NXP AUTOMOTIVE

Technical Training and Cross Selling Camp

MODEL BASED DESIGN TOOLBOX AND S32K TRAINING

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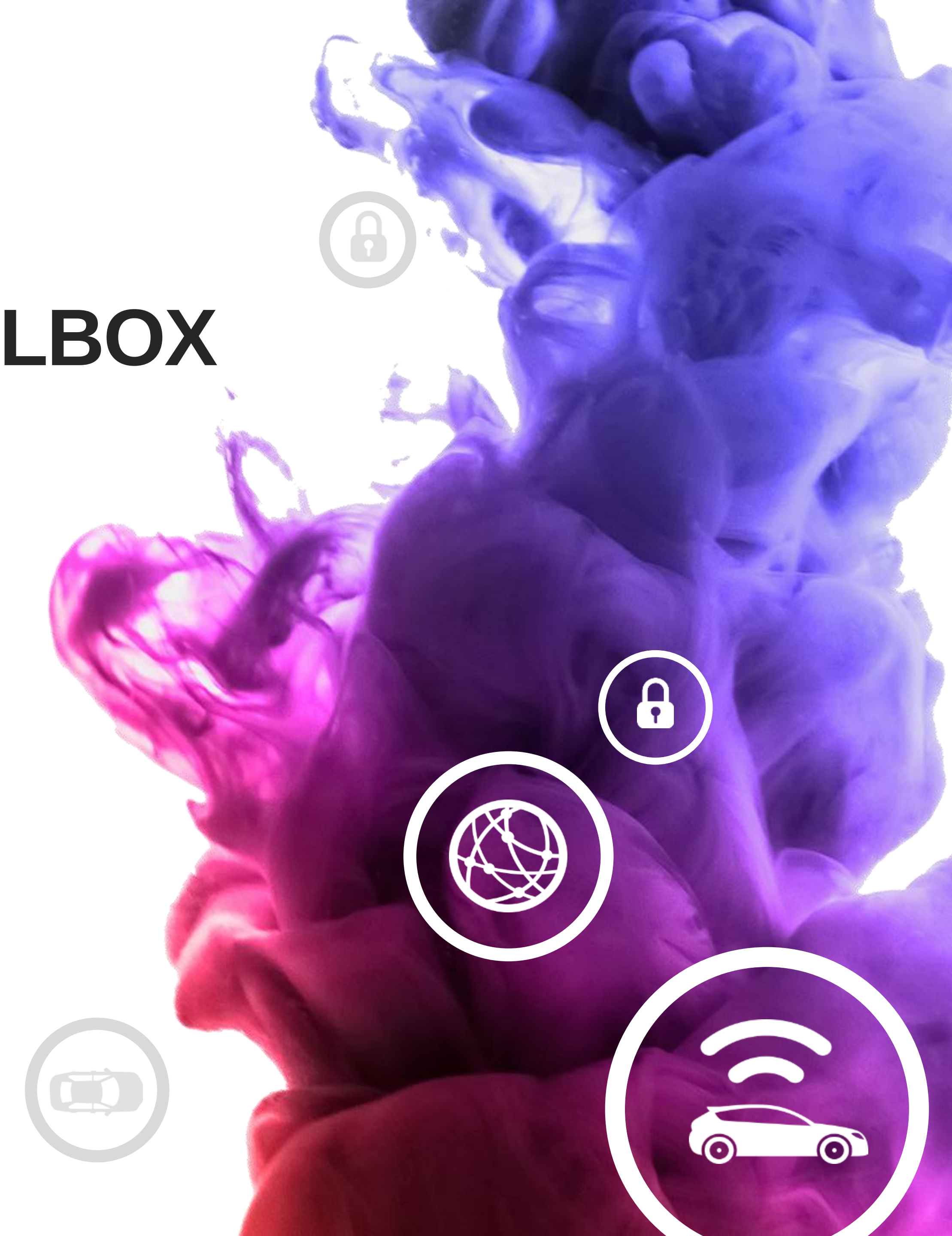

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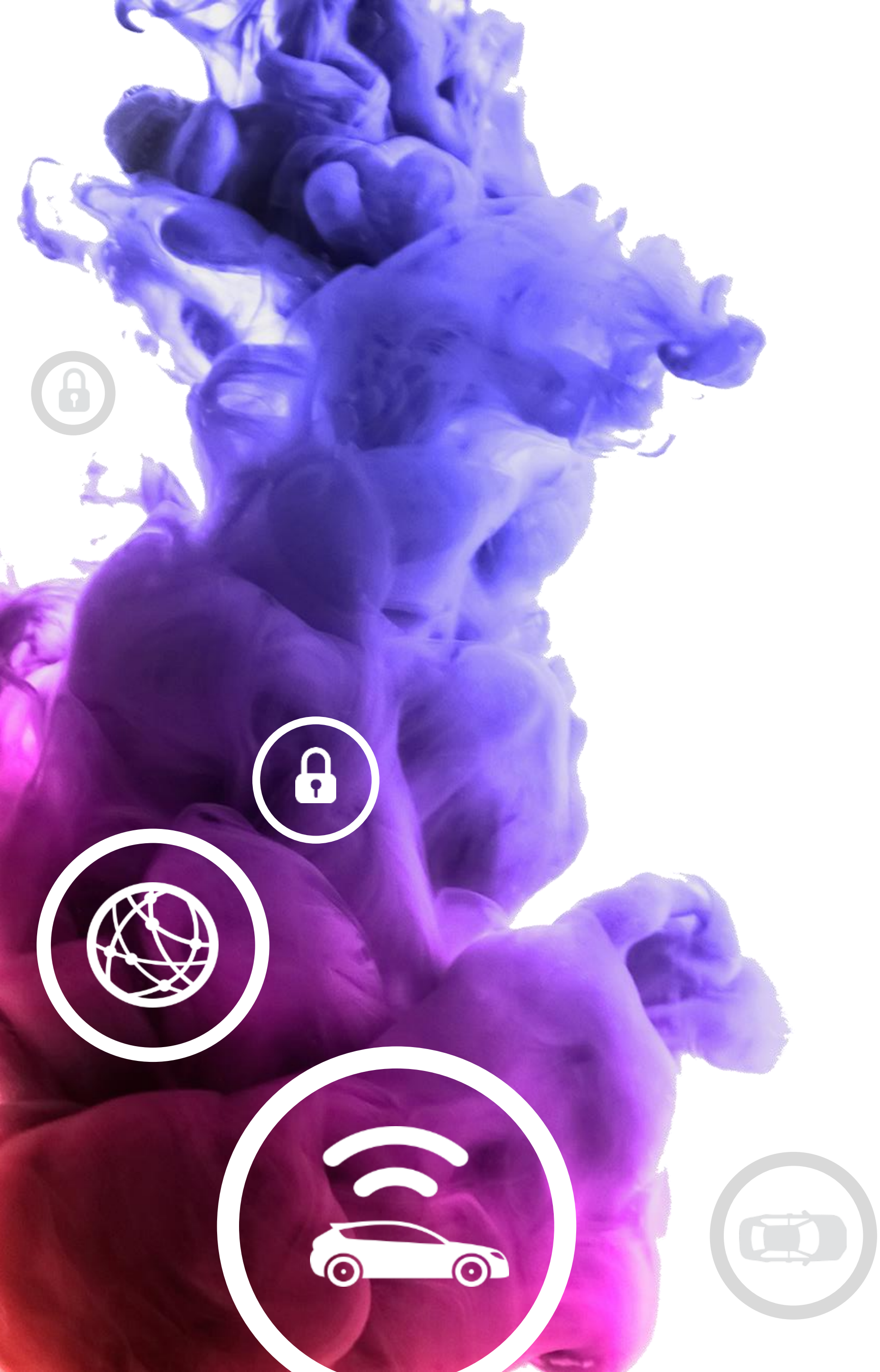
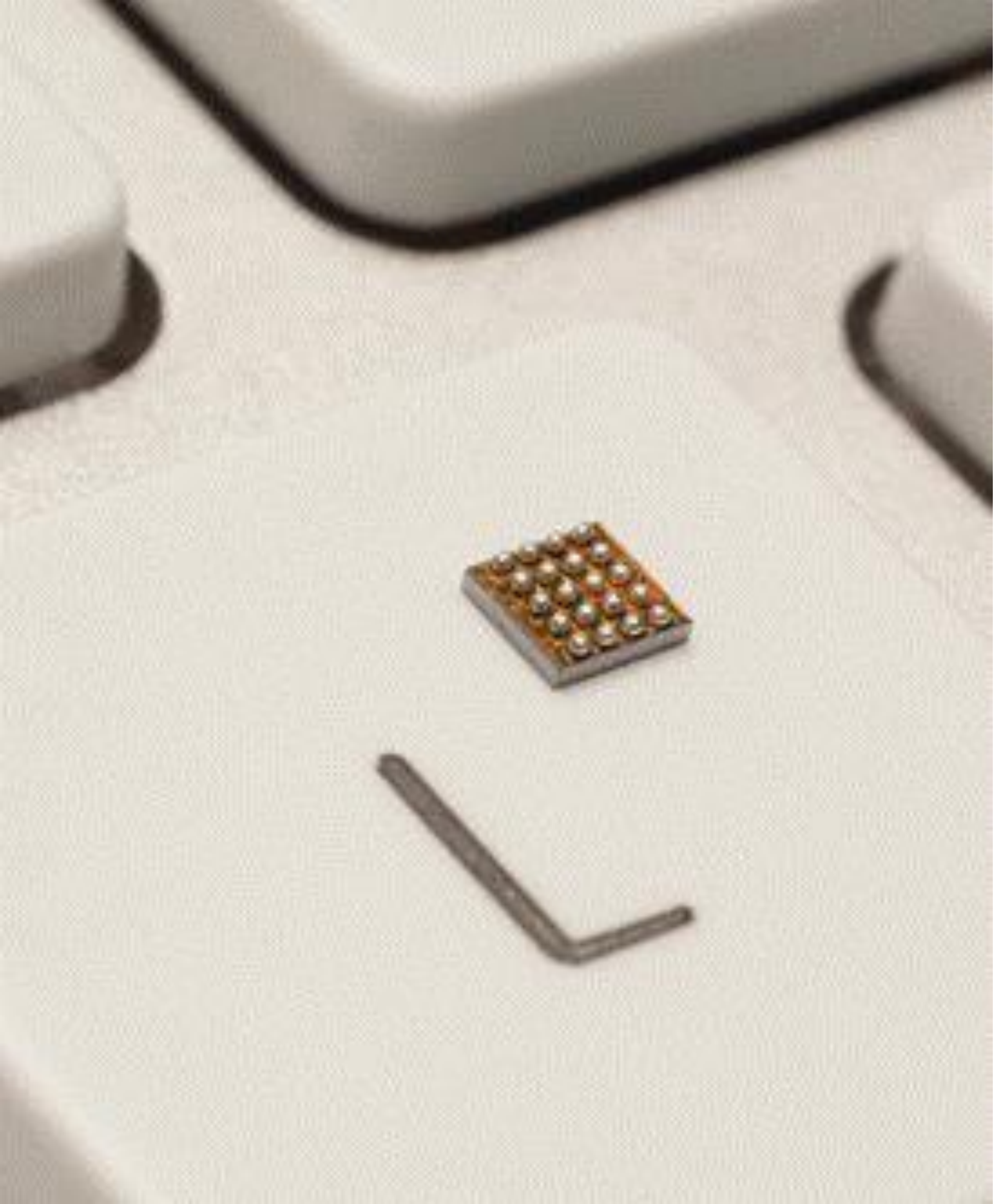


Agenda

- Overview
  - Model Based Design Toolbox: Introduction and Objectives
  - Model Based Design Toolbox: Toolchain Overview
  - Model Based Design Toolbox: Library blocks, FreeMASTER, and Bootloader
- Example: Read A/D and Toggle LED
  - Motor Kit (Describe NXP 3-Phase Motor Kit)
  - Convert simple model to run on Motor Kit with MBD Toolbox and use FreeMASTER
- Model Based Design
  - Model Based Design Steps: Simulation, SIL, PIL and ISO 26262
  - Hands-On Demo SIL/PIL Step 2 & 3 of MBD
- Summary and Q&A



Introduction: What Do We Do?

- One of the Automotive Tools Enablement & Engineering group's objectives is to develop software enablement tools to assist our customers with rapid prototyping and accelerate algorithm development on their target NXP MCU
- This includes software tools that automatically generate peripheral initialization code through GUI configuration, to generating peripheral driver code from a Model Based Design environment like Simulink™

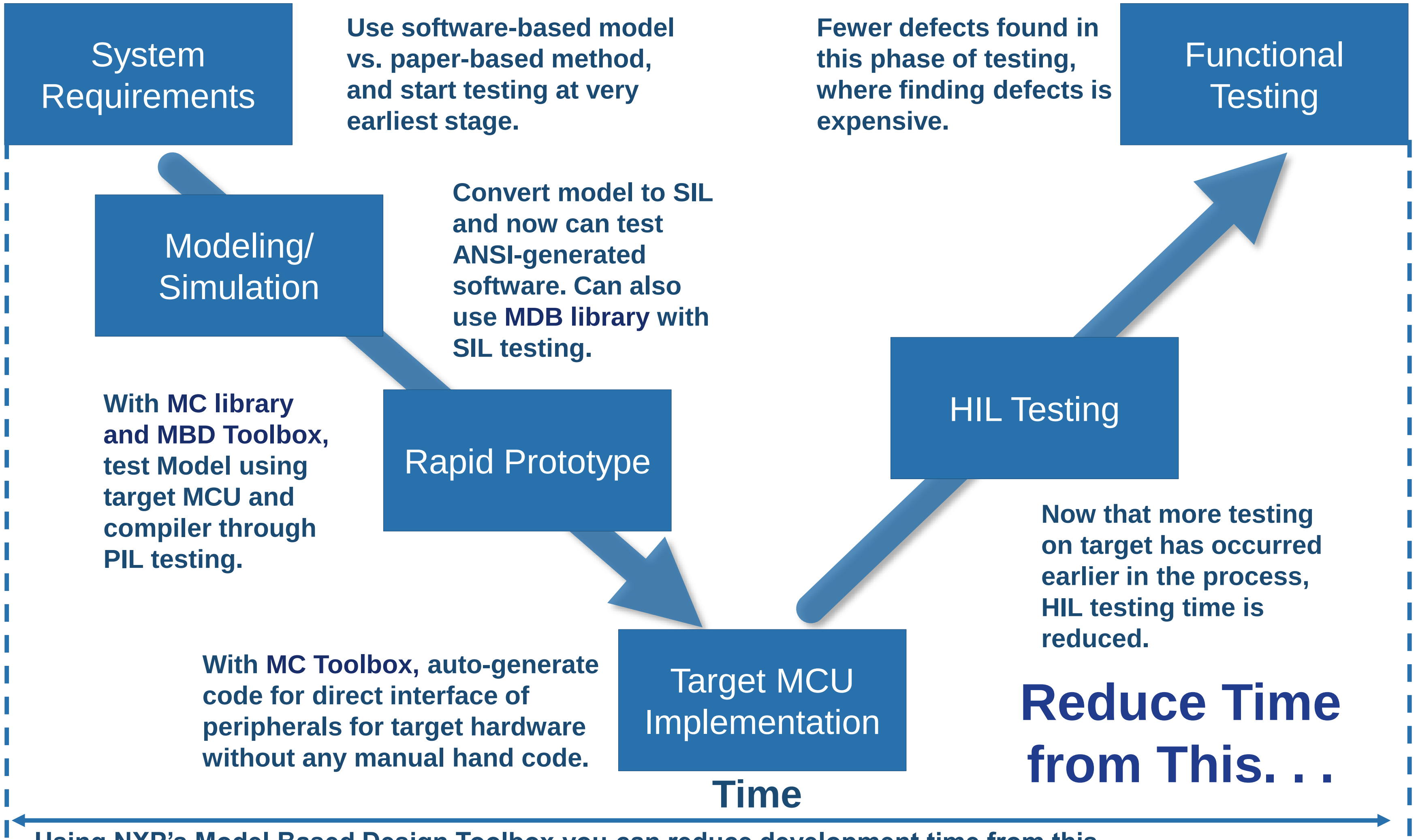
Introduction: Model Based Design (MBD)

- Model Based Design is becoming more common during the normal course of software development to explain and implement the desired behavior of a system. The challenge is to take advantage of this approach and get an executable that can be simulated and implemented directly from the model to help you get the product to market in less time and with higher quality. This is especially true for electric motor controls development in this age of hybrid/electric vehicles and the industrial motor control application space.

- Many companies model their controller algorithm and the target motor or plant so they can use a simulation environment to accelerate their algorithm development.

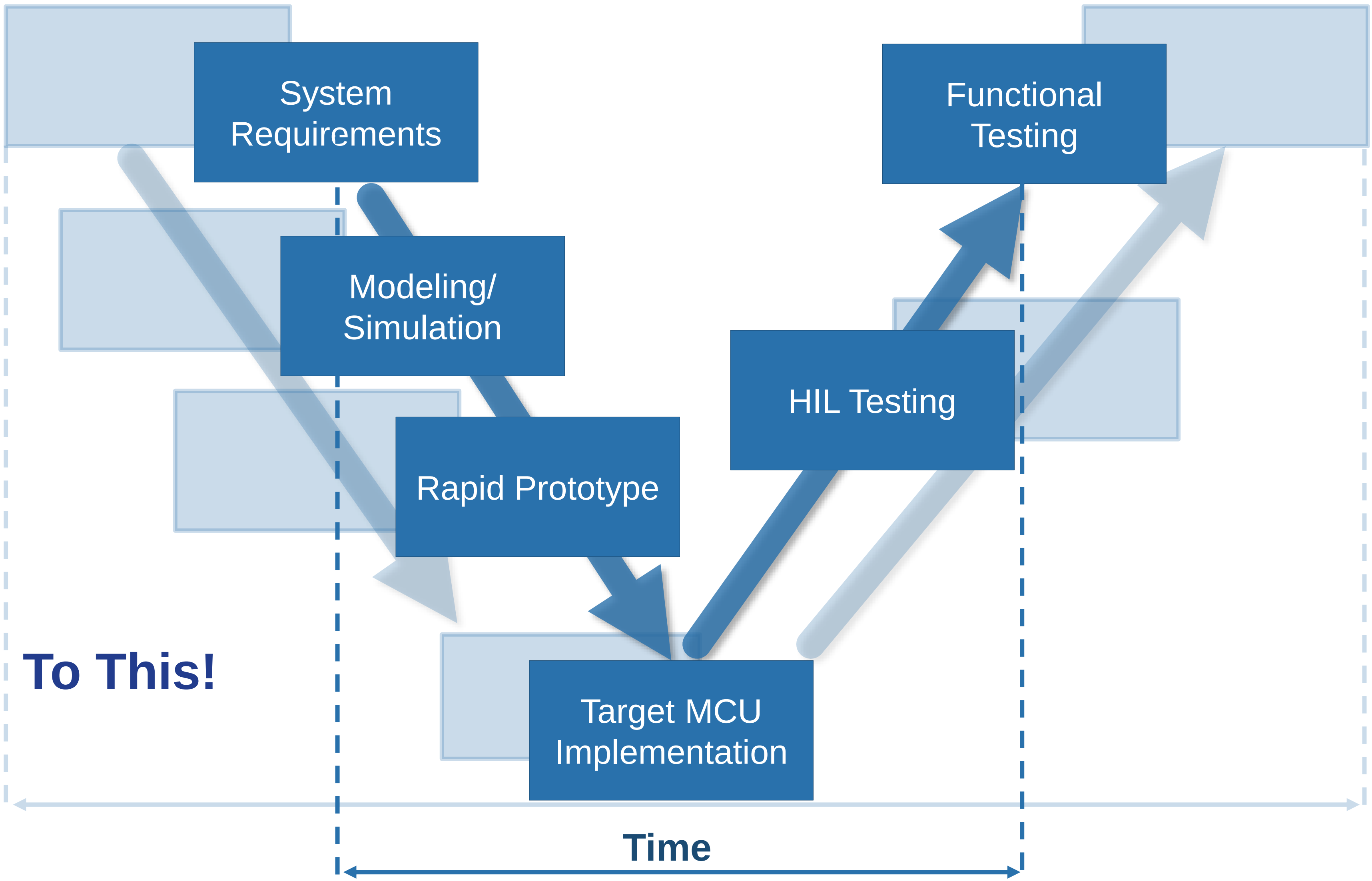
- The final stage of this type of development is the integration of the control algorithm software with target MCU hardware. This is often done using hand code or a mix of hand code and model-generated code. NXP's Model Based Design Toolbox allows this stage of the development to generate 100% of the code from the model.

Introduction: Reduce Development Time With MBD Toolbox



Using NXP's Model Based Design Toolbox you can reduce development time from this.

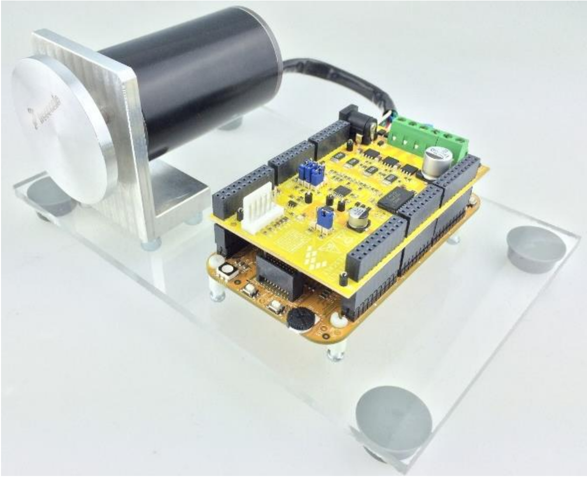
Introduction: Reduce Development Time With MBD Toolbox



Objectives

- Exposure to NXP's hardware/software enablement

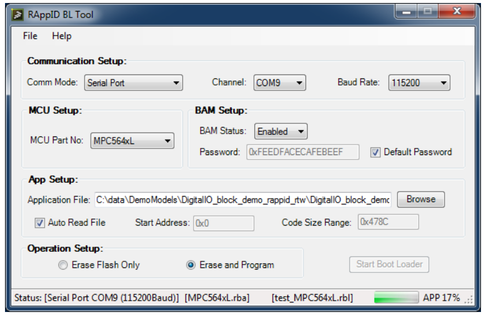
NXP S32K EVB Kit



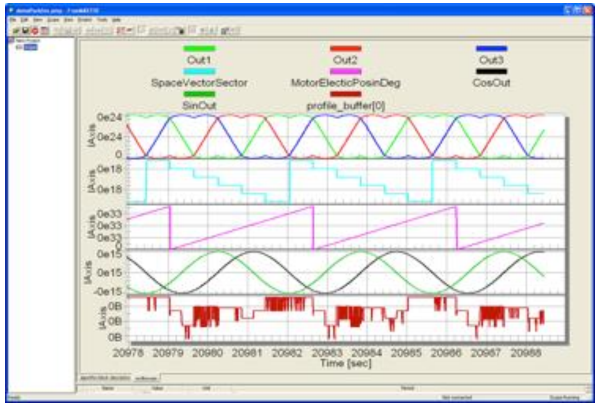
Model Based DesingToolbox
with Simulink ™

Model-based design
Driver configuration
Assignment to pins
Initialization setup

RAppID Bootloader Utility



Signal Visualization
and Data Acquisition Tool



Model Based Design Toolbox: Toolchain Overview:

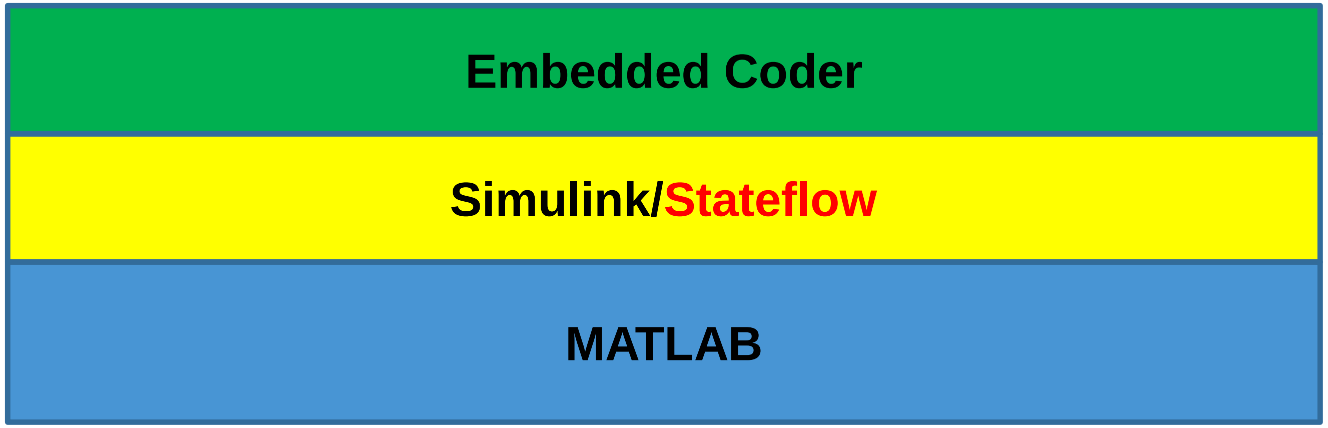
Matlab
Simulink
Stateflow
Embedded Coder
Motor Control (MC)

Overall Model Based Design Toolbox Environment

Embedded Coder is production code generation environment from MATLAB/Simulink models basic code generator that generates ANSI C source code.

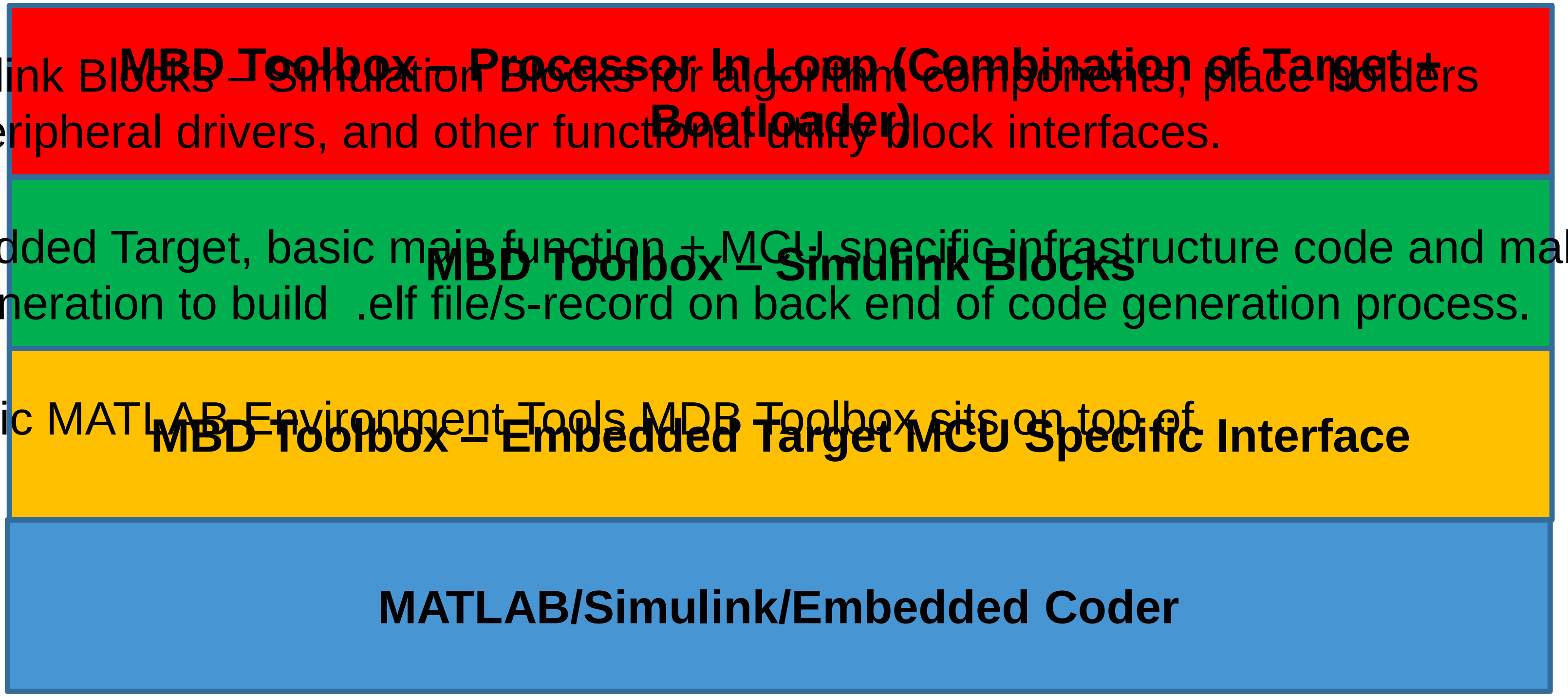
Simulink is graphical environment for building controls algorithms as well as simulation of these algorithms. Stateflow is a special case of Simulink block for state based design and flow chart controls of execution. Simulink allows for a basic solver to execute either in discrete time or continuous time modes.

MATLAB is the base tool environment: Very powerful and scriptable open environment , allows access to everything you need.



Overall Model Based Design Toolbox Environment

Processor In Loop – Combination of embedded target and bootloader



Simulink Blocks – Simulation Blocks for algorithm components, place holders for peripheral drivers, and other functional utility block interfaces.

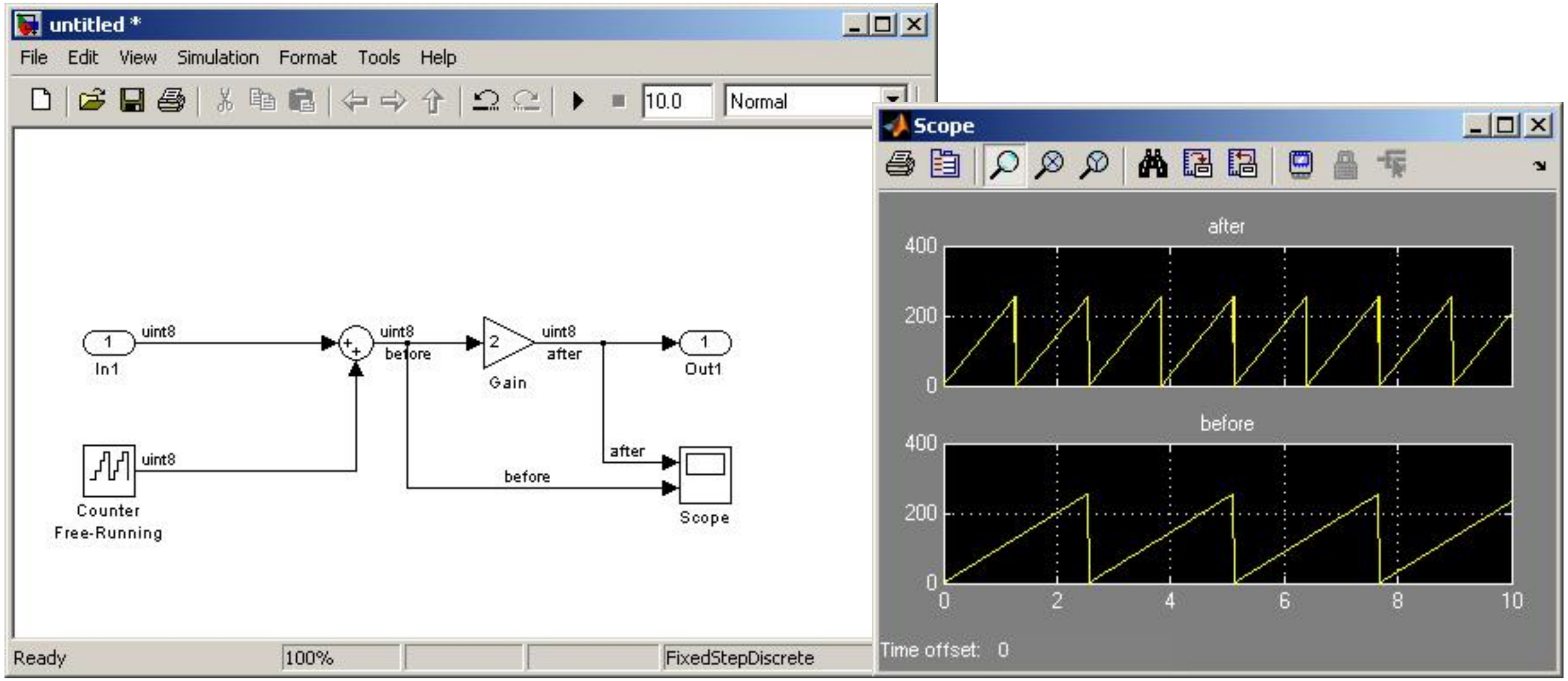
Embedded Target, basic main function + MCU specific infrastructure code and make file generation to build .elf file/s-record on back end of code generation process.

Basic MATLAB Environment Tools MDB Toolbox sits on top of

Overall Model Based Design Toolbox Environment

Simulink Environment

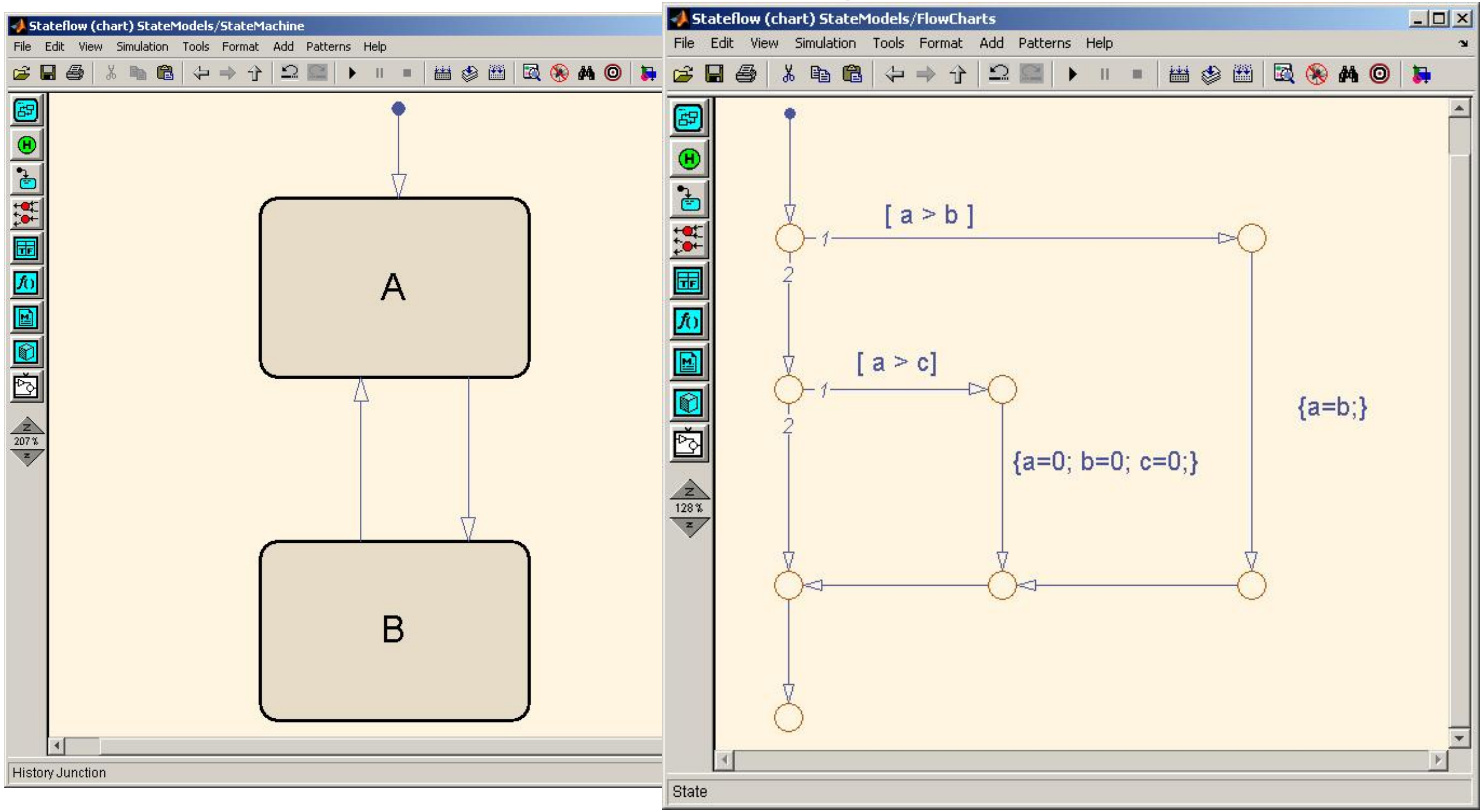
- Simple equation of adding an input to a counter multiplying by a gain value of 2
- output = (counter + input)* 2;



Overall Model Based Design Toolbox Environment

Simulink Environment

Stateflow – state machines, flow chart logic, combination of both.

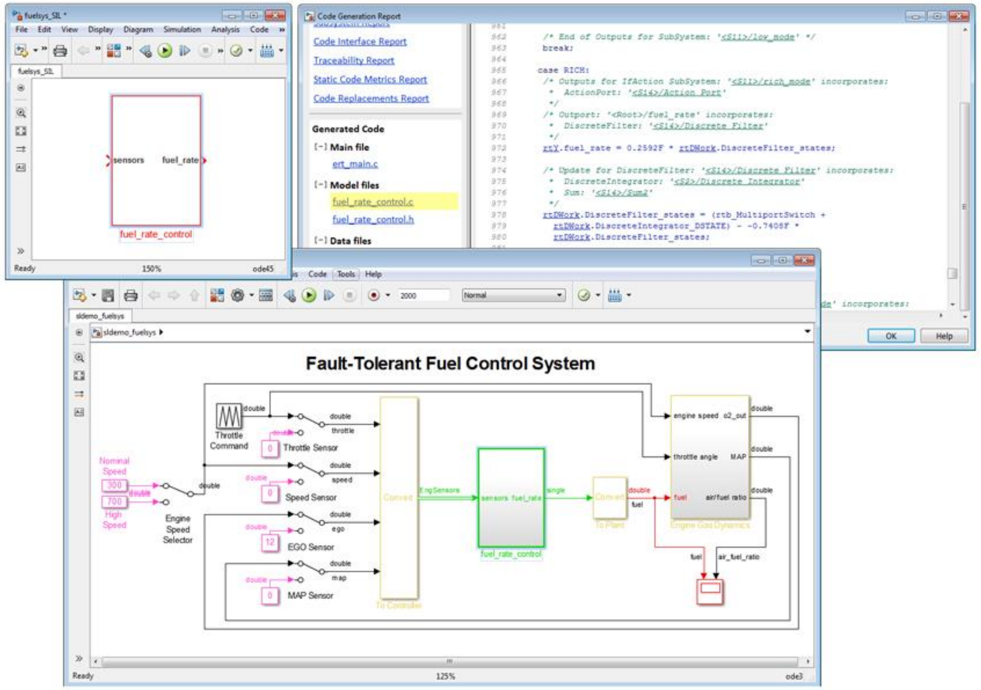


Overall Model Based Design Toolbox Environment

Embedded Coder

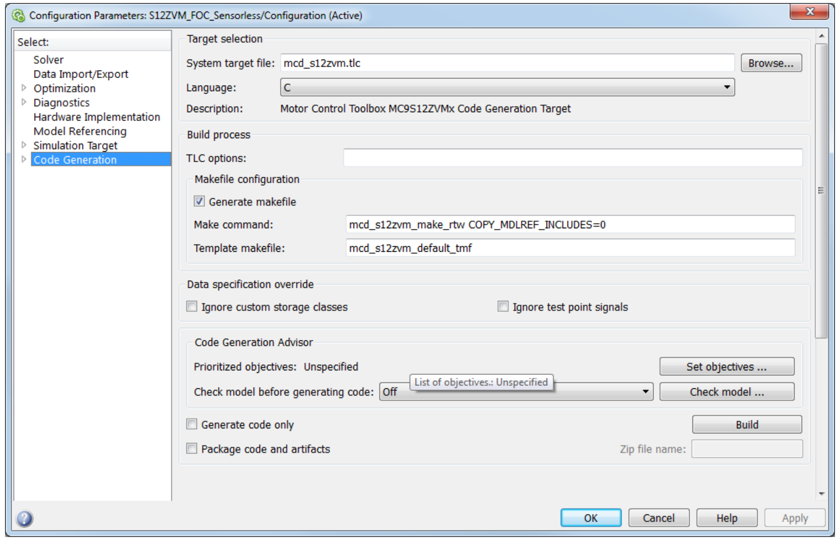
- Optimization and code configuration options that extend MATLAB Coder and Simulink Coder to generate code for processor specific targets.
- Storage class, type, and alias definition using Simulink® data dictionary capabilities.

- Processor-specific code optimization
- Code verification, including SIL and PIL testing, custom comments, and code reports with tracing of models to and from code and requirements
- Standards support, including ASAP2, AUTOSAR, DO-178, IEC 61508, ISO 26262, and MISRA C® in Simulink



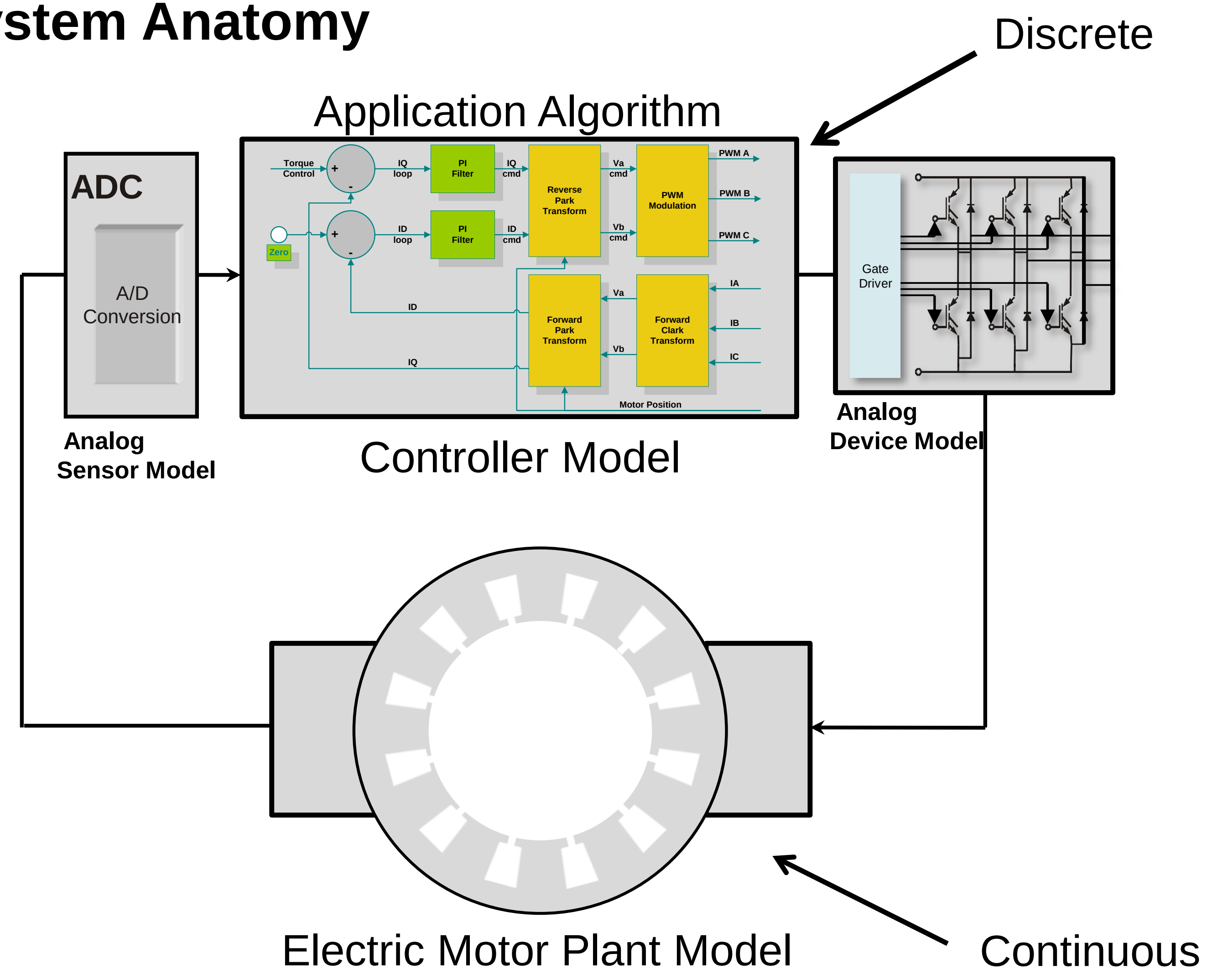
Embedded Target Code Generation Requirements

- Model Code Generation Requirements
  - Must be discrete time solver
  - Must NOT contain any continuous/special blocks
  - Code Generation Add-on :To Build Target Executable Must have embedded target selected (MBD Toolbox provides this for the S32K).
  - May generate code only or generate code and compile for a target environment .exe, .dll, .s19, .elf…).



Embedded Target Code Generation Requirements

Control System Anatomy



Embedded Target Code Generation Requirements

Embedded Target Requirements for Application Algorithm

- Start from Idealized model (double precision unconstrained mathematics).
- Need to move to target constrained model (integer code, fixed point mathematics, or single precision mathematics).
- Tradeoffs are made in this process depending on how the customer chooses to implement the controller on the target MCU.
- The simulation environment supports simulation in any of the target data types also code generation is supported when targeting the MCU.
- What is executed in simulation should be exactly the same as on the embedded target.

Embedded Target Code Generation Considerations

- Data Type Selection
  - Target Based Data Typing
  - Target MCU data sizes
  - Consider compilers options
- Consider Data use scenarios
  - Local reuse of data vs global memory data
  - Consider parameter passing
  - Consider constant data use (calibration data variables)
  - True Constant Data Use

Embedded Target Code Generation Considerations

Data in Simulink

- Two Kinds of Data
  - Simulink Signals
    - Generally are RAM Memory Variables
    - Dynamic in execution
  - Simulink Parameters
    - Constants in execution
    - Can be code generated as a calibration variable
    - Can be code generated as an inline numeric as well

- Full Control of Data Attributes
  - Naming of variables for simulation and code generation
  - Full control over data type in simulation and code generation
  - Data Size
  - Data “C” Constructs used in code generation

Embedded Target Code Generation Considerations

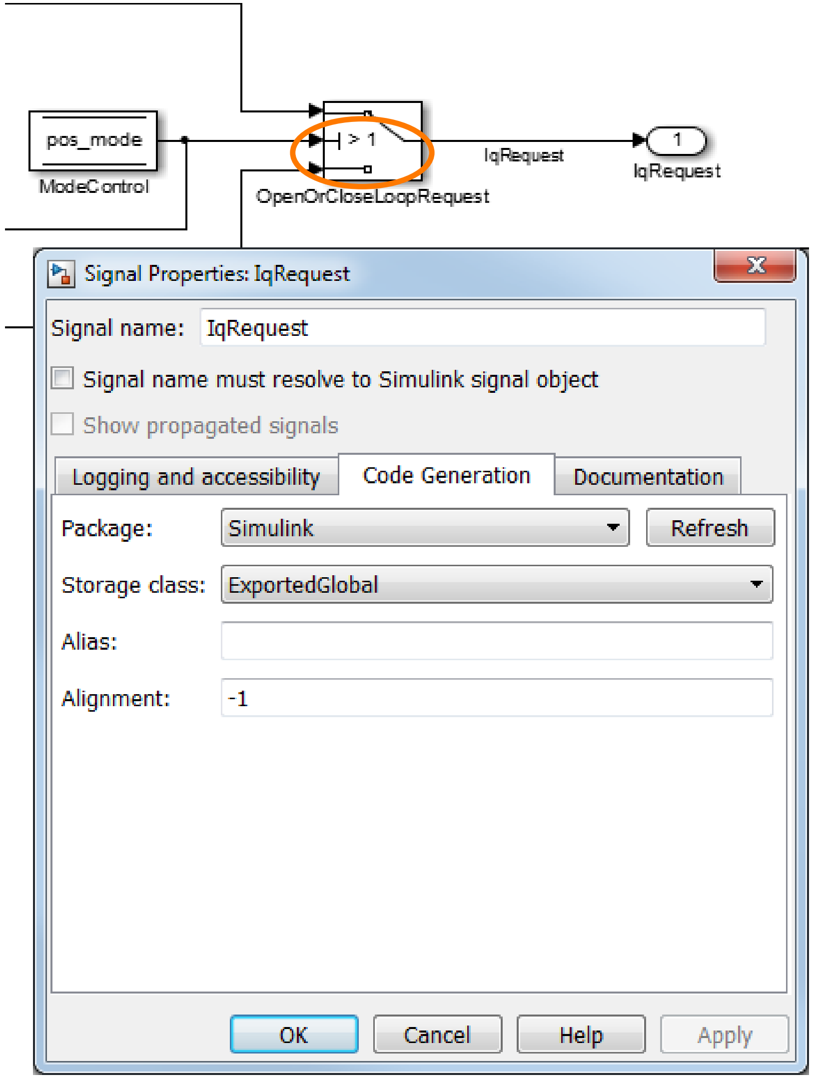
Data in Simulink

Each signal line represents a RAM variable.

Naming is done through signal name label.

Data typing is done directly on signal line or through use of a data object.

Data type, storage class, memory section location, and “C” data definition are all user controllable.



Embedded Target Code Generation Considerations

Before you start to model for Code Generation

- Must have modeling style guidelines that takes into account code generation and target software architecture
- Plan code generation to meet target software architecture
- Use of an interface Data Dictionary to minimize software integration issues is industry best practice
- Design/Refine models for code generation to target MCU
  - Learn and understand code generator optimizations (Know the Tools)
  - Optimize model for code generation with target MCU in mind
    - Data Types
    - Optimize Function/File Partitions
    - Utilize target optimized functions for key bottlenecks (custom)
    - Utilize target optimized block sets whenever possible
- Utilize MCU attributes as much as possible in your model refinement

Conclusion – Model Based Development

- MBD is popular in Automotive/Aerospace/Industrial Space especially for Motor Control Applications.
- MBD Automatic Code Generation is another level of abstraction above C-Code since algorithm, architecture, data typing and optimizations occur at the model level.
- MBD Code Generation requires planning and process to meet target executions goals.
- Target required execution times requires model refinement.
- Best to target code generation of the model to the software architecture of embedded controller environment.

Any Questions?

Model Based Design Toolbox Overview

Introduction: Model Based Design Toolbox

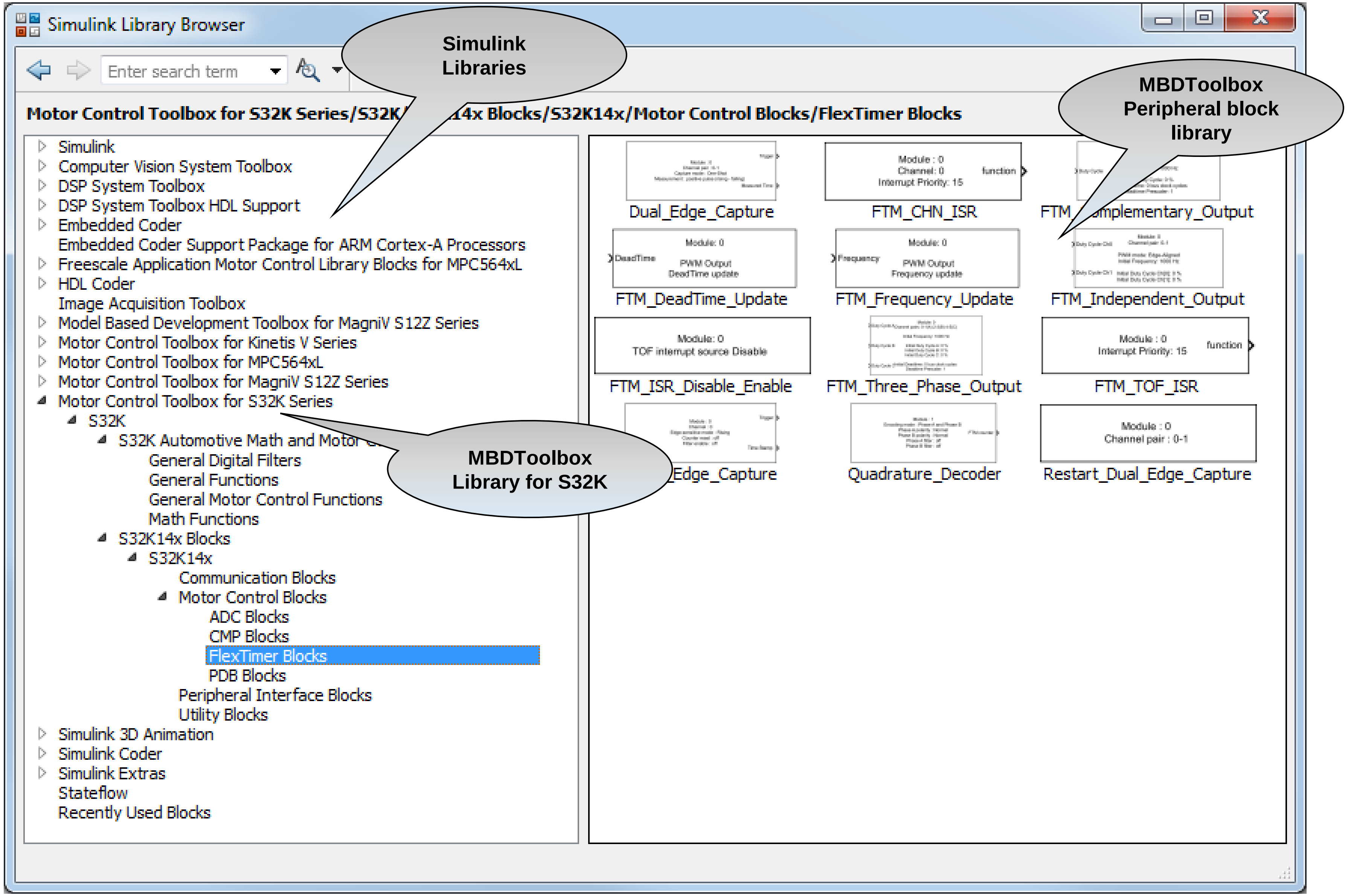
- The Model Based Design Toolbox includes an embedded target supporting NXP MCUs and Simulink™ plug-in libraries which provide engineers with an integrated environment and tool chain for configuring and generating the necessary software, including initialization routines, device drivers, and a real-time scheduler to execute algorithms specifically for controlling motors.
- The toolbox also includes an extensive Automotive Math and Motor Control Function Library developed by NXP's renowned Motor Control Center of Excellence. The library provides dozens of blocks optimized for fast execution on NXP MCUs with bit-accurate results compared to Simulink™ simulation using single-precision math.
- The toolbox provides built-in support for Software and Processor-in-the-Loop (SIL and PIL), which enables direct comparison and plotting of numerical results.

MathWorks products required for MBD Toolbox:

- MATLAB (32-Bit or 64-Bit)*
- Simulink
- MATLAB Coder
- Simulink Coder
- Embedded Coder

*Earlier released products only support 32-bit

MBD Toolbox: Toolbox Library Contents



MBD Toolbox: Toolbox Library Contents

Peripherals

- General
  - ADC conversion
  - Digital I/O
  - PIT timer
  - ISR
- Communication Interface
  - CAN driver
  - SPI driver
  - I2C
- Motor Control Interface
  - Cross triggering unit
  - PWM
  - eTimer block(s)
  - Sine wave generation
  - ADC Command List
  - GDU (Gate Drive Unit)
  - PTU (Prog Trigger Unit)
  - TIM Hall Sensor Port
  - FTM (Flex Timer Module)
  - PDB (Programmable Delay Block)

Configuration/Modes

- Compiler Options
  - CodeWarrior
  - Wind River DIAB
  - Green Hills
  - Cosmic
  - IAR
  - GCC
  - RAM/FLASH targets
- Simulation Modes
  - Normal
  - Accelerator
  - Software in the Loop (SIL)
  - Processor in the Loop (PIL)
- MCU Option
  - Multiple packages
  - Multiple Crystal frequencies

Utility

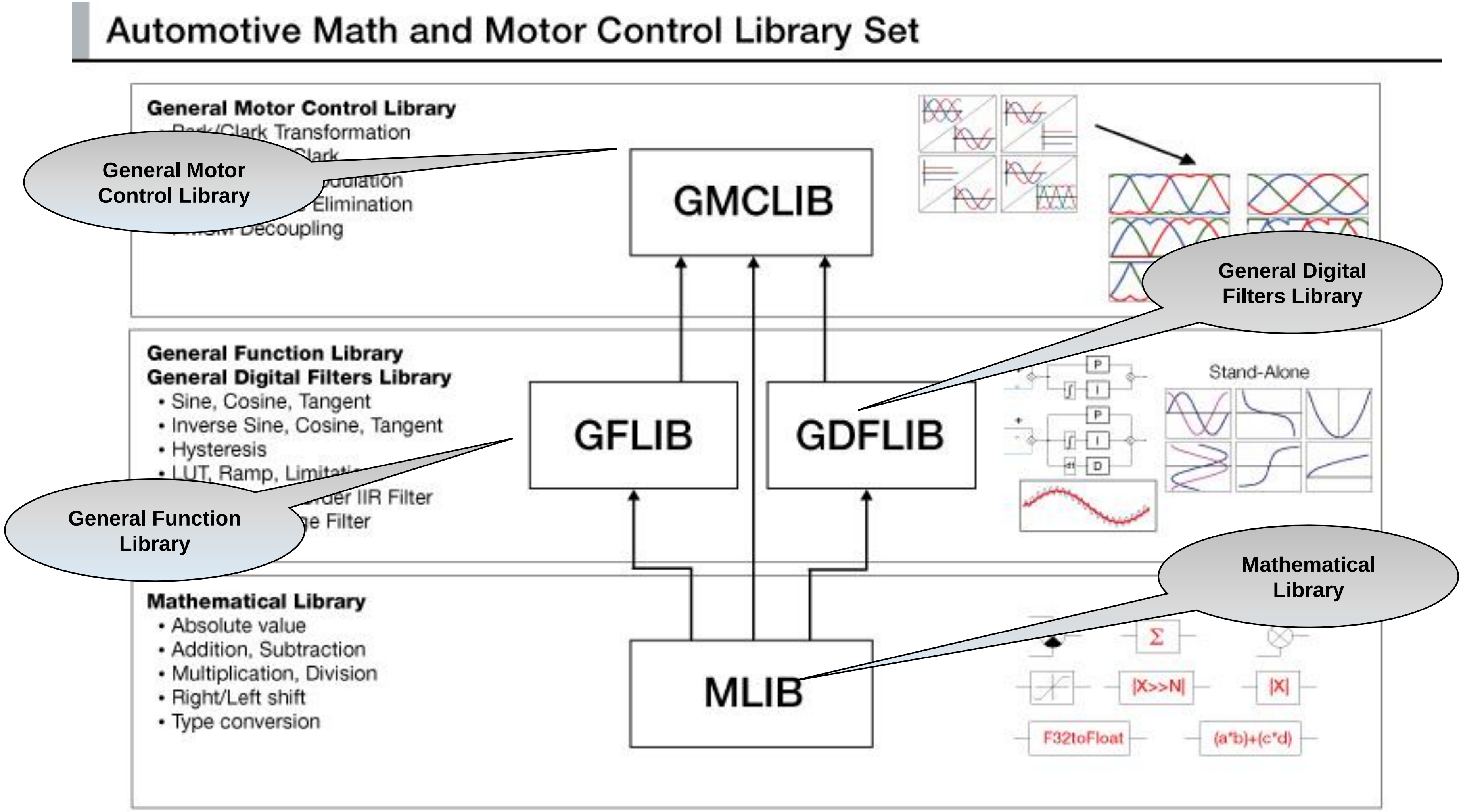
- FreeMASTER Interface
  - Data acquisition / Calibration
  - Customize GUI
- Profiler Function
  - Exec. time measurement
  - Available in PIL
  - Available in standalone
- Memory Read and Write

MCUs Supported

- MPC5643L
- MPC567xK
- MPC574xP
- S12ZVM
- **S32K**

NOTE: Peripheral Block and compiler availability is dependant on which MCU is use.

MBD Toolbox: Auto Math and Motor Control Library Contents



MBD Toolbox: Auto Math and Motor Control Library Contents

MLIB

- **Absolute Value, Negative Value**
  - MLIB_Abs, MLIB_AbsSat
  - MLIB_Neg, MLIB_NegSat
- **Add/Subtract Functions**
  - MLIB_Add, MLIB_AddSat
  - MLIB_Sub, MLIB_SubSat
- **Multiply/Divide/Add-multiply Functions**
  - MLIB_Mul, MLIB_MulSat
  - MLIB_Div, MLIB_DivSat
  - MLIB_Mac, MLIB_MacSat
  - MLIB_VMac
- **Shifting**
  - MLIB_ShL, MLIB_ShLSat
  - MLIB_ShR
  - MLIB_ShBi, MLIB_ShBiSat
- **Normalisation, Round Functions**
  - MLIB_Norm, MLIB_Round
- **Conversion Functions**
  - MLIB_ConvertPU, MLIB_Convert

GFLIB

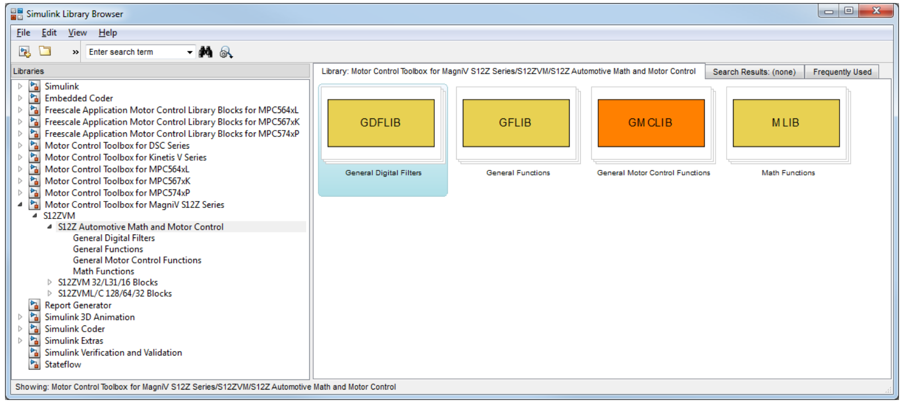
- **Trigonometric Functions**
  - GFLIB_Sin, GFLIB_Cos, GFLIB_Tan
  - GFLIB_Asin, GFLIB_Acos, GFLIB_Atan, GFLIB_AtanYX
  - GFLIB_AtanYXShifted
- **Limitation Functions**
  - GFLIB_Limit, GFLIB_VectorLimit
  - GFLIB_LowerLimit, GFLIB_UpperLimit
- **PI Controller Functions**
  - GFLIB_ControllerPIr, GFLIB_ControllerPIrAW
  - GFLIB_ControllerPIp, GFLIB_ControllerPIpAW
- **Interpolation**
  - GFLIB_Lut1D, GFLIB_Lut2D
- **Hysteresis Function**
  - GFLIB_Hyst
- **Signal Integration Function**
  - GFLIB_IntegratorTR
- **Sign Function**
  - GFLIB_Sign
- **Signal Ramp Function**
  - GFLIB_Ramp
- **Square Root Function**
  - GFLIB_Sqrt

GDFLIB

- **Finite Impulse Filter**
  - GDFLIB_FilterFIR
- **Moving Average Filter**
  - GDFLIB_FilterMA
- **1st Order Infinite Impulse Filter**
  - GDFLIB_FilterIIR1init
  - GDFLIB_FilterIIR1
- **2nd Order Infinite Impulse Filter**
  - GDFLIB_FilterIIR2init
  - GDFLIB_FilterIIR2

GMCLIB

- **Clark Transformation**
  - GMCLIB_Clark
  - GMCLIB_ClarkInv
- **Park Transformation**
  - GMCLIB_Park
  - GMCLIB_ParkInv
- **Duty Cycle Calculation**
  - GMCLIB_SvmStd
- **Elimination of DC Ripples**
  - GMCLIB_ElimDcBusRip
- **Decoupling of PMSM Motors**
  - GMCLIB_DecouplingPMSM



MBD Toolbox: RAppID Bootloader Utility

The RAppID Bootloader works with the built-in Boot Assist Module (BAM) included in the NXP Qorivva and also supports S12 MagniV, Kinetis, and DSCs family of parts. The Bootloader provides a streamlined method for programming code into FLASH or RAM on either target EVBs or custom boards. Once programming is complete, the application code automatically starts.

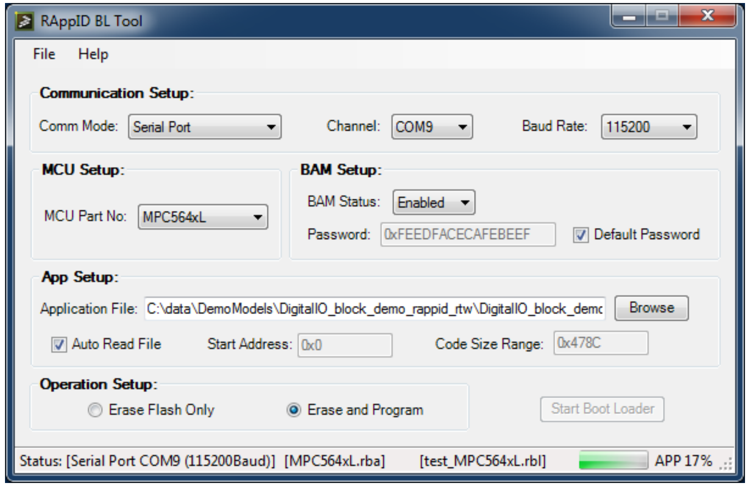
Modes of Operation

The Bootloader has two modes of operation: for use as a stand-alone PC desktop GUI utility, or for integration with different user required tools chains through a command line interface (i.e. Eclipse Plug-in, MATLAB/Simulink, …)

MCUs Supported

MPC5534, MPC5601/2D, MPC5602/3/4BC, MPC5605/6/7B, MPC564xB/C, MPC567xF, MPC567xK, MPC564xL, MPC5604/3P, MPC574xP, S12ZVM, S32K, KV10, KV3x, KV4x, KV5x, 56F82xx and 56F84xx.

Graphical User Interface

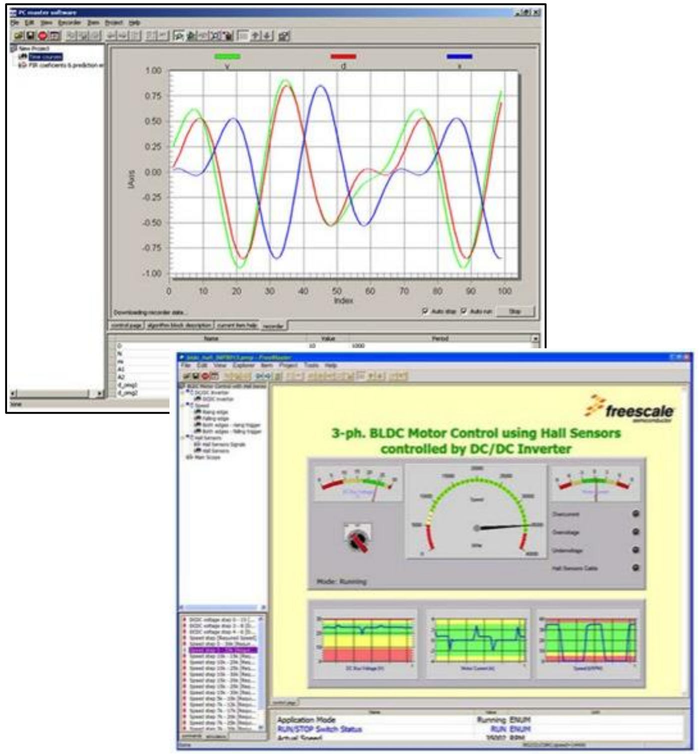


Command

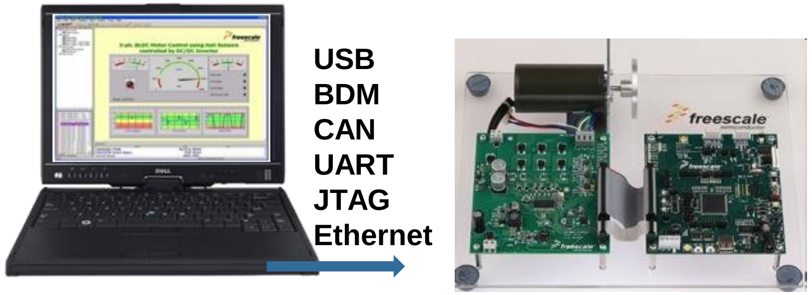
Status given in two stages: Bootloader download, then application programming

FreeMASTER — Run Time Debugging Tool

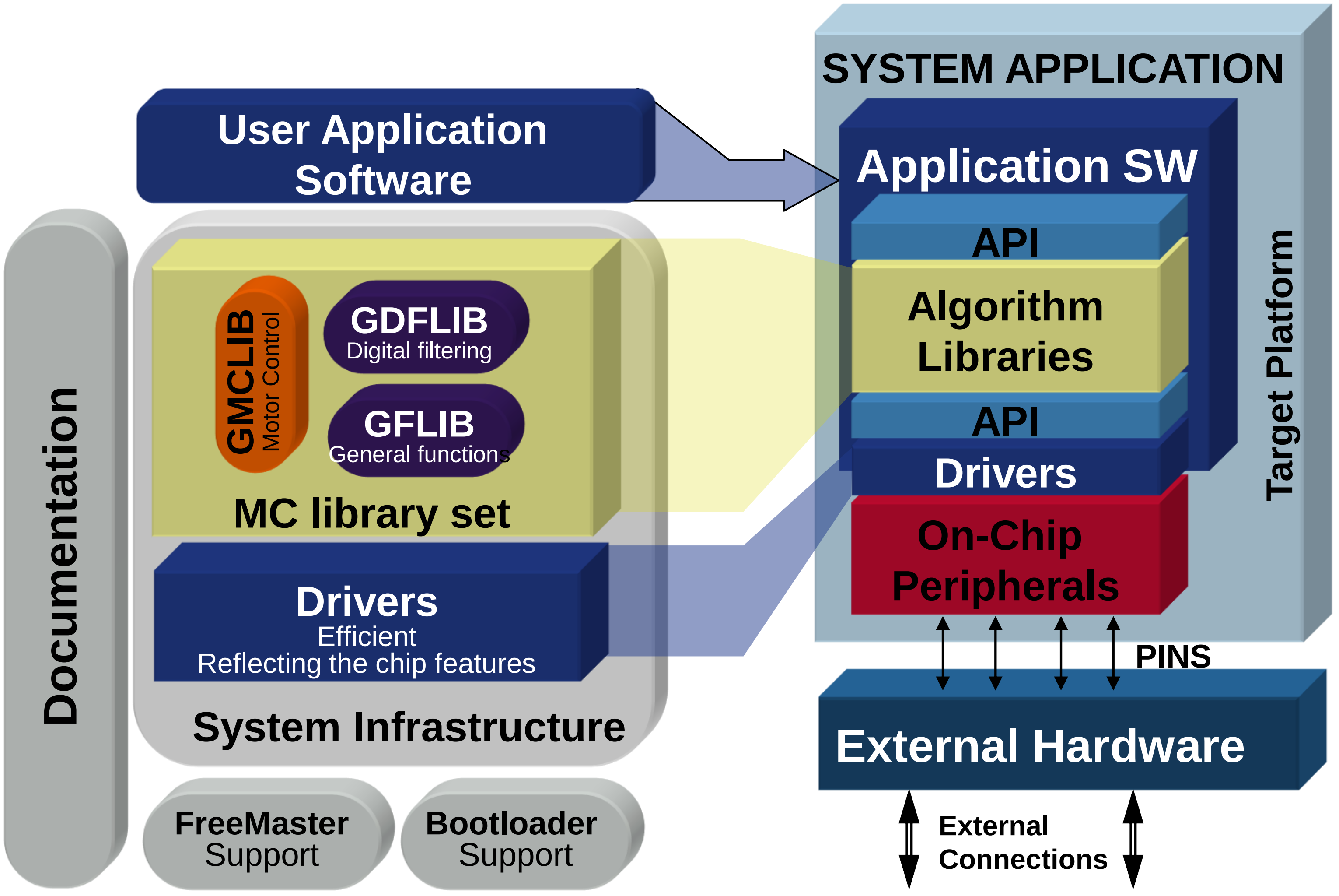
- User-friendly tool for real-time debug monitor and data visualization
  - Completely non-intrusive monitoring of variables on a running system
  - Display multiple variables changing over time on an oscilloscope-like display, or view the data in text form
  - Communicates with an on-target driver via USB, BDM, CAN, UART
- Establish a Data Trace on Target
  - Set up buffer (up to 64 KB), sampling rate and trigger
  - Near 10-µs resolution



http://www.nxp.com/freemaster



MBD Toolbox: Summary of Application Support

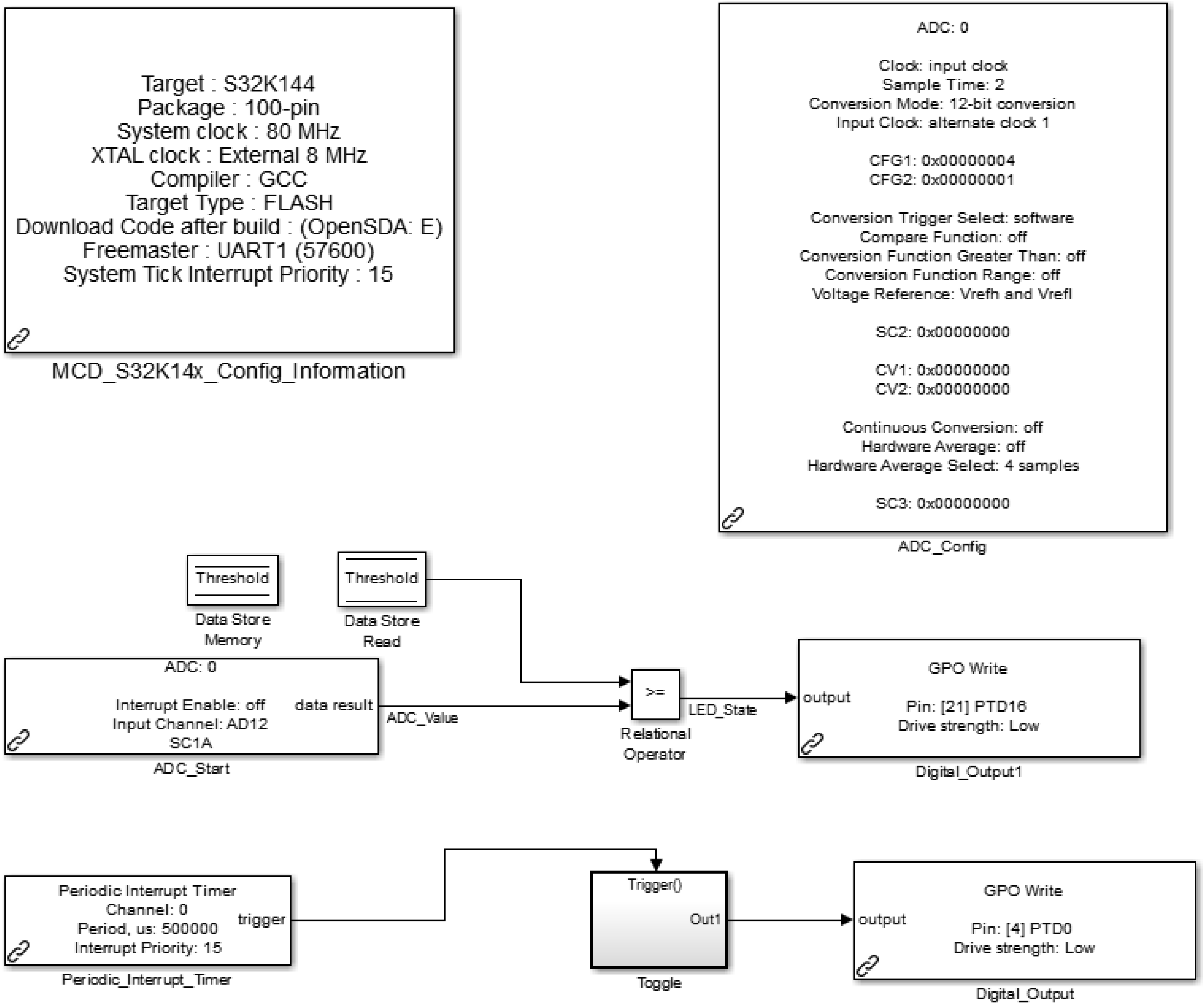


Model Based Design Toolbox Overview

Any Questions?

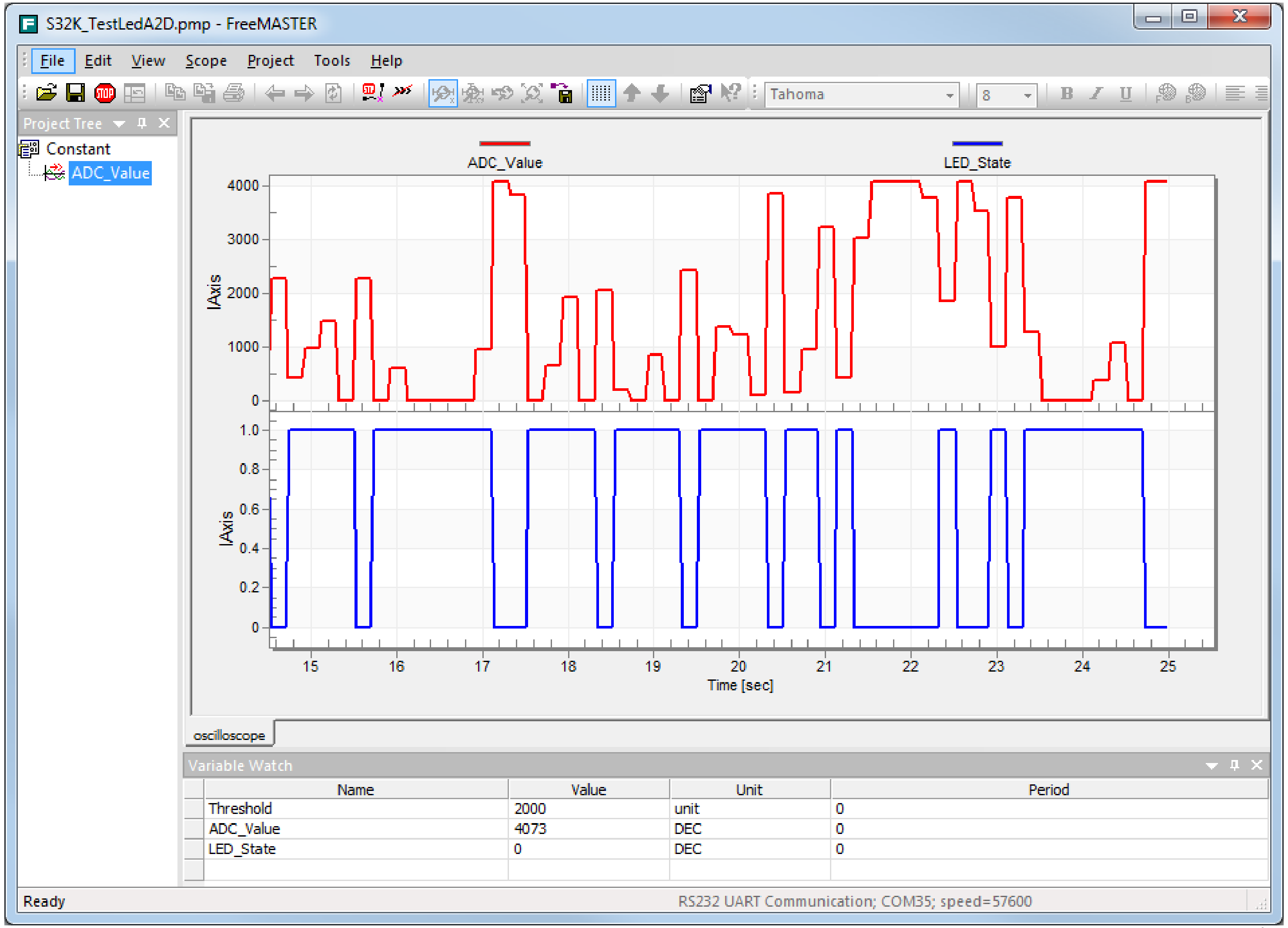
Example: Read A/D and Toggle LED Simple Model

Example: Read A/D and Toggle LED Simple Model



Example: Read A/D and Toggle LED Simple Model

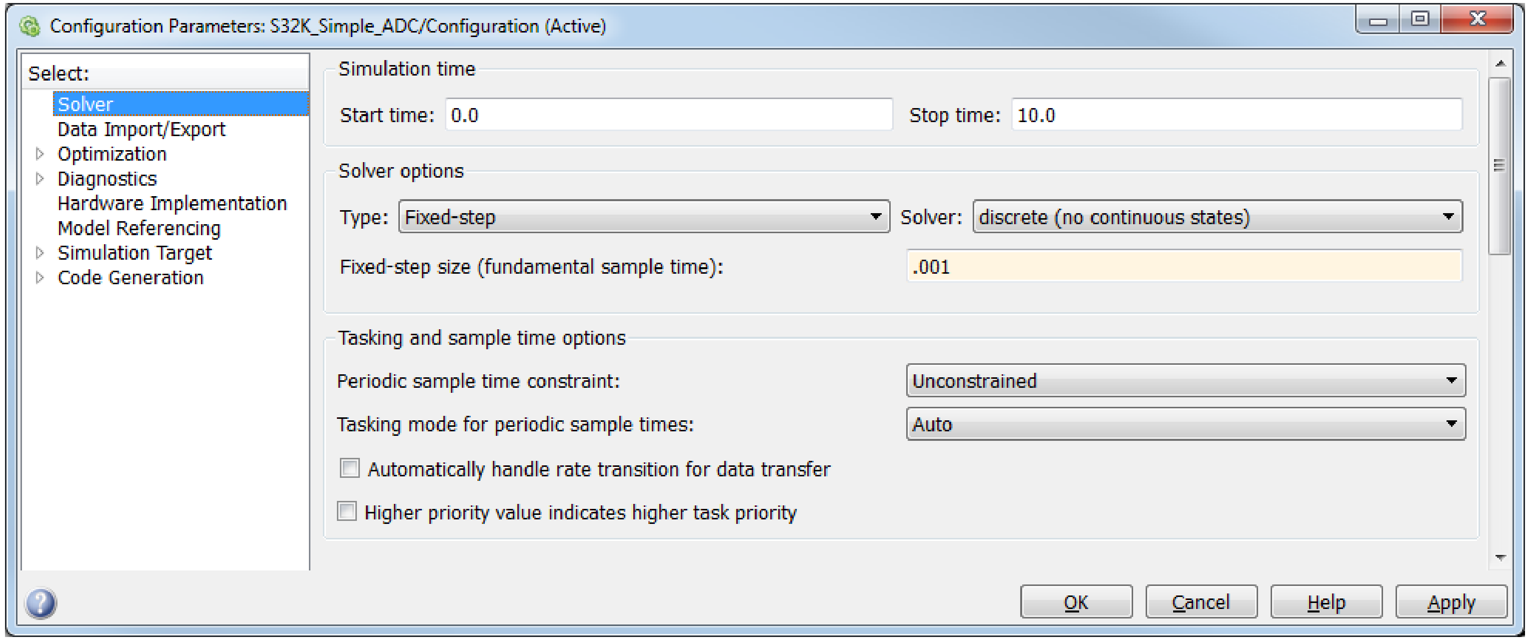
Using FreeMASTER



Example: Read A/D and Toggle LED Simple Model

Using FreeMASTER with Example

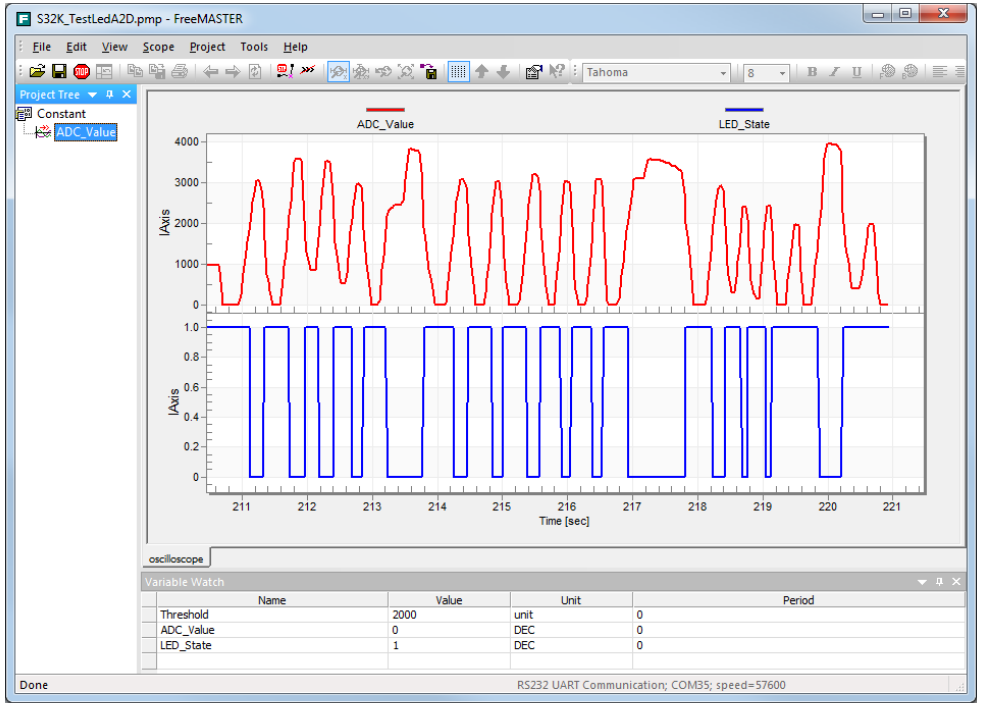
You will notice that there is dither in the A2D reading as you change the Potentiometer. This is because the system tick time in the model is too slow. To change this, go to the model and select the Simulation pull down menu. Then select Configuration parameters. Change the Fixed-step size from “auto” to “.001”



Example: Read A/D and Toggle LED Simple Model

Using FreeMASTER with Hands-On Demo

Disconnect FreeMASTER by pressing the STOP button. Then rebuild the model and have the bootloader download the software to the MCU. Re-Connect FreeMASTER and turn the Pot. You should see the following:



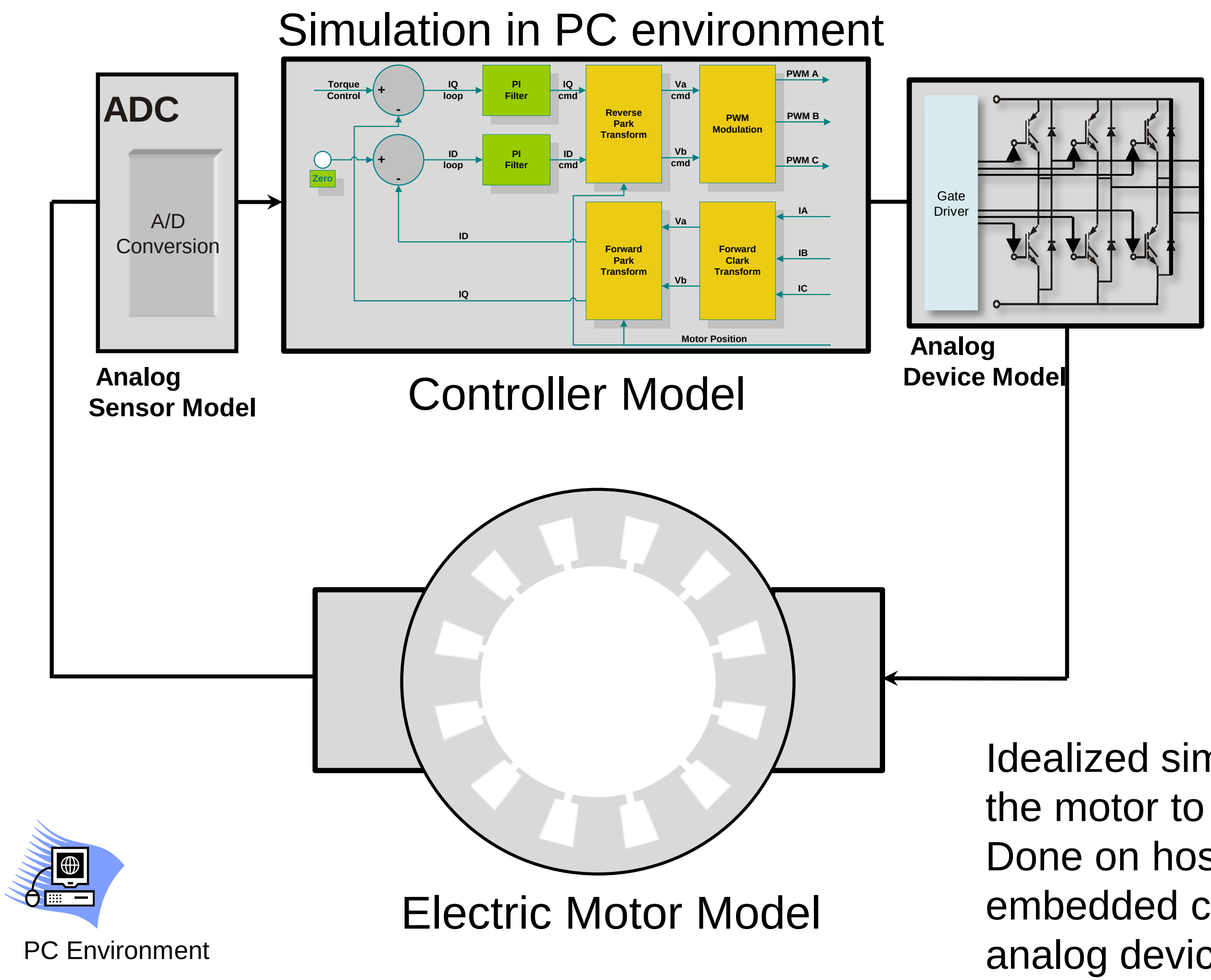
Insert demo video here – Simple A/D demo

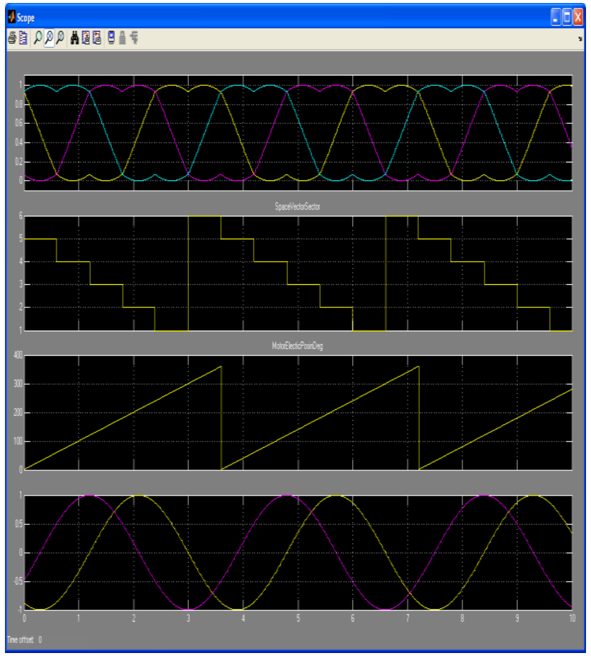
Example: Read A/D and Toggle LED Simple Model

Any Questions?

Model Based Design Steps

Model Based Design Steps: Step 1 (Simulation)

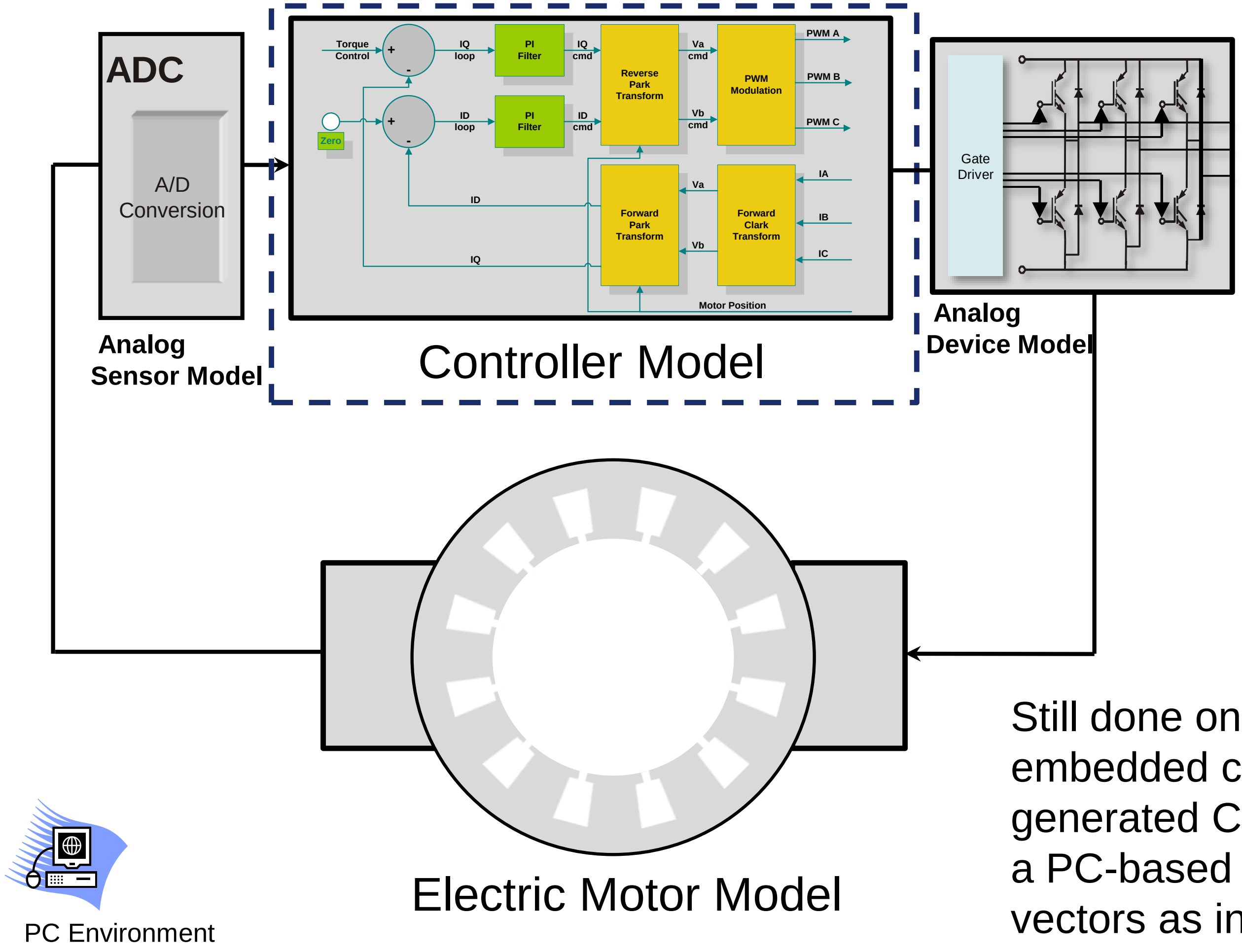


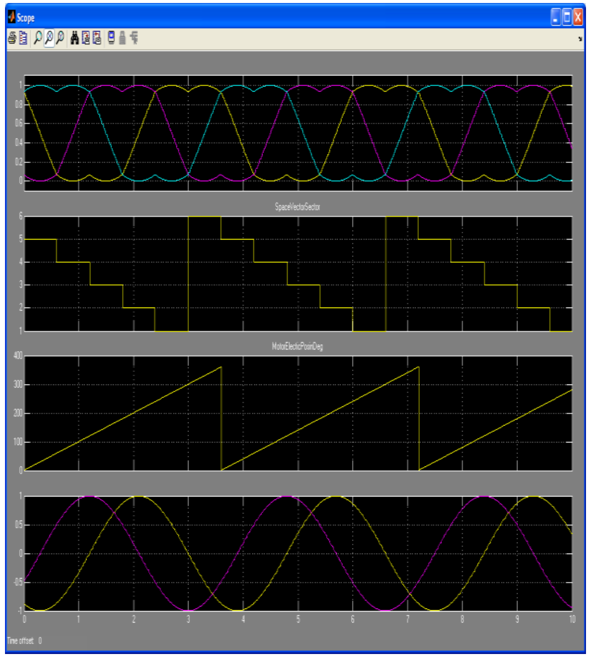


Idealized simulation of the controller and the motor to refine the control technique. Done on host PC without regard for embedded controller. Can optionally add analog device models for fault detection and signal control.

Model Based Design Steps: Step 2 (SIL)

(SIL) Generated code executes as atomic unit on PC

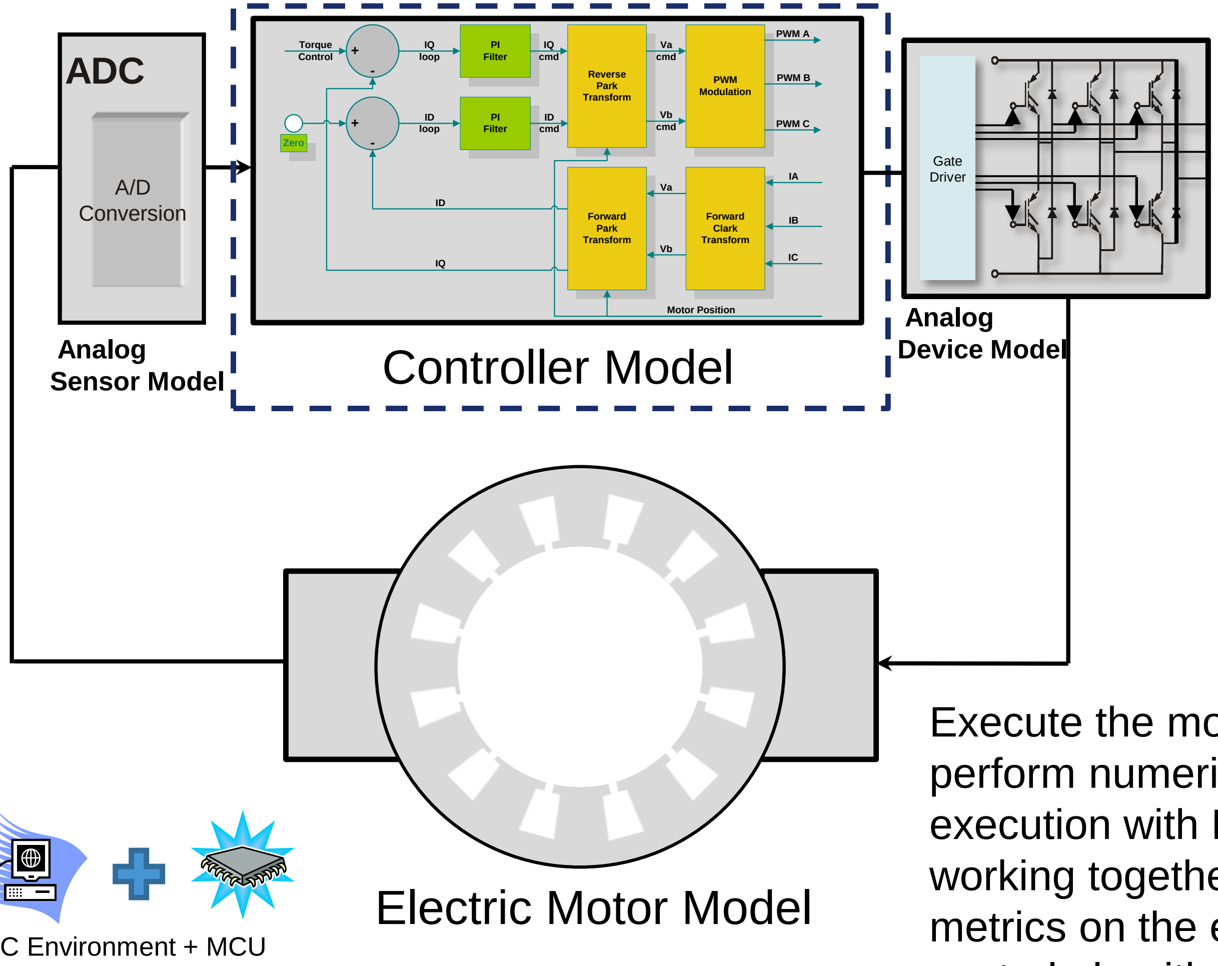


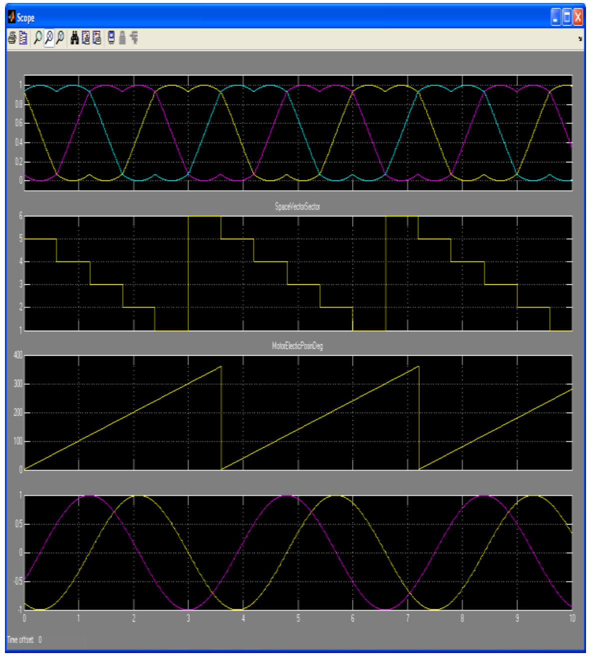


Still done on host PC without regard for embedded controller. Instead using generated C code that is compiled using a PC-based compiler. Run same test vectors as in simulation for C Code Coverage analysis and verify functionality.

Model Based Design Steps: Step 3 (PIL)

(PIL) Executes generated code on the target MCU





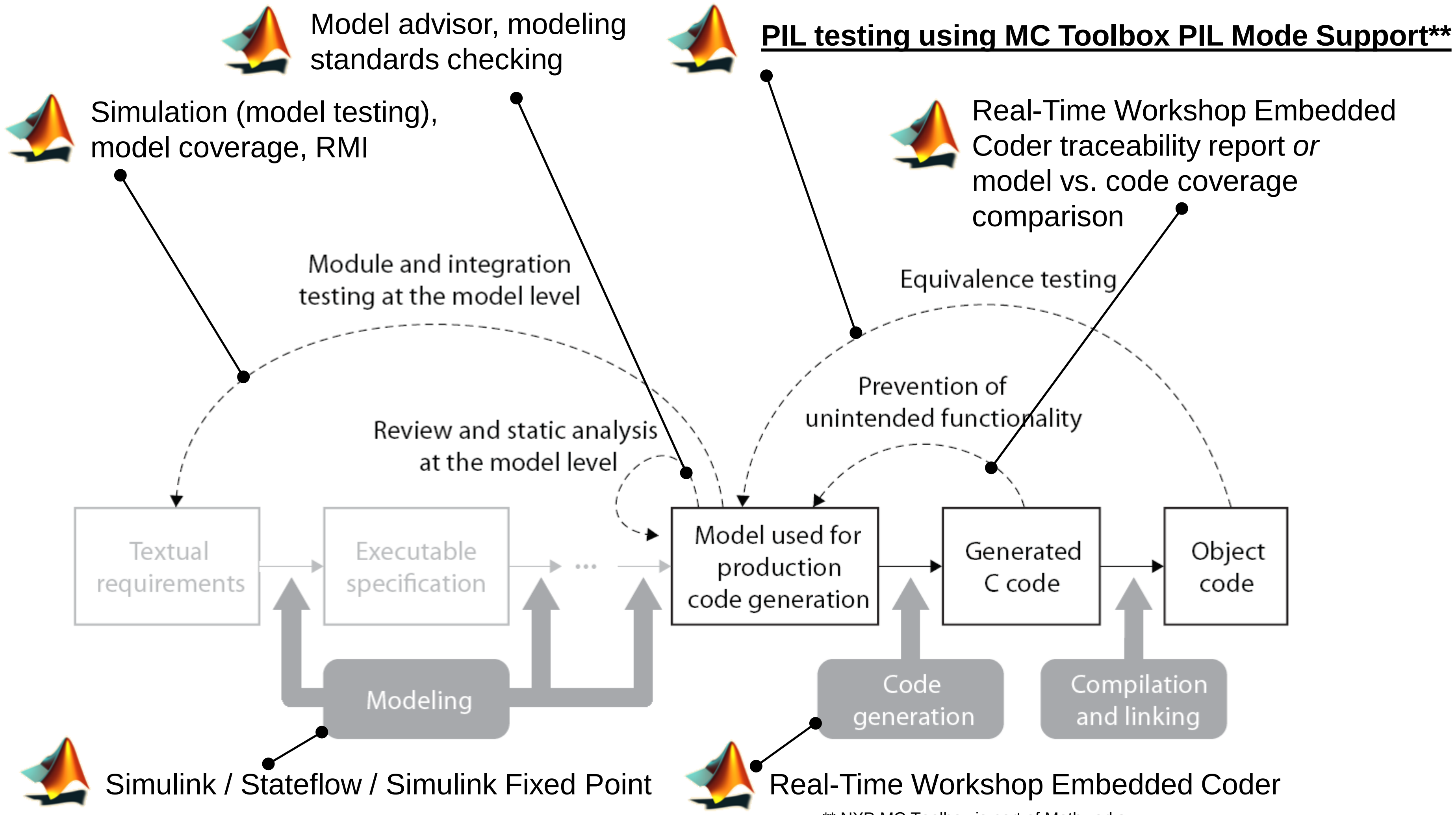
Execute the model on the target MCU and perform numeric equivalence testing. Co-execution with MCU and Model Based Design working together while collecting execution metrics on the embedded controller of the control algorithm. Validate performance on the MCU.

Model Based Design Steps: Step 3 (PIL)

Verification and Validation at Code Level

- This step allows:
  - Translation validation through systematic testing
  - To demonstrate that the execution semantics of the model are being preserved during code generation, compilation, and linking with the target MCU and compiler
- Numerical Equivalence Testing:
  - Equivalence Test Vector Generation
  - Equivalence Test Execution
  - Signal Comparison

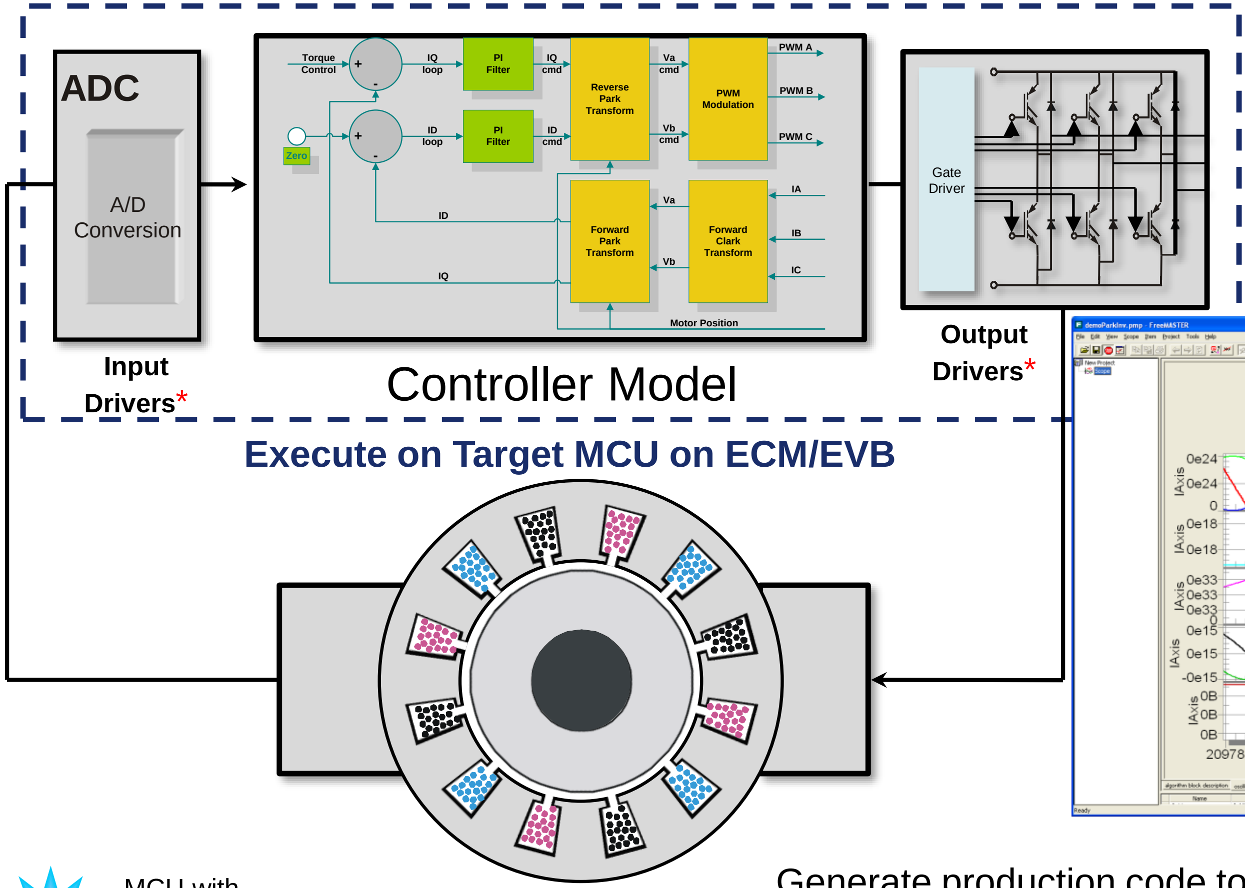
Example IEC 61508 and ISO 26262 Workflow for Model-Based Design with MathWorks Products*



*Workflow from The Mathworks™ Presentation Material Model-Based Design for IEC 61508 and ISO 26262

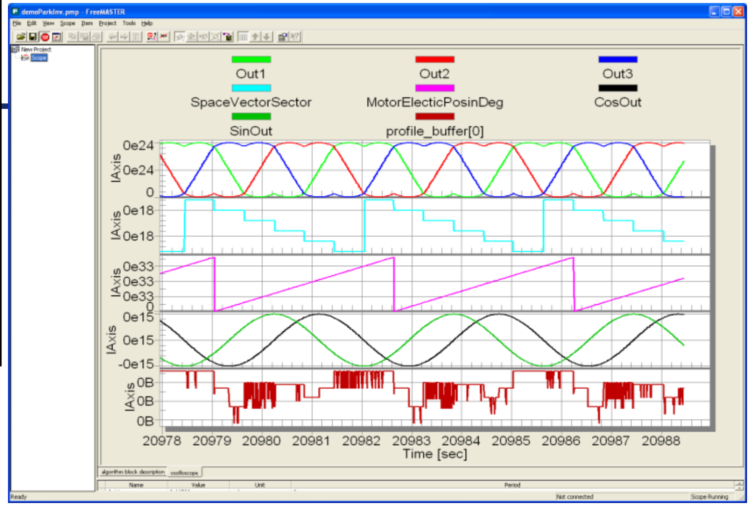
** NXP MC Toolbox is part of Mathworks Workflow outlined in The Mathworks™ Material Model-Based Design for IEC 61508 and ISO 26262 as well as part of certification qualification tool suite.

Model Based Design Steps: Step 4 (Target MCU)*



Electric Motor

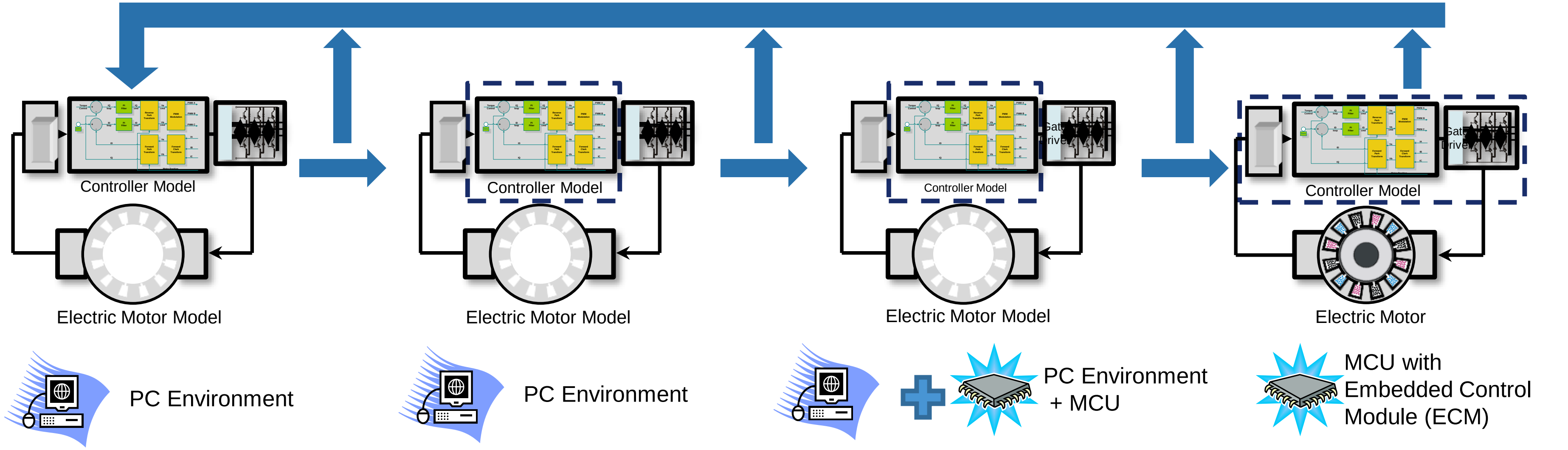
* I/O peripheral driver blocks can be included in the model, providing the analog driver interfaces needed to directly interface to devices external from the MCU.



MCU with Embedded Control Module (ECM)

Generate production code to run on embedded MCU with real motor while collecting execution metrics on the embedded controller of control algorithm. Validate performance on MCU and use FreeMASTER to tune control parameters and perform data logging.

Model Based Design Steps: Summary



Step 1 — System Requirements:
MBD Simulation Only
Software requirements
Control system requirements
Overall application control strategy

Modeling style guidelines applied
Algorithm functional partitioning
Interfaces are defined here

Step 2 — Modeling/Simulation:
MBD Simulation with ANSI C Code using SIL
Control algorithm design
Code generation preparation
Control system design
Overall application control strategy design
Start testing implementation approach

Testing of functional components of algorithm
Test harness to validate all requirements
Test coverage of model here
Creates functional baseline of model

Step 3 — Rapid Prototype:
MBD Simulation with ANSI C Code using PIL
Controller code generation
Determine execution time on MCU
Verify algorithm on MCU
See memory/stack usage on MCU
Start testing implementation approach
Target testing controls algorithm on MCU

Refine model for code generation
Function/File partitioning
Data typing to target environment done here
Scaling for fixed point simulation and code gen
Testing of functional components of algorithm
Test harness to validate all requirements
Test coverage of model here
Creates functional baseline of model
Equivalence testing

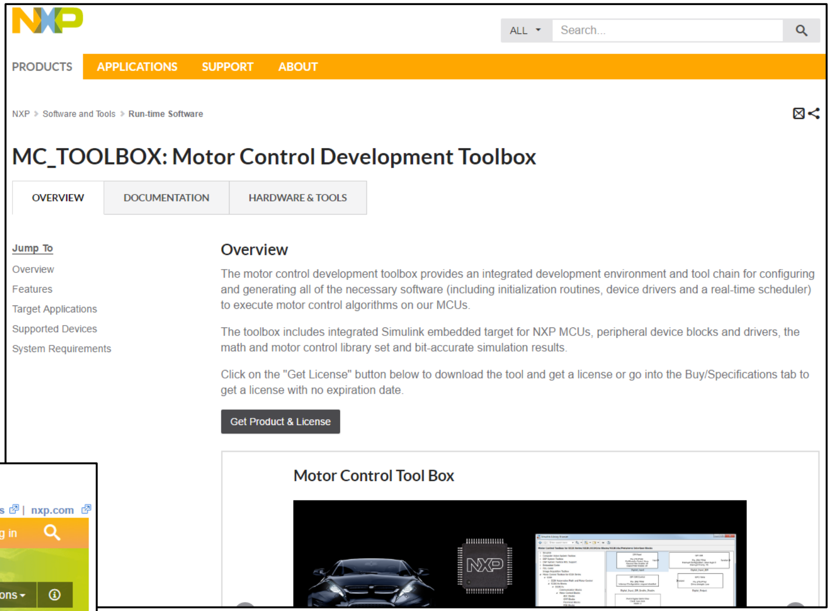
Step 4 — Target MCU Implementation
ANSI C Code Running on Target Hardware and MCU
Validation/verification phase
Controller code generation
Determine execution time on MCU
Start testing implementation on target ECM
Code generate control algorithm + I/O drivers. Complete implementation on ECM. Test system in target environment
Utilize calibration tools for data logging and parameter tuning

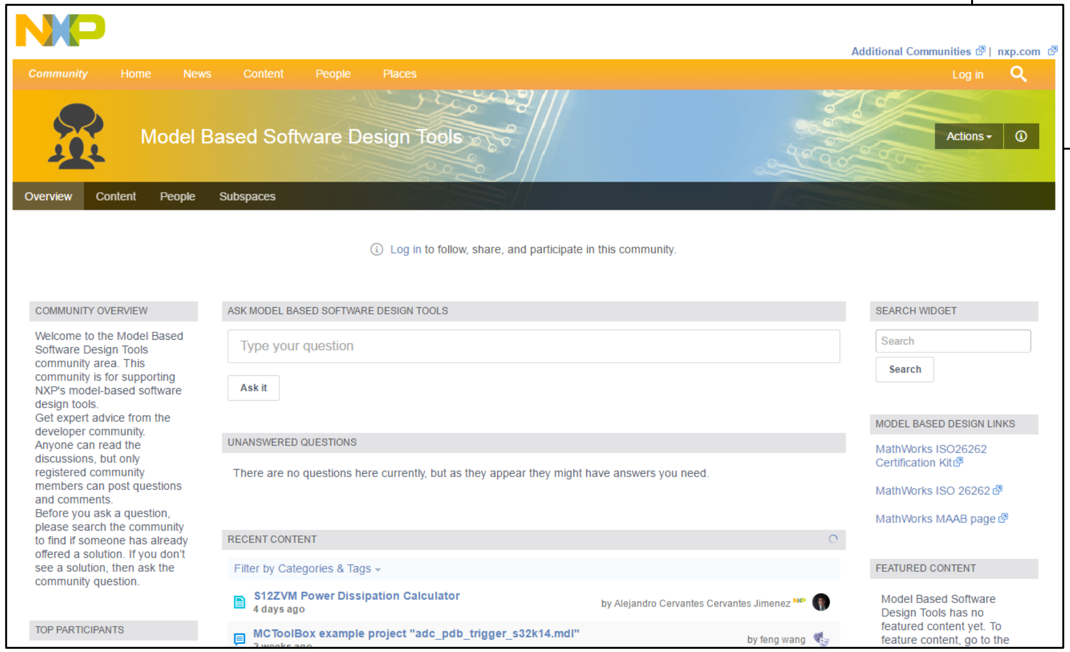
Execute code on target MCU
Functional testing in target environment
Ensure execution on target is correct as well as code generation on target is performing as desired.

How to get it and where to find support

Download and Support

- Download MBD Toolbox: www.nxp.com/mctoolbox
- MATLAB: www.mathworks.com
- Support: https://community.nxp.com/community/mbdt





Summary

Summary: Publications

MathWorks Announces Simulink Code Generation Targets in New Freescale(now NXP) Motor Control Development Toolbox
www.mathworks.com

- Simulink and Embedded Coder enable engineers to generate production code for Freescale(now NXP) MCUs in IEC 61508 (SIL3) and ISO 26262 (ASIL-D) compliant systems.

Freescale likes model-based design, says MathWorks
www.ElectronicsWeekly.com

- MathWorks says Freescale(now NXP) has made a major commitment to model-based design methodologies by adopting Simulink code generation targets in its motor control development toolbox. The toolbox, consisting of Simulink motor control blocks and target-ready …

A model-based tool to support rapid application development for Freescale(now NXP) MCUs
www.NXP.com — Beyond Bits—Issue VIII

- Model-based design (MBD) is becoming the standard methodology for developing embedded systems that implement the desired behavior of a control system. MBD is a graphical method …

NXP Automotive FAE interface for TW customer

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