Embedded Success

Simulation and testing of engine ECUs for various engine configurations

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Introduction

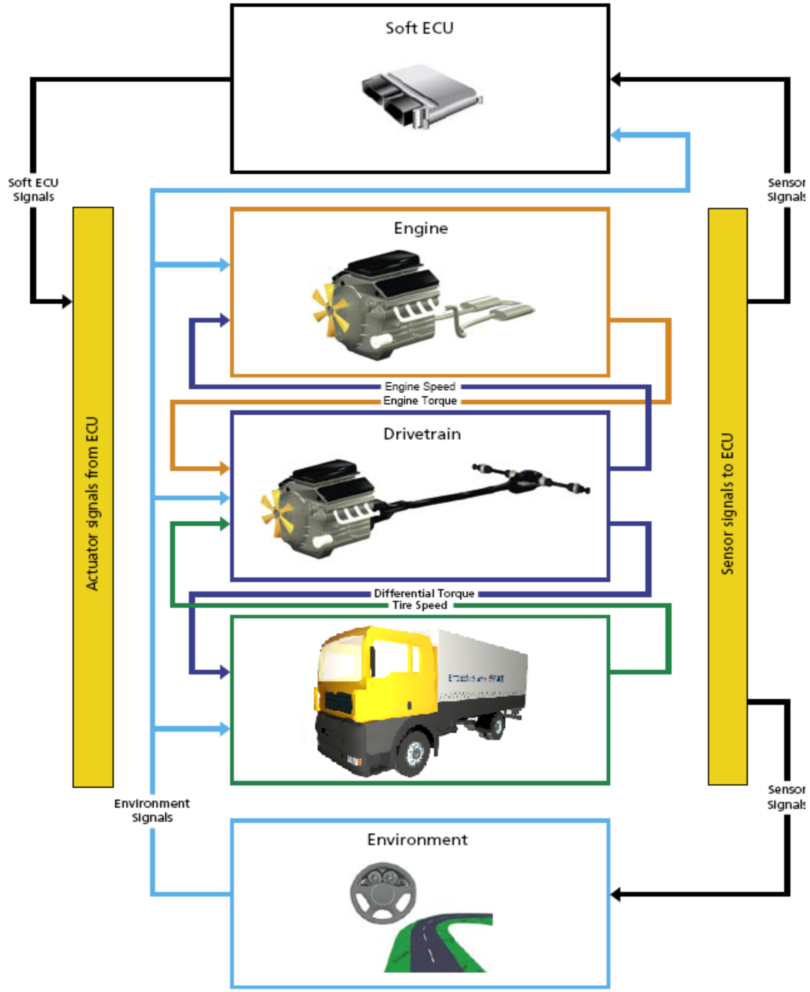
- Challenges and solutions for testing embedded software (ECU) for various configurations of engines.
- The validation and verification of embedded software includes testing for performance under normal and abnormal operating conditions, electrical wiring faults, failures, etc.
- Hardware-in-the-loop (HIL) test systems, now a proven and standard methodology to verify the increasingly complex control technology
- Testing and Simulation technology challenges in
  - Model Development and Flexibility
  - Parameterization (The KEY!)
  - Test and Data management

Model Requirements

Model Requirements

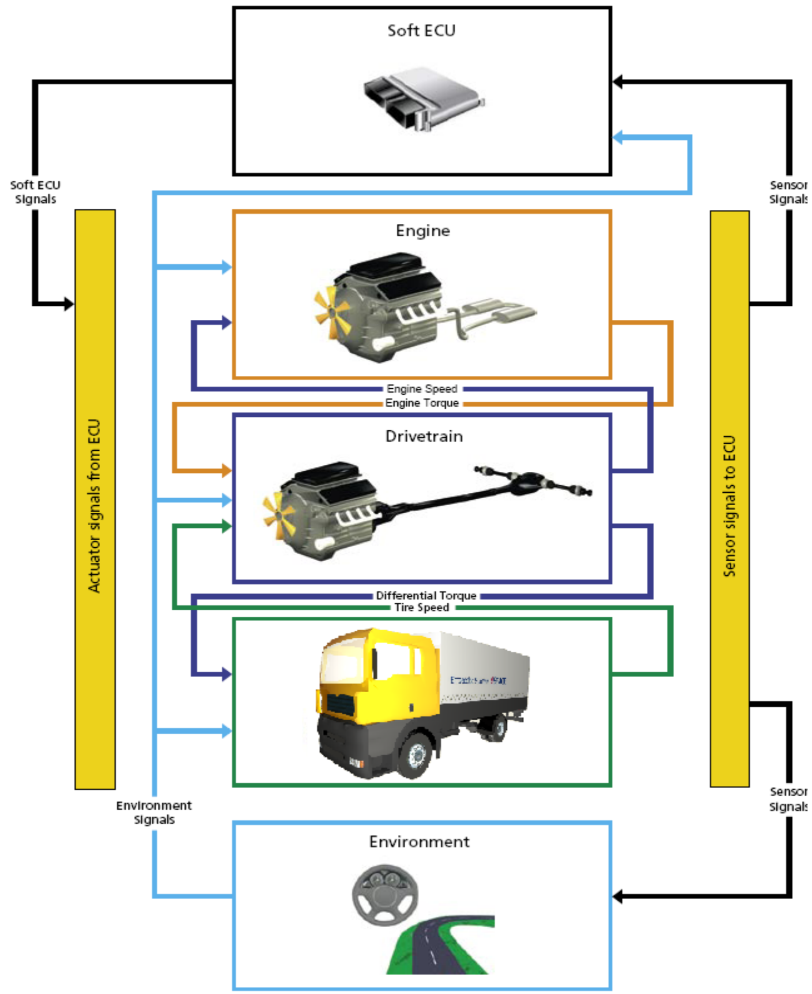
Must-Have requirements

- Real-time capable
- Easy to connect to IO
- Physically correct/Consistent IO
- Support Control Functions and OBD
- Simulate other ECUs (CAN rest-bus)
- Flexible: wide range of variants
- Easy to parameterize
- Useful for multiprocessor/multicore
- Support of standard test cycles



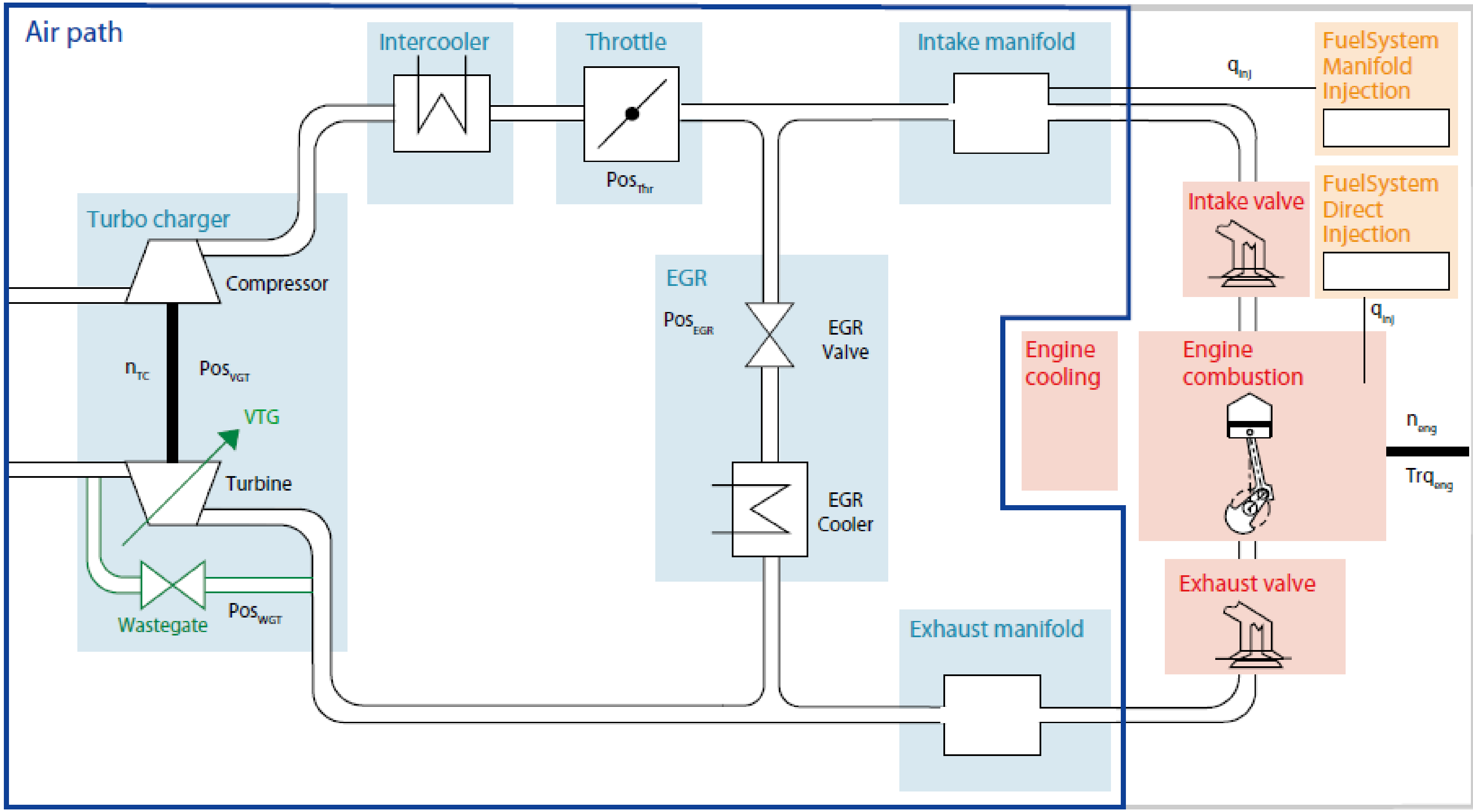
Nice to have requirements?

- Customizable - Easy to use and extend
- Share for ECU Network tests and single ECU tests (SoftECUs)
  - One model environment for both (Scalable)
- Open for verification and extension
  - Pre-instrumented for Data Analysis
- Online variant selection and parameter change
  - Minimize test time and cost
  - Ease of Use
- Extended documentation



Models for combustion engines

Requirements for Engine Models



Engine Model Requirements

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Cylinder model

- Mean Value Engine Model (MVEM) based, or in-cylinder based, depending on the Engine ECU
- Engine standstill is required.

Fuel system

- Based on modifiable Common Rail System (CRS), manifold injector models

Air path simulation

- Cooled Exhaust Gas Recirculation (EGR) and single-stage turbo for most applications
- Low-pressure EGR
- Two-stage turbocharger may be necessary (reduce NOx)

Model for engine cooling system

- Necessary in all engine models

Engine: Simulation approaches

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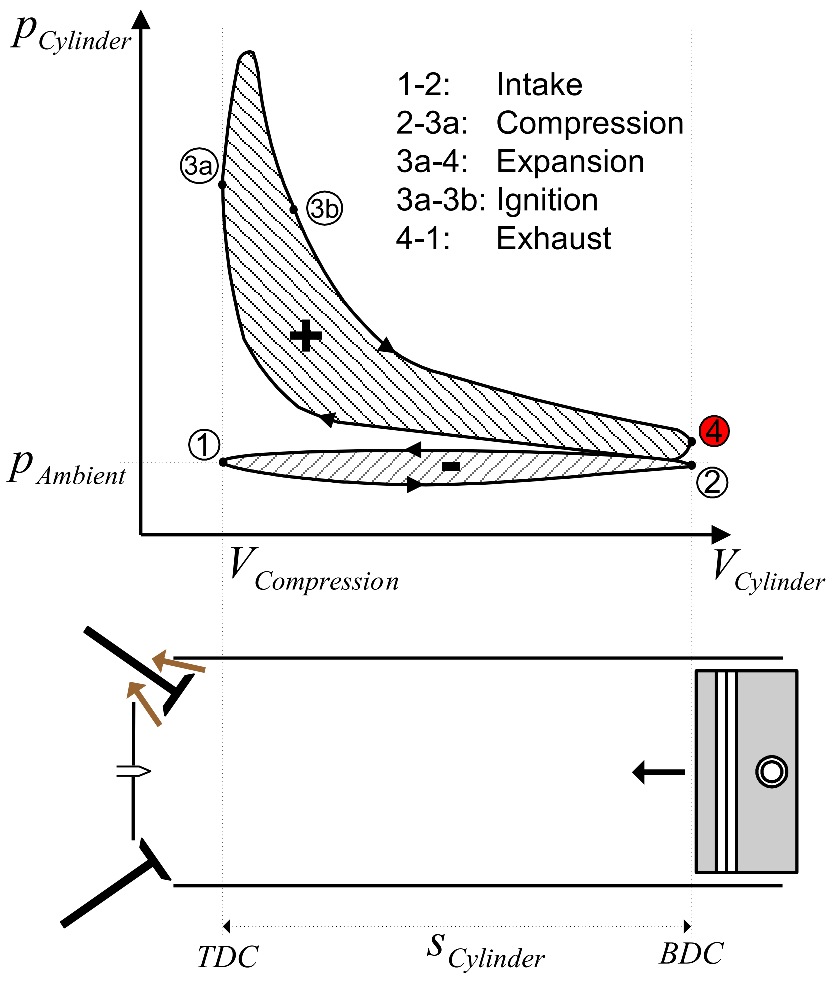
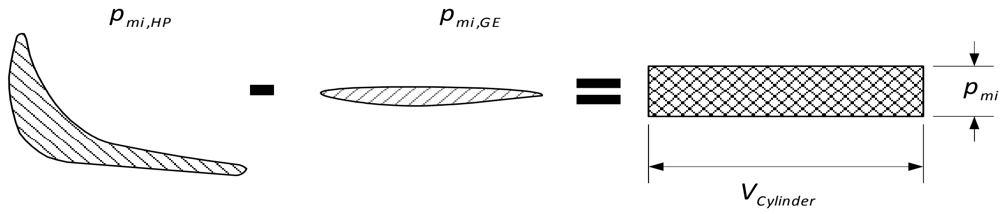
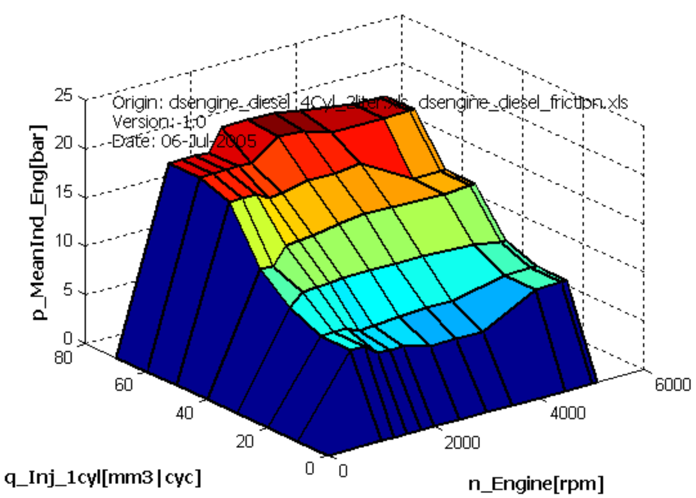
▪InCylinder Approach	▪Mean Value Approach







Engine: Fields of applications

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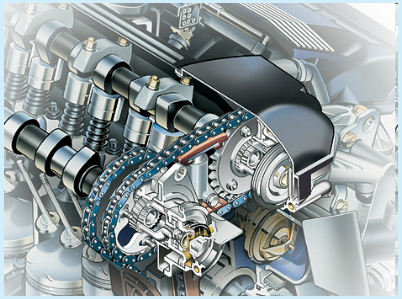
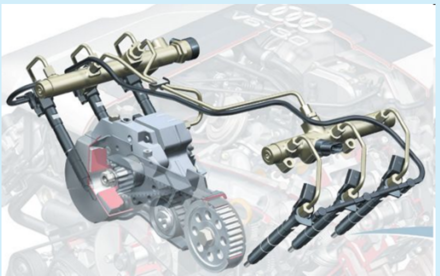
▪InCylinder Approach	▪Mean Value Approach



▪Variable Valve Train

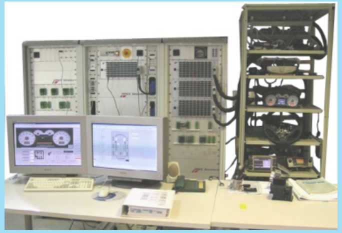
▪In-Cylinder

▪pressure sensors

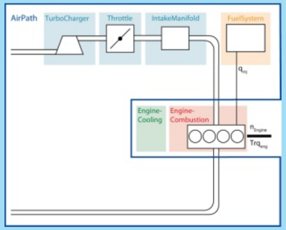


▪Multiple

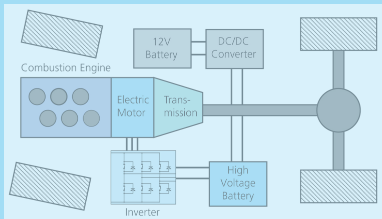
▪fuel injections



▪Network testing



▪Standard engines



▪Hybrid

▪Virtual Vehicles

Fuel System Model Requirements

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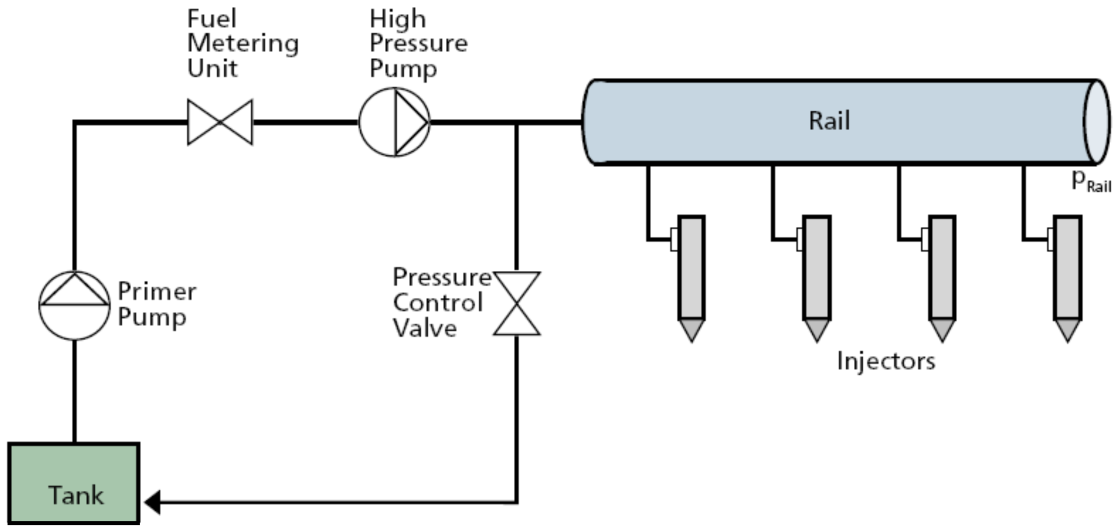
- Crucial for HIL operation and testing of Engine ECU
- Used in conjunction with precise Injection measurement
- Time-controlled injection (CRS, manifold injector models)
- Customizable Fuel System, e.g.
  - Amplified Pressure CRS
  - High-pressure Injection



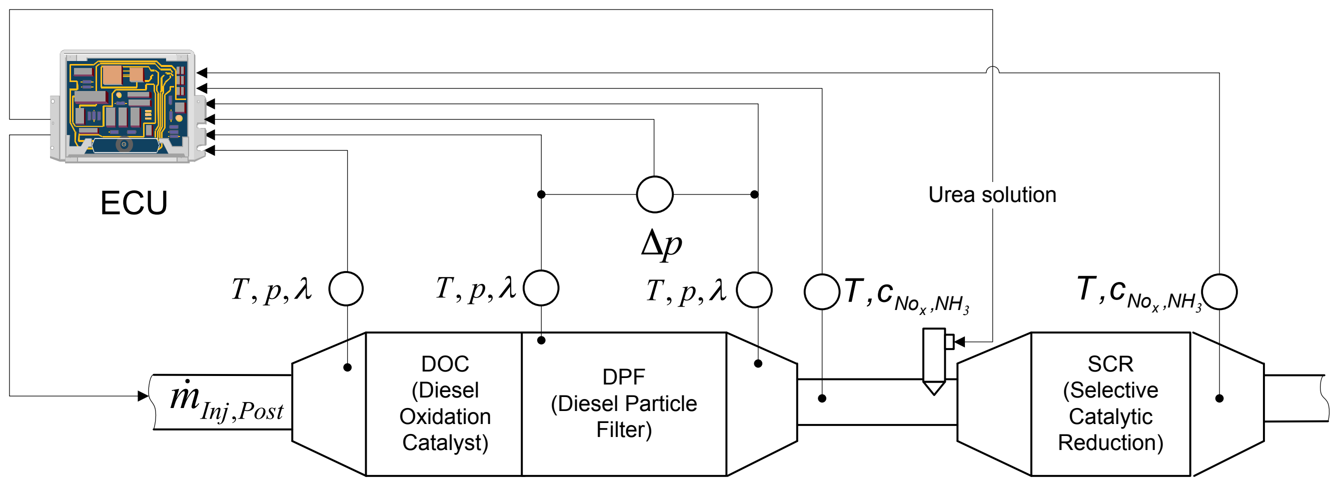
Aftertreatment System Model Requirements

Gasoline Engines

- Three-way catalyst
- Tank evaporation systems

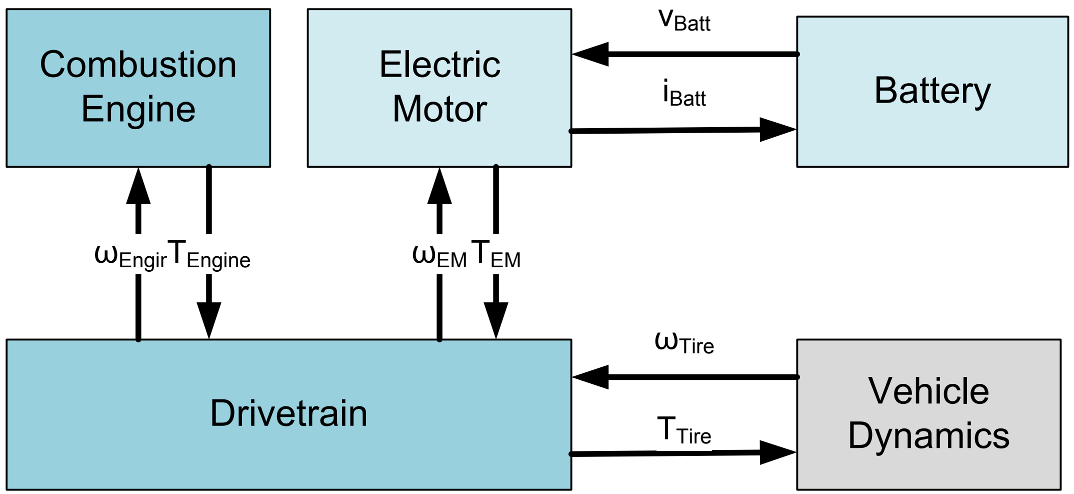
Diesel Engines

- Support soot and NOx emission controls
- DOC/DPF system model as a standard aftertreatment model
- For NOx reduction, models for SCR (incl. urea solution supply system) and LNT



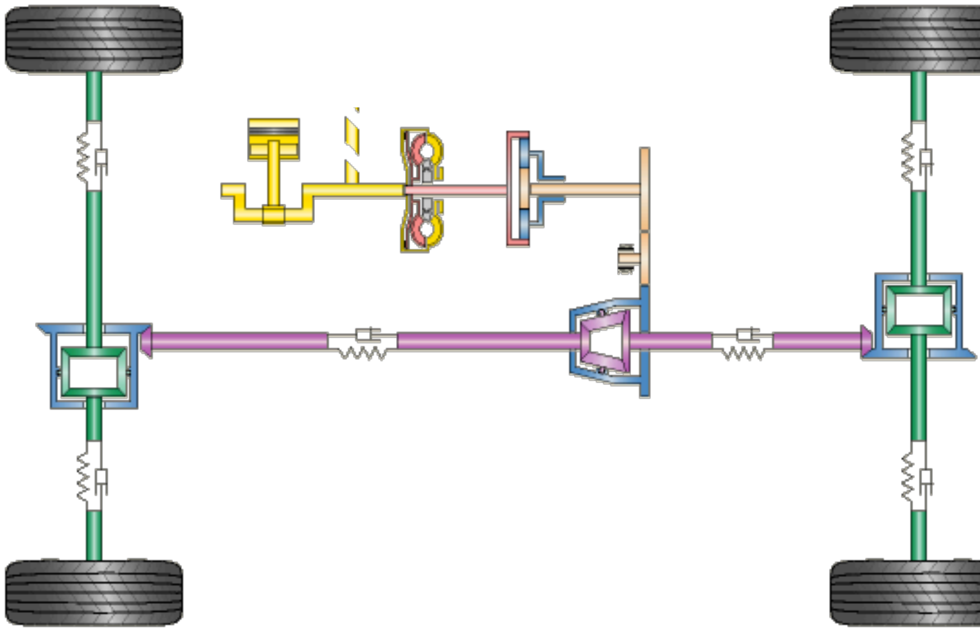
Hybrid Powertrain Requirements

- Additional model components needed, depending on degree of hybridization
- Electric motor simulation required, on
  - Signal level
  - Electric power level
  - Mechanical level
- Battery model necessary with single-cell voltage simulation



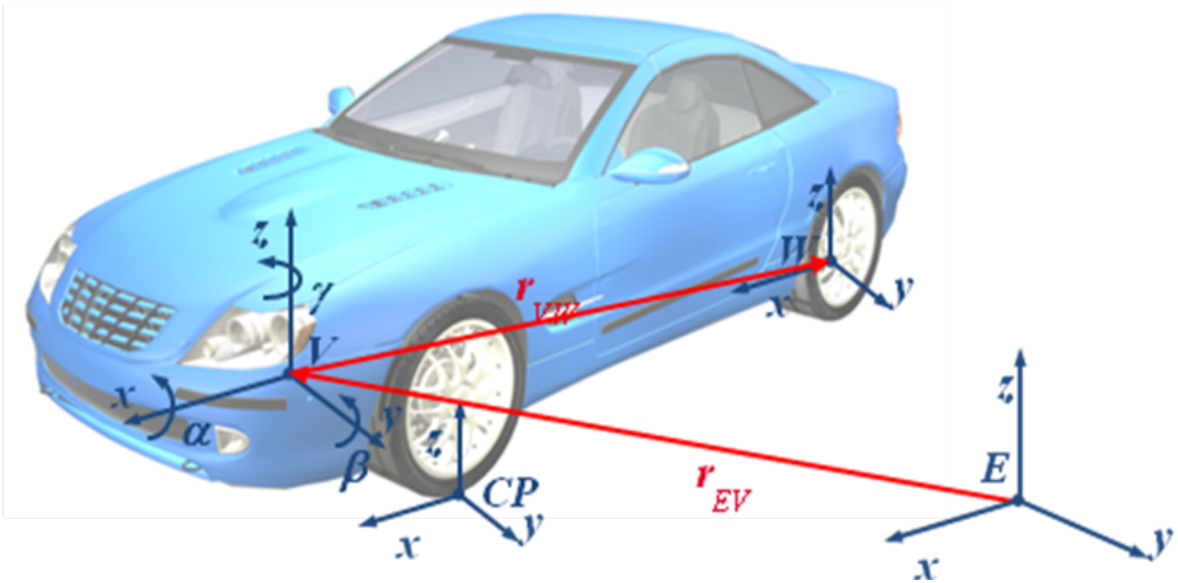
Drivetrain Simulation Requirements

- Several switchable transmission variants (MT, AMT, CVT, AT, etc)
- Starter and generator models are essential
- Retarder models for commercial vehicles
- New drivetrain combinations for hybrid applications must be easy to assemble



Vehicle Simulation Requirements

- Vehicle dynamics system with one or more degrees of freedom, depending on HIL test area (Powertrain – only Longitudinal)
- Model should be flexible so that more degrees of freedom can be added
- Complex vehicle model has to support front axle, rear axle, and all-wheel drives
- For commercial vehicles, more than two axles and twin tires
- Pneumatic system model or real brake system interface



Environment and SoftECU Simulation Requirements

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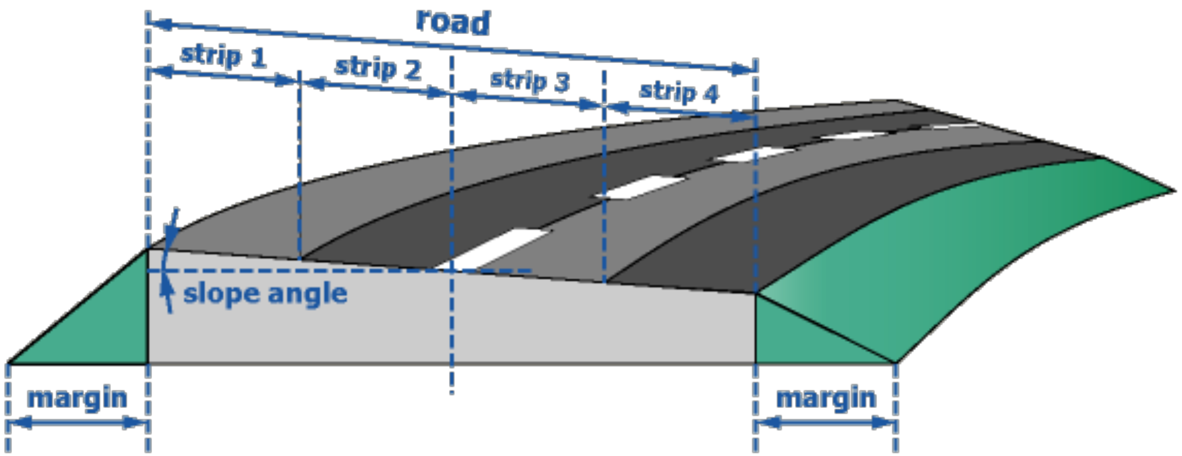
- Driver and road simulation is necessary
- Simulation on test bench with given speed and load curve
- Support of standard driving cycles like FTP-75, NEDC, J10-15
- SoftECUs required for all ECUs not present in HIL



Comparison of ECU Testing Modes

Comparison of ECU Testing Modes (I)

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Shortcomings for Open-Loop Testing

- ECUs use Closed-Loop dynamic controls e.g. to manage fuel mixture
- Open loop stimulus boxes
  - Cannot test dynamic closed loops
  - Cannot test synchronization and timing of critical I/O signals

Advantages of Closed-Loop Testing

- Tests can be automated – allows regression tests of new software releases
- Potentially damaging conditions, e.g. over-temperature in an engine, can be simulated to test if the ECU can detect it
- Simulation at extremes – evaluated without risk to the vehicle or operator
- Test integration of ECUs – evaluate system power consumption, etc

Comparison of ECU Testing Modes (II)

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Test	Closed-loop HIL Simulation	Open-loop HIL Simulation	SIL Simulation
I/O & diagnostics functionality	✓	✓	x
Control algorithm performance	✓	x	✓
Control algorithm performance including I/O functionality and ECU processor & RAM utilization	✓	x	x
Bus latencies	✓	✓*	x
Effects of bus latencies on control algorithm performance	✓	x	x

*** Limitations apply**

Comparison of ECU Testing Modes (III)

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Test	Closed-loop HIL Simulation	Open-loop HIL Simulation	SIL Simulation
Effects of electrical faults on control algorithm performance	✓	x	✓*
Network performance of control algorithms	✓	x	x
Ripple effects of errors throughout a controller network	✓	x	x
Effects of asynchronous operation of the plant and controller on algorithm performance	✓	x	x

*** Limitations apply**

Application examples

Hyundai – Virtual Engine Test Bench

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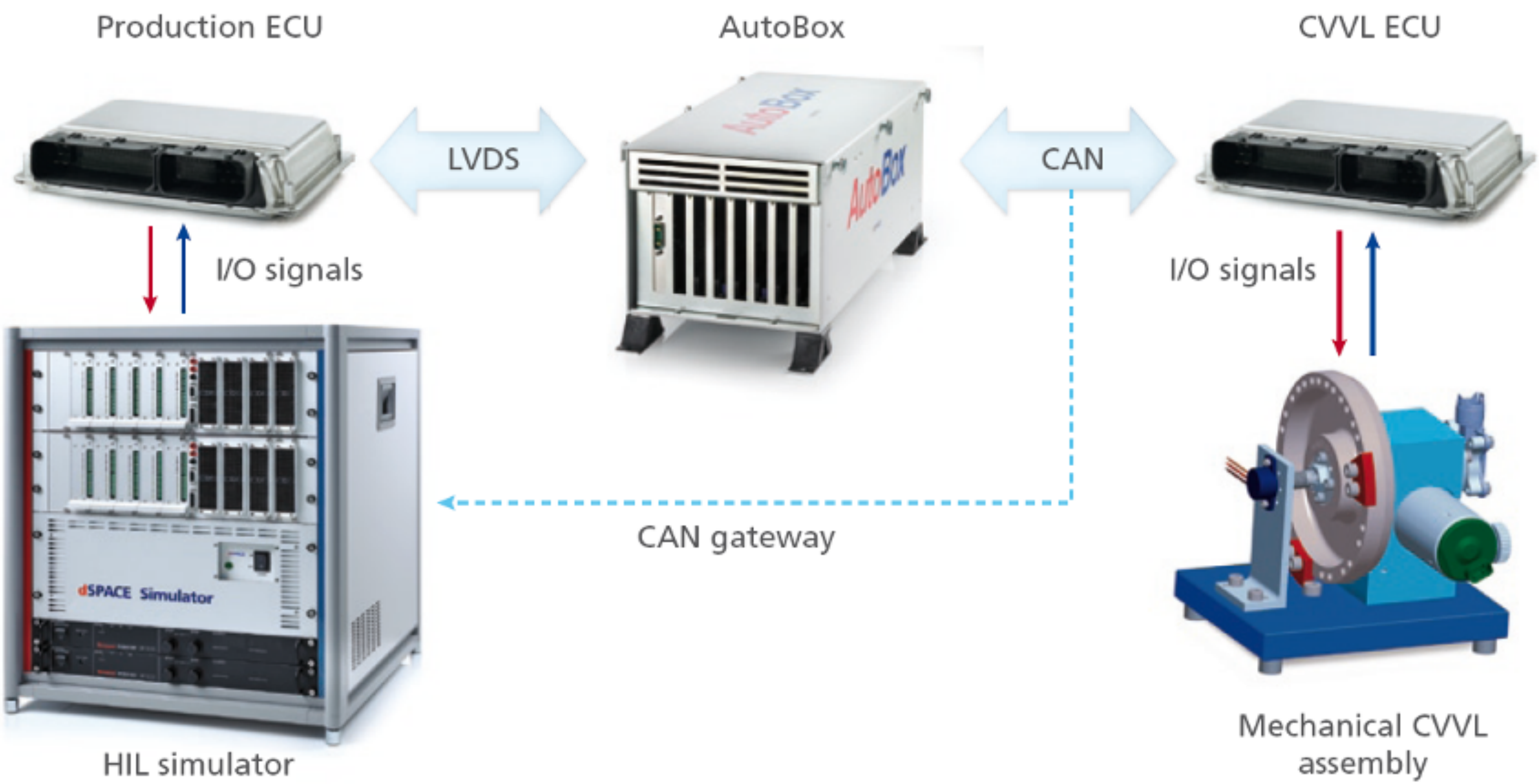
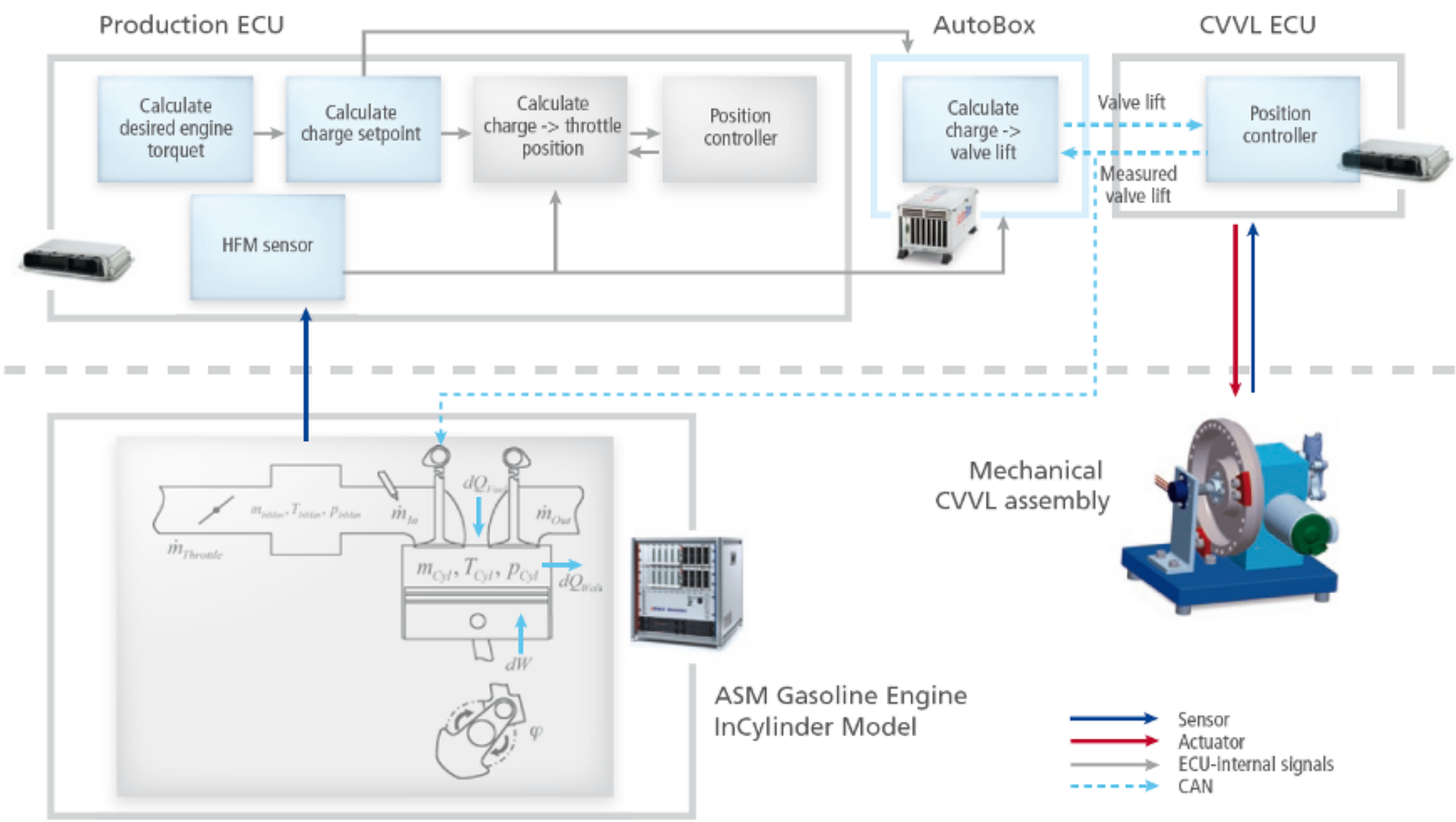
- Test bench of the future: Real-time-capable thermodynamic engine models at Hyundai Motor Europe Technical Center GmbH
- Development of Continuously Variable Valve Lift (CVVL)
- Function design with RCP system and Bypassing
- HIL-Simulator running thermodynamic model serves as controlled system (replaces engine)
- ASM Gasoline Engine InCylinder Model
- The in-cylinder pressure model calculates the pressure and mass flow values with sufficient precision, and the ECU can be operated without errors

Hyundai – Virtual Engine Test Bench



- *Design of the HIL system with a production ECU, a rapid prototyping system for the new CVVL functions, and a real load for determining the actual valve train value.*

Hyundai – Virtual Engine Test Bench



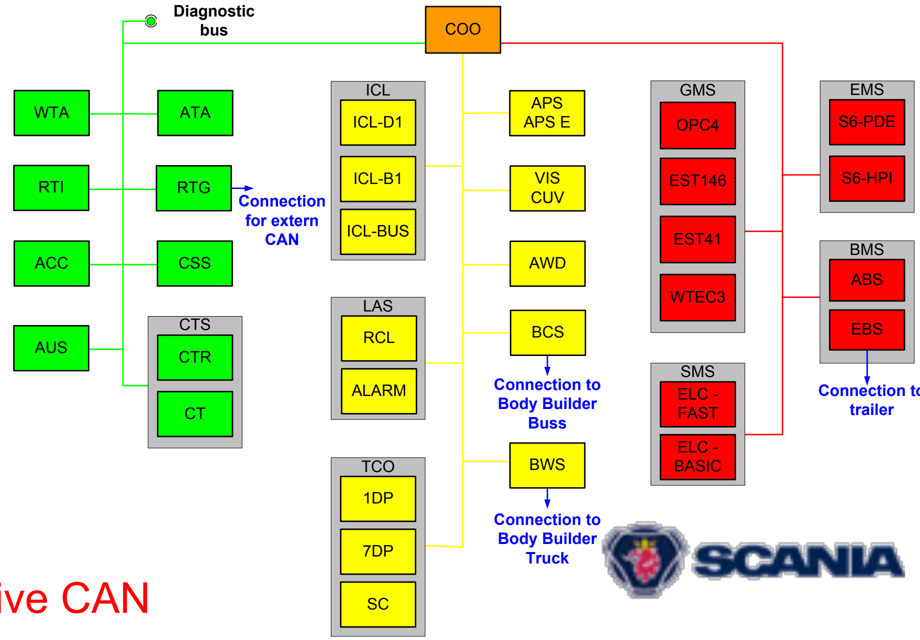
- *The development ECU, consisting of a production ECU and the AutoBox, is connected to an HIL simulator.*

Hyundai – Virtual Engine Test Bench

- "By using the HIL simulator and the new in-cylinder pressure-based engine models, we were able to develop and validate new algorithms for the charge control of a gasoline engine with continuously variable valve lift very quickly and very efficiently, and then to use them successfully in a prototype vehicle."
- *Patrizio Agostinelli,*
  Hyundai Motor Europe Technical Center GmbH

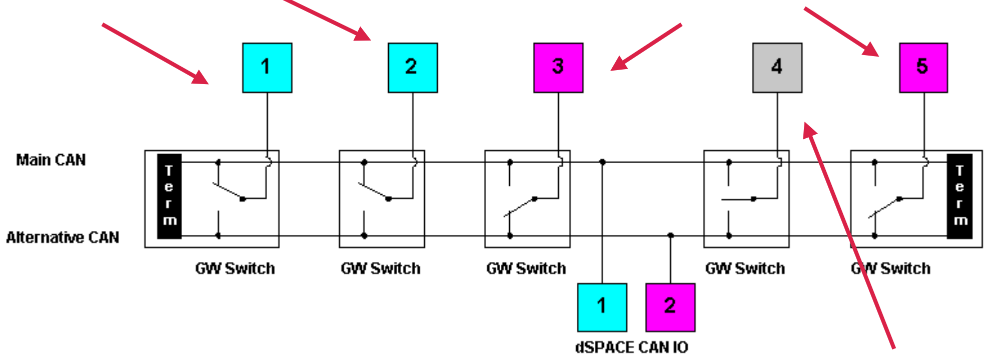
Scania: ASM for Complete Truck Electronics Tests

- Automated testing of 33 ECUs and 11 CAN networks
- A complete test environment designed to handle a large amount of vehicle variants and number of test cases
- Improved regression testing and test quality
- Automated variant testing
- Automated testing of networked ECUs



Main CAN

Alternative CAN



- Unconnected

Scania: ASM for Complete Truck Electronics Tests

ASM Engine:

- ASM Diesel Engine: models for different engines, e.g.
  - 5 cylinder 9 liter
  - 6 cylinder 12 liter
  - 8 cylinder 16 liter
- ASM Diesel Exhaust for simulation of SCR and DPF

ASM Transmission models:

- Manual transmission
- Automated manual transmission with up to 16 gears

ASM Vehicle Dynamics:

- Two or three axles (4x4, 4x2, 6x4, 6x2)
- Brake management
- Air processing
- Suspension management
- All-wheel drive
- Locking and alarm
- Bus chassis
- Retarder

Mitsubishi - Virtual Outlander

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- Mitsubishi using a virtual vehicle to develop a new Outlander
- Real-time execution of Automotive Simulation Models (ASM) with a network simulator
- Networked simulator for 20 ECUs
- Turnkey tests integrated into test automation

MITSUBISHI MOTORS

- The new Mitsubishi Outlander is equipped with numerous networked ECUs and various electric drives for comfort functions.

- **dSPACE** Newsletter

- *„Virtual vehicle tests in real time are indispensable to assuring the qualtiy of complex ECU systems."*

- **Kunihiro Sakai, Mitsubishi Motors**

Mitsubishi - Virtual Outlander

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MITSUBISHI MOTORS

- The virtual vehicle testing system as it is installed in the laboratory.

Mitsubishi - Virtual Outlander

- Automotive Simulation Models (ASM) in use
  - ASM Gasoline Engine Simulation Package
  - ASM Diesel Engine Simulation Package
  - ASM Vehicle Dynamics Simulation Package
- Important for Mitsubishi:
  - Flexibility of the ASM models, which are easy to extend by models from suppliers.
- Advantages of the Virtual Vehicle
  - Simple regression tests
  - Efficient stress tests on ECU software
  - Automated lifetime tests
  - Efficient test analysis

- **dSPACE** Newsletter 3/2007

- *„With the Automotive Simulation Models (ASM), we can virtualize the chassis and powertrain of the Mitsubishi Outlander realistically.“*

- **Masahiro Kaneda, Mitsubishi Motors**

Summary & Conclusion

Benefits and Savings (1)

Benefits of virtual system tests (Offline and HIL simulation):

- Cost reduction:
  - Reduced number of track tests, testbench tests, and prototype cars
  - Lower setup costs for these tests
  - Less fuel burned
  - Less damage of expensive prototype components/vehicles
  - Fully automated lights-out tests over night
- Many tests are just impossible in a vehicle:
  - Only possible in offline or HIL simulation
  - Safety critical tests: no danger for test engineers
  - Diagnostic tests with electrical failures (@400km/h ?)

Benefits and Savings (2)

- Process advantages:
  - Faster development (time-to-market)
  - Test are reproducable, can be automated, are more reliable
  - Test coverage and test depth can be increased
  - →Higher ECU software and hardware quality

Summary & Conclusion

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Model Requirements

- Engine, Exhaust Aftertreatment, Hybrid Powertrain, Vehicle

Comparison of test methods

- Advantages of Closed-loop Testing versus Open-loop Testing

Model Selection

- To be verified
  - Ready for Real-Time, prepared for HIL **?**
  - Capable of being integrated into complete vehicle model **?**
  - Easy to modify and expand **?**
  - Suitable Tools for User Interface and Parameterization **?**

→ In-house models, or Model from simulation software supplier

ASM – Automotive Simulation Models

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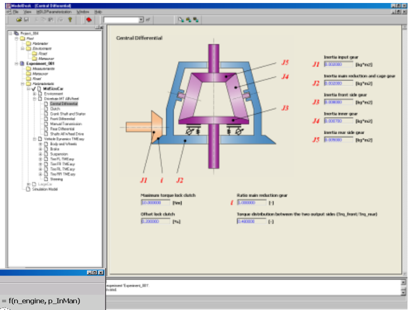
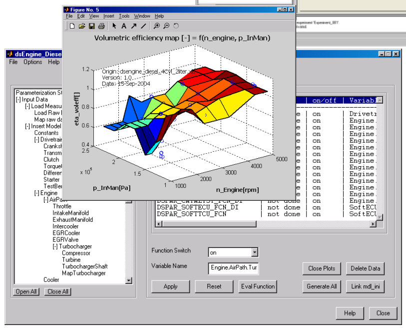
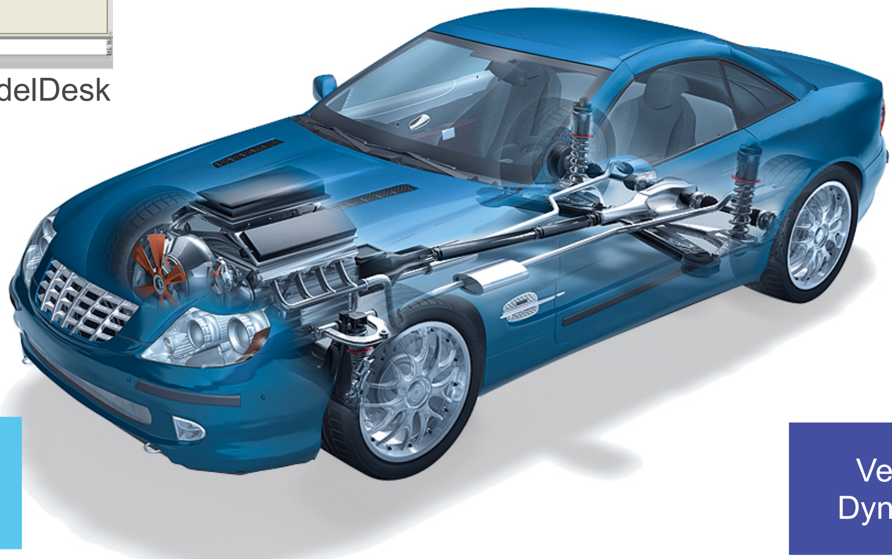


ModelDesk



ASMPara



MotionDesk

- TurboCharger
- DrivetrainBasic
- DieselExhaust
- Engine Gasoline Basic
- Engine Gasoline
- Engine Gasoline In-Cylinder
- Engine Diesel
- Engine Diesel In-Cylinder
- Electric Components
- Vehicle Dynamics
- Truck
- Trailer
- BrakeHydraulics
- Traffic

- Real-time capable
- “open” Simulink models, product-level
- Integrated into the tool chain
- Centralized parameter administration

Thanks for Listening!