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
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/
**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/](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/)
Power control application

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

1. High level system model design
2. Plant model design
3. Controller model design
4. Deployment on hardware platform
5. Optimization
6. Hardware verification
High level system model
Clarke transform

Clarke transform implementation in simulink

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

The 0 element is omitted
The 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

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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<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

The diagram illustrates the flow of information in a control system, starting from input speed and angle LED frequency, through an angle controller for speed adjustment, and then to setpoint speed. This setpoint speed is fed into a PI controller for speed adjustment and current dq, which is further processed through a Park transform to generate current qβ. Following this, a Clarke transform is applied to generate voltage qβ. The estimated angle and estimated speed are inputs to a speed and angle estimator, which feeds into the PI controller current and setpoint voltage dq. The inverse Park+Clarke transform is then applied to generate control voltage abc, which is further processed through PWM generation to control space vector. The output is then sent to the PEPPER plant and motor for deployment.
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