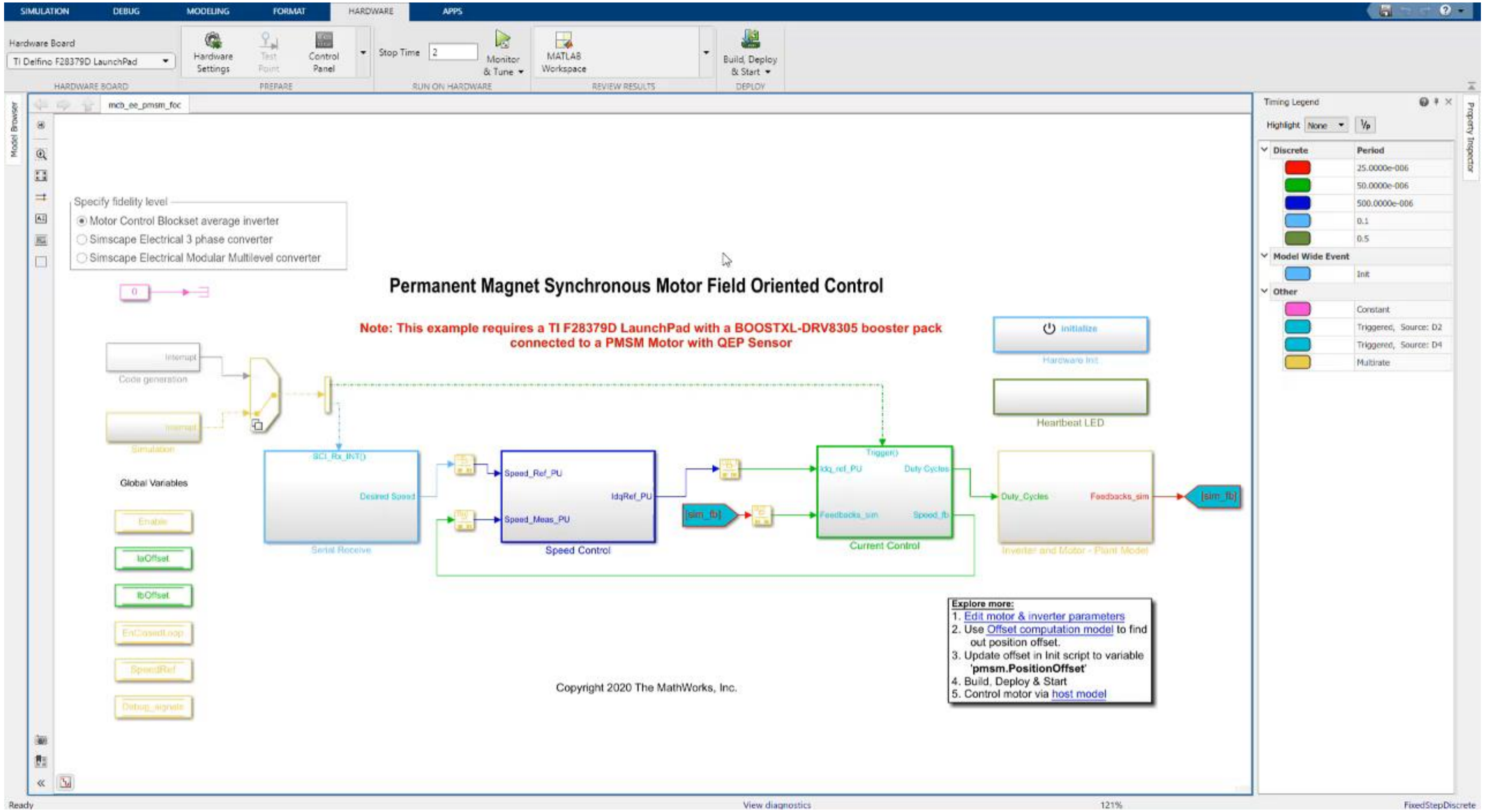
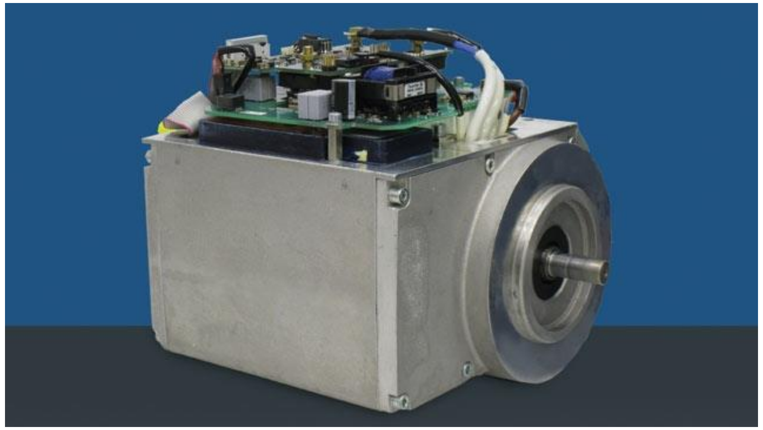
Spinning Brushless Motors with Simulink

Nukul Sehgal
Vamshi Kumbham

We will spin a brushless motor using Simulink and Model-Based Design



Brushless motors are everywhere



Developing embedded motor control software has its challenges

ITK Engineering develops IEC 62304– compliant controller for dental drill motor with Model-Based Design

Challenge
Develop and implement field-oriented controller software for sensorless brushless DC motors for use in dental drills

Solution
Use Model-Based Design with Simulink, Stateflow, and Embedded Coder to model the controller and plant, run closed-loop simulations, generate production code, and streamline unit testing

Results
- Development time halved
- Hardware problems discovered early
- Contract won, client confidence established

Dental drills featuring ITK Engineering's sensorless brushless motor control.

"Model-Based Design with Simulink enabled us to design and optimize the controller even before the motor hardware was available for testing and then generate production code for the controller once we had the motor. It would have been impossible to complete this project on schedule if we had written the code by hand."

- Michael Schwarz, ITK Engineering

Developing embedded motor control software has its challenges

- Design work needed to be started before motor hardware was available and needed extensive testing to comply with standards

- Team needed to rapidly implement control software on embedded processor once more hardware became available

- Complex algorithms running at high sample rates were difficult to implement in short amount of time

ITK Engineering develops IEC 62304– compliant controller for dental drill motor with Model-Based Design

Challenge
Develop and implement field-oriented controller software for sensorless brushless DC motors for use in dental drills

Solution
Use Model-Based Design with Simulink, Stateflow, and Embedded Coder to model the controller and plant, run closed-loop simulations, generate production code, and streamline unit testing

Results
- Development time halved
- Hardware problems discovered early
- Contract won, client confidence established

Dental drills featuring ITK Engineering's sensorless brushless motor control.

"Model-Based Design with Simulink enabled us to design and optimize the controller even before the motor hardware was available for testing and then generate production code for the controller once we had the motor. It would have been impossible to complete this project on schedule if we had written the code by hand."

- Michael Schwarz, ITK Engineering

Why Simulink for motor control?

- Verify control algorithm with desktop simulation

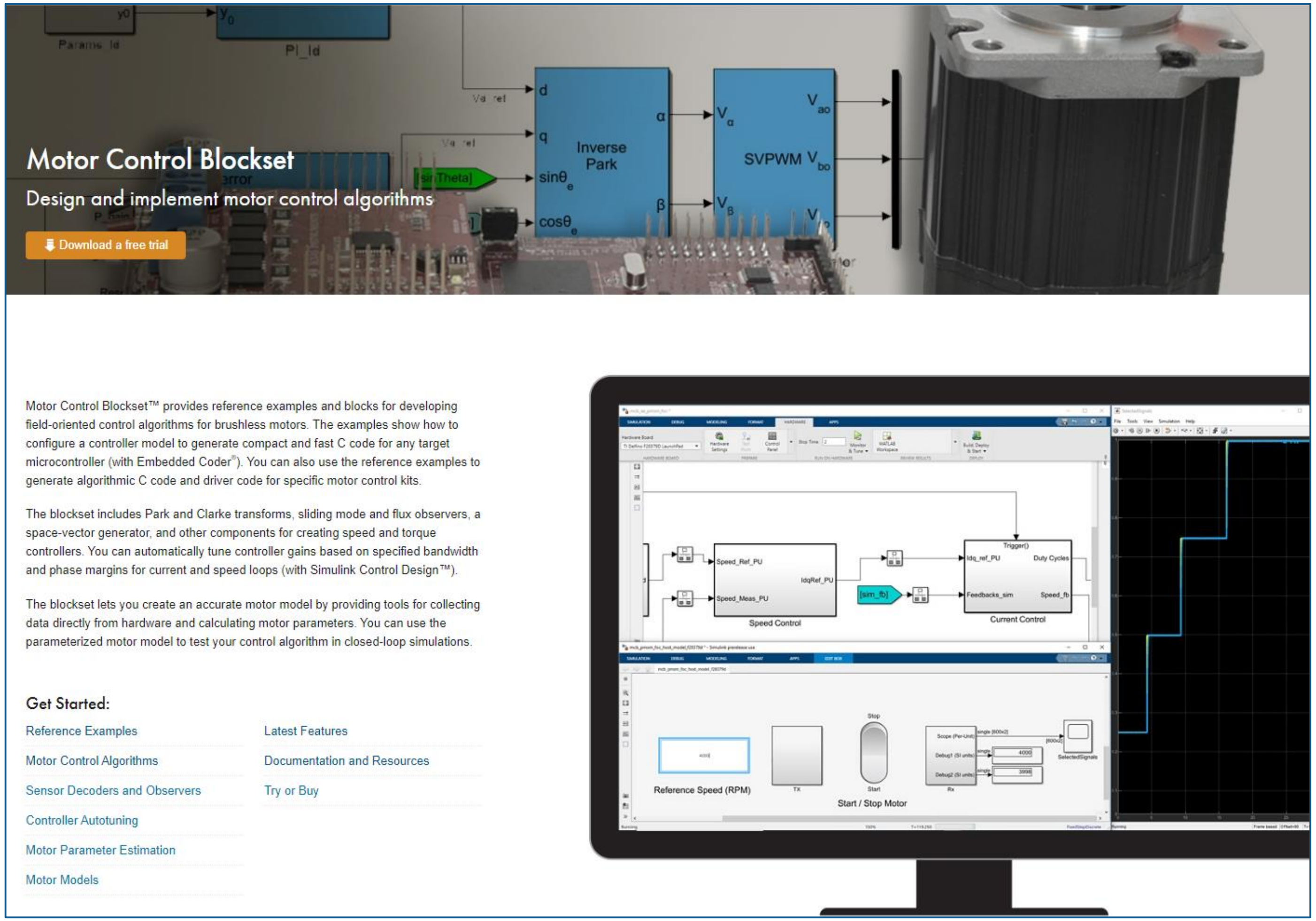
- Generate compact and fast code from models

- Minimize development time using reference examples

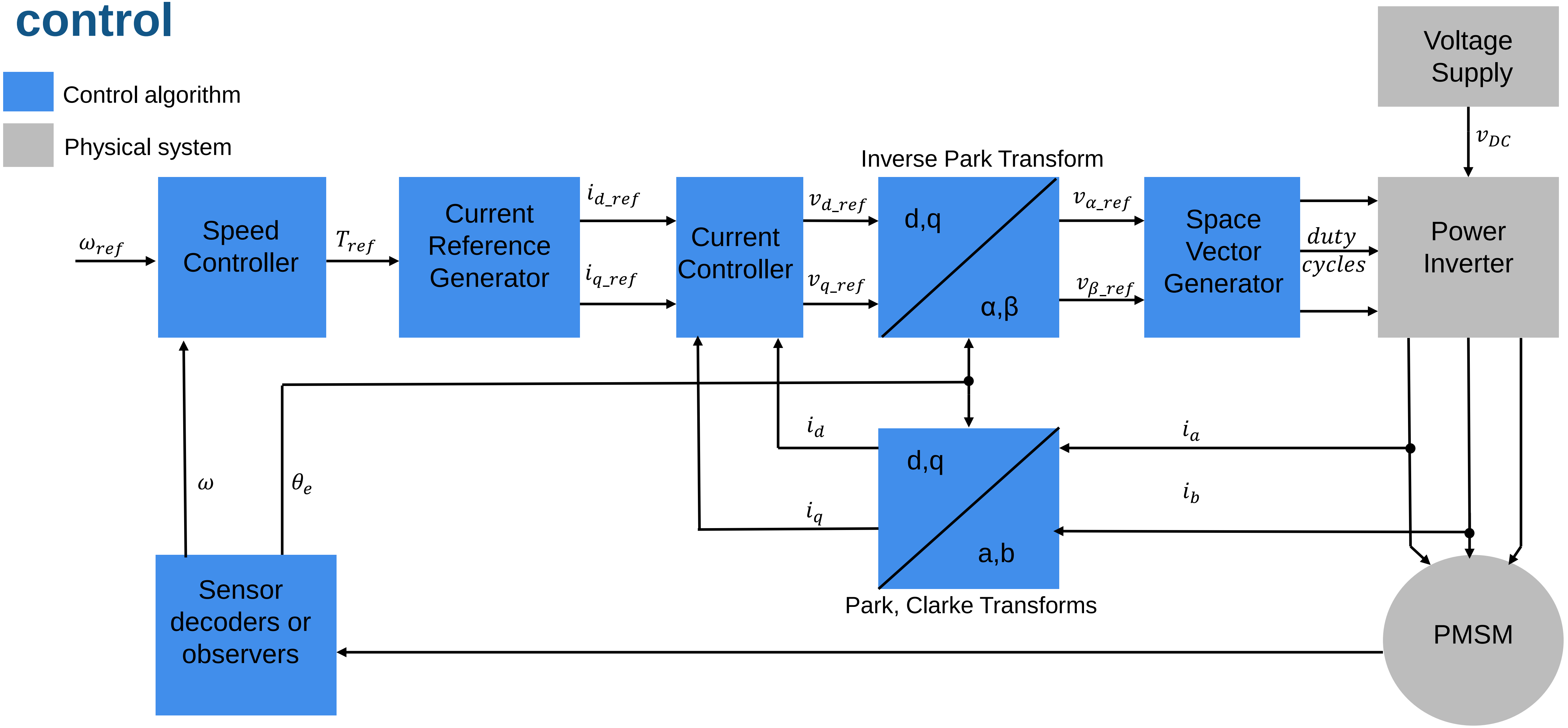
Customers routinely report 50% faster time to market

Motor Control Blockset simplifies the workflow

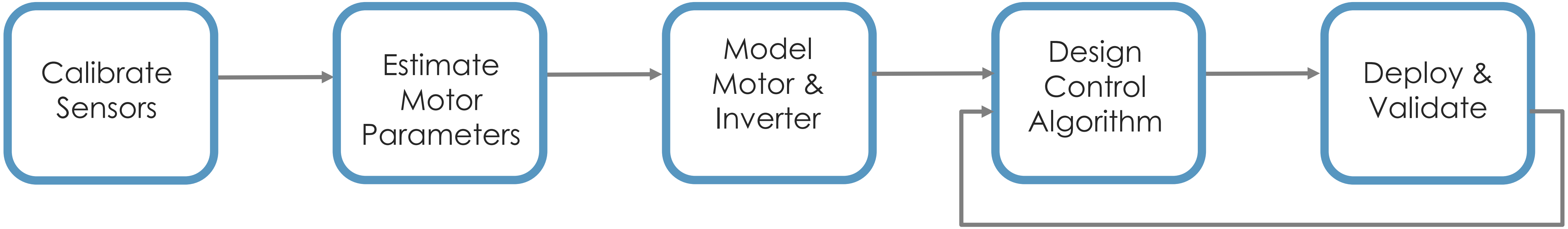
- Control blocks optimized for code generation
- Sensor decoders and observers
- Motor parameter estimation
- Controller autotuning
- Reference examples



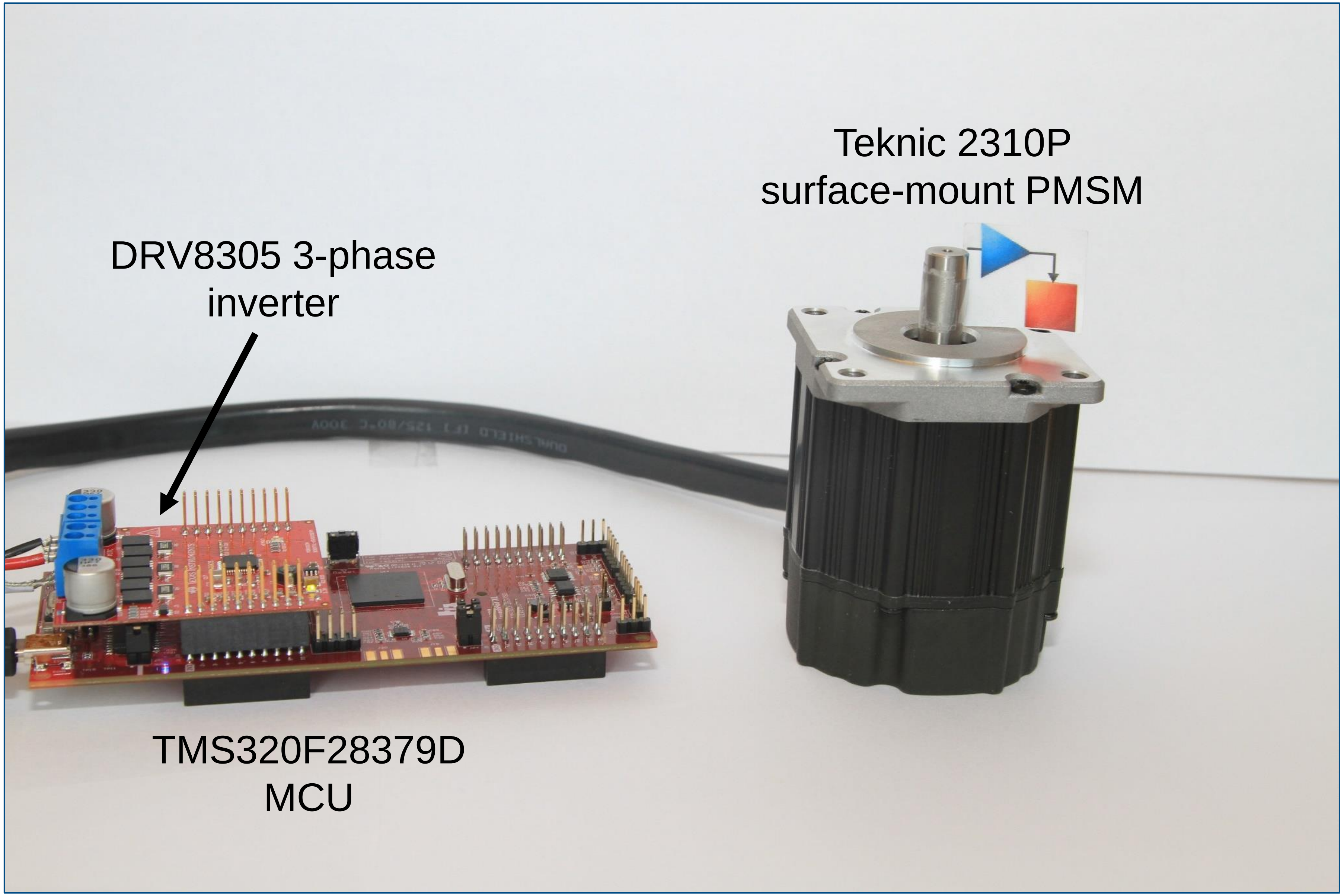
Brushless motors require complex algorithms – field-oriented control



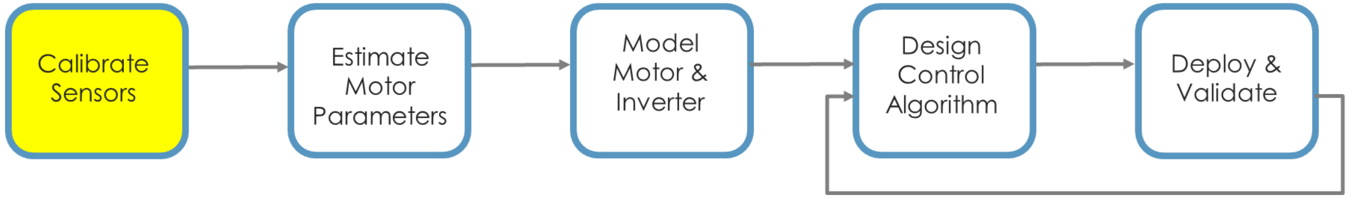
Workflow for implementing field-oriented control



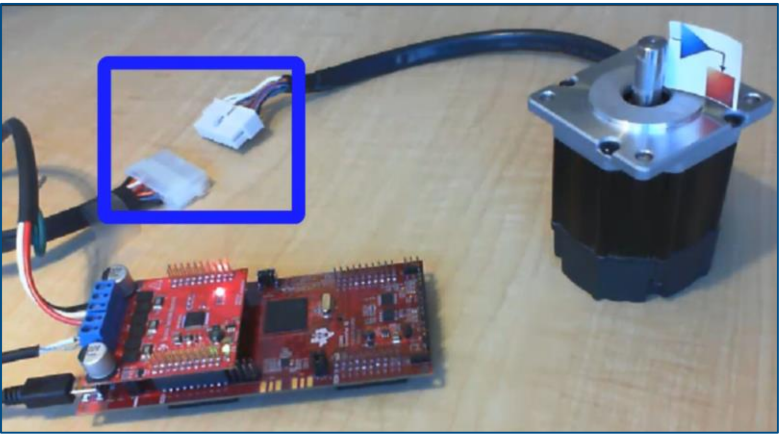
We will use Texas Instruments motor control kit

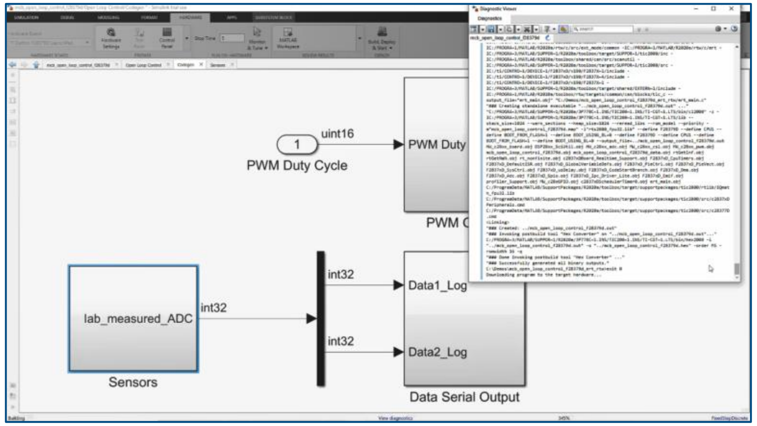


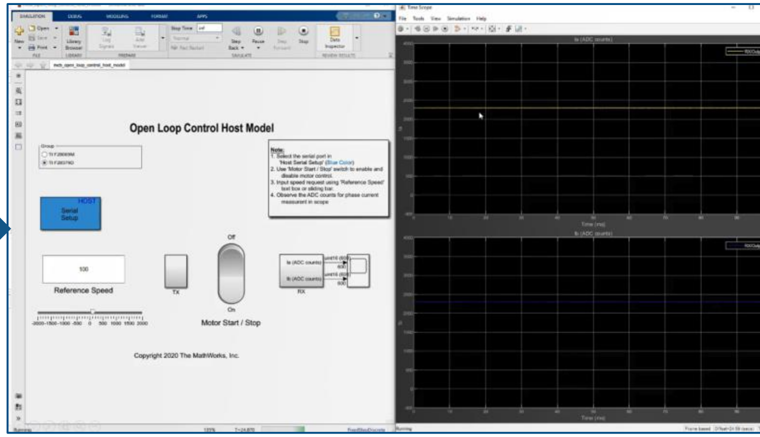
Sensor calibration

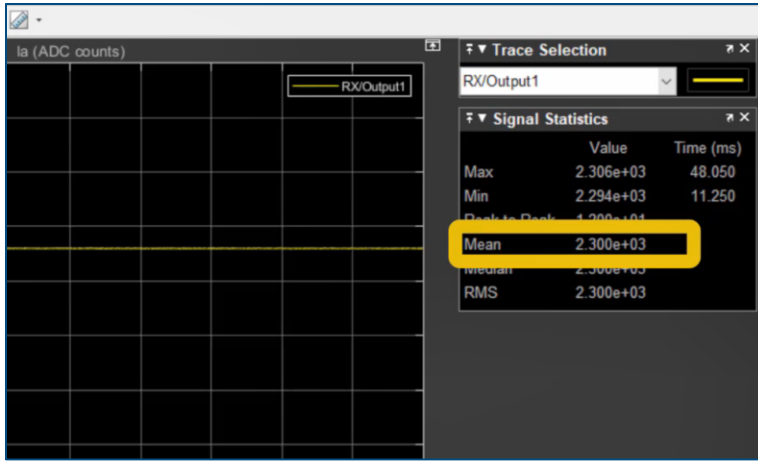


- Calibrate ADC offsets



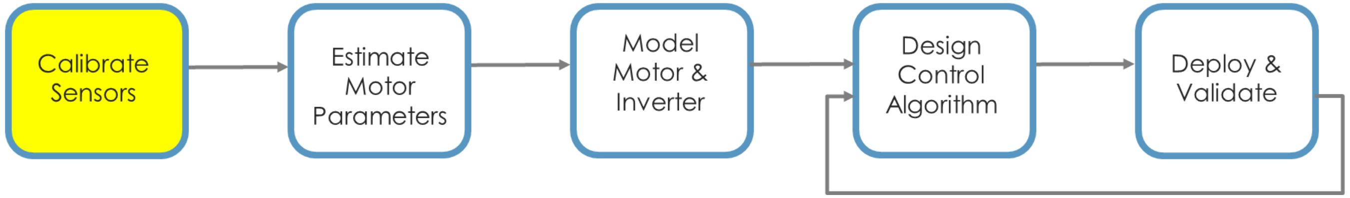






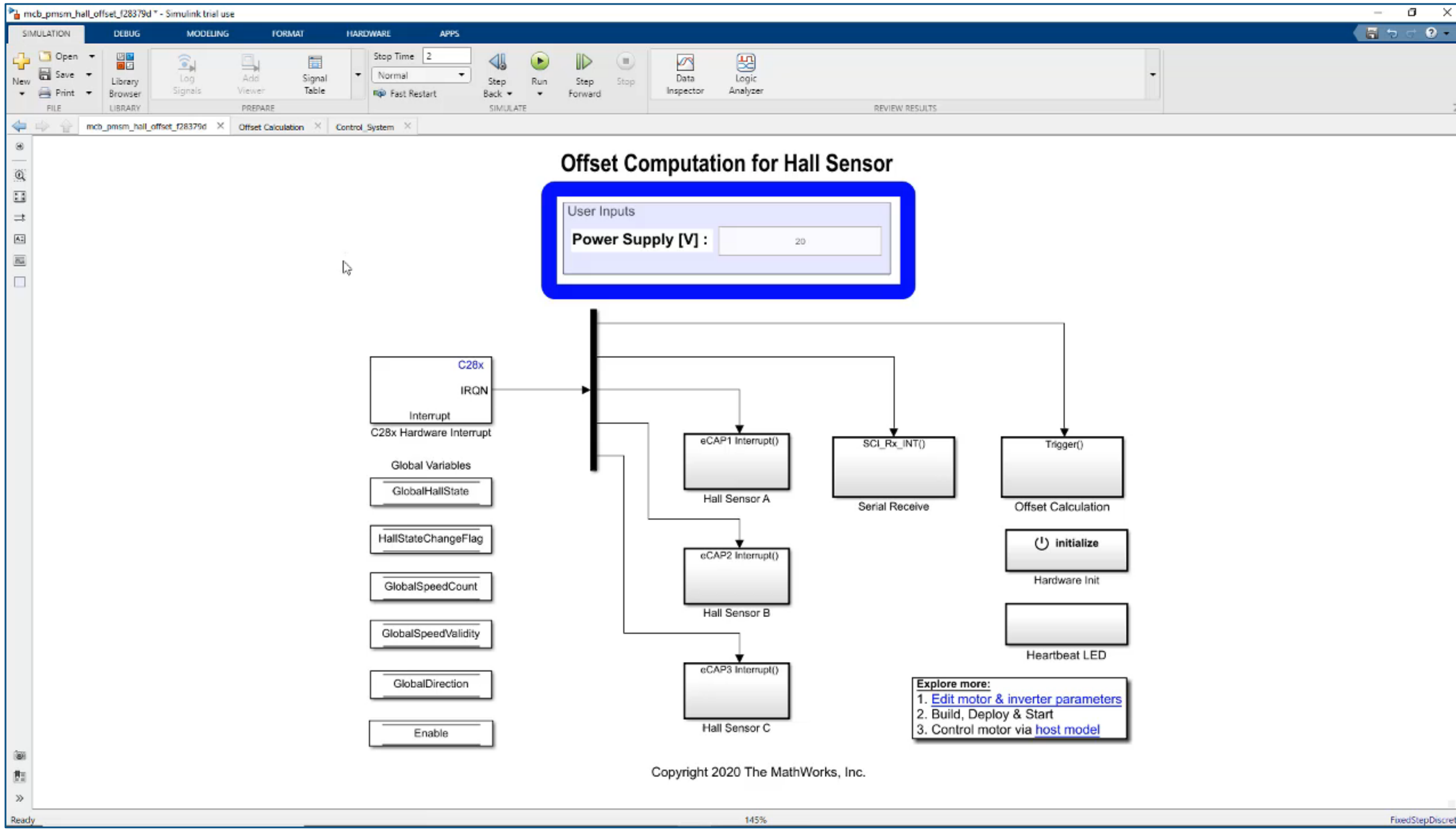

```
case 'BoostXL-DRV8305'
    inverter.model          = 'BoostXL-DRV8305';% M
    inverter.sn             = 'INV_XXXX';           %
    inverter.V_dc           = 24;       %V          //
    inverter.I_max          = 19.3;     %Amps       //
    inverter.I_trip         = 10;       %Amps       //
    inverter.Rds_on         = 2e-3;     %Ohms       //
    inverter.Rshunt         = 0.007;    %Ohms       //
    inverter.MaxADCCnt      = 4095;     %Counts     //
    inverter.CtSensAOffset  = 2300;        %Counts
    inverter.CtSensBOffset  = 2303;        %Counts
    inverter.ADCGain        = 1;        %           //
```

Sensor calibration

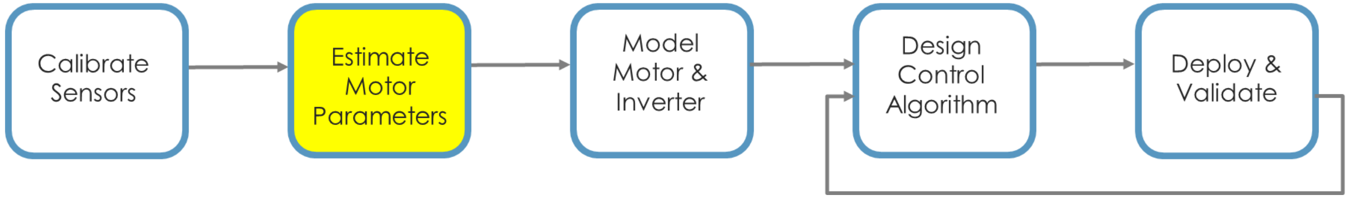


- Calibrate ADC offsets

- Calibrate position sensor offset

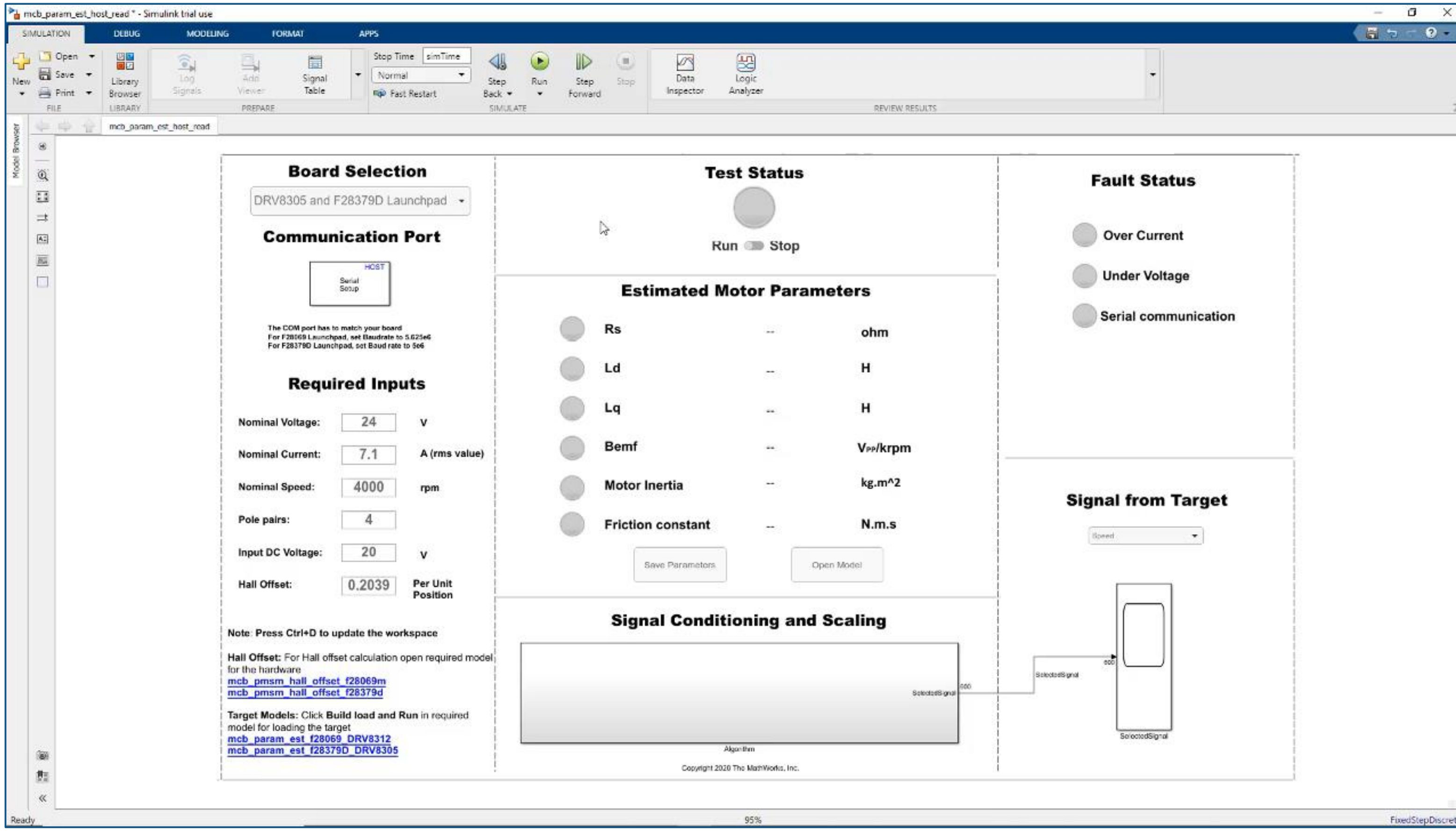


Parameter estimation

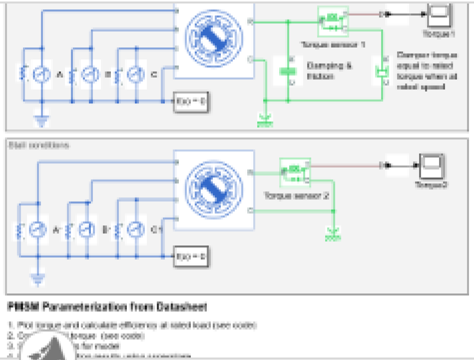


- Instrumented tests running on the target

- Host model to start and control parameter estimation



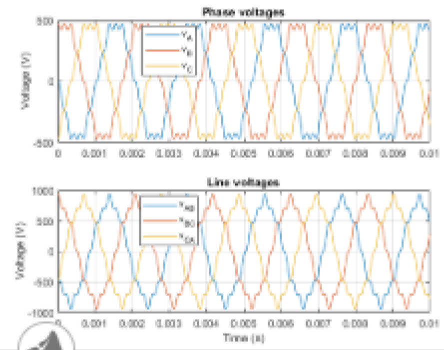
Bonus: you can use other techniques to parameterize motor models



PMSM Parameterization from Datasheet

Two test harnesses that add confidence that a PMSM is correctly parameterized from a datasheet. It also calculates motor efficiency at

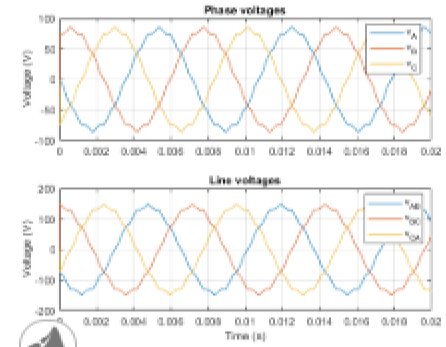
Open Model



Import IPMSM Flux Linkage Data from ANSYS Maxwell

Import a motor design from ANSYS® Maxwell® into a Simscape™ simulation.

Open Model



Import IPMSM Flux Linkage Data from Motor-CAD

Import a motor design from Motor-CAD into a Simscape™ simulation.

Open Model

Generate Parameters for Flux-Based PMSM Block

Using MathWorks tools, you can create lookup tables for an interior permanent magnet synchronous motor (PMSM) controller that characterizes the *d*-axis and *q*-axis current as a function of *d*-axis and *q*-axis flux.

To generate the flux parameters for the Flux-Based PMSM block, follow these workflow steps. Example script `CreatingIdqTable.m` calls `gridfit` to model the current surface using scattered or semi-scattered flux data.

Workflow	Description
Step 1: Load and Preprocess Data	Load and preprocess this nonlinear motor flux data from dynamometer testing or finite element analysis (FEA): • *d*- and *q*- axis current • *d*- and *q*- axis flux • Electromagnetic motor torque
Step 2: Generate Evenly Spaced Table Data From Scattered Data	Use the `gridfit` function to generate evenly spaced data. Visualize the flux surface plots.
Step 3: Set Block Parameters	Set workspace variables that you can use for the Flux-Based PM Controller block parameters.

From datasheet

Simscape Electrical

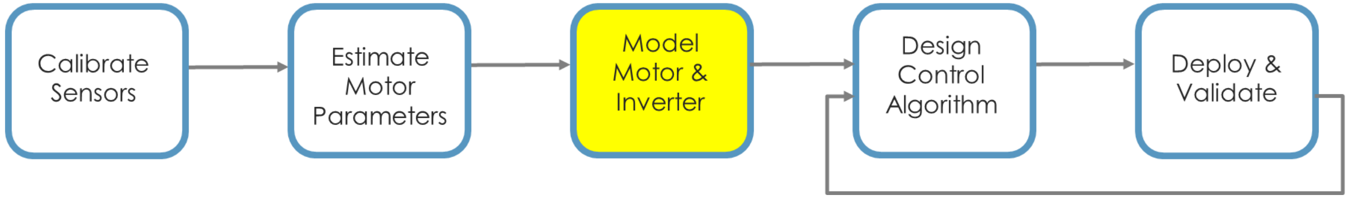
From ANSYS Maxwell, JMAG, Motor-CAD FEA tools

Simscape Electrical

From dyno data

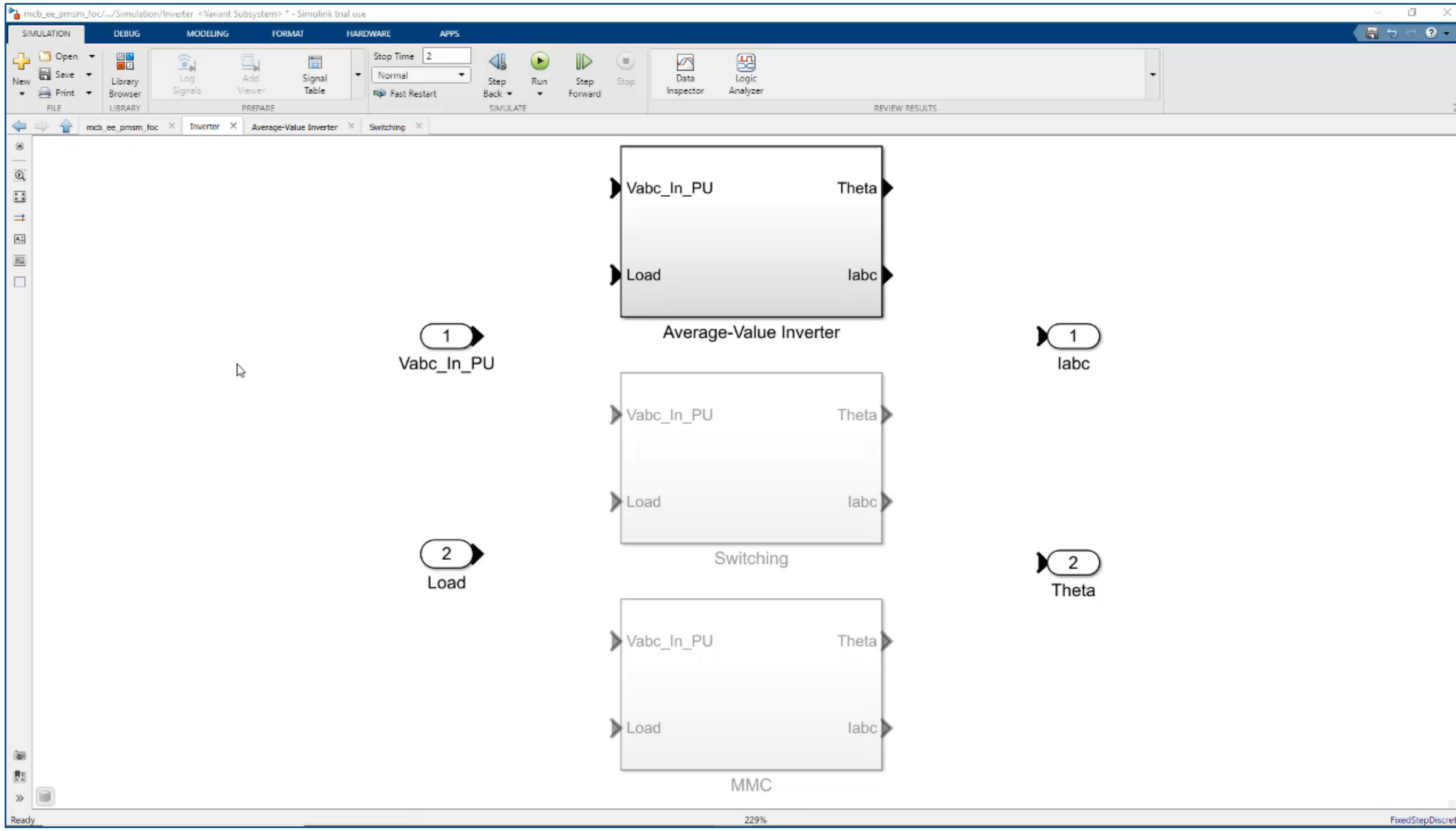
Powertrain Blockset

Modeling motor and inverter

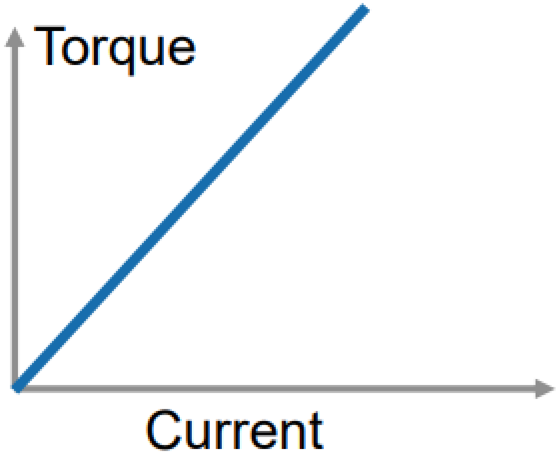


- Use linear lumped-parameter motor model

- Model inverter as an average-value inverter or model switching with Simscape Electrical

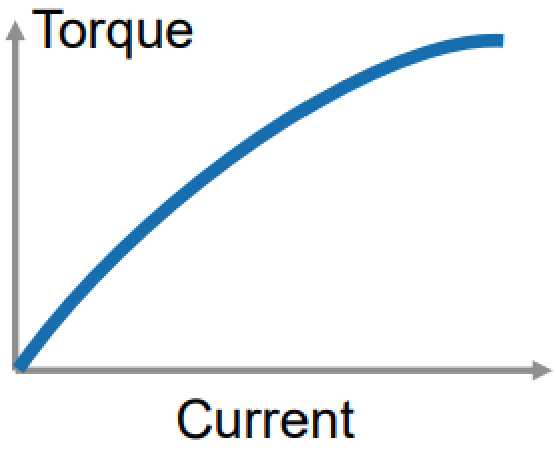


Bonus: you can model at needed level of fidelity



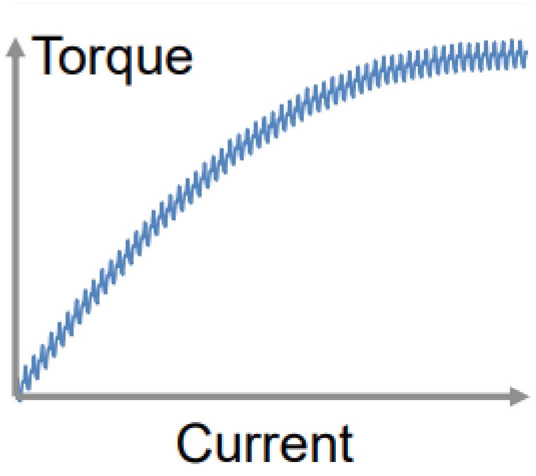
Lumped Parameter

Motor Control Blockset
Simscape Electrical



Saturation

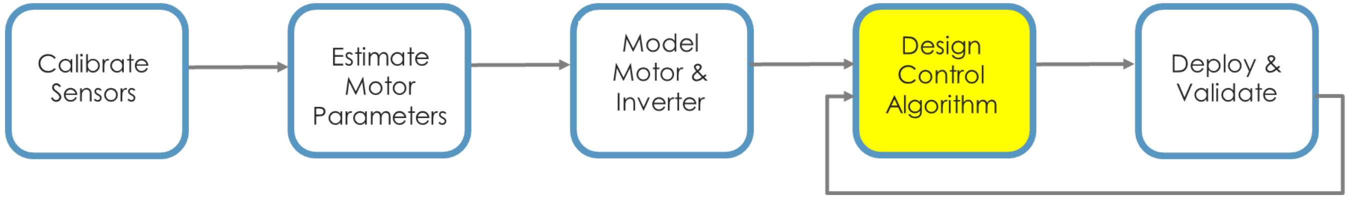
Simscape Electrical



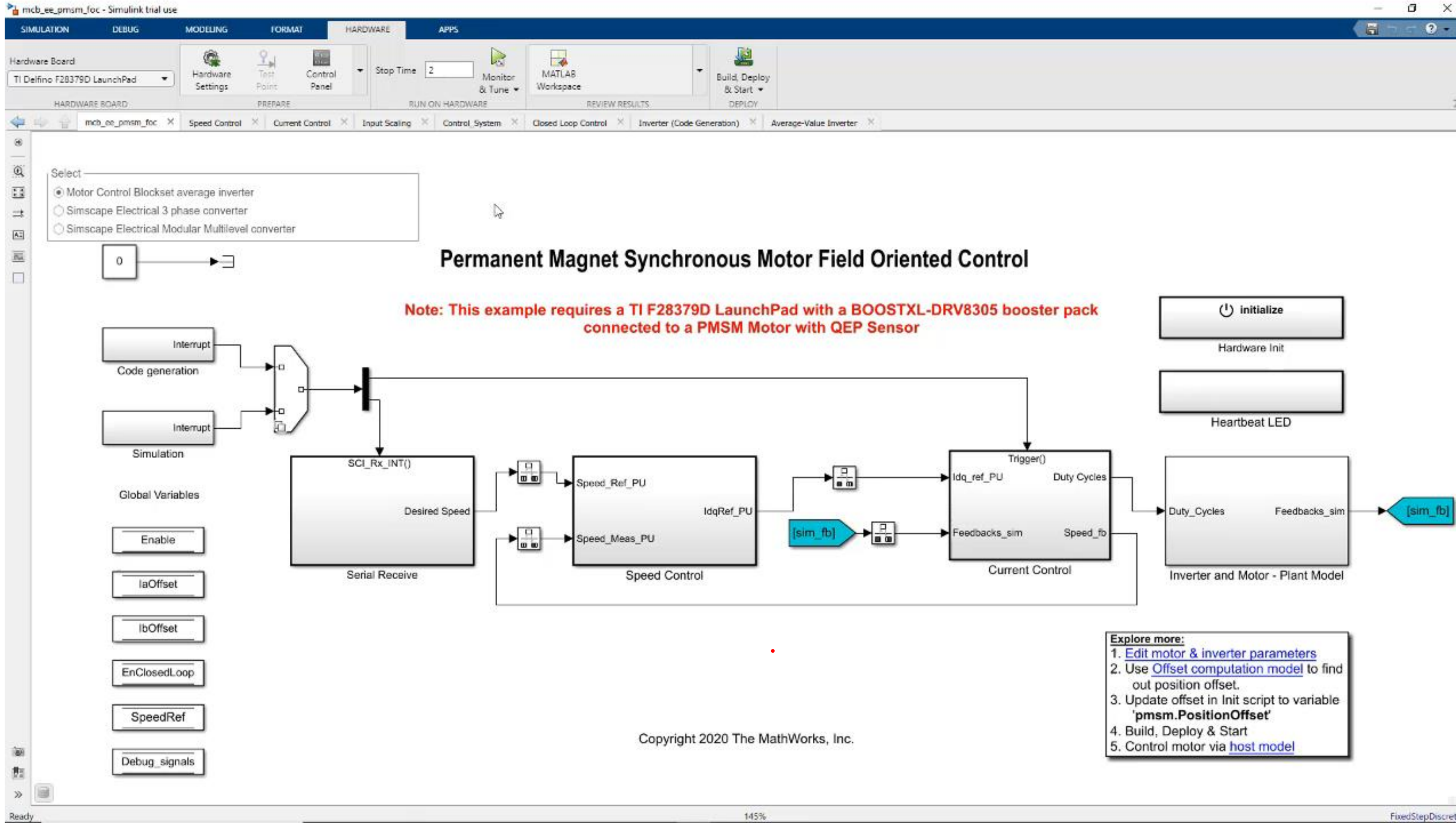
Saturation +
Spatial Harmonics

Simscape Electrical

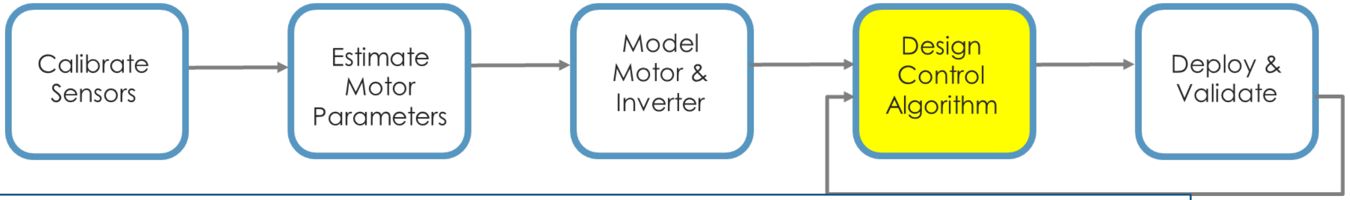
Control algorithm design



- Model field-oriented control algorithm
- Model sensor decoders or sensorless observers
- Tune loop gains
- Verify in closed-loop simulation



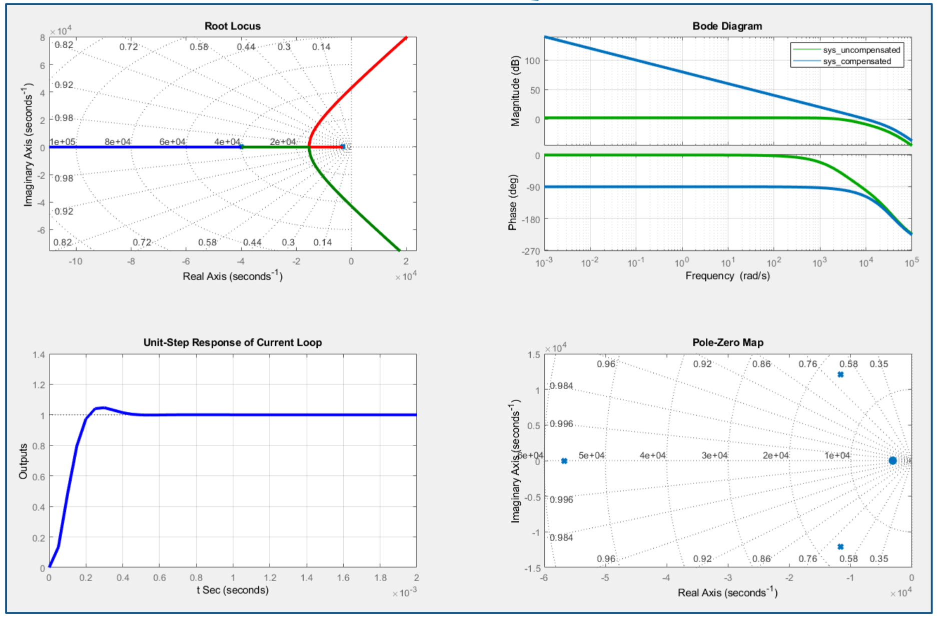
Control algorithm design




```
%% Controller design // Get ballpark values!

PI_params = mcb.internal.SetControllerParameters(pmsm,inverter,PU_System,T_pwm,Ts,Ts_speed);

%Updating delays for simulation
PI_params.delay_Currents    = int32(Ts/Ts_simulink);
PI_params.delay_Position    = int32(Ts/Ts_simulink);
PI_params.delay_Speed       = int32(Ts_speed/Ts_simulink);
PI_params.delay_Speed1      = (PI_params.delay_IIR + 0.5*Ts)/Ts_speed;
mcb_getControlAnalysis(pmsm,inverter,PU_System,PI_params,Ts,Ts_speed);
```

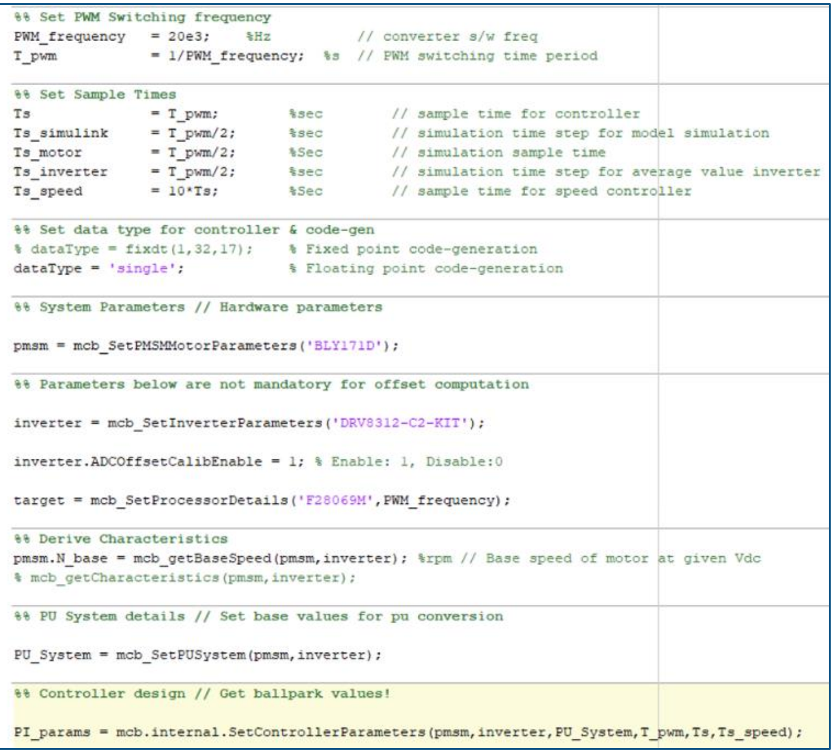
- Model field-oriented control algorithm
- Model sensor decoders or sensorless observers
- Tune loop gains
- Verify in closed-loop simulation

Field	Value
T1	5.0000e-05
T2	5.0000e-04
sigma	5.0000e-05
Ti_i	3.1922e-04
Ti_id	3.3273e-04
damping	0.7071
Kp_i	2.5778
Ki_i	8.0752e+03
Kp_id	2.6869
Ki_id	8.0752e+03
Ki_texas	0.1566
Ki_d_texas	0.1503
delta	0.0263
delay_IIR	0.0200
x	1.2000
Ti_speed	0.0378
Kp_speed	0.9231
Ki_speed	24.4215

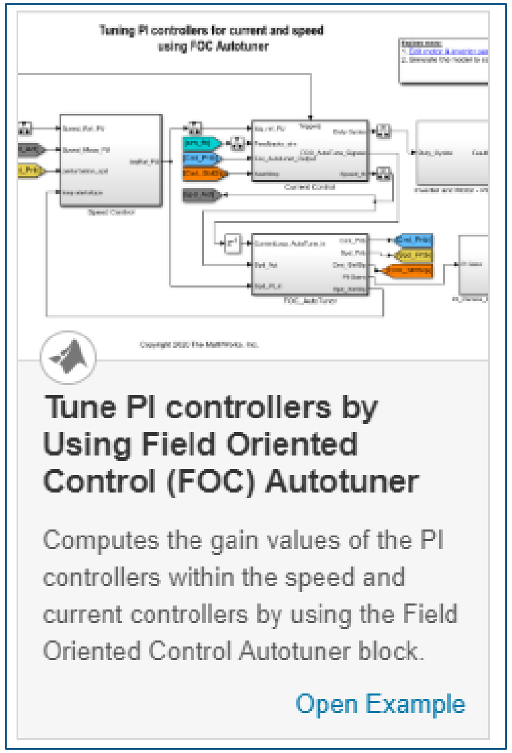


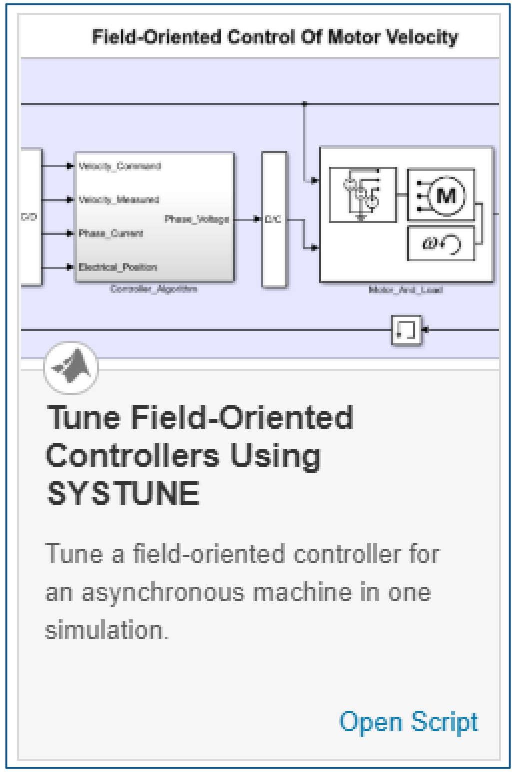
Control System Toolbox

Bonus: you can use several techniques to tune loop gains



```
%% Set PWM Switching frequency
PWM_frequency   = 20e3;    %Hz          // converter s/w freq
T_pwm           = 1/PWM_frequency;  %s  // PWM switching time period

%% Set Sample Times
Ts              = T_pwm;        %sec        // sample time for controller
Ts_simulink     = T_pwm/2;      %sec        // simulation time step for model simulation
Ts_motor        = T_pwm/2;      %Sec        // simulation sample time
Ts_inverter     = T_pwm/2;      %sec        // simulation time step for average value inverter
Ts_speed        = 10*Ts;        %Sec        // sample time for speed controller

%% Set data type for controller & code-gen
% dataType = fixdt(1,32,17);    % Fixed point code-generation
dataType = 'single';            % Floating point code-generation

%% System Parameters // Hardware parameters

pmsm = mcb_SetPMSMMotorParameters('BLY171D');

%% Parameters below are not mandatory for offset computation

inverter = mcb_SetInverterParameters('DRV8312-C2-KIT');

inverter.ADCOffsetCalibEnable = 1; % Enable: 1, Disable:0

target = mcb_SetProcessorDetails('F28069M',PWM_frequency);

%% Derive Characteristics
pmsm.N_base = mcb_getBaseSpeed(pmsm,inverter); %rpm // Base speed of motor at given Vdc
% mcb_getCharacteristics(pmsm,inverter);

%% PU System details // Set base values for pu conversion

PU_System = mcb_SetPUSystem(pmsm,inverter);

%% Controller design // Get ballpark values!

PI_params = mcb.internal.SetControllerParameters(pmsm,inverter,PU_System,T_pwm,Ts,Ts_speed);
```





Empirical Computation

Motor Control Blockset

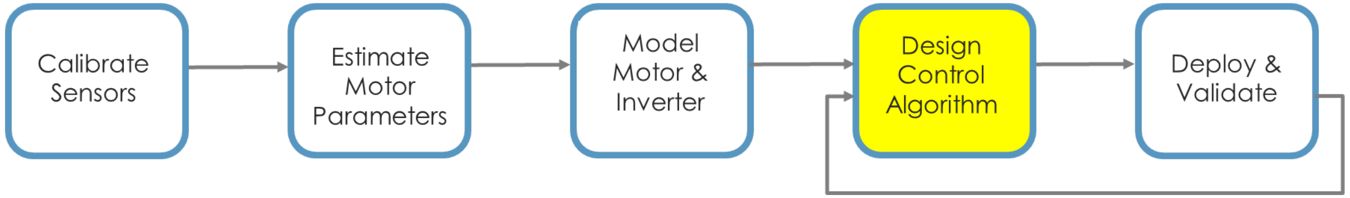
FOC Autotuner

Motor Control Blockset and Simulink Control Design

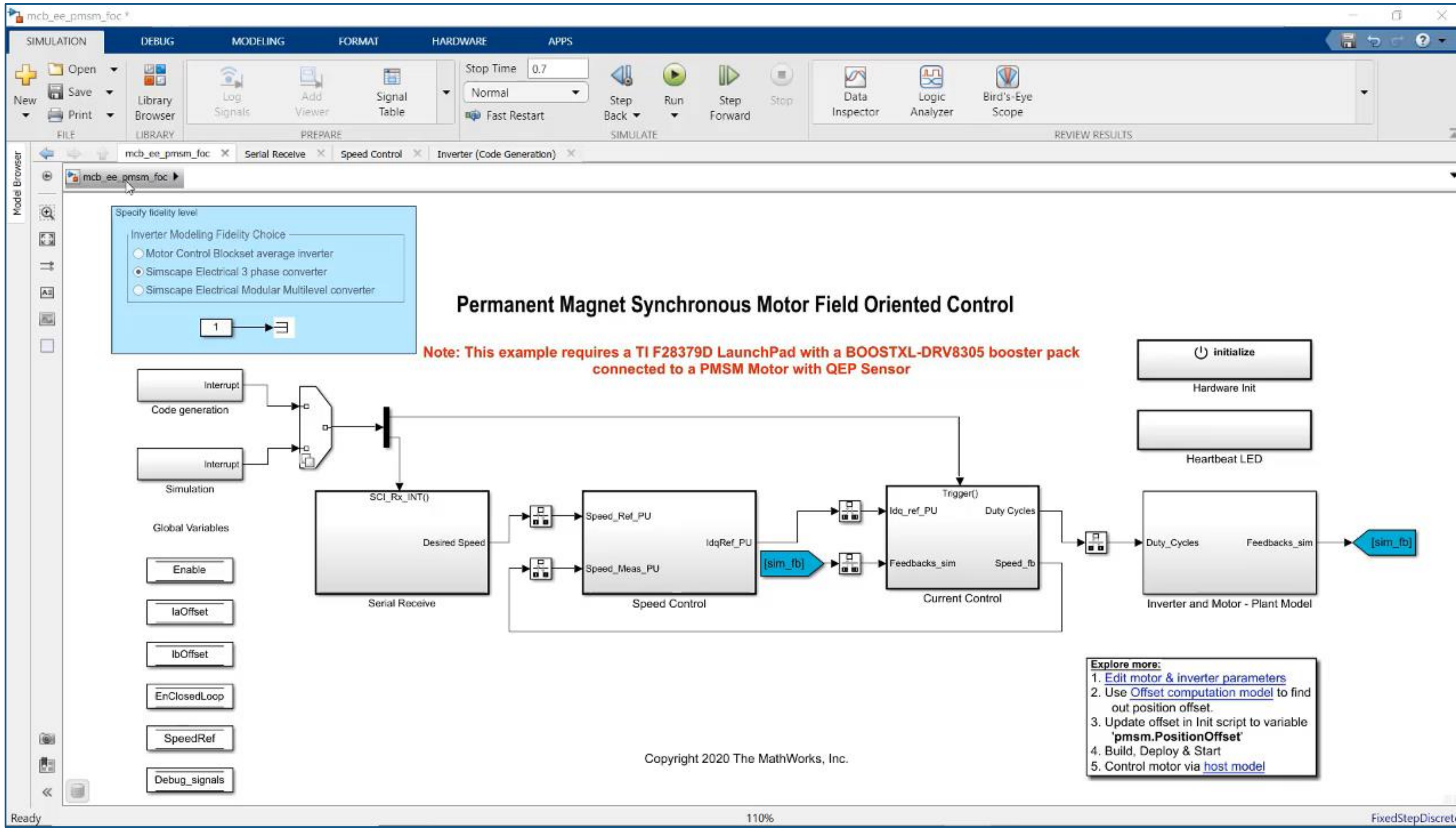
Classic Control Theory

Simulink Control Design

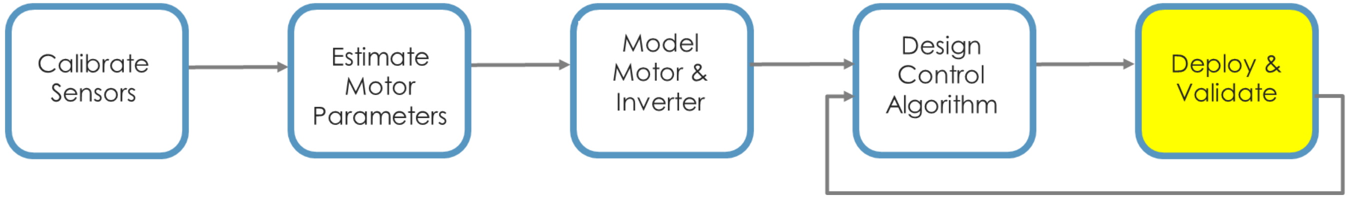
Control algorithm design



- Model field-oriented control algorithm
- Model sensor decoders or sensorless observers
- Tune loop gains
- Verify in closed-loop simulation



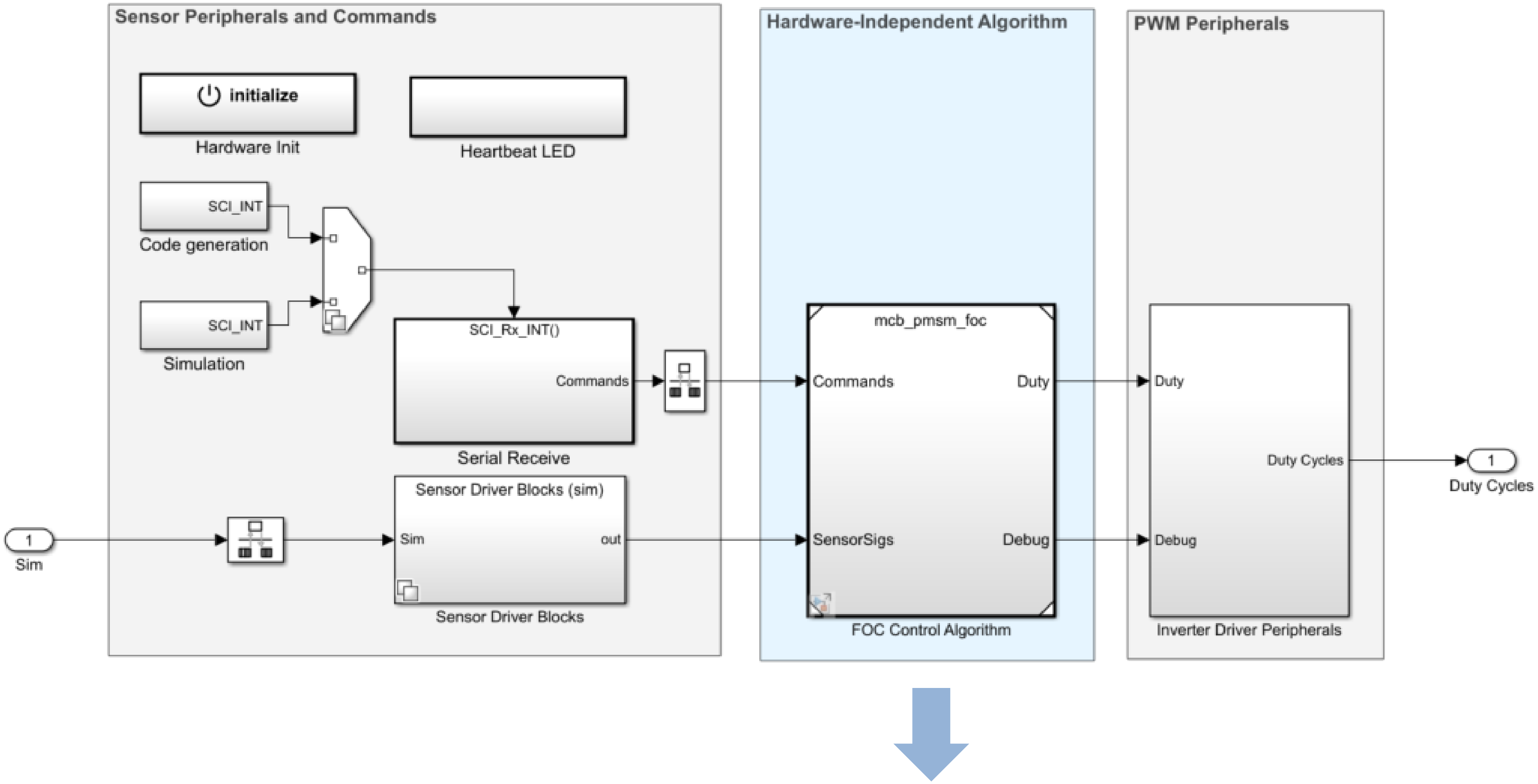
Deployment



- Target any processor with ANSI C code

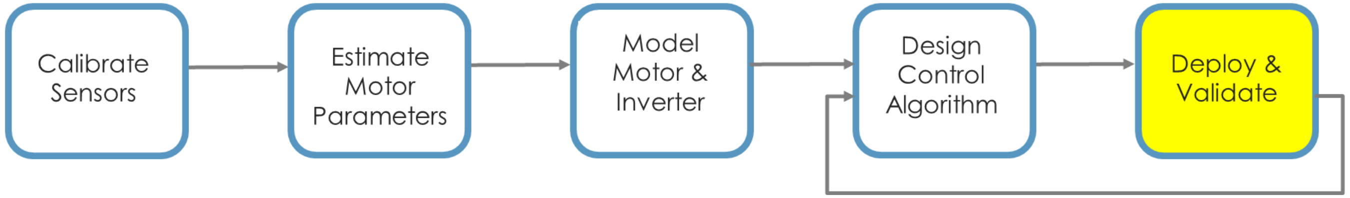
- Use provided example to partition the model into algorithmic and hardware-specific parts

- Generate algorithmic code for integration into embedded application

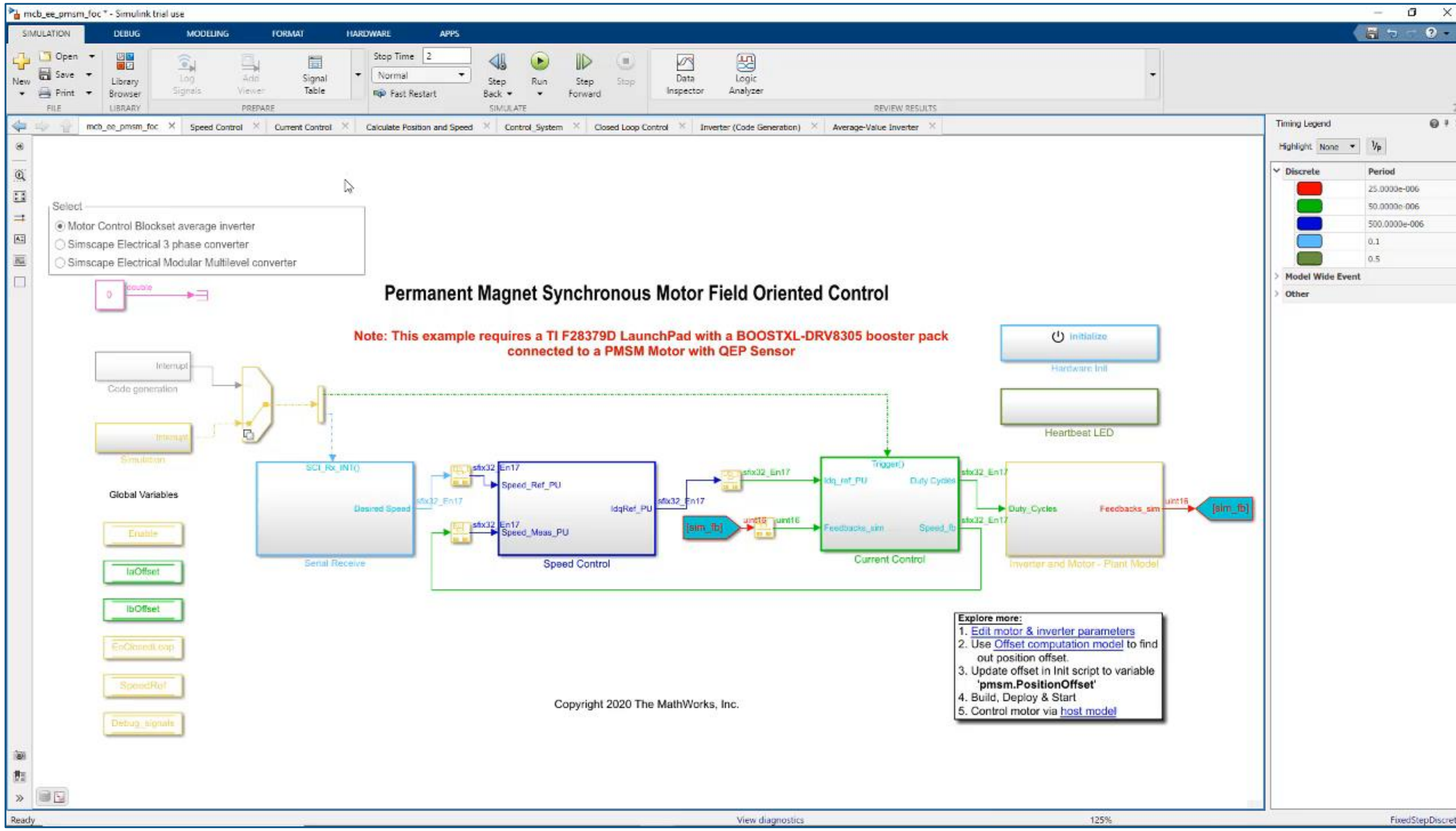


Algorithmic Code

Deployment



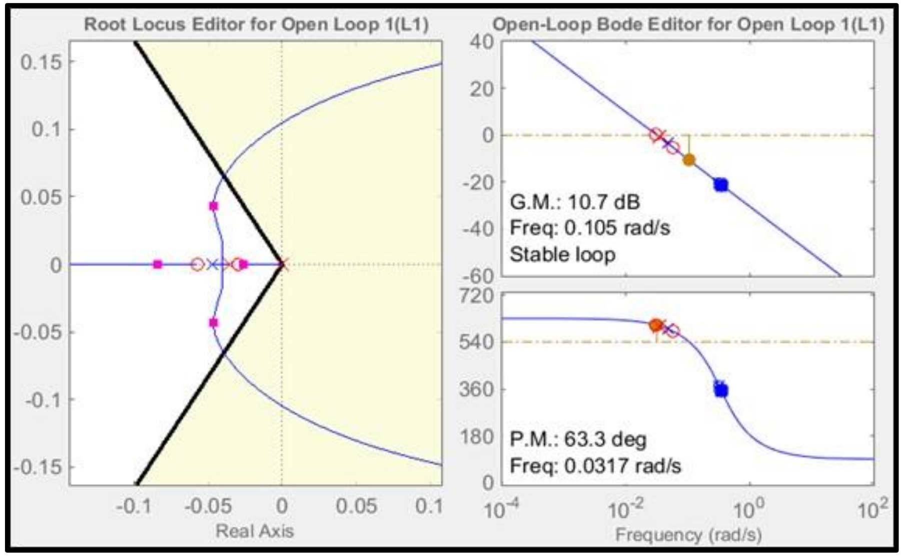
- Generate code (floating and fixed-point)
- Use host model to control and debug
- Validate on hardware



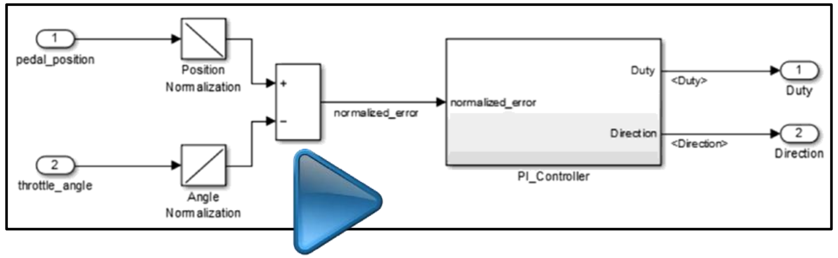
MathWorks Training Services:

Exploit the full potential of MathWorks products

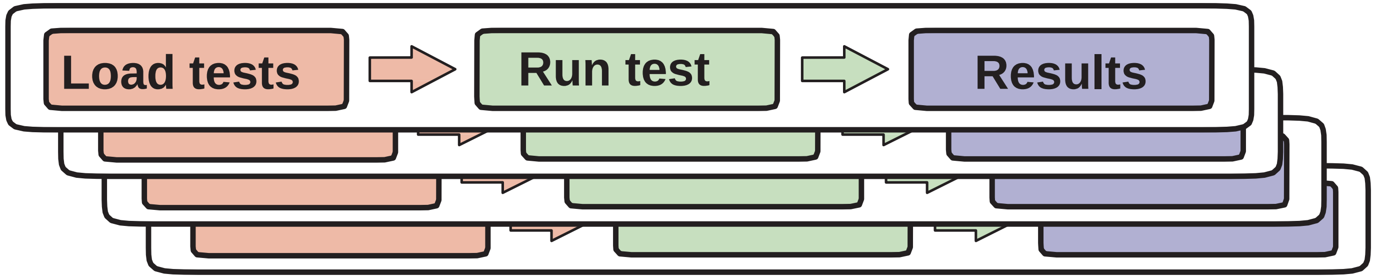
Control System Design



Production Code Generation



Simulation Based Testing



You can verify and profile code using Processor-In-the-Loop testing

Code Execution Profiling Report for mcb_pmsm_foc_sim_v2/Current Control1

The code execution profiling report provides metrics based on data collected from a SIL or PIL execution. Execution times are calculated from data recorded by instrumentation probes added to the SIL or PIL test harness or inside the code generated for each component. See Code Execution Profiling for more information.

1. Summary

Total time	50681790
Unit of time	ns
Command	report(executionProfile, 'Units', 'seconds', 'ScaleFactor', '1e-09', 'NumericFormat', '%0.0f');
Timer frequency (ticks per second)	2e+08
Profiling data created	16-Jan-2020 18:09:48

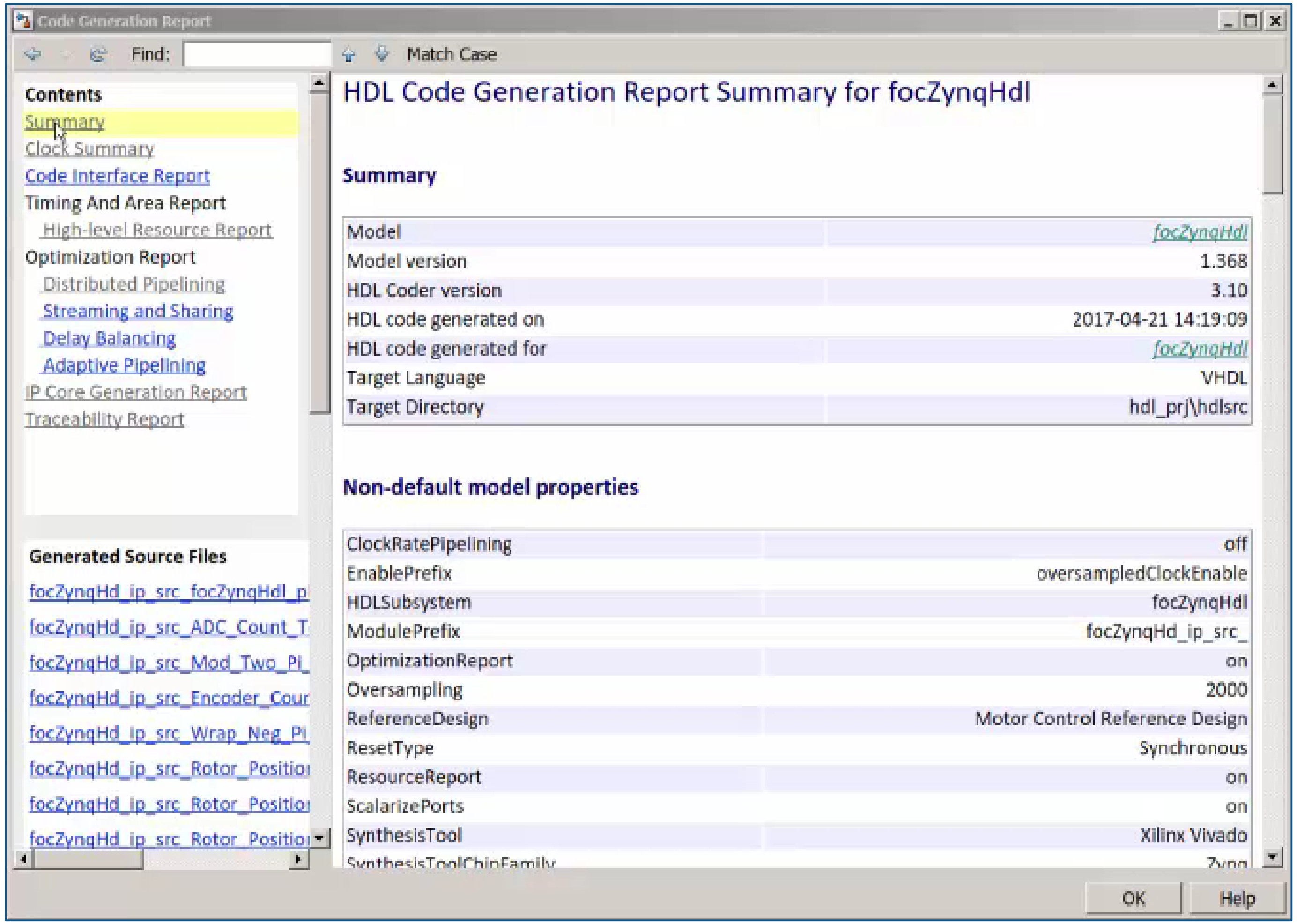
2. Profiled Sections of Code

Section	Maximum Execution Time in ns	Average Execution Time in ns	Maximum Self Time in ns	Average Self Time in ns	Calls	
[+] Current_initialize	2260	2260	1365	1365	1	
Current_step [5e-05 0]	5135	5067	5135	5067	10001	
Current_terminate	540	540	540	540	1	

3. CPU Utilization

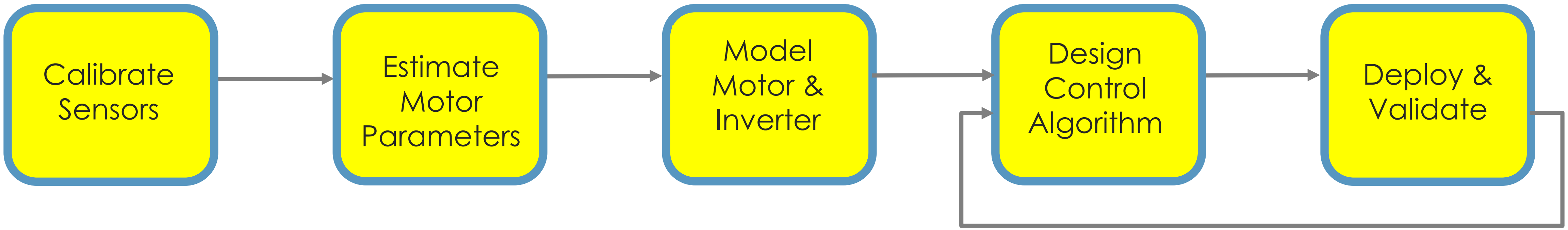
Task	Average CPU Utilization	Maximum CPU Utilization
Current_step [5e-05 0]	10.13%	10.27%
Overall CPU Utilization	10.13%	10.27%

Bonus: you can target FPGAs as well



HDL Code Generation

Workflow for implementing field-oriented control



ATB Technologies cuts electric motor controller development time by 50% using code generation for TI’s C2000 MCU

Challenge

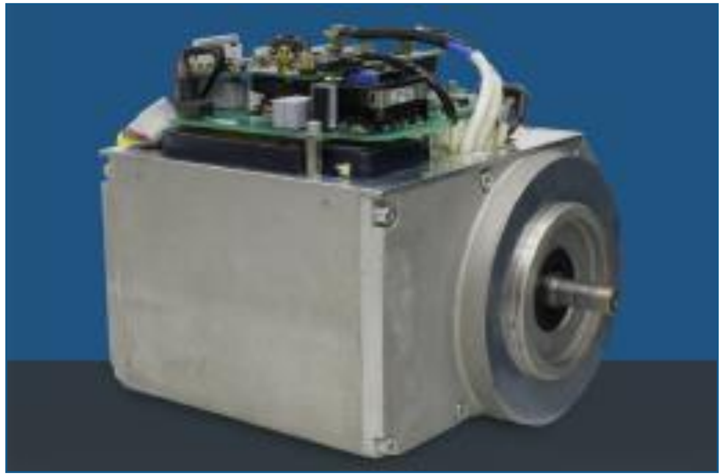
Develop control software to maximize the efficiency and performance of a permanent magnet synchronous motor

Solution

Use MathWorks tools for Model-Based Design to model, simulate, and implement the control system on a target processor

Results

- Development time cut in half
- Design reviews simplified
- Target verification and deployment accelerated



ATB Technologies permanent magnet synchronous motor.

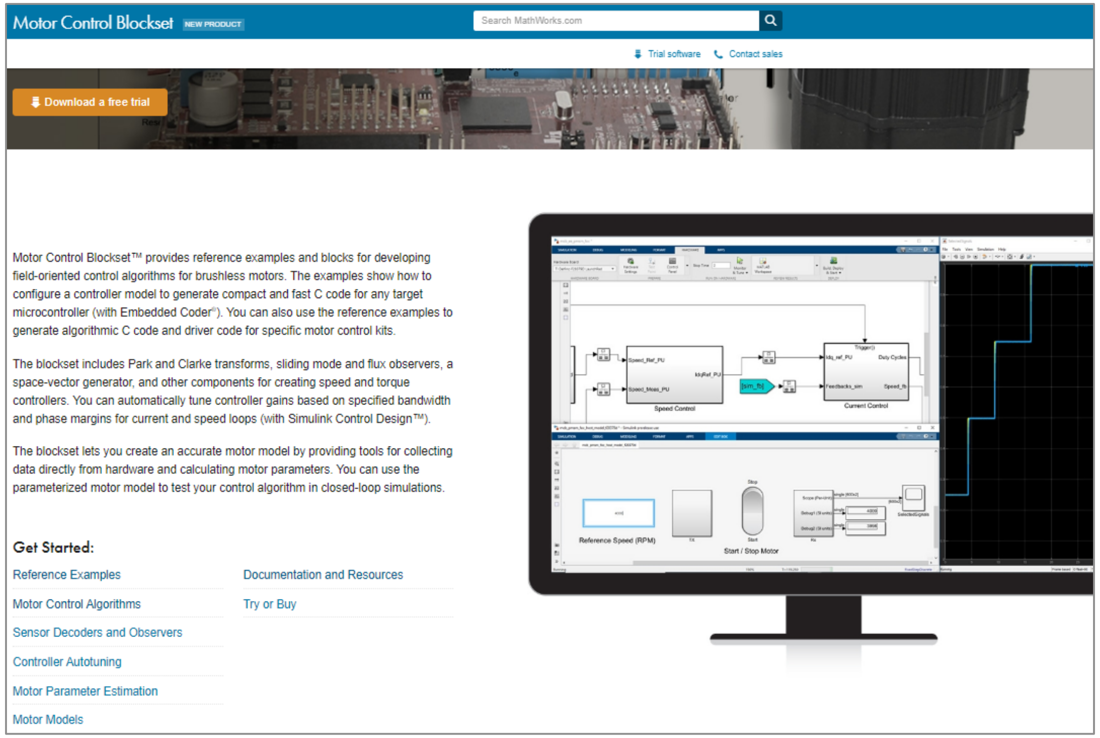
“MathWorks tools enabled us to verify the quality of our design at multiple stages of development, and to produce a high-quality component within a short time frame.”
- Markus Schertler, ATB Technologies

Use Model-Based Design for your next motor control project!

- Verify control algorithm with desktop simulation

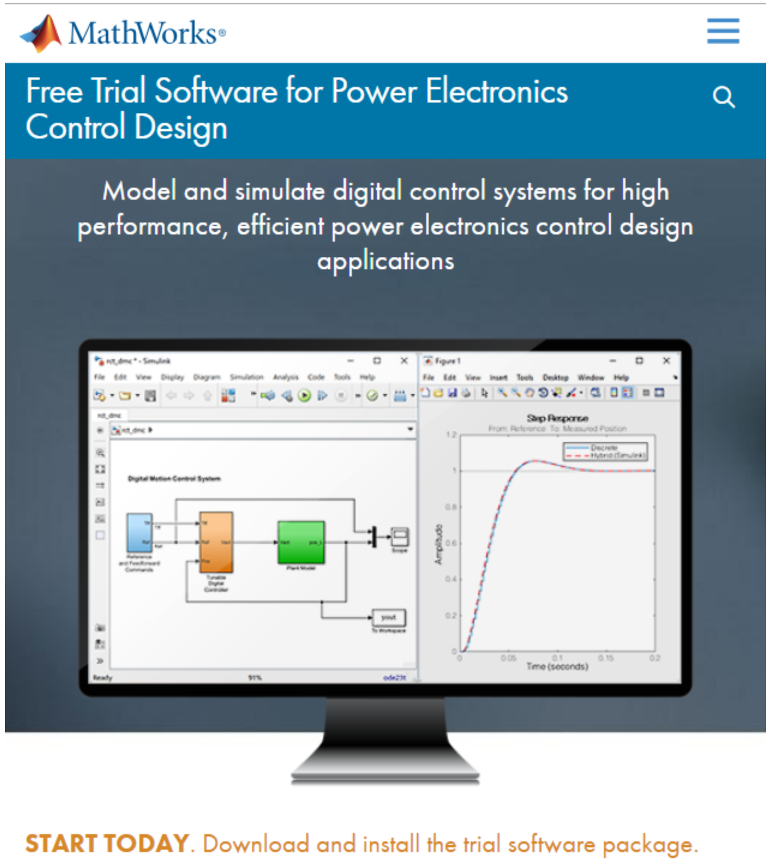
- Generate compact and fast code from models

- Minimize development time using reference examples, built-in algorithmic blocks, automated parameter estimation, and gain-tuning



Learn More

- Visit mathworks.com/products/motor-control and mathworks.com/solutions/power-electronics-control
- Get power electronics control design trial package with necessary tools for desktop modeling, simulation, control design, and production code generation of your next motor control project



As a follow up, in which area would you like to talk to us?

- Buy/Try the product
- Speak with our technical expert
- Training (Paid)
- Consulting (Paid)
- I am not ready for any of the above