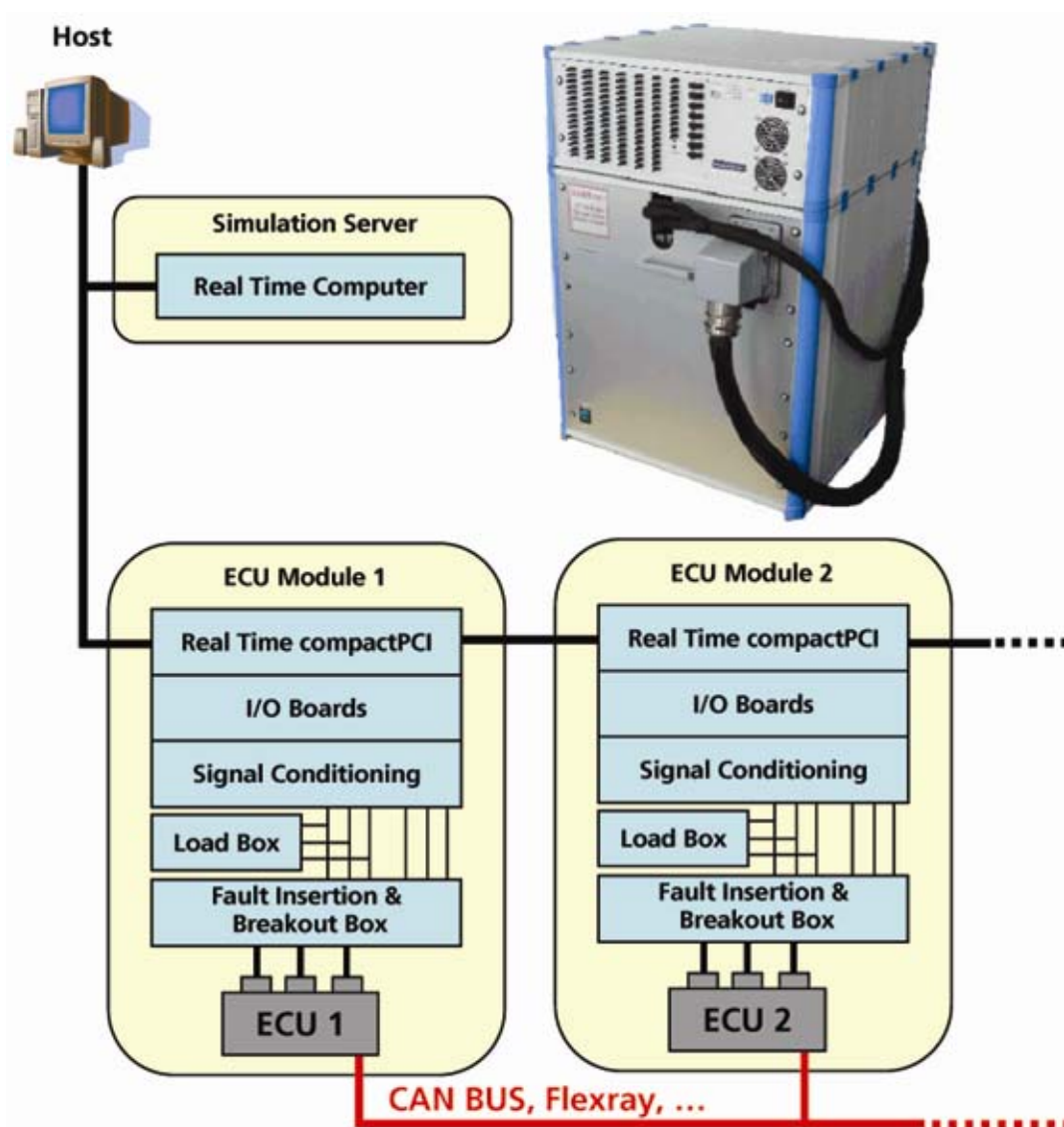


systems are not isolated, but share data in a heterogeneous network. Each iteration step in the development process adds new components to the system, which have to be validated in their functionality and interaction with other components. Detecting errors in early development cycles can save time and money. In order to meet these requirements, early tests use real-time mathematical models to simulate system interfaces, while later tests must implement software and hardware interconnections to validate the expected system performance.

In the traditional approach, calculation of the real-time models as well as signal generation and measurement are done within a centralized simulator to which all the ECU's are connected to. Such legacy tests systems are usually built from scratch, and have to be adapted in every new iterative step. Thereby isolated solutions originate which provide very limited flexibility and can hide high maintenance costs.



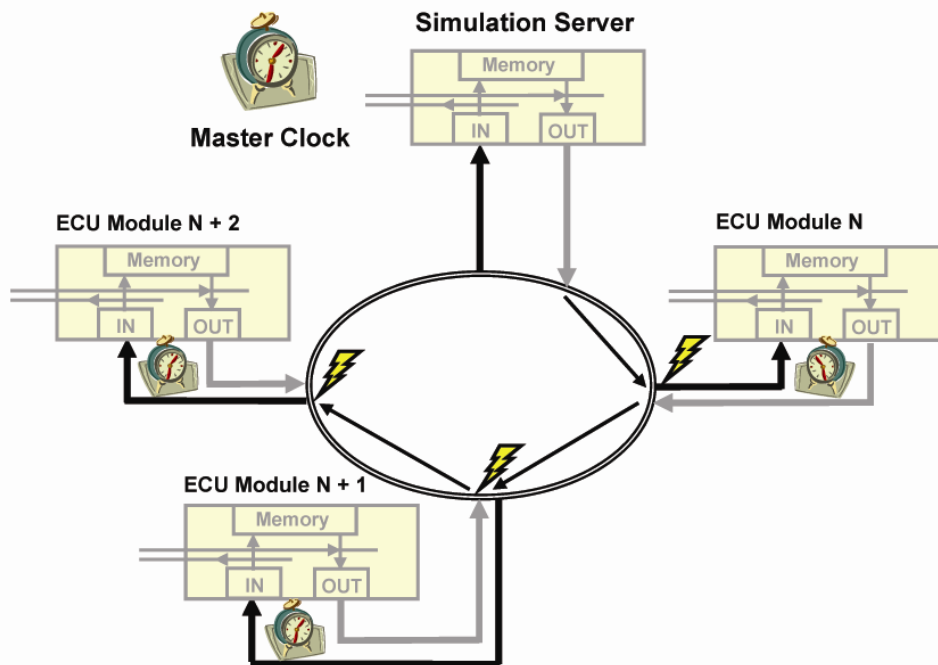
Picture 2: Modular system architecture

In modularHiL every single ECU has its dedicated real-time computer, as well as all necessary components to stimulate and measure its signals. A simulation server synchronizes the individual ECU modules and controls the test sequence. The most essential advantage of this decentralized system architecture is the high degree of scalability. The same modules can be used for a component test as well as for the

simulation of a complete vehicle. Even a test system covering a subset of the ECU network can be established, guaranteeing the possibility of testing at a much earlier stage in the development process.

Real Time Computing and Communication

Each real-time computer is provided with an Intelx86 processor and a compactPCI bus, even though Motorola traditionally dominated the real-time simulation market with its family of PowerPC processors in combination with a VME bus. Own benchmarks have shown that the achievable numerical performance is predominantly influenced by the clock rate of the processor, which is generally higher for the widely spread Intelx86 processors. In addition, a compactPCI bus is the more modern technology, and since each module only holds the I/O boards needed for one single ECU, the higher number of slots in a VME bus is usually not required. Full POSIX compliance is obtained through the use of the VxWorks operating system.



Picture 3: Network of real-time processors

Industrial real-time Ethernet solutions offer a high bandwidth for huge data blocks. However a communication based on shared memory is more adequate for simulation applications due to its better performance for low-latency small data packets, which are typical in the simulation of strongly coupled mechatronics systems.

With modularHiL a maximum of 256 nodes can be connected in a ring with extremely low latency times (e.g. 20 µs for 50 nodes) and a high-speed transfer rate of 2 Gbaud. In order to synchronize the different nodes, the simulation server sends every 1 ms a global interrupt, and each node then calculates the offset to the local time. To prevent the loss of messages and to allow for asynchronous operation, the incoming and outgoing message streams are buffered by FIFO queues. Messages are forwarded from node to node until they reach their original sender node.

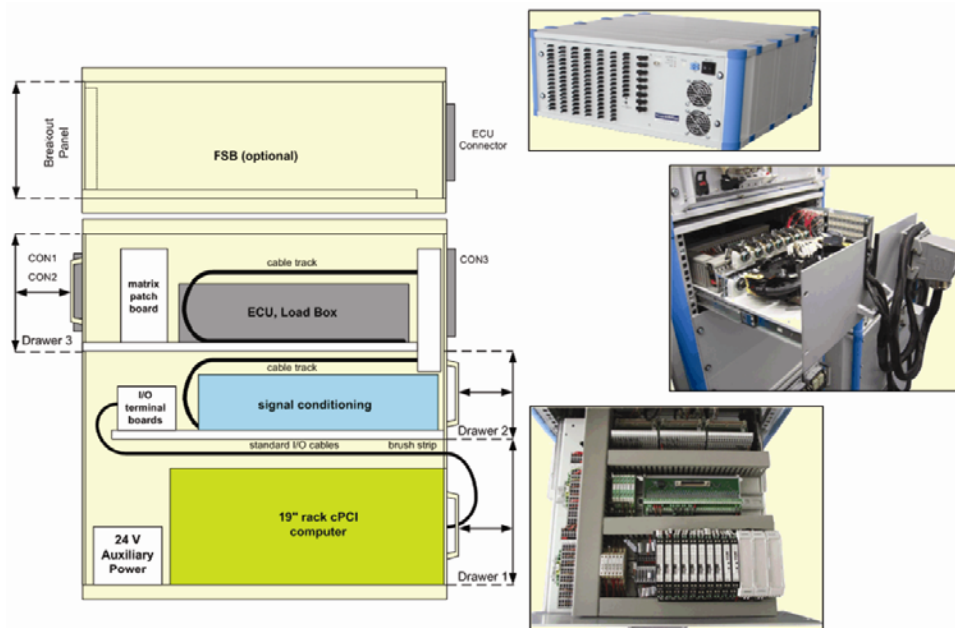
I/O Equipment and Signal Conditioning

This integrated solution bases on standard industry components as far as possible, in order to guarantee a long term availability of the components and a competitive price. Where applicable modularHiL uses commercial off-the-shelf (COTS) hardware or adapted I/O boards if the requirements are not far away from an available standard hardware (e.g. digital input interface with enhanced input voltage range). Specific

Circuits are designed if there is a need for a special function which is not covered by any COTS hardware. Galvanic isolation of signals guarantees accuracy in the stimulation and measurement chains.

Most of the used COTS hardware is based on IndustryPack (IP) modules mounted on compactPCI boards, which primarily cover the standard signal levels. Signal range conversion as well as galvanic isolation is done through terminal boards mounted on DIN rails from the industrial automation. The advantage of this field-wiring assembly is that all I/O signals along the stimulation and measurement chains are easily accessible and can be replaced with no major effort.

All external interfaces (CON1, CON2, CON3) are industry standards with rugged mechanics (e.g. Harting Han DD type) providing a working current of 10A. The connector to the ECU (CON1) has a detection mechanism in order to prevent an accidental exchange of the connectors. The distribution of the ECU signals is done by standard matrix patch boards, so one can easily adapt to changes in the ECU pin-outs. A second connector (CON2) is provided in case real vehicle components such as loads and sensors have to be placed outside the ECU module enclosure. A final third connector (CON3) is used for the inter-module communication when the ECU module is a subcomponent of an integration test system.



Picture 4: Stackable space saving design

Each ECU module is mounted on a separate 19" 12U enclosure with two drawers to provide easy access to the ECU, to the actuators, and to the I/O terminal boards (see Picture 4). At the bottom of the enclosure is the real-time computer in a 19" 4U rack. All components for the signal conditioning are located at the second level, and are connected via the I/O terminal boards. The ECU and all other real vehicle components such as actuators are placed at the third level. An optional module for fault insertion and breakout function (FSB) can be stacked on top of the enclosure.

Fault Insertion and Breakout

The breakout adapter with failure simulation and self-test capability (FSB) is an optional component of the test system modularHiL which can be integrated at any time between the ECU and the ECU module via the CON1 connector. The FSB module offers both a modular breakout panel and software-controlled error injection functions. Since in some cases only the breakout functionality is required, a cost-saving passive breakout box (BOB) is also available.

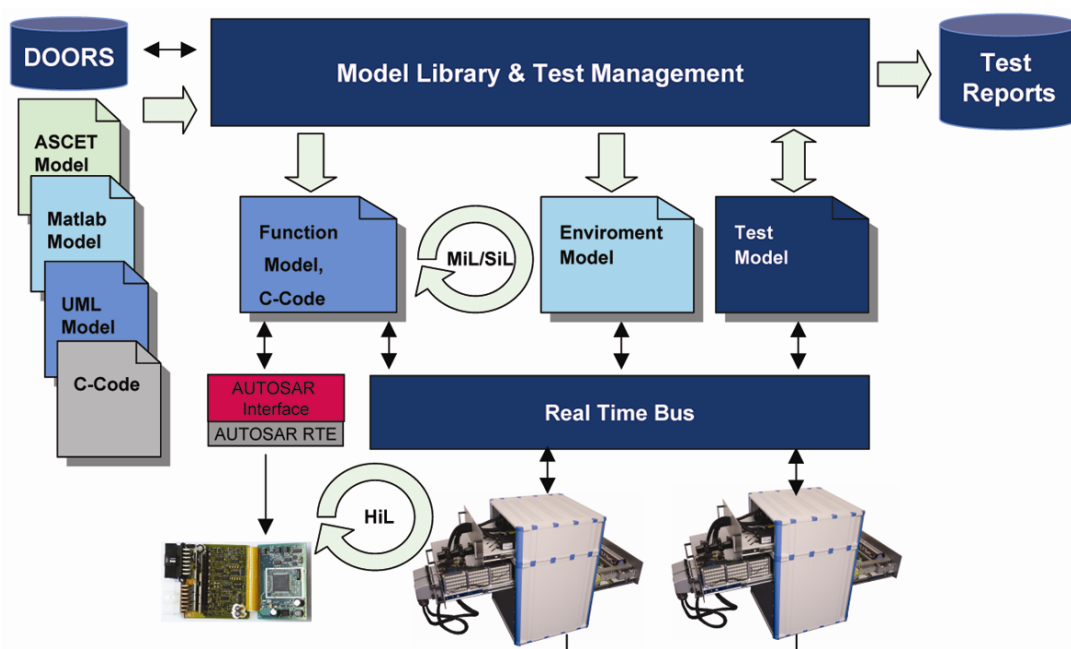
The front side contains 2mm and 4mm sockets for plug links with middle contact. Signals can manually be interrupted by pulling these plug links, in order to connect an external supply or signal to any ECU pin, or even to measure directly the ECU outputs. The failure simulation is very flexible and includes signal line interruption, short circuit to ground or to battery, and short circuit between two signal lines. This functionality is provided by numerous relay boards, which can connect up to 106 signals to two internal rails. Moreover it is possible to connect up to three FSB modules in a row. All failure cases are triggered via CAN bus. The FSB software checks if the requested failure simulation can be carried out, and in order to protect the relay boards from damage due to over current an adjustable current limiter is integrated in the rail path.

A self-test functionality is provided to assure the proper behavior of the relay boards. The self test only requires the auxiliary power supply, and will be carried out when neither the ECU nor the ECU module are connected to the FSB module.

Towards an Open Test System

Simulations and interface prototypes can access the I/O channels in modularHiL through a deterministic network based on reflective memory. Thanks to its decentralized architecture modularHiL can be scaled to fit the specific needs of a particular environment, either as a stand-alone module or in a whole vehicle test. Moreover the user is not required to produce any I/O specific drivers since all variables are mapped to the hardware channels via an XML configuration. In this way a highly specialized test system can be build on top of a generalized test system based in a long term available COTS technology. Therefore by using modularHiL, companies can save both time and money in the development process of ECUs, gaining as well a considerable amount of flexibility.

In order to bring modularHiL towards a fully open test system Berner & Mattner is developing interfaces to the most commonly used modeling tools as Matlab/Simulink, Rhapsody, and ASCET. And last but not least a support for AUTOSAR (automotive open system architecture) components and system specifications. Our aim is to provide a flexible linkage of the various abstraction levels in the development of ECUs: models (MiL), software (SiL) and hardware (HiL). Once the system interfaces have been set, having connected a virtual prototype or the real system does not make a difference to the test system (see Picture 5).



Picture 5: Open integration platform