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dSPACE MAGAZINE

2/2023

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What is SOLE?

„… cloud-based platform that emulates vehicle systems, functionality and dynamics for the purpose of developing and validating a vehicle`s embedded control system…“

Everything Virtualized

General Motors builds a cloud-capable, scalable development and integration-testing environment for software-defined vehicles

More software in vehicles means more software testing – across all vehicle domains. To drive software innovation forward, virtual testing should be quick, thorough but realistic.

To increase their testing capabilities, provide faster time to market, and enable development and validation of software-defined vehicles (SDV), General Motors has decided to create a virtual test environment. It is called SOLE and integrates all major feature components related to orchestrating and executing a vehicle-level software integration test setup:

- Virtual ECUs are co-simulated.
- The appropriate plant models are integrated into the platform via various co-simulation means.
- All necessary test tooling infrastructure is in place so that access to the simulator is made possible via various APIs.
- Orchestration and deployment to the cloud are made possible using a variety of techniques.
- Standards-based tooling makes the platform available for all necessary measurement and data recording needs.

VEOS, the software-in-the-loop (SIL) and V-ECU integration solution from dSPACE, plays a central role in this. It enables software innovation in all domains to be driven forward and validated across domains in early phases of vehicle software development. This shortens the time to market for valuable software functions.

Courtesy of General Motors.

“Seizing opportunities together to drive the mobility of the future.”

Dear readers,

The opportunity to lead a company that is as excellently positioned as dSPACE excited me from the very first second. And after almost six months at the helm of dSPACE, this enthusiasm has not decreased. For those who do not know me yet: Since April, I have had the honor of leading dSPACE as CEO. I previously worked at Bosch, Hella, and Claas, where I got to know dSPACE both from the user and customer perspectives.
My first steps lead me to you, our customers. What I am taking away from initial conversations is that our collaboration is close, effective, and productive, but that we still share many more ideas for innovations. This is why I would like to strengthen partnerships and, together with you, also precisely tailor future solutions to your individual needs. The many successful customer projects prove that we not only *want* to do this, but that we *can* do it.
In fact, dSPACE's capabilities are even greater than I had first imagined. Our extensive software portfolio, from software-in-the-loop (SIL) simulation to data-driven development and data logging, pushes the boundaries of what I knew in my previous professional life of hardware-in-the-loop (HIL) and rapid control prototyping (RCP) systems. This means that dSPACE offers solutions for almost all fields of application in vehicle development.
The close exchange with our users is our compass that guides us in the development of market-driven products. One example of this is the battery management and power HIL systems with which we are meeting the growing demand from the electromobility sector. However, we not only support you with products, but also ensure your success with our expertise. To ensure our quality and delivery reliability, we are constantly expanding our team. This year alone, I have already had the pleasure of welcoming 160 new committed minds to Paderborn.

Our global recognition is based on our motivation, our competence, and our reliability. The user reports in this issue of the dSPACE Magazine illustrate this. We are proud not only to have established OEMs such as MAN (page 10) on our side, but also to accompany start-ups from all over the world in their developments – as Human Horizons reported at the dSPACE World Conference 2023, for example.
dSPACE has a solid foundation, and we remain your reliable partner in simulation and validation. At the same time, I look forward to seizing opportunities in times of rapid change and working with you to advance the mobility of the future with new technologies and solutions.

Dr. Carsten Hoff

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Sensor-realistic simulations allow testing and validation at an extremely high level – but which features do these tools need?

Viewed Realistically

Hazardous situations in road traffic can be diverse and complicated. To prepare the newest vehicle generation for as many eventualities as possible, finely tuned test scenarios are needed which come as close as possible to reality, thereby providing test scenarios with a high degree of validity.

Innovative applications in the field of advanced driver assistance systems (ADAS) and autonomous driving (AD) are based on signals from individual vehicle sensors. They process these and, in certain circumstances, they actively intervene in the driving process. As the complexity of these functions increases, so do the demands on the technology which then, for example, can only be met with advanced sensor technology. The current advances in the fields of ADAS and AD would be therefore inconceivable without sensor-realistic simulations. Sensor-realistic simulations enable the exact simulation of vehicle sensors and environments, e.g., for different weather or light conditions, and then give the tester a clear picture of whether the environ-

ment and traffic scenarios were correctly captured and evaluated. In this way, ECUs can be tested and validated under realistic conditions, with a variety of relevant test scenarios that can be used in an exactly reproducible manner.

AURELION Connects SIL and HIL Tests

In AURELION, dSPACE has developed a tool that offers the user several advantages at once:

- While software-in-the-loop (SIL) tests can be executed at any speed, hardware-in-the-loop (HIL) tests are performed under exact real-time conditions. AURELION addresses both use cases equally so that, for example, the predevelopment can be started in a SIL environment and the simulation models including all simulation artifacts can then be seamlessly used in the HIL test.
- By scaling the processing power with processor farms or in the cloud, it is possible to execute tests in parallel, thereby executing a high number of tests and their variants, generated by parameter studies, in a manageable amount of time. This is essential for the development of functions for automated driving, as these functions have to be validated with countless test kilometers consisting of safety-relevant scenarios.
- However, realistic synthetic sensor data forms the basis for the development and validation of simulations. Whether lidar, radar, or camera sensors, the more exact the virtual sensor simulation can simulate the real counterpart, the higher the validity of the results. dSPACE therefore maintains long-standing relationships with renowned sensor manufacturers around the world so that their sensor models can be reproduced in the simulation – while respecting IP protection.
- In addition, due to close cooperation, dSPACE has the know-how to feed in the active sensor data which is already at sensor level so that >>

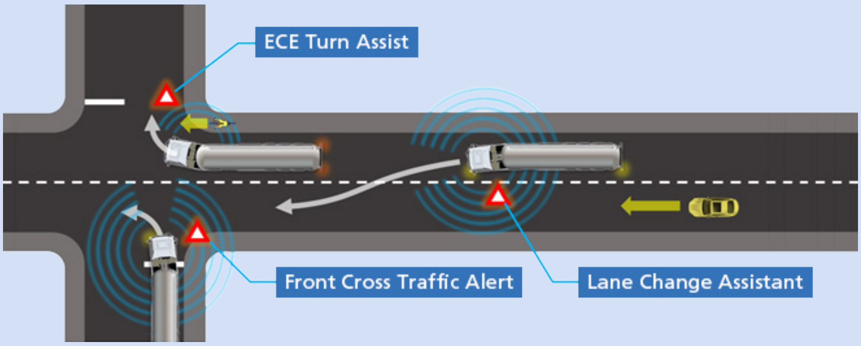
With AURELION, relevant hazardous situations can be simulated and visualized extremely close to reality for sensor development.

customers can test certain areas of the sensor processing.

Test Case Simulation Can Save Lives

The specific example demonstrates how AURELION can be used in the development of radar sensors. The partners HELLA and dSPACE have jointly set up a simulation solution with which, for example, use cases can be validated in the context of the UNECE 151 - Blind Spot Information System for the Detection of Bicycles regulation. Michael Lemm, Head of System & Software Radar Sensor Simulation, HELLA, explains: "In particular, this is intended to increase the protection of vulnerable road users on the side furthest from the driver. To this end, the trucks are to be equipped with a system to detect and warn them of obstacles in the blind spot (BSIS = Blind Spot Information System). "Possible applications for this include various integration scenarios such as the installation of two sensors at different heights to illuminate the area for which visibility is poor to non-existent.

The requirements for the system are defined in the aforementioned regulation, as are static and dynamic test cases. The static test case illustrates, for example, a traffic light situation, during which a truck stops, and a cyclist approaches the stop line on the right side of the truck. In this case, the regulation stipulates that the driver must be warned for at least 1.4 seconds before the cyclist reaches the front of the truck.



The graphic illustrates various hazardous situations, which can be defused with early sensor recognition.

Virtual Coverage of All Scenarios Already During Development

"To develop a BSIS on the basis of radar sensors, the use of radar simulation solutions such as AURELION is useful." With the help of radar simulation, the aforementioned test case

"Thanks to the sensor-realistic simulation in AURELION, we were able to take into account, for example, the usual external influences such as multipath reflections due to construction site situations or peripheral buildings as well as influences in city traffic in a wide variety of variations during the development of our Blind Spot Information Systems."

Michael Lemm, Head of System & Software Radar Sensor Simulation, HELLA

can be implemented very early in the development process," says Lemm. Different design and development activities can be executed in parallel, without having to use a real sensor. With generic radar simulation models, the influence of various sensor installation positions on the truck with reference to possible sensor illumination can be tested. In this way, the algorithms of the BSIS sensors can be developed with specialized radar simulation models, without a specific prototype being available.
"Furthermore, by coupling a complete vehicle dynamics simulation (ASM), the influence of various truck loads can be taken into account. This is helpful to be able to make statements about the covered ranges even before the real installation in the vehicle. An advantage of AURELION as a simulation solution is that the same simulation models and the same scenarios can be reused in further tests and, in a large number of use cases, implemented up to the homologation/release tests," comments Lemm.
Curves and straight roads, different semitrailers, and various weather situations can even be taken into account in the simulation and ensure that the subsequent real implementation can be well prepared and comprehensive postprocessing in sensor positioning in the reality can be avoided.

Exact Simulation to the Millisecond

According to UNECE - 151, blind spot assistance systems have to inform the driver about the potential hazardous situation between the first point of information (FPI) and the last point of information (LPI). The FPI is defined as the earliest possible spatial point at which a potential hazardous situation can be detected and the LPI is the latest possible spatial point at which the system must have informed the driver. These can be precisely simulated in AURELION down to the millisecond. The simulation enables suppliers and OEMs to configure the system in a mutually coordinated manner at an early stage.
Lemm explains: "Thanks to the sensor-realistic simulation in AURELION, we were able to take into account, for example, the usual external influences such as multipath reflections due to construction site situations or peripheral buildings as well as influences in city traffic in a wide variety of variations during the development of our BSIS."
With the vehicle dynamics model, realistic visualization of tractors and trailers in various curve scenarios is also possible. The dummies required for the homologation can also be simulated in AURELION.

Safer in the Future

Thanks to the UNECE 151 - Blind Spot Information System for the Detection of Bicycles regulation, the streets will become safer for cyclists in the future and serious to fatal accidents will hopefully be a thing of the past. This example shows very clearly how technical innovation and high-precision test scenarios can help the OEMs to further develop the technology and to fulfill this type of requirements.

With kind permission from HELLA

AURELION=
Sensor Realistic Simulation

MAN: Introducing an efficient end-to-end development process for autonomous freight vehicles as partners; with SIMPHERA, the highly scalable simulation solution

Autonomous Truck Pilot

Barely any innovation concerns the transportation industry more than autonomous driving. With dedicated feasibility studies and a data-based as well as cloud-based approach to development and virtual validation, MAN is demonstrating how autonomous driving can be made suitable for everyday use.

Picture credits: © MAN

The digital transformation already offers freight transport a wide range of opportunities to increase efficiency and reduce costs through networking, GPS logistics, assistance systems, etc. Autonomous driving promises particular potential. Transporters that drive autonomously enable a continuous flow of goods between producers, production sites, warehouses, ports, transshipment points, and customers. This scenario is almost perfect for the transportation and logistics industry. For important sections of the trajectory – especially restricted areas – the feasibility has already been proven by studies.

Autonomy for Efficiency

"At the port of Hamburg, for example, an autonomously driving truck heads for the container terminal and independently and precisely finds its way to the transshipment point," explains Dr. Eva Karrer-Müller, Senior Manager, Electric/Electronic Validation ADAS & Automation, MAN Truck & Bus SE. A safety driver monitors the journey as well as the automatic loading and unloading. The Hamburger Hafen und Logistik AG achieved this success together with MAN in the joint Hamburg TruckPilot project. Further pilot projects show valuable potentials for efficiency and prove the feasibility and practical suitability of autonomous systems:

- EDDI: Truck platoons (convoy journeys) in real logistics operations with the project partner DB Schenker
- aFAS: An unmanned safety vehicle follows fully automated mobile roadworks.
- ANITA: The 'Autonomous Innovation in Terminal Operations' makes it possible to use vehicles more flexibly by controlling the container handling process more efficiently and decoupling it from truck drivers' driving and rest times.

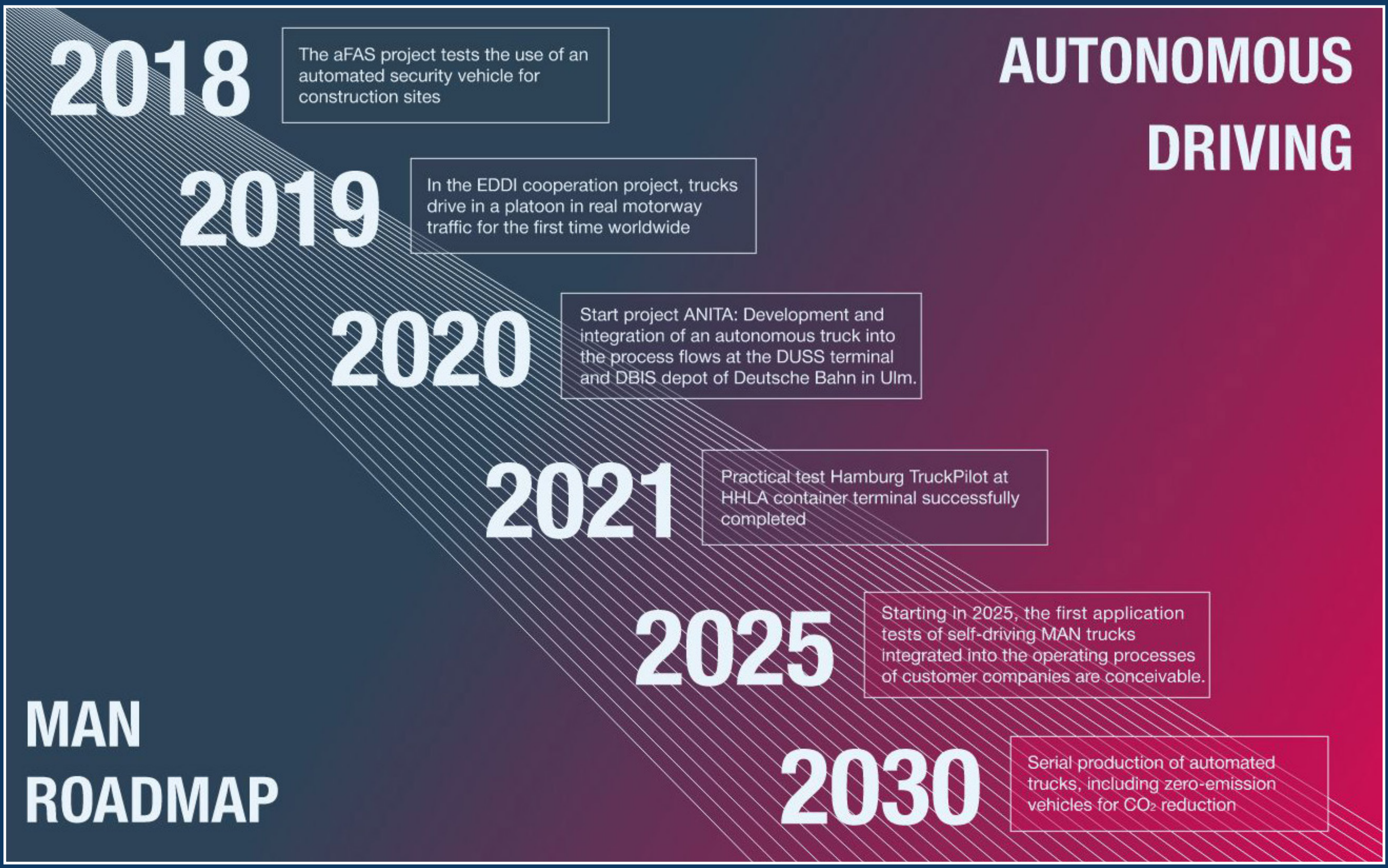
Key findings from the projects include lower fuel consumption through predictive automated driving, increased safety, and reduced manpower requirements in times of increasing staff shortages. Claus Hellberg, Vice President, Head of Electric/Electronic Verification & Validation, MAN Truck & Bus SE, emphasizes: "Autonomous driving has the potential to fundamentally change transportation."

Developing Autonomous Drivers Instead of Functions

What is particularly appealing to customers and users from the transportation industry, however, presents developers with exciting challenges. Level 4 automation causes immense, additional complexity for the development and validation of driving control. It not only involves the development and testing of technical func- >>

Advantages of Autonomous Freight Transport

- More safety on the roads and smoother traffic flow
- High reliability and availability
- High availability boosts the customer's business
- Potential for new services
- Lower overall operating costs
- Compensation of driver shortages



The pathway to autonomous driving follows a defined roadmap.

Picture credits: © MAN

tions but the replacement of the human driver as best as possible. Lorenz Bernwieser, Team Lead, Electric/Electronic Validation ADAS & Automation, MAN Truck & Bus SE, summarizes the challenges, "To build trust in the artificial autonomous driver, it needs to prove itself by driving accident-free in relevant test scenarios."

How will autonomous driving become economically successful?

The challenge facing an original equipment manufacturer (OEM) is to efficiently implement and execute a new procedure with new methods and components alongside the traditional development methods. This includes the recording of sensor data, machine learning, data-driven development and validation. "For this purpose, know-how has to be built up and new processes and tool chains have to be developed and implemented, under high time and cost pressures," reports Claus Hellberg.

Achieve Success Efficiently

MAN evaluated various providers of process consulting and of development tools for the introduction of an efficient, sustainable approach. It quickly became clear that for the best possible success, a comprehensive solution from a single source was desirable. Specifically, MAN was looking for solution expertise from data recording campaigns to homologation. The solution components already available or under development at dSPACE, supported by consultancy and engineering services as well as a partner network, were convincing and led to a cooperative partnership which is planned to last several years. Reasons to choose dSPACE:

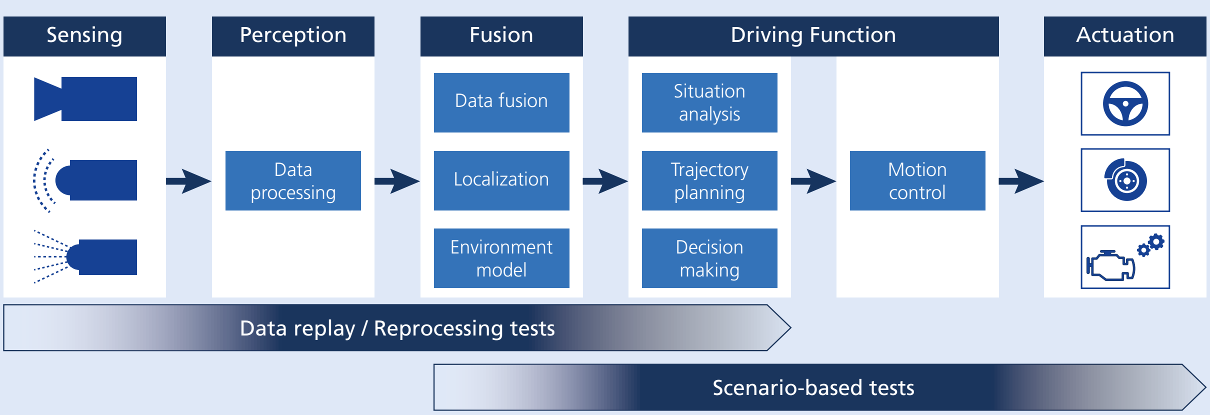
- Extensive process knowledge for the validation of advanced driver assistance systems (ADAS) and systems for autonomous driving (AD)
- Established solutions for the virtualization of ECU functionality (V-ECU)
- End-to-end portfolio for data-driven development from data acquisition to annotation and subsequent data management.
- Proven competence and experience in simulation and validation in the fields of hardware-in-the-loop (HIL) and software-in-the-loop (SIL)
- SIMPHERA, the cloud and on-site solution for highly scalable simulation of countless driving kilometers with relevant driving scenarios
- Partner network for additional subjects

Due to many years of cooperation in previous development projects with >>

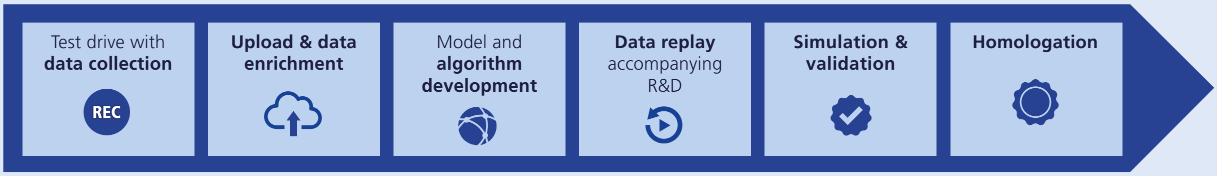
SIL

"With SIMPHERA, we put together complex, safety-critical driving situations in scenario-based tests to test and validate the system for autonomous driving with simulations executed in parallel."

Lorenz Bernwieser, Team Lead, Electric/Electronic Validation ADAS & Automation, MAN Truck & Bus SE



All processing stages of an autonomous system and the overall system are validated by simulation.



Significant process steps for reliable, efficient AD development.

conventional, model-based development and validation based on hardware-in-the-loop (HIL) simulation, MAN had a high level of confidence in dSPACE's reliability.

Partnership-Based Process Development Leads to the Goal

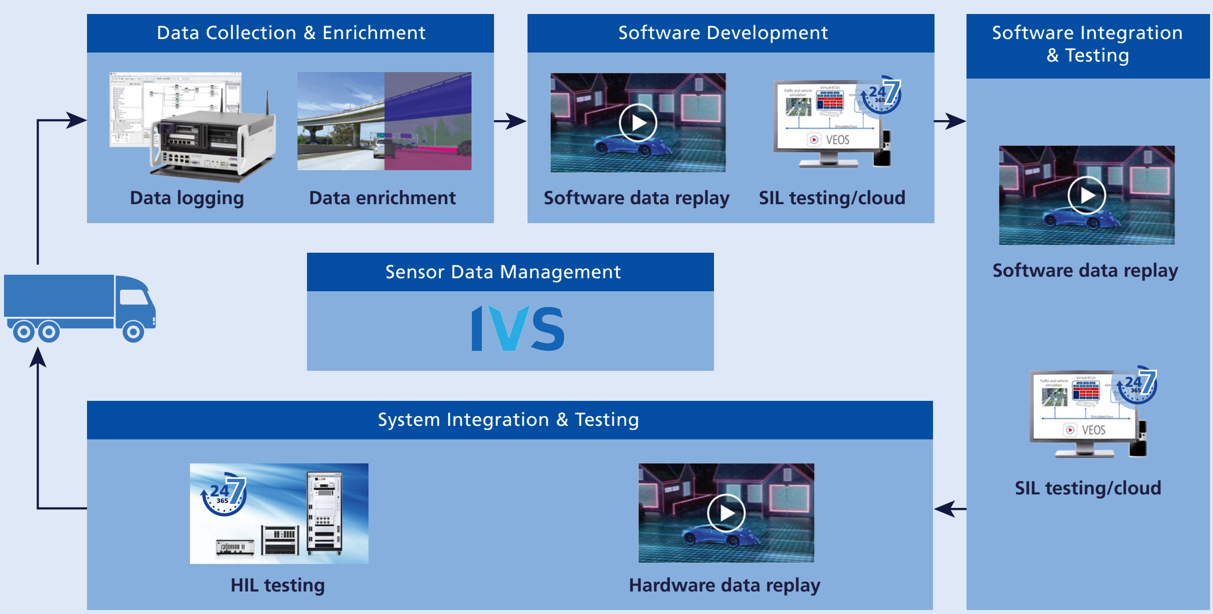
"Together with dSPACE and further partners, the multistage test strategy for the validation of an emergency brake assistant (EBA) was developed. This serves the preparation of further validation steps for future L3/L4 functions," explains Dr. Eva Karrer-Müller. The designed process introduces the paradigm shift of data-driven development and is created for the highest possible consistency. Software development and validation proceeds in the following steps:

- Targeted data recording during test drives
- Data ingest und data enrichment (annotation, tagging, selection)
- Data replay for development and testing, primarily in SIL but also using the HIL simulator
- Iterative simulation and validation throughout the development
- Derivation of homologation arguments

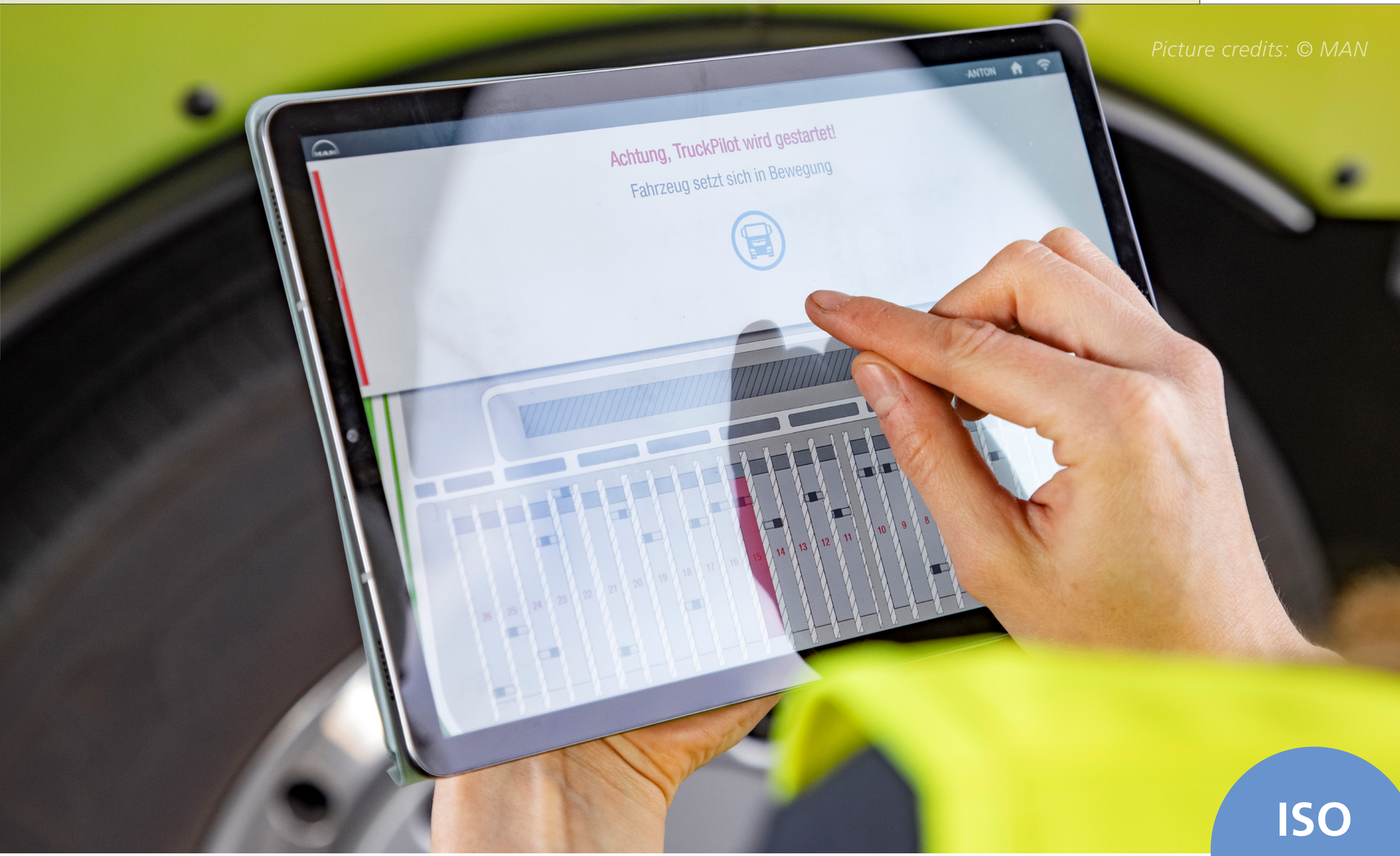
A Solution Tool Chain That Delivers

Suitable, powerful tools and competencies are required to successfully address the diverse issues associated with autonomous driving. Together with dSPACE, an integrated tool chain, with which developers can meet the many challenges, was designed, iteratively developed, and put into operation:

- MAN relies on the AUTERA AutoBox in-vehicle data logger to record all data (raw sensor data, camera videos, bus data, XCP data).
- With the help of the AUTERA Upload Station, the recorded data is imported into the storage systems and thus made available to the developers.
- The data is structured and organized using IVS, the sensor data management platform. The developers can



These tool chains and methods support the end-to-end process and have proven to be effective in developing and validating the AD stack. The IVS sensor data management platform ensures maximum consistency.



Picture credits: © MAN

access the data from all processing steps at any time and the management of the huge amounts of data is simplified.

- Virtual ECUs are created as test objects based on the production code and produced in the context of a continuous integration (CI) build pipeline.
- Using SIMPHERA, the ISO26262-certified, central, web-based simulation and test platform, open- and closed-loop test executions are configured and scaled test execution in the cloud is orchestrated.

ISO 26262

Insight into a Development and Validation Step

A practical example shows how this works in the everyday development environment of an electronic control unit (ECU). The ECU is initially created as a virtual control unit (V-ECU). MAN has to integrate their own code and components from suppliers in such a way that they remain performant, function correctly, and meet special V-ECU requirements. The following process is used for validation:

- Inclusion of integrations and of the build of the V-ECUs in the MAN continuous integration (CI) pipeline
- Validation of requirements in the area of real data via highly scaled data replay testing in SIMPHERA
- Validation of complex, safety-critical scenarios by means of scenario-based testing with highly scaled simulations in SIMPHERA

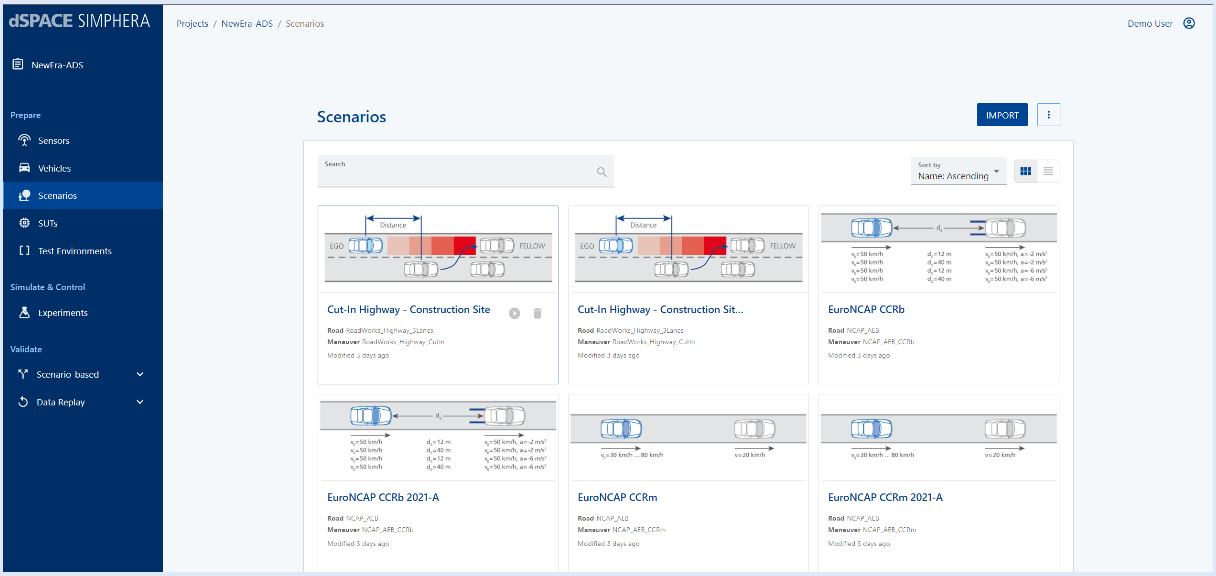
This process is carried out iteratively until the software meets the defined requirements. The software is integrated in parallel on the real ECU, and further tests are performed on the hardware-in-the-loop (HIL) simulator

V-ECU

>>

Why do we need scalable simulations?

Autonomous drive controls must meet the highest safety requirements. Every new software version of a drive control system must prove its safety in extensive tests: It must successfully manage many millions of miles of travel without catastrophic accidents. It would take decades to verify this with real-time testing. To shorten the test times, relevant safety-critical test scenarios are carried out in parallel. This is where the SIMPHERA simulation solution comes into play because it not only enables parallel simulations in the cloud, but also masters the entire spectrum of validation methods.



SIMPHERA, the cloud-based, highly scalable solution, ensures the simulation and validation of functions for autonomous driving with scenario-based tests

"A confident approach to the data-driven development process requires strong data skills combined with an end-to-end, data-driven development process. Together with our development partner dSPACE, we implement this."

Dr. Eva Karrer-Müller, Senior Manager, Electric/Electronic Validation ADAS & Automation, MAN Truck & Bus SE

Picture credits: © MAN

HIL

for selected operating points (corner cases). With SIMPHERA as a central platform, test scenarios and artifacts from SIL simulation can be used further in HIL testing. This also applies to the simulation models including their parameterizations. The scenarios used in the SIL tests are already available for selection in SIMPHERA or were created additionally for special application situations. The test parameters of the individual scenarios, such as speed, distances, etc., can be conveniently varied automatically in SIMPHERA to achieve high test coverage.

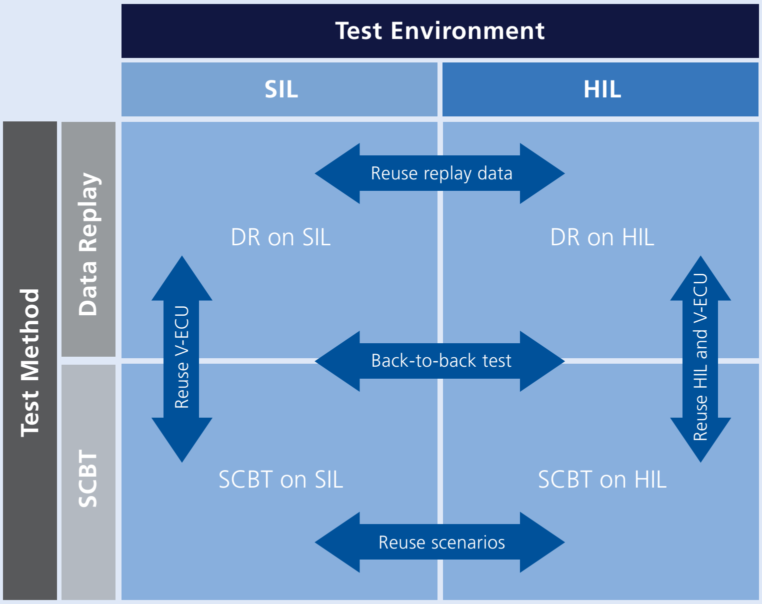
Evaluation of the Procedure

An emergency brake assistant that complies with the latest regulations is developed in the described valida-

"The partnership project lays an important technical foundation for autonomous driving in freight transport."

Claus Hellberg, Vice President, Head of Electric/Electronic Verification & Validation MAN Truck & Bus SE

tion process and procedure. Real test drives validate the degree of software maturity as an accompanying measure. In everyday development, the commonly designed process and tool chain prove their high suitability for the further demanding project on a daily basis: They will be successively rolled out to other Level 3 and Level 4 driving functions and make an essential contribution to overall validation. "As a leading customer, MAN is closely involved in the SIMPHERA development process, and there is regular mutual adjustment. The targeted, rapid approach succeeded in particular due to agile collaboration, which enables flexible responses to new requirements," reports Lorenz Bernwieser. In a partnership approach, the solution expertise of dSPACE and MAN was combined efficiently.



Methods and test environments for validation: A mixture of data replay (DR) of real sensor data and synthetically generated scenario-based testing (SCBT) on SIL and HIL platforms.

Autonomous Driving Will be a Gamechanger in Transportation

"The partnership project lays an important technical foundation for autonomous driving in freight transport," summarizes Claus Hellberg. Autonomous trucks are already driving in the virtual world and learning from the experience gained there. The replay of real sensor data combined with synthetically created scenarios forms a successful test mixture for the maturity of the algorithms. An important future topic arises with the homologation of the autonomous vehicle. The range of solutions provided by dSPACE is supplemented for this purpose by tools and services from dSPACE partners. The findings from studies and technical innovation show: AD is a game changer for the transportation industry. ■

With kind permission of MAN Truck & Bus SE

Consulting and Engineering Services

The development of complex E/E systems and software with more and more safety-critical functions, especially in the field of autonomous systems, raises the question of how to ensure functional safety. At the same time, ways for new efficient development need to be found. In the areas of functional safety, test strategy development, and verification and validation, MAN relies on dSPACE expertise and consulting to ensure a competent and efficient approach. dSPACE Consulting Services take on important conceptual tasks and ensure their efficient and successful implementation in the MAN project.

Mobility Transformer

How do you ensure that the control system of a new type of electric aircraft works reliably in all phases of flight? At Diehl Aerospace, it must first prove itself in the virtual world.

eVTOL air cabs are about to ring in a new era in aviation and convince with high flight safety – thanks to validation via simulation

Urban air mobility (UAM) by air cab enables fast and congestion-free transportation in densely populated areas. The all-electric aircraft with vertical takeoff and landing capability, also known as eVTOL (electric vertical take-off and landing), currently under development for this purpose have promising potential: They are publicly accepted, require little infrastructure, and offer high flexibility for new mobility services. In addition, they contribute to achieving sustainable mobility goals through their emission-free drive.

How much range do you need?
Currently, numerous companies are investigating different approaches to solving the technical challenges of eVTOL aircraft. The planned range of applications plays a decisive role here. Essentially, a distinction is made between intra-city flights with a range of up to 50 km and inter-city flights requiring ranges of 300 km and more. Heinrich Fischer, Head of Software and Validation+Verification Avionics at Diehl Aerospace, is convinced: "The ability to hover like a helicopter while being able to fly at a relatively high cruising speed and range makes eVTOL an effective rapid point-to-point transportation vehicle."

Transformer Transport
One possible technical solution for the propulsion of eVTOL aircraft is adjustable tiltrotors, which, depending on the rotor angle, enable both vertical takeoffs and horizontal flight. This drive concept is particularly suitable for long-distance flights. Another option is multiple conventional, rigidly mounted rotors, as known from quadcopters. Here, the flight speed and direction can be controlled by different speeds of the electrically driven rotors.

No Safe Flight Without Software
The electronic devices that are essential to the operation of modern, electrified aircraft are referred to as avionics. Avionics include the flight control computer (FCC), which incorporates control strategies that operate in response to flight conditions, aircraft configuration, and pilot preference. Heinrich Fischer explains: "Our flight control computer can fully control eVTOL platforms and supports the pilot to enable safe operations in every phase of flight. During takeoff, landing, and flight, the flight control computer is the link between the pilot and the engines as well as other systems in the aircraft. The system is able to optimally control the rotors for the individual flight phases, regulate their speeds, and, if necessary, detect errors in the system."

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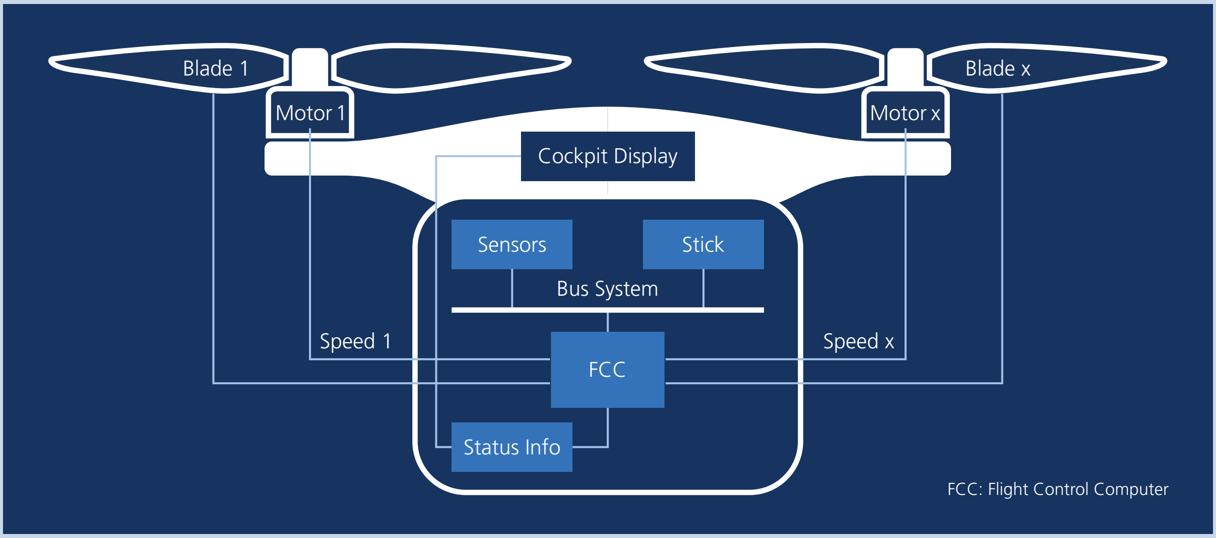


Simplified electrical system of the eVTOL. The flight control computer (FCC) uses the input data to determine the target data, e.g., motor speeds for the individual rotors. Due to the high safety requirements, monitoring algorithms are also implemented in the FCC.

High Requirements for Flying High

Safe flying is the central pillar in the development of flight control computers (FCC) – This poses special challenges for the development of these devices. The high-performance computer combines all safety-critical functions of an aircraft. Its reliability is crucial for the safety of the aircraft and its occupants. As required in aviation, the system is redundant, consisting of primary and backup control computers.

Two requirements are of particular importance for verifying the correct functionality of the FCCs at Diehl Aerospace:

- Testing the correct real-time behavior of the flight control computers (FCC)
- Testing all relevant input and output signals and the associated bus protocols

"Real-time tests in particular provide decisive statements as to whether a function is really safe and, in the event of an error, provide conclusions about, for example, inadequate timings, synchronization of signals and bus data, etc.," explains Heinrich Fischer.

To achieve efficient test execution with meaningful conclusions for troubleshooting, Diehl Aerospace placed particular emphasis on the following topics:

- Test automation (TA)
- Reproducible tests with documented results
- Easy creation of tests with available development tools, e.g., Python interface
- Stable test environment that can be kept up to date over many years

Look Closely: Safety Regulations

In the field of aerospace development, a wide variety of standards, safety regulations, and guidelines apply, which Diehl Aerospace must take into account in its development and verification activities. These include, for example:

- ARP4754: System certification
- DO-178: Developing safety-critical software
- DO-254: Developing electronic hardware
- DO-160: Environmental conditions and test procedures for aviation equipment

"The dSPACE simulator meets our requirements. With it, we succeed in developing and testing our flight control computer (FCC) according to the strict guidelines of aviation."

Heinrich Fischer,
Head of Software and Validation+Verification Avionics, Diehl Aerospace

It is obvious that a test system with such complex requirements must integrate seamlessly into existing development infrastructures. Easy expandability also played an important role in the development. “We were looking for a solution that was scalable and modular as our needs changed,” Heinrich Fischer reports.

Testing in Virtual Aircraft

With the goal of finding a test solution for the outlined requirements, Diehl Aerospace carefully evaluated the hardware-in-the-loop (HIL) simulator market and found a suitable system of hardware and software in the dSPACE HIL portfolio, which they were able to seamlessly integrate into their existing test automation environment.

The SCALEXIO HIL simulator virtually replicates the environment for the FCC, allowing it to behave as if it were in an aircraft for which it was designed. The test system is configured to communicate with the multiple interfaces of the flight control computer (FCC) to exchange signals for sensors, actuators, and control. The HIL simulator is designed to test both the primary and backup control computers. During test operation, the device to be tested can be selected in the test automation. An identical test system was set up at the system integrator to test the FCC in interaction with other components.

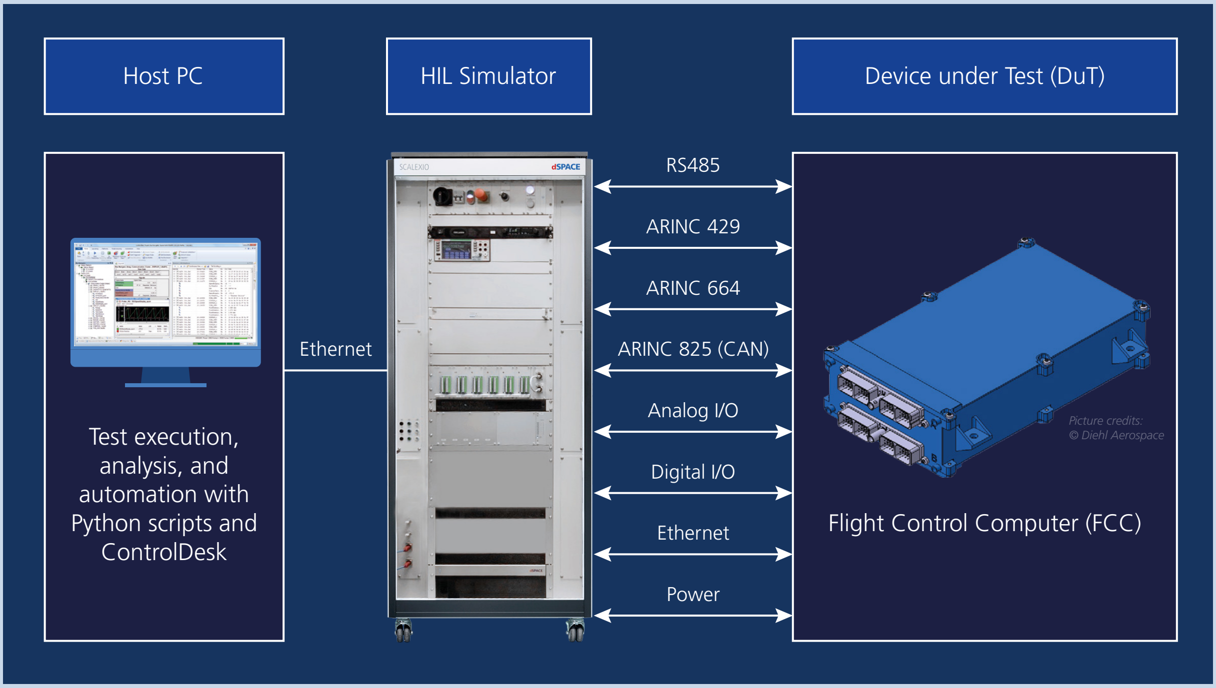
Real-Time Capability Determines Safety

“SCALEXIO allows us to stimulate

>>

About Diehl Aerospace

Diehl Aerospace is a joint venture between Diehl Aviation and the French company Thales and is one of the leading aerospace suppliers with a wide product range for various aircraft programs.



Test system setup: The central component is the simulator, to which the FCC is connected as a device under test. On the host PC, the simulator is configured with ConfigurationDesk and test automation is executed with Python scripts. Individual tests can be performed with ControlDesk.

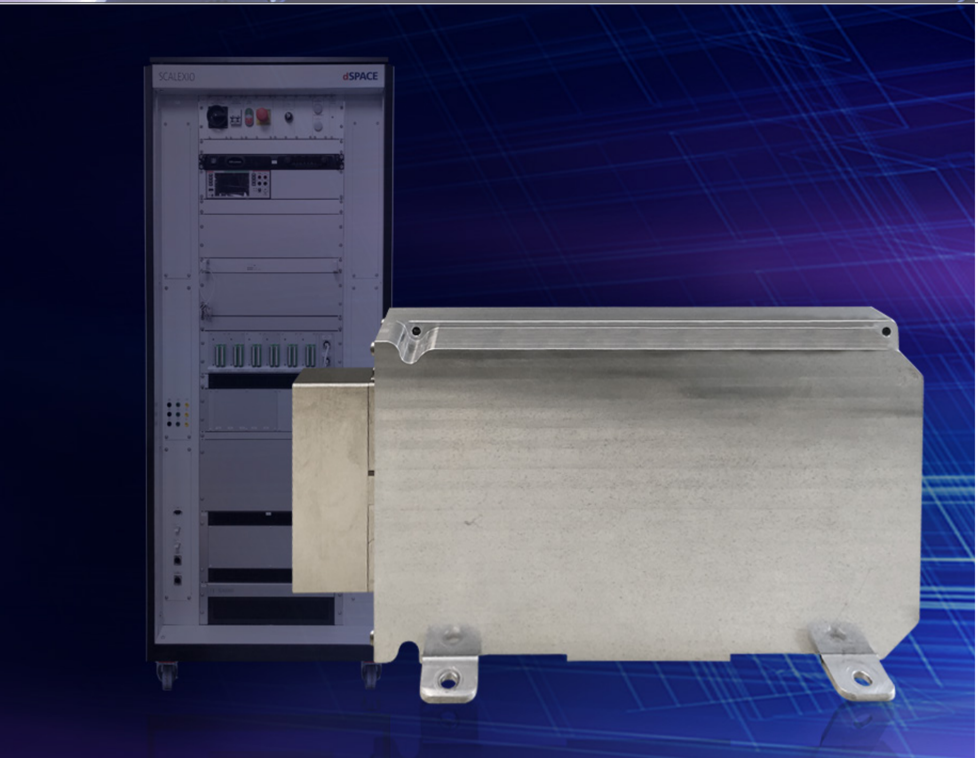
time-critical input signals in real time, while accurately monitoring the behavior of the FCC using the output signals and, if necessary, integrating other components into the test environment through simulation," Heinrich Fischer reports. He explains the further procedure: "With the simulator, we can also record important signal characteristics in real time and evaluate them graphically. Ultimately, this will allow us to simulate the operational running of the FCC and ensure it is functioning correctly."

Ensure Airworthiness via Simulation

"The SCALEXIO HIL simulator allows us to thoroughly examine our FCC and validate its safety-critical functions," Heinrich Fischer explains. The precise simulation of the controlled systems allows operation that is no different from use in the aircraft. The simulator enables flexible test creation and automated test execution including the creation of test protocols. The test system proves itself in everyday testing through high stability, robustness, and availability. Diehl Aerospace can configure the simulator individually and expand it independently. "The simulator from dSPACE meets our requirements," Heinrich Fischer summarizes. "With it, we succeed in developing and testing our

"We were really impressed with SCALEXIO's ease of expandability."

Heinrich Fischer, Head of Software and Validation+Verification Avionics, Diehl Aerospace



The flight control computer (FCC) leverages a proven dual-lane architecture combined with powerful dual-core lockstep data processing technology (real-time diagnostics using an additional processor and comparator) to provide a safe, reliable, powerful, and robust platform for flight control or other highly safety-critical functions. Functional safety is verified with automated tests on the simulator.

FCC according to the strict guidelines of aviation. The ease of expandability coupled with the wide range of configuration options really impressed us."

Onward Flight Already Booked

The FCC was recently presented at an aviation trade fair and generated a positive response, including from the European aviation authority. This encourages Diehl Aerospace to new development tasks: The deployment of additional avionics equipment, new sensors, and actuators is being prepared, and new software versions are enriching the feature set of future FCCs. Diehl Aerospace is looking forward to using dSPACE's simulator to achieve reliable success in these developments as well.

Courtesy of Diehl Aerospace

At a Glance

Application

- Validation of a flight control computer (FCC) for eVTOL (electric vertical take-off and landing) aircraft

Challenges

- Safety first: ensure the safety of the aircraft and its occupants
- Prove the correct functionality of the FCC and its safety-critical functions
- Adhere to the aviation safety standards

Solution

- Validate the FCC with an airplane which is virtualized using hardware-in-the-loop simulation
- Test time-critical signals under real-time conditions
- Automated, reproducible tests with documented results confirm the functional safety of the FCC

dSPACE Tools Used

- SCALEXIO: Modular extendable real-time computing platform for the simulation of behavior models (controlled systems) and provision of hardware interfaces
- ConfigurationDesk: Configuration of hardware interfaces and implementation of behavior models and I/O function code on SCALEXIO
- ControlDesk: Experiment and instrumentation software to perform and analyze simulations

All Onboard

Real-time simulation for auxiliary converters and onboard power supplies in rail vehicles

Speed, safety, and comfort during a train journey – that should go without saying! ABB makes sure this is the case, using its high-performance traction converters for the main vehicle propulsion and auxiliary converters for onboard power supplies. To develop and test the control software for these converters in an effective and efficient manner, ABB relies on generic real time simulation using dSPACE products.

Picture credits: © Stadler

One of the most important parameters characterizing a modern rail vehicle is the tractive effort. While it is indeed the tractive force which sets a vehicle in motion, a high-performance traction chain also requires other subsystems like auxiliary converters (Figure 1), which play an important role in the vehicle's functioning. It is difficult to imagine a train ride today without the comfort of heating, ventilation and air conditioning, lighting, or outlets for charging portable devices. In addition, not only the passengers need a "cool" ride, but traction chain components such as traction converters, traction transformers, and traction motors also require cooling to ensure reliable and efficient operation. Furthermore, air compressors are essential for operating the braking system and the pantograph. All these auxiliary loads in the train are powered by an auxiliary converter (AUX). ABB offers auxiliary converters for a wide range of vehicles, either integrated in the traction converter or as stand-alone units (Figure 2). >>

ABB

ABB is a technology leader in electrification and automation, paving the way to a more sustainable and resource-efficient future. The company's solutions connect engineering know-how and software to optimize how things are manufactured, moved, powered, and operated. For many years, ABB has also been committed to the development of leading tools for real-time simulation (RTS) to test its products. The dSPACE RTS in ABB's Traction Division offers an environment for efficient, cost-effective testing of control software of high-performance power electronics systems for rail vehicles and heavy-duty electric vehicles, such as trolleybuses, buses, and trucks.

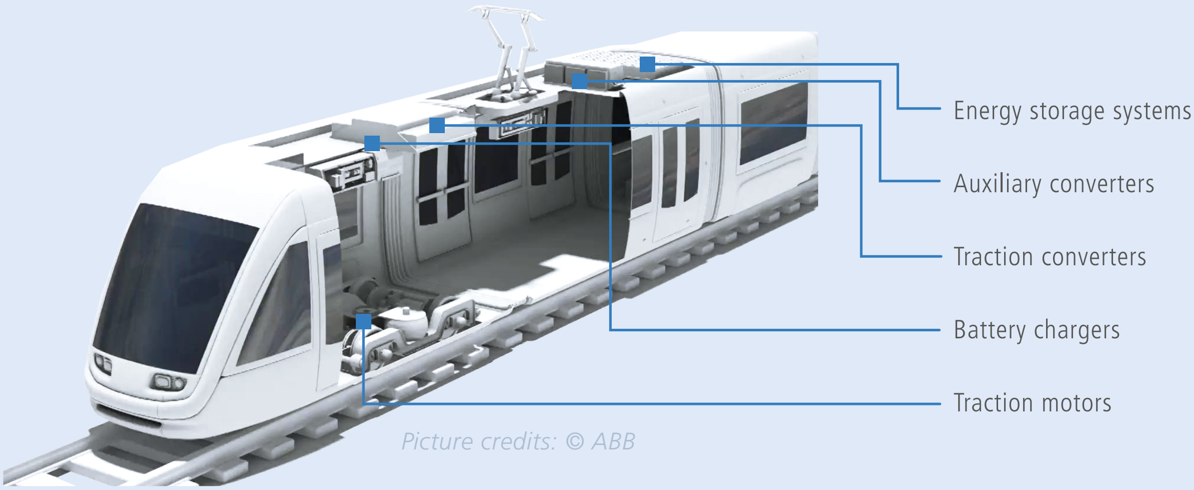


Figure 1: Light rail vehicle with ABB converter products, including auxiliary converters.

The Devil Is in the Detail

Hardware-in-the-loop (HIL) testing is the technical standard for testing the control software of traction and auxiliary converters. For this purpose ABB uses the dSPACE Development Solution, described in detail in the text box on the next page. For many years, ABB has benefited from dSPACE products – such as the HIL simulation of electric drives – to test and develop control software for optimal power transmission to the wheels. However, auxiliary converters have a higher switching frequency than traction systems. This in turn requires high simulation precision, and correspondingly high sample rates in the simulation environment – as only field-programmable-gate-array (FPGA)-based simulations can provide.

FPGA = Field-Programmable Gate Array

Focusing on the Essentials

ABB needs a generic test environment to accommodate the wide variety of controllers and onboard systems in development and validation. This allows engineers to focus on their core tasks of developing and testing auxiliary converter software, and not have to deal with complex mathematical models or FPGA programming. Therefore, the dSPACE Development Solution had to be convenient, easy to use, and flexible to adjust parameters to different requirements. The solution, especially the Electrical Power Systems Simulation Package (EPSS), carries out rapid real-time calculations from a circuit diagram modeled with Simscape Electrical™ (Specialized

Figure 3: ABB Traction Simulator with dSPACE SCALEXIO systems for combined traction and auxiliary converter simulation.

Figure 2: ABB traction converter with integrated auxiliary converter.

FPGA stands for **field-programmable gate array**. FPGAs are used in digital technology to allow modifications in an integrated circuit's functionality without replacing hardware. Instead, a specific integrated circuit is implemented as a particular configuration of the internal logic cells. The main advantages of an FPGA are its flexibility and high speed for signal processing. In the EPSS case, the numerical solution of the discrete system equations for a power electronic circuit is computed on the FPGA.

Power Systems), e.g., using an FPGA. No specific expertise is required to use EPSS other than creating circuit topologies. No FPGA programming software has to be available, nor does the responsible engineer have to perform any time-consuming synthesis of the FPGA build themselves. Using the FPGA-based approach included in EPSS, fast computing steps in increments starting from a few hundred nanoseconds are possible – depending on the application – so ABB chose this package. The EPSS package thus allows the circuit diagram developed with Simscape Electrical™ to be transferred directly to the FPGA and executed in real time without any further implementation effort by the user. This saves time and money and conserves resources. >>

dSPACE Development Solution

ABB uses SCALEXIO hardware together with the experiment and instrumentation software ControlDesk and the implementation software ConfigurationDesk. The dSPACE Electrical Power Systems Simulation Package (EPSS), which runs on a SCALEXIO unit with its dedicated processor, FPGA and multi-I/O boards (Figure 3) helps simulate the auxiliaries using FPGAs. When it comes to the simulation of auxiliary power converters, the resolution in step sizes of approximately 25 µs, which is usually used for traction simulation, is not sufficient. This is because the power semiconductors in auxiliary converters have higher switching frequencies (above 2 kHz), and the associated power electronics circuit components (inductors, capacitors, resistors, switches) have smaller time constants than in the traction system. The mathematical description of such systems requires deeper specialist knowledge in order to achieve an accurate real-time simulation.

Therefore, an approach was necessary that covered the following points:
- Physically correct modeling of the power converter by means of a circuit diagram
- Automatic generation of the mathematic description (differential equations) and discretization
- Simulation step size below 5 µs
- Exact consideration of the pulse-width modulation (PWM) switching signals
- Change of the parameterization, in particular of loads, during run time
- Precise recording of measurement data

All these points are intended to facilitate **time-saving and reproducible testing of power converters**.

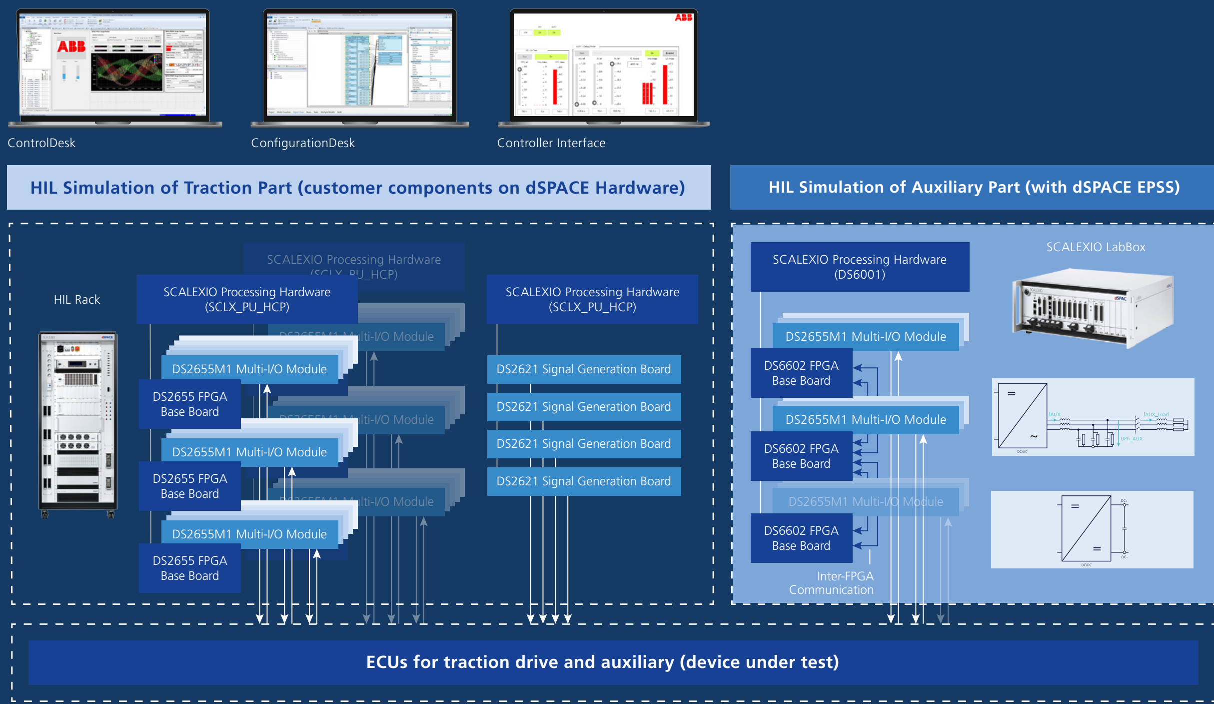


Figure 4: Example setup of the dSPACE hardware and software at ABB.

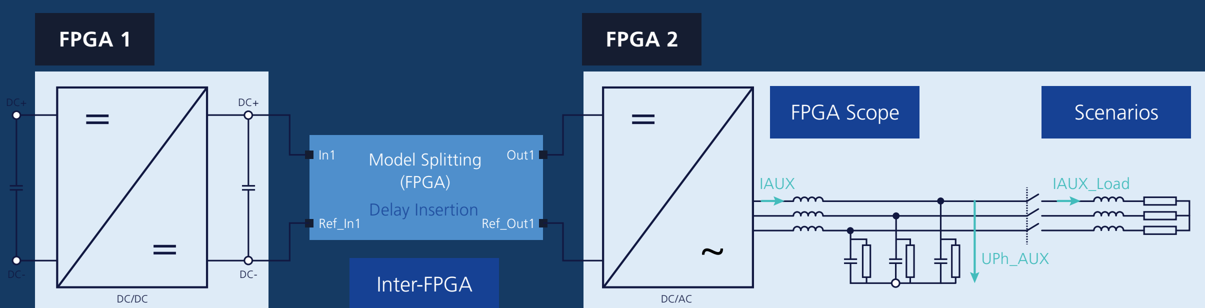


Figure 5: Auxiliary circuit topology simulated with the EPSS FPGA Solution. The simulation is split on two FPGAs which communicate with each other to ensure correct signal exchange.

Prior Analysis of the Models

As auxiliaries come in a variety of configurations and numbers (e.g., with or without a step-down DC/DC converter, more auxiliaries running in parallel), the question arises of whether the complex models can even be processed on a single FPGA, or if they must be split. If splitting is required, the point at which splitting can be performed must be identified so that the simulation remains stable and precise enough. The resulting units, which run on multiple FPGAs, must still be able to communicate

"For this project, we chose to continue our partnership with dSPACE, as we had already been working together successfully and in a spirit of trust for many years."

Alessandro Recca, Head of Control Testing and Validation, Traction at ABB

"We significantly reduce time and effort by pretesting the control software on the dSPACE RTS, including auxiliaries. As a result, we can focus only on fine-tuning our control software during the actual vehicle commissioning."

Thomas Steiner, Senior Control Engineer, Traction at ABB

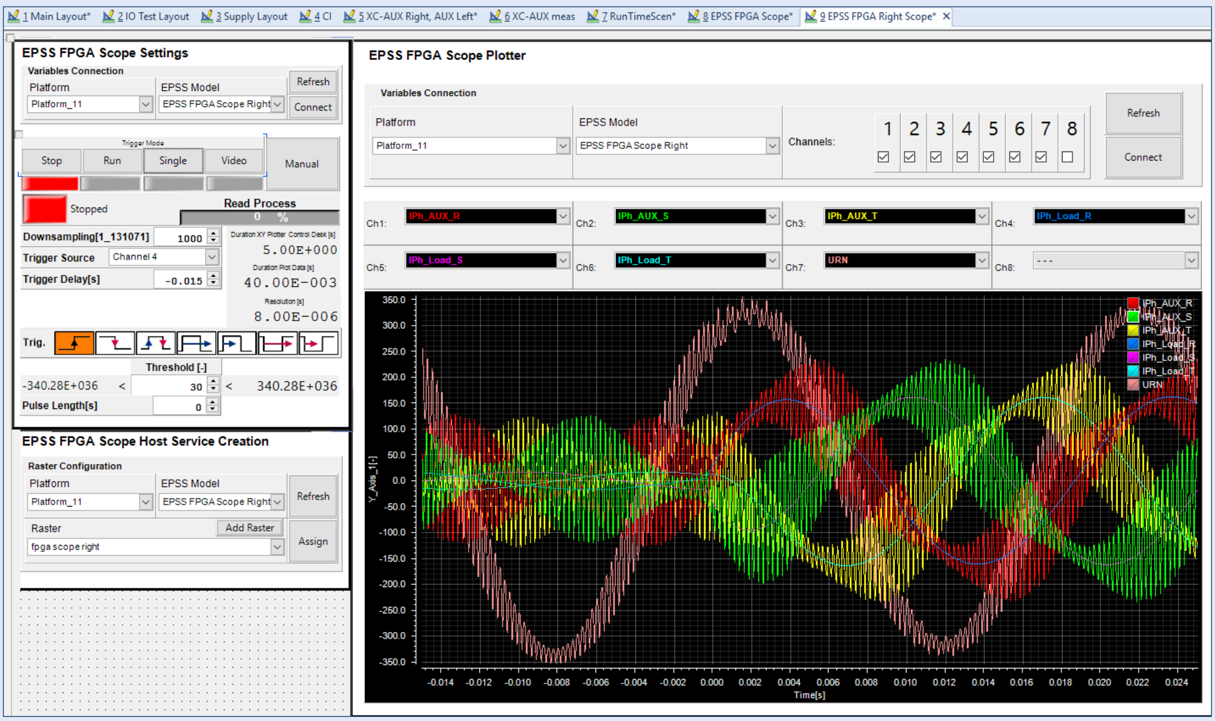
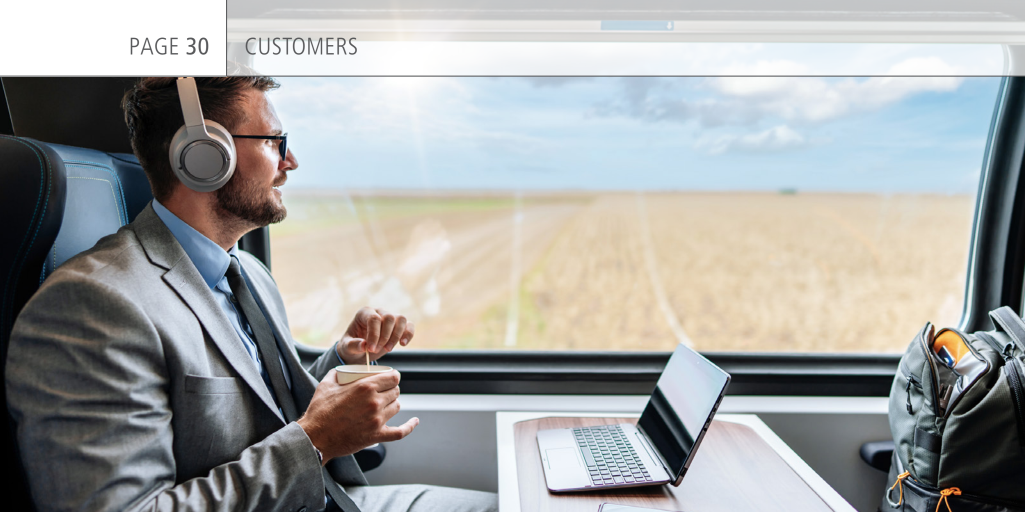


Figure 6: Capturing EPSS FPGA signals with the EPSS FPGA scope. An AUX load step (at time 0) from 10% to 100% is shown. The auxiliary load is changed during run time using the EPSS 'Scenarios' feature.

with each other without problems using an inter-FPGA connection (Figure 5). EPSS offers extensive, user-friendly tools to identify the necessity of several FPGA boards and their configuration. In this manner, for example, a graphical user interface can display whether a circuit can be implemented on an FPGA, and which components or settings require a further FPGA board. If model splitting is unavoidable, easy-to-use model splitting blocks can be inserted into the simulation model. Various splitting processes are available. In a fur- >>

"We needed a tool which could model applications simply and quickly without the responsible engineer having to deal with FPGA programming. The EPSS Package from dSPACE was the best environment to ensure this."

Markus Dähler, Senior Engineer Real-Time Simulation, Traction at ABB



Detailed Comparison of Results

The graphic (Figure 7) shows the results of an open-loop experiment, where the auxiliary DC link is fixed at 750 V, and the auxiliary converter is pulsed with a PWM switching frequency of 4 kHz and a modulation index of m=0.9. The real-time simulation with the EPSS FPGA solution running with a step size of 4 µs is compared with a step size of 0.1 µs offline reference simulation using Simscape Electrical™ (Specialized Power Systems), and with the laboratory measurements. The RTS EPSS FPGA simulation is very accurate – it is almost identical to a much more computationally expensive offline simulation and very closely matches the laboratory results. The difference in simulation compared to the laboratory data results from the ideal nature of the simulated electrical components (i.e., linear Rs, Ls, Cs, etc.). These elements are non-linear in reality, and effects such as resistance temperature dependency and non-linear L-current characteristics are omitted in simulation.

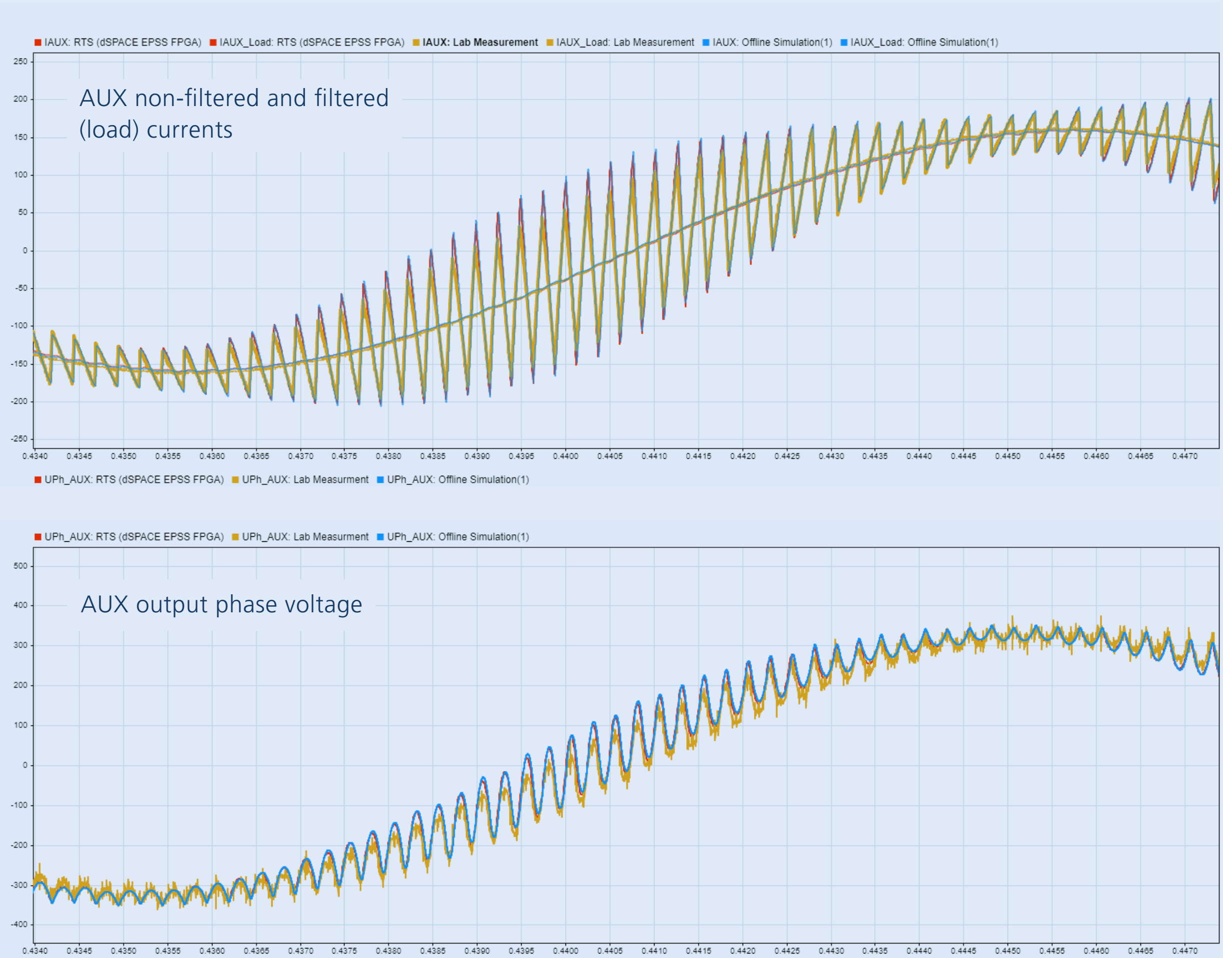


Figure 7: Comparison of real-time simulation with EPSS FPGA (red), offline simulation with Simscape Electrical™ Specialized Power Systems (blue), and laboratory measurements on the real setup (yellow).

"The dSPACE Development Solution can be easily parameterized, configured, and automated for generic simulation. It lets us combine ABB custom models with the dSPACE EPSS FPGA Package for complete propulsion and auxiliary simulation."

Dr. Roxana Ionutiu, Principal Engineer Real-Time Simulation, Traction at ABB

ther graphical interface, users can analyze which splitting points and splitting methods lead to a still-stable simulation and which splitting points are most suited for the available model. The connection of several FPGA boards can be conveniently configured via ConfigurationDesk and an integrated EPSS-specific inter-FPGA interface.

Right to the Smallest Detail – Visualizing the Results

During real-time simulation, the resulting signals are usually monitored on the processor, e.g., using the dSPACE ControlDesk software. However, as the simulation of auxiliary systems on an FPGA is carried out with a precision which cannot be represented on the processor, the processor shows averaged results. The FPGA scope supplied with EPSS, however, makes it possible to accurately record the simulation results in a specific time frame, and to display them conveniently using a ControlDesk extension. Thus, currents and voltages of the power electronics components or the PWM switching signals can be closely observed. Figure 6, for instance, shows how you can use the FPGA scope to set the trigger to capture the relevant signals at an auxiliary load step change from 10% to 100%.

No Burden with the Loads

A further challenge is that the load parameters must be changed during run time. This is not trivial in topology-based simulations, as changed parameters change the discretized differential equations. EPSS provides a graphical user interface for defining Scenarios, i.e., parameter sets for the components included in the circuitry. One can switch between these scenarios in ControlDesk during run time with only a few clicks, and the effect of auxiliary load changes can be easily tested this way.

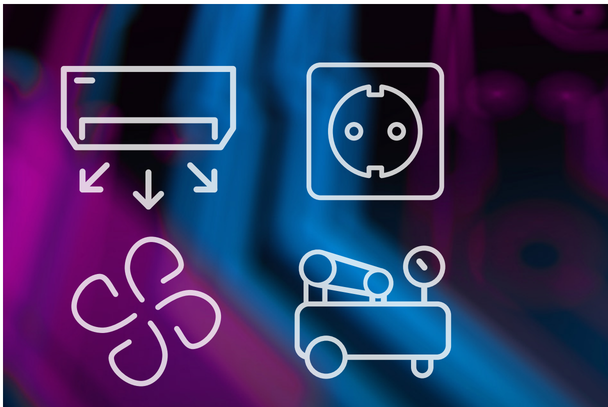
The Evidence – Laboratory Results

In the end, the ultimate question in every form of simulation is: "How close does the simulation get to the real values?" Hence, parallel to the development of the test environment, ABB carried out corresponding measurements in the laboratory, which confirm that the simulation is very accurate (Figure 7).

Summary and Outlook

Having dSPACE "onboard" means simultaneously ensuring speed, safety, and comfort for public transport. With the dSPACE Development Solution, ABB Traction performs realistic real-time HIL simulations for complete drive chain systems, which have now been extended to auxiliary converters. Encouraged by the excellent results achieved with the EPSS package for auxiliary simulation, ABB Traction will continue to develop the HIL simulator to include even more complex setups in the simulation scope. ■

Dr. Roxana Ionutiu, ABB



Auxiliary converter loads on the vehicle are simulated in real time.

***Additional thanks** to ABB colleagues Thomas Steiner, Dr. Sergio Fraga, Benjamin Grichting, Dr. Gina Steinke, and Thomas Maier for their contribution in several development stages of the AUX RTS, and David Brügger for setting up measurements on the real Auxiliary system in the lab.*

Dr. Roxana Ionutiu

Dr. Roxana Ionutiu

Dr. Roxana Ionutiu is Principal Engineer for Real-Time Simulation at ABB's Traction Division in Turgi, Switzerland.

E-Mission-Free on the Road

How will trucks, buses, and heavy equipment be powered in the future? For Hyzon Motors Inc., the answer is clear: with hydrogen fuel cells. To this end, the company is not only developing numerous key technologies, but is also actively involved in promoting a supply infrastructure for clean hydrogen. Hyzon relies on dSPACE technology for ECU validation.

The fuel cell provides electrical energy without releasing CO_2 or pollutants and is therefore increasingly attracting the attention of the energy and automotive industries as a climate-friendly energy supplier. In view of special range requirements and efficiency criteria, it is an interesting option in the mobility sector, especially for commercial vehicles. It converts chemical energy released in a reaction between hydrogen and oxygen into electrical energy. Because hydrogen only occurs in nature in compounds, for example, together with oxygen in water, it must first be isolated, often by means of electrolysis. The technology is only truly climate-neutral if the electricity used for this electrolysis has been generated without emissions.

Clean, Affordable, Available Everywhere

U.S.-based Hyzon Motors Inc., headquartered in Rochester, New York, is committed to this goal and is active in the creation of a flexible and robust supply infrastructure for clean hydrogen. The vision: affordable hydrogen that is available everywhere and produced exclusively using renewable resources such as biogas or methane, sun, wind, or waste. Together with various partners, the company is focusing on the local production of hydrogen in order to minimize costly

Developing and validating fuel cell technologies for commercial vehicles

Picture credits: © Hyzon Motors

PEM: Proton-exchange membrane

transportation. In its core business, Hyzon develops and produces emission-free PEM fuel cell systems and integrates them in commercial vehicles such as trucks. The company is one of the world's first OEMs of hydrogen fuel cell powertrain technology utilized in powering heavy-duty commercial vehicles.

No Fuel Cell System Without FCU

The brain of every fuel cell system is the fuel cell control unit (FCU). Using a range of control algorithms, it controls the entire system with its various components such as hydrogen injection, valves, pumps, and compressors. "To make the development of the required FCU software as efficient as possible, we wanted to be able to test and optimize it again and again at very early stages – even well before a real fuel cell system is available," reports Daniel Kang who, as Software Test Manager, is jointly responsible for the development of the controller software at Hyzon Motors. Hyzon therefore needed a system that could be used to test all the functions of an FCU that are relevant to the operation of a fuel cell system and that includes a fuel cell model for simulating the FCU environment. The test solution they were looking for also needed to help the development team with other tasks, such as creating a catalog of automated regression tests that are run on each new software release.

Scalable Test Solution for FCU Software

Hyzon set out to find a provider that could deliver both a suitable platform for hardware-in-the-loop (HIL) testing and a real-time-capable plant model for fuel cell systems. "dSPACE was one of the few vendors that could

>>

"The first software release for the FCU was functional very quickly, because of the numerous preliminary tests we did on the HIL system. We were able to check not only all the basic I/O, but also the closed-loop control loops to make sure that our software worked before we put it on a real system."

Daniel Kang, Software Test Manager, Hyzon Motors Inc.

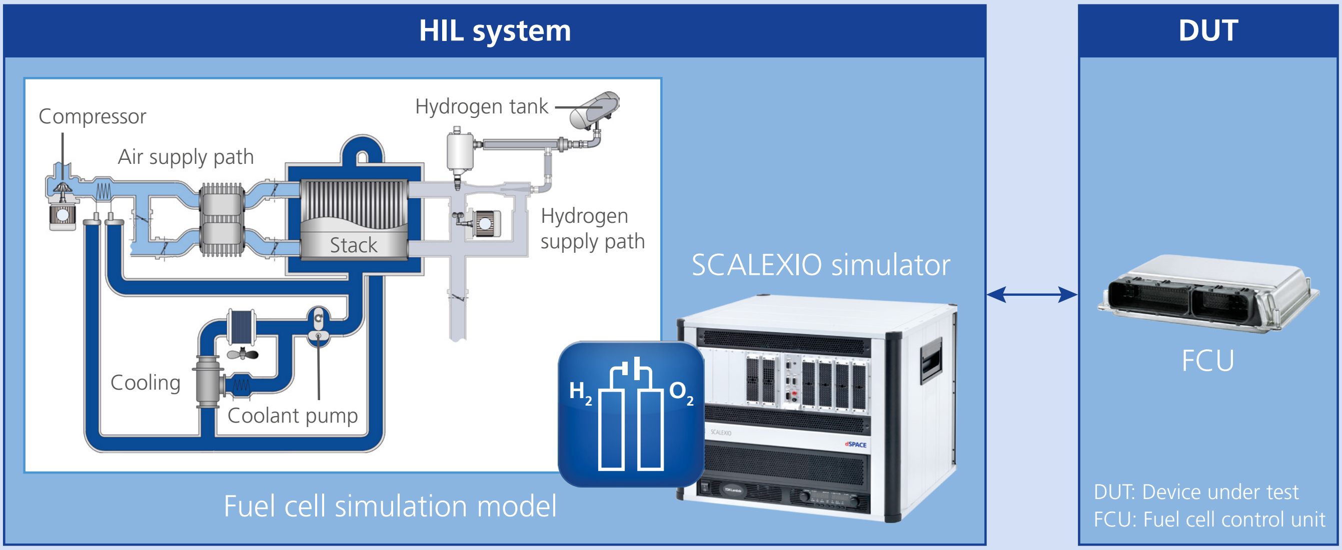
Automated stacking of cell units.

ASM: Automotive Simulation Models

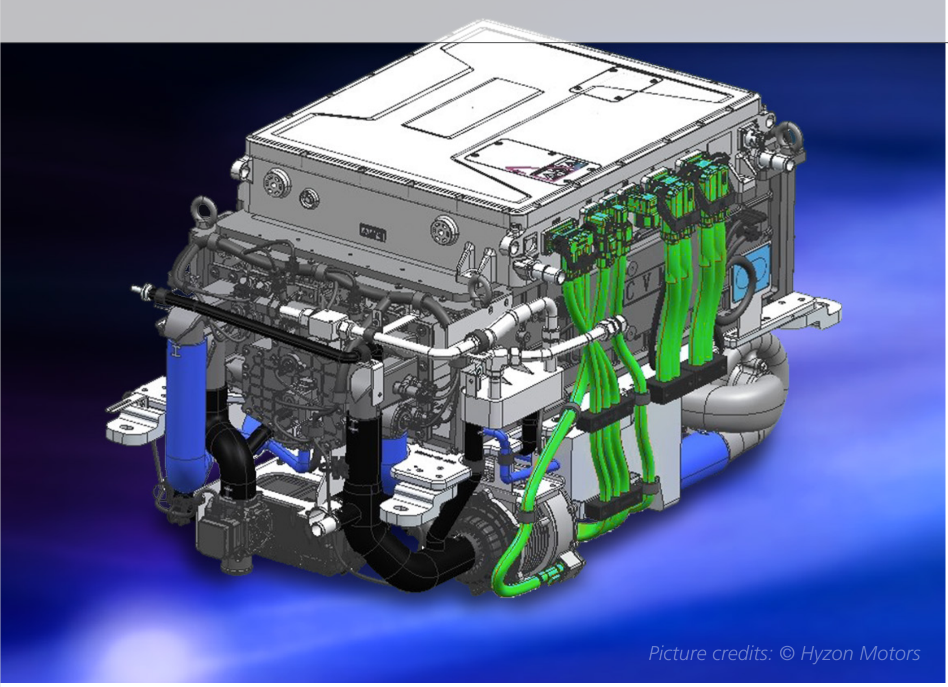
offer both of these products in one integrated solution," says Daniel Kang. Hyzon chose a flexibly scalable HIL test solution from dSPACE with powerful real-time simulation hardware that has all the relevant interfaces for connecting the FCU. On the software side, the solution is completed by the dSPACE ASM Fuel Cell model library, which contains not only the model of the fuel cell system but also models for the powertrain, electric motors, battery, and driving resistance. The solution enables real-time simulation of the fuel cell systems and the creation of a realistic test environment for the FCU. With this combination of HIL system and suitable plant model, the developers were soon able to efficiently test the FCU software and perform initial calibrations without even having to put it on a real system.

Integration of HIL Tests in FCU Development

Today, Hyzon carries out HIL tests with every new FCU software version, for example, to test software functions specifically at component level. The development team also tests new control strategies in the dSPACE HIL system first to make sure they work as expected, or to fix potential problems early on. The possibility of early software calibration has proven to be particularly efficient: When it comes to performance testing in the real system later on, the FCU software is already much more mature than was the case in earlier tests. Meanwhile, the developers also use the dSPACE



Hyzon uses an integrated solution from dSPACE to efficiently test FCUs without having to put them on a real system. The test solution combines powerful real-time simulation hardware with a real-time-capable plant model for fuel cell systems.



Single stack 200 kW fuel cell system.

HIL system to recreate and fix problems that occurred in the real fuel cell system.

From I/O to Closed Loop

The HIL tests Hyzon performs with the dSPACE solution range from basic I/O tests, where all inputs and outputs of the FCU (digital, analog, and CAN) are checked for correct operation, to closed-loop tests of the control loops. As part of the closed-loop tests, the development team checks, for example, whether it is ensured that all setpoints match their actual values after a predefined settling time and thus that all closed control loops are stable. The ASM Fuel Cell simulation model makes it possible to examine the following variables, among others, in detail:

- Anode outlet pressure
- Cathode air flow
- Compressor speed and outlet pressure
- Stack coolant inlet and outlet temperature

First Successes with the dSPACE Solution

"Thanks to the numerous preliminary tests that the development team was able to perform with the HIL system, the first software release for the FCU was functional very quickly – before it was even set up on a real system," Daniel Kang is pleased to report. When the developers were able to deploy the software on a real system, they were able to successfully get it up and running in a relatively short time. They attributed this success to their extensive testing with the HIL system. The HIL system also proves to be a gamechanger when it comes to reproducing potentially critical test scenarios: Operating ranges with cell currents, temperatures, and pressures outside the normal operating range can now be easily included in the tests – without having to fear damage to the real fuel cell system. Being able to rapidly update and expand the functions of the fuel cell system with only a few clicks also enables the development team to test new control software quickly and flexibly on different systems and system versions.

Conclusion and Outlook

When asked about his experience with the dSPACE test solution, Daniel Kang gives very positive feedback: "I have experience with other HIL systems and in my opinion, dSPACE provides some of the best HIL hardware and software in the market. The high scalability of the test systems is outstanding: They are designed in such a way that they can be easily adapted to new configurations. Overall, I'm very happy with the HIL system and how it has helped us improve our software testing capabilities." Currently, Hyzon is already successfully using the HIL systems to develop the next-generation FCU. In addition, Hyzon is continuously working on technological advances across all key components of fuel cells. So we can expect some exciting innovations and product commercialization in the hydrogen sector in the future.

Courtesy of Hyzon Motors Inc.

"In my opinion, dSPACE provides some of the best HIL hardware and software in the market. Overall, I'm very happy with the HIL system and how it has helped us improve our software testing capabilities."

Daniel Kang, Software Test Manager, Hyzon Motors Inc.

In the few years since its foundation in 2014, the Chinese electric vehicle specialist has experienced impressive development. The sales figures have grown rapidly, most recently with a plus of 34% compared with the previous year. At the end of 2021, the number of employees had already reached 15,000 globally. And now that NIO has firmly established itself in the Chinese market, the group is preparing to gain a foothold in the international markets.

Highly Dynamic ECUs, High Voltages

To realize the ambitious plans for growth, the NIO engineers need powerful development tools for the numerous challenges in the development of controller functions for electric motor ECUs. Why? Because electric motors are characterized by extremely dynamic behavior. That is why the associated electric motor ECUs work at very high clock speeds (typically 10-20 kHz). Therefore, the test systems for testing the motor ECUs have to be able to handle these high clock speeds. Added to this is the handling of system voltages beyond 1,000 V.

Decision for SCALEXIO

To also master the various challenges in the future, NIO has evaluated several test systems available on the market. Ultimately, NIO decided to use a test system based on a SCALEXIO HIL simulator and simulation models from dSPACE. Decisive factors included:

- High real-time performance
- Robust emulation of real currents and voltages
- Exact simulation results
- High precision in the measurement and output of electric variables
- User friendliness
- Quick familiarization

Time Savings of 30% Achieved

Already after a short training phase, a team of more than 50 employees was able to use the SCALEXIO system productively for various component

Picture credits: © NIO

Mission: Electric Car

The Chinese electric vehicle specialist NIO relies on dSPACE SCALEXIO simulators for the development of controller functions for electric motors.

tests. In addition, in comparison with the earlier working method, a time saving of more than 30% was achieved. Therefore, the test system based on simulation models and the SCALEXIO HIL simulator now plays a key role in NIO in a wide range of test and validation tasks for the development of new controller functions for innovative electric motors.

Next Step: Integration Test

After the SCALEXIO system has proven its abilities in various component tests, NIO will take the next step and extend the use to a broad spectrum of integration testing. ■

Courtesy of NIO.

"The real-time test system based on simulation models and the SCALEXIO simulator from dSPACE plays a central role at NIO in the processing of test and validation tasks for the development of controller functions for innovative electric motors."

George LU, NIO

Developing Battery Systems for Railroad Applications

Electric Vehicles on Rails

Electromobility has a lot of potential not only on the road, but also on rail. To tap this market, INTILION GmbH, a specialist in energy storage solutions for lithium-ion technology within the Hoppecke Group, uses a wide range of dSPACE equipment.

When people hear the term electromobility, the first thing that comes to mind is battery-powered electric cars. However, there are also many possible applications off the road, including rail vehicles (Figure 1). Depending on the topology of the powertrain, the battery is used here either as the sole or supplementary energy source. Examples include hybrid drive systems with combustion engines, fuel cells, or emergency systems such as those used in subways to travel to the next station if the main drive fails.

Example Shunting Locomotive: Optimizing Workspace

A conventional diesel shunting locomotive at a freight yard has to accelerate and brake many times a day. However, if it is converted to a hybrid drive consisting of a classic diesel generator and an additional electric motor with battery, there are immense advantages, because in part-load operation only the electric motor works with energy from the battery, and in full-load operation the diesel engine supports the electric motor.

In this way, whenever the diesel engine is actually in operation, it always operates in its optimum working range, which significantly reduces fuel consumption, pollutant emissions, and also noise.

Example Mainline Locomotive: Bridging Overhead-Line-Free Routes

Another scenario in which an additional battery-electric drive offers major advantages is a mainline locomotive or railcar on an intercity trip. Because only part of the world's rail network is electrified, conventional, overhead-line electric locomotives cannot operate everywhere. A diesel

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Figure 1: Shunting locomotives (1), track construction vehicles (2), passenger trains (3), and subways (4) are some examples where the use of a battery for rail vehicles is appropriate and brings many advantages, such as lower fuel consumption and reduced pollutant and noise emissions.

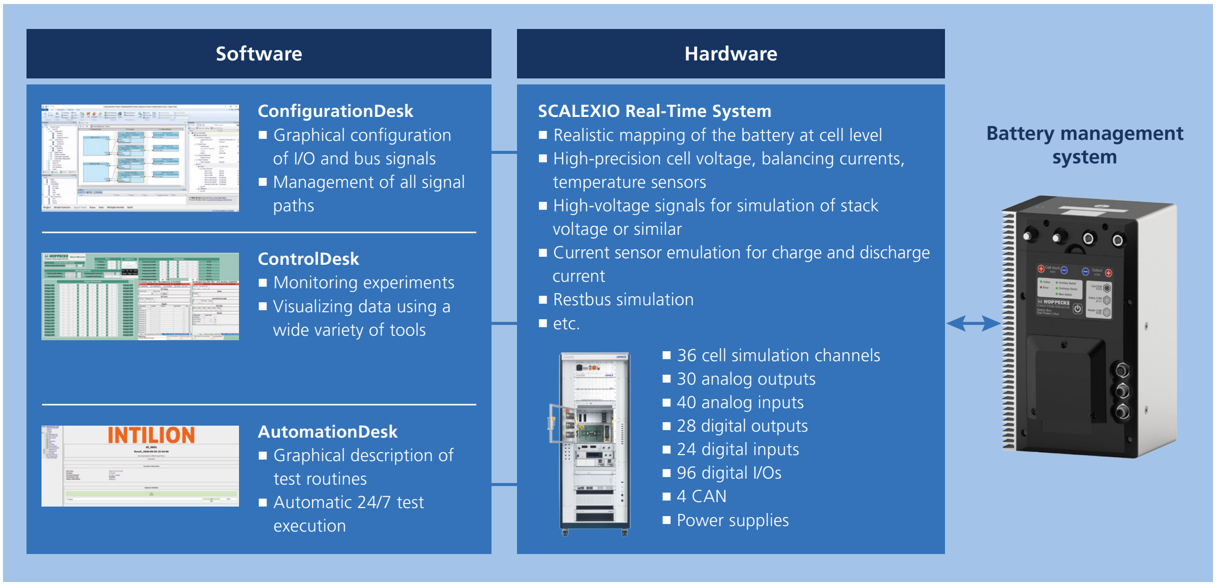


Figure 2: A SCALEXIO real-time system generates battery voltages, currents, and signals that correspond to those of a real test drive. This is used to test the battery management system.

locomotive can then be used to bridge the overhead-line-free sections of track, as is the case today, but the better alternative is an electric locomotive that is connected to an overhead line and has an additional battery to bridge the sections of track without an overhead line.

Testing the Battery Systems in the Laboratory

Just as in road vehicles, the battery in rail vehicles consists of a network of often more than a thousand battery cells that are monitored and controlled by a battery management system (state of charge detection, deep discharge protection, overcharge protection, cell balancing, temperature control, etc.). However, the test runs of locomotives on the regular rail network required to test these battery systems under everyday conditions can hardly be conducted in the midst of the closely timed everyday rail traffic. Virtual test drives in the laboratory are therefore the ideal way to simulate everyday situations and thus comprehensively test the battery systems. INTILION uses a system of dSPACE hardware and software (Figure 2) to generate realistic battery voltages, currents, and signals that exactly match those of a real test drive.

Test Environment Based on dSPACE Hardware and Software

The test system was implemented using a dSPACE SCALEXIO real-time system and a dSPACE software tool chain. The commissioning was successfully carried out using dSPACE Automotive Simulation Models (ASM). Due to the open model structure of the ASM libraries, these were easily supplemented later by INTILION's own models. The battery model was built to generate the typical characteristics of common lithium-ion-based cells (NMC, LTO, LFP, etc.). The connections of the software model to the hardware are configured using dSPACE ConfigurationDesk.
The experiment software dSPACE ControlDesk can be used to monitor experiments and test runs, and to visualize any data using a wide range of instruments. During the test runs, the SCALEXIO system generates all the voltages and currents of a real battery system and other signals required for testing the battery man-

> "Thanks to the dSPACE development environment, all tests can be completed comprehensively, quickly, and automatically, and in accordance with the norms and standards applicable to railroad applications."
>
> *Jan Hergesell, INTILION*

agement system, for example, bus communication to other control units. The responses of the coupled battery management system are then analyzed. The dSPACE AutomationDesk automation software is used to perform the various tests automatically and in a time-saving manner. Numerous templates from a function library allow the automatic tests to be set up very conveniently.

dSPACE Test Environment According to EN ISO/IEC 17025

The test sequences with the dSPACE test environment meet the standards relevant for railroad applications. These include:

- EN ISO/IEC 17025 (Laboratory management)
- EN 50155 (Electronic equipment on railroad vehicles)
- EN 50126, EN 50128, EN 50129 (Functional safety)
- DIN EN 50657 (Software on rail vehicles)
- EN 50121-3-2 (Electromagnetic compatibility)
- EN ISO/IEC 27001 (IT security)

The internationally important laboratory management standard EN ISO/IEC 17025 is of particular importance. To comply with it, laboratories must be accredited in order to be considered technically competent. For many companies and regulatory authorities, compliance with this standard is a basic requirement for cooperation with laboratories.

Cloud-Based Monitoring of All Batteries

During everyday rail traffic, the battery systems of the locomotives can continuously transmit various operating data via 4G to the Hoppecke Connected Cloud (Figure 3). This data includes the state of charge, operating temperature, number of full cycles, and total energy throughput. This global monitoring of battery

Figure 3: (a) The locomotives in everyday use can continuously send a variety of battery operating parameters to the Hoppecke Connected Cloud via 4G. (b) The development department uses the received data for the further development of the control algorithms of the battery systems. In the future, adjusted parameters will also be transmitted directly back to the locomotives (dashed arrow).

systems allows for early fault diagnosis and predictive maintenance of locomotives, minimizing their downtime. In addition, the collected data can also be used to further develop the control algorithms of the battery systems, which can then also increase battery life, among other things.

Second dSPACE Test Bench Ordered

Thanks to the dSPACE development environment, all tests can be completed comprehensively, quickly, and automatically, and in accordance with the norms and standards applicable to railroad applications. Overall, the test bench based on the dSPACE SCALEXIO real-time system provides such good support for testing that INTILION has also equipped the INTILION development center in Shanghai with a test bench. All this boosts the global exchange of know-how (test blocks, Python scripts, etc.) between the INTILION branches, which has once again reduced the effort considerably. ■

Jan Hergesell, INTILION

Jan Hergesell
Jan Hergesell, test engineer at INTILION, Germany.

Shift Gears Quickly

Aisin Corporation is developing a shift-by-wire system that enables automatic gear changes to bring about a more autonomous driving society.

Gear changes must be done safely and as quickly as possible. How do you make sure everything goes right in these few microseconds? This is a task for a simulator that enables 24-hour high-speed testing and saves massive amounts of time during development.

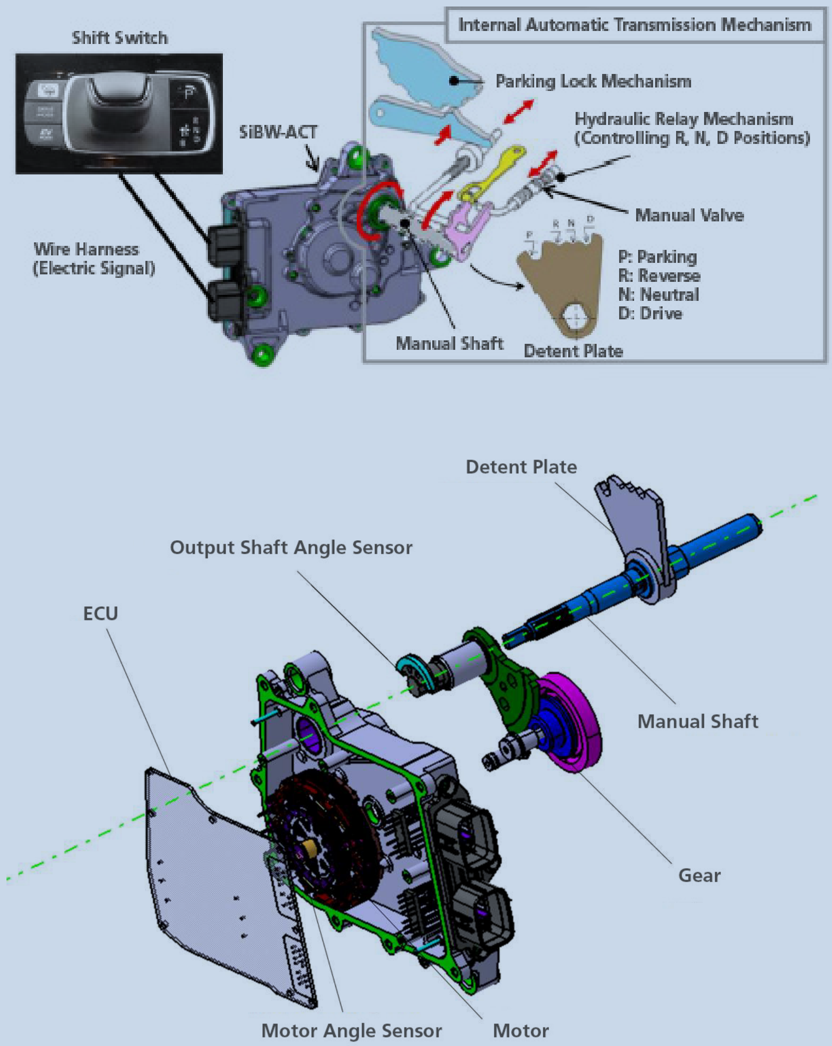


Fig. 1 In shift-by-wire systems, evacuation performance is significantly affected if operation is interrupted due to a fault. Therefore, it is essential to perform operation in a safe state as a fail-safe concept. At the same time, the concept of intrinsic safety calls for a reduction in the number of parts. As a result, Aisin Corporation has developed a highly reliable shift-by-wire actuator with improved evacuation drive performance by implementing an integrated, independent, redundant electrics/electronics (E/E) system as an integrated electromechanical actuator while reducing the number of parts (Fig. 2).

To improve fuel efficiency and reduce the use of environmentally hazardous substances, Aisin Corporation is increasingly turning to electrification. It has developed an integrated electromechanical shift-by-wire system that includes actuators (in this case electric motors), reduction gears, control units, and sensors to make shifting operations more efficient. With shift-by-wire, transmission modes in a vehicle can be switched by electronic controls without a mechanical connection between the gearshift lever and the transmission. This saves weight and space, and it also makes gear changes significantly faster. As the automation of vehicle technology progresses, by-wire technology has become indispensable. Aisin's ideal shift-by-wire system is the achievement of fast and precise shifting as a functional value and electromechanical integration as a safety value.
"We wanted to test the new technology as early as possible during development so that we would have to invest less time in downstream steps," explained Atsuto Ogino, General Manager Chassis and Vehicle Safety System at Aisin. "One of our greatest challenges was to feed faults into the shift-by-wire system at microsecond intervals in order to comprehensively test safety-critical parts of the actuator or electric motor control system. An undertaking that gave us some sleepless nights due to the complexity and precision required."

"dSPACE has a very extensive range of tools to support HIL simulations. With these tools and real-world development of HIL models, we have been able to reduce development times by 60% and the number of person hours spent on development by 30%. dSPACE HIL simulators have helped us perfectly, especially with the great challenges in terms of fault diagnosis."

Atsuto Ogino, General Manager Chassis and Vehicle Safety System Company,
1st Chassis & Vehicle Safety System Engineering Department, System Control Development Section

Simulator for ECU validation.

Software First for More Precise and Faster Development

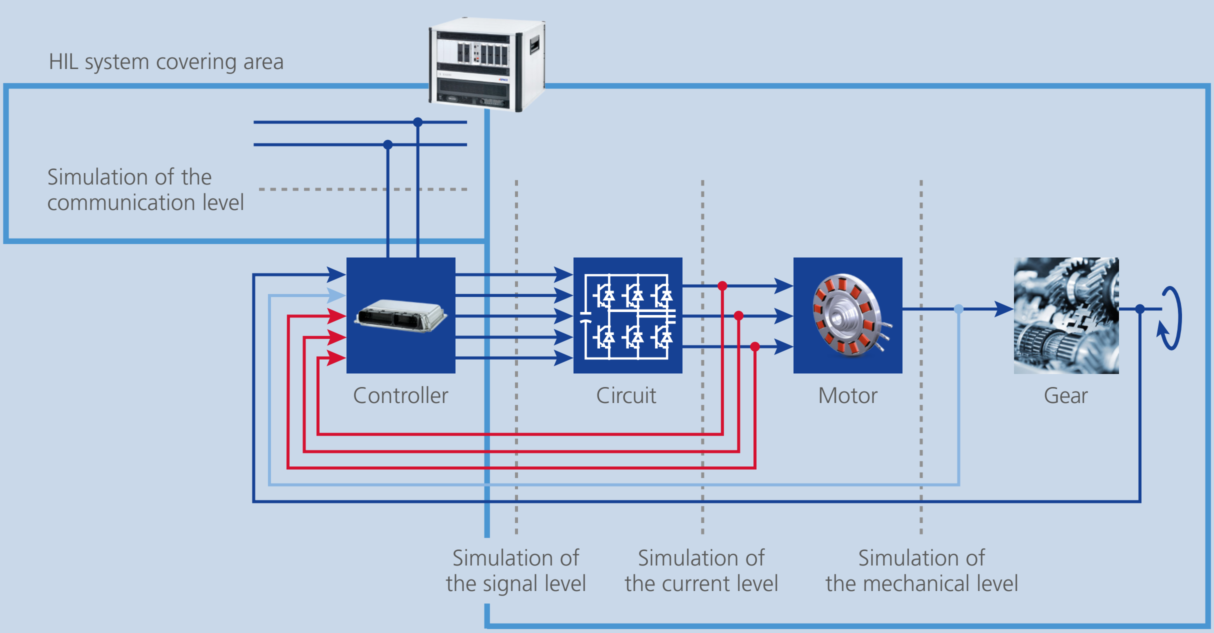
Software is becoming increasingly important not only in vehicles, but also in the field of control system development. There is a 'software first' approach that separates software from hardware and prioritizes software development. Developments that are made through repeated evaluation and refinement of traditional models, which often led to problems when processes did not run according to plan, are therefore increasingly becoming a thing of the past. Instead, the current focus is on ensuring that information gained through simulations in virtual environments is incorporated into development in a timely manner. Based on this experience, the real products can then be implemented much more precisely and quickly.

Processes can be worked out in advance through simulation, so specifications do not necessarily have to complete debugging. Design reviews based on simulation results can also be used to eliminate ambiguous specifications. The basis for this work is the continuous improvement of test environments and tools. These improvements are what makes it possible to use models to evaluate software in virtual environments instead of in real vehicles and machines.

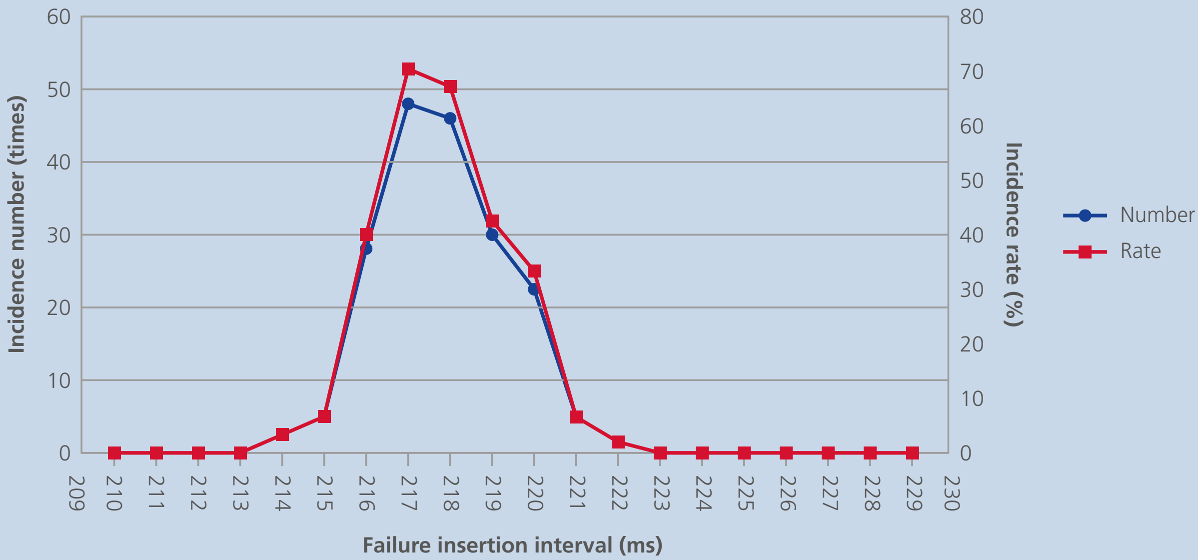
Comprehensive and Reproducible Troubleshooting Thanks to HIL Simulations

Aisin Corporation felt that HIL simulation was suitable for shift-by-wire verification because the shift-by-wire system is an integrated electromechanical product. HIL simulation makes it easy to verify the product during the development process without having an integrated electromechanical prototype.

Among other things, hardware-in-the-loop (HIL) simulations can be used to inject faults that are difficult to inject and reproduce in real vehicles. In addition, managing test patterns in a database ensures reusability, which means >>



At Aisin, HIL development plays an important role. For the new shift-by-wire system, the interaction of control, sensor, motor, and gearbox was put through its paces.



Faults had to be fed in exactly at predefined points in the µs to ns range. A challenge that the HIL simulator mastered with flying colors.

that the patterns can then be used for test bench and real vehicle evaluations. "At Aisin, HIL development plays an important role," Mr. Ogino elaborates. "HIL development combines controls, circuits, motors, and gears. This allows us to respond flexibly in simulations at the communication level, signal level, electrical level, and mechanical level. At a very early stage of development, a detailed e-motor model based on the mechanical design level, was created using a software tool for electromechanical design: JMAG Designer. In addition to the material properties, the exact geometric properties of the stator, the rotor, and the permanent magnets were defined in this model. Using defined network points, a finite element simulation (FEM) was carried out over several days, the results of which were saved in the form of a round trip time (RTT) file. With these results, we were able to finish the controller design by means of model-in-the-loop (MIL) or HIL simulation before the real e-motor was even manufactured."

Mr. Ogino adds: "In times of Covid-19, it was hard for test engineers to be on site for all the tests. At Aisin, the dSPACE HIL system was therefore connected in such a way that it was also available from the home office. To do this, the test engineers loaded test data into a cloud. Then, a PC in the company retrieved this data, ran a test in conjunction with the dSPACE solutions, and sent a test report back to the cloud. This worked smoothly."

Fit for the future: With this control unit, Aisin is addressing the increasing electrification of vehicles and the challenges of autonomous driving.

The electric motor for which the new shift-by-wire system was developed.

Data Feed and Evaluation at Microsecond Intervals

A dSPACE HIL system opened up new possibilities for the engineers to solve the problem of injecting and evaluating faults of varying speed, size, and scope related to safety-critical parts of the motor control system. Mr. Ogino reports: "Since we used a SCALEXIO real-time system equipped with a very fast field-programmable gate array (FPGA) board, we were able to simulate a highly accurate (FEM-based), fast, low-latency electric motor model using the flexible dSPACE XSG Electric Components library and JMAG Addon-Lib. We were also able to evaluate our 24/7 sweep tests on this system."

"Usually, faults are injected at regular intervals, but there were cases where faults only occurred within a specific 10 ms test gap between 213 ms and 223 ms. That was the main challenge we had to face," says Mr. Ogino.

"To master it, we injected selected faults at precisely predefined locations in the µs to ns range. With these faults, we thoroughly tested and evaluated the control system. This worked without any problems thanks to the dSPACE HIL system. We also hardly had to spend any time on test evaluations, as the rest of the tasks were done automatically after review and adjustments."

The evaluations were automatically implemented at night and the completed reports were then immediately forwarded to the parties involved. It was also possible to convert test patterns created for HIL simulations and use them for MIL simulations and vice versa. Both test methods (MIL and HIL) are successfully used at Aisin for real vehicles and machines.

Mission accomplished!

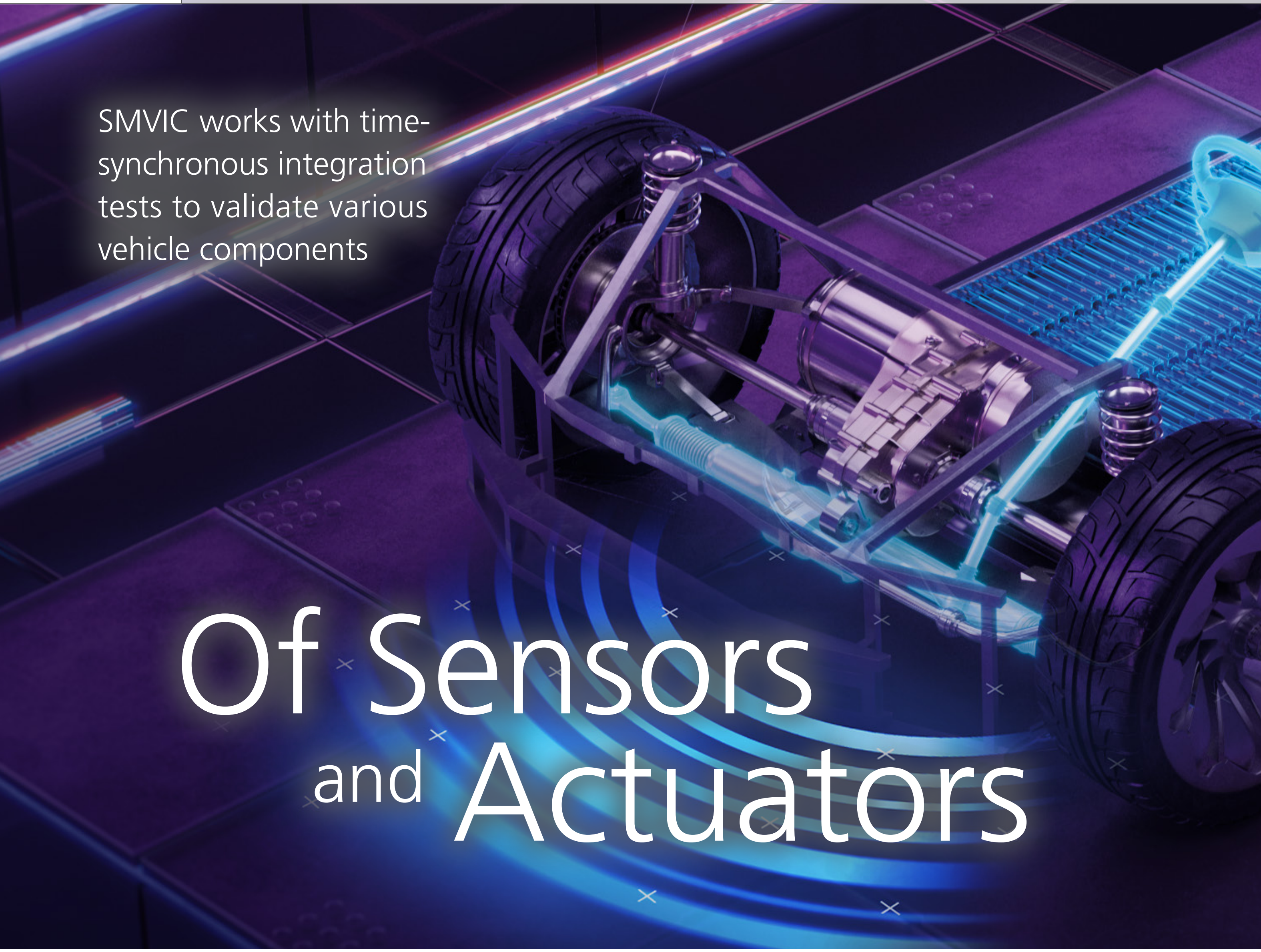
Based on the data obtained via the HIL simulations, Aisin developed a shift-by-wire transmission that provides shifting behavior with great positional accuracy and responsiveness. In addition, thanks to its helical gearing with high deceleration and high efficiency with a small number of teeth, the new system is easy to install.

Shift-by-wire will be used in a wide variety of vehicles in the future. It is an essential pillar for the increasing electrification and advancing autonomous driving. ■

Courtesy of AISIN.

About Aisin

AISIN CORPORATION is a Japanese automotive supplier specializing in the development and production of components for the automotive industry. With the goal of reducing traffic fatalities to zero, the company provides system products that enable advanced control of "driving, turning, and stopping," as well as products that improve driving enjoyment and comfort. The Chassis and Vehicle Safety System Company, of which **Atsuto Ogino** is General Manager, focuses on the development of peripheral monitoring systems, automatic parking systems, and driver monitoring systems. His main focus is on vehicle motion simulation and system and control development.



SMVIC works with time-synchronous integration tests to validate various vehicle components

Of Sensors and Actuators

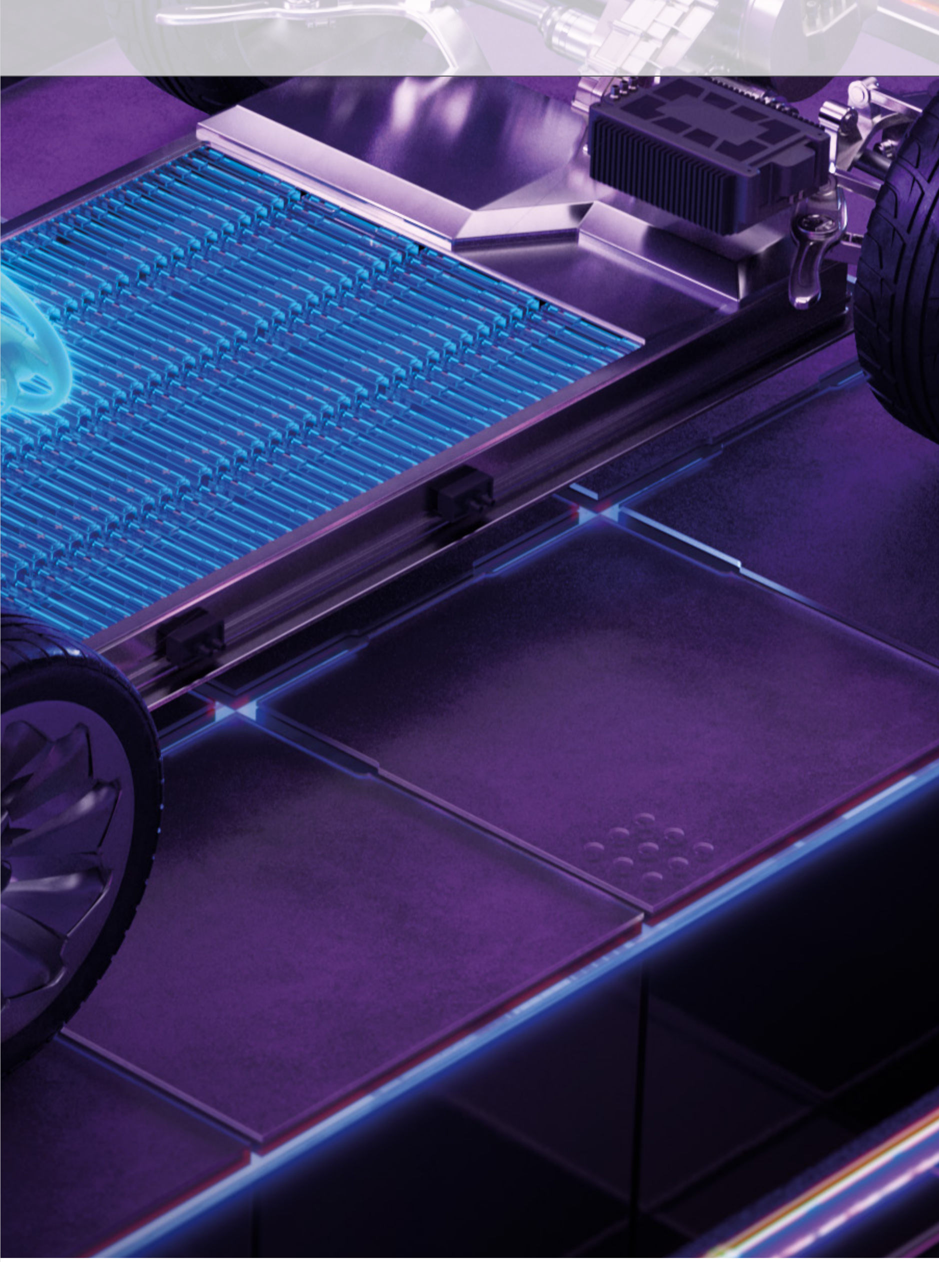
When it comes to simulation and validation, the Shanghai Motor Vehicle Inspection Certification & Tech Innovation Center is well positioned for the future. Recently, the SMVIC was entrusted with the task of comprehensively testing safety-related components of the Big Ant vehicle from Chinese manufacturer Chery. Chery's goal was to implement a complete validation process from sensor to actuator across various test scenarios.

SMVIC

The SMVIC is a Chinese government organization whose overriding goal it is to improve safety on Chinese roads. The focus of the tests was therefore on driver assistance system (ADAS) functions on the one hand and general vehicle safety on the other. This includes hardware-in-the-loop (HIL) testing of ECUs, sensor testing with raw sensor data and over-the-air stimulation as well as the mechanical testing of steering and braking systems. All of these tests took place as part of an integration test: A HIL simulation environment that simulated the entire outside world was used to send data synchronously to all individual components.

Remote Commissioning

During commissioning, project mana-



gers faced travel restrictions imposed by COVID-19. The solution: Much of the handover from dSPACE to the SMVIC team took place virtually. Both sides used videoconferencing to clarify key points. In addition, a dSPACE China engineer employee was on site to carry out the final steps of the handover. dSPACE project manager Henning Elbers commented on this type of cooperation: "Coordination also worked excellently in this way. dSPACE had used webcams during precommissioning to explain to the SMVIC all details. Onsite a dSPACE China colleague did the setup. In order to identify and solve problems at an early stage, the project committee met weekly. In my opinion, this was very useful in this project." Xianchao Zhang, ADS Simulation Advanced Engineer at SMVIC, was also convinced by this kind of cooperation: "This type of collaboration saves time and effort. It worked well during the epidemic period of COVID-19."

Solutions Found

The aim was to perform an integration test in which all the ECUs of a vehicle are security-checked together. To do this, they were connected to a virtual vehicle based on dSPACE Automotive Simulation Models (ASM), which is simulated in real time on a HIL simulator together with the vehicle environment. In order to include components such as actuators and sensors in the test in addition to the ECUs, the simulator has appropriate extensions. For example, a physically accurate environment simulation with dSPACE AURELION for the lidar and camera sensors was to be carried out, and the simulated sensor raw data had to be injected. In addition, a radar sensor was tested using the over-the-air (OTA) method. Furthermore there were also tests that focused on mechanical components. On the one hand, the Big Ant's steering system was tested on a test bench. On the other hand, the SMVIC also subjected the brake to numerous tests on a braking test bench.

Radar Tests on the Physical Level

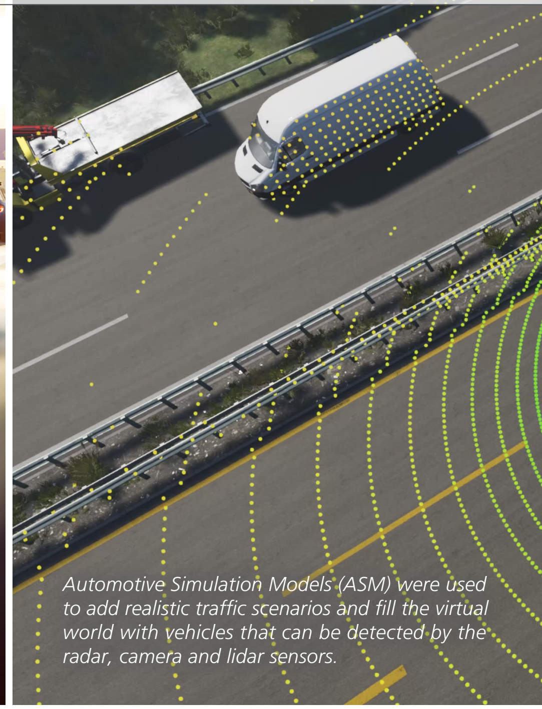
To perform the tests of the radar sensor a Radar Test Bench - Compact 3D was used to realize an over-the-air simulation of radar targets during virtual driving scenarios. The unmodified radar sensor was installed in the test bench and stimulated with generated radar echoes. This was achieved by four dSPACE Automotive Radar Test Systems (DARTS) installed in the test bench. With this test bench it is possible to simulate radar targets with programmable distance, speed, size, and angle. The OTA method allows black-box testing of the radar sensor considering the complete chain of effects. The output of the radar sensor is further processed by the ADAS and used to actuate the steering or braking systems – fully closed-loop and in real-time through dSPACE ASM.
Xianchao Zhang on the benefits: "With DARTS and dSPACE Radar Test Bench, we were able to test radar sensors for safety-relevant criteria in complex traffic scenarios with critical driving situations. They help us to fulfill the tasks required by law efficiently and easily verifiable."

Lidar and Camera Simulation

The camera sensors were tested by so called raw data simulation and the lidar sensor is simulated on point-cloud level. With the physics-based rendering and the extended 3D point cloud as two core elements of dSPACE AURELION, the sensor-realistic >>

AURELION=
Sensor Realistic Simulation

AURELION from dSPACE provided a physically accurate environment simulation for the tests.



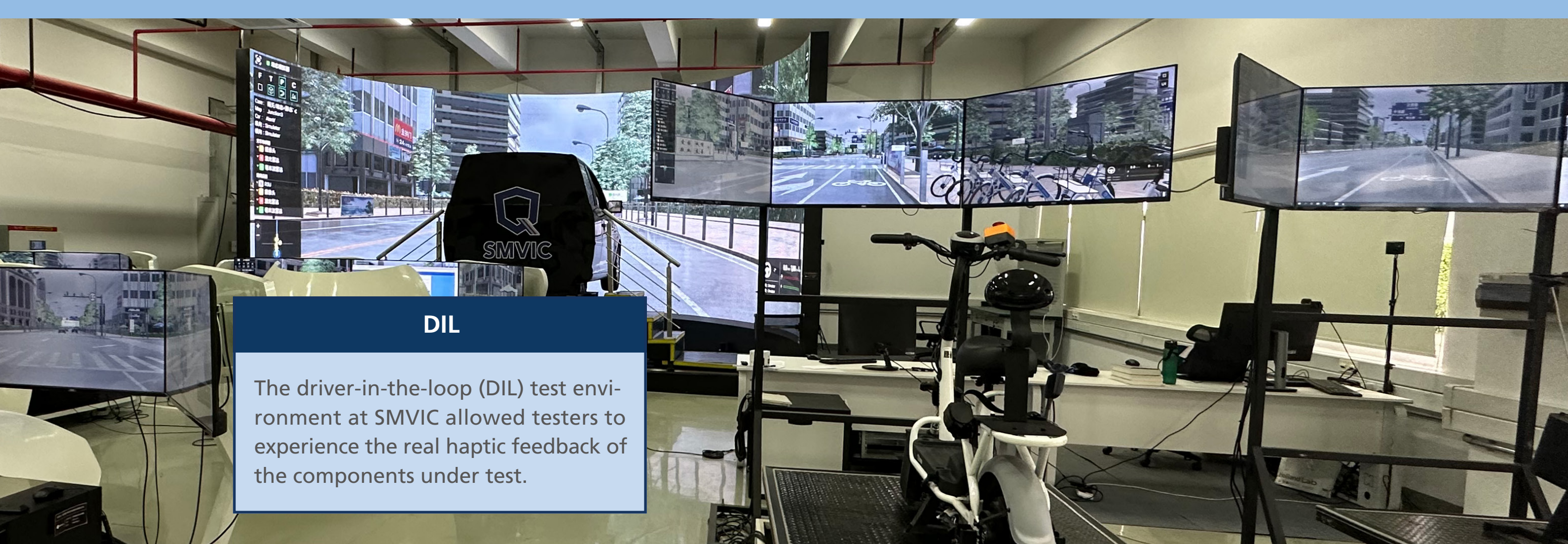
Automotive Simulation Models (ASM) were used to add realistic traffic scenarios and fill the virtual world with vehicles that can be detected by the radar, camera and lidar sensors.

simulation is the most efficient way of generating the sensor raw data required for this. The basic premise behind sensor-realistic simulation is that sensor models mimic real sensors by generating the same kinds of data. These data is converted into electrical signals to simulate the camera and lidar sensors. As part of the HIL system three high performance Sensor Simulation PCs connected to dSPACE Environment Sensor Interface (ESI) units did the job for the lidar and camera sensors – synchronized. Xianchao Zhang commented: "The realistic sensor simulation from dSPACE is a major improvement in lidar and camera sensor validation. The flexibility and quality of the simulation fulfills our requirements."

Steering and Brakes Put Through Their Paces

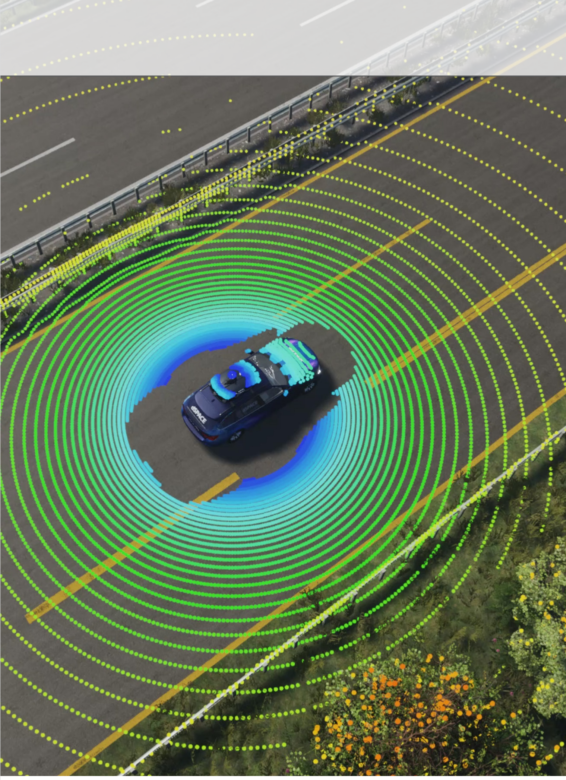
With the steering test bench, the SMVIC has a mechatronic test environment with which it is possible to realistically test the steering behavior of a vehicle under laboratory conditions using HIL simulation. The steering system is integrated in a fully closed-loop setup where the displacement of the steering rack is fed back into the simulation model to directly impact on the vehicle dynamics. In this way, the requirements for the safety of the steering of the Big Ant vehicle can be objectively evaluated in the context of ADAS operations such as lane keeping or automated parking.
For testing the brakes, a second testbench is designed so that an electro-hydraulic brake systems can be tested

The SMVIC offers solutions for the various tests



DIL

The driver-in-the-loop (DIL) test environment at SMVIC allowed testers to experience the real haptic feedback of the components under test.



"Thanks to the cross-component dSPACE HIL system, we were able to test the mechanical components such as the steering and brake in direct interaction with the sensors to check that everything worked together correctly.
The unbeatable advantage of the dSPACE solutions was their absolute time synchronization and fully-closed loop setup."

Xianchao Zhang,
ADS Simulation Advanced Engineer at SMVIC

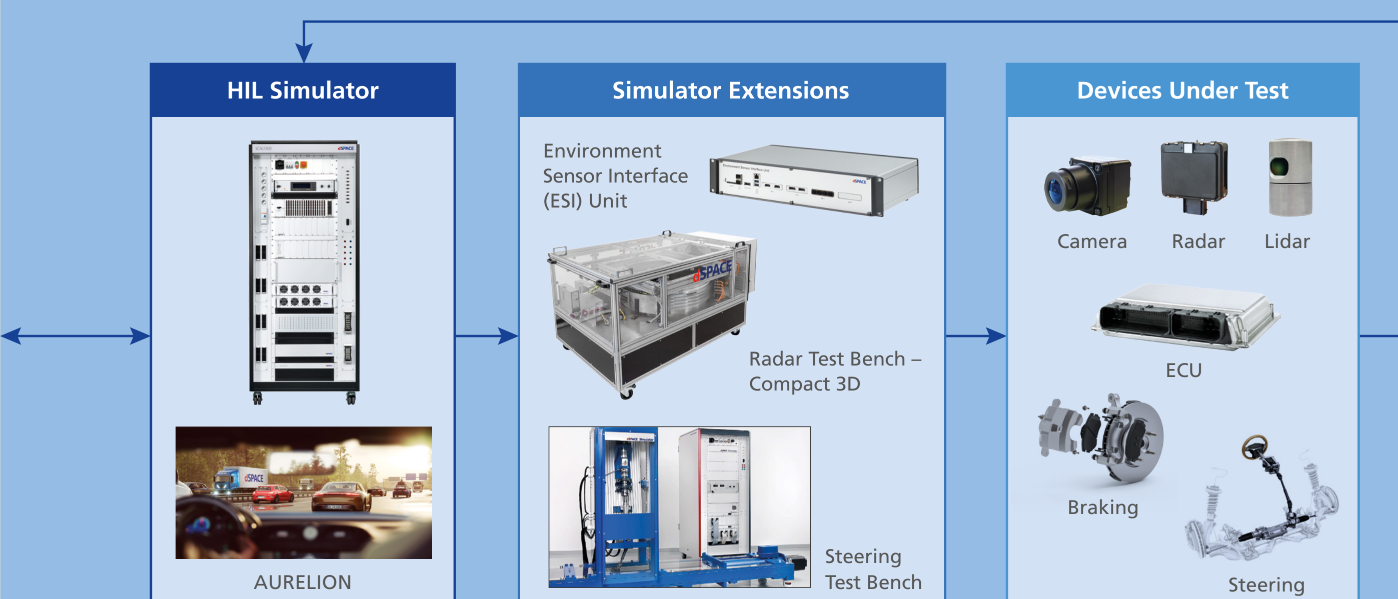
under realistic operating conditions. For this purpose, the vehicle dynamics model of dSPACE ASM is integrated and allows for a realistic consideration of the effective braking forces to the brakes via a linear actuator. In this way, braking behavior during automated emergency braking, adaptive cruise control and other assistance functions can be realistically evaluated. Xianchao Zhang explained: "Thanks to the cross-component dSPACE HIL system, we were able to test the mechanical components such as the steering and brake in direct interaction with the sensors to check that everything worked together correctly. The unbeatable advantage of the dSPACE solutions was their absolute time synchronization and fully-closed loop setup."

Expandable for the Future

In addition to testing the above-mentioned systems, the SMVIC also offers a driver-in-the-loop (DIL) environment, so that in addition to these test scenarios, testers can also experience haptic feedback directly. This will allow a wide variety of tests to be done in the future in order to meet the most diverse customer requirements. Here, dSPACE tools play the key element for simulation and validation. ■

DIL= Driver-in-the-Loop

Courtesy of Shanghai Motor Vehicle Inspection Certification & Tech Innovation Center (SMVIC)

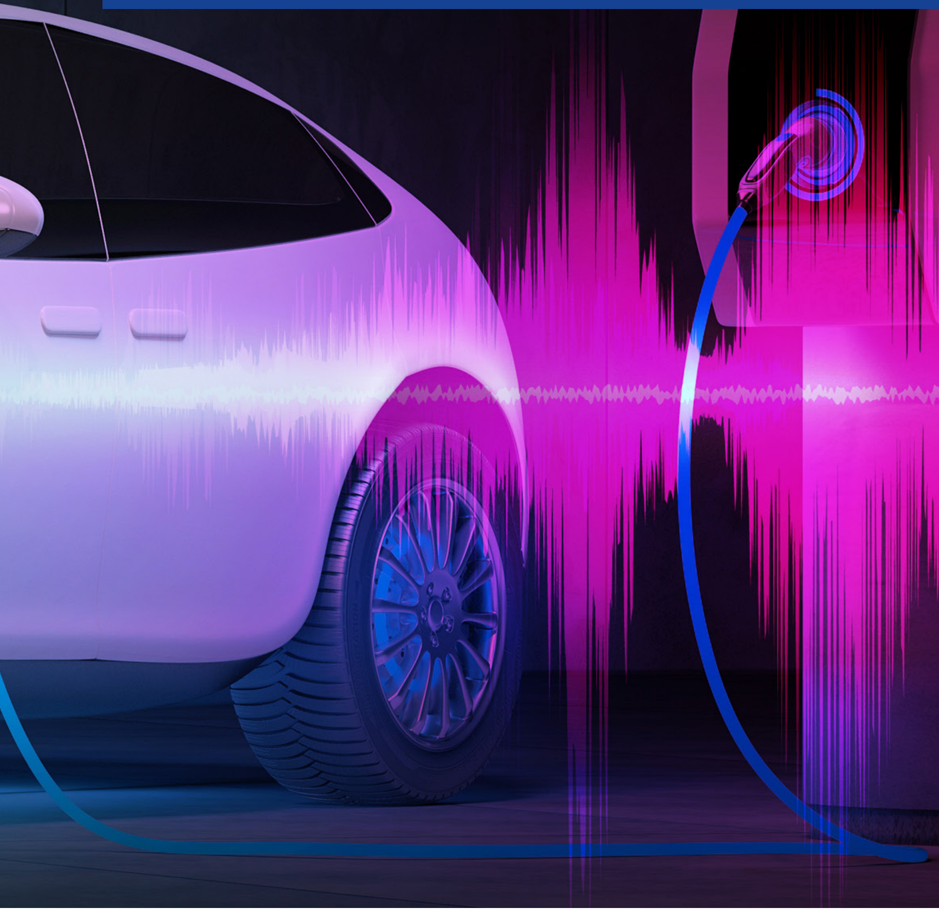


SiC drive inverters combined with dSPACE real-time system provide noise reduction in electric drives

Noise-Reducing Software

Electric vehicles are surprisingly quiet. If the acoustic character of their drives is to be deliberately altered, noise shaping by controller interventions is used. A test bench at the Fraunhofer IWU (Institute for Machine Tools and Forming Technology) in Dresden offers developers a powerful tool for suitable sound design with real electric components.

> "The MicroLabBox has exactly the right computing power and flexibility to specifically optimize the highly dynamic controllers of electric drives by high-precision injection of current harmonics for the sound design."
>
> *Dr. Thomas Windisch, Fraunhofer Institute for Machine Tools and Forming Technology IWU*

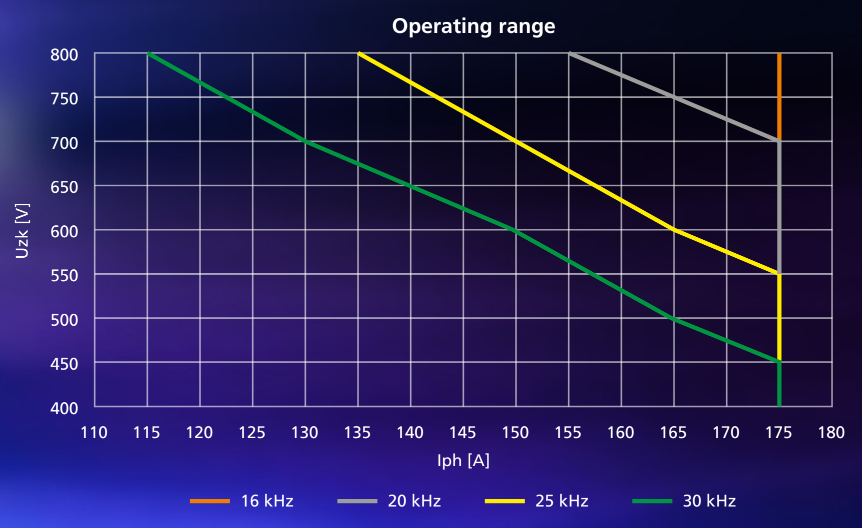


As a megatrend in the automotive industry, electromobility is driving almost all vehicle manufacturers and suppliers to develop and test new electric drives. The primary objectives are high efficiency in the drive cycle and high torque or power density at low overall system costs. In addition, particularly strict limits must be complied with in terms of noise emissions (noise vibration harshness, NVH). For battery electric vehicles, mainly electric axles, which combine the electronic control unit (ECU), inverter, e-motor, and differential transmission, are being developed for the front and rear axles. For hybrid vehicles, the electric drive is mostly integrated into the transmission housing.

Virtual Design of the Drive

Various types of machines can be considered for vehicle propulsion: permanent magnet synchronous machines (PMSM), separately excited synchronous machines, synchronous reluctance machines, and asynchronous machines. Using analytical calculations and numerical simulations, all variants can be designed and compared virtually on the computer. However, for a rapid market launch, it is essential to put the prototypes to the test as early as possible. To test the e-machine or the complete e-axis in its housing as realistically as possible and to further optimize the software parameters, a rapid control prototyping system such as the dSPACE MicroLabBox can be coupled with a universal power electronics output stage. For this, the company M&P Motion Control and Power Electronics GmbH (M&P) has developed a new experiment power converter with silicone-carbide (SiC) components, which has a special interface to the MicroLabBox. The Fraunhofer IWU uses this converter to develop active processes for noise reduction and to test these on prototype vehicle drives. The field-oriented current >>

Left: Outer view of the ready-built SiC experiment power converter
Right: Inner view of the ready-built SiC experiment power converter including MicroLabBox



Permissible operating range of the SiC experiment power converter per module.

"The MicroLabBox has all interfaces to control our power converters for the emulation of higher currents and voltages. In operation, it proves to be extremely reliable."

Ludwig Schlegel, M&P Motion Control and Power Electronics GmbH

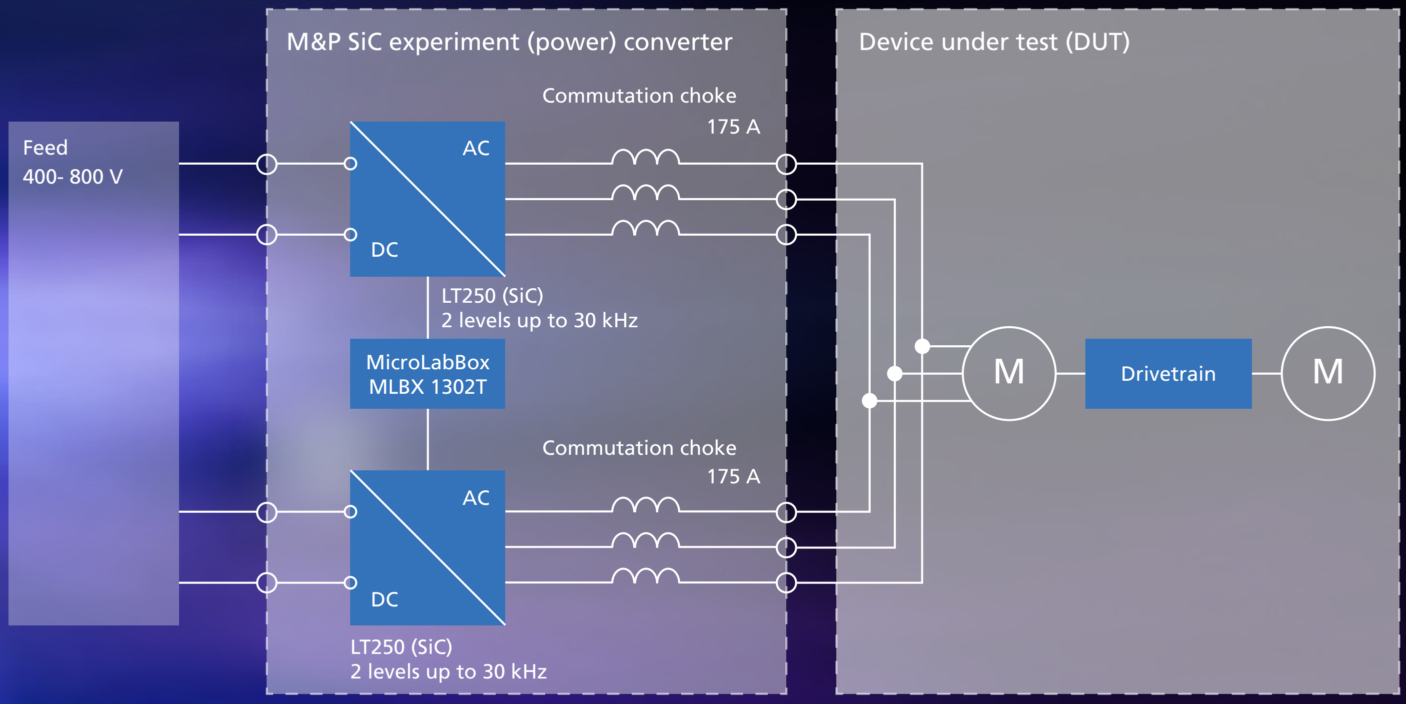
control (FOC) intervenes to selectively cancel out disturbing tonal noise components of the drive.

Safe Operation of Electric Components with Real Currents and Voltages

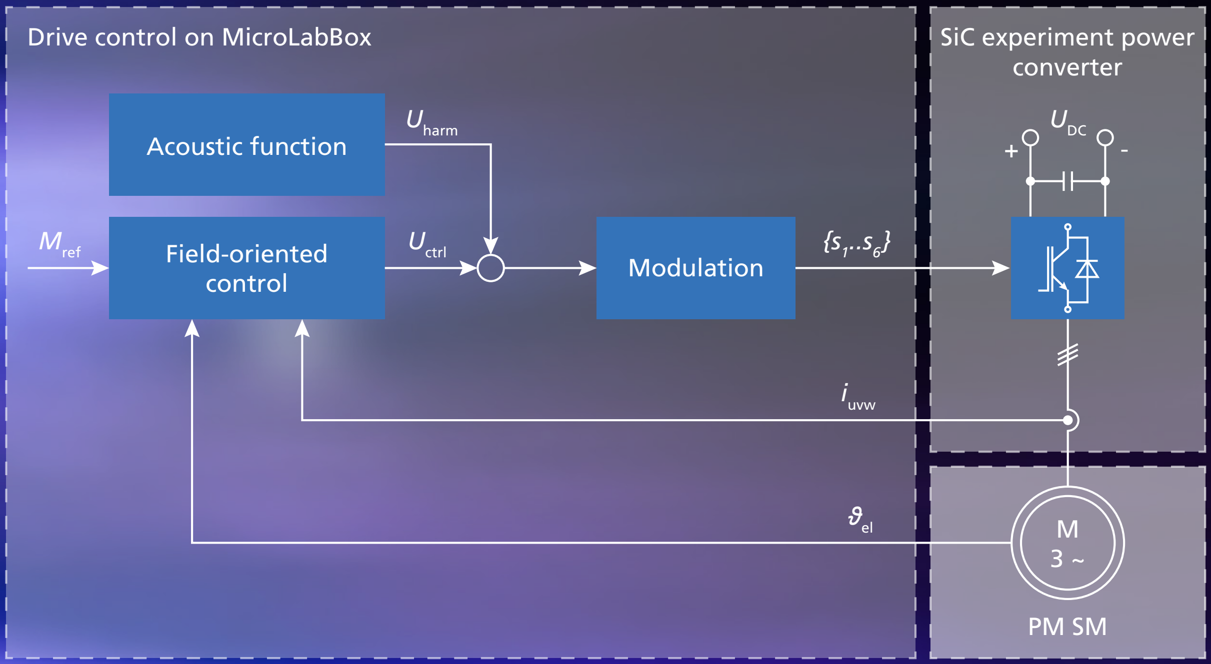
The experiment power converter consists of two modules and, as a result of the various interfaces, allows two machines to be operated with a maximum of 175 A phase current or one machine with a maximum of 350 A phase current in parallel operation using a real-time system. The maximum switching frequency is 30 kHz, thanks to the SiC technology. With this, control, modulation, thermal models, etc., can be developed and tested in Simulink. Then they can be tested directly on the MicroLabBox with the SiC experiment power converter on the real drive system. This tool chain allows for a seamless transition between simulation and testing of the active noise-reducing software components.

The experiment power converter can be expanded with additional hardware, such as additional throttles or a net filter. This way, it can also be used for the following applications, in addition to drive systems:

- Mains simulation
- Feed-in (AC/DC in the mains)
- Battery simulation (DC/DC)



Setup of the SIC experiment power converter with power supply and unit under test. The unit under test consists of the drive machine, transmission, and load machine.



Acoustic function within field-oriented drive control on the dSPACE MicroLabBox.

Electric Vehicle Drive Successfully Put into Operation

The first use of the system was the commissioning of a field-oriented control (FOC) for a vehicle drive with PMSM, including space vector modulation and active noise reduction, on the Fraunhofer IWU acoustic drive and transmission test bench (AGPS). This demonstrated that the acceleration noise level of the main motor on the housing in radial direction can be reduced by about 30 dB by active noise reduction, thereby reducing the combined noise level by about 5 dB. In particular, high-frequency tonal noise components of the electric drive, which are unpleasant for occupants of the vehicle and other road users, can be reduced very effectively using software.

How does the MicroLabBox perform on the test bench?

The MicroLabBox can be easily integrated into the test bench due to its compact design. It also has valuable electronic features which perfectly support its use with a test bench. These include:

- Relevant interfaces for the communication with various test bench components
- Fast updates of the controller software to quickly verify the effectiveness of the algorithms
- High-precision generation of pulse patterns
- High-precision evaluation of sensor signals

The combination of powerful processor, fast FPGA, and directly connected I/O provides the performance necessary for the high-precision injection of current harmonics (integer multiples of the fundamental frequency or AC current) at sampling rates of up to 33 µs.

A Service for the Automotive Industry

Thanks to the test bench, the IWU is able to perform detailed noise vibration harshness (NVH) analyses of drive systems. On customer requests, rule algorithms are developed and the influence of the acoustic system behavior is verified. ■

Ludwig Schlegel, Dr. Thomas Windisch

Ludwig Schlegel
Ludwig Schlegel is the head of hardware development for power electronics at M&P in Dresden.

Dr. Thomas Windisch
Dr. Thomas Windisch is group manager for Powertrain Acoustics at the Fraunhofer Institute for Machine Tools and Forming Technology in Dresden.

What is the future of periodic technical inspection (PTI) for autonomous and automated vehicles? This is the question that the Germany-based Kraftfahrzeug-Überwachungsorganisation freiberuflicher Kfz-Sachverständiger (KÜS, motor vehicle inspection association of freelance motor vehicle experts) has been investigating. With its innovative KÜS DRIVE test bench, it is testing the limits of what is possible. dSPACE is providing active support to the organization.

Picture credit © KÜS

Regular Testing of Driver Assistance Systems

Regular testing as the key to long-term vehicle safety

All car owners in Germany know that their vehicle has to regularly pass a mandatory PTI. In accordance with the German Road Traffic Licensing Regulations (StVZO), a test engineer examines safety-relevant mostly mechatronic, vehicle components such as lighting, brakes, the drivetrain under the vehicle, tires, etc., with regard to design, condition, function, and effect. These examinations are supported by a main inspection adapter, which communicates with the vehicle

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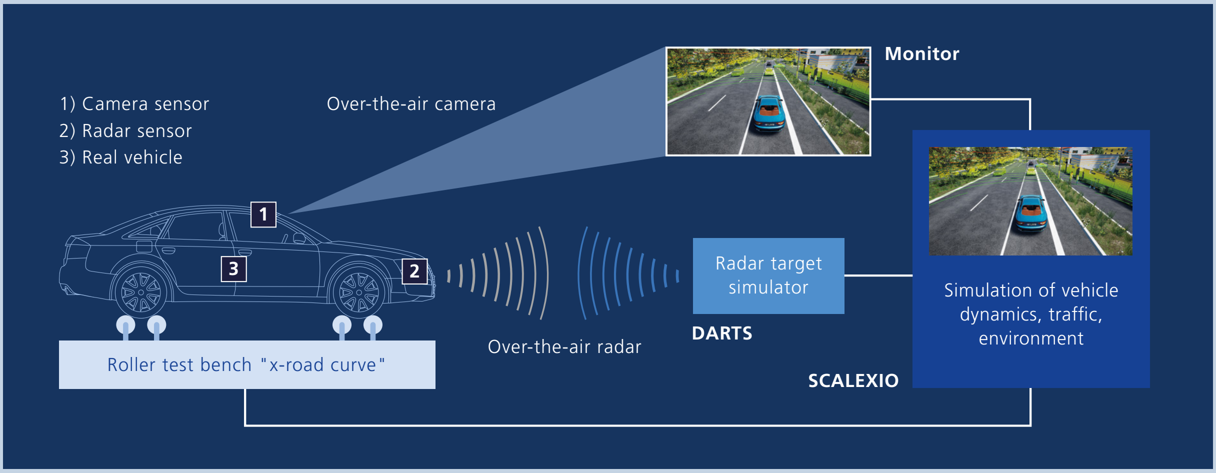
Picture credit © KÜS

The KÜS DRIVE test line is designed for testing automated vehicles.



Schematic representation of the vehicle-in-the-loop (VIL) test in the KÜS DRIVE test line. The setup consists of a steerable chassis dynamometer (x-road curve) and a simulator (SCALEXIO). The virtual vehicle environment generated by the simulator is made available to vehicle sensors at the physical level by means of over-the-air (OTA) processes. The sensors of the vehicles under test record physical quantities and the vehicle assistance systems can respond to these.

via the onboard diagnostics (OBD) interface. Due to the rapid technological development of vehicles, which is characterized in particular by the integration of advanced driver assistance systems (ADAS), the test contents of the PTI must also keep pace with this development, in order to continue to ensure road safety. Camera sensors have long been monitoring lane compliance and alerting drivers when they cross the sidelines. And if the car comes dangerously close to road users ahead, the autonomous emergency braking system (AEBS) intervenes and eases the situation.

Safe Over the Entire Vehicle Life Cycle

The first drivers on the road with cars that recognize their surroundings and drive partly autonomously, called level 2 and level 3 vehicles, rely on these and other sensors. "But how can the functional reliability of these sensitive components be ensured over the entire vehicle life cycle?" asks Dr. Thomas Tentrup, head of development at KÜS, addressing, the industry-wide question. To meet this safety-critical challenge, the German testing organization KÜS, with the support of dSPACE, has developed and implemented the KÜS DRIVE test line. This makes it possible to stimulate a vehicle's environment sensors without any manipulation of the test cars and without accessing their relevant ADAS control units. This solution facilitates the performance of relevant, scenario-based, effect-principle tests in accordance with the United Nations Economic Commission for Europe (UN-ECE) and the New Car Assessment Program (NCAP). Non-contact testing of imaging sensors using physical inputs such as radar, lidar, ultrasound, or light waves is referred to as over-the-air (OTA) testing.

dSPACE Automotive Radar Test Systems (DARTS): Over-the-air simulation of radar targets for vehicle radar sensors on the physical level.

OTA Stimulation of the Vehicle Sensors

"For valid and reproducible results, we use the vehicle-in-the-loop (VIL) simulation method, in which a real vehicle is tested in a virtual environment," explains Ahmet Karaduman, consultant at dSPACE. He adds: "This form of validation can be used

VIL: Vehicle-in-the-Loop

The dSPACE simulation solutions create a reproducible, realistic virtual world including complex driving scenarios.

"With its expertise in the field of periodic technical inspections, KÜS is a valued and promising development partner for us."

Ahmet Karaduman, consultant, dSPACE

not only in PTI, but also in end-of-line testing in automotive production, type approval/homologation, and R&D purposes." During the VIL test, the vehicle is located on Dürr Assembly's steerable roller dynamometer 'x-road curve' and is able to be quickly and accurately accelerated, braked, or steered to the right and left by the driver, according to the respective test scenario to be run. Due to the technical characteristics of the chassis dynamometer, the vehicle always remains positioned longitudinally with respect to the axis of symmetry of the dynamometer and can travel at speeds of up to 130 km/h.
Using the software interface between the steerable chassis dynamometer and the dSPACE tool chain, it is possible to transfer the real physical movements of the vehicle to a digital shadow. The shadow is calculated in real time on a simulator from dSPACE, together with the vehicle environment. The simulation feeds a monitor and radar target simulator to the OTA stimulation of the camera and radar sensors.

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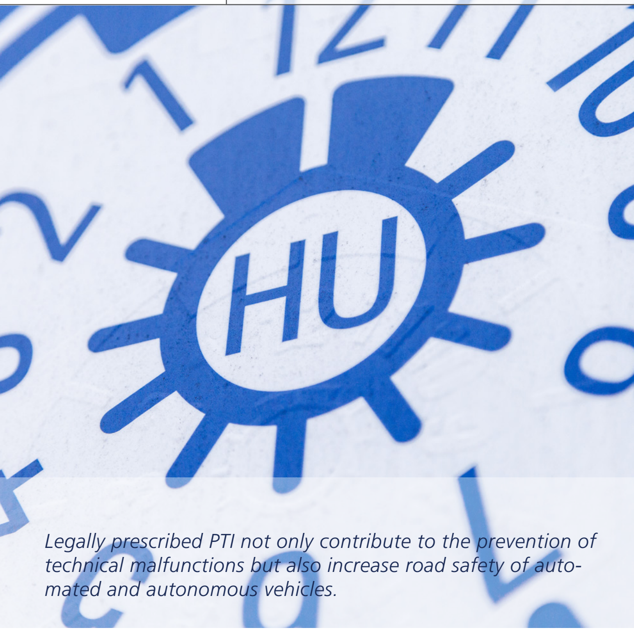
Scenario-Based Impact Principle Testing According to the OTA Method

The impact principle test technique (in short: impact test) checks the response of a technical overall system to a known, defined impulse and evaluates the difference of the response of the system with the target response. For the impact testing of driver assistance systems, this means that the stimulation via the sensor system is physical and direct (over the air), as on the road. This avoids direct access to the electronic control units, which enables assessment of the entire functional chain.



Legally prescribed PTI not only contribute to the prevention of technical malfunctions but also increase road safety of automated and autonomous vehicles.

Picture credit © KÜS

Functions for automated driving can be tested efficiently and reproducibly using vehicle-in-the-loop (VIL) testing.

The Test Setup for the Sensor System

"A monitor and a radar antenna are integrated into the test line and located directly in front of the vehicle under test. Both can be positioned horizontally, vertically and axially by means of the flexible gantry system "x-around" from Dürr Assembly Products," says Karaduman, describing the setup for the sensor test. The monitor stimulates the vehicle's camera with environment and road scenarios animated by the sensor-realistic simulation solution AURELION in the form of a 3-D world. The visualization is used to check whether the camera sensor of the vehicle under test (VUT) correctly detects the relevant objects. The correct functioning of the lane keeping assistance system (LKAS) and the lane departure warning system (LDWS) is also tested with suitable road simulations. To test the radar sensor, the antenna of the dSPACE Automotive Radar Test Systems (DARTS) radar target simulator is positioned directly in front of the sensor. DARTS emits the radar reflections of a simulated target object. The reflection waves accurately reflect the distance, size, and speed of the object, thereby stimulating the radar sensor. This enables reproducible testing of adaptive cruise control (ACC) and autonomous emergency braking system (AEBS) which is safe for the test engineers. The homogeneous and coordinated hardware and software components of the test bench thus enable a stable test sequence in real time. If required, test cases can be reproduced exactly to prove the successful elimination of errors. "Reproducible results are essential for the evaluation of technical tests, especially during a periodical inspection," notes Dr. Tentrup.

LKAS: Lane Keeping Assistance System

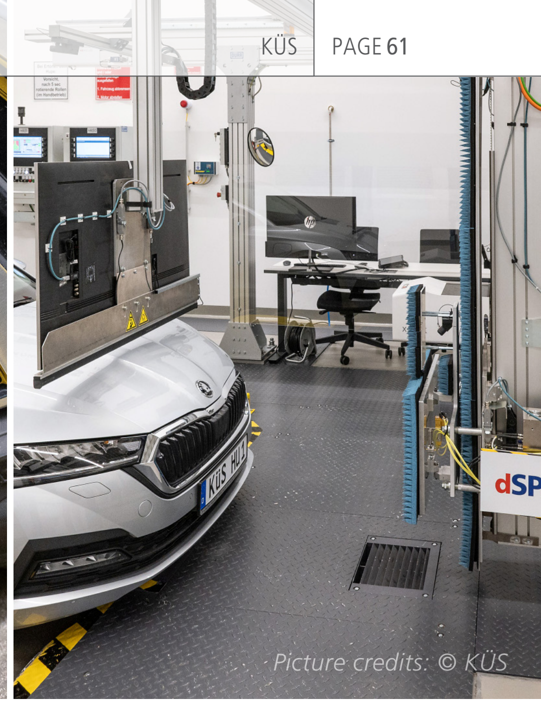
Looking to the Future

KÜS recognized at an early stage that automation in the automotive sector entails a wide range of safety issues for road-legal vehicles with a high degree of automation that need to be resolved. In order to keep pace with this technological progress in the field of functions for automated driving and driver assistance systems, the requirements for the periodic technical inspection regulated by law are constantly increasing. "For this reason, KÜS launched a research project with the KÜS DRIVE with the aim of integrating the current test scopes of the main inspection into a test lane in which the safety-relevant driver assistance systems can also be tested by means of OTA testing." With DRIVE, we are working on the innovations of tomorrow, to advance solutions to improve vehicle safety and the func-

OTA: Over-the-Air

"With the dSPACE simulation solution, we have a flexibly configurable way to efficiently and reliably check the correct functioning of sensors and driver assistance systems of real vehicles in our test centers."

Dr. Thomas Tentrup, Head of Development, KÜS



Picture credits: © KÜS

tional safety of assistance systems and automated driving throughout the entire product life cycle," explains Peter Schuler, CEO of KÜS.

Adapting PTI to Automated and Autonomous Vehicles (SAE Level 3)

Legally prescribed PTI not only contribute to the prevention of technical malfunctions but also increase road safety. Advanced driver assistance systems (ADAS) are capable of significantly reducing accidents caused by human error or incapacity. For this to happen, however, these systems must function error-free over the entire life cycle of the vehicle. Possible disruptive factors are:

- Aging of material and components
- Defective or faulty maintenance
- Manipulation of components and systems
- Unauthorized or excessive tuning
- Limits of self-diagnosis

The detection of technical defects and thus the maintenance of traffic safety is ensured, among other things, by the periodic inspection. For example, adaptive cruise control (ACC) and emergency braking assistants (AEB) can prevent rear-end collisions even at high speeds and thus contribute significantly to reducing the number of accidents. It is especially in these accidents, where a moving vehicle collides with a vehicle traveling in the same direction or a stationary vehicle, that many fatalities and serious injuries occur in addition to the high property damage. However, incorrect triggering of an emergency brake assistant that is not set correctly can also lead to rear-end collisions.

Periodic Check of Safety Systems

In the course of developments in the automotive sector, it is clear that the importance of driver assistance systems is changing. "While they were initially 'comfort systems' that made it easier for the driver to drive the car, they are increasingly evolving into 'safety systems'," Karaduman explains. From this point of view, it becomes clear how indispensable it is to include these systems in the framework of periodic technical inspection and to create the legal basis for this. The KÜS DRIVE test line already demonstrates a convincing technical solution concept for the new test scope requirements for regular main inspections of automated vehicles. The safety of functions for automated driving can be tested and demonstrated in suitably equipped test centers over the life cycle of a vehicle. ■

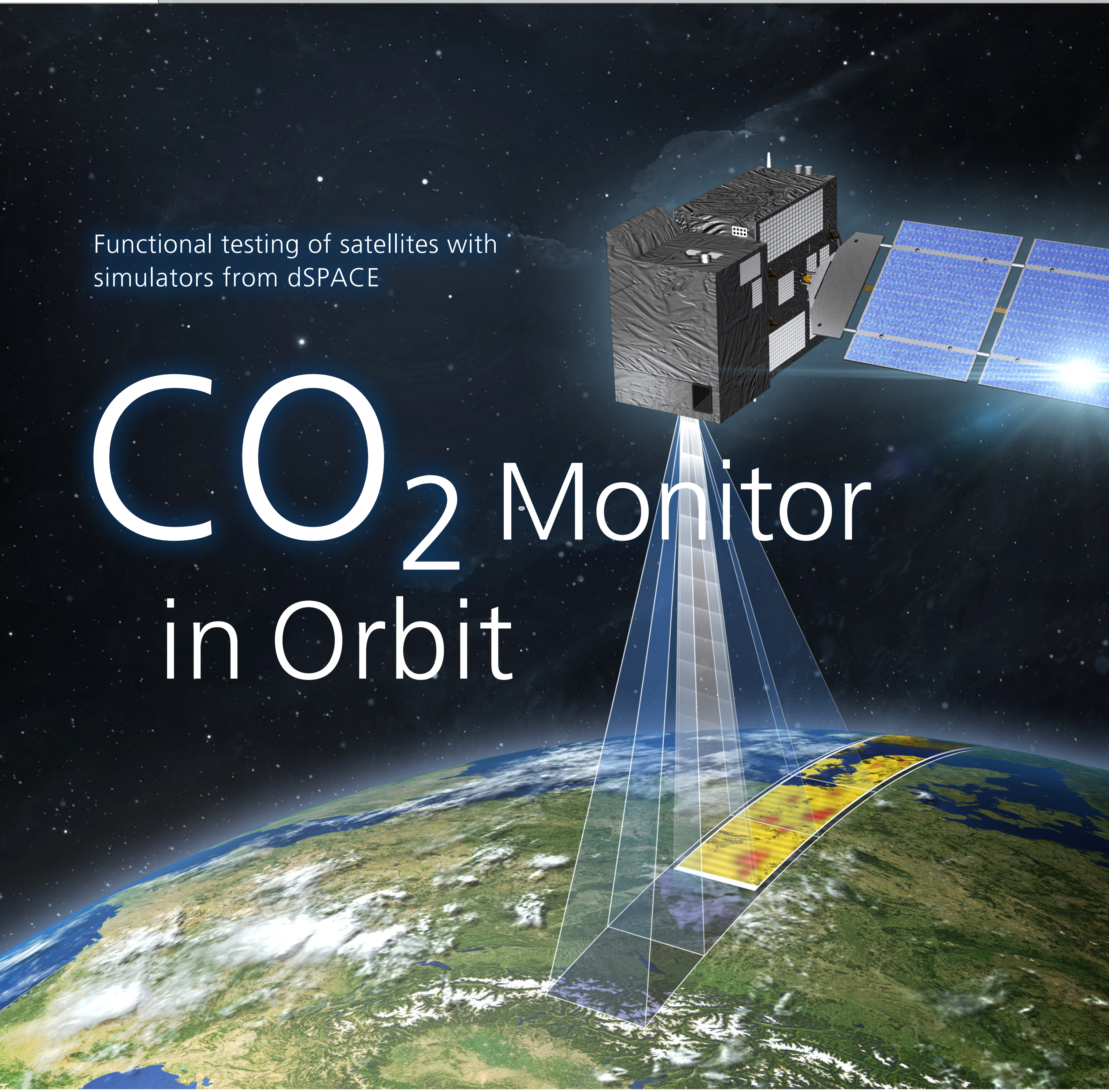
Courtesy of KÜS (Kraftfahrzeug-Überwachungsorganisation freiberuflicher Kfz-Sachverständiger, which translates to "motor vehicle inspection association of freelance motor vehicle experts")

"With KÜS DRIVE; we offer a solution to improve vehicle safety and functional safety of driver assistance systems and of automated driving over the entire product life cycle."

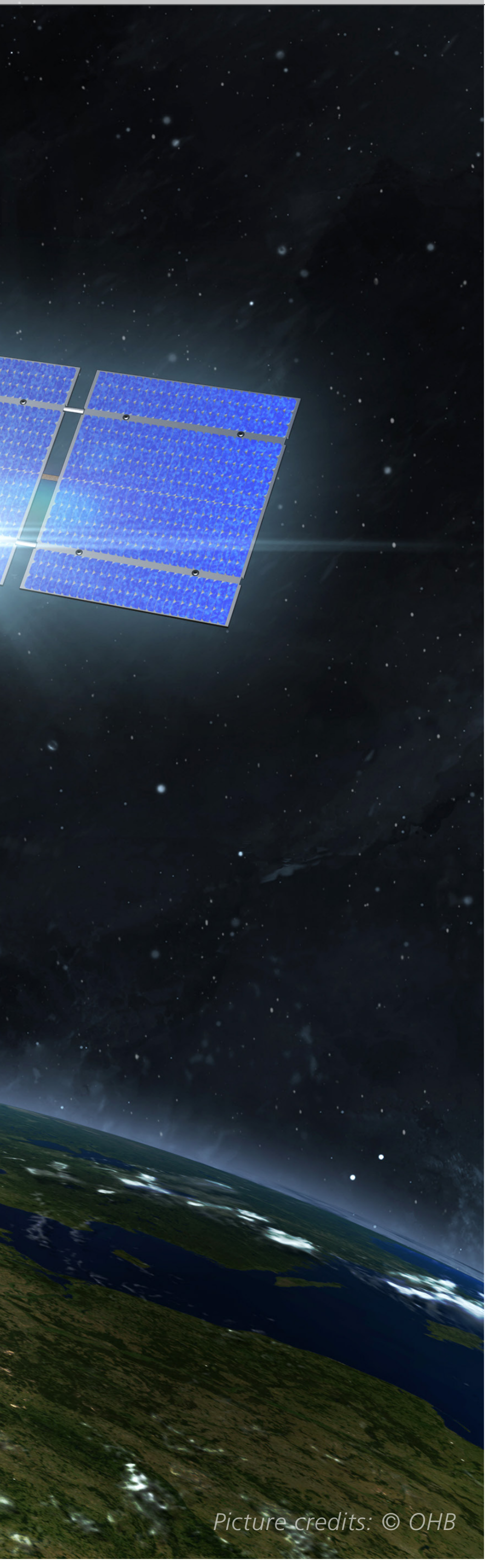
Peter Schuler, CEO, KÜS

Functional testing of satellites with simulators from dSPACE

CO_2 Monitor in Orbit



The European Space Agency (ESA) plans to launch the first of two satellites to measure global carbon dioxide (CO_2) emissions from space with unprecedented accuracy in early 2026. Space technology company OHB is testing the satellite functions using simulators built on the basis of dSPACE SCALEXIO systems and software from Astos Solutions, among others.



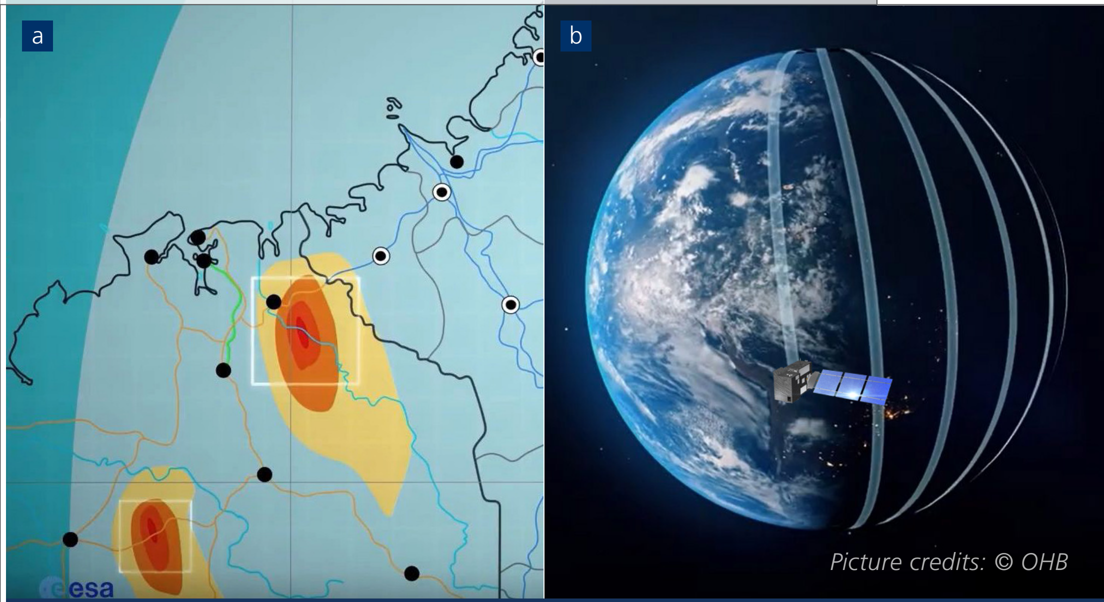


Figure 1: (a) The satellites produce highly accurate maps of man-made CO_2 emissions (cities, factories, etc., shown here in a simulation). (b) The orbital period of the satellites is just under 100 minutes. They measure the CO_2 concentration with a resolution of 2x2 km2 in a 250 km wide strip and, due to the earth's rotation, cover the entire globe once within a few days.

To combat climate change, the world needs more accurate data on global CO_2 emissions. The EU, with the support of ESA, would like to collect this data as part of the CO2M (Copernicus Anthropogenic Carbon Dioxide Monitoring) mission. The special thing about it: For the first time, it will be possible to distinguish man-made from natural CO_2 emissions. This makes the CO2M mission an important building block for achieving the goal of the 2015 UN Climate Change Conference in Paris and limiting global warming to well below two degrees above pre-industrial levels.

Determination of Man-Made CO_2

CO_2 absorbs the infrared portion of light particularly strongly. Therefore, the satellites measure the intensity of the infrared light coming from the earth's surface and derive the CO_2 concentration in the atmosphere from it. Furthermore, to distinguish man-made from natural CO_2, the satellites also measure the concentration of nitrogen dioxide (NO_2) using a similar method. This is because NO_2 is produced as a by-product of CO_2, primarily from the combustion of fossil fuels, but not as part of emissions from living organisms. NO_2 can therefore be used as a marker to identify the man-made fraction of CO_2 in the atmosphere, which, for example, is significantly higher in the atmosphere above an industrial region than above a sparsely populated tropical rainforest.

Crucial: Perfect Satellite Alignment

In order to perform accurate measurements, the satellites must precisely maintain their orientation and planned orbit. In spaceflight, this is ensured by an attitude and orbit control system (AOCS). A typical AOCS consists of a position control computer as well as sensors and actuators, for example:

- *Magnetometer:* Sensor for measuring the earth's magnetic field
- *Sun direction sensor:* Sensor for measuring the direction to the sun

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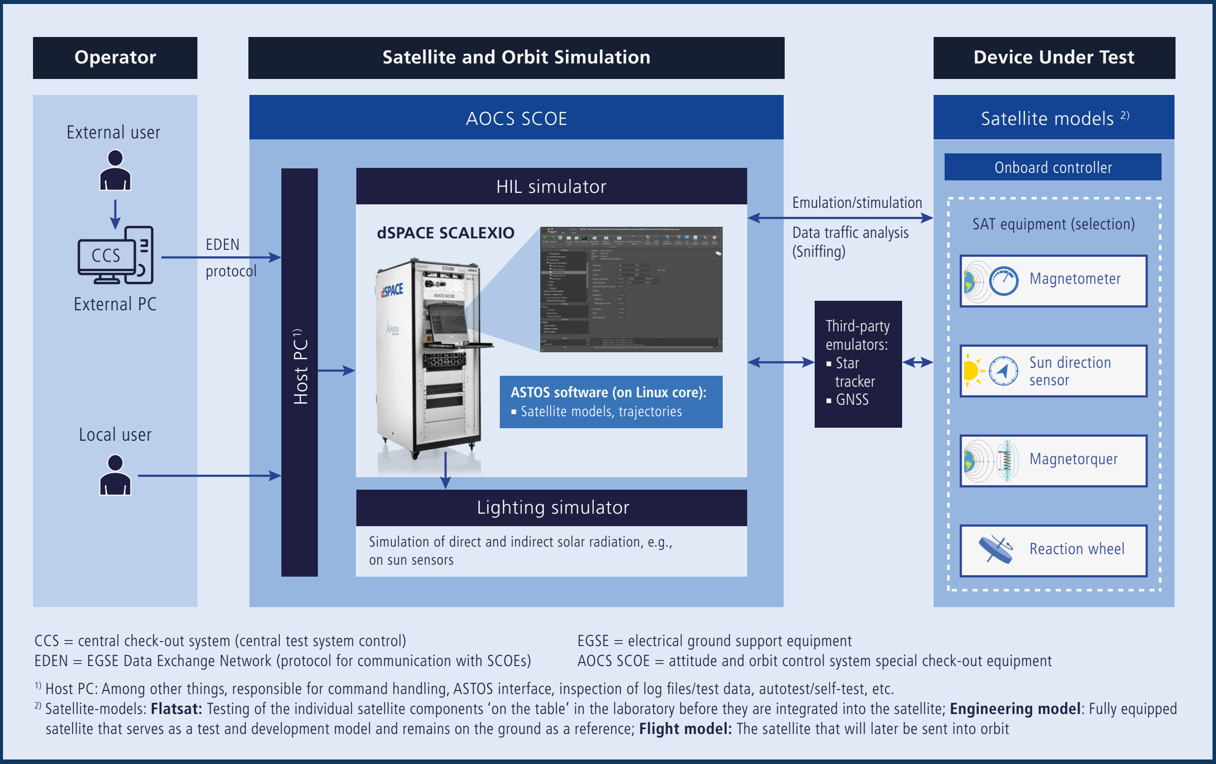


Figure 2: Architecture of the AOCS SCOE for testing the satellites. The ASTOS models are computed on the dSPACE SCALEXIO system on a Linux core (dSPACE Hypervisor Extension).

- *Magnetorquer:* Actuator that applies torque to the satellite by means of an electromagnet interacting with the earth's magnetic field
- *Reaction wheel:* Actuator that applies torque to the satellite by means of a rotating flywheel mass

In addition, there is usually also a global navigation satellite system (GNSS) receiver. To test the AOCS in the laboratory, special check-out equipment (SCOE) is used. The AOCS SCOE for testing the CO2M satellites is based on a dSPACE SCALEXIO real-time system (Figure 2).

Simulating Conditions in Orbit

The AOCS SCOE can be used to simulate on-orbit conditions in the laboratory to test satellite functions. The typical influences to which the satellite is subject include the gravitational and magnetic field and friction with the residual atmosphere, which is extremely thin but still present in orbit at an altitude of 735 km. For the tests of the satellite systems, the highest requirements apply in terms of test coverage, because any error corrections are only possible by radio, for example in the form of

"In space applications, the requirements for control software in terms of freedom from errors and reliability are extremely high. Accordingly, this also applies to the equipment for testing satellite functions. The dSPACE SCALEXIO system handles these challenging test tasks extremely well."

Sven Weikert, Astos

Figure 3: Structure of the dSPACE SCALEXIO system used for the AOCS SCOE. A separate AOCS SCOE will be built for each of the satellites.

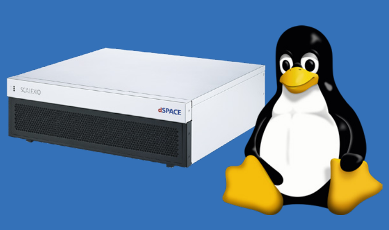
software uploads, because the satellite is no longer accessible in orbit.

Structure of the AOCS SCOE

The SCALEXIO-based AOCS SCOE is being developed in collaboration between dSPACE and dSPACE partner Astos Solutions, which will subsequently deliver it to the space company OHB. The SCALEXIO system (Figure 3) supports a wide range of interfaces, including analog, digital, RS422, MIL-STD-1553, and Ethernet, for open-loop and closed-loop testing. On the SCALEXIO system, the satellite dynamics models are computed on a Linux core (dSPACE Hypervisor Extension, see info box). With the ASTOS-internal 3D engine developed by Astos Solutions, all test scenarios and their parameters can be visualized and monitored in real time for better clarity. The dSPACE SCALEXIO system also supports comprehensive automation for tests with automatic data recording around the clock.

Special Requirements

Because the AOCS SCOE is connected directly to the hardware that will later fly into orbit, i.e., to the flight model, the dSPACE SCALEXIO system >>



Profile: SCALEXIO Hypervisor Extension

The SCALEXIO Hypervisor Extension from dSPACE uses a kernel-based virtual machine (KVM). It runs the SCALEXIO real-time operating system and virtual machines with standard Linux distributions simultaneously. This enables the integration of Linux real-time and non-real-time applications, for example, Linux-based modeling and simulation tools, into the SCALEXIO real-time PC environment and supports low-latency, high-bandwidth data exchange between the two systems.

Company Profile Astos Solutions

Astos Solutions GmbH, which was founded in 2006 and is headquartered in Stuttgart, Germany, is a medium-sized company and one of the top suppliers of software and test systems used for space mission planning and spacecraft development. With its unique range of standardized and individual products and services, Astos Solutions GmbH offers solutions for a broad spectrum of applications. Typical areas of activity include analysis, simulation, trajectory optimization, animation, and visualization of mission analysis results in space applications.

must meet very high requirements:

- Galvanic isolators to protect the satellite: both between the satellite and the AOCS SCOE and between the power supply of the AOCS SCOE and the mains
- Self-test procedure before connecting to satellites or device under test (DUT).
- Condition monitoring (temperature values, smoke development, general AOCS-SCOE status) retrievable locally on site and externally
- Time synchronization via PPS (pulse-per-second; Meinberg time signal)
- Halogen-free cable insulation
- Suitability of all components for use in the cleanroom
- Integrated host PC and slide-out console for local use
- Proof of electromagnetic compatibility

Satellite Tests at the Spaceport in Kourou

The launch of the first of the two CO2M satellites is scheduled for early 2026 from the spaceport in Kourou, French Guiana, on a Vega rocket. For this purpose, the dSPACE SCALEXIO system will also be on site in Kourou to test the satellites' functions before the launch. Both satellites are then expected to be operational in their orbit from 2026 at an altitude of 735 km. In subsequent years, the EU would like to increase the number of CO2M satellites to three. A dedicated AOCS SCOE based on dSPACE SCALEXIO systems would again be built for the additional satellite.

Company Profile OHB

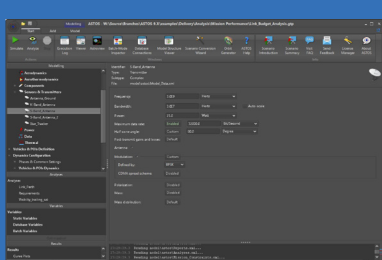
Headquartered in Bremen, OHB SE is a listed space and technology company comprising three business units: Space Systems, Aerospace, and Digital. In total, the Group has almost 3,000 employees at 15 locations throughout Europe. OHB SE's largest subsidiary, OHB System AG, which is headquartered in Bremen and has a further facility in Oberpfaffenhofen near Munich, has more than 40 years of experience in developing high-tech solutions for space flight and other fields of application. The portfolio of products and services ranges from the realization of satellite systems for earth observation, navigation, telecommunications, science, and reconnaissance to the development and implementation of missions for space exploration and the development of systems for astronautical space flight.

"Carbon dioxide measurements from the CO2M satellites make a valuable contribution to achieving the goal of the 2015 UN Paris Climate Change Conference. The dSPACE SCALEXIO systems play an essential role in testing the satellite functions."

Ann-Theres Schulz, OHB

Sven Weikert
Technical Director at Astos Solutions GmbH

Ann-Theres Schulz
Project Manager Standard Platform for Earth Observation Eos at OHB



Profile: ASTOS Software

ASTOS software is suitable for spacecraft trajectory and design optimization, mission and system concept simulation, GNC/AOCS design and analysis, space debris/launch vehicle ascent safety and risk analysis, and failure budgeting. Powerful visualization capabilities allow calculation of resistivity and solar radiation disturbances for solar sail applications. A fluid workflow from model to processor to hardware-in-the-loop simulation is embedded in validation facilities. The EGSE product family is extended by a reconfigurable AOCS SCOE based on the dSPACE HIL product family and a camera and lidar simulator for real-time testing of image-processing-based navigation algorithms.

Develop Faster, More Simply, and More Efficiently with the Open V&V Industry Platform

Looking for Partners

dSPACE is looking for partners to establish an open verification and validation industry platform. The standardized open industry platform aims to reduce the integration effort for V&V tool chains, achieving significant saving potential during setup and maintenance.

"In the future, users will test and develop faster and more efficiently with the platform," Dr. Marc Nalbach formulates the overall objective. Marc Nalbach is responsible at dSPACE for the development of the initiative and the coordination with potential industry partners. "Nowadays, users invest a lot of effort in interfaces and integration. It is high time to think about how this effort can be reduced – in the form of an open platform," he explains. Particularly in view of the challenges of development and testing software-defined vehicles and increasingly complex systems, the platform will deliver significant added value.

OEMs Want the Independent Platform

Currently, OEMs are building their tool chains from individual heterogeneous elements from different providers. And exactly this has to be possible in the future, but with significantly reduced efforts for integration and operation. This is why dSPACE initially presented the initiative on establishing an open verification and validation industry platform to some OEMs and has received positive feedback. The advantages for everyone are obvious and there is clear interest in a solution that is jointly supported by several companies. The OEMs do not want one individual company to dominate the platform. The unanimous opinion of the OEMs: A plat-

form should be independent so that no single company gains a prominent position, Nalbach summarizes the feedback from discussions with customers.

Open V&V Industry Platform: Continuity and Standards Count

"The XIL API demonstrates the leverage potential of standards," says Nalbach and adds: "Just imagine how much more a comprehensive platform can achieve, for example, by providing continuous data exchange and automation and by integrating cloud-, software-, and hardware-based tool chains."

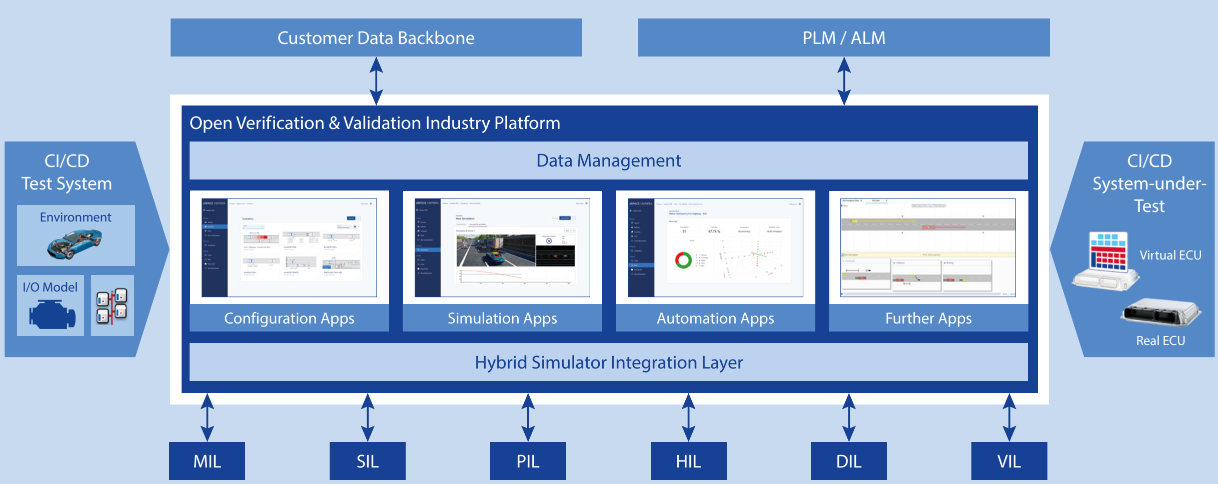
There will, of course, be close collaboration with standardization organizations such as ASAM. "The consortium will develop the industry platform. This will be a gradual process, but we have set the aim of having the first solution for pilot customers by 2024. Many customers currently consider HIL/SIL continuity to be an important subject, as both methods are required. A first approach could be to facilitate more reusability here, supplemented by a connection to test automation."

Potential Partners: All Tool Providers

Marc Nalbach summarizes the current situation: "The OEMs need all the freedom and capacity they can get to be able to concentrate on the development of the competitive differentiation of software functions for their vehicles now. Creating this freedom to increase efficiency is a mission for all players in our industry. Everyone who is involved in the tool world, irrespective of whether they have a product which is in competition with dSPACE or an addition to the dSPACE portfolio is a potential partner and participant in the platform."

For further information and discussion with interested parties, contact Marc Nalbach *mnalbach@dspace.de*. ■

Dr. Marc Nalbach is responsible at dSPACE for the development of the initiative and the coordination with potential industry partners.



The platform will offer flexible and seamless collaboration and facilitate simulation, test execution, monitoring, and reporting. It will be open so that users have access to a best-in-class V&V solution.

The race for the fastest lap time is a benchmark for technology components in racing.

AI at the Limit

The Indy Autonomous Challenge (IAC) offers remarkable insights in many ways. Highly committed students show that they are intensively studying the latest technologies in order to apply them in practice. For this, they chose a particularly challenging discipline: racing. In Monza, the teams once again tested their limits.

Picture credits: © IAC

Picture credits: © dSPACE

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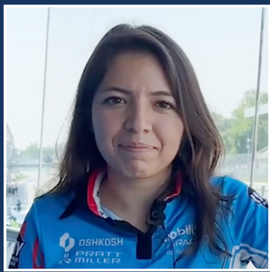
Picture credits: © dSPACE



"All those sensors generate a lot of data that needs to be processed. Without the central AUTERA processing unit, we wouldn't be able to do what we do on the racetrack."

Cindy Heredia, MIT-PITT-RW

Picture credits: © dSPACE

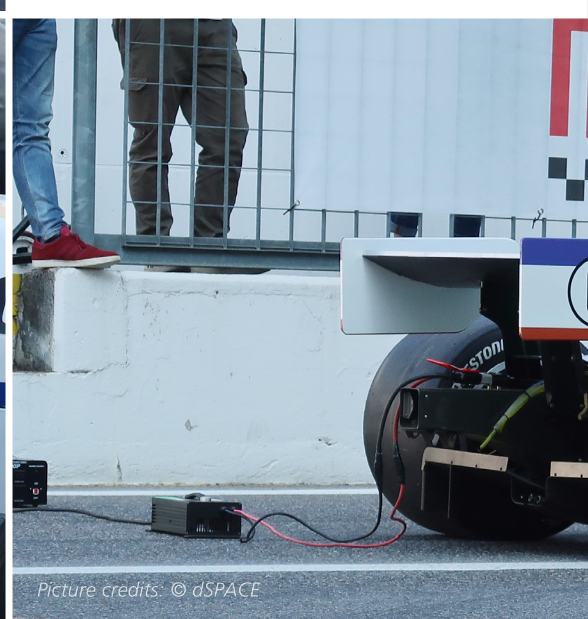
Picture credits: © dSPACE

The focus of the IAC is artificial intelligence, including fundamental aspects of autonomous driving. This includes collecting, evaluating, and assessing data from various sensors in order to derive a driving strategy. But that is not all: These complex processes always take place at the limits of driving dynamics. Always with the risk that the smallest error can lead to the total loss of the vehicle.

Benchmark for the Industry

The industry supports the competition with considerable effort and advice. As is usual in racing, the components used are among the most powerful and often the most expensive on the market. Robustness and performance, which make the difference, are the basis for component selection. An opportunity for the industry to prove

Picture credits: © dSPACE



Picture credits: © dSPACE

"AUTERA is reliable. It hasn't given us any problems, but it's given us enough computing power."

Marko Bertogna, TII Unimore Racing

the suitability of its products and to optimize them.

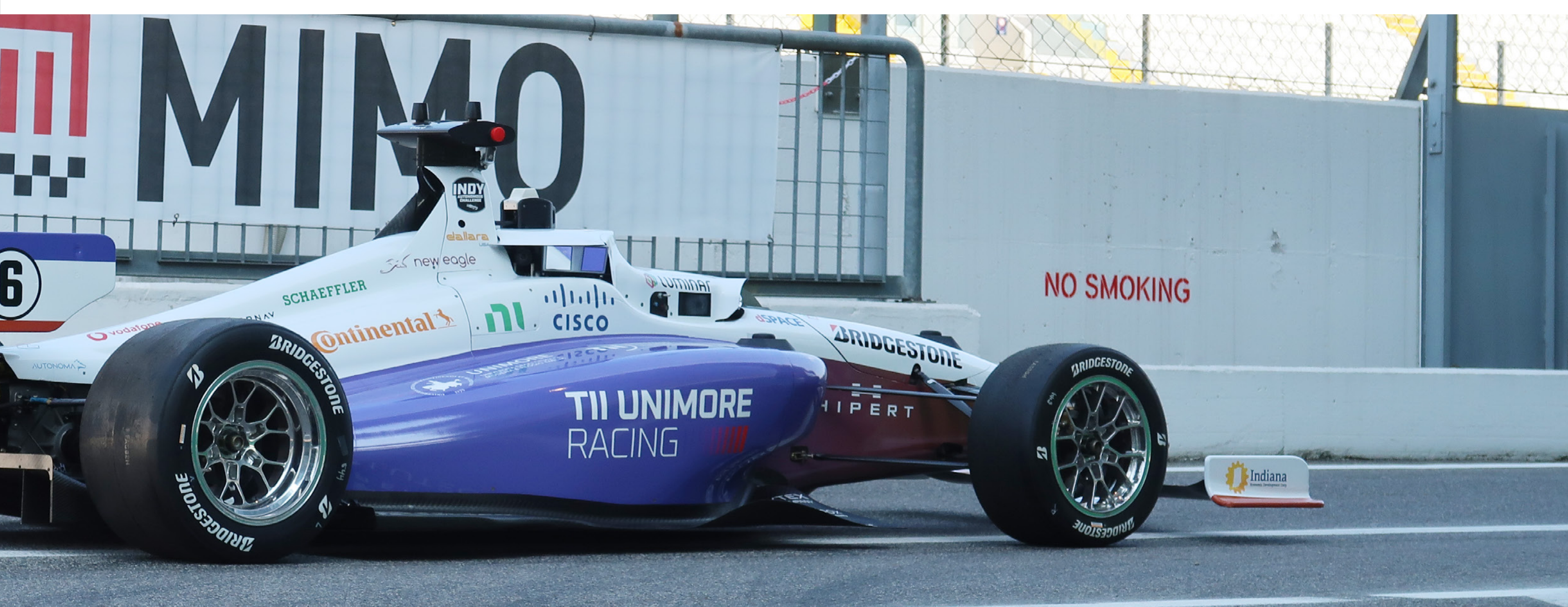
Technology and the Fascination of Motorsport

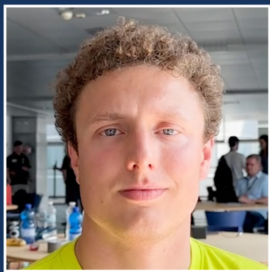
The IAC organization skillfully combines technology with the fascination of motorsport, making innovation easy to understand and experience. In doing so, the IAC does not focus on itself, but shows that technology remains controllable – especially under extreme conditions. This creates confidence in the new technologies. This confidence is necessary when it comes to commercializing the technology. Thus, the students of the IAC competition are now preparing the market for the products they will work on in the future.

Catalyst for Autonomous Driving

During the competition in Monza, we had the opportunity to talk to the teams and the president of the IAC. The enthusiasm for sports, the fascination for new technologies, and the joy of advancing something together drive the students. With their commitment, the IAC teams are a catalyst for autonomous driving. ■

Monza - The Premiere of Driverless Race Cars in the "Temple of Speed".
As part of the Milano Monza Motor Show MIMO 2023 motorsport event, the IAC was an inspiring experience from June 16 to 18: Between parades of historic race cars and high-speed runs of modern super sports cars, the autonomous racing vehicles showed their skills on the challenging track: Free practice, qualifying, and the Indy Autonomous Challenge timed race brought the Autodromo Nazionale Monza to life. Each team competed with a Dallara AV-23, which was controlled by AI-based software developed by each team. The software running on dSPACE's high-performance computer uses sensors and controls actuators so that the car can drive autonomously along the high-speed course. The PoliMOVE team from the Politecnico di Milano won the competition with the fastest lap time ahead of the teams from the Technical University of Munich TUM (2nd place) and the University of Modena and Reggio Emilia (3rd place).





"AUTERA is very robust and has a lot of useful features for autonomous vehicles."

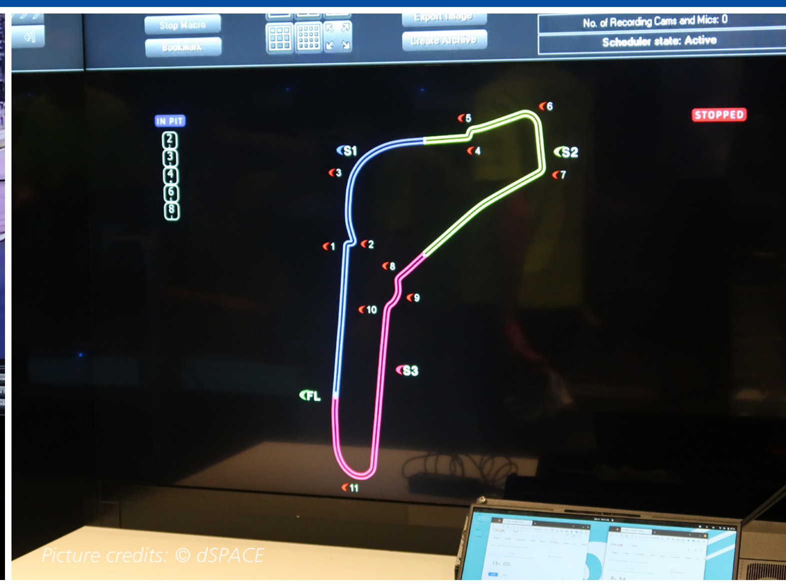
Marcello Cellina, PoliMOVE Autonomous Racing Team

Autonomous Race Cars in the IAC Series Run on Central Computers from dSPACE

dSPACE supports the Indy Autonomous Challenge (IAC) as the exclusive on-vehicle computer technology sponsor. dSPACE provides the AUTERA AutoBox, a prototyping and data recording system, for all vehicles. The dSPACE systems act as the central computer in all the vehicles and enable fully autonomous operation of the vehicles on the racetrack.

With the AUTERA AutoBox, dSPACE provides the robust, high-performance central computer that reads and processes data from lidar and radar sensors and cameras, as well as from buses and networks in the vehicle. The special feature of the AUTERA AutoBox is the unique combination of high computing power and a best-in-class data bandwidth (50 Gbit/s) in a compact form factor.

Picture credits: © dSPACE



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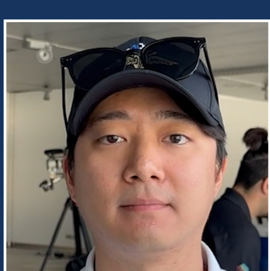

"We have to process data from many sensors – AUTERA works very well and is very robust in environments with strong vibrations."

John, KAIST (Korea Advanced Institute of Science and Technology)

"AUTERA is the brain of our car and executes the software we developed, and does so in a very reliable way."

Simon Hoffmann, FTM Institute of Automotive Technology TUM

"One thing I can say for sure about AUTERA: You do not need to worry. It is a rock-solid product. It meets the computational needs of the teams."

Paul Mitchell, CEO and President, IAC