

# Brake-by-Wire Gathers Momentum

HIL Test System for Developing a 12-V Brake-by-Wire System



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*The future of the brake is electric (brake-by-wire system). An electric motor (in the foreground) replaces the hydraulic cylinders which press against the brake disc.*



Continental is currently developing brake-by-wire systems that can use a new brake technology based on a 12-V electrical system. For Continental to perform function optimization and concept validation for this innovative brake-by-wire system, IABG developed a test system with an interface to a real-time vehicle model based on dSPACE technology.



This hardware-in-the-loop (HIL) test system has proven to be an efficient development and testing tool within the development process. Its main tasks are putting the system network into operation, function verification, fail-safe trials and investigating the energy management functions of the braking system. HIL test procedures have numerous advantages over test drives in laboratory vehicles – reproducibility, efficiency, cost efficiency, etc., – and all these are fully utilized.

#### Development Approach to Complete Brake-by-Wire Systems

The completely new braking technology in the electronic braking system utilizes a principle that is as simple as it is effective. Based on conventional friction braking, it involves no hydraulics whatsoever: the actuators are operated entirely by electronically controlled electric drives. Each wheel has its own control unit. When the car driver presses the braking pedal, an electronic signal is sent to the wheel brake. Sophisticated sensors and software optimally adjust the braking power on the wheel to a wide variety of road conditions. During braking, the friction arising between the brake pad and the brake disk generates torque on the pad. This is fed back into clamping force generation. Thus, much of the brake caliper's clamping energy is obtained from the vehicle's kinetic energy, so it does not have to be mainly fed in externally as electrical power.

The main technical point is that this braking principle consumes less energy than other systems. For the first time ever, very high clamping energies and excellent control dynamics can be achieved with the 12-V vehicle electrical systems currently in widespread use. The system also has an integrated parking brake function.

#### HIL Test System: Integral Part of the Development Process for the Electrical Braking System

The HIL test system was designed to verify the networked system functions and system communication and to perform further investigations during the development process. It acts as a system test bench for putting the system network into operation and for testing system functionality. Other purposes include investigating and optimizing basic functions and energy management in the back-up level of the braking system, and testing how the braking

system interacts with the simulated vehicle electrical system. To create a complete HIL test system, it is supplemented by an application-specific, adapted, extended simulation environment based on the dSPACE Automotive Simulation Models (ASM). This simulates the vehicle dynamics' behavior in a virtual vehicle in real time. The physical vehicle variables and mean value variables calculated for the braking system are used to control the dynamic restbus simulation and the test system actuators. The applications focus on putting the system into operation, testing the communication between system components, and studying error behavior when individual components fail. The integrated vehicle dynamics simulation makes it possible to systematically test different driving maneuvers including specific vehicle dynamics situations. The results are used to validate the system network and its functional properties, taking into account the effects of failures on driving behavior.

#### Set-up and System Architecture

Since the generation of clamping forces depends on (load) torques being transmitted via the brake disks, the task at actuator level is to implement a suitable load for the test bench under cost-efficiency constraints, i.e., to avoid using actuators operated via a real gyrating mass like

*Set-up of the HIL test bench.*



with flywheel mass test benches. This is done by means of a device that emulates loads.

On the test bench, the motors of the actuators form the interface to the simulated braking actuators. Highly dynamic load equipment consisting of servo drives is applied to the motors to ensure dynamic simulation of the real loads that would occur in the vehicle. The electrical and mechanical components are designed so that prototypes can be installed and assembled flexibly in various test configurations.

**“The seamlessly integrated development environment from dSPACE lets us carry out projects efficiently. The help given by dSPACE Support was exemplary.”**

*Franz Hangl, IABG*

The complete communication network of the electrical braking system, with the pedal unit and the additional function of the electronic parking brake, is represented in hardware form in the test system. In addition to CAN communication with the braking system's central ECU, a flexible FlexRay communication architecture was also set up. This enables all four wheel units of the brake-by-wire system to be simulated as required. Switching between the wheel units is performed by software, right through to the model. The mechanical, electrical, and communication variables of the system network are captured at various measurement points and archived in the automation system for subsequent evaluation.

*Load representation at the actuator.*

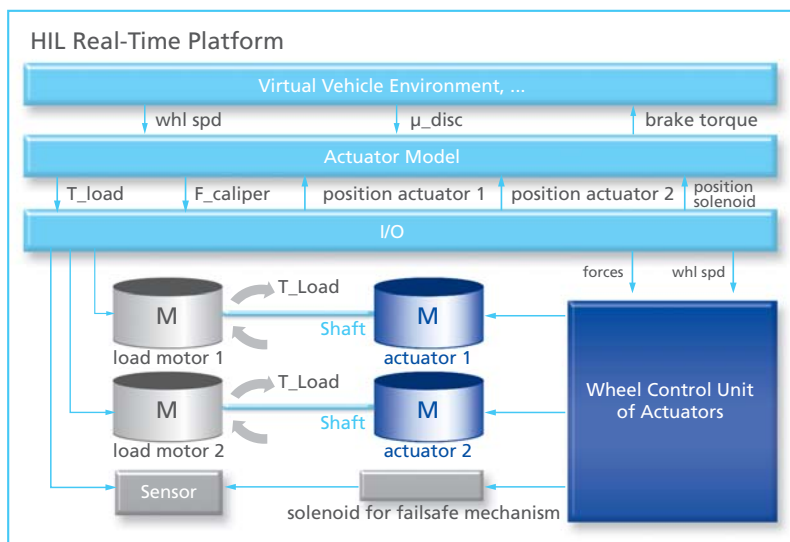
The core of the test bench automation system (AT) is a DS1005 PPC Board networked with several dSPACE I/O boards. The test bench therefore has a complex FlexRay network with a total of two independent networks in addition to CAN communication with the ECUs. To connect the test system to the FlexRay bus, the FlexRay Configuration Tool from dSPACE is used with a network description in a FIBEX (field bus exchange format) file. The vehicle model is calculated on an additional DS1005 that is

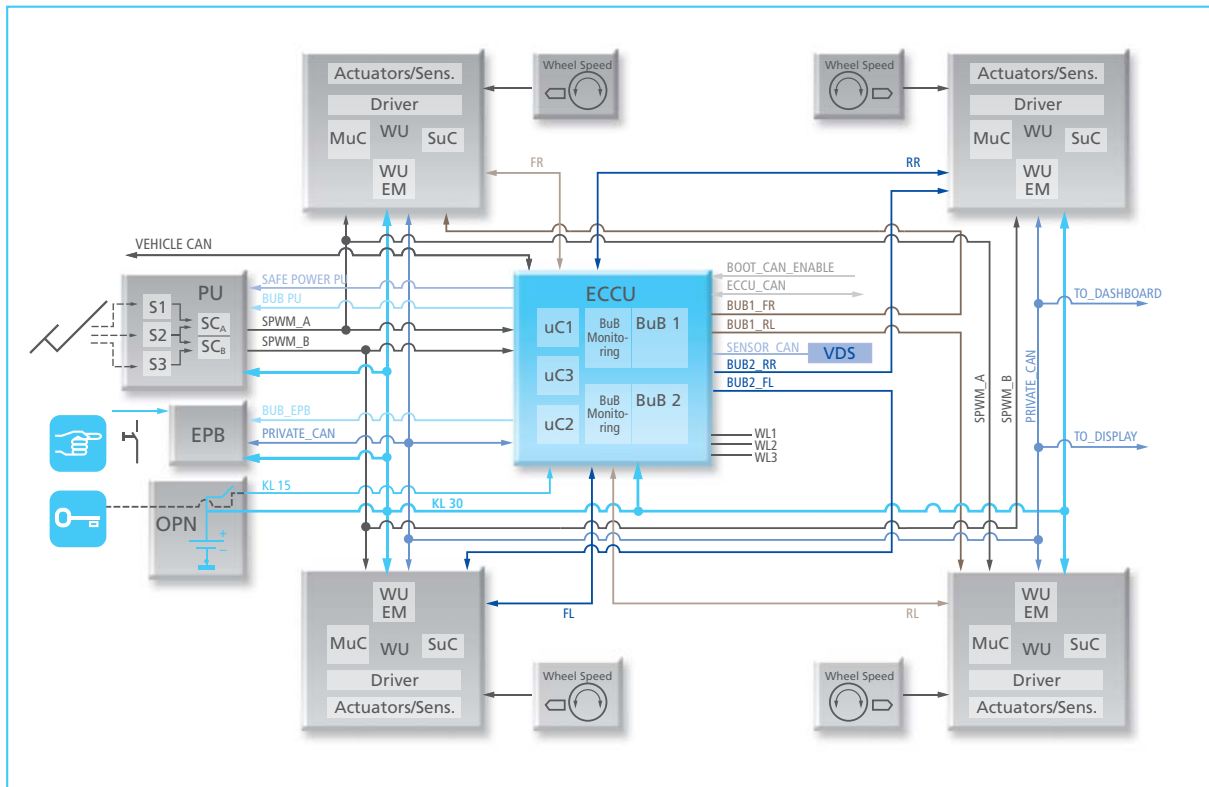
connected to the test bench automation system in real time via dSPACE Gigalink (a high-speed optical connection). The processes on the automation platform and the model platform communicate at intervals of 1 ms. On the software

side, the HIL platform provides integrated vehicle dynamics behavior based on the dSPACE Automotive Simulation Models (ASM). The major components of this simulation environment are models for the vehicle, driver, and environment, the associated model control, and model parameterization functions. One point particularly worth noting is that integrated simulation is performed for any system components that are not installed as real parts. Because the model structure is open down to the Simulink block level, it did not take long to make optimum modifications to the model components of the ASM Vehicle Dynamics Simulation Package.

The automation software builds on the MATLAB®/Simulink®/Stateflow® development environment and the ControlDesk experiment software from dSPACE. Some of the functions that have to be executed on the AT real-time system are:

- Event-discrete sequence control for the test system control and the implemented single tests
- Communication with the ECUs via FlexRay and CAN protocols
- Communication with the HIL real-time board via Gigalink interface





System architecture and communication structure of the electrical brake based on a 12-V vehicle electrical system.

In addition to basic automation, the user can also use functionalities such as:

- Implementation of the graphical user interface to handle and configure the test system
- Event-controlled layout and experiment management
- Test automation and test management with IABG software modules in conjunction with AutomationDesk to configure and generate test sequences
- Automatic evaluation and generation of test reports
- Access to ECU operating states, variables and parameters via a diagnostic interface
- Evaluation software to display measurement data graphically

### Test Automation and Failure Simulation

The task of test automation is to define single tests individually, execute them sequentially in a coordinated manner, and abort test execution in the event of a failure. A test report and test run documentation are automatically generated for each test. The user can configure the form and contents of the test report.

Test automation based on AutomationDesk was developed on the HIL test system. AutomationDesk lets the user freely define test sequences that are executed by the test bench automation system. This gives the user the greatest possible flexibility when specifying and implementing tests. The test database that was set

up now contains approx. 800 single tests of varying complexity and is constantly being added to.

The automated environment provides access to the requirements, test specifications, and test results via a direct connection to the test configuration and management tool that is used in the development and test process.

One of the applications for the test automation system is inserting fault scenarios to analyze system behavior. The following fault types can be implemented on the test bench:

- Cable harness faults
- Signal faults
- Communication faults in CAN and FlexRay

“The test system that IABG set up for us, based on dSPACE components, enables us to reliably develop innovative brake-by-wire products up to production level.”

Stephan Lehl, Continental AG

Cable harness faults are implemented by a failure simulation unit with currents of up to 50 A. The automation system controls the unit in real time via a CAN interface. Signal faults (sensitivity changes, offset drift) and communication faults (message interruptions, checksums) are switched to physical signals by the real-time system.

#### Extending the Test Features

The test system described here is completely integrated into Continental's development and testing process. Individual test sequences can be programmed graphically, which supports extensive testing of the system network and of single components.

The connection to the test configuration and management tool ensures a seamlessly integrated process from the requirements sheet for the overall system to single tests on signal software functions. Thanks to constant further development of the implemented test cases, the system network can largely be validated at an early stage on the HIL test system. ■

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## Summary

- IABG relies on dSPACE technology for complex test system solutions
- Function optimization and verification for networked vehicle control systems focusing on brake-by-wire
- Extensive test automation solution implemented with ControlDesk and AutomationDesk, including a connection to a test management tool



ControlDesk layout for controlling the test system.