In the omnibus area, the challenge is to create a vehicle that fulfills the technical requirements of commercial vehicle while providing a level of comfort and convenience at least equal to that of a passenger car. The focus here is on the development of platform systems that implement up to 120 functions on a common hardware unit. Their complexity ranges from "very simple" to "very complicated." The many possible combinations of individual functions are another requirement. A high level of customization and consideration of specific special customer wishes, sometimes even shortly before delivery, require special modularity and flexibility of the architecture in the body and convenience electronics areas. Very low volumes in comparison to the passenger car industry makes re-use desirable in all model series (urban, long-distance and tour buses). Synergy effects are exploited and costs are reduced by using standardized adaptable hardware.

In some respects, the E/E requirements of omnibuses differ significantly from those in the passenger car area, because the features of an omnibus are determined by individual customer wishes to a far great extent. This must be considered in the E/E concept, which requires especially well thought-out modularity and flexibility. The electronics (hardware) should lend itself to broad-based use within the overall range of omnibus products as much as possible and be adaptable in a cost-effective way. Other challenges include improving fuel economy, reducing exhaust emissions and performing advanced development of active and passive safety and assistance systems.
To flexibly cover all of these requirements in the E/E concept, EvoBus developed a scalable multiplex system (MUX system). Consisting of up to nine modules, the electronics architecture of this MUX system is a type of distributed system within a distributed system. The hardware and firmware of the MUX system are a sort of middleware that provides the fundamental components and tools for application development. This middleware is user-programmable by the use of IEC61131-conformant and OEM-specific logic chips, and it is positioned beneath the application level. The individual MUX modules are distributed to different bus branches of the overall vehicle network that consists of five main CAN buses for powertrain, chassis, interior, telematics and diagnostics areas as well as numerous LIN subnets.

**Testing Challenge: ECU Network of up to Nine Modules**

The scope of testing is exceptionally high, due to the high functional density and numerous degrees of freedom in configuring the MUX system. To optimize the time-intensive and complex test phase, EvoBus 2011 started up a new test bench that is individually customized for the needs of the MUX system. The test bench is based on the VT System from Vector. It is capable of simulating all components and system states of the MUX environment that are required for the tests. They include both the signals of the numerous hardware inputs and outputs as well as the CAN and LIN communication. Serving as a user interface is a PC with CANoe test and simulation software from Vector.

After tests by the supplier, component tests represent the first step in the test process chain within the V-model, which ranges from component testing to software module tests, Hardware-in-the-Loop and finally trials in the real vehicle. In component tests, the focus is on correct functionality of the middleware, while the application is considered from a later milestone in the testing process. The MUX system itself is a scalable peer-to-peer system. The number of MUX modules used in the vehicle depends on the selected equipment versions and special customer wishes. Each MUX module has a number of largely configurable digital and analog inputs and outputs. The MUX modules are interconnected via the CAN buses to form an overall system (Figure 1).

With the help of the VT System, EvoBus engineers test the fundamentals of extensive functions such as valve control for automatic suspension leveling, door control ECUs for the luggage compartment and engine compartment doors and the complex interior lighting system. The latter also leaves much freedom for fulfilling customer-specific wishes. A key challenge is network management. Status transitions such as wake-up from the power-down mode, and in the opposite direction, shut-down of the network must run trouble-free and in correct interplay with the application and hardware. Besides simulating the CAN communication of the remaining bus, OSEK network management is also simulated here. Since each MUX module always needs to be informed of the current system states of other MUX devices in a timely way, synchronization processes are continually taking place. In the exchange of process images, specified timing and real-time requirements must be fulfilled, and this represents another test criterion.

**Simulating Environments and Automating Tests**

The MUX system must also be tested to determine whether it can operate smoothly with various hardware changes. Test contents include data and diagnostic routing of the Sub-CAN and Sub-LIN buses of the MUX system. Testing of diagnostic functions requires special attention here: The I/O channels of the MUX system permit flexible and varied

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**Figure 1:** Example of a distributed function in the MUX system - side marker light.
configurations of the compact bench-top device that range to a large HiL system for the test laboratory (Figure 2). The VT System implements comprehensive emulation of the ECU environment with regard to input and output circuitry as well as communication of the connected CAN and LIN buses. The main advantage of emulation is that the behavior of drivers, passengers, vehicle equipment and other environmental components can be simulated reproducibly. Testing of door control, for example, requires repeated actuation of a pushbutton to open the omnibus door at precisely defined times. Instead of manual actuation, these actions are performed by the test system. This assures the proper timing sequences and is reproducible at any time.

Scalable Test System Enables Customized Hardware Layout

The system supports all commonly used analog and digital input and output standards including more complex functions such as generating and processing PWM signals and determining effective values. While load and measurement modules of the VT1004 type are connected to the outputs of an ECU, the VT2516 and VT2004 modules contain the electronics for stimulation of digital and analog inputs. VT7001 power supply modules regulate the operating voltages and measure the current consumption of the MUX modules. In addition, VT6104 modules are used for the network communication of the CAN and LIN networks. The VT6050 PC module is the CANoe Realtime-PC, on which the simulations and tests are executed. Only the input/output level of the EvoBus test bench – which is built in a 19” control cabinet – consists of five logical levels that are each fully populated with twelve VT System modules. Currently, the system covers requirements for five of the nine possible MUX modules. The control cabinet also has a patchboard that provides individual access to all input pins of the MUX ECUs for manual measurements; break-out contacts for all CAN/LIN buses are also provided.

Comprehensive ECU tests generally also include test sequences in which conditions prevail that deviate from normal operation. That is why the VT System was designed to generate defined errors in the ECU environment, e.g. defective sensors at the inputs or atypical load behavior of actuators connected to the outputs. Upon request, the system can generate line breaks and short circuits in feed lines, short circuits to ground and battery potential or over-voltages and under-voltages. The five electronic loads represent a special feature. They can each conduct a current of ten amperes as a source or sink, so that the MUX system can be supplied with enough power for special test cases.

Figure 2: VT System as component test bench of the Evobus MUX system.
Real-Time Capability by Modular System Layout
The remaining bus simulation utilizes the OEM package for the Daimler-specific interaction layer and OSEK network management. This assures full emulation of the sending behavior as well as realistic communication behavior on the data buses with low effort. Real-time relevant tasks, and the remaining bus simulation test sequences, are executed directly on the VT6050 real-time module. In turn, the VT6050 is connected via Ethernet to the CANoe host-PC that is used for user interactions and for viewing and analysis. This distribution of work makes an important contribution towards attaining the extraordinarily high scalability of the overall test system (Figure 3).

Standard Tool CANoe as Front-End for Test Bench
CANoe on the desktop PC serves as a platform for all user operations, test definitions and evaluation actions. The dual monitor setup at EvoBus offers sufficient space for a well-organized display of the main program windows, output pins, input pins, measurement value displays, etc. CANoe has become established as an industry standard for electronics development related to automotive applications, and it offers numerous functions from which the MUX modules benefit. The intuitive user interface has made training in user operation of the test bench run quickly and smoothly. All parameters of the VT System are accessible from CANoe. Vector’s ‘Test Feature Set’ meets the criteria for high-performance test automation. In addition, test sequences can be defined, tests executed and reports generated. In generating and executing reproducible test cases for the diagnostic protocol, CANoe Option DiVa (Diagnostic Integration and Validation Assistant) performs valuable services. The Test Automation Editor contains an interface to a DOORS database in which the test specification is stored. After test execution on the VT System, the results are documented back into the database in XML format and saved. This assures traceability of abnormal findings, their correction and statistical information about the test object for every sample level. Universality of the tool chain and minimizing the number of interfaces were important to EvoBus. These requirements are fulfilled by the Vector approach, from definition of test requirements to test execution and evaluation of the reports.

In testing the MUX ECU network, the efficiency gains realized by the VT System are enormous. Extensive tests, which required about two weeks before – including preparation of the specific test software – can now be completed in one day. The pins of the ECUs were previously fed into specially fabricated purely passive test boxes that had to be manually rewired for each individual test. Since this approach could not be automated, it offered far fewer testing options and was inherently more susceptible to errors. When tests needed to be repeated, personnel resources were tied up for longer periods of time. With the VT System, on the other hand, it is possible to reproduce test runs at the press of a button. Today, using the new system, EvoBus has now performed 500 individual tests (without diagnostics) with greater test depth, test coverage and precision, where previously only about 100 spot check type tests could be performed. Another positive aspect of the test system is its tremendous flexibility. The VT test bench is not only used for automated testing of new software versions. It also serves as an analysis tool for feedback on abnormal findings to Customer Service and Production. Such situations require quick reaction. Therefore, the hardware can also be run manually over a CANoe user interface without having to write test scripts; in this way, it can be spontaneously used to troubleshoot problems and correct them.

Further Extension of the EvoBus Test Bench Planned
The VT System at EvoBus with its fully featured, approximately two meter tall control cabinet is one of the larger VT System projects implemented by Vector. The project timeframe from the specification phase to startup and training amounted to about five months. The progressive development of new vehicle types and the introduction of hybrid drives will make an extension of the test system necessary. EvoBus plans to extend the test bench by adding an input/output module. The test bench will then be able to test MUX systems with up to six modules. It will then be necessary to supplement the system with a second control cabinet. This represents an intermediate step towards full implementation of a system that can handle nine modules. That is because the functional features of large tour buses can assume considerable dimensions, where comprehensive testing is always required for the electronics of com-
fort/convenience functions, climate control, interior lighting, distributed functions for hybrid vehicles, fast door opening and closing mechanisms, entertainment systems and other features.

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Links:
Homepage EvoBus: www.evobus.com
Homepage Vector: www.vector.com
Product information VT System: www.vector.com/vt-system
Product information CANoe: www.vector.com/canoe

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