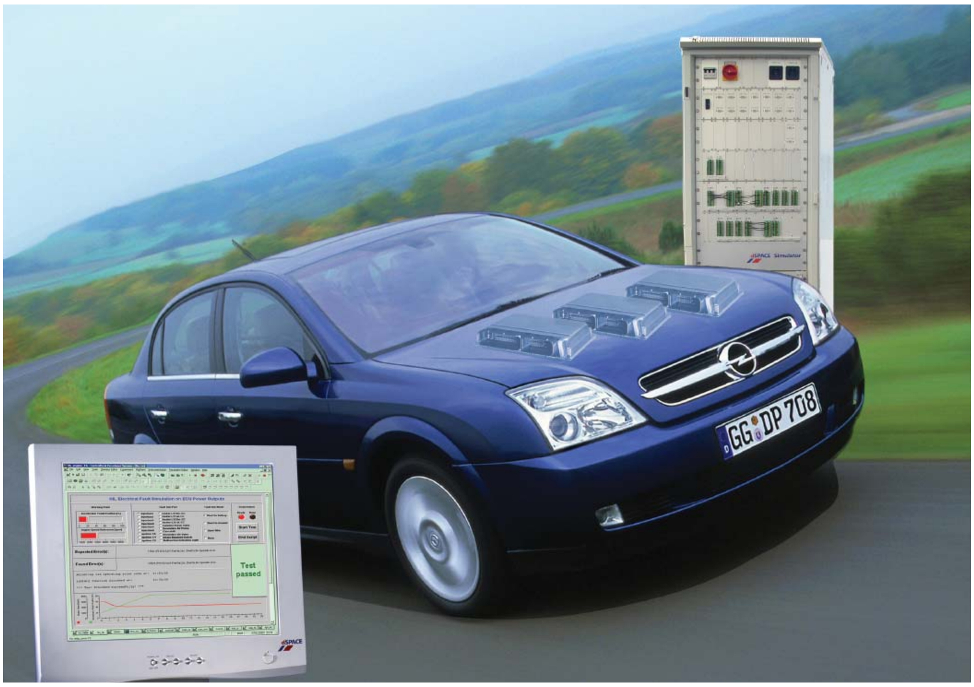
ECU Network Testing by Hardware-in-the-Loop Simulation



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Translation of: "Steuergeräte-Verbundtests mittels Hardware-in-the-Loop-Simulation"
Published at: ATZ10/2003

ECU Network Testing by Hardware-in-the-Loop Simulation

The electronics responsible for the comfort and passive safety systems in the new Opel Vectra involve a network of numerous electronic control units from different manufacturers. Testing the ECU network is a particular challenge. Existing test methods soon come up againsttheir limits. By using hardware-in-the-loop simulation, Opel achieves extensive test coverage and depth. Test automation considerably enhances the benefit of using the hardware-in-the-loop simulator. In future, test automation will also be extended to earlier phases of ECU development.

1 ECU Network for Comfort and Safety Systems in the Opel Vectra

The new Opel Vectra was designed completely from scratch. In addition to innovative design and vehicle dynamics, it also offers the very best in comfort and one of the most modern safety systems in its class, setting new standards for future mid-range vehicles. There are 15 ECUs, networked via CAN bus, for the comfort and safety systems alone. The features include electronic air-conditioning control, infotainment systems, adjustable front seats, rain sensors and parking assistance, passive safety equipment consisting of front, side and curtain airbags at head level, the Pedal Release System patented by Opel, and improved active head restraints that protect against whiplash **(Fig. 1)**.

Data bus networking of ECUs in the vehicle enables the sensor system, computed data, and the actuator system to be used jointly by a variety of functions. In addition to the network for the comfort features and the safety system (low-speed CAN), the Opel Vectra also has a high-speed CAN network (HSCAN) for the powertrain and a mid-speed CAN network (MSCAN) for controlling the infotainment systems **(Fig. 2)**. Special ECUs perform interface functions between these CAN networks. Due to the number of ECUs involved and the volume of communication, testing the interaction between all the components and their functions in a network is a major challenge. The components come from different suppliers, so only the actual automobile manufacturer can do the testing.

2 Developing and Testing the ECUs

Specifications for the ECU architecture and for the necessary communication network are produced by Opel. The ECU hardware and software are developed by various suppliers commissioned by Opel. The suppliers implement the functionality previously specified by means of

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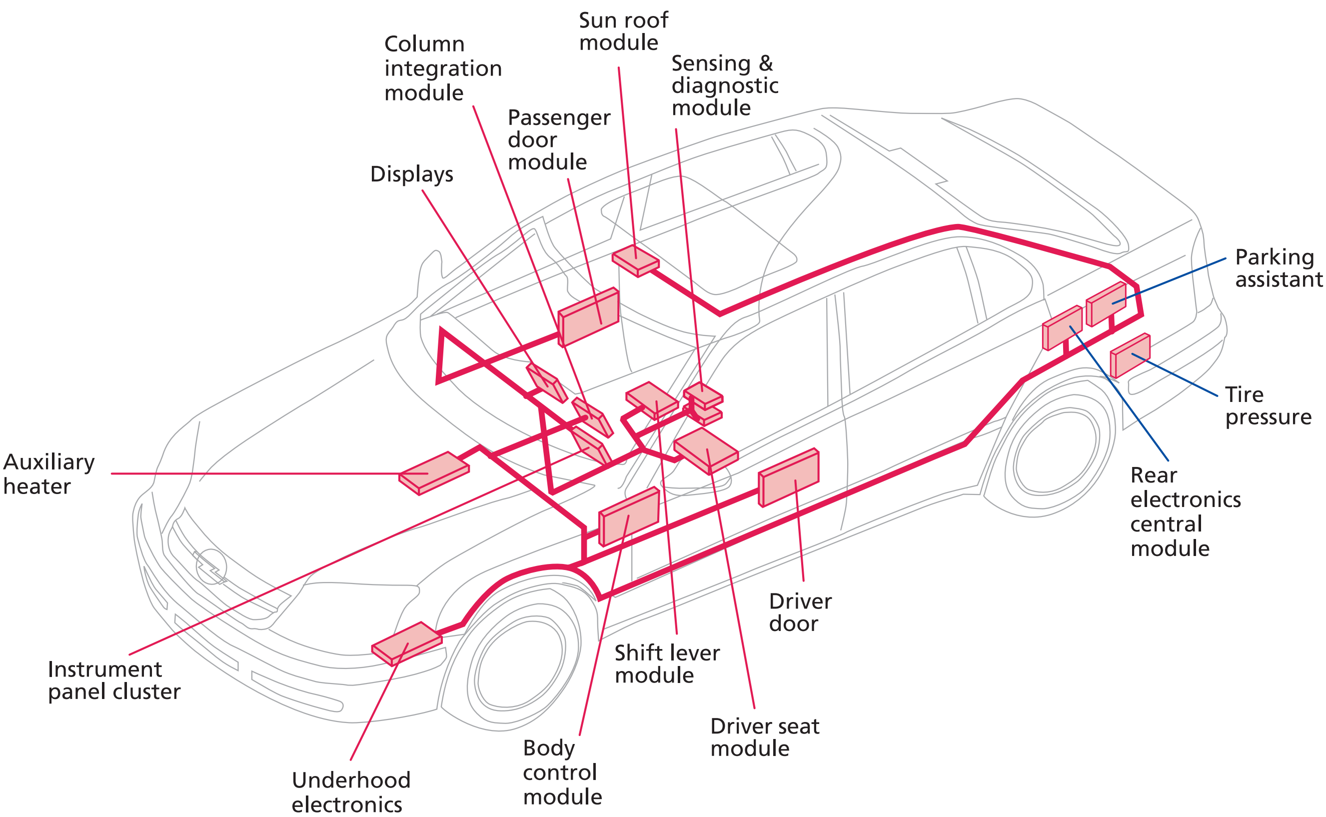

Figure 1: ECUs in the low-speed CAN network of the Vectra C.

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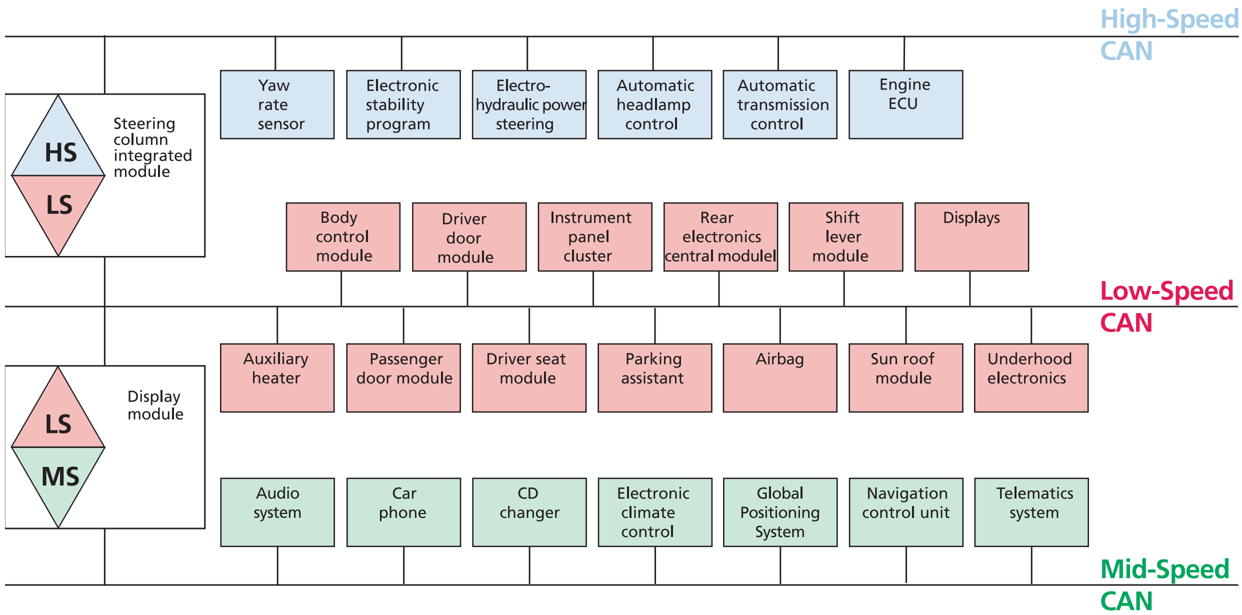

Figure 2:Topology of the CAN bus network in the Opel Vectra.

tools (such as Statemate). Altogether 16 tier-one suppliers are involved just for the hardware, software and cabling of the low-speed CAN network in the Vectra C.

Opel gives its suppliers the data needed for restbus simulation for the component tests. Each supplier is responsible for meeting the specifications and provides Opel with the results of the functionality tests.

After they are released, the ECU prototypes have to be tested for correct functioning at system level by the automobile manufacturer. Opel was looking for a system for this purpose which would allow testing of the individual ECUs, the ECU network, and the interfaces to the driver, powertrain and car body electronics.

2.1 Vehicle Tests with Prototype Vehicles and Bench Boat

Like all manufacturers, Opel subjects its vehicles to extensive test drives (summer/winter trials). In addition, there is a three-dimensional test bench (the Bench Boat, **fig. 3**) for early testing of the networked electrical components, which all the instruments, displays and lamps, even the windshield wipers, are integrated into. A driver's cab allows manual operation. Necessary signals from vehicle components that are not present in the test setup are simulated electrically or fed in later by a real prototype vehicle via a test bench.

The disadvantages are well known. Test drives are time-consuming and expensive, they are not 100% reproducible and they provide poor coverage of critical situations due to the potential hazards to the vehicle and its occupants. The tests performed on the Bench Boat are all manual and do not offer sufficient reproducibility, automatic documentation of test results or complete test coverage.

The aim is to achieve greater test depth and integration in the laboratory. Opel has therefore introduced hardware-in-the loop simulation as an additional facility for testing ECU networks for comfort and safety components.

3 Hardware-in-the-Loop Simulation at Opel

3.1 The Decision to Use Hardware- in-the-Loop Simulation

In contrast to the „spot check“ nature of manual tests (due to the great number of possible system states), automated tests provide far greater test case coverage and complete reproducibility. This is what hardware-in-the-loop (HIL) simulation provides: automated testing of ECU hardware and software in interaction with other components and in an environment that is simulated with sufficient precision.The preconditions necessary for this are [1] :

- Logging of all the relevant signal / driver outputs of the ECUs
- Control of all ECU inputs and sensor simulation
- Control of all CAN signals (including selective manipulation)
- Reproducible functional tests with different ECU variants

A dSPACE Simulator was therefore installed for network testing of the interior ECUs in the Opel Vectra as early as September 2001. Despite the very limited time available, test coverage was considerably increased up to start of production in January 2002.

3.2 Architecture of the Hardware-in-the-Loop Simulator

After evaluating the HIL simulators on the market, Opel opted for the dSPACE Simulator [2]. Apart from the open and clear hardware architecture, the decision

2.1 Vehicle Tests with Prototype Vehicles and Bench Boat

Figure 3: The Bench Boat developed at Opel.

3.2 Architecture of the Hardware-in-the-Loop Simulator

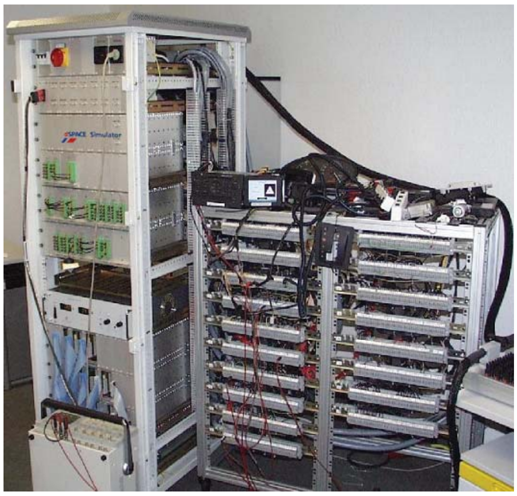

Figure 4: dSPACE Simulator after conversion from the Epsilon to the Delta platform by Opel.

was also based on the good experience that Opel had already gained in other groups with the entire dSPACE tool chain for ECU development, particularly in the development of fuel cell technology in the Global Alternative Propulsion Center (GAPC) in Germany and the USA [5], as well as with the various rapid prototyping applications in electrical/electronic advance development. In the meantime, dSPACE HIL simulation has established its position in the diagnostics test department of the GM Fiat Powertrain Joint Ventures in Rüsselsheim, where it is being used to test several engine ECUs.

The following features were the major reasons for choosing the simulator design concept described below **(Fig. 4)**, „dSPACE Simulator Full-Size" [6]:

- The great reusability and modifiability of dSPACE Simulator, with a view to later conversion for new projects
- The large number of input and output signals required (especially digital)
- The need to connect a large number of ECUs and real loads

3.2.1 Simulator Hardware

The hardware consists of the following individual components:

- Real-time processor for computing the I/O and models
- 104 digital inputs and 192 digital outputs
- 8 PWM channels
- 32 analog inputs and 16 analog outputs
- 4 resistance simulation channels
- 4 CAN interfaces for approx. 1200 signals in 200 messages
- Signal conditioning (off-the-shelf) for
  - Level adjustment
  - Protection circuit
  - Compensation of potential offset at ECU inputs
- Load simulation or real loads
- Electrical fault simulation at ECU outputs
- Voltage supply to the ECUs
- Separate component rack with ECUs and real loads (provided by Opel)

3.2.2 Simulator Software and Models

The real-time model, including integration of the I/O, is implemented in MATLAB/Simulink. C code is generated automatically using the Real-Time Workshop (RTW) and Real-Time Interface (RTI).

Unlike applications for the powertrain or vehicle dynamics, car interior comfort frequently requires only a very simple model of the controlled system (no kinematic function models or pure logic models). For example, to control the windshield wipers, the ECU expects the moving wiper to pass through the park position at regular intervals depending on the wiper speed. The feedback comes from the „wiper park position" signal, which therefore has to be activated cyclically **(Fig. 5)**.

Manual operation of the simulator is done via a ControlDesk experiment with configured layouts.

Automatic test sequences are implemented via the test automation feature integrated into ControlDesk. Opel uses both Excel-based solutions [7] and more simple solutions with tests created by a macro recorder.

3.2.3 Special Features

3.2.3.1 Testing ECU Behavior During Errors in CAN Communication

Testing CAN communication is a key aspect of network testing.

- How does the ECU or the distributed function behave when an expected

3.2.2 Simulator Software and Models

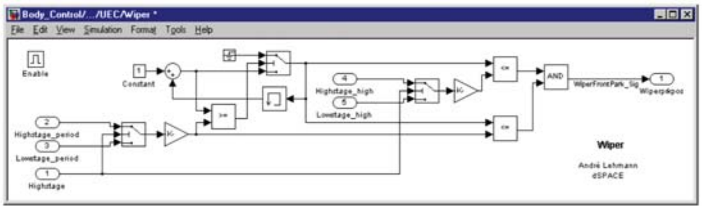

Figure 5: Logic model for the windshield wiper park position.

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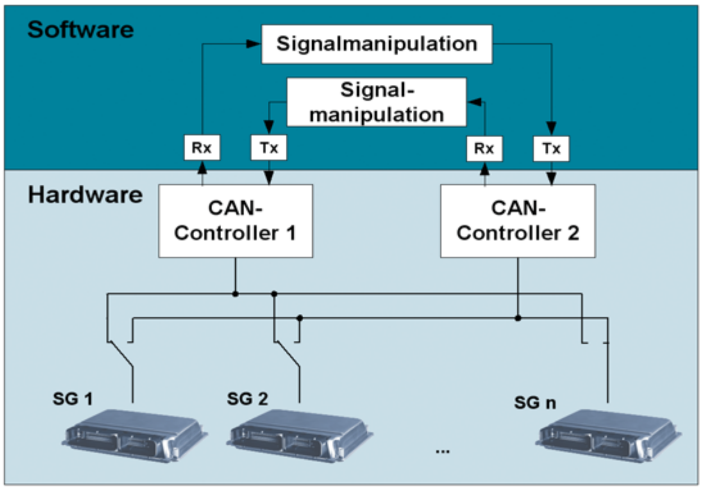

Figure 6: CAN concept with error gateway.

CAN message is absent or contains an implausible signal?

Resulting requirements:

- It must be possible to suppress and/ or manipulate either one or more targeted CAN messages of any ECU

.

This is achieved by installing in the Simulator two CAN controllers for the LSCAN bus, so that each ECU can be connected to the connectors separately as required **(Fig. 6)**. Software is used as the error gateway between the two controllers. All the messages received on one controller are immediately sent to the second controller so that each ECU receives the CAN messages of all other ECUs. Manipulation blocks (RTI CAN) allow error cases to be generated right down to message and even individual signal level. The resulting time delays do not affect the functionality of the ECUs.

3.2.3.2 Testing the ECUs' Power Consumption in Sleep Mode

Because of the large number of ECUs installed in a vehicle, it is essential to minimize power consumption, particularly when ECUs are not active. The dSPACE power switch modules allow the network management (such as sleep mode and wake-up functionality) to be tested. The power consumption is measured with great precision both in the operating state (several amperes) and in the sleep state (<1 mA).

The effects on the supply lines of voltage drops of different strengths can be investigated using two power units to supply voltage to the ECUs.

3.2.4 Converting the Simulator to the Delta Platform

Opel has meanwhile itself converted the dSPACE Simulator from the Epsilon platform (Vectra) to the Delta platform (Astra). The essential difference in the functionalities of the two platforms is optimized distribution of comfort functions across the different car body ECUs.

4 Use of the Hardware-in-the-LoopSimulator at Opel

4.1 Test Creation

As a rule, the tests specified by the ECU departments are first performed as black box tests on the network system (know-how on software structures is not taken into account). For broad test case coverage, a large number of typical operations are tested under a variety of conditions. If an error occurs, further tests are specified to locate the cause, if necessary including function tests on individual components. The results of tests on safety-critical systems (such as the airbag) are documented automatically.

4.2 Test Example: Vehicle : Unlocking by Remote Control

The steering column module has to receive and evaluate the radio signal, and then wake up and control the two ECUs involved in the unlocking function via CAN bus. Even though the executing ECUs were correctly woken up, they ignored the actual unlock command due to a software error, especially when locking and unlocking were performed in quick succession. This implementation error was found using the HIL simulator, enabling it to be remedied in time **(Fig. 7)**.

4.3 The Benefits

For Opel, the most important advantages that HIL simulation has over the Bench Boat and tests on real vehicles is its far greater test case coverage due to automation and the greater reproducibility of tests.

Not long after its installation at Opel, the benefits of the HIL Simulator quickly became clear from the ease with which tests could be input.

Within only a short time, Opel achieved more than 70% utilization of the simulator for automated tests during office hours. For approx. 20% of the time, the simulator is used for configuring and setting up new test sequences. Around 10% of the time goes on analyzing detected errors in manual operation of the test bench. Overnight tests are also run occasionally.

A typical test run contains 10 to 15 operator inputs, whose sequence and timing are

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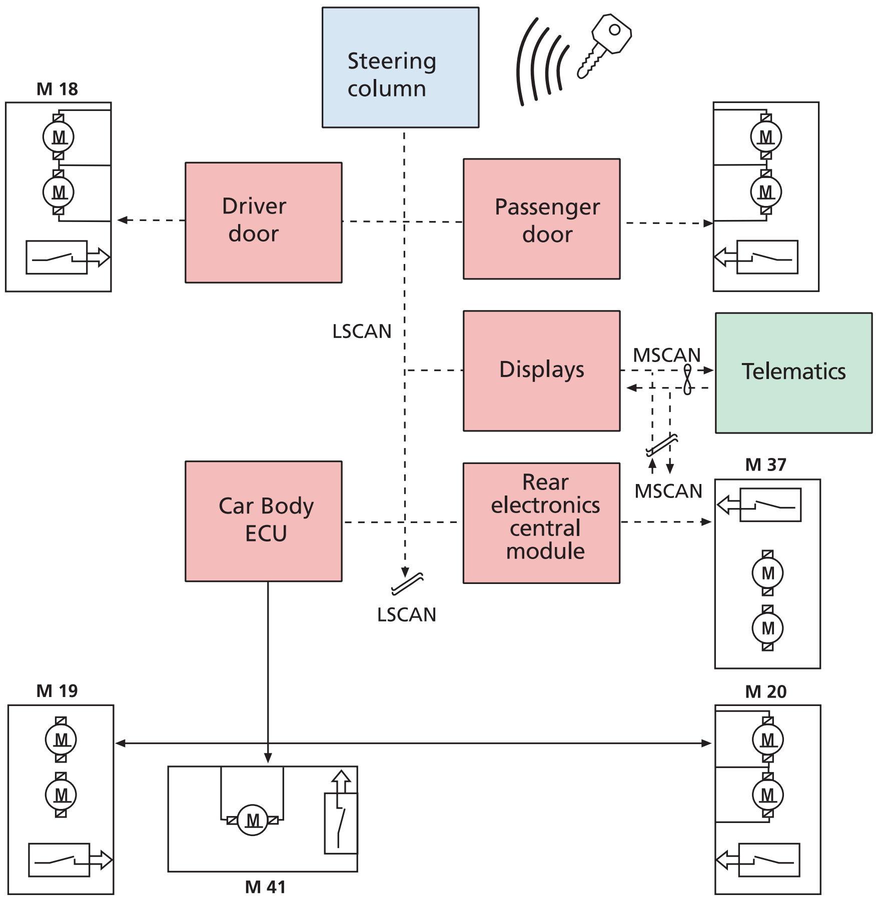

Figure 7: Components networked in the vehicle locking system.

varied automatically. Depending on the level of complexity, up to several hundred such test runs together form a subtest, for example, on „vehicle access“, „lighting“ or „wiper logic“.

So far, the errors found by means of the simulator have been mainly implementation errors. Often, the vehicle or the Bench Boat produces indications of possible faults, which can then be reproduced and analyzed on the HIL simulator. However, experience has shown that the HIL simulator enables even more errors to be discovered, which would otherwise not have been found due to the spot check nature of manual tests.

The vehicle unlocking fault (see 4.2) described above would very probably not have been discovered by manual tests. The relatively fast sequence of locking and unlocking occurs very rarely in test drives, and the faulty behavior might be interpreted as the radio range being exceeded. When hundreds of thousands of customers use the vehicle, however, such cases occur frequently. The fault would have the potential for massive customer complaints.

Although the HIL simulator was originally planned purely for testing the ECU network, its usefulness in testing the functionality of ECU groups and subsystems has also become increasingly evident. Opel is therefore aiming to distribute the overall functionality of the HIL simulators across several small simulators that can be interconnected as required. For example, the airbag system does not need connection to all the other ECUs for self-diagnosis, but because this is safety-critical, complete automated and documented testing is vital. Opel finds it important to be able to adapt the test platforms fast and without outside assistance. For the future, Opel anticipates that an HIL simulator for a vehicle platform must be available for approx. 2-3 years for function testing of components in a network system. Minor modifications are conceivable within this period.

4.4 Testing in the Overall Development Cycle

After its positive experience with HIL tests, Opel, like many other users, has no wish to stand still. The company plans to perform automated testing in other, earlier development phases. This imposes tough requirements on test development and management (Fig. 8).[Fig. 8, large]A large number of tests can be performed in earlier development phases, as soon as a particular ECU function is available as a simulation model (for example, in Simulink/Stateflow). The function model (the unit under test or UUT) and a virtual environment in the form of a system model together make up a closed control loop. This step is also known as model-in-the-loop (MIL). In contrast, in a software-in-the-loop (SIL) system the UUT is already available in the form of production code that will later be integrated into the ECU. This allows the behavior of the ECU code to be compared with that of the function model. The last step is hardware-in-the-loop simulation. The ability to reuse function tests from earlier phases is important for an efficient development process. In HIL simulation these are joined by further tests, such as diagnostic tests or testing communication in the networked systems.

Testing in early phases, the reusability of tests, and test creation and management are all supported by dSPACE AutomationDesk, a new integrated tool that has been in productive use in automotive industry projects since mid-2003 [3]. It allows fast and efficient test creation, provides a library of basic test functionalities and has a project manager component for storing and managing large volumes of tests, test data and test results.

5 Outlook

The benefit of HIL simulation for testing the ECU network in the new Opel Vectra became apparent very early on, as did the fact that the benefit appreciably exceeds the extra cost of construction and maintenance and of test creation. In addition to extending the use of automated HIL tests, Opel also regards the definition of tests for

4.4 Testing in the Overall Development Cycle Unlocking by Remote Control

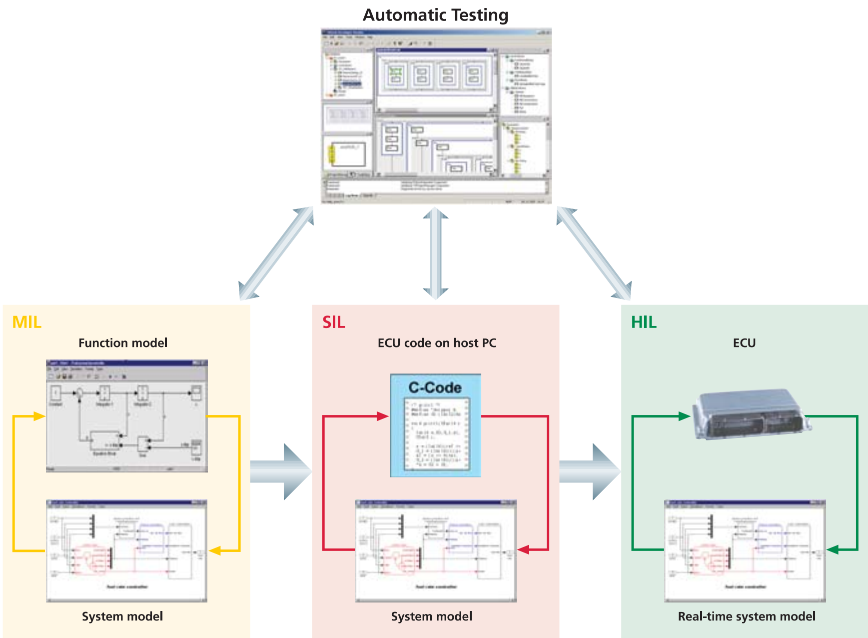

Fig. 8 Automatic, model-based tests in various phases of the ECU development cycle.

early ECU development stages (software specification, software implementation) as a vital task in the near future. These tests can then be used, and further refined, in all further development phases.

Another of Opel's objectives is to increase the number of variants. Converting the HIL simulator from the Epsilon platform to the Delta platform is only a first step in this direction. In the short term, extended simulation of the effects of the vehicle electrical system (ground offset, voltage drops, transition resistances) and integration of the dSPACE system into other test benches as the „driver" will be added.

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