Model Based Development and HILS for motor control development

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Abstract ：
The Model Based Development (MBD) is increasingly penetrated in the automotive industry as the key development approach for Electrical Control Unit (ECU) in order to get the high quality of software under higher efficiency of development. This MBD method uses the models for controller and plant, and then can share these models in each development phase to increase the development efficiency, thus MBD become more popular in the various fields. This paper explains the MBD method for motor system development and clarifies the additional functions needed for motor developments, especially for HIL implementation.

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Model Based Development and HILS for Motor Control Development

dSPACE Japan K.K.
Engineering Department
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12/7/2011

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Venue: Tokyo Conference Center, Shinagawa

An Outline of dSPACE

dSPACE

- dSPACE (digital Signal Processing And Control Engineering)
- Established in 1988, with its head office in Paderborn, Germany.
- An independent supplier of development tools
- Over 80% of the employees are engineers
- We provide products to the entire world through distributors in 11 countries, in addition to our overseas affiliated companies in Japan, America, England, and France
- We have approximately 850 employees worldwide

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Agenda

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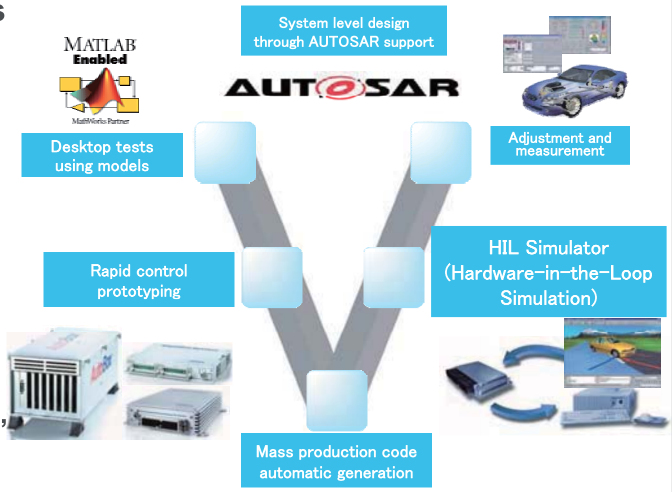
- The necessity of model based development
- Model based development phases and tools
  - Rapid control prototypes
  - Automatic generation of mass production codes
  - HIL simulators
- Applications for motor control development
  - Component technology (Models, I/O, FPGA)
  - Motor HILS
  - HEV systems
- Conclusion



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The Steps of Model Based Development

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How does one design and test controllers and control targets without using actual machines?

↓

Express control logic and control targets with numerical formulas. ⇒ Perform calculations in a virtual modeling space. ⇒ Simulation

↓

Utilize the model and the simulation for a method that efficiently progresses controller development.

↓

MBD: Model Based Development

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Establishing Control Design Through Matlab/Simulink

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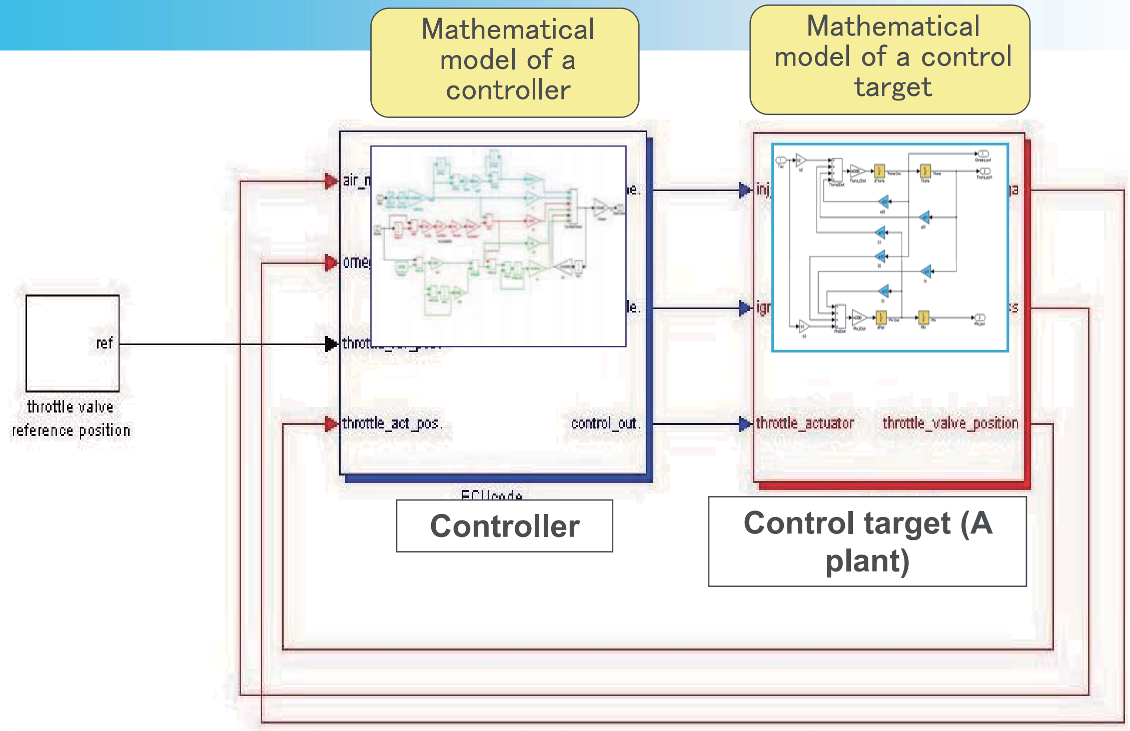

Using a model that actually moves as a specification sheet

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The V Cycle in Model Based Design

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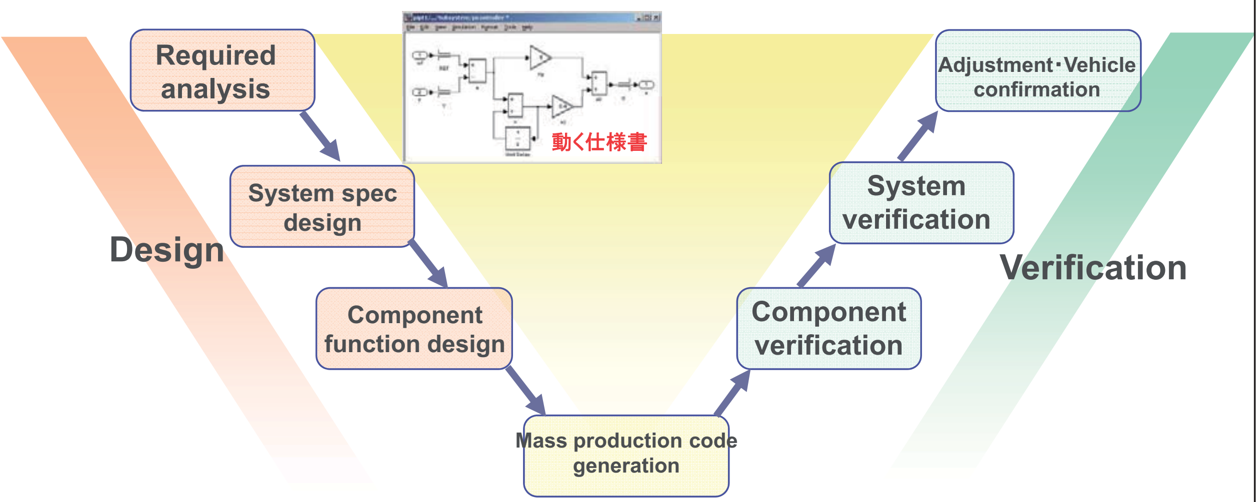
Fully using the entire V Cycle on a model ⇒ Aiming to reduce man-hours and shorten the development period.

It begins with design using a model, passes through verification of the system design on a PC, and executes verification via prototype hardware. It also generates a mass production code with the model as a base, and passes the model along to a simulation in system verification.



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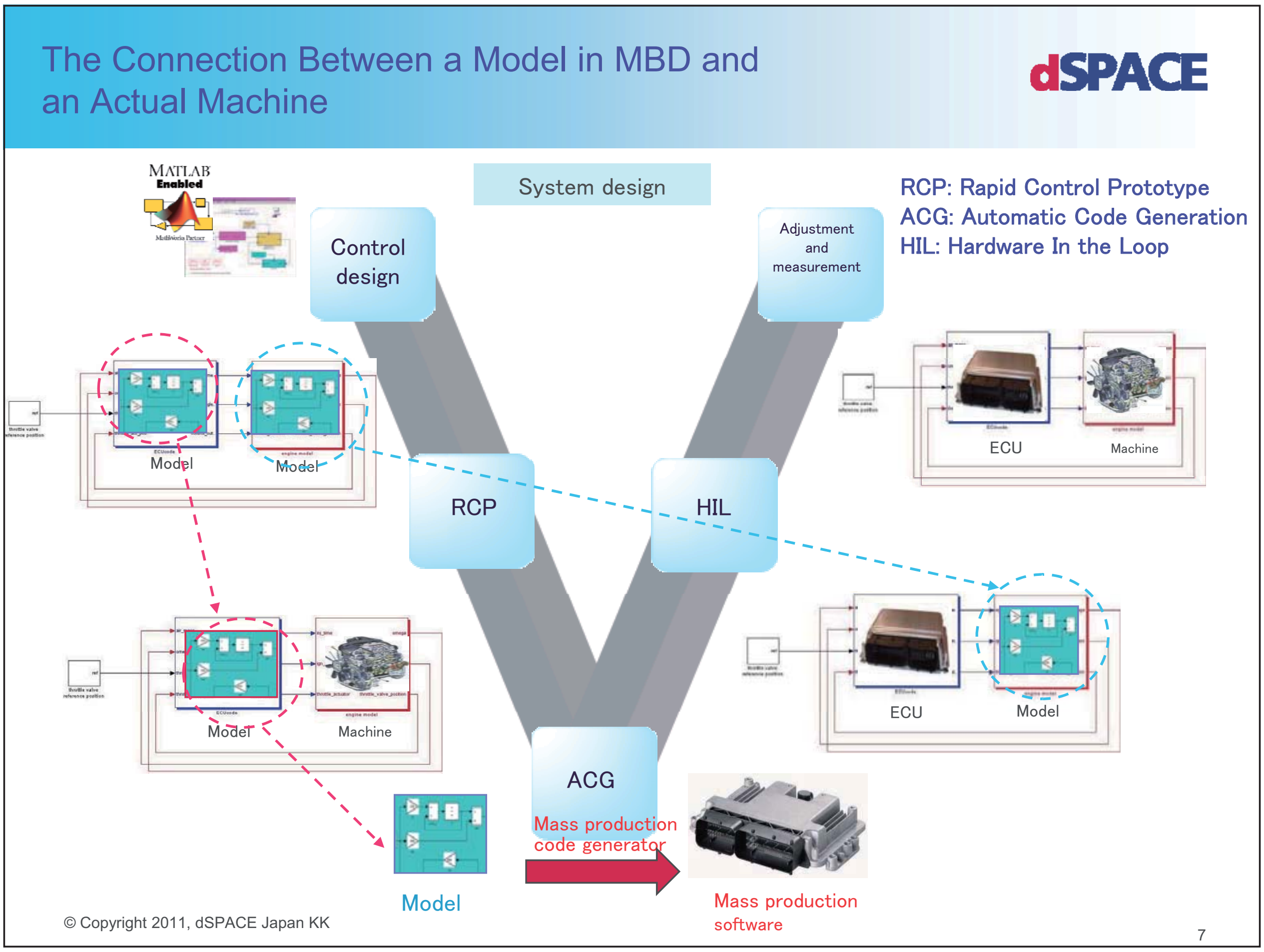
The Connection Between a Model in MBD and an Actual Machine
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System design
Control design
Adjustment and measurement
RCP: Rapid Control Prototype
ACG: Automatic Code Generation
HIL: Hardware In the Loop
Model
Model
RCP
HIL
ECU
Machine
Model
Machine
ECU
Model
ACG
Mass production code generator
Model
Mass production software
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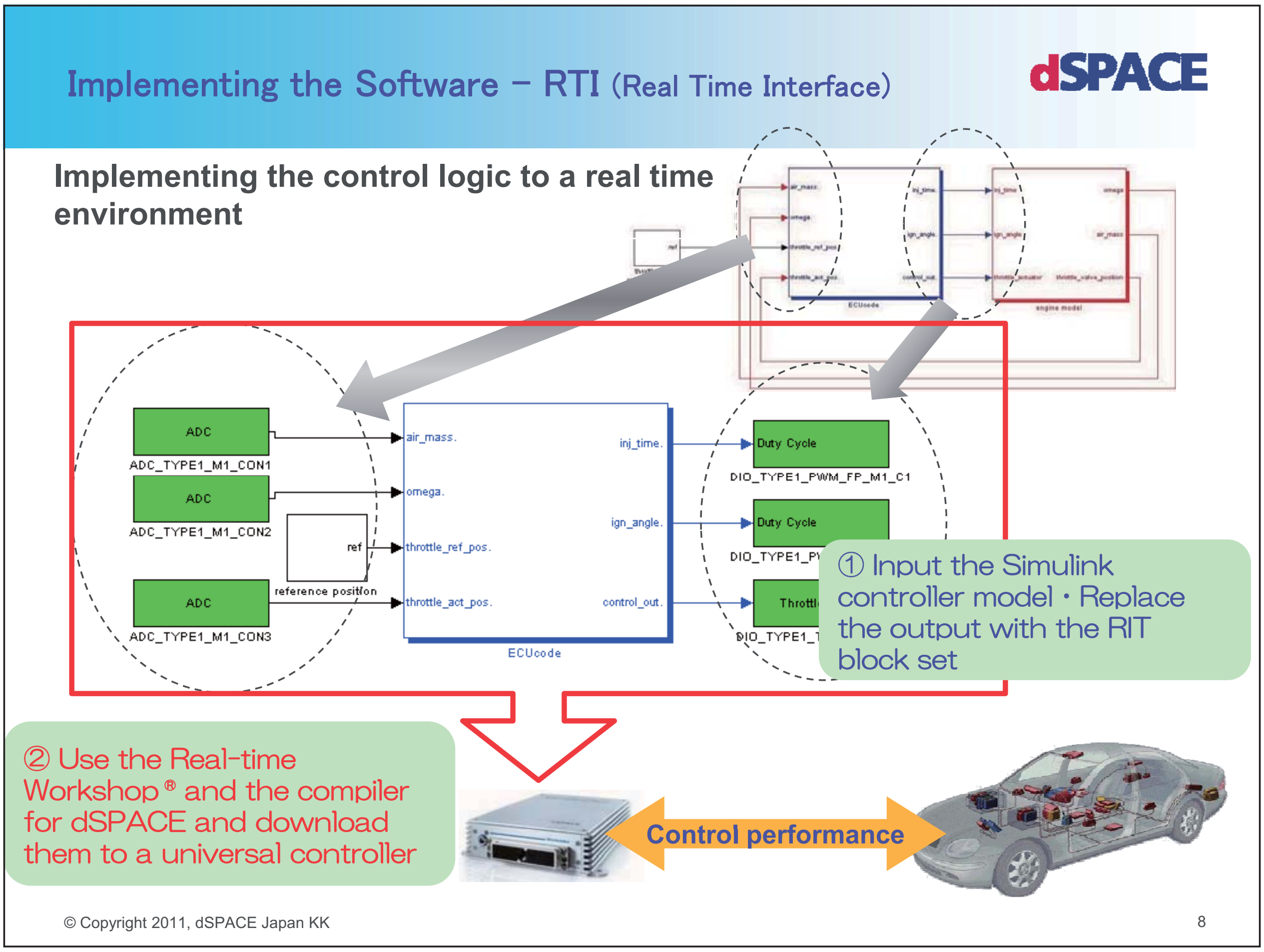
Implementing the Software – RTI (Real Time Interface)
dSPACE
Implementing the control logic to a real time environment
ADC
ADC_TYPE1_M1_CON1
ADC
ADC_TYPE1_M1_CON2
ADC
ADC_TYPE1_M1_CON3
reference position
air_mass
omega
throttle_ref_pos
throttle_act_pos
inj_time
ign_angle
control_out
ECUcode
Duty Cycle
DIO_TYPE1_PWM_FP_M1_C1
Duty Cycle
① Input the Simulink controller model・Replace the output with the RIT block set
② Use the Real-time Workshop® and the compiler for dSPACE and download them to a universal controller
Control performance
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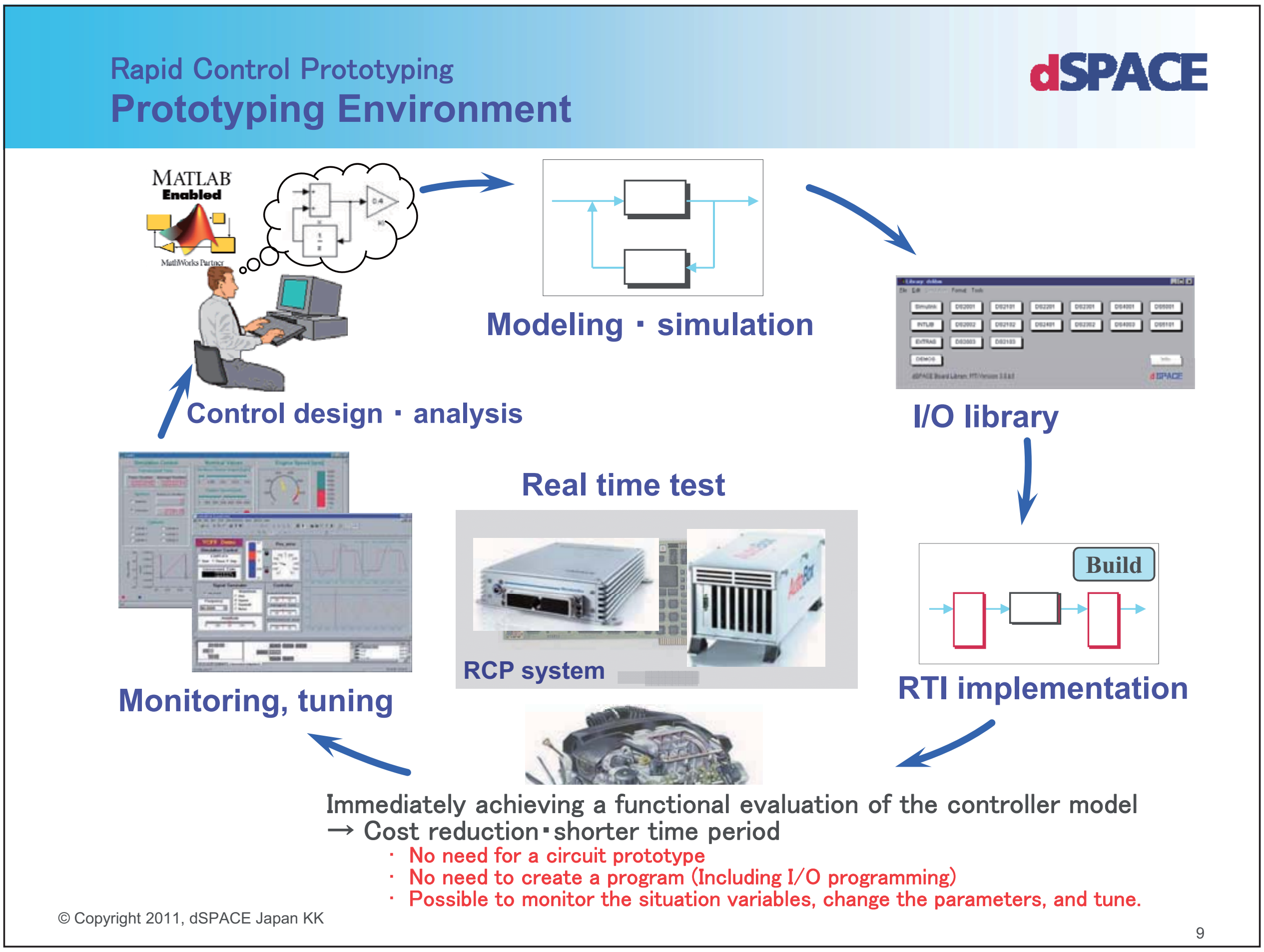
Rapid Control Prototyping
Prototyping Environment
dSPACE
MATLAB Enabled
MathWorks Partner
Modeling · simulation
I/O library
Control design · analysis
Real time test
Build
Monitoring, tuning
RCP system
RTI implementation
Immediately achieving a functional evaluation of the controller model
→ Cost reduction・shorter time period
・ No need for a circuit prototype
・ No need to create a program (Including I/O programming)
・ Possible to monitor the situation variables, change the parameters, and tune.
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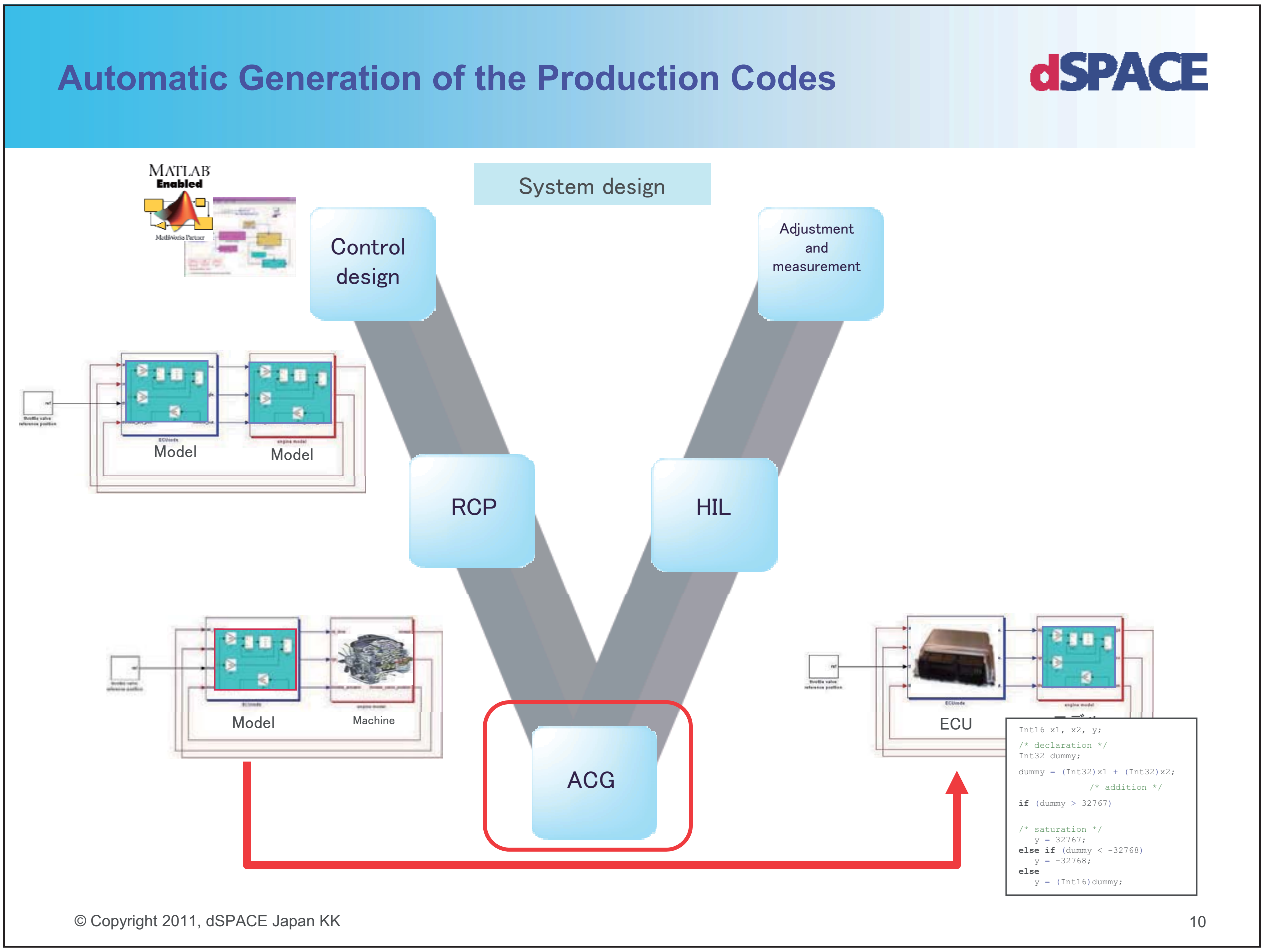
Automatic Generation of the Production Codes
dSPACE
MATLAB Enabled
System design
Control design
Adjustment and measurement
Model
Model
RCP
HIL
Model
Machine
ECU
ACG
Int16 x1, x2, y;
/* declaration */
Int32 dummy;
dummy = (Int32)x1 + (Int32)x2;
/* addition */
if (dummy > 32767)
/* saturation */
y = 32767;
else if (dummy < -32768)
y = -32768;
else
y = (Int16)dummy;
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Using the Model as a Specification Sheet

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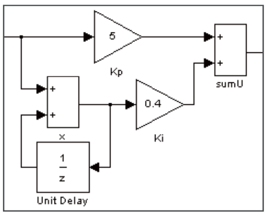
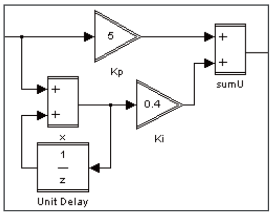
Control logic development



Control model

＝ spec sheet

Automatic conversion



TargetLink block

Rapid prototype controller

Code generation

Mass production C code

```
Int16 x1, x2, y;
/* declaration */
Int32 dummy;
dummy = (Int32)x1 + (Int32)x2;
                /* addition */
if (dummy > 32767)
                /* saturation */
   y = 32767;
else if (dummy < -32768)
   y = -32768;
else
   y = (Int16)dummy;
```

◇The model is a control spec sheet

◇It sets a clear goal of creating a program that carries out calculations identical to those of the control model

➡ It shortens the development time and improves the software quality

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ECU Verification With a Simulator

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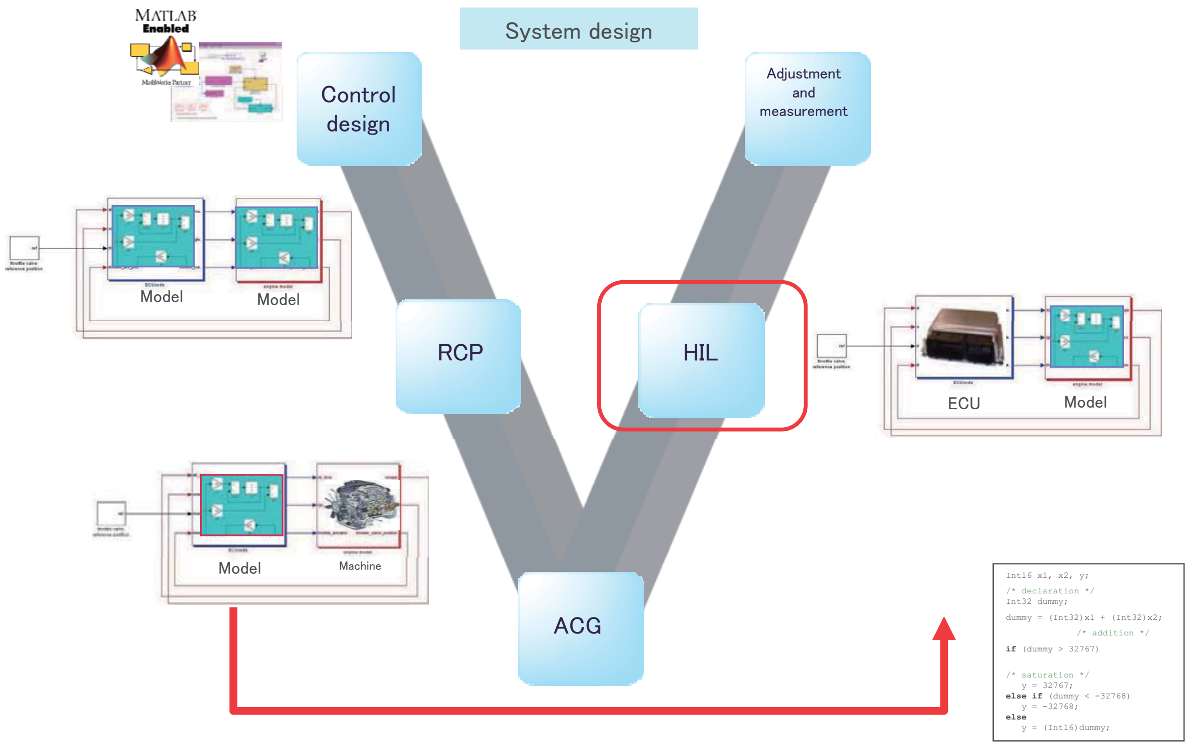

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What is HILS (Hardware In the Loop Simulator)?

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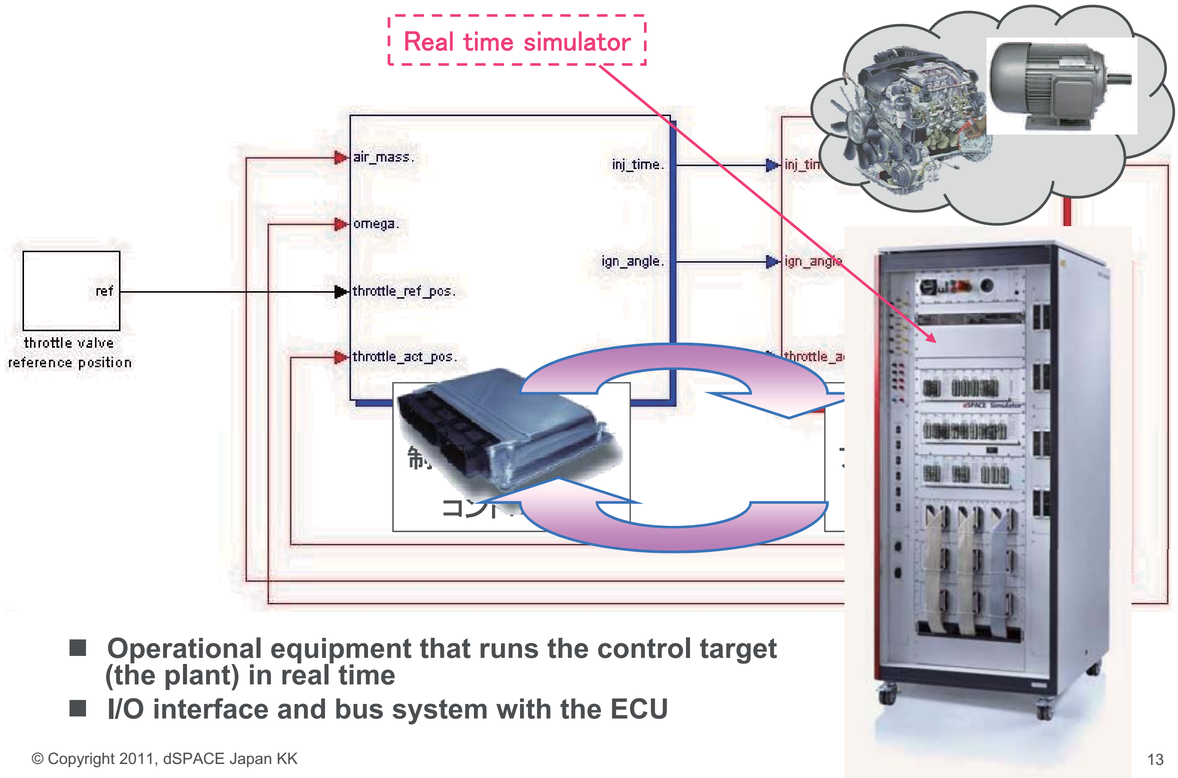

- Operational equipment that runs the control target (the plant) in real time
- I/O interface and bus system with the ECU

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The Beneifts of HILS

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HILS will not completely replace tests of prototype cars, but...

✓ No actual machines

It is possible to test in conditions where there is no actual machine, so there is no need to secure a test course and a driver.

✓Automatic testing

Automating stylized tests like OBD, and testing for 24 hours.

✓ Reproducibility

Reliable reproduction with the parameter settings even if there are complicated defect events.

✓Comprehensiveness

Improving the comprehensiveness of a test by freely changing the environmental and driving conditions.

✓Safety

Achieving test scenarios related to the safety of a test driver with HILS.

✓Reusability

It is possible to reuse test scenarios and evaluation functions that have been created.

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HILS Composition

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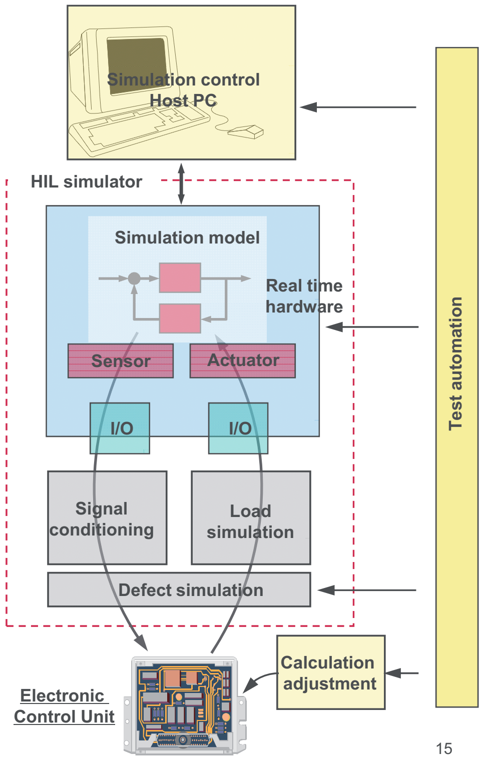
- **HILS controls: Control Desk**
  - Test project management
  - Simulation controls
  - Variable monitoring
- **Plant: ASM** (Automotive Simulation Models)
  - Engine
  - Vehicle dynamics model
- **Implementation and testing: Hardware connection**
  - RTI (Real Time Interface)
  - FIU (Failure Insertion Unit)
- **Automatic testing: AutomationDesk**
  - Testing scenario creation management
  - Automatically running tests
- **ECU measurement and adjustment: CalDesk**
  - Access to the RAM values in the ECU
  - Diagnostic code access



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Electric Drive Solutions

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The background behind motor application systems

- Motors used for vehicular application have become higher output, and they have also gone from their traditional single function to having functions that take on the burden of a part of the system.
- Motors have begun to be used for functions related to more complicated safety issues (Power trains, vehicle controls).

Necessary components for Electric Drive Solutions (Additional components for motor application)

- **Models (For a variety of motor models, batteries, and other electric elements are necessary)**
- **High speed calculation ability (The motor time constant is 2 digits smaller than the engine)**
- **High speed I/O boards (PWM signal measurement, a base of 20 kHz)**
- **High voltage support (The greatest voltage among HEVs currently in the market is 650V)**

Products and services related to Electric Drive Solutions

- **MBD: Models (ASM Electrical Component Library)**
- **HILS/RCP**
  - **FPGA boards and high speed I/O modules (PWM signal measurement/generation, position sensor signal generation/measurement)**
  - **High-speed computing model creation/operation, connection with a normal calculation model**
  - **High voltage handling (Insulated amps, protection circuits)**

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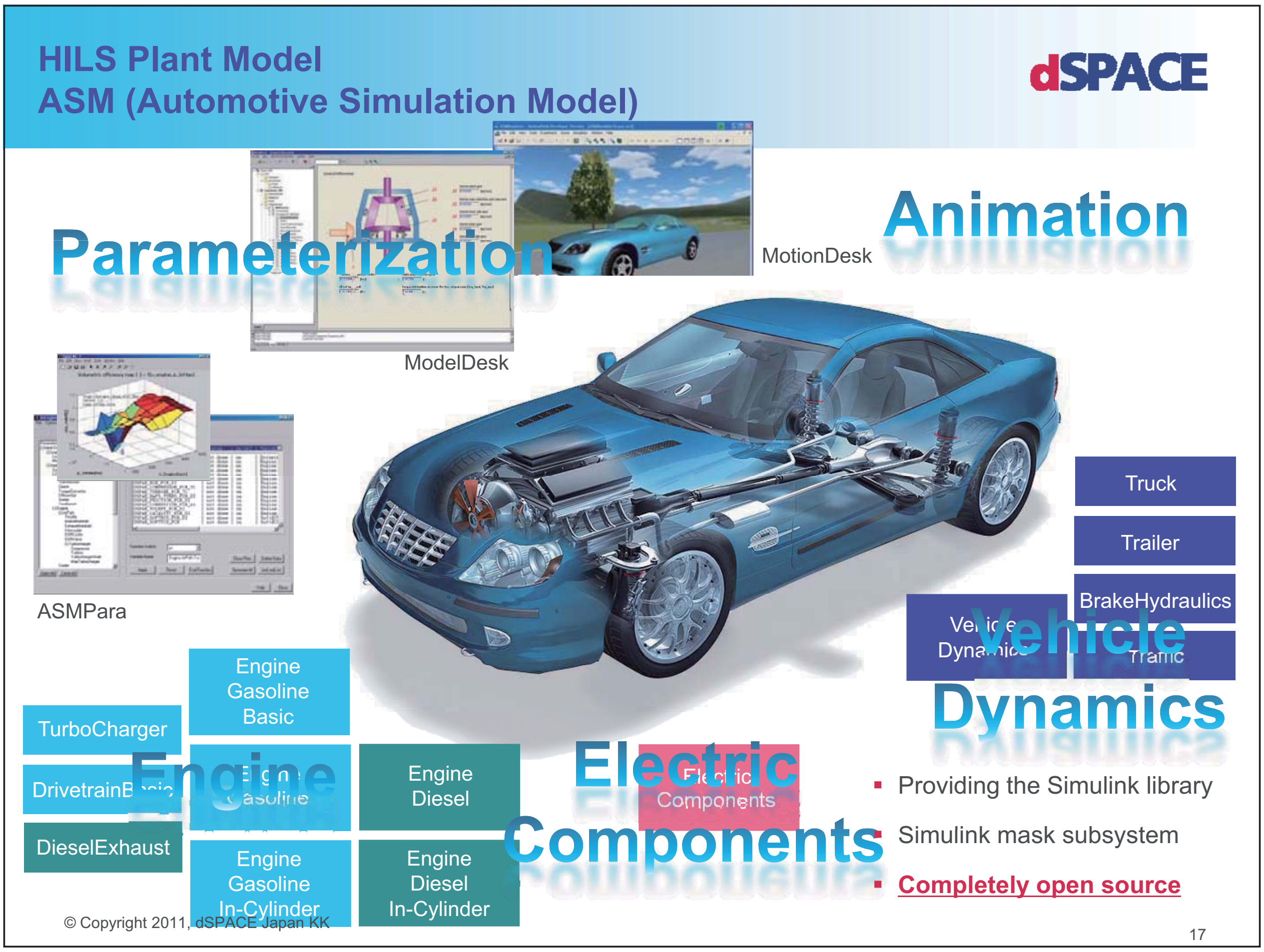
HILS Plant Model
ASM (Automotive Simulation Model)
dSPACE
Parameterization
Animation
MotionDesk
ModelDesk
ASMPara
Truck
Trailer
BrakeHydraulics
Vehicle
Dynamics
Engine Gasoline Basic
TurboCharger
DieselExhaust
Engine
Engine Diesel
Electric
Components
Engine Gasoline In-Cylinder
Engine Diesel In-Cylinder
Providing the Simulink library
Simulink mask subsystem
Completely open source
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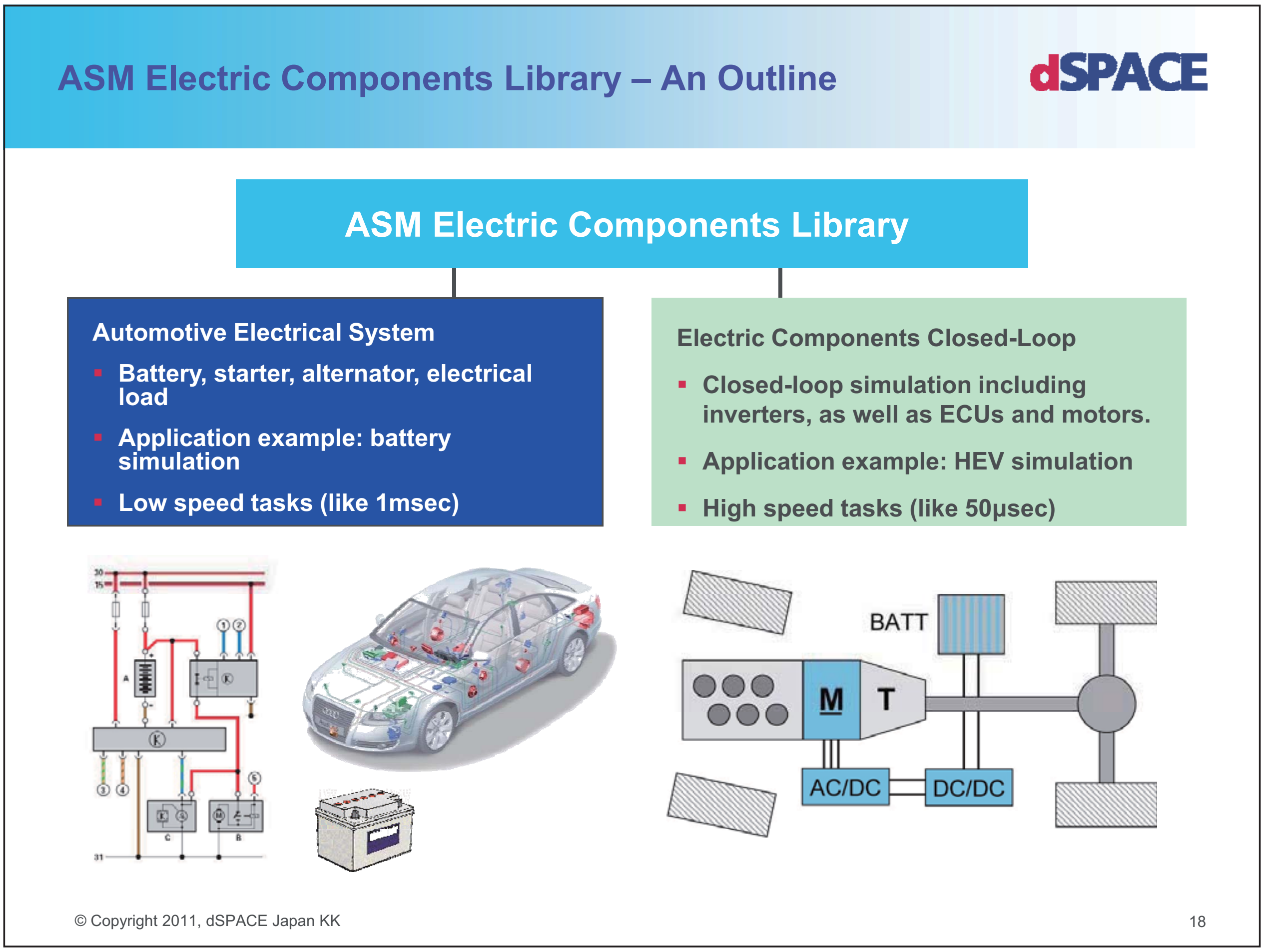
ASM Electric Components Library – An Outline
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ASM Electric Components Library
Automotive Electrical System
Battery, starter, alternator, electrical load
Application example: battery simulation
Low speed tasks (like 1msec)
Electric Components Closed-Loop
Closed-loop simulation including inverters, as well as ECUs and motors.
Application example: HEV simulation
High speed tasks (like 50μsec)
BATT
M
T
AC/DC
DC/DC
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Simulation of Signal Levels — Differences in Implementation Methods Depending on the Model Sampling

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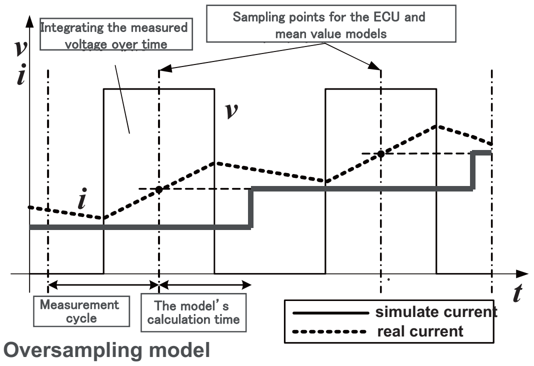
Mean Value model vs. Oversampling model:

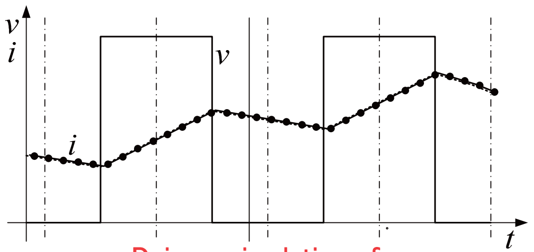
Mean Value model



- The sampling frequency is the same as the switching frequency for the ECU (or an integral multiple).
- In order to avoid noise, it is necessary to synchronize the model's sampling with the ECU's PWM switching.
  → A special IO is necessary
- There is a lag in the current output
- There is a possibility that a problem will occur the instant that the switching frequency changes.
  (E.g. Optimization of the pulse pattern, power dependency)
- The calculation load is high, but it is achievable depending on the processor's calculation ability.

→ The motor model is implemented with the processor module (DS1005,DS1006), and the IO is implemented with the FPGA (DS5202-EMH).

Oversampling model



- The sampling frequency is sufficiently higher than the ECU's switching frequency (At least 10 times)
- There is no need to synchronize because it is a quasi-continuous system simulation.
- There is almost no lag, and stability is good as well.
- The calculation load is extremely high, so it is hard to secure a sufficient sampling frequency with a processor (20 kHz PWM → 5 μs sampling cycle).

→ Implement the motor model and IO with an FPGA (DS5203)

Doing a simulation of an oversampling model in real time requires extremely fast processing and an IO that uses an FPGA.

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Electric Motors - HIL Simulation Levels

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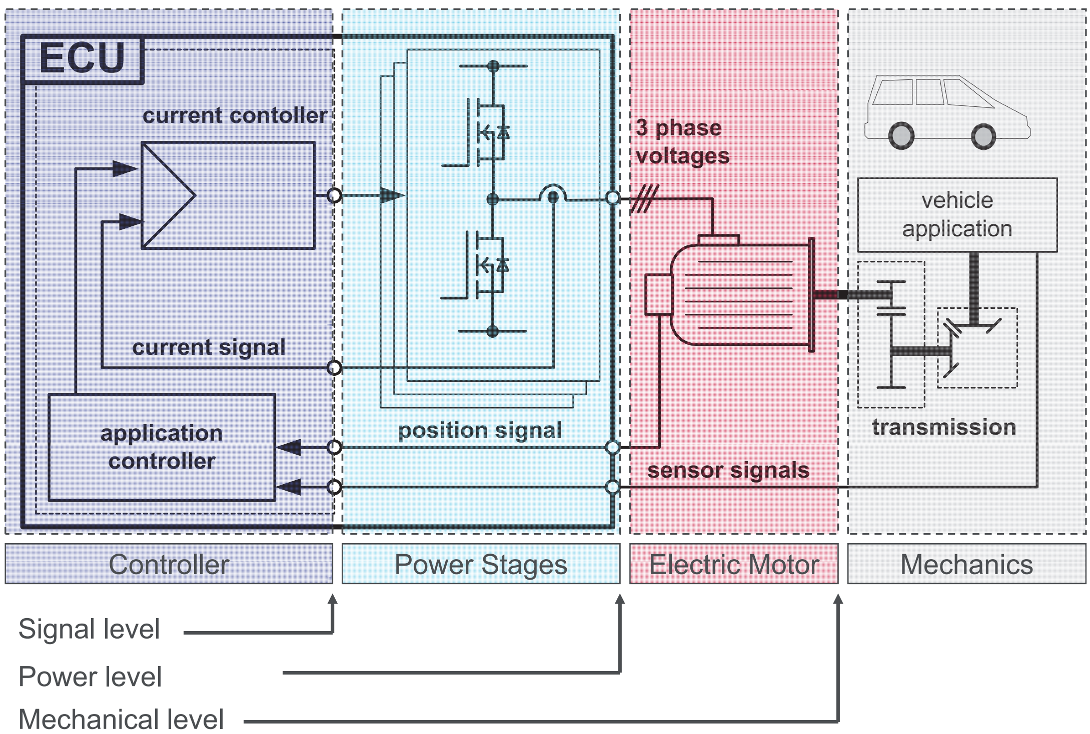

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Signal Level Simulation (DS5202-EMH)

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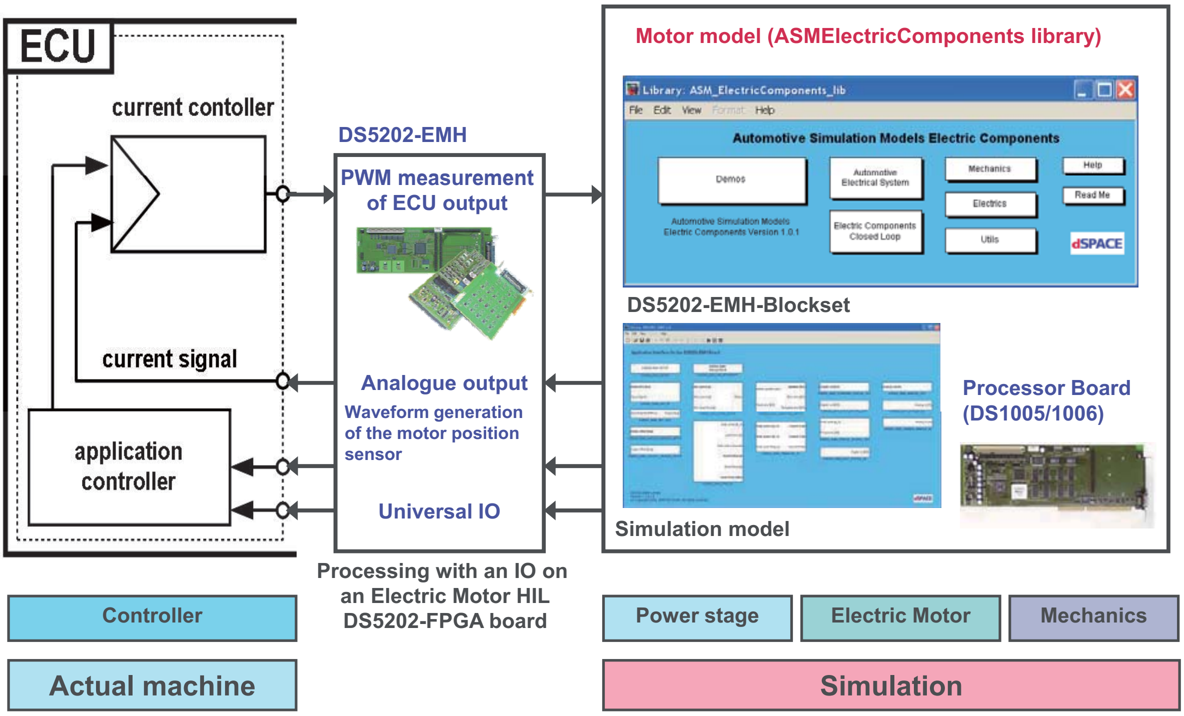

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DS5202-EMH – Resolver Breakdown Simulation

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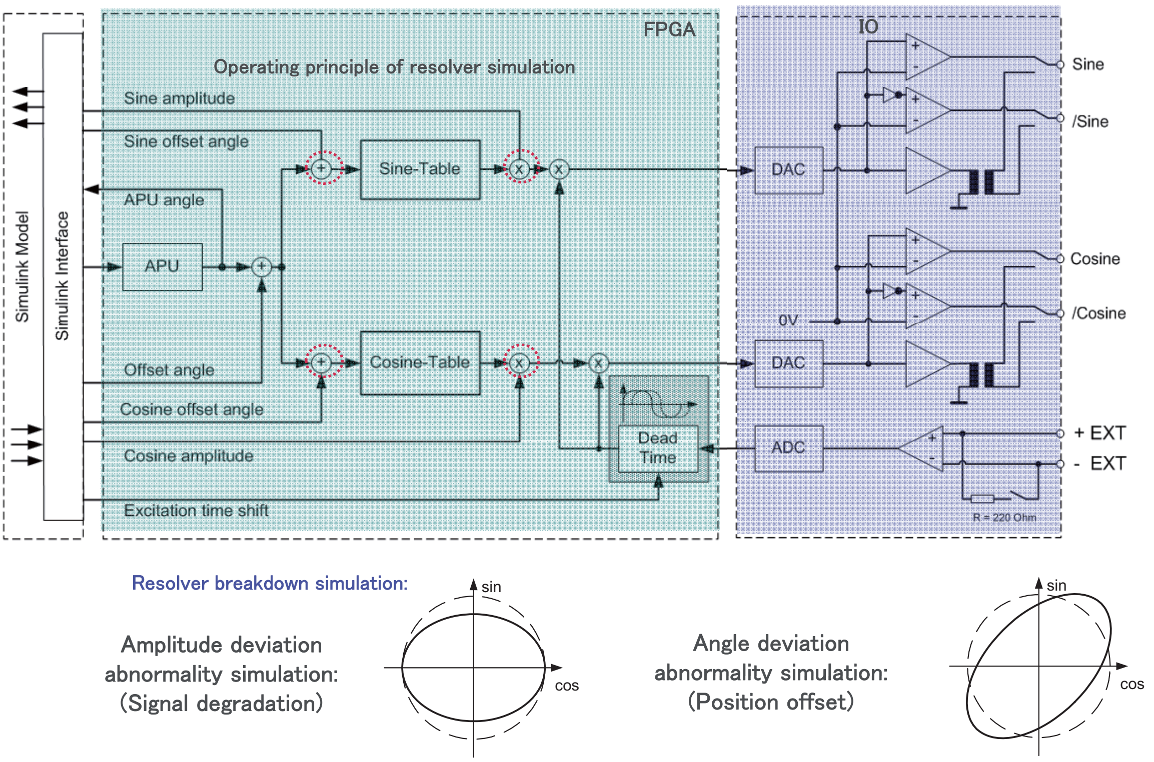

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Motor HIL – Power Level Simulation Composition

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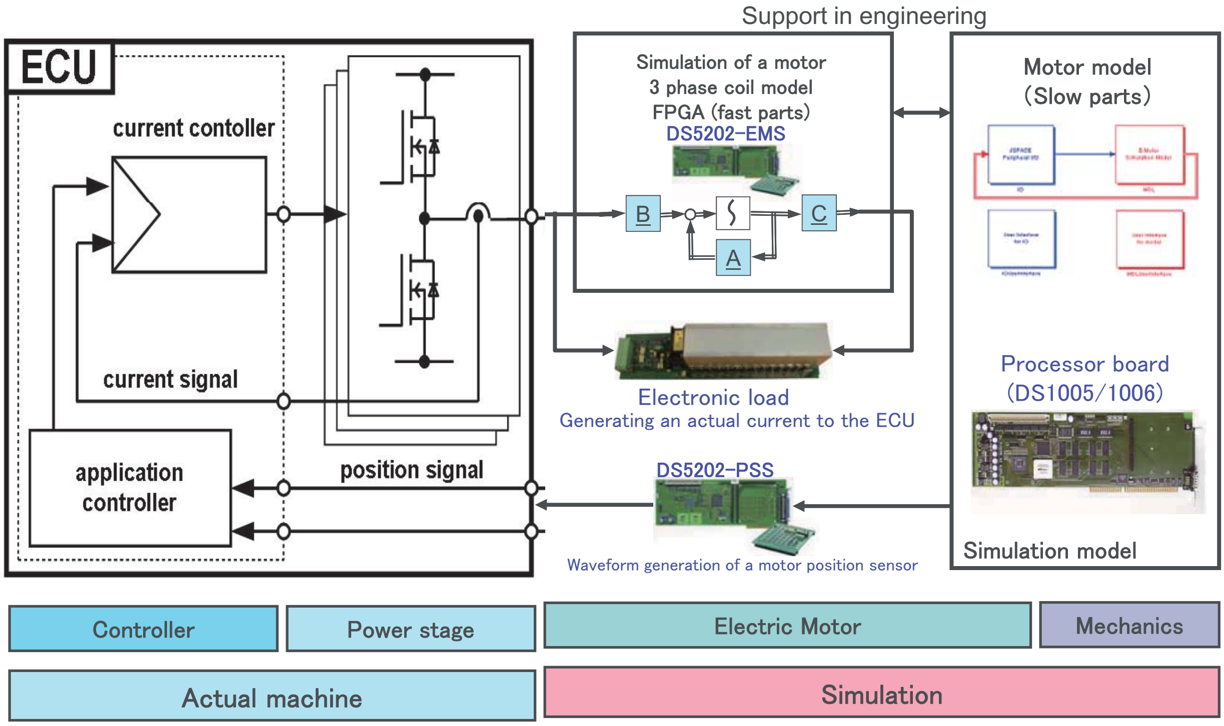

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DS5203 FPGA Board

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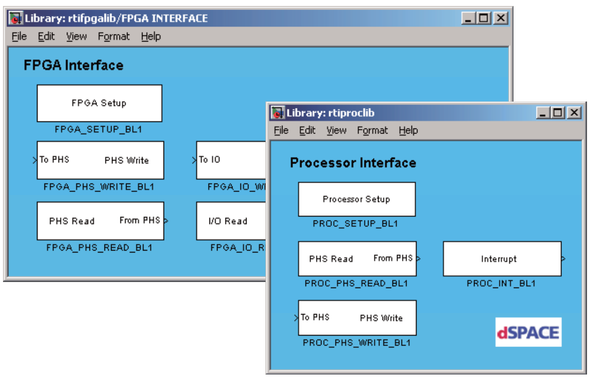
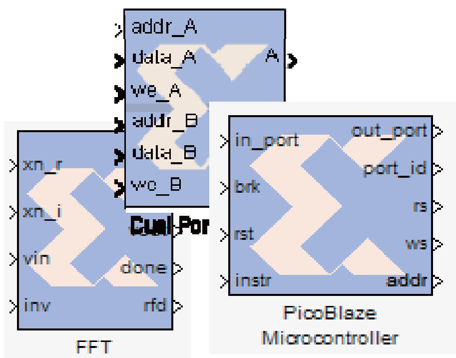
- Model construction in a Simulink environment
  - Offline simulation
  - Model divisions (The high speed calculation part is done in FPGA)
- Provision of FPGA and the processor interface
- The basic I/O is implemented on the board
- I/O expansion is possible thanks to the piggy back module
  - Production copy module (Standard I/O extension)
  - Custom modules in dSPACE
    - FPGA – Xilinx Virtex®-5 SX95T
      - Logic cells: 94298
        - Virtex-5 slices: 14720
        - DSP slices: 640
      - Distributed RAM: 1520 kBits
      - Block RAM: 8784 kBits
      - Device timing: 100 MHz





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Motor Simulation – 2 Types of Implementation Methods

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Planned for 2012

Processor based Simulation	FPGA based Simulation
+ Simulink based open implementation	+ XILINX based open implementation
+ Full host service on RT-Processor	• No host service on FPGA
• Signal level simulation	+ Signal and power level simulation
+ Parameterization in plant model	• Parameterization via processor interface
+ ModelDesk support	• Parameter file based Parameterization
+ Current depending nonlinear tables for motor inductivity	• Support of nonlinear effects depending
• Low-Rate Synchronous Sampling	+ Asynchronous Oversampling
• Limited range of switching frequency	+ Wide range of switching frequency
• Limited electric fundamental frequency	+ High electric fundamental frequency
• Mean value current output	+ Simulation of PWM effects
• High Computation Load on Processor	+ Low Computation Load on Processor

※ Items may be changed without preliminary notice.

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FPGA Based Simulation – FPGA and Processor Interface

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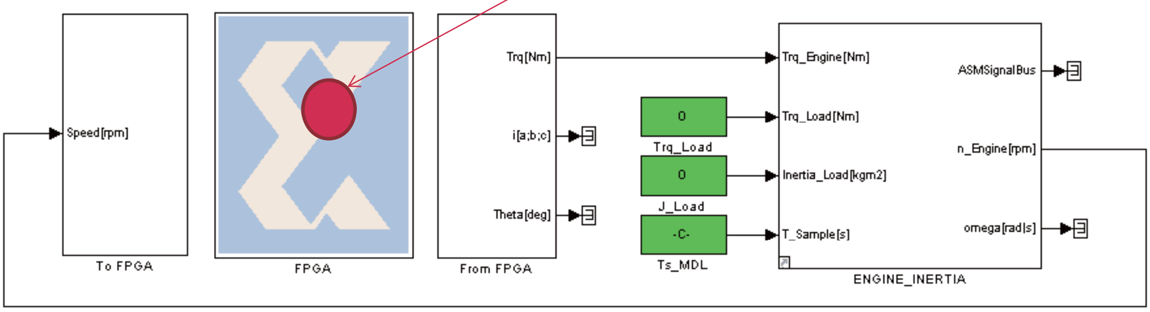
- Included in the FPGA board are:
  - Motor model
  - 3 phase inverter model
- Included in the processor board are:
  - Mechanical model
  - Vehicular power supply system
  - FPGA model parameters
  - Data exchange between the FPGA and the Processor (E.g. Speed, torque)

Model inside the FPGA board
- JMAG analysis result model
- XSG model (self-produced)
- XSG model (using library)
- VHDL



▪Preliminary – subject to change without notice

Chart: 26

Signal Level Simulation ― A Working Example
Volkswagen: Touareg Hybrid - HIL System (1)

- **Products used:**
  dSPACE Virtual Vehicle HIL Simulator,
  Automotive Simulation Models (ASM)
- **Application:**
  Development of an ECU that uses the network simulator of a Touareg Hybrid
- **Challenge:**
  - 29 ECUs
  - Advanced integration
  - A new test for a hybrid drive train
  - Ensuring safety for a high voltage battery
- **Benefits:**
  - Early function tests: Function tests and other special tests are possible during development
  - An integrated test of the network ECU functions

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Signal Level Simulation ― A Working Example
Volkswagen: Touareg Hybrid - HIL System (2)

The simulator in the laboratory and the testing equipment

Source：dSPACE Magazine 2/2010

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Conclusion

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- What is model based development (MBD)?
  - A method of distributing information by utilizing a model that actually moves as a specification sheet (Sharing the model between each phase)
  - Function verification based on the model in each development phase (Design and verification)
- The benefits of model based design
  - Elimination of a large number of setbacks in the development phase (Verification in an early development phase)
  - Reducing the number of chances for human error (Coding mistakes, mistaken interpretations of specifications)
  - Early logic verification via rapid control prototyping (Without programming)
  - Test efficiency improvement with an HIL simulator (No actual machine, and tests that are automatic and reproducible)
- Application in the motor control field (Systems and components in HEVs and EVs, etc.)
  - Component development (Motors, batteries, inverters)
    - Necessary component technology
      - Plant models (Motors, inverters, sensors)
      - High-speed I/O (ADC, DAC, Digital In/Out)
      - High-speed computing (FPGA based, flexible) JMAG models or Simulink/XSG Open models
  - System development: It is easy to add and expand subsystems that require high-speed computing or an I/O.

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Thank you for listening!

Proprietary | JMAG 2011 | December 7, 2011 | dSPACE Japan | Takashi Miyano

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