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dSPACE MAGAZINE

2/2016

Porsche
Mechatronically Validating Steering Systems | page 24

Bosch – Quickly and Reliably Evaluating a 48 Volt Hybrid | page 6

Mitsubishi – Flexibly Implementing Autonomy | page 12

"The fully electric airplane ELIAS is thoroughly tested in an aircraft-in-the-loop simulation at our parent company IABG to prepare the test flights. During the simulation, we not only verify the automatic flight, we also test switching from manual flight mode to automatic flight mode while airborne. MicroAutoBox from dSPACE is used on board as the flight guidance computer."

Dr. Hans Tönskötter, Senior Manager Airborne Systems, ACENTISS GmbH

Read the complete article about ELIAS in the next issue of dSPACE Magazine.

> "dSPACE offers a comprehensive range of products and services for the development of electric drive systems."

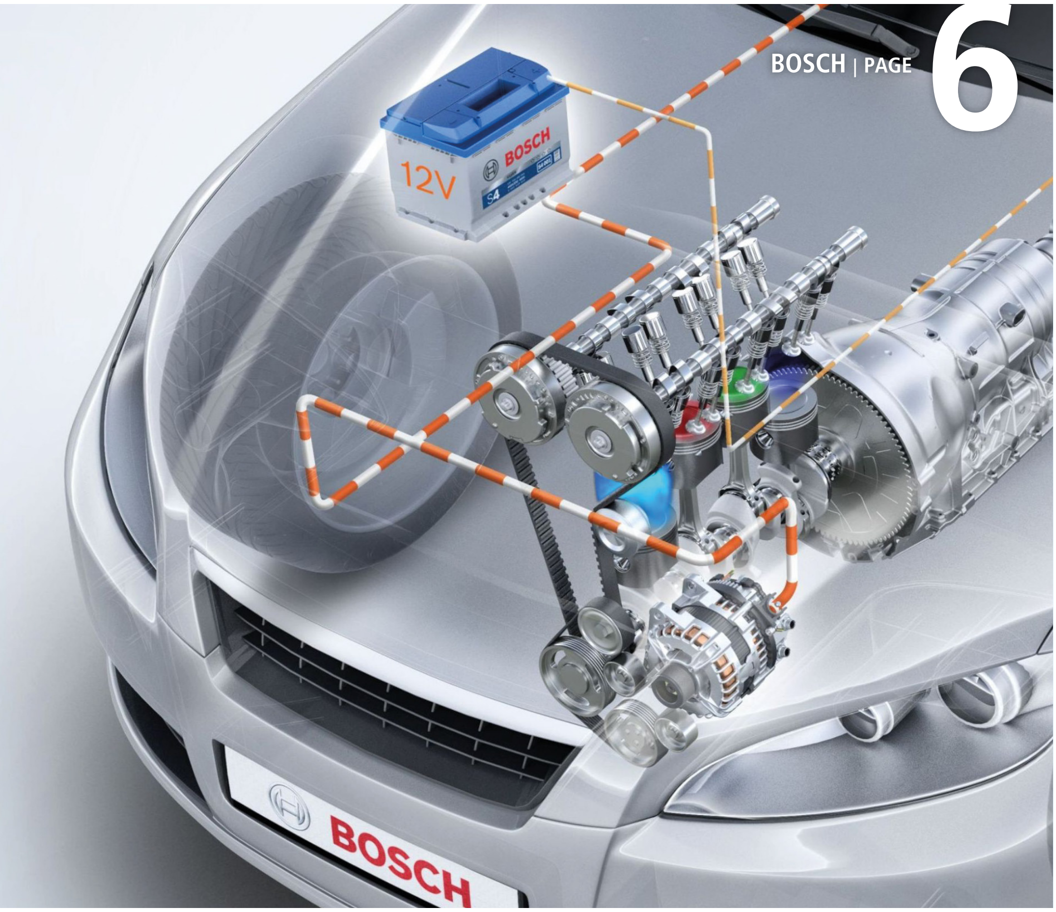
There have been quieter times for the automotive industry. Developing combustion engines that comply with emissions requirements is becoming so difficult that OEMs struggle with even the smallest improvements. I just read an article about how using variable intake manifolds could save 1 (in words: one) gram of CO_2 per kilometer in the New European Driving Cycle. To put this into perspective: Mid-size cars emit about 150 g. Electric motors that replace conventional shock absorbers could reduce CO_2 emissions by 3 g by means of recuperation, as Audi is currently demonstrating. These are just two examples of the automotive industry's extensive efforts.

Electric vehicles are now expected to jump-start emission reduction. They are often considered emission-free, although in most cases, fossil fuels have to provide the energy to charge the vehicles. This just relocates the emissions. But the political requirements are met, and that seems to be the main criterion.

Automobile manufacturers are also challenged by dynamic start-ups that focus on electric drives and aggressively pursue autonomous driving. This spurs not only drive development but also the entire vehicle electrification. dSPACE has been preparing for this over the last years by continuously expanding its range of solutions for electric drives – from the charging station, to battery management, to the motor that propels the vehicle – and for electrifying the auxiliary units.

Our mechatronic test benches for electronic power steering systems are one example for the latter. The high end of the range includes highly dynamic setups like the one described on page 24. It was preceded by several test benches of similar size that were built for other customers. This shows what dSPACE has always been doing: combining software, electronics, control engineering, and mechanical engineering. Here's a short anecdote: A customer who had ordered a test bench came to dSPACE to see how far his project had come along. He was surprised to see that there would not be a delay. He hadn't been expecting this, because the lab that the test bench would be set up in was not ready yet. A far more pleasant surprise was that the real test bench even surpassed his expectations in terms of dynamics.

Dr. Herbert Hanselmann



IMPRESSUM

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Power
Guaranteed

Rapid control prototyping of fuel-saving functions in a 48 V system

Source: © Bosch

When 48 V systems are used in vehicles, new high-performance functions and technologies can be introduced that significantly reduce fuel consumption. Within this context, Bosch Engineering China has developed a 48 V belt-driven starter generator. MicroAutoBox II, used as a prototyping controller here, has considerably accelerated the development process.

Tthe evolution of vehicle power systems in voltage level and power demand has increased significantly during the past few decades. With the development of vehicle technology, the increasing use of electrical components in vehicle systems has led to better vehicle performance and reliability. However, the trend also leads to an exponential increase in the power demand and creates new challenges for the power net.

Why 48 V?

To meet the increasing power needs in the future, the current 12 V system is in transition to a higher voltage level system [1]. In addition, the higher voltage level also reduces the energy loss during the power distribution in the vehicle system. The 36 V and 42 V systems have been well discussed and analyzed in the past few years. However, they were not widely used in vehicle applications, because only a few SAE standards (SAE = Society of Automotive Engineers) were established for them. The 48 V system is a hot topic in Europe. Major OEMs, such as Audi, BMW, Daimler, Porsche and VW, have proposed the standard LV148 [2], which defines the concept of an operating voltage in a range from 25 V to 60 V. According to LV148, the unrestricted functional operation range lies between 36 V to 52 V (with an average of 48 V), which is below the 60 V threshold, so no special, expensive protection is needed to prevent electrical hazards (figure 1). This also leads to lower system costs in comparison with hybrid vehicles which operate at voltages higher than 60 V and require

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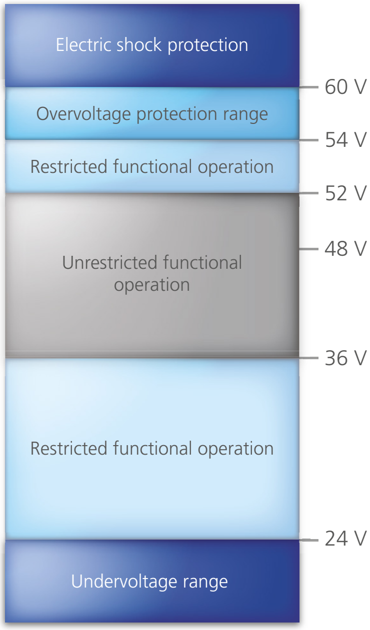


Figure 1: Safety voltage definition.

these safety mechanisms. In addition, significant fuel savings can be achieved by using a 48 V system instead of a traditional 12 V system, because the recuperation function (brake energy recuperation) in a 48 V system is capable of recuperating more energy than a 12 V system under the New European Driving Cycle (NEDC) and Worldwide Harmonized Light-Duty Vehicles Test Cycle (WLTC). Figure 2 shows the qualitative advantages of a 48 V recuperation system. The most important points that speak for the widespread use of a 48 V system are:

- It enables the operation of high-power accessories, such as the air compressor, turbo, PTC auxiliary heater (PTC = positive temperature coefficient).
- Fuel-saving hybrid driving functions in terms of recuperation, boost, and start/stop can be easily implemented.
- The driving experience can be enhanced by adding more functionalities, such as comfortable start/stop, change-of-mind start (restart during power-down), and start/stop coasting.
- With the increase of system voltage, the cable current will be reduced, thereby decreasing cable power loss and improving power efficiency.

48 V System Overview

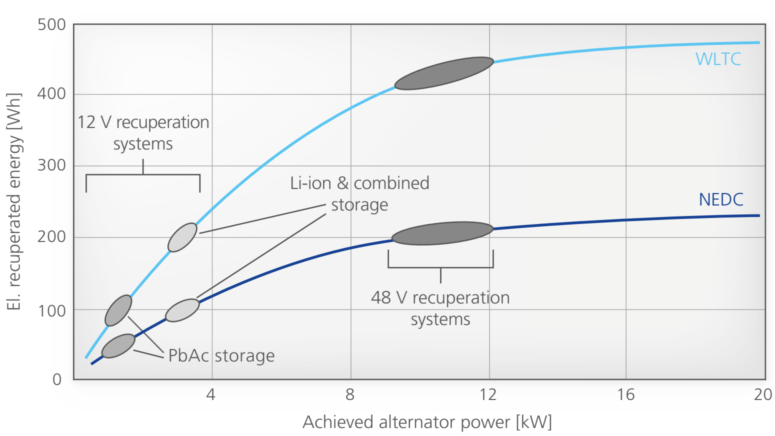
The Bosch boost recuperation system (BRS) is a 48 V belt-driven starter generator composed of three key components (figure 3): an air-cooled boost recuperation machine (BRM), a DC/DC converter (also called a power control unit, PCU), and a 48 V Li-ion battery. In the BRS, two power nets (48 V/12 V) co-exist and are connected via the PCU.

In the 48 V system, the BRM, PCU, and 48 V Li-ion battery are connected electrically. The BRM can operate either as a generator or as a motor. As a generator, it charges the Li-ion battery according to the driving status. As a motor, it assists the engine with additional torque, which either enhances drivability or saves fuel. The 48 V Li-ion battery is used to absorb the recuperated braking energy and provide the power to the BRM during the comfortable engine cranking phase and the boosting phase. The 48 V Li-ion battery system contains the battery stack, relay box, and battery management system (BMS). The BMS has CAN interfaces that can send out the battery status and also receive the commands to control the main relay or coordinate the external charging function. The PCU has a nominal power of 2.5 kW, which completely fulfils the power requirement of a normal vehicle power net. The 48 V system provides the possibility to use higher electrical loads for the PTC auxiliary heater, an e-compressor for air conditioning, electric power steering (EPS), cooling fan motors, and window heating, for example.

Boost Recuperation Machine: Efficient Prototyping with dSPACE MicroAutoBox II

Several demo vehicles with a 48 V BRS have been developed by Bosch Engineering China. Figure 4 gives an overview of a prototype 48 V BRS from one of the demo vehicles. The 48 V BRS can achieve a convenient engine start/stop function (including start/stop coasting) which uses the belt-driven boost recuperation machine to recuperate the braking energy and store it in the 48 V Li-ion battery. It also provides an additional torque on the engine crankshaft to boost the vehicle, or it can move the vehicle purely electrically with limited speed and constrained functions (called E-creep). In short, with the described 48 V system, the start/stop, coasting, recuperation, boost, and E-creep functions can be

Figure 2: Recuperation under the driving cycles New European Driving Cycle (NEDC) and Worldwide Harmonized Light-Duty Vehicles Test Cycle (WLTC).



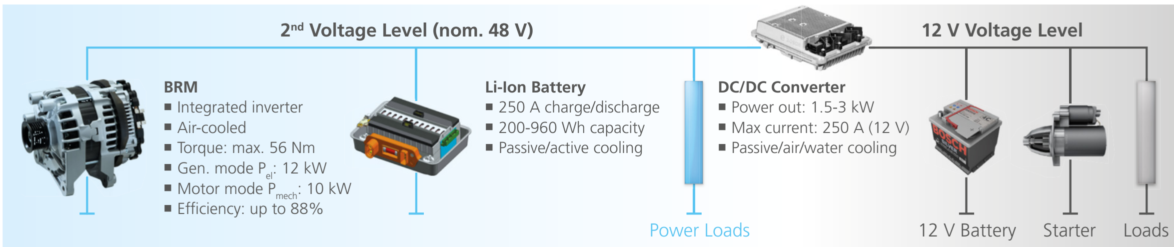


Figure 3: Layout of a Bosch 48 V belt-driven starter generator.

> "During the prototyping process, the control algorithms of the 48 V boost recuperation machine were run on a dSPACE MicroAutoBox II. This let us evaluate the influences on the entire vehicle at an early stage and significantly accelerate the development process."
>
> *Zhu Xiaofeng, Bosch Engineering China*

performed. The BRM is usually installed in the engine compartment, and the PCU and 48 V Li-ion battery are installed in the space of the rear trunk (figure 6). The BRS control algorithm runs on the MicroAutoBox II (1401/1511), which has 4 channels for CAN communication and enough resources for processing the digital/analog signals and can fully meet the control requirements at the hardware and software levels. In addition, the Gateway function in the RTI CAN Blockset provides the means to modify the original vehicle CAN network to implement the BRS functions. MicroAutoBox II is a compact module that can be installed in the vehicle and powered by the 12 V battery. The control software on the MicroAutoBox II has several layers and modules. In the application layer, there are two main modules: EEM coordination (EEM = electrical energy management) and powertrain coordination.

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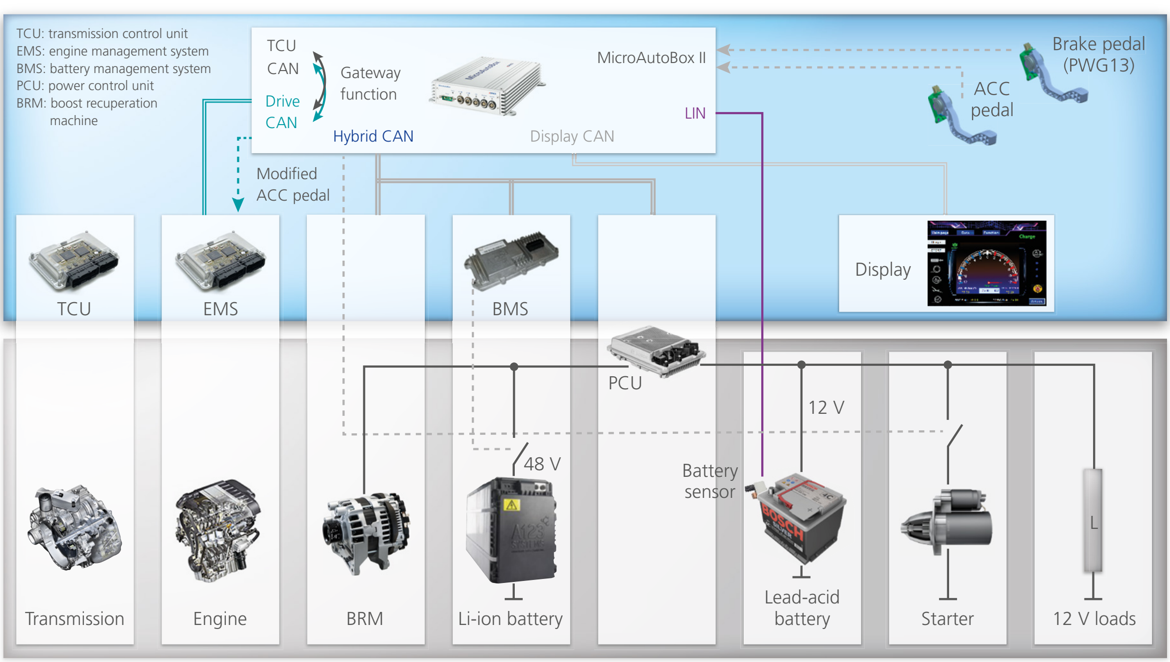
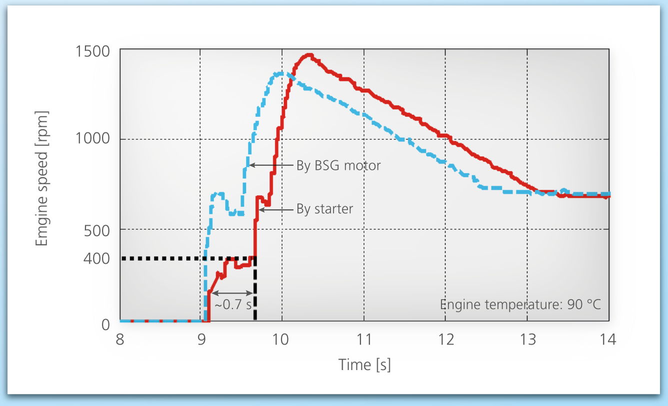
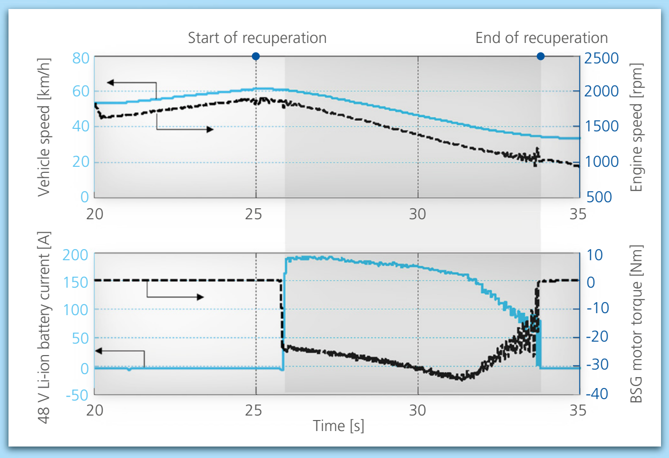
Figure 4: Prototyping a 48 V system with dSPACE MicroAutoBox II.





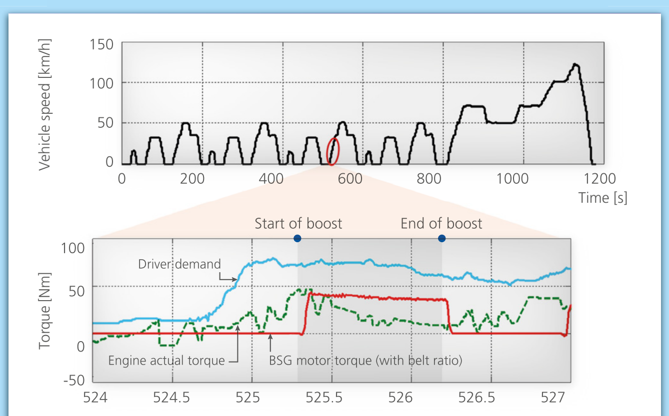
Engine Cranking

In direct comparison between a normal starter and the 48 V BSG motor, the cranking ability of the 48 V BSG motor reaches 400 rpm approximately 0.7 s faster. In addition, the BSG motor is connected with the engine crankshaft via a belt, resulting in less vibration during the engine cranking phase.



Recuperation

In this example of a typical braking process (around 8 s), the BSG motor works as a normal generator and recuperates the kinetic energy during the braking and stores it as electrical energy. The BSG torque is negative due to the recuperation command. During recuperation, the 48 V battery absorbs the energy with a current of up to 200 A. This free recuperated energy reduces fuel consumption.



Boosting During Engine Cranking

This graph shows the boosting process in the NEDC driving cycle. The 48 V BSG motor provides the torque (positive value, red solid line) to compensate the driver's demand torque (blue solid line).

Figure 5: Selected test data of the main functions in the 48 V system.

Within the EEM coordination, the Power on/off management, EEM strategy, and basic diagnostics are included. The powertrain coordination has the start/stop function and the BSG motor (BSG = belt-driven starter generator) operation mode control strategies. The two main application modules transfer and receive the signal from the Real-Time Interface (RTI)-supported drivers in the lower layer, like CAN, LIN, and digital I/O.

Summary

With dSPACE MicroAutoBox II as a prototyping controller, the efforts on coding, such as the fixed-point adaption of the controller model and management of run-time resources (like RAM and flash space), are reduced significantly. Furthermore, the control algorithm can be focused on at the very beginning of the system development phase. With the rapid control prototyping approach, the development time for the demo vehicles and first prototypes is reduced remarkably, because functions can be realized more efficiently and real measurement data for future decisions is available in the early phase of mass production. There are even more benefits for the OEM. For example, the fuel-saving functions can be investigated with the 48 V technology on the target vehicle and the interactive system influences can be further studied for the complete vehicle design. In addition, the prototyping controller (i.e., MicroAutoBox II) can be integrated into the vehicle easily due to its compact size. ■

Patrick Ziegler, Zhu Xiaofeng, Ji Guangji, Markus Wernsdoerfer, Lu Boran, Zhang Juan, BEG/EVS-CN, Bosch Engineering China

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[1] Da Silva, W.; de Paula, P., 12V/14V to 36V/42V Automotive System Supply Voltage Change and the New Technologies [J], SAE Paper 2002-01-3557
[2] Kuypers, M., Application of 48 Volt for Mild Hybrid Vehicles and High Power Loads [J], SAE Paper 2014-01-1790

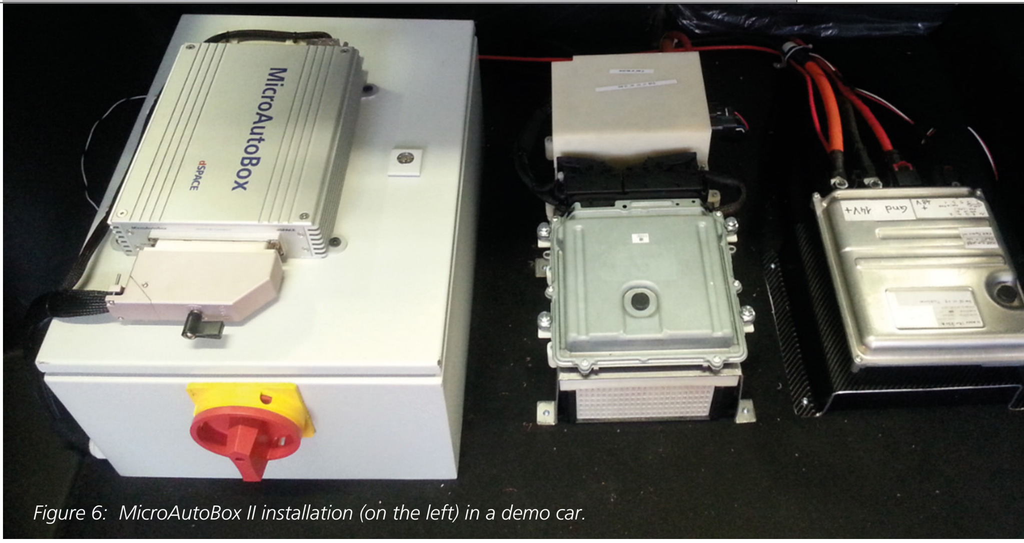

Figure 6: MicroAutoBox II installation (on the left) in a demo car.

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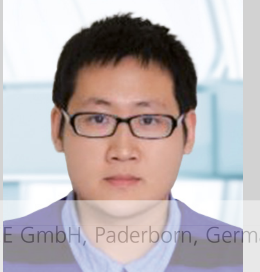

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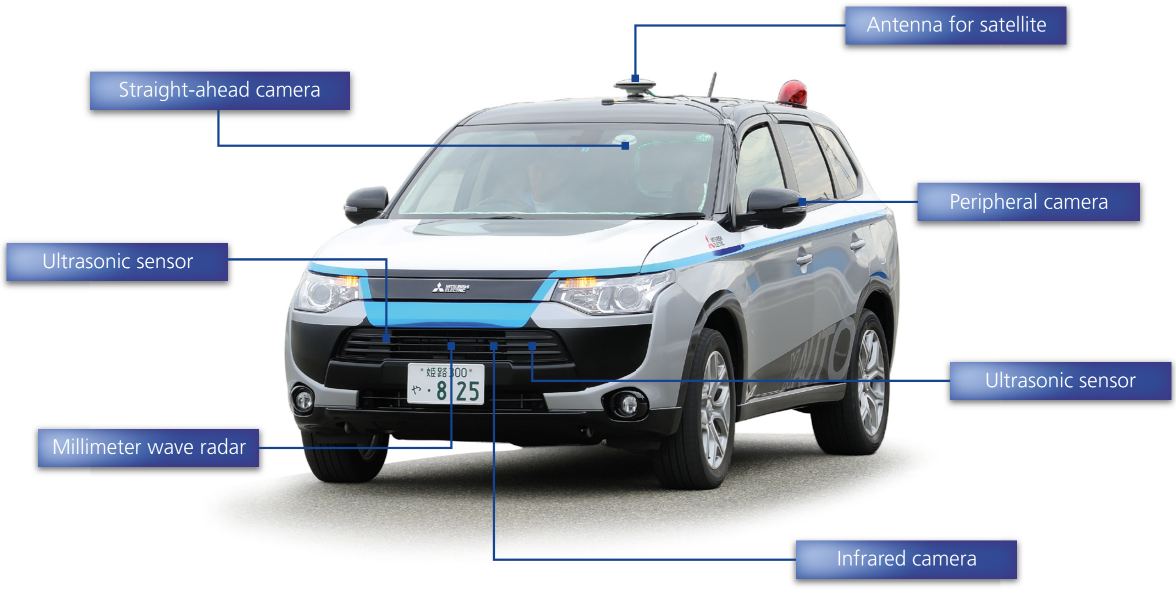
Driving Your Car from Space

Developing a satellite-based autonomous vehicle control system

The vehicle blinks, changes its lane, accelerates, and then stops exactly at the next intersection – without anybody doing anything at the steering wheel. A satellite system, multiple sensors, and dSPACE MicroAutoBox II, with autonomous vehicle steering implemented by Mitsubishi Electric, make this vision a reality.



Overview of the sensors for autonomous driving.

The rapid rise of global interest in the field of autonomous driving is ushering in a new era of automobiles. With many vehicles already offering autonomous preventative safety systems, the addition of improved road infrastructure could increase the reliability and maturity of autonomous driving functions, ultimately increasing the driver's sense of safety.

Autonomous "Diamond Safety" Technology

At Mitsubishi Electric, customers and their safety always come first. Under this motto, Mitsubishi Electric is developing Diamond Safety – a technology that contributes to level 3 autonomous vehicles. Level 3 vehicles are conditionally automated driving systems that perform all driving tasks, but rely on the driver to assume control in certain situations. For example, during highway driving, drivers can take their eyes off the road and let the vehicle take over the necessary driving functions. However, drivers still need to be able to resume control after a few seconds of warning. To verify the suitability of preventative safety technology, Mitsubishi Electric uses MicroAutoBox II, a rapid control prototyping (RCP) system from dSPACE.

High-precision positioning information is provided by the Japanese quasi-zenith satellite system.

Source: © Mitsubishi Electric Corporation

Satellite-Assisted Positioning

Level 3 autonomous driving cannot be achieved with vehicle systems alone. The Japanese quasi-zenith satellite positioning can be employed to obtain high levels of precision and safety. The Quasi-Zenith Satellite System (QZSS; nicknamed "MICHIBIKI") uses multiple satellites that have the same orbital period as

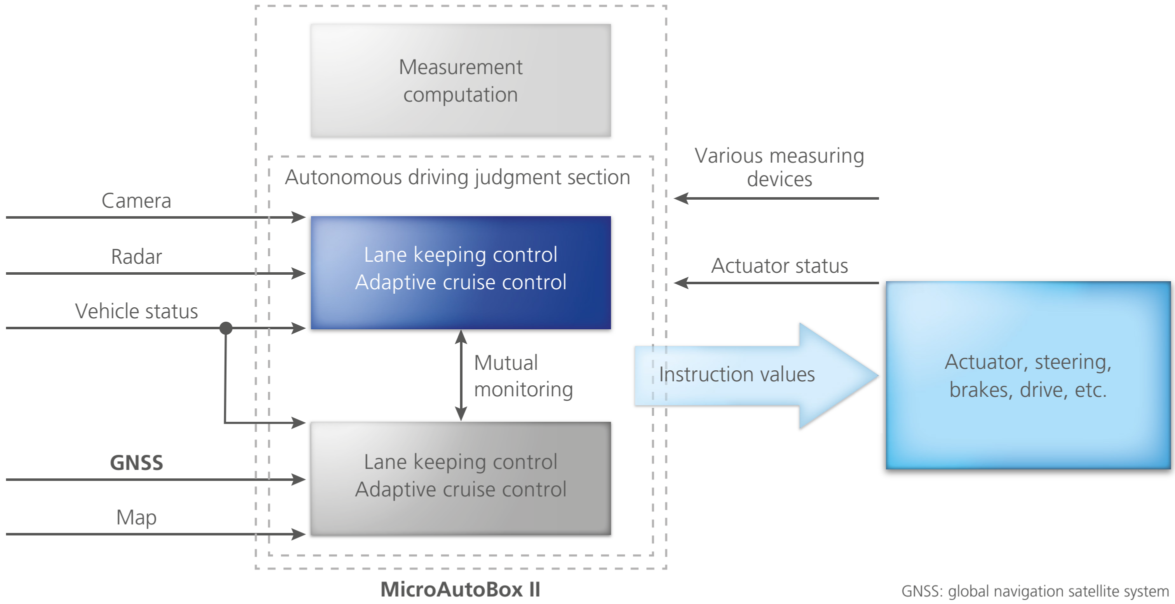


Diagram of the vehicle control system configuration.

geostationary satellites with some orbital inclinations (their orbits are known as quasi-zenith orbits). These satellites are placed in multiple orbital planes so that one satellite always appears near the zenith above the region of Japan. The system makes it possible to provide a highly accurate satellite positioning service covering close to 100% of Japan, including urban canyon and mountain terrain. The QZSS transmits its specific augmentation signals (centimeter level augmentation information) in addition to the current positioning signals. The first satellite was launched in 2010, and by 2018, the system will feature three quasi-zenith satellites and one geosynchronous satellite. By 2023, the system will operate seven satellites to enable continuous positioning. Data received from satellite positioning systems provides the vehicle with a high level of accuracy and reliability for functions such as lane keeping and lane changing.

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Dashboard of the vehicle equipped with the autonomous driving features.

Autonomous parking initiated with an external device, e.g., a smartphone.

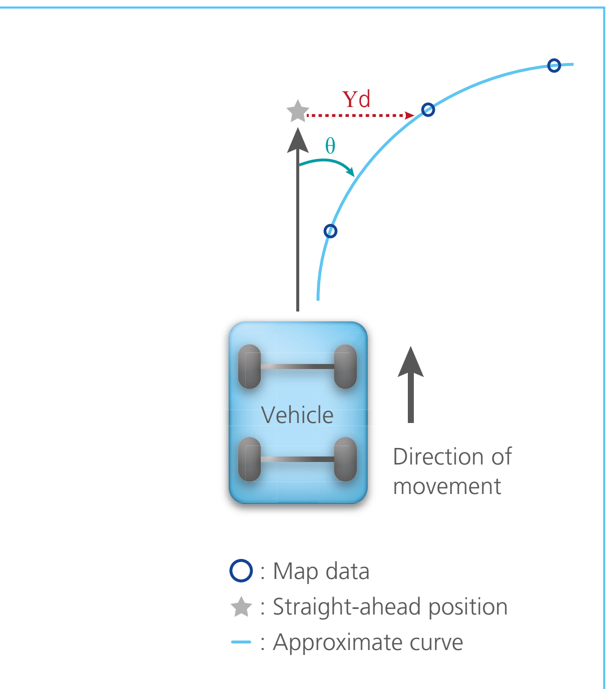

Illustration of the lateral vehicle control.

System Design Overview

The vehicle control system, implemented completely on the MicroAutoBox II, analyzes a multitude of sensor and vehicle data, including data from autonomous driving and infrastructure components, such as the forward camera, millimeter wave radar, high-precision GNSS (global navigation satellite system) receiver and a high-precision map. For example, the function of the lane keeping system makes highly reliable autonomous driving possible by correlating the target driving path based on the white-line recognition with the forward monitoring camera and the target driving path obtained from a high-precision map and high-precision positioning. In addition to vehicle speed, this data is augmented by other vehicle information, which is an input for executing autonomous features and operating the actuators.

Autonomous Vehicle Control

The lateral control of the vehicle utilizes a forward-looking model, as illustrated on the left. The forward position of the vehicle at a future point in time and the target driving path are compared and expressed by the lateral deviation Yd and the angle θ. Then, steering control is executed by using Yd, θ, and additional vehicle information. Vehicle control in the longitudinal direction is executed by the system through speed and brake controls. Speed control is performed by comparing the speed limit data provided by the map, and brake control, except for emergency braking, is set for a smooth deceleration. Stops, such as at an intersection, are executed on the basis of map data.

ControlDesk and MicroAutoBox II for Verification and Control

The dSPACE development tools allowed for a quick implementation of control algorithms developed with MATLAB® and Simulink®, making it possible to test new solutions immediately and adjust control parameters online. This is especially

The MicroAutoBox II in combination with other equipment performs the autonomous driving functions.




> "Using MicroAutoBox II and ControlDesk lets us perform and evaluate tests with a very high level of efficiency."
>
> *Kazuo Hitosugi, Mitsubishi Electric Corporation*

useful as systems gain in complexity. The tools are able to connect various sensors required to verify functions and alleviate communication delays. The abilities considerably reduce the number of items to be verified, thus improving productivity and liberating resources that would otherwise be required for analysis in different departments. If a system has the RCP equipment installed, the experiment software dSPACE ControlDesk allows the control and monitoring of various parameters on one screen, e.g., visually switching vehicle controls on and off and monitoring the input/output values of various interfaces and computational values. Additionally, with its multiple interfaces, MicroAutoBox II allows for easy vehicle operation and real-time monitoring of data from measurement devices. As a result, any evaluation can easily be completed.

Hideyuki Tanaka,
Mitsubishi Electric Corporation

Mitsubishi Electric's team of developers for the autonomous vehicle steering system.

Back row (standing, from left to right): Yu Takeuchi, Kenta Katsu, Yuji Shimizu, Kazuo Hitosugi, Takatoshi Kakuta, Tsuyoshi Kichise. Front row (squatting, from left to right): Kazuhiro Nishiwaki, Hideyuki Tanaka (Senior Manager), Toshihide Satake, Michitoshi Azuma, Rei Yoshino.

Conclusion and Outlook

The Diamond Safety technology has already reached a high level of maturity and scope of functionality. The principle of autonomous driving was successfully demonstrated on various test tracks. Our plan is to introduce individual safety functions of this technology into series production step by step. We would like to continue advancing the development of the high-level autonomous driving control system by using dSPACE products.

King of the HIL

Hardware-in-the-loop test of electrified dump trucks for surface mines

The Chinese SANY group´s SET230 dump truck can move up to 230 tons of payload. Its diesel-electric drive and a dSPACE HIL simulator provide maximum efficiency — the first in heavy-duty transport, the latter in developing and validating the complex drive control.

Have you ever seen a multi-story apartment building climb up a 20-percent grade? If not, you should definitely go see a large open-pit mine. In today's mines, the dump trucks often reach the size of a small housing block and easily have a total weight of several hundred tons. Despite their enormous mass, these giants always move safely and, in comparison to the past, very efficiently over rough and steep terrain. One of the contributing factors is the diesel-electric drive, which has become the market standard for dump trucks of this magnitude. The diesel engine drives a generator that uses an electronic inverter to supply the two three-phase motors on the rear axle with electric power to generate the propulsion energy. Without a rigid driveshaft from the diesel motor to the drive axle, this design makes it possible to work completely without a manual transmission, mechanical couplings, differentials and drive shafts, which considerably reduces the weight and maintenance costs of the vehicle. However, to guarantee high efficiency and safety during heavy-duty use in the mine, this drive concept requires highly complex control strategies for the electrical components.

Model-Based to New Dimensions

The engineers of the Chinese SANY group also had to face this challenge as they broke new ground while developing the SET230 dump truck (see the table for technical data), facing two issues at once. On the one hand, the truck's gigantic payload of 230 tons meant pressing forward into whole new dimensions for the company. On the other, the engineers only had rudimentary experience with diesel-electric drive technology. This is why SANY's goal was to use simulation to test and validate a large portion of the control development.

Turn-Key System for Virtual Vehicle Simulations

Instead of testing the real electrical components in a large laboratory, SANY decided to simulate the SET230's entire drive system with the help of a turn-key dSPACE Simulator Full-Size. This allowed the newly developed controls to be tested and validated together with an entire "virtual" vehicle immediately after implementation on the electronic control unit (ECU). Thus, the engineers were able to optimize their control strategies already on the test bench. Without having to compromise safety at all,

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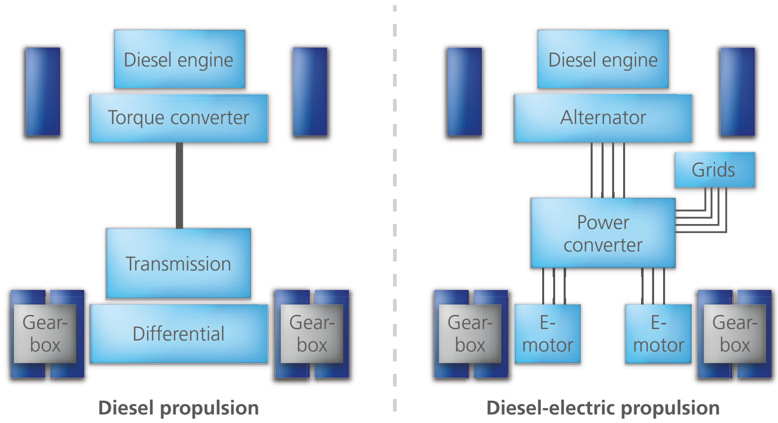
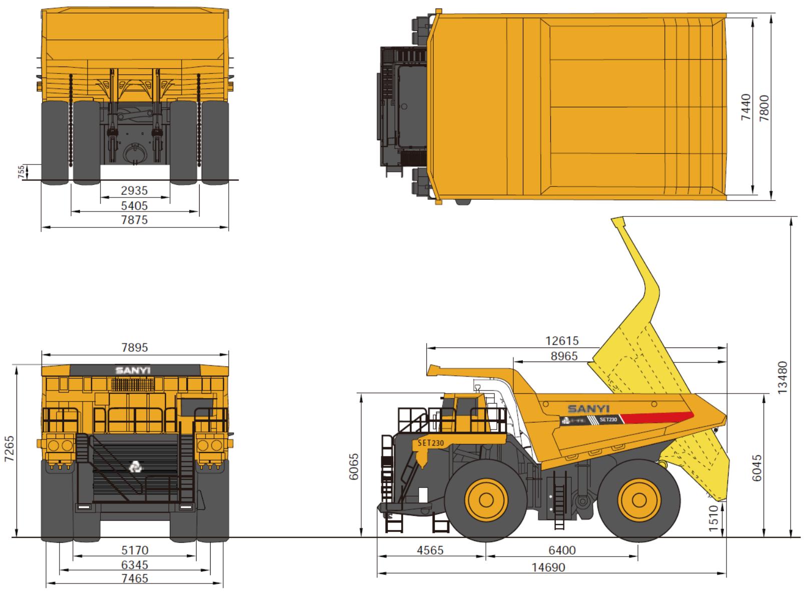
Compared to conventional diesel-powered mining trucks (left figure), diesel-electric vehicles like the SET230 do not require a rigid driveshaft from the diesel engine to the drive axle (right figure). Thus, both vehicle weight and maintenance effort are reduced significantly.





All dimensions in millimeters

Maximum grade ability	24%
Continuous grade ability	12.5%
Maximum downhill ability	-14%
Continuous downhill ability	-13%
Maximum vehicle speed	64 km/h
Weight of the electric drive system	45 t
Maximum payload	230 t
Maximum allowed gross weight	400 t

Technical data of the SANY SET230: For a vehicle weighing up to 400 t, the diesel-electric dump truck delivers impressive driving performance, even in rough terrain.

this reduces the need for expensive track tests with a real truck prototype.

Powerful and Flexible Simulator

The HIL simulator at SANY uses a DS1006 Processor Board, which can calculate even the most complex simulation models in real time, thanks to the high performance of its quad-core processor. The processor also provides the ability to distribute different calculation tasks onto its individual cores during the various function tests. For the signal processing and processor-based electric motor simulation at signal level, SANY relies on the dSPACE Electric Motor HIL (EMH) Solution, based on two DS5202 FPGA Base Boards. On the one hand, this solution measures the fast, electromotor-specific signals of the ECUs, such as the pulse-width-modulated control signals of the power electronics. On the other hand, it generates the rotary encoder signals for controlling the electric motors. dSPACE adjusted the signal conditioning exactly to SANY's specific requirements so that the sensors could be simulated at a current output with feedback signals of up to ±600 mA. To test the CAN-bus communication with the other vehicle systems, SANY uses two DS2202 HIL I/O Boards that allow its engineers to conveniently perform restbus simulation with the RTI CAN MultiMessage Blockset.

Modeling to the Last Detail

Besides powerful and flexible hardware for the simulation, SANY also focused on creating the most exact model of its dump truck and replicating its unusually harsh work environment as closely as possible. Since offline simulation with MATLAB®/Simulink® needed to be possible for both of these aspects, SANY decided to also implement an extensive range of dSPACE Automotive Simulation Models (ASM). These models either already seamlessly covered all of the dump truck's technological areas, or could be adapted to meet them without great time and effort. To simulate the diesel-electric system, one of the components used is the ASM Engine Basic model that already replicates all the necessary parameters for the diesel engine. For the various electrical components of the drive, in addition to a few customized models SANY mainly relied on the ASM Electric Components (ASM EC) Library, with some components individually adapted to match the special application. Among others, these components included the generator's separately excited synchronous motor (modified ASM EC), the inverter (ASM EC), the rectifiers, the intermediate circuit (ASM EC), the

> "Because of our good experiences with the HIL simulator and the ASM tool suite, we are going to integrate more dSPACE tools into our tool chain."

Lu Liling, Project Engineer, SANY Group

braking resistors, and the two asynchronous squirrel cage traction motors (ASM EC). The simulation models were parameterized almost completely with the ASM Vehicle Dynamics Library, which replicated all the longitudinal and transverse dynamic influence factors from the reduction gears, to the tires, steering system, brakes, and suspension. The only aspects that needed to be integrated additionally in the modeling and parameterization were the influences of the dump truck's various payload states, from empty trips up to maximum utilization of the full 230-ton payload. The environment models already included in ASM Vehicle Dynamics also allowed an accurate replication of the challenging terrain profiles that the dump truck travels through. This covered the widely diverse range of demands on the SET230's drive system, from short upward drives, to steep inclines, to continuous operation on long declining slopes.

Intuitive Parameterization, Clear Visualization

To adjust the model parameterization intuitively and manage its extensive parameter sets, including the tailored components, SANY relies on the graphical user interface of dSPACE ModelDesk. A visualization software, dSPACE MotionDesk, also comes into play. MotionDesk illustrates all of the results, including the various simulated maneuvers and scenarios, in a vivid 3-D online animation that makes the effects of parameter changes visible in real time. SANY's engineers carry out the entire operation and record test data in dSPACE ControlDesk.

Quickly Ready for Operation

The HIL simulator for the SET230 was developed by the dSPACE Engineering team, along with all its hardware and software components. Together with SANY, they modified, implemented, programmed, and tested the simulator and delivered it turn-key for operation on-site in Shanghai. Only eight months passed between receiving the order and commissioning the system, so SANY was able to start

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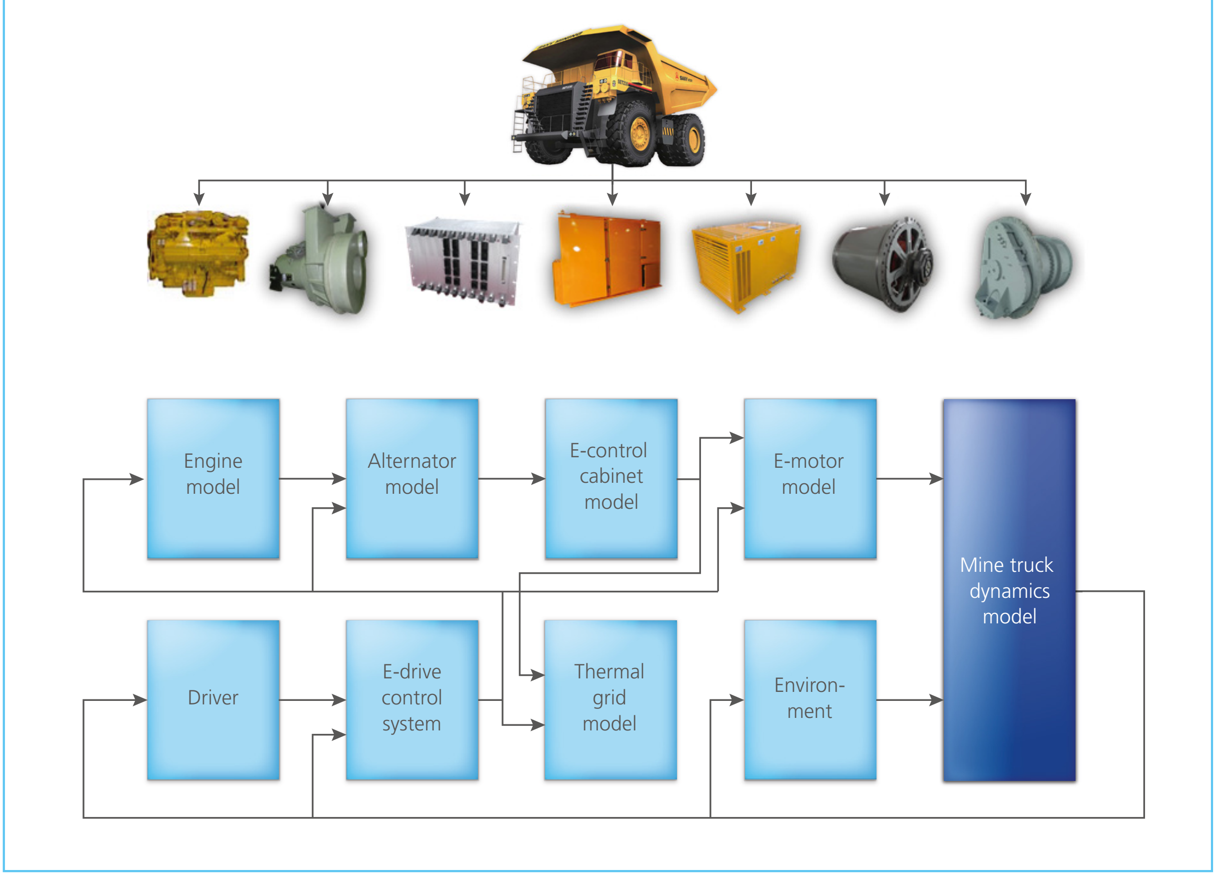
Virtual vehicle: The turn-key dSPACE Simulator Full-Size replicates the SET230's entire sensor system (on the right) and actuator components (on the left). This lets the engineers at SANY test the basic control strategies together with the other vehicle components at an early stage, without any expensive test drives with a real dump truck.

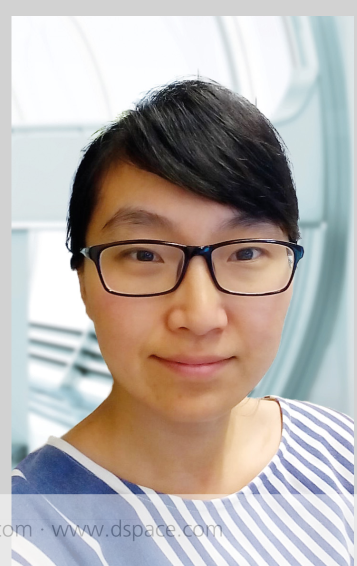


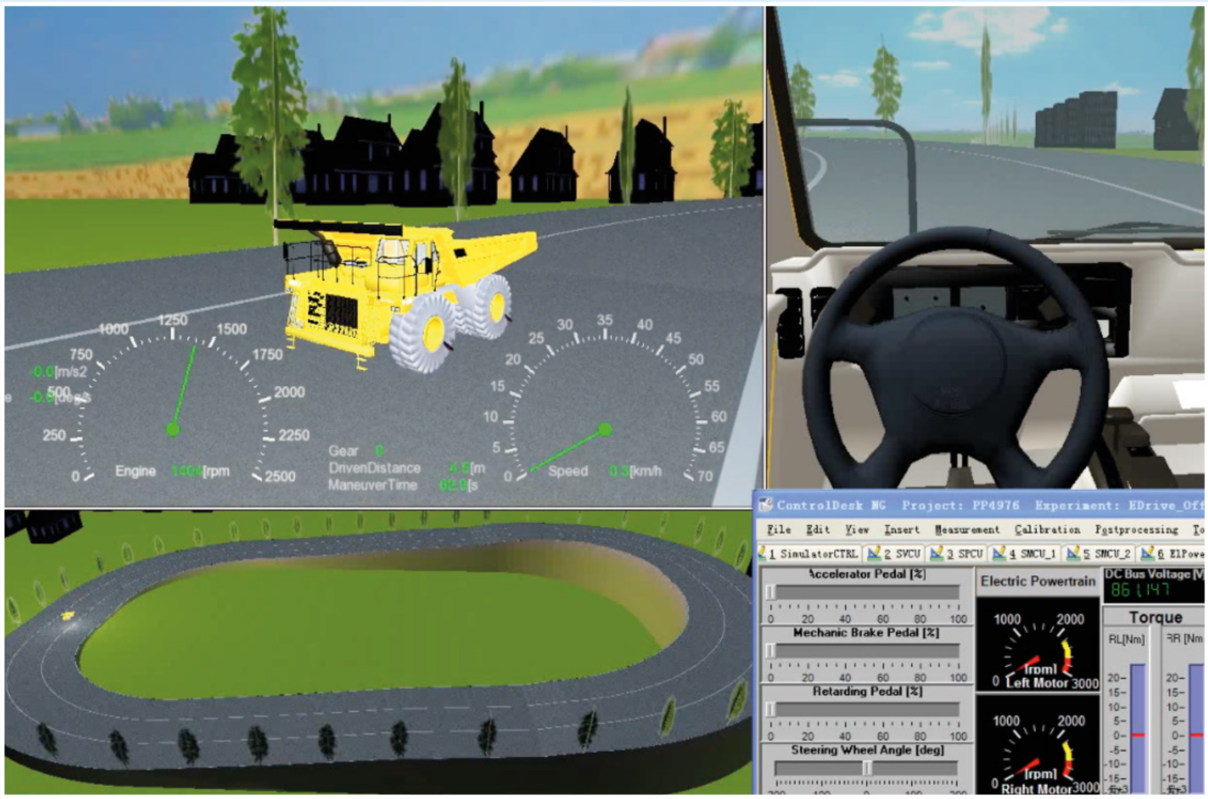
A wide range of model parameters: From the diesel motor to the components of the electric drive, the operator, and the environment, numerous factors flow into in the vehicle dynamics model of the dump truck.

developing the e-motor control of the SRET230 within schedule. By using the model-based approach and dSPACE's efficient as well as versatile tools, the engineers succeeded in staying on schedule while implementing all the development steps, testing the fundamental control strategies, and validating them on-site in Shanghai. The result at the end of the process, was an e-motor control with the maximum possible efficiency and reliability. By using dSPACE tools, the development times in the laboratory and the calibration times in the vehicle were reduced considerably, which also cut costs significantly. In addition, SANY was able to enormously expand its range of experience in electrified powertrains. Their new experience was used to establish a new, highly motivated team of developers. After the successful start with the HIL simulator and ASM models, SANY is planning to integrate more dSPACE tools in its tool chain, including products such as the test automation software AutomationDesk, the production code generator TargetLink®, and the data management tool SYNECT®. Now that SANY's SET230 has broken ground in the market segment of heavy, diesel-electrically driven dump trucks, they also plan to expand their position with even larger models in the future. Thus, it's a good possibility that the "moveable apartment buildings" are soon going to grow by another few floors. ■

Lu Liling, Qi Lie, SANY Group

Lu Liling
Lu Liling is an engineer in the development team of the SET230 mining truck at SANY Group in Shanghai, China.





Clear visuals: In dSPACE MotionDesk, SANY engineers can replicate the driving maneuvers and scenarios simulated on the HIL system in a clear 3-D online animation. This lets them visualize the effects of parameter changes in real time.

Qi Lie
Qi Lie is an engineer in the development team of the SET230 mining truck at SANY Group in Shanghai, China.

Developers with pride: The intuitive dSPACE tools not only helped SANY significantly simplify and speed up the development and testing of the dump truck. The tools also helped them gain a better overall understanding of the technology behind electrified powertrains. Their new experience will be used to establish a highly qualified team of developers.

A Test of Character for Steering Systems

Developing and fine-tuning electric steering systems with mechatronic HIL tests

Is it possible to test-drive the steering behavior of a vehicle realistically under laboratory conditions? It is. With a suitable mechatronic test rig. This is exactly what the Dr. Ing. h.c. F. Porsche AG did, efficiently optimizing the behavior of new steering systems already in early development phases.

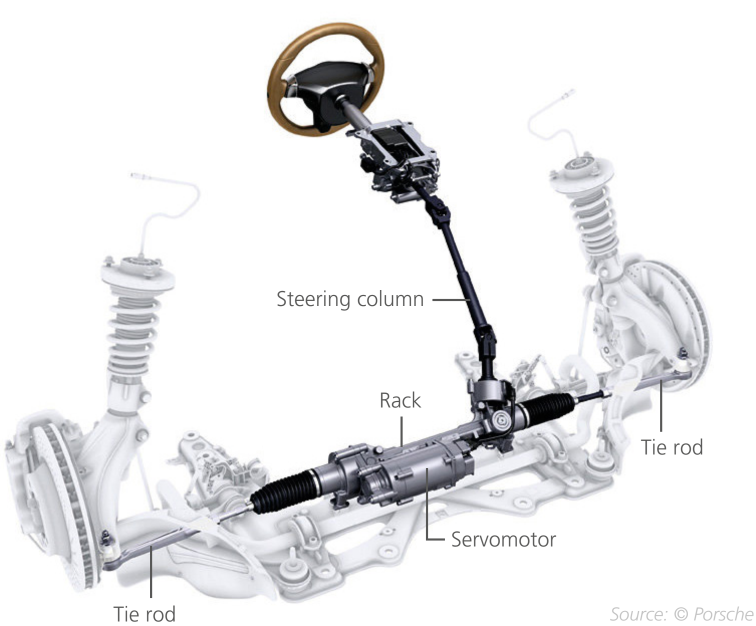
Source: © Porsche

Steering systems of today's vehicles are much more than simple components for changing directions. Supported by servomotors and plenty of assistance systems, they have become an integral part of the safety system and take stress off the driver in road traffic. On the race track, they often even determine whether it's win or lose. This is why sports car manufacturers like Porsche pay special attention to the development of steering systems. And they are not just investigating the precise and quick transmission of the steering movement to the wheels. It is also about direct feedback on the driving state – transferred exactly in the opposite direction. These two factors combined make for intuitive and safe driving. Since the driver experiences the steering system firsthand, the component is also ideal to set the company apart from competitors. Achieving a Porsche-typical steering feel, characterized by an agile and direct steering behavior, is therefore at the top of the developers' specifications. Of course, motor racing places many more, and more specialized, demands on steering torque and steering characteristics than configurations for everyday driving – above and beyond the limits of vehicle dynamics of street-legal vehicles.

Electromechanical Steering

State-of-the-art steering systems are electromechanical, often called electric power steering (EPS) systems (figure 1). In such systems, a servomotor provides additional power to the tie rods and thus actively supports the steering angle demanded by the driver. In comparison to previous generations, i.e., hydraulic steering systems, EPS systems consume much less energy and are easier to control. For example, developers can implement steering, convenience and assistance functions on the electronic control unit (ECU) integrated in the EPS system. This includes speed-dependent steering support, active steering returnability, lane keeping assistants, etc. However, one drawback of EPS systems is that the driver does not receive enough feedback about the driving states, due to the mass inertia of the assist unit and the transmission to the rack. This creates special challenges for designing the crucial feedback behavior and thus keeping the characteristic Porsche feel.

Figure 1: Setup of an electromechanical steering system. The electric motor for steering support is installed in parallel to the rack and exerts a translational force on the tie rods.



Validating the Steering System

In addition to the subjective comfort and response behavior, steering systems also have to fulfill very strict requirements. After all, they are a safety-critical vehicle component, because their failure can lead to a dangerous driving situation. The validation of the mechanics and electronics therefore complies with the most stringent safety standards. Growing amounts of software, new driver assistance systems, and the optional feature of rear-axle steering dramatically increase the need for tests in the development of steering systems. Therefore, suitable methods are needed to efficiently supply the required quality despite the high complexity. Reproducible tests, an easily extendable test scope, and a test depth that can be adjusted to each individual case can all be achieved with the industry-proven hardware-in-the-loop (HIL) method for ECUs. Efficiency can be improved even further by testing the overall system and supporting the controller design early with tests throughout the entire development process. This is why Porsche uses a mechatronic test rig to test the steering system, including the ECU, in its own lab. Suitable actuators stimulate the steering system mechanically, making it possible to test a system behavior that is very much like the behavior during a real test drive in a vehicle prototype. But it is also possible to insert synthetic stimuli at all mechanical interfaces of the steering system. This means that comprehensive tests can also be performed on the test rig. For example, developers test new functions early on, identify important parameters,

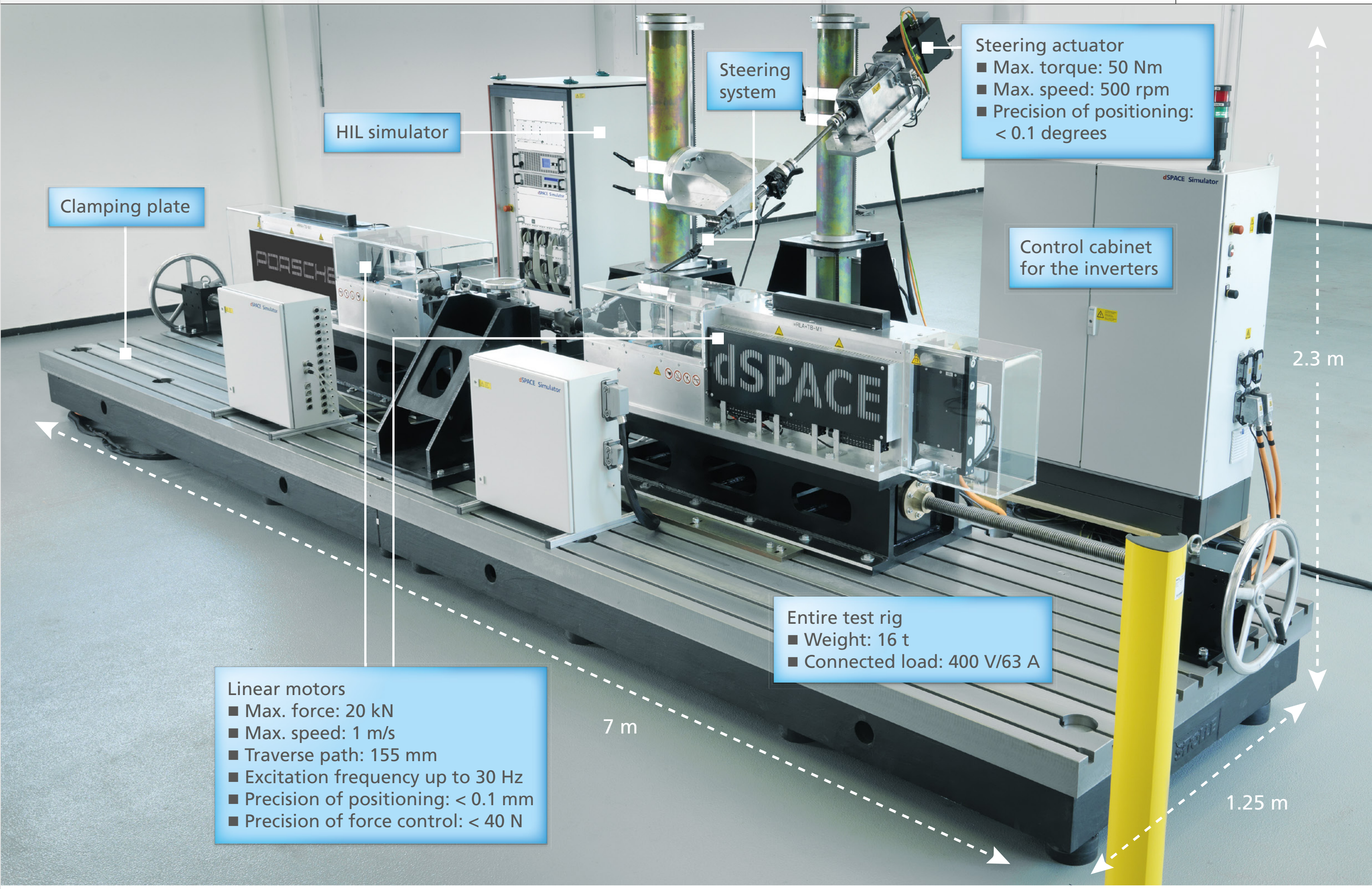


Figure 2: Setup and technical data of the steering system test rig.

and assess the limits of vehicle dynamics without running any risk at all. This also builds up valuable know-how in the company.

Flexible Test Rig Setup

The steering test rig that was developed by dSPACE and Porsche is set up so that it can hold an entire steering system, including the steering column, servomotor, rack, and tie rods (figure 2). It stands out for its variable clamping plate with various scales for positioning the individual components. Moreover, there are interfaces for energy and signal transmission between the steering system and the test rig. All this makes the test rig highly flexible, letting users adapt it perfectly to different steering systems while ensuring extremely short setup times and, thus, efficient operation.

Efficient Electric Drives

The dynamic electric drives, consisting of two linear motors that mechanically stimulate the steering system, are the heart of the test rig. They simulate forces that, in a real vehicle, are transmitted from the wheels to the two tie rods. The steering actuator (electric motor) at the other end of the steering column dynamically sets the steering angle, thus imitating a driver. Controlled drive-inverters supply power to the two linear motors and the steering actuator. The control of the linear motors is designed so they can represent high forces and precise resolutions. The inverters of all the motors are connected by a shared voltage DC link. The DC link is fed energy from the electrical grid via an active feed-in unit. Because the inverters are connected, only the current losses of the test rig have to be covered. The majority of the energy continues to flow in the circuit. This makes the test rig much more energy-efficient than the hydraulic test rigs that Porsche used until now. The external power supply works with only a standard three-phase plug (63 A). Other material, such as coolant and compressed air, are not needed.

Setup and Function of the Simulator

The motor control, test rig monitoring, and measurement data capturing are all performed by a dSPACE HIL simulator. The simulator contains the real-time processor, the required I/O, and the appropriate signal conditioning. The drive inverters are controlled via the LTi Motion TWINsync protocol which ensures that the setpoints are transmitted to the inverters in intervals of 125 µs. This control concept provides high accuracy even for highly dynamic stimuli up to 30 Hz, which corresponds to a fast drive on a cobblestone road. The HIL system also simulates the restbus, which can be based on either CAN or FlexRay,

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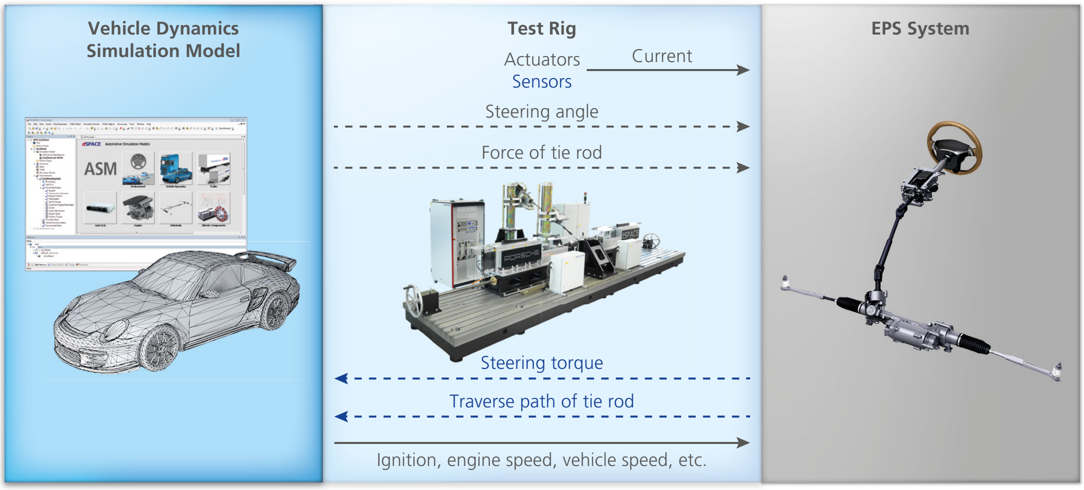

Figure 3: Components, signals, actuators and sensors of the test rig.

depending on the steering type. The tool suite dSPACE Automotive Simulation Models (ASM) is used to simulate the vehicle dynamics of a vehicle in real time. The real steering system can be connected to the ASM Vehicle Dynamics Model for closed-loop operation (figure 3). The graphical user interface of dSPACE ModelDesk is used to parameterize the various Porsche vehicle models. The software also lets developers define roads and maneuvers for the virtual test drives. To immediately visualize the vehicle behavior, the 3-D animation software dSPACE MotionDesk is used (figure 4). The experiment and instrumentation software dSPACE ControlDesk is used to control the test rig. With the test automation software dSPACE AutomationDesk, Porsche can also automate the test sequences for more convenience.

Parts of the EPS Tests

At Porsche, the steering test rig is used to identify mechanical steering parameters and analyze the transmission behavior of the steering system. The tests for parameter identification are used to understand how the supplier of the steering system implemented the mechanical requirements. In addition, repeated measurements with the same part provide information about the wear-and-tear properties of this part. The following parameters are identified during the tests:

- Transmission behavior between the pinion angle and the rack movement
- Transmission behavior between the motor angle and the rack movement
- Stiffnesses of the steering rod (torsion bar and steering column)
- Stiffness of the motor transmission (belt drive and ball screw)
- Friction of steering box and steering column
- Motor look-up table (performance, energy consumption, and efficiency)

By using AutomationDesk, Porsche can conveniently automate measurement sequences. A good example for this is the identification of the friction in the steering box and the steering column and the identification of the motor look-up table, which each require different measurements. For example, to determine the stiffnesses of the steering rod, the steering actuator starts a torque-controlled triangular signal by using automated tests. The stiffness c can be derived from the measured variables 'steering wheel torque' M_L and 'steering wheel angle' δ_L (figure 5, (3)). The analysis of the transmission behavior of an electric power steering system makes it possible to identify the properties of the servomotor. It is used to examine how well the servomotor fulfills the assist requirements for different stimulus frequencies. It is also possible to analyze the feedback behavior of the steering system. The developers influence it mainly via the software of the steering controller and design it to match the Porsche feel. The transmission behavior of forces on the rack to torques on the torsion bar is analyzed for various frequencies. The analyzed transmission criteria are:

- Transmission behavior from motor torque to rack force
- Transmission behavior from rack force to torsion bar torque

Figure 5 (4, 5) shows how a stimulus at the rack translates into a reaction of the torsion bar torque. The 'passive' curves describe the purely mechanical transmission behavior of the steering system without EPS assist. The 'active' curves describe the behavior of the steering system with activated support. The 'active' curves have markedly lower amplitudes than the ‘passive’ curves. This is caused by the assist function of the steering system, which reduces the manual torques the driver has to exert to a comfortable level. The large agreement of curves #1 and #2 illustrates the high reproducibility of the measurements with the steering test rig by dSPACE.

Testing the Overall System Behavior

The test rig provides two methods for analyzing the behavior of the overall system. First, predefined signals, e.g., from a test drive measurement, can be passed to the test rig as test vectors and then started. The advantage of this method is that the test vectors have to be recorded only once and can be reused any number of times. It is therefore not necessary to perform the driving maneuver again with the real vehicle to analyze different software states. Second, the ASM Vehicle Dynamics Model can be used to analyze the behavior of the steering system in the context of the overall system, the vehicle. For this, the ASM Vehicle Dynamics Model has to be parameterized with the data of the Porsche vehicle to be tested. In addition, ModelDesk can be used to define various driving situations. The developers can modify several variables, such as the topology of the track and the friction properties of the road surface. Both the use of test vectors and the simulations with ASM Vehicle Dynamics can support the system analysis of the test drive in the real vehicle. One main reason why the tests are so reproducible and precise is that they are independent of driver and environmental factors (figure 6).

Project Progress and Coordination

During the entire project, from the first talks in the quotation phase to the commissioning and final check,

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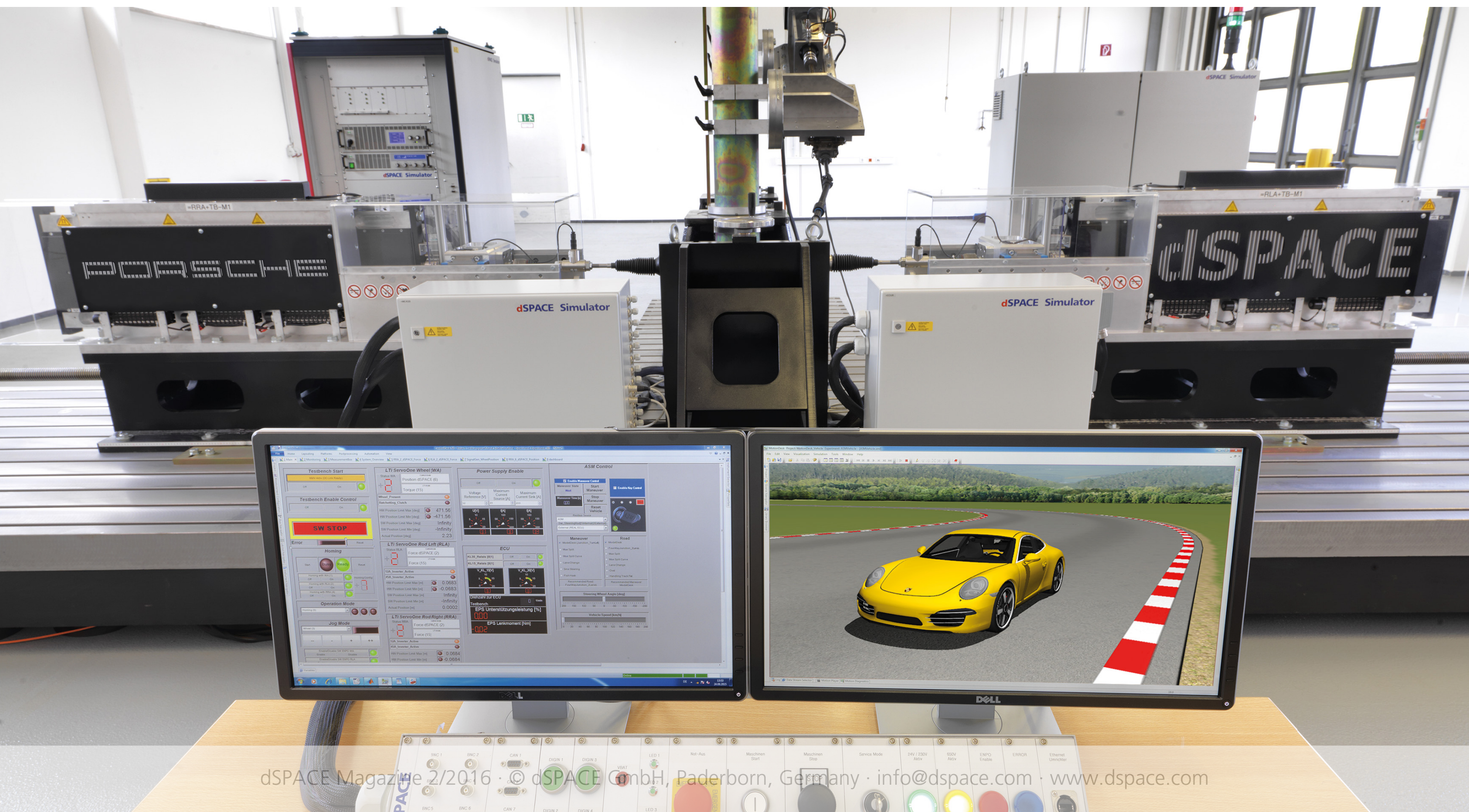
> “Because it is highly dynamic, the mechatronic test rig from dSPACE is an important development tool for us that perfectly integrates into the highly demanding Porsche steering system development.”
>
> *Anton Uselmann, Porsche AG*

Figure 4: The mechatronic test rig, including the operator workstation with ControlDesk for controlling the tests (left) and MotionDesk for visualizing the driving maneuvers (right).



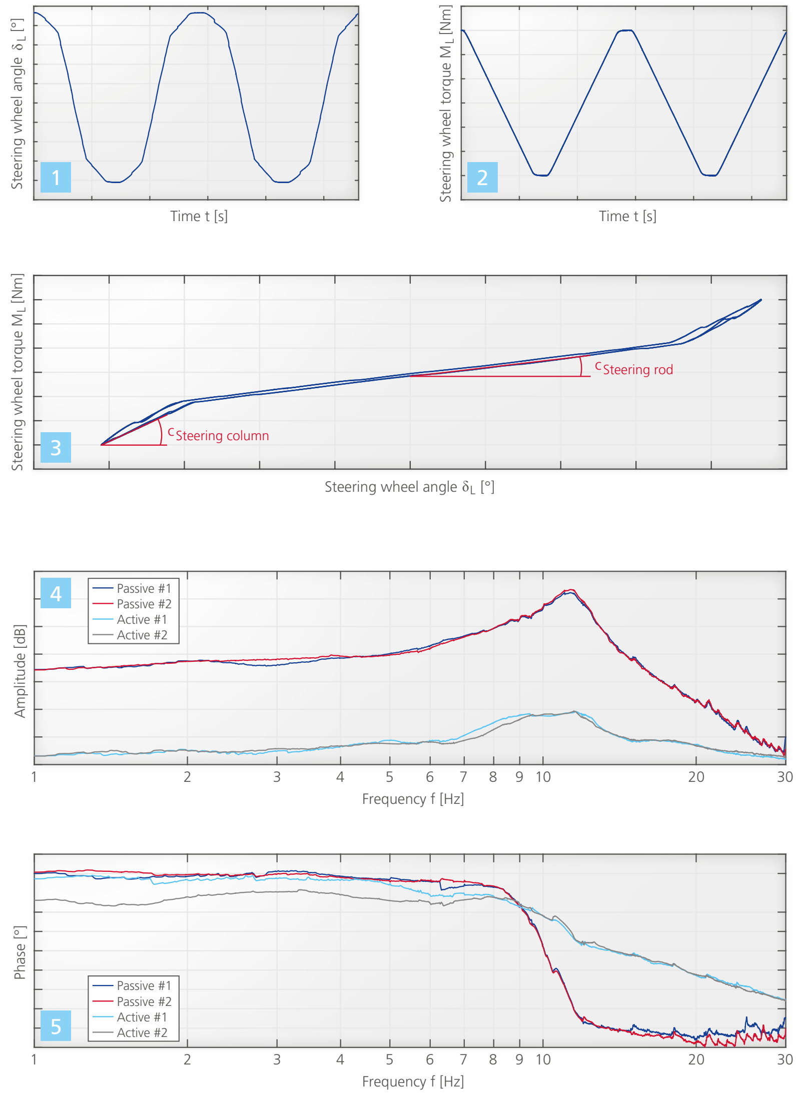
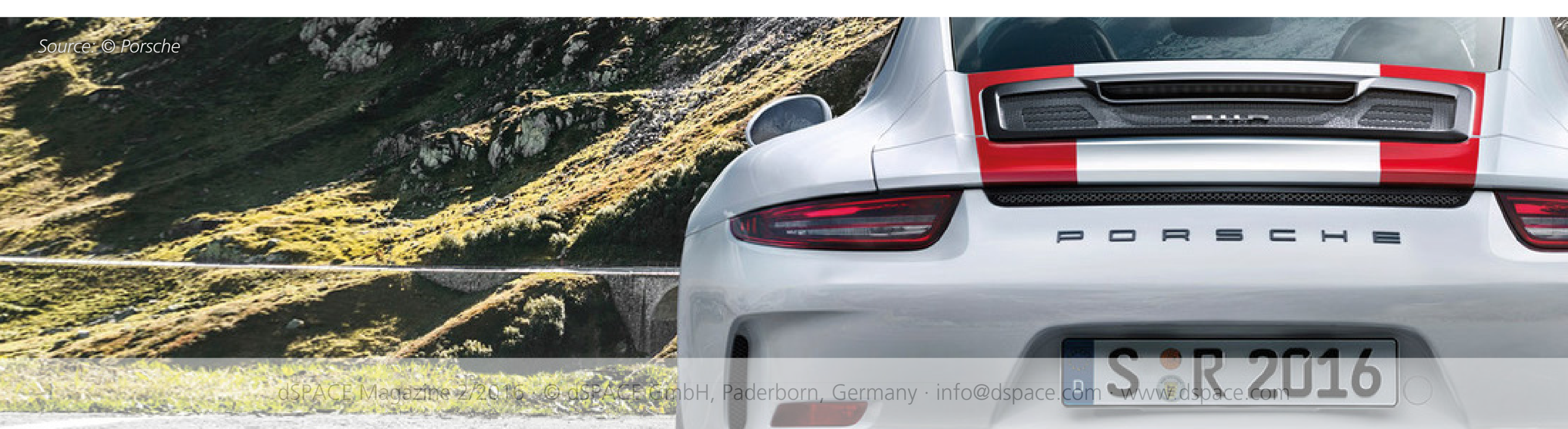


Figure 5: Various measurement values recorded during the steering wheel tests.
1, 2: Stimulation of the steering rod with steering wheel angle δ_L and steering wheel torque M_L over time t.
3: The stiffnesses of the steering rod can be derived from the gradient of the steering wheel torque M_L over the steering wheel angle δ_L.
4, 5: Transmission behavior of the steering system with purely mechanic transmission (passive) and activated assist unit (active). The curves #1 and #2 illustrate the high reproducibility of the measurements with the dSPACE test rig.

the Porsche and dSPACE employees involved in the project cooperated closely. The first project phase was about creating a test rig setup according to Porsche's requirements. It was created on the basis of a 3-D model of the mechanical setup that was revised in several steps. For example, measures concerning the construction ensured that the natural frequencies of the test rig are compatible with all the planned use scenarios, i.e., they do not lie in the frequency range of the excitation. The rotor of the linear motors also had to be optimized for the required high dynamics. Regular conference calls and on-site meetings, both at dSPACE in Paderborn and at the Porsche development center in Weissach, were an integral part of the project, making the project status transparent at all times. The test rig was delivered and commissioned on schedule. Because the entire test rig comes from a single source and was delivered turn-key, there was no coordination overhead or communication problems with third parties.

Conclusion and Outlook

The steering test rig gives Porsche greater flexibility and lets them reproduce tests with high precision, making the development and validation of the steering systems more efficient. Even after project completion, the two companies have remained in close contact. For example, dSPACE is currently working on further optimizing the control algorithms for steering test rigs. In the next phase, the two companies will integrate a



Source: © Porsche

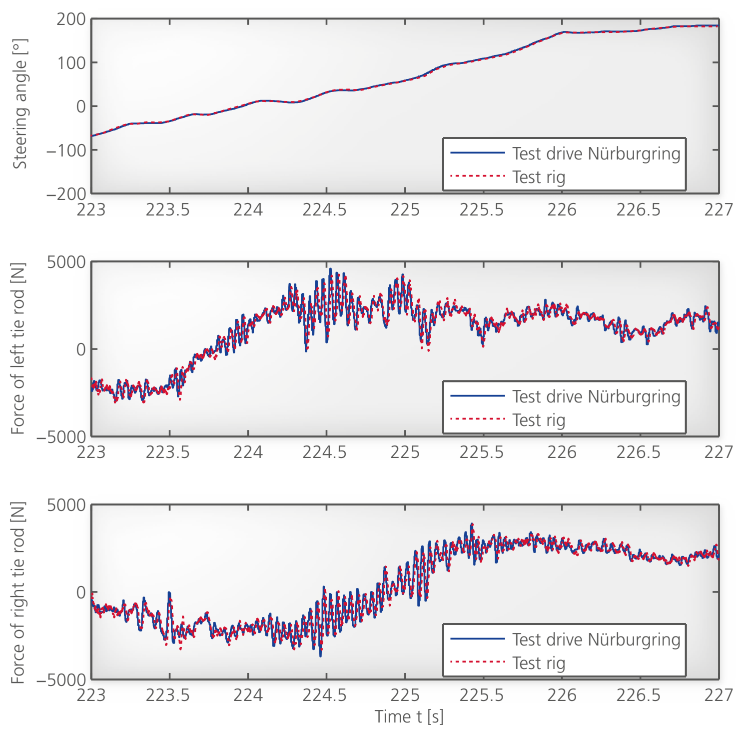


Figure 6: Measurement data recorded during a real test drive on the Nürburgring race track for the steering angle and the corresponding tie rod forces (blue), and for the values measured at the steering test rig (red).

> "We are using the real-time simulation model ASM Vehicle Dynamics to analyze the behavior of a real steering system in a virtual vehicle."
>
> *Benedikt Schrage, Porsche AG*

rear-axle steering system in the test rig. Including a steer-by-wire architecture could be another project. In addition, Porsche is planning on integrating a temperature chamber for the unit under test. The necessary interfaces are already included on the HIL simulator. ■

Anton Uselmann, Eric Preising, Benedikt Schrage, Dario Düsterloh, Porsche AG

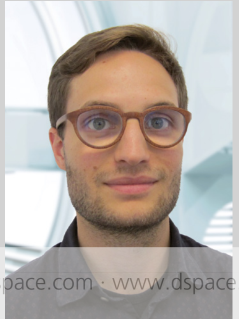
Watch the video to learn more about how the test rig works: www.dspace.com/go/dMag_20162_mHIL_E

Anton Uselmann
Anton Uselmann is responsible for the function development of steering systems at Porsche AG in Weissach, Germany.

Eric Preising
Eric Preising is an expert for chassis test benches in the test bay at Porsche AG in Weissach, Germany.

Benedikt Schrage
Benedikt Schrage is a test engineer for chassis test benches and is responsible for the steering test rig at Porsche AG in Weissach, Germany.

Dario Düsterloh
Dario Düsterloh is a PhD candidate at Porsche AG in Weissach, Germany researching function optimization and complexity management in the development process for steering systems.



Chain-Free Cycling

Serial hybrid drive for bicycles

Until now, almost all pedelecs (pedal electric cycles) have been equipped with parallel hybrid drives with a mechanical connection between the pedal and the drive wheel. Serial hybrid drives leave this high-maintenance coupling out, but give cyclists a very unnatural feel during the ride. The serial hybrid EE-SpeedBike by IAI GmbH overcomes this disadvantage. Thanks to the smart control strategy, developed with dSPACE tools, it delivers a highly authentic ride.

The market for pedelecs in Germany and Europe is booming, with an annual growth rate of almost 10%. Today's mid-priced pedelecs not only have a chain drive or a belt drive. They are also equipped either with a mid-drive motor near the pedals or with a rear hub motor. These drive concepts are commonly known as parallel hybrid drives.

Serial Hybrid Drives

For over 40 years already, engineers have been working on serial hybrid drives for bicycles. The original idea goes back to Augustus Kinzel, an American who was granted the first patent for this concept in 1975. Back then, the concept assumed that the pedals are connected directly to a generator. The pedaling power of the cyclist generated electric power which flowed through a cable to the front wheel motor. The design worked without the customary mechanic coupling between the pedals and the rear wheel. Many different bicycle models with serial hybrid drives were introduced in the years after that, but for various reasons, such as the unnatural feeling during the ride and the lack of counter torque at the pedals, to name a few, they did not reach market maturity.

The Road to the Future

The initial motivation for the first studies on serial hybrid drives at the Institut für Automatisierung und Informatik GmbH (Institute for Automation and Computer Science, IAI) came from discussions with a bicycle manufacturer. During this discussion, the wear and maintenance of parallel hybrid drive pedelecs, especially regarding the chain and derailleur, were seen as disadvantageous faults. These studies mainly consisted of analyzing the performance of various conventional bicycles. The development objective was to design a serial hybrid drive bicycle as an evaluation model that provides at least as much performance as a pedelec with a parallel hybrid drive and keeps the same pedal feel of a conventional bicycle. As part of one of the projects funded by the Federation of Industrial Research Associations (AiF), synchronous drives were developed on the basis of the driving performance analysis by using the associated measurement and control technology and power electronics that were first tested on a converted commercial bicycle. The torques demanded from the motor and generator are substantially different than for auxiliary drives available on the market. In serial hybrid drives, the drive motor must be able to translate all the drive power that the bicycle needs. In contrast, the generator must be able to produce adequate counter torque against the chain drive to give the cyclist haptic feedback that fits the particular ride. The first generation of drives did not fulfill these requirements completely, because the conflict of objectives between the required torque and the small size could only be solved with an optimized transmission. Nevertheless, this first model did prove that it is possible to emulate the chain drive with special control algorithms via software simulation.

The X-PESA Concept

Following the functional evidence, the drives were made smaller by integrating planetary gears, the torque was increased, and the concept was installed in a customized frame. A further functional model, the X-PESA, designed as a 25 km/h pedelec, measured up to the performance of parallel hybrid drive pedelecs that are currently available on the market. During an early development stage, though, it was clear that the generator was too large and too heavy to achieve the desired torques with a one-stage planetary gear.

The Next Generation

Funding from the State of Saxony-Anhalt as part of the state initiative ELISA (Electric Mobility and Lightweight Engineering) made it possible to resume re-engineering the drives. The gene-

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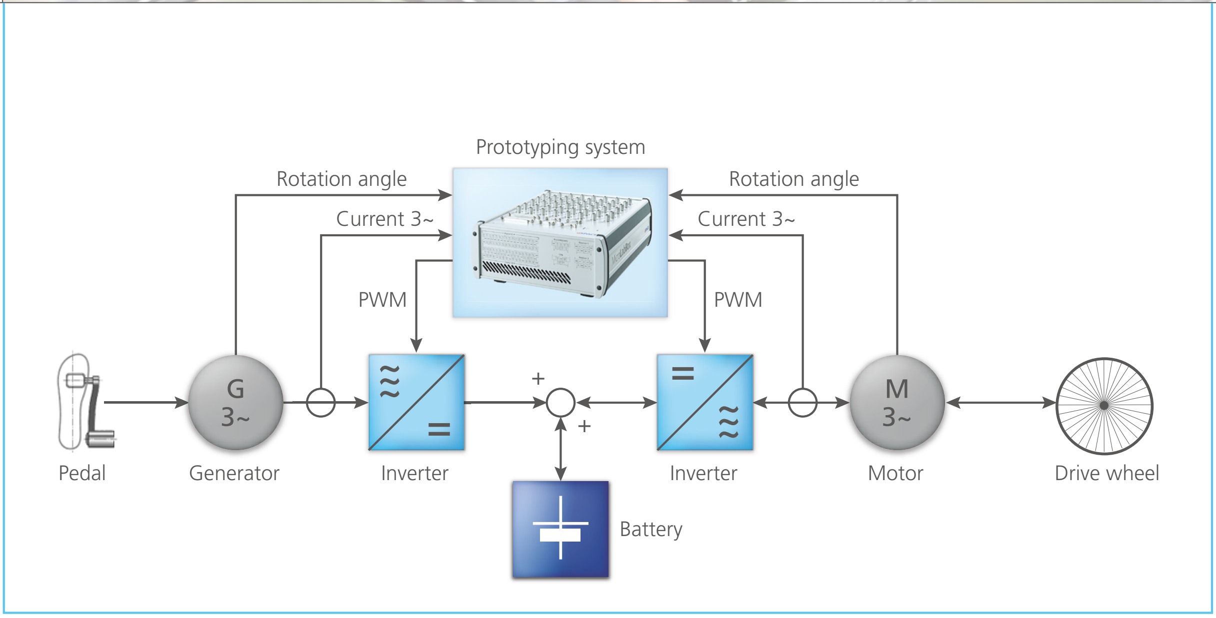

Figure 1: Power flow of a serial hybrid drive with the dSPACE MicroLabBox as a prototyping system.

rator, now equipped with a two-stage planetary gear, delivers a maximum torque of 180 Nm at a total weight of 2.9 kg, so a cyclist weighing 100 kg feels enough counter torque, even during more aggressive rides. The drive motor, using the installation space of the rear sprocket, reaches a peak torque of 120 Nm and temporarily generates 2 kW of power. With this performance, the motor is designed for use in the S-Pedelec category up to 45 km/h and can also be used by all types of bikes (city bikes, mountain bikes, cargo bikes, rickshaws, etc.) under a speed limit of 25 km/h. The motor and generator are completely maintenance-free. Despite the double energy conversion, the efficiency and costs of this drive system are, in principle, comparable to that of parallel hybrid drives, since the mechanical coupling between the pedal and rear wheel and the mechanical circuit are removed. In terms of its functionality, the serial hybrid drive is unique worldwide.

Convenient Control via Smartphone

The heart of the drivetrain is a 16-bit microcontroller that controls the motor and generator in real time, performs the monitoring tasks, and handles communication with the control display and the smartphone connected by Bluetooth. The smartphone displays all the ride parameters, such as the speed, battery level, and performance, with a specially developed app. In addition, the smartphone also sets the various operating modes. In manual switching mode, a control display operates the virtual 20-speed gearing, which represents a conventional derailleur. As an alternative option, the serial hybrid drive has a continuous automatic derailleur that lets cyclists set the desired stride rate via the control display. The variable setting of the battery support allows for adjustments of the cyclist`s electric "tailwind". With medium support, the battery pack gives the EE-SpeedBike a range of 80 km, which can be extended to any distance. If the cyclist generates more pedal power during the trip than the drivetrain requires, the excess power charges the battery. At a speed of 45 km/h, when a greater part of the drive power is provided by the battery pack, the range is still 45 km. As an alternative to reloading the battery via a power socket, the exercise bike mode allows charging the bicycle´s 850 Wh battery while it is standing still. During rear wheel braking, the motor is operated in a continuously controllable recuperation mode and transforms the kinetic energy back into electrical energy, which is fed into the battery before and while the mechanical brake engages.

Figure 2: The user interface of the smartphone, connected via Bluetooth.

Initial Commissioning

The commissioning and evaluation of the drive components was done with

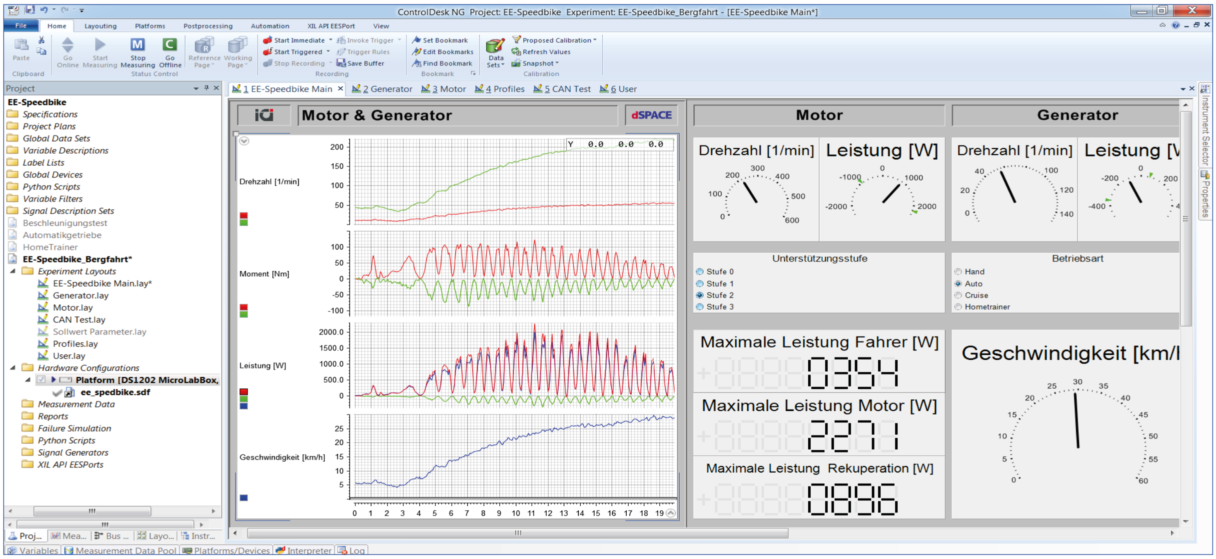

Figure 3: Torques, rotational speeds, and different levels of power from the motor and generator during a simulated mountain ride on a test bench.

> "The comprehensive I/O functionalities of dSPACE MicroLabBox gave us maximum flexibility for testing our new drive concept on the test bench."

Steffen Braune, Institut für Automatisierung und Informatik GmbH (IAI)

the help of a DS1103 PPC Controller Board. The performance of the prototyping system allowed real-time testing of even CPU-intensive control algorithms developed in MATLAB®/Simulink®, initially without considering runtime optimizations. The extensive peripheral functions of the DS1103 made it possible to perform fully comprehensive trial runs on a test bench for the motor or generator.

From the DS1103 to MicroLabBox

Recently, IAI has started using a MicroLabBox on the test bench. With higher computing power than the DS1103 and the extended peripherals, in particular multi-channel PWM signal generation, MicroLabBox made it possible to test the motor and generator simultaneously on the test bench. This enabled the researchers to reach a better understanding of how the two drives interact, and thus to continue improving both the ride feeling related to the generator and the motor's torque generation. The RTI USB Flight Recorder Blockset lets IAI record all relevant process data with a high sampling rate over a longer period and makes performing an analysis much easier. The extended features of ControlDesk 5.5, such as the new Variable Browser and the ability to save individual plotters as new measurements, enable the quick and efficient implementation and evaluation of test series.

Conclusion and Outlook

Together, the EE-SpeedBike and its predecessor X-PESA have put several thousand test kilometers on the road and on the test bench without any notable problems. In December 2015, the drive concept was honored with third place in the Hugo Junkers Award for Research and Development of the state of Saxony-Anhalt in the category "Most Innovative Projects in Applied Research". The next development step is to industrialize the current model in order to manufacture high numbers of bicycles through production technology. ■

Steffen Braune and Knut Hahne, Institut für Automatisierung und Informatik GmbH (IAI)

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Developing advanced exercise machines

Smart Training

Researchers from Cleveland State University are developing new kinds of exercise machines for athletic conditioning, rehabilitation and exercise in space. dSPACE MicroLabBox is used to collect measurement data and operate the machine prototypes, which are capable of adapting to their users.

The use of exercise machines can be traced at least to Industrial Revolution times. Since then, these machines have evolved in their sophistication to include electronic displays providing key indicators such as levels of resistance, speed, and heart rate (figure 1). They are designed to emphasize strength (e.g., weight-lifting machines) or aerobic exercise (e.g., gym rowers and treadmills). While the amount of weight can be selected in a lifting machine, and resistance can be adjusted in a gym rower, the kind of opposition to motion (the mechanical impedance) is always the same.

The Aim: Individualized Mechanical Impedances

The motivation for this research project is that fixed impedances are not the best option for an efficient training. Rehabilitation machines should not merely resist motion, but also assist it. Moreover, therapists and doctors should be able to program machines to customize the balance between assistance and resistance within a single motion cycle, within a single session, or as part of a longer-term rehabilitation program. For astronauts in space, weight lifting must be emulated by powered means and any equipment flown into space is subject to severe mass and volume constraints. All these requirements indicate that the same hardware should be used for resistance and aerobic exercise. The research team has collaborated with the NASA Glenn Research Center and its Exercise Countermeasures Program to design >>

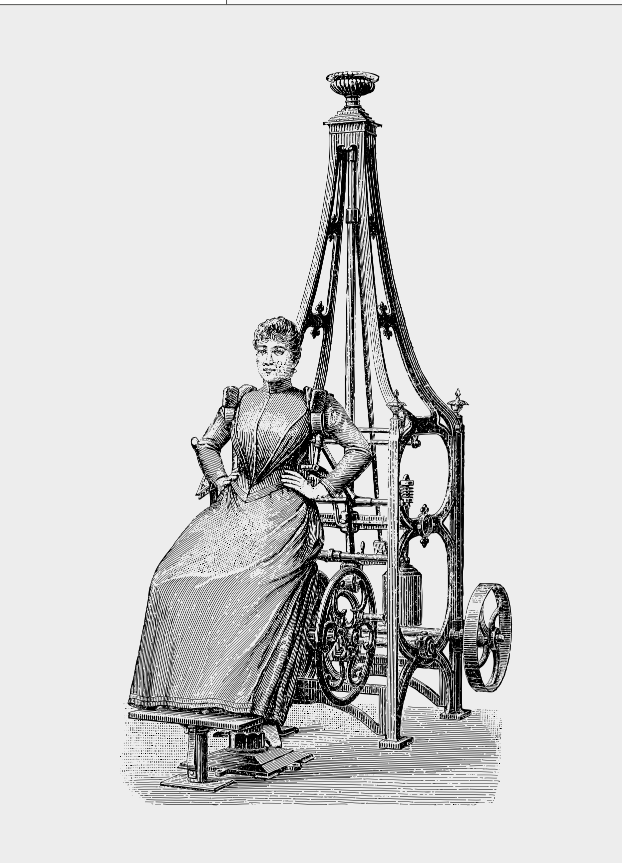


Figure 1: Exercise machines have evolved in their appeal and user interactivity, but their mechanical function remains essentially the same in many cases.

machines meeting these stringent specifications. The team also leveraged their expertise in energy regeneration control to demonstrate a scaled version of a rowing machine, which offered programmable impedances and was entirely powered by the subject performing the exercise. The self-sufficient power feature offers an additional advantage over other solutions, as the machine does not draw power from the space vehicle's grid, and may even be able to return some energy.

Characteristics of Advanced Exercise Machines

The above-mentioned application scenarios require characteristics for advanced exercise machines, where motors and control systems are used to generate continuously adjustable mechanical impedances:

- Use of a combination of direct sensing and model-based estimation to generate detailed real-time information about current human performance
- Use of current performance indications to modify its own mechanical characteristics to maximize a preselected, programmable objective
- Generation of optimal real-time cues for excercisers to modify their mechanical outputs
- Monitoring, managing and resolving conflicts between man and machine objectives with an overriding safety criterion (figure 2)

The Challenges

The new machines will vary their impedance over single motion cycles and over extended periods of time. The effects of such variations on the body – specifically on targeted measures of muscular strength – must be well understood. This understanding will come through modeling, which is the ultimate basis for determining the impedance variations that are beneficial. In an implementation, optimal impedance adjustments will be made based on information about the current status of the exerciser and the machine. A control system must make these changes effective on the machine by appropriately commanding its motors.


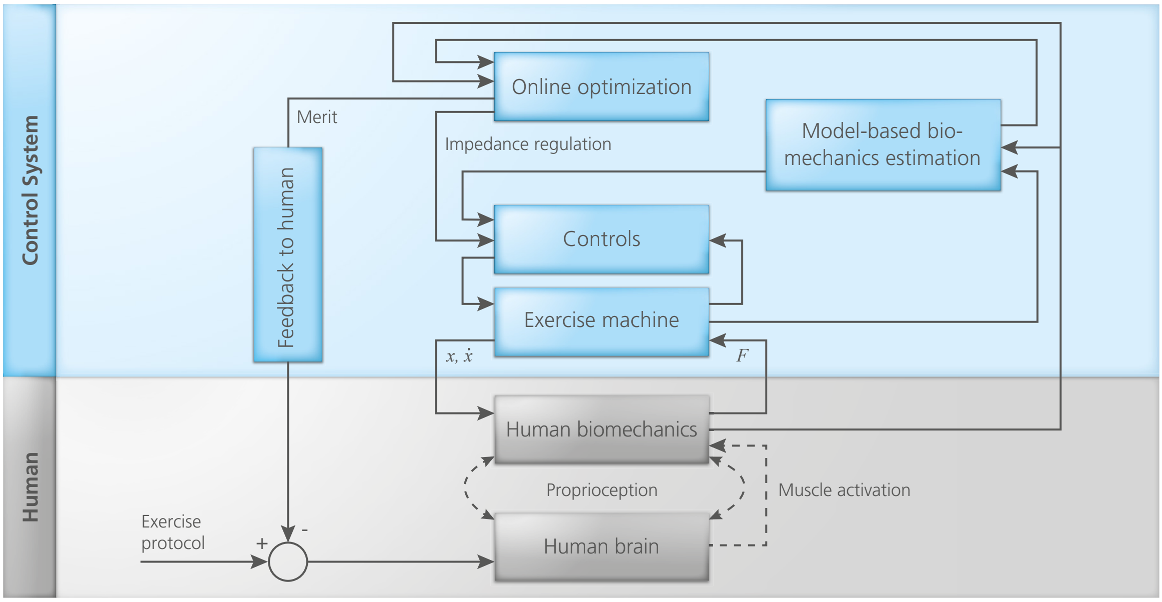

Figure 2: Functional block diagram for the advanced exercise machine concept. The system generates cues to modify human behavior during exercise. These changes, together with machine impedance variations, are generated by the system to achieve optimum performance.

Optimal Exercise

Exercise can be optimized for specific goals. For losing weight, the exercise should distribute the load optimally among as many muscles as possible so the endurance is maximized. In rehabilitation or bodybuilding, the goal might be to strengthen one muscle group. For muscles that cross more than one joint, such as the hamstrings, it is not immediately obvious how such exercise should be designed. Because individuals respond differently to a training stimulus, it is important to create custom exercise programs to fit individual needs. With controlled exercise systems, athletes can optimize their training performance while eliminating injuries by allowing only the loads suited to their specific physiology. Older individuals and rehabilitation patients could exercise safely to address musculoskeletal problems.

Biomechanical Modeling

In an advanced exercise machine, motion and force are continuously monitored by the control system. This data is used to estimate motions and forces in the muscles. This allows assessment of exercise and real-time feedback to the user about the training. In order to perform this assessment, a detailed mathematical model of musculoskeletal dynamics is required, combined with state estimation techniques that are robust enough to produce reliable results even when the data is noisy and incomplete and the model is not perfect. Models will be validated using motion capture and electromyography (EMG) recordings.

State Estimation

To control a system to achieve desired goals, the controller needs to first estimate some of the unobserved quantities of the system. These can include system parameters, unmeasured inputs, and the internal system status or state. With an exercise machine, these quantities could include the force applied by the user, friction parameters, muscle activation signals, and many others. For estimating unknown system quantities, the team is planning to rely on Kalman filtering in their

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> "With dSPACE MicroLabBox, it was easy to collect initial data and operate machine prototypes in real time. This made it possible to focus on the control algorithms themselves rather than the details of their implementation."

Hanz Richter, Cleveland State University

Figure 3: During a trial, dSPACE MicroLabBox (left picture) collects 16-channel electromyography (EMG) data and machine mechanical data at a sampling rate of 1 kHz. A separate system collects motion data using visual markers (shiny spots) and metabolic data. Data from all systems is synchronized by offline postprocessing.

exercise machine development, along with more advanced estimators such as unscented Kalman filtering and H-infinity filtering.

Optimization

To provide the greatest benefit to the user, several components of the exercise machine need to be optimized, including the machine design itself, the estimator, the control algorithm, and even the control objectives. Beside the fact that many system components will be unknown or unmeasurable, some of the system components may even change over time because of aging or because of changes in the external environment. The human model will certainly change over time, as different subjects use the machine. For optimization, the team will rely on fast evolutionary algorithms, which include a set of solutions to an optimization problem. As the potential solutions are tested and evaluated in real time, they exchange information with each other in carefully planned ways to maximize performance.

Real-Time Control via MicroLabBox

Model-based control algorithms must be specified that can effect optimal impedance variations, while guaranteeing safety for the exerciser. The team is relying on theories including passivity and extremum seeking control as part of their development framework. Real-time implementation requires a high-performance data acquisition and control system capable of handling multi-channel analog data at fast rates, while offering a high-level user interface. The team selected dSPACE MicroLabBox to collect initial data and ultimately operate machine prototypes in real time (figure 3). The experiment software ControlDesk allows preparing data collection and real-time control experiments quickly and efficiently, since existing MATLAB®/Simulink® simulation models can be converted easily into real-time interfaces. This allows researchers to focus on the control algorithms themselves rather than the details of their implementation.

First Trials on a Rowing Machine

The first phase of the project has focused on the rowing exercise. The objective was to gain extended insight about this exercise by using a conventional machine. This involves collecting machine-specific and human-specific data on the rowing exercise beyond what is currently available in the research literature. Machine-specific variables include the force on the pull chain and the velocities of the rotating components inside the machine, namely the chain sprocket and the flywheel (figure 4). Human-specific data is more extensive and can be divided into three groups: motion, muscle activation, and metabolic data. Data collection trials were performed in Prof. van den Bogert's Human Mo-

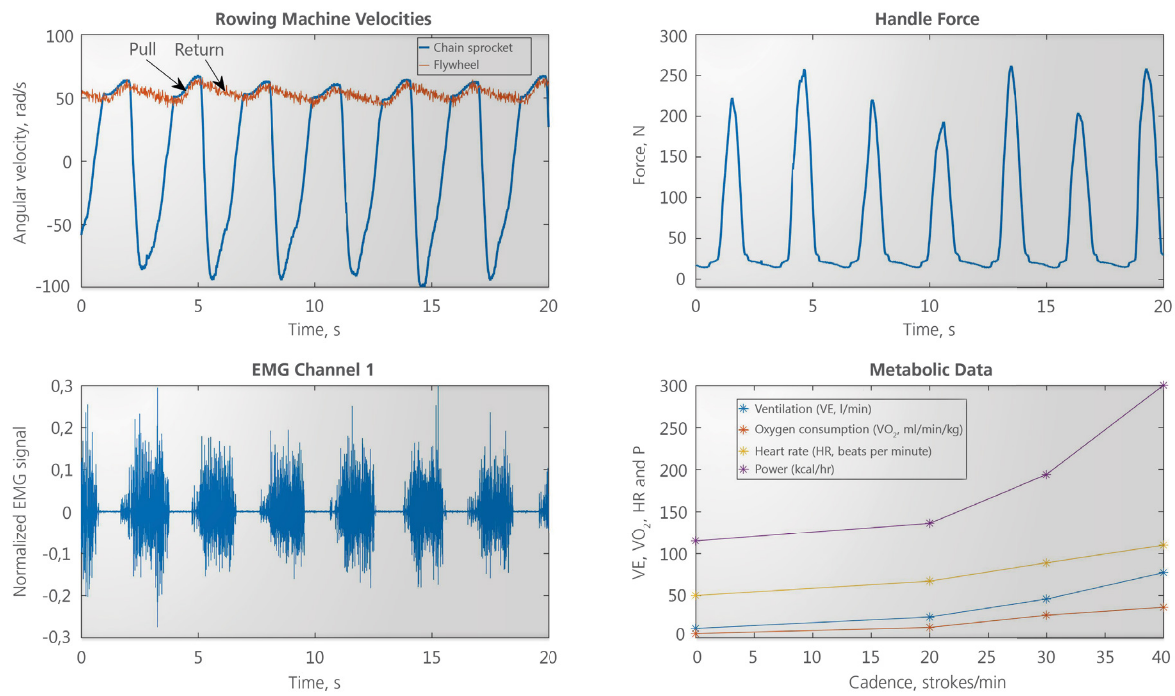


Figure 4: Sample data set (marker data not shown). The chain sprocket and flywheel have the same velocities during the pull and become decoupled in the return. Metabolic data is plotted for trials at various cadences (strokes/min) and rest.

tion and Control Lab. The lab is equipped with a 10-camera motion capture system (Motion Analysis Corp.) with Cortex software. A 16-channel wireless EMG/accelerometer system (Delsys) is used to collect muscle activation data. Software tools for musculoskeletal modeling and simulation include OpenSim, Autolev, MATLAB, IPOPT, SNOPT, GPOPS, and in-house code (MATLAB and C++) for predictive simulation via direct transcription of musculoskeletal dynamics and optimization criteria. Data arising from these trials will be used to build and validate biomechanical models and to design the motorized machines. ■

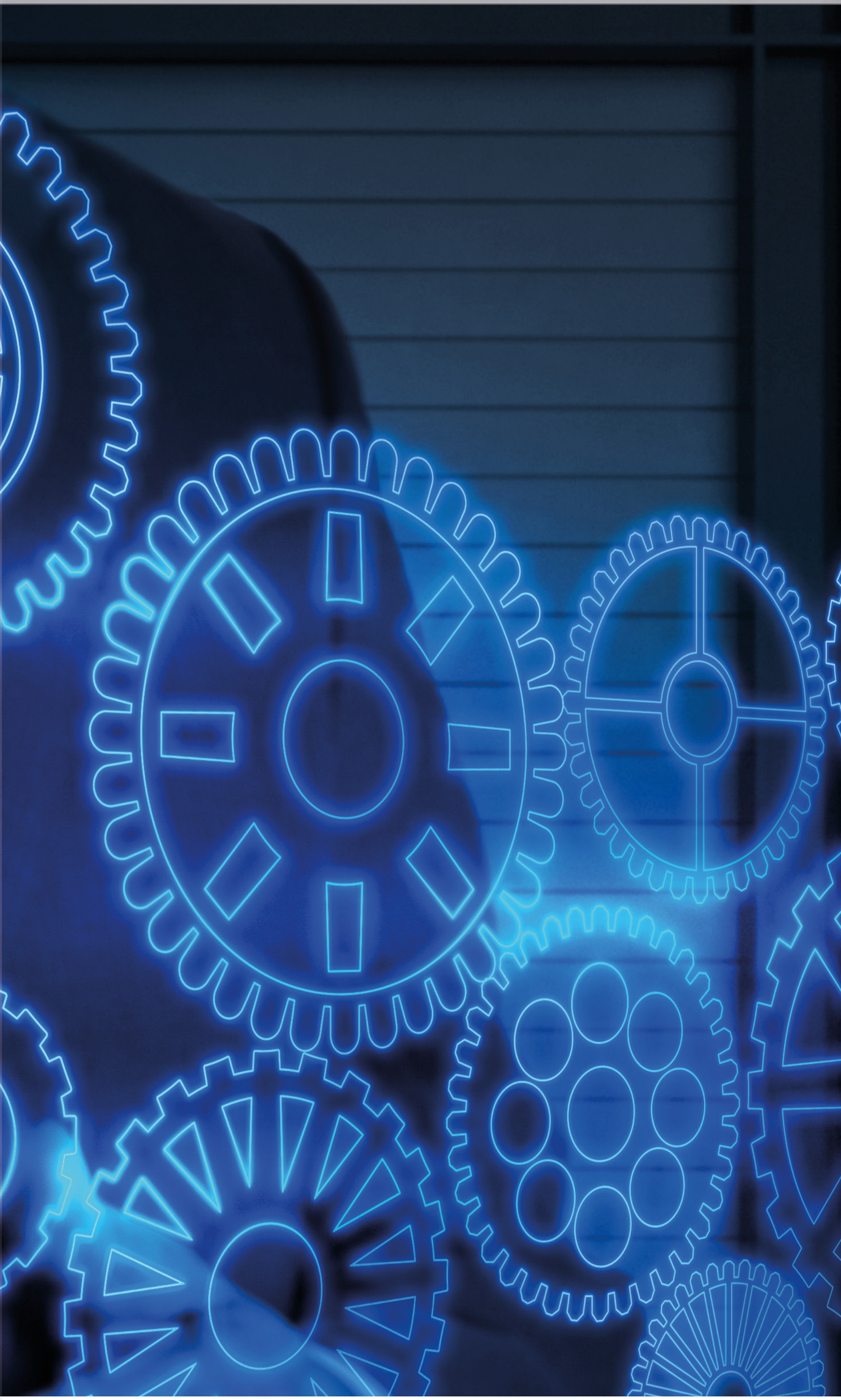
Hanz Richter, Cleveland State University

Figure 5: The research team (from left): Hanz Richter, PhD (Associate Professor, Mechanical Engineering), Antonie van den Bogert, PhD (Professor, Mechanical Engineering), Kenneth Sparks, PhD (Professor, Human Performance) and Dan Simon, PhD (Professor, Electrical Engineering and Computer Science, University's Associate Vice President for Research).

Efficient software development process for transmission ECUs

Handling High Numbers of Variants

The high number of variants is one of the many challenges that have to be tackled during the development of electronic control unit (ECU) software. That is why automotive suppliers such as ZF Friedrichshafen AG use methods that involve tool support for crucial development steps. One such tool is dSPACE's production code generator, TargetLink.



The continuous pressure for innovation in the automotive industry constantly requires new functionalities, which have to be brought to the market at ever shorter intervals. The wide range of versions and variants of current vehicle generations is therefore increasing. This trend does not stop at transmission development, where the tried-and-tested automatic transmissions with a torque converter provide a growing number of gears and cover a wide range of applications up to hybrid drives. This variety of versions and the new transmission functions create new challenges for software development. The many functions of hybrid controls, which are often networked and sometimes safety-relevant, have to be integrated in existing software environments and implemented on ECUs with limited resources in terms of memory and computing power. Handling the transmission variants and complying with ISO 26262 and other safety-relevant standards places important requirements on development methods and the development process. In addition, solutions to new functional requirements have to be included in series production fast and efficiently. Here, quality is a decisive factor.

Development Methods and the Development Process

To meet all of the requirements and make software available as soon as possible, the software development for embedded systems often uses model-based development methods. This especially holds true for the automotive industry. Here, the development method influences the entire development process, from requirements definition to software release. To fully benefit from the advantages of model-based development, there has to be an overall development concept that uses this method in all phases. There are three main goals that can be reached with model-based development: Improvements in quality, short development times, and comprehensive automation. Safety-relevant functions should also be programmed on the basis of models. This entails strict requirements for tools and processes, because they have to comply with many stringent standards and achieve a very low error rate. Efficiency is increased by model reuse, a joint tool chain, and purposeful variant management. The goal is to front-load more tasks to detect errors early on and thus shorten development times.

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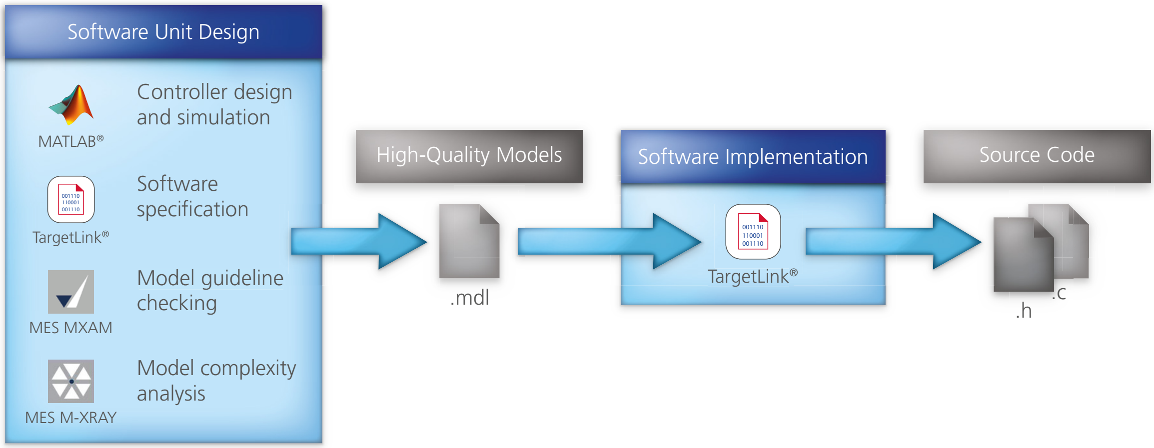


Tool chain and workflow for model-based development.

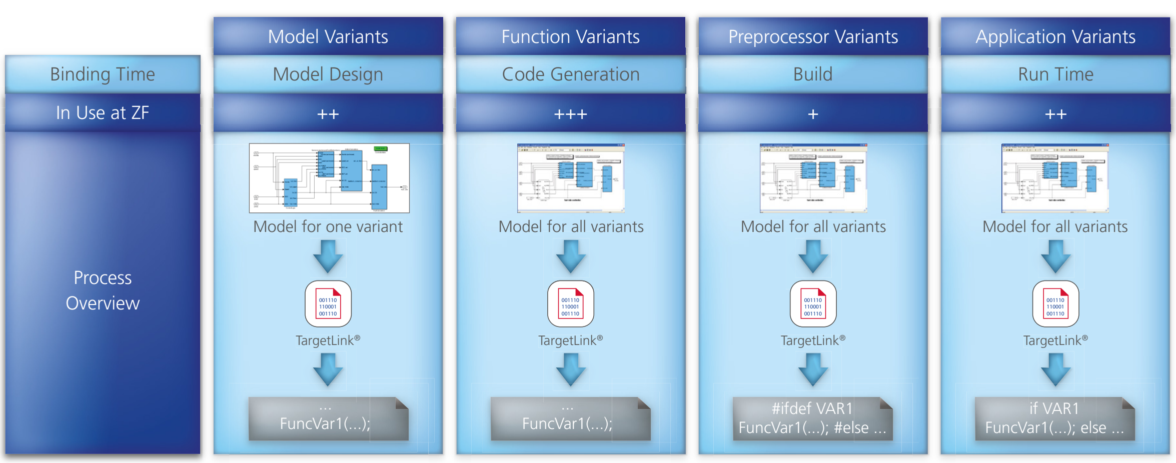
The Tool Chain

The most important tools for model-based software development are the modeling platform and the production code generator. ZF uses MATLAB®/Simulink® by MathWorks® as the modeling platform in almost all of their projects. dSPACE TargetLink® is used as the code generator. The module tests are executed with the TargetLink-integrated simulation concept and the MTest tool from Model Engineering Solutions GmbH (MES). The tools MXAM and MXRAY, also from MES, are used to perform automatic checks of compliance with modeling guidelines and to analyze the model complexity. Together, they ensure the high quality of a model. Other tools support the process during model analysis and testing as well as in the configuration and variant management. The tool chain is used throughout the company, and production code generated by TargetLink has been used in many products since the tool's introduction in 2008.

Developing Safety-Relevant Functions

Typically, QM functions (validation with traditional tools) are not the only ones to be created on the basis of models. The same applies to safety-relevant functions. One major advantage is that the production code generator TargetLink was certified according to ISO 26262 by TÜV SÜD (German international certification authority) and is therefore approved for the development of safety-relevant systems up to ASIL-D. In practice, this means that no tedious code reviews are needed, for example. Furthermore, dSPACE provides a reference workflow for the model-based software development of safety-relevant systems that ZF integrated into their

The various ways of variant handling.



standard process. To establish project-independent as well as project-specific methods, ZF use their own modeling guidelines, which are based on the prevalent standards. This ensures that the methods and recommendations of ISO 26262 are already considered in the modeling phase.

Various Ways to Handle Variants

To be able to use as many carry-over parts as possible for several variants, ZF uses various kinds of variant handling. The capabilities of the code generator, TargetLink, are very similar to those of traditional programming. However, in model-based development, these are extended by additional methods. One way to handle variants is using model variants that code is generated for selectively. The basis is always formed by an overall model that consists of multiple submodules. Most of the modules are the same for the different variants. This means, each module exists only once. However, some modules are variant-dependent. In this case, there is one module for each variant. When the overall model is built, the relevant modules are used according to the selected variant. This type of variant handling is used when the overall model is set up. Once the overall model is complete, it is no longer possible to use a different variant. Other ways to handle variants include using function variant switches and preprocessor switches. When function variant switches are used, TargetLink generates variant-dependent code parts. Software parts that are irrelevant for the selected variant are not generated. Preprocessor switches, on the other hand, work as you would expect from traditional software development. The production code generated by TargetLink contains all variants, and the variant-dependent evaluation is executed when the code is being compiled. TargetLink can also handle data variants that are controlled dynamically by the software application.

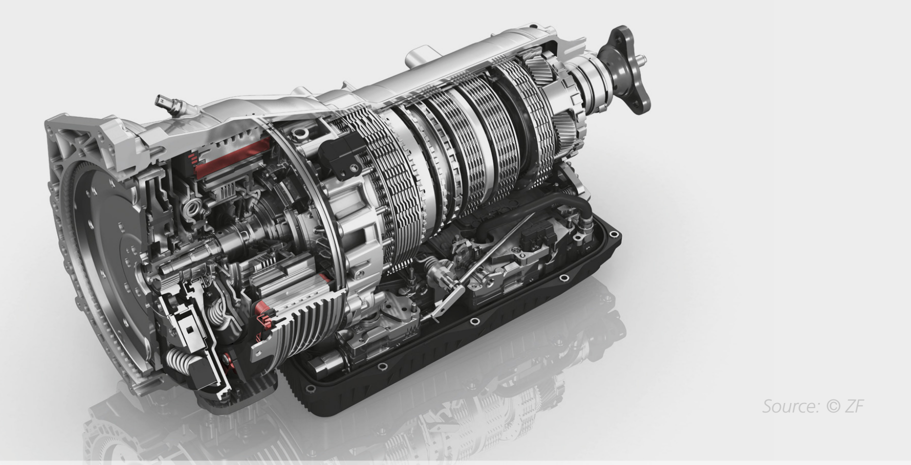
SYNECT is data management and collaboration software with a special focus on model-based development. SYNECT helps engineers handle models, signals and parameters, their dependencies, versions and variants, and the underlying requirements.

Outlook: Using Feature Management

To manage the growing complexity of diverse customer and function variants even better, many companies are thinking about using feature management systems in the future. They take various feature models to generate sets of parameter settings and use them in the TargetLink model or code. This requires a multistage approach that uses feature models for both the entire project and individual components. Because this approach is expected to be very complex and requires high traceability, many development departments are researching the possibility to integrate data management systems, such as dSPACE SYNECT®, into their tool chains and processes by coupling it to requirements management.

With the kind permission of the ZF Friedrichshafen AG.

The 8-gear plug-in hybrid drive is one variant of the 8 HP series from ZF for which production code is generated with TargetLink.



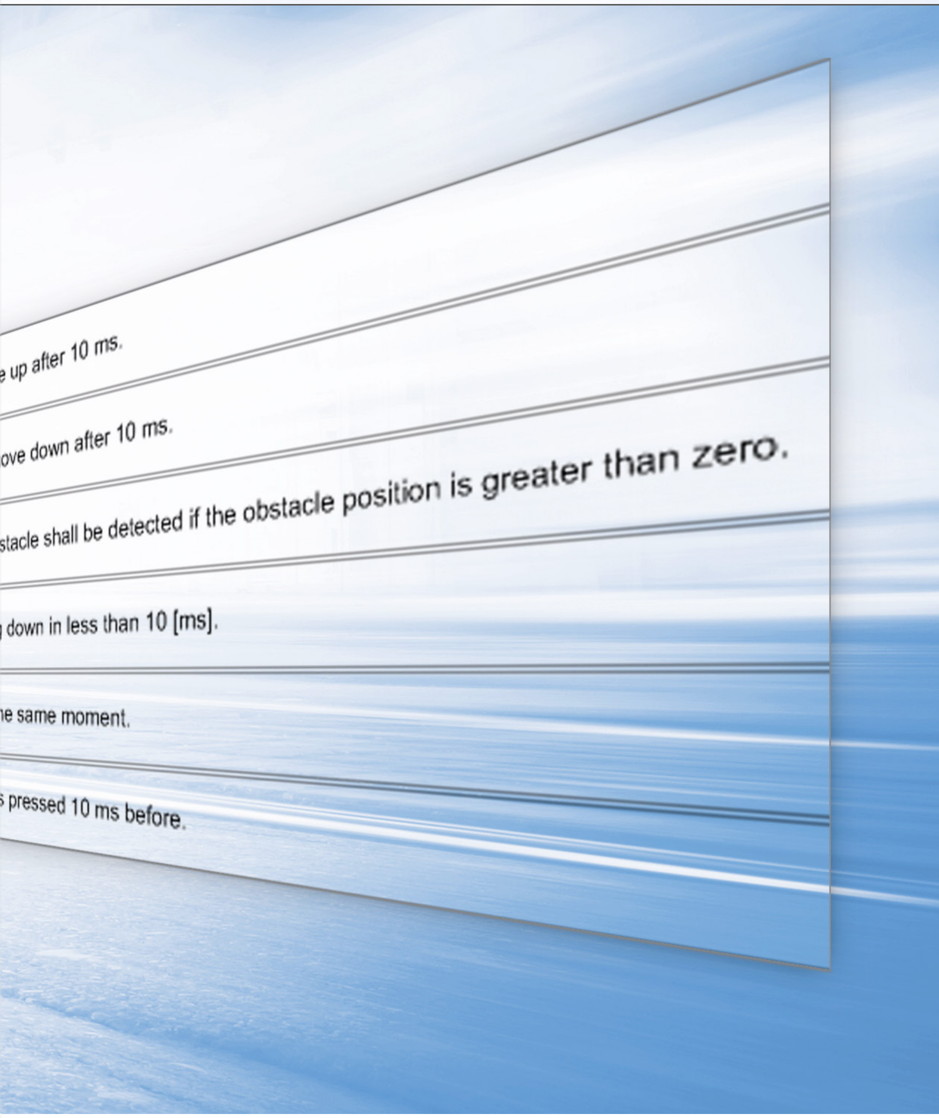
Source: © ZF

Continuous monitoring of safety-critical applications

Keeping an Eye on Safety

How much testing is necessary to validate safety-critical systems? How can you balance safety requirements and effort? A new solution by dSPACE and BTC for the simulation-based formal verification of safety-critical ECU functions brings effort and feasibility closer together. At the same time, the test depth increases.

As the world strives for innovation, user convenience and more safety, the number of electronic safety-relevant systems is growing. In various areas, the times of mechanical fallback systems are long gone due to design or cost considerations. It is therefore inevitable that the tests of these electronic systems face stringent requirements. Examples of such systems are x-by-wire steering and autonomous driving, where system failure could have disastrous effects.
This puts developers in a difficult place: Despite the high system complexity and the seemingly endless list of requirements, the time required for validation has to stay within reasonable limits. The developers also have to comply with a number of important guidelines. For example, the ISO 26262 standard ("Road vehicles – Functional safety") recommends performing a formal verification of safety-critical functions of electronic control units (ECUs).
In the light of these challenges, dSPACE and BTC together have developed a solution for the simulation-based formal verification of safety-critical applications. It can be used to monitor the compliance



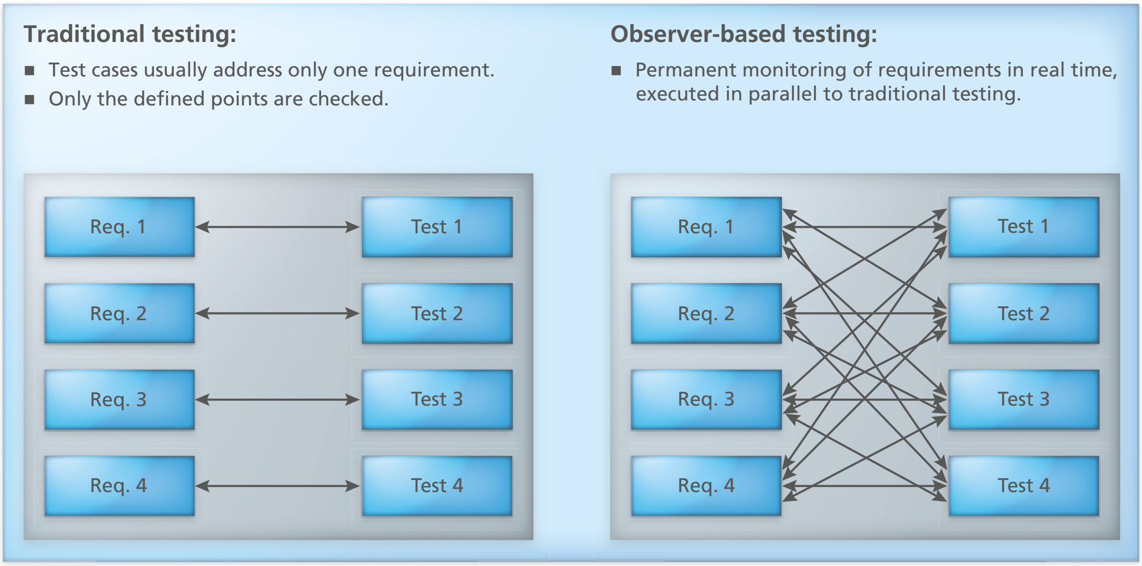
with safety-critical requirements permanently and in real time on dSPACE platforms.

More Test Depth

In the traditional testing process, running all the necessary test cases for each safety-critical function while considering all the requirements and cross-references can cause serious problems in terms of effort and time. After all, how many test cases would you have to define to cover absolutely all eventualities, cross-references, and concurrencies? And even if you were able to define such a long list of test cases, how much time would you need to run through all of them to achieve the desired test depth? The innovative solution from dSPACE and BTC combines the new dSPACE Real-Time Testing (RTT) Observer Library with the specification tool BTC Embedded-Specifier®. These tools complement existing model-in-the-loop (MIL), software-in-the-loop (SIL) and hardware-in-the-loop (HIL) environments with real-time-capable requirement observers. During a running simulation, the observers are running in parallel and monitor the compliance with all safety-critical requirements. It is also possible to immediately see which requirements are covered by the implemented test cases and which are not. This lets developers efficiently assess the overall quality and the progress of the test process. The simulation-based, permanent formal verification is the ideal addition to traditional requirements-based testing, which is still the basis. The combination of traditional tests and observer-based testing significantly increases the test depth. Think of the observers as executable test criteria that can be conveniently used on various dSPACE platforms. Since the observers are decoupled from the actual simulation models, existing simulation models do not have to be modified for their use. Existing traditional tests can easily be extended by observers without having to be modified. >>

"The long-standing experience of BTC EmbeddedSystems in requirement formalizing and formal verification is now combined with the established and powerful simulation platforms and systems from dSPACE. This results in a perfectly fine-tuned and unique tool chain that takes the quality and meaningfulness of testing to a new level, especially for safety-critical applications."

Hans Jürgen Holberg, Board of Management, BTC Embedded Systems AG



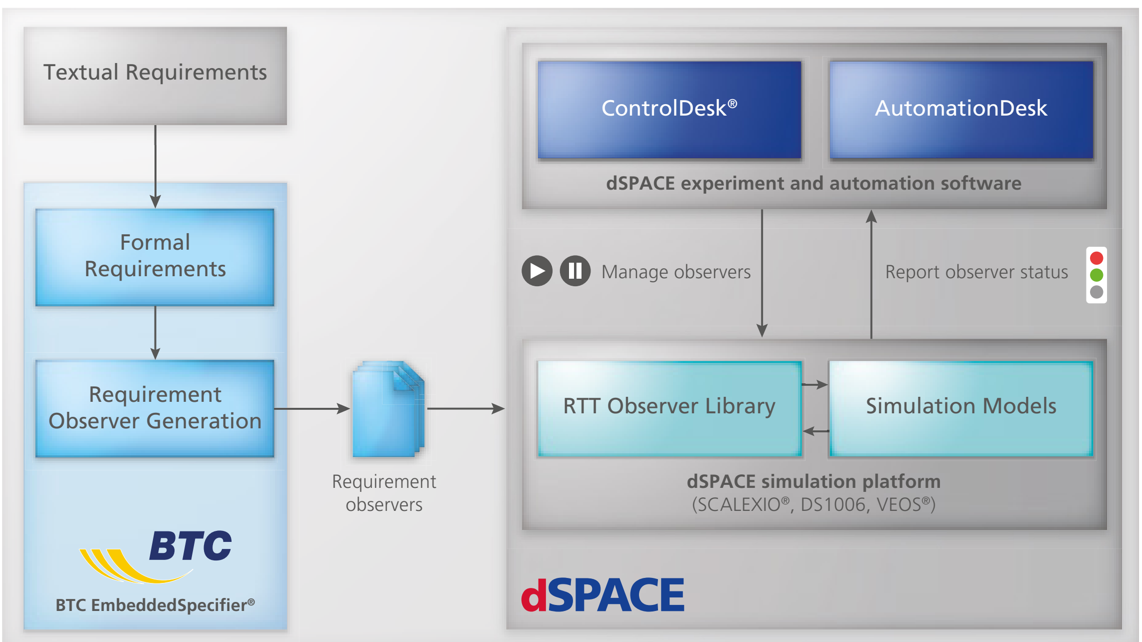


Figure 1 (above): Observer-based tests increase the test depth.
Figure 2 (below): The generated real-time-capable observers function as executable test criteria that are easy to use on dSPACE platforms.

More Quality

Thanks to BTC EmbeddedSpecifier, the quality of the requirements from which the observers are generated also increases. BTC EmbeddedSpecifier provides tool support and thus makes it easy to translate informal requirements into a formal representation and then into executable observers for the dSPACE platform. The guided, stepwise elimination of ambiguities in the previously language-based requirements and the direct reference of concrete model variables helps the users formulate their requirements as precisely as possible. This also helps comply with the relevant safety standards and guidelines.

Ideal Integration

To allow users to quickly use the requirement observers, dSPACE provides test templates for the test auto-

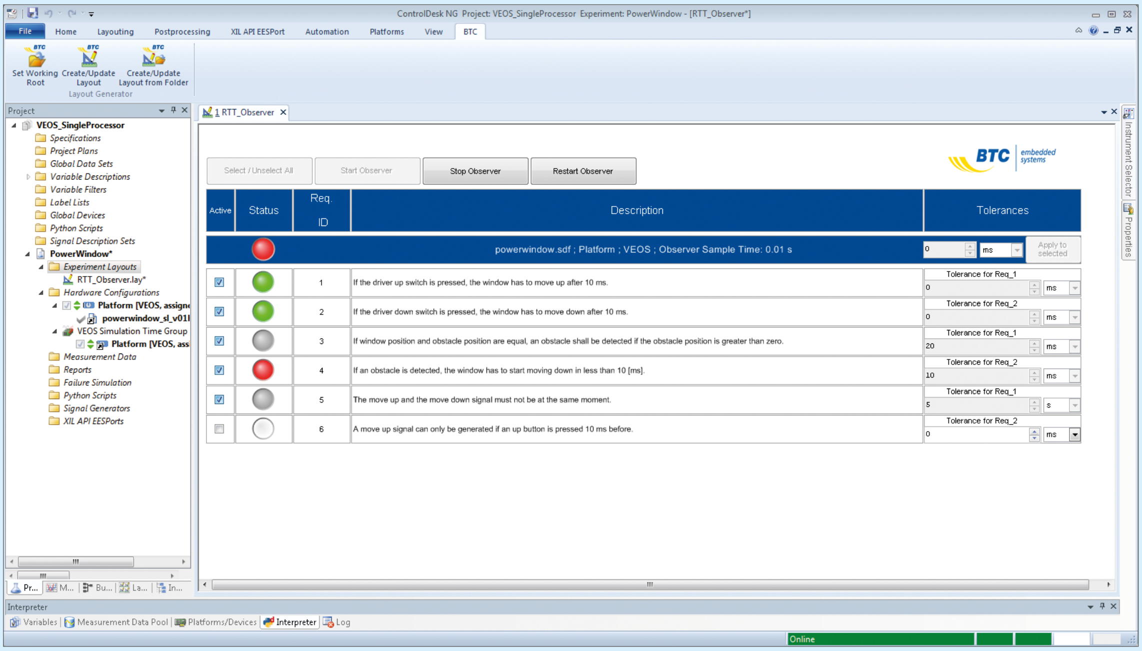


Figure 3: The observers can be started, stopped and reset in ControlDesk. Requirements that are met (green) and not met (red) are visible immediately. Observers that have not started yet because their precondition has not been fulfilled are displayed in gray.

mation software AutomationDesk and layouts for the experiment software ControlDesk. The solution can also be integrated in alternative tools. For the users' convenience, they can automatically generate observer-specific layouts for ControlDesk that display the compliance status of each requirement during the entire execution (figure 3).
With the ControlDesk layout, the observers can be started, stopped and reset individually and completely independently of the simulation model. The AutomationDesk templates let developers use the observers to permanently check the requirements while a specified test sequence is being executed in AutomationDesk.
In this case, the generated test report includes not only the results of the individual test cases but also those of the observers. The time when an observer was triggered can be used to identify the cause of the trigger and thus the error.

Use on Various Platforms

The generated requirement observers can be used on various dSPACE simulation platforms (SCALEXIO®, DS1006, VEOS®), and an observer that was used on one platform can be reused on another. This way, observers that were created in the SIL and MIL development stage for virtual validation on dSPACE VEOS can be reused immediately for HIL tests, e.g., on SCALEXIO platforms, if these tests have the same test level. HIL tests can also be prepared by using test-the-test runs in VEOS. ■

Conclusion

The combination of the dSPACE Real-Time Testing (RTT) Observer Library and BTC EmbeddedSpecifier creates a high-quality solution that massively improves test depth, especially for safety-critical applications, without prolonging the duration of the tests. To achieve a great test depth, it is important to permanently monitor the compliance state of each requirement independently of the current test case and simulation scenario. This minimizes the risk of undiscovered errors caused by unintentional side effects. The tool-supported requirement formalizing with BTC EmbeddedSpecifier also increases the quality of the requirements. The new solution integrates perfectly into the dSPACE tool chain for HIL tests and virtual validation.

When electronic control units (ECUs) are tested, realistically simulating communication is essential. The new dSPACE Bus Manager gives users one central tool for configuring the bus signals for various simulation platforms.

Bus systems are the aorta of ECU networks: In modern vehicles, up to 100 ECUs exchange over 10,000 bus signals. This communication has to be simulated and tested during the entire ECU development process so that it also works reliably in critical situations. With its Bus Manager, dSPACE provides a central implementation tool for all bus applications – from function development, to virtual validation, to comprehensive hardware-in-the-loop (HIL) tests.

Bus Simulation for All

Be it virtual ECUs (V-ECUs), real ECU prototypes, or simulated ECUs in restbus simulation, the Bus Manager can be used in all of these cases to configure the bus communication and the data transmission to the test system. It supports the various validation scenarios of PC-based simulation with VEOS® and of HIL simulation with SCALEXIO® – seamlessly throughout the entire development process. This way, the best simulation type is used in each case.

Central Configuration Software

The Bus Manager provides several ways to select the parts to be simulated. For example, all signals needed for bus simulation can be grouped either by communication cluster or by the related ECU. This increases efficiency when users handle configurations with multiple, and even different, buses. The Bus Manager makes it possible to reuse such configurations for various simulation systems. Its current version supports the CAN, CAN FD and LIN protocols.

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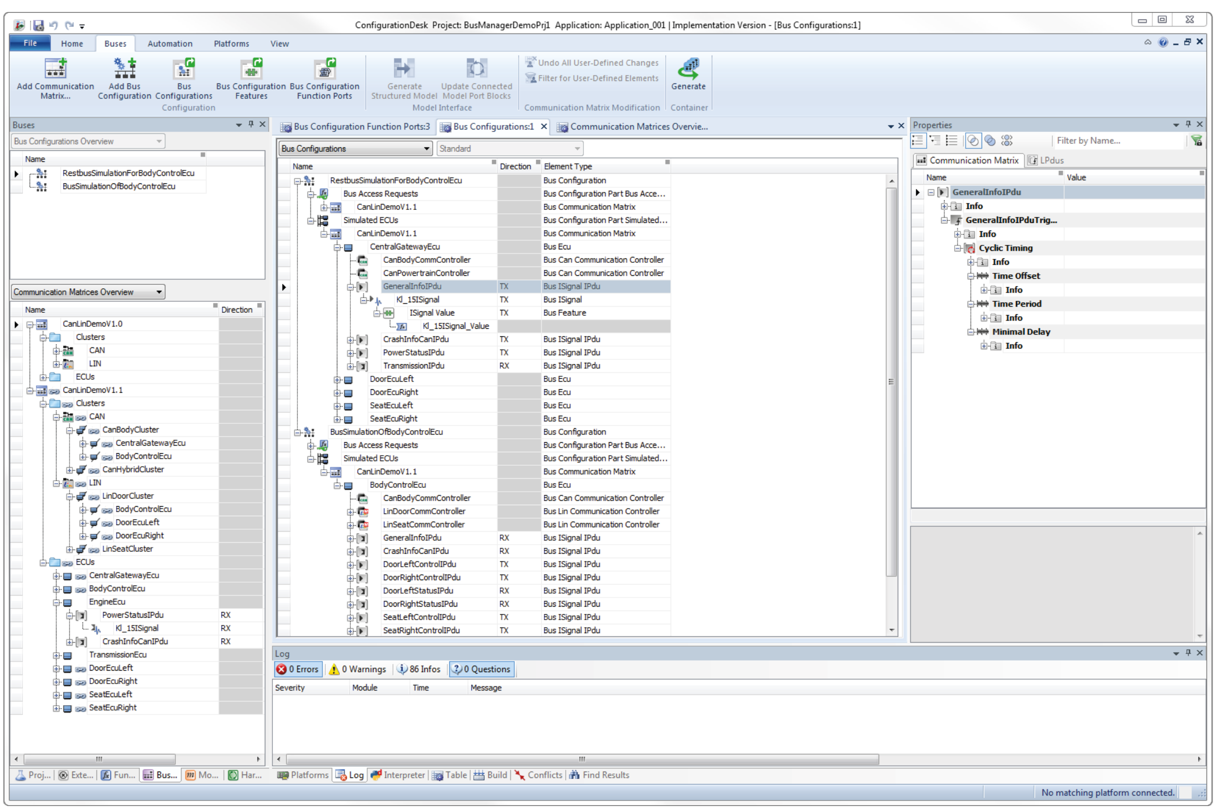
Figure 1: The Bus Manager provides convenient graphical configuration for LIN, CAN, and CAN FD bus simulation.



Configuring bus systems and networks centrally

Communication Is Key

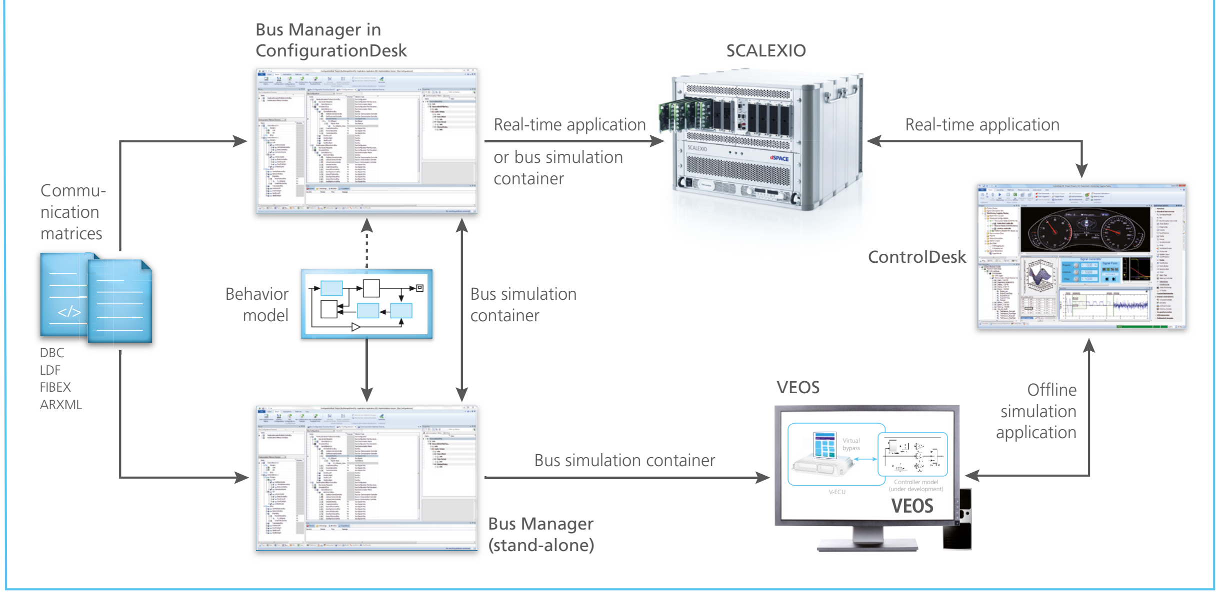


Figure 2: The configuration files generated by the Bus Manager can be used for and exchanged with various simulation platforms.

Other protocols, such as FlexRay and Ethernet, will be supported by future versions. Because only one tool is used to specify all the settings and configurations in all development phases and for all protocols, it is not necessary to familiarize with new tools in each test phase. This eliminates potential error sources.

Configuring Communication with the Bus Manager

Each configuration starts with a communication matrix from which all relevant information is extracted automatically. The Bus Manager supports all major file formats for communication, such as DBC, LDF, FIBEX, and ARXML.
Users take the necessary elements from one or more communication matrices and create their communication configuration. They can switch between different views in the Bus Manager to always have the best possible overview during a variety of tasks, for example, of all available configurations and model interfaces. The final configuration can then be exported as a bus simulation container (BSC) and transferred to the target platform. Using the BSC format makes it much easier to reuse bus configurations in future simulation scenarios so the same configuration is available throughout the entire development process. In addition to Simulink models, existing simulation models can also be integrated in the BSC. The Bus Manager also allows for static restbus simulation without Simulink models, so users can perform simple tests immediately. For simulation with VEOS, users can work with the Bus Manager either as a stand-alone version or as a ConfigurationDesk component. During HIL simulation with dSPACE SCALEXIO, the Bus Manager is always a component of the implementation software ConfigurationDesk. Users therefore need only one software product to centrally configure all bus and network protocols.

Seamlessly from Virtual Validation...

Bus support adds important test features for PC-based simulation with VEOS. Now, the communica-

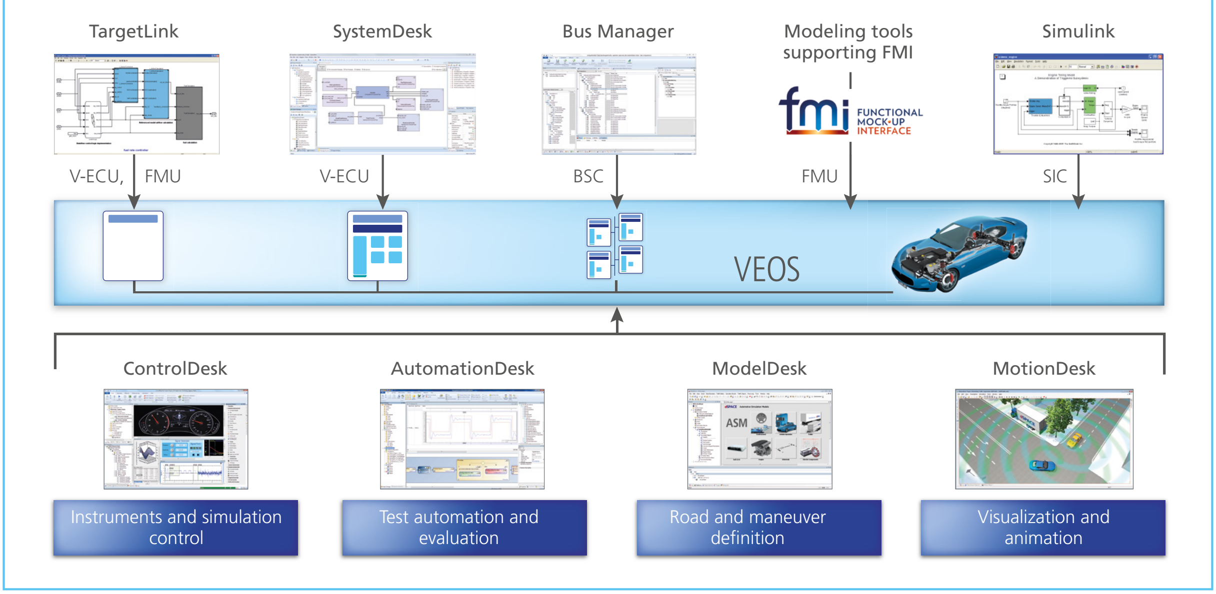


Figure 3: Together with bus communication, VEOS lets users perform realistic simulations for initial function tests on the PC.

tion outside of V-ECUs can also be simulated, tested, and visualized. With VEOS, users can import model parts from various sources and connect them (figure 3). Bus configurations created for VEOS can be reused later in HIL simulation, which ensures consistency throughout the entire development process.
At the same time, function testers using VEOS benefit from existing test configurations for HIL simulations, which they can use as their starting point.

... to HIL Simulation

The great advantage of the Bus Manager and BSCs for HIL simulation is that they can be used for several project variants. BSCs contain both the bus configuration and model parts, so the bus signals can be mapped to the model signals, for example. The interfaces to the plant model remain the same when a BSC is used for a different variant. This means that if a project changes, it is easy to replace the bus parts. This also makes it easier to reuse bus configurations in various projects. If necessary, parameters and properties of the simulated elements can be changed during a running simulation – with both VEOS and SCALEXIO. For example, users can view, analyze, and modify signal values in the experiment software ControlDesk® during a running simulation. If a simulation requires signals whose values change dynamically during run time, behavior models from tools such as MATLAB®/Simulink® can be used.

Bus Simulation Container (BSC)

A bus simulation container (BSC) is a data format for exchanging bus configurations. It contains not only the data needed for the bus configuration, but also a mapping or scaling model in the form of a Simulink implementation container (SIC). The SIC combines all MATLAB/Simulink functions required for bus communication. It also contains data for the experiment software ControlDesk.
The standardized interfaces of the BSC simplify the exchange of bus configurations between different application areas and projects, thereby making it easier to reuse the complex bus parts.

Right on Target

On-target prototyping merges function and production development

With the dSPACE on-target prototyping solution, new functions can be integrated directly into existing electronic control unit (ECU) code and tried without having to perform complex software integration. This prototyping solution is extremely efficient regarding the resources of the control unit and allows a seamless transition to series production by using the production code generator dSPACE TargetLink.

When only the functionality of an existing production ECU needs to be extended, function development can be done directly on the ECU. If enough resources are still available and the existing I/O is sufficient, this can save the costs and effort for integrating and using additional prototyping hardware. Moreover, using the production code generator that is also used for the final ECU makes the code more efficient in terms of memory and execution time. On-target prototyping therefore automatically ensures that the resource limits of the ECU are observed. This reduces the project risk. Furthermore,

using the production code generator results in a seamless transition to the actual production development, including the convenience and quick iteration that is expected of prototyping. The dSPACE on-target prototyping solution with the production code generator TargetLink® can be used not only for developing new functions on the basis of Simulink®/ TargetLink models. With minimal effort, these new functions can also be integrated as optimized code into existing ECU code for prototyping.

The dSPACE On-Target Prototyping Tool Chain

The core of the dSPACE on-target prototyping solution consists of the ECU Interface Manager, the dSPACE Internal Bypassing Service, the RTI Bypass Blockset and TargetLink (figure 1). The developers use the ECU Interface Manager to configure the bypass interfaces, which are required to integrate the new functions into the ECU code. Simulink/TargetLink are used to model the new functions. Afterwards, the new functions are connected to the existing ECU software with the RTI Bypass Blockset. This blockset connects the inports and outports of the function models with the interfaces that were

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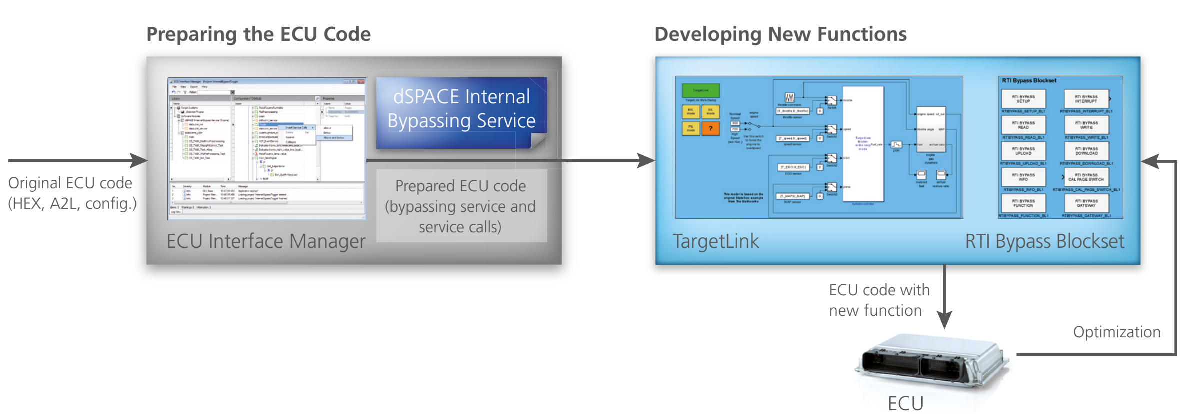
Figure 1: In combination with the RTI Bypass Blockset, TargetLink implements new ECU functions in the ECU code, which was prepared with the ECU Interface Manager.



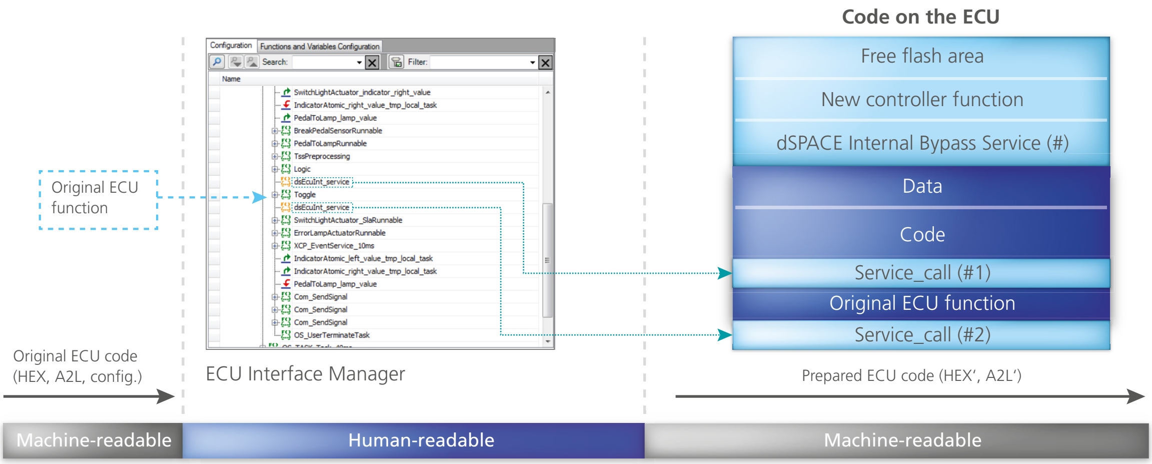


Figure 2: To prepare the ECU code, the ECU Interface Manager analyzes the binary ECU software and displays it in a structured form, including the function names. Based on this, the bypassing service and the service calls are integrated into the new functions.

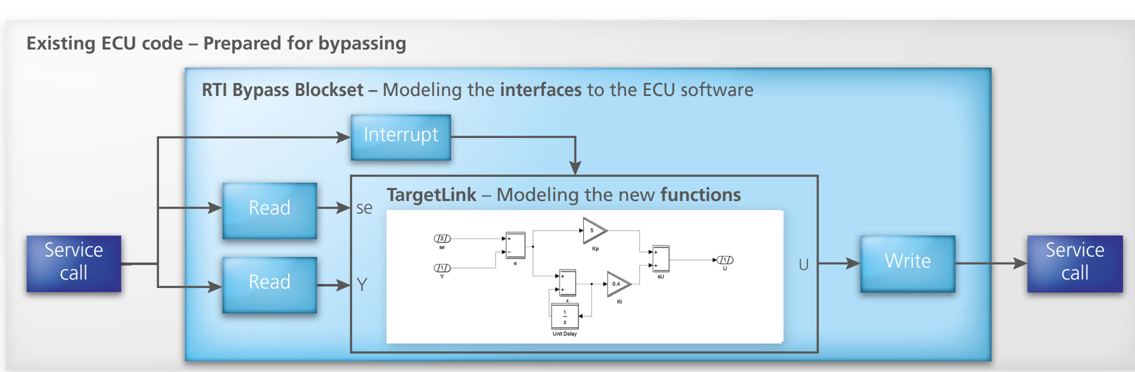
previously prepared in the existing binary code. Subsequently, the developers generate the production code with TargetLink and create the binary code for the ECU. The result is a revision of the ECU, which contains the newly developed functions. This revision is then transferred to the flash memory of the ECU. The developers can complete all these steps independently because no access to either the source code of the ECU software or a stand-alone build environment is required.

Integrating Bypassing Services Quickly and Easily

The ECU Interface Manager is an integral part of the on-target prototyping tool chain. The tool quickly integrates the bypassing services and the interfaces for the new functions into the ECU code, which is available as a binary file. No access to either the source code or the build environment of the ECU is required. The ECU supplier has to provide only some configuration information, e.g., free memory areas. No further iterations with the supplier are necessary, which saves project costs and time. The ECU Interface Manager, by contrast, uses a binary image of the ECU software to directly integrate the dSPACE Internal Bypassing Service into the ECU and to instrument the existing software in such a way that the new TargetLink functions can be integrated in all the required places. The ECU Interface Manager analyzes the program flow of the

> Developing new functions on the ECU fast and with optimized resource consumption

Figure 3: TargetLink and RTI Bypass Blockset for developing new functions.



existing code for the supported processor families Infineon TriCore™, Renesas V850™ and NXP MPC 5xxx and provides the developers with the software structure and the relevant function names in a clear user interface for configuration (figure 2). In this user interface, the developers can specify, directly in the binary image, which interfaces are available during on-target prototyping. If functions are to be completely replaced, the developers can also specify to fully delete them from the ECU code and reuse the memory. In the end, the ECU Interface Manager generates a new ECU image that contains the bypassing service and the required service calls for the integration of the function that is to be developed.

Efficiently Using the ECU Resources

After the new ECU image has been prepared in the ECU Interface Manager, the new functions are developed with Simulink/TargetLink and the RTI Bypass Blockset. As a production code generator, TargetLink generates optimized ECU code and thus supports the optimal use of the limited resources. In addition, using TargetLink enables a seamless transition to production. The tool chain supports two different scenarios for modeling new functions:

1. *Developing Based on a TargetLink Model:* In this case, all TargetLink functions are directly available for the developers, who can make all the specifications that are desired for the final ECU code in the model as early as the function development phase.
2. *Developing Based on a Simulink Model:* TargetLink generates production code from the model and combines the code efficiency of TargetLink with reliable information about the used resources at maximum convenience.

In both cases, the universal RTI Bypass Blockset connects the modeled function and the ECU code (figure 3). The blockset offers flexible options for integrating the modeled function into the functional flow of the existing software. It provides access to variables of the existing software and makes it possible to call Simulink subsystems synchronously with the processing of the original ECU application.
After configuring the connection to the ECU software, the developers can start the automatic build process for new functions at the click of a button. The build process automatically integrates the function into the ECU image. For this, it even uses fragmented memory areas to optimally use available resources. Optionally, it starts the flash process and thus directly transfers the newly created ECU image to the ECU without the need for manual steps. Access to the measurement and calibration parameters is provided via the existing ECU interfaces, as usual. ■

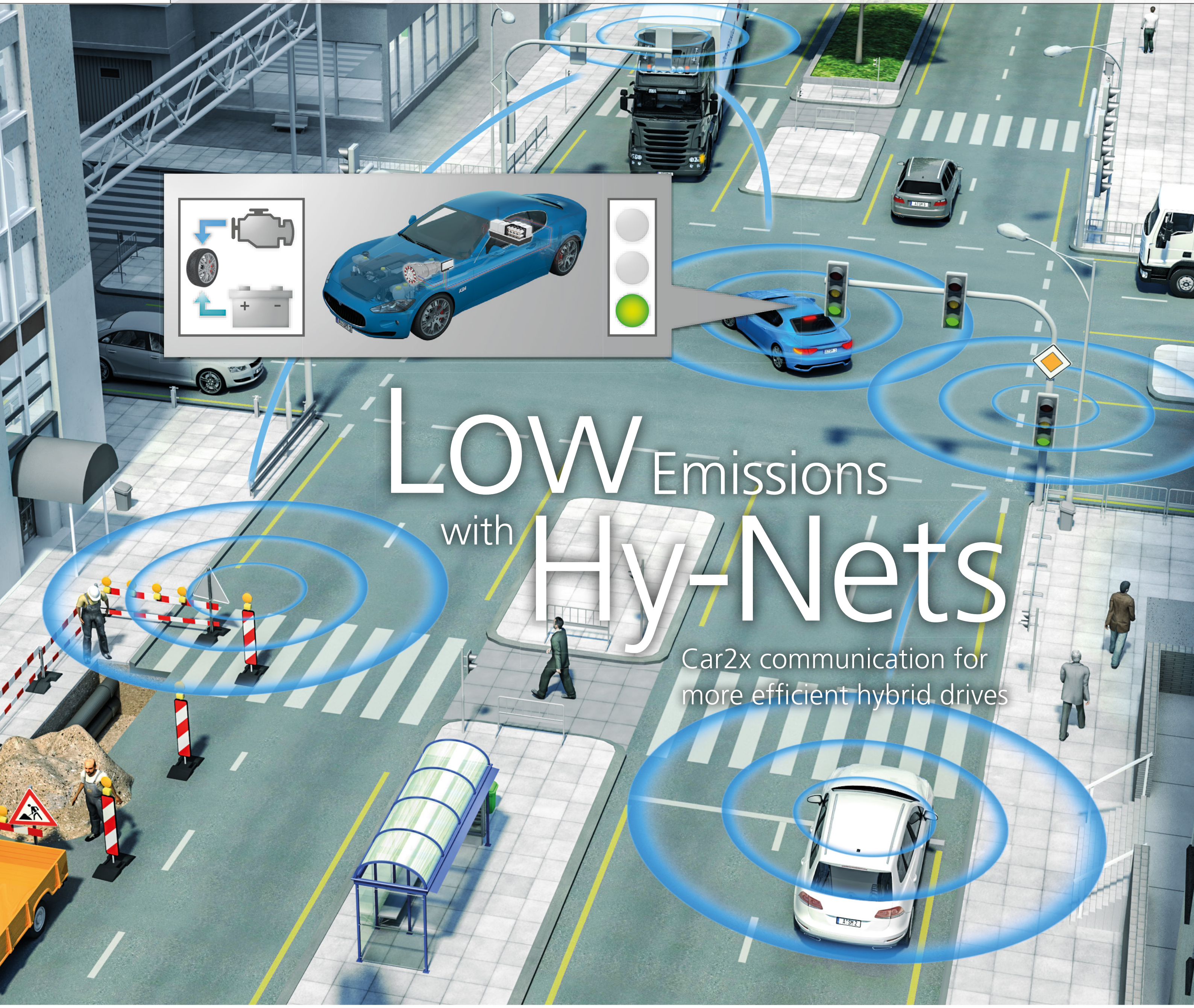
Table 1: The tool chain for close-to-production on-target prototyping.

dSPACE Tool	Task
ECU Interface Manager	Intuitive tool for quickly integrating service calls for bypassing directly into existing ECU code
dSPACE Internal Bypassing Service	ECU service for extending existing ECU code with service calls for bypassing
TargetLink®	Software system that automatically generates production code (C code) directly from the graphical MATLAB®/Simulink®/Stateflow® development environment
RTI Bypass Blockset	Simulink blockset for easily connecting new functions with existing ECU code
Target-specific compiler (third-party product: HighTec compiler)	Transferring C code into object code for the processor families Infineon TriCore™, Renesas V850™, and NXP MPC5xxx

The tool chain described is valid as of TargetLink 4.2 (dSPACE Release 2016-B).

Benefits and Future Innovation

The combination of the ECU Interface Manager, RTI Bypass Blockset and TargetLink reconciles the fast iterations of rapid control prototyping with the high demands for efficiency and configurable production code. The existing production ECU can be conveniently used as prototyping hardware. As a result, resource consumption is kept under control, and due to the continued use of the function models with TargetLink, a seamless transition to production development is possible.
The binary-code-based integration of service calls for bypassing with the ECU Interface Manager saves tedious integration loops that involve the ECU supplier. Thus, prototyping can start immediately. For future dSPACE Releases, the new feature for virtual bypassing with TargetLink and dSPACE VEOS® on a host PC will increase productivity even further.



Low Emissions with Hy-Nets

Car2x communication for more efficient hybrid drives

Car2x communication is already a hot topic, especially when it comes to accident prevention. But cars that "cooperate" with each other and with the infrastructure could also improve propulsion.

Would it be possible to use the advancing digitalization of mobility to improve not only the safety of future vehicles but also their fuel consumption and emissions? This question led dSPACE, DENSO, RWTH Aachen University and the University of Paderborn to initiate their research project "Hy-Nets: Efficient Hybrid Propulsion using Vehicular Communication".
In the fall of 2015, the project was a success at the "MobilitätLogistik.NRW" competition and therefore receives funds from the European Regional Development Fund (ERDF) for 30 months. The city of Paderborn and the engineering office Geiger & Hamburgier (IGH) support the project as associated partners.

Analyzing Digital Mobility with a View to Efficiency

Hy-Nets aims at bundling several topics of vehicle technology that up to now have been observed separately, to open up entirely new effi-

"For the very first time, Hy-Nets makes it possible to measure the direct effects of future networked traffic scenarios on a real hybrid drive and evaluate the interaction with the environment with a view to energy consumption and vehicle flow."

Ulrich Schwarz, Senior Manager EV/HV, DENSO

ciency potentials for the hybrid vehicles of tomorrow. In contrast to existing controls of hybrid drives, which are primarily based on vehicle-internal information, Hy-Nets for the first time also considers Car2x communication, i.e., the communication between vehicles and/or between vehicles and the infrastructure.
It is this holistic approach considering all the different levels that brings entirely new efficiency maximization methods into researchers' focus. These methods include predictive energy management, new autonomous driving functions and, especially, the "cooperation" of communicating vehicles in cooperative traffic scenarios.

Connecting Real Propulsion Technology with Simulated Traffic Scenarios

To accurately analyze the interaction of the real hardware and software of a hybrid drivetrain with such complex traffic scenarios, Hy-Nets is building a prototype of a state-of-the-art hybrid drive (DENSO) and will install it in one of the most advanced test facilities in Europe (RWTH Aachen University).
On a test bench, the prototype will be connected to a powerful simulator that simulates the traffic environment of the hybrid vehicle (dSPACE), the general traffic flow, and the entire vehicle and infrastructure communication (University of Paderborn) with utmost precision. This makes it possible to operate the real hybrid drive in complex simulated driving scenarios that are based on real traffic data (city of Paderborn) and traffic light control data (IGH). The researchers of the Hy-Nets project hope to use the insights from the test bench to develop a more demand-appropriate design of future hybrid drives. This would mean that the digitalization of mobility could also open up entirely new and promising possibilities in an ecological context. ■

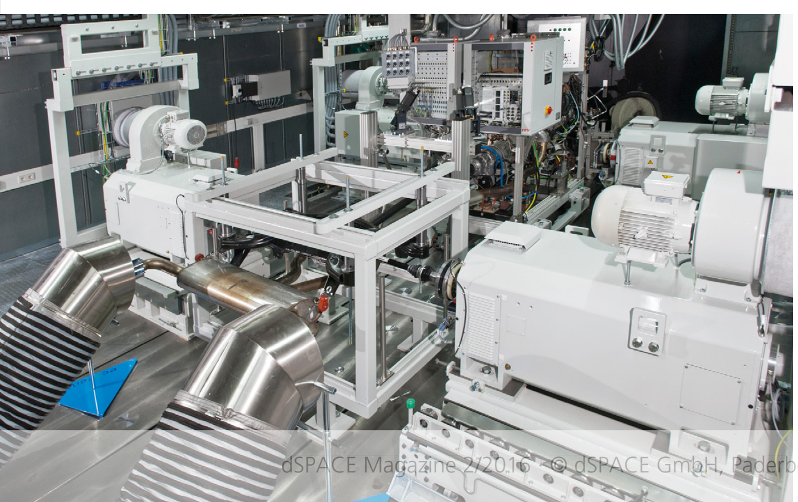
HY NETS

EUROPEAN UNION
Investing in our Future
European Regional Development Fund

EFRE.NRW
Investitionen in Wachstum und Beschäftigung

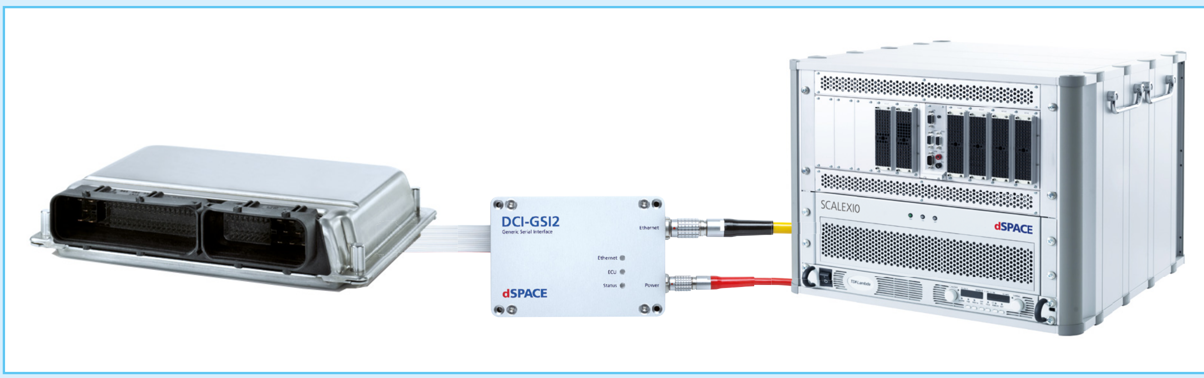
With the kind permission of the Hy-Nets project consortium.

Test facility in Aachen: For the Hy-Nets project, a real hybrid drive is connected to a hardware-in-the-loop simulator on a test bench. The simulator simulates the vehicle environment, the general traffic flow, and the entire vehicle and infrastructure communication. This creates virtual traffic scenarios that can be used to thoroughly test the hybrid components. This work is done partially at the Center for Mobile Propulsion, which is funded by the Deutsche Forschungsgemeinschaft (DFG, the largest independent research funding organization in Germany).



Real-Time ECU Access with SCALEXIO

In hardware-in-the-loop (HIL) tests, direct real-time access from the HIL simulator to the unit under test is necessary to be able to synchronously measure and adjust internal electronic control unit (ECU) variables. The dSPACE HIL simulator SCALEXIO® does this by using either the serial dSPACE DCI-GSI2 hardware or an XCP-on-Ethernet interface that is already on the ECU.
To access the variables in the ECU code, bypass service calls are needed as access points in the ECU code. These service calls can be inserted manually on the basis of the ECU source code, or automatically on the basis of binary code. For automatic insertion, dSPACE provides the ECU Interface Manager, a powerful and intuitive tool that lets test engineers make the necessary adjustments for ECU access whenever they need to. This gives users the ability to access the ECU under test conveniently from the real-time application. They can, for example, simulate values of inaccessible ECU sensors, such as the temperature, pressure or acceleration sensors, directly in the ECU without real stimulations that cost a lot of time and money. This way of access also lets them react to the internal states of the ECU software during a running test and thus specifically and immediately influence the progress of the test. Moreover, isolated tests of the ECU software's subfeatures can be performed on the ECU hardware (white-box testing).

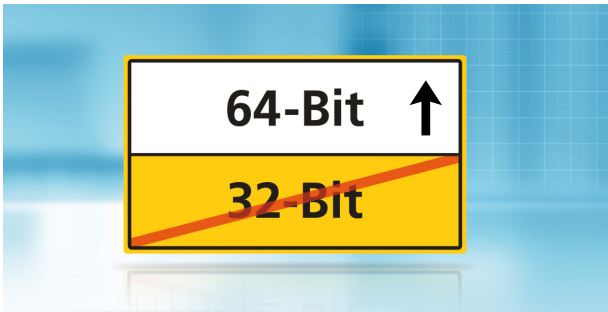


Seamless CAN FD Support

Since 2014, dSPACE has supported the CAN FD communication protocol. It is now integrated completely in the dSPACE software and hardware tool chain. Rapid control prototyping systems, such as MicroAutoBox II, communicate via CAN FD during initial function validation in the lab or vehicle. SCALEXIO® does so in hardware-in-the-loop tests of the ECU communication. In addition to the software-configurable support of ISO CAN FD and non-ISO CAN FD that has been provided since 2015, wake-up and sleep functions as well as partial networking are now also available. To configure CAN FD communication, you can use either the Bus Manager or the implementation software Real-Time Interface (RTI). The experiment software ControlDesk® makes it possible to monitor and modify the real-time communication.

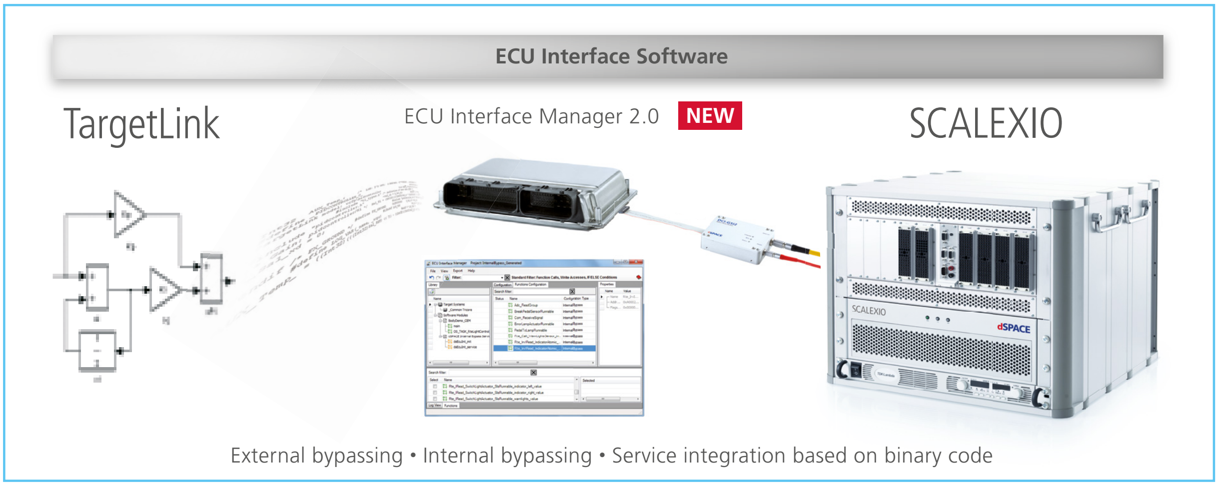
dSPACE Software Only as 64-Bit Versions

As of dSPACE Release 2016-B, all dSPACE software products for Windows are available only as 64-bit versions. This concludes the stepwise transition to the 64-bit technology that started with dSPACE Release 2015-B.
Since the 64-bit technology can address more memory, you can create and translate more complex models, perform more extensive tests, and manage a larger volume of measurement data. Some use scenarios are also executed faster. With the use of the 64-bit technology, the main memory requirements of the PC increase to 8 GB.

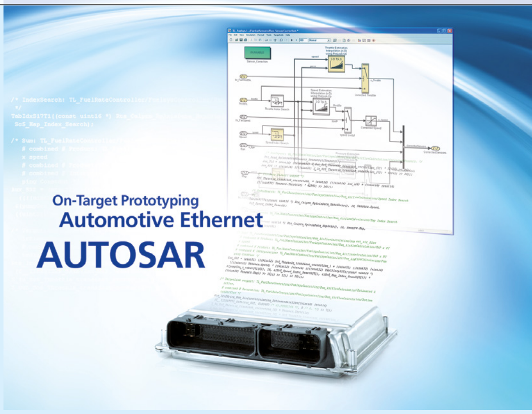


ECU Interface Software: New Functions, Easier Packaging

With dSPACE Release 2016-B, planned for November 2016 (subject to change), new functions and an easier, application-oriented packaging are added to the dSPACE ECU interface software, which includes the ECU Interface Manager. One main extension to the ECU Interface Manager 2.0 is the support of SCALEXIO® and ConfigurationDesk®. By accessing internal electronic control unit (ECU) variables, users can now influence HIL test sequences and simulate inaccessible sensors during a running ECU test (page 60). Another new feature is the TargetLink® support for on-target prototyping (internal bypassing) on a production ECU (page 54). In addition to the automatic integration of bypassing services on the basis of binary code, TargetLink code can now be implemented and validated in existing ECU software. Using TargetLink therefore allows for a seamless transition to production code and a more efficient use of the limited ECU resources. In addition, the resources required for series production can be identified very early on.



TargetLink 4.2: On-Target Prototyping, Automotive Ethernet, and Much More

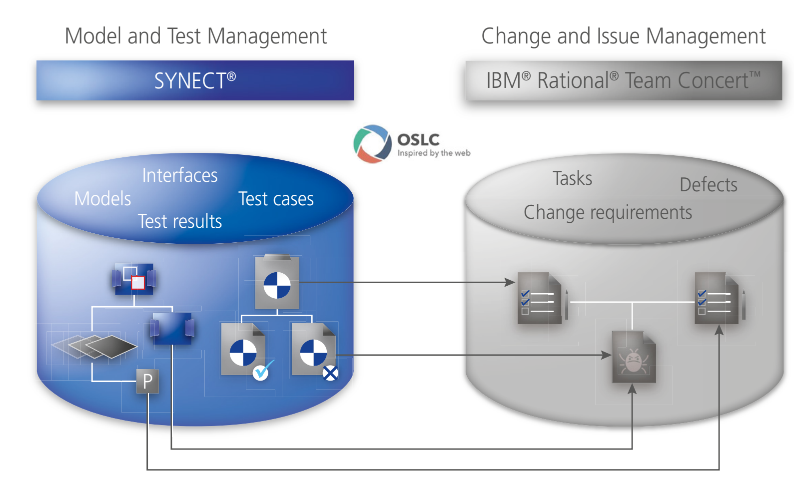


TargetLink® 4.2 (dSPACE Release 2016-B), the new version of dSPACE's production code generator, for the first time supports the dSPACE on-target prototyping tool chain (page 54). This lets developers benefit from the highly efficient TargetLink code in production-close prototyping and minimizes project risks by means of resource profiling and the seamless transition to series production. Another important new feature is TargetLink's ability to generate enumeration types and variables (C enums), which further increases the code's readability and makes integrating legacy code even easier. For AUTOSAR-compliant development, TargetLink now supports AUTOSAR 4.2.2 and increases the performance of multi-core systems via asynchronous client-server communication. In addition to more AUTOSAR improvements, such as non-scalar interrunnable variables, TargetLink 4.2 offers complete support for Automotive Ethernet. The modeling possibilities in Simulink®/ Stateflow® were extended further by Stateflow Superstep semantics, activity flags for states, and an easier handling of buses. The new TargetLink version also further improves the MISRA-C:2004-/MISRA-C:2012 compliance of the generated code. Shortly after the release of TargetLink 4.2, a new version of the SYNECT Add-On for TargetLink will be released, which makes it much easier to use TargetLink in large, distributed development teams and automates large parts of the use. ■

SYNECT – Seamless Data Exchange via OSLC

dSPACE's data management software, SYNECT®, supports the Open Services for Lifecycle Collaboration (OSLC) standard. On the basis of OSLC, SYNECT can directly communicate and interact with other data management systems that also support the standard. Data can be viewed, modified and linked in different tools. This is a great advantage for TargetLink® users, for example, as they develop and test their models. From within the SYNECT test management project, users can quickly generate a "Defect" (problem report) for a failed test case in OSLC-capable change and issue management systems, such as IBM® Rational® Team Concert™. Change requests resulting from the problem report can then easily be linked to the models, interfaces and parameters that are centrally managed in SYNECT. This lets users view the necessary changes, trace them to their source and implement them at any time. ■

Link data is kept in different data management systems, and traceability and visibility are created across tool boundaries.



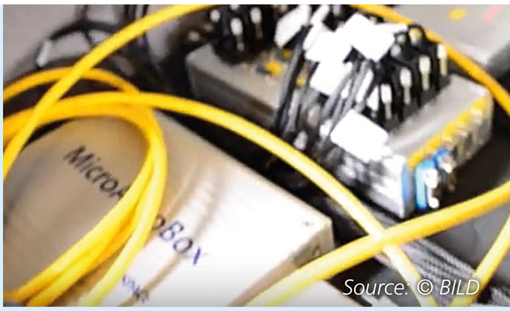
dSPACE on Board

Discover intriguing and innovative applications, achieved with dSPACE development tools

Skillfully Avoiding Collisions

ZF has developed a new emergency steer assistant that will help avoid rear-end collisions of trucks. The company recently demonstrated to the German press how reliably the advanced driver assistance system works. dSPACE MicroAutoBox was one of the tools used for the setup of the controller prototype.

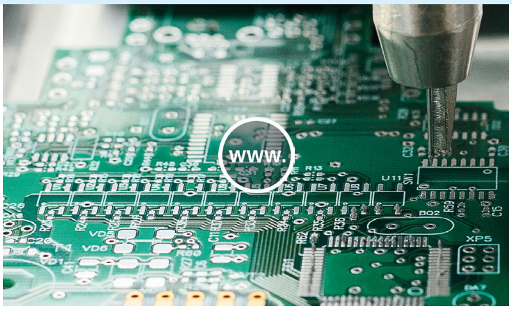
The motto for the new emergency steer assistant EMA (Evasive Maneuver Assist) by ZF is collision avoidance and maintaining driving stability.
www.dspace.com/go/dMag_20162_ZF



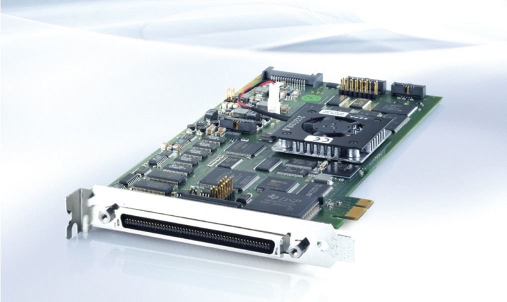
ZF uses a MicroAutoBox as the prototype controller in the truck.

Adaptive Control for Assembly Machines

Chinese researchers use an adaptive control with integrated disturbance observation to optimize the positioning precision of surface-mount-technology (SMT) assembly machines for circuit boards. To demonstrate their solution, they used an experimental setup based on the universal dSPACE DS1104 R&D Controller Board and dSPACE ControlDesk.



An SMT-based assembly requires high-precision positioning capabilities.
www.dspace.com/go/dMag_20162_SMT

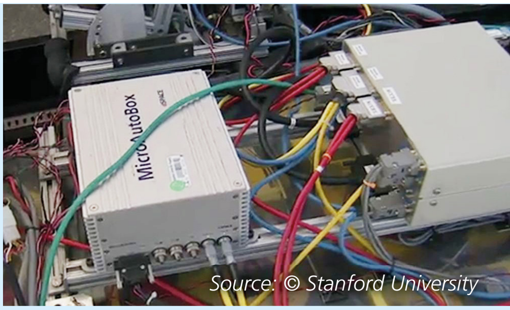


The adaptive algorithms are calculated on the DS1104 R&D Controller Board.

Driving School for Autonomous Vehicles

Students of Stanford University developed high-performance algorithms for their autonomous vehicle to avoid accidents. They installed a dSPACE MicroAutoBox in the vehicle to help them achieve intelligent driving functions with which the vehicle can avoid sudden obstacles, for example.

Students train their autonomous vehicle to recognize and avoid obstacles.
www.dspace.com/go/dMag_20162_Stanford



Electronic components for the autonomous control. The MicroAutoBox plays a central role in their development.

Learn more about these applications online, via videos, photos, and reports:
www.dspace.com/go/dMag_20162_REF_E

dSPACE Test Benches – Highly Dynamic with Maximum Flexibility

Whether you're developing electric steering systems, brake systems, or electronic control units with integrated sensors – dSPACE provides tailor-made test benches for each use case. Put your systems to the test under extreme conditions, with forces and torques from measurement data or real-time vehicle dynamics simulations. Benefit from our know-how that covers everything: design, planning, installation, and support. All from a single source. Our scalable systems range from small rotary test benches for office use, to large test benches for complete steering systems.

Maximum flexibility and turn-key solutions – from dSPACE.

Embedded Success dSPACE