High-Performance Motion Control with the PEPPER/MINT System-on-Chip Platform

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Agenda

- Introduction 3T
- Model-based Design
- Projects
- Platforms & building blocks
- Sensorless Field Oriented Control (FOC) for BLDC
Company profile

- Founded in 1982, 3T since 1994
- Co-development, manufacturing and support of customer specific electronics
- ISO 9001:2015 and EN ISO 13485:2016 certified
- 80 employees
- Offices in Enschede and Eindhoven
- Strong partner network
Systems are becoming more intelligent, more complex

- Model-Based Design is a way to deal with this
ASML

Wafer Handler robot

Wind Turbine

Tracking Radar

SR E-drive system
Platforms & building blocks

- Systems are becoming more intelligent and more complex
  - increasing use of advanced motor/power control
  - increasing use of System on Chip (SoC) devices

- Generic platforms & building blocks: **MINT, VIPER, PEPPER**
  - prove feasibility early in the design phase
  - reduce development risks, cost and time to market
  - kick-start customer projects
MINT: INTEL SoC Multi-INTerface development board

- INTEL SoC: FPGA and dual-core ARM Cortex-A9
- USB3, Ethernet, SFP+ and QSFP sockets, UART, SPI, i2C, GPIO, RS-485
- Linux
- Board Support Package (BSP) for Model-Based Design using MATLAB/Simulink
- FMC connector for extension boards e.g. PEPPER

See: [http://3t.nl/mint/](http://3t.nl/mint/)
VIPER: Flexible Motor Control

- Power up to 50V/60A (scalable)
- Support BLDC / PMSM / IPM / steppers (microstepping)
- Interface UART, CAN, Ethernet
- 3 phase sensorless sinus steering based upon FOC (Field Oriented Control)

See: http://3t.nl/viper/
PEPPER: Flexible Digital Precision Amplifier

- Flexible 4-channel GaN FETs based power amplifier
- Output power $4 \times 50V \times 5A = 1kW$ (scalable)
- High efficiency, accuracy and bandwidth
- FMC (FPGA Mezzanine Card)
- Board Support Package (BSP) for Model-Based Design using MATLAB/Simulink
- See: [http://3t.nl/pepper/](http://3t.nl/pepper/)
Sensorless Field Oriented Control (FOC) for Brushless DC (BLDC) Motors
Goal

- Develop sensorless FOC (Field Oriented Controller) for BLDC motor on MINT & PEPPER platform
- Design FOC, motor position estimator, path planner / motion control
- Realize demonstrator
The demonstration setup

- Computer running MATLAB
- Motor with letter wheel
- PEPPER & MINT
Demonstration

Speed: 3000 rpm
Flash: 50Hz
Field Oriented Control (FOC)

- Geometric transformations
  3-phase AC to 2-phase DC
- Torque control
- No frequency dependency

Source: https://www.switchcraft.org
3T SoC/MINT Workflow

Run model on MINT
Model-Based Design steps

- High level system model design
- Plant model design
- Controller model design
- Deployment on hardware platform
- Optimization
- Hardware verification
Clarke transform

Clarke transform implementation in simulink

\[
\begin{bmatrix}
\alpha \\
\beta \\
0
\end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix}
1 & -\frac{1}{2} & -\frac{1}{2} \\
0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \\
\sqrt{\frac{1}{2}} & \sqrt{\frac{1}{2}} & \sqrt{\frac{1}{2}}
\end{bmatrix}
\begin{bmatrix}
a \\
b \\
c
\end{bmatrix}
\]

The 0 element is omitted
Park transform

Clarke to park transform implementation in simulink

\[
\begin{bmatrix}
    d \\
    q \\
    0
\end{bmatrix} =
\begin{bmatrix}
    \cos(\theta) & \sin(\theta) & 0 \\
    -\sin(\theta) & \cos(\theta) & 0 \\
    0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
    \alpha \\
    \beta \\
    0
\end{bmatrix}
\]

The 0 element is omitted
Plant

Block Parameters: Motor

This block represents a permanent magnet synchronous motor with sinusoidal flux distribution.

Right-click on the block and select Simscape block choices to access variant implementations of this block.

Settings

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<thead>
<tr>
<th>Main</th>
<th>Mechanical</th>
<th>Variables</th>
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<td>Angle between the a-phase magnetic axis and the q-axis</td>
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Controller | Deployment

Controller

Plant

PEPPER

Motor

Deploy
Deployment on hardware platform

- Set Target
  MINT Board Support Package (BSP)
- Prepare Model for Code Generation
- HDL Code Generation
- Embedded System Integration
HDL Coder optimizations

- Fixed-point vs floating point
- Sample rate conversion
- Resource sharing
- Pipelining

Automatic resource sharing is a powerful feature.
Hardware verification

- Simulink in external mode to control deployed model
Simulink
External mode

Runtime parameter tuning on target for phase calibration
Conclusions

- The project results show that Model-Based Design helps to:
  - Shortened lead time (letter wheel completed in 10 weeks, instead of planned 20 weeks)
  - Positive customer feedback
  - Assess feasibility through simulation
  - Improve collaboration between different disciplines
  - Respond quickly to changing requirements, hours instead of days