Real-Time Simulation for Control System Development

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Agenda

1. Introduction and Basics
2. Signal Level Simulation
   - Processeor based
   - FPGA based

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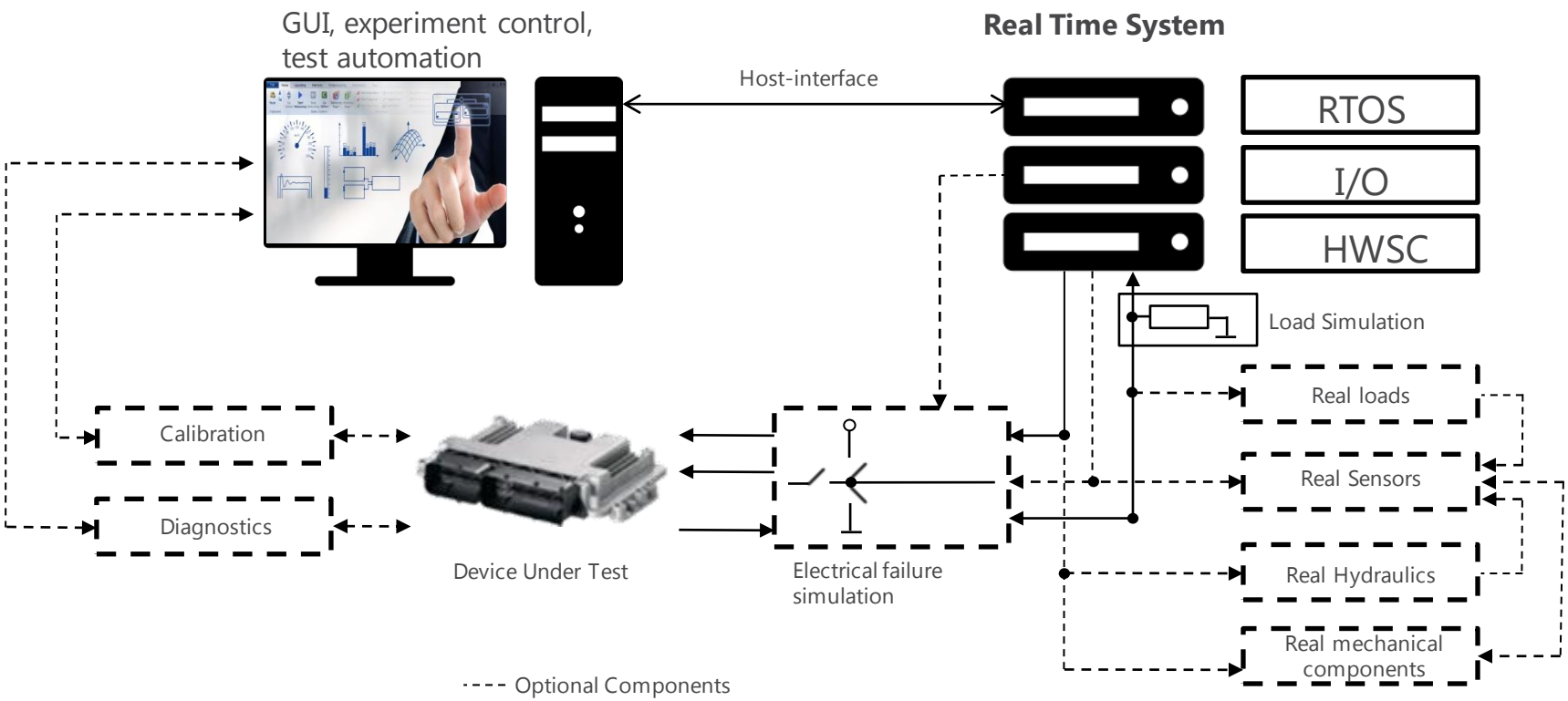
System Introduction



Goals and Advantages of the HIL-Simulation

Goals of the HIL-simulation

- Increased productivity (higher coverage of potential test cases)
- Reduction of development cost (less test benches and prototype vehicles)
- Coping with increased complexity

Advantages of HIL-tests

- Function tests in early development stages
- HIL-tests can be reproduced and automated
- Certain test are not possible or too dangerous with a real system
- HIL-tests give the possibility to reproduce a certain error condition (diagnostic tests, emergency run programs, fall-back programs)

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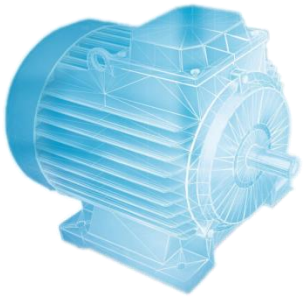
Basic Considerations for E-Drive Simulation

Drive physics

- Characteristic Dependencies (current, position, temperature, ...)
- Motor Type (PMSM, IM, ...)
- Motor Commutation (sinusoidal, trapeziodal, ...)

Simulation Level

- Signal, Power or Mechanical level



Simulation Model

- Mathematical Approach (equation, maps, state-space)
- Coordinate System (a/b/c, α/β, d/q)
- Parameter (characteristic data or maps)

Real-Time Platform

- Target Real-Time Platform (Processor, FPGA)
- Sampling Startegy (synchronized, over-sampling)

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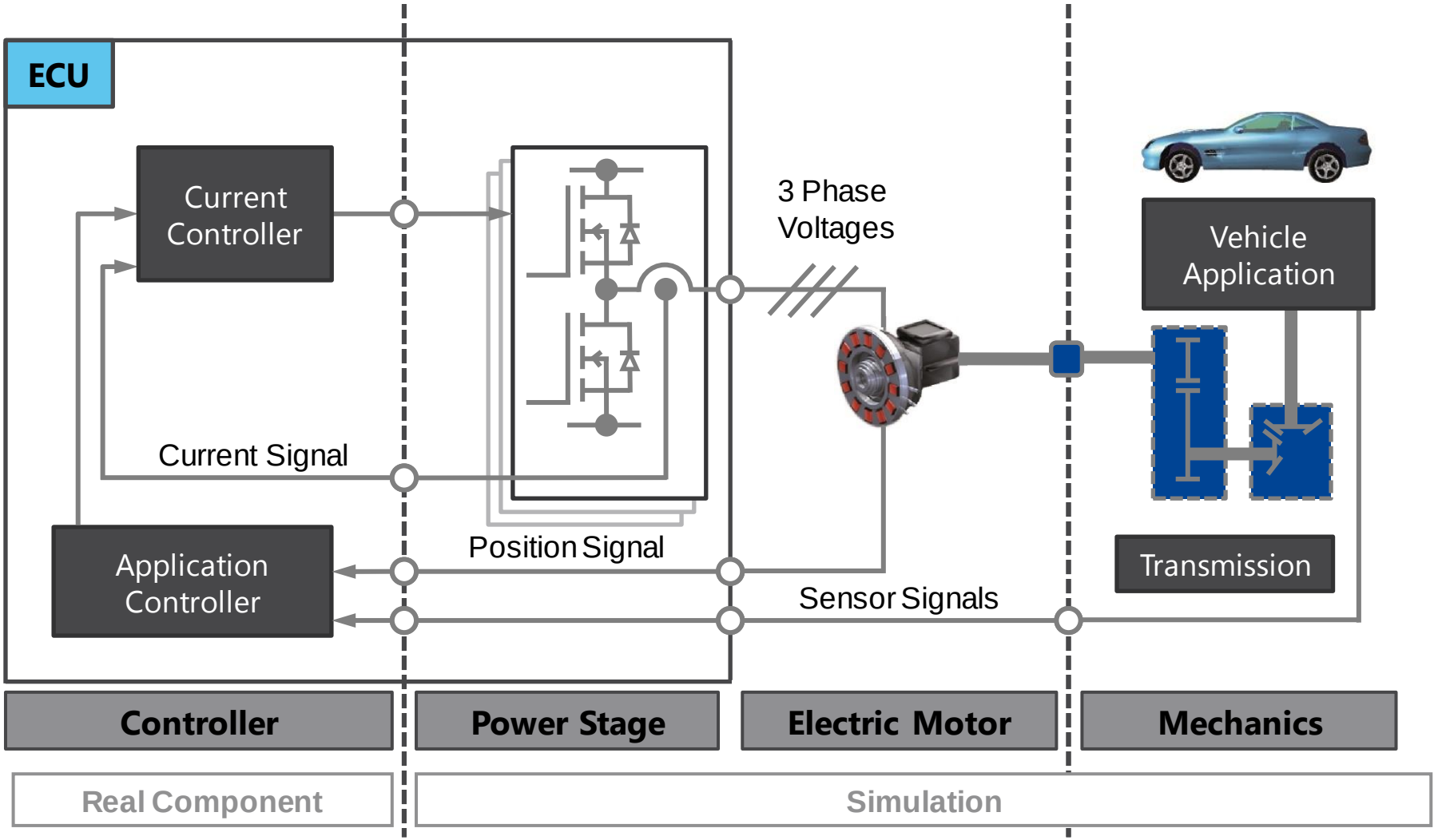
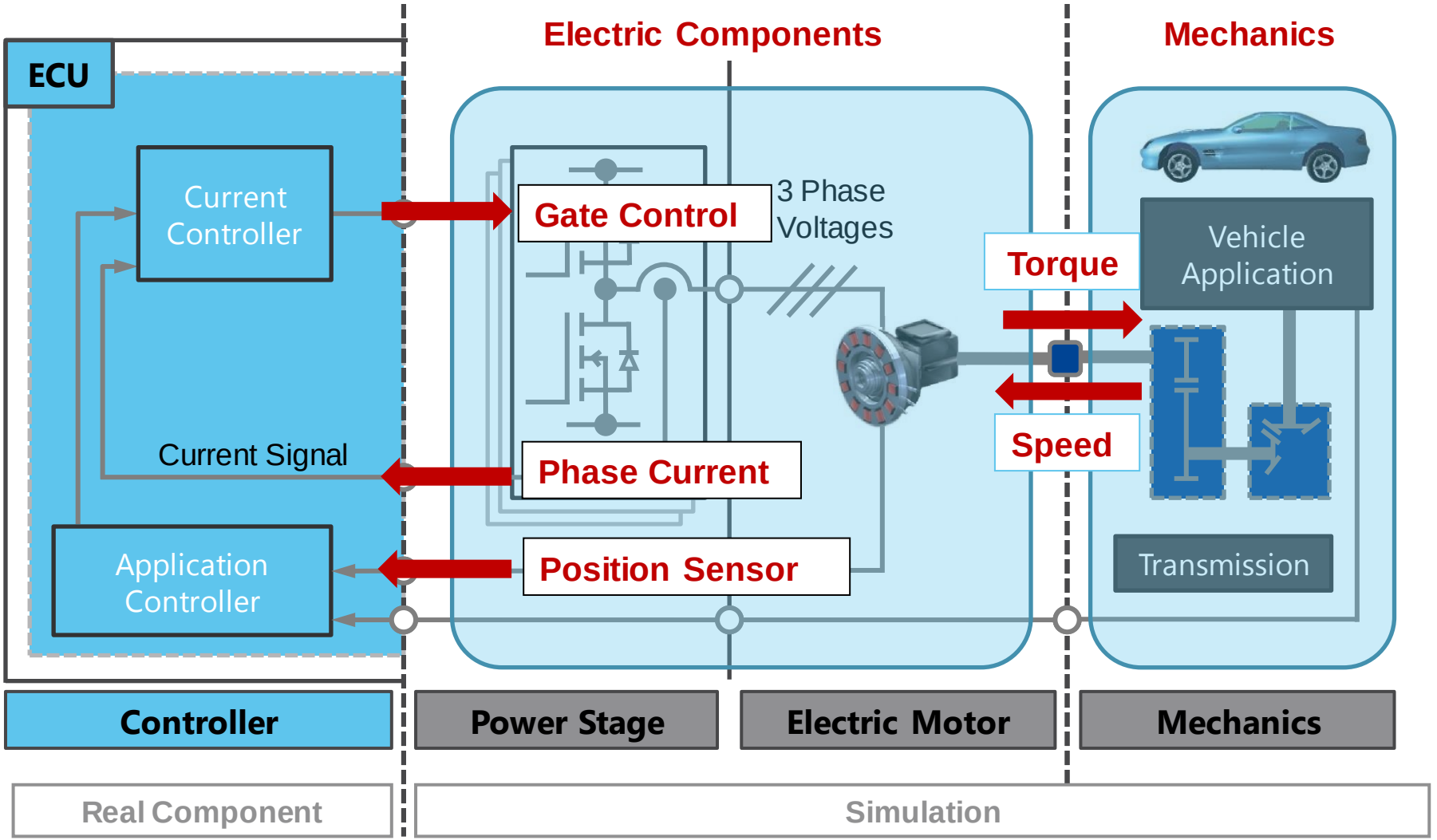
Interfaces for Simulation of e-drive



Signal Level Simulation



Preconditions for Simulation on Signal Level

- **Internal Signals of the ECU have to be accessible**
  - Current Sensor Feedback Signals (e.g. ADC that measures the HALL transduced feedback
  - Power Electronic Control Signals (e.g. Gate Driver PWM signals)

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- **Processor based Simulation**
  - For Drives that operate at low switching frequencies, typically 16-20kHz
  - Running at moderate frequencies (< 2kHz electric fundamental frequency)
  - The additional delay of the average model can be neglected

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- **FPGA based Simulation**
  - For Drives that operate at higher switching frequencies
  - Are running at high frequencies
  - A quasi continuous current simulation is required for the control algorithms of the DUT

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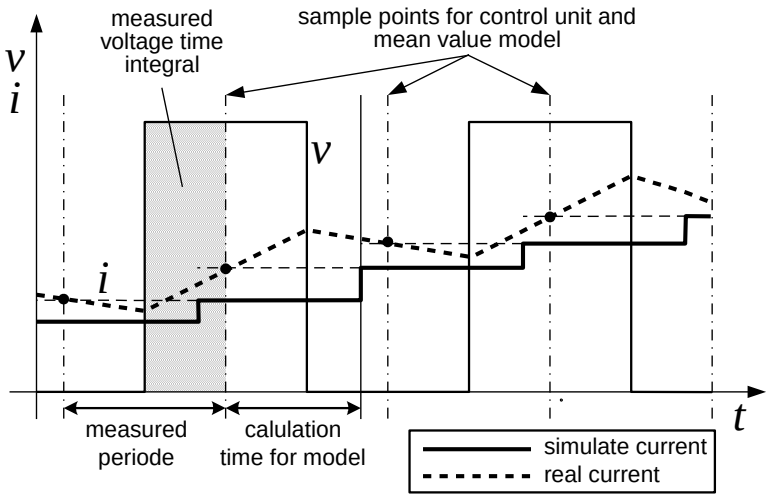
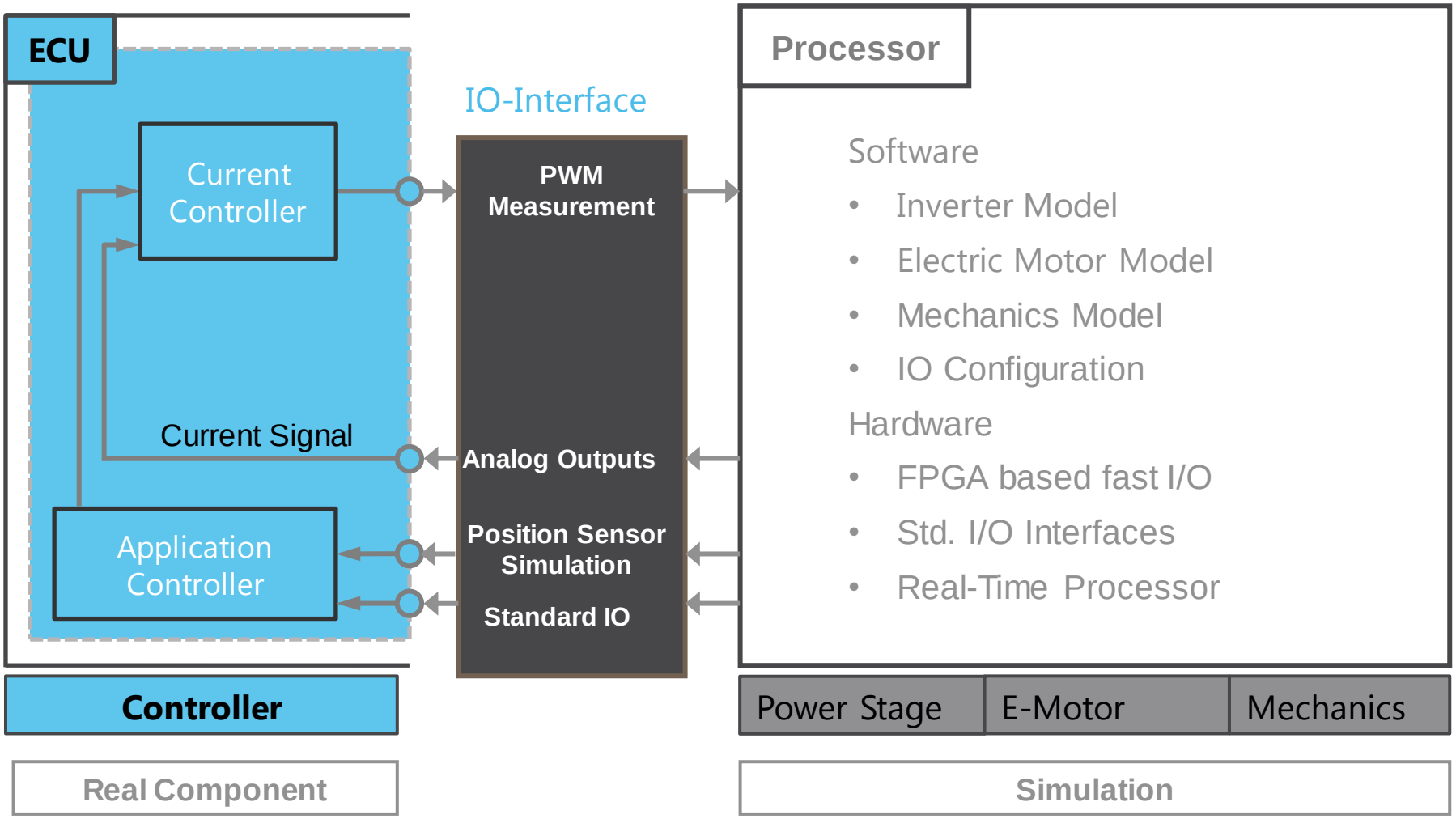
Processor based E-drive Simulation

- **Advantages**
  - Sampling frequency is usually same as switching frequency of the ECU (Sometimes oversampling by a factor 2 or 4 possible)
  - **Mean value models** are sufficient
  - **Full traceability** of internal model signals
  - Simulation in a **well known environment**



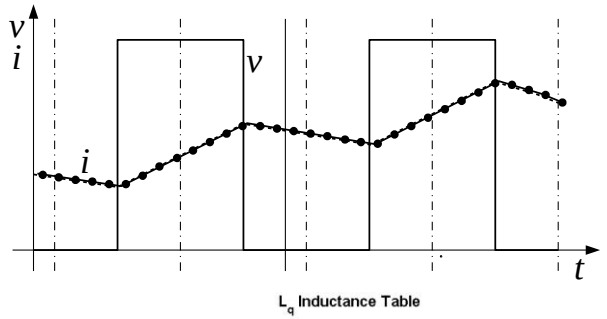
- **Disadvantages**
  - Synchronized model Calulation required
  - Limited electric fundamental frequency
  - Limited range of switching frequency
  - Mean value current output with delay
  - High computation load on processor

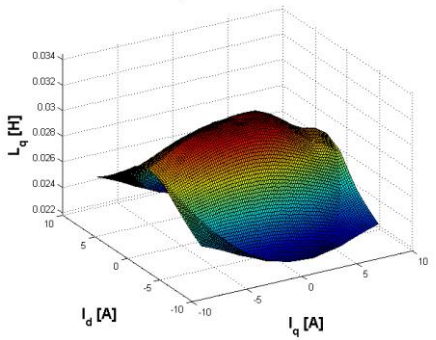
Processor based E-drive Simulation



FPGA based E-Drive Simulation

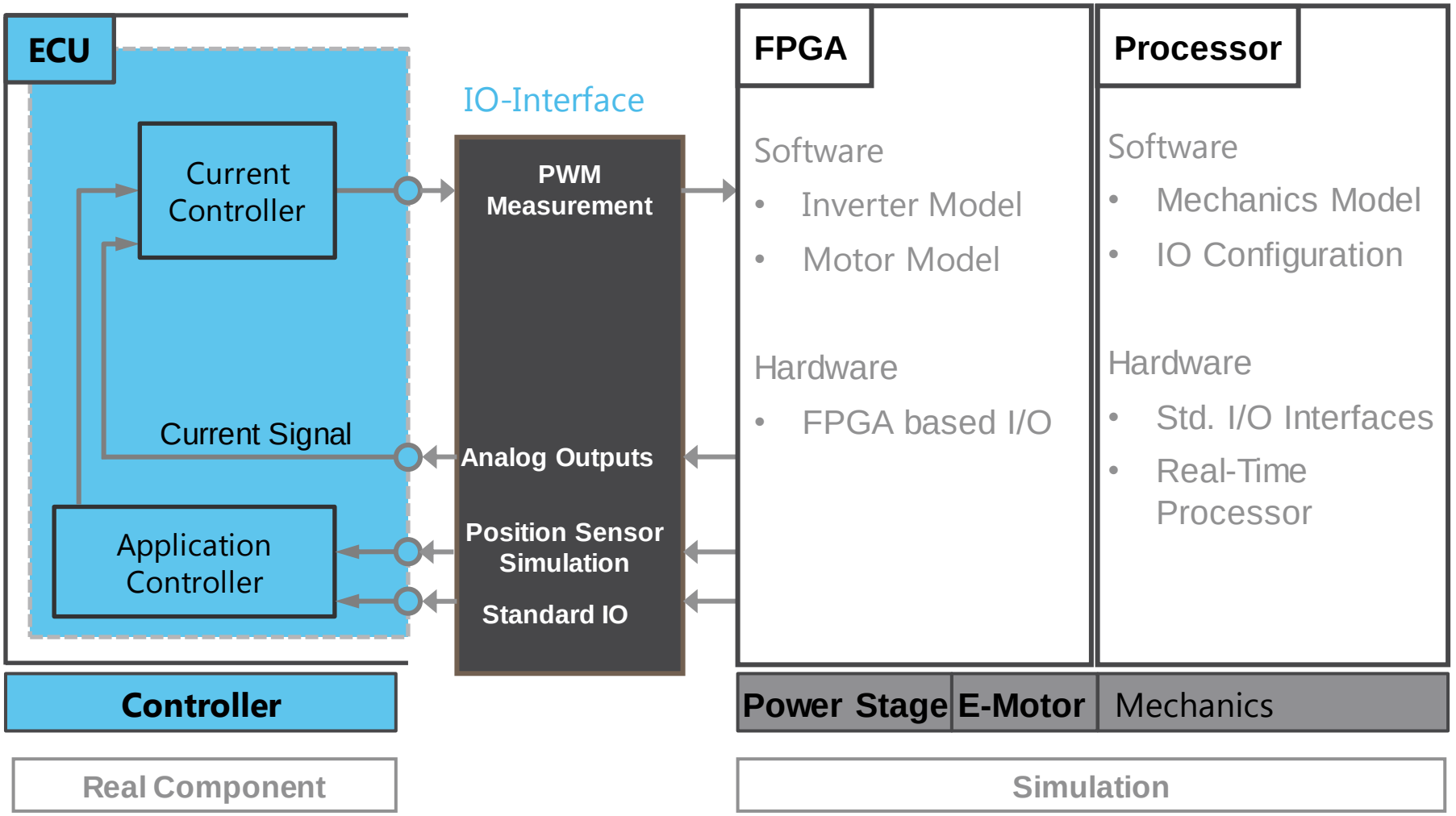
- **Advantages**
  - Sampling frequency is much higher than switching frequency of the ECU
  - **Quasi-continuous current output** without delay (Simulation of PWM effects)
  - Control of Electronic loads possible
  - Wide range of **switching frequency**
  - High electric **fundamental frequency**
  - Low computation load on processor
  - Non linear effects such as **spatial harmonics**





- **Disadvantages**
  - Limited topology size per FPGA
  - No tracability of internal model signals by default

FPGA based E-Motor Simulation



Questions