

Simulink[®] Coder[™] 8

Getting Started Guide

MATLAB[®]
& SIMULINK[®]

How to Contact MathWorks



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Simulink® Coder™ Getting Started Guide

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When to Use Simulink Coder

Simulink® Coder™ (formerly Real-Time Workshop®) generates and executes C and C++ from Simulink® diagrams, Stateflow® charts, and MATLAB® functions. The generated source code can be used for real-time and nonreal-time applications, including simulation acceleration, rapid prototyping, and hardware-in-the-loop testing. You can tune and monitor the generated code using Simulink or run and interact with the code outside MATLAB and Simulink.

Related Products

The following table summarizes MathWorks® products that extend and complement Simulink Coder software. For information about these and other MathWorks products, see www.mathworks.com.

Product	Extends Code Generation Capabilities for ...
Aerospace Blockset™	Aircraft, spacecraft, rocket, propulsion systems, and unmanned airborne vehicles
Communications System Toolbox™	Physical layer of communication systems
Computer Vision System Toolbox™	Video processing, image processing, and computer vision systems
Control System Toolbox™	Linear control systems
DSP System Toolbox™	Signal processing systems
Embedded Coder™	Embedded systems, on-target rapid prototyping boards, microprocessors in mass production, and real-time simulators
Fuzzy Logic Toolbox™	System designs based on fuzzy logic
Gauges Blockset™	Linking generated code executing on a target system with graphical instrumentation in a Simulink model
Model-Based Calibration Toolbox™	Developing processes for systematically identifying optimal balance of engine performance, emissions, and fuel economy, and reusing statistical models for control design, hardware-in-the-loop testing, or powertrain simulation
Model Predictive Control Toolbox™	Controllers that optimize performance of multi-input and multi-output systems that are subject to input and output constraints
Real-Time Windows Target™	Rapid prototyping or hardware-in-the-loop simulation of control system and signal processing algorithms

Product	Extends Code Generation Capabilities for ...
SimDriveline™	Driveline (drivetrain) systems
SimElectronics®	Electronic and electromechanical systems
SimHydraulics®	Hydraulic power and control systems
SimMechanics™	Three-dimensional mechanical systems
SimPowerSystems™	Systems that generate, transmit, distribute, and consume electrical power
Simscape™	Systems spanning mechanical, electrical, hydraulic, and other physical domains as physical networks
Simulink® Fixed Point™	Control and signal processing systems implemented with fixed-point arithmetic
Simulink® 3D Animation™	Systems with 3D visualizations
Simulink® Design Optimization™	Systems requiring maximum overall system performance
Simulink® Report Generator™	Automatically generating project documentation in a standard format
Simulink® Verification and Validation™	Applications requiring automated requirements tracing, model standards compliance checking, and test harness generation
System Identification Toolbox™	<p>Systems constructed from measured input-output data</p> <p>Support exceptions:</p> <ul style="list-style-type: none"> • Nonlinear IDNLGREY Model, IDDATA Source, IDDATA Sink, and estimator blocks • Nonlinear ARX models that contain custom regressors • neuralnet nonlinearities • customnet nonlinearities

Product	Extends Code Generation Capabilities for ...
Vehicle Network Toolbox™	Support exception: CAN Configuration, CAN Receive, and CAN Transmit blocks in the CAN Communication library
xPC Target™	Rapid control prototyping, hardware-in-the-loop (HIL) simulation, and other real-time testing applications
xPC Target Embedded Option™	Deploying real-time embedded systems on a PC for production, data acquisition, calibration, and testing applications

Prerequisite Knowledge

MATLAB Users

Be familiar with:

- Code generation from MATLAB
- MATLAB Function block

If you are familiar with C language constructs and want to learn how to map commonly used C constructs to code generated from MATLAB program design patterns, see “Developing Model Patterns that Generate Specific C Constructs” in the Embedded Coder documentation.

Simulink Users

Be familiar with:

- Simulink and Stateflow software to create models or state machines as block diagrams, running simulations in Simulink, and interpreting output in the MATLAB base workspace.
- High-level programming language concepts applied to real-time systems.
- Real-time system concepts, terminology, parameters, design constraints, and environments.

If you are familiar with C language constructs and want to learn how to map commonly used C constructs to code generated from Simulink and Stateflow model design patterns, see “Developing Model Patterns that Generate Specific C Constructs” in the Embedded Coder documentation.

About Simulink Coder and MathWorks C/C++ Code Generation

MathWorks® Code generation technology generates C or C++ code and executables for algorithms that you model programmatically with MATLAB or graphically in the Simulink environment. You can generate code for any MATLAB functions and Simulink blocks that are useful for real-time or embedded applications. The generated source code and executables for floating-point algorithms match the functional behavior of MATLAB code execution and Simulink simulations to high degrees of fidelity. Using the Simulink Fixed Point product, you can generate fixed-point code that provides a bit-wise accurate match to model simulation results. Such broad support and high degrees of accuracy are possible because code generation is tightly integrated with the MATLAB and Simulink execution and simulation engines. The built-in accelerated simulation modes in Simulink use code generation technology.

You apply code generation explicitly with the Simulink Coder and Embedded Coder products. Using the Simulink Coder product, you can:

- Generate source code and executables for discrete-time, continuous-time (fixed-step), and hybrid systems modeled in Simulink.
- Use the generated code for real-time and non-real-time applications, including simulation acceleration, rapid prototyping, and hardware-in-the-loop (HIL) testing.
- Tune and monitor the generated code by using Simulink blocks and built-in analysis capabilities, or run and interact with the code completely outside the MATLAB and Simulink environments.
- Generate code for finite state machines modeled in Stateflow event-based modeling software.
- Produce source code for many Simulink products and blocksets provided by MathWorks and third-party vendors.

The Embedded Coder product *extends* the Simulink Coder product with features for embedded software development. Using the Embedded Coder add-on product, you can generate code that has the clarity and efficiency of professional handwritten code. For example, you can:

- Generate code that is compact and fast, which is essential for real-time simulators, on-target rapid prototyping boards, microprocessors in mass production, and embedded systems.
- Customize the appearance of the generated code.
- Optimize the generated code for a specific target environment.
- Integrate existing (legacy) applications, functions, and data.
- Enable tracing, reporting, and testing options that facilitate code verification activities.

Product	Typical Applications	Key Capabilities
Simulink Coder	Simulation acceleration Simulink model intellectual property protection Rapid prototyping HIL testing	Generate code for discrete-time, continuous-time (fixed-step), and hybrid systems modeled in Simulink. Tune and monitor the execution of generated code by using Simulink blocks and built-in analysis capabilities or by running and interacting with the code outside the MATLAB and Simulink environments. Generate code for finite state machines modeled in Stateflow event-based modeling software. Generate code for many MathWorks and third-party Simulink products and blocksets. Integrate existing applications, functions, and data.
Embedded Coder	All applications listed for the Simulink Coder product Embedded systems On-target rapid prototyping boards	All capabilities listed for the Simulink Coder product. Generate code that has the clarity and efficiency of professional handwritten code.

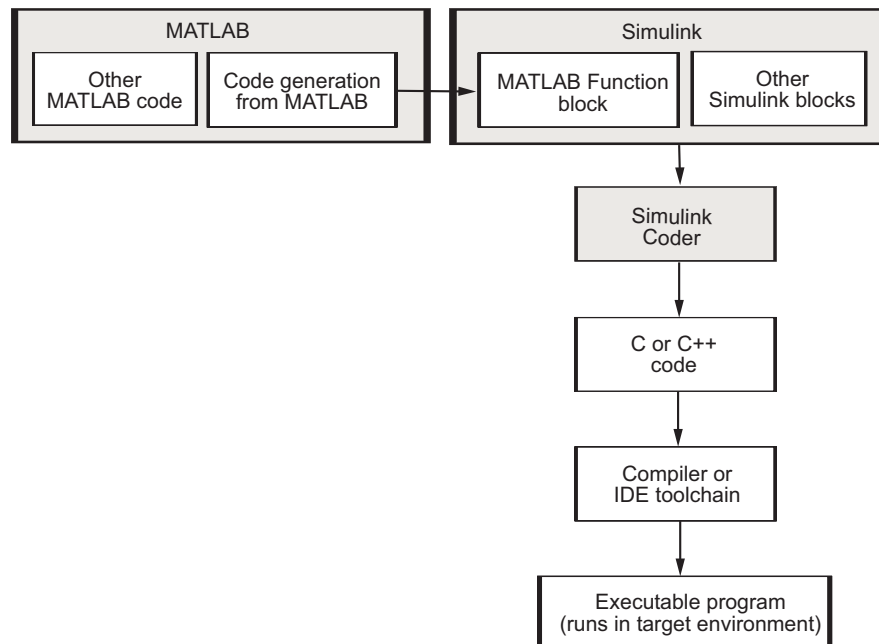
Product	Typical Applications	Key Capabilities
	Microprocessors in mass production	Customize the appearance and performance of the code for specific target environments. Enable tracing, reporting, and testing options that facilitate code verification activities.

Algorithm Development Workflows

You can use MathWorks code generation technology to generate standalone C or C++ source code for rapid prototyping, simulation acceleration, and hardware-in-the-loop (HIL) simulation:

- By developing Simulink models and Stateflow charts, and then generating C/C++ code from the models and charts with the Simulink Coder product
- By integrating MATLAB code into Simulink models, using code generation from MATLAB and the Simulink MATLAB Function block, and then generating C/C++ code with the Simulink Coder product

The following figure shows these design and deployment environment options. Although not shown in the figure, other products that support code generation, such as Stateflow software, are available.



If you are familiar with C language constructs and want to learn about how to map commonly used C constructs to code generated from model design

patterns that include Simulink blocks, Stateflow charts, and MATLAB functions, see “Developing Model Patterns that Generate Specific C Constructs” in the Embedded Coder documentation.

Simulink and Stateflow Model Workflow

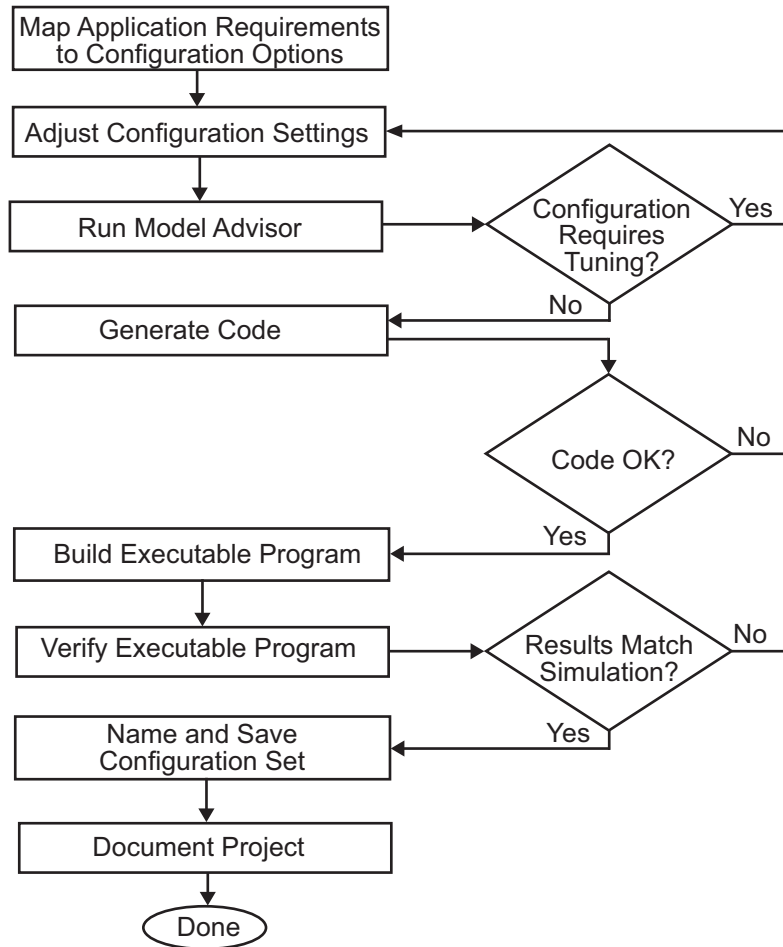
About the Workflow

Simulink support for dynamic system simulation, conditional execution of system semantics, and large model hierarchies provides an environment for modeling periodic and event-driven algorithms commonly found in embedded systems. You can generate code for most Simulink blocks and many MathWorks products.

The typical workflow for applying the Simulink Coder software to the application development process is:

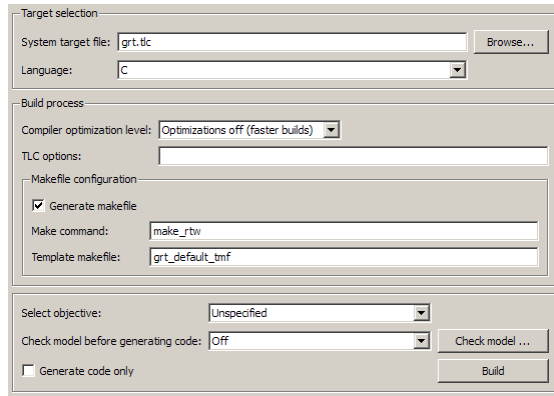
- 1** Map your application requirements to available configuration options.
- 2** Adjust configuration options as necessary.
- 3** Run the Model Advisor tool.
- 4** If necessary, tune configuration options based on the Model Advisor report.
- 5** Generate code for your model.
- 6** Repeat steps 2 to 5, until you successfully verify the generated code.
- 7** Build an executable program image.
- 8** Verify that the generated program produces results that are equivalent to those of your model simulation.
- 9** Save the configuration, and alternative configurations, with the model.
- 10** Use Simulink Report Generator to automatically document the project.

Sections following the figure describe the steps in more detail.



Mapping Application Requirements to Configuration Options

The first step in applying the Simulink Coder software to the application development process is to consider how your application requirements, particularly with respect to debugging, traceability, efficiency, and safety, map to code generation options available through the Simulink Configuration Parameters dialog box. The following graphic shows the **Code Generation** pane of the Configuration Parameters dialog box.



Parameters that you set in the various panes of the Configuration Parameters dialog box affect the behavior of a model in simulation and the code generated for the model. The Simulink Coder software automatically adjusts the available configuration parameters and their default settings based on your target selection. For example, the preceding dialog box display shows default settings for the generic real-time (GRT) target. Become familiar with the various parameters and be prepared to adjust settings to optimize a configuration for your application.

As you review the parameters, consider: questions such as the following:

- What settings will help you debug your application?
- What is the highest priority for your application — efficiency, traceability, extra safety precaution, or other criteria?
- What is the second highest priority?
- Can the priority at the start of the project differ from the priority required for the end of the project? What tradeoffs can you make?

Once you have answered these questions, you can either:

- Use the Code Generation Advisor to identify changes to model constructs and settings that improve the generated code. For more information, see “Configuring Code Generation Objectives” in the Simulink Coder *User’s Guide*.

- Review “Recommended Settings Summary”, which summarizes the impact of each configuration option on efficiency, traceability, safety precautions, and debugging, and indicates the default (factory) configuration settings for the GRT target. For additional details, click the links in the Configuration Parameter column.

To see the settings that the Code Generation Advisor recommends, review the “Recommended Settings Summary”.

If you use a specific embedded target, a Stateflow target, or fixed-point blocks, consider the mapping of many other configuration parameters. For details, see the documentation specific to your target environment.

Adjusting Configuration Settings

Once you have mapped your application requirements to appropriate configuration parameter settings, adjust the settings accordingly. Using the Default column in “Mapping Application Requirements to the Solver Pane”, identify the configuration parameters to modify. Then, open the Configuration Parameters dialog box or Model Explorer and make the necessary adjustments.

Tutorials in Chapter 2, “Getting Started Tutorials” guide you through exercises that modify configuration parameter settings. For more information on setting configuration parameters for code generation, see “Preparing Models for Code Generation” in the Simulink Coder documentation. For descriptions of parameters specific to the Simulink Coder product, see “Configuration Parameters for Simulink Models” in the Simulink Coder reference documentation.

Note You also can use `get_param` and `set_param` to individually access most configuration parameters both interactively and in scripts. The relevant configuration parameters are listed in the “Parameter Reference” in the Simulink Coder documentation.

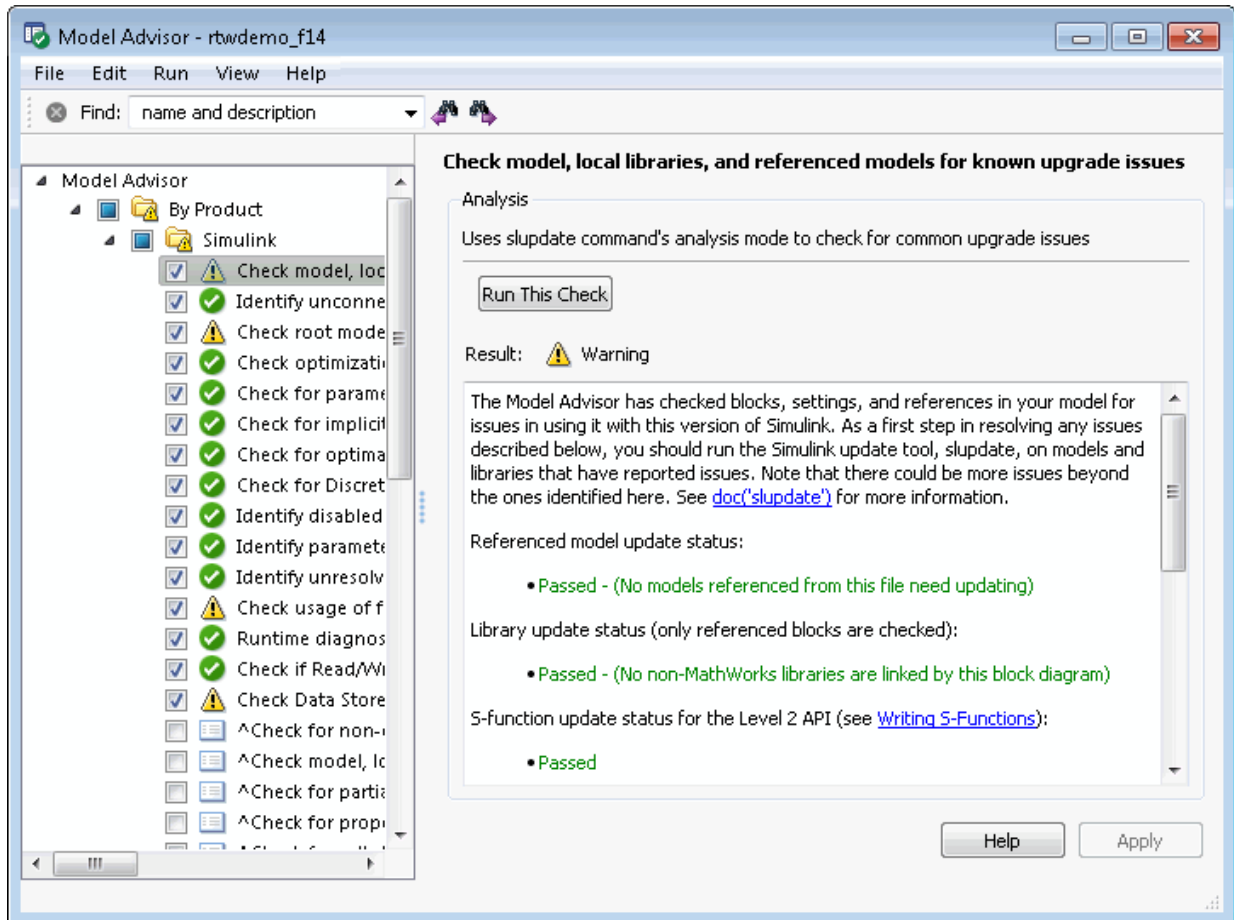
Running the Model Advisor

Before you generate code, it is good practice to run the Model Advisor. Based on a list of options that you select, this tool analyzes your model and its parameter settings. The tool then generates results that list findings with information on how to correct and improve the model and its configuration.

To start the Model Advisor, in your model window, select **Tools > Model Advisor**. A new window opens listing specific diagnostics that you can individually select or clear. Some examples of the diagnostics are:

- Identify blocks that generate expensive saturation and rounding code
- Check optimization settings
- Identify questionable software environment specifications

The Model Advisor is particularly useful for identifying aspects of your model that limit code efficiency or impede deployment of production code. The following figure shows the Model Advisor.



For more information on using the Model Advisor, see “Getting Advice About Optimizing Models for Code Generation” in the Simulink Coder documentation.

Generating Code

After fine-tuning your model and its parameter settings, you can generate code. Typically, the first time through the process of applying Simulink Coder software for an application, you want to generate code without compiling and linking it into an executable program. Some reasons for not compiling and linking the code are:

- Inspecting the generated code. Is the Simulink Coder code generator creating what you expect?
- Integrating custom handwritten code.
- Experimenting with configuration option settings.

You specify code generation by selecting the **Generate code only** check box available on the **Code Generation** pane of the Configuration Parameters dialog box (changing the label of the **Build** button to **Generate code**). The code generator then analyzes the block diagram that represents your model, generating C code, and placing the resulting files in a build folder within your current working folder.

After generating the code, inspect it. Is it what you expected? If not, determine what model and configuration changes to make, rerun the Model Advisor, and regenerate the code. When you are satisfied with the generated code, build an executable program image, as described in “Building an Executable Program” on page 1-19.

For details on the **Generate code only** option, see “Generate code only”.

Verifying the Generated Code

Verify whether the generated code behaves correctly, generates correct results, and meets required performance by using these verification techniques:

- “Logging Data for Analysis”
- “Comparing Simulation and Generated Code Output Data”
- “Tracing Generated Code”
- “Profiling Code Performance”

Building an Executable Program

When you are satisfied with the code generated for your model, build an executable program image. If the **Generate code only** option on the **Code Generation** pane of the Configuration Parameters dialog box is selected, clear it. This action changes the label of the **Generate code** button back to **Build**.

To initiate a build, click the **Build** button. The code generator:

- 1** Compiles the model — The Simulink Coder software analyzes your block diagram (and any models referenced by Model blocks) and compiles an intermediate hierarchical representation in a file called `model.rtw`.
- 2** Generates C code — The Target Language Compiler reads `model.rtw`, translates it to C code, and places the C file in a build folder within your working folder.

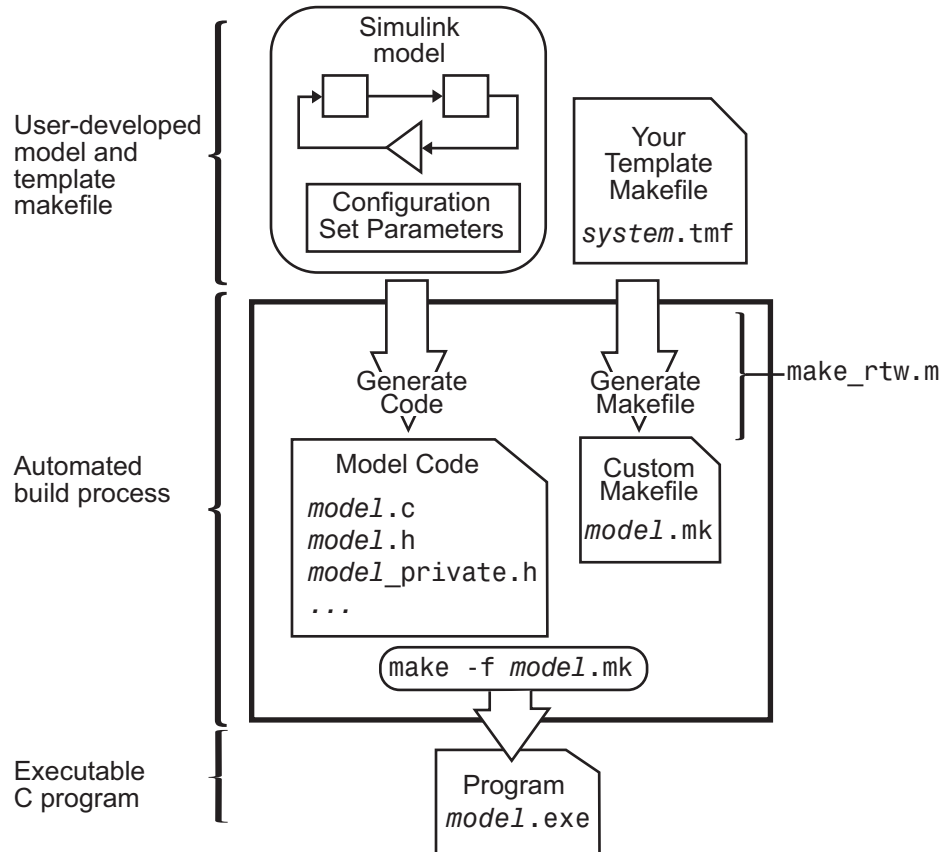
When you click **Generate code** processing stops. See “Generating Code” on page 1-18.

- 3** Generates a customized makefile — The Simulink Coder software constructs a makefile from the appropriate target makefile template and writes it in the build folder.
- 4** Generates an executable program — Instructs your system’s `make` utility to use the generated makefile to compile the generated source code, link object files and libraries, and generate an executable program file called `model` (UNIX®) or `model.exe` (Microsoft® Windows®). The makefile places the executable image in your working folder.

If you select **Create code generation report** on the **Code Generation > Report** pane, a navigable summary of source files is produced when the model is built. The report files occupy folder `html` in the build folder. The report contents vary depending on the target, but all reports include links to generated source files.

If the software detects code generation constraints for your model, it issues warning or error messages.

The following figure illustrates the complete process. The box labeled “Automated build process” highlights portions of the process that the Simulink Coder software executes.



In the Configuration Parameters dialog box, in the **Build process** section of the **Code Generation** pane, the MATLAB command file specified by the **Make command** field controls an internal portion of the build process. By default, the name of the command file is `make_rtw`. The build process invokes this file for most targets. Any options specified in this field are passed into the makefile-based build process. In some cases, targets customize the `make_rtw` command. However, preserve the arguments used by the function.

Although the command may work for a standalone model, if you use the `make_rtw` command at the command line you might get an error. For example, if you have multiple models open, verify that:

- The current subsystem contains the model that you want to build. You can find the current subsystem by entering `gcs` in the MATLAB Command Window.
- In the Configuration Parameters dialog box, the **Make command** specified for the target environment is `make_rtw`.
- The model includes Model blocks. Models containing Model blocks do not build by using `make_rtw` directly.

To build (or generate code for) a model from the MATLAB Command Window, use one of the following `rtwbuild` commands, where *model* is the name of the model:

```
rtwbuild model
rtwbuild('model')
```

Verifying the Executable Program

Once you have an executable image, run the image and compare the results to the results of your model simulation.

- 1 Log output data produced by simulation runs.
- 2 Log output data produced by executable program runs.
- 3 Compare the results of the simulation and executable program runs.

Does the output match? Can you explain any differences? Do you need to eliminate any differences? You might need to revisit and possibly fine-tune your block and configuration parameter settings.

For an example, see “Verifying the Generated Code” on page 1-18.

Naming and Saving the Configuration Set

When you close a model, save it to preserve your configuration settings (unless your recent changes are dispensable). If you want to maintain several

alternative configurations for a model (e.g., GRT and Rapid Simulation targets, inline parameters on/off, different solvers, etc.), you can set up a configuration set for each set of configuration parameters and give each set an identifying name. You can do this easily in Model Explorer.

To name and save a configuration:

- 1** Open Model Explorer from the model window by selecting **Model Explorer > View**.
- 2** In the **Model Hierarchy** pane, click the + sign preceding the model name to reveal its components.
- 3** Under the mode name, click the **Configuration (active)** node.
The Configuration Parameters dialog box opens in the right pane.
- 4** In the **Configuration Parameters** pane, in the **Name** field, type a name you want to give the current configuration.
- 5** Click **Apply**. In the **Model Hierarchy** pane, the name of the active configuration changes to the name that you typed.
- 6** Save the model.

Adding and Copying Configuration Sets

You can save the model with more than one configuration so that you can instantly reconfigure it at a later time. Copy the active configuration to a new one, or add a new one, then modify and name the new configuration:

- 1** Open Model Explorer from your model window by selecting **Model Explorer > View**.
- 2** In the **Model Hierarchy** pane, click the + sign preceding the model name to reveal its components.
- 3** To add a new configuration set, while the model is selected in the **Model Hierarchy** pane, from the **Add** menu, select **Configuration Set** or on the toolbar, click the yellow gear icon:



In the **Model Hierarchy** pane, you see a new configuration set named **Configuration**.

- 4 To copy an existing configuration set, in the **Model Hierarchy** pane, right-click its name and drag it to the + sign in front of the model name.

In the **Model Hierarchy** pane, you see a new configuration set with a numeral (for example, 1) appended to its name.

- 5 If you want, rename the new configuration by right-clicking it, selecting **Properties**, and in the Configuration Parameters dialog box that opens, type the new name in the **Name** field. Then click **Apply**.
- 6 Make the new configuration the active one. In the **Model Hierarchy** pane, right-click the new configuration. From the context menu, select **Activate**.

In the right pane, the content of the **Is Active** field changes from **no** to **yes**.

- 7 Save the model.

Documenting the Project

Consider documenting the design and implementation details of your project to facilitate:

- Project verification and validation.
- Collaboration with other individuals or teams, particularly if dependencies exist.
- Archiving the project for future reference.

Use the Simulink Report Generator software to document a code generation project. You can generate a comprehensive Rich Text Format (RTF), Extensible Markup Language (XML), or Hypertext Markup Language (HTML) report that includes:

- Model name and version
- Simulink Coder product version

- Date and time the code generator created the code
- List of generated source and header (include) files
- Optimization and Simulink Coder target selection and build process configuration settings
- Mapping of subsystem numbers to subsystem labels
- Listings of generated and custom code for the model

To generate a code generation report, see the demo `rtwdemo_codegenrpt` and “Documenting a Code Generation Project” in the Simulink Coder documentation. For details about the Report Generator, see the *Simulink Report Generator User’s Guide*.

MATLAB Code with Simulink Model Workflow

You might use both MATLAB code and Simulink models for a Model-Based Design project if you:

- Start by using MATLAB to develop an algorithm for research and early development.
- Later want to integrate the algorithm into a graphical model for system deployment and verification.

Benefits of this approach include:

- Richer system simulation environment
- Ability to verify the MATLAB code
- Simulink Coder and Embedded Coder C/C++ code generation for the model and MATLAB code

The following table summarizes how to generate C or C++ code, using this approach, and identifies where you can find more information.

If you develop algorithms using...	You generate code by...	For more information, see...
Code generation from MATLAB and Simulink	Including MATLAB code in Simulink models or subsystems by using the MATLAB Function block. To use this block, you can do one of the following: <ul style="list-style-type: none"> • Copy your code into the block. • Call your code from the block by referencing the appropriate files on the MATLAB path. 	Code generation from MATLAB documentation MATLAB Function block in the Simulink documentation

Target Environments and Applications

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“Types of Target Environments Supported By Simulink® Coder” on page 1-26

“Applications of Supported Target Environments” on page 1-28

About Target Environments

In addition to generating source code for a model or subsystem, the code generator produces make or project files to build an executable for a specific target environment. The generated make or project files are optional. If you prefer, you can build an executable for the generated source files by using an existing target build environment, such as a third-party integrated development environment (IDE). Applications of generated code range from calling a few exported C or C++ functions on a host computer to generating a complete executable using a custom build process, for custom hardware, in an environment completely separate from the host computer running MATLAB and Simulink.

The code generator provides built-in *system target files* that generate, build, and execute code for specific target environments. These system target files offer varying degrees of support for interacting with the generated code to log data, tune parameters, and experiment with or without Simulink as the external interface to your generated code.

Types of Target Environments Supported By Simulink Coder

Before you select a system target file, identify the target environment on which you expect to execute your generated code. The most common target environments include those environments listed in the following table.

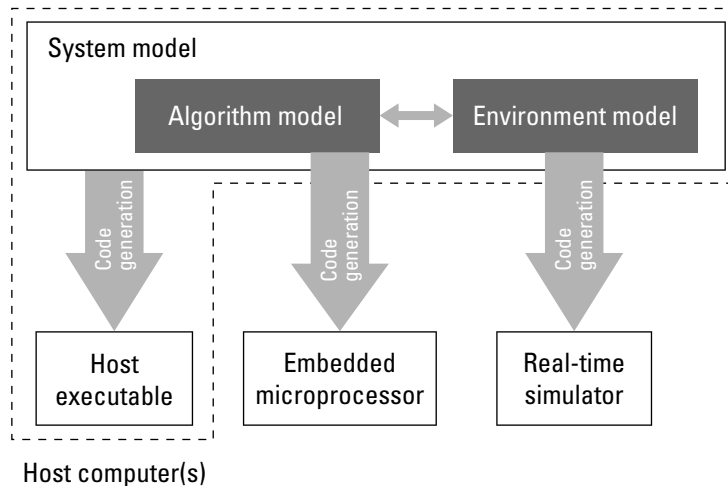
Target Environment	Description
Host computer	<p>The same computer that runs MATLAB and Simulink. Typically, a host computer is a PC or UNIX¹ environment that uses a non-real-time operating system, such as Microsoft Windows or Linux^{®2}. Non-real-time (general purpose) operating systems are nondeterministic. For example, those operating systems might suspend code execution to run an operating system service and then, after providing the service, continue code execution. Therefore, the executable for your generated code might run faster or slower than the sample rates that you specified in your model.</p>
Real-time simulator	<p>A different computer than the host computer. A real-time simulator can be a PC or UNIX environment that uses a real-time operating system (RTOS), such as:</p> <ul style="list-style-type: none"> • xPC Target system • A real-time Linux system • A Versa Module Eurocard (VME) chassis with PowerPC[®] processors running a commercial RTOS, such as VxWorks[®] from Wind River[®] Systems <p>The generated code runs in real time and behaves deterministically. The exact nature of execution varies based on the particular behavior of the system hardware and RTOS.</p> <p>Typically, a real-time simulator connects to a host computer for data logging, interactive parameter tuning, and Monte Carlo batch execution studies.</p>
Embedded microprocessor	<p>A computer that you eventually disconnect from a host computer and run as a standalone computer as part of an electronics-based product. Embedded microprocessors range in price and performance, from high-end digital signal processors (DSPs) to process communication signals to inexpensive 8-bit fixed-point microcontrollers in mass production (for example, electronic parts produced in the millions of units). Embedded microprocessors can:</p> <ul style="list-style-type: none"> • Use a full-featured RTOS • Be driven by basic interrupts • Use rate monotonic scheduling provided with code generation

A target environment can:

- Have single- or multiple-core CPUs
- Be a standalone computer or communicate as part of a computer network

In addition, you can deploy different parts of a Simulink model on different target environments. For example, it is common to separate the component (algorithm or controller) portion of a model from the environment (or plant). Using Simulink to model an entire system (plant and controller) is often referred to as closed-loop simulation and can provide many benefits, such as early verification of component correctness.

The following figure shows example target environments for code generated for a model.



Applications of Supported Target Environments

The following table lists several ways that you can apply code generation technology in the context of the different target environments.

1. UNIX[®] is a registered trademark of The Open Group in the United States and other countries.
2. Linux[®] is a registered trademark of Linus Torvalds.

Application	Description
Host Computer	
Accelerated simulation	You apply techniques to speed up the execution of model simulation in the context of the MATLAB and Simulink environments. Accelerated simulations are especially useful when run time is long compared to the time associated with compilation and checking whether the target is up to date.
Rapid simulation	You execute code generated for a model in nonreal time on the host computer, but outside the context of the MATLAB and Simulink environments.
System simulation	You integrate components into a larger system. You provide generated source code and related dependencies for building a system in another environment or in a host-based shared library to which other code can dynamically link.
Model intellectual property protection	You generate a Simulink shareable object library for a model or subsystem for use by a third-party vendor in another Simulink simulation environment.
Real-Time Simulator	
Rapid prototyping	You generate, deploy, and tune code on a real-time simulator connected to the system hardware (for example, physical plant or vehicle) being controlled. This design step is crucial for validating whether a component can adequately control the physical system.
System simulation	You integrate generated source code and dependencies for components into a larger system that is built in another environment. You can use shared library files for intellectual property protection.
On-target rapid prototyping	You generate code for a detailed design that you can run in real time on an embedded microprocessor while tuning parameters and monitoring real-time data. This design step allows you to assess, interact with, and optimize code, using embedded compilers and hardware.
Embedded Microprocessor	

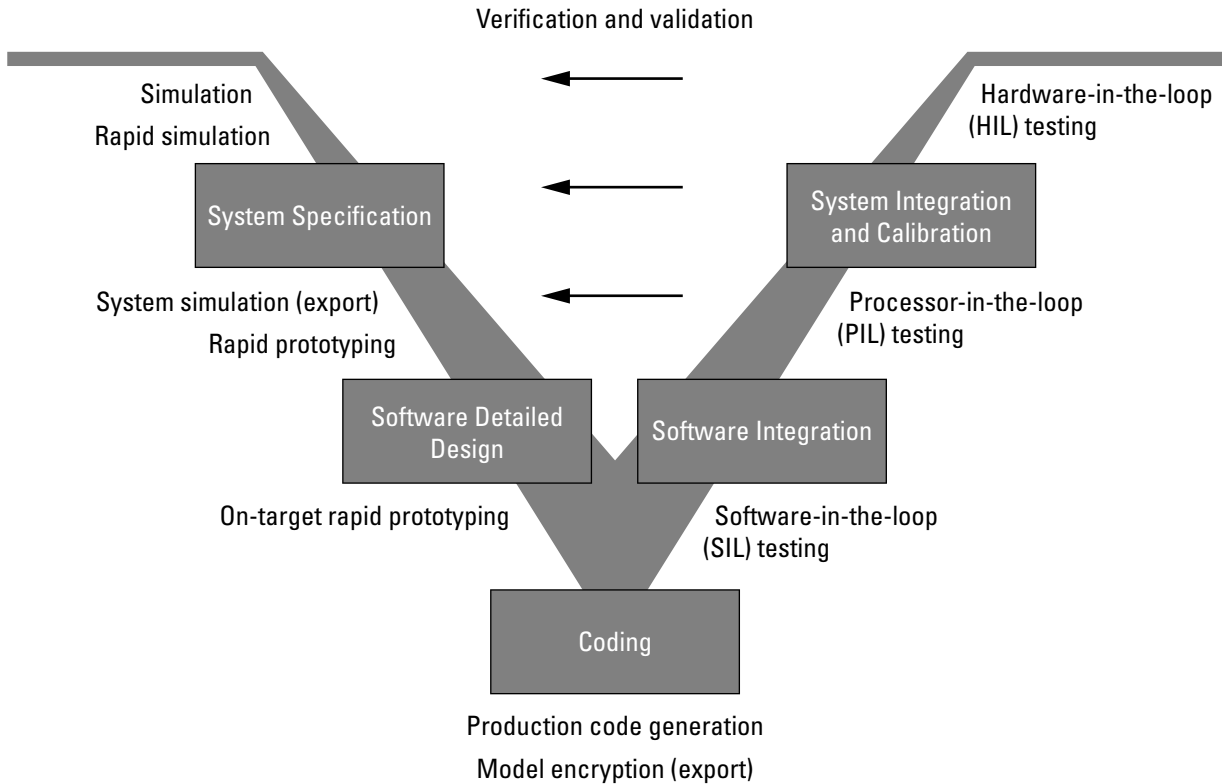
Application	Description
Production code generation	From a model, you generate code that is optimized for speed, memory usage, simplicity, and if necessary, compliance with industry standards and guidelines.
“Verifying Generated Code With SIL and PIL Simulations”	You execute generated code with your plant model within Simulink to verify successful conversion of the model to code. You might change the code to emulate target word size behavior and verify numerical results expected when the code runs on an embedded microprocessor. Or, you might use actual target word sizes and just test production code behavior.
“Verifying Generated Code With SIL and PIL Simulations”	You test an object code component with a plant or environment model in an open- or closed-loop simulation to verify successful model-to-code conversion, cross-compilation, and software integration.
Hardware-in-the-loop (HIL) testing	You verify an embedded system or embedded computing unit (ECU), using a real-time target environment.

V-Model for System Development

In this section...
“What Is the V-Model?” on page 1-31
“Types of Simulation and Prototyping” on page 1-33
“Types of In-the-Loop Testing for Verification and Validation” on page 1-34

What Is the V-Model?

The V-model is a representation of system development that highlights verification and validation steps in the system development process. As the following figure shows, the left side of the V identifies steps that lead to code generation, including requirements analysis, system specification, detailed software design, and coding. The right side of the V focuses on the verification and validation of steps cited on the left side, including software integration and system integration.



Depending on your application and its role in the process, you might focus on one or more of the steps called out in the V-model or repeat steps at several stages of the V-model. Code generation technology and related products provide tooling that you can apply at each step.

The following sections compare:

- Types of simulation and prototyping
- Types of in-the-loop testing for verification and validation

For an information map on applications of code generation technology identified in the figure, see the following tables:

- “Documenting and Validating Requirements”

- “Developing a Model Executable Specification”
- “Developing a Detailed Software Design”
- “Generating the Application Code”
- “Integrating and Verifying Software”
- “Integrating, Verifying, and Calibrating System Components”

Types of Simulation and Prototyping

The following table compares the types of simulation and prototyping identified on the left side of the V-model diagram.

	Host-Based Simulation	Standalone Rapid Simulations	Rapid Prototyping	On-Target Rapid Prototyping
Purpose	Test and validate functionality of concept model	Refine, test, and validate functionality of concept model in nonreal time	Test new ideas and research	Refine and calibrate designs during development process
Execution hardware	Host computer	Host computer Standalone executable runs outside of MATLAB and Simulink environments	PC or nontarget hardware	Embedded computing unit (ECU) or near-production hardware

	Host-Based Simulation	Standalone Rapid Simulations	Rapid Prototyping	On-Target Rapid Prototyping
Code efficiency and I/O latency	Not applicable	Not applicable	Less emphasis on code efficiency and I/O latency	More emphasis on code efficiency and I/O latency
Ease of use and cost	<p>Can simulate component (algorithm or controller) and environment (or plant)</p> <p>Normal mode simulation in Simulink enables you to access, display, and tune data during verification</p> <p>Can accelerate Simulink simulations with Accelerated and Rapid Accelerated modes</p>	<p>Easy to simulate models of hybrid dynamic systems that include components and environment models</p> <p>Ideal for batch or Monte Carlo simulations</p> <p>Can repeat simulations with varying data sets, interactively or programmatically with scripts, without rebuilding the model</p> <p>Can connect to Simulink to monitor signals and tune parameters</p>	<p>Might require custom real-time simulators and hardware</p> <p>Might be done with inexpensive off-the-shelf PC hardware and I/O cards</p>	<p>Might use existing hardware, thus less expensive and more convenient</p>

Types of In-the-Loop Testing for Verification and Validation

The following table compares the types of in-the-loop testing for verification and validation identified on the right side of the V-model diagram.

	SIL Testing	PIL Testing on Embedded Hardware	PIL Testing on Instruction Set Simulator	HIL Testing
Purpose	Verify component source code	Verify component object code	Verify component object code	Verify system functionality
Fidelity and accuracy	Two options: Same source code as target, but might have numerical differences Changes source code to emulate word sizes, but is bit accurate for fixed-point math	Same object code Bit accurate for fixed-point math Cycle accurate because code runs on hardware	Same object code Bit accurate for fixed-point math Might not be cycle accurate	Same executable code Bit accurate for fixed-point math Cycle accurate Use real and emulated system I/O
Execution platforms	Host	Target	Host	Target
Ease of use and cost	Desktop convenience Executes only in Simulink No cost for hardware	Executes on desk or test bench Uses hardware — process board and cables	Desktop convenience Executes only on host computer with Simulink and integrated development environment (IDE) No cost for hardware	Executes on test bench or in lab Uses hardware — processor, embedded computer unit (ECU), I/O devices, and cables
Real-time capability	Not real time	Not real time (between samples)	Not real time (between samples)	Hard real time

Getting Started Tutorials

- “About the Tutorials” on page 2-2
- “Tutorial – Becoming Familiar with the Example Model and Testing Environment” on page 2-4
- “Tutorial – Configuring the Model and Generating Code” on page 2-18
- “Tutorial – Configuring the Data Interface” on page 2-26
- “Tutorial – Calling External C Functions from a Model and Generated Code” on page 2-37

About the Tutorials

In this section...
“Introduction” on page 2-2
“Prerequisites” on page 2-2
“Required Files” on page 2-3

Introduction

The following tutorials will help you get started with using Simulink Coder to generate code from Simulink models and subsystems:

- “Tutorial – Becoming Familiar with the Example Model and Testing Environment” on page 2-4
- “Tutorial – Configuring the Model and Generating Code” on page 2-18
- “Tutorial – Configuring the Data Interface” on page 2-26
- “Tutorial – Calling External C Functions from a Model and Generated Code” on page 2-37

Each tutorial focuses on a specific aspect of code generation or integration and is self-contained. Skim or skip tutorials that do not apply to your needs.

If you are licensed to use the Embedded Coder product, additional tutorials, based on the same models and test harness, are available.

Prerequisites

For these tutorials, you must know how to use MathWorks products to do the following:

- Create Simulink models
- Include Stateflow charts in Simulink models
- Run Simulink simulations and evaluate the results

Required Files

Each tutorial uses a unique example model file and data set.

- Before you use each example model file, place a copy in a writable location and add it to your MATLAB path.
- As you proceed through a tutorial, save your changes for future examination.
- To avoid potentially introducing errors, begin each tutorial by opening a new model and loading new data.

Tutorial – Becoming Familiar with the Example Model and Testing Environment

In this section...
“About This Tutorial” on page 2-4
“Understanding the Functional Design of the Model” on page 2-5
“Viewing the Top Model” on page 2-5
“Viewing the Subsystems” on page 2-6
“Understanding the Simulation Testing Environment” on page 2-8
“Checking the Model for Adverse Conditions and Simulation Settings” on page 2-13
“Running Simulation Tests” on page 2-14
“Key Points” on page 2-16
“Learn More” on page 2-16

About This Tutorial

Learning Objectives

- Understand the functional behavior of the example model.
- Understand the role of the example test harness and its components.
- Apply model checking tools to discover conditions and configuration settings resulting in inaccurate or inefficient simulation.
- Run simulation tests on a model.

Prerequisites

- Ability to open and modify Simulink models and subsystems.
- Understand subsystems and how to view subsystem details.
- Understand referenced models and how to view referenced model details.

- Ability to set model configuration parameters.
- Ability to use the Simulink Model Advisor.

Required Files

Before you use each example model file, place a copy in a writable location and add it to your MATLAB path.

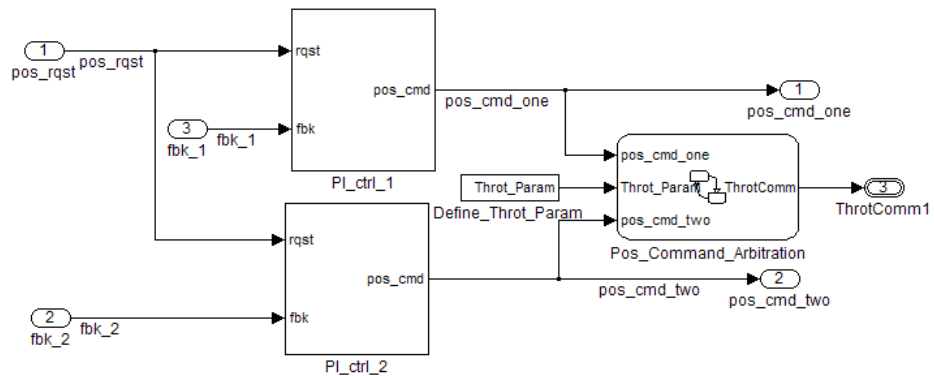
- `rtwdemo_throttlecntrl.mdl`
- `rtwdemo_throttlecntrl_testharness.mdl`

Understanding the Functional Design of the Model

This tutorial uses a simple, but functionally complete, example model of a throttle controller. The model features redundant control algorithms. The model highlights a standard model structure and a set of basic blocks in algorithm design.

Viewing the Top Model

Open `rtwdemo_throttlecntrl.mdl` and save a copy as `throttlecntrl.mdl` in a writable location on your MATLAB path.



The top level of the model consists of the following elements:

Subsystems	PI_ctrl1_1 PI_ctrl1_2 Define_Throt_Param Pos_Command_Arbitration
Top-level input	pos_rqst fbk_1 fbk_2
Top-level output	pos_cmd_one pos_cmd_two ThrotComm1
Signal routing	
<i>No blocks that change the value of a signal, such as Sum and Integrator</i>	

The layout uses a basic architectural style for models:

- Separation of calculations from signal routing (lines and buses)
- Partitioning into subsystems

You can apply this style to all types of models.

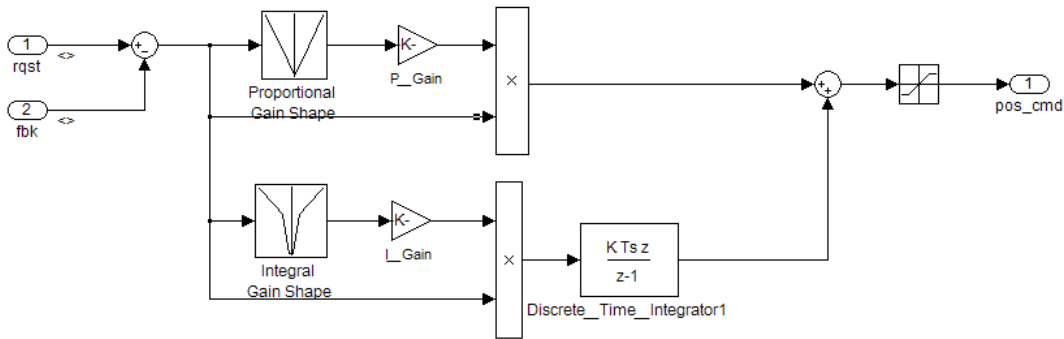
Viewing the Subsystems

Explore two of the subsystems in the top model.

- 1 If not already open, open `throttlectrl.mdl`.

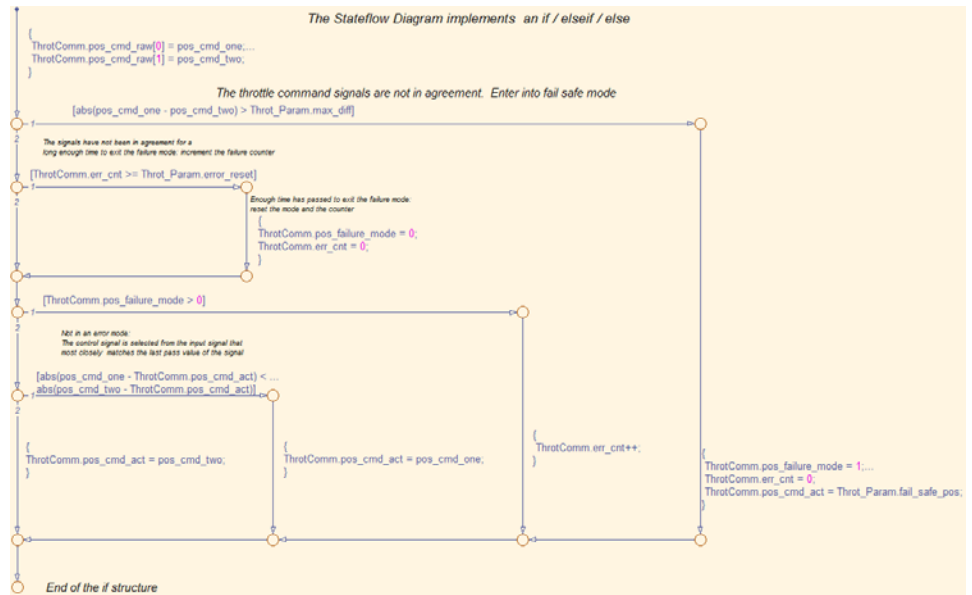
Two subsystems in the top model represent proportional-integral (PI) controllers, `PI_ctrl1_1` and `PI_ctrl1_2`. At this stage, these identical subsystems, use identical data. If you have an Embedded Coder license, you can use these subsystems in a tutorial that shows how to create reusable functions.

- 2 Open the `PI_ctrl1_1` subsystem.



The PI controllers in the model are from a *library*, a group of related blocks or models for reuse. Libraries provide one of two methods for including and reusing models. The second method, model referencing, is described in “Understanding the Simulation Testing Environment” on page 2-8. You cannot edit a block that you add to a model from a library. You must edit the block in the library. This restriction ensures that instances of the block in different models remain consistent.

- 3** Open the Pos_Command_Arbitration subsystem. This Stateflow chart performs basic error checking on the two command signals. If the command signals are too far apart, the Stateflow diagram sets the output to a fail_safe position.



4 Close throttlecntrl.mdl.

Understanding the Simulation Testing Environment

To test the throttle controller algorithm, you incorporate it into a *test harness*. A test harness is a model that evaluates the control algorithm and offers the following benefits:

- Separates test data from the control algorithm.
- Separates the plant or feedback model from the control algorithm.
- Provides a reusable environment for multiple versions of the control algorithm.

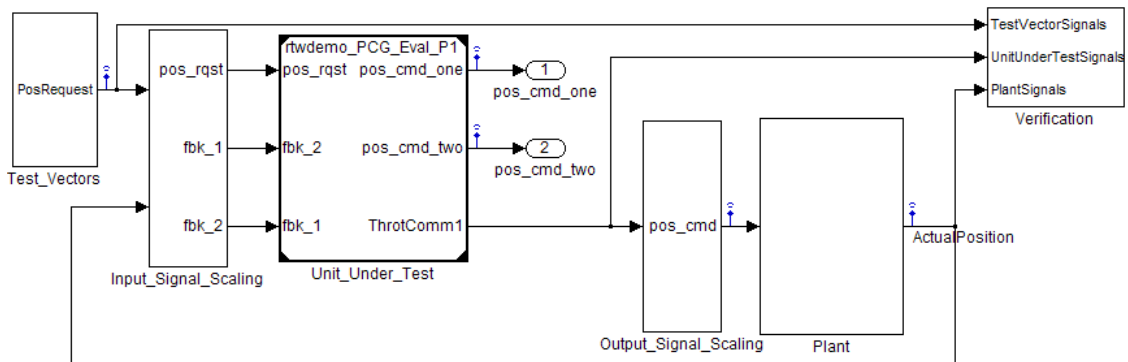
The test harness model for this tutorial implements a common simulation testing environment consisting of the following parts:

- Unit under test
- Test vector source
- Evaluation and logging

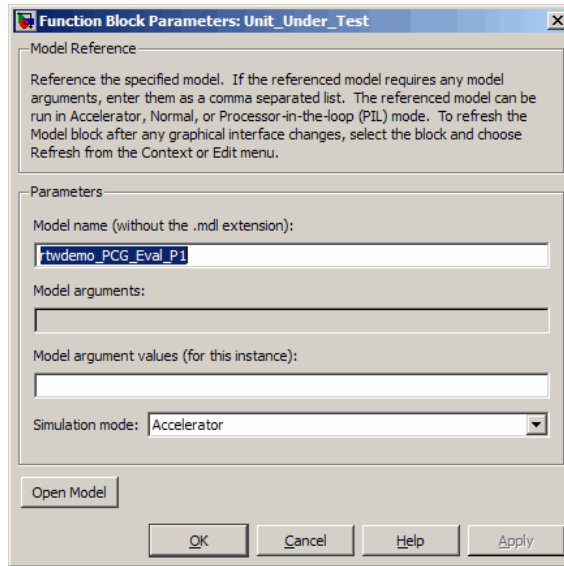
- Plant or feedback system
- Input and output scaling

Explore the simulation testing environment.

- 1 Open the test harness model `rtwdemo_throttlecntrl_testharness.mdl` and save a copy as `throttlecntrl_testharness.mdl` in a writable location on your MATLAB path.



- 2 Set up your `throttlecntrl` model as the control algorithm of the test harness.
 - a Open the `Unit_Under_Test` block and view the control algorithm.
 - b View the model reference parameters by right-clicking the `Unit_Under_Test` block and selecting **Model Reference Parameters**.



rtwdemo_PCG_Eval_P1 appears as the name of the referenced model.

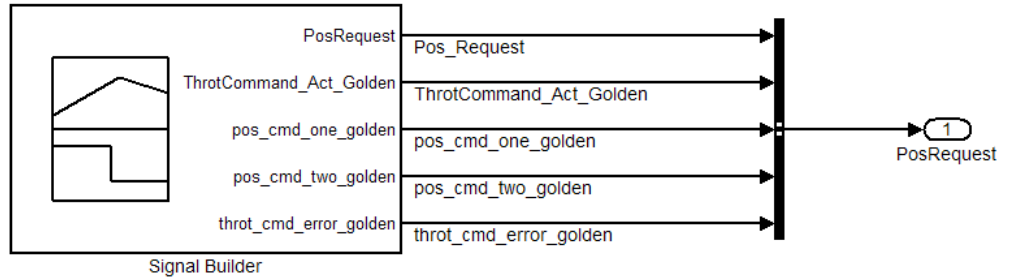
- c Change the value of **Model name** to `throttlecntrl`.
- d Update the test harness model diagram by clicking **Edit > Update Diagram**.

The control algorithm is the *unit under test*, as indicated by the name of the Model block, `Unit_Under_Test`.

The Model block provides a method for reusing components. From the top model, it allows you to reference other models (directly or indirectly) as *compiled functions*. By default, Simulink software recompiles the model when the referenced models change. Compiled functions have the following advantages over libraries:

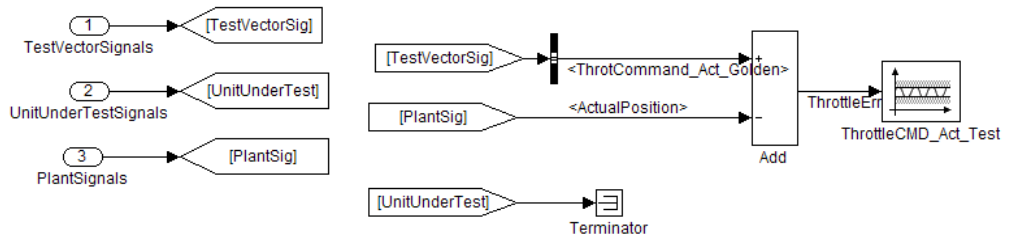
- Simulation time is faster for large models.
- You can directly simulate compiled functions.
- Simulation requires less memory. Only one copy of the compiled model is in memory, even when the model is referenced multiple times.

- 3 Open the *test vector source*, implemented in this test harness as the Test_Vectors subsystem.



The subsystem uses a Signal Builder block for the test vector source. The block has data that drives the simulation (PosRequest) and provides the expected results used by the Verification subsystem. This example test harness uses only one set of test data. Typically, you create a test suite that fully exercises the system.

- 4 Open the *evaluation and logging* subsystem, implemented in this test harness as subsystem Verification.

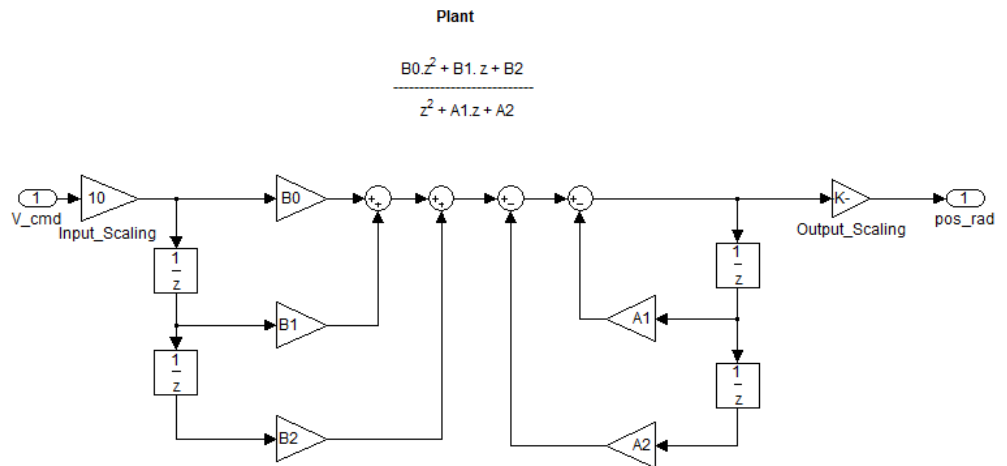


A test harness compares control algorithm simulation results against *golden data* — test results that exhibit the desired behavior for the control algorithm as certified by an expert. In the Verification subsystem, an Assertion block compares the simulated throttle value position from the plant against the golden value from the test harness. If the difference between the two signals is greater than 5%, the test fails and the Assertion block stops the simulation.

Alternatively, you can evaluate the simulation data after the simulation completes execution. You can use either MATLAB scripts or third-party

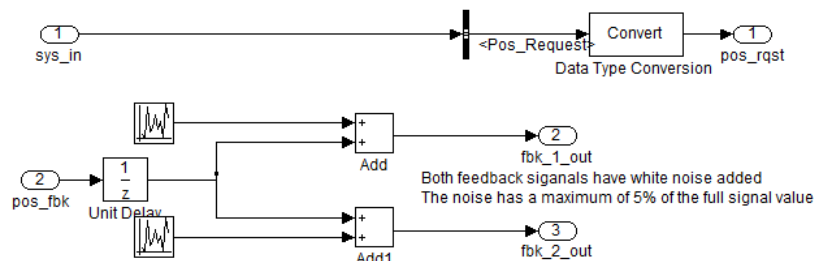
tools to perform the evaluation. Post-execution evaluation provides greater flexibility in the analysis of data. However, it requires waiting until execution is complete. Combining the two methods can provide a highly flexible and efficient test environment.

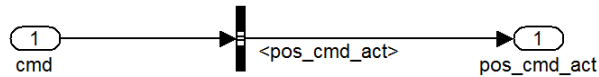
- 5 Open the *plant or feedback system*, implemented in this test harness as the Plant subsystem.



The Plant subsystem models the throttle dynamics with a transfer function in canonical form. You can create plant models to any level of fidelity. It is common to use different plant models at different stages of testing.

- 6 Open the *input and output scaling* subsystems, implemented in this test harness as Input_Signal_Scaling and Output_Signal_Scaling.





The subsystems that scale input and output perform the following primary functions:

- Select input signals to route to the unit under test and output signals to route to the plant.
- Rescale signals between engineering units and units that are writable for the unit under test.
- Handle rate transitions between the plant and the unit under test.

7 Save and close `throttlecntrl_testharness.mdl`.

Checking the Model for Adverse Conditions and Simulation Settings

Before simulating a model and running simulation tests, use the Simulink Model Advisor to check the model for conditions and configuration settings resulting in inaccurate simulation of the system that the model represents.

- 1** Open your copy of the throttle controller model, `throttlecntrl.mdl`.
- 2** Start the Model Advisor by selecting **Tools > Model Advisor**. A dialog box opens showing the model system hierarchy.
- 3** Click `throttlecntrl` and then click **OK**. The Model Advisor window opens.
- 4** Expand **By Product** and **Simulink**. By default, all checks that do not trigger an Update Diagram are selected.
- 5** In the left pane, enable the unselected checks and select **Simulink**.
- 6** In the right pane, select **Show report after run** and click **Run Selected Checks**. The report shows a **Run Summary** that flags seven warnings.

Run Summary

<input checked="" type="checkbox"/> Pass	<input checked="" type="checkbox"/> Fail	<input checked="" type="checkbox"/> Warning	<input checked="" type="checkbox"/> Not Run	Total
 17	 0	 7	 0	24

- 7 Follow the report instructions to correct the warning conditions and rerun the checks.

Running Simulation Tests

- 1 In the MATLAB Command Window, enter `mex -setup` to set up your C compiler. Specify a valid, installed compiler.
- 2 Check that your working folder is set to a writable folder, such as the folder into which you placed copies of the tutorial model files.
- 3 Open your copy of the test harness model, `throttlecntrl_testharness`.
- 4 Start a test harness model simulation.

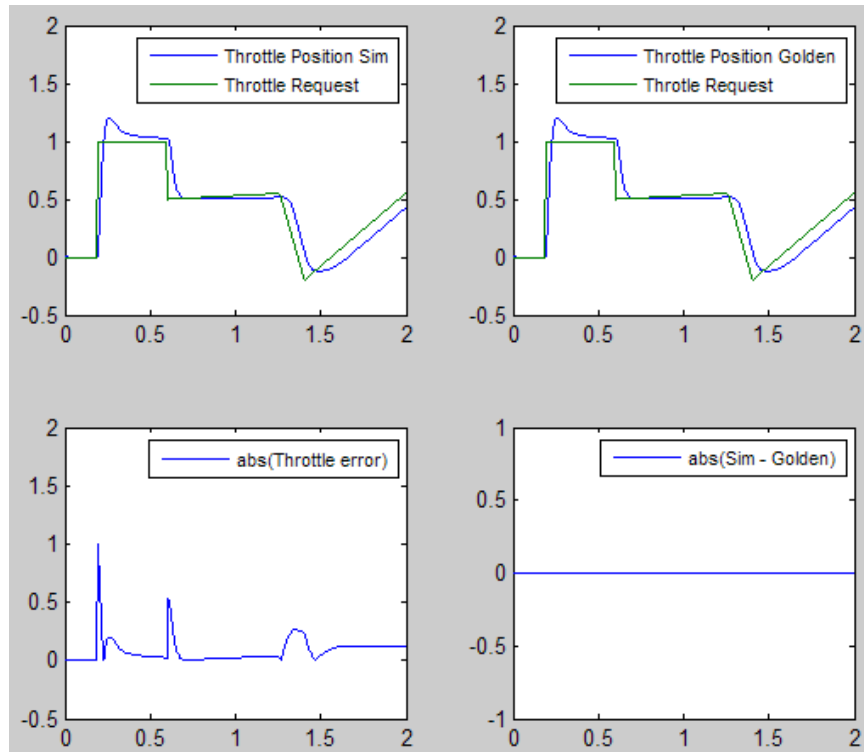
The first time that the test harness runs, the code generation software compiles the referenced model. You can monitor the compilation progress in the MATLAB Command Window.

During the compilation, an error dialog box appears reporting the following error:

```
Model 'throttlecntrl' is referenced in Normal Mode and does not have 'Inline parameters' enabled. Go to the Optimization > Signals and Parameters pane of the Configuration Parameters dialog for model 'throttlecntrl' and enable 'Inline parameters'
```

- 5 Enable inline parameters for the throttle control model, as instructed in the error message.
 - a Open `throttlecntrl.mdl`.
 - b Select **Simulation > Configuration Parameters > Optimization > Signals and Parameters > Inline parameters**.

- c Click **OK** to save the change and close the dialog box.
- 6 Restart the simulation. When the simulation is complete, Simulink software displays the results.



The lower-right hand plot shows the difference between the expected (golden) throttle position and the throttle position that the plant calculates. If the difference between the two values is greater than ± 0.05 , the simulation stops.

- 7 Save and close throttle controller and test harness models.

Key Points

- A basic model architecture separates calculations from signal routing and partitions the model into subsystems
- Two options for model reuse include block libraries and model referencing.
- If you represent your control algorithm in a test harness as a Model block, be sure that you specify the name of the control algorithm model correctly in the Model Reference Parameters dialog box.
- A test harness is a model that evaluates a control algorithm and typically consists of a unit under test, a test vector source, evaluation and logging, a plant or feedback system, and input and output scaling components.
- The unit under test is the control algorithm being tested.
- The test vector source provides the data that drives the simulation which generates results used for verification.
- During verification, the test harness compares control algorithm simulation results against golden data and logs the results.
- The plant or feedback component of a test harness models the environment that is being controlled.
- When developing a test harness,
 - Scale input and output components.
 - Select input signals to route to the unit under test.
 - Select output signals to route to the plant.
 - Rescale signals between engineering units and units that are writable for the unit under test.
 - Handle rate transitions between the plant and the unit under test.
- Before running simulation or completing verification, consider checking a model with the Model Advisor.

Learn More

- “Supporting Model Referencing” in the Simulink Coder documentation
- “Building Executables” in the Simulink Coder documentation

- “Configuration Parameters” in the Embedded Coder documentation
- “Working with Signal Groups” in the Simulink documentation

Tutorial – Configuring the Model and Generating Code

In this section...
“About This Tutorial” on page 2-18
“Configuring the Model for Code Generation” on page 2-19
“Saving Your Model Configuration as a MATLAB Function” on page 2-20
“Checking the Model for Adverse Conditions and Code Generation Settings” on page 2-21
“Generating Code for the Model” on page 2-22
“Reviewing the Generated Code” on page 2-22
“Generating an Executable” on page 2-24
“Key Points” on page 2-24
“Learn More” on page 2-25

About This Tutorial

Learning Objectives

- Configure a model for code generation.
- Apply model checking tools to discover conditions and configuration settings resulting in generation of inaccurate or inefficient code.
- Generate code from a model.
- Locate and identify generated code files.
- Review generated code.

Prerequisites

- Ability to open and modify Simulink models and subsystems.
- Ability to set model configuration parameters.
- Ability to use the Simulink Model Advisor.

- Ability to read C code.
- Set up a C compiler. In the MATLAB Command Window, enter `mex -setup` and specify a valid, installed compiler.

Required Files

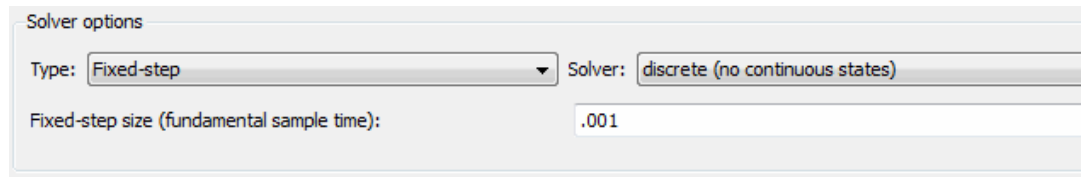
`rtwdemo_throttlecntrl.mdl`

Configuring the Model for Code Generation

Model configuration parameters determine the method for generating the code and the resulting format.

- 1 Open `rtwdemo_throttlecntrl.mdl` and save a copy as `throttlecntrl.mdl` in a writable location on your MATLAB path.
- 2 Open the Configuration Parameters dialog box Solver pane. To generate code for a model, you must configure the model to use a fixed-step solver. For this example, set the parameters as noted in the following table.

Parameter	Setting	Effect on Generated Code
Type	Fixed-step	Maintains a constant (fixed) step size, which is required for code generation
Solver	discrete (no continuous states)	Applies a fixed-step integration technique for computing the state derivative of the model
Fixed-step size	.001	Sets the base rate; must be the lowest common multiple of all rates in the system



- 3 Open the **Code Generation > General** pane and make sure that **System target file** is set to `grt.tlc`.

Note The GRT (Generic Real-Time Target) configuration requires a fixed-step solver. However, the `rsim.tlc` system target file supports variable step code generation.

The system target file (STF) defines a target, which is an environment for generating and building code for execution on a certain hardware or operating system platform. For example, one property of a target is code format. The `grt` configuration requires a fixed step solver and the `rsim.tlc` supports variable step code generation.

- 4 Open the **Code Generation > Custom Code** pane, and under **Include list of additional**, select **Include directories**. In the **Include directories** text field, enter:

```
"$matlabroot$\toolbox\rtw\rtwdemos\EmbeddedCoderOverview\"
```

This directory includes files that are required to build an executable for the model.

- 5 Apply your changes and close the dialog box.

Saving Your Model Configuration as a MATLAB Function

You can save the settings of model configuration parameters as a MATLAB function by using the `getActiveConfigSet` function. In the MATLAB Command Window, enter:

```
thcntrlAcs = getActiveConfigSet('throttlecntrl');  
thcntrlAcs.saveAs('throttlecntrlModelConfig');
```

You can then use the resulting function (for example, `throttlecntrlModelConfig`) to:

- Archive the model configuration.
- Compare different model configurations by using differencing tools.
- Set the configuration of other models.

For example, you can set the configuration of model `myModel` to match the configuration of the throttle controller model by opening `myModel` and entering:

```
myModelAcs = throttlecntrlModelConfig;  
attachConfigSet('myModel', myModelAcs, true);  
setActiveConfigSet('myModel', myModelAcs.Name);
```





For more information, see “Saving Configuration Sets” and “Loading Saved Configuration Sets” in the Simulink documentation.

Checking the Model for Adverse Conditions and Code Generation Settings

Before generating code for a model, use the Simulink Model Advisor to check the model for conditions and configuration settings that can result in inaccurate or inefficient code.

- 1 Open `throttlecntrl.mdl`.
- 2 Start the Model Advisor by selecting **Tools > Model Advisor**. A dialog box opens showing the model system hierarchy.
- 3 Click `throttlecntrl` and then click **OK**. The Model Advisor window opens.
- 4 Expand **By Product** and **Embedded Coder**. By default, all checks that do not trigger an Update Diagram, with one exception, are selected.
- 5 In the left pane, select the remaining checks and select **Embedded Coder**.
- 6 In the right pane, select **Show report after run** and click **Run Selected Checks**. The report shows a **Run Summary** that flags three warnings.

Run Summary

<input checked="" type="checkbox"/> Pass	<input checked="" type="checkbox"/> Fail	<input checked="" type="checkbox"/> Warning	<input checked="" type="checkbox"/> Not Run	Total
 11	 0	 3	 0	14

- 7 Review the report. The warnings highlight issues for embedded systems. At this point, you can safely ignore them.

Generating Code for the Model

- 1 Open `throttlecntrl.mdl`.
- 2 In the Configuration Parameters dialog box, select **Code Generation > Generate code only**.
- 3 On the **Code Generation > Report** pane, select **Create code generation report**.
- 4 Click **Apply**.
- 5 Return to the **Code Generation** pane, click the **Generate code** button, and watch the messages that appear in the MATLAB Command Window. The code generator produces standard C and header files, and an HTML code generation report. The code generator places the files in a *build folder*, a subfolder named `throttlecntrl_grt_rtw` under your current working folder.

Reviewing the Generated Code

- 1 Open Model Explorer, and in the **Model Hierarchy** pane, expand the node for the `throttlecntrl` model, and select the **Code for** node.
- 2 In the **Contents** pane, select **HTML Report**. Model Explorer displays the HTML code generation report for the throttle controller model.
- 3 In the HTML report, click the link for the generated C model file and review the generated code. Note the following:
 - Identification, version, timestamp, and configuration comments.
 - Links to help you navigate within and between files

- Data definitions
- Scheduler code
- Controller code
- Model initialization and termination functions
- Call interface for the GRT target — output, update, initialization, start, and terminate

4 Save and close `throttlecntrl.mdl`.

Consider examining the following files. In the HTML report **Contents** pane, click the links. Or, in your working folder, explore the generated code subfolder.

File	Description
<code>throttlecntrl.c</code>	C file that contains the scheduler, controller, initialization, and interface code
<code>throttlecntrl_data.c</code>	C file that assigns values to generated data structures
<code>throttlecntrl.h</code>	Header file that defines data structures
<code>throttlecntrl_private.h</code>	Header file that defines data used only by the generated code
<code>throttlecntrl_types.h</code>	Header file that defines the model data structure

For more information, see “Generated Source Files and File Dependencies”.

At this point you might also want to consider logging data to a MAT-file. For an example, see “Logging Data for Analysis”.

Generating an Executable

- 1 If you have not already done so, set up your C compiler. In the MATLAB Command Window, enter `mex -setup` and specify a valid, installed compiler.
- 2 Open `throttlecntrl.mdl`.
- 3 In the Configuration Parameters dialog box, clear the **Code Generation > Generate code only** check box.
- 4 Click the **Build** button. Watch the messages in the MATLAB Command Window. The code generator uses a template make file associated with your target selection to create an executable that you can run on your workstation, independent of external timing and events.
- 5 Check the contents of the build folder. Find the file `throttlecntrl.exe` file for your model.
- 6 Run the executable. In the Command Window, enter `!throttlecntrl`. The `!` character passes the command that follows it to the operating system, which runs the standalone program.

The program produces one line of output in the Command Window:

```
** starting the model **
```

At this point you might also want to consider logging data to a MAT-file. For an example, see “Logging Data for Analysis”.

Key Points

- To generate code change the model configuration to specify a fixed-step solver and then select a system target format. Using the `grt.tlc` file requires a fixed-step solver. If the model contains continuous time blocks then a variable-step solver can be used with the `rsim.tlc` target.
- After debugging a model, consider configuring a model with parameter inlining enabled.
- Use the `getActiveConfigSet` function to save a model configuration for future use or to apply it to another model.

- Before generating code, consider checking a model with the Model Advisor.
- The code generator places generated files in a subfolder (*model_grt_rtw*) of your working folder.

Learn More

- “Preparing Models for Code Generation”
- “Saving Configuration Sets” and “Loading Saved Configuration Sets” in the Simulink documentation.
- “Consulting the Model Advisor” in the Simulink documentation.
- “Generating Code and Building Executables”

Tutorial – Configuring the Data Interface

In this section...
“About This Tutorial” on page 2-26
“Declaring Data” on page 2-27
“Using Data Objects” on page 2-28
“Adding New Data Objects” on page 2-31
“Enabling Data Objects for Generated Code” on page 2-32
“Effects of Simulation on Data Typing” on page 2-33
“Managing Data” on page 2-34
“Key Points” on page 2-35
“Learn More” on page 2-35

About This Tutorial

Learning Objectives

- Configure the data interface for code generated for a model.
- Control the name, data type, and data storage class of signals and parameters in generated code.

Prerequisites

- Understanding ways to represent and use data and signals in models.
- Familiarity with representing data constructs as data objects.
- Ability to read C code.

Required File

rtwdemo_throttlecntrl_datainterface.mdl

Declaring Data

Most programming languages require that you *declare* data before using it. The declaration specifies the following information:

Data Attribute	Description
Scope	The region of the program that has access to the data
Duration	The period during which the data is resident in memory
Data type	The amount of memory allocated for the data
Initialization	An initial value, a pointer to memory, or NULL (if you do not provide an initial value, most compilers assign a zero value or a null pointer)

The following data types are supported for code generation.

Supported Data Types

Name	Description
double	Double-precision floating point
single	Single-precision floating point
int8	Signed 8-bit integer
uint8	Unsigned 8-bit integer
int16	Signed 16-bit integer
uint16	Unsigned 16-bit integer
int32	Signed 32-bit integer
uint32	Unsigned 32-bit integer
Fixed point data types	8-, 16-, 32-bit word lengths

A *storage class* is the scope and duration of a data item. For more information about storage classes, see

- “Tunable Parameter Storage Classes”

- “Signals Storage Classes”
- “Block State Storage Classes”

Using Data Objects

In Simulink models and Stateflow charts, the following methods are available for declaring data: *data objects* and *direct specification*. This tutorial uses the data object method. Both methods allow full control over the data type and storage class. You can mix the two methods in a single model.

In the MATLAB and Simulink environment, you can use data objects in a variety of ways. This tutorial focuses on the following types of data objects:

- Signal
- Parameter
- Bus

To configure the data interface for your model using the data object method, in the MATLAB base workspace, you define data objects and then associate them with your Simulink model or embedded Stateflow chart. When you build your model, the build process uses the associated base workspace data objects in the generated code.

A data object has a mixture of *active* and *descriptive* fields. Active fields affect simulation or code generation. Descriptive fields do not affect simulation or code generation. They are used with data dictionaries and model-checking tools.

- Active fields:
 - Data type
 - Storage class
 - Value (parameters)
 - Initial value (signals)
 - Alias (define a different name in the generated code)
 - Dimension (inherited for parameters)

- Complexity (inherited for parameters)
- Descriptive fields:
 - Minimum
 - Maximum
 - Units
 - Description

You can create and inspect base workspace data objects by entering commands in the MATLAB Command Window or by using Model Explorer. Perform the following steps to explore base workspace signal data objects.

- 1** Open `rtwdemo_throttlecntrl_datainterface.mdl` and save a copy as `throttlecntrl_datainterface.mdl` in a writable location on your MATLAB path.
- 2** Open Model Explorer.
- 3** Select **Base Workspace**.
- 4** Select the `pos_cmd_one` signal object for viewing.

The screenshot shows the Simulink Signal Inspector for a signal named 'pos_cmd_one'. On the left, a tree view lists various signals in the workspace, with 'pos_cmd_one' selected. The right pane displays the configuration for this signal:

- Simulink.Signal: pos_cmd_one**
- Data type: double
- Complexity: auto
- Dimensions: -1, Dimensions mode: auto
- Sample time: -1, Sample mode: auto
- Minimum: -1, Maximum: 1
- Initial value: 0, Units: Norm
- Code generation options: Storage class: ExportedGlobal, Alias: (empty)
- Description: Throttle position command from the first PI controller

You can also view the definition of a signal object. In the MATLAB Command Window, enter `pos_cmd_one`:

```
pos_cmd_one =

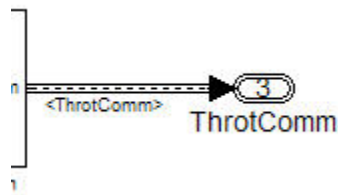
Simulink.Signal (handle)
    RTWInfo: [1x1 Simulink.SignalRTWInfo]
    Description: [1x54 char]
    DataType: 'double'
    Min: -1
    Max: 1
    DocUnits: 'Norm'
    Dimensions: -1
    DimensionsMode: 'auto'
    Complexity: 'auto'
    SampleTime: -1
    SamplingMode: 'auto'
    InitialValue: '0'
```


- 5 To view other signal objects, in Model Explorer, click the object name or in the MATLAB Command Window, enter the object name. The following table summarizes object characteristics for some of the data objects in this model.

Object Characteristics	pos_cmd_one	pos_rqst	P_InErrMap	ThrotComm*	ThrottleCommands*
Description	Top-level output	Top-level input	Calibration parameter	Top-level output structure	Bus definition
Data type	Double	Double	Auto	Auto	Structure
Storage class	Exported global	Imported extern pointer	Constant	Exported global	None

* `ThrottleCommands` defines a Bus object; `ThrotComm` is an instantiation of the bus. If the bus is a nonvirtual bus, the signal generates a structure in the C code.

You can use a bus definition (`ThrottleCommands`) to instantiate multiple instances of the structure. In a model diagram, a bus object appears as a wide line with central dashes, as shown below.



Adding New Data Objects

You can create data objects for named signals, states, and parameters. To associate a data object with a construct, the construct must have a name.

To find constructs for which you can create data objects, use the Data Object Wizard. This tool finds the constructs and then creates the objects for you.

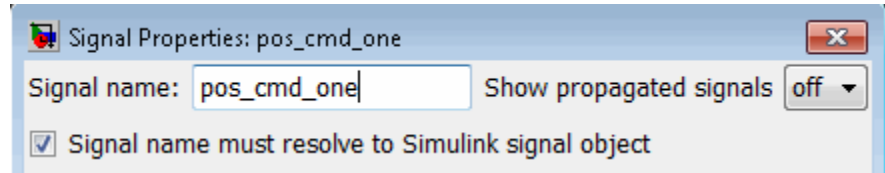
The model includes two signals that are not associated with data objects: fbk_1 and pos_cmd_two.

To find the signals and create data objects for them:

- 1 In the model window, select **Tools > Data Object Wizard**. The Data Object Wizard dialog box opens.
- 2 To find candidate constructs, click **Find**. Constructs fbk_1 and pos_cmd_two appear in the dialog box.
- 3 To select both constructs, click **Check All**.
- 4 To apply the default Simulink package for the data objects, click **Apply Package**.
- 5 To create the data objects, click **Create**. Constructs fbk_1 and pos_cmd_two are removed from the dialog box.
- 6 Close the Data Object Wizard.
- 7 In the **Contents** pane of the Model Explorer, find the newly created objects fbk_1 and pos_cmd_two.

Enabling Data Objects for Generated Code

- 1 In the Model Explorer **Model Hierarchy**, expand the throttlecntrl_datainterface model node.
- 2 Click the **Configuration (Active)** node. Make sure that you select, **Optimization > Signals and Parameters > Inline parameters**.
- 3 Enable a signal to appear in generated code.
 - a In the model window, right-click the pos_cmd_one signal line and select **Signal Properties**. A Signal Properties dialog box opens.
 - b Make sure that you select the **Signal name must resolve to Simulink signal object** parameter.



- 4 Enable signal object resolution for all signals in the model simultaneously. In the MATLAB Command Window, enter:

```
disableimplicitsignalresolution('throttlecntrl_datainterface')
```

- 5 Save and close throttlecntrl_datainterface.mdl.

Effects of Simulation on Data Typing

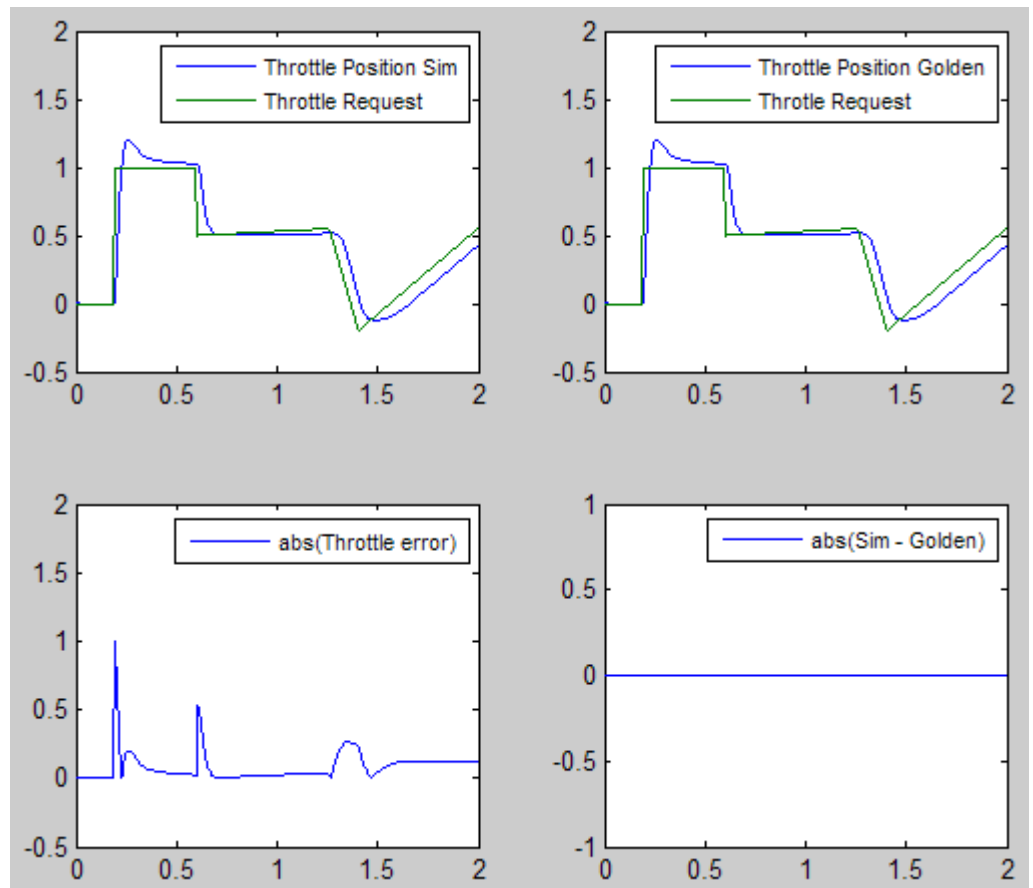
In the throttle controller model, all data types are set to double. Because Simulink software uses the double data type for simulation, do not expect changes in the model behavior when you run the generated code. You verify this by running the test harness.

Before you run your test harness, update it to include the throttlecntrl_datainterface model.

Note The following procedure requires a Stateflow license.

- 1 Open throttlecntrl_datainterface.mdl.
- 2 Open your copy of test harness, throttlecntrl_testharness.mdl.
- 3 Right-click the Unit_Under_Test Model block and select **Model Reference Parameters**.
- 4 Set **Model name (without the .mdl extension)** to throttlecntrl_datainterface. Click **OK**.
- 5 Update the test harness model diagram.
- 6 Simulate the test harness.

The resulting plot shows that the difference between the golden and simulated versions of the model remains zero.



7 Save and close `throttlecenr1_testharness.mdl`.

Managing Data

Data objects exist in a separate file from the model in the base workspace. To save the data manually, in the MATLAB Command Window, enter `save`.

The separation of data from the model provides the following benefits:

- One model, multiple data sets:
 - Use of different parameter values to change the behavior of the control algorithm (for example, for reusable components with different calibration values)
 - Use of different data types to change targeted hardware (for example, for floating-point and fixed-point targets)
- Multiple models, one data set:
 - Sharing data between models in a system
 - Sharing data between projects (for example, transmission, engine, and wheel controllers might all use the same CAN message data set)

Key Points

- You can declare data in Simulink models and Stateflow charts by using data objects or direct specification.
- From the Model Explorer or from the command line in the MATLAB Command Window, you manage (create, view, configure, and so on) base workspace data.
- The Data Object Wizard provides a quick way to create data objects for constructs such as signals, buses, and parameters.
- You must explicitly configure data objects to appear by name in generated code.
- Because Simulink software uses the `double` data type for simulation, if all data types are set to `double` for a model, expect simulation and generated code behavior to match.
- Separation of data from model provides several benefits.

Learn More

- “Working with Data” in the Simulink documentation
- “Defining Data Representation and Storage for Code Generation”
- “Creating and Using Custom Storage Classes” in the Embedded Coder documentation

- “Managing Placement of Data Definitions and Declarations” in the Embedded Coder documentation

Tutorial – Calling External C Functions from a Model and Generated Code

In this section...

“About This Tutorial” on page 2-37

“Including External C Functions in a Model” on page 2-38

“Creating a Block That Calls a C Function” on page 2-38

“Validating External Code in the Simulink Environment” on page 2-40

“Validating C Code as Part of a Model” on page 2-42

“Calling a C Function from Generated Code” on page 2-44

“Key Points” on page 2-44

“Learn More” on page 2-45

About This Tutorial

Learning Objectives

- Evaluate a C function as part of a model simulation.
- Call an external C function from generated code.

Prerequisites

- Ability to open and modify Simulink models and subsystems.
- Ability to set model configuration parameters.
- Ability to read C code.
- Set up a C compiler. In the MATLAB Command Window, enter `mex -setup` and specifying a valid, installed compiler.

Required Files

- `rtwdemo_throttlenrl_extfunccall.mdl`

- `rtwdemo_ValidateLegacyCodeVrsSim.mdl`
- `/toolbox/rtw/rtwdemos/EmbeddedCoderOverview/stage_4_files/SimpleTable.c`
- `/toolbox/rtw/rtwdemos/EmbeddedCoderOverview/stage_4_files/SimpleTable.h`

Including External C Functions in a Model

Simulink models are one part of Model-Based Design. For many applications, a design also includes a set of preexisting C functions created, tested (verified), and validated outside of a MATLAB and Simulink environment. You can integrate these functions easily into a model and the generated code. External C code can be used in the generated code to access hardware devices and external data files during rapid simulation runs.

This tutorial shows you how to create a custom block that calls an external C function. Once the block is part of the model, you can take advantage of the simulation environment to test the system further.

Creating a Block That Calls a C Function

To specify a call to an external C function, use an S-Function block. You can automate the process of creating the S-Function block by using the Simulink Legacy Code Tool. Using this tool, you specify an interface for your external C function. The tool then uses that interface to automate creation of an S-Function block.

- 1 Make copies of the files `SimpleTable.c` and `SimpleTable.h`, located in `matlabroot/toolbox/rtw/rtwdemos/EmbeddedCoderOverview/stage_4_files`. Put the copies in your working folder.

Note `matlabroot` represents the name of your top-level MATLAB installation folder.

- 2 Create an S-Function block that calls the specified function at each time step during simulation:
 - a In the MATLAB Command Window, create a function interface definition structure:


```
def=legacy_code('initialize')
```

The data structure `def` defines the function interface to the external C code.

```
def =

    SFunctionName: ''
InitializeConditionsFcnSpec: ''
    OutputFcnSpec: ''
    StartFcnSpec: ''
    TerminateFcnSpec: ''
    HeaderFiles: {}
    SourceFiles: {}
    HostLibFiles: {}
    TargetLibFiles: {}
    IncPaths: {}
    SrcPaths: {}
    LibPaths: {}
    SampleTime: 'inherited'
    Options: [1x1 struct]
```

- b** Populate the function interface definition structure by entering the following commands:

```
def.OutputFcnSpec=['double y1 = SimpleTable(double u1,',...
    'double p1[], double p2[], int16 p3)'];
def.HeaderFiles = {'SimpleTable.h'};
def.SourceFiles = {'SimpleTable.c'};
def.SFunctionName = 'SimpTableWrap';
```

- c** Create the S-function:

```
legacy_code('sfcn_cmex_generate', def)
```

- d** Compile the S-function:

```
legacy_code('compile', def)
```

- e** Create the S-Function block:

```
legacy_code('slblock_generate', def)
```

A new model window opens that contains the `SimpTableWrap` block.

Tip Creating the S-Function block is a one-time task. Once the block exists, you can reuse it in any model.

3 Save the model to your working folder as: `s_func_simpltablewrap.mdl`.

4 Create a Target Language Compiler (TLC) file for the S-Function block:

```
legacy_code('sfcn_tlc_generate', def)
```

The TLC file is the component of an S-function that specifies how the code generator produces the code for a block.

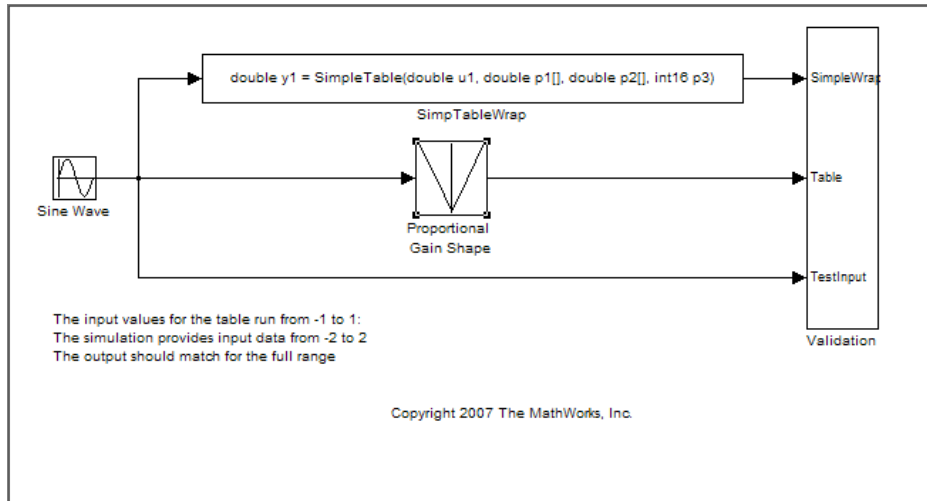
For more information on using the Legacy Code Tool, see:

- “Integrating Existing C Functions into Simulink Models with the Legacy Code Tool” in the Simulink documentation
- “Automating Generation of Files for Fully Inlined S-Functions Using Legacy Code Tool”

Validating External Code in the Simulink Environment

When you integrate external C code with a Simulink model, before using the code, always validate the functionality of the external C function code as a standalone component .

1 Open the model `rtwdemo_validateLegacyCodeVrsSim.mdl`. This model validates the S-function block that you just created.

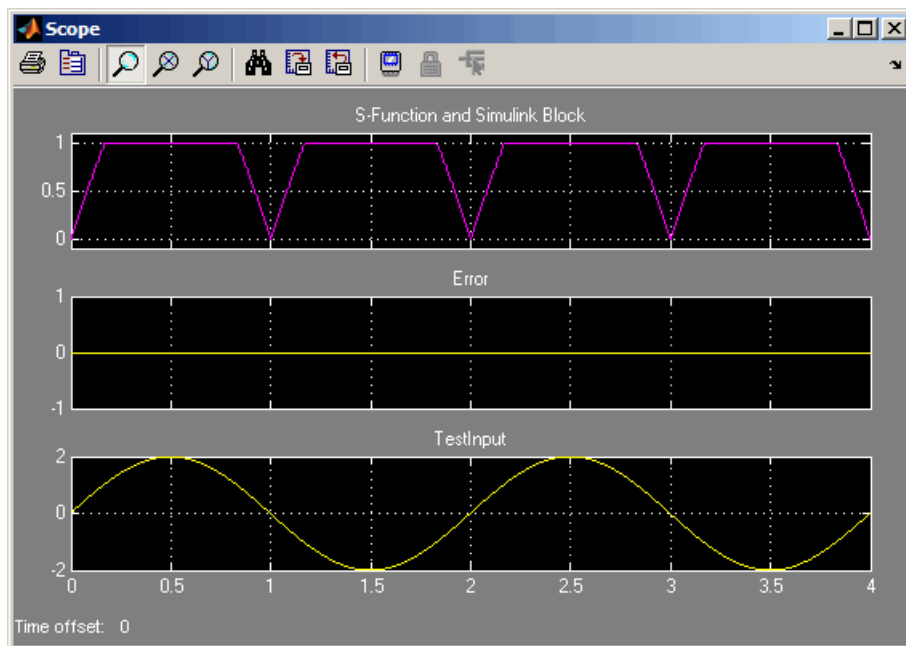


- The Sine Wave block produces output values from $[-2 : 2]$.
- The input range of the lookup table is from $[-1 : 1]$.
- The output from the lookup table is the absolute value of the input.
- The lookup table output clips the output at the input limits.

2 Simulate the model.

3 View the validation results by opening the Validation subsystem and, in that subsystem, clicking the Scope block.

The following figure shows the validation results. The external C code and the Simulink Lookup table block provide the same output values.



4 Close the validation model.

Validating C Code as Part of a Model

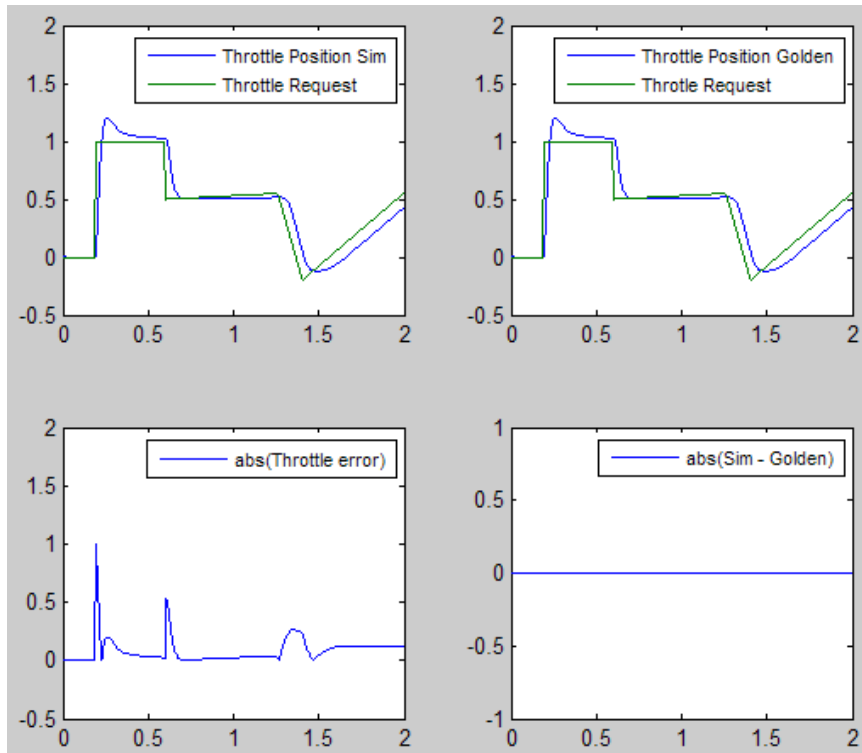
After you validate the functionality of the external C function code as a standalone component, validate the S-function in the model. Use the test harness model to complete the validation.

Note The following procedure requires a Stateflow license.

- 1 Open `rtwdemo_throttlectrl_extfunccall.mdl` and save a copy as `throttlectrl_extfunccall.mdl` in a writable folder on your MATLAB path.
- 2 Examine the `PI_ctrl_1` and `PI_ctrl_2` subsystems.
 - a Lookup blocks have been replaced with the block you created using the Legacy Code Tool.

- b** Note the block parameter settings for `SimpTableWrap` and `SimpTableWrap1`.
- c** Close the Block Parameter dialog boxes and the PI subsystem windows.
- 3** Open the test harness model, right-click the `Unit_Under_Test` Model block, and select **Model Reference Parameters**.
- 4** Set **Model name (without the .mdl extension)** to `throttlecntrl_extfunccall`. Click **OK**.
- 5** Update the test harness model diagram.
- 6** Simulate the test harness.

The simulation results match the expected golden values.



- 7 Save and close `throttlecntrl_extfunccall.mdl` and `rtwdemo_throttlecntrl_testharness.mdl`.

Calling a C Function from Generated Code

The code generator uses a TLC file to process the S-Function block. Calls to C code embedded in an S-Function block:

- Can use data objects.
- Are subject to *expression folding*, an operation that combines multiple computations into a single output calculation.

- 1 Open `rtwdemo_throttlecntrl_extfunccall.mdl`.
- 2 Generate code for the model.
- 3 Examine the generated code in the file `throttlecntrl_extfunccall.c`.

The following code fragment shows code for a Lookup Table block before you replaced the block with the external `SimpleTable` function:

```
throttlecntrl_extfunccall_B.Discrete_Time_Integrator1 = throttlecntrl_extfunccall_P.I_Gain *
    rt_Lookup((const real_T *)throttlecntrl_extfunccall_P.I_InErrMap, 9, rtb_Sum3,
    (const real_T *)throttlecntrl_extfunccall_P.I_OutMap) * rtb_Sum3 * 0.001 +
    throttlecntrl_extfunccall_DWork.Discrete_Time_Integrator1_DSTAT;
```

After you integrate the `SimpleTable` function, the generated code appears as follows:

```
throttlecntrl_extfunccall_B.Discrete_Time_Integrator1 = throttlecntrl_extfunccall_P.I_Gain *
    SimpleTable( (real_T)rtb_Sum2, (real_T*)throttlecntrl_extfunccall_P.I_InErrMap, (real_T*)
    throttlecntrl_extfunccall_P.I_OutMap, (int16_T)9) * rtb_Sum2 * 0.001 +
    throttlecntrl_extfunccall_DWork.Discrete_Time_Integrator1_DSTAT;
```

- 4 Close `throttlecntrl_extfunccall.mdl` and `throttlecntrl_testharness.mdl`.

Key Points

- You can easily integrate external functions into a model and generated code by using the Legacy Code Tool.

- Always validate the functionality of external C function code which you integrate into a model as a standalone component.
- After you validate the functionality of external C function code as a standalone component, validate the S-function in the model.

Learn More

- “Integrating Existing C Functions into Simulink Models with the Legacy Code Tool” in the Simulink documentation
- “Integrating External Code With Generated C and C++ Code” in the Simulink Coder documentation

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