Testing Transmission ECUs With Integrated Sensors

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Transmission ECUs with integrated sensors are tested by HIL simulation on the basis of dSPACE Simulator. Version handling for different ECU types and varying environment data are incorporated into a single HIL simulator. The example used is the German car maker Audi, who has successfully implemented tests based on this approach.

Test procedure is a precondition for testing electronic control units

The control of modern automatic transmissions would be inconceivable without suitable electronic and hydraulic control units. There is also a clear trend towards merging electrical and mechanical assemblies. For example, electronic control units (ECUs) and hydraulic systems are put together to form electrohydraulic control units.

But integration has gone beyond simply combining the hydraulic and electronic systems, including sensor systems (E-modules). The electrohydraulic control unit is now being integrated directly into the automatic transmission as an add-on ECU. Taking system integration to its logical conclusion in this way makes it possible to construct autonomous system components for use at the actual point of operation. The associated transmission control functions are implemented as software. Proving that the software implementation actually matches the specifications requires real-time-capable test procedures in closed-loop operation. To achieve this, many automotive manufacturers and their suppliers have opted for hardware-in-the-loop simulation (HIL simulation). This test procedure is a precondition for testing electronic control units and associated software sufficiently, before releasing them for use.

ECU Testing with Hardware-in-the-Loop Simulation

In hardware-in-the-loop simulation, the electronic control unit is not tested in a real vehicle but connected to an HIL simulator. A mathematical model of the entire ECU environment is executed on the simulator's real-time hardware. This basically consists of models of the engine, the gearbox and the powertrain. These models trick the test ECU into believing that it is installed in a real vehicle. The ECU environment also includes the signals communicated via the CAN bus. These also have to be generated (rest-bus simulation). Without them, it would not be possible to achieve realistic operation of the ECU in a laboratory environment. From all of this, it is easy to derive objective requirements for an HIL simulator, such as powerful processor hardware, flexible I/O hardware and the modularity of all software and hardware components. The depth of testing made possible by HIL simulators means enormous savings in cost and time in the development of ECU software. The tests are comprehensive, representative and reproducible. But in order to support ECU development efficiently, there are also some additional requirements:

- Many automotive manufacturers feel that it is too late, and therefore unacceptable, to begin HIL simulation when series production is about to start. The HIL simulator should be available throughout all development phases. ECU tests should be included in the development process very early on. The sooner the HIL simulator is available, the sooner errors (software, hardware, I/O and CAN errors) can be detected and corrected.
- HIL simulators must be able to handle different versions of ECU types without major adaptation. It must be possible to couple various ECUs with the simulator in as short a time as possible. Moreover, the software should improve version handling – for example by means of graphical selection menus.

Testing the ECU's Functionality

In this context, the car maker Audi has opted for solutions from dSPACE in Paderborn, Germany. dSPACE produces HIL simulators which consist to a large extent of off-the-shelf products. Additional engineering services on the hardware side are kept to a minimum. Set-up times are correspondingly short, allowing the fast availability of each HIL simulator.

In the case presented here, the HIL simulator is used to test the E-module (E-module = ECU + sensor system) for the new Tiptronic 6HP26 automatic transmission from ZF, which Audi intends to supply in top-of-the-range vehicles. Audi has specified a variety of test scenarios, all of which have to be mapped by the HIL simulator. They include the testing of diagnostic functions on the ECU, which involves setting the desired operating point and stimulating the ECU with a defined fault. The ECU passes the test if it detects the fault, goes to the relevant substitute program and logs the event in the fault memory. Typical substitute programs include fail-safe programs aimed at preserving functionality according to specifications, thus retaining driveability when faults are detected.

Verifying Fault Detection

Depending on the type of fault, there are different strategies for maintaining driveability. If a sensor fails, for example, its signals are replaced or estimated by substitute signals. As a rule, this results in only a slight or even no impairment of driveability. The fault is logged in the ECU and detected during the next scheduled visit to the garage, so that the cause of the problem can be eliminated. If a more serious fault occurs, this is brought to the driver's attention and restrictions are applied to driving operation. If elementary components fail, the electronic control of the gears is switched off completely. In this operating state, the transmission stays in one specific automated transmission mode. The vehicle can still be driven to a garage with the help of the torque converter (hydraulic back-up level). The way the ECU interacts with other ECUs is also investigated. For example, tests are run to determine whether the transmission unit requests the engine control unit to reduce torque, ensuring that gear changes are smooth. There are also tests for the desired manipulation/corruption of CAN messages. Other studies look at how the ECU reacts to the absence of plausible or expected sensor signals. This involves testing whether the substitute data placed in the ECU's memory is actually used when a fault occurs. Such test case scenarios are covered systematically and reproducibly using the HIL simulator.

Program control within the ECU is achieved by a 32-bit microcontroller

The 6HP26 Six-Gear Automatic Transmission from ZF

The 6HP26 is a hydraulic planetary gear set designed for vehicles with standard drives and torques of up to 600 Nm. It is smaller and lighter than its five-gear predecessor. The hydraulics system is located in the area of the oil sump, together with the E-module. The E-module, consisting of the ECU and integrated sensor systems, is connected to the actuators via a connector strip. Program control within the ECU is achieved by a 32-bit microcontroller (MPC 555).

Implementing the ECU as an add-on unit in this way allows ZF to achieve an enormous reduction in coupling pins and in the cabling involved (enhanced system reliability): Whereas the ECU for the predecessor transmission had 88 contacts, the version produced for the 6HP26 has only 16. Further advantages from merging the E-module, the hydraulics system and the transmission are:

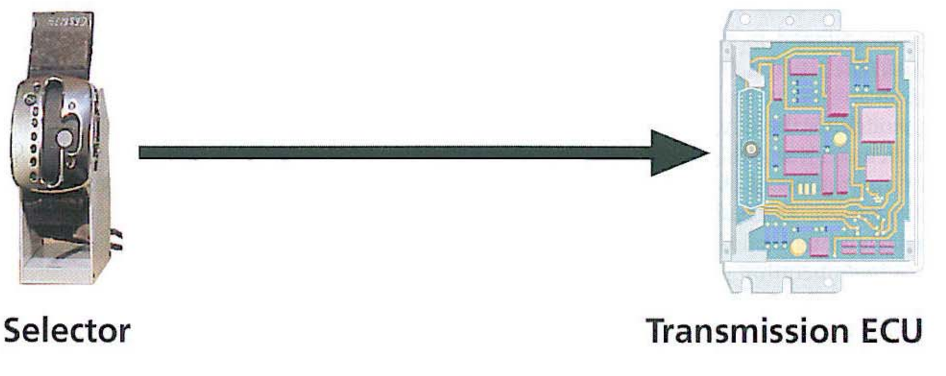
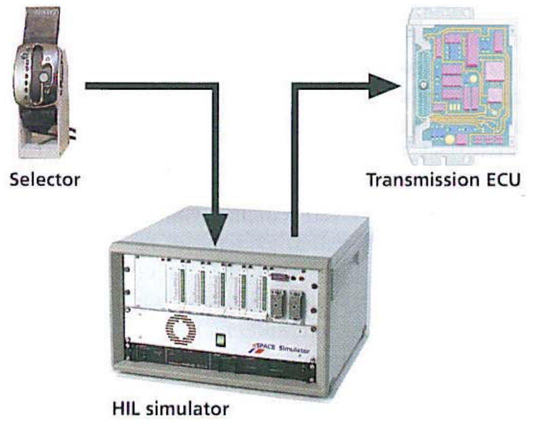


Figure 1: The position of the selector can be manipulated by the HIL simulator as required and passed on to the ECU.



- small installation space
- reduced weight
- no additional housing for the sensor system.

The integrated sensor system comprises the gear set's input and output speed in addition to transmission oil temperature and selector position. Unlike its predecessor, this version has Hall sensors rather than inductive sensors to monitor the engine speed. This means that a speed range of 4 Hz (stationary vehicle) to 7 kHz can be achieved. The sensor detecting the position of the selector consists of four integrated oil-tight sensors whose output signals are made available to the ECU in 4-bit code.

The HIL Simulator

The 19" desktop rack as a fundamental part of the HIL simulator (Figure 3) contains the signal conditioning and real parts such as the instrument panel.

The simulation models are computed in real time on the real-time hardware. These models basically cover a representation of the engine, gears, torque converter and vehicle as Simulink blocks. Simulink is the graphical program language from The MathWorks providing convenient modelling of dynamic systems. The implemented Simulink models are taken out of corresponding, pre-defined block libraries. They are available as a commercial package from TESIS GmbH and are completely parameterisable according to the specific requirements. The desired adaptation to represent the real world is therefore significantly simplified.

Figure 2: Electrohydraulic ECU comprising the hydraulic unit and E-module.

Modelling the Environment Components

The models used for modelling the environment are a representation of their real world counterparts. Basically, they feature the following characteristics:

Engine model: The data in the engine model is placed in look-up tables and derived from differential equations. The required operating points are targeted within the engine-specific look-up table characteristics. The gear control unit interprets the data as operating data from a real engine and processes it accordingly.

Transmission model, converter model: The transmission and converter models supply data such as the speeds of the input and output shafts to the gear control unit. The position of the selector is made available to the ECU as a single-step binary code.

Vehicle model: The vehicle model includes the longitudinal dynamics of the vehicle with parameters for vehicle weight, aerodynamic drag, tyre radius, etc.

ECU Mount Assignment

Because the E-module contains integrated sensors, these have to be stimulated by appropriate signals. These signals must be a direct derivation from the signal characteristics occurring during the simulation run. In other words, signals from the modelled environment have to be used to excite the integrated sensors

The control signals issued by the ECU for the actuators also have to be detected. Thus, in terms of hardware, the E-module is connected to the HIL simulator by an additional element; the ECU mount. This allows the easy connection of the ECU to the simulator via contact sockets and sensor stimulation units. Since the ECU mount features various types of ECUs – even those without sensors included – it makes testing with the HIL simulator very flexible. Consequently, the mount contains important components such as:

Equivalent loads: The ECU controls the pressure regulators and solenoid valves of the hydraulics unit according to the implemented switching strategy. The valves are mapped electrically within the ECU mount. Mapping is adjusted to the requirements of the model; in other words, according to the load characteristics, it contains either pure resistive loads or resistive/inductive loads.

Sensor stimulation: As mentioned above, an important feature implemented within the ECU mount is the stimulation of the integrated sensors. For example, the Hall sensors for registering the engine speed are stimulated by corresponding coils that generate the necessary (varying) magnetic fields. The signal conditioning required for this is also integrated into the ECU mount.

Also included are level converters for converting the automotive signal level (e.g., 0-24 V) into TTL levels, which the HIL simulator's I/O hardware requires as inputs. However, this alone does not ensure suitable signal conditioning or the interchangeability of different ECU versions as described above. Older versions of transmission control units had inductive sensors to register the speeds. As the technology developed, these were replaced by Hall sensors, which provide a different characteristic signal behaviour. The signals therefore need to be suitably adjusted to allow the simulator to be run with older ECU versions.

Operating Philosophy

The simulator is operated via ControlDesk from dSPACE. ControlDesk is the core software tool for test control, visualization and documentation. The instrumentation libraries enable experiment data to be suitably represented. All the data associated with the test – engine speeds, torques, pressures – is displayed by corresponding instruments in ControlDesk. A key aspect is version handling. The ECU being tested can be run with different engine/gear/converter/vehicle versions. Developers put together the desired system configuration from several different libraries and connect it to the real gear control unit via the HIL simulator. For example, there are dedicated screens that allow developers to select whether the model should be computed with a special model for different engines on the simulator's real-time hardware.

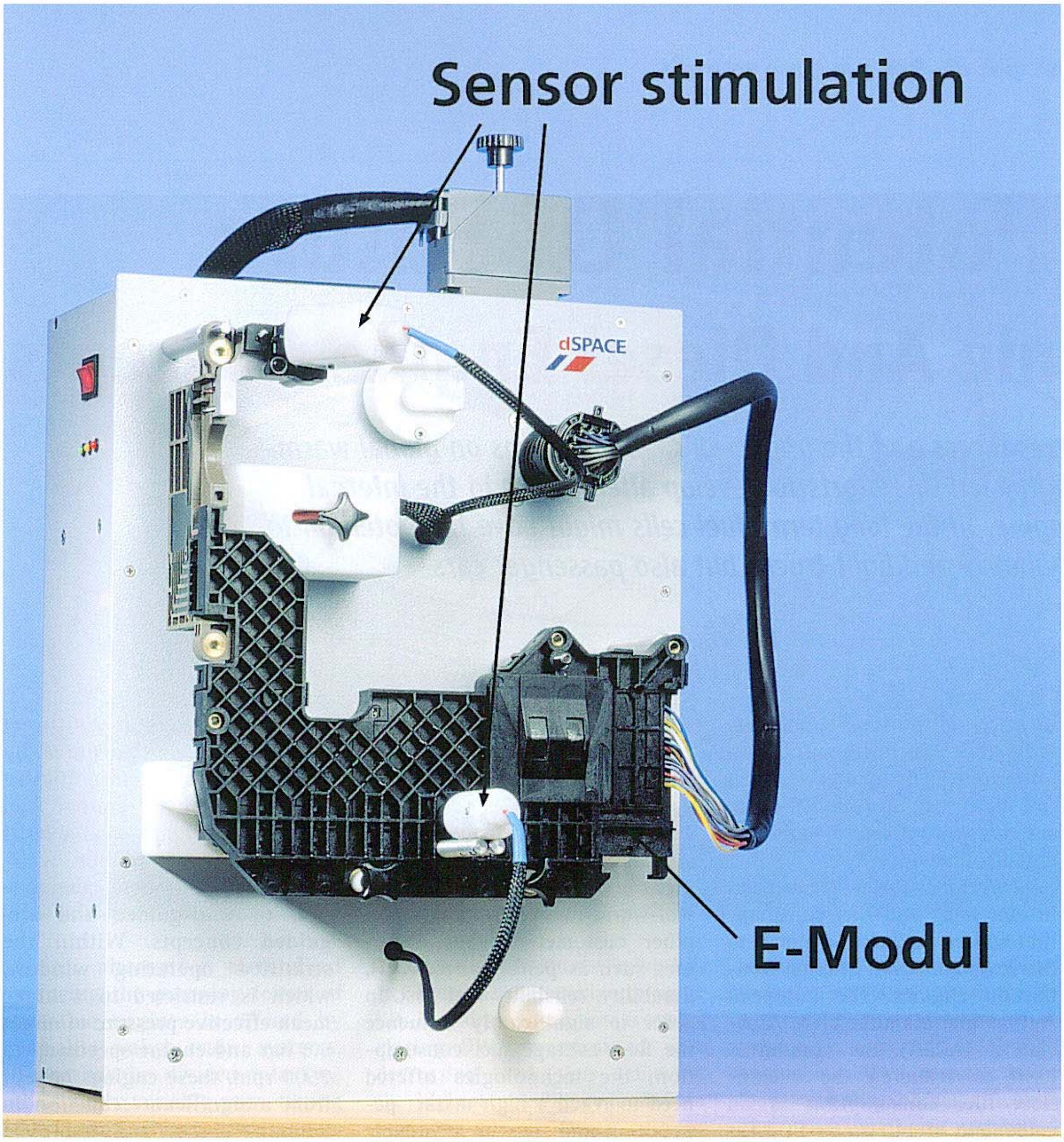


Figure 3: ECU mount with E-module.

The ability to handle different types of vehicle components in this way is absolutely essential in view of all the different vehicle versions that come off the assembly line. Country-related differences, for example, in speed limits, fuel consumption and comfort features, all have to be taken into consideration. Thus, the HIL simulator also has to cover all these different possible component variations when testing the gear control unit.

Conclusions

HIL simulation is established as a standard part of the design cycle of ECUs. Manual test procedures with open-loop stimulation are not appropriate for adequate testing of complex ECU software. Modern ECUs, whether they control the engine, the transmission or vehicle dynamics, expect plausible input data, which can be achieved only by complex simulation engineering. The new approach to setting up an HIL system capable of handling different types of ECUs, even those with integrated sensors, proved to be successful. With the advent of new ECU and transmission generations, Audi still implements the same dSPACE Simulator, with just a few modifications. As shown in this article, dSPACE Simulator can be adapted to different ECUs in just a few minutes, making it an investment with long-term viability.

[1] U. Rühringer, G. Birkenmaier, K. Engelsdorf, „Mechatronikeinsatz im hydraulischen Planetengetriebe – Anforderungen und Lösungen", VDI Berichte 1533

[2] W. Runge, „Elektronikentwicklung bei Automatikgetriebe und Lenkung", Automotive Electronics, January 2000, Edition 01, Page 30-32

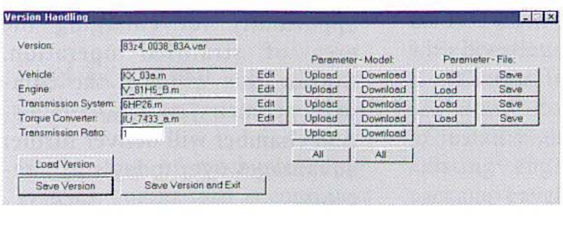


Figure 4: Dialogue to choose between vehicle components.

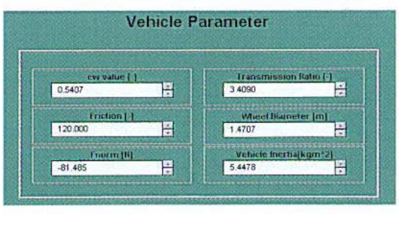


Figure 5: Screen for interactive parameterisation of vehicle data.