A Flexible and Reconfigurable Hardware-in-the-loop Simulator for a Vehicle Programme at Jaguar & LandRover

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Introduction

- Research Fellow in the Electrical & Simulations group in the IARC
- Peter Jones & Ross McMurran
- Evolutionary Validation of Complex Systems (EVoCS)
- VITAL (Virtual Integration and Test Automation Laboratory) at JLR (Whitley)
- Alexandros Mouzakitis & team
Seminar Outline

- Electronics in a vehicle
- ECU
- Hardware-in-Loop (HIL) platform
- Limitations of this platform
- Reconfigurable & Flexible HIL platform based on patented add2 Genix technology
Electronics in a Car

Just about everything!
The vast majority of new technology looks like this:
Typical automotive electrical architecture

HIGH SPEED CAN
- Adaptive Cruise Control
- Electronic Parking Brake
- Transmission Control System
- Restraints Control System
- Engine Management System
- Dynamic Stability Control
- Gear Shift System

LOW SPEED CAN
- Parking Aid System
- Body Control Module
- Tire Pressure Monitoring System
- Hood Control System
- Electric Seat Control ECUs
- Keyless Vehicle System
- Climate System

LIN
- Battery Backed Sounder
- Door Control ECUS
- Door Modules
- Seat Modules

ELECTRONIC BODY SYSTEMS
- Keyless Entry System
- Keyless Ignition System
- Parking Aid System
- Hood Control System
- Climate System
- Keyless Vehicle System

INFORMATION CONTROL MODULE
- Information Control Module
- Human Machine Interface
- Bluetooth
- Radar
- Radio
- Phone

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Electronic Control Unit (ECU) Overview

ECU is the generic term for automotive electronic control units
What is inside an ECU

- Power Supply
- Application Software implementing controller algorithms and diagnostic functions
- Application Programming Interface
- Base Software Functional Layer (Operating System, Communication...)
- Hardware
- Connector
- Communication Interface
- Data Network
- Hardwired I/O (Sensors/Actuators)
The Hardware Interface of an ECU

INPUTS from Sensors

- Analog Inputs
- Digital Inputs
- PWM Inputs
- Voltage, Current & Load Inputs

Power Supply

OUTPUTS to Loads/Actuators

- Analog Outputs
- Digital Outputs
- PWM Outputs
- Voltage, Current & Load Outputs

COMMS
ECU Development Process

OEM ACTIVITIES

- ECU#1 HW SPEC
- ECU#1 Software SPEC
- ECU#2 HW SPEC
- ECU#2 MODEL-BASED SPEC

SUPPLIER ACTIVITIES

- Hardwork Design
- Handcode Software
- Hardware Design
- Autocode Generation

ECU#1

ECU#2
HIL Systems

PXI (National Instrument)  LabCar (ETAS)  RT-Lab (Opal-RT)

Microgen  Autobox  MicroAutoBox
Various Interactions between ECU & HIL
A Typical HIL System

[Diagram of a typical HIL system with labels for slave server, master server, test bench with prototype ECUs, optical fibre, and host PC with Matlab, ControlDesk, RealTime Workshop.]
The inside of a typical HIL system

- LAN
- Main Processor System Running Real-time Code
- Memory
- Power Supply
- I/O Cards
- Signal Conditioning (not software configurable)
- Fault Insertion
- BUS Communication
  - LIN
  - CAN
  - MOST
  - FLEXRAY
- Hardwired I/O
- ECU
Advantages of using a HIL platform for validation of ECU functionality

- Reduced development costs and timescales
- Availability of the system for 24 hours
- Safer testing conditions because of the ability to simulate operating conditions like fault and damaged conditions
- Functionality testing can begin earlier in the design process with models of the ECUs even before the actual ECU hardware become available
Weaknesses of existing HIL Platform

Main weaknesses are:

- Wiring harness HIL simulation platform needs to be redone each time the hardware interface of an ECU changes
- Uncertainty in module specifications
- Number of likely model variants
- Requirement for reusing HIL system in different applications
- Reusability of the HIL platforms from one vehicle programme to another is limited
Jaguar Reconfigurable HIL Platform

- Genix SC Pods
- ECU PSU Switching
- CAN Switching
- LIN Switching
- Programmable PSU’s
- I/O Routers
- dSPACE PX20
- Real-Time Target
Connector Panel Arrangement for an add2 HIL simulator
Genix Subrack
BackPlane of Genix SubRack
Outline illustration of add2 HIL Simulator

<table>
<thead>
<tr>
<th>Genix Subrack #6</th>
<th>[SR6]</th>
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</thead>
<tbody>
<tr>
<td>Genix Subrack #5</td>
<td>[SR5]</td>
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<tr>
<td>Genix Subrack #4</td>
<td>[SR4]</td>
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<td>Genix Subrack #3</td>
<td>[SR3]</td>
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<tr>
<td>Genix Subrack #2</td>
<td>[SR2]</td>
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<tr>
<td>Genix Subrack #1</td>
<td>[SR1]</td>
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<tr>
<td>PSU #9</td>
<td></td>
</tr>
<tr>
<td>PSU #1</td>
<td></td>
</tr>
<tr>
<td>I/O Router</td>
<td></td>
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<tr>
<td>I/O Router</td>
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<td>I/O Router</td>
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<tr>
<td>I/O Router</td>
<td></td>
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<tr>
<td>Real-Time Hardware</td>
<td></td>
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</tbody>
</table>

(c) 7 Slot Subrack with Genix PSU

(d) USB Card Positions within a Subrack
The Genix Pod

- **DG** – Differential Genix
- **DGF** – Differential Genix with Fault Insertion
- **DGLF** – Differential Genix with Load & Fault Insertion
- **DGELF** – Differential Genix with External Load and Fault Insertion
Genix Pods

DGF Front Panel

DGELF Front Panel
Typical Front Panel Wiring
Type DG
Type DGF
Type DGELF

![Diagram of Type DGELF system](image-url)

- **Fault Control**
- **Config Bus**
- **ECU+**
- **ECU-**
- **Load+**
- **Load-**
- **Signal Conditioning Module**
- **Jumper Config**
- **Optional Load Module**
- **HIL I/O+**
- **HIL I/O-**

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The HIL Power Supply System

- Each Genix Pod can be connected to three different external voltage sources (Vext1, Vext2 or Vext3) as the high power rail

- one of two different 0V references (0V1 or 0V2) as the two low power rail

- A typical Genix Pod will reference to Vext1 which is supplied by PSU1, normally used as the VBatt supply, and 0V1 which is tied to ground.

- When a programmable power supply is used as a source, the voltage can be continuously varied within the operating range of 5 to 22V
Signal conditioning which is reconfigurable by software

The unique and novel innovation in this HIL platform is the use of Genix configurable signal conditioning.

Each of the channel can be configured individually under software control

The front end can be designed and customized for different kind of sensors and has the capability to support all feasible combinations of the I/O interface of the ECUs.
Signal Conditioning which is software reconfigurable

The Genix based Pods have the capability to configure each channel according to its

→ signal type
→ Direction
→ Bandwidth
→ Gain
→ Loading requirements

→ internal loads can be pulled up to a supply rail or pulled down to ground
Signal Conditioning which is software reconfigurable

- has the ability to support either internal or external loads
- digital input circuit has a configurable threshold detection capability
- gain of the analogue inputs and outputs can be varied
- Analogue inputs can be conditioned using one of 3 preset filters
HIL Configuration Utility (HCU)

H1-7DS(Differential UP) Configuration

- Subrack Addr: 3
- Slot: 1
- Pod Slot: 1
- Width: 1

Channels Filtered: 1

Card Description:
DGELF_T7.5 - Genix Signal Conditioning Carrier

ECU Name: TRM
Channel Name: RIGHT DIRECTION INDICATOR

- IO Type
  - Digital Input
  - Analogue Input
- Digital Input
  - Threshold: Vext/2
  - Range: 30V
- Filter
  - Input Filter Bandwidth: Full
- Advanced Input Type
- Programmable Load
  - Show E12 Values Only
  - Impedance Value: 1.0228K Ohms to VT

ECU (Front of Genix)

Vin+ to VThr = Vext/2
Vin- to NC
RL1.0228K
GND
Genix Module Input/Output Capability

<table>
<thead>
<tr>
<th>Genix Module Type</th>
<th>Function</th>
<th>Digital Input</th>
<th>Digital Output</th>
<th>Analogue Input</th>
<th>Analogue Output</th>
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<tbody>
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<td>H1 Type 4 - DIOA</td>
<td>Fully Configurable I/O</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td>H1 Type 5 - AO</td>
<td>Analogue Output</td>
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<td>H1 Type 6 - DO</td>
<td>Digital Output</td>
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<td>H1 Type 7 - ADI(DS)</td>
<td>Analogue/Digital Input</td>
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<td>H1 Type 7 - ADI-DD</td>
<td>Analogue/Digital Input</td>
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<td>H1 Type 7 - ADI(SD)</td>
<td>Analogue/Digital Input</td>
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<td>Y</td>
<td>N</td>
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<td>H1 DCO</td>
<td>Digital Current Output</td>
<td>N</td>
<td>Y*</td>
<td>N</td>
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</table>
## Genix Module Configuration Capability

<table>
<thead>
<tr>
<th>Genix Module Type</th>
<th>Direction (In/Out)</th>
<th>Type (Digital/Analogue)</th>
<th>Load Value</th>
<th>Pull-Up/Down</th>
<th>Range/Threshold</th>
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<tbody>
<tr>
<td>H1 Type 4 - DIOA</td>
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</table>
The CAN Switching Strategy

- CANAH
- CANBH
- CANCH
- CANDH
- CANDL
- CANCL
- CANBL
- CANAL

TO CHANS 1..4

COMMON FAULT RELAYS

R_{\text{term}}

ECU

CANH

CANL

CANFAULTL

CANFAULTH

V_{\text{EXT}}

ECU 0V
Other Key Features of the Software
Reconfigurable HIL platform

→ CAN, Power Supply and LIN Switching either the HCU software or using the CAN based configuration bus

→ High Current Capabilities

→ Fault Insertion Capabilities

→ Digital Current Output Modules

![Graph showing high and low current outputs](image-url)
Example

![Diagram of a flexible and reconfigurable hardware-in-the-loop simulator for a vehicle programme at Jaguar.](image)

- **Gain**: Pull up to $V_{ext}$
- **Filter**: Pull down to ground
- **Configurable Resistive Load**: Connection to external load
- **Fault Insertion**: Fault control
- **Signal Conditioning**: Configuration bus
- **Simulator**: To dSPACE ADC card
- **ECU**: $V_{in+}$

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Conclusion

→ Software reconfigurable HIL platform described was fully implemented for a vehicle programme at JLR

→ Reconfigurable platform has guaranteed high flexibility and portability in interfacing all kinds of ECUs, sensors and actuators

→ Easier to suit the wiring harness of the test rig to adapt the ECU under test

→ Robustness inbuilt in its design through its ability to support high current loads

→ The unique feature of the Genix signal conditioning module is that it has external load capabilities, fault insertion capabilities and high current capabilities all on one Pod card.

→ Genix modules have signal conditioning that is configurable by software.