

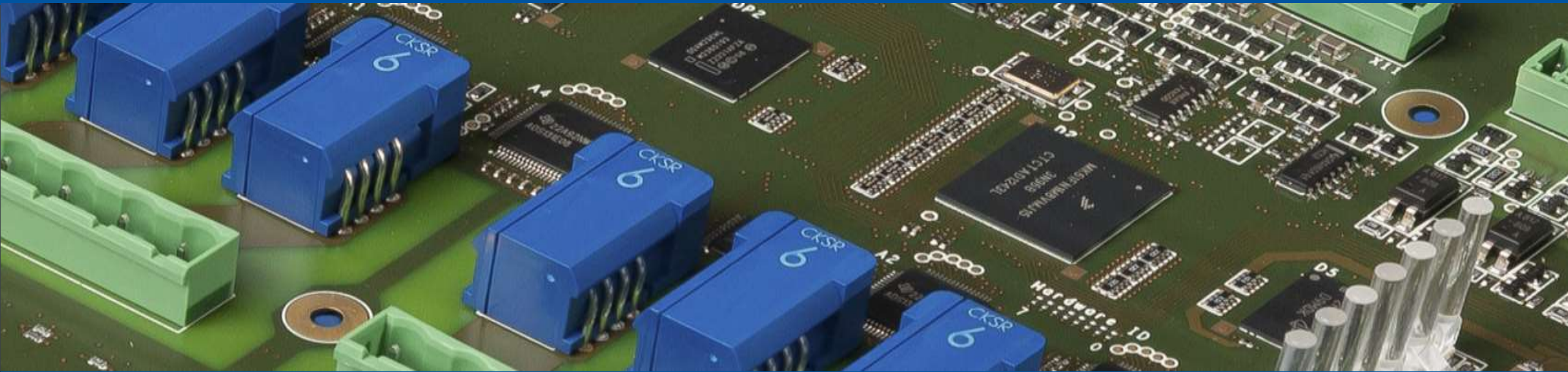


electronics & embedded systems

CO-DEVELOPMENT

MANUFACTURING

INNOVATION & SUPPORT



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

Ronald Grootelaar, Consulting Engineer

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

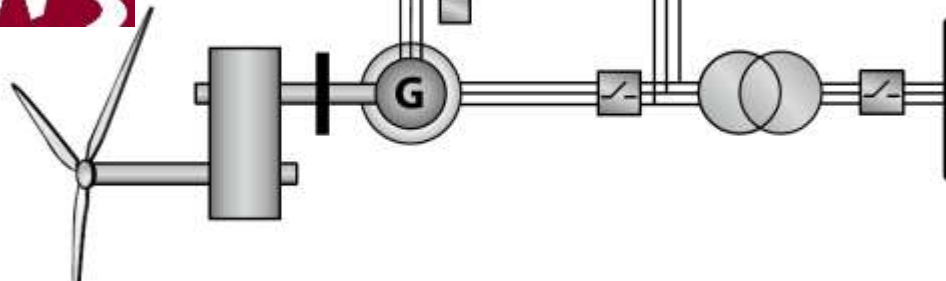
ASML



Wafer Handler robot



Tracking Radar



Wind Turbine

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/>

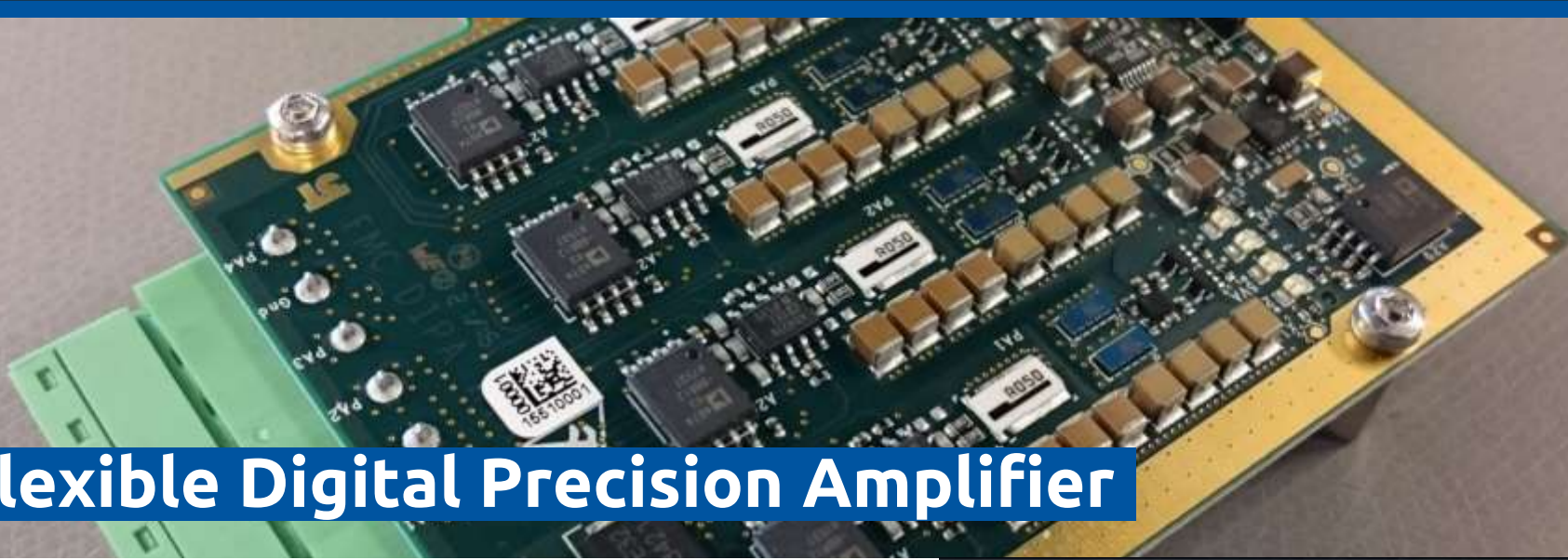




VIPER: Flexible Motor Control

- 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/>





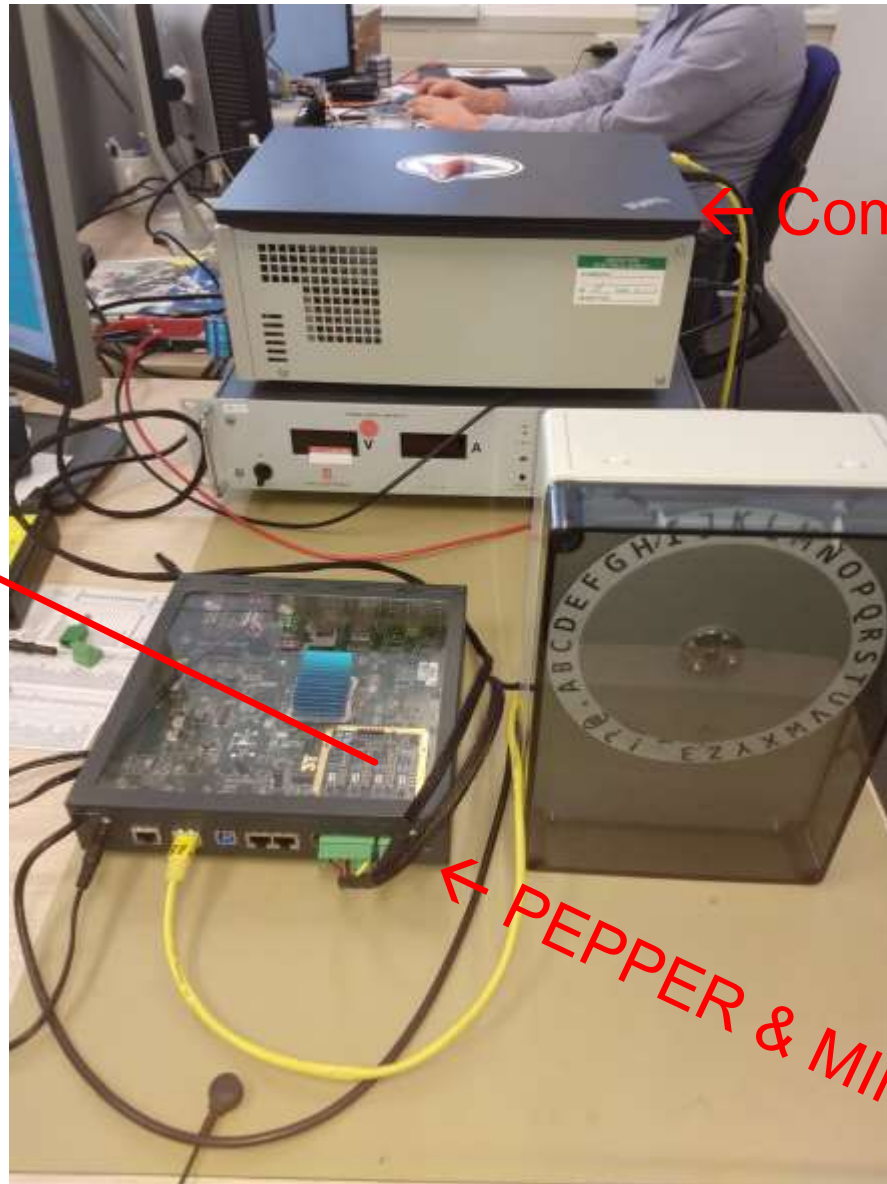
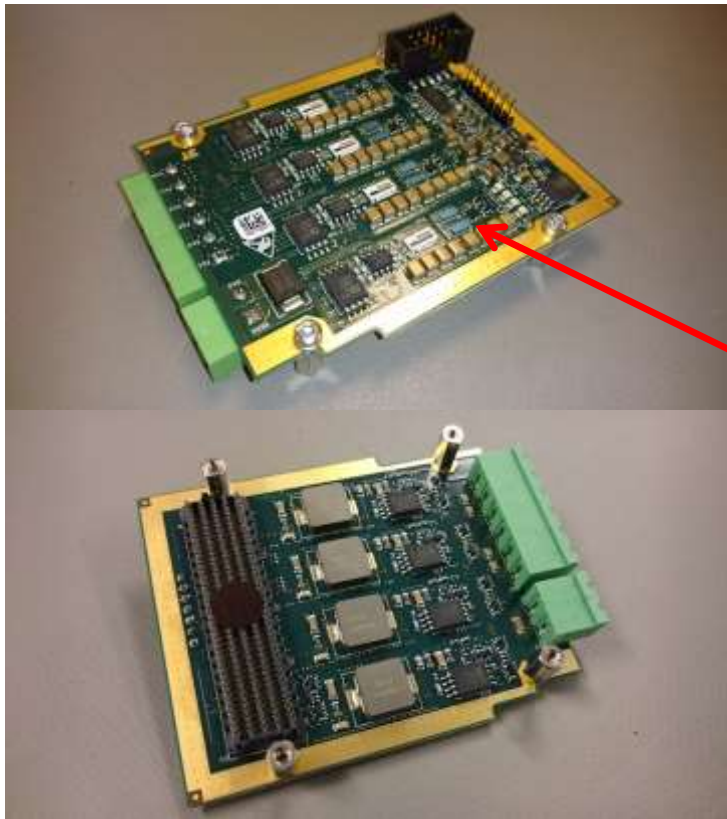
Power control application

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

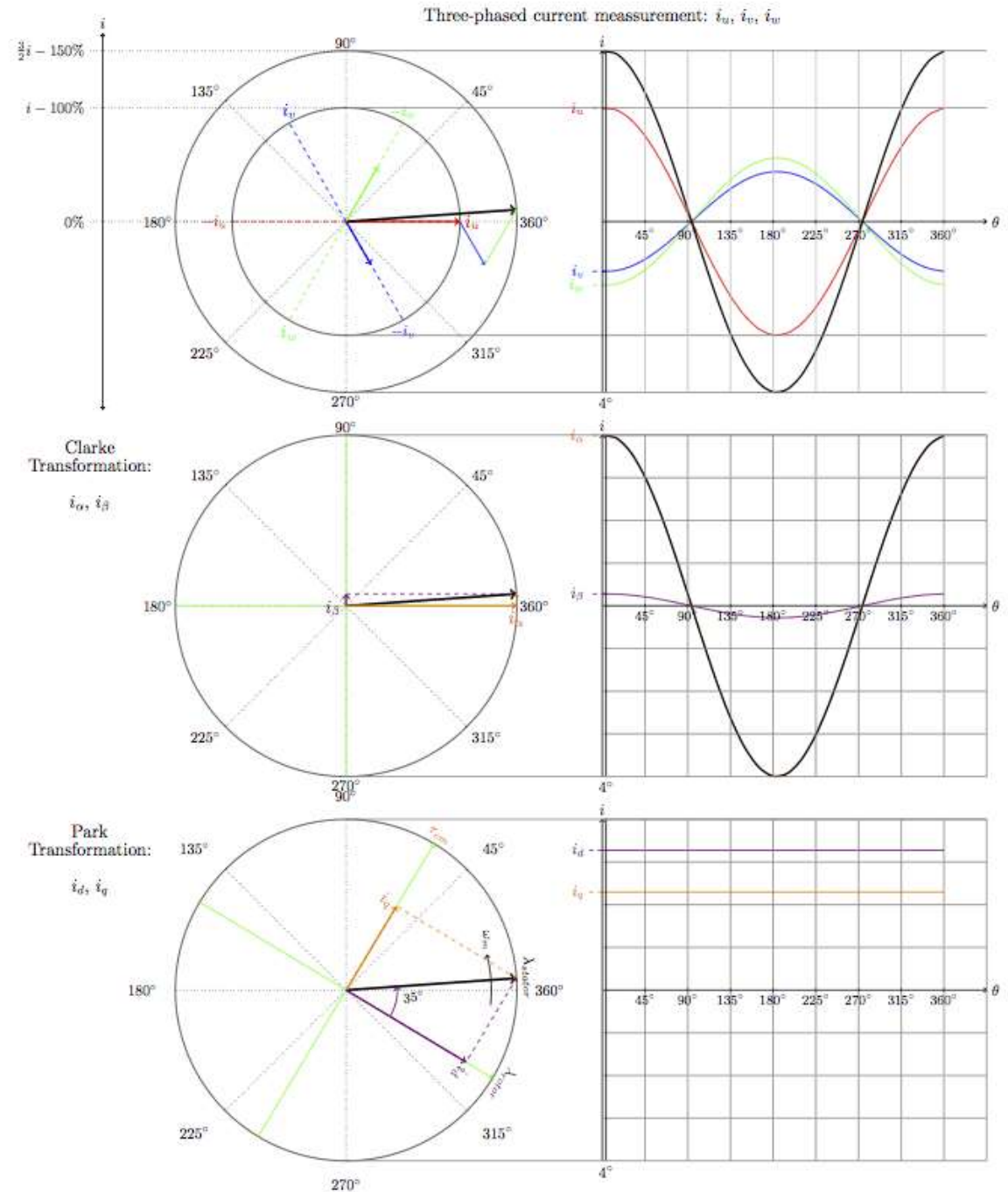
Demonstration

Speed: 3000 rpm
Flash: 50Hz

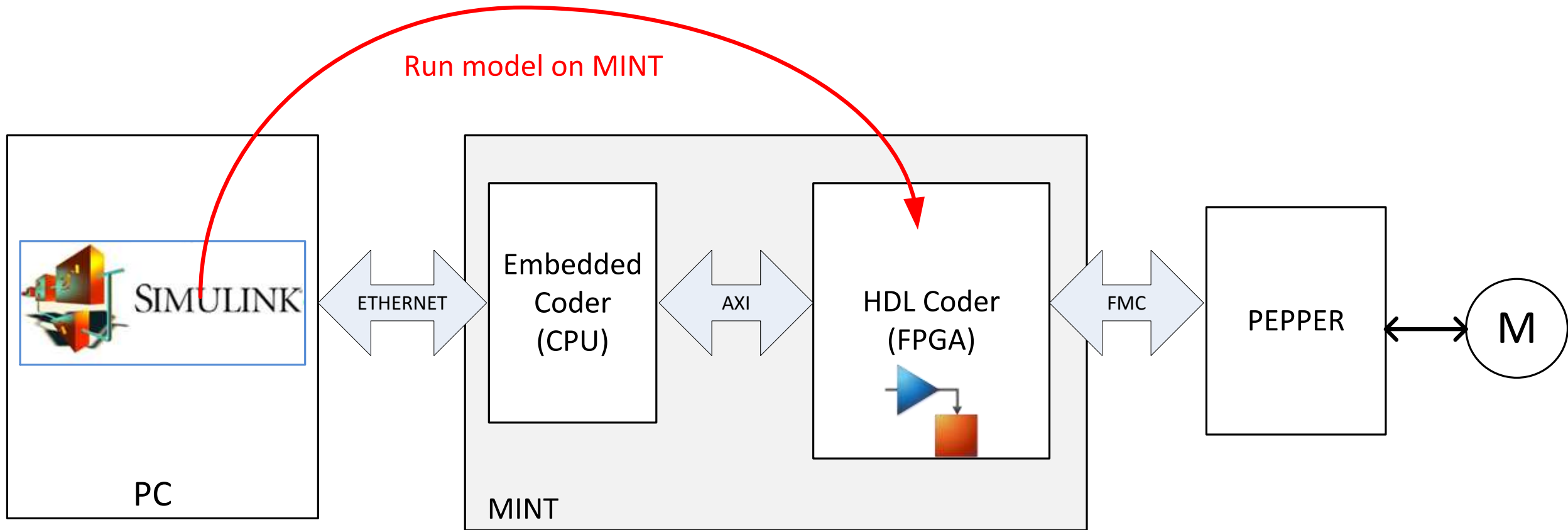


Field Oriented Control (FOC)

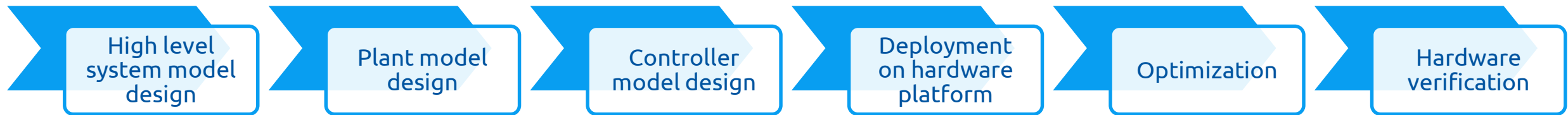
- Geometric transformations
3-phase AC to 2-phase DC
- Torque control
- No frequency dependency



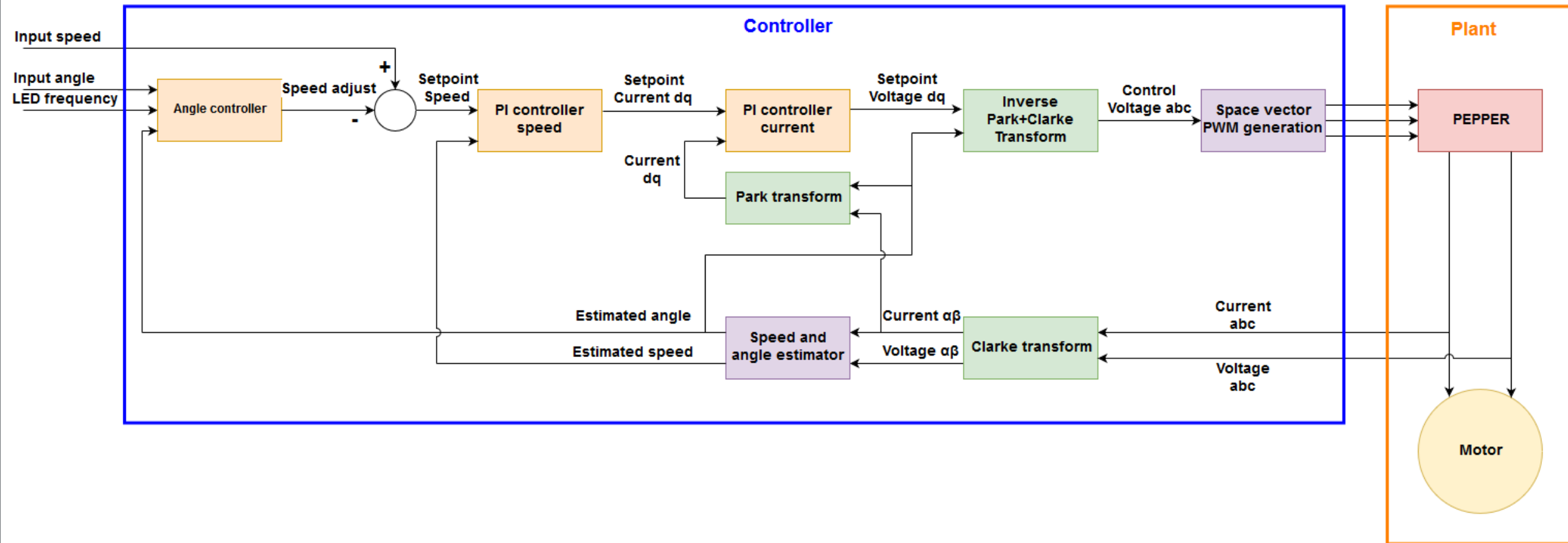
3T SoC/MINT Workflow



Model-Based Design steps



High level system model

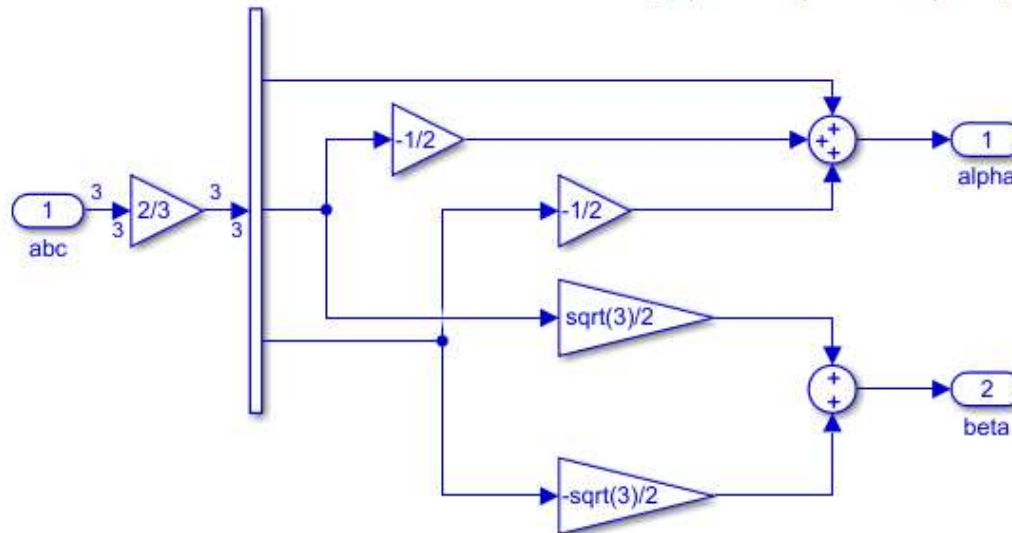


Clarke transform

Clarke transform implementation in simulink

The 0 element is omitted

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

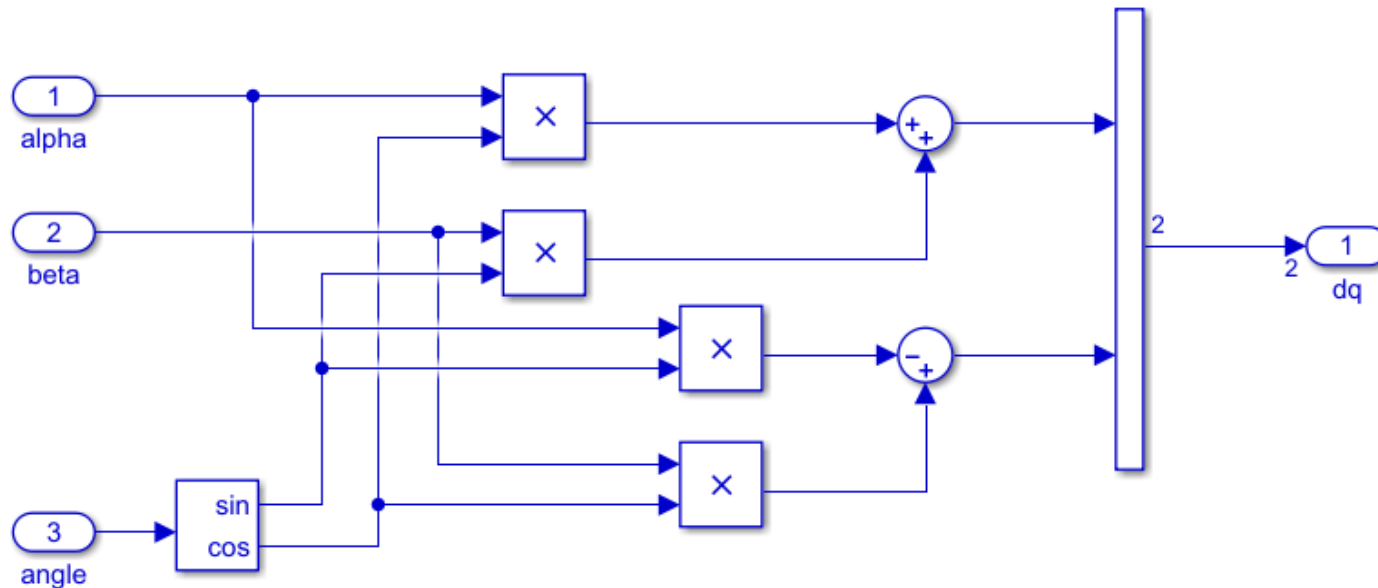


Park transform

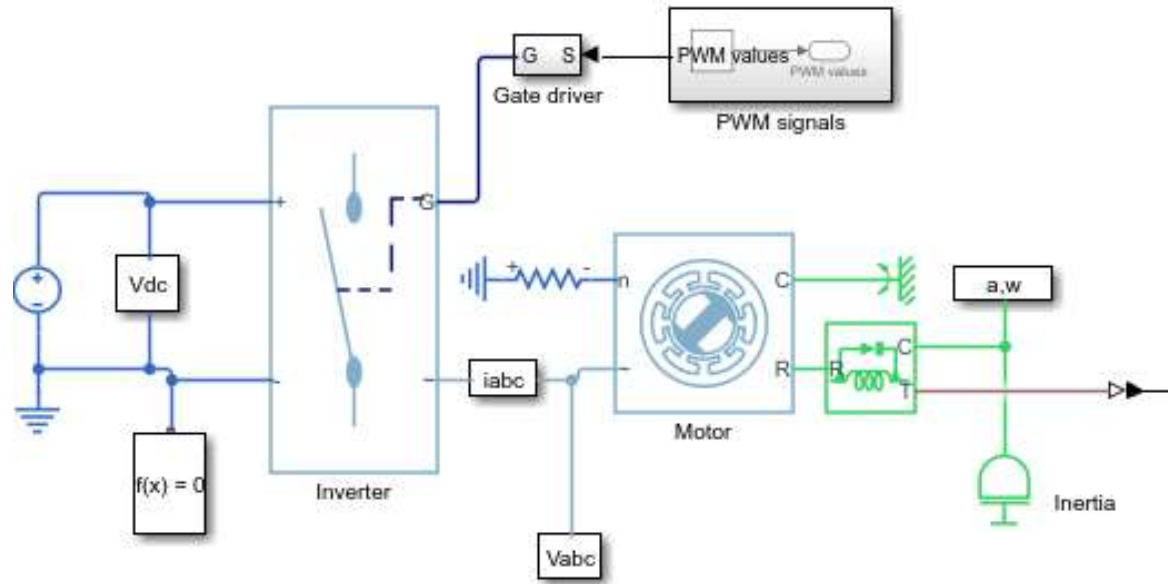
Clarke to park transform implementation in simulink

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

The 0 element is omitted



Plant



Block Parameters: Motor

Permanent Magnet Synchronous 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.

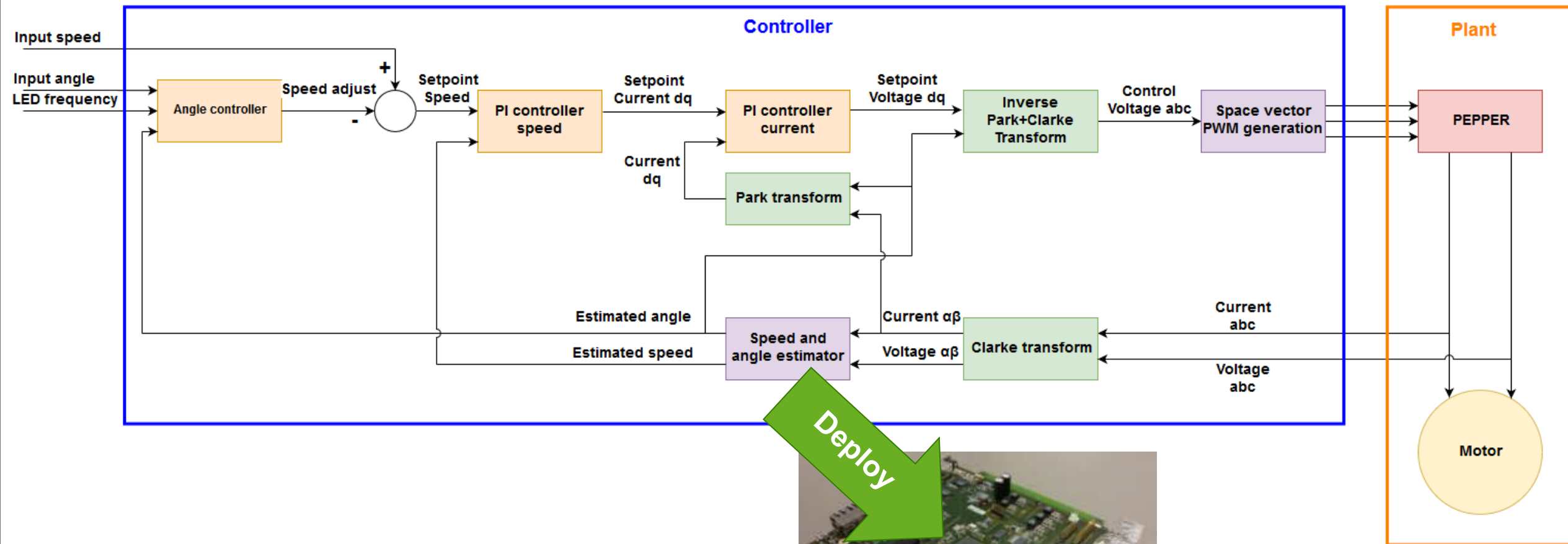
Settings

Main Mechanical Variables

Number of pole pairs:	npp	
Permanent magnet flux linkage parameterization:	Specify flux linkage	
Permanent magnet flux linkage:	pmfl	Wb
Stator parameterization:	Specify Ld, Lq, and L0	
Stator d-axis inductance, Ld:	Ld	H
Stator q-axis inductance, Lq:	Lq	H
Stator zero-sequence inductance, L0:	0.00016	H
Stator resistance per phase, Rs:	Rs	Ohm
Zero sequence:	Exclude	
Rotor angle definition:	Angle between the a-phase magnetic axis and the q-axis	

OK Cancel Help Apply

Controller | Deployment



Deployment on hardware platform

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

The screenshot shows the HDL Workflow Advisor interface for a project named 'hdlcoder_pwm_ui_demo/mint_fmc_md1'. The left sidebar displays a project tree with the following steps:

- 1. Set Target
 - ^1.1. Set Target Device and Synthesis Tool
 - ^1.2. Set Target Interface (highlighted)
- 2. Prepare Model For HDL Code Generation
- 3. HDL Code Generation
- 4. Embedded System Integration
 - 4.1. Create Project
 - 4.2. Generate Software Interface Model
 - 4.3. Build FPGA Bitstream
 - 4.4. Program Target Device

The main window displays the '1.2. Set Target Interface' configuration panel. It includes the following settings:

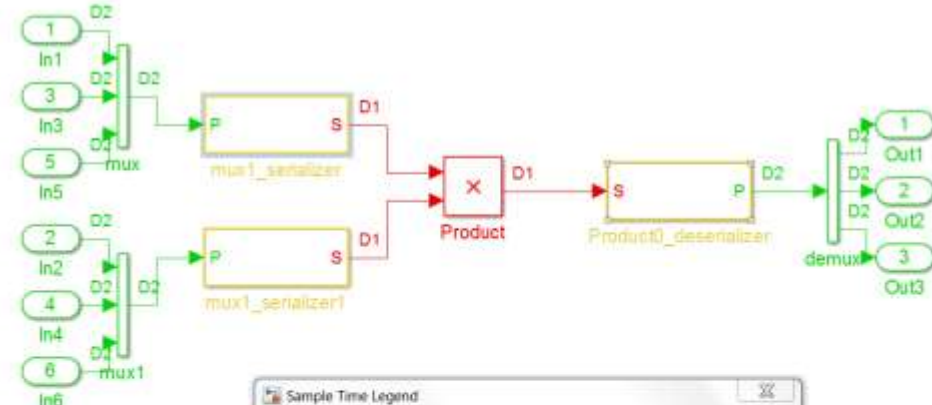
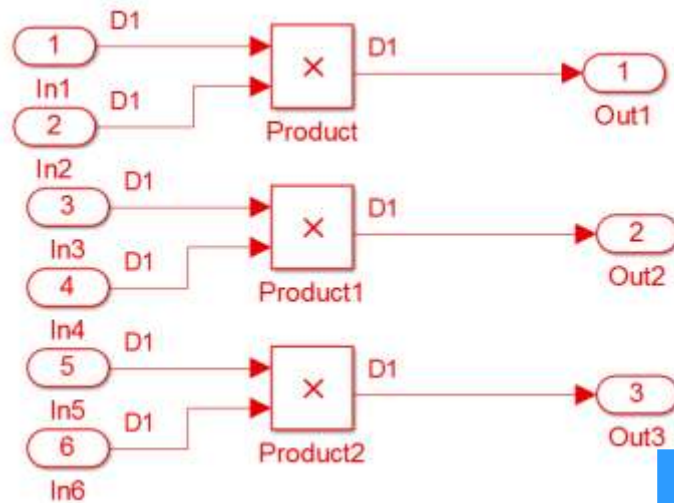
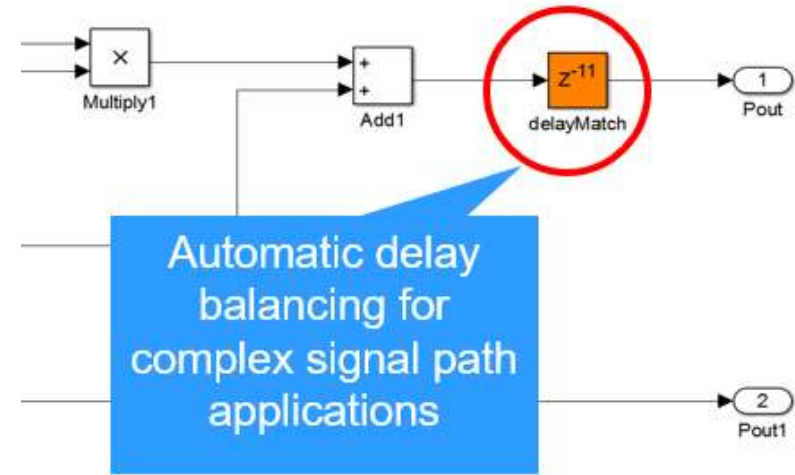
- Analysis (^Triggers Update Diagram)
- Set target interface for HDL code generation
- Input Parameters
 - Reference design: MINT+PEPPER system (Qsys 15.0)
 - Reference design path: [Browse...]
 - Processor/FPGA synchronization: Free running
- Target platform interface table

Port Name	Port Type	Data Type	Target Platform Interfaces	Bit Range
Blink_frequency	Inport	ufix4	AXI4	x*100*
Blink_direction	Inport	boolean	AXI4	x*104*
pwm_value	Inport	uint8	AXI4	x*108*
Enable_pwm	Inport	boolean	AXI4	x*10C*
LED_pepper	Inport	boolean	AXI4	x*110*
I1_in	Inport	uint16	ADC in I1 [0:15]	[0:15]
I1_in_valid	Inport	boolean	ADC in I1 valid	[0]
U1_in	Inport	uint16	ADC in U1 [0:15]	[0:15]
U1_in_valid	Inport	boolean	ADC in U1 valid	[0]
LED	Output	ufix4	LEDs General Purpose red [0:3]	[0:3]
Read_back	Output	uint8	AXI4	x*114*
PWM_1_sync	Output	boolean	PWM output ch1 sync	[0]
PWM_1_value	Output	uint8	PWM output ch1 [0:7]	[0:7]

Buttons for 'Help' and 'Apply' are located at the bottom right of the configuration panel.

HDL Coder optimizations

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



A screenshot of the HDL Coder configuration window. The 'SharingFactor' is set to 3. Other settings include 'InputPipeline' (0), 'OutputPipeline' (0), and 'StreamingFactor' (0). Buttons for 'OK', 'Cancel', 'Help', and 'Apply' are visible at the bottom.

Automatic resource sharing is a powerful feature.

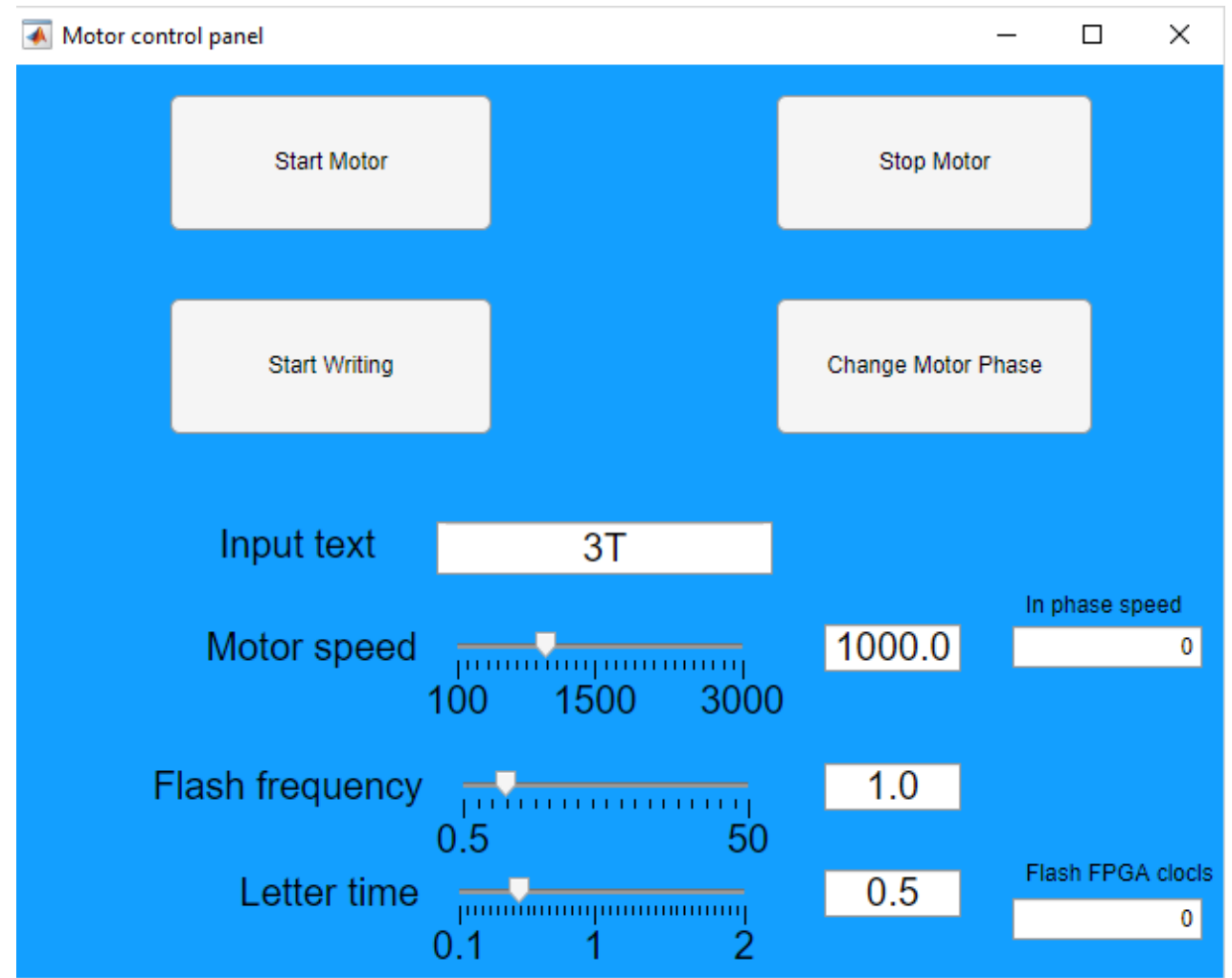
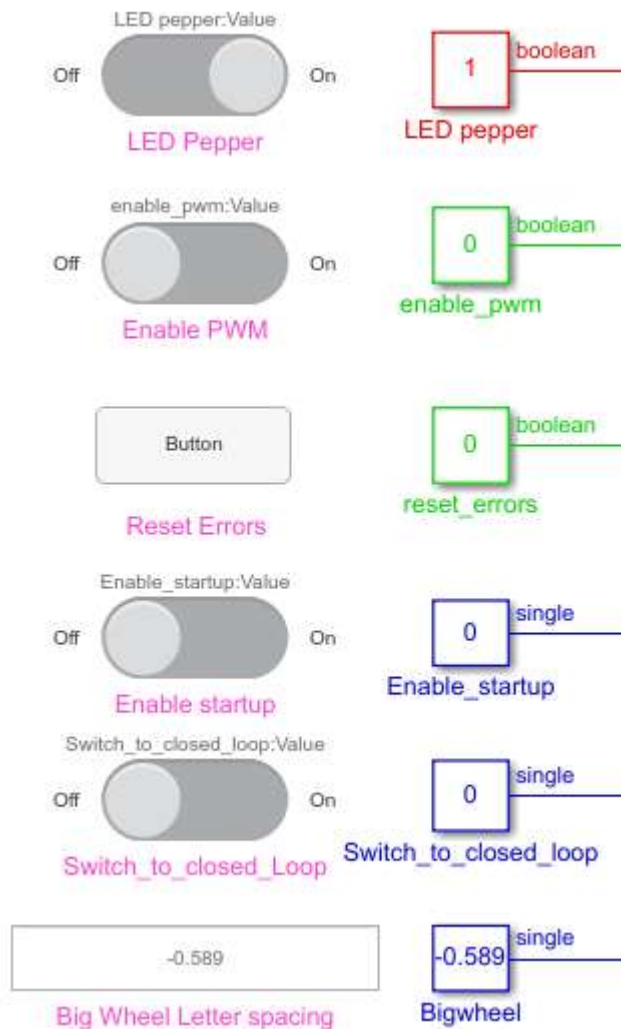
A screenshot of the 'Sample Time Legend' window. It shows a table of sample times for 'gm_share_multiplier'.

Color Annotation	Description	Value
Red	D1 Discrete 1	0.00033333
Green	D2 Discrete 2	0.001
Yellow	H Hybrid	Not Applicable

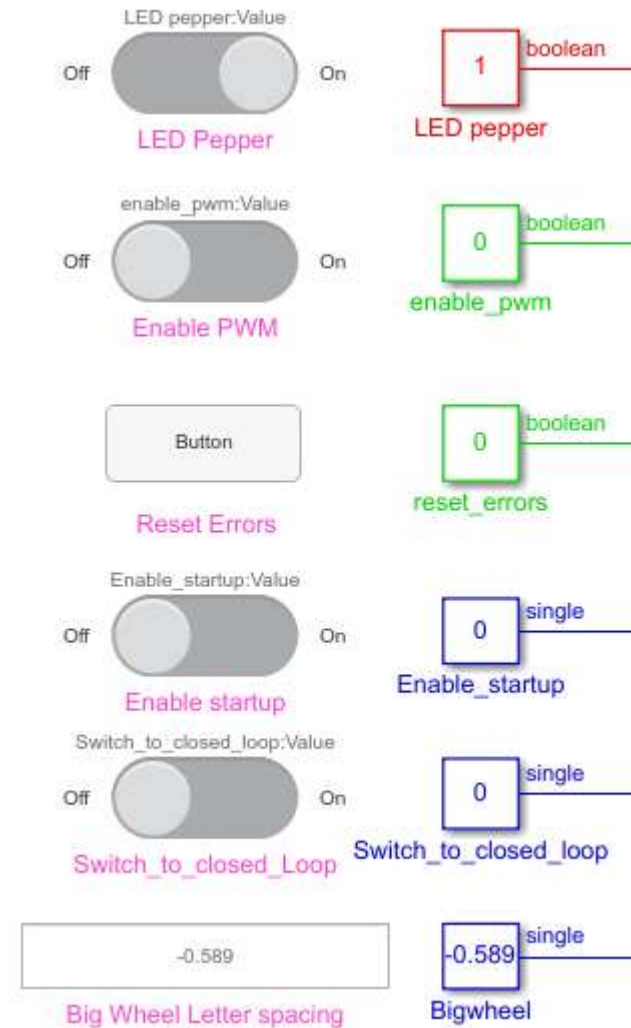
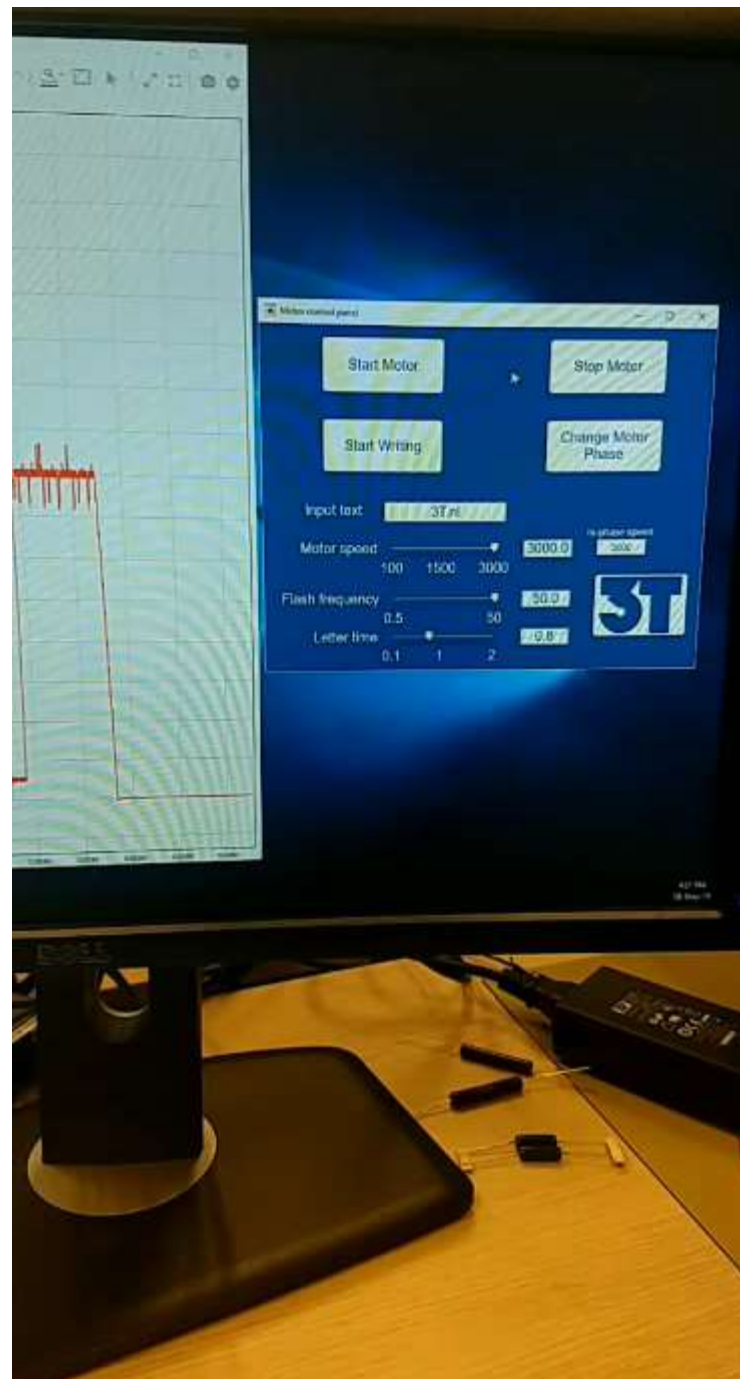
Buttons for 'Print' and 'Help' are also visible.

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



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