Automotive Solutions
Systems and Applications
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The Challenge of ECU Development

The challenges for automotive electronics are constantly growing. Today’s electronic systems account for 30% of manufacturing costs, and this figure is still rising. Developing these systems is a critical phase along the road to launching a new vehicle.

Standardized Development Systems
Increased safety and comfort are pushing the complexity of vehicle systems up exponentially. Intense competitive pressure is forcing companies to drastically reduce development times. As many automotive manufacturers and suppliers have realized, standardized development systems streamline development phases and shorten them effectively. Clearly formulated specifications, modern processes, and a seamless development tool chain reduce the manual workload and help avoid expensive mistakes.

Single-Source Solutions
dSPACE has pioneered and optimized ECU development for many years as an independent system partner. Cooperating closely with the automobile industry, we have created a comprehensive development environment that has become a standard in many companies. dSPACE supports all the development phases, from architecture-based system design and block-diagram-based function prototyping to autocoding and ECU testing and calibration. Our solutions provide considerable savings in time and cost, greatly enhanced software quality, and more efficient cooperation between manufacturers and suppliers.
Working with dSPACE Products

Whichever dSPACE tool you use, the user interface will be familiar to you. Whether you develop, program, or test electronic control units, you work in the same comprehensive environment. This accelerates and simplifies the development process, helping you put your ideas into practice faster and eliminate errors sooner.

**Graphical Specification**
With SystemDesk, dSPACE’s architecture tool, you can design and refine the system and software architecture models of your electronic control units and simulate them offline. You can use standard tools such as MATLAB®/Simulink®/Stateflow® from The MathWorks to model your ECU and diagnostic functions, and simulation models for ECU testing, graphically in a block diagram. Your work is always based on the same model, whether you are validating your functions in the vehicle, generating the code for the production ECU, or performing tests in a hardware-in-the-loop environment. Because all your models are based on block or state diagrams, your specification will always be up-to-date and correct throughout all design modifications.

**Accelerated Development Steps**
Fast iteration steps are the prerequisite for rapid and problem-free development, so block diagram models can be implemented on dSPACE real-time hardware by a simple click. Design iterations can be performed simply and quickly, and almost all errors are eliminated. The same applies to autocode: Unlike handcode, autocode can be optimized as often as required, because it takes only seconds to implement the model in C code.

**Virtual Instrumentation**
ControlDesk is the central component of our experiment software, enabling you to manage, instrument and automate your experiments.
We also have software for automatic, model-based testing throughout every phase of the development process, for visualization by 3-D online animation, and for experiment control and data capture under MATLAB®.
CalDesk is a versatile tool for function prototyping, calibration, and diagnostics.

**dSPACE Sets Standards**
As you would expect, dSPACE is oriented to standards such as ASAM, OSEK, ISO, and AUTOSAR. What is unique, though, is that dSPACE has also stayed independent of specific ECU manufacturers. In this age of tough competition, this is especially important for our customers.
A Fully Integrated Process

**System Architecture**
At the start of the development process, the software architecture and system model can be specified without reference to the real electronic control units (ECUs). The ECU system can be described in SystemDesk, and its behavior can be verified with an early PC-based simulation (p. 6).

**Control Design**
MATLAB®/Simulink® models can be reused in all phases of the development process. The advantages are clear: If all the members of a team use the same model, the risk of errors is minimized, and development cycles are shorter. Moreover, evaluations and predictions can be made much faster and more reliably with a single model as a basis (p. 9).

**Rapid Prototyping**
With dSPACE's flexible prototyping systems, you can optimize the control designs for the real ECU, all without any manual programming. Your block diagram design is automatically implemented on the system and calculated in real time. dSPACE prototyping systems also provide bypass solutions for integrating new functions into existing ECUs. To connect sensors and actuators to the prototyping hardware, you can use the compact, modular RapidPro System (p. 10).

**ECU Autocoding**
Automatic code generation for a production ECU is a key development phase. As soon as your functions are sufficiently validated, TargetLink generates highly efficient C code – in minimum time (p. 14).

**HIL Testing**
When your ECU has been programmed, you can test its functions quickly and automatically with dSPACE Simulator. Unlike test drives in a real vehicle, these tests are completely safe, and any errors that occur can be reproduced at any time. Simulation models such as dSPACE's Automotive Simulation Models, combined with powerful real-time hardware, allow you to mimic real test drives in the laboratory (p. 18).

**ECU Calibration**
Parameter calibration has become a key issue in the development of ECUs. No matter where or when measurement, calibration, and diagnostic tasks are performed – in test drives, on a test bench, or in early phases of software development – a powerful system is indispensable (p. 22).

**Engineering**
dSPACE systems are easy to get up and running. However, if a project is more complex, if individual solutions are needed or if there is high time pressure, customers can trust dSPACE's fast, competent engineering and consulting services (p. 38).
Modern electronic control units (ECUs) have such an enormous number of functions, and such a high level of networking, that handling several hundred software modules is not uncommon any more. Keeping track of such ECU systems and coping with their complexity often causes problems for vehicle manufacturers and suppliers. To help you stay on top of this task, dSPACE offers SystemDesk, the system architecture software.

Reusing Software Components
Reusable, interchangeable software components is one of the current trends in the development of automotive ECU software. AUTOSAR is the key here. The AUTOSAR consortium is a development partnership whose objective is the joint development of a standardized electric/electronic architecture concept. Reusability saves both time and money, since not all components need to be developed from scratch. It requires strict separation of the software architecture and the hardware topology, and compliance with interface specifications.

Describing Software Architectures Systematically
The complexity of ECU systems is a major challenge for automobile manufacturers and their suppliers. So when suppliers develop functionalities for an ECU system, formal system models facilitate communication between the OEM (or client) and the supplier (or service provider). The graphical display of components and connections also makes it easier to understand the relationships between them and to exchange information.

Production Projects Under Control
- Graphical modeling of ECU systems
- Libraries of reusable objects
- Connection to version control systems
- Activities automated via script

SystemDesk supports all the tasks involved in the model-based development of ECU systems.
SystemDesk

SystemDesk is dSPACE’s architecture tool for starting the model-based development process at system level. By using SystemDesk, developers can speed up the planning, implementation, and integration of their complex system architectures and distributed electronic control systems.

Different System Aspects Modeled Separately
Different system aspects such as the software architecture, hardware topology, and network communication are modeled separately in SystemDesk. One great advantage of this is reusability: For example, one software architecture can be used for several hardware topologies.

AUTOSAR Integration
SystemDesk makes sure your developments are AUTOSAR-compliant. You can create descriptions for new AUTOSAR software components, for example, or load existing components into SystemDesk for further processing. SystemDesk also has an autocoder for generating the AUTOSAR run-time environment (RTE). This RTE generator is based on dSPACE’s many years of experience in code generation and optimization with TargetLink.

Connection with TargetLink
SystemDesk works hand in hand with TargetLink (p. 14), dSPACE’s production code generator, which can be used to generate production code for the software components in SystemDesk architecture models. For function design itself (p. 9), well-established tools such as Simulink®/Stateflow® can be used.

Three aspects – software architecture, hardware topology, and network communication – are developed independently and brought together to make a system.
Simulation and Verification

Errors in the logical links between functionalities are often not found until after the electronic control units (ECUs) are implemented by suppliers and integrated by the OEM. With SystemDesk, you can perform realistic, ECU-close simulation to verify component behavior.

Important Features

- Simulating single software components and ECU networks
- Simulating network communication
- Bus simulation
- Emulating the basic software
- Integrating Simulink models as AUTOSAR software components
- Test automation via COM interface
- Graphical display of measured data
With constant pressure on the automotive industry to reduce development times and still create innovative products, you need efficient development methods. Model-based control design is a time-saving and cost-effective approach that lets you work in an integrated software environment, using a single model of a function or a complete system that is also an executable specification.

Development Tools
The model-based development process results in an optimized and fully tested system, with no risk that individual components do not fit together optimally. dSPACE systems support model-based design because of its many advantages. To model controller strategies and the internal behavior of software components, tools such as MATLAB®/Simulink®/Stateflow® from The MathWorks and TargetLink (p. 14) from dSPACE can be used. For verification in the real environment, such controller models can be integrated into dSPACE prototyping systems (p. 10). Moreover, TargetLink is ideal for designing software components that will be used in SystemDesk (p. 7), dSPACE’s system architecture software for starting model-based design at system level. In SystemDesk, several software components can be combined to form a software architecture that can be used as a part of an overall system model.

Overview
- MATLAB® is an integrated development environment for numeric computations, with a large library of mathematical analysis techniques. Application-specific toolboxes are also available.
- Simulink® is integrated into MATLAB® as an interactive environment for modeling, analyzing, and simulating. You can create models based on block diagrams via drag & drop.
- Stateflow® extends Simulink® with options for implementing state charts.
- Real-Time Workshop and Stateflow® Coder are used with dSPACE’s Real-Time Interface to provide a seamless transition from block diagram to dSPACE real-time hardware. Simulink models can be integrated in SystemDesk (p. 7) by using Real-Time Workshop.
- TargetLink (p. 14), the production code generator from dSPACE, comes with its own blockset, a subset of Simulink that is highly suitable for modeling control functions.
Rapid Prototyping

As a design engineer, you have one main concern: You want to concentrate completely on your ECU functions, and run quick and targeted trials of your designs. Not only offline, but in the actual vehicle or on a test bench. Producing a prototype would be expensive and inefficient. The ideal solution is to use a dSPACE prototyping system instead.

The Right Solution for All Applications
Whether you are developing ECU functions for the engine, gear, vehicle dynamics, airbags, comfort systems, or any other applications, you will find just the prototyping system you need in dSPACE’s comprehensive range of hardware and software products. dSPACE prototyping systems provide flexible, model-based development environments. You can optimize your function designs on the test bench or in the actual vehicle, until they meet the requirements – all without having to do any programming. Design faults are found immediately and can be corrected on-the-spot.

No Programming Needed
Function prototyping begins with graphical descriptions of control functions, created and tested in a modeling and simulation environment such as MATLAB®/Simulink®/Stateflow®. Changes to the function model can therefore be carried out fast and conveniently, and downloaded to the prototyping system via automatic code generation at a click. This procedure provides the shortest possible iteration times on the real object (vehicle or test bench): You can test and optimize your function designs immediately. A modular system of ready-made yet flexible components is also available for sensor and actuator integration, so you do not need to construct a system yourself.

Early Focus on Production Code
To streamline the process from prototyping to production, dSPACE prototyping systems allow you to think ahead and take production aspects into account while still at an early stage of development. If you follow guidelines and use the TargetLink blockset for modeling (free TargetLink Blockset Stand-Alone available), you can use the same models for rapid prototyping and for generating highly efficient production code (for more details, please contact dSPACE).
**Fullpassing and Bypassing**

**Fullpassing: Using a Prototyping System as a Flexible Experimental ECU**

If a new ECU or a new set of control functions has to be developed from scratch, quick trials have to be run at an early stage to verify the correctness of the control strategy. Producing an application-specific prototype ECU would be expensive, time-consuming and inflexible. Instead, developers can use a powerful off-the-shelf dSPACE prototyping system as an experimental ECU. dSPACE prototyping systems offer plenty of computing power and memory, and maximum flexibility.

**Bypassing: New Functions for Existing Controllers**

The dSPACE prototyping systems are ideal for developing new functions for existing ECUs or for previous or prototype versions of ECUs. The functions are implemented on the dSPACE prototyping system, while the ECU executes the existing code and takes care of input/output. Complex ECUs and short development cycles often do not allow all the software functions for new ECU generations to be developed from scratch. In these cases, existing code can simply be adapted and extended by this method, which is known as “bypassing”. The communication between the ECU and the prototyping system runs via dedicated ECU interfaces (see graphic below), and task execution on the two systems is synchronized. Sensors and actuators are interfaced via the existing harness of the ECU, and only the I/O which is additionally required needs to be connected to the prototyping system. The bypass technology of the dSPACE prototyping systems can be used on almost any ECU processor.

![Diagram](image-url)

External bypassing: New functions run on the prototyping system, while unchanged algorithms stay on the ECU.

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1) For information on possible product combinations, please contact dSPACE.
The Complete System for Rapid Prototyping

**Software and Hardware Optimally Integrated**

dSPACE prototyping systems are based on an integrated combination of software and hardware, and can be used as complete development systems for prototyping ECU software, either in a vehicle or on the test bench. The MATLAB®/Simulink® modeling tool is seamlessly integrated.

**Automatic Implementation**

With Real-Time Interface (RTI), you can implement Simulink® models on the dSPACE prototyping hardware automatically and without programming knowledge.

- Graphical configuration of all input/output interfaces in the block diagram
- Support of software interrupts
- Support of hardware interrupts (for example, for angle-based execution of subsystems such as the computation of ignition and injection times)
- Dialog-based configuration of real-time scheduling
- Automatic real-time code generation from the block diagram and download to the dSPACE prototyping hardware

**Interactive Real-Time Control**

dSPACE offers you easy-to-use, versatile software for the real-time control of your prototyping experiments. ControlDesk, for example, is a comprehensive experiment environment that makes it easy for you to manage, control, and automate your experiments. The virtual instruments you use to design the functions will also support you later during in-vehicle prototyping. You can modify parameters online, read look-up tables, and capture data during test drives. CalDesk is an experiment environment for function prototyping, calibration, and more. CalDesk is optimized for use in a vehicle, and you can perform various tasks such as function prototyping, calibration, measurement, and data analysis in a single tool.

Interfaces such as CAN and LIN are completely integrated into the block diagram.

ControlDesk interactive: Displays, plotters, sliders, and 3-D table editors.

CalDesk: Same tool for function prototyping, measurement and ECU calibration.
Versatile Hardware Platforms

The Right Hardware for Every Job
The hardware in a dSPACE prototyping systems contains at least one powerful real-time processor to compute the new functions. Bypassing lets you combine the functions you are developing with existing ECUs. Sensors and actuators can be integrated via flexible signal conditioning and power stage units. dSPACE prototyping systems are ideal for in-vehicle use, with optimally integrated hardware and software. The hardware is configured comfortably via software. There are several hardware platforms to choose from:

<table>
<thead>
<tr>
<th>dSPACE Prototyping Hardware</th>
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<td>(Selection from the overall range, with automotive focus)</td>
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**MicroAutoBox**
- High processing power
- Comprehensive input/output interfaces with typical signal conditioning
- Very compact, so usable almost anywhere in the vehicle
- Choice of CAN, LIN, and FlexRay interfaces

**AutoBox System**
- Modular system with scalable processing power and I/O functionality for the toughest requirements
- Large range of interface boards (e.g., CAN, LIN, FlexRay) and processor boards

**RapidPro**
- Flexible signal conditioning and power stages from a large selection of configurable modules (no self-construction necessary)
- Intelligent I/O subsystems
TargetLink: Production Code from Simulink®/Stateflow®

With TargetLink, function developers and production code developers can translate functions and models from MATLAB®/Simulink®/Stateflow® directly into production C code. TargetLink provides particularly efficient, high-quality implementation, which helps cut coding and development times significantly. The autocode is integrated on the electronic control unit (ECU) together with the drivers and a real-time operating system. TargetLink is being used with great success in numerous production projects all over the world, including safety-critical applications. The list of TargetLink applications covers all areas of the vehicle, such as powertrain, chassis, driver assistance, comfort, and active and passive safety systems.

TargetLink’s outstanding qualities are its automotive focus, high reliability, process integratability, and support of standards such as AUTOSAR, OSEK, and ASAM-MCD 2MC (ASAP2).

Bridging the Gap
TargetLink bridges the gap between model-based function design and production software development. By automatically generating production code straight from MATLAB/Simulink/Stateflow models, TargetLink helps function and software developers move their control strategies from block diagrams to a production-intent ECU faster and more reliably, without compromising code efficiency. This significantly shortens coding and development times and considerably enhances the quality of the production code – as described in greater detail below. The optional TargetLink AUTOSAR Module (p. 17) also makes TargetLink’s modeling, simulation and code generation features available for designing AUTOSAR software components.

High-Quality Code for Mass Production
Numerous benchmark tests and user reports show that the efficiency of TargetLink autocode is comparable to that of manual code. TargetLink translates the model, and any changes made to it, into code reliably, reproducibly, and consistently. TargetLink ensures that the autocode is always consistent with the model design. It is also easy to keep the documentation up-to-date, since this can be generated along with the code. TargetLink uses the model and the code to generate ASAM-MCD 2MC (ASAP2) files with all the information on measurement variables and calibratable variables that is needed. This means that up-to-date data is always available for calibration. Several guidelines are available for TargetLink, such as the dSPACE modeling guidelines, offering best practices for TargetLink models, and the MISRA modeling guidelines (MISRA-AC-TL) for TargetLink with a focus on functional safety (www.misra.org.uk). TargetLink-generated code respects the vast majority of MISRA C rules. If deviations from the MISRA C standard are a technical necessity, they are identified and well documented.

Reduced Development Time
Working together, model-based development and automatic code generation cut the time needed for coding. But that is not all: They also speed up the iterations performed in the ECU software development process. You can implement and try out changes fast, and verify their impact immediately via simulation – once again saving time and avoiding errors. Overall, TargetLink helps you master increasing complexity despite shorter development times, and achieve highest code quality. Our customers routinely generate large parts of their ECU code with TargetLink, and save up to 50% of their total development time for ECU code by doing so.
More Than Just a Production Code Generator

**Code Efficiency**

Efficiency is the key to production-quality code. Efficient code is code that requires a minimum of execution time, RAM resources, ROM resources, and stack size when run on an embedded processor. TargetLink has been specifically designed for production-quality autocoding. It can easily match the efficiency of human programmers in terms of memory consumption and execution speed – without compromising readability. TargetLink uses a variety of state-of-the-art optimization techniques to meet the high standards that apply to production code generation. TargetLink can generate specially optimized code for a wide selection of processor/compiler combinations. This can be either fixed-point or floating-point code, or a mixture of the two.

**Configurable Code**

Autocoding offers more than just efficiency. When code runs on preconfigured prototyping hardware, how it looks is irrelevant. But when code has to be implemented on a production ECU, many of its details become quite important. The memory layout has to be managed, efficient ways of embedding external code are needed, and the code output format must comply with specific standards. The precise way in which TargetLink autocodes can be customized to meet these needs.

**Process Integration**

TargetLink is easy to integrate into existing development environments. All processes can be automated via the TargetLink API. The dSPACE Data Dictionary, a special tool for managing data, manages the data for the model and allows data import/export from and to existing in-house data dictionaries or other file formats. TargetLink can also generate an ASAM-MCD 2MC (ASAP2) file containing all the information about measurable and calibratable variables, and for implementation on OSEK/VDX-compliant operating systems, it generates code according to the OSEK/VDX OS standard. In addition, TargetLink performs autocoding for AUTOSAR software components and exports the standardized AUTOSAR software component description.

**Model-Based Testing**

As software becomes increasingly complex and development cycles shorter and shorter, it is vital to test the software as early and as thoroughly as possible. One major advantage of using model-based design methods with integrated tools like TargetLink is that you can perform verification at an early stage by means of simulation, without changing the development environment.
Software Verification and Validation

Integrated Test Environment
Although automatic code generation produces virtually flawless results in comparison to manual programming, the autocode itself and the underlying specification still need to be tested. TargetLink provides powerful, easy-to-use means of verifying the generated code. The code tests are performed in the same development environment that was used to specify the underlying simulation model. If the results of block-based and state-chart-based simulations match the results of the code test, the code is functionally identical to the model.

Test Against Specification
Verification means checking the implementation against the specification. The specification is the simulation model executed by Simulink and Stateflow; it was already tested and can therefore be used as a reference. The implementation is the C code that was generated and compiled; it is executed on the target processor. TargetLink provides an environment for a three-step process verifying that the specification and the implementation are functionally identical:

- Simulating the function model on the development PC (host PC) as an executable specification – called model-in-the-loop (MIL) simulation.
- Simulating the autocode on the development PC – called software-in-the-loop (SIL) simulation. The autocode is translated by a host compiler.
- Simulating the autocode on an evaluation board, which typically contains the target processor used in the ECU – called processor-in-the-loop (PIL) simulation. The autocode is translated by the appropriate target compiler.

The simulation results can be compared very conveniently in TargetLink (signal logging/plotting).

Other Testing Options
The simulations are supplemented by code coverage analysis. While Simulink provides various coverage metrics at model level, TargetLink supports measurements for statement coverage and decision coverage at code level during the simulation or test run. For example, it is possible to identify code parts that are never executed despite a large number of tests. Additional test cases can then be defined especially for these parts. In some cases, specific parts of the model or code may even be removed if they are unreachable and therefore superfluous.

There are several external test tools that support testing with TargetLink (for example, for model checking and test vector generation).
**Flexibility via Modularity**

**Modularity That Keeps Pace**
The basic module, the TargetLink Base Suite, can be extended by optional modules with additional functionalities. These include options for optimized code generation for different processor/compiler combinations.

**TargetLink Base Suite and TargetLink Blockset**
The TargetLink Base Suite contains all the functions needed for autocoding. At the click of a button, it generates highly efficient ANSI C code for a controller model. The TargetLink Base Suite includes the TargetLink Blockset, which can also be obtained as a stand-alone version free of charge. TargetLink models can therefore be developed without the TargetLink Base Suite. This greatly reduces costs when TargetLink is used by a team, since not all the workstations need to have full autocoding functionality.

**Optimization and Simulation Modules**
TargetLink’s code efficiency can even be increased by using a Target Optimization Module to generate target-optimized code for a specific processor/compiler combination. The Target Simulation Module supports different target processors, so developers can test the generated C code directly on an evaluation board equipped with the target processor. The advantages are that the autocode is translated by the target compiler itself, and the actual execution times and memory consumption for the functions generated by TargetLink can be measured at an early stage.

**OSEK/VDX and AUTOSAR**
The OSEK module supports multirate autocoding in compliance with the OSEK/VDX operating system standard. Tasks can be defined at model level and used in the simulation process. A module that supports AUTOSAR software components ensures AUTOSAR-compliant modeling using a special blockset and also AUTOSAR-compliant autocoding. AUTOSAR component description files can be exported in XML format.

<table>
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<th>TargetLink Module Overview</th>
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<tr>
<td><strong>TargetLink Base Suite</strong></td>
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<td>ANSI C-coder</td>
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<td>Data Dictionary(^1)</td>
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<td>TargetLink Blockset(^2)</td>
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<td>Document-generator</td>
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<td>Worst-case autoscaling</td>
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<td>ASAM-MCD 2MC file generation</td>
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<td>Infineon C16x</td>
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<td>NEC V850</td>
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<td>Renesas M32R</td>
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<td>Renesas SH-2</td>
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<td>Texas Instruments TMS470</td>
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<td><strong>Target Simulation Module</strong></td>
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<td>OSEK/VDX module</td>
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<td>AUTOSAR module</td>
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\(^1\) Data Dictionary Manager also available as a standalone license
\(^2\) Can also be used without Base Suite license
Test drives are an expensive business. They often take place in the freezing cold or the searing heat to test ECUs in extreme conditions. And these are just some of the difficulties you face as an ECU tester. A more serious problem occurs when testing is delayed because vehicle prototypes are not ready on time. This violates the principle of simultaneous engineering, in which development processes run in parallel.

**ECU Testing: The Key Phase**

As the complexity and size of software increases at a breathtaking pace, comprehensive ECU tests are necessary more than ever before. Without such tests, the risk of vehicle recalls is unavoidable. Test drives are affected by the weather and require vehicle prototypes. Actual physical danger and incomplete test results also give test engineers a hard time. Not to mention the fact that the tests cannot be reproduced or automated, and are immensely time-consuming and expensive. The same applies to test benches.

That is why almost all automotive OEMs and suppliers have made ECU tests with hardware-in-the-loop (HIL) simulation a key phase in their development and release processes.

**Virtual Test Drives**

In hardware-in-the-loop simulation, ECUs are connected to a simulator for testing instead of being installed in a real vehicle. The environment is simulated as a model in real time. Virtual test drives can be made long before the first vehicle prototype has been produced, saving an enormous amount of time and money. Moreover, a simulator can handle test drives outside the safe limits, where using real vehicles would be impossible. Any arbitrary operating point can be set, for example to utilize the entire engine torque range. The tests are reproducible and automatable (lights-out testing).

For virtual test drives, the models themselves and the calculations performed for them have to be real-time-capable. The sensor signals to be generated are extremely complex in reality, and simulating them is another major challenge. For example, the actuator control signals have to be captured, and loads have to be simulated to “outsmart” the ECU’s diagnostic functionality. dSPACE has years of accumulated know-how in developing simulators, and can give you excellent solutions for all these exacting requirements.

dSPACE constructs several hundred simulators every year and is the world market leader as an ECU-independent specialist for hardware-in-the-loop simulation. For our customers, dSPACE Simulator is the key to testing ECUs fast, automatically, and at lower cost.
The complexity and multilayered nature of modern ECU software means that every ECU has to be tested from all angles. dSPACE Simulator covers every conceivable test scenario.

### Verifying Control Algorithms
In the verification of control algorithms, ECUs are operated in the normal way and checked against the specifications. This is done by running virtual test drives on as many different vehicle and component versions as possible, either manually or in automated form. Moose tests for ESP control units and standard drive cycles, such as FTP75 for testing engine controls, are well-known examples.

### Testing Diagnostic Functions
Testing diagnostic functions (such as OBDII and EOBD) involves observing the ECUs’ response to failures. The vehicle is simulated in a closed control loop and systematically runs through all the defined operating points, including the inserted electrical faults. Any errors that occur are recorded in the ECU and can be read out by diagnostic tools. Typical diagnostic tests relate to the plausibility of signals or defective electrical connections. Diagnostic tests have to be completely automatable to minimize the time taken by the release tests that come at the end of the development phase. dSPACE Simulator flexibly creates scenarios for all kinds of ECUs, to help you cope with the great diversity of variants.

### Integration Tests on Networked ECUs
In integration tests on networked ECUs, the main concern is to test the interaction between all the ECUs in a network such as CAN, LIN, MOST, and FlexRay. Network tests are mainly necessitated by the growing number of ECUs from different manufacturers that perform their overall function only when networked. For ECU network testing, either the whole vehicle is simulated, or individual ECUs that are not yet available. These are then gradually replaced by their real counterparts.

### ECU Calibration
Modern simulators can be used to carry out some of the ECU calibration tasks at a very early stage. This is important because the number of ECU parameters, and their mutual effects, is growing fast, making it increasingly difficult to get the final vehicle right. Realistic vehicle models enable ECUs to be parameterized in advance in the lab, even automatically. This means less work in the subsequent calibration process.

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**Vehicle Dynamics**
- Active front steering
- Electronic stability program (ESP) including subfunctionality (ABS, ASR, ...)
- Electronic air suspension
- Continuous damping control
- Electronic parking brake
- Electronic wedge brake

**Diesel**
- Up to 24 cylinders
- Turbocharger
- EGR
- Common rail and unit injection
- Exhaust systems, incl. DPF, SCR
- In-cylinder pressure sensors
- Passenger car, heavy-duty trucks, off-highway vehicles

**Gasoline**
- Up to 16 cylinders
- Manifold injection
- Direct injection
- EGR
- Formula One engines
- Turbocharger

**Driver Assistance Systems**
- Adaptive cruise control (ACC)
- Lane departure warning
- Park assist systems

**Vehicle Types**
- Passenger cars
- Light trucks
- Heavy-duty trucks
- Off-highway vehicles
- Formula One

**Multimedia/Infotainment**
- Radios, amplifiers
- Displays
- MMI (man-machine interface)
- Head unit

**Others**
- Body electronics
- Comfort electronics
- Air-conditioning control systems (HVAC)
- Restraint systems (airbag, belt pretensioner)
- Door modules
- Seat modules
- Interior and exterior lighting
- Vehicle with trailer

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**Test Scenarios with dSPACE Simulator**

The complexity and multilayered nature of modern ECU software means that every ECU has to be tested from all angles. dSPACE Simulator covers every conceivable test scenario.
Turnkey Systems for ECU Tests

dSPACE Simulator is a turnkey system that provides everything you need to perform ECU tests in a hardware-in-the-loop environment. All the software and hardware components are modular and can be put together to create individual, turnkey solutions for use in all vehicle domains. The result is a highly transparent overall system of integrated hardware and software components that sets new standards.

Automotive Simulation Models (ASMs)
The Automotive Simulation Models (ASMs) are open Simulink models for the real-time simulation of automotive applications such as diesel engine, gasoline engine, and vehicle dynamics, even whole virtual vehicles. The implementation of each model is viewable right down to Simulink basic block level, so it is easy to supplement or replace components with customer-specific models. This means that the properties of each model can be optimally adapted to individual projects. ModelDesk is a graphical tool that makes it easy to parameterize components, and also to create roads and driving maneuvers.

Visualizing Virtual Test Drives
The MotionDesk software visualizes virtual test drives in 3-D online animations, making it much easier to observe simulated mechanical systems. As an aid to choosing the best control strategy, you can play several simulations synchronously to compare and evaluate vehicle behaviors.

Instrumentation
You can instrument and automate your dSPACE Simulator test runs from your PC. The ControlDesk software is used during test development to create layouts and test sequences that are tailor-made for your application. A subset of functions can be selected to make the test system quicker to learn and to protect your completed experiments against undesired modifications.

Together, the dSPACE Simulator and dSPACE software form a perfectly coordinated turnkey system.
Automating Tests
Test automation ensures systematic ECU testing. The AutomationDesk test automation tool sets new standards with regard to planning, systematization, and reusability.
- Tests based on measurement data or scripts, e.g., slalom tests or FTP drive cycles
- Variation of model parameters during run time, for example, speed, gear change, friction coefficient

Intelligent Hardware Architecture

Powerful Processor Hardware
In today’s hardware-in-the-loop environments, complex vehicle dynamics models with 40 or more degrees of mechanical freedom, requiring calculation in less than 1 ms, are not uncommon. The dSPACE hardware provides unprecedented computing power and I/O flexibility.

Modular Hardware
Modular design ensures that you can extend your system any way you want – in terms of I/O, the number of processors, connection to other simulators, and simulator networks. dSPACE Simulator can be adapted to new requirements faster than any other system. As an option, dSPACE can integrate your own hardware components or third-party hardware such as:

Sensor Signal Simulation
Simulating sensor signals is a particular challenge to hardware-in-the-loop simulation. For example, powerful I/O hardware is required to generate crankshaft-synchronous signals and to simulate faulty sensors. dSPACE Simulator includes intelligent I/O cards that generate and measure signals independently and flexibly by themselves. Signal conditioning, failure simulation, and load simulation with substitute and real loads are based on an intelligent modular concept that guarantees quick configuration and maximum flexibility.

Signal Generation and Measurement
These are just a few of the automotive signals that can be generated and measured by dSPACE Simulator:
- Algorithm- and waveform-based signal generation (crankshaft, camshaft, knocking signals, etc.)
- Generation of PWM sensor signals and Hall sensor signals (wheel speed, fuel level, etc.)
- Generation of resistance-based sensor signals (temperature, etc.)
- Generation and measurement of analog and digital sensor signals (throttle, switches, lamps, relays, etc.)
- Simulation of linear lambda probes
- Angle-based measurement of injection and ignition pulses
- Measurement of PWM actuator signals (solenoid valves, etc.)
- Connection to CAN, LIN, FlexRay, MOST, and serial interfaces
Future-Proof ECU Calibration

Software parameterization, also known as ECU calibration, is a standard part of ECU development. Apart from actual functionality, the key criteria for a calibration tool are a guaranteed future, the investment cost, and integration ease. Usability and a first-rate support service are also decisive. The dSPACE Calibration System gives you mature solutions for performing your measurement, calibration, and diagnostic tasks – in the vehicle, at the test bench, or at your desk.

Modern Vehicles: Computers on Wheels
In-vehicle electronics and software have advanced alongside processor technology over the past few years. This is reflected in almost every aspect of the vehicle, from engine management to safety and comfort. The number of parameters to be processed during ECU calibration already runs into the thousands in some areas, and will continue to grow. Constantly expanding functionality, and increased networking of functions and ECUs, are major challenges for control engineers. They need optimized working procedures and tools to meet these challenges.

Minimizing the Workload
Coping with calibration tasks generally requires a lot of human and material resources at automotive manufacturers and ECU suppliers. A correspondingly large number of calibration and measurement systems are in use, involving high costs for acquisition, maintenance, training, and support. In the face of stiff competition and growing pressure on prices, economy and investment protection are vital. To keep the cost of calibration within reasonable bounds, the objective must be to perform tasks with restricted resources, using tools that cover a wide range of application scenarios.
One System for Many Interfaces

So Many Scenarios
Modern vehicles contain widely varying ECUs from different manufacturers and a diversity of ECU interfaces. The dSPACE Calibration System supports numerous ECU interfaces and calibration concepts. It provides an emulation memory that can be adapted to widely varying microcontrollers and ECUs, and a generic serial interface. This allows calibration to be performed via different on-chip debug interfaces such as JTAG/Nexus, JTAG/SDI, JTAG/OCDS, NBD and AUD/AUD2. The ASAM standards XCP and CCP are also supported. Calibration tasks can be performed both offline and online. The dSPACE Calibration System supports concepts with one and two calibration pages.

Flexible Interface Concept
In addition to calibration interfaces, the dSPACE Calibration System also provides interfaces for CAN and LIN monitoring, CAN data output, and diagnostic tasks. This includes support of KWP2000 on K-Line, KWP2000 on CAN, Transport Protocol TP 2.0, Unified Diagnostic Services (UDS), and GMLAN. dSPACE also offers an XCP Service for the CAN, USB, and Ethernet transport layers, supporting a wide variety of application scenarios: function bypassing via external prototyping systems, calibration, measurement data capture, and ECU flash programming. In addition to XCP, the dSPACE Calibration System also provides options for flashing ECUs via the emulation memory, the generic serial interface, and the diagnostic interfaces. The serial DCI-GSI1 interface can be used to write to ECUs completely independently of previous programming. This is called brain-dead flash programming. No boot loader is required on the ECU as it is in flash programming with XCP.

Overview of the ECU interfaces of the dSPACE Calibration System.
Flexible Hardware

Minimal Hardware Requirement
The dSPACE Calibration System requires only a few hardware components to process measurement, calibration, and diagnostics tasks. The host PC, and the application interfaces in or on the ECU, are connected directly via USB, with no additional hardware. The USB standard has several advantages: USB is an established standard PC interface with long-term availability that allows a high data throughput and Plug & Play. To meet the automotive field's tough requirements regarding temperature, robustness, and sensitivity, dSPACE offers special USB cables, for example, with integrated galvanic separation and for covering long distances. The hardware of the dSPACE Calibration System has been designed for reuse across projects: Thus, both the emulation memory and the generic serial interface can be adapted to greatly varying ECUs.

Adding Interfaces as Required
dSPACE's Calibration Hub provides two USB 2.0 and two CAN interfaces as standard. Cascading several Calibration Hubs is a simple, cost-efficient way of extending the number of interfaces to match requirements precisely. Such scalability ensures maximum flexibility for processing a great diversity of calibration scenarios.

Integrate Measurement Modules as Required
Calibration often involves capturing different physical variables such as pressure and temperature. The interface concept of the dSPACE Calibration System enables you to integrate measurement modules from different manufacturers into your system, so you can run the dSPACE Calibration System with your existing measurement equipment.
Scalable Software

Scalable by Software Modules
CalDesk is scalable measurement and calibration software that can be adapted inexpensively to tasks in the fields of rapid prototyping, ECU diagnostics, and automation. In addition to standardized calibration interfaces to the ECU, standard interfaces for automation purposes also play an important part. To reduce the work involved in the calibration phase, automobile manufacturers are increasingly shifting calibration tasks to the test bench or solving them by simulation techniques such as HIL tests. This requires a powerful automation interface for measurement, calibration, and diagnostics tasks. CalDesk provides such an interface in the form of ASAM-MCD 3.

Diagnostics with CalDesk
Diagnostics based on Open Diagnostic Data Exchange (ODX) integrate seamlessly into CalDesk. Measurement, calibration, and diagnostics tasks can be performed in one and the same development environment. The advantages of this include the time-correlated capture of measurement data and fault memory entries. Moreover, the same interface hardware can be used for measurement, calibration, and diagnostics, so hardware setups are simpler and less expensive. The diagnostics module also supports ECU flash programming via a diagnostic interface.

Function Prototyping and Bypassing
CalDesk is used for rapid prototyping and bypassing tasks as well as calibration. Bypass technology plays an important part in function development, as a simple method of optimizing or extending ECU functions (p. 11). The complexity of ECU functions and pressure on development times are making it necessary to perform calibration tasks as early as the control design phase. This makes it all the more important to have a single tool for function prototyping, calibration, and diagnostics.

The intuitive user interface of CalDesk, the measurement and calibration software.

CalDesk has additional modules for adaptation to different tasks.
Success Stories

dSPACE systems are used in numerous applications throughout the automotive industry and by a wide range of customers – with great success, as the following examples show.

Standardized Development Systems

Many manufacturers and suppliers have realized that standardized development systems can streamline and shorten development phases. dSPACE products support modern processes and a seamless development tool chain, which reduces the manual workload and avoids expensive errors.

Satisfied Customers

dSPACE systems are being used successfully by customers such as Audi, Behr-Hella, BMW, Caterpillar, Daimler, DENSO, Fiat, Ford, General Motors, Hitachi, Honda, Magneti Marelli, Mitsubishi, Motorola, New Venture Gear, Nissan, PSA Peugeot Citroën, Renault, Toyota, Visteon, Volvo, VW, various Formula One teams and many more, in fields such as engine, powertrain, vehicle dynamics, comfort, interior systems, noise cancellation, pollution reduction, cruise control, brake assistance, and diagnostics.

The following success stories will give you an idea of the wide range of applications in which dSPACE systems are used.

Valeo: Eco-Friendly Starter-Generator

dSPACE Tools for the Whole Development Process

Valeo Electrical Systems, a member of the Valeo group, used dSPACE tools throughout the entire development process for a reversible, belt-driven starter-alternator. This innovative concept brings together the features of an alternator and a starter in one product to reduce fuel consumption and CO₂ emissions.

The development process started with automatic code generation with TargetLink and continued with other dSPACE tools combined with Valeo facilities and methodologies. dSPACE Simulator, ControlDesk and AutomationDesk were used for validation and testing.

The StARS micro-hybrid system: electric machine, three-phase cable, and control box.
MAGNA STEYR: Hybrid Drive

MAGNA STEYR and its cooperation partners integrated new hybrid components in a production vehicle and implemented a control system using a dSPACE prototyping system (MicroAutoBox plus RapidPro). The hybrid demo vehicle HySUV (Mercedes M-class) with a dSPACE prototyping system as the central drivetrain control made the hybrid drive a reality. MAGNA STEYR and its partners use the demo vehicle as a platform for further optimization of vehicle behavior, consumption, and emissions.

Drive Systems for the Future
MAGNA STEYR worked with MAGNA POWERTRAIN and Siemens VDO1) to develop modular hybrid drive systems (combustion engine plus electric drive), building on research findings from K-net KFZ, the competence network for “Vehicle Drives of the Future”. With the support of the OEMs, hybrid components developed by MAGNA are integrated in the drivetrains of prototypes to investigate optimization potential for consumption, dynamics, and emissions. The control system and the cross-linking of new components in the drivetrain are implemented with the dSPACE prototyping system (MicroAutoBox plus RapidPro) according to a central hybrid drive strategy. MAGNA STEYR put all this into operation in the hybrid demo vehicle HySUV. The automatic transmission and transfer case of an ML350 were replaced by an automated manual transmission and a hybrid module. A full hybrid drivetrain with electrical all-wheel drive was implemented in this way.

Prototyping Hardware and Function Development
The control software comprises the functions and interfaces of the entire torque path in the drivetrain. The objective was to control all the components of the hybrid drivetrain with just one prototyping system. The MicroAutoBox chosen for this has since become a standard tool at MAGNA STEYR. Internal or external hardware development did not make sense due to the limited development time and the small quantity needed. MAGNA STEYR therefore decided to use the RapidPro system. Its flexibility, provided by software- and hardware-configurable signal I/O, proved to be an advantage, particularly in early phases of prototype development when the sensor and actuator systems are not yet completely defined. After the function software had been successfully implemented and tested, MAGNA STEYR entered the test drive phase, with the objective of further software optimization.

Demo vehicle HySUV: All the components of the hybrid drivetrain are controlled via the dSPACE prototyping system (MicroAutoBox plus RapidPro hardware).

1) today: Continental.
Ford Otosan: Active Chassis Control

A Ford Transit Connect equipped with continuous damping control (CDC) dampers and a double pinion active steering system is being used by Ford Otosan (Turkey) for research on active chassis control. The dSPACE system (MicroAutoBox and RapidPro) is used for implementing the active chassis controller. The research vehicle has a semi-active suspension controller that works in coordination with the steering controller for improved ride and handling characteristics. The dSPACE system allows easy modification of the control algorithms being tested.

Semi-Active Suspensions
Passive suspensions require a compromise between the requirements ride comfort and handling performance. Active suspensions allow the best of both worlds at a relatively high cost. Semi-active suspensions are the intermediate, lower cost solution. Semi-active CDC dampers were used to improve ride comfort without compromising the handling performance of the Ford Transit Connect research vehicle. Skyhook, groundhook and hybrid CDC control algorithms were tested using the MicroAutoBox and RapidPro system for implementation and rapid controller prototyping (RCP). Testing was conducted at the Ford Otosan grounds, on a four-poster and on a test road with different levels of surface irregularities.

Active Chassis Control and Instrumentation
In active chassis control, the semi-active suspension and active steering controllers work in cooperation. The active steering either mimics the original hydraulic steering behavior of the Ford Transit Connect or works as a programmable, compliant steering system. The CDC dampers are adjusted to reduce undesired body motion transients during handling maneuvers and when the yaw stability controller is active. The RapidPro and MicroAutoBox combination with its software programmable signal levels, large variety of I/O choices and rapid controller programming feature have facilitated research vehicle implementation.

Hardware-in-the-Loop-Tests
Instrumentation of the research vehicle including the dSPACE systems, control algorithm development and implementation are carried out by the teams provided by Ford Otosan and the Autocom (Automotive Control and Mechatronics Research) center. An active steering hardware-in-the-loop (HIL) test system at the Autocom center is used for steering controller designs before the test vehicle implementation phase. This HIL test system has the same hardware as the research vehicle. A quarter car semi-active suspension control HIL test setup is being built at the Autocom center for developing the CDC controllers before research vehicle testing.
Dongfeng: Automated Manual Transmission

Vehicles with automated mechanical transmission (AMT) combine the comfort features of an automatic transmission with the cost advantages of a manual gearbox. A research team at Dongfeng developed a new Automated Mechanical Transmission based on the EQ4195 truck with a 12-speed manual transmission. The system consists of a 12-speed mechanical gearbox and an automatic shift control system (ASCS). The ASCS includes several sensors and actuators, and a transmission control unit (TCU). The actuators are powered by air supply. The TCU takes input signals such as velocity, brake pedal position, gas pedal position, and engine speed into account to control the actuators. The input signals are delivered by directly connected sensors or derived from the vehicle CAN.

To implement the model on the TCU equipped with a Freescale MC9S12DT128B microcontroller, fixed-point object code had to be generated. The automatic scaling features of TargetLink were of great help in fine-tuning the fixed-point code. Automatic scaling was a huge time saver as it took away the tedious and error-prone task of manually scaling each variable and each operation in the software. The precision of the scaled code was easily judged by comparing model-in-the-loop (MIL) with software-in-the-loop (SIL) simulations; errors like overflows were detected that way. The final object code was generated using the CodeWarrior compiler and merged with custom code.

When the production code generator TargetLink is used, the definition of the module function is clearer, and implementing and validating the arithmetics is more convenient and takes less time. The model data is completely managed in TargetLink. In addition, the A2L file which is required by the calibration software also can be generated with TargetLink. Overall, the efficiency and quality of development can be greatly improved.

By implementing this automatic shift control system, the Dongfeng research team has succeeded in considerably reducing fuel consumption and improving powertrain efficiency. For example, the driver has much less work to do than with the predecessor systems.

The tool chain supplied by dSPACE, with its largely automated procedures, makes the process to a large extent seamless and ensures very good reproducibility. This considerably reduced the time used to develop the TCU and also increased the quality of the code that was produced, and greatly facilitates the development and implementation of control systems.

The automatic shift control system was developed for the EQ4195 truck from Dongfeng.
Audi: Systematic AUTOSAR Migration

Audi implemented a shock absorber control that complies with the AUTOSAR concept. This project provided important insights on setting up a tool chain in which TargetLink is used for modeling and generating AUTOSAR-compliant ECU software.

**Shock Absorber Control**
The control consists of four body acceleration sensors, four distance sensors, and four continuously controlled shock absorbers. A central ECU evaluates the sensor signals and calculates the shock absorber control, taking into account further vehicle dynamics variables such as the steering angle, yaw rate, brake signal, lateral acceleration, vehicle speed, and engine torque. The ECU receives these variables from the vehicle’s CAN bus. The ECU communicates with the active shock absorbers via a FlexRay bus.

**Prototype Development Environment**
- TargetLink for model-based development and automatic production code generation for AUTOSAR SWCs
- Elektrobit’s EB tresos® for configuring the AUTOSAR-compliant basic software (e.g. OS) and generating the run-time environment (RTE)
- Configuration tools for the FlexRay stack
- Production-close ECU prototypes

**AUTOSAR Software**
TargetLink supports AUTOSAR-compliant modeling with AUTOSAR blocks. The AUTOSAR-specific data for SWCs, runnables, interfaces, etc., is stored in the dSPACE Data Dictionary and linked to the actual model. Thus, the entire workflow established for model-based design with TargetLink can also be applied to developing AUTOSAR software.

An AUTOSAR function model can be simulated and tested with TargetLink at the model (MIL) and the software (SIL) level. As well as generating the AUTOSAR-compliant code, TargetLink automatically produces the AUTOSAR software component descriptions. The shock absorber control is subdivided into several AUTOSAR software components, each comprising several runnables.

**Implementing the AUTOSAR Software**
The AUTOSAR operating system was configured and the RTE was generated by EB tresos®. The Infineon TriCore microcontroller family was used to set up the prototype. Successful function implementation on the production-close ECU was verified both in test drives and in tests on the simulator. These clearly showed that the AUTOSAR-compliant code generated by TargetLink meets the production requirements on size and run-time behavior.
Daimler: TargetLink for Engine Controls

To benefit from process standardization in the powertrain development of electronic control units (ECUs), the Engine Control department at Daimler has switched completely to automatic code generation for the function and software development of in-house functionalities. TargetLink passed exhaustive testing and proved its abilities as a production code generator. This is partly thanks to its technical features and to the ease with which it could be adapted to Daimler’s requirements and integrated into the existing development environment.

Standardization for Greater Transparency
One of Daimler’s major objectives in ECU development is to streamline the cooperation between different development areas. They place great importance on constantly improving and simplifying the exchange of models between individual developers and teams by means of standardized development processes. TargetLink plays a major role in their standardization efforts, as the automatically generated code avoids the individual differences inherent in handcoding and thus eliminates the majority of possible error sources. This ensures maximum transparency throughout the entire in-house process.

Function Development with TargetLink
As the basis for code generation, Daimler provided a special Simulink® block library for automotive applications, and dSPACE adapted this to TargetLink. The design engineers implement the models in TargetLink, supported on site by dSPACE from the Project Center in Stuttgart whenever requested. This cuts traveling times and ensures a fast response when queries arise. dSPACE support includes individual adaptations and developments in the areas of autoscaling and support of model-based tests (code coverage). The Engine Control department is now performing further development and the development of new functions exclusively on the basis of TargetLink. Moreover, code generated automatically using TargetLink is also being integrated into existing projects.

Same Code for Same Model Components
The Powertrain Control department sees the great advantage of automatic code generation with TargetLink, compared to the procedures previously used, in the consistency of the generated code with the model, and in having the same code for comparable model components. This allows functions that are needed in different projects to be interchanged easily.
Deutz: Dynamic Models

**Release Tests for Diesel Engine ECUs**
To run release tests on its electronic control units (ECUs) for diesel engines, Deutz AG is using a system that includes dSPACE Simulator and the ASM Diesel Engine Simulation Package. Fast ECU variant handling, test automation, and the ability to change model parameters during run time all add up to efficient ECU testing.

**Flexible Diesel Engine Model**
Four ECUs from different suppliers can be run with the Deutz HIL system, including controllers for the pump-nozzle, pump-line-nozzle and common-rail injection systems. The dSPACE engine model allows problem-free switching between the three injection systems, plus parameterization and simulation. As well as the engine model itself, the dSPACE ASM Diesel Engine Simulation Package includes a transmission model and a vehicle dynamics model. All model parts are open, so they can easily be extended to suit different engine variants.

The Deutz TCD 2015 V8 4V weighs approx. 1280 kg and has a maximum torque of 3050 Nm.

FEV Motorentechnik: Hybrid Drive Operating Strategy

**HIL Simulator for Validating Motor Control**
A combination of a turbocharged engine and an electric motor delivers the same power as a larger naturally aspirated engine, but consumes less fuel and cuts toxic emissions. A project running at FEV Motorentechnik aims to optimize the operating strategy for these "downsized engines". They consume considerably less fuel, yet have excellent acceleration behavior. FEV is using a hardware-in-the-loop (HIL) simulator from dSPACE to validate the engine control.

**Real and Modeled Components**
The real components in the set-up were the engine control of the original vehicle and the hybrid control. In addition to these, some of the original engine’s actuators and the cockpit module were connected to one another on a breadboard via the engine cable harness. Where powertrain components were not available, they were modeled with MATLAB®/Simulink® and downloaded to the DS1005 via Real-Time Workshop®. These included the engine and the electric motor, the supercap unit, the clutch, the transmission, the longitudinal dynamics of the drivetrain, and the driver.
Scania has set up an integration lab to perform automated testing of networked electronic control units (ECU). The integration lab is based on HIL simulators and real-time Automotive Simulation Models (ASMs) from dSPACE. It is a virtual rebuild of a Scania bus/truck, equipped with 33 ECUs and 11 CAN networks. The lab’s architecture allows a larger number of possible vehicle configurations to be tested, making it ideal for performing regression tests. For heavy truck and bus manufacturer Scania, the sheer volume of testing required to evaluate the complex vehicles has made manual testing a virtual impossibility and automated testing a necessity. Scania conducted in-depth testing to verify the communication between various ECUs carrying out multiple functions across multiple communication buses.

**Networked Simulators**

The heart of the Scania integration lab includes five Simulator Full-Size racks from dSPACE and associated ECU racks. The racks are equipped with various I/O devices. Several processor boards are connected via Gigalink cables, so that the Integration Lab is a comprehensive multiprocessor system. All the ECUs and connections are outlined in a 50-MB Simulink® model. All the tests are visualized by MotionDesk, which gives a realistic view of the moving truck’s behavior. This environment has enabled Scania to bring a much wider range of vehicle variants into its testing loop.

**Simulation Models**

Two of the five simulator racks are dedicated to the integration testing of powertrain and mandatory truck ECUs. The simulation models that Scania uses for the tests are the Diesel Engine Simulation Package and exhaust gas aftertreatment models from dSPACE’s ASMs. Two further simulator racks are dedicated to the testing of vehicle dynamic ECUs. The ASM Diesel Engine Simulation Package and the ASM Vehicle Dynamics Simulation Package for Trucks were used for testing all the networked truck ECUs. By also using ASMs for another powertrain simulator, Scania was able to exchange model parts and parameterization sets between the different systems efficiently.

**Benefits of the Integration Lab**

The integration lab demonstrates that dSPACE Simulator technology is capable of handling complex vehicle networks. Script-based testing enhances reproducibility. The ability to conduct regression testing on multiple ECUs across distributed functions with interchanging variants has greatly simplified Scania’s process for developing and testing ECUs.
Mitsubishi Motors: Virtual Outlander

To develop the Mitsubishi Outlander, a test system was required for the over 20 networked electronic control units (ECUs) and various electric drives. Mitsubishi aimed to meet market launch deadlines and also fulfill quality requirements by running early integration tests on the networked functions. The test system was designed as a virtual vehicle consisting of a network simulator and the Automotive Simulation Models (ASMs) from dSPACE.

**Special Requirements**
The variant diversity and various internal requirements resulted in the following requirement profile for the test system:

- Simulation of three different engines: 4- and 6-cylinder gasoline and 4-cylinder diesel
- Simulation of continuously variable transmission (CVT) and automatic transmission
- Integration and simulation of supplier models (transmissions, electric drives)
- Simulation of lock logics for electric doors and electric glass roof
- Different country variants: Japan, USA, Europe
- Installation of real parts such as power windows and power hatch in the HIL environment

Different hardware versions of some ECUs had to be included. This required simple version detection on the part of the test system so that the correct test models are automatically activated when the ECU changes. Another requirement was to perform automated monkey tests for all the vehicle’s driver functions that can be activated by switch or button.

**Configurable Virtual Vehicle**
The specified system is called a virtual vehicle and is equipped with push-button configuration for different variants. It consists of five networked HIL simulators, to which all the ECUs and real parts have to be connected. The models of the components to be simulated are installed on the simulators. For the engines and vehicle dynamics, these are the ASMs from dSPACE. The models of various electric drives and the CVT were provided by the suppliers and integrated into the dSPACE models.

**Virtual Vehicle in Action**
The virtual vehicle based on networked dSPACE simulators enables Mitsubishi to test all the ECU functions in the Mitsubishi Outlander, including diagnostic functions, reliably and systematically with a single test system. In addition to the systematic tests, Mitsubishi successfully performs monkey tests to validate the controls of the electric body systems. dSPACE developed a special function for this, which works like a random generator and can be connected with all the relevant function inputs. The new dSPACE system makes it possible to perform functional tests as well as to study the behavior of all ECUs and network communication during any maneuver. During all tests, the HIL also lets developers monitor the power consumption of each ECU, which is especially important when the ECU network enters sleep mode.

The Mitsubishi Outlander is equipped with numerous networked ECUs and various electric drives for comfort functions.
Deutz: Developing Hybrid Drives

Hybrid Drives for Mobile Work Machines
Deutz used several dSPACE tools to develop a hybrid drive for a wheel loader:
- MicroAutoBox (as the hybrid system ECU)
- Real-Time Interface (for setting up the I/O interfaces for the MicroAutoBox)
- RTI CAN MultiMessage Blockset (for setting up CAN communication)
- ControlDesk and CalDesk (for calibrating the hybrid functions)

Several hybrid functions were implemented by means of this development environment: power boost (switching in the electric motor during performance peaks), shifting the load point in the diesel engine, start/stop (switching the engine on and off during idle phases) and energy recovery (storing excess energy in the Li-ion battery.) Using RTI

DENSO CORPORATION: Driver Assistance Systems

Pre-Crash and Adaptive Cruise Control
For the development of Pre-Crash and Adaptive Cruise Control, DENSO uses an environment with several dSPACE tools. CalDesk, the universal measurement and calibration software, provides parallel access to ECUs and MicroAuto-Box, which is used for calculating new functions in bypass mode. CalDesk also has an ASAM-MCD 3 COM interface to provide direct data exchange with DENSO’s software tool for evaluating video and radar data.

The Setup with dSPACE Equipment
An electronic control unit (the driver assistance ECU) evaluates the data from a radar and video sensor to decide whether it needs to activate the brake or the seatbelt tensioner. Calibration, measurement, and bypass access to the ECU runs via the microcontroller’s NBD on-chip debug interface and the DCI-GSI1. The dSPACE Calibration and Bypassing Service is integrated in the driver assistance ECU. The service provides access to the ECU application, and communication between the ECU and the other dSPACE equipment.
General Motors: XCP on CAN and CalDesk

General Motors is employing XCP on CAN and CalDesk, the measurement and calibration tool, to develop software and parameterize the electronic control unit (ECU) advanced transmission projects. CalDesk gives the company a complete experiment environment for measurement, calibration, and bypass applications. This has numerous advantages compared with using a combination of different tools: For example, measurements on ECUs and prototyping platforms can be run according to a common time base, with simultaneous parameter adjustments.

Accessing ECUs in the Transmission

ECUs in the transmission area are becoming more compact, and increasingly being installed in inaccessible places. This makes it all but impossible to connect additional interface hardware in or on the ECU for software development purposes – as is the case with General Motors’ new six-speed transmission, where the ECU is located inside the actual transmission. General Motors Advanced Transmission Group is using CCP for calibration and measurement access via CalDesk, while bypass communication between the ECU and the prototyping hardware (MicroAutoBox in this case) runs via XCP on CAN. The dSPACE XCP on CAN Service runs in parallel to CCP on the same CAN channel, without the two affecting each other. The CCP implementation was already available in the development ECU software, and is being used for measurement and calibration tasks. The XCP on CAN Service and the necessary bypass hooks (service calls) were integrated into the ECU code. Unlike CCP, the dSPACE XCP Service provides special mechanisms for function bypassing, such as task-synchronous writing of variables, ensuring data consistency, and several error detection options for bypass communication. The dSPACE XCP Service is designed for a wide range of applications, from measurement and calibration to bypassing and right through to ECU flash programming.

CalDesk for Calibration and Rapid Control Prototyping

CalDesk enables vehicle ECUs and their buses, and rapid control prototyping platforms, to be accessed simultaneously. CalDesk users have an integrated experiment environment for performing function prototyping, calibration, measurement, and data analysis tasks in a single tool.

The Advantages of CalDesk

Using CalDesk has a lot of advantages:

- A single tool for various use cases
- Common time base for variable measurement on ECUs and dSPACE prototyping systems
- Simultaneous parameter adjustment on ECUs and dSPACE prototyping systems in the same step (proposed calibration)
- The same automation interface used for access to ECUs and dSPACE prototyping systems
dSPACE –
Your System Partner

For more than 20 years, dSPACE has been the world’s leading supplier of tools for developing and testing new mechatronic control systems. Over 900 employees and more than 15,000 installed systems are proof of this success. dSPACE customers are supported by the company headquarters in Paderborn, Germany, by subsidiaries in the USA, France, the United Kingdom, Japan, and China, and by representatives worldwide.

Automotives a Key Industry
The automotive industry provides 80% of our annual revenue and is the largest application field for our systems. We know that in the automotive industry, good development tools are essential if a company wants to remain competitive. At dSPACE, we are committed to fulfilling ECU-specific requirements. Developers in the automotive industry can benefit enormously from the experience we have gathered in drives, industrial automation, aerospace, and other fields.

Involvement on International Bodies
Through its active membership, dSPACE contributes its years of know-how to major international bodies such as the AUTOSAR development partnership, ASAM, the FlexRay consortium, and Nexus 5001™. In the creation of standards for interfaces, architectures, and processes, dSPACE’s involvement in the relevant bodies gives you the assurance that new technologies will immediately find their way into dSPACE products, and that requirements that emerge from practical development work will be incorporated into future standards.

Training and Support
To help you get off to a flying start with your dSPACE systems, we regularly offer training in Germany, France, Japan, the UK, and the USA. However, that is not the end of the story. Our sales, applications, and support engineers will help you on all issues involving your dSPACE system, worldwide and if necessary on-site. The quality and speed of our technical support always get top grades from customers—a fact of which we are particularly proud.
dSPACE Engineering Services

System Engineering
Hardware-in-the-loop simulation and production code generation are having a tremendous impact on mechatronics development processes. This is especially true of automobile manufacturers and their suppliers. To support you in developing your mechatronic systems, we offer you additional services in all aspects of the development process.

Experience has shown that integrating dSPACE systems is easy. Even so, in the early stages of any project, questions crop up that need answering promptly. To give you the best possible support, we offer:

- Special customer training
- Feasibility studies and development of scenarios for your application
- Pilot projects
- Benchmarking
- Support in selecting and configuring systems

Turn-Key Solutions
Even though dSPACE systems are easy to install and handle, customers often ask us for turn-key systems. The reason is the enormous pressure of time they are under to develop ECUs.

With turn-key delivery and commissioning, customers can concentrate on their core activities, the development and testing of ECUs, without losing time. This service has been especially welcomed in the field of HIL simulators.

The typical services provided with turn-key systems are:

- Custom hardware development (building on a flexible, modular concept of signal conditioning)
- Integration of third-party products
- Parameterization
- Programming customer-specific interfaces
- On-site commissioning, including training

Maintenance of dSPACE Systems
To ensure that your system works optimally, dSPACE support continues far beyond system delivery, helping you to adapt your system to future developments as they occur. The open architecture of our systems makes this possible. Your system will always be up-to-the-minute – so your investment has long-term protection. Our maintenance services include:

- Software updates
- Interface extensions
- Hardware modification and expansion
- Model adaptation

The open architecture of dSPACE systems means you can easily modify and extend your dSPACE hardware.
Several thousand systems sold, constantly rising sales figures, a steadily increasing workforce: the numbers speak for themselves. Our subsidiaries and representatives have also contributed to our success. With their dedication and expert know-how, they make dSPACE products accessible to customers all over the world.

**Headquarters**
Germany: dSPACE GmbH, Paderborn
Branches: Stuttgart, Munich

**Subsidiaries**
USA: dSPACE Inc., Detroit
France: dSPACE SARL, Paris
UK: dSPACE Ltd., Cambridge
Japan: dSPACE Japan K.K., Tokyo, Nagoya
China: dSPACE GmbH Shanghai Office, Shanghai

**Representatives**
Australia: Sydney
Brazil: São Paulo
China: Beijing
Czech Republic and Slovakia: Prague
India: Bangalore
Korea: Seoul
Netherlands: Rotterdam
Poland: Cracow
Sweden: Stockholm
Taiwan: Taipei

**Try us!**
We know that plenty can still be done to make the ECU development process even more efficient and seamless. Our constant growth is the basis for continual investments in the improvement of the entire tool chain. Our employees’ talent for innovation, and above all the input we get from our customers, ensure that we never run out of ideas.

Interested? Then please contact us, or visit our Web site at www.dspace.com.
We will gladly send you detailed information about dSPACE, our systems, and their fields of application.

**Our Customers**
dSPACE systems can now be found in almost all companies in the automotive industry, from A for Audi to Z for ZF. Many of our customers have even completely standardized their processes to dSPACE. Here are some of our current automotive customers:

- Audi
- AVL
- Behr-Hella
- BMW
- BorgWarner
- Bosch
- Bridgestone
- Brose
- Centro Ricerche Fiat
- Chery
- Continental
- DAF
- Daihatsu
- Daimler
- Delphi
- Detroit Diesel
- DENSO
- Dongfeng
- Eaton
- ELASIS
- FAW
- FEV
- Ford
- GM
- GETRAG
- Haldex
- Hella
- Hitachi
- Honda
- Hyundai
- IAV
- International Truck and Engines
- Isuzu
- IVECO
- Jaguar Land Rover
- Jatco
- John Deere
- Johnson Controls
- LuK
- MAGNA STEYR
- Magneti Marelli
- Mahindra & Mahindra
- MAN
- Mazda
- Michelin
- Mitsubishi
- Nissan
- Opel
- Porsche
- PSA Peugeot Citroën
- Renault
- Ricardo
- Rolls Royce
- SAAB
- SAIC
- Suzuki
- Tata
- Toyota
- TRW
- VALEO
- VDO Automation
- VISTEON
- Volkswagen
- Volvo
- WABCO
- Yamaha
- ZF