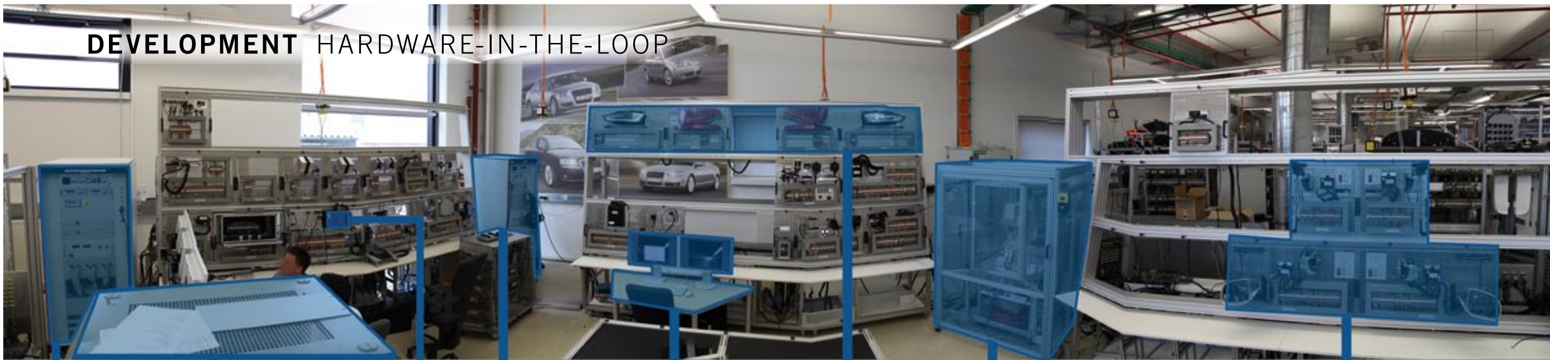

A NEW ARCHITECTURE FOR AUTOMOTIVE HARDWARE-IN-THE-LOOP TEST

As automotive electronic system design evolves, so must the HiL testbench and automotive test platforms. The fundamental functional design approach has been modular and ECU-centric, but the ECU count has steadily increased. The next big shift is to achieve functionality through the integration of multiple ECUs. Audi is responding to these challenges by radically re-thinking the architecture of the HiL test platform and defining a next generation approach. The new approach introduces the concept of a HiL-Bus to integrate the functionality of multiple existing HiL sub-systems and meet the needs of a modular best-in-class test ecosystem. By using a data orientedapproach the complexity of the testbench is reduced making it easier to integrate hardware and software products from different vendors. One of the enabling technologies (Connext DDS) is developed by Real Time Innovations Inc.

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CHALLENGES AND APPROACH

The previous ECU-centric system architecture with its point-to-point communication infrastructure is no longer an efficient design approach. Automotive electronic systems are becoming truly distributed to achieve increased system functionality by tightly coupling ECUs. These changes encourage a significantly revised approach to automotive system test. This shift in system design is reflected in the evolution of ISO26262 [1], derived from IEC61508 [2], with its focus on functional safety assurance. It has a huge impact on automotive test platforms, Hardware-in-the-loop(HiL) simulation, test platform provider. Audi is responding to these challenges by radically re-thinking the architecture of the HiL test platform and defining a next generation approach.

The new approach introduces the concept of a HiL-Bus to integrate the functionality of multiple existing HiL sub-systems and meet the needs of a function-centric test environment.

FUNCTIONALITY THROUGH DISTRIBUTED ECUS

We need to start by describing the shift towards function-centric testing from the perspective of automotive design. Here are a few examples:

: A simple “air bag computer” fires the air bags at the time of a crash. This ECU now becomes an integral element of a complex safety sub-system with more safety functions. The safety computer has to have an automatic crash detection capability (“Audi pre-sense”) and it has to perform fully automated braking support, deploy the air bags, tension the

- seat belts, close the windows and roof and move seats into an upright position.
- Dedicated ECUs for radio, navigation or rear seat entertainment are evolving into a "main entertainment unit."
- Dedicated ECUs for the reading light, interior light and body electronics are combined into a "body control module" and enriched with new capabilities such as bending light, matrix LED head light, camera-based night vision and traffic sign detection.

This is a different way of looking at vehicle development. It has a fundamental impact on the way in which the automotive HiL test platform needs to be designed. It requires a much more flexible and scalable test environment that is capable of bringing together many different HiL simulation platforms into one tightly integrated test platform.

A NEW HiL – DESIGN OBJECTIVE

The HiL test platforms available from the ecosystem of platform suppliers for a wide range of automotive sub-system simulations (such as powertrain, engine management, braking and air bag deployment), have evolved with the historic requirements of the stand-alone function-centric ECUs. However, new test requirements of the full car HiL simulation and function-centric test environment need something new and different to validate the functions of future cars.

Audi identified that different HiL test platforms from different suppliers offer differing levels of fidelity with respect to their simulation and test capabilities. New highly integrated and distributed functions need a highly distributed HiL ecosystem. Multiple HiL sub-systems provided by different suppliers have to be tightly coupled to reflect the integrated distributed function being tested, ❶. The HiL suppliers may only be providing the very best sub-system HiL simulation and test capabilities for a fraction of the overall function test objective. This would require the automotive vendor to compromise the full system test fidelity if they source the entire platform from one supplier.

Why can't the automotive company select the best HiL-sub-systems and bus simulations from across the industry to build a new best-in-class function test HiL platform? This is the question at the heart of Audi's research into their Modular HiL Next Generation mHIL-NG project.

This project is looking beyond test platforms; it wants to be able to bring the advanced model-based and computer-aided development tools used in actual ECU development into the HiL ecosystem.

THE NEW HiL TEST CHALLENGES

Automotive HiL must stay ahead of the developments in ECU integration, or at least integrate existing ECU development processes to keep pace with the rate of change in automotive development.

A next generation automotive HiL must be able to deal with:

- increasing scale of ECU function simulation
- increasing complexity of functional test requirements
- integration of a wide variety of HiL modules into function sets
- integration of ECU modeling platforms for test validation and stimulation
- standardised and simplified interface for user interaction and control
- signal measurement and stimulation across different modules.

Perhaps the most significant decision that Audi has made is to base the new HiL architecture on an open standard middleware or bus. The new distributed functional test demands, and Audi's qualitative objective (and motto), "Truth in Engineering," can only simultaneously be met using open market-accessible integration technology.

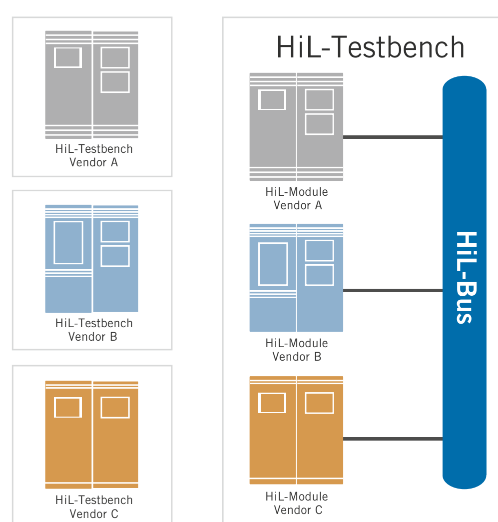
Audi searched for a software infrastructure that is real-time capable, scalable, field proven to be reliable and an open standard. After researching available options, Audi identified the open standard DDS (Data Distribution Service) from the OMG [3] and the conformant implementation from Real-Time Innovations, which not only met these criteria, but was also able to deliver the required virtual bus architecture. RTI Connext DDS is also demonstrably integrated with leading modeling environments widely used in software development.

A DATA-CENTRIC CORE FOR THE HiL-BUS

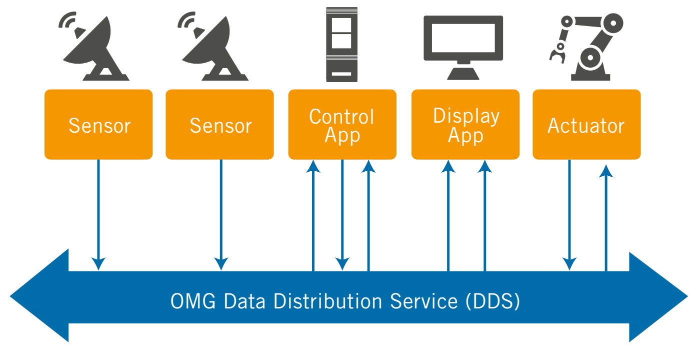
At the 2013 VDI automotive electronics conference in Baden-Baden, the keynote [6] emphasised a huge change in the automotive software development paradigm. Specifically, to deal with the complexity of future electronic systems design, the industry must move to a data-centric approach. Audi also noted that viewing the integration bus as a software databus was the only way to bring the best-in-class elements of existing proprietary HiL sub-system suppliers together with the modeling and development tools used in ECU development.

Every HiL testbench or sub-system is seen as a module. Each module either produces or consumes data, and the data is important to the test system. The changing state of data represents changes in system or sub-system state. A state change is at the core of being able to understand and validate whether a suite of ECUs meet a specific functional objective. A data-centric system infrastructure, ❷, makes state changes visible on the software bus by updating data values, just as a database in an enterprise system updates its rows and columns. It sustains a real-time view of the system-wide state that is immediately accessible to all sub-systems.

With a data-centric infrastructure in place, Audi maintains control of the communication infrastructure and can decide how to evolve the HiL-Bus to meet functional test needs in a simple and elegant fashion. This sort of de-coupling capability facilitates the evolution of a true plug-and-play automotive test platform. The ability to rapidly bring together multiple HiL system suppliers



❶ Audi HiL-Bus – Connecting Multi-Vendor HiL Testbenches



❷ The OMG DDS databus architecture

into a single functional test environment has the potential for huge savings in set-up time and cost and simultaneously supports the best-in-class modular selection objective. Of course, it must be simple and easy to connect different supplier HiL solutions onto the HiL-Bus to investigate multiple combinations of HiL test platforms to derive the optimal functional test platform.

The timing of when a signal change in a module occurs is as important to a real-time system as the fact that the signal change occurred. To this end, the DDS standard [4] includes Quality of Service (QoS) capabilities that provide the ability for applications to specify their timing constraints and notify applications if these constraints are not satisfied. These real-time-capabilities are important for measuring signals across different HiL-modules.

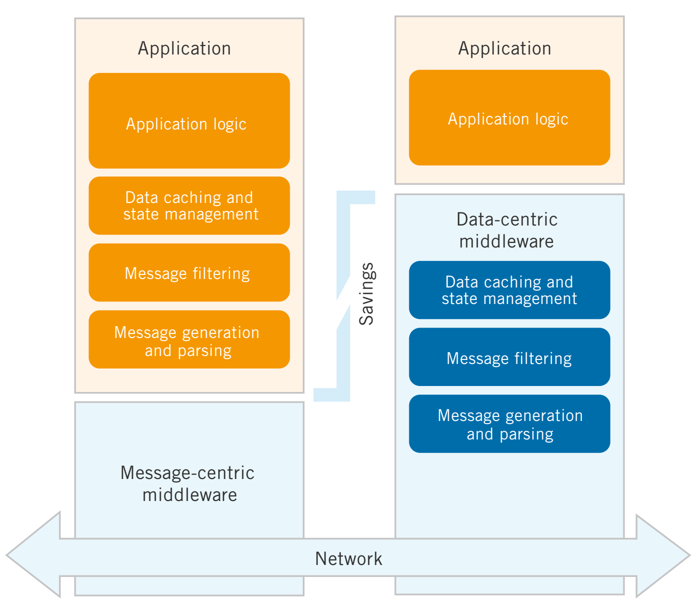
AN OPEN BUSINESS MODEL

RTI Connext DDS is the implementation of the open standard DDS that Audi chose to work with. Apart from its validated real-time performance, its field proven robustness and the depth of its supporting development tools, RTI Connext DDS has one other key value: its business model. As Stan Schneider (CEO of RTI) stated in his keynote at a FACE [5] technical symposium, „RTI is committed to an open architecture that expands thedselection of applications and reduces the cost of procurement, system integration, upgrades and technology refresh, while significantly reducing the total lifecycle cost“. To foster an ecosystem of HiL simulation suppliers we must maintain a low barrier to entry for them to integrate to the Audi HiL-Bus.

Audi provides data definitions to its partners for interfacing to the HiL-Bus. This lets them be part of a wider functional Automotive HiL test platform, but the HiL supplier still needs to connect at the software infrastructure level. RTI Connext DDS uses an Open Community Source (OCS) licensing model. Through OCS, any Audi partner can gain access to the basic DDS software (including source) at no charge and with royalty free deployment. The software license has none of the copyleft-style restrictions typical of many open source software products. This makes the integration of new supplier-modules very easy and comfortable.

THE IMPORTANCE OF DECOUPLING

The other benefit of the real-time-capable data-centric infrastructure of the HiL-Bus is the highly decoupled modular development capabilities it supports and enforces. It is very important in an open architecture such as the HiL-Bus that independent, modular development can be advanced by contributing developers and ecosystem partners. DDS acts as the communication and real-time arbiter in this software bus system. Its true peer-to-peer architecture means that it supports an "any order" boot sequence. DDS provides a discovery mechanism that treats every modular participant as both a sink (subscriber) and a source (publisher) of data (and thus state changes) to the wider system of systems. By moving the communication complexity into the bus, Audi massively reduces the integration problems of connecting different sub-systems developed by different partner companies using different methodologies. Now, integrators just have to characterise their data outputs and source requirements and align them with the Audi data model. Dr. Jan Effertz of VW Research described the benefits of DDS in their driver safety systems research as, "Think about the data, not how to communicate" [6]. Developers just place data on the HiL-Bus or take it from the HiL-Bus. They do not need to think about how to communicate with a specific end-point which may have attendant unique requirements for message exchange, ❸.

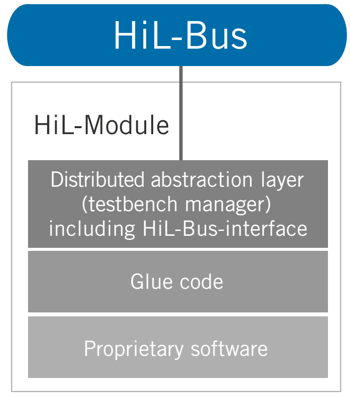


❸ Message-centric vs data-centric middleware [5]

TEST AUTOMATION

Automotive vendors such as Audi have invested many years in their test automation environment. Those environments include many proprietary setup tools that meet the special needs of their manufacturing and development organisations, and an incumbent workforce skilled with those tools. The introduction of the HiL-Bus must embrace existing user interfaces to the test platform and make it simpler to develop new test capabilities. Audi calls the abstraction layer their “testbench manager.” Such tools can be characterised by their data use, and easily interfaced, unchanged, onto the HiL-Bus, ❹, as simply as attaching a plug adaptor for power when travelling abroad.

The testbench manager is a software library developed by Audi. It consists of two parts: the HiL-Bus interface and the test-bench manager itself. This library is integrated in every sub-module of a testbench, ❺, and enriched by vendor specific glue code for accessing proprietary module functions via the HiL-Bus.



❹ Testbench manager as distributed abstraction layer

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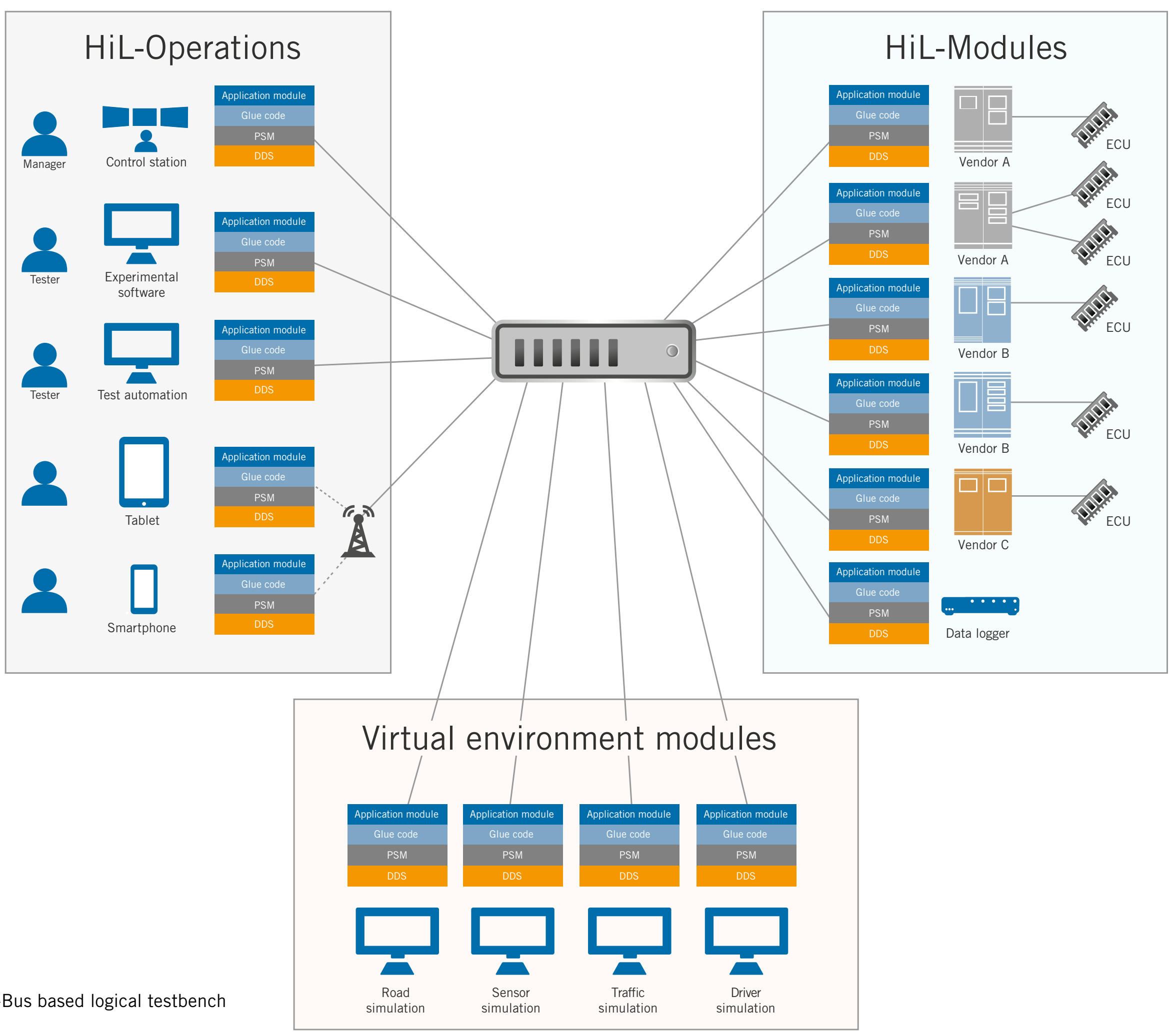

❺ Audi HiL-Bus based logical testbench architecture