Virtual Bus

Verifying the maturity of a new bus E/E architecture with HIL integration tests

Articulated or double-decker, lowerable, with up to four double doors and a wide range of comfort and safety systems, urban bus or tourist coach: the variations are endless. This also affects the design of an HIL test bench, which has to handle the possible variants and make it possible to switch between them quickly. Together, EvoBus, the MBtech Group and dSPACE implemented just such a test system for ECU validation.

At EvoBus, the world's leading manufacturer of buses and coaches, the main objective is always to give customers what they require. So top product quality is an absolute must. In bus transportation, vehicles must have high availability with very little down time, and a long lifespan. To launch innovations on the market quickly yet still provide only mature, proven systems, it is essential to have an integrated development process from specification to release. And a test chain with a large test depth is vital. The mechanical, pneumatic, hydraulic and electrical systems installed in passenger buses are connected via a central electrical/electronic (E/E) architecture for controlling functions. The integration of these different kinds of systems into an overall vehicle network has to be validated, and the HIL tests used for this are a major component in the development process. Automating the tests provides even greater benefits.
The architecture of a modern coach or bus must be able to bring together a wide range of requirements. These can be anything from a sophisticated articulation control system in an urban bus that has to interact with the brakes, the engine, the floor-lowering feature also known as "kneeling", the assistance systems and the instruments, or even a multimedia system in a tourist coach that gives passengers a choice of entertainment plus a wide range of information on the journey. These numerous different functions and information sources are distributed across several systems, but nevertheless have to function smoothly in a network. Developers have to make sure of this at a very early stage of development, before the systems have been installed in a vehicle, and it makes tough demands on the test environment and the test strategy.

Test Environment and Test Focus

A hardware-in-the-loop (HIL) simulator has been set up for testing functions and diagnostics at the component and network levels. The HIL simulations particularly focus on testing the bus-specific systems and the interactions between the functions of different components. Wherever possible, components that are available from other sections of the manufacturing group are reused. Thus, parts of the HIL test bench, including the simulation models, are copies of other test benches. General test case libraries and test specifications were adapted to EvoBus requirements.

The Challenge of Diversity

Integrating numerous different systems and functions is one challenge to bus and coach development. The enormous number of special features requested by customers is another. This necessitates very short development times for the software modules. Only a few weeks were scheduled for development and testing, from initial requirements to release and installation in the customer's vehicle. At the same time, the EvoBus E/E

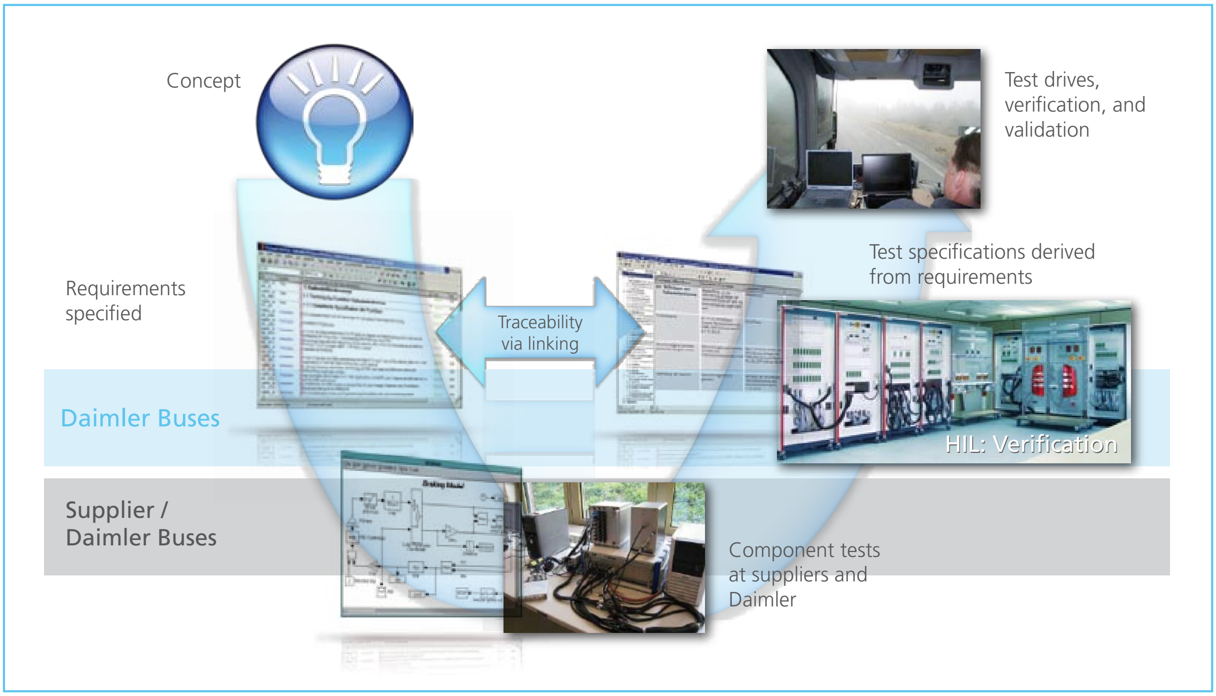

Figure 1: HIL simulation is a standard part of the EvoBus development process.



architecture is a "construction kit" for all integral buses and coaches in Europe. It is used to create the architectures for all other vehicles, from a simple bus with little equipment to a high-end two-level tourist coach or an articulated town bus that is 20 meters long. This diversity is reflected in the ECUs' extensive parameterization and the number of ECU variants, or even sometimes requires completely different ECUs, for example, for different types of transmission. Testing engineers therefore need to be able to switch quickly between different vehicle variants on the HIL test bench. In other words, the model, the ECU network and the parameterization have to adaptable.

Motivation for HIL Integration Tests

To achieve high product quality, EvoBus designed its development process for electrics/electronics and diagnostics according to CMMI process models. This means complying with optimum standard processes and continuously improving them. One of the improvement measures is an integrated test chain on the right-hand branch of the development V-cycle (figure 1). As many ECU and ECU software tests as possible are performed by suppliers. EvoBus coordinates and monitors them with a supplier management system. Before the first integration tests on the overall integration test bench, additional internal component tests are performed to verify the networking and diagnostics capability. Their precise nature depends on the system's maturity level and on the software sections being tested. The main focus of integration tests is on verifying functions that are distributed across different systems.

Requirements for Test System and Test Operation

The basic preconditions for smooth test operation are reliable hardware and fast support when problems occur. The test system must be flexibly extensible so that it can cope with additional requirements or new systems. Evobus decided to entrust all testing activities, including setting up the test bench, maintenance, modeling, test implementation and test execution, to a central operator and partner. The partner is responsible for ensuring that the HIL system runs without problems. EvoBus supplies the test specifications; the test results are evaluated jointly by the HIL tester and the function developers. dSPACE produced component specifications and set up the HIL test systems, while the actual operation and model creation were done by MBtech. Carrying out development work at several different locations is an additional challenge, since the developers responsible in each case are often not available on site. It requires standardized procedures, clearly defined processes, seamless documentation and constant communication between everyone involved.

> "By using hardware-in-the-loop simulation early in the development process, we are able to establish and validate the ECUs' maturity at an early stage."
>
> *Ian Suckow, EvoBus GmbH*

Technical Design of the HIL Test System

To test the functions and ECUs, a complete network of all the systems was reproduced by using 8 HIL simulator racks (figure 2). These comprise the powertrain, interior, and chassis domains. This overall integration test bench makes it possible to simulate all European integral buses from EvoBus. The set-up consists of two multiprocessor systems: 4 dSPACE Simulator Full-Size racks for simulating the powertrain with 5 processor boards for calculating the environment model, and 4 Full-Size racks with 4 processor boards for the interior. The tests for the chassis ECUs were also integrated into the 8 racks. The simulators communicate via Gigalink connections. To distribute the overall computing load across the processors, the environment model can be partitioned, and each partition assigned to a processor node. Altogether, approx. 45 ECUs with 2800 pins can be connected. The simulators for the vehicle's interior are currently being extended by two extra Full-Size racks to allow the simulation of additional systems. When the extension is finished, there will be a total of 10 processor kernels for calculating the model of an urban bus or tourist coach.
One part of the simulator concept is to include bus components in the simulation as real loads. They are connected to the simulator via component assemblies. The real loads include the compressed air system for the brakes, the lighting system, parts of the transmission, and throttles and valves in the engine. To ensure that the HIL system operated smoothly, dSPACE provided the HIL operator, MBtech, with comprehensive hardware documentation.

Brake Simulation with Real Loads

The braking system consists of a central module and axle modulators for the bus's three axles. The ECUs are networked with each other and with the electronic stability program (ESP) via four CAN buses. All the CAN connections can be disconnected separately via a switch matrix and the dSPACE DS4302 CAN Interface Board for use in restbus simulation. To simulate the brake in real time, a real load assembly containing the brake pneumatics with original valves and sensors was connected to the simulator. All 32 pressure sensors and 20 valves in the brake system were connected to the real-time simulation in this way. Realistic simulation of the entire compressed air system would have been considerably more expensive.

Representing the Powertrain

EvoBus offers three types of transmission for its buses and coaches: automatic with torque converter, semi-automatic, and manual. The ECUs for these transmission types are connected to the simulator via coded cable harnesses. This means that it is sufficient to have only one set of I/O resources on the simulator, yet each ECU can be operated with its specific real loads. Changing the test system from one transmission type to another requires only a few simple actions and a change of simulation model.

Interior and Chassis Components

To test the ECUs for the vehicle's interior functions, all the bus-specific components were provided for real-time simulation, including the following:

- Climate system with a variable number of substations
- Variable number of door controls with pneumatic or electric drives
- Electronically controlled spring suspension and damping
- Additional electronic hydraulic steering for the third axle
- Articulation angle control for articulated buses
- 6 MUX modules whose inputs and outputs can largely be configured freely – by digital or analog means, continuously, or by pulse width modulation (PWM).

A total of 1300 ECU pins were connected to the vehicle interior simulators. Sensors or actuators are simulated on 672 of these pins, and electrical failure simulation is also possible on them. Thus, they can be used for switching open circuits, short circuits to supply or to other pins, and short circuits over variable resistances.

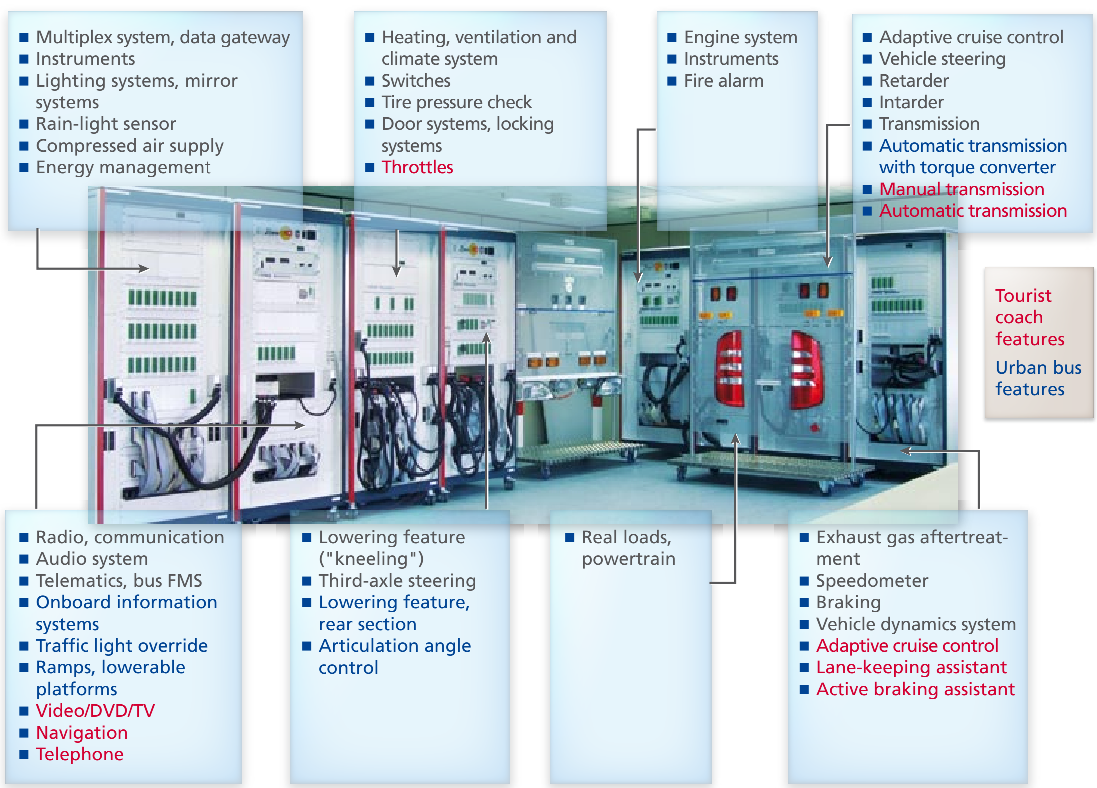

Figure 2: The complete HIL test stand comprises 8 Simulator Full-Size racks and component assemblies for the lighting and brake systems.

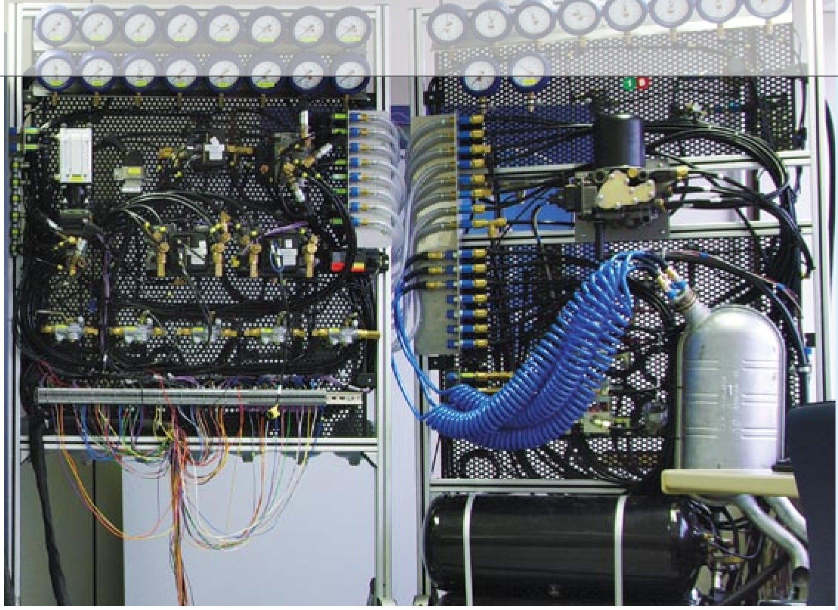

Figure 3: The entire compressed air system in the brakes was recreated with the original valves.

> "Together with other forms of testing such as suppliers' tests, internal component tests and test vehicles, the HIL tests provide high system maturity for prototype testing and large test depth."
>
> *Ian Suckow, EvoBus GmbH*

Glossary

Axle modulator – Used to implement the desired brake pressure on the axles.

CMMI (Capability Maturity Model Integration) – Systematic preparation of processes and practices to improve workflows. Maturity level 3 means that projects are carried out according to an adapted standard process and that there is continuous, organization-wide process improvement.

MUX module – Flexibly programmable ECU

Tri-state – Digital switch elements whose outputs not only have two states (0 and 1) but also a third one known as high-impedance.

The MUX modules with their variable functions are a particular challenge. MUX modules are special bus and coach ECUs that control numerous electrical consumers, such as roof ventilation, electrical system management, subfunctions of the door control and kneeling systems, coffee machines and water boilers. Each module can drive continuous currents up to 10 A and evaluate tri-state or analog levels at the inputs. For failure simulation, the simulator included the pins of a MUX module with a high-current-capable failure insertion unit (FIU) that can switch failure currents of up to 50 A. In addition, the ECU topology varies from vehicle to vehicle. The MUX modules can therefore be connected to different vehicle CAN buses automatically via a switch matrix.

Special Features of a Bus Environment Model

Realistic models of the environment and the controlled system are indispensable for performing comprehensive function and integration tests in an appropriate simulation environment. All the vehicle's subsystems – powertrain, chassis and interior – have to be included. MBtech was responsible for creating and maintaining the environment models, to which new functions were added during test operation.
The basic model for the urban bus actually consists of two identical basic models for the vehicle's forward and rear sections, which are connected by a joint. Functions such as articulation angle control, third-axle steering and kneeling are important aspects of the chassis model. In contrast, the tourist coach was modeled as a single-section vehicle, so its chassis representation is very different. Engine model is based on individual models for the characteristics of the drag, starting, braking and engine torques, which are added together to obtain the total torque. The braking system is represented by real loads and a real pressure circuit, so only the resulting braking torque and the connection to the modeled powertrain in the environment model have to be calculated.
A characteristic of buses and coaches is that they have different types of doors with a wide range of variations and functions, for example, either electric or pneumatic control. The availability of their functions is especially important in public transportation. Finally, the simulation model also contains representations of the climate system, the switches, and the rain/light sensor.

Testing Process

The approach to implementing tests is based on a reference process, PROVEtech:TP5. This consists of five steps:

- *Test Strategy:* The main objective is to extract an overall system view from all the detail views, and to identify and prioritize distributed functions. A general decision is taken on which test objectives are focused on in which test stage.

- *Test Planning:* Test topics for the integration test are assigned with reference to the testing activities of other test teams such as the ECU supplier and later test drives.
- *Test Specifications:* Work on these began before the test system was set up. They describe detailed test cases for the HIL operating team to work with. In a multi-location development project, they are also indispensable for communication between developers and testers.
- *Test Implementation:* Automated tests are created according to the test specifications.
- *Test Evaluation:* Errors that are found are kept in a central list that is directly linked to the associated requirements, test specifications and test results. Suppliers are informed of errors that concern them, and deadlines and activities for remedying the errors are agreed on.

The statuses of all testing and error-remedying activities are regularly collected in a report so that information on current progress and system maturity at all hierarchy levels is always available.

> "The numerous possibilities for reusing test systems and test cases make it easier to introduce complex network simulators, even for new projects."
>
> *Stefan Abendroth, MBtech Group*

Automating Tests

The MBtech operating team's main task on the integration test bench is to implement and execute automated ECU tests. This involves continuously putting new ECU functions into operation, and also extending and maintaining the HIL hardware, adapting and further developing the environment models, and supporting work on the test system, for example, when measurements or interactive tests are performed. One of the bottlenecks in test automation is the first-time execution of a test with the ECU network. Depending on the complexity of the test case and/or the ECU functions, this can take a long time and require complete access to the test system. The modularity of the HIL system pays off here, as the subsystems for interior/chassis and for the powertrain are separate and can be operated in parallel. The programming of automated tests (figure 4) is initially performed independently of the test system, so test case development and other system support activities can be carried out simultaneously.

Reusing Tests

When the model is changed from the urban bus to the tourist coach, or from one vehicle variant to another, the aim is to reuse as many of the test cases already created and tested as possible. To do so, test automation is based on the Daimler group's tried-and-tested library concept, which uses descriptions of vehicle-specific test parts. The same tests can therefore be used for different vehicle variants by replacing basic vehicle data at a central point in the test. In the long term, this increases the efficiency of test implementation and also makes it easier to compare individual test results.

One Year of Testing Experience

In the first year of its operation, the integration test bench was the place where the various ECUs of the new E/E platform were networked and interacted with one another for the first time. The test bench faced its first major trial when the first complete network integration and first use of the test system were both performed at the same time. Even at this early stage, it was possible to identify and analyze problems in the test objects. In the first year, all the

Left: Ian Suckow, Daimler Buses – EvoBus GmbH, Germany
Ian Suckow is Project Leader for integration and system testing at EvoBus in Mannheim and Neu-Ulm, Germany.

Middle: Stefan Abendroth, MBtech Group, Germany
Stefan Abendroth is head of Commercial Vehicle Testing at MBtech Group in Sindelfingen, Germany.

Right: Martin Müller, dSPACE GmbH, Germany
Martin Müller plans and designs HIL simulators that are tailor-made for specific customers at dSPACE's Project Center Stuttgart, Germany.

systems were successfully run in a closed loop, including two extremely demanding subsystems – the powertrain and the chassis – and complex environment models. Virtual test drives can be implemented under laboratory conditions in this way, even including brake interventions by an ABS and complex driving maneuvers. Previously specified test cases were implemented and automatically executed in test bench operation. Automated regression tests are performed on new sample versions of the ECUs and bug fixes. The test results from the simulator allow early function validation for the whole network with a large test depth. The maturity of the system network is enhanced by the entire integrated development process, which takes a lot of the load off the testing of prototype vehicles and promises to deliver high product quality for the series. Used in conjunction with an operator model for operative testing, which relieves ECU developers of the duty of operating the very complex test system, the HIL integration test has earned itself a permanent role in bus E/E development.

The integration test bench is currently being extended for testing additional systems in tourist coaches. EvoBus is preparing to use HIL tests for additional safety systems and alternative drives such as hybrid and fuel cell functionalities in the future.

Ian Suckow, Daimler Buses – EvoBus GmbH
Stefan Abendroth, MBtech Group
Martin Müller dSPACE GmbH

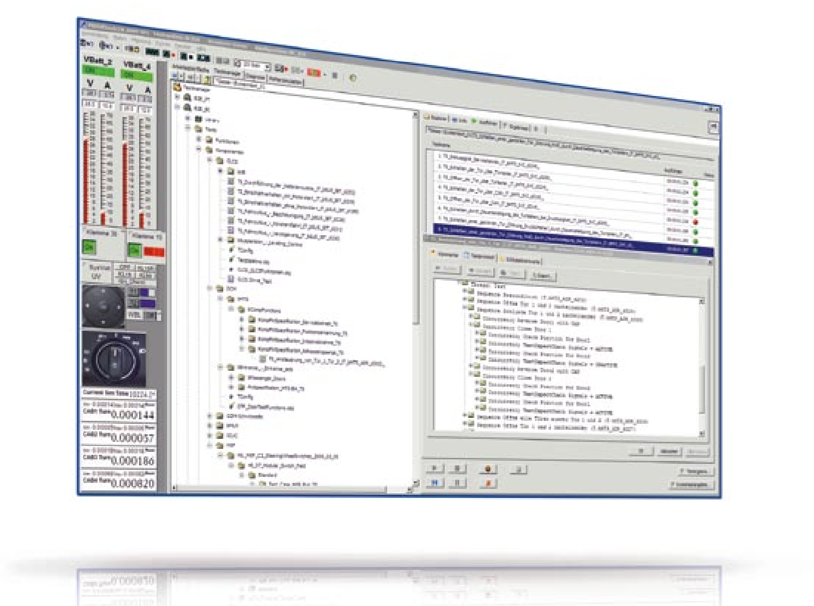

Figure 4: The PROVEtech:TA test software from MBtech.

Summary

- HIL simulation used in parallel with ECU development for a bus E/E architecture
- Early virtual test drives made possible by smooth interaction between the environment model and the simulator hardware
- Frontloading error detection in the testing process shortens development and test times