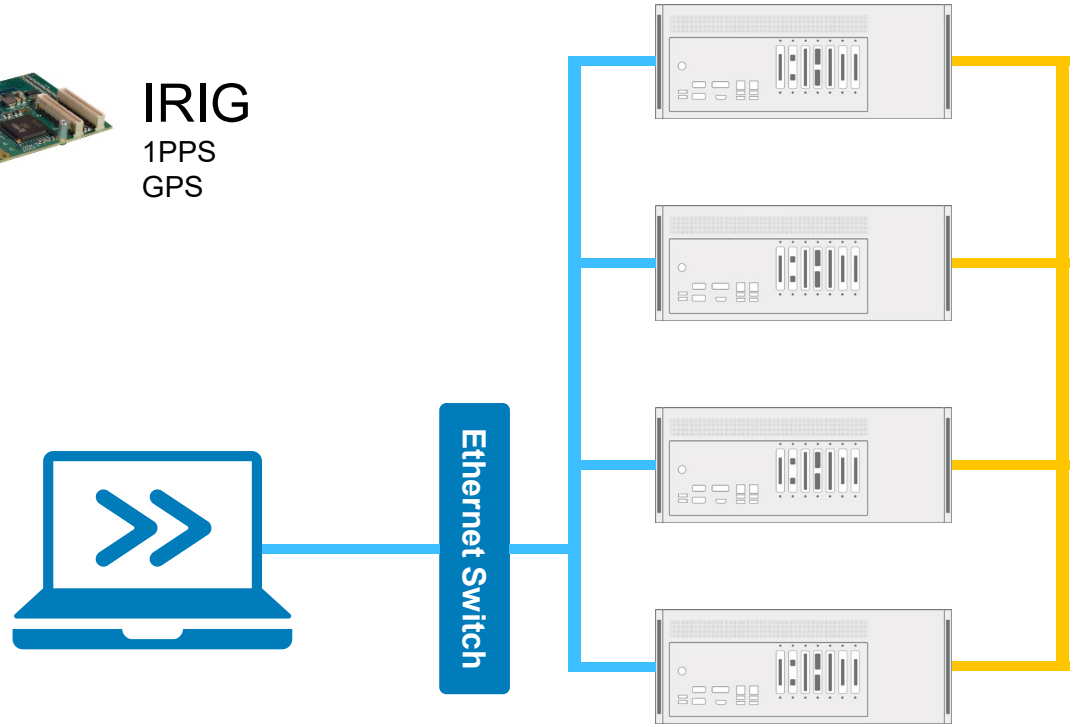
More information

Shared Memory

Precision Time Protocol
IEEE 1588-2008

IRIG
1PPS
GPS



## Made for Simulink, Tailored to the Customers Needs

# Speedgoat Modular HIL Rack System




## Made for Simulink, Tailored to the Customers Needs

# Speedgoat Modular HIL Rack System

- Power Supplies
  - Control power supplies from Simulink or a GUI designed with MATLAB App Designer.
- Break-Out Panels
  - Providing easy access to all signals for measurement purposes.
- Signal-Conditioning
  - Project specific signal-conditioning for level conversion, galvanic and loop powered isolation.


Rack Systems

# Real-Time Simulation for Academia

## For Research

**Accelerate** your research projects using industry proven solutions.

## For Teaching

Provide your students a **hands-on learning experience**.

***If you know how to use Simulink, you know how to use Simulink Real-Time and Speedgoat!***

Hardware

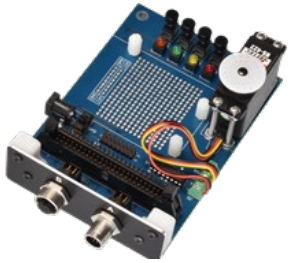
# Demo Kits and Reference Applications

**We get you started**

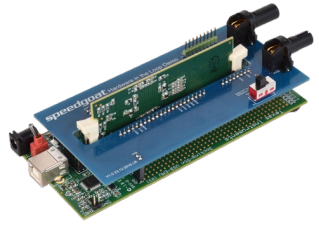
## Demo Kits

Electric Motor Control Kit - EMCK

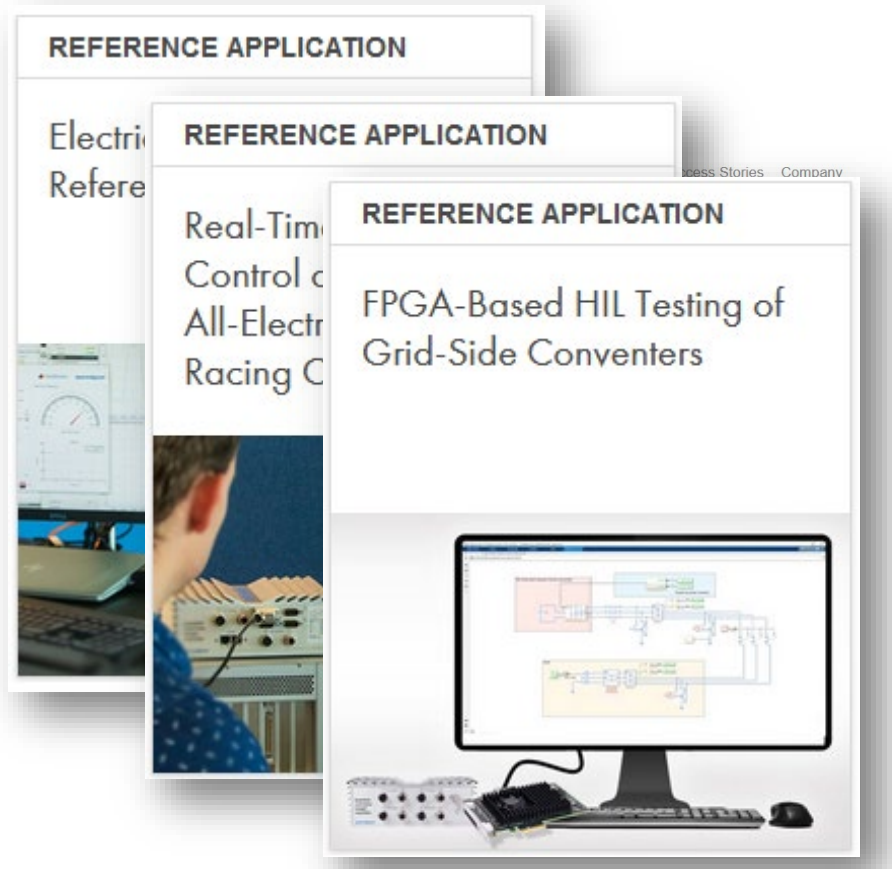

Device Under Test Kit - DUT



Hardware-in-the-Loop Kit - HIL



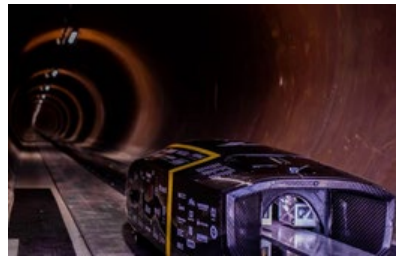

## Reference Applications



# Student Competitions and Sponsoring

- Formula Student Teams


- Hyperloop



- Roborace

- FVA – Scientific Aviation Association