TI | Developer Conference

21-30 May 2008 Seoul · Taipei · Shenzhen · Shanghai · Beijing

INNOVATION IDEAS

Minds in Motion

Design and Implementation of Motor Control Systems with MATLAB, Simulink, and TI C2000™ DSPs

A Model-Based Design Approach

Jing Wu

Applications Engineer

The MathWorks

Texas Instruments

DEMO – From Models to Hardware –

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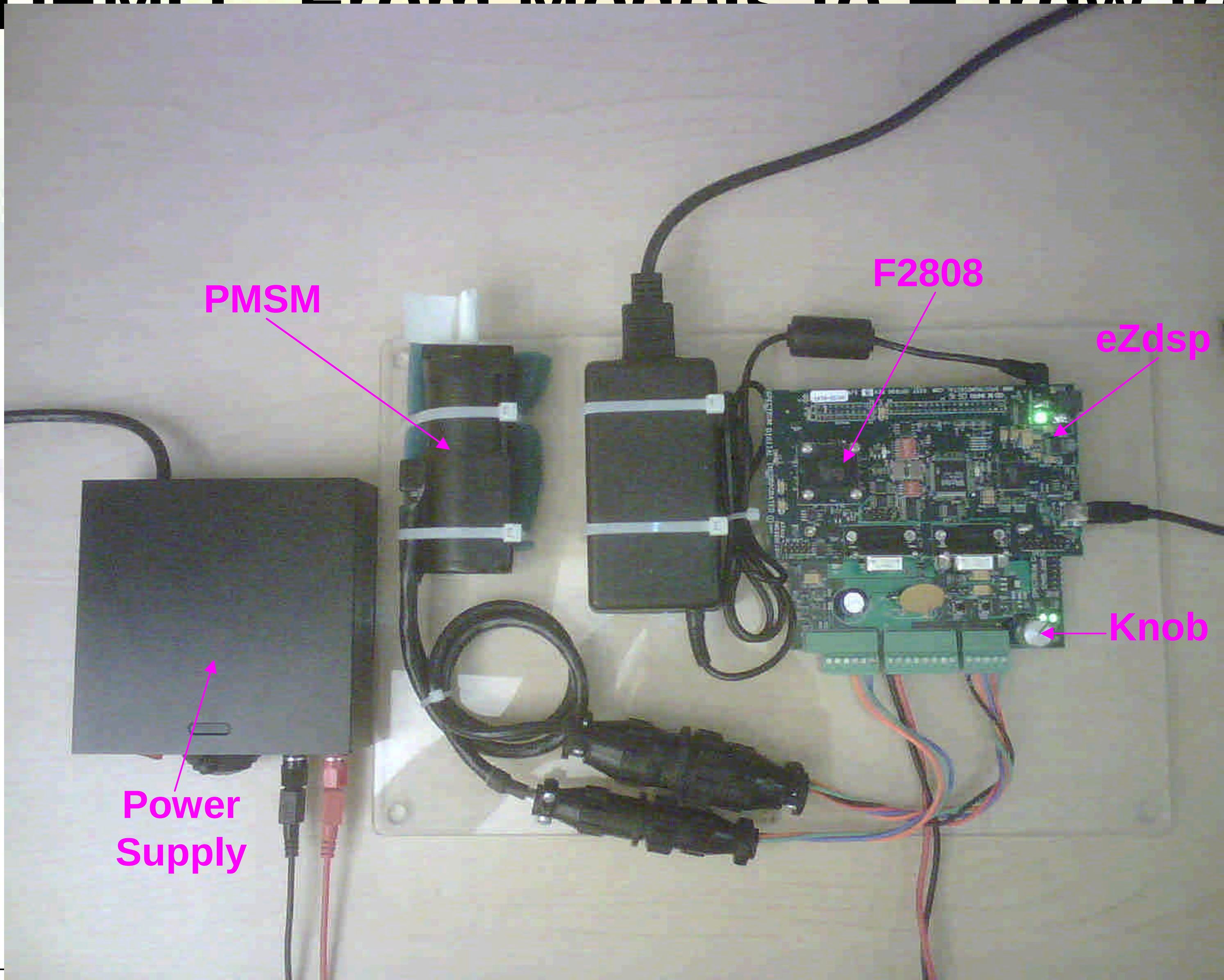
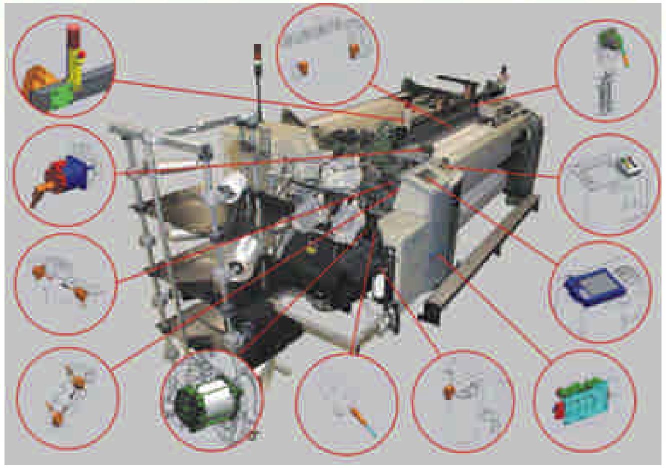


Agenda

- **Model Based Design w/ MATLAB and Simulink**
  - Overcome today's design challenges
- **Motor Control Systems Design**; a PMSM example
  - 4 Steps to design and implement your system
    - Design with simulation
    - Rapid Prototyping
    - Verify your code
    - Generate production code
  - Validate and verify your system
- **Summary and Next Step**

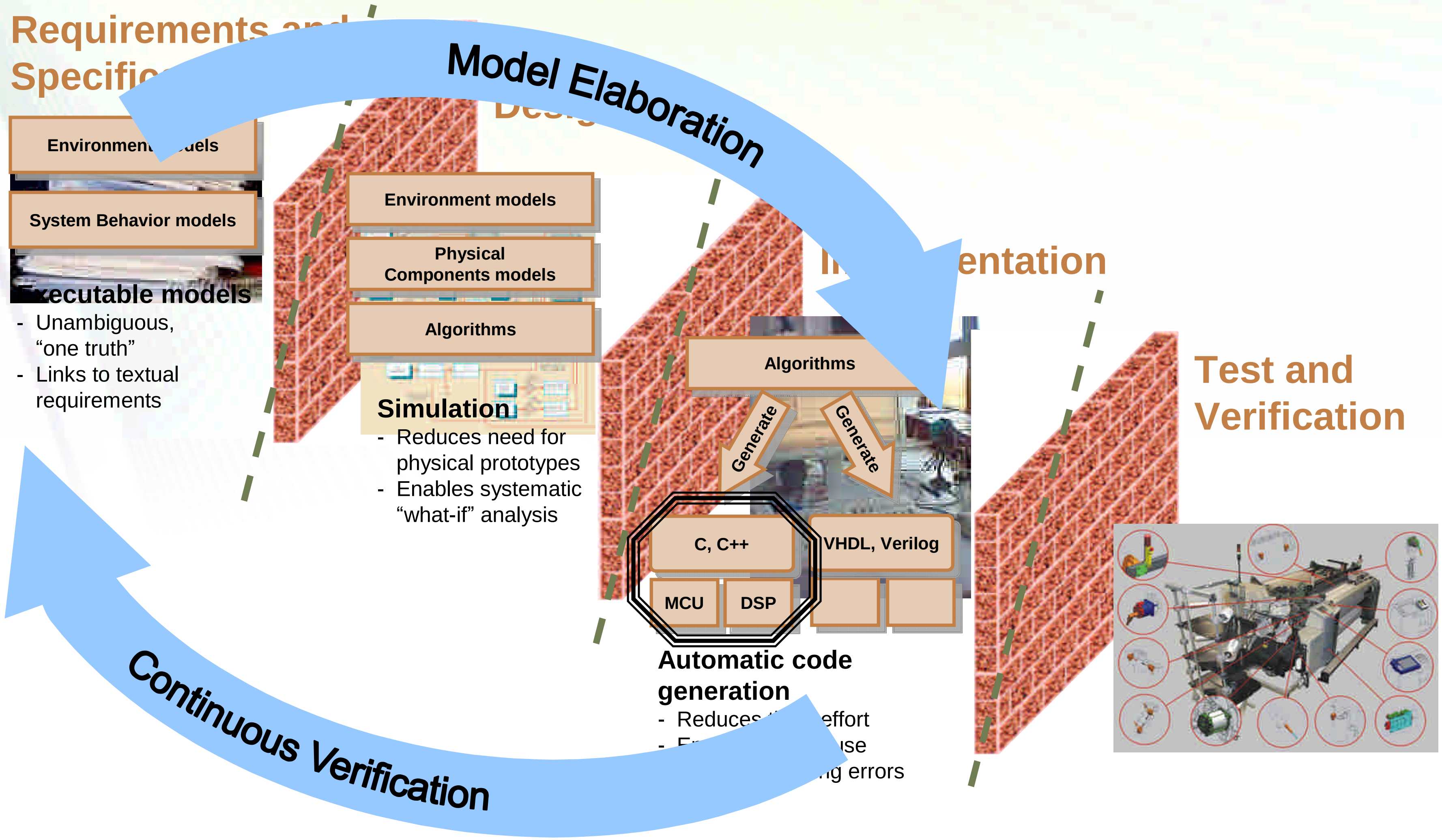
Today's Design Challenges

- Increasing complexity
  - Standardization
  - Security



- Intensified Competition
  - Time-to-market pressure
  - Cut product costs
  - Preserve product quality
- Design team integration
  - Analog/Mixed-Signal, digital hardware, DSP/control software

From Traditional Embedded System Development to Model-Based Design



Model Based Design Workflow

Requirements and Specifications

Environment models

System Behavior models

Executable models
- Unambiguous, "one truth"
- Links to textual requirements

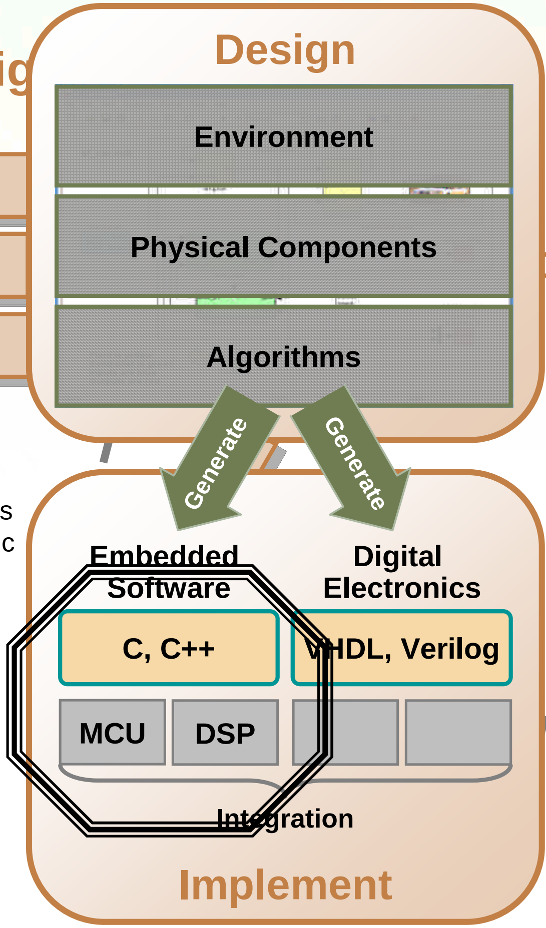
Design

Environment models

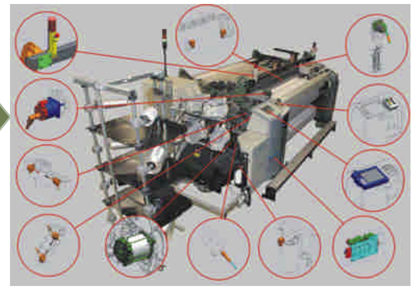
Physical Components models

Algorithms

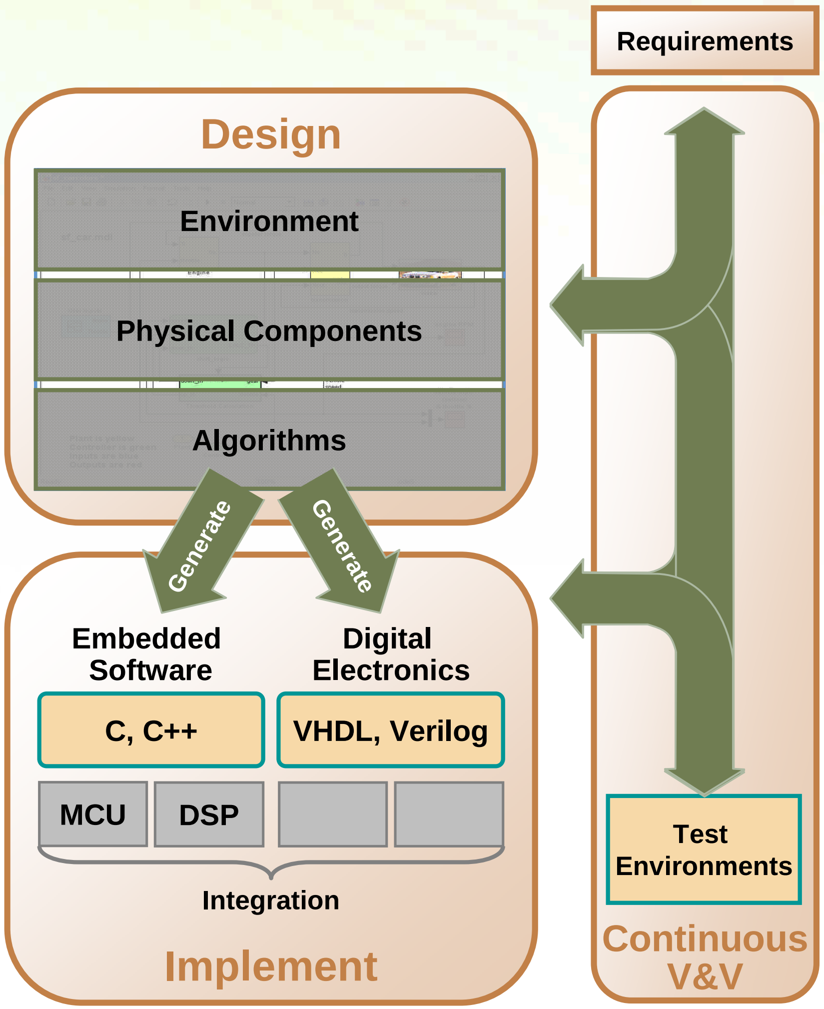
Simulation
- Reduces need for physical prototypes
- Enables systematic "what-if" analysis



Test and Verification



Model Based Design Workflow



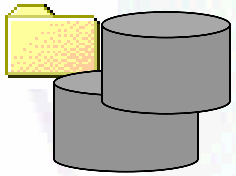
Model-Based Design with MATLAB and Simulink

MATLAB Product Family

The Platform for Model-Based Design

MATLAB: Technical computing environment

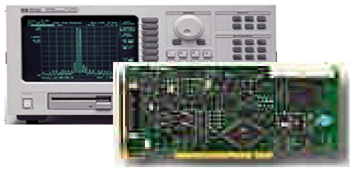
Data



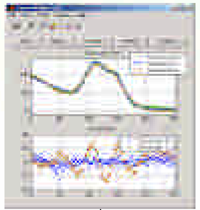
Software

*Languages
*Applications

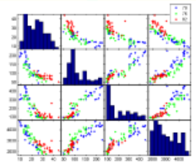
Hardware

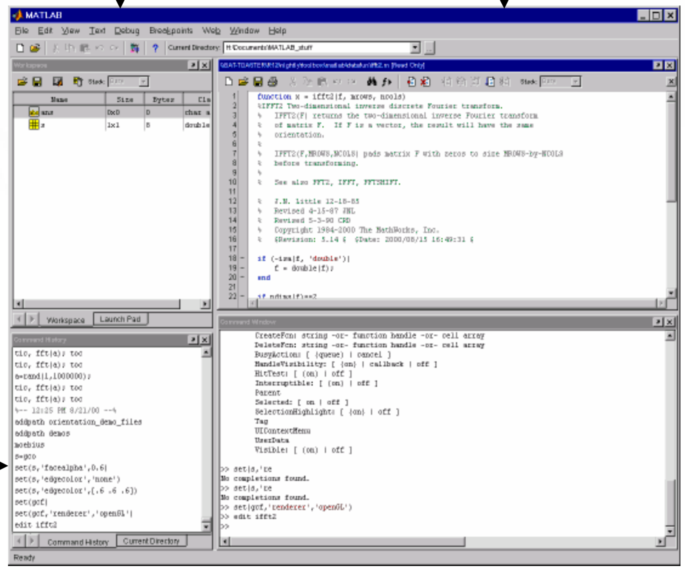


Analysis



Visualization





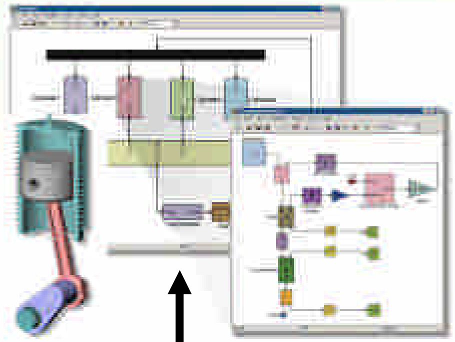
Reporting & Documentation

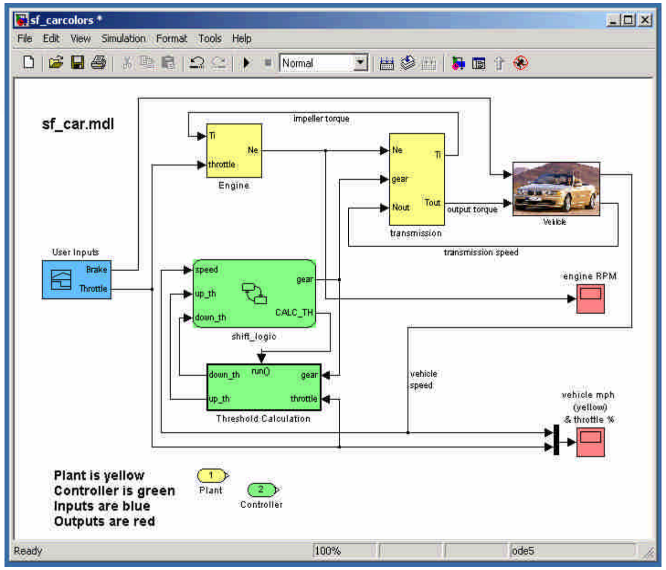
Deployment

Simulink for Model-Based Design

Simulink: Graphical, modeling and simulation environment

Multi Domain Modeling

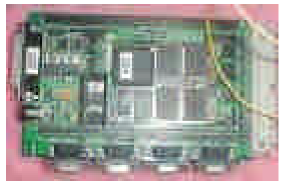




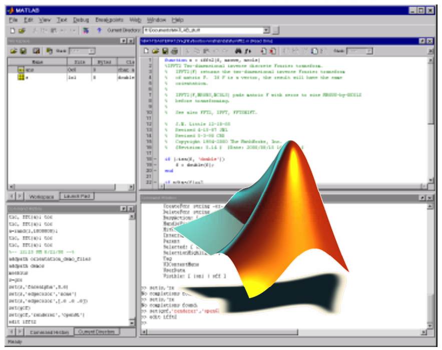
Rapid Prototyping

Hardware in the loop

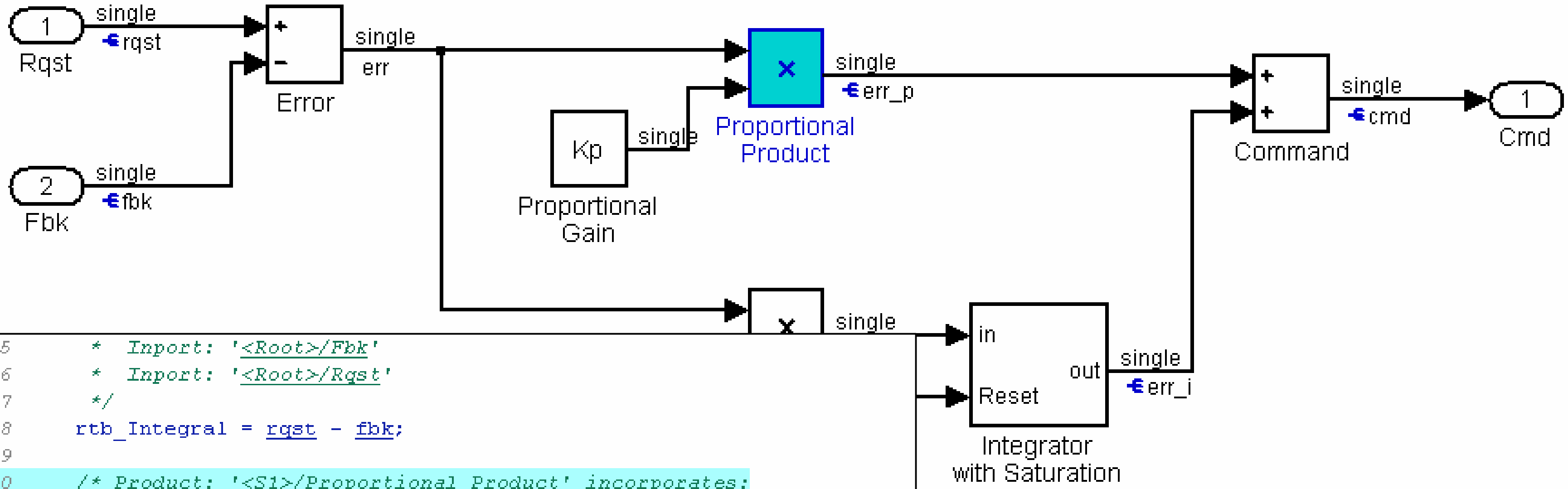
Embedded Systems



MATLAB Products



Trace Between Code and Specification



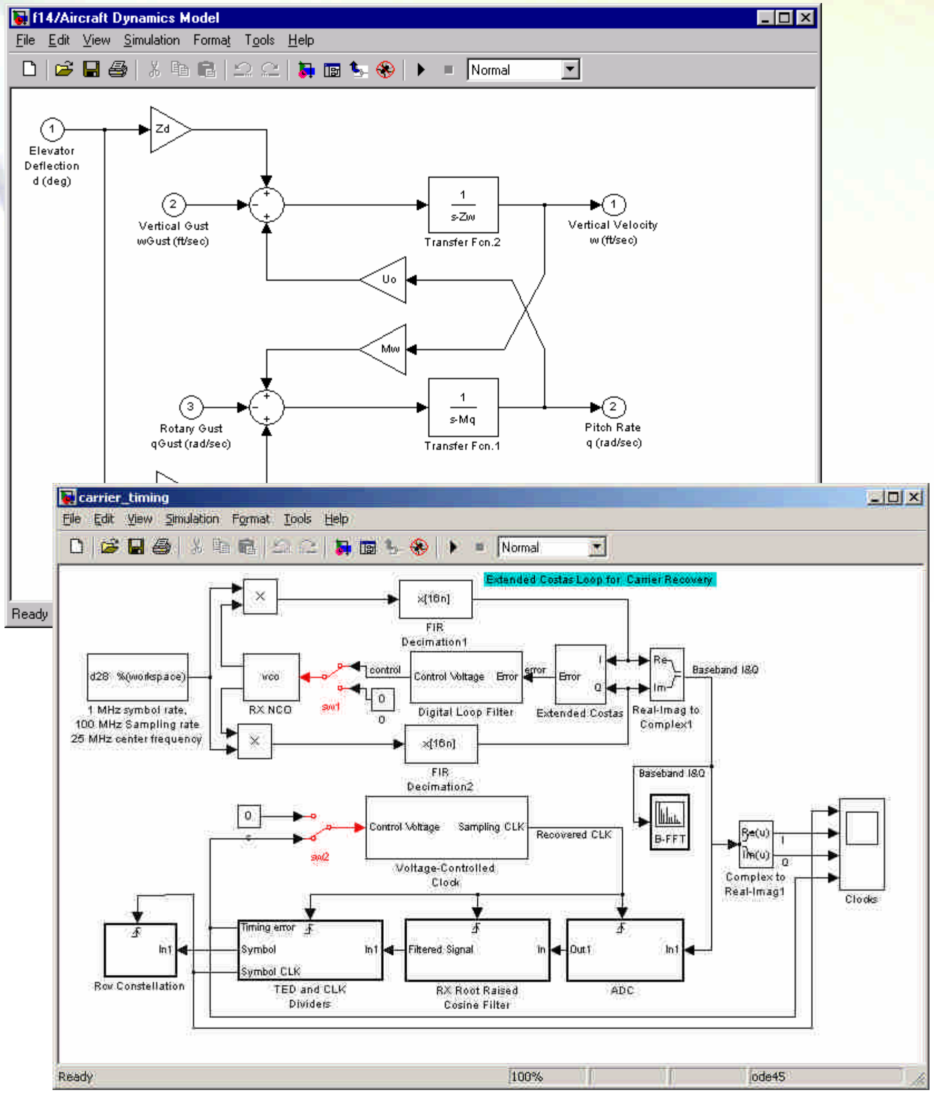

```
 * Inport: '<Root>/Fbk'
 * Inport: '<Root>/Rqst'
 */
rtb_Integral = rqst - fbk;

/* Product: '<S1>/Proportional Product' incorporates:
 * Constant: '<S1>/Proportional Gain'
 */
err_p = rtb_Integral * Kp;

/* Product: '<S1>/Integral Product' incorporates:
 * Constant: '<S1>/Integral Gain'
 */
rtb_IntegralProduct = rtb_Integral * Ki;

/* Switch: '<S2>/Reset Switch' incorporates:
 * Constant: '<S2>/Reset Value'
 * Inport: '<Root>/Reset'
 * UnitDelay: '<S2>/Unit Delay'
 */
if (reset != 0.0F) {
  rtb_Integral = 0.0F;
```

Complex Timing and Concurrency



- Complex timing
  - Feedback
  - Asynchronous edge triggered blocks
  - Multi-rate digital with arbitrary sample rates
- Concurrency
  - True expression of parallelism
  - Important for whole system or hardware sub-system design

Who is Using Model-Based Design and Code Generation and for What Type of Application

- Big companies as well as startups
  - Toyota
  - BAE
  - Intacton, Duhyney…
- General applications as well as safety critical applications
  - Control, audio, video, medical, process
  - DO178B, Autosar, ABS systems…

Toyota Uses MathWorks™ Tools to Increase Quality, Reduce Costs, and Speed Time to Market of New Vehicles

Challenge

To speed up design, increase quality, and reduce R&D costs by finding an alternative to traditional design methods

Solution

Use MathWorks tools for control design to prototype, model, test, and refine control strategies in an integrated design environment

Results

- Deliver a better product to market faster — and at a lower cost
- Reduced time to embedded code
- Forge a pathway to innovation

"MATLAB®, Simulink®, and Stateflow®… have become the *de facto* standard at Toyota for simulation, data processing, and controls design. It would be impossible to list all of the applications for these tools at Toyota."

Akira Ohata
Toyota

Safety-Critical Certification

May 18-19, 2004

Software Tools Forum

Federal Aviation Administration

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY

1:45-2:10	Verification Tool Research Sponsored by FAA	Hayhurst (NASA) Santhanam, Waldrop, Chilenski (Boeing)
2:10-2:55	Use of the MathWorks Tool Suite to Develop DO178B Certified Code	Potter (Honeywell)
2:55-3:25	*Break*	
3:25-4:05	Tool Qualification - A Living Process	Roth (Honeywell)
4:05-4:30	Structural Coverage Analysis for Level A	Romanski (Verocel)
4:30-4:55	Model-Based Analysis and Test Generation for Complex Systems	Busser, Blackburn, Nauman (T-VEC Technologies)
4:55-5:00	Wrap up	
5:00-	*Reception*	

More than one million lines of automatically generated flight code certified to DO-178B within past year

8:45-9:00	Verification Tool Qualification: A Commercial Tool Vendor's Perspective of the FAA Qualification Process	Reeve (Patmos) Whipple (Metrowerks)
9:00-9:15	TTP-Verify	Schwarz (TTTech)
9:15-9:30	Experience Using an Automated Analysis/Code Coverage Tool for a Joint Strike Fighter Component and Space Shuttle Flight Software Verification Support Software	Badgley, Davis (GBTech)
9:30-10:00	*Break*	
	Process and Emerging Technology	
10:00-10:40	Tool Intensive Software Development: New Challenges for Verification, Validation, & Certification	Heimdahl (Univ. of Minnesota)
10:40-11:20	Embedded System Architecture Analysis Using the SAE AADL	Feiler, Hudak (SEI) Gluch (ERAU)
11:20-11:35	Using AADL for Safety and Security Features	Colbert (Univ. of South California) Land (High Integrity Solutions)
11:35-11:50	Reusing Tool Qualification Data: CAST Perspective (Draft Paper)	Kierson (FAA)
11:50-12:10	Application of the Reusable Software Component (RSC) Guidance to the Qualification of a Software Verification Tool	Waldrop, Martz, Santhanam (Boeing)
12:10-1:30	*Lunch*	
1:30-1:45	The Simulink/Stateflow Analyzer (SSA)	Galloway, Toyn, Iwu, McDermid (U. of York)
1:45-2:00	A Revolution in Avionics Software Safety Verification Traceability	O'Leary (Verocel)
2:00-2:15	Using Tool Service History for Tool Qualification	Petesch (Hamilton Sunstrand)
2:15-2:30	A High-Productivity Tool for Developing Complex Safey-Critical Software	Crocker (Escher Technologies)
2:30-3:00	Software Verification with Emerging Technologies	Thornton, Frey (Honeywell)

Honeywell, FAA Software Tools Forum, May 2004

http://www.mathworks.com/company/newsletters/aero_digest/aug04/Honeywells.pdf

Successful Deployments of Model-Based Design

Caterpillar
- *Engine and Machine Control*

DaimlerChrysler
- *Cruise Control, Trucks*
- *Body Control, Cars*

Delphi
- *Climate Control*

General Motors
- *Powertrain ECU Software*

Jaguar
- *Body Controls*

Motorola
- *Seats, Battery, and Chassis Controls*

Siemens
- *Chassis Controls for Commercial Vehicles*

Toyota
- *Powertrain ECU Software*

Visteon
- *Powertrain Controls and Audio Systems*

Boeing
- *Radar, Imaging and Controls*

Honeywell
- *DO178B Safety Critical Systems*

Lockheed Martin
- *Flight Controls, Joint Strike Fighter*

NASA Hyper-X
- *Achieved SEI CMM Level 5 with MBD*

Northrop Grumman
- *UAV and Radar Systems*

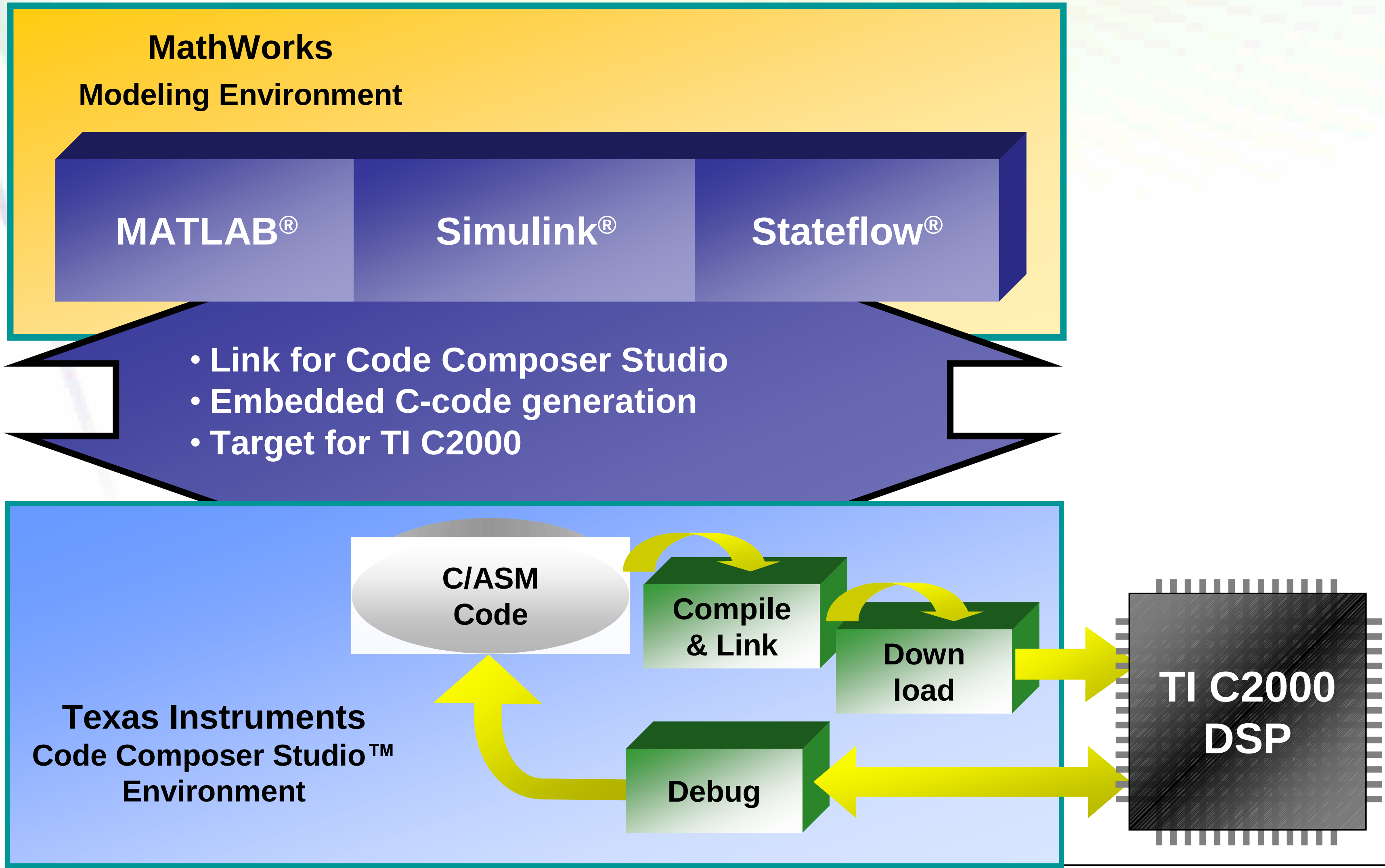
RealTek
- *Audio system CODECs*

Sandia
- *FPGA-based Radar Systems*

For a full list of user stories, see *http://www.mathworks.com/company/user_stories*

Motor Control Systems with MATLAB, Simulink, and TI C2000™ DSPs

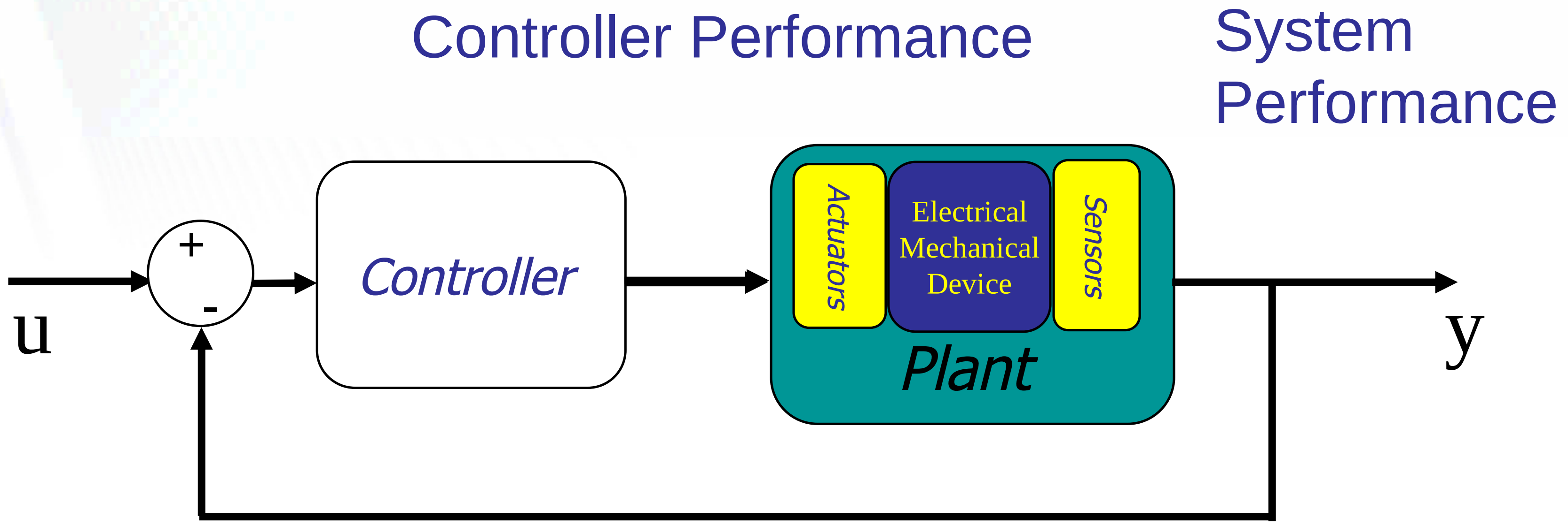
MATLAB, Simulink, and TI C2000™ DSPs



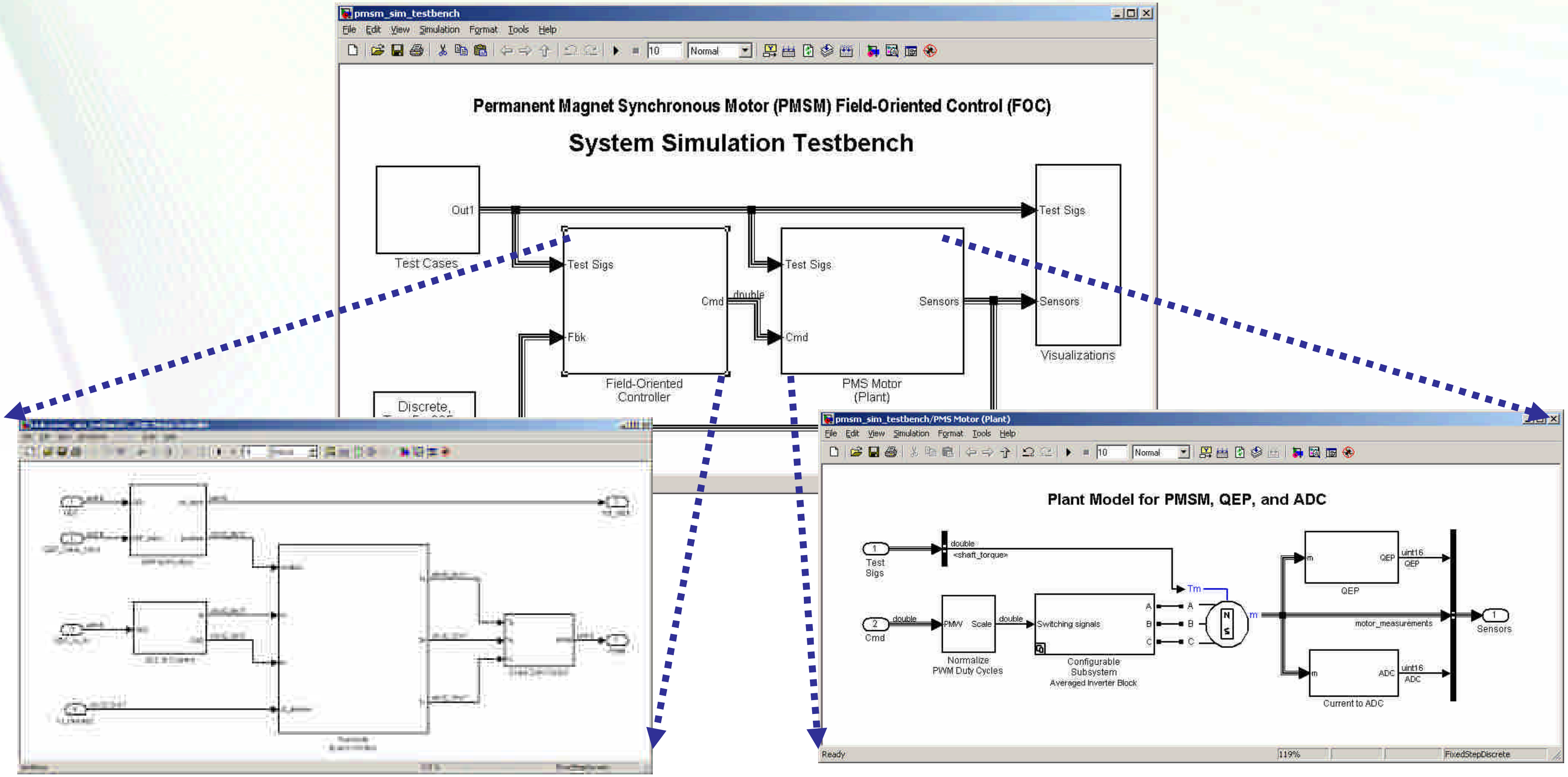
4 Steps of Design

1. Design with simulation
2. Rapid Prototyping
3. Verify your code
4. Generate production code

STEP 1 - Simulate controller and electro-mechanical plant models to verify specification and optimize system performance.

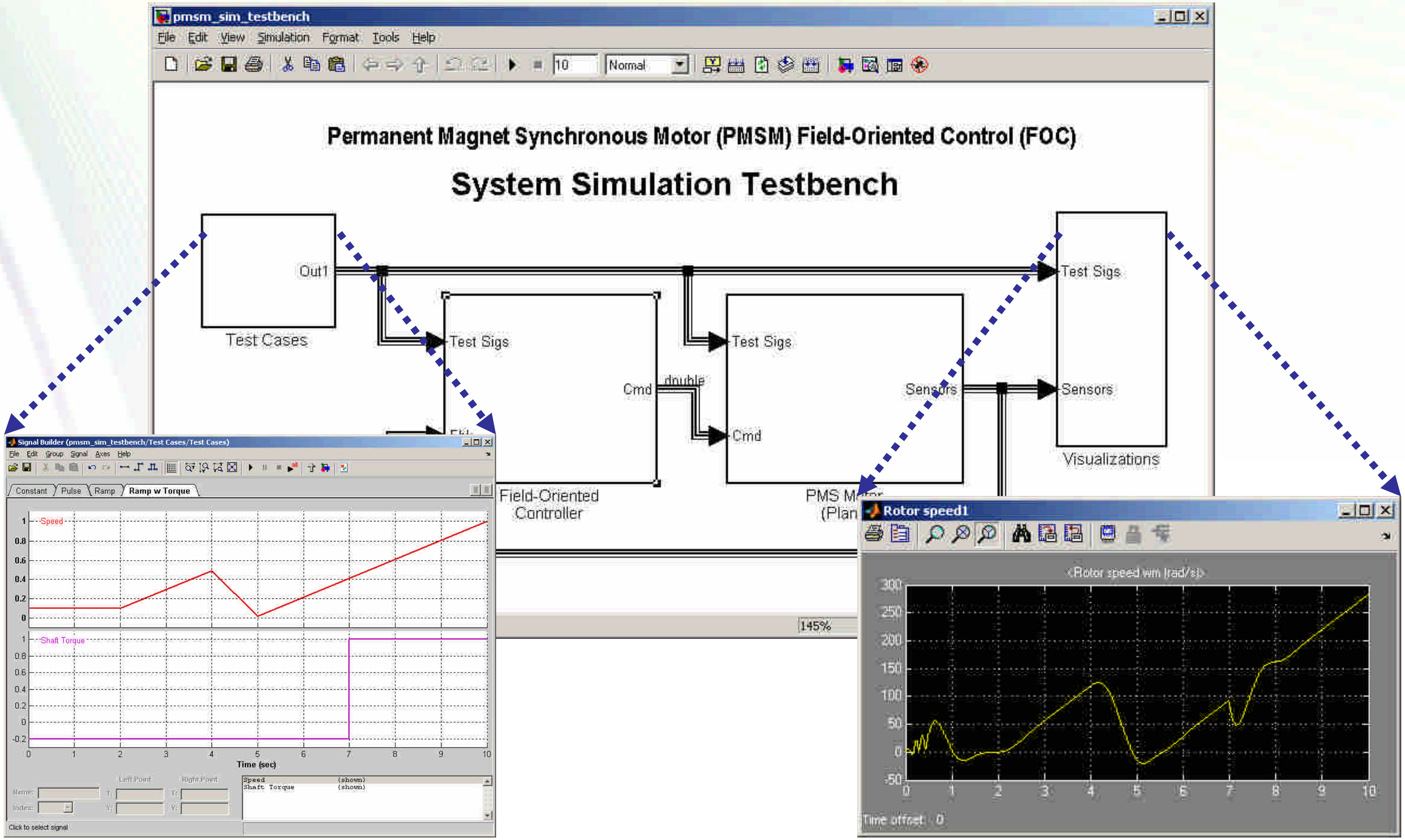


A PMSM System - Design and Tune through Simulation

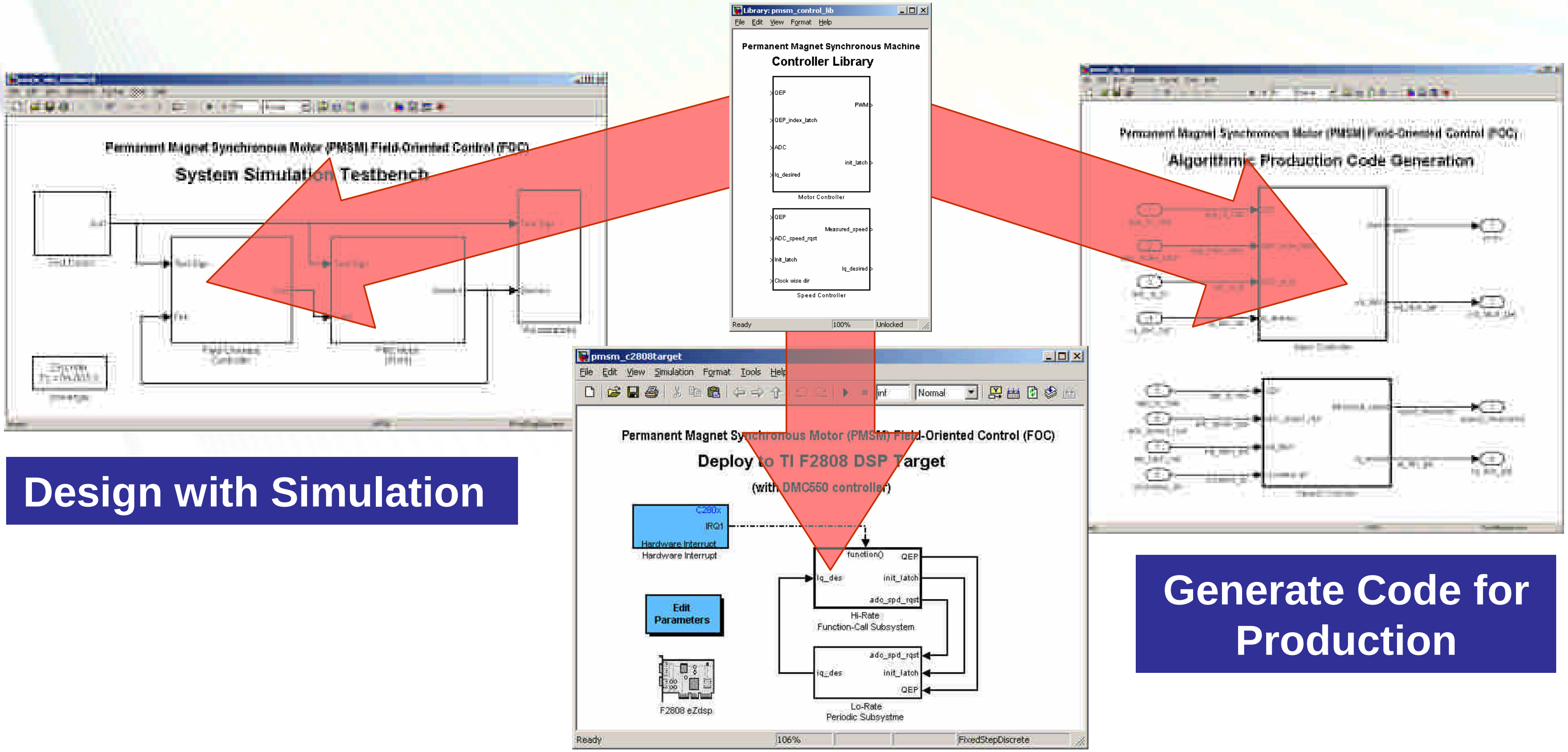


- **Design Fixed-Point Controller**
- **Specify Motor (Plant) Dynamics**

Specify Tests and Visualize Results



Algorithm Specifications and Reuse

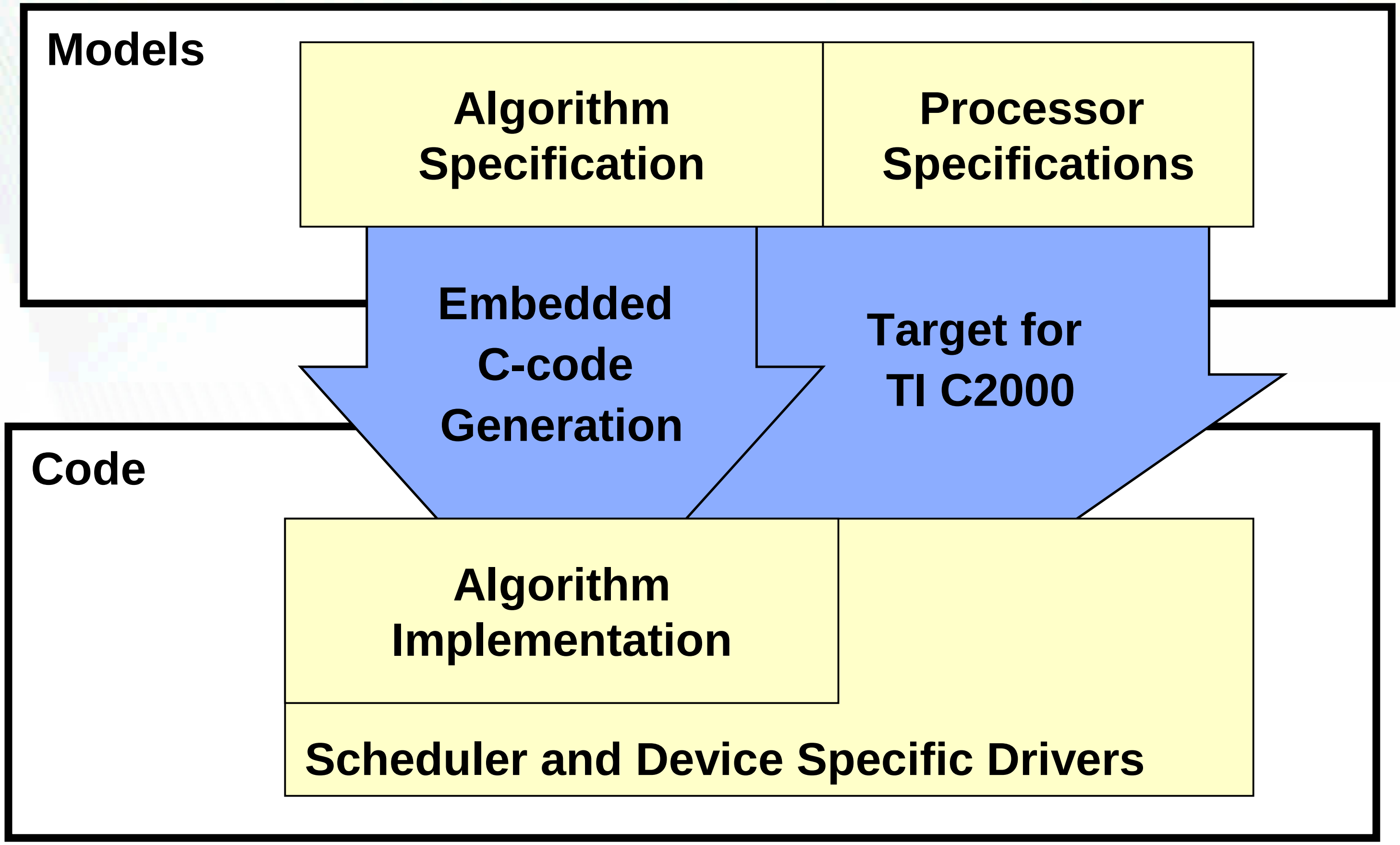


Design with Simulation

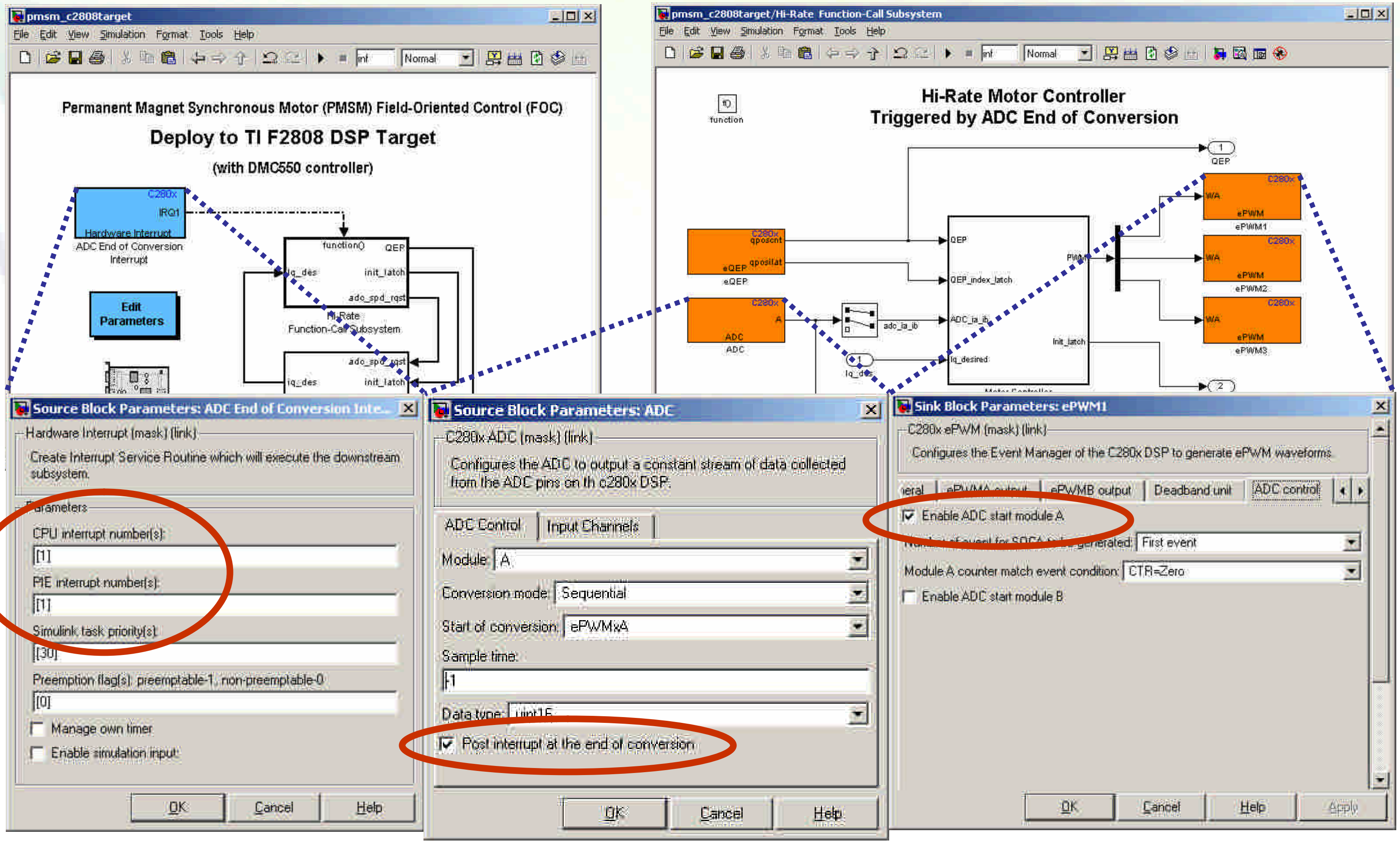
Generate Code for Production

Generate Code for Rapid Prototyping

STEP 2 - Rapid Prototyping - "Target Support Package TC2™" for testing in a real environment



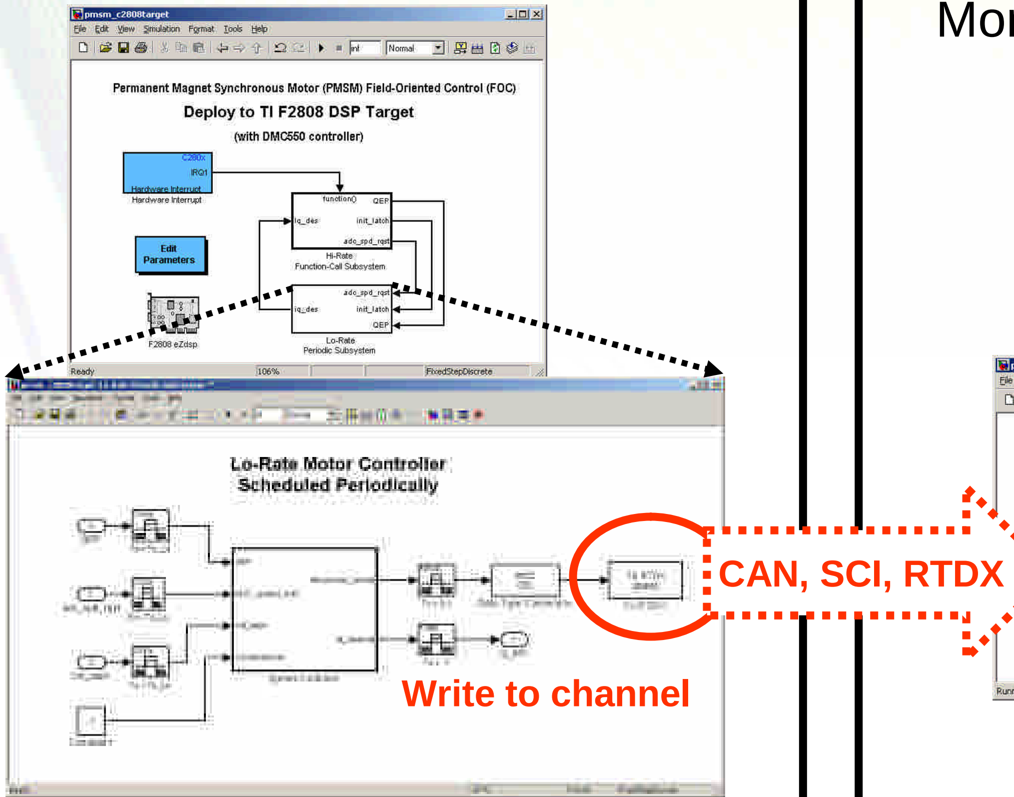
Rapid Prototyping - Asynchronous Scheduler and Device Drivers: Synchronizing ADC and PWM for F2808



Target – Host Communications for Tuning and Monitoring

Target Side Model

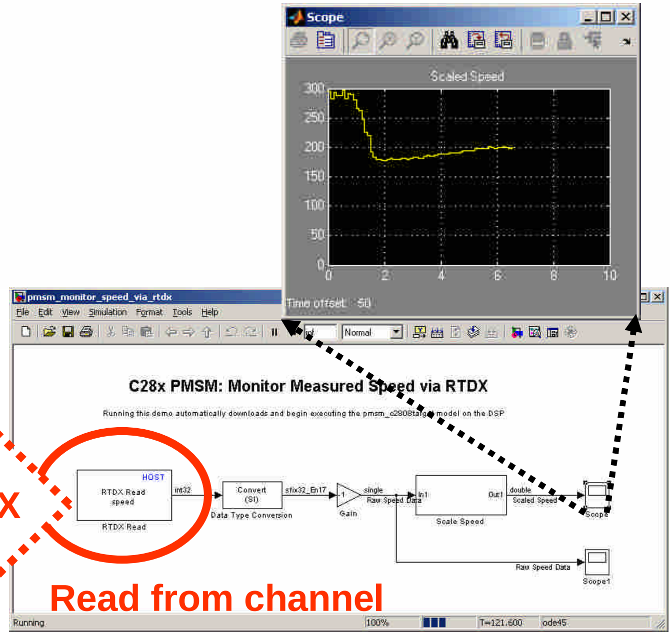
Generated Code runs on DSP



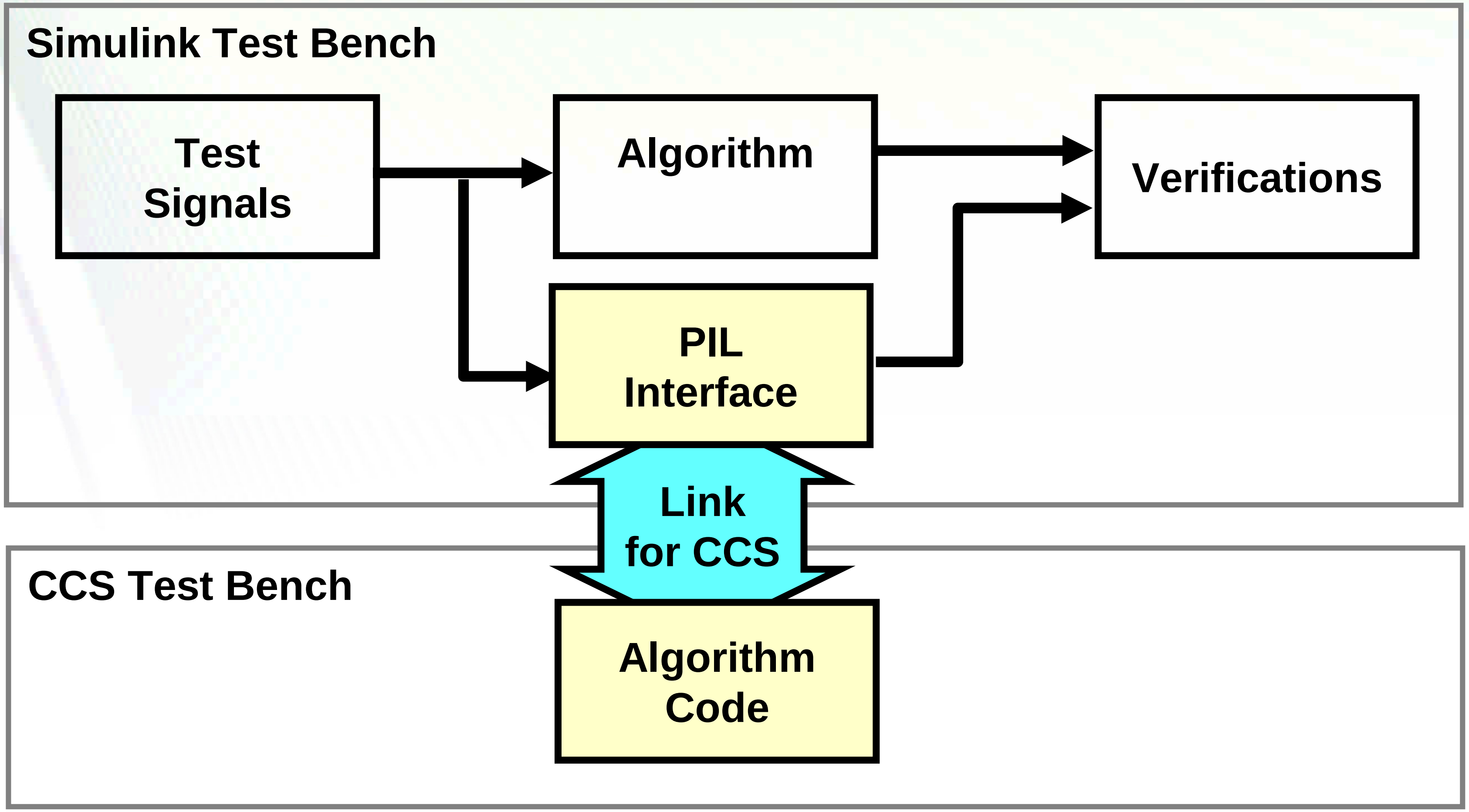
Host Side Model

Model executes on PC

Monitor or tune low-rate data



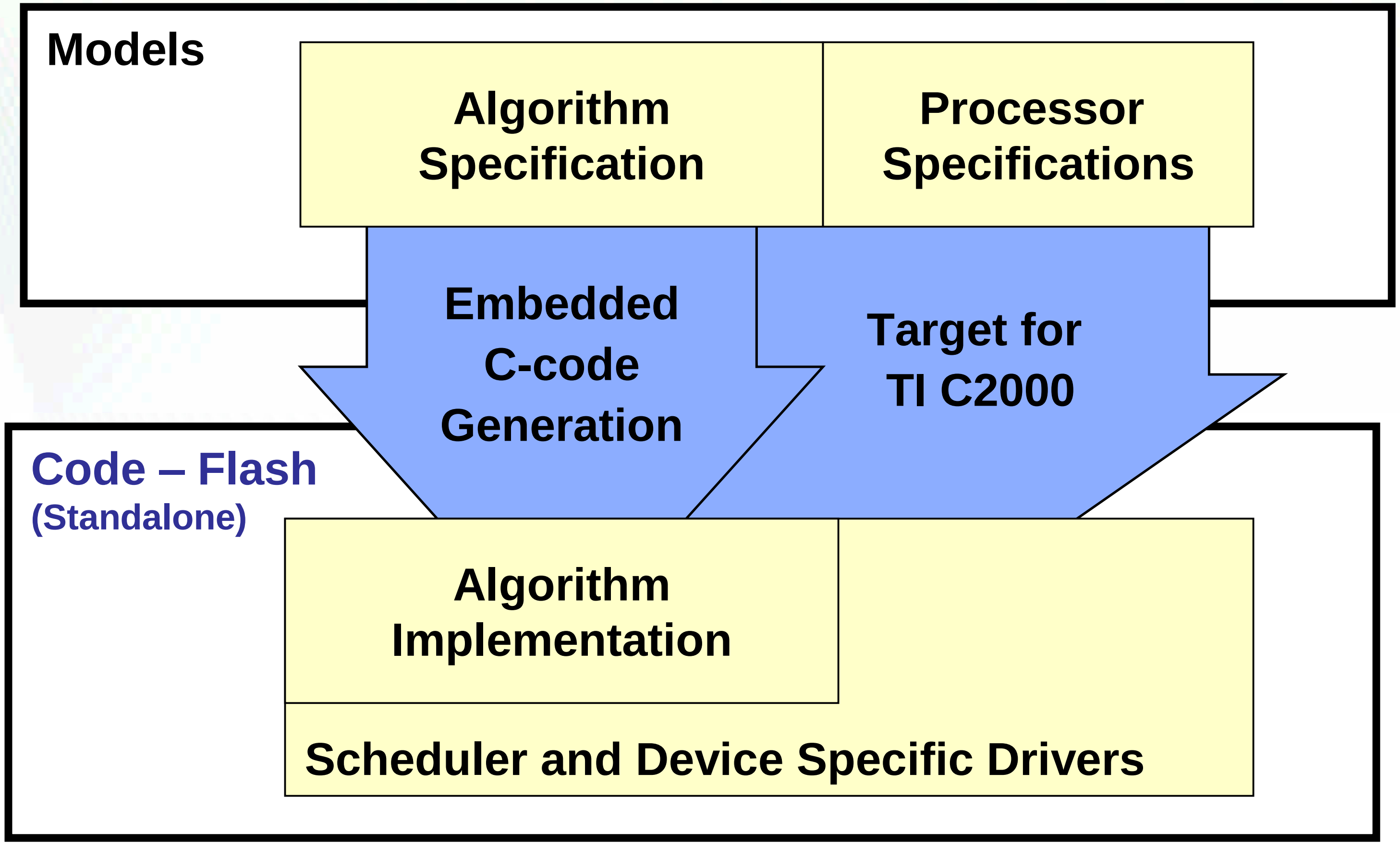
STEP 3 - Code Verification using Processor-In-the-Loop Testing (PIL)



Need for Code Verification

- Target C compiler optimization settings
- Code generation optimization settings
- Integration of custom code
- Defects in hardware, compiler, linker, or code generator

STEP 4 - Production Code Generation
Method 1:Generate Standalone Code



Production Code Generation: Method 2

Algorithm Export for Integration with your Drivers and Scheduler

Models

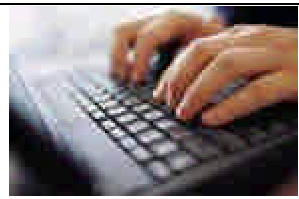
Algorithm Specification

Processor Specifications

Embedded C-code Generation

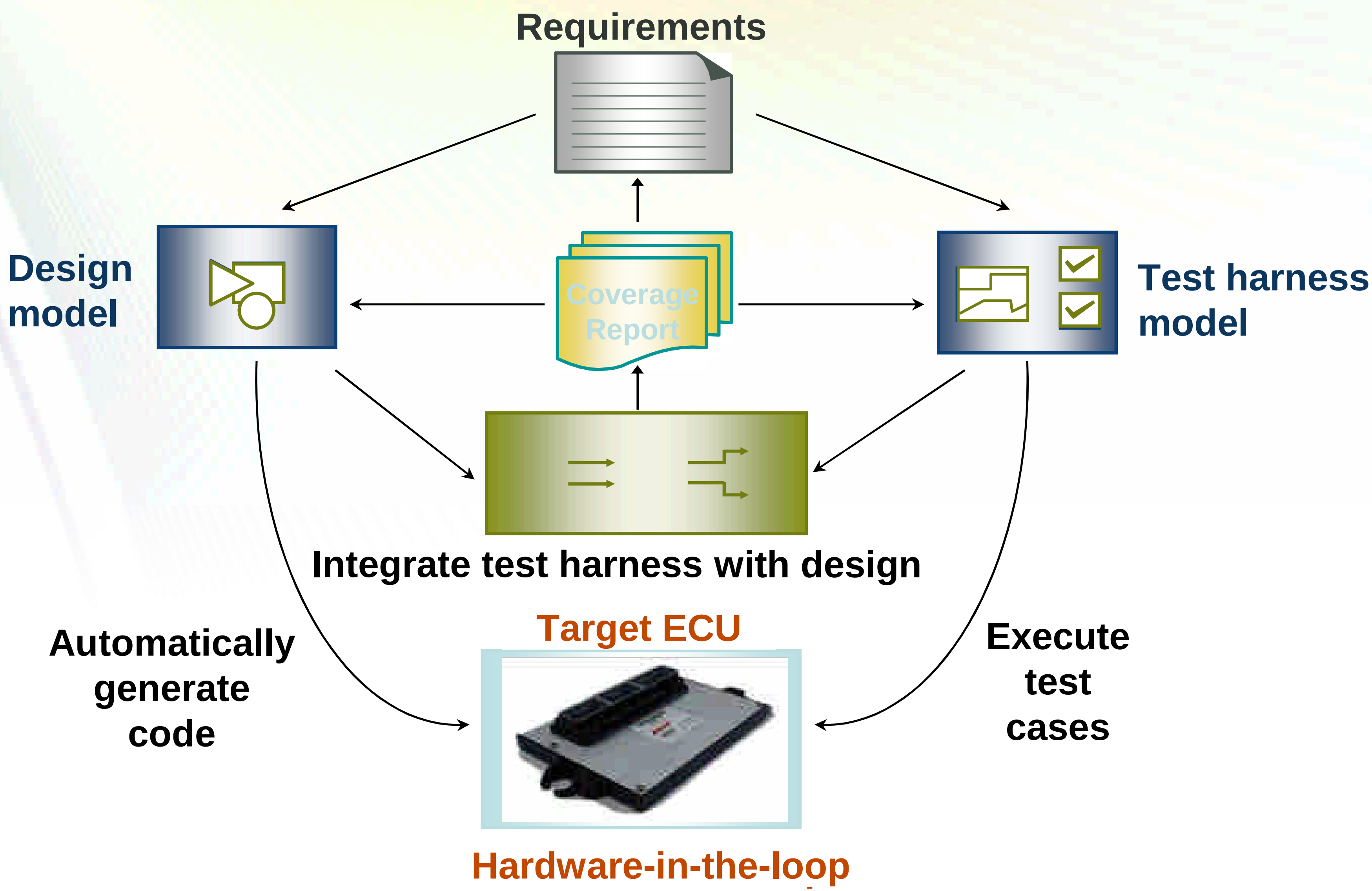
Code – Flash
(Standalone)

Algorithm Implementation



Scheduler and Device Specific Drivers

Verify and Validate



Summary and Next Steps

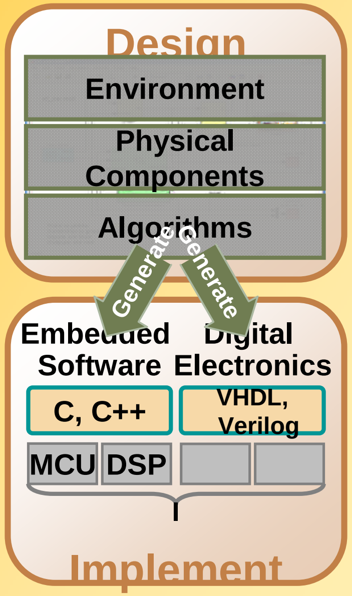
Addressing Embedded Programming Challenges

Challenge	Response
Processor specific code	TFL and Legacy Code Tool
Production Code Deployment	Generate code for deployment to Flash
Execution speed from Flash	Ability to assign data and functions to be copied from Flash to RAM
Verification of Code Execution	Processor-in-the-Loop testing
Asynchronous Scheduling	Capture and act upon hardware and software interrupts

Model-Based Design Benefits

Model-Based Design

- Executable specification
- Design with simulation
- Implementation through code generation
- Continuous test and verification



Innovation

- **Rapid** design iterations
- “What-if” studies
- Unique features and differentiators

Quality

- **Reduce** design errors
- **Minimize** hand coding errors
- **Improve** communication internally and externally

Cost

- **Reduce** expensive physical prototypes
- Reduce re-work
- Reduce testing

Time-to-market

- **Get it right the first time**

Production Code Deployment

Example applications of production deployment include:

- Engine and transmission control
- Hybrid electric vehicle battery control
- Commercial aircraft fly-by-wire system, certified to Level A DO178B

Summary and Next Steps

Some of the MathWorks Products Featured Today:

- MATLAB, Simulink, Real-Time Workshop Embedded Coder
- Embedded IDE Link CC (for use with Code Composer Studio)
- Target Support Package TC2 (for use with TI C2000)

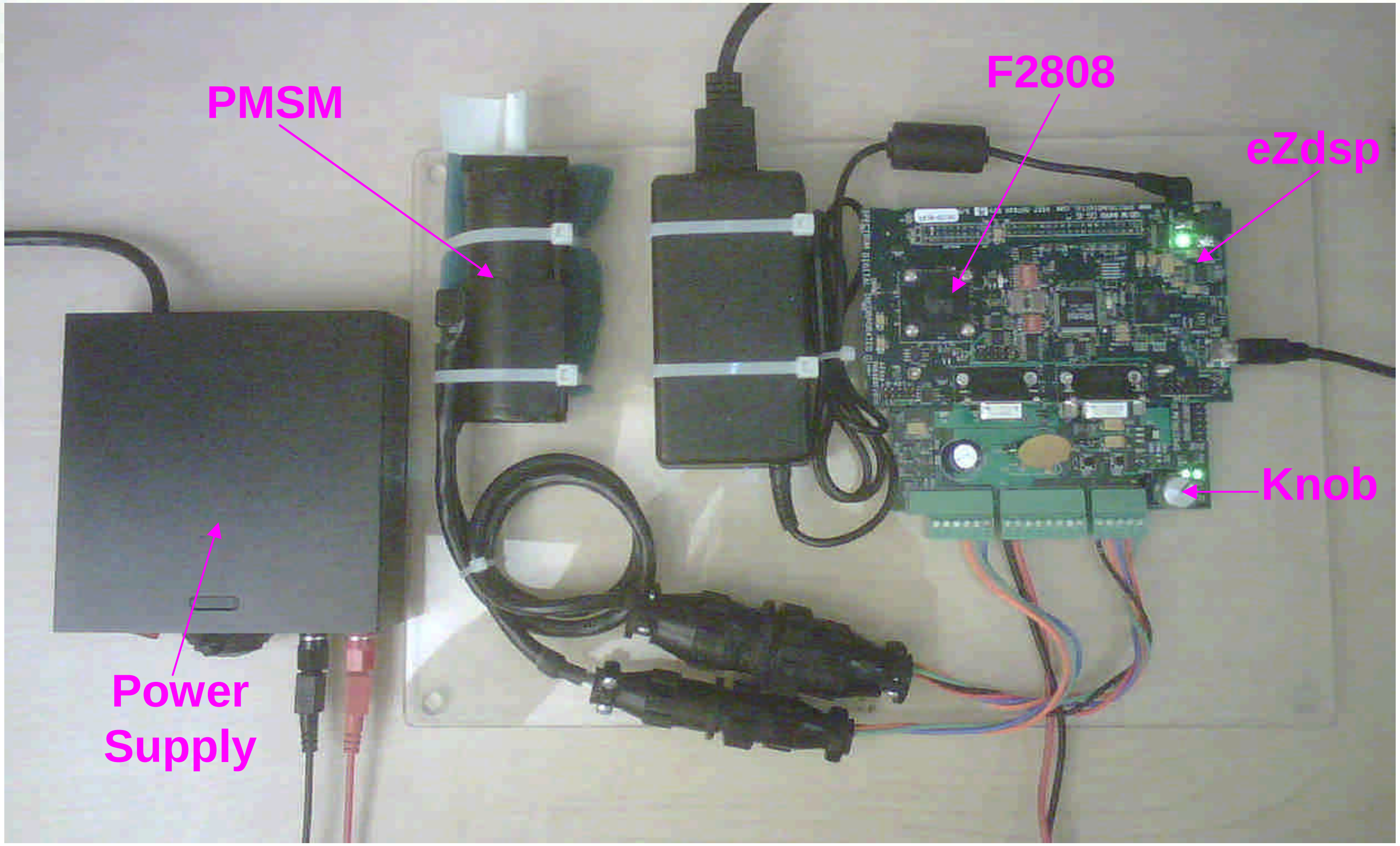
Next Steps

1. Get more information
   - www.mathworks.com/ applications/ controldesign/
   - Watch a free webinar: www.mathworks.com/webinars

2. Contact your MathWorks Sales rep
   - Arrange a customer visit with MathWorks' engineers to help your company save money and time to market

Thank You !

From Models to Hardware – Design and Implementation of a Permanent Magnet Synchronous Motor Controller



Modeling Dynamic Systems in Simulink

Modeling Approaches

First Principles Modeling ⟷ **Data-Driven Modeling**

Simscape
SimMechanics
SimDriveline
SimHydraulics
SimPowerSystems

Simulink

Simulink Parameter Estimation

System Identification Toolbox

Neural Network Toolbox

Tools for Modeling Dynamic Systems

Thank You!