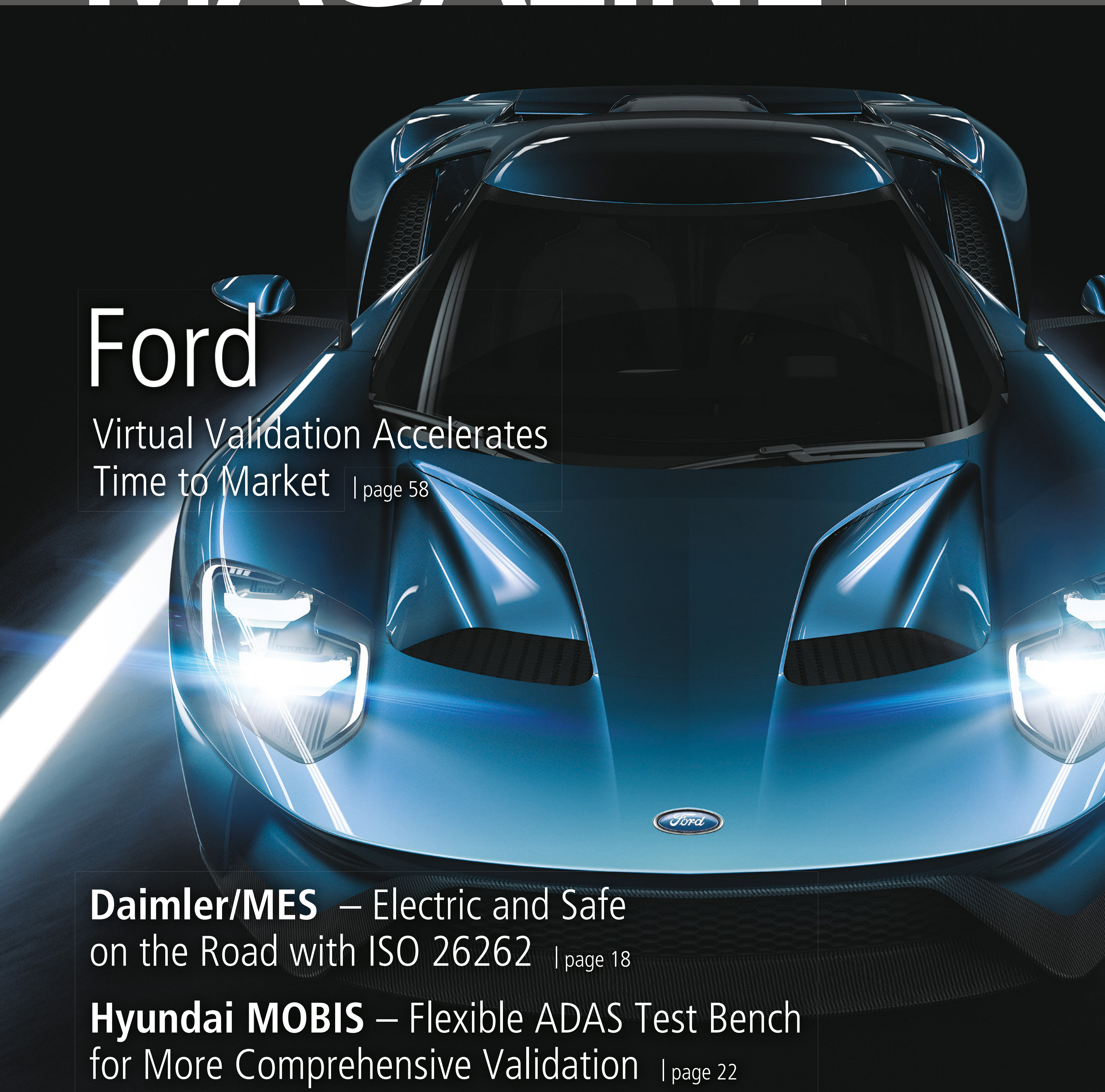
dSPACE MAGAZINE

1/2016



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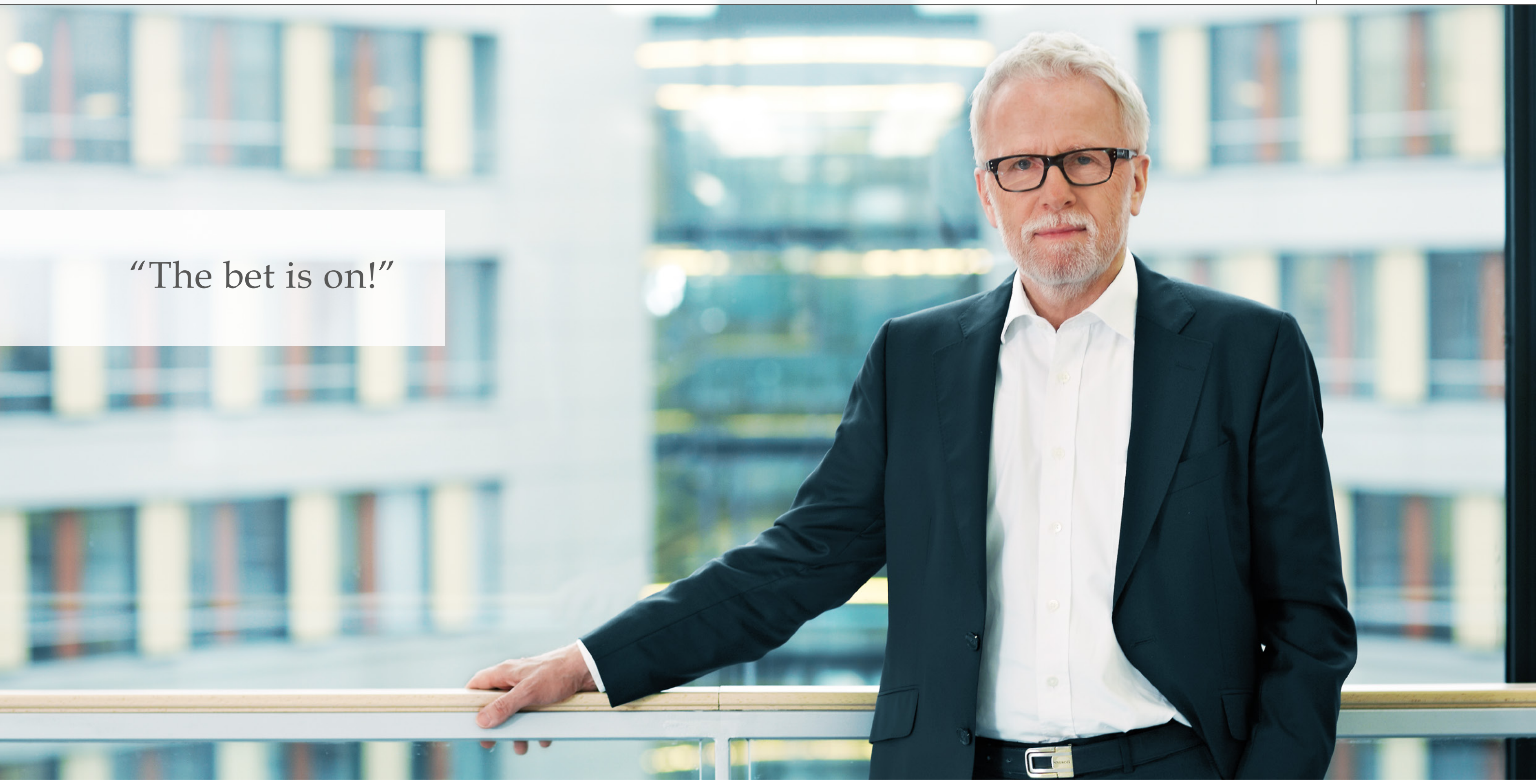
Powerful Tool Chain for ADAS and Automated Driving

dSPACE and Intempora signed an exclusive cooperation that aims at providing a complete tool chain for developing advanced driver assistance systems (ADAS) and highly automated driving functions. RTMaps from Intempora has a key role in this. It is a component-based software development and run-time environment that lets users capture, time-stamp, synchronize and replay data from different sensors and vehicle buses. The integration of RTMaps in the dSPACE tool chain ensures bidirectional, low-latency communication between RTMaps and the dSPACE platforms.
Learn more on page 66.



"The bet is on!"

I vividly remember my mother playing "driver assistant" in the passenger seat: "Herbert, slow down! Slow down!" But as they say, "You brake, you lose!" and "The later you brake, the faster you go." I'm just kidding, of course, because cautious driving is very important to me. First of all, it is safer. Second, I have never liked converting precious drive energy into mere heat. This is why I am enjoying my new electric city car with brake energy recuperation. However, in the small car I have to do without additional driver assistance systems, a luxury I enjoy in larger vehicles. I have been driving with adaptive cruise control (radar) for a long time. Today, I also benefit from lane keeping and blind spot assistants as well as headlight beam control, traffic sign detection, a speed limiter, a surround camera system and, last but not least, the rarely used mother assistant that blinks and beeps and even supports the brake process instead of just shouting "Slow down! Slow down!" – Although it would probably be possible to program it that way. We get used to these systems very quickly and don't want to do without them in our next vehicle. One of the strongest motivators in the automotive industry today, and therefore also at dSPACE, is advanced driver assistance systems – from predictive to autonomous driving. We have seen a lot of these projects and the topic is picking up speed as I write. It is also gaining speed at dSPACE, as you can see from our cooperation with Intempora (page 66).

What's remarkable is that, apparently, the largest challenge of the industry is not to develop the functions, but to test them. I have heard from various sources that "our tests would have to cover hundreds of millions of kilometers more than before" because the systems are that complex. Since this is simply impossible in reality, we will face enormous challenges in test design and test implementation. One great help is frontloading tests to perform them on the PC before the HIL tests. We also support this method, which is spurred in particular by advanced driver assistance systems.

In light of the systems' complexity and the related legal issues, I made a bet last year. I claimed that 20 years from now, we will not see a higher proportion of driverless cars in Paderborn – although I will gladly treat the winner to the promised magnum bottle of champagne if I am wrong.

Dr. Herbert Hanselmann

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Functional SIL stations at BMW

Virtual Validation in Practice

The higher the number of people involved in the development of ECU software, the more important it is to test the individual components early and realistically. BMW has chosen dSPACE VEOS as their central, PC-based simulation platform.

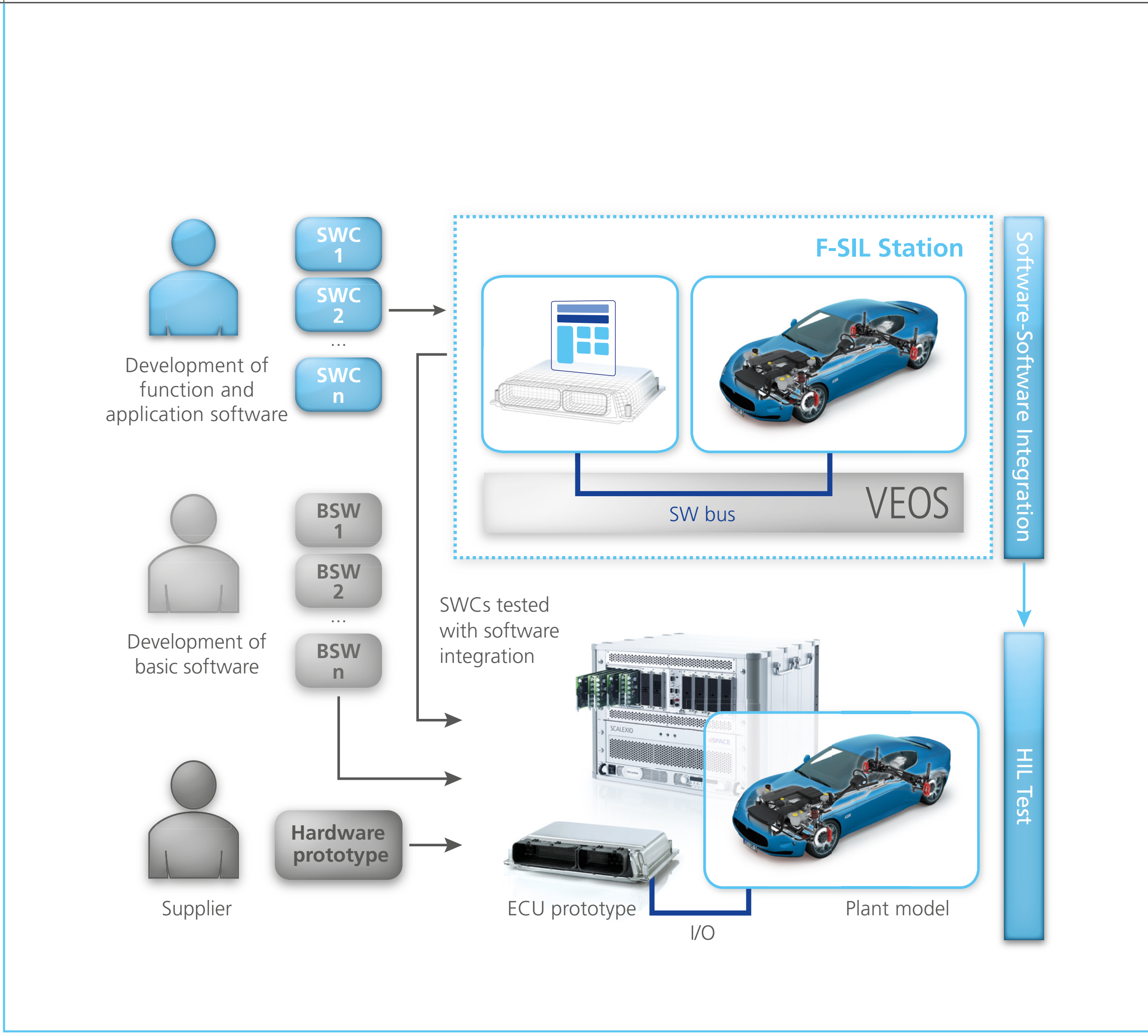


Figure 1: The F-SIL station adds a new step – the software-software integration that takes place before software-hardware integration.

Virtualizing a vehicle opens up new ways for testing and simulation in the development of new control strategies. Virtualization helps tackle two major challenges:

1. Reducing errors caused by distributed development

The individual components, such as the function and application software, basic software, and electronic control unit (ECU) hardware prototypes, are delivered by various teams. Identifying the error sources can therefore be tedious if the errors occur during integration.

2. Overcoming the limitations of MATLAB®/Simulink®

When simulating realistic AUTOSAR Software Components and basic software modules, MATLAB®/Simu-

link® soon reach their limits. The development of new functions is becoming increasingly complex and therefore involves more work areas than before. Because development tasks are distributed across more teams and departments while time to market is becoming shorter, tests in the early development phases are a must.

Solution for Challenge No. 1: F-SIL Stations

The current development process involves three main teams:

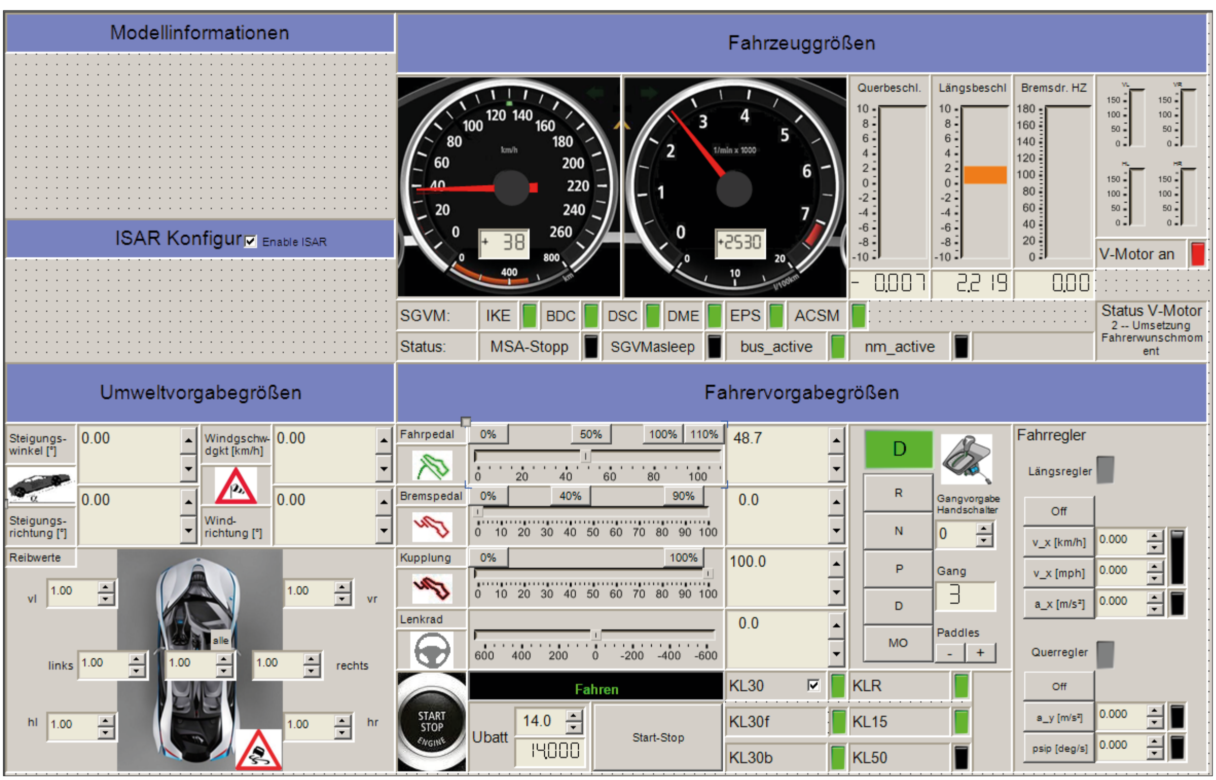
- Developers of function and application software: They provide the software components (SWCs).
- Developers of the basic software: They provide the basic software components (BSWCs).
- Suppliers: They provide the ECU hardware prototype.

At a certain point in time, software-hardware integration starts. Here, all SWCs and BSWCs are integrated and loaded onto the ECU prototype. The next step is comprehensive hardware-in-the-loop (HIL) testing. BMW has introduced a step that comes before software-hardware integration: They use a functional software-in-the-loop (F-SIL) station to first perform a purely software-based integration (figure 1). This makes it possible to test the interaction of the components developed for function and application software early on. The developers can check each new development state and correct potential errors right away. Thanks to these tests and corrections, the software reaches a high quality early in the development cycle. During the subsequent integration tests, only a few, easily identifiable errors occur.

Setup of the F-SIL Stations

BMW chose dSPACE VEOS as the basis of the F-SIL station, which is the company's integration and simulation platform. Because the software-software integration has to be independent of the hardware specifications of the target platform, the conventional Windows® PCs are ideal, as they are the everyday working environment at BMW. Another clear advantage of VEOS is its solid support of several de facto standards, such as AUTOSAR and the Functional Mock-up Interface (FMI), and MATLAB®/Simulink®. In addition, VEOS can be easily connected to existing hardware-in-the-loop (HIL) test and experiment tools, such as dSPACE ControlDesk® Next Generation and ECU-TEST from TraceTronic. This connection makes it easy to integrate the F-SIL station into the existing BMW tool chain. >>

Figure 2: Virtual BMW cockpit in ControlDesk Next Generation.



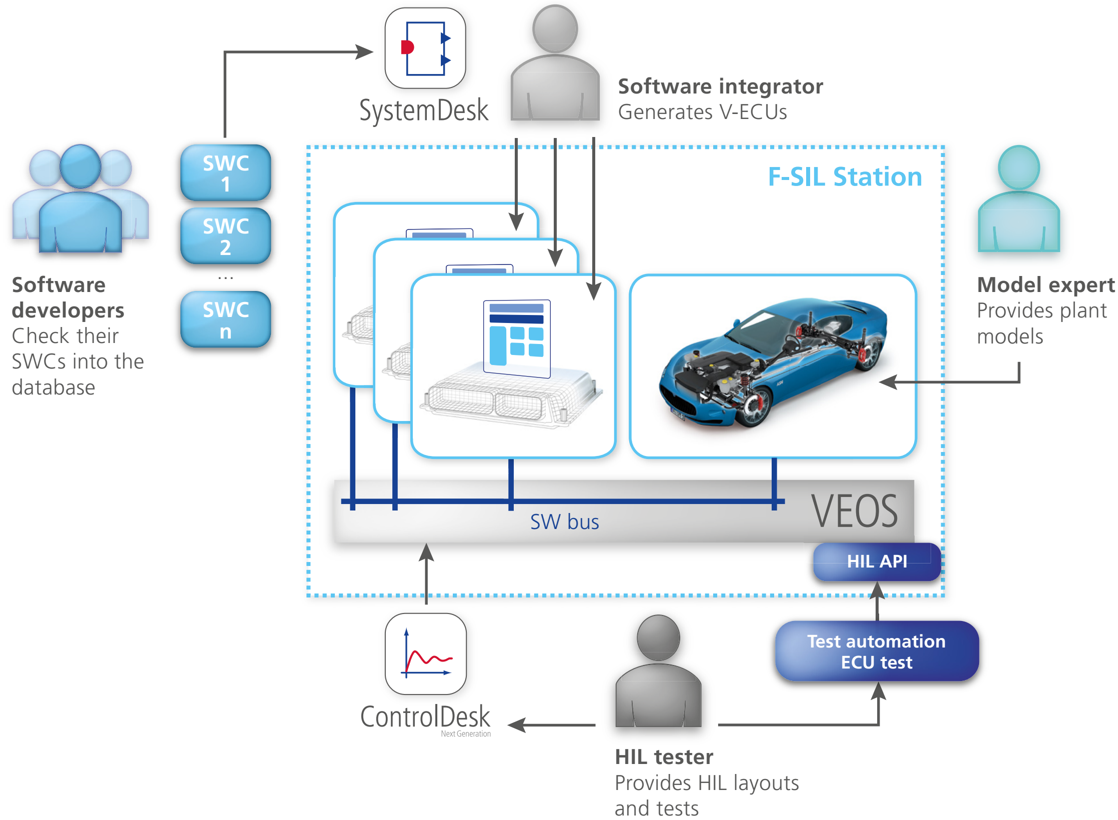


Figure 3: Overview of the products, artifacts and roles involved in the F-SIL station.

Solution for Challenge No. 2: VEOS-Based Workflow

Work on the F-SIL station clearly shows the strong interdisciplinarity and the exchange of information between various teams. As soon as the AUTOSAR SWCs are available, the software integrator generates virtual ECUs (V-ECUs), including the appropriate A2L description file. Interface and linker errors are easy to eliminate in this step. After creating the V-ECU, the software integrator connects the interfaces between the V-ECU and the plant model or environment model. The models are provided by the model preparation team, which also makes these models available to the HIL department. This involves connecting several thousand signals, so this integration step is done completely automatically. In the last step, the software integrator receives the ControlDesk Next Generation project files and layouts from the HIL department (figure 2). They are used to test the V-ECU functions in a closed-loop simulation on the F-SIL station. If everything goes as planned, the software integrator publishes a project configuration that the function and software developers can use for their own tests on the F-SIL station (figure 3). VEOS' open interface and the supporting standards make it possible to reuse existing HIL test scenarios and layouts for testing on the F-SIL station. This reduces the workload and ensures a seamless transition between tests. Because the function developers use realistic test scenarios, they can now avoid the limitations of simulation based on MATLAB/Simulink alone.

Importance of the F-SIL Stations at BMW

Function and software developers mainly use the F-SIL station in the early integration phase, because at this point in time, target platforms either do not exist or are not available, due to the low number of units or high costs. BMW currently has over 60 users working with three F-SIL stations for the virtual validation of four different project configurations. Because the software-software integration takes place before the software-hardware integration, the stressful integration

phase is much more relaxed. In addition, software and function developers can work on their PC as if on a HIL simulator, while still benefitting from the advantages of non-real-time simulation, such as debugging, code coverage analysis, and parameter optimization.
The F-SIL tool chain perfectly supports the tools currently being used in the validation process, so there are no noteworthy acceptance problems among the various teams and roles in the company. This opens up new possibilities for interdisciplinary work and ensures that new validation steps are readily accepted. ■

With the kind permission of BMW AG.

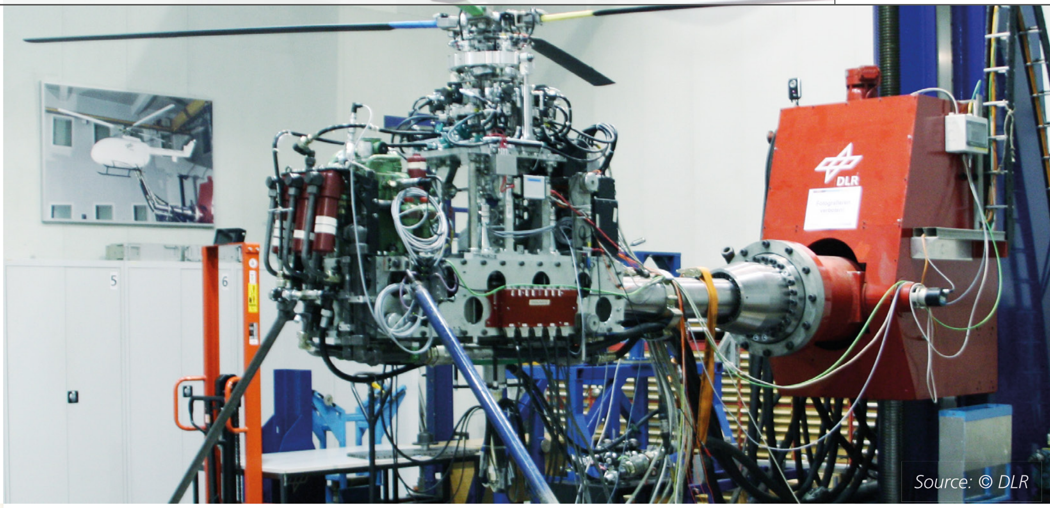
Conclusion and Outlook

It has already been shown that for BMW, including a new validation step in the development process has paid off significantly. While introducing this new step did entail some effort because the interaction of the various departments requires more coordination, the synergies more than make up for it. Furthermore, using VEOS as the simulation platform has even more advantages, which were not expected at the beginning. For example, VEOS helped considerably reduce issues related to compatibility and performance with MATLAB®/Simulink® during the pure offline simulation. There will be more users and project configurations in the future. The F-SIL stations are now an established key component of the validation process and are already an inherent part of the next production series.

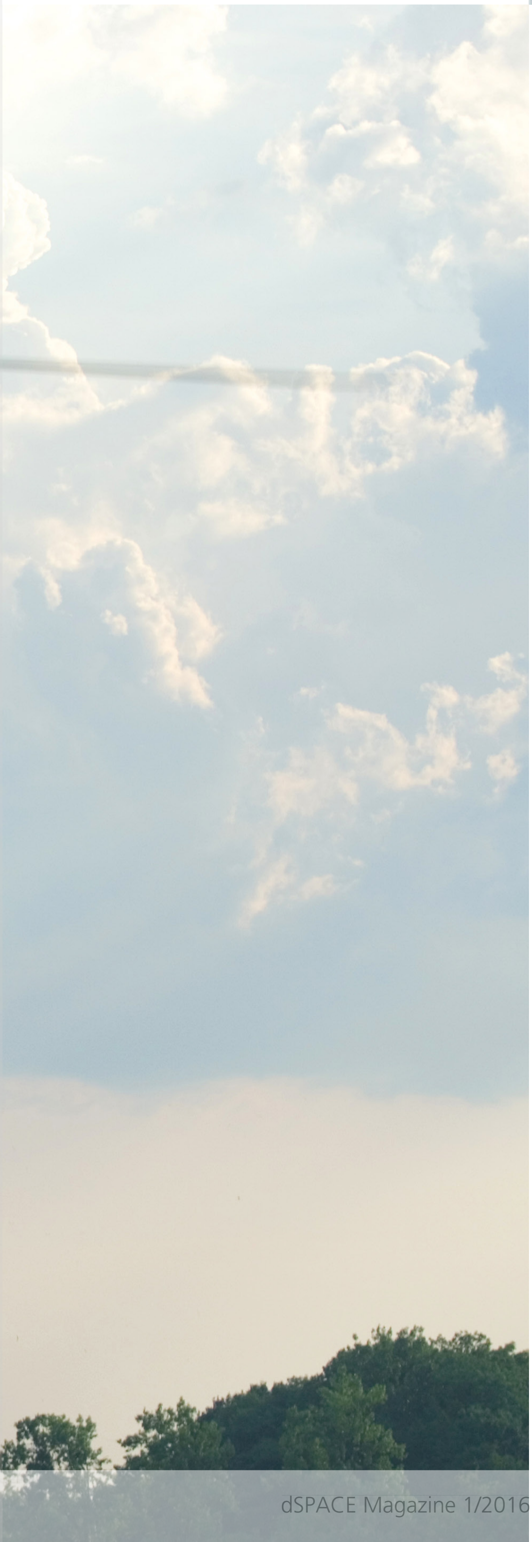
A fast-spinning rotor creates the desired thrust and lift for a helicopter – audible even for the hard of hearing. With a new kind of rotor control, the German Aerospace Center (DLR) proves that a helicopter can soar through the skies with far less noise and vibrations.

Agile Blades

A multiple-swashplate system for helicopters actively reduces noise and vibrations



DLR test setup for developing active controls for helicopter rotors.



For a helicopter in forward flight, the flows resulting from the forward movement of the helicopter and the rotation of the rotor blades overlap. This creates highly unsymmetrical flow conditions within the rotor disk. This causes various aerodynamic, aeroelastic and aeroacoustic effects, such as dynamic stall, noise, and vibrations. These effects usually occur periodically with the rotor's rotational frequency and integer multiples thereof (rotor-harmonic frequencies). One approach to counter or at least mitigate these effects focuses directly on the helicopter's rotor controls.

Controlling the Helicopter

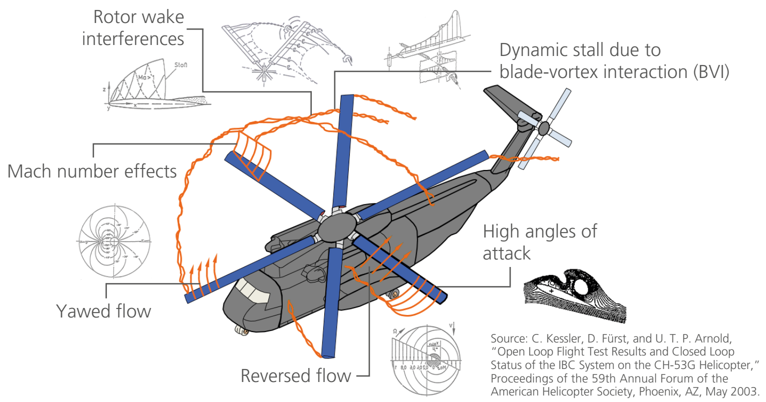
The main mechanical control unit of a helicopter is called a swashplate. It transfers the pilot's commands to the rotating blades. This is done by a combination of collective pitch control, i.e., changing the pitch angle of all main rotor blades to change the lift, and cyclic pitch control to influence forward and sideward thrust. The latter causes a variation of the blades' pitch angles to occur once every revolution of the rotor, or 1/rev.

Taking Action

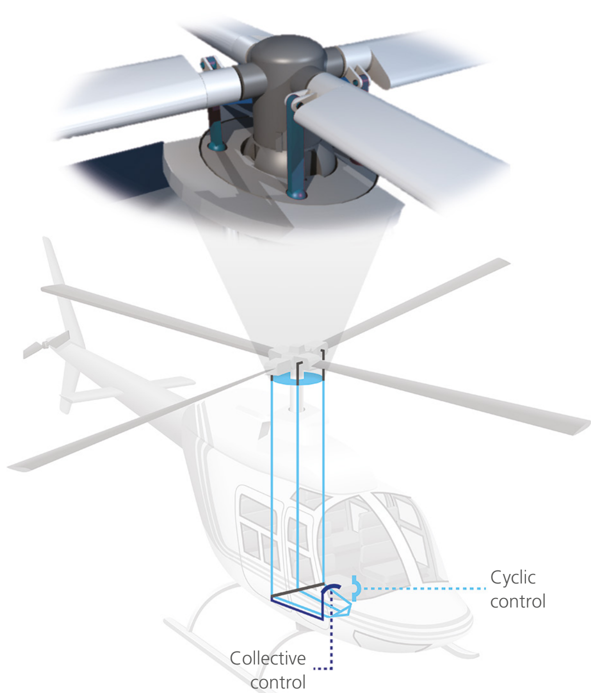
To mitigate undesired effects, the pitch angles of the rotor blades can be modified by stimulating the rotor blades with an integer multiple of the rotor frequency and a low amplitude. To reduce vibrations, the frequency, amplitude, and phase of the control signal is chosen such that vibrations are canceled out by interference. But also noise emissions and the power consumption of the rotor can be positively influenced by this method. Conventional (collective and cyclic) helicopter controls cannot effectively influence the higher harmonics of the undesired aerodynamic effects, and are only used to control the flight attitude. This is why as early as the mid-20th century, researchers tried to counter such phenomena and their effects by means of active rotor control. In addition to the pitch angle changes at all blades that are implemented by the primary controls, active rotor control introduces high-frequency pitch angle changes at a certain multiple of the rotor frequency (rotor-harmonic frequencies). This significantly reduces the vibrations in the helicopter and the noise radiation, and can also improve thrust and lift.

Active Rotor Control

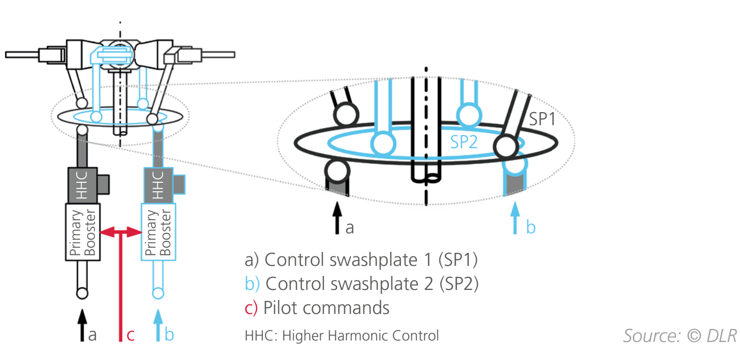
Existing approaches to active rotor control often have significant drawbacks. Systems that create the dynamic pitch angle changes by moving the swashplate (through actuators) are individual-blade-control (IBC)-capable only for rotors with up to 3 blades. For rotors with four or more blades, as are common today, this approach is limited for reasons of swashplate kinematics. Other systems are fully IBC-capable but use actuators in the rotating system that are subject to high loads and have to be supplied with energy and control signals via slip rings, which can pose a major challenge in and of itself. >>



Aerodynamic phenomena of helicopter rotors in forward flight.



The collective and cyclic pitch control of the rotor blades via a swashplate makes it possible to fly a helicopter vertically and horizontally.



How the multiple-swashplate system works: One swashplate controls two opposing rotor blades.

New Approach: Multiple Swashplates

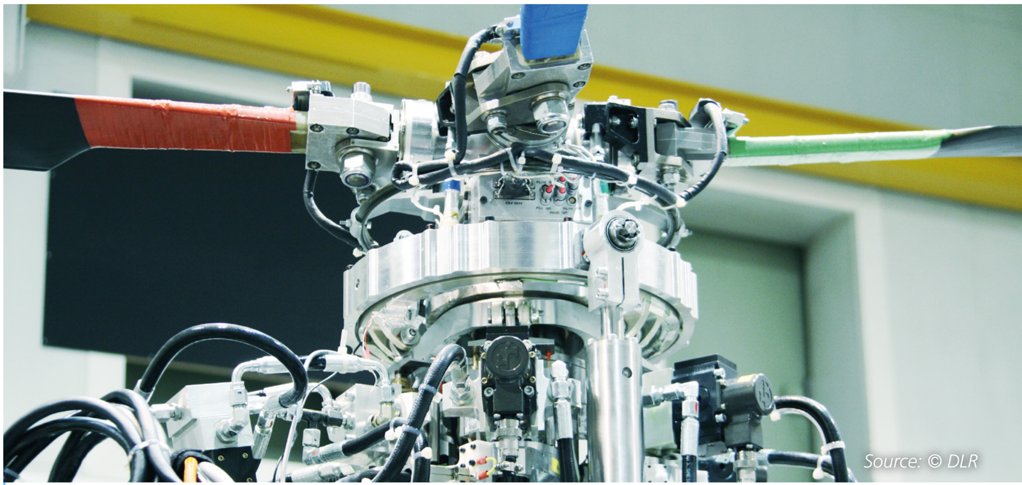
The multiple-swashplate system (META) patented by DLR and tested on a four-blade rotor on the rotor test rig in Braunschweig is a novel approach for an active rotor control. Electrohydraulic actuators induce high-frequency movements of multiple concentric swashplates. The swashplates then generate the desired dynamic changes of the individual blade pitch angles on the rotor. The actuators are installed below the swashplates, which are each connected to two blades. Using multiple swashplates makes the system IBC-capable, i.e., it is possible to modify the pitch angle of each rotor blade individually and with arbitrary control functions and frequencies. META thus combines the advantages of existing approaches without having to suffer from their drawbacks.

Initial Test Setup

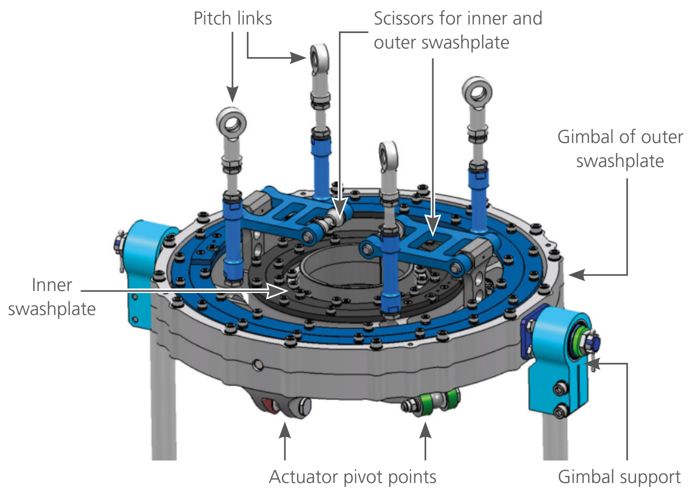
During the VAR-META project (VAR-META = fully active rotor control via multiple swashplates) within the framework of the Federal Aeronautical Research Programme, the multiple-swashplate system was tested for the first time on the rotor test rig at the DLR in Braunschweig. In these tests, a Mach-scaled wind tunnel model of a hingeless Bo105 rotor with a diameter of approx. 4 m was used. The model was equipped with the multiple-swashplate system for the first time. As a result of the Mach-scaling, the flow conditions largely reflect those of the actual helicopter rotor. However, this also increases the rotor speed. A particular challenge of the project was to control the electrohydraulic actuators that position and move the two swashplates. On the one hand, the desired changes to the pitch angles of all four rotor blades have to be translated into the corresponding piston movements of the actuators. On the other hand, these actuator movements have to be controlled actively.

Controller Requirements

The requirements for the open and closed loop control system are high: During testing, the model's rotor spins at 1050 rpm. Therefore, a planned blade control frequency from the first to sixth rotor harmonic results in an actuator frequency range from 0 Hz (static positioning) to 105 Hz, in which a high control accuracy must be achieved (approx. 0.05 mm). The maximum stroke of the actuators is ±4 mm, which corresponds to a pitch angle of approx. ±3.7° at the rotor blade. The pitch angle of a rotor blade always depends on the current azimuth angle of the rotor. Therefore, an angle encoder at the rotor mast is used to create trigger signals that provide information about the current azimuth angle and are used by all open and closed loop controls and measurement systems of the rotor test rig. To achieve the desired control accuracy, the actuators of the multiple-swashplate system are controlled 256 times per revolution. At a rotor frequency of 17.5 Hz, this results in a clock speed of almost 4.5 kHz for the control system. This means that all computations for the control of six actuators and their closed loop control have to be calculated at this speed, including signal processing and analysis as well as filters and feedforward control.



Prototype construction of the multiple-swashplate system.



Mechanical construction of the multiple-swashplate system. *Source: © DLR*

Developing the Controller Model

First, the entire system kinematics were modeled in MATLAB®/Simulink® to derive the real-time-capable control laws. The actuator movements required for the desired control case are computed via control matrices (some with > 50 columns) that convert individual pitch angle modifications (and coupling terms) into the corresponding control signals for the actuators. The subsequent actuator control consists of a PID controller with a feedforward loop. Because this feedforward control contains a complete harmonic signal analysis and a digital 8th-order low-pass filter, the simultaneous computation of a control signal for six actuators is also very demanding. After an actuator model

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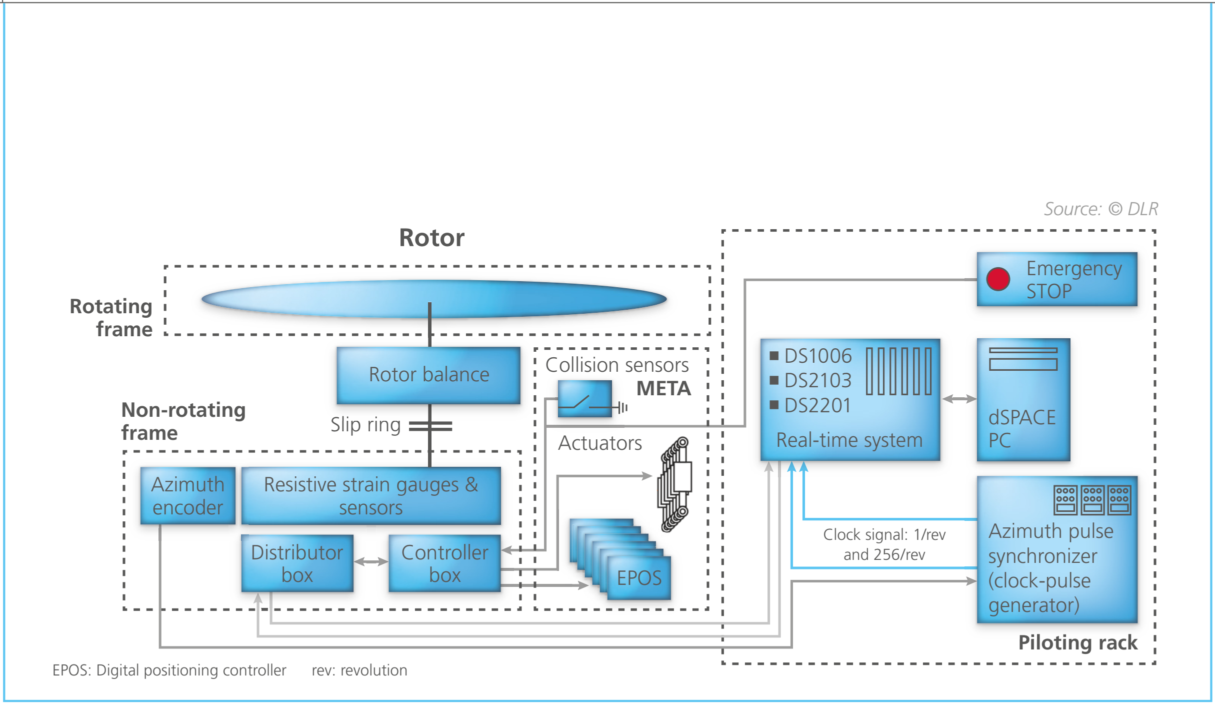
> "With the powerful dSPACE real-time system, we were able to extensively test the algorithms of our active rotor control and successfully prove the functionality of our multiple-swashplate concept."
>
> *Philip Küfmann, DLR*



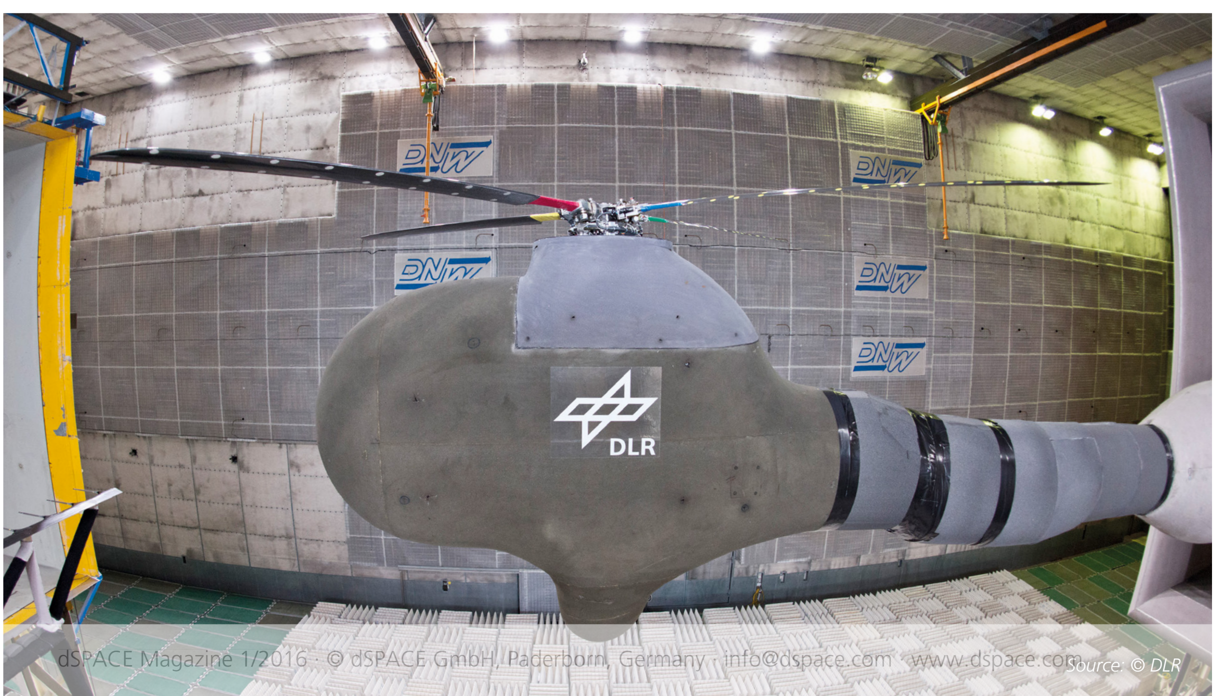
Signal flow chart of the test setup.

and the open and closed loop controls were modeled and validated in Simulink, the system had to become real-time-capable to control the hardware during actual tests.

Designing a Real-Time-Capable Control

The open and closed loop control of the multiple-swashplate system was implemented on a dSPACE system with a quad-core DS1006 Processor Board and the I/O boards DS2103 and DS2201. An Ethernet module was used to be able to communicate with measurement computers and data servers during the tests. The controls modeled in Simulink were distributed across multiple processor cores. One core each was used for the open loop control, closed loop control, and other tasks (such as network communication). Real-Time Workshop™ was used to compile the controls and run them on the dSPACE system. The signals of the angle encoder are used to trigger the program via hardware interrupts so the program runs synchronously to the remaining control and measurement hardware. Thus, it was possible to fulfill the high requirements for the clock speed of less than 250 µs per control step and achieve the desired control accuracy. Developers can use ControlDesk® Next Generation and a specially designed graphical user interface therein to access all the important parameters during a running operation, such as the controller gain,

Experimental setup in the wind tunnel.



Control and monitoring systems for the wind tunnel test, with two ControlDesk layouts (on the right).

> "We use dSPACE ControlDesk to carry out all of the measurement and control tasks needed for the dynamic operation of META efficiently and conveniently."

Philip Küfmann, DLR

feedforward parameters, control frequencies and amplitudes.

Conclusion and Further Steps

The tests and proof of the system's IBC capability at the DLR in Braunschweig helped bring the VAR-META project to successful completion. After the hardware and software were updated and developed further, the multiple-swashplate system completed its first wind tunnel test in the low-speed wind tunnel of German-Dutch Wind Tunnels (DNW) in September 2015. The wind tunnel test was conducted within the FTK-META project (FTK = advanced swashplate concepts) and took nine days. The aim of the tests was to prove the influence of active rotor control on noise, vibration and performance, as well as a first function test of the multiple-swashplate system under various simulated flight conditions. The active rotor control strategies realized with META proved to reduce noise emissions by up to 5 dB and vibrations by up to 90% (in individual components). In rapid forward flight, the required rotor power was reduced by up to 4%. The system consisting of actuators and a dSPACE real-time PC operated without errors during the entire test. In the follow-up project SKAT (= scalability and risk minimization of technology with innovative design), the multiple-swashplate system will be used to research active rotor control concepts on the new five-blade rotor system. The project will also test a new controller developed on a dSPACE system that detects undesired vibrations at the model and balances them out by corresponding control commands at the two swashplates. ■

Philip Küfmann, DLR

Watch META in the wind tunnel: www.dspace.com/go/dMag_20161_META_E

The Multiple Swashplate System was invented by Prof. Dr. Berend van der Wall und Mr. Rainer Bartels at the DLR Institute of Flight Systems and was patented in 2008 (Pat. Nr.: DE-10-2006-030-089-D).

Philip Küfmann

Philip Küfmann is responsible for models and software for controlling the multiple-swashplate system at the German Aerospace Center (DLR) Institute of Flight Systems in Braunschweig, Germany.

Together with the TargetLink Strategic Partner Model Engineering Solutions, Mercedes-Benz Research & Development North America developed automatically testable conformity rules for modeling with dSPACE TargetLink, which comply with important requirements of the ISO 26262 standard.

Mercedes-Benz Research & Development North America (MBRDNA), with a location in Redford, Michigan, amongst others, is responsible for developing and integrating inverter software (current conversion for electric machines). This software, developed with dSPACE TargetLink®, is used for various vehicle applications in the Mercedes-Benz e-drive portfolio. One main component, and the actual innovation, is the e-motor control and associated torque and high-voltage safety concept that is implemented according to the ASIL C requirements of ISO 26262.

Development Process and Model Quality

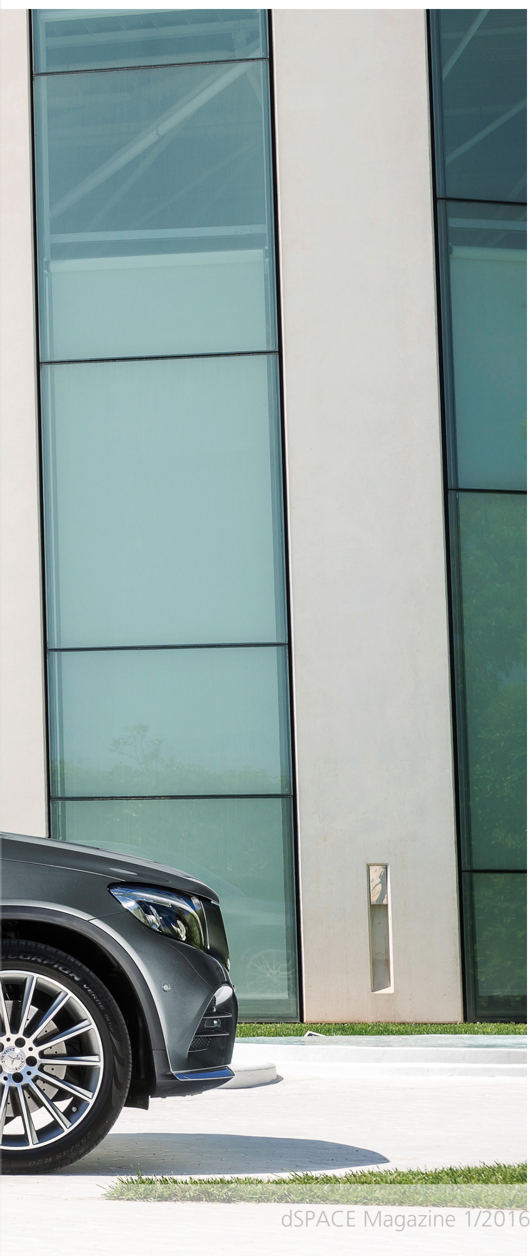
The e-drive software is based on the AUTOSAR software architecture and

Using modeling guidelines to validate e-drive software

Electric and Safe

© Mercedes-Benz

can be scaled for many electrified drivetrains. The complete control software is developed with the model-based design method according to the V-cycle. TargetLink, dSPACE's production code generator, is a core component of the development tool chain. TargetLink supports modeling and code generation of an AUTOSAR-compliant software architecture and is certified up to ASIL D for safety-related software. Modeling the function software in Simulink® and TargetLink plays a central role for early requirement validation, because a higher quality of the models used for code generation directly translates into a higher quality of the generated software. Using Simulink/TargetLink for software modeling is an accepted, industry-proven method to generate high-quality software. This is also in line with ISO 26262, which recommends using a semi-formal modeling language such as Simulink. MBRDNA uses a combination of static and analytical validation measures to ensure a high model quality. Independently of the functional customer requirements, MBRDNA defined development methods that ensure an optimal integration of the software into the target environment.



Rules for the Software Design

An important part of this method is the consistent use of modeling and conformity rules for software design. The rules used at MBRDNA are based on Daimler-internal regulations for model development and have been adapted to the development requirements of the e-drive software. The Daimler modeling guidelines are based on modeling standards and tool-specific guidelines such as MAAB, MISRA Simulink/Stateflow, MES Functional Safety Guidelines, MISRA TargetLink, and the dSPACE TargetLink Modeling Guidelines (figure 1). Because all of these guidelines have a different focus, a smart combination of them is needed to cover all aspects required for modeling safety-related software according to ISO 26262. The rules of the MAAB (MathWorks Automotive Advisory Board) focus on design aspects of simulation and controller models with an emphasis on readability, serviceability, and best practices. The MAAB rules do not accentuate production code generation. The MISRA Simulink/Stateflow and MISRA TargetLink guidelines, however, focus on safety aspects of the models and the code generated from them. They define a safe language range for Simulink and Stateflow, modeling patterns for safe code patterns, and an appropriate configuration of the simulation environment. Tool-specific guidelines such as the MISRA/TargetLink and dSPACE TargetLink Modeling Guidelines predominantly refer to code generation with TargetLink. Compliance with these guidelines means that there must not be any modeling patterns or configurations of the model or code generator that can negatively affect the properties of the generated code. The MES Functional Safety Guidelines largely refer to safety considerations of the model and the generated code. These guidelines were derived from the requirements of ISO 26262 and other safety standards, and complement the existing guidelines for the design of safety-related software. Key elements of the analyses are checks for data flow and control flow.

Automated Testing for TargetLink Models

With its goal of making it easier to use the modeling guidelines, MBRDNA tailored the Daimler modeling guide-

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> "The increasing complexity of software systems pushes traditional testing to its limits. Automated analyses of the created models and the translated software are an integral part of our software quality assurance."

Alexander Dolpp, Mercedes-Benz Research & Development North America, Inc.

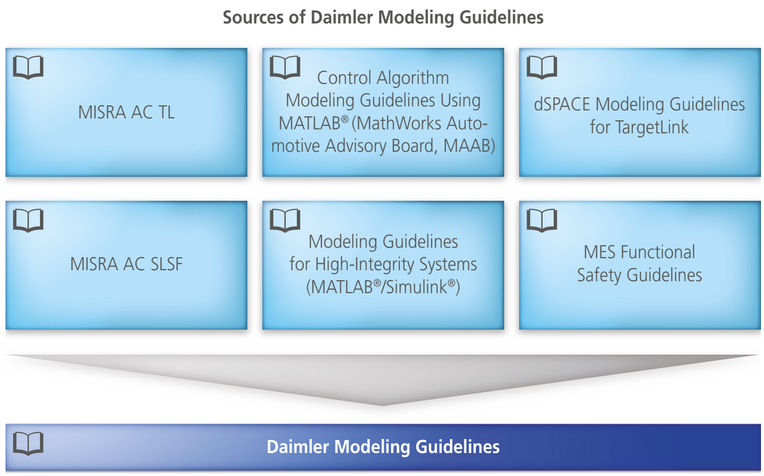


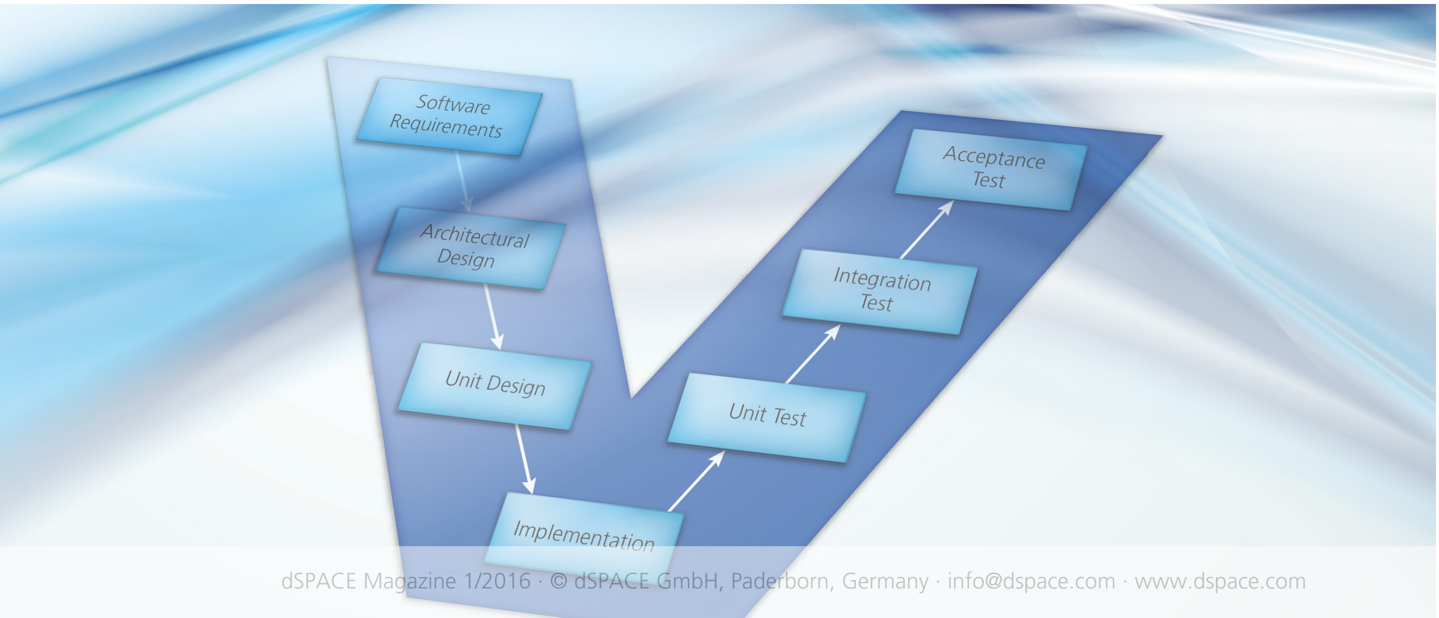
Figure 1: The Daimler modeling guidelines are based on numerous established standards and guidelines.

lines together with Model Engineering Solutions GmbH (MES), a TargetLink Strategic Partner, on the basis of the existing documents, and extended them to cover Daimler-specific needs. The guidelines are managed in MES Model Examiner (MXAM) and automated tests for TargetLink models are provided. By adhering to the modeling guidelines, MBRDNA can comply with the modeling requirements of ISO 26262, implement best practices, avoid modeling mistakes, and consider tool-specific configurations, such as uniform settings in the simulation environment or the code generator.

Safety in Detail

For example, as an adapted MISRA modeling guideline, the Daimler modeling guidelines determine the correct execution order of Stateflow transitions. Here, the Daimler guidelines contradict the MISRA guidelines by stating that the execution order should be defined only by the user, not by the graphical order of states and transitions, to avoid a misinterpretation of the Stateflow semantics. If, for instance, a state is moved for layout reasons (change in syntax), this can inadvertently change the execution behavior of the state (change in semantics), see figure 2a. The same holds true for Stateflow transitions that are evaluated at junctions, as shown in figure 2b. This misinterpretation or unintended

> "Using modeling guidelines and a guideline checker like MES Model Examiner makes it possible to automatically implement the requirements of ISO 26262 and give the model experts more freedom. We want them to focus on their main task: developing the control function."
>
> *Dr. Ingo Stürmer, Model Engineering Solutions*



> "With its native AUTOSAR support, TargetLink for code generation is a core element of our development tool chain."

Alexander Dolpp, Mercedes-Benz Research & Development North America, Inc.

change of the execution behavior can easily be avoided by using the Stateflow configuration "User specified state/transition execution order" to calculate the execution order as specified by the modeling expert. Model checking in MES Model Examiner (MXAM) is used to automatically verify whether a model complies with these guidelines and to correct the model immediately.

Clear Processes

All modeling experts and software developers must adhere to the modeling guidelines. Automatic model checking with MXAM has to be performed each time a new functionality is added. Software can be checked into a version management system only if it complies with the modeling guidelines and the associated functional model-in-the-loop (MIL) tests were performed. The modeling expert is responsible for eliminating all violations that were identified on the basis of the guidelines. This static modeling analysis method is part of all validation measures in the V-cycle for developing and validating the e-drive software. By using the Daimler modeling guidelines together with MXAM for automatic conformity checks and the dSPACE production code generator TargetLink, Mercedes-Benz Research & Development North America uses an industry-proven approach to comply with ISO 26262 requirements, improve model quality early on and significantly increase code quality. ■

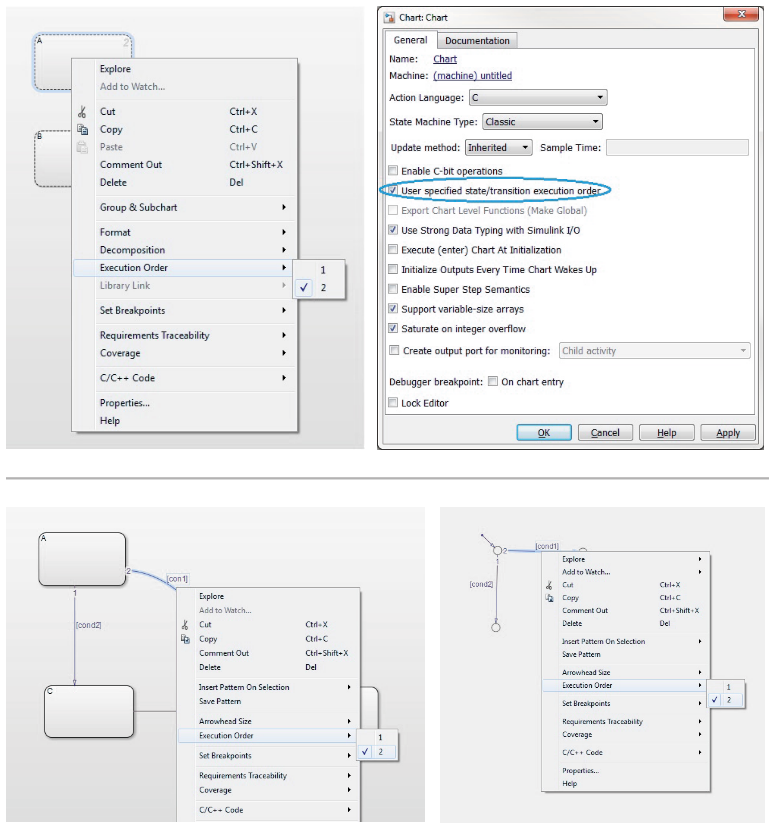
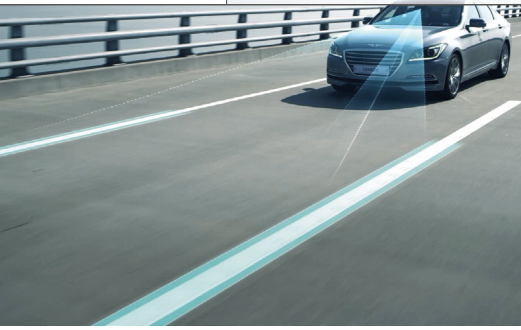


Figure 2a (top): A typical case for MES Model Examiner – Execution order of parallel states, here specified in Stateflow.
Figure 2b (bottom): Execution order of transitions.

Alexander Dolpp
Alexander Dolpp is Director for E-Drive Software at Mercedes-Benz Research & Development North America, Inc., Redford, Michigan, USA.

Dr. Ingo Stürmer
Dr. Ingo Stürmer is the founder and former CEO of Model Engineering Solutions GmbH. Since January 2016, Dr. Stürmer heads Model Engineering Solutions Ltd. (UK).



Source: © Hyundai MOBIS

Developing modern driver assistance systems involves an ever-growing amount of data which must be processed in real time. Hyundai MOBIS uses a HIL setup that is based on dSPACE SCALEXIO and can develop and test multiple driver assistance systems at the same time.

Developing driver assistance functions with a simple method in the laboratory means that it must be possible to simulate the various driving situations realistically and reproducibly on a test bench under defined conditions. This task is becoming more complex because many driver assistance functions involve combining and evaluating measurement data from different environment sensors in real time. One of many examples is automatic emergency braking. In this example, first the cameras visually detect the road users, while the radar measures the distances and velocities of these traffic participants. On the basis of this overall picture, the vehicle computer can then decide whether emergency braking is required and calculate the appropriate instructions for the brakes. This combining of measurement data from different sensors in a split second, also called sensor fusion, is one of the biggest challenges when developing the driver assistance systems of tomorrow.

Six in One Blow

Besides automatic emergency braking, there are many other situations in which several driver assistance systems need to interact with each other. In the first step, Hyundai MOBIS is using a SCALEXIO® HIL simulator to test a total of six driver assistance functions:

- Parking assistance system (SPAS = Smart Parking Assist System)
- Lane departure warning system (LKAS = Lane Keeping Assist System)
- Automatic proximity control (SCC = Smart Cruise Control)
- Emergency braking (AEB = Autonomous Emergency Braking)
- Assisted steering (MDPS = Motor Driven Power Steering)
- Electronic stability control (ESC = Electronic Stability Control)

Realistic Driving in the Lab

The central elements of the setup are a dSPACE SCALEXIO HIL simulator equipped with simulation models from dSPACE, and 3-D online animation via dSPACE MotionDesk to visualize the driving maneuvers. This development environment is connected to multiple test benches for various driver assistance systems (figure 2). There is one test bench for the radar scan of the vehicle environment, one for camera-based

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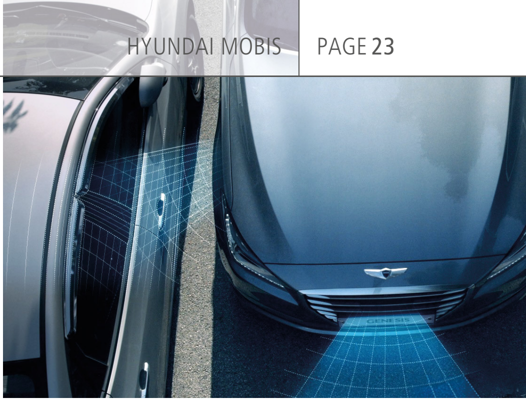

All You Can Test

Performing parallel tests on multiple driver assistance systems

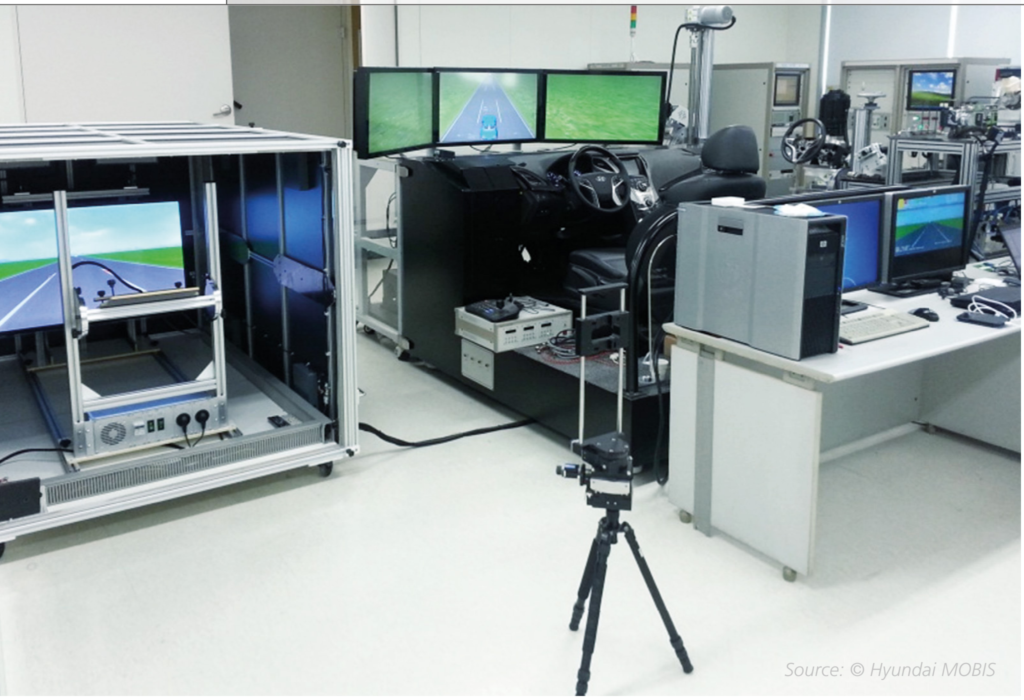

Figure 1: Part of the lab setup: The camera test bench (on the left), the driver's seat (in the middle), and the HIL simulator (in the back right).

detection of driving lanes, another for the ultrasound-based parking assistant, and one for the steering assistant and the brakes.
The Automotive Simulation Models (ASM) from dSPACE for vehicle dynamics and traffic applications are run on the HIL simulator so that the various tests can be performed realistically. ASM Traffic includes generic sensor models for radar and ultrasonic applications, like detecting object contours for park assistance systems. The radar system control unit and the SPAS control unit are connected as actual control units, and the LKAS control unit is initially replaced by a dSPACE MicroAutoBox®. To develop the algorithms in the radar control unit for the proximity control SCC, for example, the radar control unit can also be replaced by a MicroAutoBox. In the real-time simulation, the radar sensor model uses the behavior of the test vehicle's dynamics and the traffic environment as a basis to generate information, such as the speed difference, distance and azimuth of the vehicles ahead, which is transmitted via CAN to the SCC algorithm on the MicroAutoBox. To integrate the actual radar control unit in the closed-loop simulation, a radar target simulator is planned to be used to generate the reflections resulting from the relative velocities and distances of the vehicles ahead as a real radar echo.

The test and experiment software dSPACE ControlDesk is used to monitor the experiments, record data, generate specific errors, and postprocess data, to name just a few tasks. In the future, for the

1 Radar test bench

The radar sensor test bench is used to perform basic function tests of the radar sensor. It is an anechoic chamber with electrically conductive walls that electromagnetically shield the interior chamber from the outside world (Faraday cage). To recreate realistic traffic situations, the appropriate generic sensor model from ASM runs on the HIL simulator. A dSPACE MicroAutoBox takes on the role of the radar control unit.

2 Camera test bench

The key to testing camera-based driver assistance systems in the lab is a real-time representation of realistic vehicle environments, which are interpreted as real traffic situations by the front camera. The driving situations are visualized by dSPACE MotionDesk and thus perfectly stimulate the camera. At this measuring station, a dSPACE MicroAutoBox is initially used to calculate the LKAS algorithms, because the development of the final control unit has not been finished yet.

Tae Seung Kim
Tae Seung Kim is responsible for the Active Safety Test Development Team in the System Test Development Division of Hyundai MOBIS in Yongin-Shi, South Korea.

> "The test benches of dSPACE hardware and software gave us the capability to efficiently test multiple driver assistance systems in interaction."
>
> *Tae Seung Kim, Hyundai MOBIS*

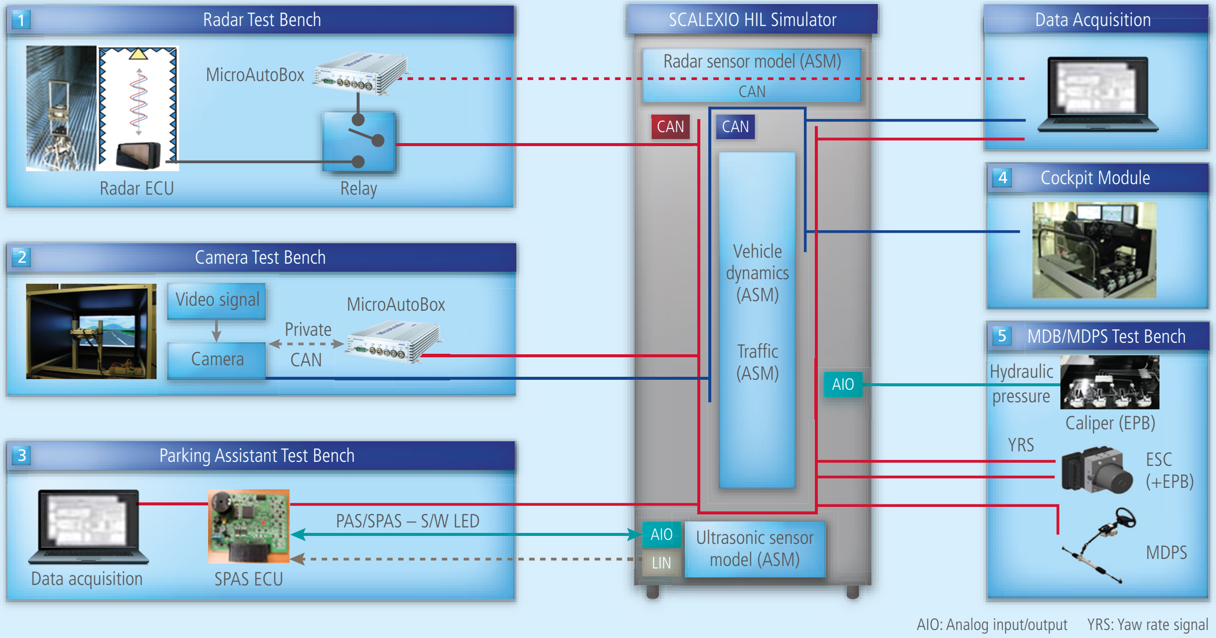

Figure 2: With the test bench of dSPACE hardware and software, several driver assistance systems can be tested in interaction.

3 Parking assistance system

The test bench for the ultrasound-based parking assistance system consists of the final production ECU and the ASM contour sensor model for ultrasonic applications that runs on the dSPACE HIL simulator. Actual ultrasonic waves are not necessary here.

4 Driver's seat

Here the experimenter can intuitively run through any driving maneuver that is calculated by dSPACE ASM and visualized by dSPACE MotionDesk, almost as in real traffic. These maneuvers can then be used for the camera test bench 2 for example.

5 Power steering (MDPS) and ESC

Here, real components (steering rods and brakes, including the ESC control unit) are connected and fed with data from the dSPACE ASM simulation for different driving situations or optional driver inputs to verify that the system functions correctly.

camera measuring station, a stereo camera is planned to be used in addition to the mono camera.

Evaluation of the dSPACE System

Using new technologies like camera and radar directly in a vehicle leads to new challenges for validating the developed systems. The testing system that dSPACE designed in accordance with the requirements of Hyundai MOBIS is the first HIL-based test solution for ADAS developments in Korea. Day after day, the reliability of SCALEXIO and the other dSPACE products are an important basis, allowing the developers to work successfully. The continuous support from dSPACE and MDS, dSPACE's distributor in Korea, helps develop and launch new groundbreaking driver assistance systems.

More Sensor Data in the Future

It can already be foreseen that the future vehicle will continue to have a higher number of sensors. This means an increase in the volume of measurement values that must be processed in real time. Using a HIL simulator in the laboratory under defined conditions helps test the most practical methods for handling these data sets in order to generate meaningful instructions for the vehicle systems. Drivers need to have an overall picture that is easy and fast to comprehend at all times so that the driver assistance systems help them, rather than hinder them. ■

Tae Seung Kim,
Hyundai MOBIS

Highly dynamic control of a test bench for high-speed train pantographs

Keeping Contact at 300 km/h

Electric rail vehicles must never lose contact with the power supply, not even at the highest speeds. But the complex interactions with the overhead contact line pose an enormous challenge for the calibration of pantographs. The Vienna University of Technology (TU Wien) and Siemens are therefore working on a new kind of test bench in order to transfer parts of the usual test runs to the lab. On board with them: tools from dSPACE.

The speed of today's rail traffic is constantly increasing. For example, reaching 300 km/h is no longer a challenge for modern trainsets – but it can be for their power supply. The dynamic interaction between the pantographs and the overhead line is particularly important. This elastic, connected system is prone to vibrations, especially at high speeds. If the contact forces are too weak, the pantograph is separated from the wire, resulting in arcing, which contributes to electrical wear of the carbon contact strips. If the contact forces are too high, they increase mechanical wear and cause strong dynamic loads in the overhead line and the contact strips. The different rail power systems, overhead line setups and national regulations pose additional challenges, especially in international rail traffic. This is why a growing number of modern high-performance pantographs can be controlled actively to optimize the contact forces even at high speeds. Until now, complex dynamic simulations can support these developments and mechatronic design but are not able to replace cost-intensive test runs. The pantograph manufacturer Siemens therefore uses dynamic hardware-in-the-loop tests of real pantographs as early as possible when developing suitable controllers. In these tests, the actual pantograph is the unit under test and is connected to a virtual overhead line. This enables Siemens to combine realistic test results with the advantages of lab-based development, such as reproducibility. Due to the dynamics of the overhead line in particular, it is very difficult to describe its behavior and implement a correct connection to the unit under test. If these tasks are mastered with a high quality, however, such test benches can perform fast, informative tests, in the form of virtual test runs, and give the developers a better understanding of the coupled dynamic interaction of the pantograph and the overhead line on the tracks. Test benches thus help reduce the number of effort-intensive and expensive field tests for newly developed vehicles during the test and evaluation phases.

High Dynamics on the Test Bench

In cooperation with Siemens, the Institute of Mechanics and Mechatronics of the Vienna University of Technology (TU Wien) has enhanced the existing highly dynamic pantograph test bench, which is now able to emulate the complex interactions with a virtual overhead contact line in real time. This means that real

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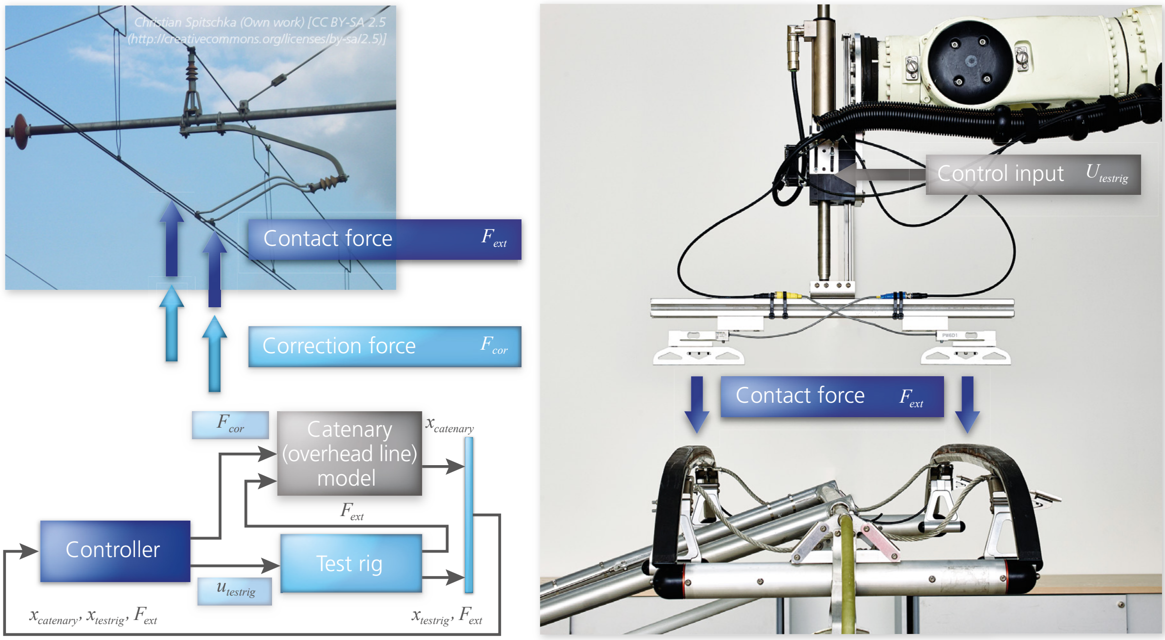
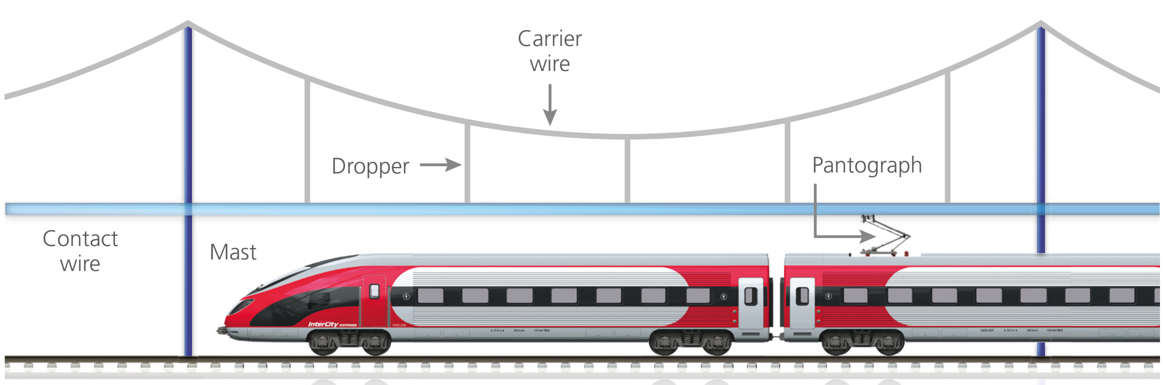


Figure 1: Thanks to the methods developed by TU Wien, realistic high-speed train drives can be emulated on the pantograph test bench from Siemens.

pantographs can be tested realistically and reproducibly in virtual test runs. An industrial robot combined with a linear motor takes on the role of the overhead line. A combined controller enables these two actuators to accurately simulate the behavior of the overhead line at the pantograph's current contact point, while measuring the resulting contact forces (figure 1). The unit under test, the pantograph, is subjected to the same forces that would also occur during dynamic contact with a real overhead line. To make the simulation as realistic as possible, an extremely efficient mathematical model of the dynamics of the overhead line has to be developed first. This model has to consider not only correct mechanical admittance but also wave propagation phenomena. Moreover, it has to be real-time-capable. The main components of the real overhead line are the contact wire and the carrier wire, both interconnected by droppers (figure 2). To create the mathematical model of the wires' dynamic behavior, the developers first formulated the

Figure 2: All components of a real overhead line, simplified in this figure, had to be included when modeling the virtual overhead line.



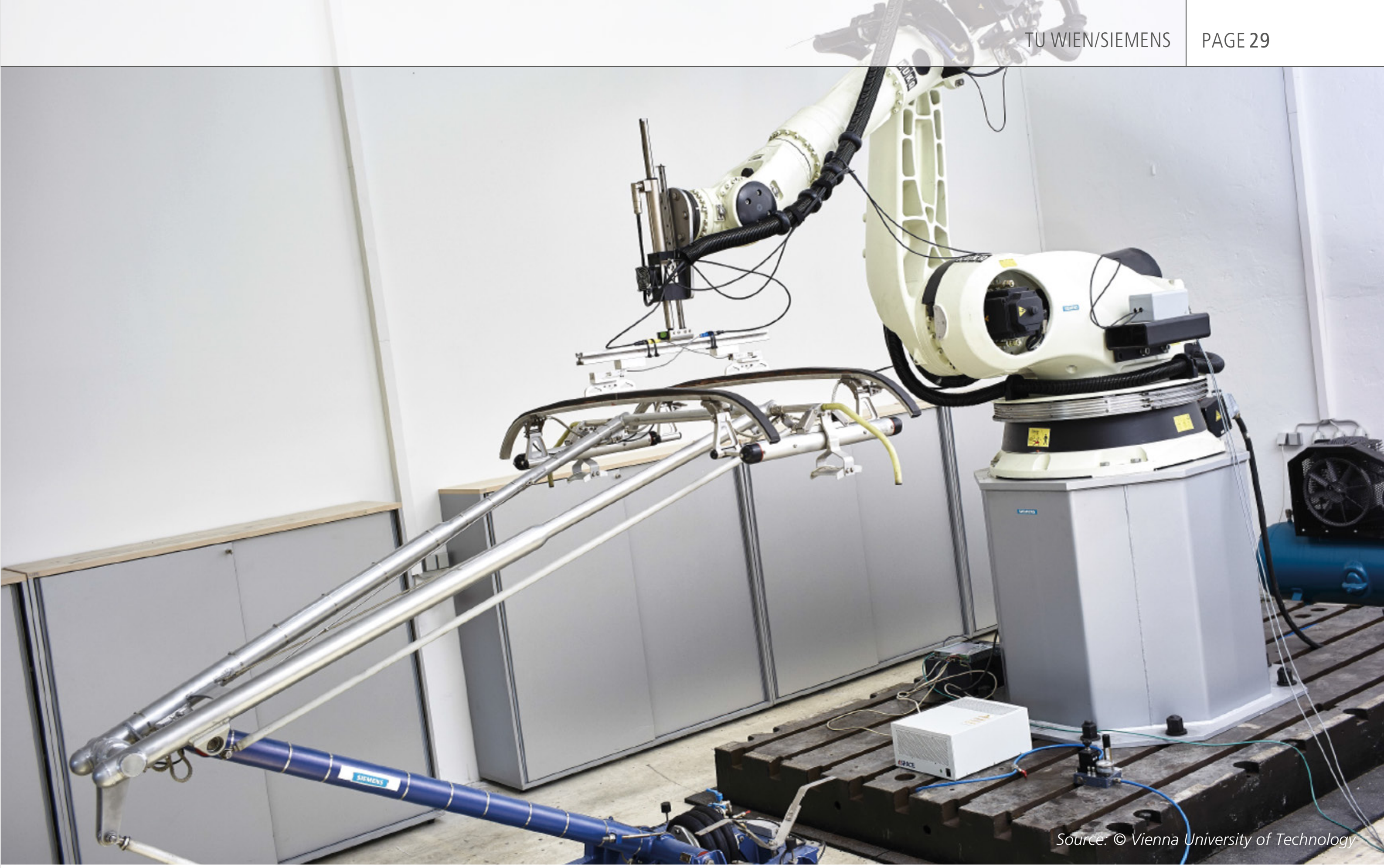


Figure 3: On the test bench system from Siemens, which enables pantograph testing, TU Wien uses a DS1006 Processor Board with numerous I/O extensions.

equations of motion (in this case, partial differential equations). They are formulated in co-moving coordinates so that only the movements of the overhead line close to the contact point of the pantograph have to be considered. These equations can then be solved with appropriate approximation methods (finite differences, finite elements). Special optimized absorbing boundary conditions allow stimulated waves to travel out of the computational domain. This lets the developers consider only a small section of the overhead line while still being able to realistically simulate the complex overhead line dynamics of a larger section. Naturally, the correct relative positions of the droppers need to be included. This results in a time-variant system structure that requires a comprehensive and automated preprocessing of the model data.

Coupling the Virtual and Real Worlds

The test bench control now has to establish a physically correct connection between the virtual power line and the real unit that is currently being tested. To achieve this, the developers use a predictive controller. Together with the precise models of the overhead line and the test bench actuators, the controller predicts the respective behaviors and makes the right control decisions beforehand. Thus, the overhead line can be simulated as realistically as possible on the test bench. This control system also ensures that the controller always observes physical limits, such as the maximum allowed motor current and position limits. To realize this behavior, complex mathematical optimization problems are solved in each sampling interval.

To deliver physically correct results even for difficult, highly dynamic test cases, even if the test bench is not fast enough to follow the virtual overhead line, the research team developed and implemented unique new extensions for traditional hard-

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> "The dSPACE tools not only reliably cover our high demand for computing power, they also give us the greatest flexibility possible and can be used for a wide range of tasks."
>
> *Professor Stefan Jakubek, Vienna University of Technology*

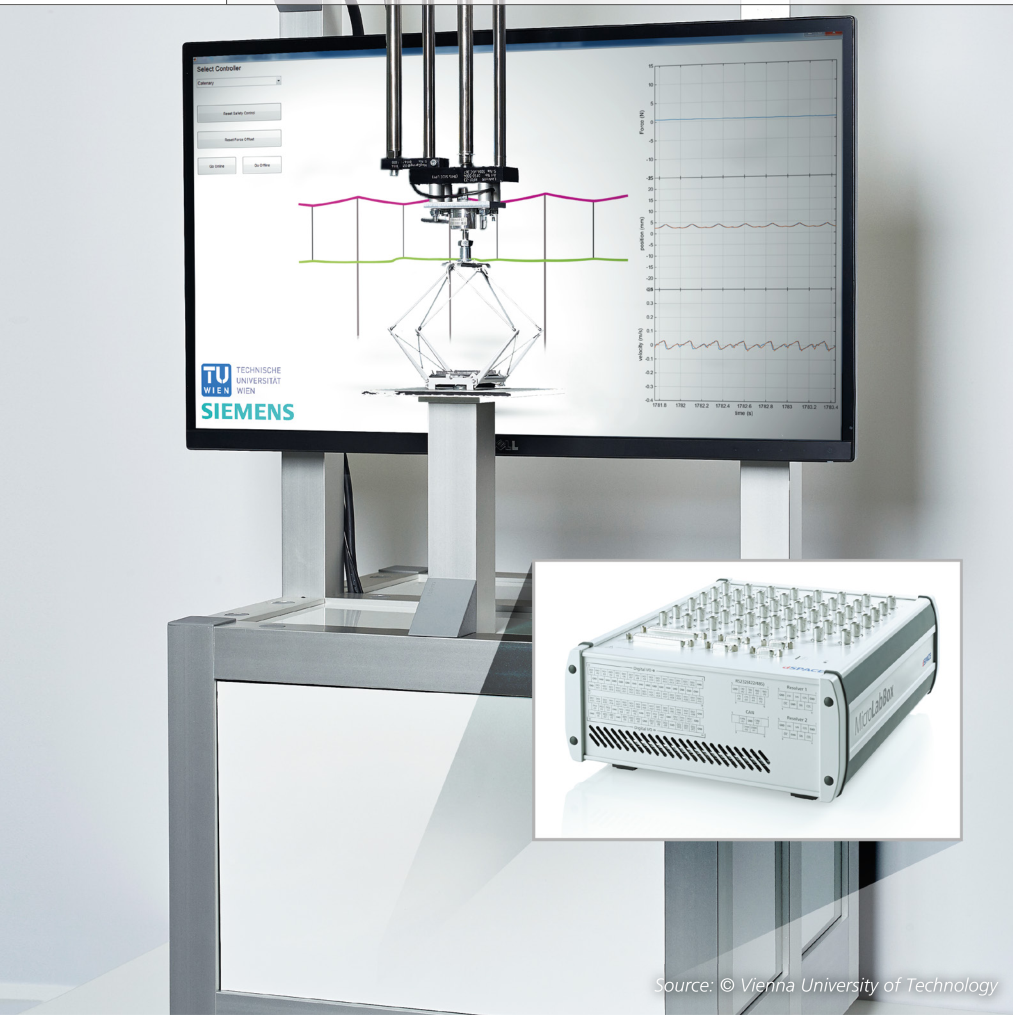

Figure 4: A MicroLabBox was used to build a smaller demonstrator model of the pantograph test bench. Because it is so easy to transfer the developed control concepts from the test bench to the demonstrator, they can be used as illustrative examples in the classroom.

Figure 5: Test drives can be used to demonstrate how effectively the new pantographs prevent electric arcs.

ware-in-the-loop control concepts. A separate formulation is used to consider the two conserved quantities of impulse and energy directly within the controller. This ensures that the virtual overhead line and the real pantograph consistently exchange these conserved quantities, making the test results even more realistic. Simulating the complex interactions of the virtual overhead line and the real pantograph requires high model precision, while model complexity has to be kept to a minimum so that the model can still be computed in real time. The real-time system also has to prepare the measurement data received from state observers and estimate disturbances such as friction forces. To complete all these tasks in real time, TU Wien needed not only new numeric methods but also an extremely powerful real-time platform.

Flexible dSPACE Tool Chain

TU Wien chose real-time tools from dSPACE. In the course of the research project, the test bench concept was developed on two different dSPACE platforms. The backbone of the test bench that can be used to test life-size pantographs is a DS1006 Processor Board (figure 3). Its 2.8 GHz quad-core processor allows developers to perform complex system simulations and use controls with high sampling rates, because the computation load can be distributed efficiently. For example, one processor core is responsible for the basic connection and control of the test bench (5 kHz sampling rate), while another core performs the predictive impedance control (200 Hz). A third core simulates a precise model of the overhead line (200 Hz). In each sampling step, the test bench controller is initialized according to the model states. For the tailored communication with the test bench components, the developers use a DS4302 CAN Interface Board (linear motor), a

DS3002 Incremental Encoder Interface Board (position sensor), a DS2201 Multi-I/O Board (control variables), and a DS4121 ECU Interface Board (industrial robot). Most of the developed algorithms were implemented in MATLAB®/Simulink® and compiled directly from there. The team also used the easy integration of external libraries for efficiently solving complex mathematical problems. A user interface developed with the experiment software dSPACE ControlDesk® makes controlling the virtual test runs on the test bench highly intuitive. In addition to the life-size test bench, the developers also built a downscaled laboratory test bench for development purposes and for the classroom (figure 4). The laboratory test bench clearly demonstrates the interactions between the pantograph and the overhead line, as well as the basics of impedance control, and makes them easy to understand. For this, TU Wien for the first time used the new compact MicroLabBox. The high compatibility and seamlessness of the dSPACE tool chain allow for an easy transfer of the algorithms from the test bench to the smaller lab demonstrator.

Results and Outlook

The described tools can be used to build a highly dynamic and powerful pantograph test bench. In particular, thanks to the extended overhead line model it is possible to analyze the influence of multiple traction, i.e., a train with numerous pantographs raised simultaneously, already on the test bench. The performance of future pantographs can thus be quantified reliably and early in the development cycle. Siemens' pantograph test bench, developed further in cooperation with TU Wien, is the very first hardware-in-the-loop test bench worldwide that can simulate the system dynamics of partial differential equations consistently in conserved quantities. The realistic, highly dynamic tests that are now possible and their reproducibility significantly improve high-performance pantographs and are therefore a valuable asset for making future rail travel even more efficient. Due to the easy transfer of tests to the smaller demonstrator, the control models can also be used in the classroom for educational purposes and to spark young engineers' interest in railway technology. So it is quite possible that future rail traffic will continue to set new records in speed and efficiency. ■

Prof. Stefan Jakubek, Dr. Alexander Schirrer, Dipl.-Ing. Guilherme Aschauer, Vienna University of Technology
M.Sc. Christian Saliger, Siemens AG Austria

This video shows you the Siemens pantograph test bench, developed in cooperation with TU Wien, in action so you can learn more about its new type of highly dynamic control.

www.dspace.com/go/dMag_20161_tuwien_e
(© Strukt GmbH)

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The development of innovative combustion processes for engines often demands extremely fast control loops that enable engineers to intervene even in an ongoing combustion process. RWTH Aachen University used a dSPACE MicroAutoBox II for an in-cycle control to ensure a stable and controlled autoignition for gasoline engines.

When thinking about alternative propulsion technologies, developers nowadays tend to focus merely on the aspect of electromobility. This can be shortsighted when it comes to combustion engines, which are sometimes regarded as phase-out models, but whose development potential is far from being exhausted. New and innovative combustion processes promise a considerable increase in efficiency. Autoignition, for example, which was previously a monopoly of diesel engines, can also be employed in gasoline engines. Gasoline controlled autoignition (GCAI) is expected to significantly reduce emissions of carbon dioxide, nitrogen oxides, and particulates. However, implementing GCAI requires complex control and regulation processes. For this reason, closed loops using an indicated combustion chamber pressure as an input value have proved to be particularly promising. A direct and thermodynamic analysis of the pressure curve enables developers to immediately evaluate combustion and adjust in-cycle setpoints. Researchers at the Institute for Combustion Engines (VKA) of RWTH Aachen University are engaged in finding methods of rapid control prototyping that ensure an adequately fast in-cycle control with integrated index analysis and with minimum latencies.

Highly Variable Research Engine

For this, the researchers in Aachen use a single-cylinder engine with direct injection and an outward-opening piezoelectrically actuated hollow cone injector in a central position (figure 1). The research engine is further equipped with a fully variable electromechanical valve train (EMVT). Because the valve train can be disconnected completely from the crank drive, it is possible to specify the high proportion of internal residual gas required for autoignition for each cycle and according to the operating point. dSPACE's MicroAutoBox II together with its freely programmable Xilinx® Kintex®-7 FPGA has proved to be an ideal develop-

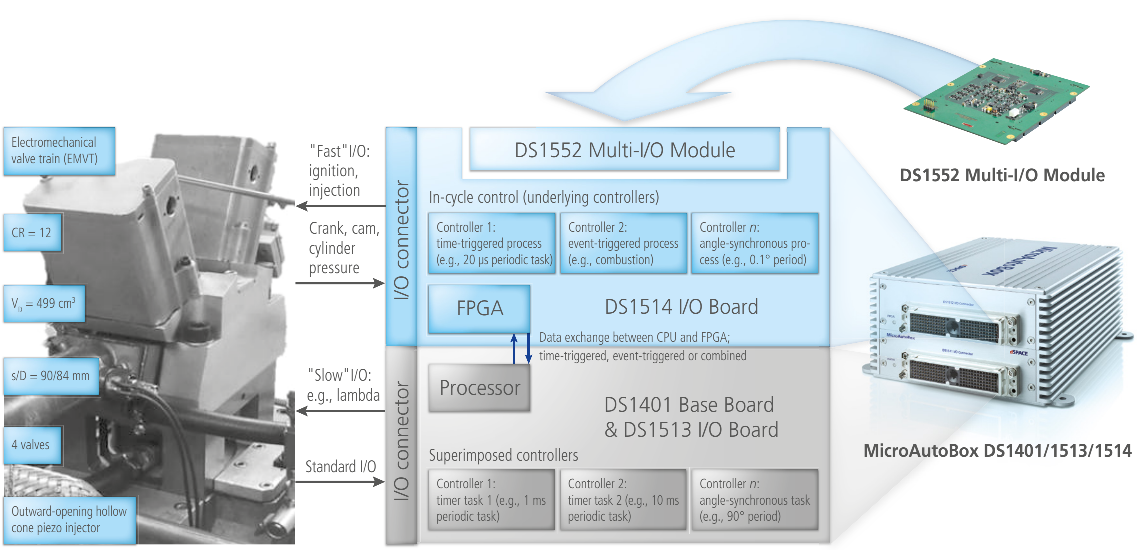

Figure 1: Single-cylinder research engine with an electromechanical valve train (on the left); Development ECU MicroAutoBox II with Kintex-7 FPGA (on the right).

ment ECU for the planned research work. For the first time, the institute used the XSG Advanced Engine Control Solution with MicroAutoBox II. The solution is an open library, designed for a model-based FPGA design from within Simulink® and based on Xilinx System Generator (XSG).

Real-Time Indication

A characteristic feature of the solution is its real-time-capable evaluation and cylinder pressure indication (CPI). The crankshaft, camshaft and encoder signals are first evaluated on the FPGA by an angular computation unit (ACU), and an angle signal with a resolution of 0.1° is generated as a basis for further real-time evaluations. The cylinder pressure signals are sampled at 1 MHz and processed crank-angle-synchronously. During this process, the thermodynamic values required for the in-cycle control are specified, such as the heat release behavior, the indicated mean effective pressure of the high-pressure loop and the gas exchange, as well as the peak pressures and pressure gradients. To ensure real-time capability, only causal algorithms are used. In a comparison test, the algorithms of the CPI used were validated via the well-established indication tool Combustion Analysis System (CAS) of FEV GmbH. With less than one percent, the occurred deviations were negligibly small, so that the parameters required for an in-cycle control can be provided at the rate of the FPGA. The fast actuators (EMVT, fuel injection) are also controlled directly via the XSG Advanced Engine Control Solution, enabling control intervention within just a few nanoseconds. Thus, it can be performed within one combustion cycle and serve as a correction variable for the slow and global control that was implemented on the processor unit of MicroAutoBox II. >>

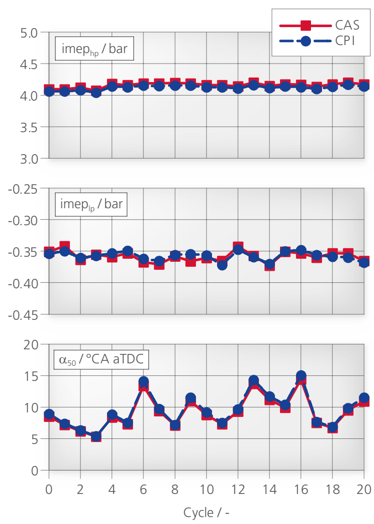

Figure 2: Exemplary comparison of the cylinder pressure indication (CPI) via the Advanced Engine Control Solution and via the tool Combustion Analysis System (CAS). The deviations of the indicated mean effective pressure $imep_{hp}$ and $imep_{lp}$ as well as of the center of combustion (α_{50}) were negligibly low.

In-Cycle Control Concept

During the research experiments, the high proportion of internal residual gas required for autoignition was realized by means of combustion chamber recirculation. In this approach, the exhaust valve is closed early and the intake valve opens late, symmetrically to the top dead center of the gas exchange. During this phase, the exhaust gas remaining in the combustion chamber is compressed. As a result of the unburned fuel, a late and incomplete combustion is typically followed by an early combustion with a high pressure increase. There is a clear correlation between the pressure level during intermediate compression and the subsequent point of combustion. An extremely late combustion therefore leads to a significant heat release during intermediate compression (figure 3). This correlation was used in an in-cycle control. The Advanced Engine Control Solution was employed to determine the maximum cylinder pressure signal during intermediate compression, which serves as an input signal for the control loop. The crankshaft angle at which the intake valve closes is used as a control variable (IVC in figure 4). Delaying this action reduces the effective compression ratio. Consequently, the conditions for autoignition and the center of combustion are also delayed. Closing the intake valve earlier encourages autoignition and therefore results in an early center of combustion. If the real-time evaluation of the cylinder pressure performed during intermediate compression reveals a low peak pressure at the top dead center of the gas exchange, the control variable for the closing intake valve is moved to an earlier point within the same cycle, in order to prevent a late center of combustion, and vice versa. As a result, the control loop closes between the top dead center of the gas exchange and the activation of the intake valve, within a crankshaft angle of approximately 90° CA, which corresponds to a time slot of 10 ms at a rotational speed of $n = 1500\ min^{-1}$.

> "dSPACE's tools enable extremely fast in-cycle control, opening the door for the development of innovative combustion processes."

Prof. Dr.-Ing. Jakob Andert, RWTH Aachen University

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Prof. Dr.-Ing. Jakob Andert
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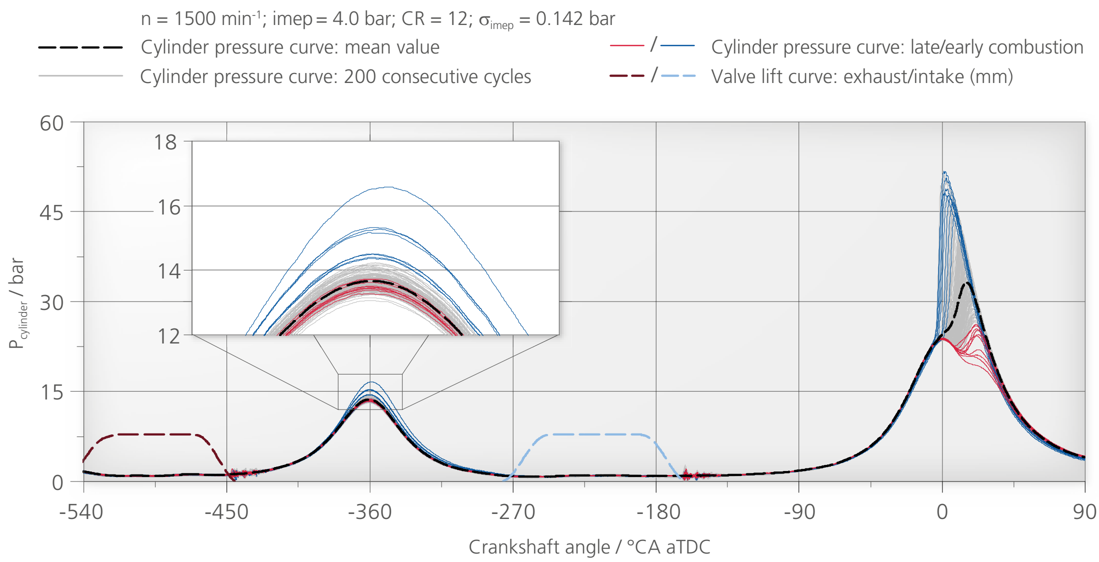


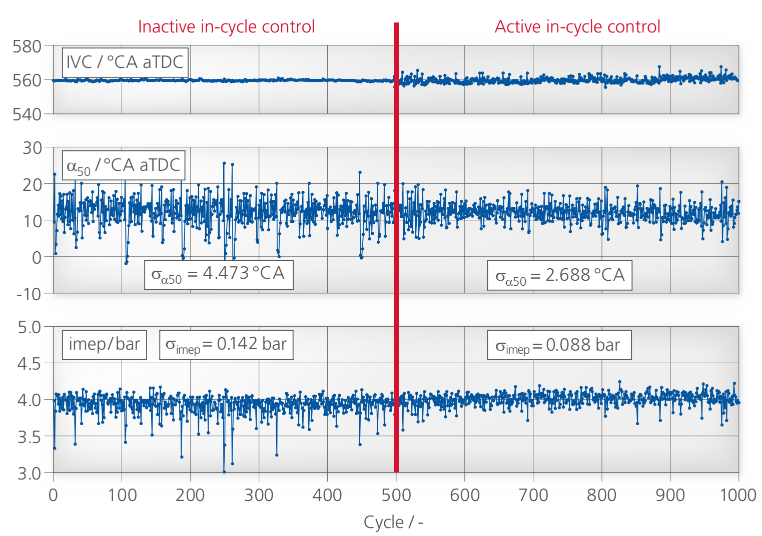
Figure 3: Cylinder pressure traces with a late (red) or early (blue) combustion point. The cyclic fluctuations that are quantified by a high standard deviation of the indicated mean effective pressure σ_{imep} = 0.142 bar, are clearly visible.

Convincing Results

Evaluations of the described in-cycle control clearly reveal that extreme load deviations can be avoided by an active control, which considerably decreases the standard deviations of the indicated mean effective pressure (figure 4). The center of combustion also improves significantly. An extremely early or late center of combustion can be avoided reliably. By using the correlation between intermediate compression and subsequent combustion, the researchers of the RWTH Aachen University successfully implemented the intended in-cycle control and use it with the research engine. The potential of fast control interventions became evident. Further research projects of the university will aim at using the capabilities of the FPGA of MicroAutoBox II for even more complex control algorithms. By this, the researchers seek to optimize the prediction of the combustion process via the real-time evaluation of cylinder pressure. There is also a need for further research in the area of control variables that allow control interventions within an ongoing cycle. In this context, the Institute for Combustion Engines is presently scrutinizing strategies for multiple injection and water injection, in particular. So there is a good chance that the internal combustion engine will not become a phase-out model after all. ■

Dipl.-Ing. Bastian Lehrheuer, Prof. Dr.-Ing. Jakob Andert, M.Sc. Maximilian Wick, RWTH Aachen University

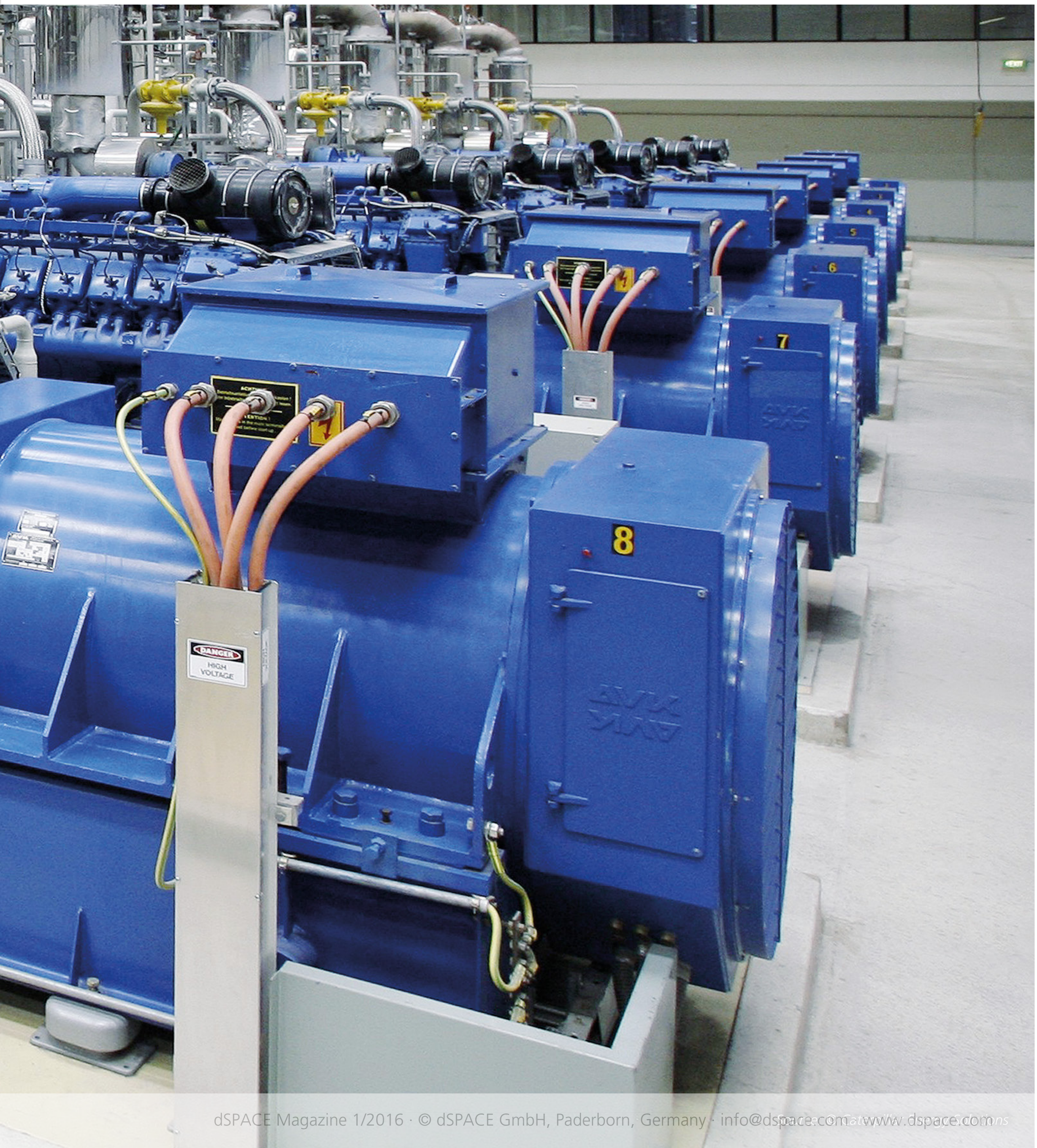
Figure 4: IVC (control variable for the closing intake valve), α_{50} and imep, for 1000 consecutive cycles with an active and inactive in-cycle control. With an active control, the standard deviation of the indicated mean effective pressure decreases considerably from σ_{imep} = 0.142 bar to σ_{imep} = 0.088 bar (at the bottom). An extremely early or late center of combustion can be avoided reliably (center).



Top Performer

Controlling high-performance gas engines for energy supply

One thing is for certain: If you start a large high-performance gas engine with a suitable generator, you are the best-motorized employee on site – at an electric power of up to 4,500 kW. Such powerful machines are used primarily for the stationary generation of energy and heat. Caterpillar Energy Solutions developed an entirely new control to ensure that future energy plants remain efficient, dynamic, and maintenance-friendly.



Plants for decentralized energy generation can be used in many different fields. They can be used as independent power producers (IPP) to ensure a flexible and powerful energy supply in places that would otherwise not have power at all, such as remote areas where raw materials are being extracted, barely developed settlements, and areas where using the existing infrastructure would be too expensive for several reasons. In addition, the industrial and agricultural sectors often produce flammable gases as a by-product. It can therefore make sense to use these gases for one's own energy supply, to feed the generated energy into the public grids for a financial benefit, or to resell the energy directly, e.g., to neighboring production plants. These independent power producers, consisting of gas engines and generators, are also very well suited for covering the peak loads of the public power grid. The machines are furthermore used to produce process heat, e.g., by generating hot water or water vapor, and to reuse waste gas directly, e.g., for CO_2 fertilization in greenhouses.

Gas engines for energy generation.

Complete Plants for Generating Energy and Heat

Caterpillar Energy Solutions GmbH is one of the leading providers of highly efficient, environmentally friendly holistic systems for decentralized energy and heat generation. The product range of the brands Cat and MWM includes gas engines, customer-specific power plant solutions, complete turn-key systems, container cogeneration plants, and flexible modular gas power plants that are easy to set up, economical and environmentally friendly. The company also offers comprehensive advice, plant design, engineering services for installing systems and putting them into operation, and worldwide services such as customer support and maintenance.

Requirements for Operating Gas Engines

A reliable power plant is particularly important for applications without access to the public power grid, which have to produce energy independently. In parallel grid operation, the consumers can still use the public, integrated power grid if necessary. In isolated grids, however, consumers depend on the few energy providers in a small area, and power supply sometimes hinges on only a few gas engines. But to cover peak loads, the public grid needs a power supply that is reliable and readily available. This also applies to heat generation. Reliability, efficiency, and flexibility are therefore the holy grail of energy supply. These three factors are, in turn, closely connected to maintenance, because a machine should require as little servicing as possible, while operation downtimes have to be kept short and maintenance costs low. In addition to further developing the engine mechanics to minimize the use of lubricants, the control development team is working on methods to minimize the costs of maintenance. Therefore, the mechanical factors are just one part of the solution. Rather, a sophisticated electronic plant control is needed to meet the requirements.

Towards a New Plant Control

The goal of Caterpillar Energy Solutions is to use this new control to make future plants even more efficient, flexible, and maintenance-friendly, and to use the newly developed control across the entire prod-

uct range. Therefore, the company decided to replace third-party electronic control units (ECUs) in future plants with their own electronic control units. When applied to gas engines for energy production, this task can be even more challenging than for conventional combustion engines (e.g., for passenger cars). The costs, size, and production time for one high-performance gas engine are considerable, and there are many product variants, so it is usually not possible to have special prototypes for testing. The development team therefore constantly faced the risk of severely damaging the real engine when performing tests at the limits and under high loads due to intensive testing of start, stop and emergency stop behavior, which would cause extremely high costs and delay the project. Testing also had to be possible before a real engine was available. It was therefore all the more important to test the engine control system in offline function development (software-in-the-loop, SIL) and on a hardware-in-the-loop (HIL) simulator, in the plant network and with a HIL system of the superordinate control system. Another requirement of Caterpillar Energy Solutions was to make the HIL simulation environment flexible and scalable to test the many engine variants, and to make it a fundamental element of future software release processes with the aim of becoming more and more independent of physical testing with real engines. >>

Motor Specification

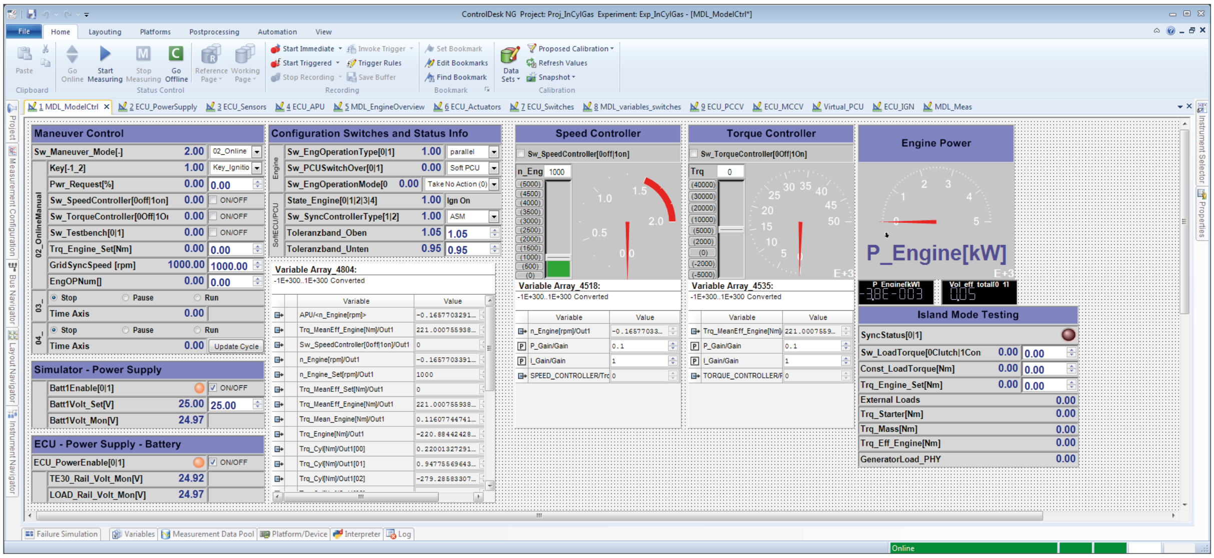
- Cylinders: 8 - 20
- Power range: Usually 400 - 4,500 kW_{el}
- All gas types: Natural gas, landfill gas, sewage gas, mine gas, coke oven gas, biogas
- "Traditional" engine control (e.g., throttle valves) plus process control (e.g., for cooling, gas pressure, electrical phases)
- Special emergency strategies (e.g., emergency stop)

The high number of cylinders to be controlled required a particularly efficient simulation model for SIL and HIL testing.

Ralph Staudt (left) and Sreenivasa Ravipati (right) of Caterpillar Energy Solutions used a dSPACE Simulator to perform extensive HIL testing of the engine ECU.

> "As a supplier for tools and engineering services, dSPACE has been our go-to partner for the many detailed questions about our HIL system, from simulator specification to closed-loop operation with the real ECU. This helped us speed up the project considerably."

Magnus Euler, Caterpillar Energy Solutions



Experiment control with ControlDesk Next Generation.

Requirements for the Simulation Model

To simulate a gas engine for ECU development, the simulation model has to replicate the specific engine characteristics precisely enough. The scope and quality of the simulation have to be high enough for the specific use case and supply the ECU with plausible values for all work steps. Caterpillar Energy Solutions particularly considered industry-proven models that are easy to adjust to the characteristics of gas engines. This resulted in the following requirements for the plant model of the combustion engine:

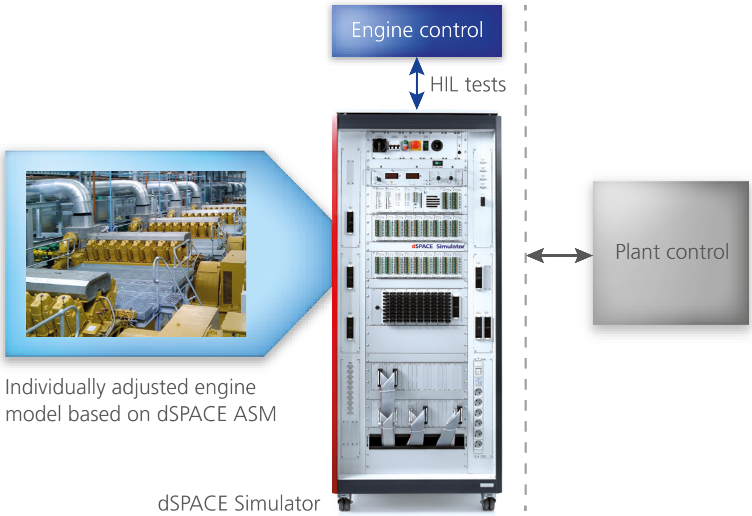
- An adjustable open model architecture that can also be used with gas engines for energy production
- High computational efficiency for real-time simulations with up to 24 cylinders
- A high quality of detail to suitably address potential cylinder pressure sensors
- Flexible parameterization of the model with simulation data with a limited number of load points

dSPACE ASM for Gas Engines

With the support of dSPACE Engineering Services, it was possible to adjust the original ASM Gasoline Engine InCylinder model – an open, granular Simulink® model – for Caterpillar Energy Solutions so that it can now be used to simulate gas engines. The model was adjusted in several steps:

- Partially reusing library blocks to adjust the basic model to the specific engine schema with units such as intercoolers and valves. This entailed only a reasonable amount of effort because by default the ASM model is parameterized for an engine topology with a twin turbocharger and V-engine architecture.
- Restructuring the automotive combustion engine model according to the requirements of the energy supply technology
- Changing the physical, chemical, and thermal parameters of the basic model
- Automatically optimizing the parameters by evaluating measurement values to improve the simulation results
- Validating the model via ASM Engine Testbench during offline simulation

> “With the ASM Gasoline Engine InCylinder model adjusted to our requirements, we were able to perform a sufficiently realistic yet real-time-capable simulation of the gas engine.”
>
> *Magnus Euler, Caterpillar Energy Solutions*



By using a dSPACE Simulator and a modified model based on ASM Gasoline Engine InCylinder, Caterpillar Energy Solutions was able to perform early HIL tests of the engine control without the need for a real engine.

Testing the New Engine Controller

The plant and engine controller developed by Caterpillar Energy Solutions had to undergo testing in various areas. For example, the behavior of the controller and the engine before, during and after synchronization with the electrical phase has to be tested, including start, stop and emergency stop behavior, to guarantee smooth operation in a power grid. Offline function tests via SIL simulation and ECU tests on the HIL simulator were used. The specially adjusted ASM models were used in all test phases.

HIL Test System

A dSPACE Simulator Full-Size was used for HIL testing. The simulator is equipped with two expansion boxes that each contain a DS1006-based system with extensive I/O. This made it possible to perform powerful multicore and multiprocessor operations, especially for reducing simulation times by computing the ASM model separately from the I/O. The dSPACE simulator also contained modules for signal conditioning, a Failure Insertion Unit for inserting electric faults, and modules for current measurement and load simulation. Real loads, such as injectors, throttle valves, and wastegate valves, were used for testing. The simulator was also connected to the larger HIL system of the plant control. All the simulation tasks were executed with dSPACE's experiment software ControlDesk® Next Generation. ■

Magnus Euler,
Caterpillar Energy Solutions GmbH

Conclusion

The new plant and engine control system developed by Caterpillar Energy Solutions laid the foundation for even more efficient, flexible, and maintenance-friendly Cat and MWM products. The fact that dSPACE provided a one-stop solution for important tools as well as engineering and support services significantly contributed to the success and quick implementation of the project. By frontloading many tests to SIL and HIL simulation, Caterpillar Energy Solutions was able to perform a large share of the development work before the real engines were available. These tests then did not have to be performed on the expensive real engine later on. This, in turn, shortened the time needed for development. The dSPACE tools were used to create a development environment for engine ECUs across the entire product range and for engines with different numbers of cylinders. ASM is already being used in new engine development projects.

Magnus Euler
Magnus Euler is head of Engine Control in the Electrical Engineering department of Caterpillar Energy Solutions GmbH, Mannheim, Germany.


AMAZONE
CLAAS
550
ARION
ARION
CMATIC

Smooth Success

Developing an infinitely variable transmission for tractors

Source: © CLAAS

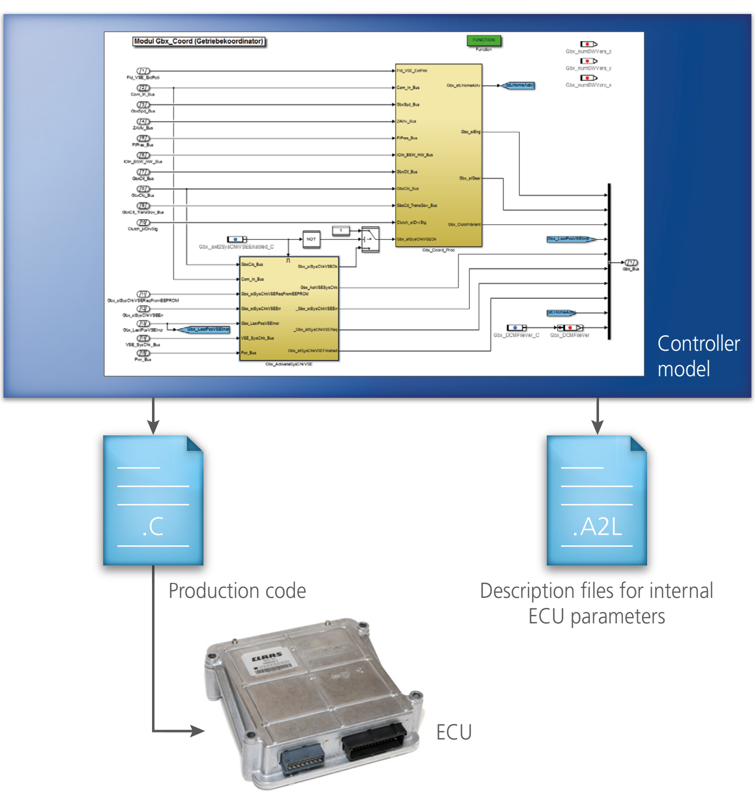
Before they developed their new tractor transmission, CLAAS Industrietechnik (CIT) did not have any experience in model-based software development. In the end, the product surpassed even their highest expectations. Part of this success story: the powerful tools from dSPACE.

The heavy tractor starts on a hill without a single jolt, accelerates evenly and reaches its maximum speed without any noticeable loss in tractive force. The only thing the driver does is use the accelerator. The clutch and gearshift are obsolete. A new tractor transmission from CLAAS Industrietechnik GmbH (CIT) makes this possible. The infinitely variable transmission EQ 200 reliably keeps the tractor in an active idle state, even on a slope, and promptly reacts to accelerator commands. It is designed so that the tractor drives with a very low engine torque of 1,500 revolutions per minute even at the maximum speed of 50 km/h. This saves valuable fuel on the road. CIT developed their own transmission to increase efficiency and comfort. "The transmissions on the market did not satisfy our demands," states Jan-Willem Verhorst, head of the CIT product division.

Tractors as Mobile Energy Sources

One main feature of tractors is that they drive working tools, such as hay tedders, via a power take-off (PTO). "That's why we should think of tractors not only as vehicles, but also as mobile power sources," explains Helmut Konrad, head of electronics development at CIT. "Of course, this entails new challenges." He particularly focuses on the process speed of the attached farm implements, which have to be controlled independently of the tractor's propulsion. The decisive challenges for the CIT team are efficient processes and a consistently optimum efficiency over the entire speed range.

TargetLink generates efficient production code from the controller model and implements it on the ECU.



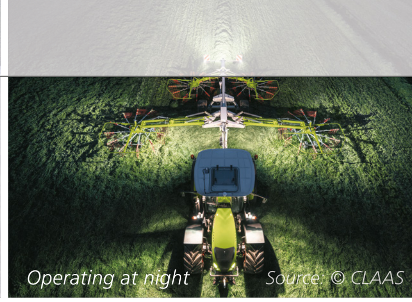
Technical Requirements

To ensure ideal operation for the diverse use cases of tractors, CIT uses drive controls that automatically identify the best strategies for driving and operating the implements. Furthermore, the controller realizes the manufacturer-specific drive philosophy, which Verhorst explains as follows: "In general, we try to achieve a low torque and thus low fuel consumption. At the same time, we want to make the tractor highly dynamic." What is more, there are strict requirements in agricultural engineering concerning fail-safe functioning, because a vehicle that cannot be used due to a technical defect can significantly reduce production or even cause the loss of the entire harvest.

Development Task: Infinitely Variable Transmission

The overall goal of harmonizing all of these requirements was the decisive factor for CIT to develop the infinitely variable transmission (IVT) EQ 200 themselves, including the transmission ECU and drive controller. "Because we did not have a predecessor project in this performance class at CIT that we could have built on, our developers started out with a blank sheet of paper," recalls Thomas Gohde, system engineer for R&D Tractor Powertrain. "That's why our visions were unlimited at first." The initial drafts resulted in a specification whose requirements were so high that it went down in company history as "A Driver's Dreamland". At the same time, the developers also had to consistently adhere to common requirements,

Winter maintenance



Operating at night

Source: © CLAAS

> "MicroAutoBox enabled us to test and assess our control strategies easily and quickly in the vehicle."
>
> *Jan-Willem Verhorst, head of R&D Drivetrain, CLAAS Industrietechnik GmbH*

such as automotive standards and the ISO 25119 standard, which defines the functional safety of electronic control units (ECUs) for agricultural vehicles.

Choosing a Tool Chain

For the drive control and the EQ 200's ECU, for the very first time CIT opted for a model-based software development process (MBD). But because they were very new to this field, they wanted to use only standard, industry-proven tools. That's why Simulink® was quickly chosen as the development environment. But how was CIT to generate the target code for the two ECUs? After consulting previous research from other departments at CLAAS, they chose dSPACE's production code generator, TargetLink®. Another well-established dSPACE tool for vehicle development – MicroAutoBox® – was selected to test the algorithms in the tractor prototype. In a later development phase, two dSPACE hardware-in-the-loop (HIL) simulators were added for ECU testing.

Developing the Functions

At the outset of the project, CIT had a team of four, but the team soon grew to work on additional tasks. However, the truth was that the specifications were just too high – even for the rapidly growing team. A revised specification document, called "Down to Earth", set a new, more realistic course. Despite the initial lack of experience in model-based development, the first successes were soon apparent, not least because of the dSPACE products. "The tool chain we used improved the communication with the mechanics in the transmission development, because we were able to focus on function development without having to tackle too many coding tasks," says Gohde. CIT was even able to take the project for the transmission ECU, which was carried out by a development partner at first, and continue it themselves.

Implementing the Functions

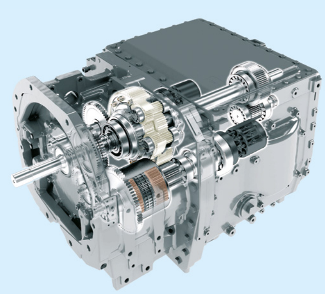
CIT uses the TargetLink Blockset to develop the function models. "In addition to the native TargetLink blocks, we created our own library for often-used functionalities, such as filters," Gohde explains. The development team also benefitted from the distributed development via model referencing. In model referencing, partial functions are created, generated, and tested individually. Then they are included in a superordinate integration model, from which TargetLink generates the glue code for software integration. Furthermore, the team used

>>

Infinitely Variable Transmission EQ 200

The components of the EQ 200 include a multiple-ratio planetary transmission, a hydrostatic transmission unit, and two multi-plate clutches. The transmission parts were combined in such a way that the transmission has a particularly high and nearly constant efficiency at all speeds. When gears are shifted automatically, not only the gear ratio but also the overall power flow through the transmission changes. The torques of the two clutch shafts approach each other as speed increases until they both have the same torque. When the two torques are exactly synchronous, the multi-plate clutches change gears. The gears therefore switch without a jump in rotational speed or torque, even under load, which enables a smooth acceleration behavior.

Learn more about how the EQ 200 transmission works in this video. www.dspace.com/go/dMag_20161_CLAAS_E



The EQ 200 transmission convinces with its jolt-free gear changes and smooth performance.

"By using TargetLink, we saved an entire development step and always generated reliable production code."

Thomas Gohde, system engineer for R&D Tractor Powertrain, CLAAS Industrietechnik GmbH

the page-switching technique to reserve storage areas for easy switching between parameterization variables, and for the A2L files generated by TargetLink for calibration and measurement tools. CIT was able to thoroughly test the code with TargetLink's own features and BTC EmbeddedTester, enabling them to detect and eliminate errors early on. The efficient production code generated with TargetLink was then implemented on the control units.

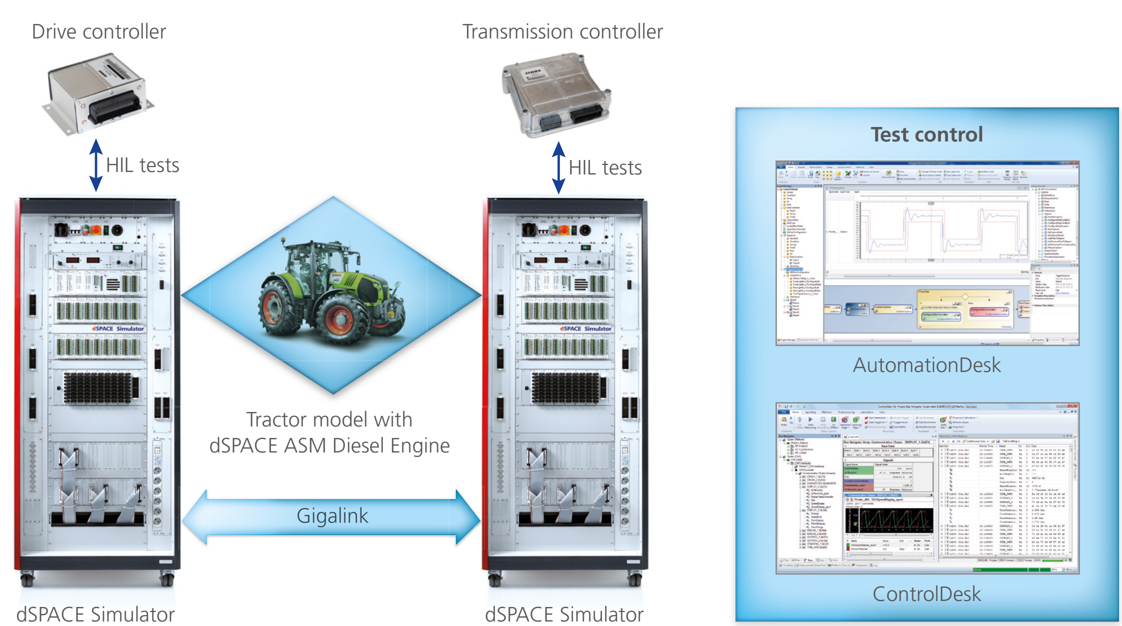
Validating the ECU Software

"Even at the very beginning of the project, we knew that testing the ECUs would entail just as much effort as developing the ECU software," Konrad recalls. "This is why we built two equally strong teams for development and testing, and separated them so each team maintained its own vantage point." The HIL tests started with the drive control ECU. CIT developed most of the simulation models needed for this task themselves, while they used the ASM Diesel Engine model from dSPACE for engine simulation. Throughout the development process, the developers built a test library in AutomationDesk to execute the many tests automatically. This enabled them to test new software versions overnight and evaluate the results on the very next day.

Verifying and Validating via System Tests

Once the component tests are complete, i.e., the ECUs for drive and transmission control were tested on their own, integration tests of the two networked ECUs were performed. CIT extended the developed test libraries to be able to test the interaction of

Setup of the HIL test bench, which can run overnight thanks to test automation.



Clearing

Spreading

Source: © CLAAS

the two ECUs in the restbus-simulated vehicle. The two dSPACE Simulators and AutomationDesk made it possible to perform a complete system test, with two test engineers, in just three weeks. The depth of the tests helped certify the ECUs according to ISO 25119. The subsequent field tests demonstrated the high software maturity achieved in the lab: While similar projects required approximately 11,500 hours for testing the electronics system, the new, model-based method required only 3,500 test hours.

Successful Start of Production

In 2014, the infinitely variable transmission EQ 200 and the drive control were successfully brought to market. They are used in tractors of the ARION 500/600 series, whose efficiency and convenience immediately convinced many customers. In the meantime, CIT has sold more units of this series than forecast in the business plan, so customers have to be patient and wait approximately one year for their tractor to be delivered. But the commercial success is not all. The development team around Verhorst, Konrad, and Gohde is even more thrilled about the positive customer feedback concerning the tractors' driving behavior and fuel consumption: "What made this project the largest and most successful project at CIT is not just our determined effort, but also our efficient and easy-to-operate tool chain. Even though our developers started out without any special MBD knowledge, we were able to deliver the right product at the right time, a product that has been in the fields for a whole year and has yet to produce a software error." ■

With the kind permission of CLAAS Industrietechnik GmbH, Paderborn, Germany.

The Project

The Task
Developing a drive control and transmission ECU for tractors.

The Challenge
Introducing the model-based development method and an appropriate tool chain for function development and validation of ECU software according to ISO 25119.

The Solution
Setting up a model-based ECU development process. Efficiently using MicroAutoBox for rapid control prototyping, TargetLink for software implementation, and the dSPACE Simulator with AutomationDesk for validating the ECUs. For future projects, CIT plans to manage and evaluate the comprehensive test cases and test data with the data management software dSPACE SYNECT®.

"The dSPACE Simulators helped us considerably increase software and hardware quality."

Helmut Konrad, head of Electronics Development, CLAAS Industrietechnik GmbH

Quick Multi-Platform Tests

The scope of testing is growing, the number of platforms to be tested is rising, but time and resources remain scarce. Can this conflict be solved? According to Chinese automobile manufacturer Brilliance, it's all a matter of efficiency, so they rely on a fully equipped simulator system from dSPACE.

Setting up a flexible, automated test environment for multiple vehicle platforms

Source: © Brilliance

When complex electronic control unit (ECU) networks are validated under time-critical conditions, efficient tests are an important key to success. The electrics/electronics (E/E) department at Brilliance even needs to deal with the daunting challenge of testing multiple vehicle platforms (cars, minivans, SUVs) at the same time. And even if just a single platform is involved, there are many different configurations, which increases the testing effort enormously. To master this test task successfully despite limited human resources, it was planned to set up a flexible, automated test system that can handle especially E/E tests of different vehicle platforms and configurations and supports easy and quick switching between the platforms to be tested.

Requirements on the Test System

To obtain a test system with exactly the scope of performance necessary to implement the test tasks successfully, the test team detailed the requirements and formulated their expected benefits in comparison to the capabilities of the currently used test tools and methods. The functional requirements included function tests, diagnostic tests, test error injection, and integration tests. As for the expectations, improved test efficiency ranked number one. Accuracy, guaranteed test coverage, easy reproducibility and high flexibility were also >>

> "dSPACE's simulation system is highly flexible and easy to handle, so we can test the different vehicle platforms efficiently and reliably."
>
> *Zhan Dekai, Brilliance Auto*

crucial issues. On the other side, there was a limited budget and not so much experience in test automation yet.

Choosing a Test System

A holistic approach was used to choose the appropriate test system. The issue was not just about the right hardware and software, but also about the engineering and on-site training. For the decision makers, the most important factor was long-term assistance and support in order to get direct help during ongoing test projects. In this respect, dSPACE made a very convincing all-inclusive offer. The offer included a turn-key simulator system that covers all the specific requirements, with test automation designed especially for the application and on-site service that can support the developers at Brilliance in their projects if necessary. dSPACE's particularly flexible simulator concept promised to cover all platforms with one test system, so it was possible to fit the total costs within the planned budget. Brilliance therefore decided on the solution proposed by dSPACE.

Simulator Setup and Multi-Platform Features

The simulator set up by dSPACE is designed for week-long 'round-the-clock' operation (24/7 tests) and masters 'lights-out tests': i.e., repetitive, automated test processes that do not require supervision. The setup consists of four networked simulators. The controlled systems for applications in powertrain, chassis and body are set up partially as real components and are also available as virtual simulation models from the Automotive Simulation Models (ASM) tool suite. To test the various platforms with a single system, a separate load board construction including a cable harness was developed for each platform and connected manually to the simulator. The preconfigured models for each platform make it easy and quick to switch between the platforms. All that needs to be done is replug the cable harness and select the associated model configuration in ModelDesk, the parameterization software.

The test team works with programs such as ControlDesk, MotionDesk and ModelDesk on the simulator's operator stations to adapt a vehicle dynamics simulation.

Source: © Brilliance

Performance Range and Advantages

The test system is refined to meet Brilliance's requirements and handles standard test tasks as well as special tests integrated through engineering solutions.

Failure insertion: Failure Insertion Units (FIUs) are used for automated implementation of short circuits and broken wires at low currents and high currents.

Measuring the quiescent current: The quiescent currents of individual ECUs or the entire ECU network can be measured accurately with the inserted DS285 Power Switch Module.

Analyzing the instrument cluster: Displays such as the speedometer, tachometer or warning lights are detected with an intelligent camera and analyzed to check the values during the test process.

Checking the air conditioning system: To test the regulation of the air conditioning system, it is used as a real component and all the control knobs are emulated by special hardware.

Testing the power windows: To test the control of the power windows (e.g., its anti-pinch system) an electric load (electronic load module, type B) that emulates the electric motor is used. The position of the window can be saved on a CompactFlash.

Switching between the real component and simulation: A click of a button on the host PC is all that is needed to switch between the real loads and sensors, as well as between

Examples of the various vehicle platforms whose E/E systems are tested using the dSPACE Simulator (source: © Brilliance).

their modeled, virtual representations. This lets manual tests and automated tests be implemented simply and quickly.

CAN manipulation: The CAN manipulation gateway by dSPACE makes it possible to manipulate individual CAN signals in order to give the ECUs incorrect messages and thereby examine their behavior.

Test automation (TA): Together, Brilliance and dSPACE used AutomationDesk to set up a test framework, including all TA libraries. The developers use this framework as the basis for expanding the test scope by implementing new test cases via simple graphic methods.

Conclusion and Outlook

Ever since its startup phase, the simulator is the central tool for all of Brilliance's test tasks. Thanks to the simulator's high flexibility and easy handling, all tests so far have been completed on time. Even unplanned platform switches, which often used to cause considerable delays, were handled with confident ease. The automation and informative test reports gave the developers exact information about the quality of the software, so it was easy for them to check bug fixes. For the future, Brilliance plans to optimize the implemented processes and workflows even further. dSPACE's data management tool SYNECT is planned to play a decisive role in this. ■

Zhan Dekai, Mi Yanxin, Li Shunzhi, Zhang Jianxin, Brilliance Auto

Tested ECUs

Body ECUs:
- Air Condition Module (AC)
- Around View Monitor (AVM)
- Body Control Module (BCM)
- Tire Pressure Monitoring System (TPMS)
- Driver Seat Module (DSTM)
- Immobilizer (IMMO)
- Passive Entry Passive Start (PEPS)
- Electronic Steering Column Lock (ESCL)
- Park Distance Control (PDC)
- MultiMedia Unit

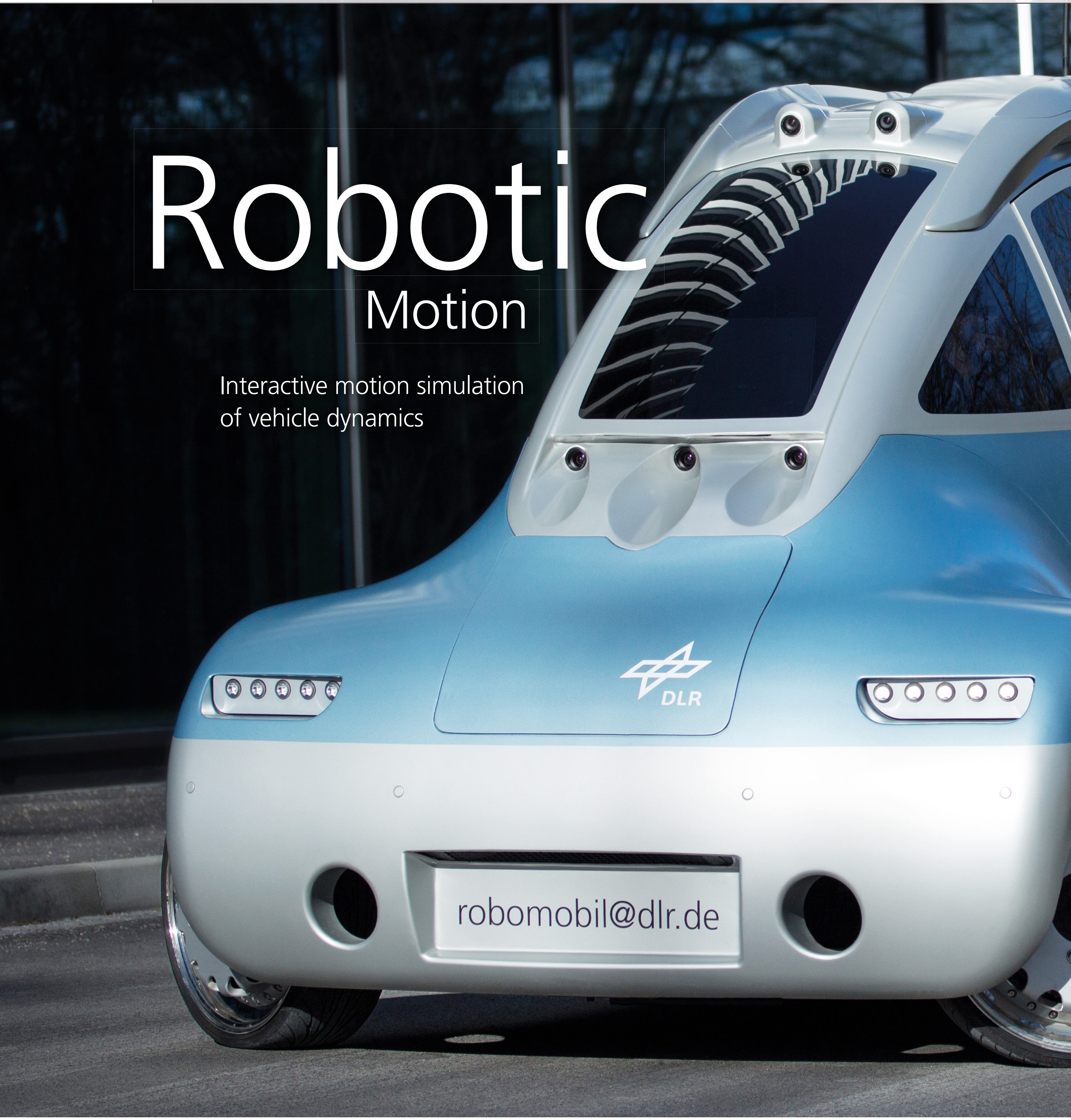
Drivetrain and chassis ECUs:
- Engine Control Module (ECM)
- Transmission Control Module (TCM)
- Electronic Stability Control (ESC)
- Airbag (ABAG)
- Adaptive Front Light System (AFS)
- Auto Park Assist (APA)

dSPACE Tools in Use
- 4 dSPACE Simulators
- AutomationDesk
- ControlDesk Next Generation
- ASM Electric Components
- ASM Engine Gasoline Basic
- ASM Vehicle Dynamics
- ASM Traffic
- ASM Brake Hydraulics
- ModelDesk
- MotionDesk
- DCI-CAN interface
- Failure Insertion Units (FIU)

Members of the test team in Shenyang, China. From left to right: Mi Yanxin (developer), Li Shunzhi (developer), Zhang Jianxin (developer), Zhan Dekai (Section Manager), Sun Lizhu (Group Leader)

Robotic Motion

Interactive motion simulation of vehicle dynamics



How are we going to drive the cars of the future? To get a physically realistic impression, the German Aerospace Center (DLR) is using a robotic motion platform to develop and evaluate input devices for future automobiles.


Source: © DLR

X-by-wire technology creates new challenges, but the liberation from mechanical constraints also opens up new possibilities for designing modern automotive human-machine interfaces (HMI). ROboMObil – the German Aerospace Center's robotic x-by-wire research platform – takes advantage of these new freedoms to implement independent four-wheel steering and to help develop haptic input devices. An important step in the development of new HMI concepts is to evaluate the robustness under the physical coupling of vehicle accelerations through the driver's body onto the steering device, e.g., a joystick. To reproduce these disruptive effects in a hardware-in-the-loop (HIL)-based rapid control prototyping process, the DLR Robotic Motion Simulator (RMS) is operated in conjunction with a HIL system consisting of ROboMObil and a real-time vehicle dynamics simulation on dSPACE SCALEXIO®. This robotic HIL setup lets engineers not only perform pure component function tests but also investigate the interaction between the driver, vehicle behavior, and input device in realistic, interactive motion simulations. The goal of these studies is to reliably suppress the driver-induced physical disturbance through appropriate kinematically decoupled input devices, suitable generation of control variables, and force feedback strategies. >>

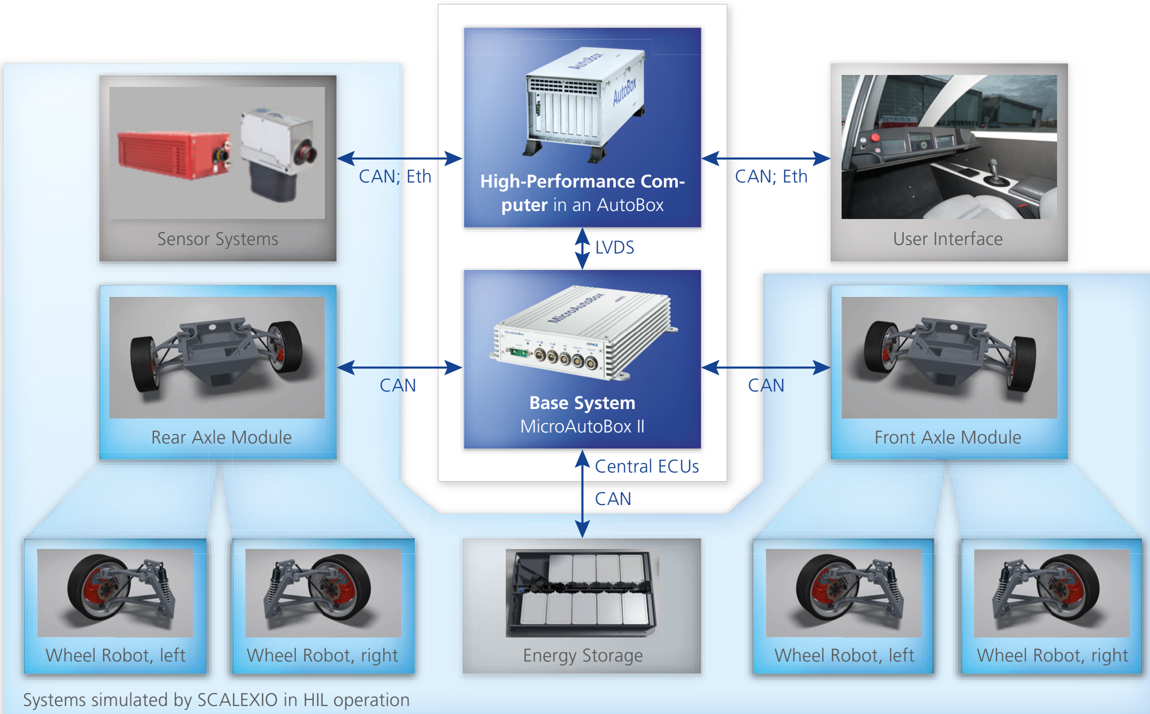


Figure 1: Setup of ROboMObil's computer network (Eth = Ethernet connection). The components represented virtually by the real-time vehicle dynamics simulation, i.e., simulated on SCALEXIO, are shaded in light blue.

ROboMObil Research Platform

Inspired by space robotics, DLR's ROboMObil is an x-by-wire research platform with an electric drivetrain. Thanks to its four highly-integrated, structurally identical "Wheel Robots", the platform has extraordinarily high maneuverability. Its x-by-wire architecture (figure 1), made possible by the Wheel Robots, enables a range of vehicle level applications. These include operating modes such as cockpit control, teleoperation control, and partial or full autonomous driving. This makes ROboMObil an excellent platform for a wide range of research tasks in areas such as vehicle dynamics control, autonomous driving, and the further development of human-machine interfaces. Its high maneuverability permits three fundamentally different modes of motion, namely longitudinal driving, lateral driving, and turning the vehicle around a center of rotation. Controlling each type of motion requires a specific HMI concept, which is analyzed within the robotic HIL setup. The current input device of ROboMObil is a force-feedback joystick with three degrees of freedom. The scientific challenge in developing this HMI is the realization of the ergonomic mapping of the joystick's one rotational and two translational degrees of freedom onto the control of the vehicle's three horizontal degrees of freedom, depending on the mode of motion.

Real-Time Vehicle Dynamics Simulation

At DLR, simulation tools play a central role for both the development and the validation of vehicle dynamics controls. For this purpose, DLR's virtual design and test environment contains detailed multibody dynamics models based on the object-ori-

> "The programmable interfaces provide the possibility to easily connect the SCALEXIO HIL system to non-dSPACE systems, such as the Robotic Motion Simulator, and integrate it into the interactive vehicle dynamics simulation as a motion simulator."

Peter Ritzer, DLR

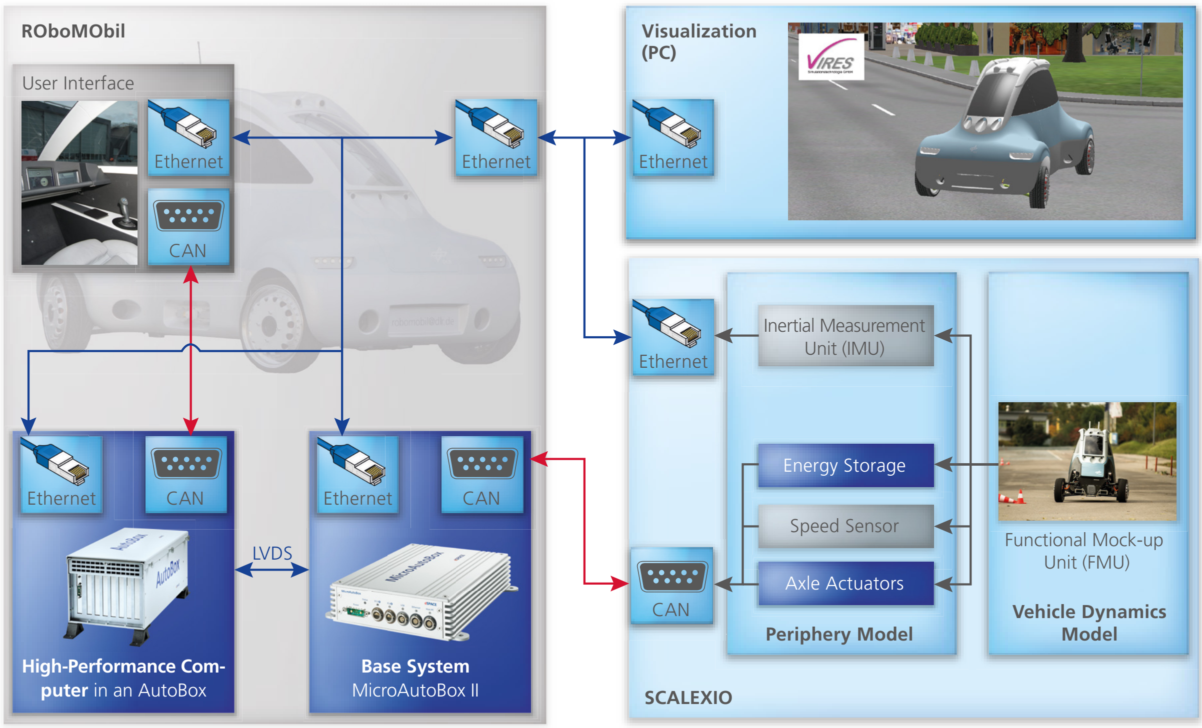


Figure 2: RObοMObil in motionless HIL operation to test the operating software and controls safely.

ented modeling language Modelica. In addition to multibody dynamics, these models also include sensors and electromechanical actuators to combine the various domains, such as the mechanics, electrics and hydraulics, into one model. To develop the new vehicle dynamics controls in Simulink®, the real-time-capable, full vehicle models are co-simulated using the Functional Mock-up Interface (FMI) standard. During the test phase, the algorithms implemented on RObοMObil's central electronic control units (ECUs), a network consisting of MicroAutoBox II and AutoBox, are validated on a SCALEXIO-based HIL system. This system performs real-time vehicle dynamics simulations that cover not only the multibody vehicle dynamics model and the tires, including their contact points, but also all of RObοMObil's peripheral devices, shown in figure 1 in light blue. The HIL architecture illustrated in figure 2 lets the engineers carry the methods of the FMI-based design process over to the validation process of the control software. Using the SCALEXIO system makes it possible to incorporate a Functional Mock-up Unit (FMU) from Dymola (a modeling and simulation environment for Modelica models). As a result, existing Modelica libraries from the DLR design and test environment can be utilized, which reduces the development effort necessary for real-time simulation of the vehicle dynamics.

Robotic Motion Simulator

In contrast to popular hexapod systems, the DLR Robotic Motion Simulator (figure 3) employs an industrial robot combined with a linear axis and therefore has a much larger, dynamically usable operational space, at comparatively lower costs. This improved operational space enables dynamic simulations of risky scenarios, such as dynamic driving maneuvers near the limit of adhesion. For such scenarios, DLR is currently developing real-time trajectory planning algorithms in order to generate realistic movement dynamically and interactively. One application of the RMS is to research human-machine interfaces for ground vehicles and aircraft. To keep the RMS flexible for different applications, it has a modular setup that facilitates an uncomplicated exchange of instruments or the entire cabin and, in turn, quick switches between different simulation scenarios, such as control via steering wheel and pedals or control via joystick.

Entire Robotic HIL System

Whereas conventional HIL concepts with driving simulation in a motionless cabin are fully sufficient for >>

Source: © DLR

Figure 3: To increase the operational space, a linear axis is used for the DLR Robotic Motion Simulator (RMS).

investigating the functionality of the software and hardware, evaluating the new haptic HMI requires more effort. In addition to pure function tests, this involves researching the interplay between the driver behavior and vehicle behavior. This is realized by the combination of the subsystems shown in figure 4. This setup makes it possible to account for the disturbances acting on the HMI, induced by the force coupling through the driver. During the experiment, the driver sits in the cabin of the RMS and drives the ROboMObil interactively through a virtual landscape. In this complex HIL system, in addition to the visual feedback (virtual reality) via in-cabin projectors, the vehicle motion simulated by the RMS also acts on the driver.

Outlook: User Studies

With the help of a robotic HIL, the DLR will conduct user studies in the future to compare the newly developed control interfaces to conventional systems involving a steering wheel and pedals. A great advantage of a robotic HIL for these scientific studies of HMI concepts is the comfortable exchange of the different HMI hardware and the ability to compare them in a consistent environment. In addition to user studies, the Robotics and Mechatronics Center (RMC) at the DLR is also concentrating on the further development of the ROboMObil HMI concept to meet the particular needs of this vehicle architecture. On the one hand, the control interface must be capable of addressing all of ROboMObil's three horizontal degrees of freedom; on the other hand, it must provide the required simple interface for future assistance systems, such as path-following control and platooning (driving in a convoy). This RMC research project on the interaction of the haptic channel with such semi-autonomous functions complements the developments achieved by the DLR Institute of Transportation Systems in automatic driving within the DLR project "Next Generation Car (NGC)". ■

Peter Ritzer, Michael Panzirsch, Jonathan Brembeck, German Aerospace Center (DLR)

> "We can transfer the FMI-based process used during the design phase directly into the validation phase. Integrating a Functional Mock-up Unit from Dymola into ConfigurationDesk significantly reduces the development effort necessary for emulating the physical environment in the HIL simulator."
>
> *Jonathan Brembeck, DLR*

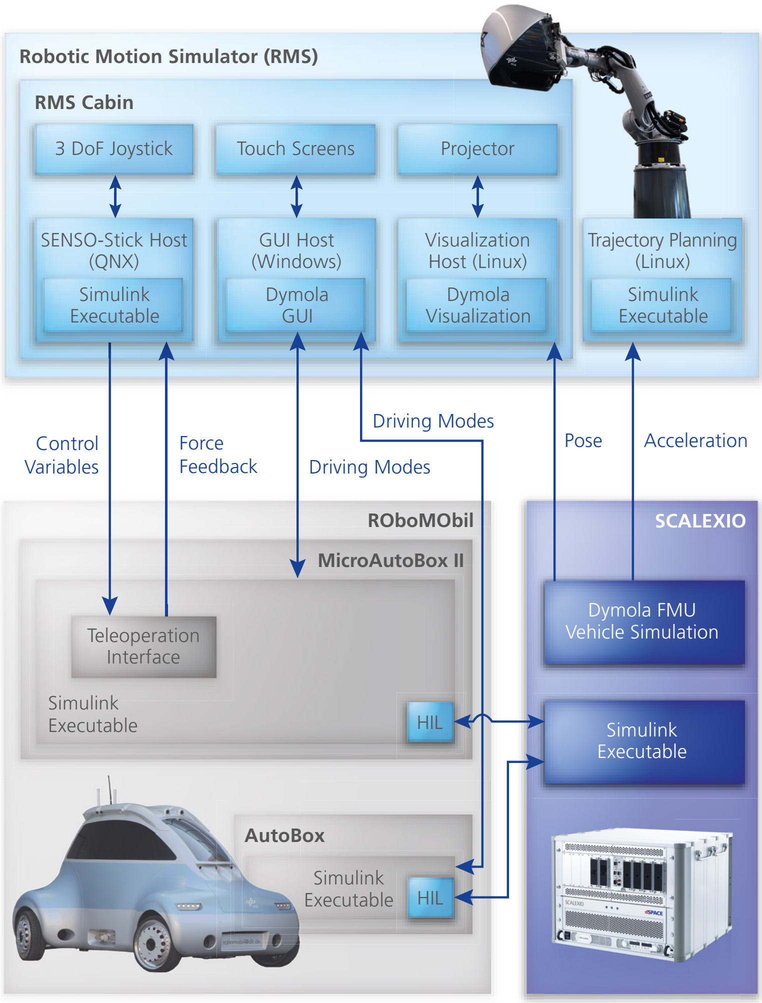


Figure 4: Entire system setup. The goal of this special HIL application is to evaluate innovative HMI concepts under real and known laboratory conditions.

Words of Thanks:

We thank the following persons for helping us set up the infrastructure of the mobile HIL. Tobias Bellmann, Andreas Seefried and Miguel Neves from the Robotic Motion Simulator Team, who were responsible for the integration and adaption of the motion simulator, and Christoph Winter from the ROboMObil Team, who was responsible for the 3-D visualization. We also thank Dr.-Ing. Tilman Bünte for his collaboration on this article.

See the ROboMObil in action: www.dspace.com/go/dMag_20161_DLR

More information on ROboMObil: http://www.dlr.de/rmc/sr/robomobil

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Ford was looking for a method to train individuals who are migrating to AUTOSAR and to address a common challenge for the software industry, especially in automotives: software delivery schedules. Simply put, everyone knows more software is being delivered at a faster rate than ever, and this trend continues. Unlike some products in the consumer electronics industry, the automotive industry is unique, because the products are not disposable and are required to operate despite environmental extremes. Yet consumers demand an experience akin to consumer electronics. How can the automotive industry keep pace with consumer electronics while addressing stringent validation requirements? Simply implementing AUTOSAR does not alleviate the concern, since many AUTOSAR users still test their code too late in the development cycle. Adding more people is successful only if they understand the methods that can accelerate the pace of development. The challenge was how to train those new to the process efficiently. By providing a simulation environment with dSPACE VEOS®, Ford enables its developers to test software sooner and even before hardware is available, and provides an environment for them to experiment with AUTOSAR.

Acceleration via Simulation

Virtual ECU simulation supports these goals in several ways. First, it can identify and eliminate many issues on the feature developer's computer prior to costly, resource-limited hardware-in-the-loop (HIL) testing. This non-HIL approach maximizes the utility and return on investment of HIL resources, which are now used for their intended purpose of executing HIL tests without costly interruptions due to non-HIL tasks. In terms of virtual simulation tools from dSPACE, feature developers use ControlDesk® Next Generation, which is the same calibration and visualization tool used by the HIL team and calibrators. Therefore, the experiments, layouts, and settings are developed first by the feature developers, providing earlier test preparation for HIL engineers. While it is true that model-based design processes include software-in-the-loop (SIL) simulation, oftentimes this means that 'soft ECUs' in Simulink are used to approximate the functional behavior of a missing ECU.

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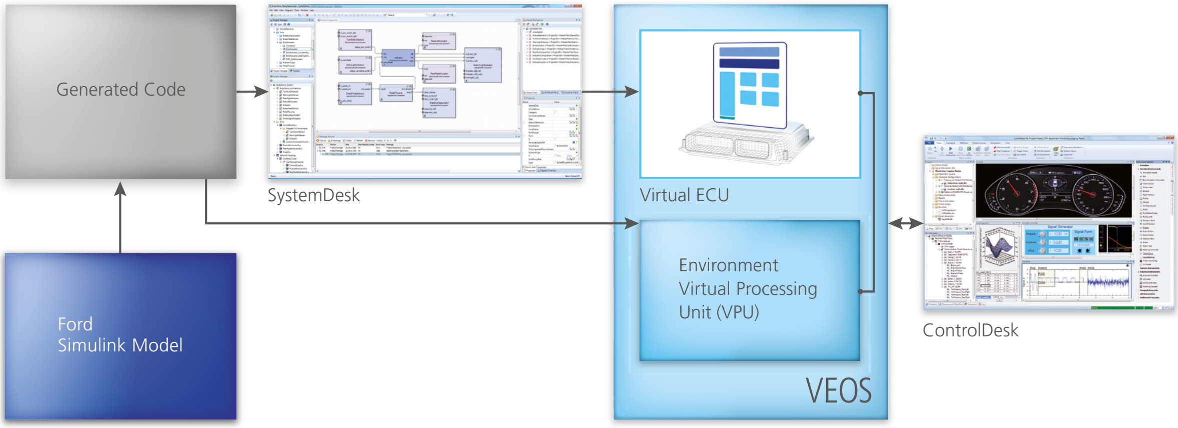
Source: © Ford

AUTOSAR simulation with VEOS

Rapid AUTOSAR Adoption

The Ford Motor Company needed a tool chain that on the one hand accelerates the development process to meet customers' expectations and on the other hand reduces the time and effort required by new adopters to familiarize with its methods. With the dSPACE virtual validation tool chain, they found both.



VEOS simulates AUTOSAR code produced with SystemDesk by using a bottom-up workflow. The simulation software integrates with the well-known, industry-standard calibration and measurement tool ControlDesk.

However, this practice is susceptible to errors. A better approach is to integrate the real-time operating system and other lower-level components' software with the application layer. In the best case, with all ECUs included, the simulation is essentially a virtual ECU breadboard, and hardware unavailability should not prevent networked, system-level testing.

Top-down or Bottom-up

In many cases, Ford's AUTOSAR workflow design process actually begins in a behavioral modeling tool instead of an authoring tool because many models already exist today. But there are some cases when a new architecture is developed. In that case, the workflow begins in SystemDesk®. Although it is tempting to always begin in the SystemDesk authoring tool, Ford found it more beneficial to begin the workflow with a model constructed in Simulink. SystemDesk automatically sets up everything in accordance with the imported Simulink model, saving significant time compared to performing manual configuration steps. Since many of these steps are architectural and reflect the model's structure, data types, and interfaces, this information is easily acquired from the Simulink model and was a real time-saver.

Flexible Tool Chain

Like many software tool providers, dSPACE partitions its tools into various subcomponents to appeal to a wide customer base. Different tool combinations can be used depending on work responsibility. In a production environment, employees require only subsets of the tool chain based on their job function. For example, a system architect might be the only team member requiring SystemDesk, lowering the average cost per seat.

Allocation with Ease

Once the software components (SWCs) are imported into SystemDesk, a composition diagram is built showing the interconnections of the software components. This composition diagram maps easily to the system in SystemDesk. The system describes the integration of AUTOSAR software components into a network of ECUs. All software components can be allocated or mapped to the same ECU instance. If another ECU is added to the system, the system architect can remap certain SWCs to a new ECU. SystemDesk automatically handles any implications of the reallocation.

The Right Level of Basic Software, Automatically

Users, especially those new to AUTOSAR, benefit from SystemDesk's automatic functionality that greatly simplifies the workflow. The Automatic Configuration and Generate step creates basic software (BSW) code for the RTE and I/O. For example, in the New ECU Configuration dialog of SystemDesk, users can choose from predefined configurations. When users select Default Single ECU Configuration, SystemDesk automatically generates the required subset of the basic software layer tailored for simulation. This is helpful

> "With VEOS, Ford went from training and software evaluation to significant results within months."

Kurt Osborne, Ford Motor Company

since SystemDesk generates a custom ECU configuration based on the application layer. Ford benefited from the range of virtual ECU abstraction levels and automatic configurations offered by SystemDesk. Furthermore, all runnables can be mapped to operating system tasks automatically. This is a great starting point, which also simplifies the task for new adopters. Exploiting an industry-standard scheduler eliminates the need to develop one in a Simulink model. An automatic configuration and generation step also creates virtual processing unit (VPU) ports for connecting V-ECUs to VPUs. I/O Hardware Abstraction and Data Access Point modules are manually added to the ECU configuration to access the ports from the environment virtual processing unit. "Environment virtual processing unit" is the name for the plant model. Via the Auto Configure and Generate button, users can have SystemDesk generate ECU code for simulation purposes. After code generation, the simulation system for simulation on the VEOS platform is built.

Virtual ECU Simulation with VEOS

Ironically, the backbone of this simulation environment is a tool that intentionally has minimal direct user interaction. VEOS, the offline simulation platform, has been available since 2012 but can be somewhat inconspicuous.

VEOS provides a unique simulation environment. Simulink alone can perform SIL validation with AUTOSAR-based C code for the application layer. However, VEOS takes the next step by providing the ability to simulate a fully integrated application layer with the rest of the AUTOSAR stack (i.e., BSW and RTE). VEOS delivers an integrated solution that allowed Ford to find problems earlier in the development cycle.

Simulation log files can be produced for the simulation, universal calibration protocol (XCP), and bus communication, and there is feedback on controller area network (CAN) bus loading. CAN bus trace information can be analyzed by the user to determine the loading or exported to another tool. Inspired by this project's feedback, a future software release will include integration with ControlDesk's Bus Navigator.

Automate, Automate, Automate

One deliverable of Ford's project was an automated, model-based workflow to aid new adopters. During a presentation at the MAC 2015 in Stuttgart, MathWorks stressed the importance of automating the AUTOSAR workflow. This AUTOSAR presentation highlighted nine recommendations. One was "automate, automate, automate". Ford automates two separate parts of the workflow, which was partitioned by tool chain components. The Simulink part was automated by using a MATLAB M script. The workflow of the dSPACE tools was automated via a Python script, which makes it easy to put the recommendation into practice.

Next Steps

dSPACE and Ford made a great development team that quickly established a virtual ECU simulation environment useful for rapid AUTOSAR adoption and accelerated software time to market. Ford went from training and software evaluation to significant results within months. Due to this success, Ford will be able to quickly increase its efforts in AUTOSAR. Already, there is interest from other colleagues who are eager to apply VEOS for their projects. ■

Kurt Osborne,
Dalya Kozman,
Ford Motor Company

Why Virtual Validation?

- This non-HIL approach maximizes the utility and return on investment of HIL resources.
- SystemDesk automatically sets up everything in accordance with the imported Simulink model, saving significant time compared to performing manual configuration steps, and automatically handles any implications of the reallocation.
- Virtual validation enables Ford to accelerate software time to market.

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Dalya Kozman
Dalya Kozman is a research engineer in model-based design and software architecture in Research and Advanced Engineering at Ford Motor Company in Dearborn (MI), USA.


LabBox
dSPACE
SCALEXIO
DS6051
DS6101
DS6101
DS6201
DS6301
IOCNET
IOCNET
Router
Multi-I/O
Digital I/O

Flexible function tests

Desktop Simulator

A small, variable, custom hardware-in-the-loop simulator would be ideal to quickly test a new function or controller. This is exactly what the new SCALEXIO LabBox from dSPACE offers.

Checking new ideas quickly and on the fly is important, especially when the development of new functions is still in its infancy. With the desktop version of SCALEXIO® LabBox, users can run hardware-in-the-loop (HIL) simulations directly at their desk.

SCALEXIO LabBox

With its dimensions of 45x35x18 cm, SCALEXIO LabBox takes up just as much space as a sheet of paper in DIN A3 format (approx. US Ledger size). Up to 18 SCALEXIO I/O boards can be inserted to meet different requirements. All of the I/O boards of SCALEXIO LabBox can also be used in a larger SCALEXIO HIL system, letting users exchange boards between the two systems. In large SCALEXIO systems, the SCALEXIO I/O boards can be used seamlessly with other SCALEXIO boards, such as MultiCompact I/O units and HighFlex boards. The following boards can be used in SCALEXIO LabBox:

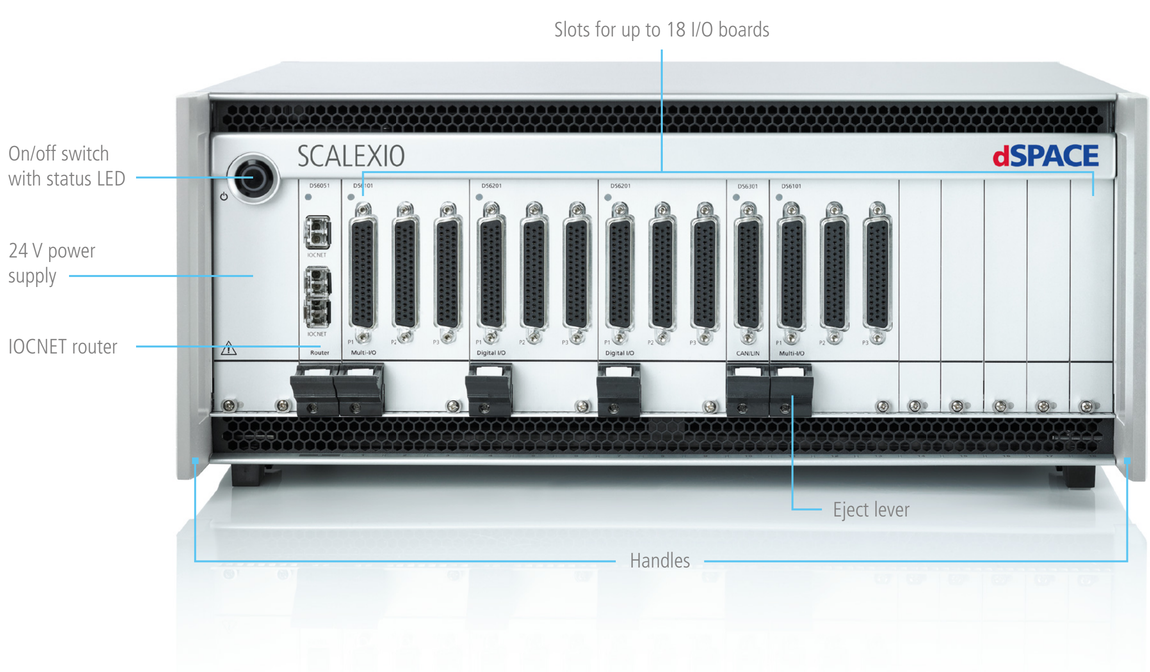
- The DS6101 Multi-I/O Board lets users generate and measure typical automotive signals and provides a high number of I/O functions for HIL simulation.
- The DS6201 Digital I/O Board provides a high number of digital I/O channels, which can all be configured as input or output channels. The available I/O functions include digital, PWM and PFM functions.
- The new DS6301 CAN/LIN Board supports the CAN/CAN FD and LIN bus protocols.
- The DS2655 FPGA Base Board and its I/O modules – the DS2655M1 Multi-I/O Module and the DS2655M2 Digital I/O Module – provide a user-programmable FPGA and are designed for applications that require high-speed, high-resolution signal processing.

To provide computing power, the SCALEXIO Processing Unit is connected to SCALEXIO LabBox via an IOCNET cable and the IOCNET router. With IOCNET and the IOCNET router, multiple LabBoxes can be connected to one SCALEXIO Processing Unit. SCALEXIO LabBox systems can therefore be adjusted to project requirements as needed. This combination creates a very powerful and highly flexible system that can test a wide range of functions in a first HIL simulation. The SCALEXIO Processing Unit has an Ethernet connector that can be used to connect it to Ethernet devices and networks.

New Board for CAN and LIN

The DS6301 CAN/LIN Board is the latest I/O board for the SCALEXIO HIL simulator. It offers four CAN/CAN FD channels (ISO and non-ISO CAN FD) as well as four LIN channels. Due to the high channel density, the costs for each bus channel are low. The channels can be configured with the Real-Time Interface MultiMessage Blockset or the Bus

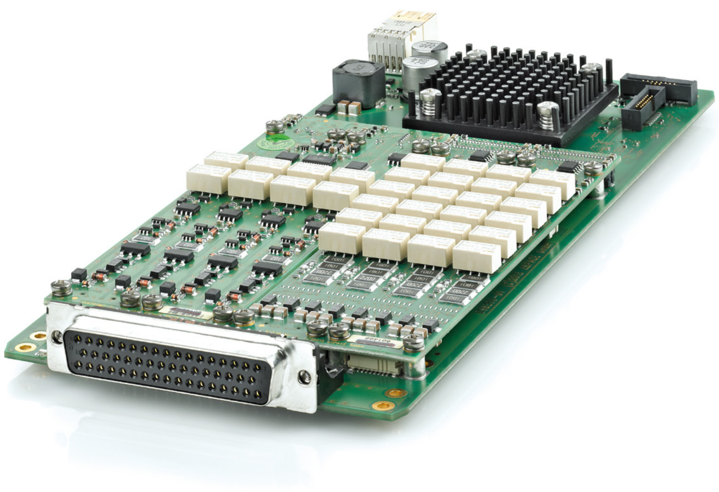
The new SCALEXIO LabBox makes first function tests easy.



Manager. In combination with ConfigurationDesk®, the Bus Manager lets users configure the channels graphically.

Standardized and Flexible

All the boards for SCALEXIO LabBox can be used for typical automotive functions without special adjustments. They all provide standardized 50-pin Sub-D connectors for connecting electronic control units (ECUs) with two different pin assignments: one for up to 20 differentiated channels and one for up to 32 single-ended signals. Using standardized connectors makes wiring easier than using different connectors for different boards. Signal conditioning is already integrated, so function tests can be performed right away. For test scenarios with electrical error simulation, the large SCALEXIO system offers the required components. The users can exchange the I/O boards as needed. Because some boards need more than one slot, the maximum number of boards depends on the project. Since it is so easy to switch boards, new ideas can be tested quickly. When functions are modified, the system can be adjusted flexibly. The channels are configured graphically in ConfigurationDesk, while the simulation is controlled via ControlDesk®. Existing ConfigurationDesk configurations and ControlDesk layouts from other projects can also be used seamlessly on the larger SCALEXIO system for further testing, e.g., with failure simulation. ■



The DS6301 CAN/LIN Board lets developers use CAN, CAN FD and LIN communication.

Two LabBox Variants

SCALEXIO LabBox is available in two variants.

Together with the SCALEXIO Processing Unit, the desktop version can be used for first HIL tests on the developer's own desk.

The rack-mount version can be installed in a 19" system. It is used predominantly in project-specific HIL systems.

Rising to Multisensor Challenges

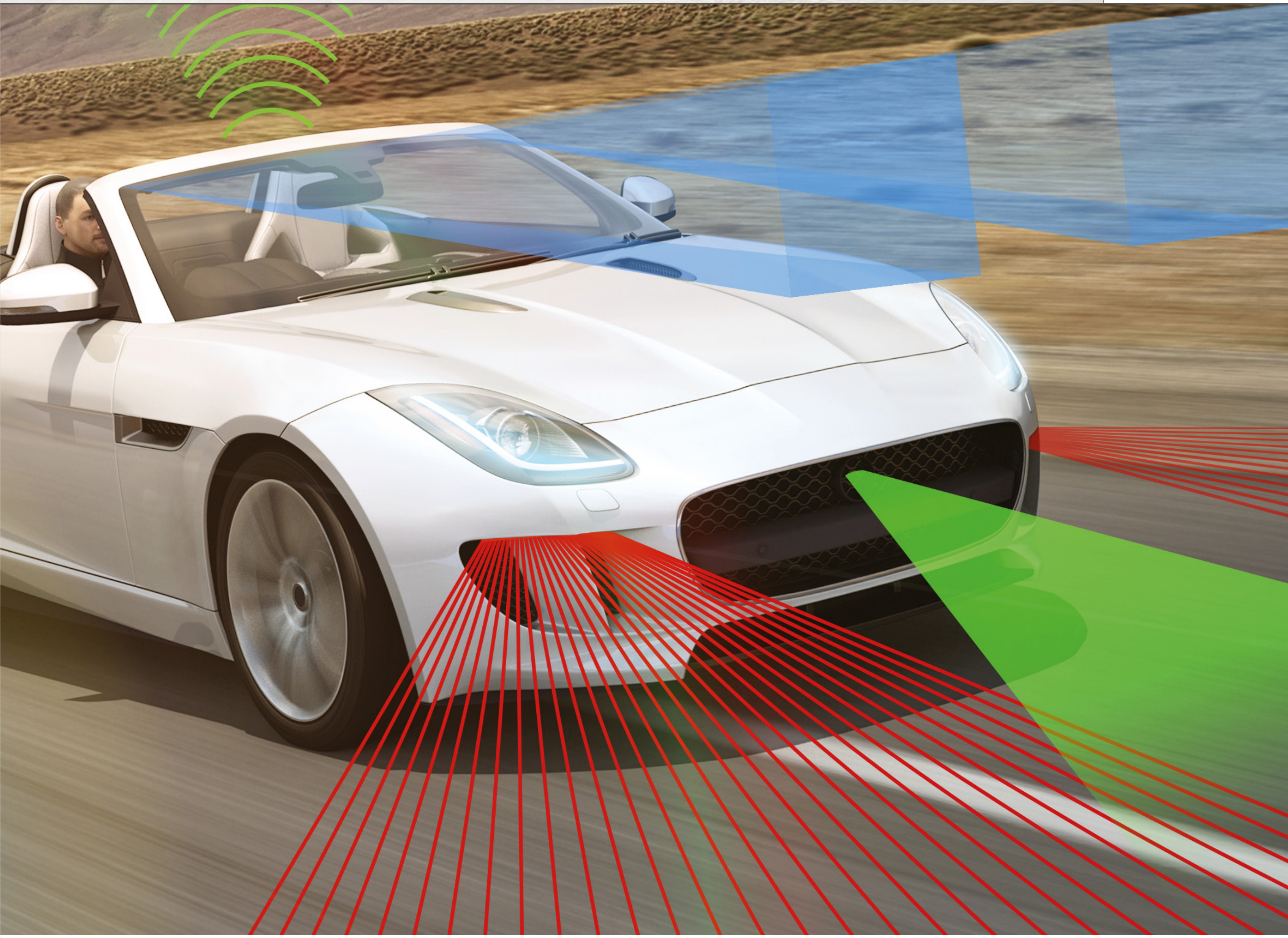
Superior tool chain for ADAS and automated driving

dSPACE and Intempora signed a cooperation that aims at providing a superior tool chain for developing advanced driver assistance systems and highly automated driving functions. In line with this agreement, dSPACE will globally and exclusively distribute RTMaps from Intempora, an unparalleled software environment for multisensor applications.

Multisensor applications play an essential role in many areas such as advanced driver assistance systems, autonomous driving, multimodal human-machine interfaces, robotics and aerospace. Developing these kinds of applications in the lab or in the vehicle typically requires capturing, synchronizing and processing data in real time from various sensors such as cameras, laser scanners, radar sensors or GNSS receivers and interfacing with communication networks, such as CAN, LIN or Ethernet. During the test and development phase, it is also essential to be able to record, visualize and play back time-correlated data. RTMaps (Real-Time Multisensor applications) from Intempora (www.intempora.com) is designed specifically for these use cases. It provides a modular development and run-time environment for x86- and ARM-based platforms supporting operating systems such as Microsoft Windows® and Linux.

Seamless Integration of RTMaps into the dSPACE Tool Chain

dSPACE integrates RTMaps tightly into its comprehensive tool chain with an interface blockset designed spe-



> "RTMaps is a perfect fit for the comprehensive dSPACE tool chain, which today can be seen as a de facto standard for ECU software development. Hence, we are proud to team up with dSPACE as a market leader whose worldwide recognition and distribution capabilities will foster the future development of our highly innovative product RTMaps in this field."
>
> *Nicolas du Lac, Managing Director, Intempora*

cifically for bidirectional, low-latency communication and time synchronization between RTMaps and dSPACE tools like real-time systems or the PC-based simulation platform VEOS®. The experiment and visualization software dSPACE ControlDesk® Next Generation can also be connected to RTMaps via the ASAM XIL API. With this connection, users can monitor and parameterize components which are implemented and processed in RTMaps.

Overview of RTMaps

RTMaps (figure 1, figure 2) from Intempora is a component-based software development and execution environment which enables users to time-stamp, record, synchronize and play back data from various sensors and vehicle buses. By means of block diagrams and the integration of the user's own C++ or Python code via dedicated software development kits, it provides a powerful environment for integrating, testing and benchmarking advanced functions such as signal processing, computer vision and data fusion in the context of multisensor applications. Comprehensive component libraries for various automotive sensors and

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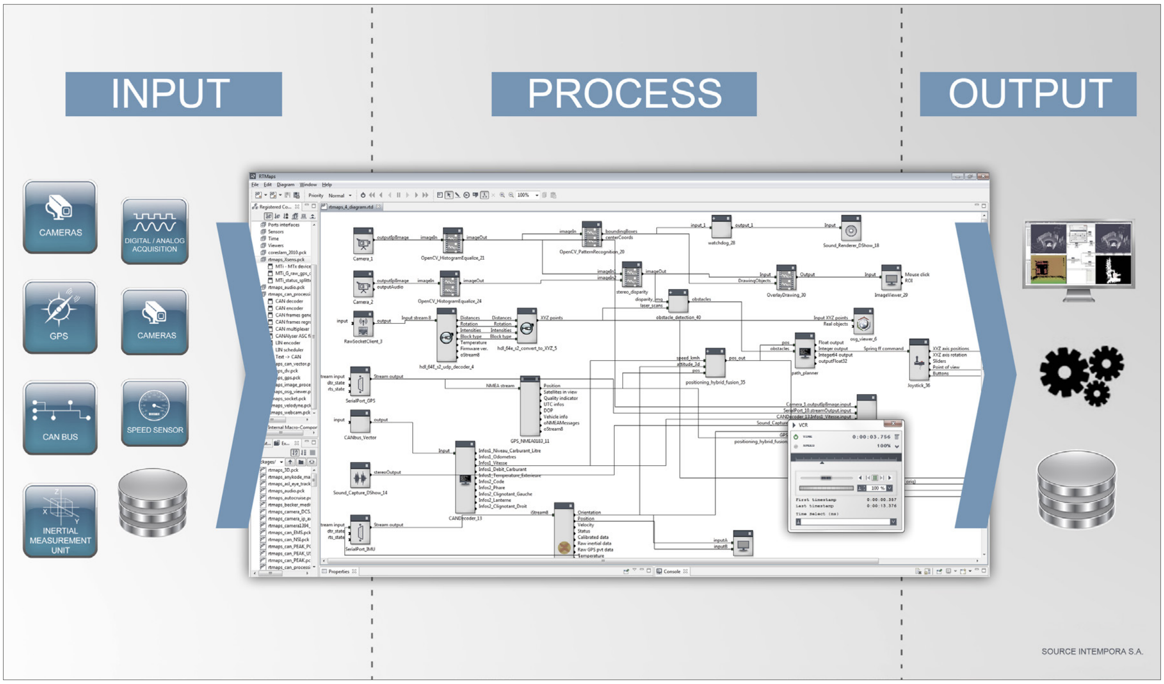


Figure 1: The work method of RTMaps (Real-Time Multisensor applications): The data from various sources, such as cameras, laser scanners, and radar sensors, is captured, precisely time-stamped, processed and visualized in real-time. Because all data is recorded with time correlation, the user can also play back the data synchronously for offline development.

buses, visualization functions, data communication, preprocessing, etc., facilitate function development. In addition to ADAS and automated driving, the application areas of RTMaps extend to mobile robots and advanced human-machine interfaces, among others. The development of the powerful software architecture of RTMaps started at the renowned and prestigious École des Mines de Paris University in 1998.

Facts About Intempora

Intempora was founded in 2000 on the basis of research performed at the Center of Robotics of École des Mines de Paris (now Mines ParisTech). Since then, the company's team of software engineers has been working on the development of RTMaps and related products, turning them into a robust and easy-to-use software framework and meeting the needs of demanding customers from the industry. Among others, Intempora is member of the Groupement ADAS, a team of members of the French Mov'eo cluster, which is dedicated to the field of advanced driver assistance systems.

Summary

dSPACE and Intempora have signed a strategic partnership for establishing a superior tool chain for ADAS and automated driving. For this, dSPACE integrates RTMaps,

"The cooperation between dSPACE and Intempora is an essential milestone in our strategy to provide a complete tool chain for ADAS and automated driving. Due to its superior performance on multicore x86 and ARM platforms and its ease of use, RTMaps ideally extends our product portfolio."

André Rolfsmeier, Lead Product Manager for Advanced Applications and Technologies, dSPACE

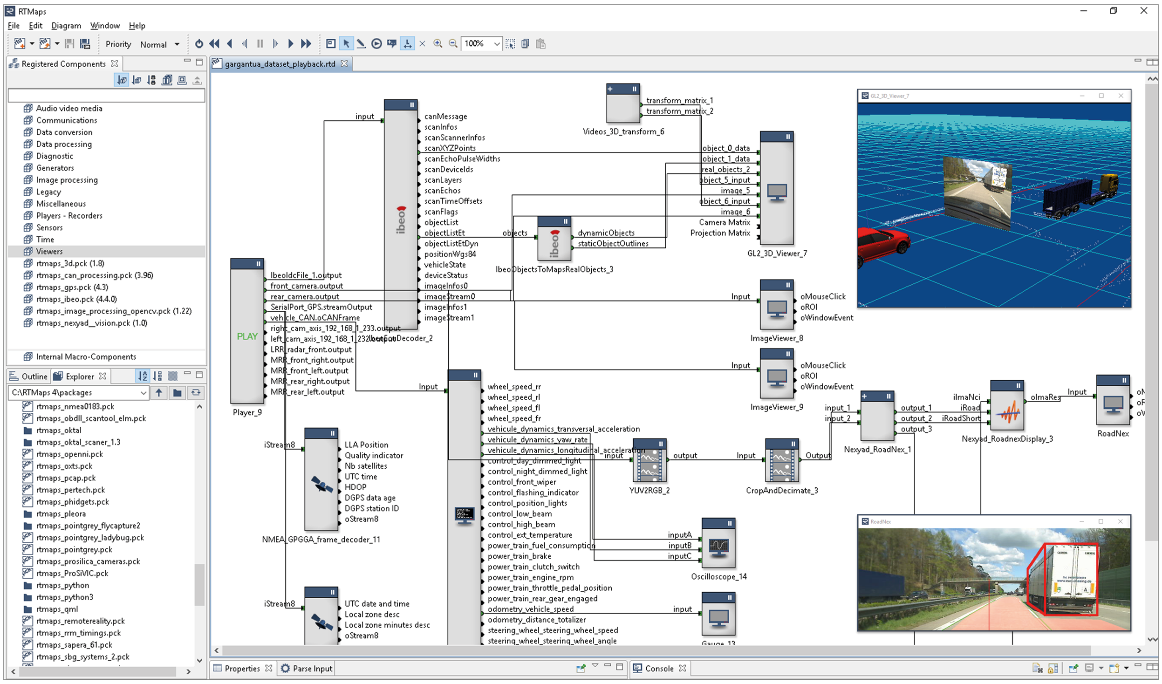


Figure 2: The user interface of RTMaps: A modular, multithread framework for real-time multisensor applications. The user benefits from comprehensive component libraries for a wide range of sensors, buses and perception algorithms. It is even possible to process data on multiple distributed platforms while preserving time coherence and synchronization of heterogeneous data streams.

Intempora´s software environment for developing multisensor applications, into the dSPACE tool chain by providing dedicated interfaces to its prototyping and simulation platforms and ControlDesk. And there is more to come ... stay tuned. Apart from France, which will be served by Intempora itself, dSPACE will also globally and exclusively distribute RTMaps. ■

The video shows RTMaps in action. www.dspace.com/go/dMag_20161_RTMaps

For more information about RTMaps, see www.dspace.com/RTMaps

Overview of Supported Sensors, Buses, and Protocols

- Cameras (GigE Vision, USB 2.0, USB 3.0, FireWire, analog, Camera Link, HDR, etc. from Point Grey, IDS, Basler, AVT, NIT, etc.)
- Stereo-vision heads
- Laser scanners (Ibeo, Velodyne, SICK, Hokuyo, Quanergy, etc.)
- Radars (Delphi, Autocruise, Continental, etc.)
- Time-of-flight sensors (LeddarTech)
- CAN, LIN (PEAK, Vector, NI, .dbc files decoder, etc.)
- GPS, IMUs (SBG Systems, OxTS, Xsens, VectorNav, iXSea, Phidgets, etc.)
- Communication (TCP & UDP, ASAM XCP over Ethernet, DDS, ASAM XIL API, etc.)
- Eye trackers (Pertech, faceLAB, Smart Eye, SMI, The Eye Tribe, etc.) and biometrics (BIOPAC, Becker Meditec, etc.)
- Motion capturing (Kinect, Xtion, Vicon, etc.)
- Access to I/O and bus signals of dSPACE MicroAutoBox and AutoBox
- ... and much more

HIL

Five years of SCALEXIO – Looking back and to the future

Simulation Revisited

In 2011, SCALEXIO was introduced as the new dSPACE hardware-in-the-loop (HIL) system. Tino Schulze, responsible for HIL test systems at dSPACE explains the past development and the plans for the future.

What did dSPACE expect when introducing SCALEXIO® five years ago? Were these expectations fulfilled?
Yes, definitely. With SCALEXIO, we have a strong technology that covers current and future developments such as new in-vehicle bus systems, the increased use of electric drives, new motor functions, advanced driver assistance systems, and functions for autonomous driving. SCALEXIO-based HIL systems address all of these system requirements. Furthermore, we have recognized the trend towards larger and more complex simulation models and support it with high, scalable computing power in the shape of SCALEXIO Processing Units and easy configurability via the ConfigurationDesk® software. Here, too, our expectations were met.

What application areas can SCALEXIO be used for?
After watching SCALEXIO on the market for 5 years, we can say that it addresses all application areas – from small systems for component tests up to large networked setups for validating complete E/E systems. New setups are usually built with SCALEXIO because the system makes it easy for our customers to meet their project requirements. For example, we use the SCALEXIO data bus IOCNET to build large HIL systems with distributed I/O channels controlled by a central real-time PC. This opens up entirely new possibilities for HIL setups.

What is the difference between SCALEXIO and its market competitors?
Our unique selling point is SCALEXIO's broad support for automotive requirements. With just one system, dSPACE offers the entire range of applications from a single source: from pure bus tests up to highly specialized setups for testing electric drives. This is SCALEXIO's strong suit. We also provide I/O boards whose individual channels provide the possibility to simulate faults. The electrical faults can then be configured easily and safely with the configuration software ConfigurationDesk. This and the flexible I/O channels make it easy to adjust the SCALEXIO HIL simulator for different projects, especially for component tests. In addition to an excellent connection to MATLAB®/Simulink®, ConfigurationDesk makes it possible to integrate other model formats, such as Functional Mock-up Units (FMUs), making our customers flexible and fit for the future.

Why is SCALEXIO the avant-garde in HIL simulation?
SCALEXIO systems provide a high flexibility in terms of channels and functions. Because the system is configured only via software, changing the system setup only requires minor hardware changes. In addition, dSPACE regularly updates the SCALEXIO Processing Units with new, more powerful variants. The high flexibility, outstanding computing power and easy modification ensure that SCALEXIO users are prepared for the challenges of the future.

How does dSPACE support the transition to the SCALEXIO world?
To make the first steps easier, customers can use the dSPACE test and experiment software of dSPACE Simulator for SCALEXIO, too. They can

> SCALEXIO's unique technology addresses the current and future challenges of testing mechatronic components.

SCALEXIO Profile

- Hardware-in-the-loop simulator
- Industrial PC as the processing unit for high computing power
- High flexibility through comprehensive I/O functions
- Integrated signal conditioning and failure simulation
- Completely software-configurable
- Model integration via Simulink® or Functional Mock-up Interface
- Support for virtual ECUs
- Comprehensive support for bus simulation
- Connection of electronic loads for simulating electric drives

> For HIL tests, dSPACE provides a one-stop solution: Software, hardware, process integration and support on-site at the customer.

continue to use existing software such as ControlDesk®, AutomationDesk, MotionDesk, ModelDesk and ASM with only minor modifications. SCALEXIO also supports the common test automation and modeling tools from third parties. Here, dSPACE consistently uses industry standards like Functional Mock-up Interface (FMI) and XIL API to create a largely standardized connection that makes it easier to use existing software. It is also possible to couple SCALEXIO and dSPACE Simulator via a real-time-capable connection. And, of course, our experienced dSPACE Engineering teams provide worldwide support for customers who introduce a new system, offering turnkey projects, on-site support, and trainings, for example.

Are there any special projects that you would like to highlight?
Yes, there are. Especially in aviation. For example, we had an aviation project with more than 1,500 channels. Those are special conditions, but not unusual for the aviation industry. Daimler even took SCALEXIO to the test track. SCALEXIO's software configurability made it easy for them to adjust the system without having to modify the hardware. Another exciting field is research projects. Together with RWTH Aachen University, we are currently working on an international project to analyze how to use SCALEXIO on engine test benches. In this scenario, the remaining vehicle is simulated.

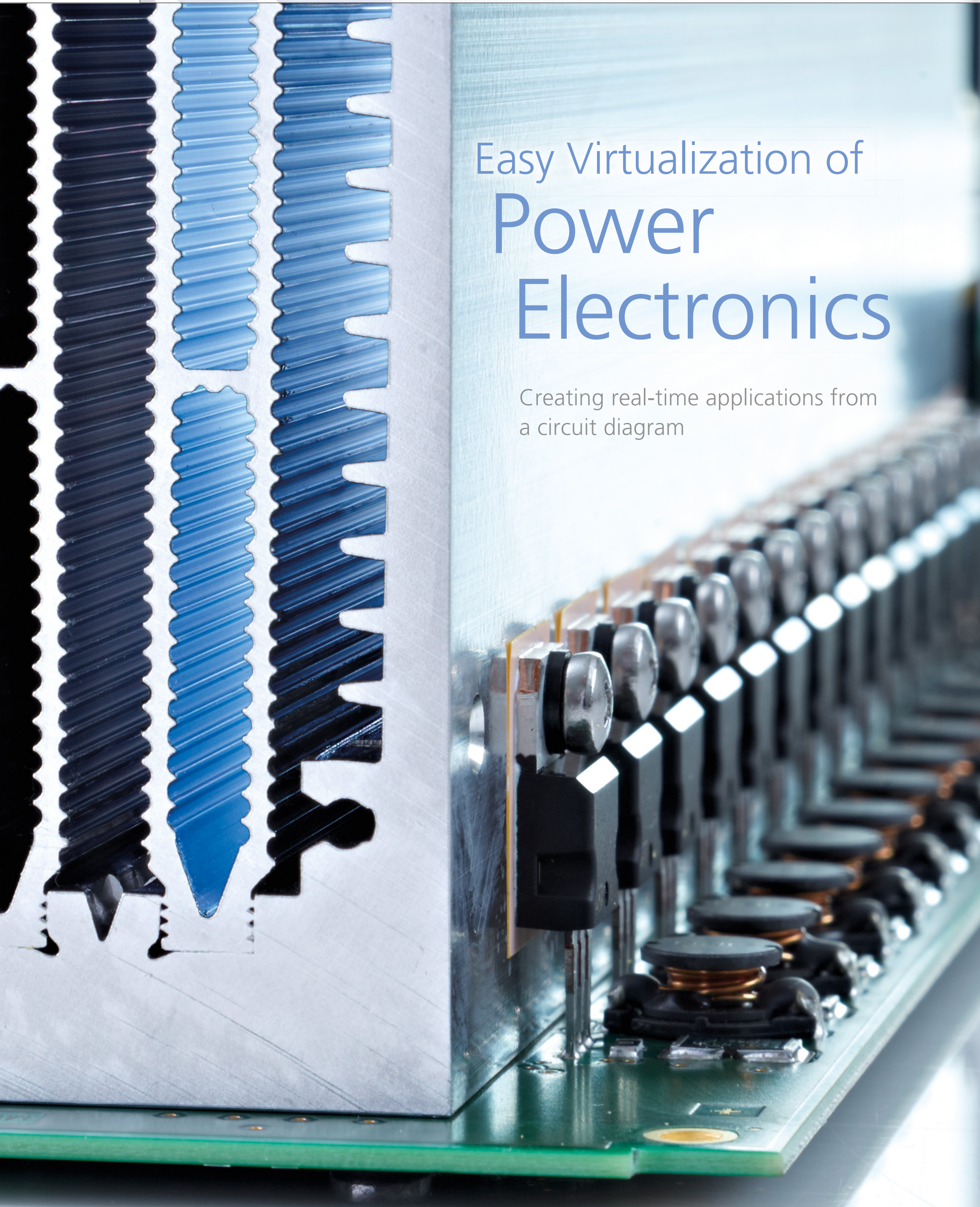
What developments do you have planned for the future?
In the course of the year, we will introduce a new system size, SCALEXIO LabBox. Together with the SCALEXIO Processing Unit, SCALEXIO LabBox can be used on a desk, as a desktop simulator so to speak, or it can be installed in a larger system setup. For bus simulation, we will provide additional boards that support more bus systems and a software program for the central configuration of the bus simulation: the Bus Manager. And we have many more ideas, which we implement in close coordination with our customers.

Mr. Schulze, thank you for talking with us!

As Lead Product Manager Hardware-in-the-Loop Testing Systems, Tino Schulze is responsible for the entire HIL tool chain at dSPACE GmbH, Paderborn, Germany.

Easy Virtualization of Power Electronics

Creating real-time applications from a circuit diagram



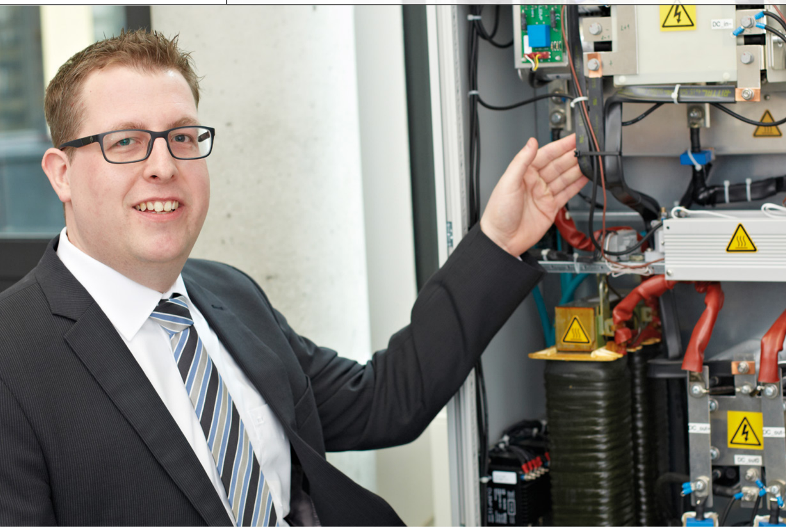
Are you developing controllers for power electronics and want to perform realistic HIL tests early on? You can now create tailored simulation models at the click of a button, even for complex unique circuits. Frank Puschmann, who played an important role in developing this new technology, explains how it works.

Mr. Puschmann, dSPACE provides simulation solutions for a wide range of application areas. Where does dSPACE stand in the simulation of electric motors and power electronics?
For over 20 years, dSPACE has been providing hardware-in-the-loop (HIL) solutions for the simulation of electric motors and power electronics. Our customers already use a high number of such systems, with great success. Due to the different requirements, there are solutions for processor-based simulation and FPGA-based simulation (FPGA = field-programmable gate array). We offer comprehensive libraries with ready-to-use simulation models for both platforms to cover even the most diverse applications. These applications range from auxiliary devices in vehicles, to traction transmissions for electromobility, up to industrial generators and multipoint inverters of regenerative power generators. A high number of analysis tools round off our portfolio. As an alternative to the existing solutions based on model libraries, dSPACE now also makes it possible to generate real-time applications directly from the circuit diagram, for both the processor and the FPGA.

Why does dSPACE provide this additional solution?
So far, we have given our customers ready-made solutions for the known and established topologies and structures. For example, dSPACE provides complete library elements for a B6 bridge circuit up to a three-phase induction motor. Special requests and customer demands, such as DC/DC converters, are covered by engineering solutions. However, we have come to notice that many applications are becoming more complex and more individual. Electric and hybrid vehicles have electrical systems with different voltage levels. The need for HIL simulation of power electronics systems is also increasing in the renewable energy and smart grid sectors. Especially for these systems with inherently different setups, we doubt that simulation based on ready-to-use library elements is useful. Individual engineering models often involve a high amount of work. With our new solution, customers can create the simulation model directly from within the circuit topology.

When will the solution become available?
From now on. In early 2016, we added an FPGA-based solution to >>

> With the Electrical Power Systems Simulation Package, users can create simulation models directly from the circuit topology.



> In addition to automotive applications, our products are also used for industrial applications such as wind energy generation, photovoltaics, and power grid simulation.

the already introduced processor-based solution. Both are now available in our Electrical Power Systems Simulation Package.

What development environments are compatible with the Electrical Power Systems Simulation Package?
The Electrical Power Systems Simulation Package can generate real-time circuit models for many development and circuitry tools, so we can always provide a customer-oriented workflow. Due to current demand, we are presently focusing on SimPowerSystems™, which the package is ideal for.

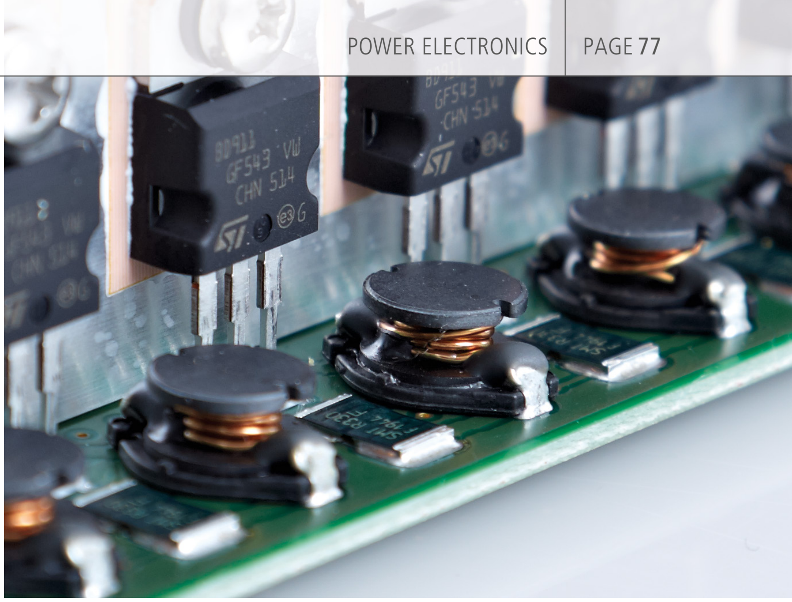
Can the offered packages and solutions be combined?
Yes, customers can always use the Electrical Power Systems Simulation Package with the existing model libraries, XSG Electric Components and ASM Electric Components. For example, if customers want to integrate parts of the circuitry in the simulation environment, but the parts are not included in our model libraries, they can create these parts from basic components. Customers can then generate complete applications for simulation on processor- or FPGA-based platforms. The dSPACE multiprocessor technology provides a decisive advantage, because customers can use large, distributed systems for processor-based applications. For applications with high dynamic requirements, customers can outsource model parts that have to be simulated with a very small step size to the FPGA.

What's in it for the customers and who is this package for?
Customers benefit from the fast availability of unique models and the very low amount of effort involved in creating them. The various model libraries and tools can be combined and extended successively, so we always provide the best solution. Our new products still target our main application area, automotive engineering. Of course, we always have to keep an eye out for the latest trends. The shift towards electric drives is hard to miss. The technologies used in this field are very similar to those used in other industries, so only small adjustments are needed to also serve customers from areas such as wind power, photovoltaics, and power grid simulation.

What will the next extensions to the platforms and libraries be?
We are in an excellent position with our DS2655 FPGA Base Board. In mid-2016, we will introduce the SCALEXIO EMH Solution (EMH = Electric Motor Simulation). Together with the new SCALEXIO Real-Time PC, this solution improves the handling of our processor-based applications even further. In motor modeling, there is an increased need for multiphase drives. Nonlinear effects are also being focused on more often. This is why we are currently working on a generic e-motor model that can be parameterized with the usual characteristics, and also with data determined by the finite element method (FEM). Another functional extension we are planning is the realistic simulation of electrical faults.

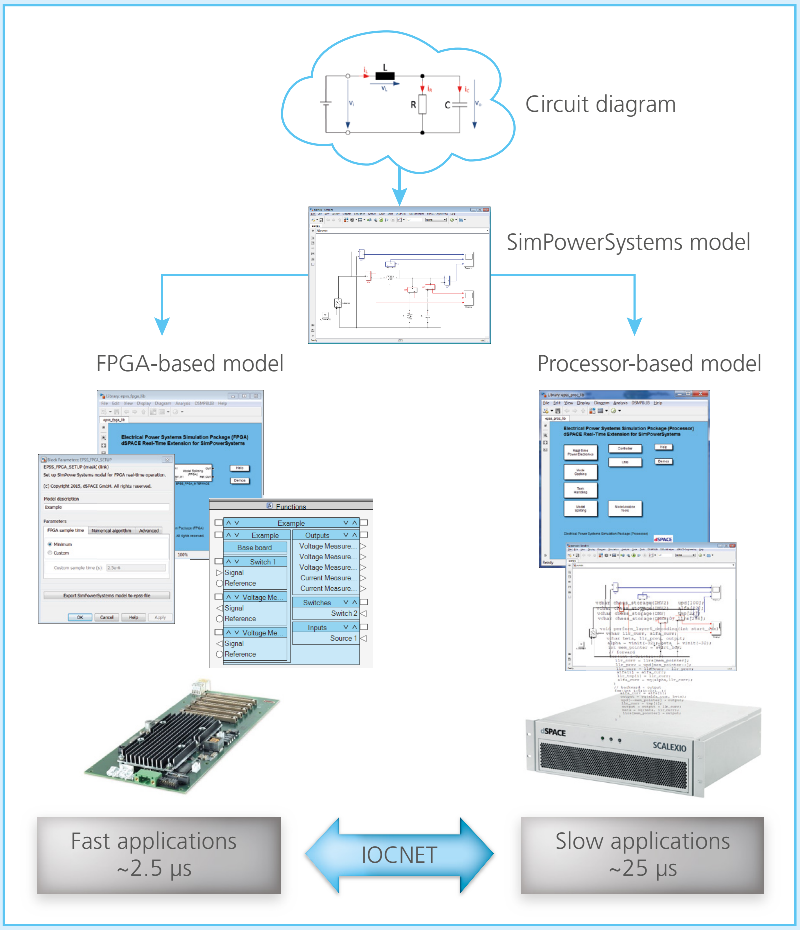
Mr. Puschmann, thank you for talking with us!

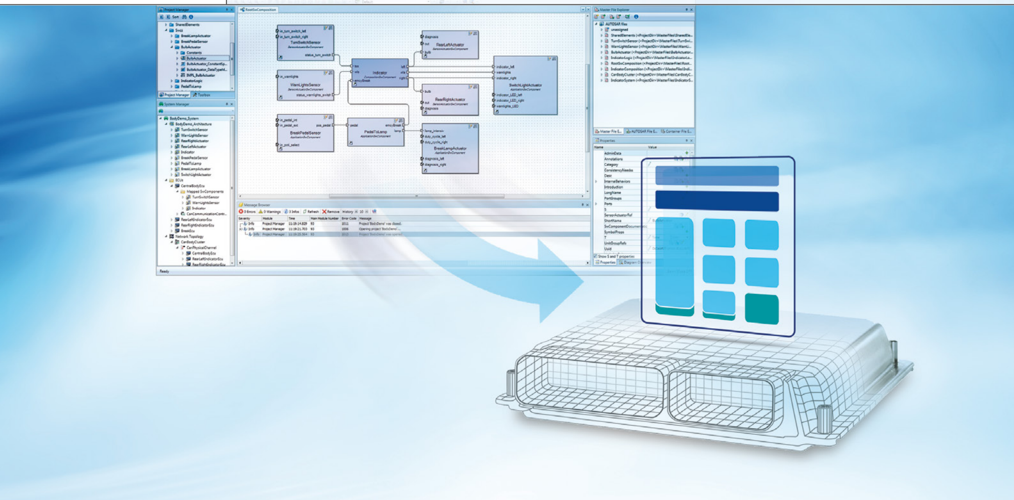
Frank Puschmann is a Senior Application Engineer in the E-Drive HIL group of the Application Engineering department.



The Electrical Power Systems Simulation Package

The new Electrical Power Systems Simulation Package generates real-time simulation models from information on the circuitry. Combined with SimPowerSystems™, the package offers an ideal development environment for testing electrical systems. In addition to model splitting and the mean value models for power electronics bridge circuits you already know from the dSPACE Power RealTime Library, you can now also perform FPGA-based model computation. The package provides ready-to-use FPGA applications so you can integrate your own SimPowerSystems models without having to program the FPGA for each application. The Electrical Power Systems Simulation Package therefore combines the functions of the Power RealTime Library with a new, FPGA-based method. In a networked system, this combination lets you compute each model part on the ideal real-time platform for the respective latency requirements. The automatic translation of circuitry information into real-time code saves time during engineering and provides very precise, realistic simulation results, particularly when the FPGA-based solution is used. This generic solution is recommendable especially if the required topologies cannot be simulated with the dSPACE standard libraries (XSG Electric Components and ASM Electric Components). You can use the Electrical Power Systems Simulation Package for applications such as auxiliary devices in vehicles, traction drives for electromobility, and electrical energy conversion of regenerative power generators.





SystemDesk 4.5 Strengthens Support for V-ECU Generation

Version 4.5 of dSPACE SystemDesk provides extended support for creating virtual electronic control units (V-ECUs). You can use V-ECUs to test and simulate new ECU functions virtually, without the need for a real ECU.

New in SystemDesk 4.5:

- Easier configuration of NVRAM (nonvolatile RAM) and creation of V-ECUs, including NVRAM for virtual simulation. This makes it possible to comprehensively test the interface between the application software and NVRAM. The ECU behavior in the simulation becomes more realistic, which improves test quality.
- Importing and exporting the RTE (run-time environment) configuration for exchange with BSW (basic software) configuration software. RTE configuration aspects already defined in SystemDesk, such as the runnable-to-task mapping, can be exported and then imported into a third-party configuration software for further editing.
- V-ECU wizard for automatically creating V-ECUs on the basis of an existing software architecture. You do not need specialized AUTOSAR know-how to generate V-ECUs.

DCI-CAN2: Accessing CAN FD Networks

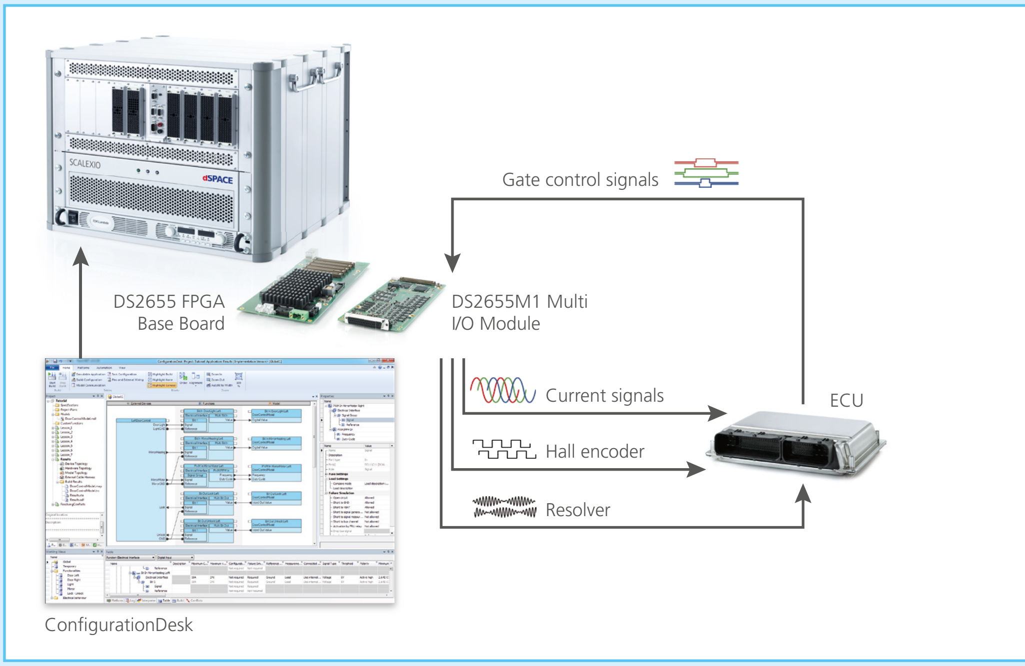
dSPACE recently extended its tool chain by adding the new DCI-CAN2. The DCI-CAN2 has the functionality of DCI-CAN1 (accessing CAN networks) and also supports access to CAN FD networks (FD = flexible data rate). The DCI-CAN2 transmits messages between CAN/CAN FD networks and the host PC via USB (universal serial bus). This makes it easy to use a PC to capture measurement data in CAN and CAN FD networks, achieving a much larger data throughput for measurement tasks. The DCI-CAN2 furthermore makes it possible to visualize CAN FD bus communication in ControlDesk Next Generation (also in the Bus Navigator), and to access electronic control units via CCP and XCP on CAN FD.

SCALEXIO for Electric Motors

dSPACE's hardware-in-the-loop (HIL) system SCALEXIO® now offers new hardware and software to help you develop electric motors.

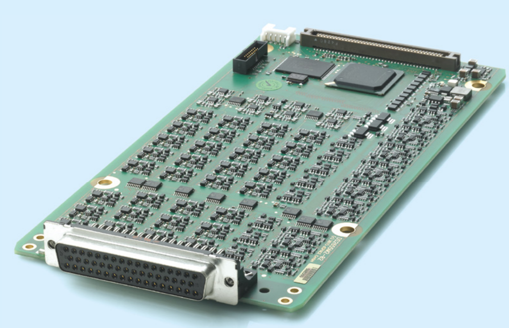
Processor-Based Simulation of Electric Motors

The new SCALEXIO EMH Solution provides a ready-to-use FPGA application with a comprehensive I/O library for processor-based HIL simulation of electric motors. You can use it to configure the simulation of up to two electric motors on one DS2655 FPGA Base Board from within ConfigurationDesk®. Thanks to the predefined function blocks, you no longer have to program or generate FPGA code. The fast I/O of the DS2655M1 Multi-I/O Module and the integrated angular processing unit (APU) with a resolution of 8 ns let you use high-resolution I/O to measure applications in the areas of pulse width modulation (PWM) and position sensor simulation (PSS). The variable I/O channel mapping and the flexible support of up to five DS2655M1 Multi-I/O Modules let you tap the hardware's full potential. You do not have to replace hardware to switch from processor-based simulation to FPGA-based simulation. You can simply continue to use the existing hardware system.



Controlling and Simulating Electric Motors

The new DS2655M2 Digital I/O Module adds 32 digital I/O channels to the DS2655 FPGA Base Board, letting you capture or generate more digital signals – e.g., for position sensors. Furthermore, the I/O channels can be configured as senders or receivers for RS232- and RS485-based communication. With the appropriate FPGA-based programming, you can thus simulate protocol-based position sensors (such as SSL, EnDat and Hiperface) and digital encoders (such as incremental encoders). The FPGA is programmed for each case via Xilinx® System Generator. The FPGA application generated by the dSPACE FPGA Programming Blockset is then easy to import into dSPACE ConfigurationDesk to configure the entire SCALEXIO system graphically. The DS2655 FPGA Base Board can be connected by ribbon cable with up to five I/O modules, offering a highly flexible number of available channels.

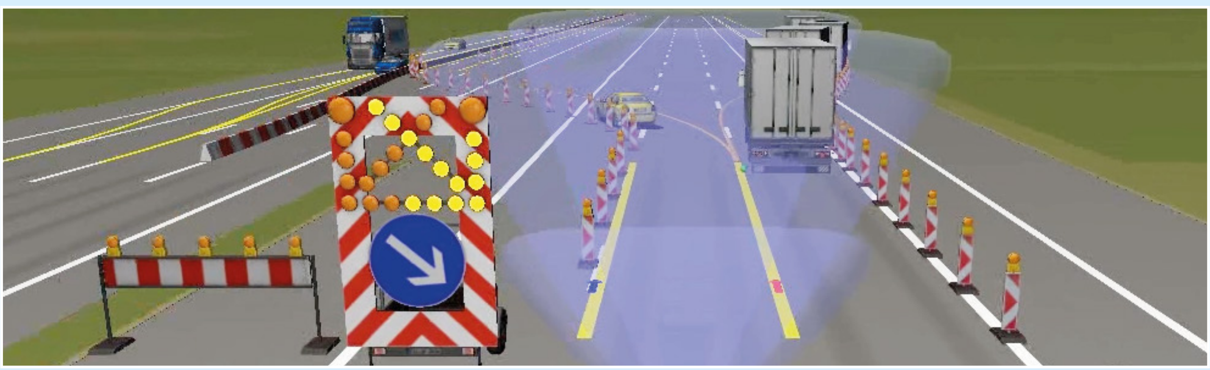


Lane Detection for Automated Driving

As of version 8.2, the Automotive Simulation Models (ASM) provide new functions for environment and sensor definition, so you can perform realistic simulations of construction site assistants and lane departure warning systems. This gives you greater flexibility for creating the lines required for lanes, parking spots and other road markings, making it possible to represent all of the marking types considered in the EU regulation 351/2012. You can now also create lines, barriers, and other objects independently of the lanes to create complex construction site scenarios. To visualize the simulation of such scenarios, the 3-D animation software MotionDesk also includes an extended library with construction site objects.

This video shows you the new features for defining construction site scenarios.

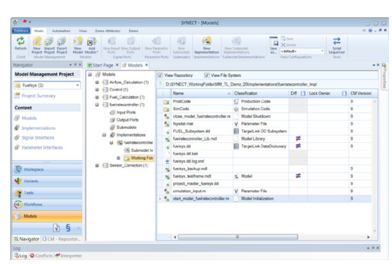
www.dspace.com/go/dMag_20161_ASM



SYNECT: Mastering Complex HIL Systems and Managing TargetLink Models Centrally

Complex processes, such as those for large HIL systems, are easy to handle with the established dSPACE Workflow Management solution. With the help of workflows, users can prepare the dSPACE tool chain for handling high numbers of variants and versions. Test automation makes the processes reproducible and reliable. For example, it is possible to open the modeling environment and automate everything up to the real-time application or prepare a HIL simulator for manual and/or automatic tests in a very short time. The basis for workflow management is SYNECT®, the dSPACE data management software for model-based development and ECU testing. It enables developers to centrally manage data such as variant information, tests, and models.

A new add-on makes it possible to connect dSPACE's production code generator, TargetLink®, so function and software developers can manage their models, related interfaces, signals and parameters in SYNECT. Interface inconsistencies are easier to find and prevent, and individual models can easily be integrated to make an overall model. Because the managed data is interconnected, data adjustments and their effects are transparent, and modifications are traceable. This makes it much easier for teams to work on distributed, component-based development.



The ASAM XIL Standard in dSPACE's Tool Chain

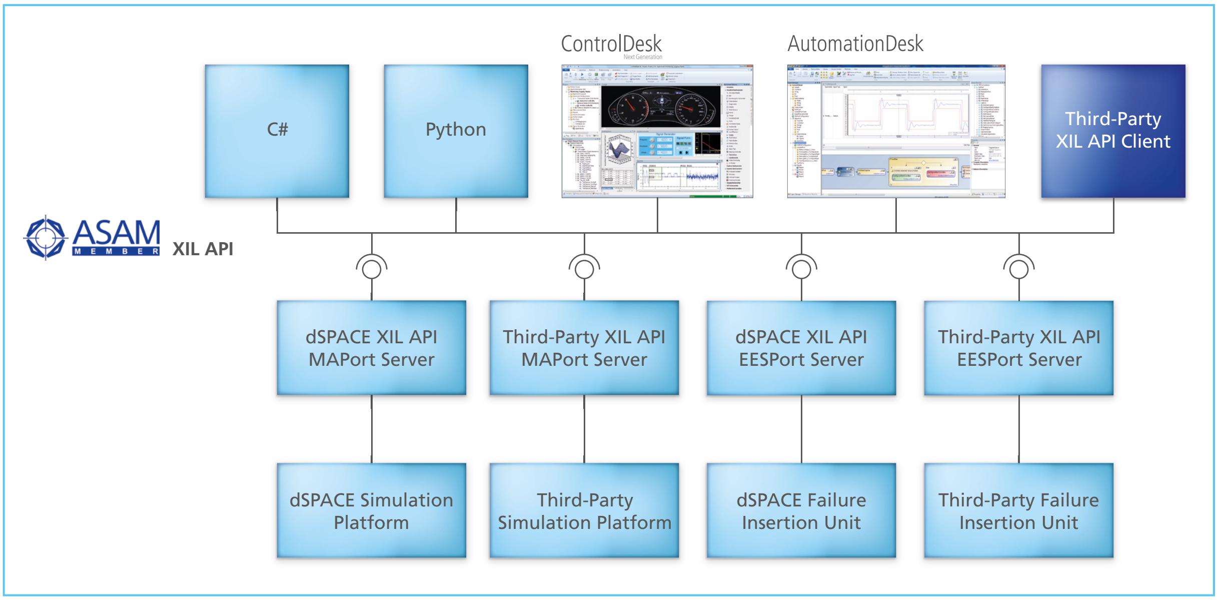
XIL API is a standard for communication between test automation tools and test benches. Since 2015, dSPACE ControlDesk® has offered model access via the XIL API Model Access Port (MAPort) and access to electrical error simulation via the XIL API Electrical Error Simulation Port (EESPort), thus replacing proprietary accesses.

Support for XIL API MAPort

As client tools, ControlDesk and AutomationDesk provide an ASAM-XIL-compliant MAPort access for accessing simulation model variables. AutomationDesk includes intuitive libraries for XIL-API-based reading, writing, measuring and stimulating. AutomationDesk further lets you use XIL framework mapping to access variables via an alias. This separates the test implementation from the test hardware and software, making it easy for you to reuse tests. Signal-based testing in AutomationDesk and stimulation in ControlDesk's Signal Editor are also based on the XIL API MAPort, which makes them platform- and model-independent as well. ControlDesk can access ASAM-XIL-compliant MAPort servers via the XIL API MAPort platform. This lets you access third-party hardware that support the standard from within ControlDesk.

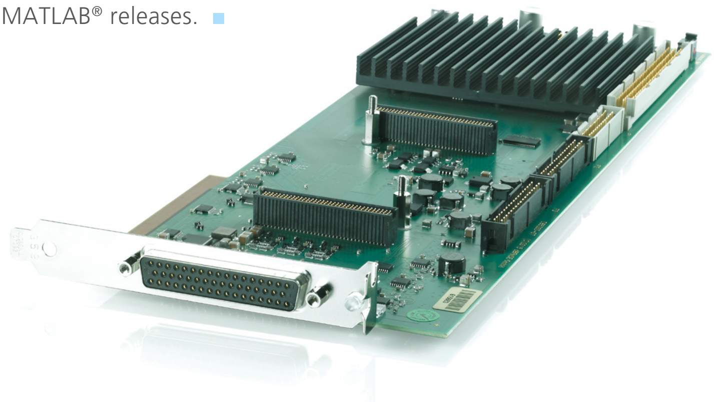
Support for XIL API EESPort

AutomationDesk and ControlDesk support the EESPort. You can therefore use error configurations to simulate electrical errors such as short circuits or broken wires via Failure Insertion Units (FIUs). The new dSPACE Failure Simulation Package contains an XIL API EESPort server implementation and the XIL API EESPort GUI component for ControlDesk. The XIL API EESPort GUI lets you configure error scenarios for all dSPACE FIUs in the same way. This shows that dSPACE is open to including third-party hardware in the entire tool chain.



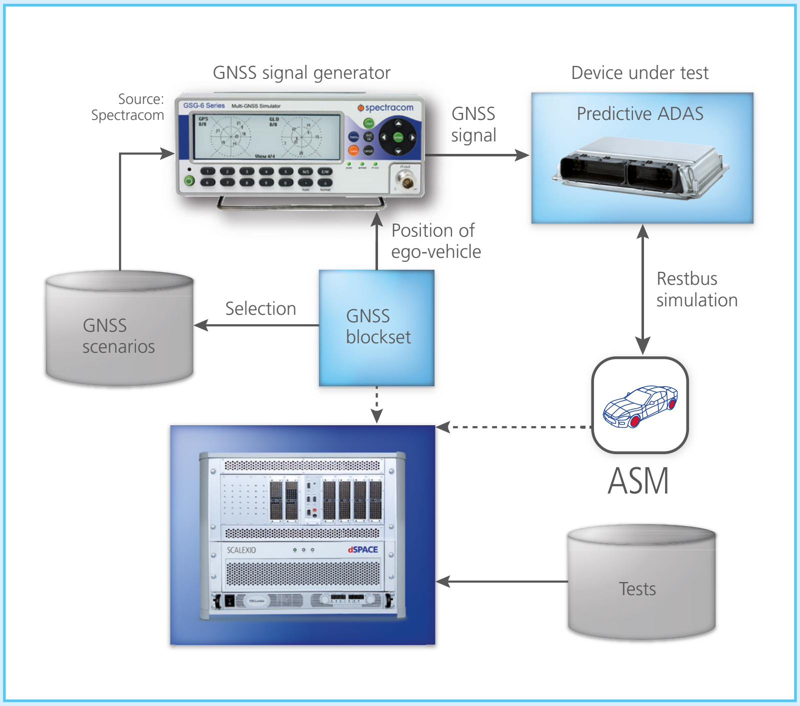
DS5203 FPGA Board in Two New Variants

The flexible DS5203 FPGA Board for demanding tasks such as power electronics simulation, signal preprocessing, and support for special interfaces and protocols, is now available in two new, even more powerful variants.
The DS5203 7K325 with a Xilinx® Kintex® 7K325 FPGA and the DS5203 7K410 with a Xilinx Kintex 7K410 FPGA are supported by the new design software Xilinx Vivado®. Users can therefore continue to program the board conveniently via the tried-and-tested Xilinx System Generator (XSG) in Simulink. This also ensures compatibility with the current MATLAB® releases.



GNSS Signal Generation in HIL Simulation

Predictive driver assistance systems require satellite-supported capturing of the vehicle position. To ensure the robustness of these systems in everyday operation, it must be possible to test different satellite constellations and scenarios such as dense urban areas, tunnels, and adverse weather conditions. dSPACE offers a special Simulink blockset that lets developers connect Global Navigation Satellite System (GNSS) signal generators from Spectracom (www.spectracom.com) to dSPACE hardware-in-the-loop (HIL) simulators. Once the signal generators are integrated in the simulation environment and connected to the dSPACE Automotive Simulation Models (ASM), the blockset selects predefined GNSS scenarios and controls the signal generators. In a typical test, first the route and driving maneuver of the ego-vehicle are parameterized in the ASM model and the desired GNSS scenario is selected, e.g., the number of satellites, the atmospheric model or multipath propagation. During test execution, the HIL simulator then consistently sends the position data of the ego-vehicle to the GNSS signal generator, which prepares the data as a high-frequency GNSS signal according to the scenario and the device under test.

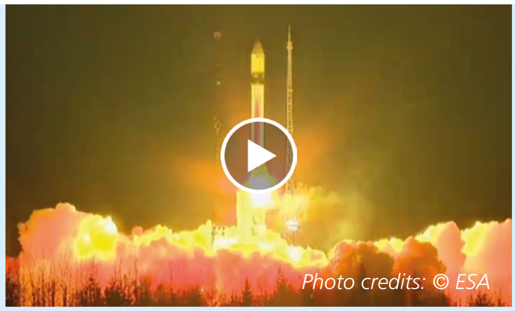


dSPACE on Board

Discover intriguing and innovative applications, achieved with dSPACE development tools

TargetLink Code Reaches Orbit

On February 16, 2016, a launch vehicle lifted off from the Russian space center in Plesetsk, carrying the Sentinel-3A earth-observing satellite into orbit at an altitude of 800 km. The manufacturer, Thales Alenia Space, used tools such as dSPACE TargetLink® to develop the powerful software that monitors and controls all the onboard systems.



The Rockot launch vehicle carries the satellite and TargetLink code into orbit.
www.dspace.com/go/dMag_20161_Thales1

Report on developing the control software at Thales Alenia Space:
www.dspace.com/go/dMag_20161_Thales2

On-Road Tests with Assistants

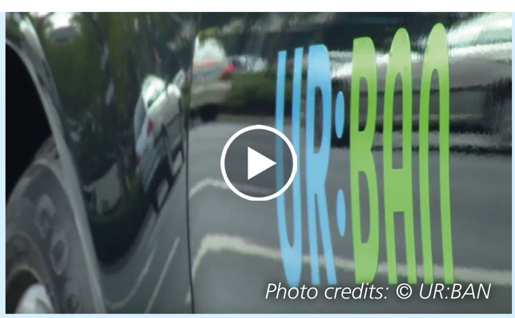
Developers at BMW are working on driver assistance systems, such as ConnectedDrive, for the entire fleet. They use prototypes to practically test the results of their research on the road. A dSPACE AutoBox with prototyping hardware is installed in the trunk of each test vehicle, giving the developers the flexibility needed to use and test new functions quickly.

Developing advanced driver assistance systems with simulated scenarios in the lab.
www.dspace.com/go/dMag_20161_BMW

A dSPACE AutoBox is installed in the vehicle for field tests.

Cognitive Assistance

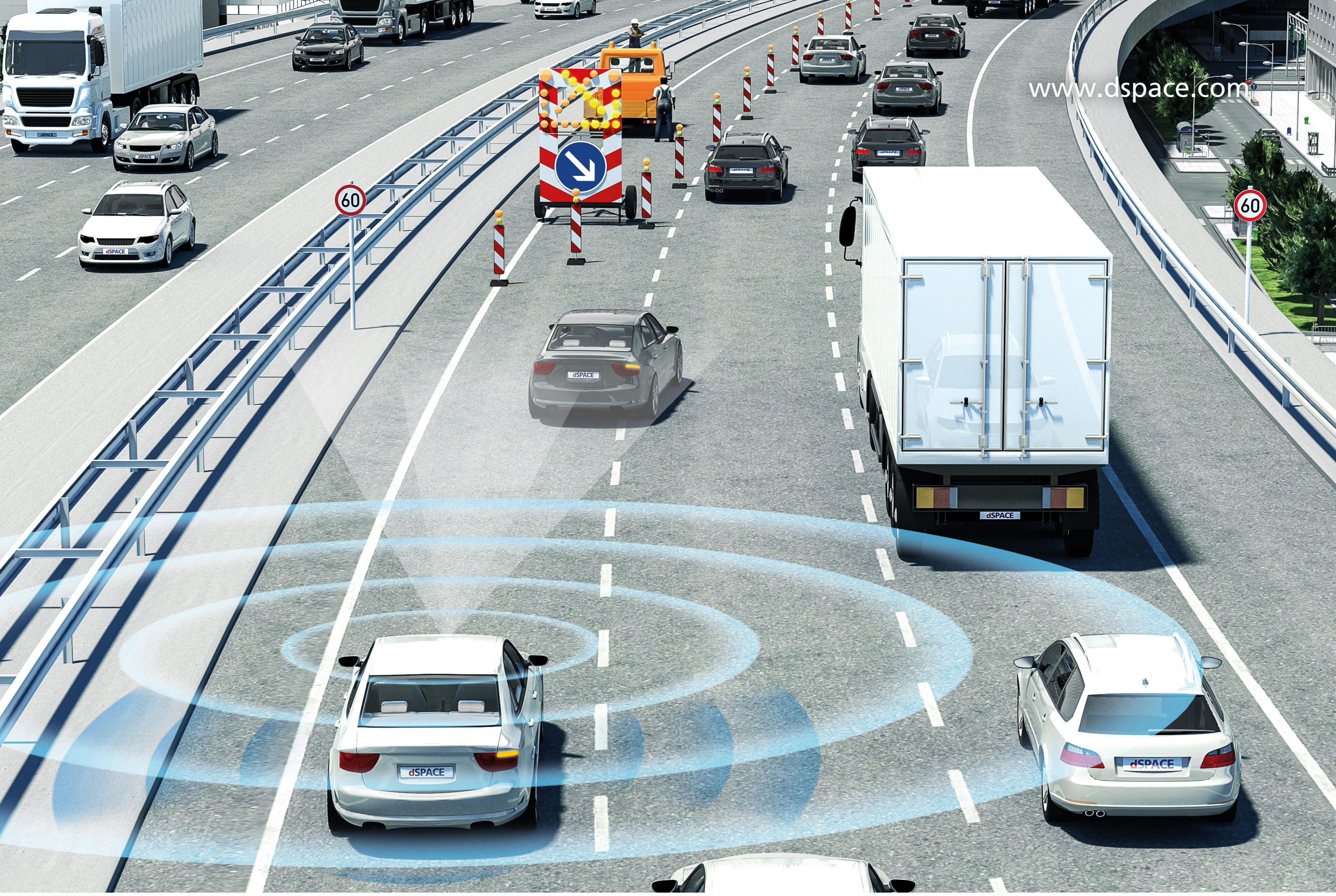
Thirty partners, including manufacturers of automobiles, electronics, communication technology and software, as well as suppliers, research institutes, and cities are working together in the joint project UR:BAN, which develops advanced driver assistance and advanced traffic management systems for urban areas. Depending on the type of application, the project's test vehicles are equipped with prototyping systems in a dSPACE AutoBox.



Project UR:BAN: Cognitive assistance for more safety in tomorrow's vehicles.
www.dspace.com/go/dMag_20161_URBAN

AutoBox is the basis for prototyping systems that are used for development tasks in the field of autonomous driving.

Learn more about these applications online, via videos, photos, and reports:
www.dspace.com/go/dMag_20161_REF_E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