

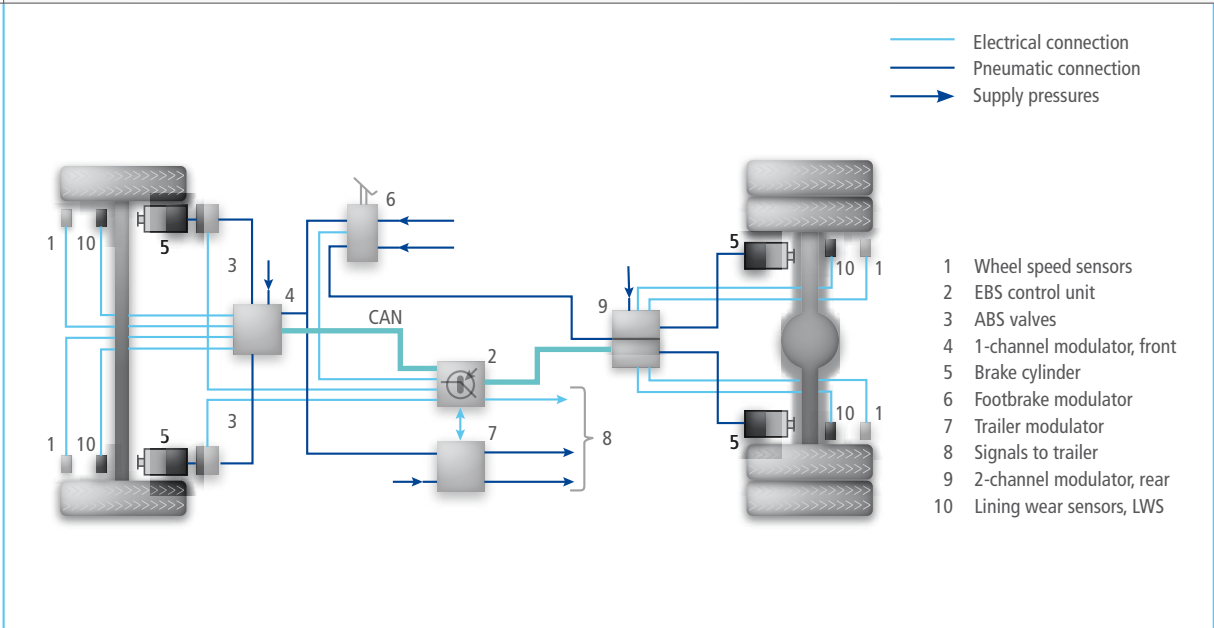
Big on Safety

Volvo 3P's innovative product development include HIL simulations to test and verify brake system controllers





Back in the old days a truck carried next to nothing compared to the load that a modern heavy-duty truck hauls safely on the road today. Maintaining 100% reliable and safe operation under all road, load, and traffic conditions is a challenge for the brakes. Volvo 3P relies on HIL simulation to test and verify the controllers when developing brake systems.



Overview of the EBS on a truck with two axles.

Braking by Air and Wire

In cars, the brake pressure and the brake force depend on the force applied to the brake pedal. The pressure is boosted by a vacuum taken from the engine’s intake manifold and transferred to the brake by a hydraulics system. For large, heavy trucks and buses, this vacuum is not strong enough, and a hydraulic system is inconvenient when it comes to coupling and decoupling trailers. The brake systems of such vehicles therefore work with air pressure.

The force that press the brake pads against the brake disc is applied pneumatically and regulated by the brake pedal. These are electropneumatic brakes which are fully based on by-wire technologies. The compressed air for the pneumatic system is stored in reservoirs and passed to the brakes by electronically controlled modulators. To avoid overheating, fading, and excessive wear, trucks utilize auxiliary brakes such as retarders and engine brakes. The brake system has to coordinate the auxiliary brakes with the service brakes for the different brake system functions that control the speed, maintain vehicle stability and stop the vehicle. All these brake actuator systems

“Cars are driven by people. Therefore the guiding principle behind everything we make at Volvo is – and must remain – safety.”

Assar Gabrielsson and Gustaf Larson, the founders of Volvo, 1927

and functions have to work together efficiently and safely. A job for an electronic controller: the electronic brake system (EBS).

Truck Brake System Features

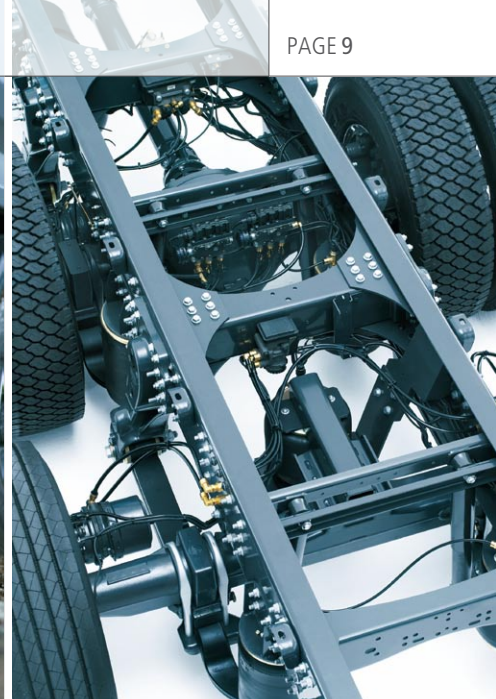
Numerous sensors provide information on a truck’s dynamic behavior if it is equipped with an EBS and ESP function: wheel speed, yaw rate, lateral acceleration and steering angle. Moreover, the brake system has to be adaptive to meet the special requirements of trucks, such as coping with unbalanced loads, liftable axles, attached trailers, or service requirements like even wear on the brake pads. Thus, sensor signals such as the axle load and brake lining wear have to be taken into account to determine the best braking strategy. If the truck is equipped with any auxiliary brakes, the characteristics of these brake systems are transmitted to the EBS so that safe and comfortable brake blending control can be achieved.

Braking the Trailer

The brake system on the trailer is separate from the truck. It can be either a conventional pneumatically controlled system or an electronically controlled pneumatic system. The truck and the trailer can have different brake systems: pneumatically or electronically controlled. The trailer has its own energy storage (air pressure tanks) supplied from the truck. The brake control signal to the trailer brake system comes from the truck and can be either purely pneumatic or both electric and pneumatic. The trailer brake system is required to brake its own mass. The coupling force control (CFC) function in the EBS helps to achieve the brake balance between the truck and the trailer.

EBS and Modulators

All the brake functions, including the anti-lock braking system (ABS) and the electronic stability program (ESP), are integrated in the EBS. The



EBS communicates with up to four modulators that control the pneumatic pressure on the brakes. Each modulator interface on the EBS ECU can be connected to either a 1-channel or a 2-channel modulator; this makes the EBS system modular so it can be adapted for different truck variants. Each modulator controls the brake pressure in either one or two circuits depending on whether it is a 1- or 2-channel modulator. This is done in feedback control mode, as the modulator has a pressure sensor for each circuit. Under normal operation the modulators receive a brake pressure request from the EBS ECU on a CAN bus, but if the electronics fail, the modulator brake pressure will be controlled by a pneumatic control signal that comes from the foot brake modulator.

Truck Vehicle Dynamics

A fully loaded, heavy-duty truck can have almost three times the weight of the unloaded truck. Thus, the vehicle dynamics of the truck are heavily influenced by its cargo. With swap bodies, the same truck can be used for different types of transport, which the chassis systems have to adapt to. As the differences in vehicle weight are so large, some

Functions of an Electronic Brake System

Basic brake pressure calculation: Calculates brake pressure based on the brake pedal position and truck load.

Adhesion-optimized brake force distribution: Adapts brake pressure to the individual brake circuits according to axle load distribution and the driving situation.

Brake blending: Automatically distributes the retardation request between service brakes and auxiliary brakes to reduce the load on the service brakes.

Brake assistance: Increases the brake pressure automatically if the brake pedal depressing gradient is high (emergency brake assistance).

Coupling force control: Balances the longitudinal force between truck and trailer in order to equalize the wear on the brakes.

Tilt prevention: Prevents the vehicle tilting forward (important for solo tractors braking downhill).

Wear-optimized brake force distribution: Equalizes the wear on the brake pads on the different axles.

Antilock braking: A safety function (called ABS) that prevents the wheels from locking up.

Drag torque control: Controls engine drag torque if the driven wheels start locking due to the engine drag torque.

External brake demand: Interface used by other ECUs to request braking, for example, in adaptive cruise control.

Fading warning: Brake temperature warning.

Lining wear prediction and wear display: Estimates the mileage to the next brake pad replacement and displays the current pad wear status.

Traction control: Controls drive wheel slip due to engine propulsion in order to maintain traction.

ESP: Includes the yaw control function, which prevents the truck from skidding, and the rollover prevention function.

Differential lock control: Automatically synchronizes the left and right drive wheels during diff-lock engagement, including automatic diff-lock engagement.



trucks have rear axles that can be lifted to reduce tire wear and fuel consumption. It also optimizes traction on the driven axle if the truck is hauling only a light load or none at all. For maneuverability reasons, and to reduce tire wear, some trucks have one or two steerable rear axles. The steering angles on these axles are controlled according to the steering wheel angle and vehicle velocity by an ECU and a hydraulics actuator system. The rear axle steering (RAS) ECU is only active in low speed if the steered axle is the last axle, as otherwise it would affect vehicle stability. For the brake system functions that help the driver to keep the truck on track in demanding traffic and road conditions, the challenge is to handle different truck variants, different loads, and different operation mode conditions safely. The brake system functions have to adapt to

different load distributions between the axles and different centers of gravity, which affect load distribution when braking or cornering. When braking hard, each axle needs to be braked against the axle load in the same proportion to utilize the same level of the available road friction on all axles.

Challenges for the Test System

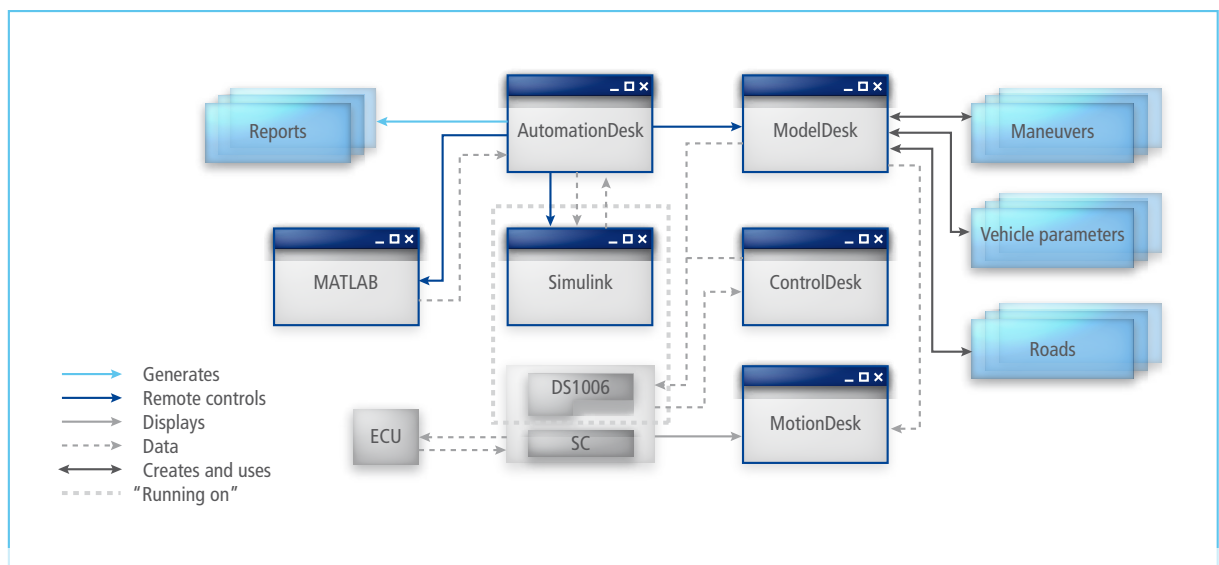
To test and verify the controllers for future truck brake systems and to ensure their functional safety Volvo 3P decided to install a hardware-in-the-loop (HIL) test system, that can perform manual and automated test runs. The test system has to meet the following challenges:

- Quick, convenient configuration of Volvo 3P's many brake system truck configurations
- Virtualization of the complex pneumatics system

- Testing different ECU generations
- Including the modulator electronics of the EBS
- Including models of auxiliary brakes
- Including a hydraulics model of the rear axle steering system

Thus the HIL simulator model had to represent different truck variants just by changing parameters in the real-time environment. The parameterization of the compiled HIL simulator model had to include the listed submodels that were developed by Volvo 3P, plus all the parameters used for switching either a 1-channel or a 2-channel modulator to the EBS ECU and to the I/O pins, since the I/O used for the 1-channel modulator on a specific modulator position had to be reused if a 2-channel modulator needed to be connected to test the right truck variant.

The dSPACE HIL simulator tool chain, from test case and vehicle parameters definition, to automated batch simulations, to test reports.



High Demands on Productivity

Other important requirements were easy-to-use graphics-based tools to support interactive simulations, create test cases conveniently, and handle all the variants efficiently. The goal was a system that runs with push-button ease, without requiring any engineering resources for development and maintenance. It was important to find a supplier that could deliver a complete HIL simulator tool chain that covered all the requirements, rather than integrate different tools from different suppliers to make a complete HIL simulator.

Basic Setup of the HIL System

dSPACE used Volvo 3P's specifications and the documentation on sensor and actuator characteristics to configure a HIL simulator. The system is based on two DS1006 processor boards for real-time processing, one for the truck and trailer models and the other for the I/O model. The truck's behavior and components are simulated with the Automotive Simulation Models (ASM) created in MATLAB®/Simulink® by dSPACE. Truck parameters, roads and maneuvers are used to configure and parameterize the models. The test cases are defined and performed in dSPACE AutomationDesk®. Each automated test run delivers a report.

Integration of Volvo 3P's Plant Models

To test the EBS and RAS control functions, the respective controlled systems need to be simulated. Volvo 3P's developed plant models of the wheel brake, the pneumatic pressure system and the steering system actuators therefore had to be included in the ASM truck model. The complete HIL simulator model also had to be supplemented by subsystems that could switch in the right modulator brake pressure to the right axle depending on truck variant, and switch the right model wheel speed

“For truck vehicle dynamics simulation with this electronic brake system simulator we rely on the Automotive Simulation Models (ASM).”

Per Olsson, Volvo 3P

to the right modulator depending on truck variant. Close integration was achieved thanks to the ASMs' open structure.

The Simulator's Truck-Specific Features

All the modulators were included as real loads. To save space, just the modulators' printed circuit boards (PCB) and solenoids were assembled in a load box. Two load boxes were built for the HIL simulator for different EBS generations. The I/O model was made generic for both EBS generations, so to change the HIL simulator setup from one EBS generation to the other, all that needs to be done is to change the load box and EBS ECU, and download a new parameter set defined in ModelDesk. It takes less than 5 minutes.

Depending on the truck variant, different modulator configurations – either a 1-channel or a 2-channel modulator or none at all – need to

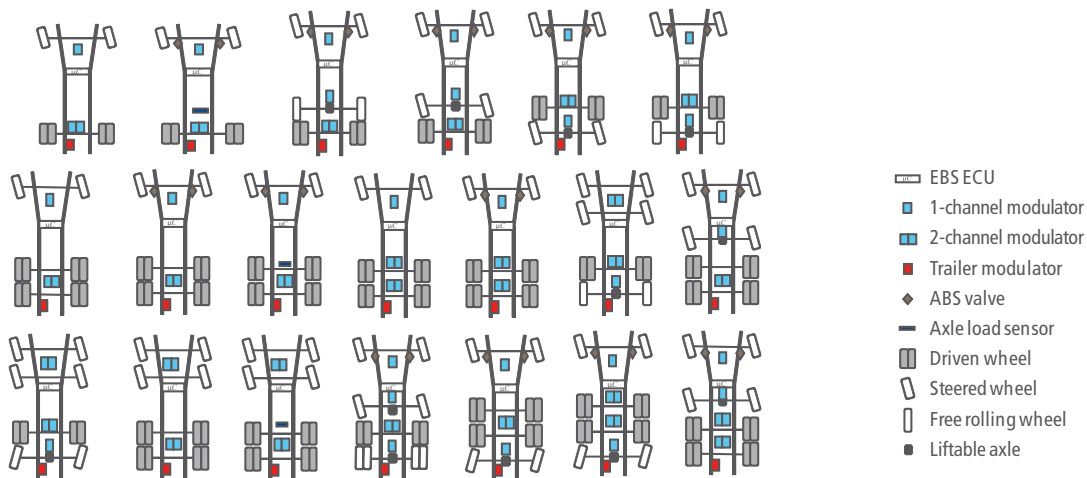
be connected to the four modulator positions of the EBS ECU and to the dSPACE Simulator I/O. This was solved by using a dedicated board which Volvo 3P has specified for these applications and which is used in other test systems within the company. This board features load switching, short circuit fault injection and signal conditioning as well as a 1-bit ADC, which were used to obtain isolated differential measurements of the EBS solenoid activations. The boards' configuration is controlled by an RS232 protocol. Volvo 3P created a driver model based on this protocol that runs on the DS1006 board. With parameterizations for the different truck variants, this driver model selects the right modulator configuration.

Variant Handling

Because customer-specific models can be added to the ASM models,

Real-time animation of the simulated truck.





Differences in the truck variants that have to be simulated for brake system controller development.

all the parameters for the standard ASMs and also the submodels added by Volvo 3P can be controlled from ModelDesk, where entire parameter sets can be defined for the HIL simulator configuration for the different truck variants and EBS generations. ModelDesk's graphical support for parameterization makes the whole process intuitive and convenient. It takes just a few mouse clicks to modify the truck geometry – its length, the number of axles, the tire model and so forth. An entire library with the parameters of all the variants can be created and managed in this way.

Per Olsson
Per Olsson is Technical Specialist for HIL simulations at Volvo 3P in Gothenburg, Sweden



“Without this HIL simulator, it would not have been possible to get the necessary test and verification coverage so quickly.”

Per Olsson, Volvo 3P

Scope of Simulation

The HIL simulator simulates:

- Truck and trailer dynamics, such as suspension, wheels, tires, roll, pitch and yaw
- Dynamics of the brake system's pneumatic components
- Road and driver characteristics
- Dynamic communication between the EBS ECU and the rest of the truck electrical system
- Rear axle steering system hydraulics
- Manual and automated test runs
- Fault injection tests

The HIL simulator was delivered with a set of automated tests programmed in AutomationDesk:

- ABS, straight-line braking on high and low μ
- ABS, split μ braking
- Sine with dwell
- Closing curve

These automated tests are generic and automatically adapted to the tested truck variant. Volvo 3P will use

AutomationDesk to program more test cases that eventually will cover all the EBS functions for all truck variants. With this HIL simulator, Volvo 3P is aiming for an automated test process for the EBS software and parameters releases covering all the truck variants.

Manual Testing

Initially, manual tests are used to define proper maneuvers and test conditions for the automated tests to be created. It is also used for special tests like follow-up tests and resolving problems reported from real test trucks. The configurability of the HIL simulator makes it easy to perform quick manual tests on the effects of EBS parameters on special truck variants that can be difficult to access. During manual tests, results can easily be monitored by 3-D animation.

Test Automation

Automated test runs are defined in AutomationDesk and are ideal for performing reproducible regression tests to verify a complete EBS soft-

ware and parameter release. All the test cases have variables so that it is possible to execute them at different speeds and load situations, and with different tire or road friction. During batch simulation in AutomationDesk, parameters like the velocity of a maneuver or the weight of the load can change. The truck behavior for such parameters can be presented in tables and diagrams. The results of a complete simulation run are automatically collected in a global result list. With ModelDesk's tool automation interface, individual truck variants can be selected during automated test runs, so multiple variants can be tested overnight. Again, this process is very efficient since the plant model does not need to be recompiled for a new variant.

Ensuring Functional Safety

Since the EBS is safety-critical, it is important to ensure its functionality even if the system is subjected to various faults like sensor defects and functional degradation, and to make sure it performs safely in all operation modes. The HIL simulator gives engineers total control over all EBS sensors, actuators and related CAN signals, which makes it much easier and safer for them to perform these kinds of tests in the HIL simulator compared to tests in real trucks.

First Results

Since its installation, the HIL Simulator has run a lot of tests supporting several EBS software and parameter releases. Thanks to the HIL simulator tests, corrections to the software and parameters were made before they reached the test trucks. This alone has saved a lot of time and money by avoiding costly investigations on the prototype trucks.

Evaluation of dSPACE Products

The HIL simulator matches Volvo 3P's specifications and operates stably. It is a vital tool for the verification of the EBS functions. A lot of things need to work together perfectly for such a test system to deliver the desired results. This HIL simulator delivers, without engineers having to waste time fiddling around with the system. Without the HIL simulator, it would not have been possible to get the needed test and verification coverage of the EBS so quickly. Testing so many different variants reliably by automated means is enormously time-saving. The HIL simulator tool chain supports manual tests, automated tests, animation, and online model parameterization including customer-added submodels, and is a good platform to work with. ■

*Per Olsson
Volvo 3P*

Outlook

The next step is to automate the tests of all EBS functions according to Volvo 3P's requirements and test specifications. In a further step, the parameters of all truck variants will be included in the simulations and validated. The test cases in AutomationDesk will be extended to increase test depth until a fully automated release process for the EBS parameters and software for all truck variants is achieved. It is also planned to investigate the efforts required for homologation by simulation according to United Nations Economic Commission for Europe (UNECE) regulation 13-H.

