

# Vitis Model Composer User Guide

UG1483 (v2022.2) October 19, 2022

Xilinx is creating an environment where employees, customers, and partners feel welcome and included. To that end, we're removing non-inclusive language from our products and related collateral. We've launched an internal initiative to remove language that could exclude people or reinforce historical biases, including terms embedded in our software and IPs. You may still find examples of non-inclusive language in our older products as we work to make these changes and align with evolving industry standards. Follow this [link](#) for more information.





# Table of Contents

<b>Chapter 1: Overview.....</b>	<b>4</b>
Navigating Content by Design Process.....	4
Introduction.....	5
What's New and Limitations.....	6
Installation.....	7
Supported MATLAB Versions and Operating Systems.....	10
Recommended Display Resolution.....	11
<b>Chapter 2: HDL Library.....</b>	<b>12</b>
Introduction.....	12
Hardware Design Using HDL Library.....	19
Performing Analysis in Model Composer.....	113
Using Hardware Co-Simulation.....	127
Importing HDL Modules.....	149
Compilation Types for HDL Library designs.....	171
Creating Custom Compilation Targets.....	180
Xilinx Waveform Viewer.....	189
<b>Chapter 3: HLS Library.....</b>	<b>198</b>
Introduction.....	198
Creating a Model Composer Design.....	199
Importing C/C++ Code as Custom Blocks.....	216
Generating Outputs.....	248
Simulating and Verifying Your Design.....	272
Select Target Device or Board.....	276
<b>Chapter 4: AI Engine Library.....</b>	<b>278</b>
Introduction.....	278
Vitis Model Composer for AI Engine Development.....	280
Creating an AI Engine Design using Vitis Model Composer.....	283
AI Engine DSPLib.....	330
Setting Signal Size to Avoid Buffer Overflow.....	331

Simulation and Code Generation.....	335
<b>Chapter 5: Hardware Validation Flow for AI Engines and PL.....</b>	<b>357</b>
Introduction.....	357
High-Level Flow for Generating a Hardware Image.....	357
Setting up the Tool to Generate an Image File for Hardware Validation Flow.....	360
Generating the Hardware Image Outside the MATLAB Environment.....	363
Design Considerations.....	363
<b>Chapter 6: Connecting AI Engine and Non-AI Engine Blocks.....</b>	<b>365</b>
AI Engine/Programmable Logic Integration.....	365
Connecting Source and Sink Blocks.....	379
<b>Chapter 7: Xilinx Toolbox.....</b>	<b>382</b>
Xilinx Toolbox Block Description .....	382
HDL Blockset.....	397
HLS Blockset.....	735
AI Engine Blockset.....	846
Utility Blocks.....	912
<b>Appendix A: Model Composer Utilities and Programmatic Access</b>	<b>934</b>
AI Engine Utilities.....	934
HDL Utilities.....	939
Programmatic Access.....	976
<b>Appendix B: Additional Resources and Legal Notices.....</b>	<b>1000</b>
Xilinx Resources.....	1000
Documentation Navigator and Design Hubs.....	1000
References.....	1000
Revision History.....	1001
Please Read: Important Legal Notices.....	1002

# Overview

---

## Navigating Content by Design Process

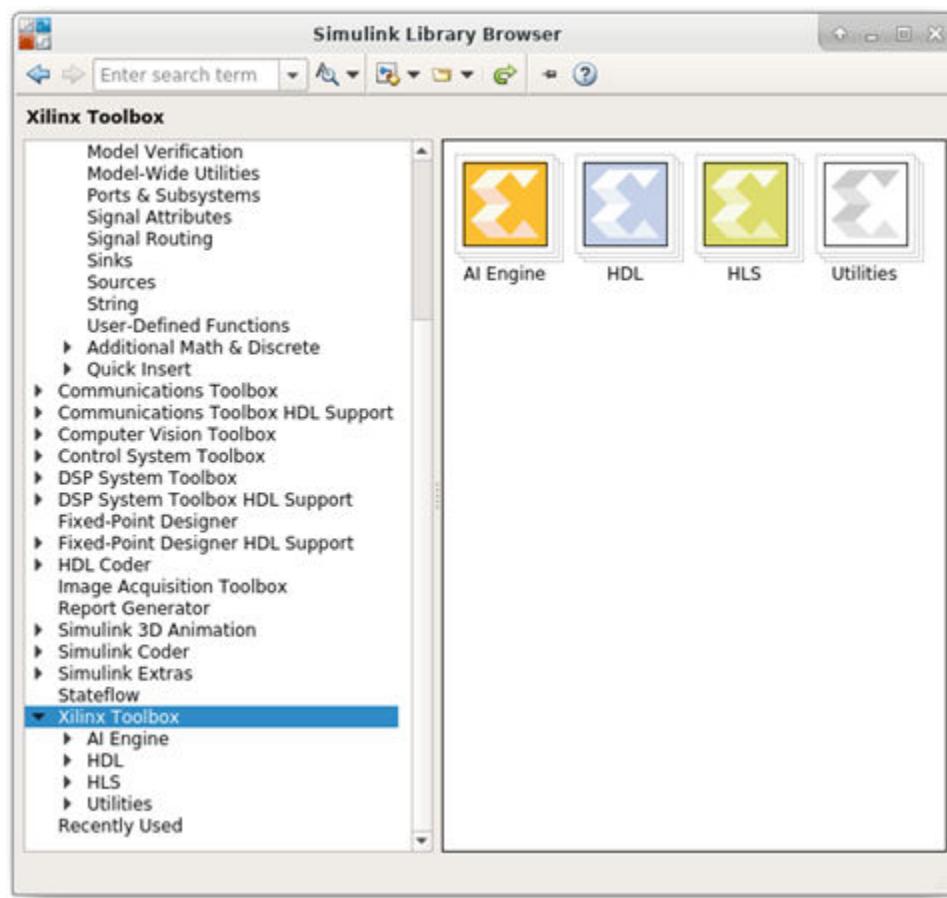
Xilinx® documentation is organized around a set of standard design processes to help you find relevant content for your current development task. All Versal® ACAP design process [Design Hubs](#) and the [Design Flow Assistant](#) materials can be found on the [Xilinx.com](#) website. This document covers the following design processes:

- **AI Engine Development:** Creating the AI Engine graph and kernels, library use, simulation debugging and profiling, and algorithm development. Also includes the integration of the PL and AI Engine kernels. Topics in this document that apply to this design process include:
  - [Creating an AI Engine Design using Vitis Model Composer](#)
  - [Simulation and Code Generation](#)
  - [Chapter 6: Connecting AI Engine and Non-AI Engine Blocks](#)
- **Hardware, IP, and Platform Development:** Creating the PL IP blocks for the hardware platform, creating PL kernels, functional simulation, and evaluating the Vivado® timing, resource use, and power closure. Also involves developing the hardware platform for system integration. Topics in this document that apply to this design process include:
  - [Hardware Design Using HDL Library](#)
  - [Creating a Model Composer Design](#)
  - [Compilation Types for HDL Library designs](#)
- **System Integration and Validation:** Integrating and validating the system functional performance, including timing, resource use, and power closure. Topics in this document that apply to this design process include:
  - [Performing Analysis in Model Composer](#)
  - [Using Hardware Co-Simulation](#)

# Introduction

Vitis™ Model Composer is a model-based design tool that enables rapid design exploration within the Simulink® environment and accelerates the path to production on Xilinx devices through automatic code generation. This provides a library of performance-optimized blocks for design and implementation of algorithms on Xilinx devices using HDL, HLS, and AI Engine blocks.

Figure 1: Simulink Library Browser



You can focus on expressing algorithms using blocks from these libraries as well as custom user-imported blocks, without worrying about implementation specifics, and leverage all the capabilities of Simulink's graphical environment for algorithm design, simulation, and verification.

The AI Engine library in Vitis Model Composer contains blocks to import kernels and graphs which can be targeted to the AI Engine portion of Versal® devices. Also included is a set of complex AI Engine DSP building blocks related to FIR, FFT, DDS, and Mixers. The tool transforms your AI Engine design specification into a top level connected graph to implement AI Engine-based devices.

The HDL library in Vitis Model Composer contains DSP building blocks. These blocks include the basic element blocks such as adders, multipliers, and registers. Also included are a set of complex DSP building blocks such as FFTs, filters, and memories. These blocks leverage the Xilinx IP core generators to deliver optimized results for the selected device.

The HLS library in Vitis Model Composer offers predefined blocks which includes functional blocks for Math, Linear Algebra, Logic, and Bit-wise operations. The tool transforms your algorithmic specifications to production-quality implementation through automatic optimizations that extend the Xilinx High Level Synthesis technology.

The utility library in Vitis Model Composer contains common utilities such as Vitis Model Composer Hub and connectors. These are used to generate output and analyze blocks that support connection between AI Engine and HDL libraries and AI Engine to HLS libraries, and other common utilities for building and debugging the application.

The rest of this document describes information on features and specific blocks related to the:

- **HDL Library:** Refer to [Chapter 2: HDL Library](#)
- **HLS Library:** Refer to [Chapter 3: HLS Library](#)
- **AI Engine Library:** Refer to [Chapter 4: AI Engine Library](#)

---

## What's New and Limitations

System Generator - the previous standalone design environment to develop DSP algorithms and generate HDL as an output - is now part of Vitis™ Model Composer. As a result of this product unification, HLS, AI Engine, and System Generator (HDL) libraries in the Xilinx toolbox have been merged to develop algorithms in a single MATLAB session.

The HDL Library in the Xilinx Toolbox contains all the library blocks previously contained in the System Generator blockset. Any existing System Generator design can be opened in Vitis Model Composer. Furthermore, you can develop new algorithms using the HDL library similarly to using the System Generator tool.

For information related to what is new for a specific release of Model Composer, refer to *What's New* at <https://www.xilinx.com/products/design-tools/vitis/vitis-model-composer.html#whats-new>.

In addition, while Model Composer is a toolbox built onto the MathWorks Simulink environment, there are certain features of Simulink that are not supported in Model Composer. The following is a list of some of the unsupported features:

- Simulink Performance Advisor.
- Model referencing.

- Variant subsystems.
  - Model Composer blocks do not support Simulink fixed-point types and only support Xilinx® fixed-point types.
  - Fixed-point designer does not integrate with Model Composer.
  - Accelerator mode and Rapid Accelerator mode.
- 

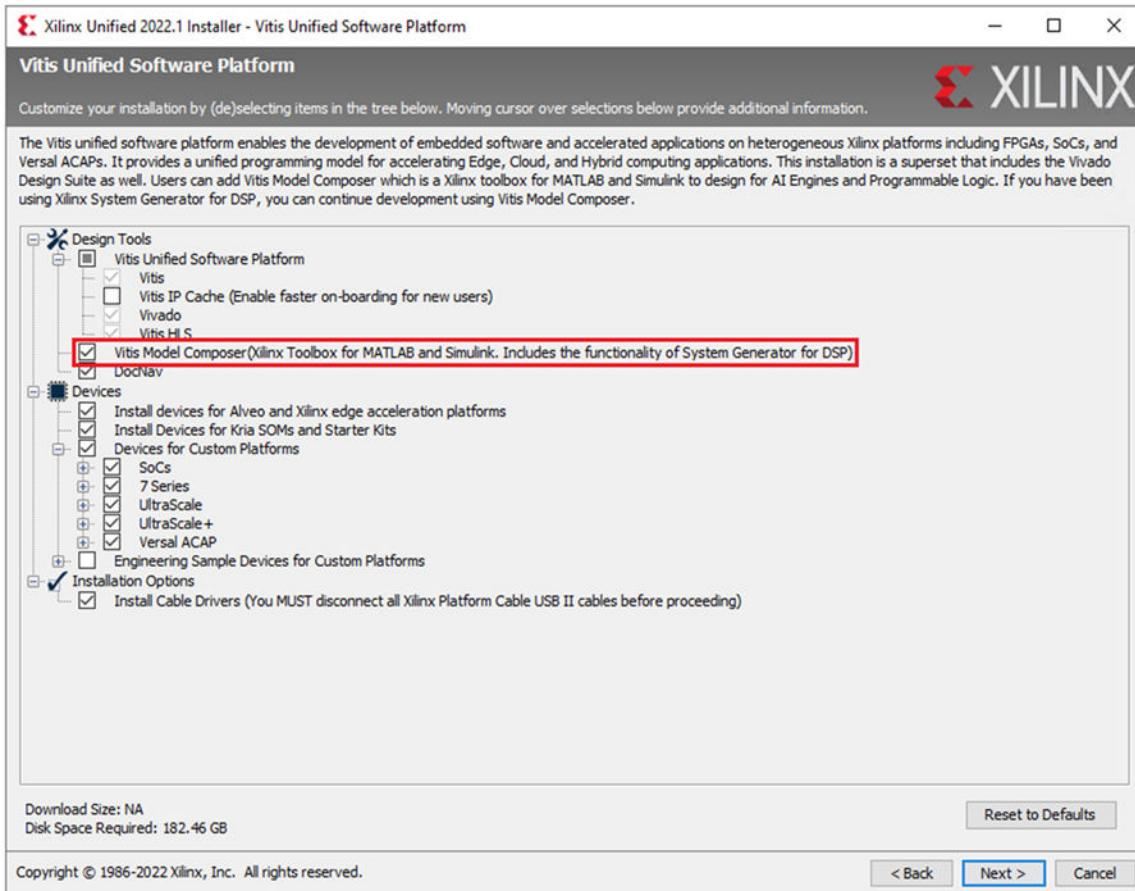
# Installation

## Downloading

Vitis™ Model Composer is part of Vivado® as well as the Vitis software platform, which can be downloaded from the [Xilinx](#) website. The AI Engine library is available only in the Vitis software platform, it is not part of the Vivado installation.

The Vitis Model Composer tool is selected by default in the Xilinx Unified Installer Window irrespective of whether you choose Vitis or Vivado as a product. The following figure shows the Vitis installer window and the Vitis Model Composer install option.

Figure 2: Vitis Installer



## Launching Vitis Model Composer

You can launch the Vitis Model Composer tool directly from the desktop or from the command line. Double-click the **Vitis Model Composer** icon, or launch it from the Start menu in Windows, or use the following command from the command prompt.

```
model_composer
```



**TIP:** The command-line use of Vitis Model Composer requires that the command shell has been configured as follows. You must change directory to `<install_dir>/Model_Composer/<version>` and run the `settings64-Model_Composer.bat` (or `.sh`) file. Where `<install_dir>` is the installation folder and `<version>` is the specific version of the tool. MATLAB opens, and the HLS, HDL and AI Engine libraries and features are overloaded onto this environment.

Vitis Model Composer supports the latest releases of MATLAB. For more information on Supported MATLAB versions and operating systems, refer to [Supported MATLAB Versions and Operating Systems](#). If you have multiple versions of MATLAB installed on your system, the first version found in your PATH will be used by the tool. You can edit the PATH to move the preferred version of MATLAB to precede other versions. You can also direct the tool to open a specific version of the tool using the `-matlab` option as follows:

```
model_composer -matlab C:\Progra~1\MATLAB\R2021a
```



**TIP:** When you specify the path to the MATLAB version, do not specify the full path to the executable (`bin/MATLAB`). The string `C:\Progra~1\` is a shortcut to `C:\Program Files\` which eliminates spaces from the command path. The command-line use of the Vitis Model Composer tool requires that the command shell has been properly configured as previously discussed.

After launching the tool, you will see the following in the MATLAB command window. Use these links to access the documentation and product examples.

**Figure 3: Documentation and Examples Links**

Vitis Model Composer: [Block Reference](#) [User Guide](#) [Tutorial](#) [Examples](#)  
[Provide feedback](#) for Vitis Model Composer.

# Supported MATLAB Versions and Operating Systems

Vitis Model Composer supports the following MATLAB versions:

- R2021a
- R2021b

The following operating systems are supported on x86 and x86-64 processor architectures:

- **Windows 10 Pro and Enterprise:** 10.0 1903 Update; 10.0 1909 Update; 10.0 2004 Update; 10.0 20H2; 10.0 21H1

**Note:** The AI Engine block is not supported on the Windows platform.

- **Red Hat Enterprise Workstation/Server 7:** 7.9
- **Red Hat Enterprise Workstation/Server 8:** 8.2; 8.3; 8.4; 8.5; 8.6
- **Ubuntu Linux 18:** 18.04.4 LTS; 18.04.5 LTS; 18.04.6 LTS
- **Ubuntu Linux 20:** 20.04, 20.04.1, 20.04.2, 20.04.3 LTS, 20.04.4 LTS

- **Prerequisites for using Model Composer on Ubuntu 20 OS:**

- Ubuntu 20 comes with gcc 7.x to 9.x versions by default; you need to either install gcc 6.x manually or create a symbolic link using the following sudo commands:

- sudo ln -s /usr/include/asm-generic /usr/include/asm
  - sudo ln -s /usr/include/x86\_64-linux-gnu/sys /usr/include/sys
  - sudo ln -s /usr/include/x86\_64-linux-gnu/bits /usr/include/bits
  - sudo ln -s /usr/include/x86\_64-linux-gnu/gnu /usr/include/gnu

- Ubuntu 20 by default comes with dash shell. To avoid any issue that you may encounter while running the downstream AI Engine flows, it is recommended to change the shell from dash to bash using the following sudo command:

```
sudo dpkg-reconfigure dash
```

- **SUSE Enterprise Linux:** 12.4, 15.2

**Note:** SUSE Enterprise Linux OS is supported only for the HDL library.

**Note:** Model Composer simulation and code generation is not supported in Windows OS for designs that include blocks from the AI Engine library.

# Recommended Display Resolution



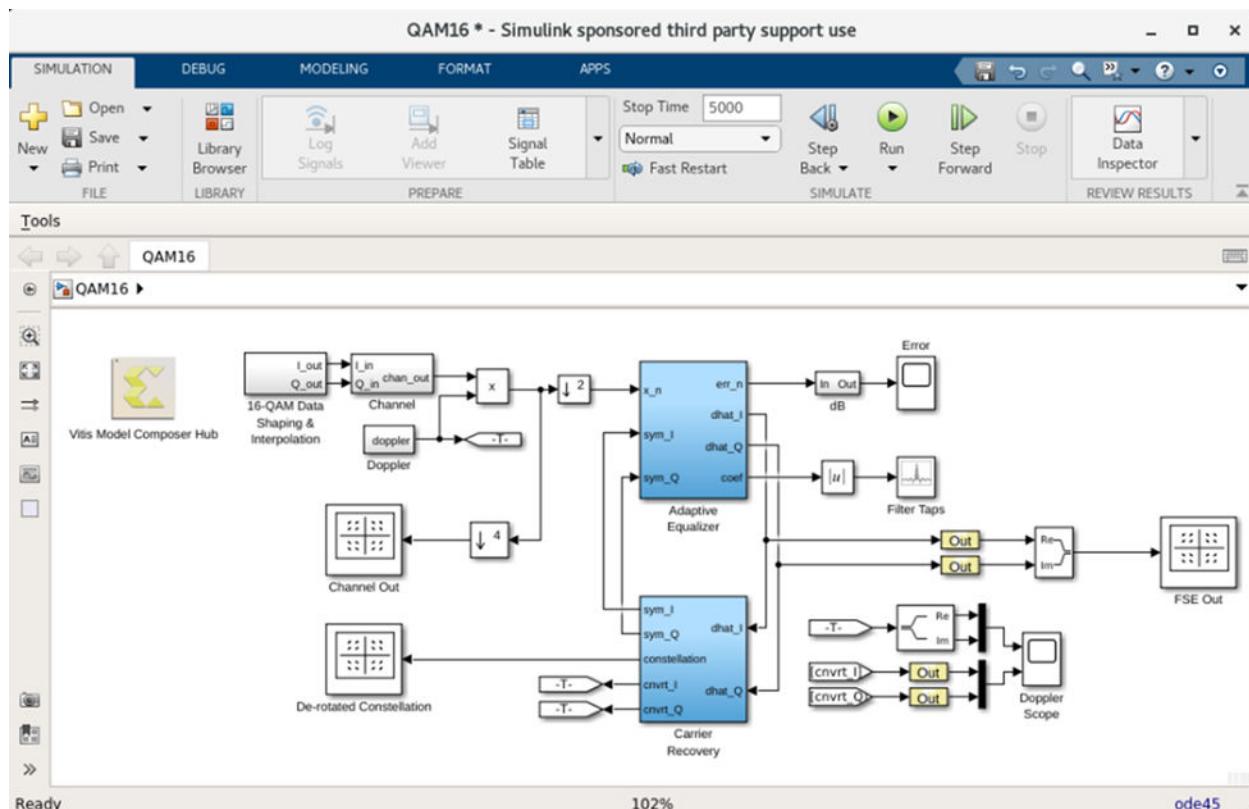
**RECOMMENDED:** *The recommended display resolution for both Windows and Linux is 1920 x 1080 with scaling set at 100%. The blocks will look best with these settings.*

# HDL Library

## Introduction

Vitis™ Model Composer provides the HDL blockset in Xilinx toolbox that enables the use of the MathWorks model-based Simulink design environment for FPGA design. Previous experience with Xilinx FPGAs or RTL design methodologies are not required when using the Model Composer HDL blockset. Designs are captured in the DSP friendly Simulink modeling environment using the HDL blockset. The Model Composer design can then be imported into a Vivado IDE project using the IP catalog.

*Figure 4: Model Composer HDL Design*

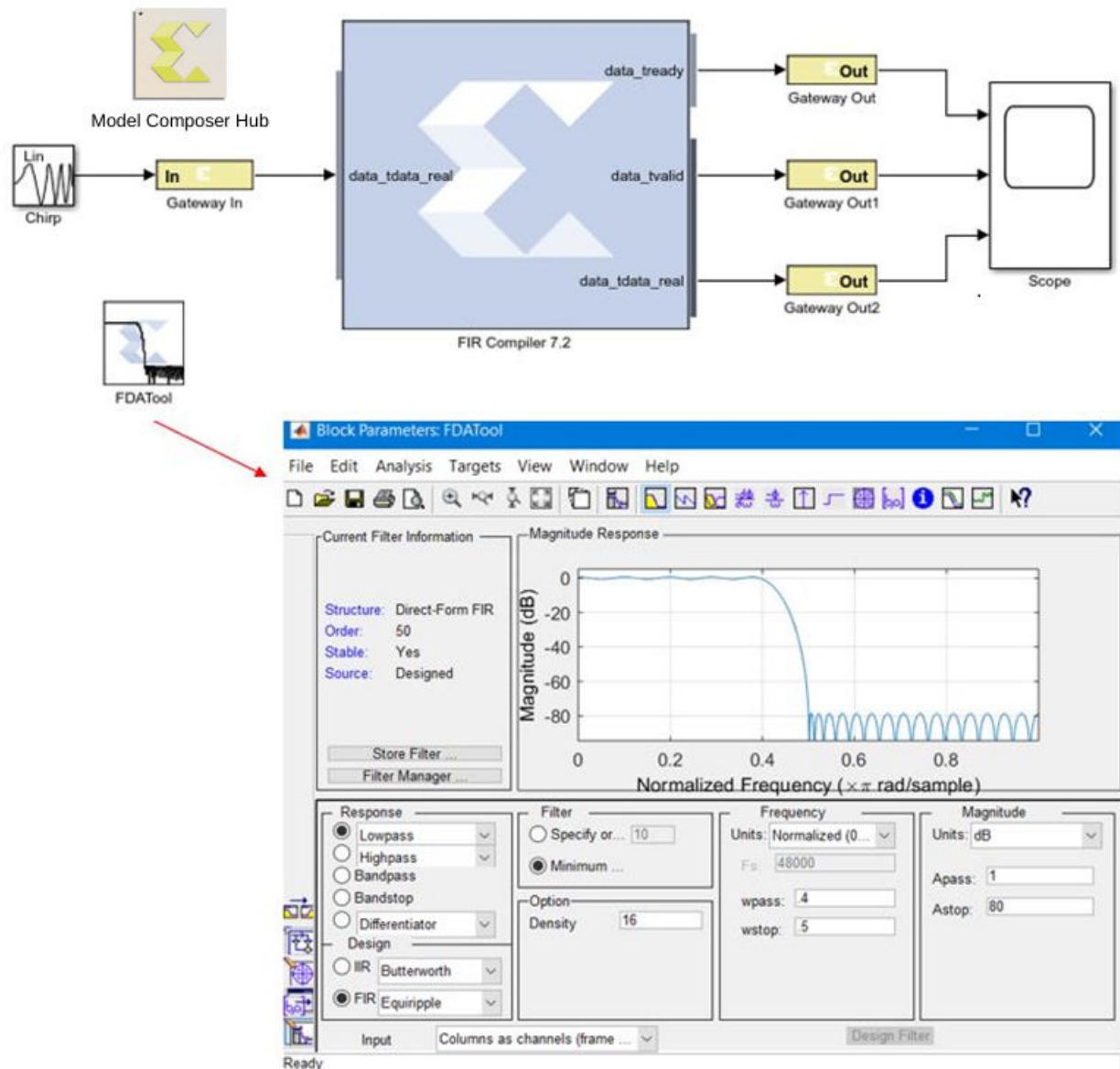


Refer to the *Vitis Model Composer Tutorial* ([UG1498](#)) for hands-on lab exercises and step-by-step instruction on how to create a model using HDL blockset and then import that model into a Vivado IDE project.

## FIR Filter Generation

The HDL Blockset in Model Composer includes a FIR Compiler block that targets the dedicated DSP48E1, DSP48E2, and DSP58 hardware resources in the 7 series, UltraScale™ and Versal® devices respectively to create highly optimized implementations. Configuration options allow generation of single rate, interpolation, decimation, Hilbert, and interpolated implementations. Standard MATLAB® functions such as `fir2` or the MathWorks FDA tool can be used to create coefficients for the Xilinx® FIR Compiler.

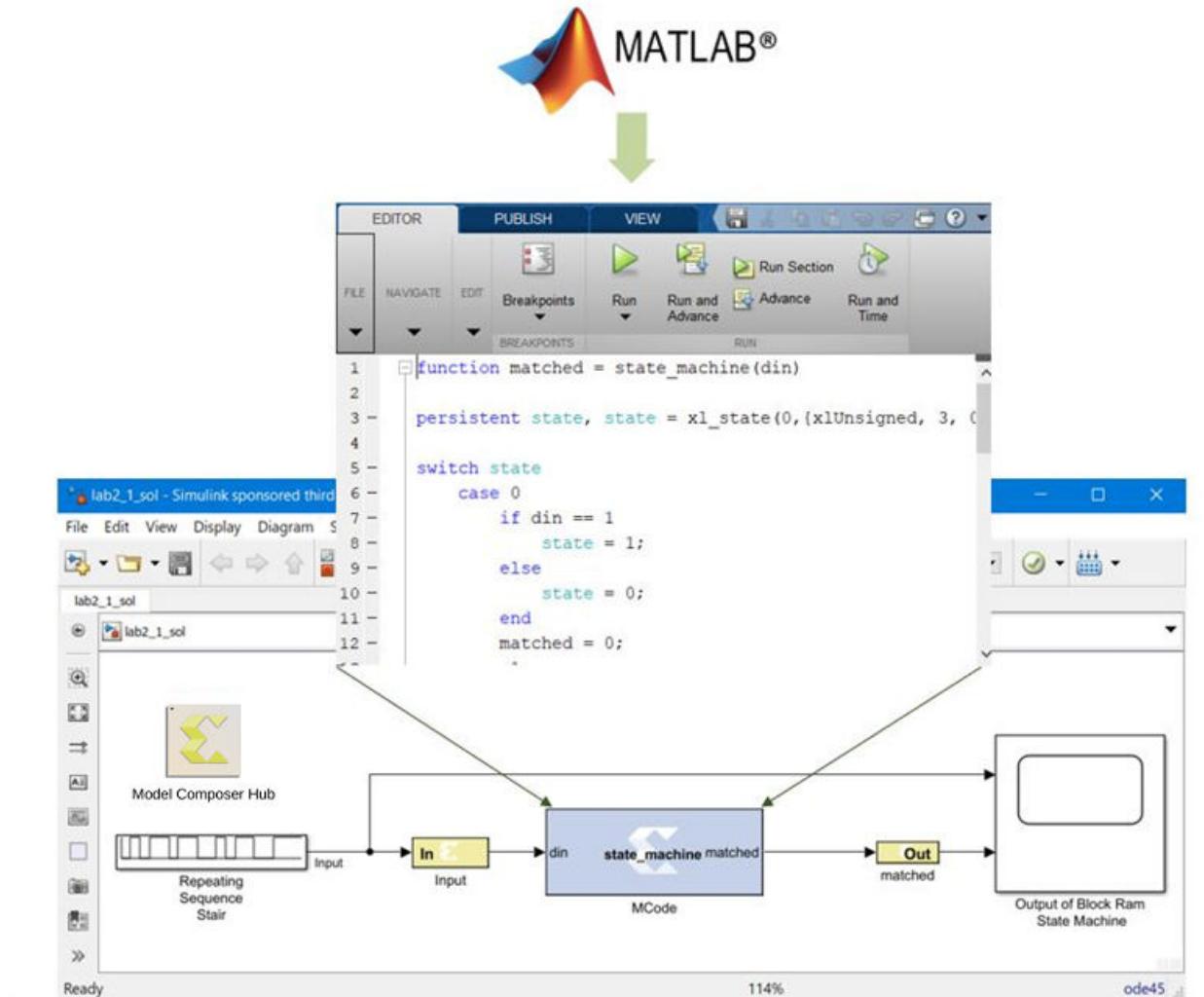
Figure 5: FDA Tool Example



## Support for MATLAB

The HDL Library in Model Composer consists of an MCode block that allows the use of non-algorithmic MATLAB® for the modeling and implementation of simple control operations.

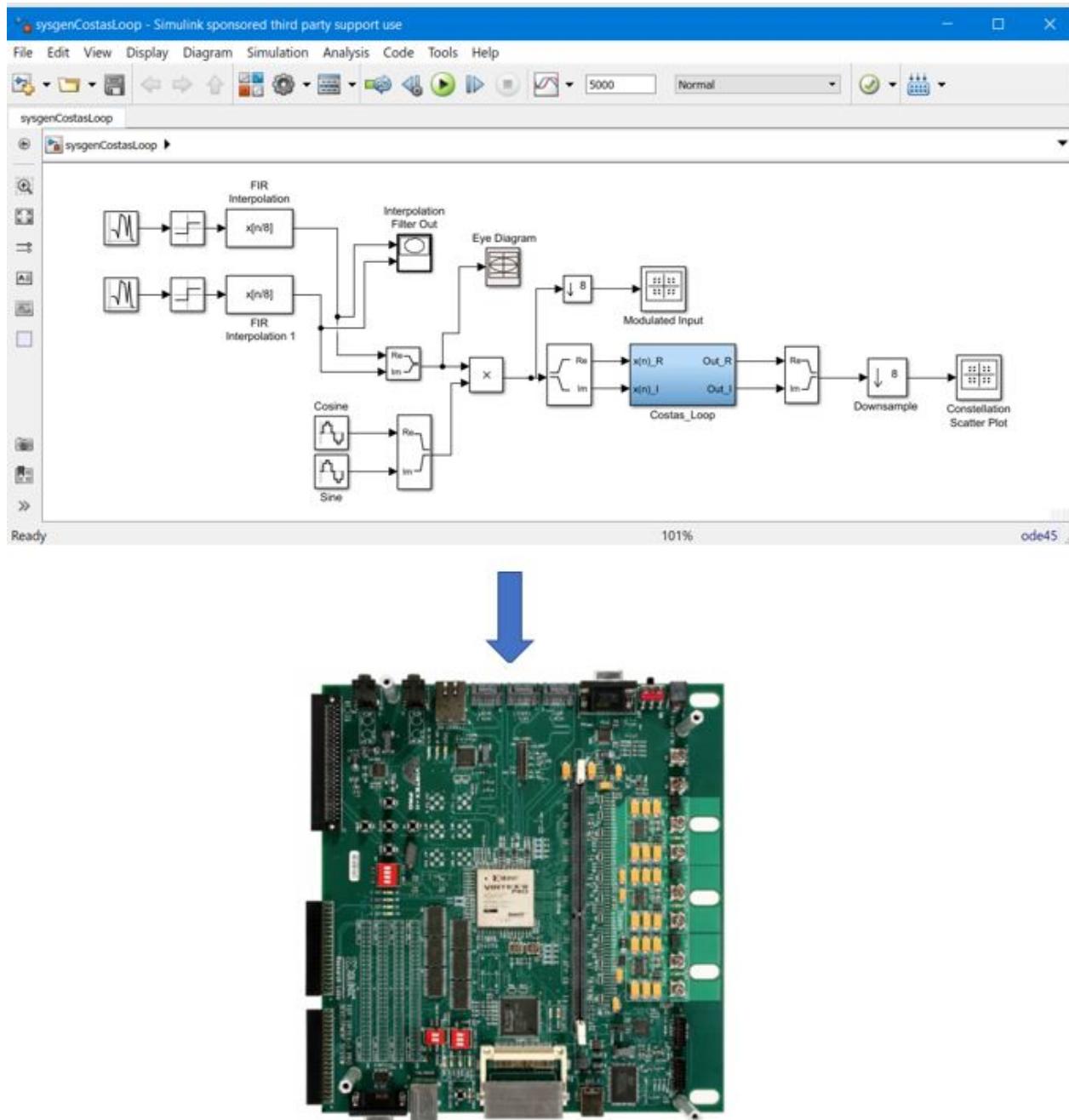
Figure 6: MCode Block Example



## Hardware Co-Simulation

Model Composer provides accelerated simulation through hardware co-simulation. Model Composer will automatically create a hardware simulation token for a design captured in the Xilinx® HDL blockset that will run on supported hardware platforms. This hardware will co-simulate with the rest of the Simulink® system to provide up to a 1000x simulation performance increase.

Figure 7: Hardware Co-Simulation



## System Integration Platform

Model Composer provides a system integration platform for the design of DSP FPGAs that allows the RTL, Simulink®, MATLAB® and C/C++ components of a DSP system to come together in a single simulation and implementation environment. Model Composer supports a black box block that allows RTL to be imported into Simulink and co-simulated with either Questa or Xilinx® Vivado® simulator, and provides a Vitis™ HLS block that allows integration and simulation of C/C++ sources.

## Post-Installation Tasks

### ***Compiling Xilinx HDL Libraries***

The Xilinx tool that compiles libraries for use in Questa SE is named `compile_simlib`.

To compile the Xilinx HDL libraries, launch Vivado and then enter `compile_simlib` in the Vivado Tcl console.

**Note:** You can enter `compile_simlib -help` in the Vivado Tcl Console for more details on executing this Tcl command.

### ***Managing the Model Composer HDL block Cache***

Model Composer incorporates a disk cache to speed up the iterative design process. The cache does this by tagging and storing files related to simulation and generation, then recalling those files during subsequent simulation and generation rather than rerunning the time consuming tools used to create those files.

### ***Specifying Board Support in Model Composer HDL Blockset***

When Vitis Model Composer is installed on your system as part of a Vivado Design Suite installation, Model Composer will have access to any Xilinx® development boards installed with Vivado.

Additional boards from Xilinx partners are available and a Board Interface file that defines a board (`board.xml`) can be downloaded from a partner website and installed as part of the Vivado Design Suite. You can also create custom Board Interface files, detailed at this [Link](#) of the *Vivado Design Suite User Guide: System-Level Design Entry* ([UG895](#)). Both Vivado and Model Composer must be configured to add partner boards and custom boards to the repository of boards available for use.

The procedure for configuring the Vivado Design Suite for use with boards is detailed in this [Link](#) in the *Vivado Design Suite User Guide: System-Level Design Entry (UG895)*. The Vivado Design Suite lets you create projects using Xilinx target design platform boards (TDP), or user-specified boards that have been added to a board repository. When you select a specific board, Vivado tools show information about the board, and enable additional designer assistance as part of IP customization, and for IP integrator designs.

After you have configured the board for use with the Vivado Design Suite, you must do the following to make the board available in Vitis Model Composer:

1. Run the following command in the MATLAB Command Window:

```
[status, boardTable, partTable] = xmCHubReloadDeviceInfo;
```

2. Check that the variable `boardTable` in the MATLAB workspace contains information about your board:

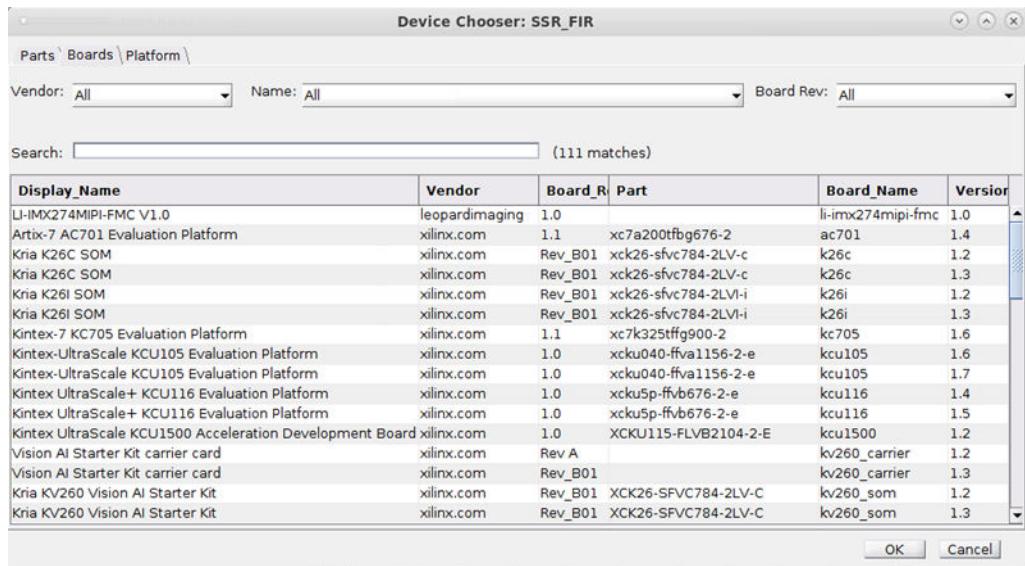
```
boardTable
```

```
>> [status, boardTable, partTable] = xmCHubReloadDeviceInfo;
***** vivado v2022.2 (64-bit)
**** SW Build 3664533 on Wed Oct 5 19:12:00 MDT 2022
**** IP Build 3663802 on Wed Oct 5 23:08:35 MDT 2022
** Copyright 1996-2022 Xilinx, Inc. All Rights Reserved.

Sourcing tcl script          ./Xilinx/Vivado/Vivado_init.tcl'
42 Beta devices matching pattern found, 42 enabled.
enable_board_device_time (s): cpu = 00:00:10 ; elapsed = 00:00:11 . Memory (MB): peak = 2183.500 ; gain = 131.508 ; free physical = 46124 ; free virtual = 62330
source ./loadDevice.tcl
# set_param board.repoPaths .
# load librdi_dsp_tcltasks.so
# dsp_write_board_objects -dirpath                         /Vivado/2022.2/data/xhub/boards
dsp_write_board_objects: Time (s): cpu = 00:00:06 ; elapsed = 00:00:06 . Memory (MB): peak = 2206.051 ; gain = 102.008 ; free physical = 46021 ; free virtual = 62228
# dsp_write_part_objects -dirpath                         /model_composer/data
# exit
INFO [Common 17-206] Exiting Vivado at Thu Oct 6 15:52:05 2022...
>> boardTable
boardTable =
71x6 table
   Display_Name      Vendor      Board_Rev      Part      Board_Name      Version
   _____
   {'LT_IMX274MP1-FMC_V1.0'}  {'leopardimaging'}  {'1.0'}    {0x0 char}  {'11-imx274mp1-fmc'}  {'1.0'}
   {'Kria K26 SOM'}        {'xilinx.com'}     {'1.1'}    {'xck26-sfcv784-2LV-2'}  {'k261'}       {'1.4'}
   {'Kria K26 SOM'}        {'xilinx.com'}     {'1.1'}    {'xck26-sfcv784-2LV-c'}  {'k261'}       {'1.4'}
   {'Kria K26 SOM'}        {'xilinx.com'}     {'Rev_B01'}  {'xck26-sfcv784-2LV-c'}  {'k261'}       {'1.2'}
   {'Kria K26 SOM'}        {'xilinx.com'}     {'Rev_B01'}  {'xck26-sfcv784-2LV-c'}  {'k261'}       {'1.3'}
   {'Kria K26 SOM'}        {'xilinx.com'}     {'Rev_B01'}  {'xck26-sfcv784-2LV-1'}  {'k261'}       {'1.4'}
   {'Kria K26 SOM'}        {'xilinx.com'}     {'Rev_B01'}  {'xck26-sfcv784-2LV-1'}  {'k261'}       {'1.2'}
   {'Kria K26 SOM'}        {'xilinx.com'}     {'Rev_B01'}  {'xck26-sfcv784-2LV-1'}  {'k261'}       {'1.3'}
```

3. Restart Vitis Model Composer.

The board will now be visible under the Boards tab of the Device Chooser within the Vitis Model Composer Hub block.



## Hardware Co-Simulation Support

If you have an FPGA development board, you may be able to take advantage of Model Composer's ability to use FPGA hardware co-simulation with Simulink® simulations. The Model Composer software includes support for all Xilinx® Development Boards. Model Composer board support packages can be downloaded from the [Boards and Kits](#) page on the Xilinx website.

## UNC Paths Not Supported

Model Composer does not support UNC (Universal Naming Convention) paths. For example Model Composer cannot operate on a design that is located on a shared network drive without mapping to the drive first.

---

# Hardware Design Using HDL Library

Model Composer is a system-level modeling tool that facilitates FPGA hardware design. It extends Simulink® in many ways to provide a modeling environment that is well suited to hardware design. The tool provides high-level abstractions that are automatically compiled into an FPGA at the push of a button. The tool also provides access to underlying FPGA resources through low-level abstractions, allowing the construction of highly efficient FPGA designs.

<a href="#">Design Flows Using Model Composer</a>	Describes several settings in which constructing designs in Model Composer is useful.
<a href="#">System-Level Modeling in Vitis Model Composer</a>	Discusses Model Composer's ability to implement device-specific hardware designs directly from a flexible, high-level, system modeling environment.

Automatic Code Generation	Discusses automatic code generation for Model Composer designs using the HDL Library.
Compiling MATLAB into an FPGA	Describes how to use a subset of the MATLAB programming language to write functions that describe state machines and arithmetic operators. Functions written in this way can be attached to blocks in Model Composer HDL Library and can be automatically compiled into equivalent HDL.
Importing a Model Composer HDL Design into a Bigger System	Discusses how to take the VHDL netlist from a Model Composer design and synthesize it in order to embed it into a larger design. Also shows how VHDL created by Model Composer can be incorporated into a simulation model of the overall system.
Variant Subsystems and Model Composer	Explains how to use Configurable Subsystems in Model Composer. Describes common tasks such as defining Configurable Subsystems, deleting and adding blocks, and using Configurable Subsystems to import compilation results into Model Composer designs.
Notes for Higher Performance FPGA Design	Suggests design practices in Model Composer that lead to an efficient and high-performance implementation in an FPGA.
Using the FDATool in Digital Filter Applications	Demonstrates one way to specify, implement and simulate a FIR filter using the FDATool block.
Multiple Independent Clocks Hardware Design	The design can be partitioned into groups of Subsystem blocks, where each Subsystem has a common cycle period, independent of the cycle period of other Subsystems.
AXI Interface	Provides an introduction to AMBA AXI4 and draws attention to AMBA AXI4 details with respect to Model Composer
AXI4-Lite Slave Interface Generation	Describes features in Model Composer that allow you to create a standard AXI4-Lite interface for a Model Composer module and then export the module to the Vivado® IP catalog for later inclusion in a larger design using IP integrator.
Tailor Fitting a Platform Based Accelerator Design in Model Composer	Describes how to develop an accelerator in Model Composer which is part of a platform framework developed in the Vivado IP integrator.

## Design Flows Using Model Composer

Model Composer can be useful in many settings. Sometimes you may want to explore an algorithm without translating the design into hardware. Other times you might plan to use a Model Composer design as part of something bigger. A third possibility is that a Model Composer design is complete in its own right, and is to be used in FPGA hardware. This topic describes all three possibilities.

### ***Algorithm Exploration***

Model Composer is particularly useful for algorithm exploration, design prototyping, and model analysis. When these are the goals, you can use the tool to flesh out an algorithm in order to get a feel for the design problems that are likely to be faced, and perhaps to estimate the cost and performance of an implementation in hardware. The work is preparatory, and there is little need to translate the design into hardware.

In this setting, you assemble key portions of the design without worrying about fine points or detailed implementation. Simulink blocks and MATLAB M-code provide stimuli for simulations, and for analyzing results. Resource estimation gives a rough idea of the cost of the design in hardware. Experiments using hardware generation can suggest the hardware speeds that are possible.

Once a promising approach has been identified, the design can be fleshed out. Model Composer allows refinements to be done in steps, so some portions of the design can be made ready for implementation in hardware, while others remain high-level and abstract. Model Composer's facilities for hardware co-simulation are particularly useful when portions of a design are being refined.

## ***Implementing Part of a Larger Design***

Often Model Composer is used to implement a portion of a larger design. For example, Model Composer is a good setting in which to implement data paths and control, but is less well suited for sophisticated external interfaces that have strict timing requirements. In this case, it may be useful to implement parts of the design using Model Composer, implement other parts outside, and then combine the parts into a working whole.

A typical approach to this flow is to create an HDL wrapper that represents the entire design, and to use the Model Composer portion as a component. The non-Model Composer portions of the design can also be components in the wrapper, or can be instantiated directly in the wrapper.

## ***Implementing a Complete Design***

Many times, everything needed for a design is available inside Model Composer. For such a design, pressing the **Generate** button instructs Model Composer to translate the design into HDL, and to write the files needed to process the HDL using downstream tools. The files written include the following:

- HDL that implements the design itself.
- An HDL test bench. The test bench allows results from Simulink simulations to be compared against ones produced by a logic simulator.
- Files that allow the Model Composer HDL to be used as a Vivado IDE project.

For details concerning the files that Model Composer writes, see the topic [Compilation Results](#).

## ***Note to DSP Engineers***

Model Composer extends Simulink to enable hardware design, providing high-level abstractions that can be automatically compiled into an FPGA. Although the arithmetic abstractions are suitable to Simulink (discrete time and space dynamical system simulation), Model Composer also provides access to features in the underlying FPGA.

The more you know about a hardware realization (e.g., how to exploit parallelism and pipelining), the better the implementation you'll obtain. Using IP cores makes it possible to have efficient FPGA designs that include complex functions like FFTs. Model Composer also makes it possible to refine a model to more accurately fit the application.

Scattered throughout the Model Composer documentation are notes that explain ways in which system parameters can be used to exploit hardware capabilities.

## Note to Hardware Engineers

Model Composer does not replace hardware description language (HDL)-based design, but does make it possible to focus your attention only on the critical parts. By analogy, most DSP programmers do not program exclusively in assembler; they start in a higher-level language like C, and write assembly code only where it is required to meet performance requirements.

A good rule of thumb is this: in the parts of the design where you must manage internal hardware clocks (e.g., using DDR or phased clocking), you should implement using HDL. The less critical portions of the design can be implemented in Model Composer, and then the HDL and Model Composer portions can be connected. Usually, most portions of a signal processing system do not need this level of control, except at external interfaces. Model Composer provides mechanisms to import HDL code into a design (see [Importing HDL Modules](#)) that are of particular interest to the HDL designer.

Another aspect of Model Composer that is of interest to engineers who design using HDL is its ability to automatically generate an HDL test bench, including test vectors. This aspect is described in the topic [HDL Testbench](#).

Finally, the hardware co-simulation interfaces described in the topic [Using Hardware Co-Simulation](#) allow you to run a design in hardware under the control of Simulink, bringing the full power of MATLAB and Simulink to bear for data analysis and visualization.

## System-Level Modeling in Vitis Model Composer

Vitis Model Composer allows device-specific hardware designs to be constructed directly in a flexible high-level system modeling environment. In a Model Composer design, signals are not just bits. They can be signed and unsigned fixed-point numbers, and changes to the design automatically translate into appropriate changes in signal types. Blocks are not just stand-ins for hardware. They respond to their surroundings, automatically adjusting the results they produce and the hardware they become.

Vitis Model Composer allows designs to be composed from a variety of ingredients. Data flow models, traditional hardware description languages (VHDL and Verilog), and functions derived from the MATLAB programming language, can be used side-by-side, simulated together, and synthesized into working hardware. Vitis Model Composer HDL block simulation results are bit and cycle-accurate. This means results seen in simulation exactly match the results that are seen in hardware. Model Composer simulations are considerably faster than those from traditional HDL simulators, and results are easier to analyze.

<a href="#">Model Composer HDL Blocksets</a>	Describes how Vitis Model Composer's HDL blocks are organized in libraries, and how the blocks can be parameterized and used.
<a href="#">Signal Types</a>	Describes the data types used by Model Composer and ways in which data types can be automatically assigned by the tool.
<a href="#">Bit-True and Cycle-True Modeling</a>	Specifies the relationship between the Simulink-based simulation of a Vitis Model Composer model and the behavior of the hardware that can be generated from it.
<a href="#">Timing and Clocking</a>	Describes how clocks are implemented in hardware, and how their implementation is controlled inside Vitis Model Composer. Explains how Model Composer translates a multirate Simulink model into working clock-synchronous hardware.
<a href="#">Synchronization Mechanisms</a>	Describes mechanisms that can be used to synchronize data flow across the data path elements in a high-level Vitis Model Composer design, and describes how control path functions can be implemented.
<a href="#">Block Masks and Parameter Passing</a>	Explains how parameterized systems and Subsystems are created in Simulink.

## **Model Composer HDL Blocksets**

A Simulink® blockset is a library of blocks that can be connected in the Simulink block editor to create functional models of a dynamical system. For system modeling, Model Composer HDL library blocksets are used like other Simulink blocksets. The blocks provide abstractions of mathematical, logical, memory, and DSP functions that can be used to build sophisticated signal processing (and other) systems. There are also blocks that provide interfaces to other software tools (e.g., FDATool, Questa) as well as the Model Composer code generation software.

Model Composer HDL blocks are *bit-accurate* and *cycle-accurate*. Bit-accurate blocks produce values in Simulink that match corresponding values produced in hardware; cycle-accurate blocks produce corresponding values at corresponding times.

### **Xilinx HDL Blockset**

The Xilinx® HDL Blockset is a family of libraries that contain basic Model Composer HDL blocks. Some blocks are low-level, providing access to device-specific hardware. Others are high- level, implementing (for example) signal processing and advanced communications algorithms. The libraries are described in the following table.

**Table 1: HDL Blockset Libraries**

Library	Description
Basic Elements	Standard building blocks for digital logic.
DSP	Digital signal processing (DSP) blocks.
Interfaces	Blocks that support connection with Simulink blocks.
Logic and Bit Operations	Blocks for performing logic and bit operations.
Memory	Blocks that implement and access memories.
Signal Routing	Blocks that support Routing signals.
Sources	Blocks that generate signal data
Tools	"Utility" blocks. For example, code generation (Vitis Model Composer Hub block), resource estimation, HDL co-simulation, etc.
User-Defined functions	Blocks that support importing custom functions.

## Signal Types

In order to provide bit-accurate simulation of hardware, HDL blocks operate on Boolean, floating-point, and arbitrary precision fixed-point values. By contrast, the fundamental scalar signal type in Simulink® is double precision floating point. The gateway blocks in the Model Composer HDL library allow connection between HDL blocks in the Xilinx toolbox and blocks in the Simulink library. The Gateway In converts a double precision signal into a Xilinx signal, and the Gateway Out converts a Xilinx signal into double precision. Simulink® continuous time signals must be sampled by the Gateway In block.

Most HDL blocks are polymorphic, i.e., they can deduce appropriate output types based on their input types. When *full precision* is specified for a block in its parameters dialog box, Model Composer chooses the output type to ensure no precision is lost. Sign extension and zero padding occur automatically as necessary. *User-specified precision* is usually also available. This allows you to set the output type for a block and to specify how quantization and overflow should be handled. Quantization possibilities include unbiased rounding towards plus or minus infinity, depending on sign, or truncation. Overflow options include saturation, truncation, and reporting overflow as an error.

**Note:** Model Composer data types can be displayed by selecting **Display**→**Signals & Ports**→**Port Data Types** in Simulink. Displaying data types makes it easy to determine precision throughout a model. If, for example, the type for a port is **Fix\_11\_9**, then the signal is a two's complement signed 11-bit number having nine fractional bits. Similarly, if the type is **Ufix\_5\_3**, then the signal is an unsigned 5-bit number having three fractional bits.

In the Model Composer portion of a Simulink model, every signal must be sampled. Sample times may be inherited using Simulink's propagation rules, or set explicitly in a block customization dialog box. When there are feedback loops, Model Composer is sometimes unable to deduce sample periods and/or signal types, in which case the tool issues an error message. Assert blocks must be inserted into loops to address this problem. It is not necessary to add assert blocks at every point in a loop; usually it suffices to add an assert block at one point to "break" the loop.

**Note:** Simulink can display a model by shading blocks and signals that run at different rates with different colors (**Display** → **Sample Time** → **Colors** in the Simulink pulldown menus). This is often useful in understanding multirate designs.

## Floating-Point Data Type

Many Model Composer HDL blocks across various libraries support the floating-point data type.

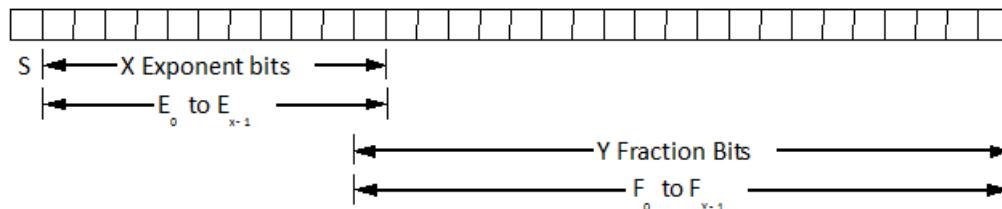
Model Composer uses the Floating-Point Operator v7.1 IP core to leverage the implementation of operations such as addition/subtraction, multiplication, comparisons and data type conversion.

The floating-point data type support is in compliance with IEEE-754 Standard for Floating-Point Arithmetic. Single precision, Double precision and Custom precision floating-point data types are supported for design input, data type display and for data rate and type propagation (RTP) across the supported HDL blocks.

### IEEE-754 Standard for Floating-Point Data Type

As shown below, floating-point data is represented using one Sign bit (S), X exponent bits and Y fraction bits. The Sign bit is always the most-significant bit (MSB).

Figure 8: Floating-Point Data



According to the IEEE-754 standard, a floating-point value is represented and stored in the normalized form. In the normalized form the exponent value E is a biased/normalized value. The normalized exponent, E, equals the sum of the actual exponent value and the exponent bias. In the normalized form, Y-1 bits are used to store the fraction value. The F0 fraction bit is always a hidden bit and its value is assumed to be 1.

S represents the value of the sign of the number. If S is 0 then the value is a positive floating-point number; otherwise it is negative. The X bits that follow are used to store the normalized exponent value E and the last Y-1 bits are used to store the fraction/mantissa value in the normalized form.

For the given exponent width, the exponent bias is calculated using the following equation:

$$\text{Exponent\_bias} = 2^{(X - 1)} - 1$$

Where X is the exponent bit width.

According to the IEEE standard, a single precision floating-point data is represented using 32 bits. The normalized exponent and fraction/mantissa are allocated 8 and 24 bits, respectively. The exponent bias for single precision is 127. Similarly, a double precision floating-point data is represented using a total of 64 bits where the exponent bit width is 11 and the fraction bit width is 53. The exponent bias value for double precision is 1023.

The normalized floating-point number in the equation form is represented as follows:

$$\text{Normalized Floating-Point Value} = (-1)^S \times F0.F1F2 . FY-2FY-1 \times (2)^E$$

The actual value of exponent ( $E_{\text{actual}}$ ) =  $E - \text{Exponent\_bias}$ . Considering 1 as the value for the hidden bit F0 and the  $E_{\text{actual}}$  value, a floating-point number can be calculated as follows:

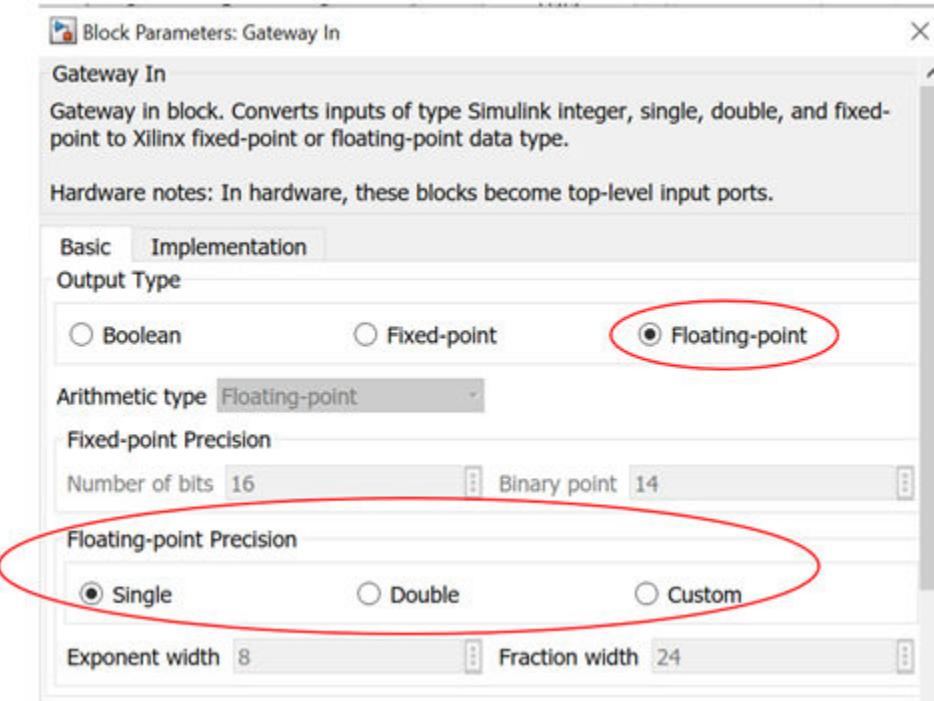
$$\text{FP\_Value} = (-1)^S \times 1.F1F2 . FY-2FY-1 \times (2)^{(E_{\text{actual}})}$$

### Floating-Point Data Representation in Model Composer

The HDL Gateway In block supports Boolean, Fixed-point, and Floating-point data types as shown in the following figure. You can select either a **Single**, **Double** or **Custom** precision type after specifying the floating-point data type.

For example, if Exponent width of 9 and Fraction width of 31 is specified then the floating-point data value will be stored in total 40 bits where the MSB bit will be used for sign representation, the following 9 bits will be used to store biased exponent value and the 30 LSB bits will be used to store the fractional value.

Figure 9: Floating-point Precision

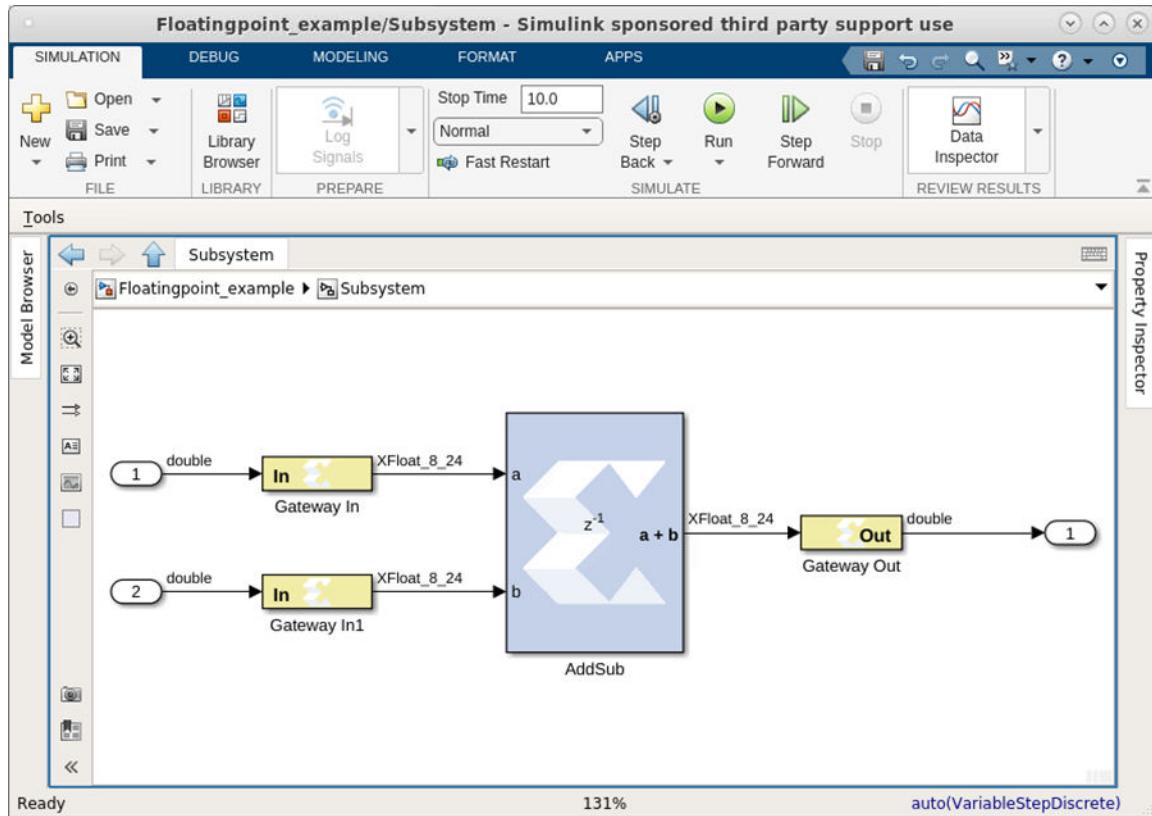


In compliance with the IEEE-754 standard, if **Single** precision is selected then the total bit width is assumed to be 32; 8 bits for the exponent and 24 bits for the fraction. Similarly when **Double** precision is selected, the total bit width is assumed to be 64 bits; 11 bits for the exponent and 53 bits for the fraction part. When **Custom** precision is selected, the **Exponent width** and **Fraction width** fields are activated and you are free to specify values for these fields (8 and 24 are the default values). The total bit width for **Custom** precision data is the summation of the number of exponent bits and the number of fraction bits. Similar to fraction bit width for **Single** precision and **Double** precision data types the fraction bit width for **Custom** precision data type must include the hidden bit F0.

### Displaying the Data Type on Output Signals

As shown in the following figure, after a successful rate and type propagation, the floating-point data type is displayed on the output of each HDL block. To display the signal data type as shown in the following figure, select **Debug** → **Diagnostics** → **Information Overlays** → **Port Data Types**.

Figure 10: Floating-point Data Type



A floating-point data type is displayed using the format:

`XFLOAT_<exponent_bit_width>_<fraction_bit_width>`. Single and Double precision data types are displayed using the string "XFLOAT\_8\_24" and "XFLOAT\_11\_53", respectively.

If for a Custom precision data type the exponent bit width 9 and the fraction bit width 31 are specified, then it will be displayed as "XFLOAT\_9\_31". A total of 40 bits will be used to store the floating-point data value. Because floating-point data is stored in a normalized form, the fractional value will be stored in 30 bits.

In Model Composer the fixed-point data type is displayed using format

`XFIX_<total_data_width>_<binary_point_width>`. For example, a fixed-point data type with the data width of 40 and binary point width of 31 is displayed as `XFIX_40_31`.

It is necessary to point out that in the fixed-point data type the actual number of bits used to store the fractional value is different from that used for floating-point data type. In the example above, all 31 bits are used to store the fractional bits of the fixed-point data type.

Model Composer uses the exponent bit width and the fraction bit width to configure and generate an instance of the Floating-Point Operator core.

## Rate and Type Propagation

During data rate and type propagation across a Model Composer HDL block that supports floating-point data, the following design rules are verified. The appropriate error is issued if one of the following violations is detected.

1. If a signal carrying floating-point data is connected to the port of an HDL block that doesn't support the floating-point data type.
2. If the data input (both A and B data inputs, where applicable) and the data output of an HDL block are not of the same floating-point data type. The DRC check will be made between the two inputs of a block as well as between an input and an output of the block.

If a Custom precision floating-point data type is specified, the exponent bit width and the fraction bit width of the two ports are compared to determine that they are of the same data type.

**Note:** The Convert and Relational blocks are excluded from this check. The Convert block supports Float-to-float data type conversion between two different floating-point data types. The Relational block output is always the Boolean data type because it gives a true or false result for a comparison operation.

3. If the data inputs are of the fixed-point data type and the data output is expected to be floating-point and vice versa.

**Note:** The Convert and Relational blocks are excluded from this check. The Convert block supports Fixed-to-float as well as Float-to-fixed data type conversion. The Relational block output is always the Boolean data type because it gives a true or false result for a comparison operation.

4. If Custom precision is selected for the Output Type of blocks that support the floating-point data type. For example, for blocks such as AddSub, Mult, CMult, and MUX, only Full output precision is supported if the data inputs are of the floating-point data type.
5. If the Carry In port or Carry Out port is used for the AddSub block when the operation on a floating-point data type is specified.
6. If the Floating-Point Operator IP core gives an error for DRC rules defined for the IP.

## AXI Signal Groups

Model Composer HDL blocks found in the DSP library contain interfaces that conform to the AXI4 specification. Blocks with AXI4 interfaces are drawn such that ports relating to a particular AXI4 interface are grouped and colored in similarly. This makes it easier to identify data and control signals pertaining to the same interface. Grouping similar AXI4 ports together also make it possible to use the Simulink Bus Creator and Simulink Bus Selector blocks to connect groups of signals together. More information on AXI4 can be found in the section titled [AXI Interface](#). For more detailed information on the AMBA AXI4 specification, please refer to the Xilinx AMBA AXI4 documents found at the [AMBA AXI4 Interface Protocol](#) page on the Xilinx website.

## Bit-True and Cycle-True Modeling

Simulations in Model Composer are *bit-true* and *cycle-true*. To say a simulation is bit-true means that at the boundaries (i.e., interfaces between Model Composer HDL blocks and non-HDL blocks), a value produced in simulation is bit-for-bit identical to the corresponding value produced in hardware. To say a simulation is cycle-true means that at the boundaries, corresponding values are produced at corresponding times. The boundaries of the design are the points at which Model Composer HDL gateway blocks exist. When a design is translated into hardware, Gateway In (respectively, Gateway Out) blocks become top-level input (resp., output) ports.

## Timing and Clocking

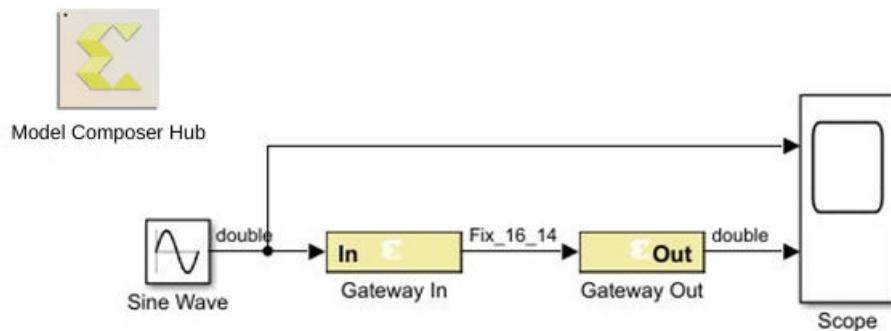
### Discrete Time Systems

Designs in Model Composer are discrete time systems. In other words, the signals and the blocks that produce them have associated sample rates. A block's sample rate determines how often the block is awoken (allowing its state to be updated). Model Composer sets most sample rates automatically. A few blocks, however, set sample rates explicitly or implicitly.

**Note:** For an in-depth explanation of Simulink discrete time systems and sample times, consult the Using Simulink reference manual from the MathWorks, Inc.

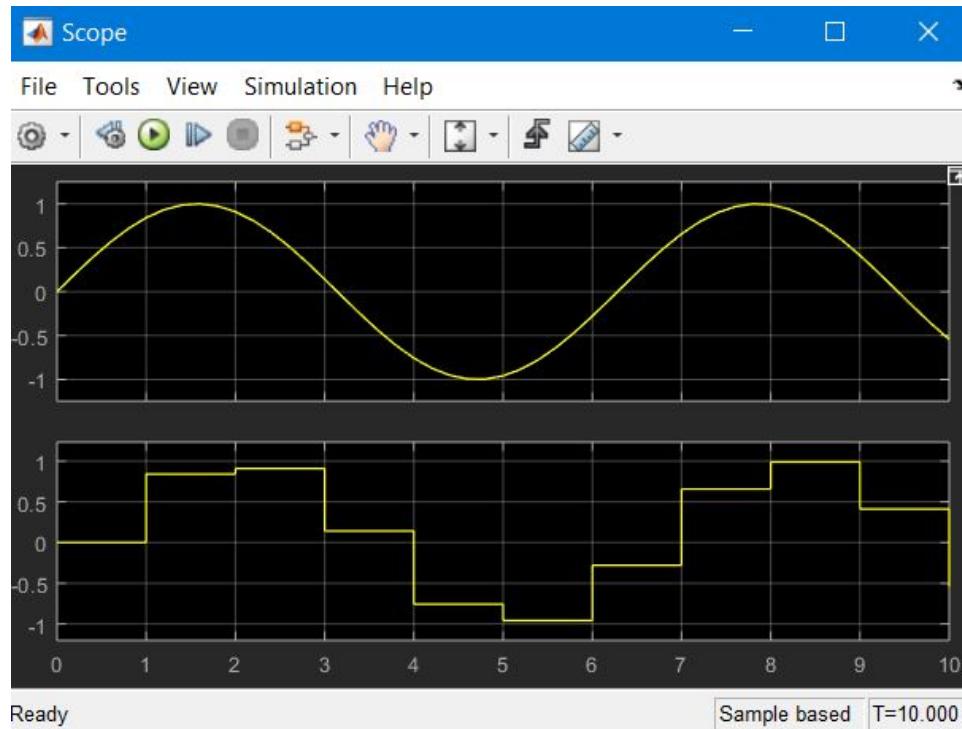
A simple Model Composer model illustrates the behavior of discrete time systems. Consider the model shown below. It contains a gateway that is driven by a Simulink source (Sine Wave), and a second gateway that drives a Simulink sink (Scope).

Figure 11: Discrete Time System



The Gateway In block is configured with a sample period of one second. The Gateway Out block converts the Xilinx fixed-point signal back to a double (so it can be analyzed in the Simulink scope), but does not alter sample rates. The scope output below shows the unaltered and sampled versions of the sine wave.

Figure 12: Scope Output



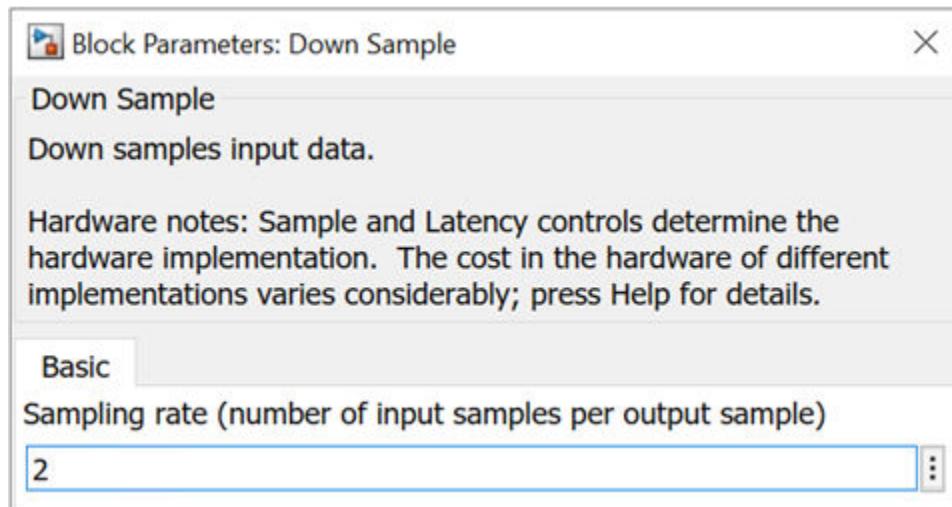
## Multirate Models

Model Composer supports *multirate* designs, i.e., designs having signals running at several sample rates. Model Composer automatically compiles multirate models into hardware. This allows multirate designs to be implemented in a way that is both natural and straightforward in Simulink.

## Rate-Changing Blocks

The Model Composer HDL library includes blocks that change sample rates. The most basic rate changers are the Up Sample and Down Sample blocks. As shown in the following figure, these blocks explicitly change the rate of a signal by a fixed multiple that is specified in the block's dialog box.

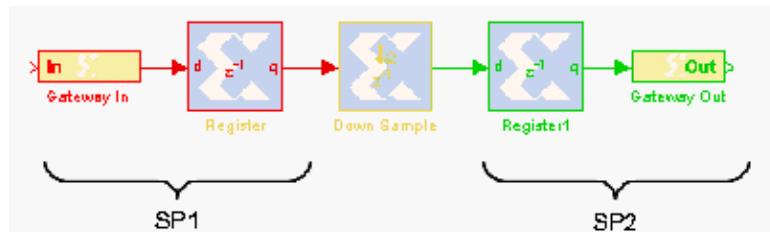
Figure 13: Rate Change Dialog



Other blocks (e.g., the Parallel To Serial and Serial To Parallel converters) change rates implicitly in a way determined by block parameterization.

Consider the simple multirate example below. This model has two sample periods, SP1 and SP2. The Gateway In dialog box defines the sample period SP1. The Down Sample block causes a rate change in the model, creating a new rate SP2 which is half as fast as SP1.

Figure 14: Multirate Example



### Hardware Oversampling

Some HDL blocks are oversampled, i.e., their internal processing is done at a rate that is faster than their data rates. In hardware, this means that the block requires more than one clock cycle to process a data sample. In Simulink such blocks do not have an observable effect on sample rates.

Although blocks that are oversampled do not cause an explicit sample rate change in Simulink, Model Composer considers the internal block rate along with all other sample rates when generating clocking logic for the hardware implementation. This means that you must consider the internal processing rates of oversampled blocks when you specify the **Simulink system period** value in the Model Composer Hub block dialog box.

## Asynchronous Clocking

Model Composer focuses on the design of hardware that is synchronous to a single clock. It can, under some circumstances, be used to design systems that contain more than one clock. This is possible provided the design can be partitioned into individual clock domains with the exchange of information between domains being regulated by dual port memories and FIFOs. The remainder of this topic focuses exclusively on the clock-synchronous aspects of Model Composer. This discussion is relevant to both single-clock and multiple-clock designs.

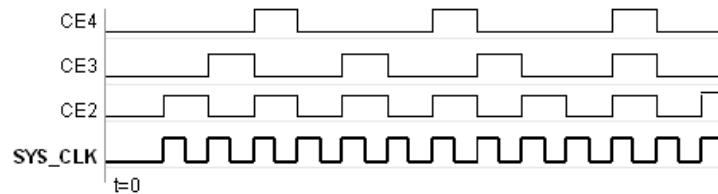
## Synchronous Clocking

By default, Model Composer creates designs with synchronous clocking, where multiple rates are realized using clock enables. When Model Composer compiles a model into hardware, it preserves the sample rate information of the design in such a way that corresponding portions in hardware run at appropriate rates. In hardware, Model Composer generates related rates by using a single clock in conjunction with clock enables, one enable per rate. The period of each clock enable is an integer multiple of the period of the system clock.

Inside Simulink, neither clocks nor clock enables are required as explicit signals in a Model Composer design. When Model Composer compiles a design into hardware, it uses the sample rates in the design to deduce what clock enables are needed. To do this, it employs two user-specified values from the Model Composer Hub block: the **Simulink system period** and **FPGA clock period**. These numbers define the scaling factor between time in a Simulink simulation, and time in the actual hardware implementation. The Simulink system period must be the greatest common divisor (gcd) of the sample periods that appear in the model, and the FPGA clock period is the period, in nanoseconds, of the system clock. If  $p$  represents the Simulink system period, and  $c$  represents the FPGA system clock period, then something that takes  $k_p$  units of time in Simulink takes  $k$  ticks of the system clock (hence  $k_c$  nanoseconds) in hardware.

To illustrate this point, consider a model that has three Simulink sample periods 2, 3, and 4. The gcd of these sample periods is 1, and should be specified as such in the **Simulink system period** field for the model. Assume the **FPGA clock period** is specified to be 10 ns. With this information, the corresponding clock enable periods can be determined in hardware.

In hardware, refer to the clock enables corresponding to the Simulink sample periods 2, 3, and 4 as CE2, CE3, and CE4, respectively. The relationship of each clock enable period to the system clock period can be determined by dividing the corresponding Simulink sample period by the Simulink System Period value. Thus, the periods for CE2, CE3, and CE4 equal 2, 3, and 4 system clock periods, respectively. A timing diagram for the example clock enable signals is shown in the following figure.

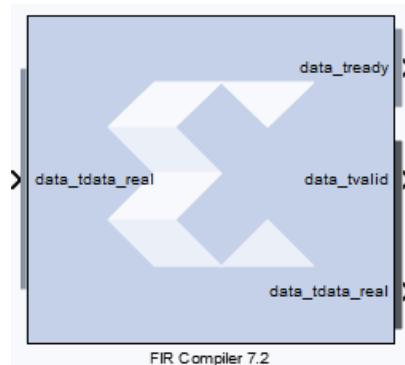
*Figure 15: Timing Diagram*

## Synchronization Mechanisms

Model Composer does not make implicit synchronization mechanisms available. Instead, synchronization is the responsibility of the designer, and must be done explicitly.

### Valid Ports

Model Composer provides several blocks (in particular, the AXI FIFO) that can be used for synchronization. Several blocks provide optional AXI signaling interfaces to denote when a sample is valid (TValid) and when the interface is ready for data (TReady). Note that the tvalid / tready ports may not be visible based on the configuration of the IP. Color association denotes a collection of ports for each interface on the block as shown below. Blocks with interfaces can be chained, affording a primitive form of flow control. Examples of such blocks with AXI interfaces include the FFT, FIR, and DDS.

*Figure 16: Block with AXI Interface*

## Indeterminate Data

Indeterminate values are common in many hardware simulation environments. Often they are called "don't cares" or "Xs". In particular, values in Model Composer simulations can be indeterminate. A dual port memory block, for example, can produce indeterminate results if both ports of the memory attempt to write the same address simultaneously. What actually happens in hardware depends upon effectively random implementation details that determine which port sees the clock edge first. Allowing values to become indeterminate gives the system designer greater flexibility. Continuing the example, there is nothing wrong with writing to memory in an indeterminate fashion if subsequent processing does not rely on the indeterminate result.

HDL modules that are brought into the simulation through HDL co-simulation are a common source for indeterminate data samples. Model Composer presents indeterminate values to the inputs of an HDL co-simulating module as the standard logic vector 'XXX . . . XX'.

Indeterminate values that drive a Gateway Out become what are called NaNs (Not a Number). In a Simulink scope, NaN values are not plotted. Conversely, NaNs that drive a Gateway In become indeterminate values. Model Composer provides an Indeterminate Probe block that allows for the detection of indeterminate values. This probe cannot be translated into hardware.

In Model Composer, any arithmetic signal can be indeterminate, but Boolean signals cannot be. If a simulation reaches a condition that would force a Boolean to become indeterminate, the simulation is halted and an error is reported. Many Xilinx blocks have control ports that only allow Boolean signals as inputs. The rule concerning indeterminate Booleans means that such blocks never see an indeterminate on a control port.

A UFix\_1\_0 is a type that is equivalent to Boolean except for the above restriction concerning indeterminate data.

## Block Masks and Parameter Passing

The same scoping and parameter passing rules that apply to ordinary Simulink blocks apply to HDL blocks. Consequently, blocks in the Xilinx HDL Blockset can be parameterized using MATLAB variables and expressions. This capability makes possible highly parametric designs that take advantage of the expressive and computational power of the MATLAB language.

### Block Masks

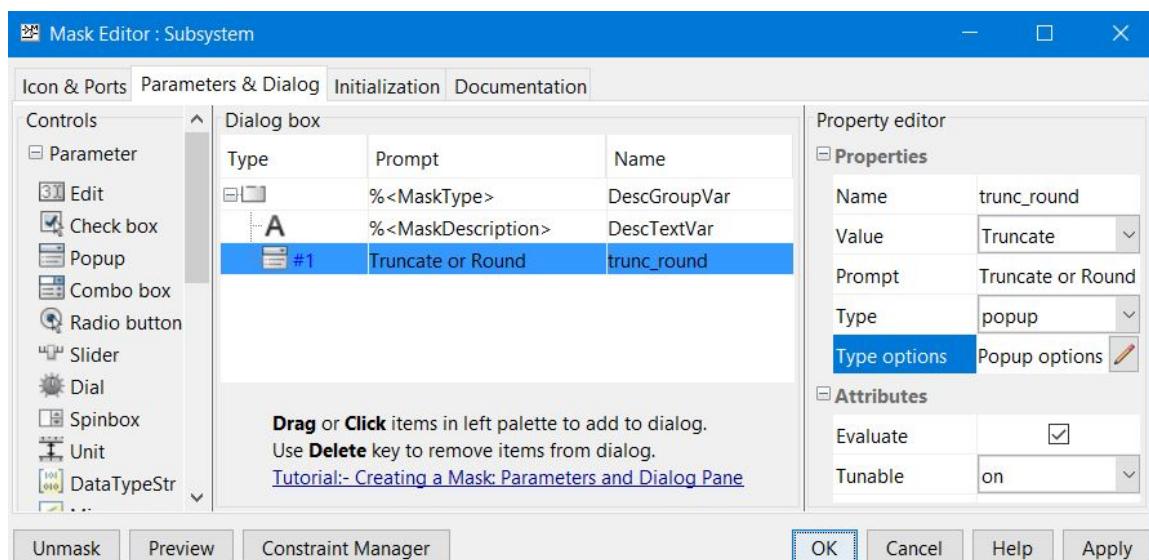
In Simulink, blocks are parameterized through a mechanism called *masking*. In essence, a block can be assigned *mask variables* whose values can be specified by a user through dialog box prompts or can be calculated in mask initialization commands. Variables are stored in a *mask workspace*. A mask workspace is local to the blocks under the mask and cannot be accessed by external blocks.

**Note:** It is possible for a mask to access global variables and variables in the base workspace. To access a base workspace variable, use the MATLAB evalin function. For more information on the MATLAB and Simulink scoping rules, refer to the manuals titled *Using MATLAB* and *Using Simulink* from The MathWorks, Inc.

## Parameter Passing

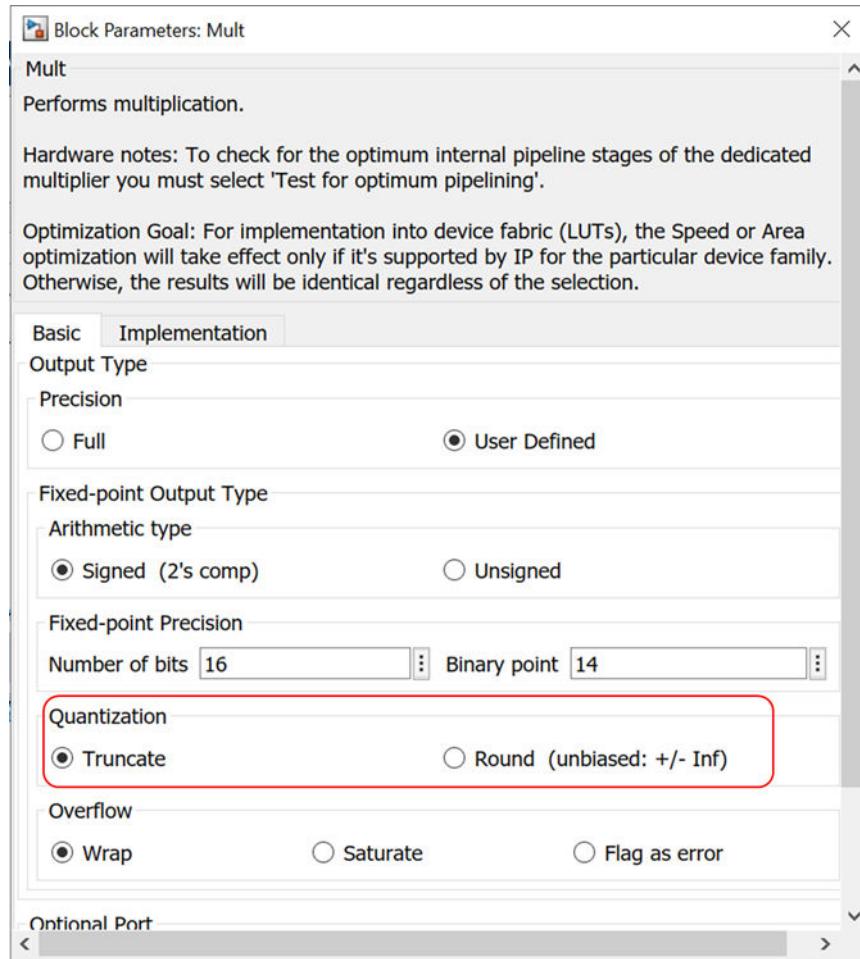
It is often desirable to pass variables to blocks inside a masked Subsystem. Doing so allows the block's configuration to be determined by parameters on the enclosing Subsystem. This technique can be applied to parameters on blocks in the Xilinx HDL blockset whose values are set using a listbox, radio button, or checkbox. For example, when building a Subsystem that consists of a multiply and accumulate block, you can create a parameter on the Subsystem that allows you to specify whether to truncate or round the result. This parameter will be called `trunc_round` as shown in the figure below.

Figure 17: Creating a Parameter



As shown in the following figure, in the Block Parameters dialog for the accumulator and multiplier blocks, there are radio buttons that allow either the Truncate or Round option to be selected.

Figure 18: Editing a Parameter



## Automatic Code Generation

Vitis Model Composer automatically compiles designs into low-level representations. The ways in which Model Composer compiles a model can vary, and depend on settings in the Model Composer Hub block. In addition to producing HDL descriptions of hardware, the tool generates auxiliary files. Some files (e.g., project files, constraints files) assist downstream tools, while others (e.g., VHDL test bench) are used for design verification.

<a href="#">Compiling and Simulating Using the Model Composer Hub</a>	Describes how to use the Vitis Model Composer Hub Block to compile designs into equivalent low-level HDL.
<a href="#">Compilation Results</a>	Describes the low-level files Vitis Model Composer produces when <b>HDL Netlist</b> is selected on the Model Composer Hub block and <b>Generate</b> is pushed.
<a href="#">Vivado Project</a>	Describes the example project Vitis Model Composer produces when <b>HDL Netlist</b> or <b>IP Catalog</b> is selected on the Model Composer Hub block and <b>Generate</b> is pushed.
<a href="#">HDL Testbench</a>	Describes the VHDL test bench that Model Composer can produce.

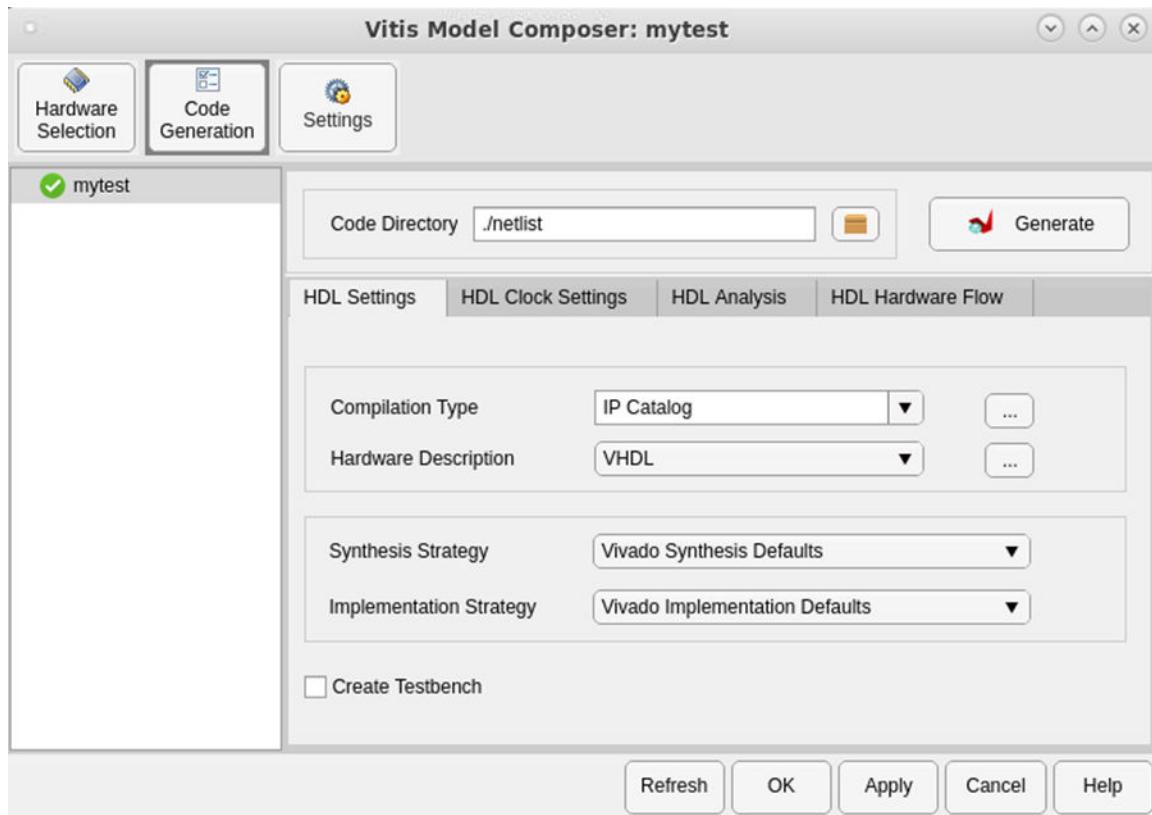
## Compiling and Simulating Using the Model Composer Hub

Vitis Model Composer automatically compiles designs into low-level representations. Designs are compiled and simulated using the Model Composer Hub block. This topic describes how to use the Vitis Model Composer Hub block.

A design must contain at least one Vitis Model Composer Hub block at the top level of the model. This block controls code generation for all of the subsystems within a model. Some parameters, such as clock frequency, can be specified on a subsystem-by-subsystem basis.

Once a Vitis Model Composer Hub block is added, it is possible to specify how code generation and synthesis should be handled. The Model Composer Hub block dialog box is shown in the following figure:

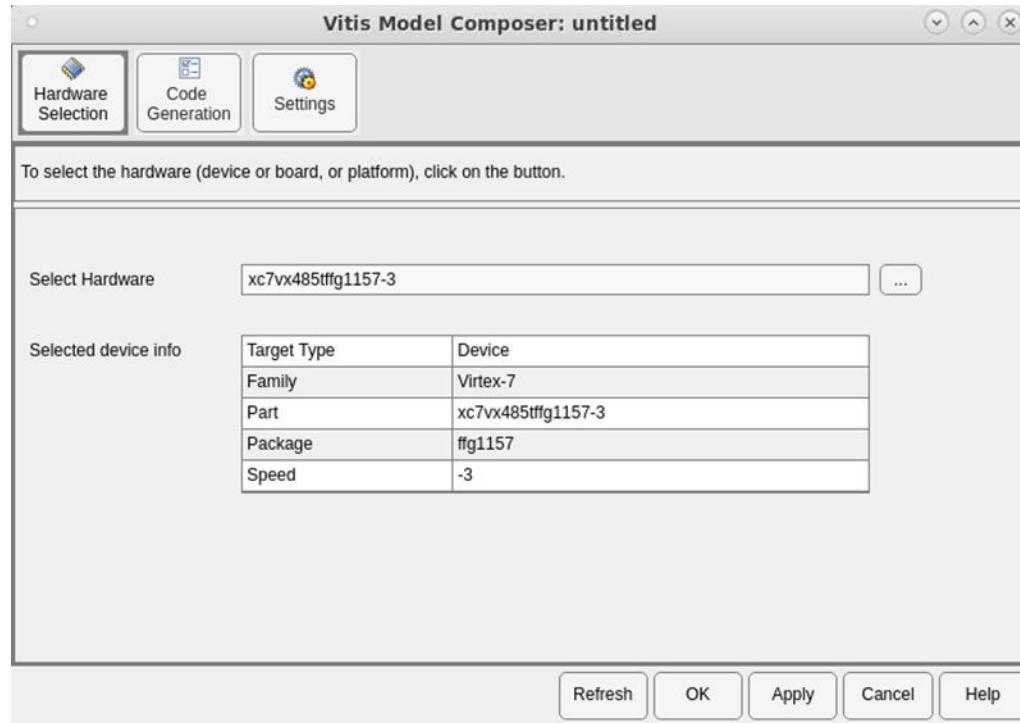
Figure 19: Model Composer Hub Block



### Hardware Selection

This tab allows you to specify a Xilinx, Partner, or Custom board you will use to test your design.

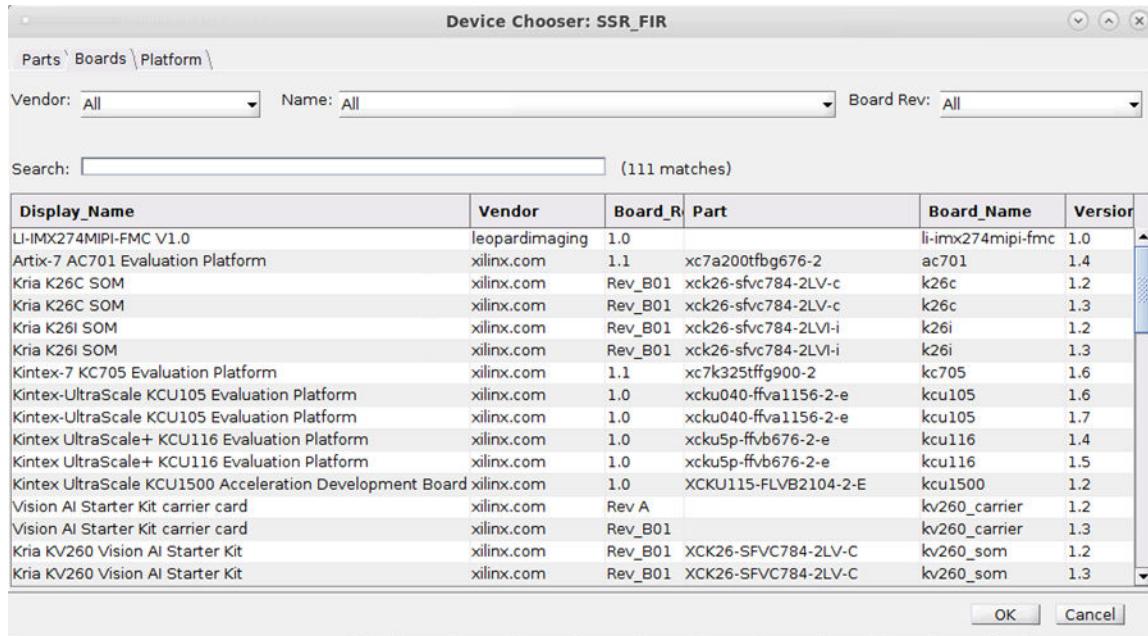
Figure 20: Hardware Selection Tab



Clicking the browse button (...) displays the Device Chooser dialog box. This allows you to select a part, board, or platform to which your design is targeted.

For a Partner board or a custom board to appear in the Board list, you must configure Model Composer to access the board files that describe the board. Board awareness in Model Composer is detailed in [Specifying Board Support in Model Composer HDL Blockset](#).

**Figure 21: Device Chooser**



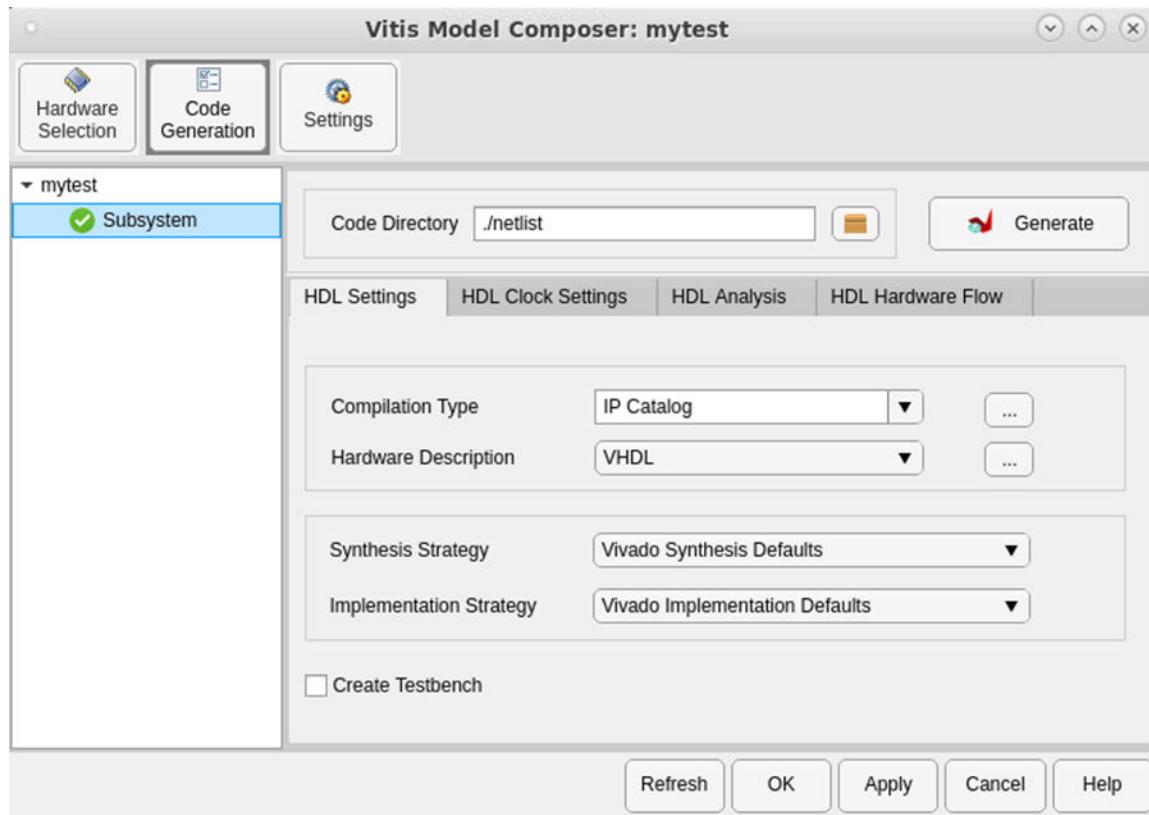
## Code Generation and the Generate Button

The Code Generation tab contains, on the left side, a list of subsystems in the model. Subsystems denoted with a green check mark are ready to generate HDL, HLS, or AI Engine code. To configure code generation for a subsystem, select it from the list. Selecting a subsystem will generate code for it along with any of its child subsystems.

If a subsystem is not denoted with a green check mark, select it to view the reason why the subsystem cannot generate code, along with troubleshooting steps.

The Code Directory field allows you to specify where the code generation products are created.

Figure 22: Code Generation



For a detailed description of the code generation settings available, refer to the relevant Model Composer Hub block section:

- [Vitis Model Composer Hub \(HDL\)](#)
- [Vitis Model Composer Hub \(HLS\)](#)
- [Vitis Model Composer Hub \(AI Engine\)](#)

Pressing the **Generate** button instructs Model Composer to compile a portion of the design into equivalent low-level results. Different output products are available depending on the type of code (HDL, HLS, or AIE) being generated.

This **Settings** tab allows you to specify whether the Model Composer Hub block should treat your model as a legacy System Generator design. When you automatically upgrade a System Generator token to the Model Composer Hub block, this check box is automatically enabled. When the check box is enabled, you can use the Model Composer Hub block without requiring changes to your legacy designs. However, newer capabilities provided by the Model Composer Hub block, such as the Hardware Validation Flow, will not be available.

## Compilation Results

This topic discusses the low-level files Model Composer produces when **HDL Netlist** is selected on the Model Composer Hub block and **Generate** is clicked. The files consist of HDL that implements the design. In addition, Model Composer organizes the HDL files, and other hardware files into a Vivado® IDE Project. All files are written to the target directory specified on the Model Composer Hub block. If no test bench is requested, then the key files produced by Model Composer are the following:

**Table 2: Compilation Files**

File Name or Type	Description
<design_name>.vhd/.v	This file contains a hierarchical structural netlist along with clock/clock enable controls
<design_name_entity_declarations>.vhd/.v	This file contains the entity of module definitions of HDL blocks in the design.
<design_name>.xpr	This file is the Vivado IDE project file that describes all of the attributes of the Vivado IDE design.

If a test bench is requested, then, in addition to the above, Model Composer produces files that allow simulation results to be compared. The comparisons are between Simulink® simulation results and corresponding results from Questa, or any other RTL simulator supported by Vivado® IDE such as Vivado simulator, or VCS. The additional files are as follows:

**Table 3: Additional Compilation Files**

File Name or Type	Description
Various .dat files	These contain the simulation results from Simulink.
<design_name>_tb.vhd/.v	This is a test bench that wraps the design. When simulated, this test bench compares simulation results from the digital simulator against those produced by Simulink.

## Using the Constraints File

When a design is compiled during code generation, Model Composer produces *constraints* that tell downstream tools how to process the design. This enables the tools to produce a higher quality implementation, and to do so using considerably less time. Constraints supply the following:

- The period to be used for the system clock.
- The speed, with respect to the system clock, at which various portions of the design must run.
- The pin locations at which ports should be placed.
- The speed at which ports must operate.

The system clock period (i.e., the period of the fastest hardware clock in the design) can be specified in the Model Composer Hub block. Model Composer writes this period to the constraints file. Downstream tools use the period as a goal when implementing the design.

## Multicycle Path Constraints

Many designs consist of parts that run at different clock rates. For the fastest part, the system clock period is used. For the remaining parts, the clock period is an integer multiple of the system clock period. It is important that downstream tools know what speed each part of the design must achieve. With this information, efficiency and effectiveness of the tools are greatly increased, resulting in reduced compilation times and improved hardware realizations. The division of the design into parts, and the speed at which each part must run, are specified in the constraints file using multicycle path constraints.

## IOB Timing and Placement Constraints

When translated into hardware, Model Composer's HDL Gateway In and Gateway Out blocks become input and output ports. The locations of these ports and the speeds at which they must operate can be entered in the Gateway In and Out parameter dialog boxes. Port location and speed are specified in the constraints file by IOB timing.

This topic describes how Model Composer handles hardware clocks in the HDL it generates. Assume the design is named <design>, and <design> is an acceptable HDL identifier. When Model Composer compiles the design, it writes a collection of HDL entities or modules, the topmost of which is named <design>, and is stored in a file named <design>.vhd / .v.

## The "Clock Enables" Multirate Implementation

Clock and clock enables appear in pairs throughout the HDL. Typical clock names are `clk_1`, `clk_2`, and `clk_3`, and the names of the companion clock enables are `ce_1`, `ce_2`, and `ce_3` respectively. The name tells the rate for the clock/clock enable pair; logic driven by `clk_1` and `ce_1` runs at the system (i.e., fastest) rate, while logic driven by (say) `clk_2` and `ce_2` runs at half the system rate. Clocks and clock enables are not driven in the entity or module named <design> or any subsidiary entities; instead, they are exposed as top-level input ports

The names of the clocks and clock enables in Model Composer HDL suggest that clocking is completely general, but this is not the case. To illustrate this, assume a design has clocks named `clk_1` and `clk_2`, and companion clock enables named `ce_1` and `ce_2` respectively. You might expect that working hardware could be produced if the `ce_1` and `ce_2` signals were tied high, and `clk_2` were driven by a clock signal whose rate is half that of `clk_1`. For most Model Composer designs this does not work. Instead, `clk_1` and `clk_2` must be driven by the same clock, `ce_1` must be tied high, and `ce_2` must vary at a rate half that of `clk_1` and `clk_2`.

## IP Instance Caching

For compilation targets that perform Vivado synthesis to generate their output products, Model Composer incorporates a disk cache to speed up the iterative design process.

With the cache enabled for your design, whenever your compilation generates an IP instance for synthesis, and the Vivado synthesis tool creates synthesis output products, the tools create an entry in the cache area.

After the cache is populated, when a new customization of the IP is created which has the exact same properties, the IP is not synthesized again; instead, the cache is referenced and the corresponding synthesis output in the cache is copied to your design's output directory. Because the IP instance is not synthesized again, and this process is repeated for every IP referenced in your design, generation of the output products is completed more quickly.

The following compilation targets invoke Vivado synthesis; these compilation targets will access the cache to synthesize IP in your design.

- Hardware Co-Simulation
- Synthesized Checkpoint

Also, when you compile your design and **Perform analysis** is selected for either **Timing** or **Resource** analysis, Vivado synthesis always runs, regardless of the compilation target. Since timing analysis or resource analysis may be performed several times for a design, enabling IP caching will improve overall performance. For a description of the **Perform analysis** compilation option, see [Performing Timing Analysis](#) or [Performing Resource Analysis](#).

The IP cache is shared across multiple Simulink models on your system. If you reuse an IP in one design by including it in another design, and the IP is customized identically and has the same part and language settings in both Simulink models, you can gain the benefit of caching when you compile either of the designs.

To find the location of the IP cache directory on your system, enter the command `xilinx.environment.getipcachepath` on the MATLAB command line. The full path to the IP cache directory will display in the MATLAB command window.

```
>> xilinx.environment.getipcachepath
ans =
C:/Users/your_id/AppData/Local/Xilinx/Sysgen/SysgenVivado/win64.o/ip
```

IP caching in Model Composer is similar to IP caching in the Vivado Design Suite, described at this [link](#) in the *Vivado Design Suite User Guide: Designing with IP* ([UG896](#)). However, the IP cache for Model Composer designs is in a different location than the IP cache for Vivado projects.

## Vivado Project

The **HDL Netlist** and **IP Catalog** compilation targets also generate an example Vivado project, which represents an integration of the results of Code Generation.

In the case of the **HDL Netlist** compilation target, the Vivado project sets the module designed in Model Composer as the top level and includes instances of IP. Also, if **Create testbench** is selected in the Model Composer Hub block, a test bench and stimulus files (\*.dat) are also added to the project.

In the case of the **IP Catalog** compilation target, an example project is created with the following features:

- The IP generated from Model Composer is already added to the IP catalog associated with the project and available for the RTL flow as well as the IP integrator-based flow.
- The design includes an RTL instantiation of IP called <ip>\_0 underneath <design>\_stub that indicates how to instantiate such an IP in the RTL flow
- The design includes an RTL test bench called <design>\_tb that also instantiates the same IP in the RTL flow.

**Note:** A test bench is not created if **AXI4-Lite** slave interface generation is selected in a Gateway In or Gateway Out block.

- The project also includes an example IP integrator diagram with a Zynq-7000 subsystem if the part selected in this example is a Zynq-7000 SoC part. For all other parts, a MicroBlaze™-based subsystem is created.

## HDL Testbench

Ordinarily, Model Composer designs are bit and cycle-accurate, so Simulink simulation results exactly match those seen in hardware. There are, however, times when it is useful to compare Simulink simulation results against those obtained from an HDL simulator. In particular, this makes sense when the design contains black boxes. The **Create Testbench** checkbox in the Model Composer Hub block makes this possible.

Suppose the design is named <design>, and a Model Composer Hub block is placed at the top of the design. Suppose also that in the token the **Compilation** field is set to **HDL Netlist**, and the **Create Testbench** checkbox is selected. When the **Generate** button is clicked, Model Composer produces the usual files for the design, and in addition writes the following:

- A file named <design>\_tb.vhd/.v that contains a test bench HDL entity.
- Various .dat files that contain test vectors for use in an HDL test bench simulation.

You can perform RTL simulation using the Vivado Integrated Design Environment (IDE). For more details, refer to the document *Vivado Design Suite User Guide: Logic Simulation (UG900)*.

Model Composer generates the .dat files by saving the values that pass through gateways. In the HDL simulation, input values from the .dat files are stimuli, and output values are expected results. The test bench is simply a wrapper that feeds the stimuli to the HDL for the design, then compares HDL results against expected ones.

## Compiling MATLAB into an FPGA

Model Composer provides direct support for MATLAB through the MCode block. The MCode block applies input values to an M-function for evaluation using Xilinx's fixed-point data type. The evaluation is done once for each sample period. The block is capable of keeping internal states with the use of persistent state variables. The input ports of the block are determined by the input arguments of the specified M-function and the output ports of the block are determined by the output arguments of the M-function. The block provides a convenient way to build finite state machines, control logic, and computation heavy systems.

In order to construct an MCode block, an M-function must be written. The M-file must be in the directory of the model file that is to use the M-file or in a directory in the MATLAB path.

The following text provides examples that use the MCode block:

- Example 1 [Simple Selector](#) shows how to implement a function that returns the maximum value of its inputs;
- Example 2 [Simple Arithmetic Operations](#) shows how to implement simple arithmetic operations;
- Example 3 [Complex Multiplier with Latency](#) shows how to build a complex multiplier with latency;
- Example 4 [Shift Operations](#) shows how to implement shift operations;
- Example 5 [Passing Parameters into the MCode Block](#) shows how to pass parameters into a MCode block;
- Example 6 [Optional Input Ports](#) shows how to implement optional input ports on an MCode block;
- Example 7 [Finite State Machines](#) shows how to implement a finite state machine;
- Example 8 [Parameterizable Accumulator](#) shows how to build a parameterizable accumulator;
- Example 9 [FIR Example and System Verification](#) shows how to model FIR blocks and how to do system verification;
- Example 10 [RPN Calculator](#) shows how to model a RPN calculator – a stack machine;
- Example 11 [Example of disp Function](#) shows how to use disp function to print variable values.

## Simple Selector

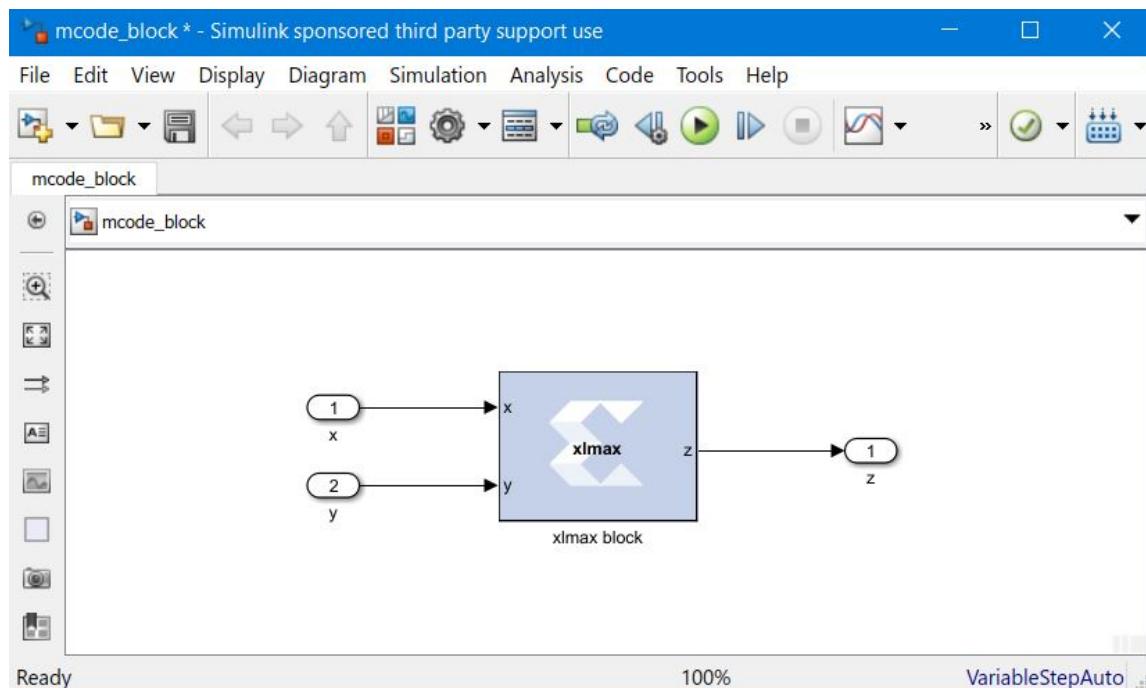
This example is a simple controller for a data path, which assigns the maximum value of two inputs to the output. The M-function is specified as the following and is saved in an M-file `xlmax.m`:

```
function z = xlmax(x, y)
if x > y
    z = x;
else
    z = y;
end
```

The `xlmax.m` file should be either saved in the same directory of the model file or should be in the MATLAB path. Once the `xlmax.m` has been saved to the appropriate place, you should drag a MCode block into your model, open the block parameter dialog box, and enter `xlmax` into the **MATLAB Function** field. After clicking the **OK** button, the block has two input ports `x` and `y`, and one output port `z`.

The following figure shows what the block looks like after the model is compiled. You can see that the block calculates and sets the necessary fixed-point data type to the output port.

Figure 23: Simple Selector Design



## Simple Arithmetic Operations

This example shows some simple arithmetic operations and type conversions. The following shows the `xlSimpleArith.m` file, which specifies the `xlSimpleArith` M-function.

```
function [z1, z2, z3, z4] = xlSimpleArith(a, b)
    % xlSimpleArith demonstrates some of the arithmetic operations
    % supported by the Xilinx MCode block. The function uses xfix()
    % to create Xilinx fixed-point numbers with appropriate
    % container types.%
    % You must use a xfix() to specify type, number of bits, and
    % binary point position to convert floating point values to
    % Xilinx fixed-point constants or variables.
    % By default, the xfix call uses xlTruncate
    % and xlWrap for quantization and overflow modes.
    % const1 is Ufix_8_3
    const1 = xfix({xlUnsigned, 8, 3}, 1.53);
    % const2 is Fix_10_4
    const2 = xfix({xlSigned, 10, 4, xlRound, xlWrap}, 5.687);
    z1 = a + const1;
    z2 = -b - const2;
    z3 = z1 - z2;
    % convert z3 to Fix_12_8 with saturation for overflow
    z3 = xfix({xlSigned, 12, 8, xlTruncate, xlSaturate}, z3);
    % z4 is true if both inputs are positive
    z4 = a>const1 & b>-1;
```

This M-function uses addition and subtraction operators. The MCode block calculates these operations in full precision, which means the output precision is sufficient to carry out the operation without losing information.

One thing worth discussing is the `xfix` function call. The function requires two arguments: the first for fixed-point data type precision and the second indicating the value. The precision is specified in a cell array. The first element of the precision cell array is the type value. It can be one of three different types: `xlUnsigned`, `xlSigned`, or `xlBoolean`. The second element is the number of bits of the fixed-point number. The third is the binary point position. If the element is `xlBoolean`, there is no need to specify the number of bits and binary point position. The number of bits and binary point position must be specified in pair. The fourth element is the quantization mode and the fifth element is the overflow mode. The quantization mode can be one of `xlTruncate`, `xlRound`, or `xlRoundBanker`. The overflow mode can be one of `xlWrap`, `xlSaturate`, or `xlThrowOverflow`. Quantization mode and overflow mode must be specified as a pair. If the quantization-overflow mode pair is not specified, the `xfix` function uses `xlTruncate` and `xlWrap` for signed and unsigned numbers. The second argument of the `xfix` function can be either a double or a Xilinx fixed-point number. If a constant is an integer number, there is no need to use the `xfix` function. The Mcode block converts it to the appropriate fixed-point number automatically.

After setting the dialog box parameter **MATLAB function** to `xlSimpleArith`, the block shows two input ports `a` and `b`, and four output ports `z1`, `z2`, `z3`, and `z4`.

Figure 24: xlSimpleArith MCode Parameter

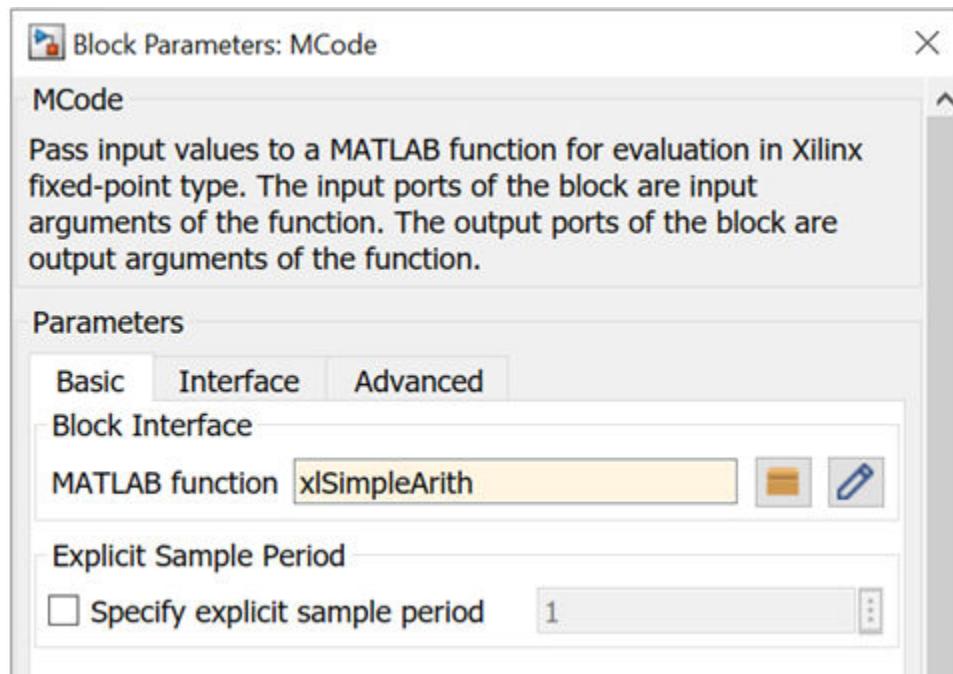
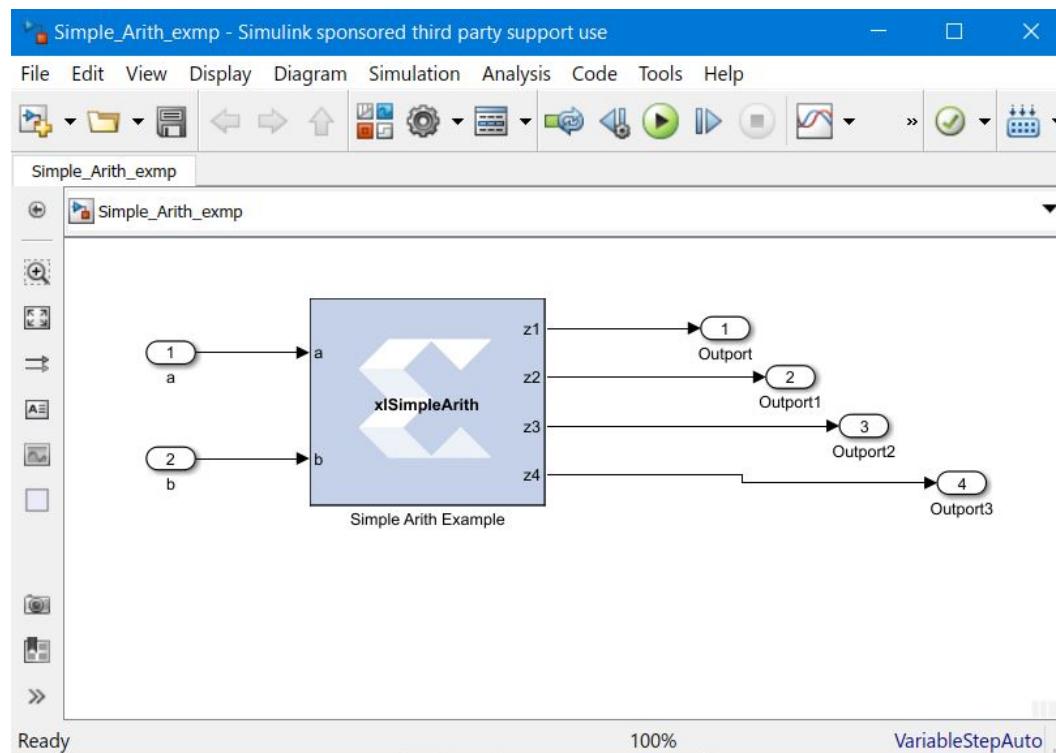


Figure 25: xlSimpleArith Design



M-functions using Xilinx data types and functions can be tested in the MATLAB Command Window. For example, if you type: `[z1, z2, z3, z4] = xlSimpleArith(2, 3)` in the MATLAB Command Window, you'll get the following lines:

```
UFix(9, 3): 3.500000
Fix(12, 4): -8.687500
Fix(12, 8): 7.996094
Bool: true
```

Notice that the two integer arguments (2 and 3) are converted to fixed-point numbers automatically. If you have a floating-point number as an argument, an `xfix` call is required.

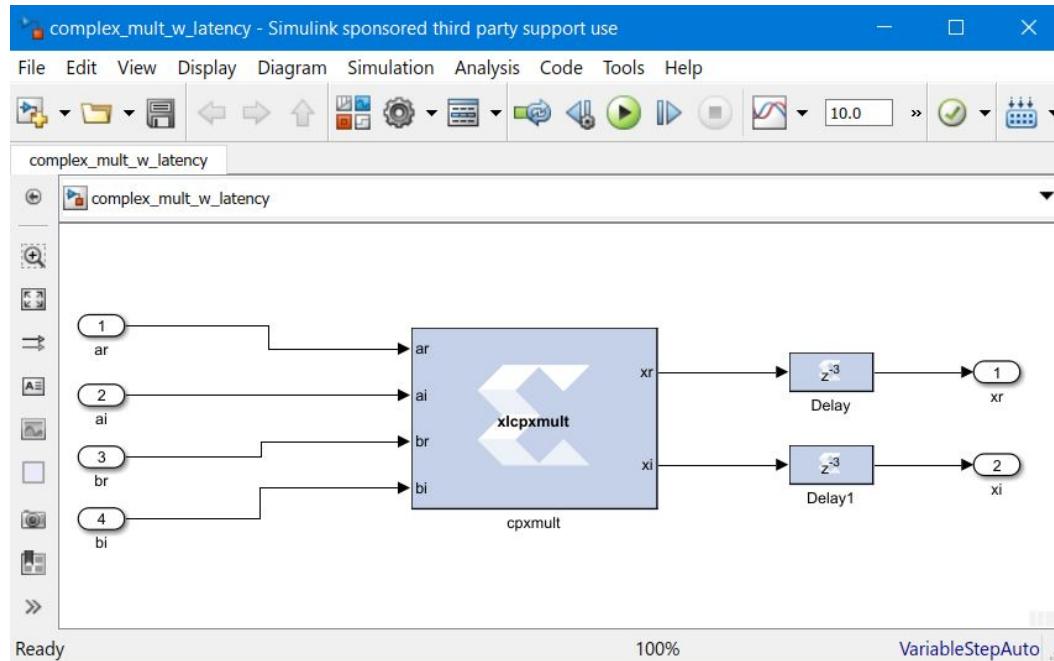
## Complex Multiplier with Latency

This example shows how to create a complex number multiplier. The following shows the `xlcpymult.m` file which specifies the `xlcpymult` function.

```
function [xr, xi] = xlcpymult(ar, ai, br, bi)
    xr = ar * br - ai * bi;
    xi = ar * bi + ai * br;
```

The following diagram shows the subsystem:

Figure 26: Complex Multiplier Subsystem



Two delay blocks are added after the MCode block. By selecting the option **Implement using behavioral HDL** on the Delay blocks, the downstream logic synthesis tool is able to perform the appropriate optimizations to achieve higher performance.

## Shift Operations

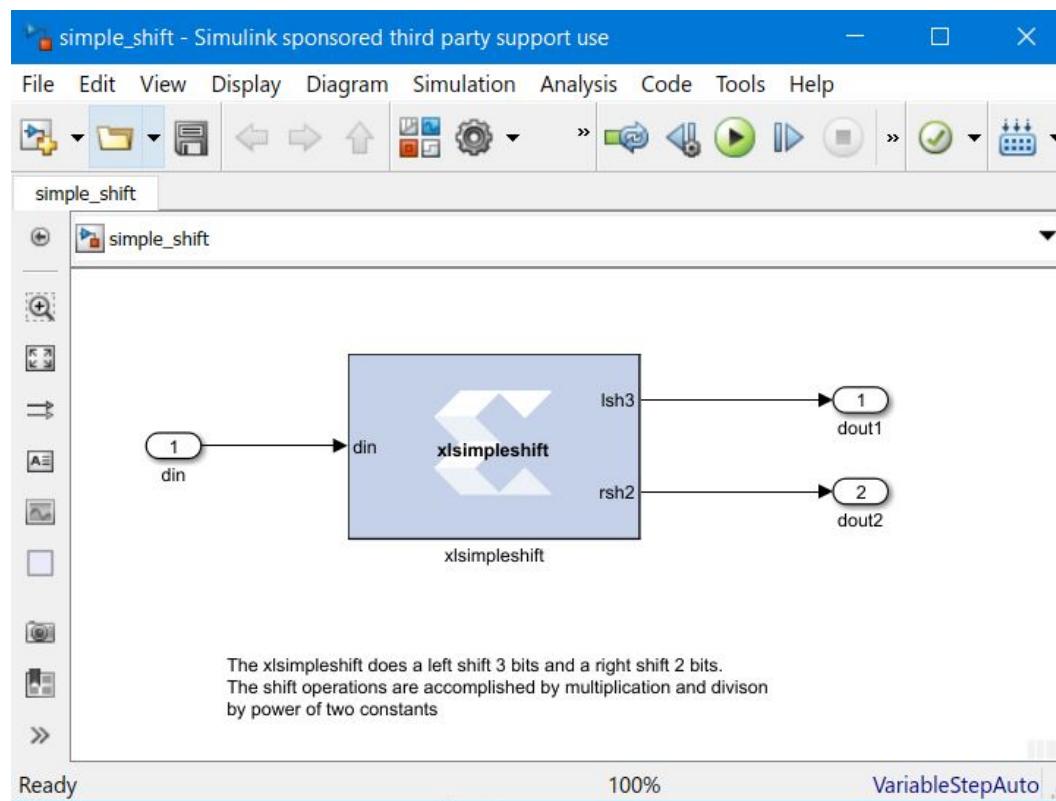
This example shows how to implement bit-shift operations using the MCode block. Shift operations are accomplished with multiplication and division by powers of two. For example, multiplying by 4 is equivalent to a 2-bit left-shift, and dividing by 8 is equivalent to a 3-bit right-shift. Shift operations are implemented by moving the binary point position and if necessary, expanding the bit width. Consequently, multiplying a Fix\_8\_4 number by 4 results in a Fix\_8\_2 number, and multiplying a Fix\_8\_4 number by 64 results in a Fix\_10\_0 number.

The following shows the `xlsimpleshift.m` file which specifies one left-shift and one right-shift:

```
function [lsh3, rsh2] = xlsimpleshift(din)
    % [lsh3, rsh2] = xlsimpleshift(din) does a left shift
    % 3 bits and a right shift 2 bits.
    % The shift operation is accomplished by
    % multiplication and division of power
    % of two constant.
    lsh3 = din * 8;
    rsh2 = din / 4;
```

The following diagram shows the subsystem after compilation:

Figure 27: Shift Operations



## Passing Parameters into the MCode Block

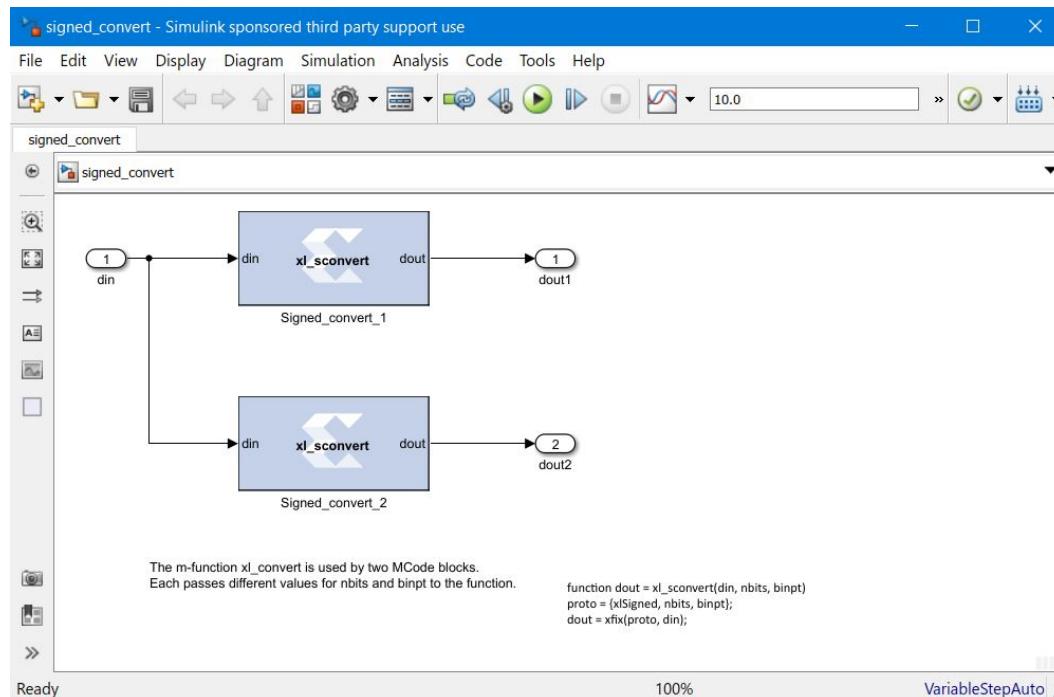
This example shows how to pass parameters into the MCode block. An input argument to an M-function can be interpreted either as an input port on the MCode block, or as a parameter internal to the block.

The following M-code defines an M-function `xl_sconvert` that is contained in file `xl_sconvert.m`:

```
function dout = xl_sconvert(din, nbits, binpt)
    proto = {xlSigned, nbits, binpt};
    dout = xfix(proto, din);
```

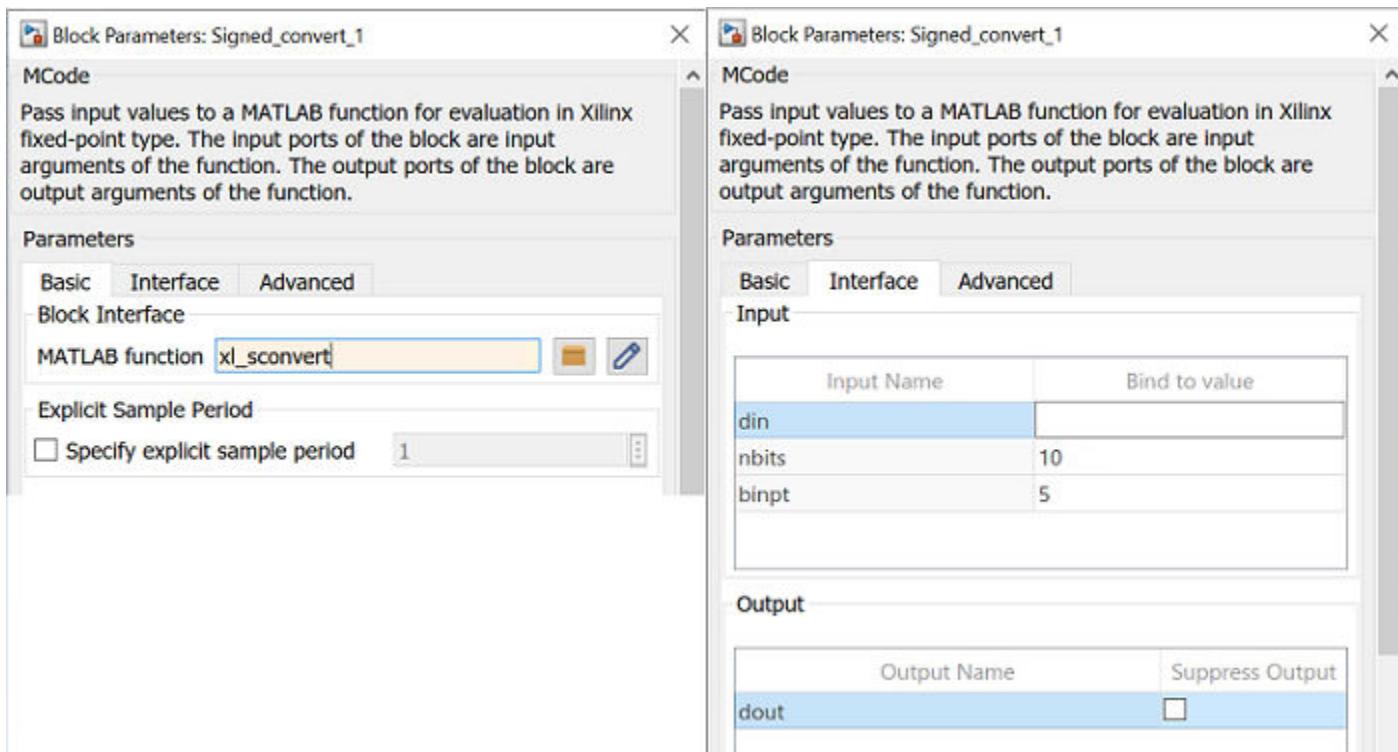
The following diagram shows a Subsystem containing two MCode blocks that use M-function `xl_sconvert`. The arguments `nbits` and `binpt` of the M-function are specified differently for each block by passing different parameters to the MCode blocks. The parameters passed to the MCode block labeled `signed convert 1` cause it to convert the input data from type `Fix_16_8` to `Fix_10_5` at its output. The parameters passed to the MCode block labeled `signed convert 2` causes it to convert the input data from type `Fix_16_8` to `Fix_8_4` at its output.

Figure 28: Subsystem with Two MCode Blocks



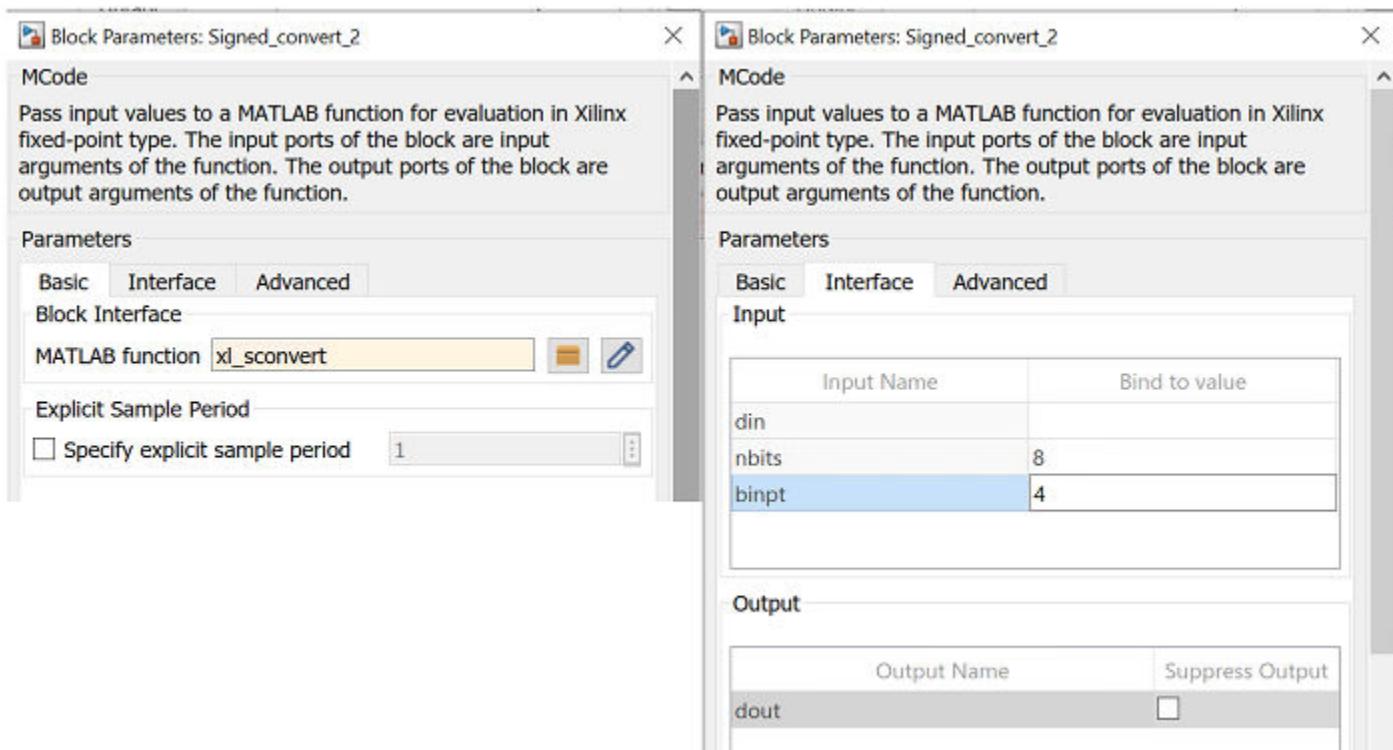
To pass parameters to each MCode block in the diagram above, you can click the **Edit M-File** button on the block GUI then set the values for the M-function arguments. The mask for MCode block `signed convert 1` is shown below:

Figure 29: Masking MCode Block



The above interface window sets the M-function argument `nbits` to be 10 and `binpt` to be 5. The mask for the MCode block `signed convert 2` is shown below:

Figure 30: Mask for MCode Block Signed Convert 2



## Optional Input Ports

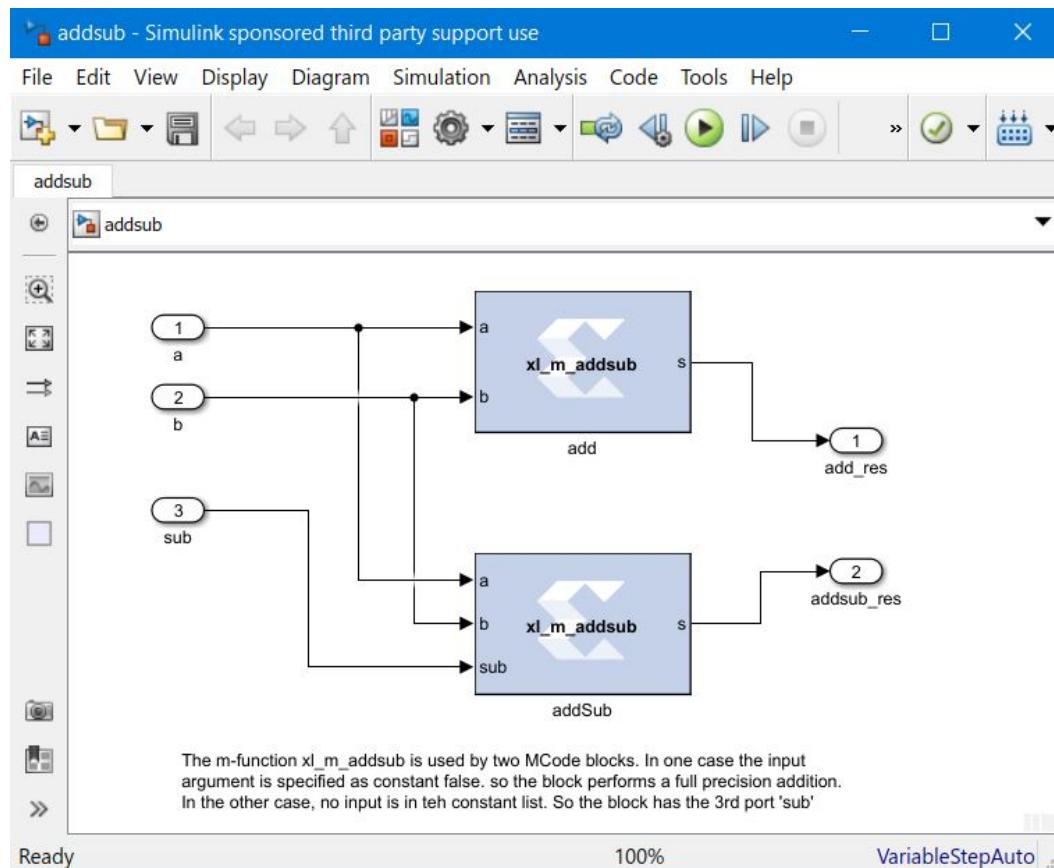
This example shows how to use the parameter passing mechanism of MCode blocks to specify whether or not to use optional input ports on MCode blocks.

The following M-code, which defines M-function `xl_m_addsub` is contained in file `xl_m_addsub.m`:

```
function s = xl_m_addsub(a, b, sub)
    if sub
        s = a - b;
    else
        s = a + b;
    end
```

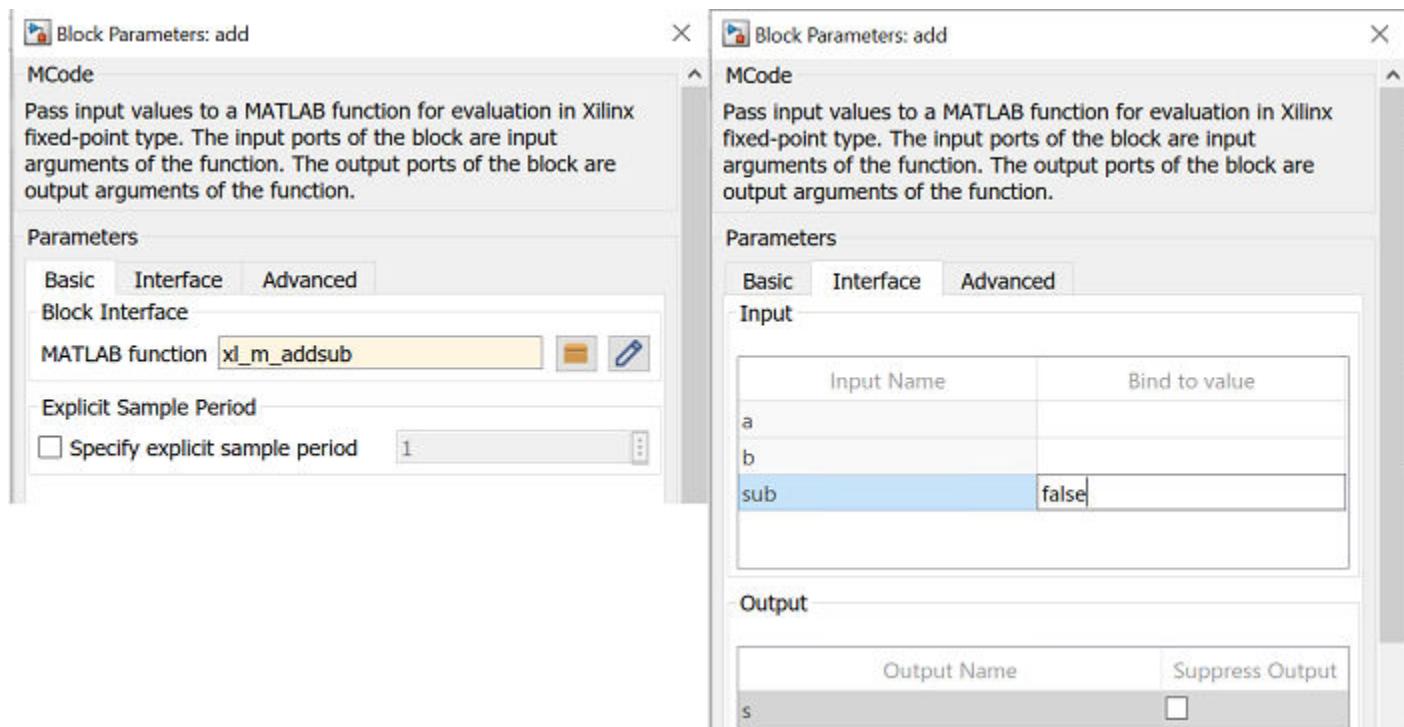
The following diagram shows a Subsystem containing two MCode blocks that use M-function `xl_m_addsub`.

Figure 31: Two MCode Blocks Using M-Function



The labeled add is shown in below.

Figure 32: Block Interface Editor of the MCode Block

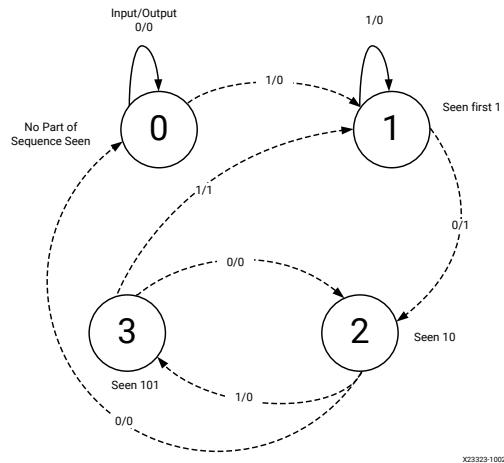


As a result, the `add` block features two input ports `a` and `b`; it performs full precision addition. Input parameter `sub` of the MCode block labeled `addsub` is not bound with any value. Consequently, the `addsub` block features three input ports: `a`, `b`, and `sub`; it performs full precision addition or subtraction based on the value of input port `sub`.

## Finite State Machines

This example shows how to create a finite state machine using the MCode block with internal state variables. The state machine illustrated below detects the pattern 1011 in an input stream of bits.

Figure 33: Finite State Machine Diagram



The M-function that is used by the MCode block contains a transition function, which computes the next state based on the current state and the current input. Unlike example 3 though, the M-function in this example defines persistent state variables to store the state of the finite state machine in the MCode block. The following M-code, which defines function `detect1011_w_state` is contained in file `detect1011_w_state.m`:

```
function matched = detect1011_w_state(din)
% This is the detect1011 function with states for detecting a
% pattern of 1011.

seen_none = 0; % initial state, if input is 1, switch to seen_1
seen_1 = 1;    % first 1 has been seen, if input is 0, switch
               % to seen_10
seen_10 = 2;   % 10 has been detected, if input is 1, switch to
               % seen_1011
seen_101 = 3;  % now 101 is detected, if input is 1, 1011 is
               % detected and the FSM switches to seen_1

% the state is a 2-bit register
persistent state, state = xl_state(seen_none, {xlUnsigned, 2, 0});

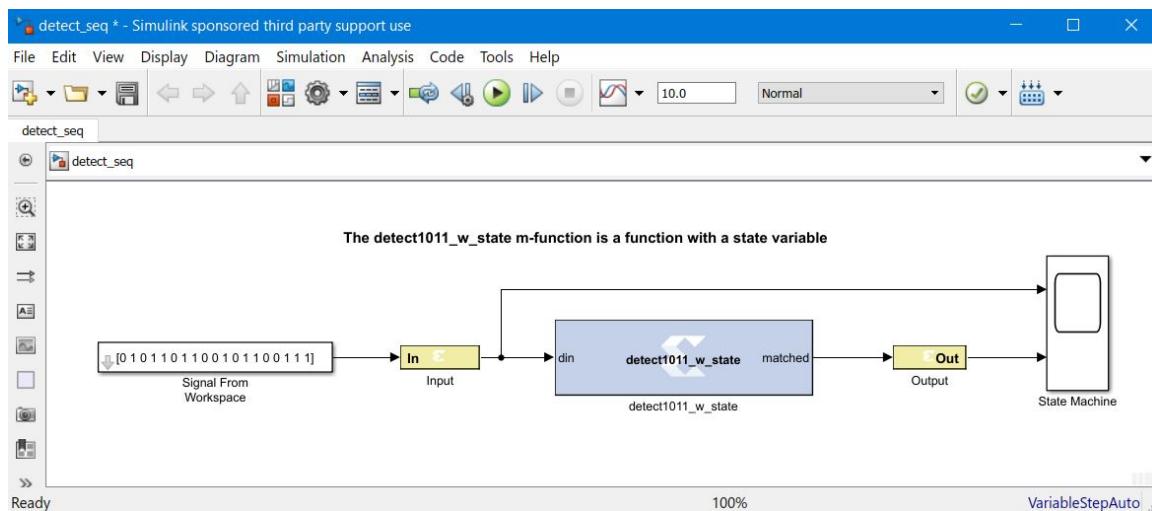
% the default value of matched is false
matched = false;

switch state
  case seen_none
    if din==1
      state = seen_1;
    else
      state = seen_none;
    end
  case seen_1 % seen first 1
    if din==1
      state = seen_1;
    else
      state = seen_10;
    end
  case seen_10 % seen 10
    if din==1
      state = seen_101;
    end
end
```

```
else
% no part of sequence seen, go to seen_none
state = seen_none;
end
case seen_101
if din==1
    state = seen_1;
    matched = true;
else
    state = seen_10;
    matched = false;
end
end
```

The following diagram shows a state machine Subsystem containing a MCode block after compilation; the MCode block uses M-function `detect1101_w_state`.

Figure 34: Subsystem Containing MCode Block After Compilation



## Parameterizable Accumulator

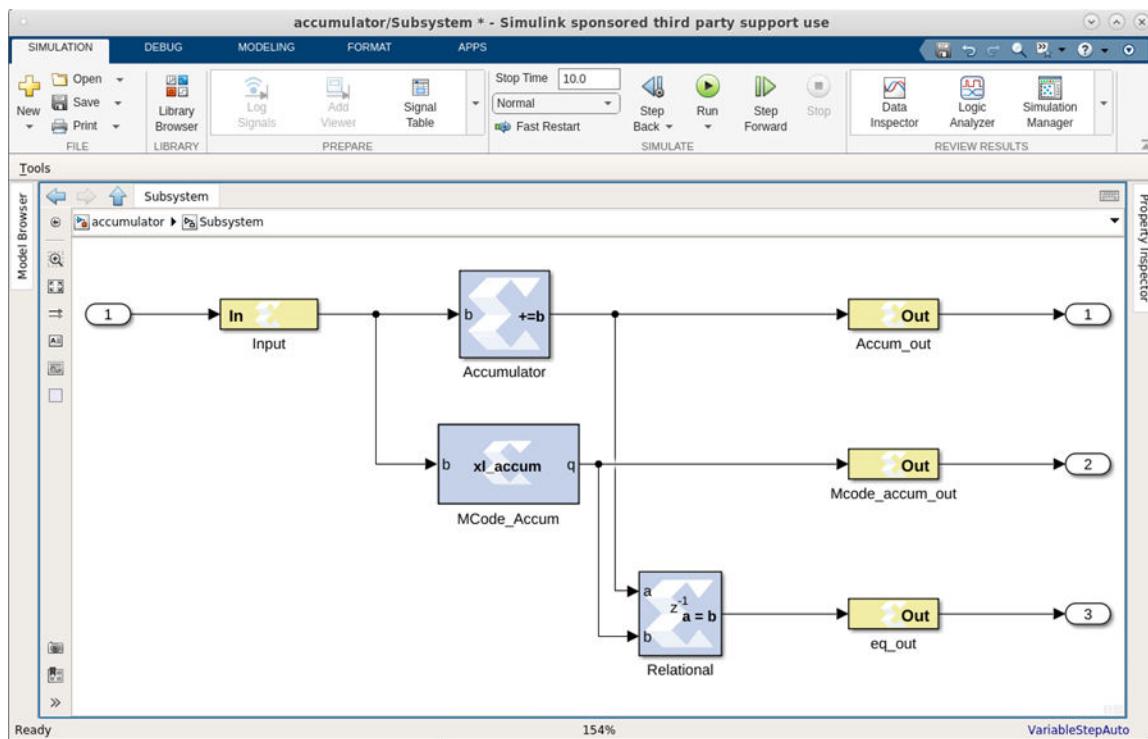
This example shows how to use the MCode block to build an accumulator using persistent state variables and parameters to provide implementation flexibility. The following M-code, which defines function `xl_accum` is contained in file `xl_accum.m`:

```
function q = xl_accum(b, rst, load, en, nbits, ov, op, feed_back_down_scale)
% q = xl_accum(b, rst, nbits, ov, op, feed_back_down_scale) is
% equivalent to our Accumulator block.
binpt = xl_binpt(b);
init = 0;
precision = {xlSigned, nbits, binpt, xlTruncate, ov};
persistent s, s = xl_state(init, precision);
q = s;
if rst
    if load
        % reset from the input port
        s = b;
    else
```

```
% reset from zero
s = init;
end
else
if ~en
else
% if enabled, update the state
if op==0
s = s/feed_back_down_scale + b;
else
s = s/feed_back_down_scale - b;
end
end
end
```

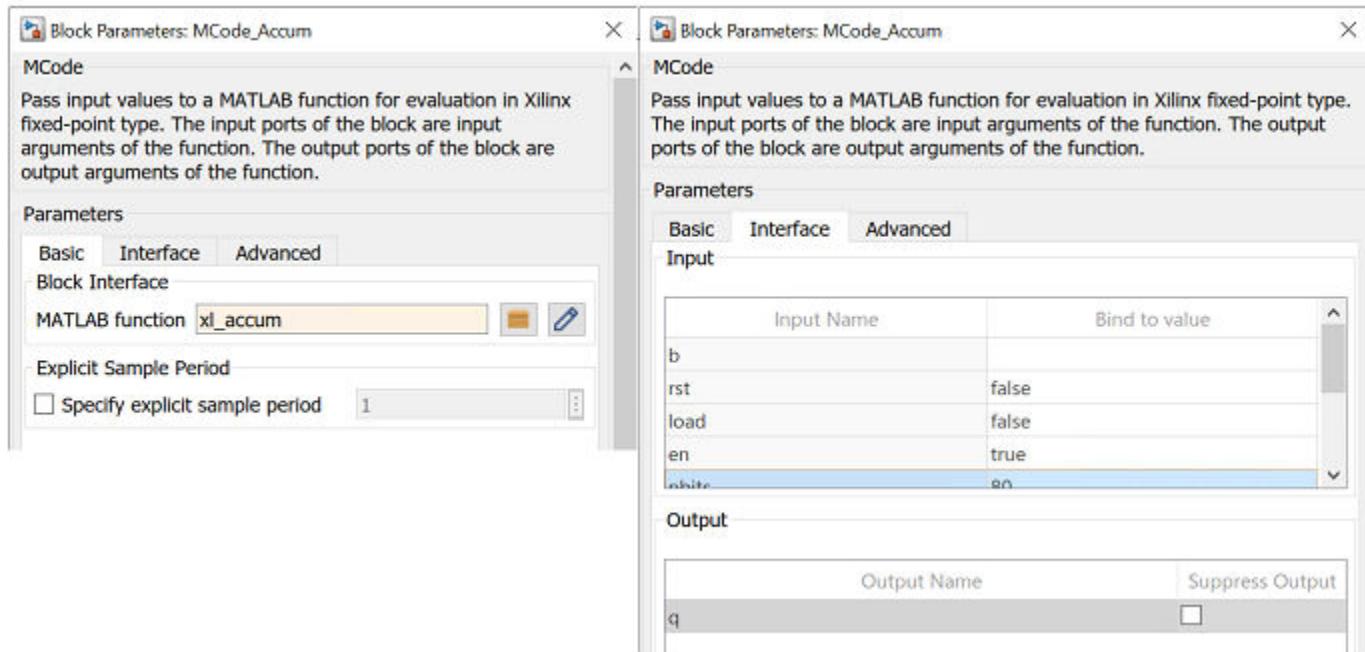
The following diagram shows a Subsystem containing the accumulator MCode block using M-function `xl_accum`. The MCode block is labeled MCode Accumulator. The Subsystem also contains the Xilinx Accumulator block, labeled Accumulator, for comparison purposes. The MCode block provides the same functionality as the Xilinx Accumulator block; however, its mask interface differs in that parameters of the MCode block are specified with a cell array in the Function Parameter Bindings parameter.

Figure 35: MCode Accumulator



Optional inputs `rst` and `load` of block `Accum_MCode1` are disabled in the cell array of the Function Parameter Bindings parameter. The block mask for block MCode Accumulator is shown below:

Figure 36: Mask for MCode Accumulator

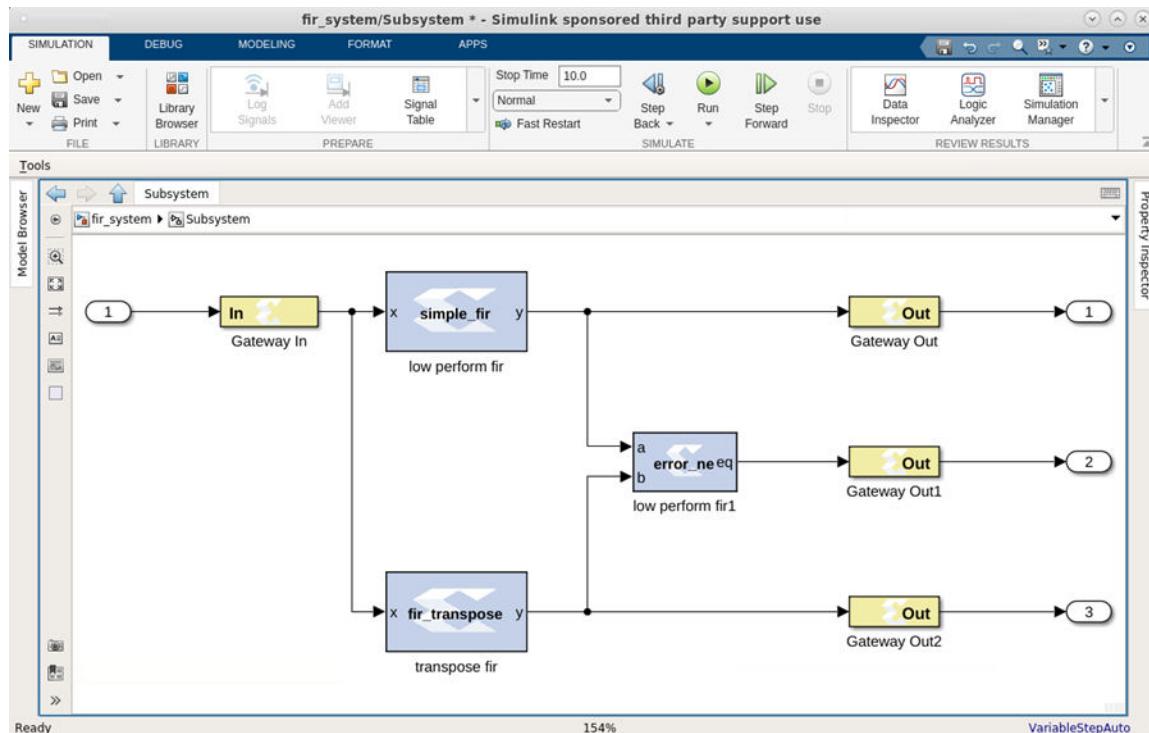


The example contains two additional accumulator Subsystems with MCode blocks using the same M-function, but different parameter settings to accomplish different accumulator implementations.

## FIR Example and System Verification

This example shows how to use the MCode block to model FIRs. It also shows how to do system verification with the MCode block.

Figure 37: FIR Example



The model contains two FIR blocks. Both are modeled with the MCode block and both are synthesizable. The following are the two functions that model those two blocks.

```
function y = simple_fir(x, lat, coefs, len, c_nbBits, c_binpt, o_nbBits,
o_binpt)
    coef_prec = {xlSigned, c_nbBits, c_binpt, xlRound, xlWrap};
    out_prec = {xlSigned, o_nbBits, o_binpt};

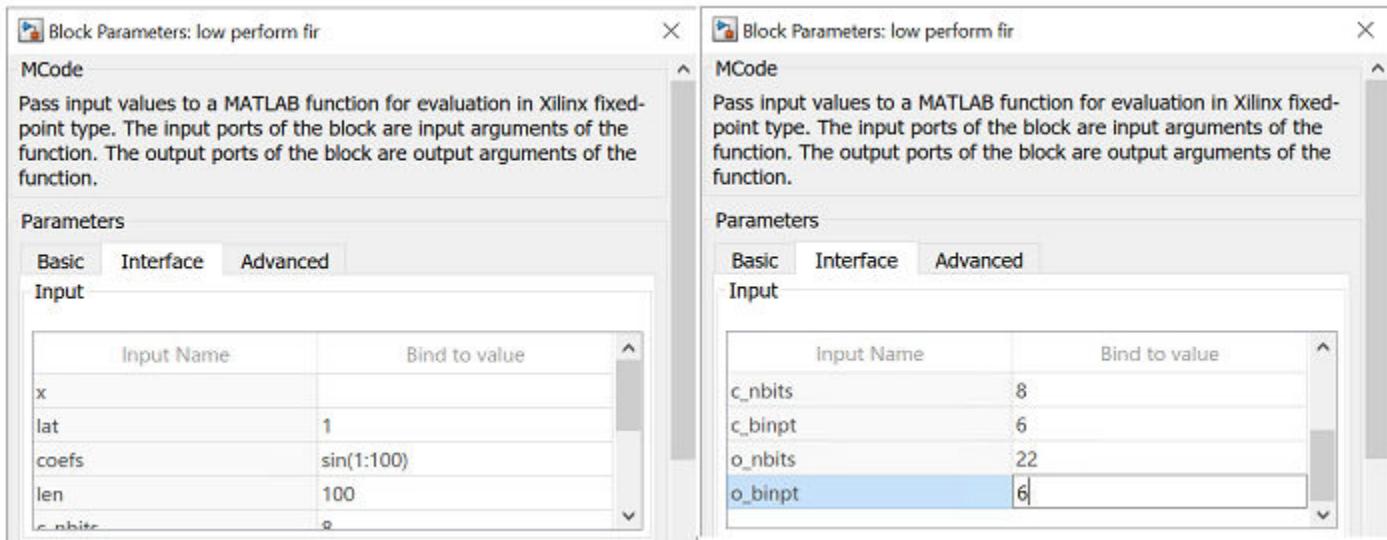
    coefs_xfix = xfix(coef_prec, coefs);
    persistent coef_vec, coef_vec = xl_state(coefs_xfix, coef_prec);
    persistent x_line, x_line = xl_state(zeros(1, len-1), x);
    persistent p, p = xl_state(zeros(1, lat), out_prec, lat);

    sum = x * coef_vec(0);
    for idx = 1:len-1
        sum = sum + x_line(idx-1) * coef_vec(idx);
        sum = xfix(out_prec, sum);
    end
    y = p.back;
    p.push_front_pop_back(sum);
    x_line.push_front_pop_back(x);
function y = fir_transpose(x, lat, coefs, len, c_nbBits, c_binpt, o_nbBits,
o_binpt)
    coef_prec = {xlSigned, c_nbBits, c_binpt, xlRound, xlWrap};
    out_prec = {xlSigned, o_nbBits, o_binpt};
    coefs_xfix = xfix(coef_prec, coefs);
    persistent coef_vec, coef_vec = xl_state(coefs_xfix, coef_prec);
    persistent reg_line, reg_line = xl_state(zeros(1, len), out_prec);
    if lat <= 0
        error('latency must be at least 1');
    end
```

```
lat = lat - 1;
persistent dly,
if lat <= 0
    y = reg_line.back;
else
    dly = xl_state(zeros(1, lat), out_prec, lat);
    y = dly.back;
    dly.push_front_pop_back(reg_line.back);
end
for idx = len-1:-1:1
    reg_line(idx) = reg_line(idx - 1) + coef_vec(len - idx - 1) * x;
end
reg_line(0) = coef_vec(len - 1) * x;
```

The parameters are configured as following:

Figure 38: Parameters



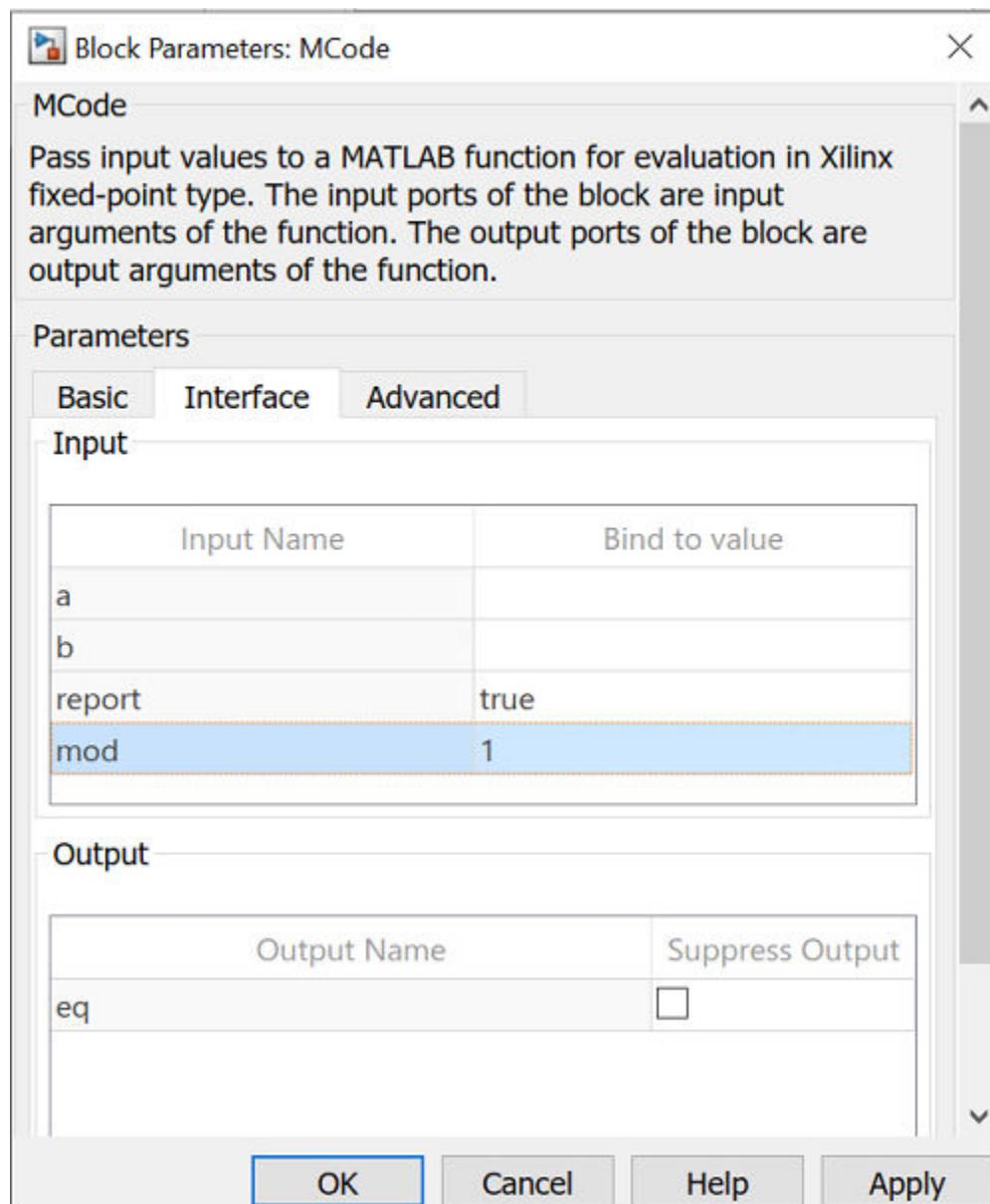
In order to verify that the functionality of the two blocks is equal, another MCode block is used to compare the outputs of the two blocks. If the two outputs are not equal at any given time, the error checking block will report the error. The following function performs the error checking:

```
function eq = error_ne(a, b, report, mod)
    persistent cnt, cnt = xl_state(0, {xlUnsigned, 16, 0});
    switch mod
        case 1
            eq = a == b;
        case 2
            eq = isnan(a) || isnan(b) || a == b;
        case 3
            eq = ~isnan(a) && ~isnan(b) && a == b;
        otherwise
            eq = false;
            error(['wrong value of mode ', num2str(mod)]);
    end
    if report
```

```
if ~eq
    error(['two inputs are not equal at time ', num2str(cnt)]);
end
end
cnt = cnt + 1;
```

The block is configured as following:

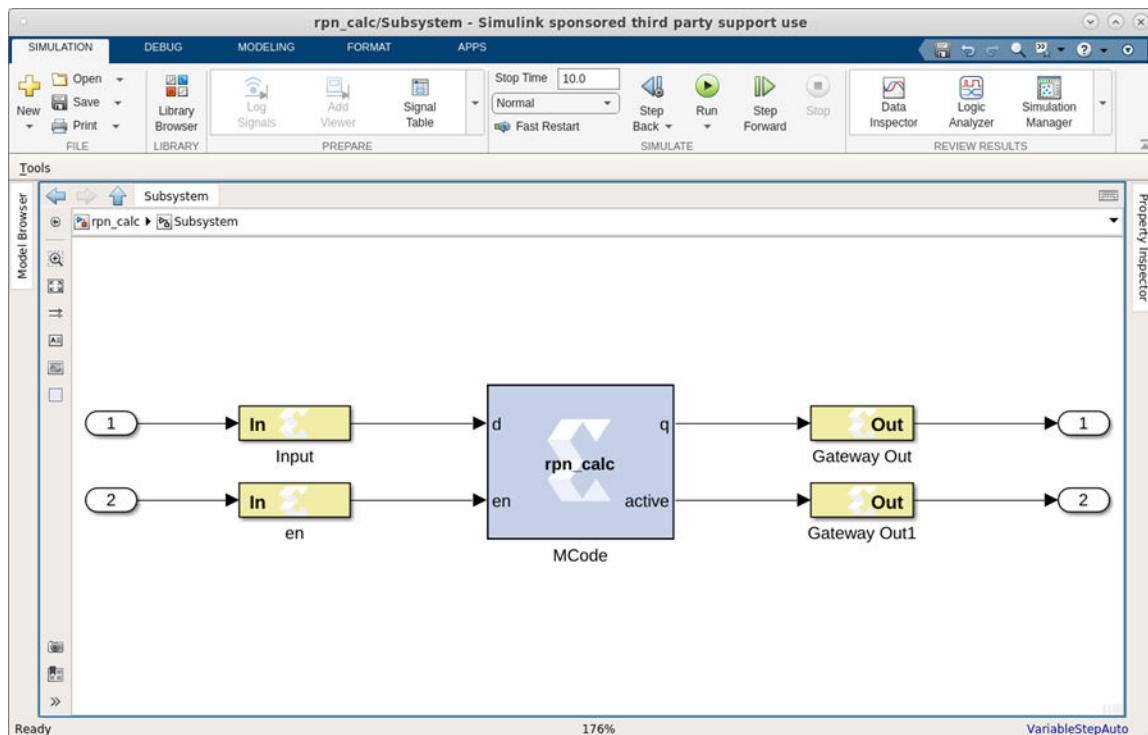
Figure 39: Block Configuration



## RPN Calculator

This example shows how to use the MCode block to model a RPN calculator which is a stack machine. The block is synthesizable:

Figure 40: RPN Calculator



The following function models the RPN calculator.

```
function [q, active] = rpn_calc(d, rst, en)
    d_nbBits = xl_nbBits(d);
    % the first bit indicates whether it's a data or operator
    is_oper = xl_slice(d, d_nbBits-1, d_nbBits-1)==1;
    din = xl_force(xl_slice(d, d_nbBits-2, 0), xlSigned, 0);
    % the lower 3 bits are operator
    op = xl_slice(d, 2, 0);
    % acc the the A register
    persistent acc, acc = xl_state(0, din);
    % the stack is implemented with a RAM and
    % an up-down counter
    persistent mem, mem = xl_state(zeros(1, 64), din);
    persistent acc_active, acc_active = xl_state(false, {xlBoolean});
    persistent stack_active, stack_active = xl_state(false, ...
        {xlBoolean});
    stack_pt_prec = {xlUnsigned, 5, 0};
    persistent stack_pt, stack_pt = xl_state(0, {xlUnsigned, 5, 0});
    % when en is true, it's action
    OP_ADD = 2;
    OP_SUB = 3;
    OP_MULT = 4;
    OP_NEG = 5;
    OP_DROP = 6;
```

```
q = acc;
active = acc_active;
if rst
    acc = 0;
    acc_active = false;
    stack_pt = 0;
elseif en
    if ~is_oper
        % enter data, push
        if acc_active
            stack_pt = xfix(stack_pt_prec, stack_pt + 1);
            mem(stack_pt) = acc;
            stack_active = true;
        else
            acc_active = true;
        end
        acc = din;
    else
        if op == OP_NEG
            % unary op, no stack op
            acc = -acc;
        elseif stack_active
            b = mem(stack_pt);
            switch double(op)
                case OP_ADD
                    acc = acc + b;
                case OP_SUB
                    acc = b - acc ;
                case OP_MULT
                    acc = acc * b;
                case OP_DROP
                    acc = b;
            end
            stack_pt = stack_pt - 1;
        elseif acc_active
            acc_active = false;
            acc = 0;
        end
    end
end
stack_active = stack_pt ~= 0;
```

## Example of disp Function

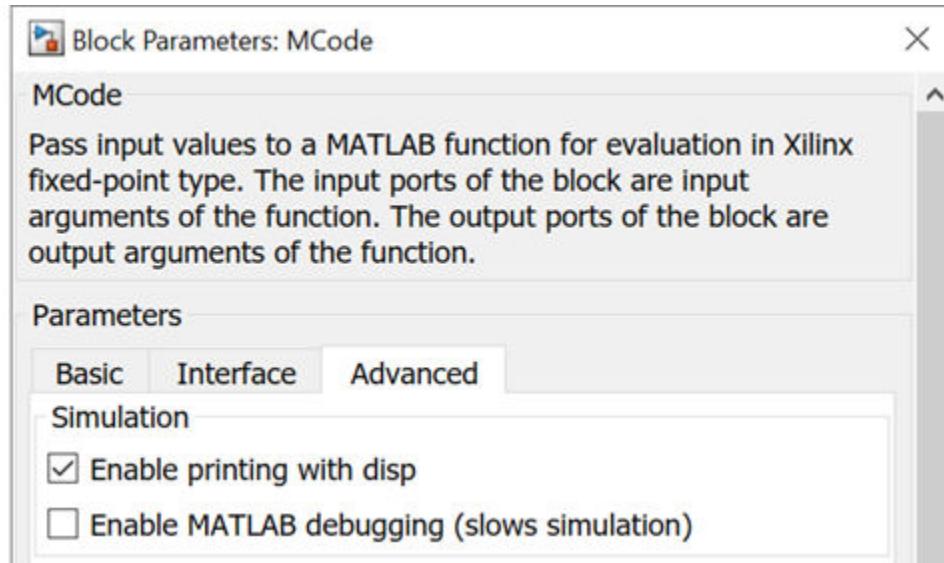
The following MCode function shows how to use the disp function to print variable values.

```
function x = testdisp(a, b)
persistent dly, dly = xl_state(zeros(1, 8), a);
persistent rom, rom = xl_state([3, 2, 1, 0], a);
disp('Hello World!');
disp(['num2str(dly) is ', num2str(dly)]);
disp('disp(dly) is ');
disp(dly);
disp('disp(rom) is ');
disp(rom);
a2 = dly.back;
dly.push_front_pop_back(a);
x = a + b;
disp(['a = ', num2str(a), ' ', ' ', ... ...
      'b = ', num2str(b), ' ', ' ', ...
      'x = ', num2str(x)]);
```

```
disp(num2str(true));
disp('disp(10) is');
disp(10);
disp('disp(-10) is');
disp(-10);
disp('disp(a) is ');
disp(a);
disp('disp(a == b)');
disp(a==b);
```

Check the **Enable printing with disp** option.

Figure 41: Enable Printing with disp



Here are the lines that are displayed on the MATLAB console for the first simulation step.

```
mcode_block_disp/MCode (Simulink time: 0.000000, FPGA clock: 0)
Hello World!
num2str(dly) is [0.000000, 0.000000, 0.000000, 0.000000, 0.000000,
0.000000, 0.000000, 0.000000]
disp(dly) is
    type: Fix_11_7,
    maxlen: 8,
    length: 8,
    0: binary 0000.0000000, double 0.000000,
    1: binary 0000.0000000, double 0.000000,
    2: binary 0000.0000000, double 0.000000,
    3: binary 0000.0000000, double 0.000000,
    4: binary 0000.0000000, double 0.000000,
    5: binary 0000.0000000, double 0.000000,
    6: binary 0000.0000000, double 0.000000,
    7: binary 0000.0000000, double 0.000000,
disp(rom) is
    type: Fix_11_7,
    maxlen: 4,
    length: 4,
    0: binary 0011.0000000, double 3.0,
    1: binary 0010.0000000, double 2.0,
    2: binary 0001.0000000, double 1.0,
```

```
3: binary 0000.0000000, double 0.0,
a = 0.000000, b = 0.000000, x = 0.000000
1
disp(10) is
    type: UFix_4_0, binary: 1010, double: 10.0
disp(-10) is
    type: Fix_5_0, binary: 10110, double: -10.0
disp(a) is
    type: Fix_11_7, binary: 0000.0000000, double: 0.000000
disp(a == b)
    type: Bool, binary: 1, double: 1
```

## Importing a Model Composer HDL Design into a Bigger System

A Model Composer design is often a sub-design that is incorporated into a larger HDL design. This topic shows how to embed two Model Composer designs into a larger design and how VHDL created by Model Composer can be incorporated into the simulation model of the overall system.

### HDL Netlist Compilation

Selecting the **HDL Netlist** compilation target from the Model Composer Hub block instructs Model Composer to generate HDL along with other related files that implement the design. In addition, Model Composer produces auxiliary files that simplify downstream processing such as simulating the design using an Vivado simulator, and performing logic synthesis using Vivado synthesis. See [Compilation Types for HDL Library designs](#) for more details.

### Integration Design Rules

When a Model Composer model is to be included into a larger design, the following two design rules must be followed.

- **Rule 1:** No Gateway should specify an IOB/CLK location.

Also, IOB timing constraints should be set to "none".

- **Rule 2:** If there are any I/O ports from the Model Composer design that are required to be ports on the top-level design, appropriate buffers should be instantiated in the top-level HDL code.

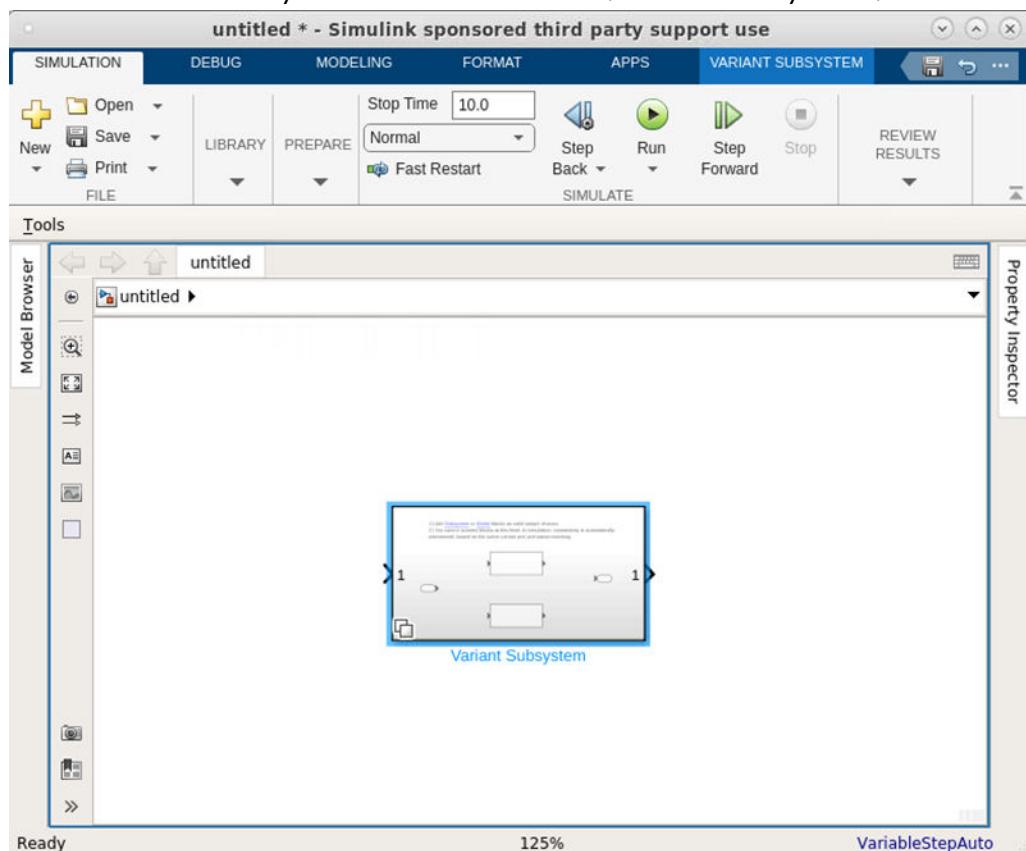
## Variant Subsystems and Model Composer

A variant Subsystem is a type of block that is made available as a standard part of Simulink. In effect, a variant Subsystem is a block for which you can specify several underlying blocks. Each underlying block is a possible implementation, and you are free to choose which implementation to use. In Model Composer you might, for example, specify a general-purpose FIR filter as a variant Subsystem whose underlying blocks are specific FIR filters. Some of the underlying filters might be fast but require much hardware, while others are slow but require less hardware. Switching the choice of the underlying filter allows you to perform experiments that trade hardware cost against speed.

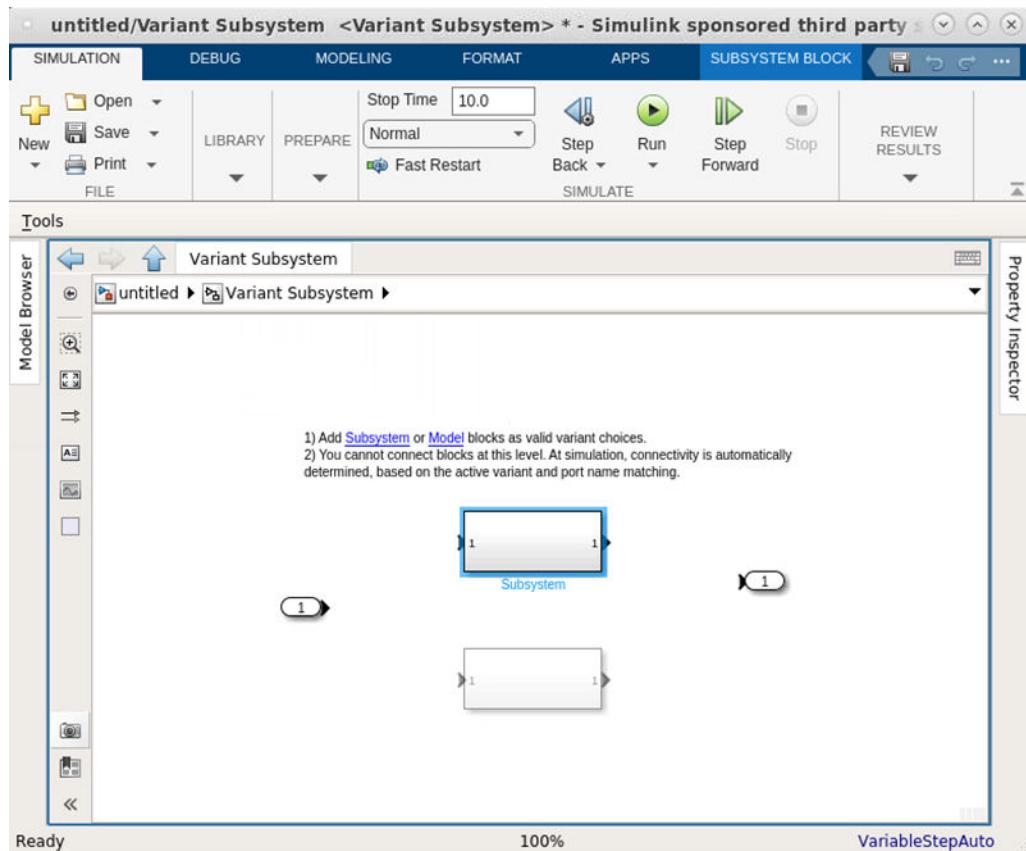
### Defining a Variant Subsystem

A variant subsystem can be created by dragging a Variant Subsystem block from the Library Browser into your model. This block will then contain underlying blocks to implement each variant. To create a variant subsystem, do the following:

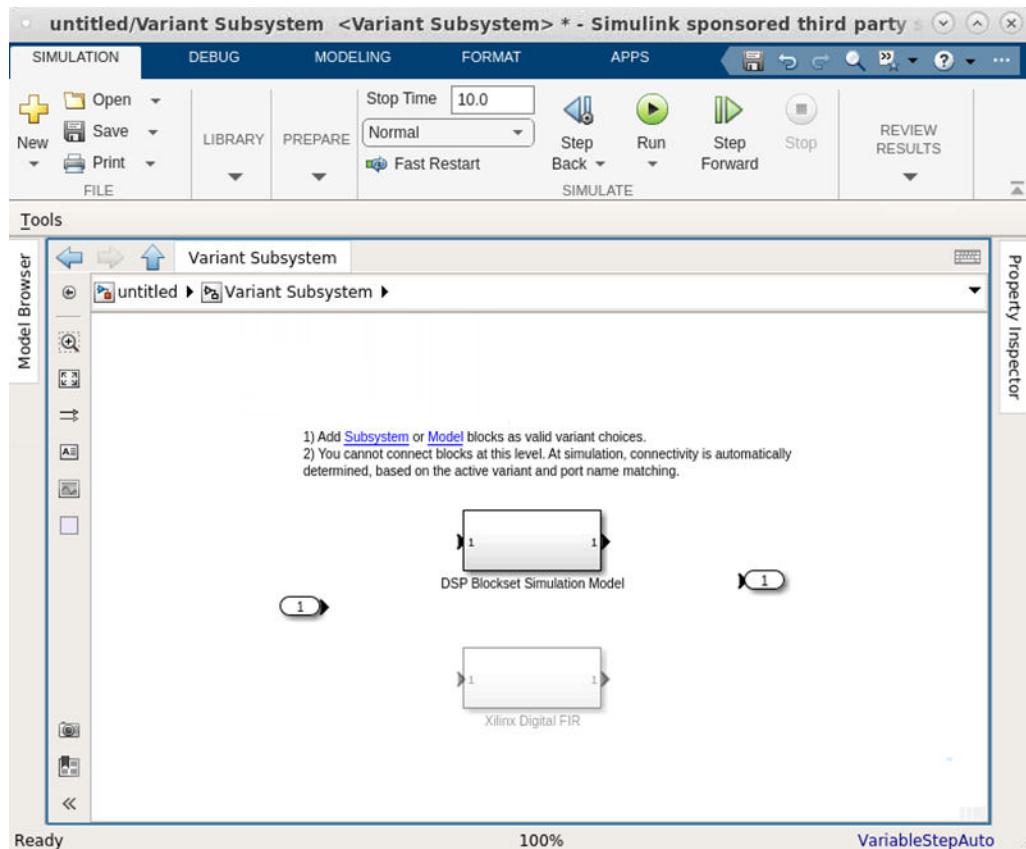
1. Drag a Variant Subsystem block into your model. (The Variant Subsystem block can be found in the Simulink Library Browser under Simulink/Ports & Subsystems/Variant Subsystem.)



2. Double-click the Variant Subsystem block.



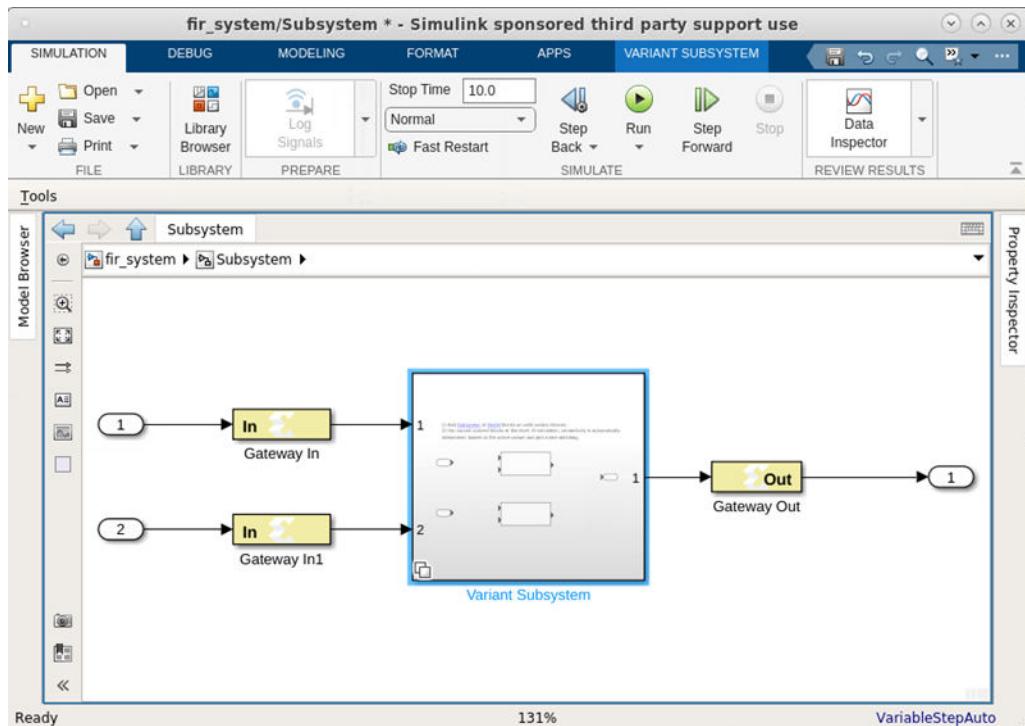
3. Each variant choice is defined in a Subsystem or Model block within the Variant Subsystem. You can define each variant choice's implementation by populating the empty Subsystem blocks in the model, or by copying Subsystem or Model blocks in from elsewhere. Rename each Subsystem block to describe which variant selection it represents. Note that the Variant Subsystem block inputs and outputs should not be connected; the port connectivity will be determined at runtime based on which variant is active.



## Using a Variant Subsystem

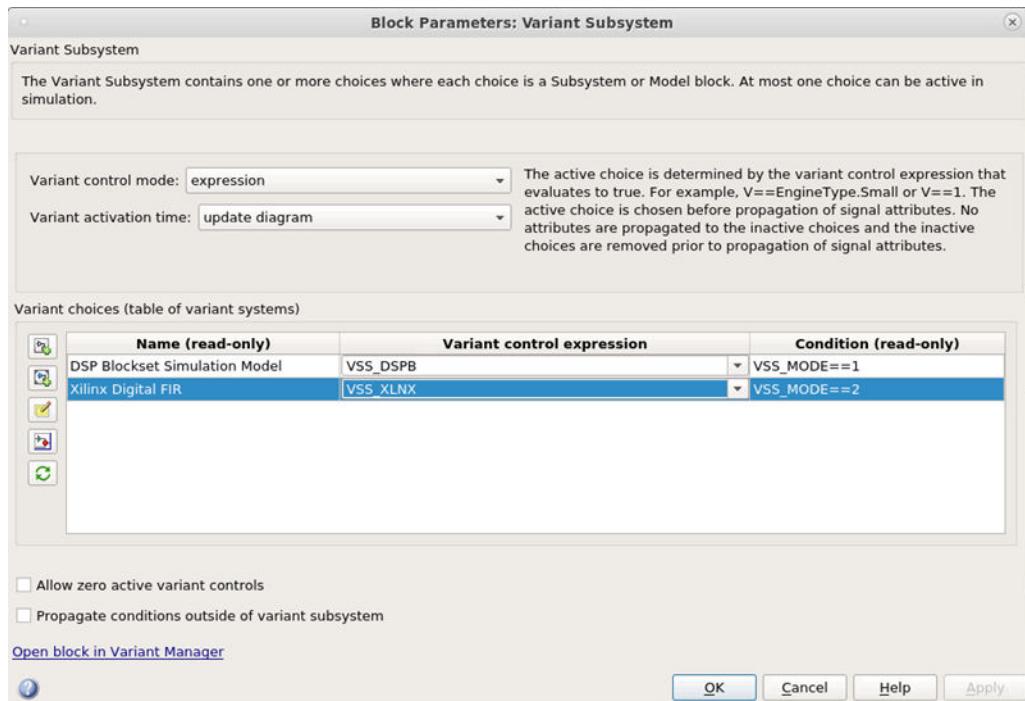
To use a Variant Subsystem in a design after its variant selections have been implemented, do the following:

1. Create the variant subsystem and insert it into the design at the appropriate location.

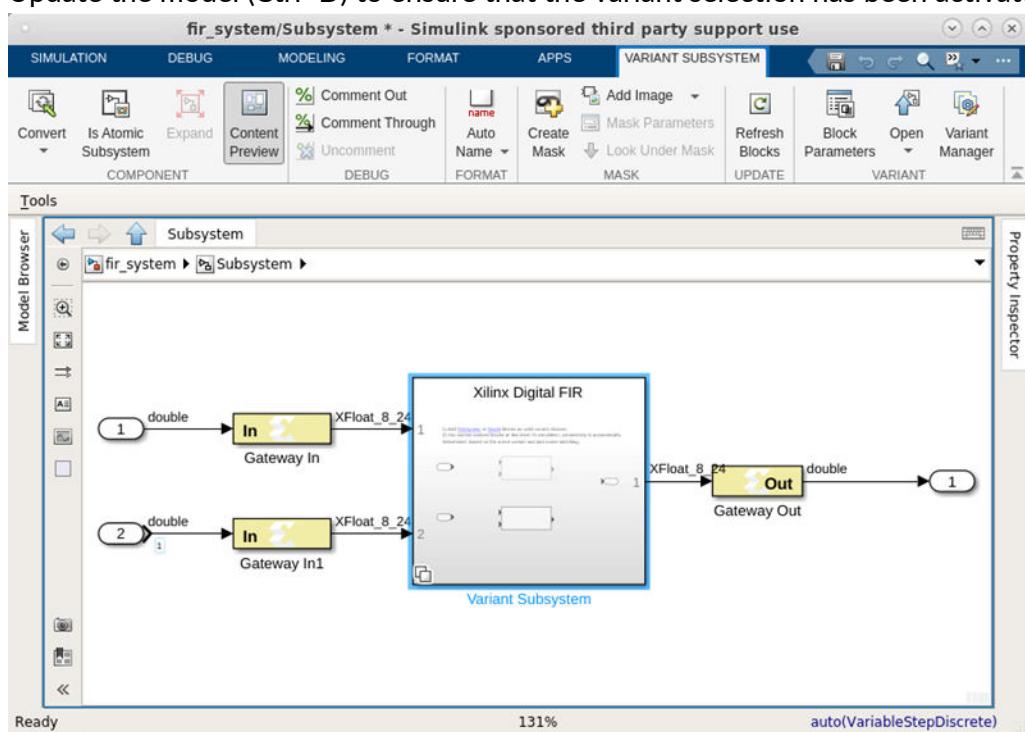


2. Right-click the variant block and select **Block Parameters**. The Block Parameters dialog box for the variant block opens.
3. To select the active Variant based on the evaluation of the Variant conditions, use the **expression** mode. Otherwise, select **label** mode. When you select the Variant control mode as **label**, the Label mode active choice option is available. In label mode, Variant control need not be created in the global workspace. You can select an active Variant choice from Label mode active choice options.
4. Use the options available on the **Block Parameter** dialog box to add variant controls and corresponding variant conditions.

The following figure shows an example configuration for expression mode:



5. To activate a variant selection, type the variant name in the MATLAB® command window. For example, type `VSS_MODE = 2`.
6. Update the model (Ctrl+D) to ensure that the variant selection has been activated.



## Notes for Higher Performance FPGA Design

If you focus all your optimization efforts using the back-end implementation tools, you may not be able to achieve timing closure because of the following reasons:

- The more complex IP blocks in a Model Composer design like FIR Compiler and FFT are generated under the hood. They are provided as highly-optimized netlists to the synthesis tool and the implementation tools, so further optimization may not be possible.
- Model Composer netlisting produces HDL code with many instantiated primitives such as registers, BRAMs, and DSP48E1s. There is not much a synthesis tool can do to optimize these elements.

The following tips focus on what you can do in Model Composer to increase the performance of your design before you start the implementation process.

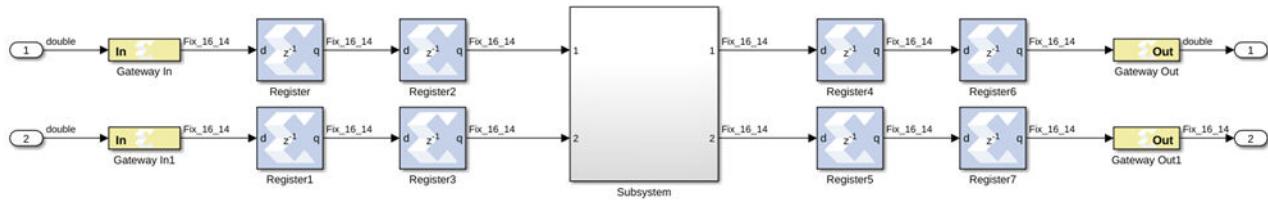
- [Review the Hardware Notes Included with Each Block Dialog Box](#)
- [Register the Inputs and Outputs of Your Design](#)
- [Insert Pipeline Registers](#)
- [Use Saturation Arithmetic and Rounding Only When Necessary](#)
- [Set the Data Rate Option on All Gateway Blocks](#)
- [Pipeline for Maximum Performance](#)
- [Other Things to Try](#)

### ***Review the Hardware Notes Included with Each Block Dialog Box***

Pay close attention to the Hardware Notes included in the block dialog boxes. Many blocks in the Xilinx Blockset library have notes that explain how to achieve the most hardware efficient implementation. For example, the notes point out that the Scale block costs nothing in hardware. By contrast, the Shift block (which is sometimes used for the same purpose) can use hardware.

### ***Register the Inputs and Outputs of Your Design***

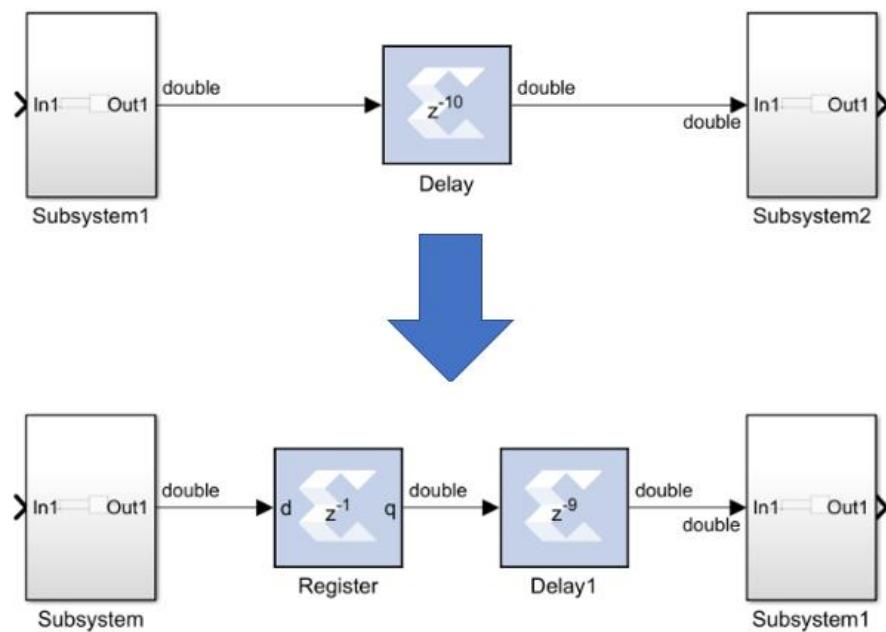
Register the inputs and outputs of your design. As shown below, this can be done by placing one or more Delay blocks with a latency 1 or Register blocks after the Gateway In and before Gateway Out blocks. Selecting any of the Register block features adds hardware.

**Figure 42: Register Inputs and Outputs**

Double registering the I/Os may also be beneficial. This can be performed by instantiating two separate Register blocks, or by instantiating two Delay blocks, each having latency 1. This allows one of the registers to be packed into the IOB and the other to be placed next to the logic in the FPGA fabric. A Delay block with latency 2 does not give the same result because the block with a latency of 2 is implemented using an SRL32 and cannot be packed into an IOB.

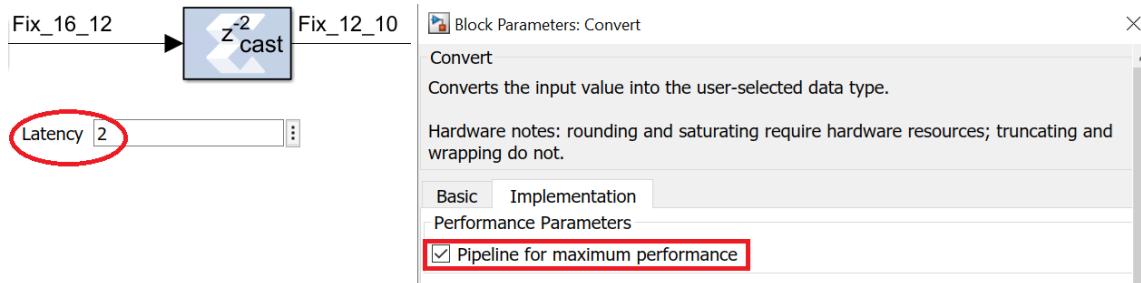
## Insert Pipeline Registers

Insert pipeline registers wherever possible and reasonable. Deep pipelines are efficiently implemented with the Delay blocks since the SRL32 primitive is used. If an initial value is needed on a register, the Register block should be used. Also, if the input path of an SRL32 is failing timing, you should place a Register block before the related Delay block and reduce the latency of the Delay block by one. This allows the router more flexibility to place the Register and Delay block (SRL + Register) away from each other to maximize the margin for the routing delay of this path.

**Figure 43: Pipeline Registers**

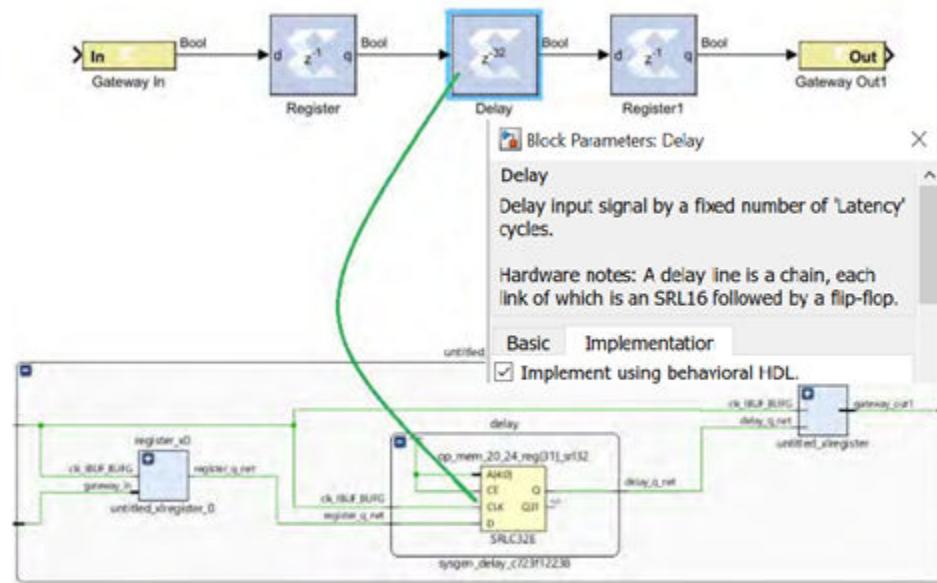
As shown in the following figure, the Convert block can be pipelined with embedded register stages to guarantee maximum performance.

Figure 44: Convert Block



To achieve a more efficient implementation on some Xilinx blocks, you can select the **Implement using behavioral HDL** option. As shown below, if the delay on a Delay block is 32 or greater, Xilinx synthesis infers a SRLC32E (32-bit Shift-Register) which maps into a single LUT.

Figure 45: Implement Using Behavioral HDL



For block RAMs (BRAMs), use the internal output register. You do this by setting the latency from 1 (the default) to 2. This enables the block RAM output register.

When you are using DSP48E1s, use the input, output and internal registers; for FIFOs, use the embedded registers option. Also, check all the high-level IP blocks for pipelining options.

## ***Use Saturation Arithmetic and Rounding Only When Necessary***

Saturation arithmetic and rounding have area and performance costs. Use only if necessary. For example a Reinterpret block doesn't cost any logic. A Convert (cast) block doesn't cost any logic if Quantization is set to Truncate and if Overflow is set to Wrap. If the data type requires the use of the Rounding and Saturation options, then pipeline the Convert block with embedded register stages. If you are using a DSP48E1, the rounding can be done within the DSP48E1.

## ***Set the Data Rate Option on All Gateway Blocks***

Select the IOB timing constraint option **Data Rate** on all **Gateway In** and **Gateway Out** blocks. When **Data Rate** is selected, the IOBs are constrained at the data rate at which the IOBs operate. The rate is determined by the **Simulink system period (sec)** field in the Model Composer Hub block and the sample rate of the Gateway relative to the other sample periods in the design.

## ***Pipeline for Maximum Performance***

For Model Composer HDL blocks that use Xilinx LogiCORE™ IP internally, the default tool behavior is to place at least one register outside of the core. For latency values greater than the optimum value of the core, the optimal pipeline registers are placed inside the core, and the remainder of the registers get pushed out.

### ***Other Things to Try***

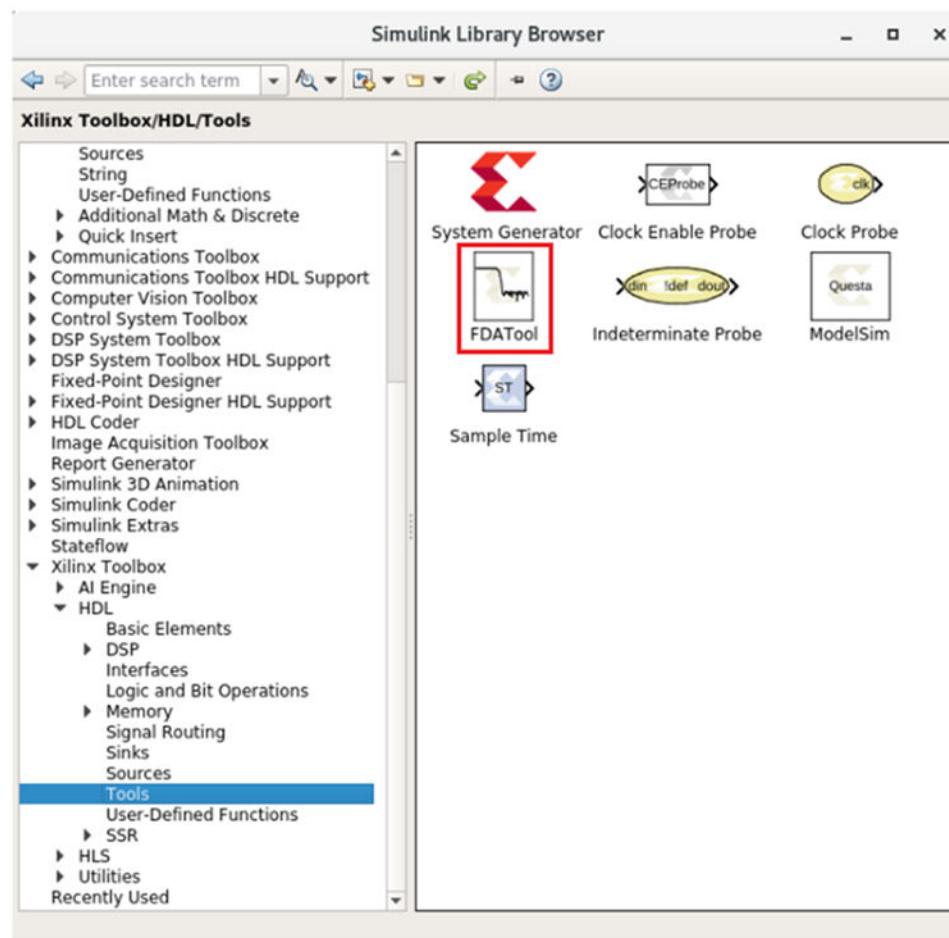
- Change the Source Design
  - Use Additional Pipelining
    - Use the Output and Pipeline registers inside block RAM and DSP48s.
  - Run Functions in Parallel
    - Run functions in parallel at a slower clock rate
  - Use Retiming Techniques
    - Move existing registers through combinational logic.
  - Use Hard Cores where Possible
    - Use Block RAM instead of distributed RAM.
  - Use a Different Design Approach for Functions
- Avoid Over-Constraining the Design
  - Do not over-constrain the design and use up/down sample blocks where appropriate.
- Consider Decreasing the Frequency of Critical Design Modules

- Squeeze Out the Implementation Tools
  - Try Different Synthesis Options.
  - Floorplan Critical Modules

## Using the FDATool in Digital Filter Applications

The FDATool block is used to define the filter order and coefficients, and the HDL blocks are used to implement a filter. The Tools library in the HDL Blockset contains the FDATool block.

Figure 46: FDATool Block



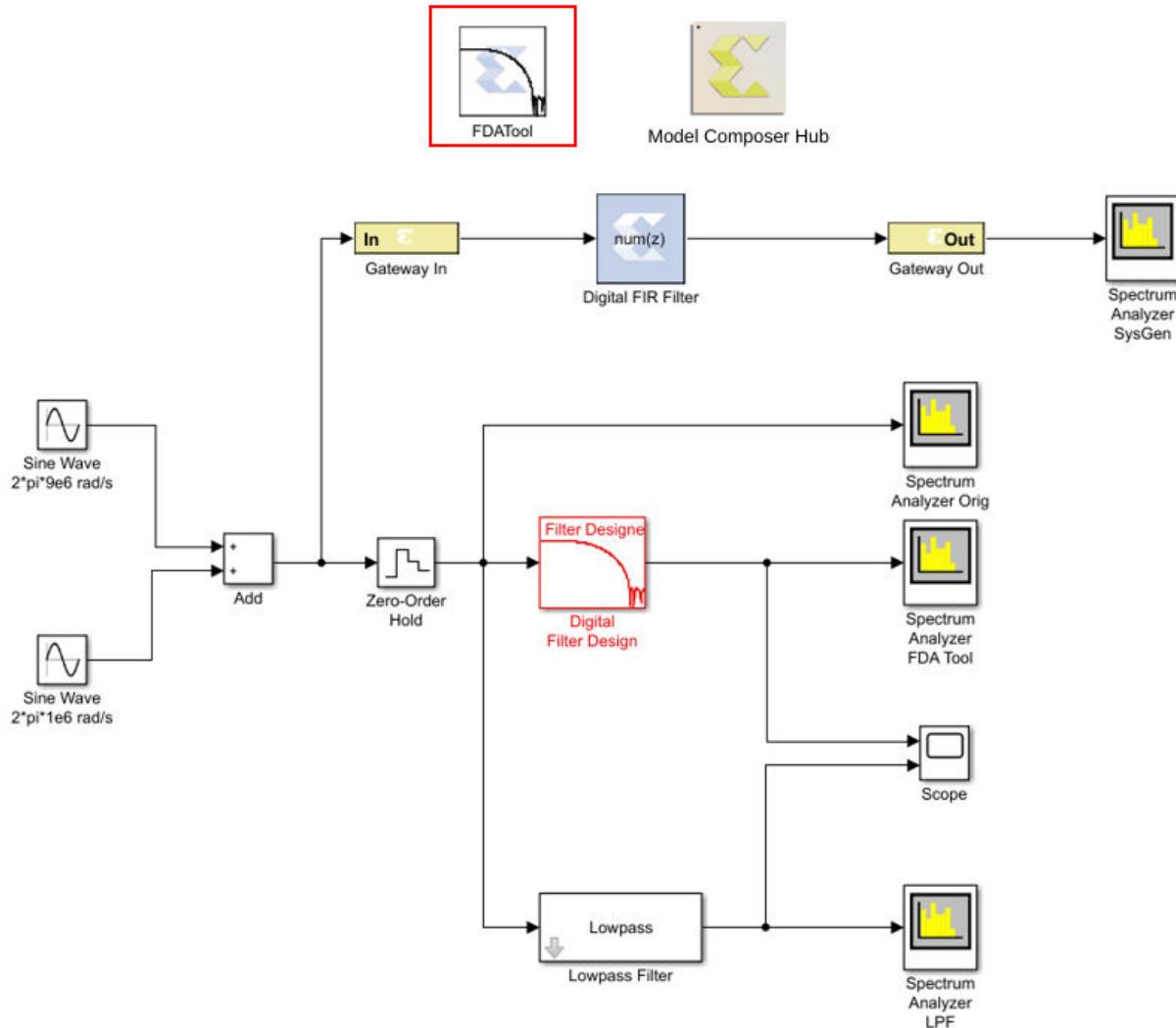
A simple Model Composer model below illustrates a standard FIR filter design using the FDATool and digital FIR filter block.

The design uses two sine wave sources which are being added together and passed separately through two low-pass filters.

- The first filter is the one that could be implemented using the Xilinx HDL blockset. It is a digital low pass filter implemented using the Digital FIR filter block.
- The second filter is what is referred to as a reference filter. A low pass filter is implemented using a Direct-form FIR structure.

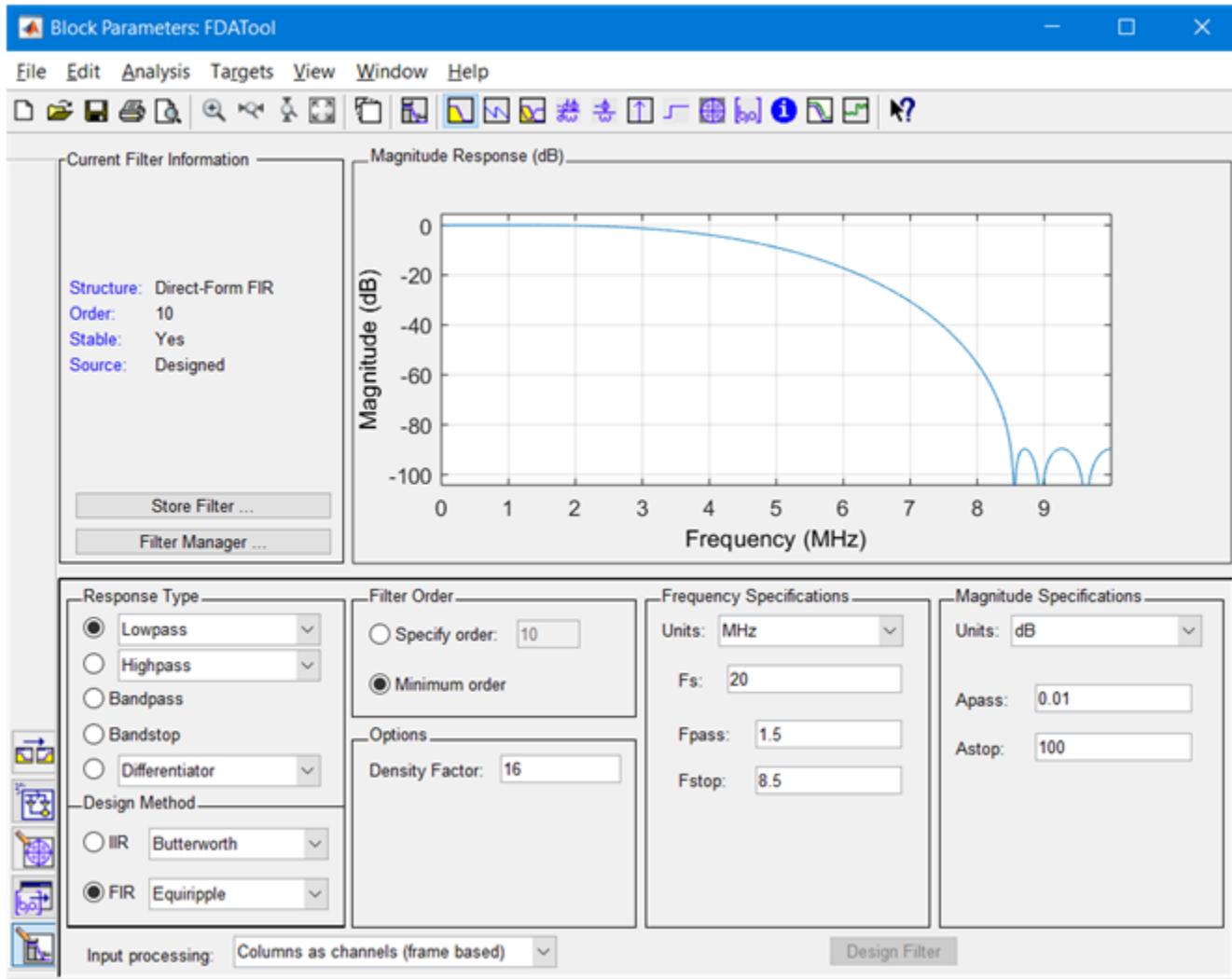
The frequency response of both filters visualized in Spectrum Analyzer block.

Figure 47: Spectrum Analyzer Block



The Xilinx version of the FDATool can be used to define the coefficients of the low-pass filter to eliminate high-frequency noise. The filter configuration parameters like Response Type, Filter Order, Frequency Specification, and Magnitude Specification can be modified from the Properties Editor of the FDATool as shown below.

Figure 48: Filter Configuration



The Design Filter option at the bottom of the tool window allows you to find out the filter order and observe the Magnitude Response. You can also view the Phase Response, Impulse Response, Coefficients, and more by selecting the appropriate icon at the top-right of the window. You can display the filter coefficients in the MATLAB® workspace by typing the following:

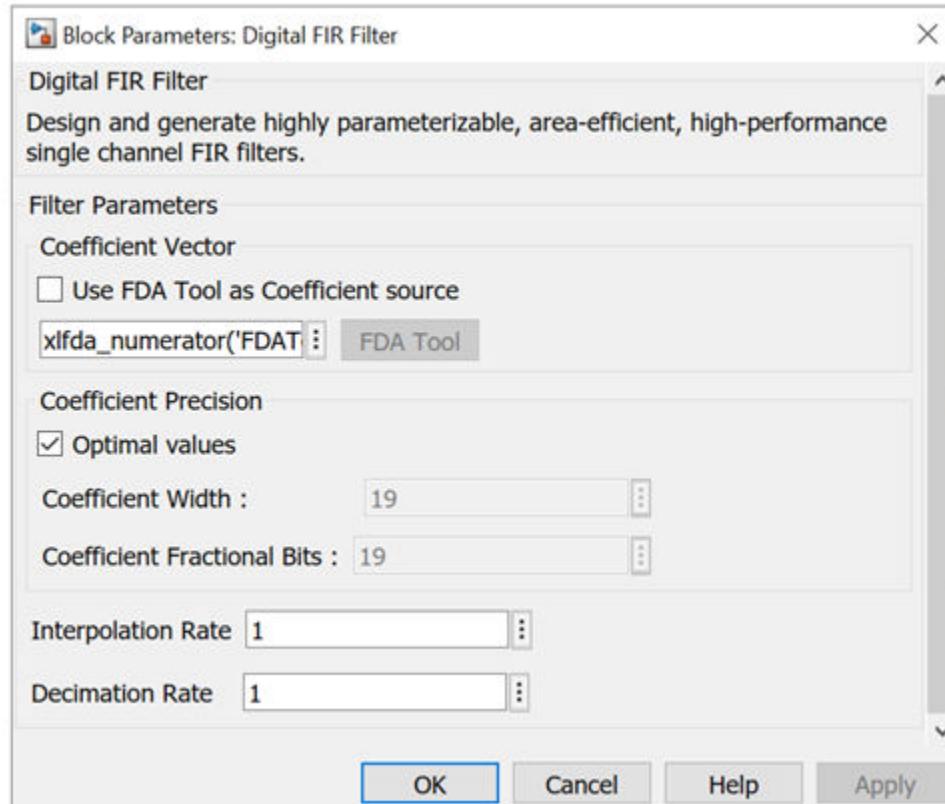
```
>> xlfdn_numerator('FDATool')
```

The following functions help you find the maximum and minimum coefficient values to adequately specify the coefficient width and binary point:

```
>> max(xlfdn_numerator('FDATool'))
>> min(xlfdn_numerator('FDATool'))
```

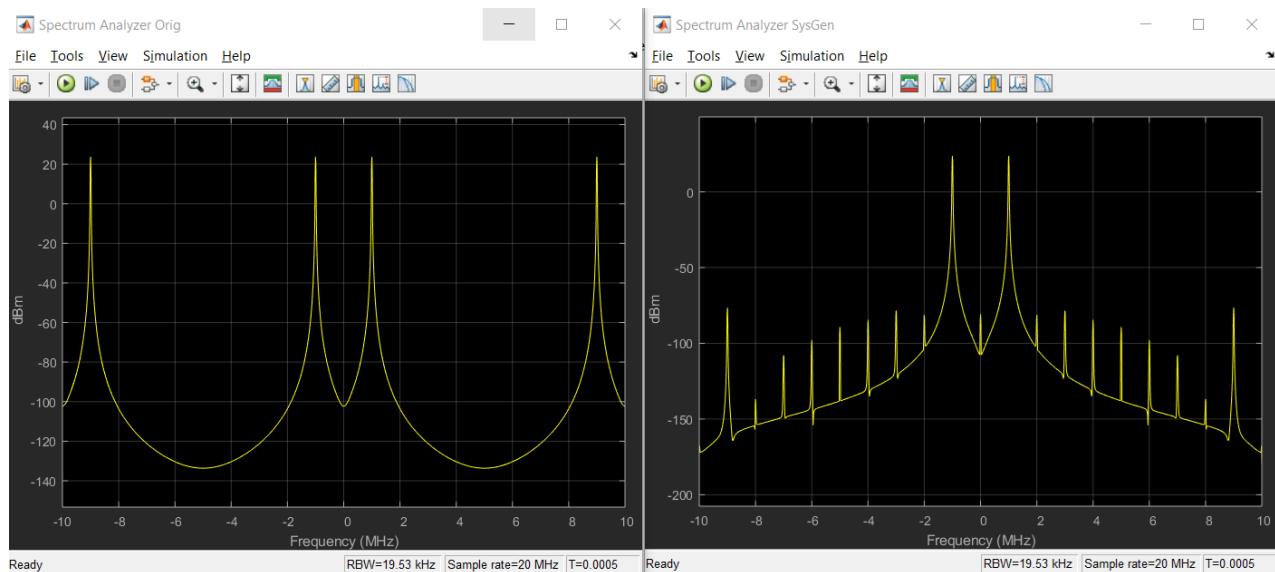
Now, the filter parameters of the FDATool instance can be associated with the Digital FIR filter instance.

Figure 49: Digital FIR Filter



The Xilinx Filter response can be viewed and compared with the Simulink® response using the Spectrum Analyzer.

Figure 50: Spectrum Analyzer



**Note:** The frequency response results of Model Composer (right side), shown above, differs slightly with the original design (left side) due to the quantization and sampling effect inherent when a continuous time system is described in discrete time hardware.

For complete example along with steps to use the FDATool, refer to the *Vitis Model Composer Tutorial* ([UG1498](#)).

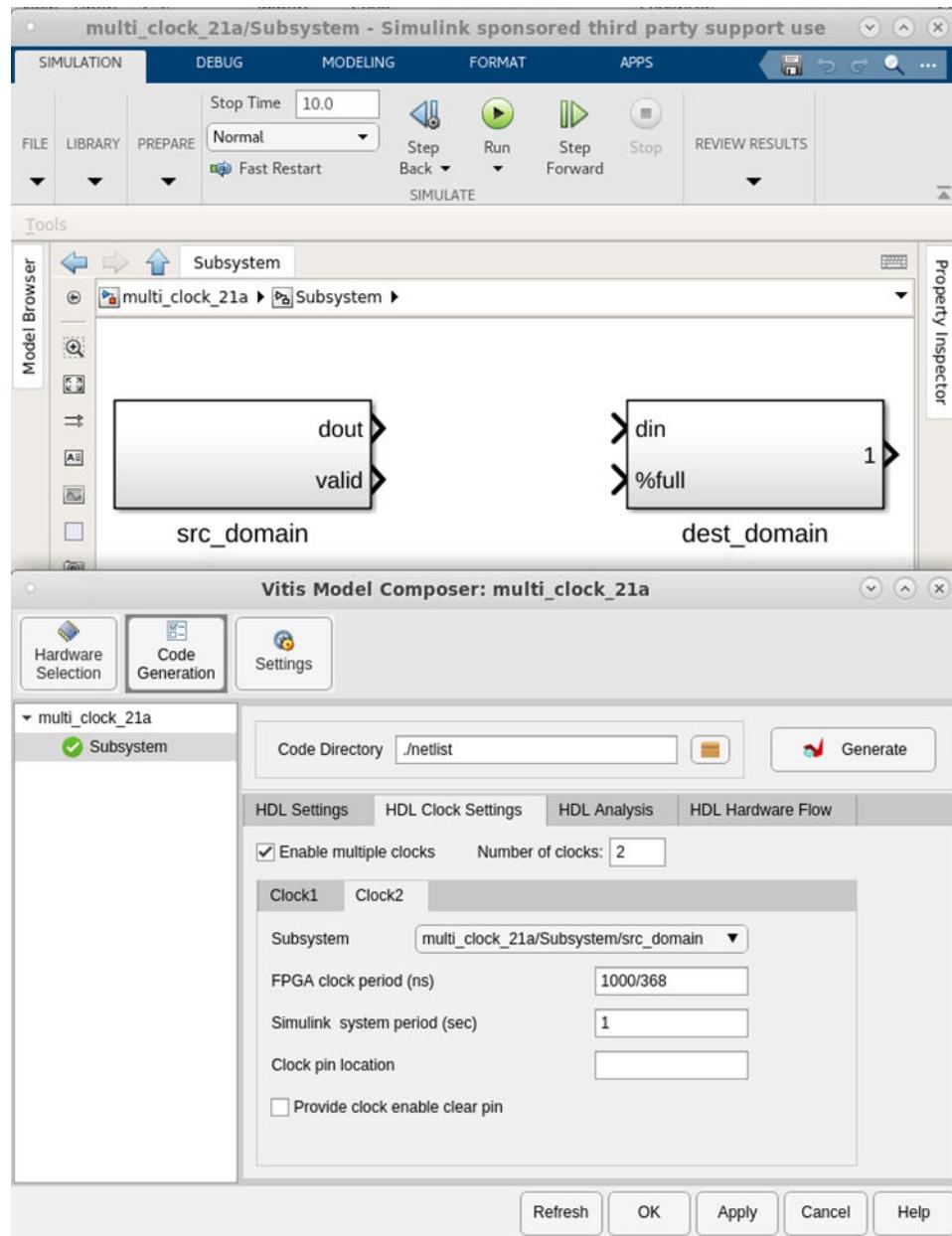
## Multiple Independent Clocks Hardware Design

Vitis Model Composer is a cycle-accurate, high-level hardware modeling and implementation tool where the notion of a cycle is analogous to that of clock in hardware. The design can be partitioned into groups of Subsystem blocks, where each Subsystem has a common cycle period, independent of the cycle period of other Subsystems. This section details how blocks can be grouped into one cycle or clock domain and how data can be transferred between these cycle domains. In the rest of this section, the terms cycle and clock are used interchangeably.

### ***Grouping Blocks within a Clock Domain***

Blocks are grouped together in Vitis Model Composer by using a Subsystem. Subsystems can also be used to group blocks within a clock domain. Clock settings for each subsystem can then be controlled by enabling multiple clocks on the HDL Clock Settings tab of the Vitis Model Composer Hub block.

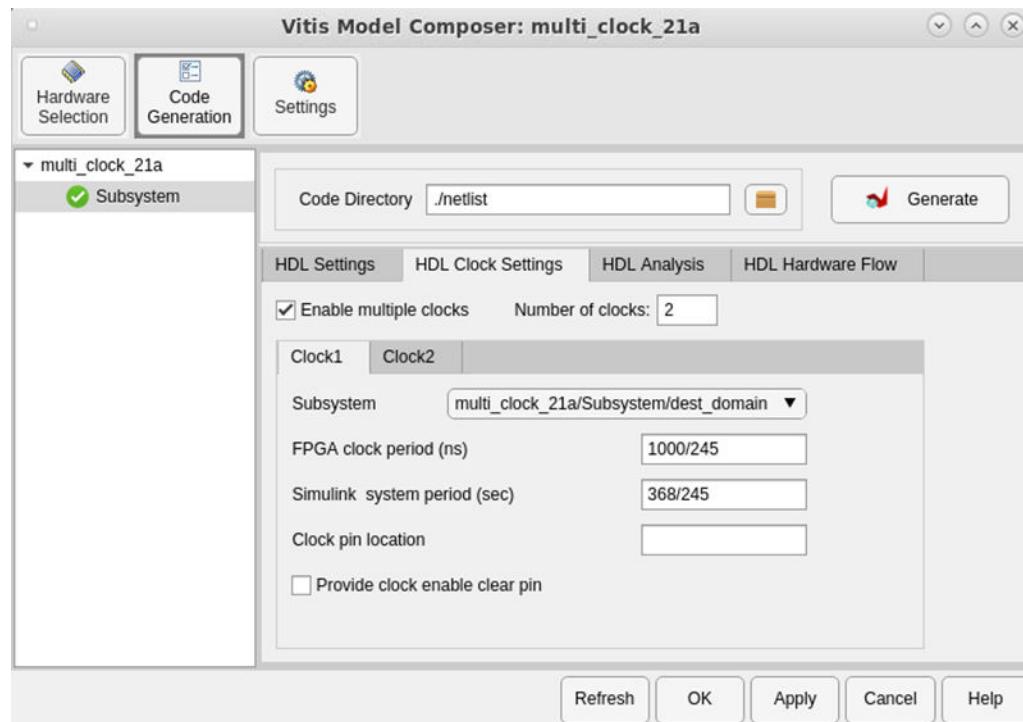
Figure 51: Source Clock Domain



In the previous figure, a clock domain Subsystem called `src_domain` has been created. On the **HDL Clock Settings** tab, the FPGA clock period has been set to (1000/368) ns (368 MHz) and the Simulink system period to 1 sec. This implies that an advance of 1 Simulink second corresponds to (1000/368) ns of FPGA clock.

Similarly, another group of blocks representing another clock domain is included in a Subsystem called `dest_domain`. This Subsystem is configured to run at an FPGA clock period of 1000/245 ns (245 MHz). The Simulink system period is set to 368/245. This is done because the Simulink system period of the `src_domain` Subsystem is set to 1. Hence, you normalize the System period from the faster `src_domain`.

Figure 52: Destination Clock Domain



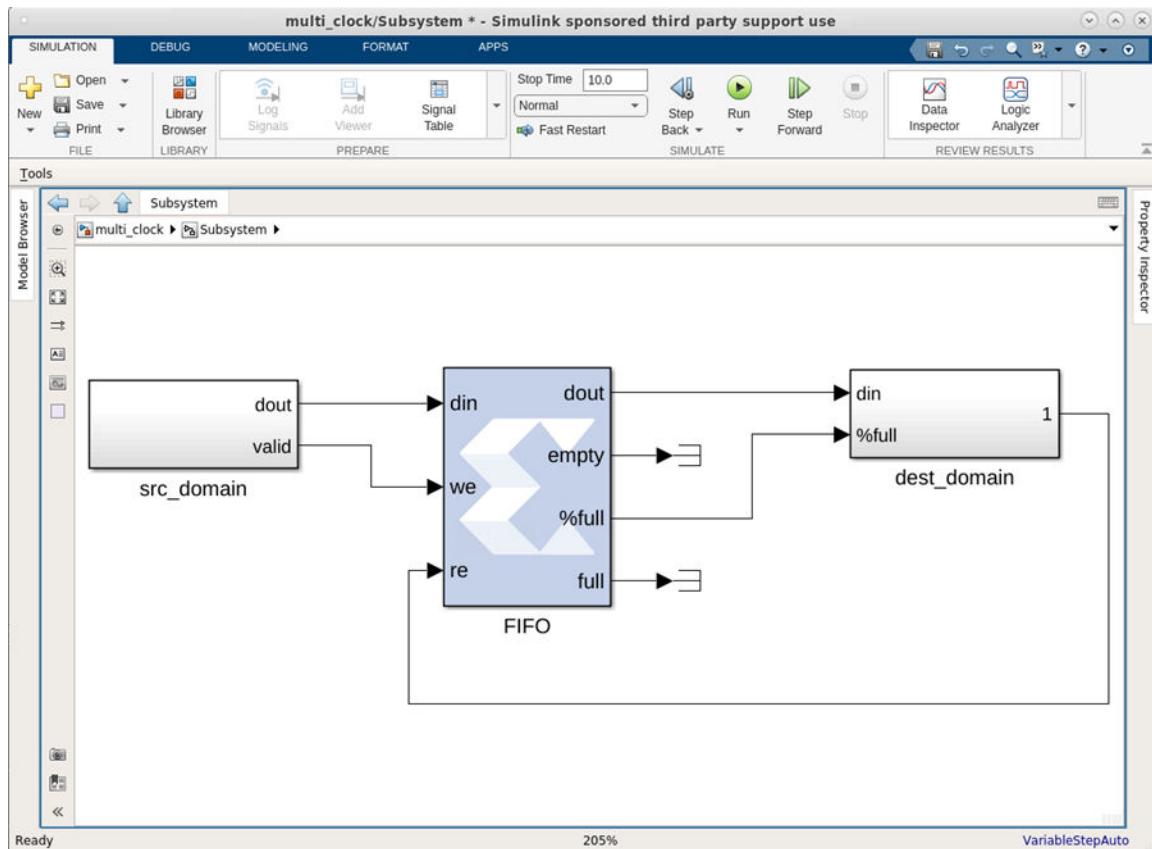
### ***HDL Blocks used to Create Asynchronous Clock Domains***

To pass data between the `src_domain` and `dest_domain` Subsystems, you can use any one of the following logics:

1. FIFO block
2. Dual Port RAM block
3. Register block
4. Black Box block, which allows existing VHDL, Verilog, and EDIF to be brought into a design.  
For more information about Black Box utility, please refer to [Importing HDL Modules](#).

These blocks configure themselves to be either synchronous single clock blocks or multiple clock blocks based on their context in the design. In this design, the FIFO block is used to cross the clock domains as shown in the figure below.

Figure 53: Cross Domain FIFO Block



To complete the design, the FIFO block at the top level of the design is included to enable Code Generation.

### Configuring the Vitis Model Composer Hub Block

The Vitis Model Composer Hub block has to be configured to indicate that the Code Generation must proceed for a multiple clock design. This is indicated by turning on the Enable multiple clocks check box on the HDL Clock Settings tab. This indicates to the Code Generation engine that the clock information for the Subsystems `src_domain` and `dest_domain` must be obtained from each clock's sub-tab. If this check box is not enabled, then the design will be treated as a single clock design.

## Clock Propagation Algorithm

For all HDL blocks in the `src_domain`, the clocking is governed by the Clock 1 tab in the Model Composer Hub block. Similarly for the `dest_domain` Subsystem, the clocking is governed by the Clock 2 tab in the Model Composer Hub block. For the FIFO block, the clocks are derived from its context in the design. Because the `we` and `din` ports are driven by signals emanating from the `src_domain` Subsystem, the `wr_clk` of the FIFO is tied to the `src_domain` clock. Because the `dout`, `full`, and `re` ports either drive or load signals from `dest_domain`, the `rd_clk` of the FIFO is tied to the `dest_domain` clock. Mixing and matching these signals across clock domains or using any other block (other than FIFO or Dual Port RAM) to cross clock domains will result in a DRC error.

## Debugging Clock Propagation

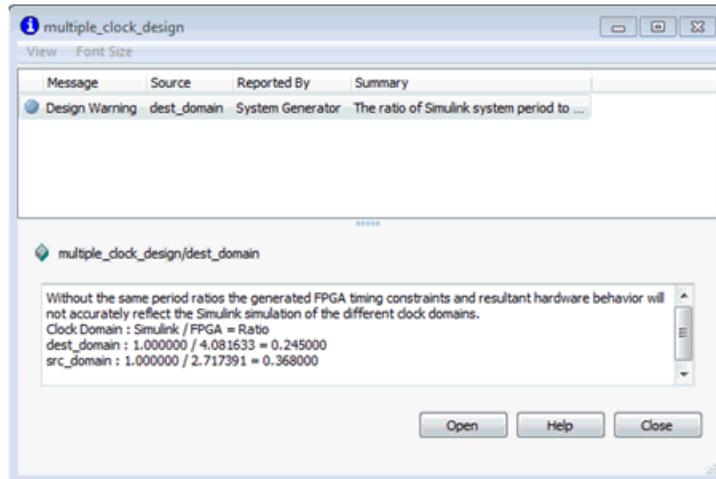
The Model Composer Hub block can be used to control the display of all HDL Block Icons using the Block Icon Display control in the HDL Analysis tab. From this tab, you can either select Normalized sample periods or Sample frequencies to help understand how clocks get propagated in the design. For multiple clock designs, the behavior of Normalized sample periods is that the smallest Simulink system period is used to normalize all the sample periods in the design.

For Sample Frequencies, the port icon text display is the result of the following computation:

$$(1e6/\text{FPGA clock period}) * \text{Simulink system period}/\text{Port sample period}$$

where FPGA clock period is the FPGA clock period specified in ns in the domain's Clock Settings tab, and Simulink system period is the Simulink system period in seconds specified in the domain's HDL Clock Settings tab.

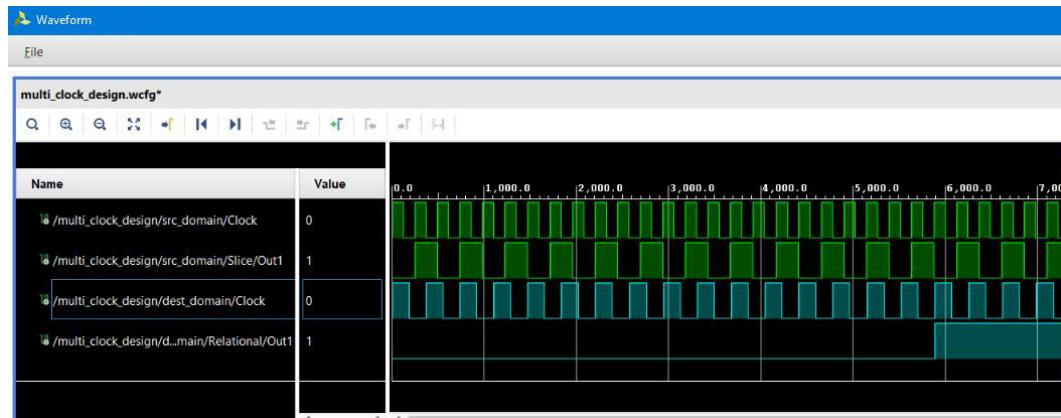
To ensure that the simulation models the hardware behavior relatively with respect to the clocks, the ratio of Simulink system period to FPGA clock period in each domain must be the same. If this relationship is not complied with the correct ratio, a warning is thrown to indicate this problem as shown in the following figure:

*Figure 54: Warning*

## ***Debugging Multiple Clock Domain Signals***

In Vitis Model Composer you can use cross probing between the signal in the Xilinx Waveform Viewer and the Simulink diagram to aid the debugging process.

To add a signal to the Waveform viewer, right-click the signal in the model and select **Xilinx Add To Viewer**. Simulating the design should launch the Waveform Viewer as shown below.

*Figure 55: Waveform Viewer*

All signals in same clock domain are colored similarly. In the figure above: `src_domain/Slice/Out1` and `dest_domain/Relational/Out1` are in different clock domains.

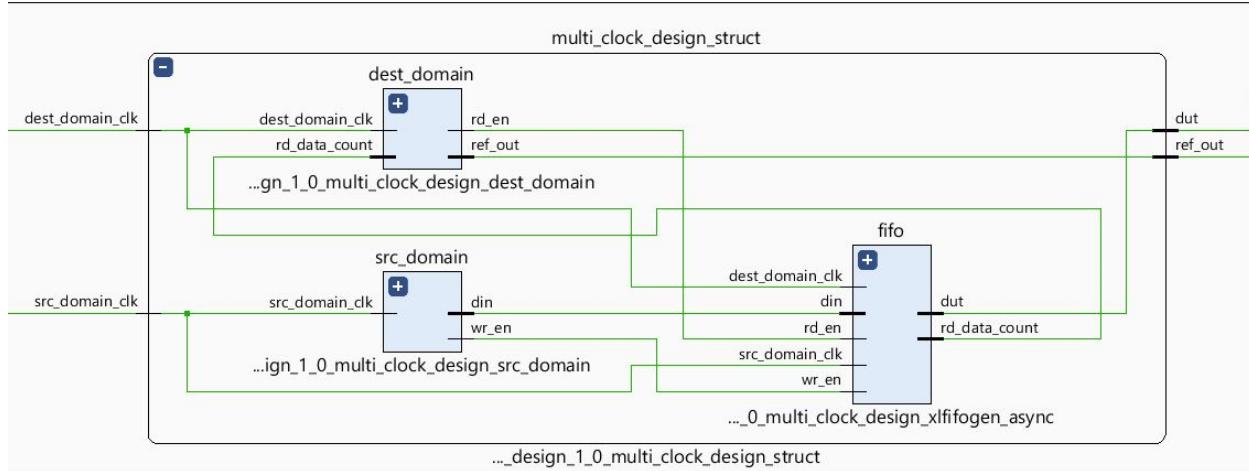
## ***Code Generation***

Code generation for a Multiple Clock design supports the following compilation targets:

- HDL Netlist
- IP Catalog
- Synthesized Checkpoint

A screen shot of the top-level hardware is shown in the figure below.

Figure 56: Top-Level Hardware



As many clock ports as there are clock domains are exposed at the top level and can be driven by a variety of Xilinx clocking constructs like MMCM, PLL etc. It is assumed that these clocks are completely asynchronous and the following period constraints are created:

```
1 | create_clock -name src_domain_clk -period 2.717 [get_ports src_domain_clk]
2 | create_clock -name dest_domain_clk -period 4.082 [get_ports dest_domain_clk]
```

These are the only constraints that are required because only FIFO or Dual Port RAM are allowed which have any additional clock domain constraints embedded in the IP.

## Known Issues

The following are some of the known issues:

- The HWCosim Compilation Target is not supported for Multiple Clock Designs.
- Only FIFO & Dual Port RAM blocks can be in the top-level of the design when using multiple clocks.
- The behavior of blocks that aid in the crossing of Multiple clock domains is NOT cycle accurate.
- Unconnected or terminated output ports cannot be viewed in the Waveform Viewer.

## AXI Interface

AMBA AXI4 (Advanced eXtensible Interface 4) is the fourth generation of the AMBA interface defined and controlled by Arm®, and has been adopted by Xilinx as the next-generation interconnect for FPGA designs. Xilinx and Arm worked closely to ensure that the AXI4 specification addresses the needs of FPGAs.

AXI is an open interface standard that is widely used by many 3rd-party IP vendors since it is public, royalty-free and an industry standard.

The AMBA AXI4 interface connections are point-to-point and come in three different flavors: AXI4, AXI4-Lite Slave, and AXI4-Stream.

- AXI4 is a memory-mapped interface which support burst transactions
- AXI4-Lite Slave is a lightweight version of AXI4 and has a non-bursting interface
- AXI4-Stream is a high-performance streaming interface for unidirectional data transfers (from master to slave) with reduced signaling requirements (compared to AXI4). AXI4-Stream supports multiple channels of data on the same set of wires.

In the following documentation, AXI4 refers to the AXI4 memory map interface, and AXI4-Lite Slave and AXI4-Stream each refer to their respective flavor of the AMBA AXI4 interface. When referring to the collection of interfaces, the term AMBA AXI4 shall be used.

The purpose of this section is to provide an introduction to AMBA AXI4 and to draw attention to AMBA AXI4 details with respect to Model Composer. For more detailed information on the AMBA AXI4 specification please refer to the Xilinx AMBA-AXI4 documents found on the [AMBA AXI4 Interface Protocol](#) page on the Xilinx website.

### ***AXI4-Stream Support in Model Composer***

The three most common AXI4-Stream signals are TVALID, TREADY and TDATA. Of all the AXI4-Stream signals, only TVALID is denoted as mandatory, all other signals are optional. All information-carrying signals propagate in the same direction as TVALID; only TREADY propagates in the opposite direction.

Since AXI4-Stream is a point-to-point interface, the concept of master and slave interface is pertinent to describe the direction of data flow. A master produces data and a slave consumes data.

### **Naming Conventions**

AXI4-Stream signals are named in the following manner:

```
<Role>_<ClassName>[_<BusName>]_[<ChannelName>]<SignalName>
```

For example:

```
m_axis_tvalid
```

Here `m` denotes the Role (master), `axis` the ClassName (AXI4-Stream) and `tvalid` the SignalName.

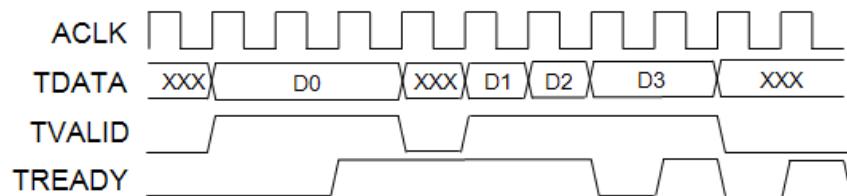
```
s_axis_control_tdata
```

Here `s` denotes the Role (slave), `axis` the ClassName, `control` the BusName which distinguishes between multiple instances of the same class on a particular IP, and `tdata` the SignalName.

### Notes on TREADY/TVALID Handshaking

The TREADY/TVALID handshake is a fundamental concept in AXI to control how data is exchanged between the master and slave allowing for bidirectional flow control. TDATA, and all the other AXI4-Stream signals (TSTRB, TUSER, TLAST, TID, and TDEST) are all qualified by the TREADY/TVALID handshake. The master indicates a valid beat of data by the assertion of TVALID and must hold the data beat until TREADY is asserted. TVALID once asserted cannot be de-asserted until TREADY is asserted in response (this behavior is referred to as a "sticky" TVALID). AXI also adds the rule that TREADY can depend on TVALID, but the assertion of TVALID cannot depend on TREADY. This rule prevents circular timing loops. The timing diagram below provides an example of the TREADY/TVALID handshake.

Figure 57: TREADY/TVALID Handshake Timing Diagram



### Handshaking Key Points

- A transfer on any given channel occurs when both TREADY and TVALID are high in the same cycle.
- TVALID once asserted, may only be de-asserted after a transfer has completed (TREADY is sampled high). Transfers may not be retracted or aborted.
- Once TVALID is asserted, no other signals in the same channel (except TREADY) may change value until the transfer completes (the cycle after TREADY is asserted).
- TREADY may be asserted before, during or after the cycle in which TVALID is asserted.
- The assertion of TVALID may not be dependent on the value of TREADY. But the assertion of TREADY may be dependent on the value of TVALID.

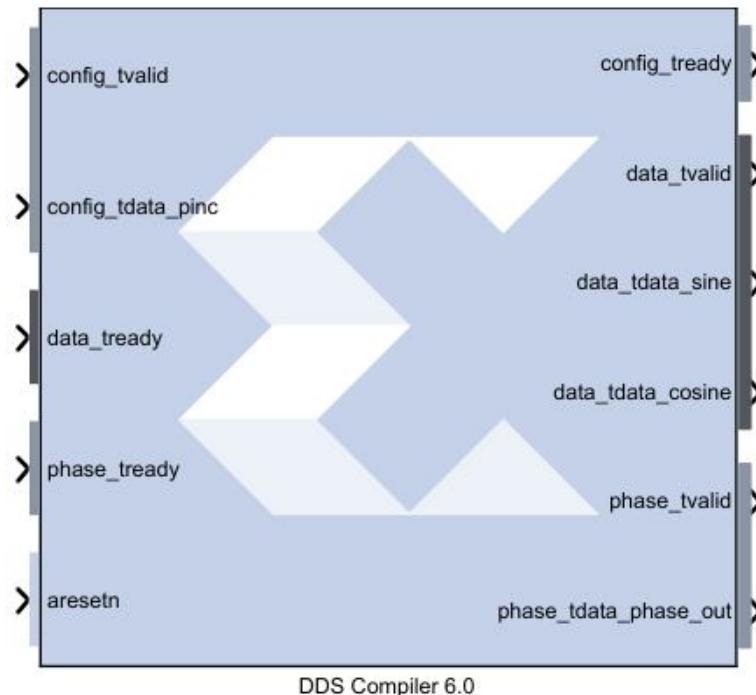
- There must be no combinatorial paths between input and output signals on both master and slave interfaces:
  - Applied to AXI4-Stream IP, this means that the TREADY slave output cannot be combinatorially generated from the TVALID slave input. A slave that can immediately accept data qualified by TVALID, should pre-assert its TREADY signal until data is received. Alternatively TREADY can be registered and driven the cycle following TVALID assertion.
  - The default design convention is that a slave should drive TREADY independently or pre-assert TREADY to minimize latency.
  - Note that combinatorial paths between input and output signals are permitted across separate AXI4-Stream channels. It is however a recommendation that multiple channels belonging to the same interface (related group of channels that operate together) should not have any combinatorial paths between input and output signals.
- For any given channel, all signals propagate from the source (typically master) to the destination (typically slave) except for TREADY. Any other information-carrying or control signals that need to propagate in the opposite direction must either be part of a separate channel ("back-channel" with separate TREADY/TVALID handshake) or be an out-of-band signal (no handshake). TREADY should not be used as a mechanism to transfer opposite direction information from a slave to a master.
- AXI4-Stream allows TREADY to be omitted which defaults its value to 1. This may limit interoperability with IP that generates TREADY. It is possible to connect an AXI4-Stream master with only forward flow control (TVALID only).

## ***AXI4-Stream Blocks in Model Composer***

HDL blocks that present an AXI4-Stream interface can be found in the Vitis Model Composer HDL Blockset Library entitled DSP/AXI4. Blocks in this library are drawn slightly differently from regular (non AXI4-Stream) blocks.

## Port Groupings

Figure 58: DDS Compiler 6.0

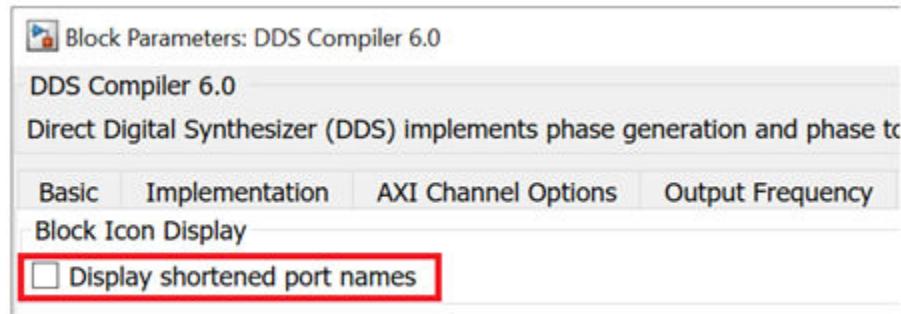


Blocks that offer AXI4-Stream interfaces have AXI4-Stream channels grouped together and color coded. For example, on the DDS compiler 6.0 block shown above, the input port `data_tready`, and the three output ports, `data_tvalid`, `data_tdata_sine`, `data_tdata_cosine` belong in the same AXI4-Stream channel. Similarly, the input port `config_tvalid`, `config_tdata_pinc` and output port `config_tready` belong in the same AXI4-Stream channel. As does `phase_tready`, `phase_tvalid`, and `phase_tdata_phase_out`.

Signals that are not part of any AXI4-Stream channels are given the same background color as the block; `aresetn` is an example.

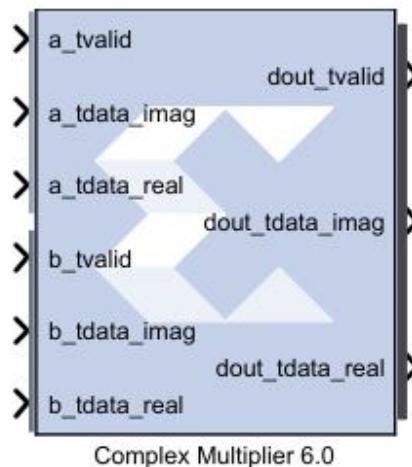
## Port Name Shortening

In the example shown below, the AXI4-Stream signal names have been shortened to improve readability on the block. Name shortening is purely cosmetic and when netlisting occurs, the full AXI4-Stream name is used. Name shorting is turned on by default; you can uncheck the **Display shortened port names** option in the block parameter dialog box to reveal the full name.

*Figure 59: DDS Compiler 6.0*

### Breaking Out Multi-Channel TDATA

In AXI4-Stream, TDATA can contain multiple channels of data. In Model Composer, the individual channels for TDATA are broken out. So for example, the TDATA of port `dout` below contains both real and imaginary components.

*Figure 60: Complex Multiplier 6.0*

The breaking out of multi-channel TDATA does not add additional logic to the design and is done in Model Composer as a convenience to the users. The data in each broken out TDATA port is also correctly byte-aligned.

## AXI4-Lite Slave Interface Generation

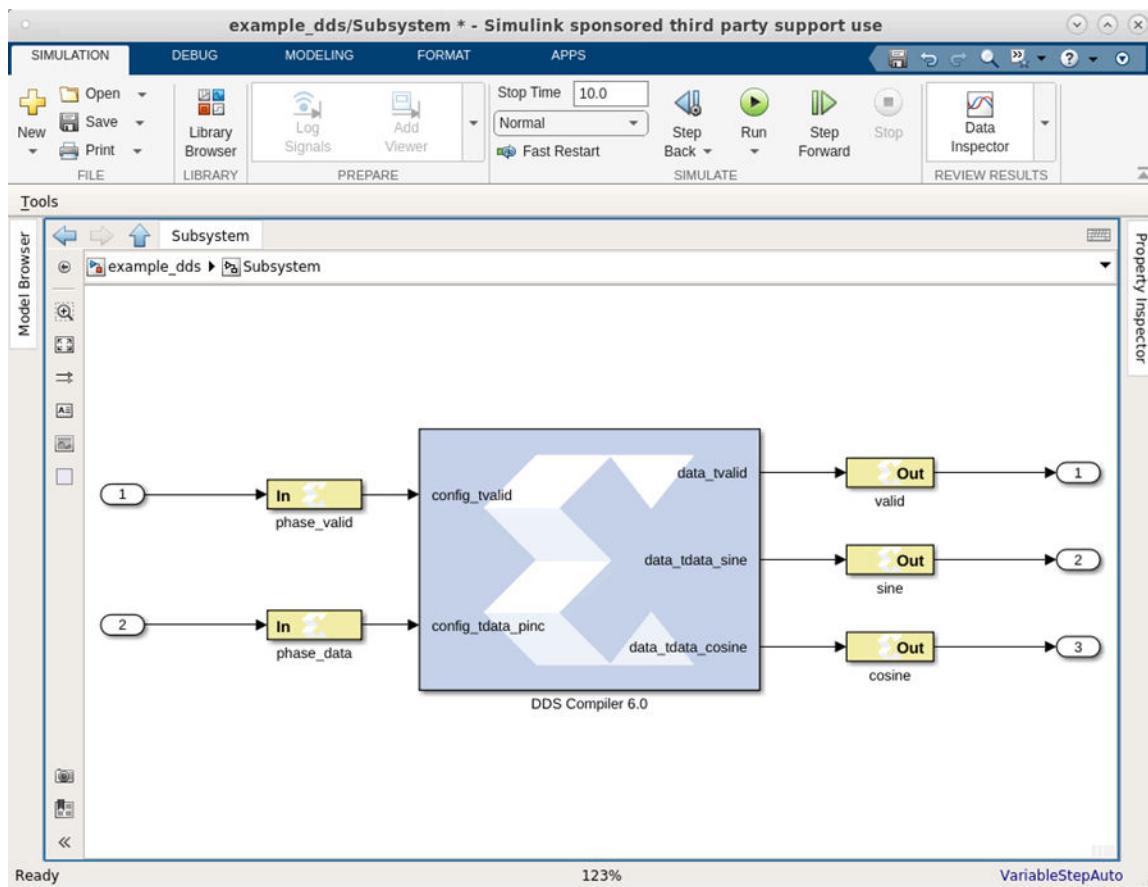
Design modules that are developed using Model Composer usually form a Subsystem of a larger DSP or Video system. These Model Composer modules are typically algorithmic and data path heavy modules that are best created in the visually-rich environment like MATLAB/Simulink. The larger system is typically assembled from IP from the Vivado® IP catalog. These IP typically use standard stream and control interfaces like AXI4-Lite Slave and the larger system is typically assembled using a tool like the Vivado IP integrator.

This topic describes features in Model Composer that allow you to create a standard AXI4-Lite Slave interface for a Model Composer module and then export the module to the Vivado® IP catalog for later inclusion in a larger design using IP integrator. Model Composer also allows creation of multiple AXI4-Lite Slave interfaces across multiple clock domains.

### ***AXI4-Lite Interface Synthesis in Vitis Model Composer***

Design creation and verification is exactly the same as any other Model Composer design that does not include an AXI4-Lite interface. Consider the `example_dds` design shown below.

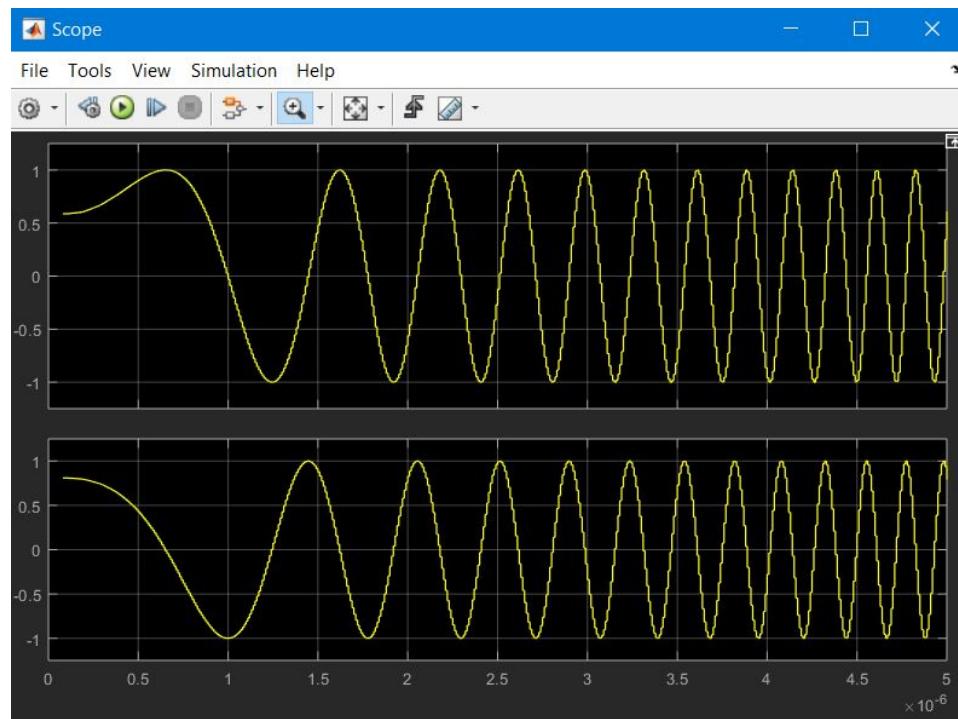
**Figure 61: Example DDS Design**



This design contains a DDS Compiler where the two input ports, `config_tvalid` and `config_tdata_pinc` are used to control the output frequency.

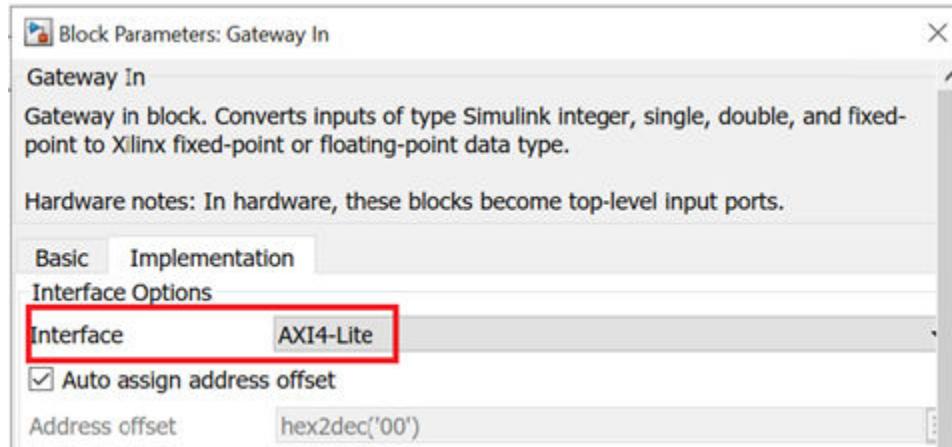
Following are the simulation results of this design which indicate both sine and cosine output separately.

Figure 62: Simulation Results



### Configuring the Design for an AXI4-Lite Interface

In the example\_dds design, Gateway In and Gateway Out blocks mark the boundary of the Cycle and Bit accurate FPGA portion of the Simulink design. Control of the DDS Compiler frequency is accomplished by “injecting” the correct value on the signals attached to the output port of Gateway In’s called `phase_valid` and `phase_data`. This is accomplished by modifying the Interface Options, as shown below for the `phase_valid` block.

**Figure 63: Interface Options**

As you can see, the Interface is specified as a slave AXI4-Lite Interface in Model Composer, which means that it will be transformed to a top-level AXI4-Lite interface.

The following options are also of particular interest:

**Auto assign address offset (Enabled):** Each Gateway is associated with a register within the AXI4-Lite Interface and this control specifies that Automatic assignment of address offsets will take place in the design based on number of different Gateway Ins mapped to the AXI4-Lite interface. Addresses are byte aligned to a 32-bit data width.

**Address offset (Disabled):** This option is only enabled if **Auto assign address offset** is unchecked. It allows the user to manually override of Address Offset.

**Interface Name:** Assigns a unique name to this interface. This name can be used to differentiate between multiple AXI4-Lite interfaces in the design.

---

 **IMPORTANT!** The Interface Name must be composed of alphanumeric characters (lowercase alphabetic) or an underscore (\_) only, and must begin with a lowercase alphabetic character. `axi4_lite1` is acceptable, `1Ax4-Lite` is not.

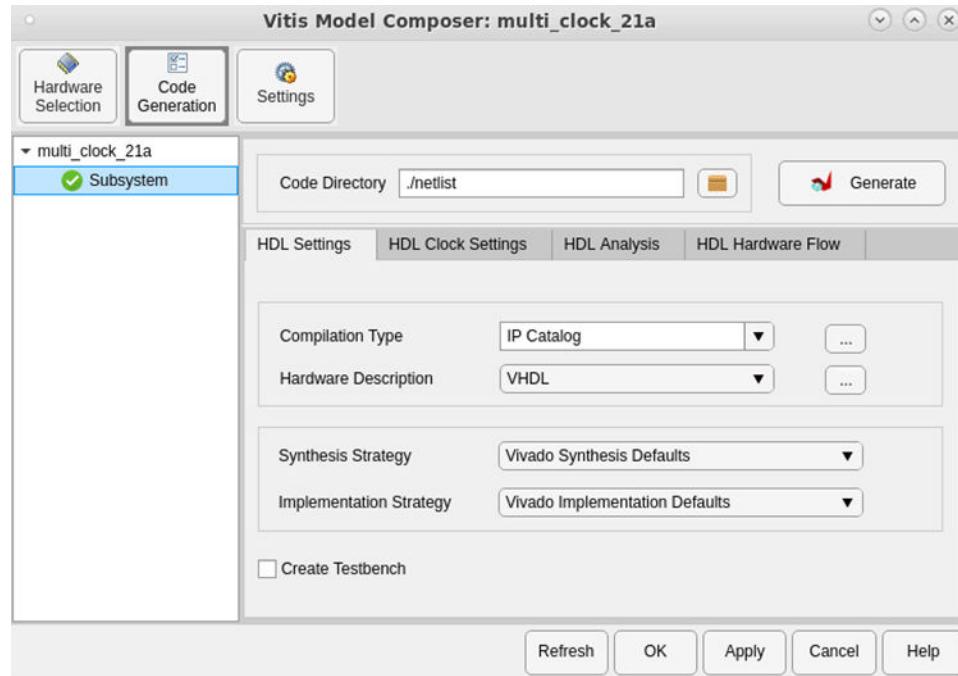
---

**Description:** The text you enter here is captured in the "Interface Documentation" that is automatically created when the design is exported to the Vivado IP catalog.

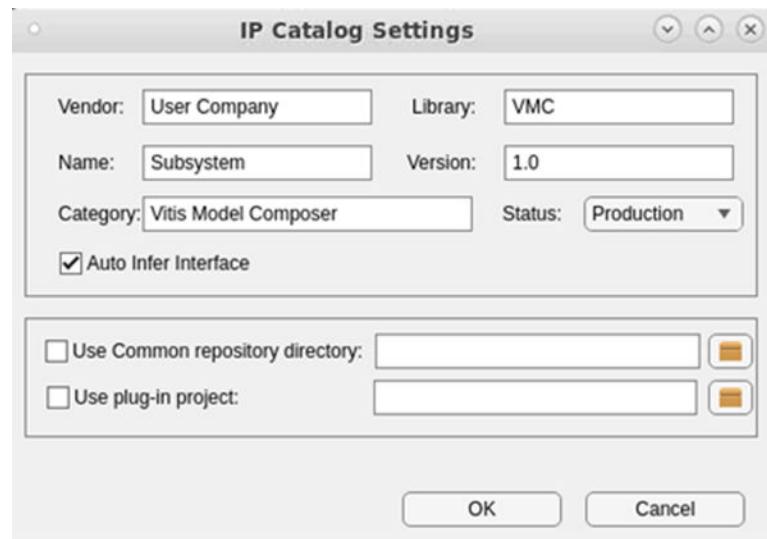
Configure the other Gateways in the design in a similar fashion.

## Packaging the Design for Use in Vivado IP Integrator

When you complete the verification in Vitis Model Composer, you can package the design for use in IP integrator.

*Figure 64: Model Composer Verification*

The HDL block must first be configured to a Compilation Type of IP Catalog (the default generation target). This compilation type will consolidate all hardware source created from Vitis Model Composer (RTL + IP + Constraints) into an IP. In addition, you may also use the button on to the right of the Compilation Type drop-down menu to change the information that goes along with the IP. In this case, the default values shown below are used.

*Figure 65: IP Catalog Settings*

When you click the **Generate** button in the Model Composer Hub block, the RTL code is generated and packaged along with constraints into an IP.

## Description of the Generated Results

Based on the Model Composer settings shown above, the following folders and files are created.

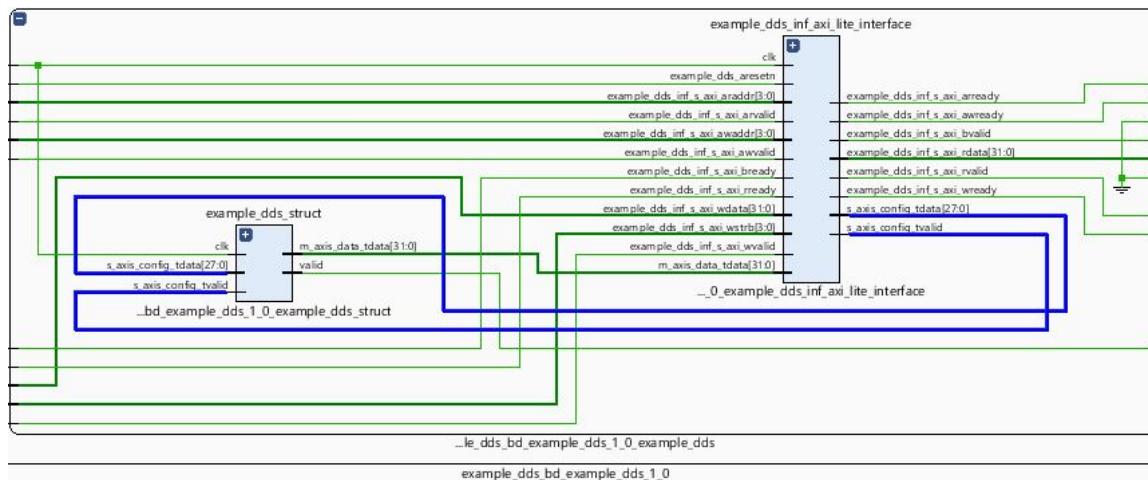
- `<code_directory>/ip`: This directory contains all the IP-related hardware files, as well as the software drivers. It is this directory that you must add to the IP Catalog.
- `<code_directory>/ip_catalog`: This directory contains an example Vivado IDE project called `example_dds.xpr`.

## Mapping to AXI4-Lite Interfaces

Gateway Ins and Gateway Outs that are tagged as AXI4-Lite registers are mapped to different 32-bit registers within a Memory Map as shown in the Schematic below.

The schematic below is an example of mapping to a single AXI4-Lite interface, assuming all gateways have the same interface name. In a schematic with multiple AXI4-Lite interfaces, for each group of gateways having the same interface name you would see a separate AXI4-Lite Interface.

Figure 66: Single AXI4-Lite Interface



As you can see in the diagram, a module called `example_dds_inf_axi_lite_interface` is inserted into the design RTL, and drives the `config_tvalid` and `config_tdata` ports of the Model Composer design. And at the top level, a slave AXI4-Lite Interface is exposed. It is within this module that address decoding is done and the `config_tvalid` and `config_tdata` ports are driven based on the address obtained from the processor.

The number of bits required for addressing (`s_axi_araddr` and `s_axi_awaddr`) is determined by the number of AXI4-Lite interface registers and the offset specifications of each AXI4-Lite register. Enough bits are provided during module generation to uniquely decode each register. In this example, there are two Gateways – `phase_data` and `phase_valid`. Each port is assigned an address offset of `0x0000` & `0x0004`. Hence three address bits are allocated.

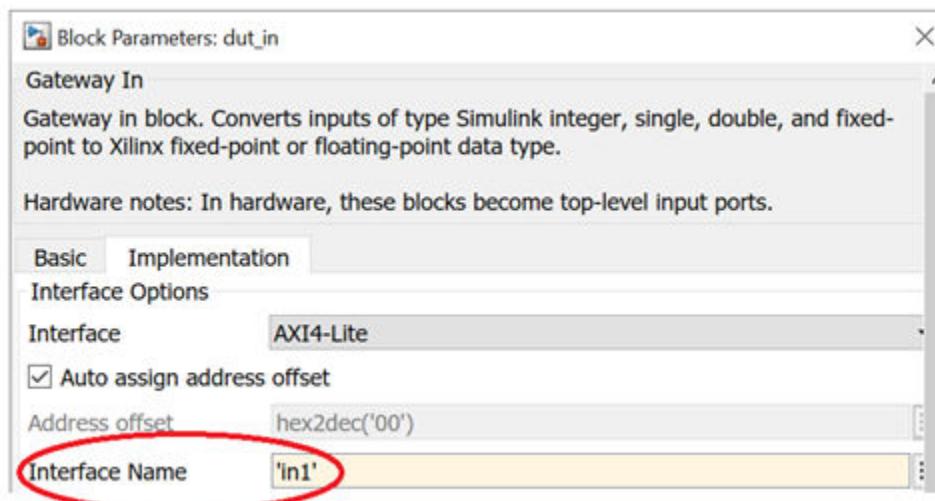
## Managing Multiple AXI4-Lite Interfaces

Model Composer supports creation of IP with multiple AXI4-Lite interfaces. You can group Gateway In and Gateway Out blocks into different AXI4-Lite interfaces. This feature can be used in Multiple Clock designs as well. Software drivers will also be provided.

To assign a name to an AXI4-Lite interface, use the **Interface Name** control for the Gateway In and Gateway Out blocks associated with the interface.

All Gateway Ins and Gateway Outs with the same **Interface Name** are grouped into one AXI4-Lite Interface. An **Interface Name** must begin with a lower case alphabetic character, and can only contain alphanumeric characters (lowercase alphabetic) or an underscore ( \_ ). Having the same **Interface Name** across multiple clock domains is not supported.

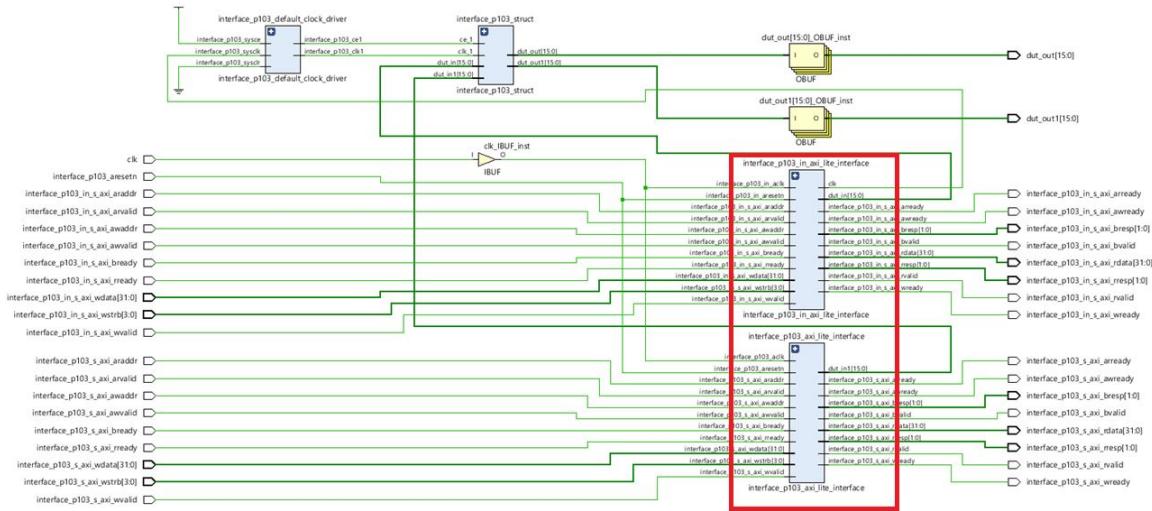
Figure 67: Interface Name



To generate the netlist you can use the **IP Catalog** or the **HDL Netlist** compilation type.

If you specify the **HDL Netlist** compilation type in the Vitis Model Composer Hub block, and then elaborate the design in Vivado, two AXI4-Lite Decoders will be created, as shown in the red rectangle in the following figure.

Figure 68: AXI4-Lite Decoders

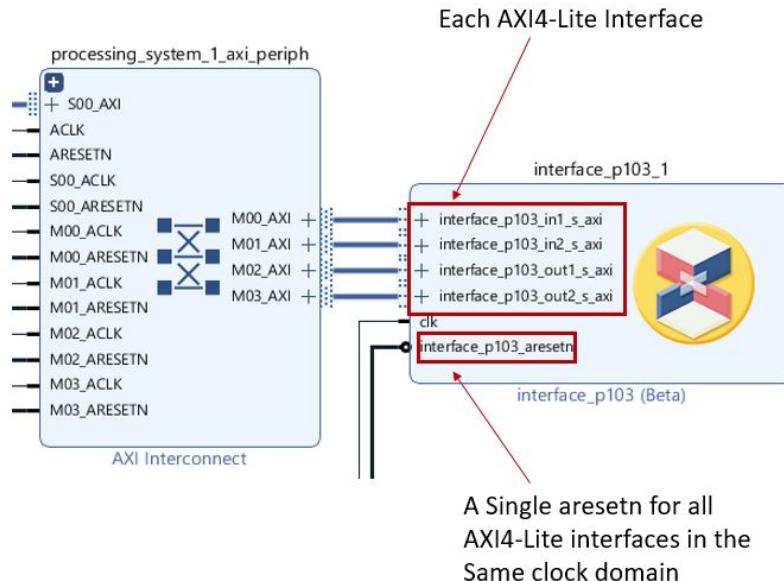


If you specify the **IP Catalog** compilation type in the Vitis Model Composer Hub block, the flow will also generate an example BD with multiple AXI4-Lite interfaces and an `aresetn` signal.

The naming convention for an interface is:

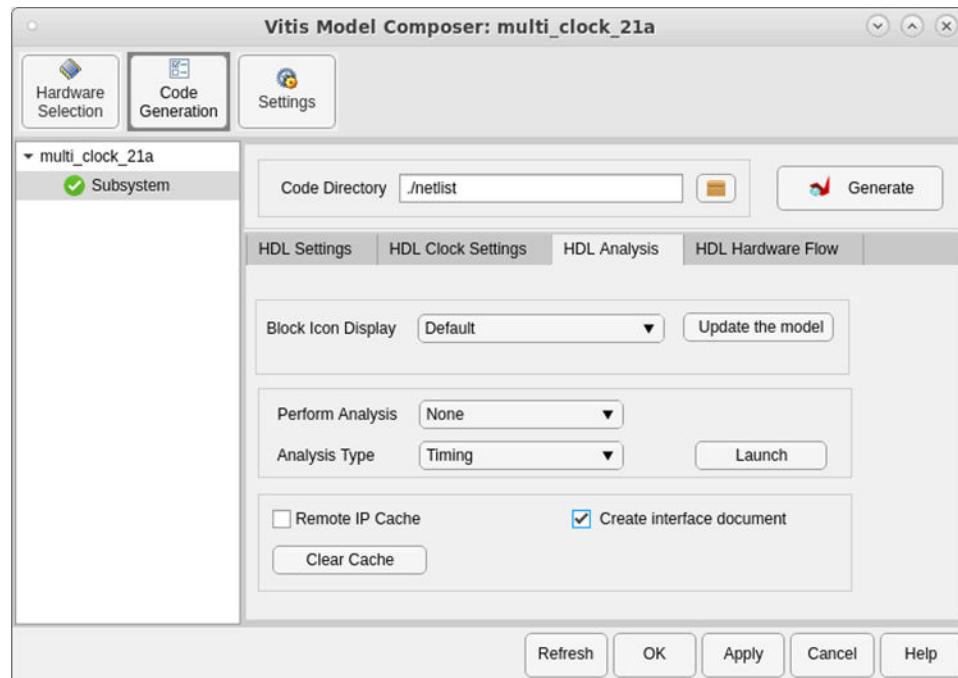
```
<clock domain name/design name>_<interface name>_s_axi
```

Figure 69: Example BD



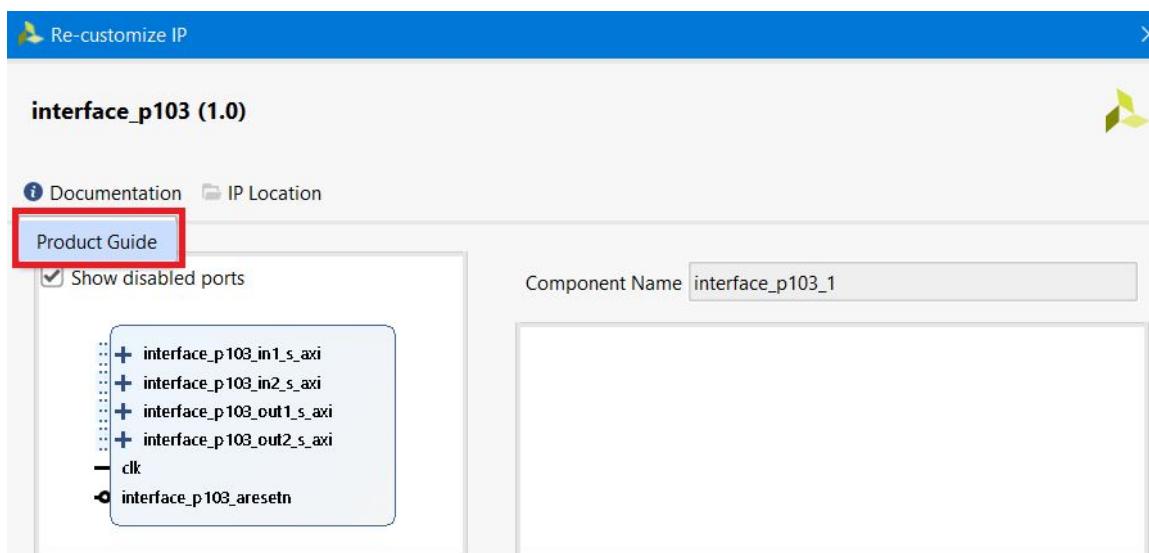
To generate a document describing the IP, select the **Create interface document** option on the **HDL Analysis** tab of the Vitis Model Composer Hub block before you perform the compilation.

Figure 70: Create Interface Document



Access the document the same way you access the document for any other Vivado IP. Double-click the IP in the Vivado schematic, then select **Documentation**→**Product Guide**.

Figure 71: Accessing Documents



A document (HTML file) will open up (see example below).

Figure 72: Sample Document



02-Feb-2019

interface\_p103

### Port Interface

This section documents the port interface of interface\_p103. All the *Gateway In* and *Gateway Out* blocks in a System Generator design are translated to top-level input and output ports. *System Generator Type* refers to the type of signals emanating from *Gateway Ins* and driving *Gateway Outs*. *Type* refers to one of the following -

- Data - Signals that are synchronized to Clock
- Clock - Clock signal for the design. All operations of the core are synchronized to the rising edge of the Clock signal
- Clock Enable - Clock Enable signal is attached to the clock enable pins of flip-flops. A valid clock signal occurs only when Clock Enable Signal attached to CE pin of flip-flops is high on a rising clock edge. If CE is Low, the flip-flops are held in their current state.

*Period* refers to the sampling period of a particular signal. Please refer to the section below on Multi-rate Realization for more details.

Name	Direction	HDL Type	Type	System Generator Type	Period	Description
dut_out	out	std_logic_vector(15 downto 0)	data	Fix_16_14	1	
dut_out1	out	std_logic_vector(15 downto 0)	data	Fix_16_14	1	
interface_p103_aresetn	in	std_logic	data	-	1	
interface_p103_in1_s_axi_awaddr	in	std_logic	data	-	1	

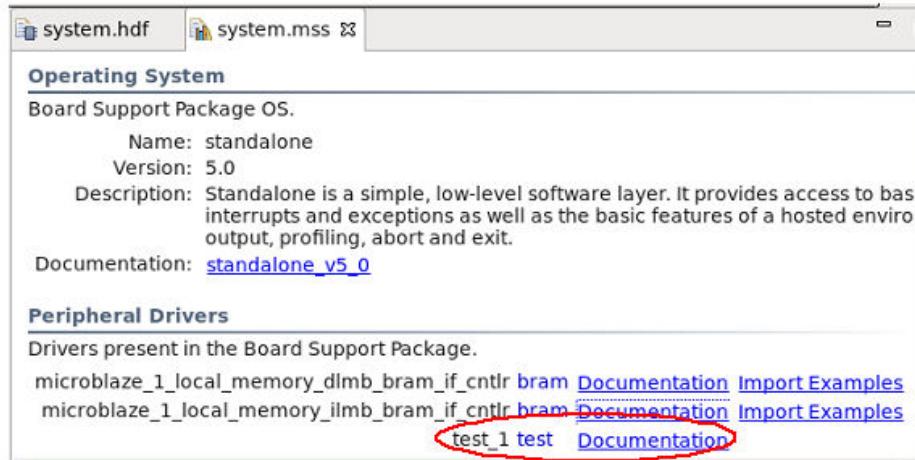
This document contains a section on the Memory Map for the IP. If you selected **Auto assign address offset** in the Gateway In or Gateway Out port for the AXI4-Lite interfaces, you can find out the address offset the different interfaces are mapped to.

### Memory Map

The table below documents the memory map for System Generator design :

Name	Type	Interface Name	Address Offset	Description
dut_in1	Fix_32_2	in	00000000	
dut_in	Fix_32_2	in	00000004	
dut_out	Fix_32_2	out	00000000	
dut_out1	Fix_32_2	out	00000004	

Software Drivers are automatically generated and packaged as well in the Vitis™ software platform. The documentation for the software drivers can be found in the Vitis environment.

**Figure 73: Software Driver Documentation**

## ***Address Generation***

The following assumptions are made in the automatic address-generation process:

1. Each AXI4-Lite gateway is associated with a unique address offset that is aligned with a 32-bit word boundary (i.e., will be a multiple of 4).
2. Addressing begins at zero.
3. Addressing is incrementally assigned in the lexicographical order of the gateways. In the event two gateways have the same name - disambiguation will be arbitrary.
4. All AXI4-Lite gateways must be less than 32-bits wide else an error is issued.
5. If an AXI4-Lite gateway is less than 32-bits wide, then from the internal register, LSBs will be assigned into the Design Under Test (DUT).
6. The following criteria is used to manage the user-specified offset addresses:
  - a. All user-specified addresses are allocated to AXI4-Lite gateways before automatic allocation.
  - b. If two user-specified addresses are the same, an error is issued only during generation (otherwise it will be ignored).
  - c. If the remaining AXI4-Lite gateways that are set to allocate address automatically, Model Composer attempts to fill the "holes" left behind by user-specified addressing.

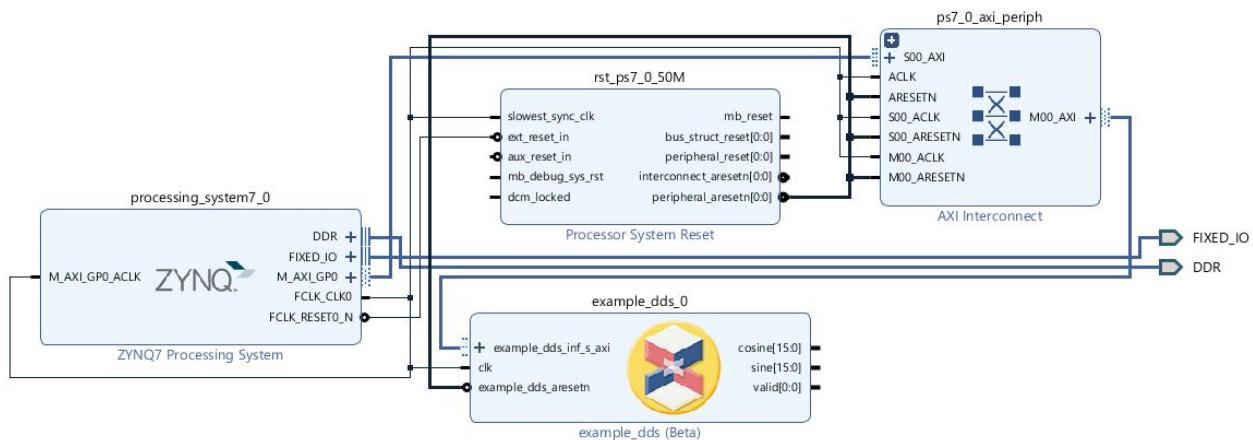
## ***Features of the Vivado IDE Example Project***

The Vivado® IDE example project (<code directory>/ip\_catalog/example\_dds.xpr) is created to help you jump start your usage of the IP created from Vitis Model Composer.

1. The IP generated from Model Composer is already added to the IP catalog associated with the project and available for the RTL flow as well as the IP integrator-based flow.

2. The design includes an RTL instantiation of IP called example\_dds\_0 underneath example\_dds\_stub that indicates how to instance such an IP in RTL flow.
3. The design includes a test bench called example\_dds\_tb that also instances the same IP in RTL flow.
4. The design includes an example IP integrator diagram with a Zynq®-7000 Subsystem as the part selected in this example is a Zynq®-7000 SoC part. For all other parts, a MicroBlaze-based Subsystem is created.

Figure 74: IP Integrator Diagram



5. If the part selected is the same as one of the supported boards, the project is set to the first board encountered with the same part setting.
6. A wrapper instancing the block design is created and set as Top.



**TIP:** The interface documentation associated with the IP is accessible through the block GUI. To access this documentation, double-click the Model Composer IP, and click the **Documentation** button in the GUI.

## Software Drivers

Bare-metal software drivers are created based on the address offsets assigned to the gateways. These drivers are located in the folder called <target\_directory>/ip/drivers. <target\_directory>/ip must be added to the Vitis™ environment search paths to use these drivers.

For each Gateway In mapped to an AXI4-Lite interface, the following two APIs are created.

```
/*
 * Write to <Gateway In id> of <design name>. Assignments are LSB-justified.
 *
 * @param InstancePtr is the <Gateway In id> instance to operate on.
 * @param Data is value to be written to gateway <Gateway In id>.
 *
 * @return None.
 */
```

```
* @note      <Text from Description control of the Gateway In GUI>
*
*/
void <Gateway In id>_write(example_dds *InstancePtr, u32 Data);

/***
* Read from <Gateway In id> of <design name>. Assignments are LSB-justified.
*
* @param InstancePtr is the phase_valid instance to operate on.
*
* @return u32
*
* @note      Phase Valid Port That Must Be Asserted.
*
*/
u32 <Gateway In id>_read(example_dds *InstancePtr);
```

<Gateway In id>:<design\_name>\_<gateway\_name> where <design\_name> is the VHDL/Verilog top-level name of the design and <gateway\_name> is the scrubbed name of the gateway.

Gateway Outs generate a similar driver, but are read-only.

### ***Known Issue in AXI4-Lite Interface Generation***

Test Bench generation is not supported for designs that have gateways (Gateway In or Gateway Out) configured as an AXI4-Lite Interface.

## **Tailor Fitting a Platform Based Accelerator Design in Model Composer**

Platform based accelerators use a bottom-up design methodology to ease the development of larger systems. Two distinct design portions are created: the connectivity platform which connects board level interfaces to a processing system, and the differentiated logic accelerator(s) which represent the data path internal to the SoC and are controlled and/or fed by the connectivity platform design. DSP data paths or accelerators can take advantage of automation to tie into the connectivity platform and its interfaces to external devices.

To speed up creating a design in the Vivado IP Integrator in which the accelerator portion of the design will be developed in Model Composer, the following procedure can be used:

1. Create a Block Diagram (BD) of your design in the Vivado IP Integrator. This will act as your connectivity platform.
2. Import the connectivity platform into Model Composer.
3. Enter the accelerator portion of the design in Model Composer.
4. In Model Composer, compile the accelerator model using the IP Catalog flow, to create a Vivado project containing the original design (from the Vivado BD file) and the circuitry in the Model Composer model.

## Step 1: Create a Connectivity Platform in Vivado as an IP Integrator Block Diagram (.bd)

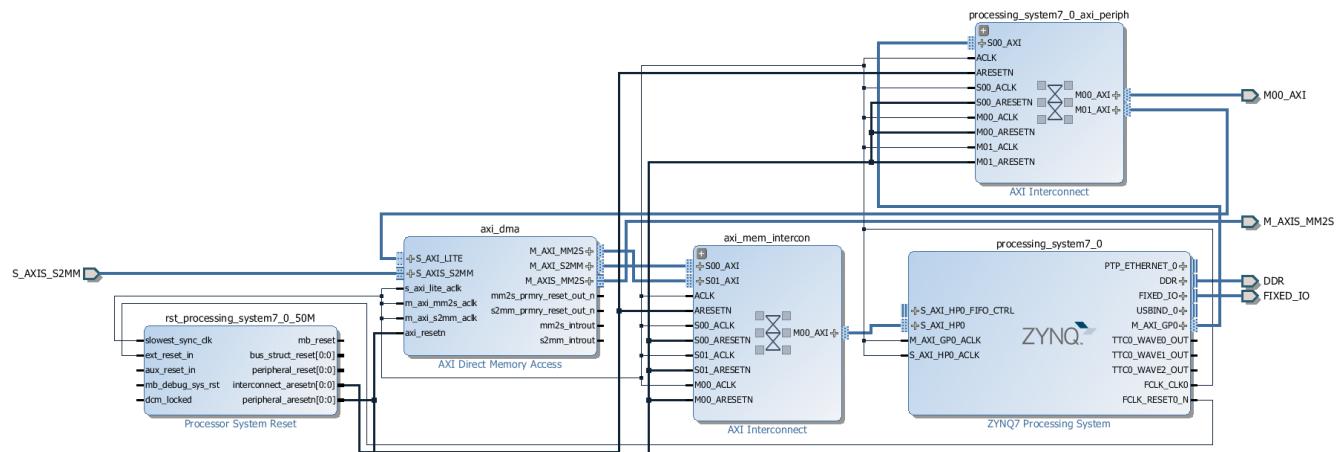
First, you must create a block diagram containing your platform design in the Vivado® IP integrator. You may use a configurable example design, a reference design, or a custom-built design as the platform based system that will contain the accelerator part of the design.

In the example below, the platform design contains a Zynq®-7000 Processing System, and AXI DMA. The connectivity platform designer intends to transfer data to and from the DDR memory using the DMA, perform DES Encryption on the data received from the DDR, and then send the encrypted data back into the DDR. The AXI4-Stream ports M\_AXIS\_MM2S and S\_AXIS\_S2MM (Data Path) are made external to the Block Diagram (BD). It shows the intent of the platform designer that these interfaces are available for Model Composer to use during the Model Composer BD import process. An AXI4-Lite interface, M00\_AXI, is also made external, indicating that there will be a control interface on the accelerator IP.

These are requirements for the design in the IP integrator:

- This system has to be built for a specific board or part. This ensures that certain ports and interfaces have known location attributes assigned to them.
- The AXI Interfaces that you want to bring into the accelerator portion of the design have to be made external.

*Figure 75: AXI Interfaces*



Currently Xilinx supports the following interfaces from the platform framework point of view:

*Table 4: Supported AXI Interfaces*

Interface	Master	Slave
AXI4	Yes	No
AXI4-Lite	Yes	No

**Table 4: Supported AXI Interfaces (cont'd)**

Interface	Master	Slave
AXI4-Stream	Yes	Yes

## **Step 2: Parse the BD File and Import Un-Located Ports and Interfaces into Model Composer**

You can now use the `xilinx.utilities.importBD` utility in Model Composer to import the BD (Block Diagram) that you created in the Vivado® IP integrator.

This utility takes in the platform framework Vivado project and the name of the new model to be created in Model Composer. It parses the platform design for potential Model Composer ports and external interfaces (that is, interfaces whose ports do not have location attributes, based on the board connectivity and automation) and creates a sample stub in Model Composer representing the accelerator portion of the design.

### COMMAND USAGE:

`xilinx.utilities.importBD` takes in the platform Vivado project and the name of the new model to be created. It parses the platform for potential Model Composer ports and interfaces and creates a sample stub for the user to make development easy. If the new model name is not specified an untitled model will be opened.

Inputs are: The Vivado project and the model\_name (optional)

### USAGE:

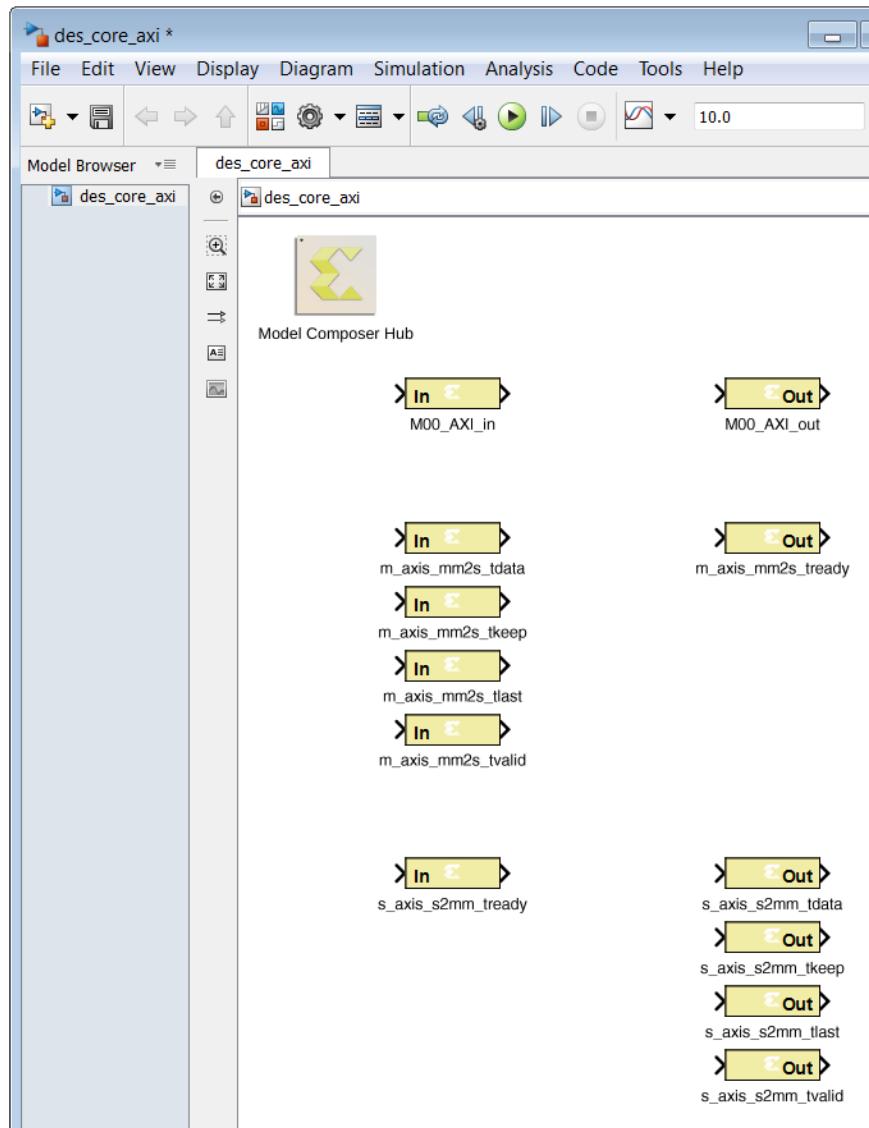
```
xilinx.utilities.importBD('<full_or_relative_path_to_vivado_project_directory>/<project_name>.xpr', 'mynewmodel')
```

### EXAMPLES

```
xilinx.utilities.importBD('C:\test_importBD\platform.xpr', 'mynewmodel')
xilinx.utilities.importBD('C:\test_impportBD\platform.xpr')
```

In Model Composer, the resulting model will look like the example below.

Figure 76: Model Composer Model



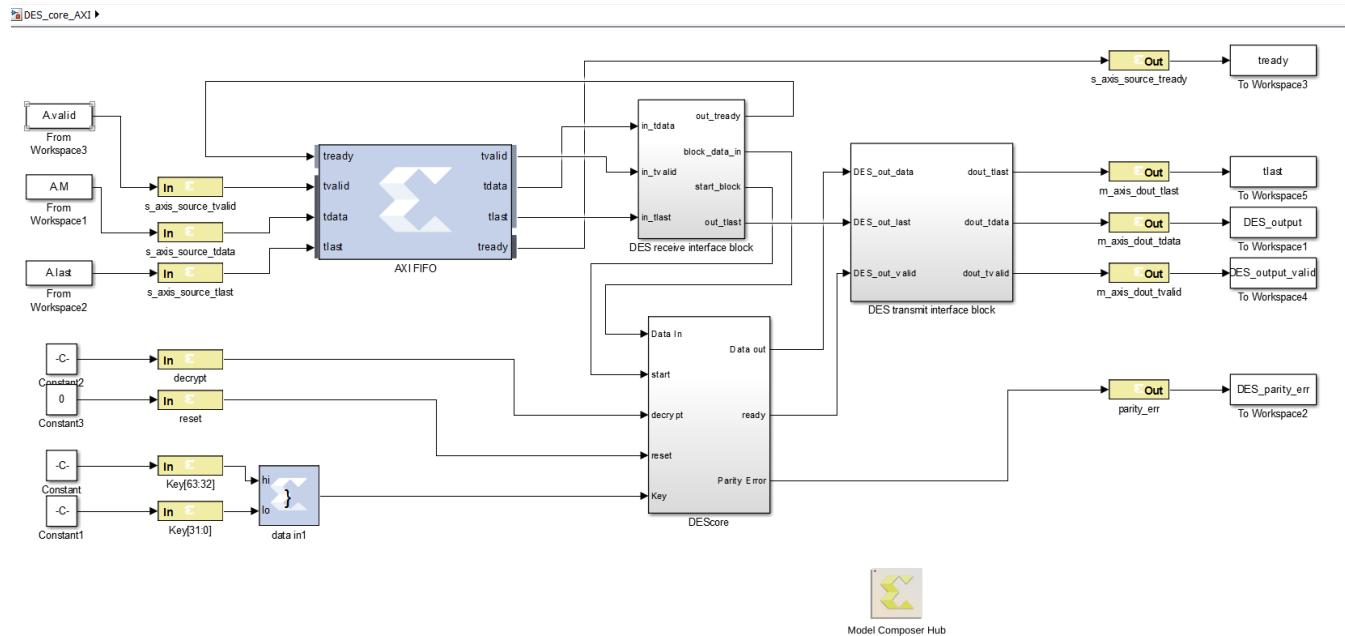
The model in Model Composer will have these features:

- For each AXI4-Lite interface, a Gateway In and a Gateway Out block will appear. You can then replicate and add as many AXI4-Lite gateways as your design requires.
- For an AXI4-Stream interface, the associated TDATA, TVALID, TREADY, and other AXI4-Stream ports will appear.
- The model's Model Composer Hub block is set to a Compilation target of **IP Catalog** and the **Part or Board** will be set to the same Xilinx device or board as that of the Vivado project.

### Step 3: In Model Composer, Connect Logic to the BD Socket

At this point you can create the accelerator in Vitis Model Composer. In the following example, you have connected to some other logic, and renamed the gateways.

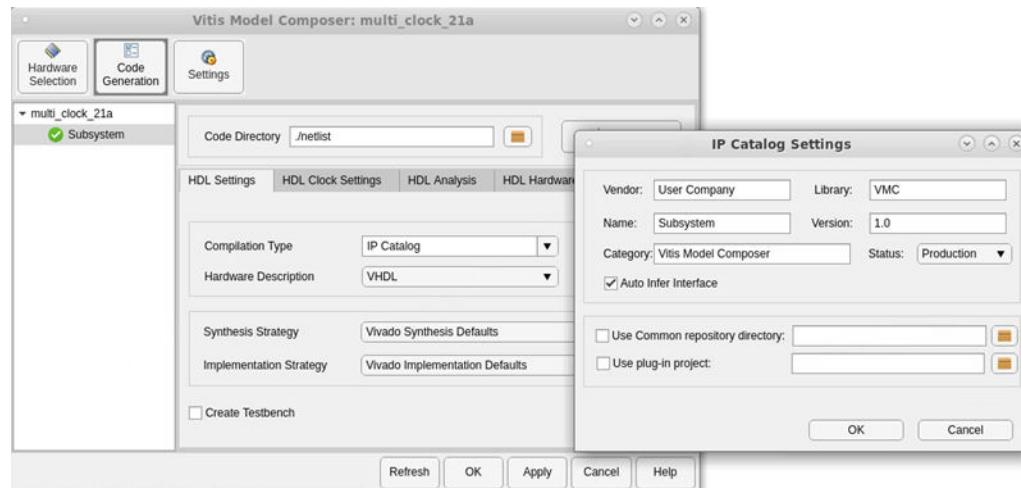
Figure 77: Connect to BD Socket



### Step 4: Compile the Accelerator Model (IP Catalog Flow) to Create a Complete Design

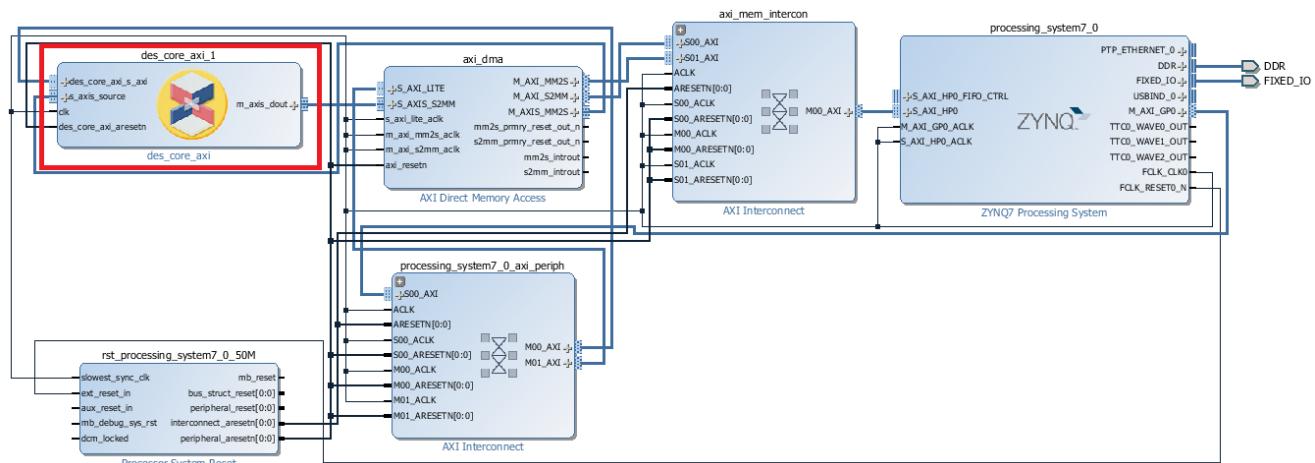
You can now use the IP catalog compilation flow to create a complete design. When you double-click the Model Composer Hub block in IP catalog flow and click the **Settings** button, the **Use Plug-in project** directory must point to the Vivado® IP integrator project from which the design was imported (see below). When you click the **Generate** button, a new Vivado project based on the original Vivado platform/framework/system plus the accelerator IP created in Model Composer, along with a software driver, will be created. This project will be located in an **ip\_catalog** directory under the Model Composer Hub block's **Code directory**, and can also be placed into a common IP repository.

Figure 78: Target Directory



You can open this new project in Vivado to complete the implementation of your design. The block highlighted in the following figure indicates a block developed using Model Composer HDL Blockset.

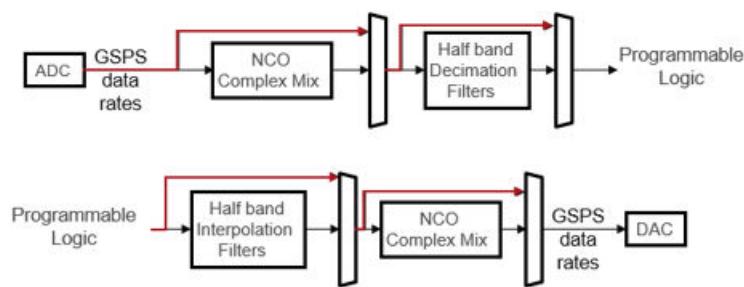
Figure 79: New Project



## Using Super Sample Rate (SSR) Blocks in Model Composer

While the Super Sample Rate (SSR) feature introduced in this section is applicable to all Xilinx® devices, this section refers specifically to Xilinx RFSoC devices. The integration of direct RF-sampling data converters with Xilinx's technology offers the most flexible, smallest footprint, and lowest power solution for a wide range of high performance RF applications such as Wireless communications, cable access, test & measurement, and radar. RFSoC devices provide hardened Digital Up Converters (DUC) and Digital Down Converters (DDC). NCO, Complex Mixers, and Filters are hard Macros, and filter characteristics are optimized for general Commercial applications.

Figure 80: RFSoC Device



Depending on what is needed, RFSoC devices can be used in two ways.

- Use the available hardened NCO & Complex Mix and Half Band Decimation/interpolation filters.
- If the sequence of the hardened blocks does not meet the design requirement, you can bypass them as shown in the figure above.

In the latter case, to meet the design requirements, you may need to implement the NCO, Complex Mixers and DDC blocks in the fabric using the HDL Blockset in Model Composer. To do this, bypass the hardened blocks, and let Model Composer IPs run at Programmable Logic (PL) clock frequency. When the sample rate from the ADC is in GSPS, and PL handles only the MSPS range of data, you must accept and compute multiple parallel samples every clock cycle for each data channel. The number of parallel samples is determined by calculating the ratio between the sample frequency and the Programmable Logic clock frequency, which is defined as an SSR parameter.

### What is SSR?

SSR is a parameter that determines how many parallel samples to accept for every clock cycle.

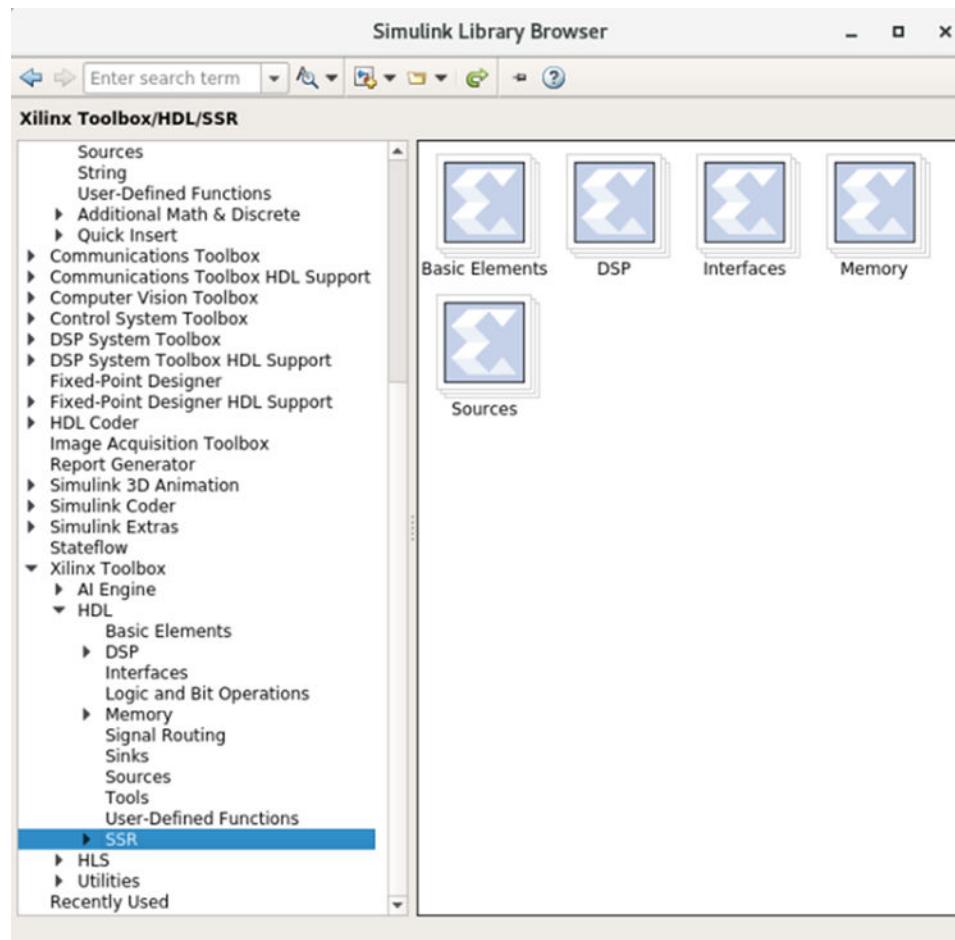
### How SSR helps users?

- SSR is beneficial for users who cannot use the hardened RFSoC DUC and DDCs.
- SSR provides programmatic subsystems for NCO and Complex Mixer among many others. The user input parameters in the block mask and Model Composer programmatically construct the underlying subsystem with multiple DDS blocks.
- SSR avoids manual and structural modifications to your design, which accelerates the design-cycle.

### SSR Library

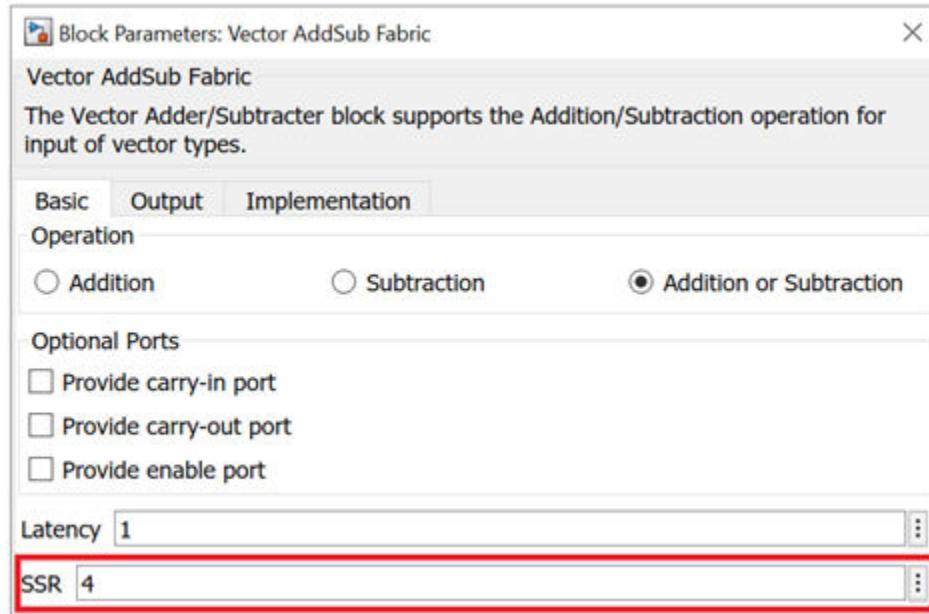
Model Composer provides a separate set of library blocks for handling SSR. Currently, Model Composer supports 25 vector blocks, which can be accessed from the Simulink Library Browser.

Figure 81: SSR Block set in HDL Library



The SSR parameter can be defined for all the blocks present in the SSR block set. When you add a block from the library, the default SSR value is 4, and the maximum SSR value is 256.

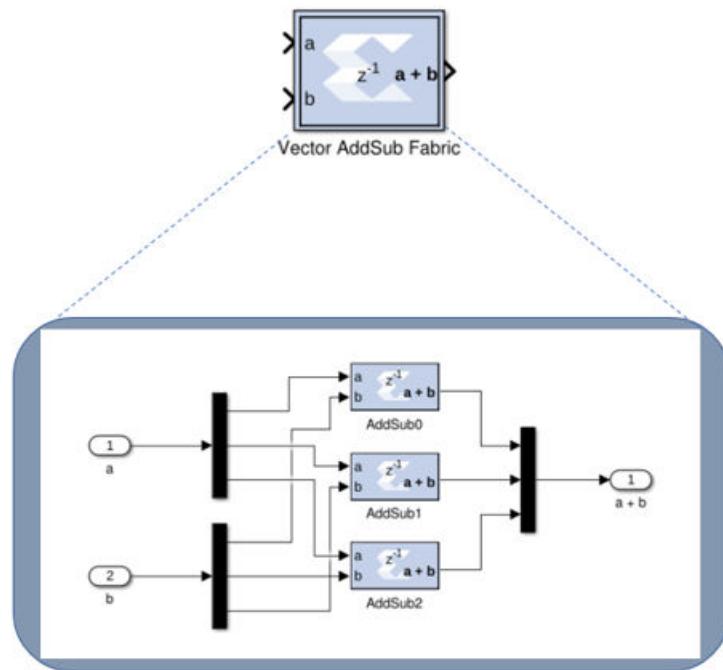
The SSR block set is defined in Xilinx SSR Blockset.

**Figure 82: Default SSR Value**

No matter what the SSR rate is, you only need to provide a limited number of signal connections as with a normal IP block. Model Composer automatically takes care of all the parallel path connection internal to the SSR block, according to the SSR parameter value provided.

For example, for a Vector AddSub block, when SSR parameter is modified to 3, the internal connections are done automatically as shown below. This creates 3 parallel paths for computation and results in single output.

Figure 83: Vector AddSub Fabric Example



## Performing Analysis in Model Composer

Model Composer is a bit and cycle accurate modeling tool. You can verify the functionality of your designs by simulating in Simulink®. However, to ensure that your Model Composer design will work correctly when it is implemented in your target Xilinx® device, these analysis tools have been integrated into Model Composer:

- **Timing Analysis:** To ensure that the HDL files generated by Model Composer operate correctly in hardware, you must close timing. To help accelerate this process, timing analysis has been integrated into Model Composer.
- **Resource Analysis:** To ensure that the HDL files generated by Model Composer will fit into your target device, you may need to analyze the resources being used. To help accelerate this process, resource analysis has been integrated into Model Composer.

<a href="#">Timing Analysis in Model Composer</a>	Presents an overview of timing analysis in Model Composer.
<a href="#">Performing Timing Analysis</a>	Describes how to perform timing analysis on your model.

<a href="#">Cross Probing from the Timing Analysis Results to the Model</a>	Describes how you can cross probe from a row in the Timing Analyzer table to the Simulink model, highlighting the corresponding HDL blocks in the path.
<a href="#">Accessing Existing Timing Analysis Results</a>	Describes how to re-launch the Timing Analyzer table on pre-existing Timing Analysis results.
<a href="#">Recommendations For Troubleshooting Timing Violations</a>	Describes methods to help you discover the source of timing violations in your design.
<a href="#">Resource Analysis in Model Composer</a>	Presents an overview of resource analysis in Model Composer.
<a href="#">Performing Resource Analysis</a>	Describes how to perform resource analysis on your model.
<a href="#">Cross Probing from the Resource Analysis Results to the Model</a>	Describes how you can cross probe from a row in the Resource Analyzer table to the Simulink model, highlighting the corresponding block or subsystem in the design.
<a href="#">Accessing Existing Resource Analysis Results</a>	Describes how to re-launch the Resource Analyzer table on pre-existing Resource Analysis results.
<a href="#">Recommendations for Optimizing Resource Analysis</a>	Describes methods to help you use the Resource Analyzer to optimize resource utilization in the design.

## Timing Analysis in Model Composer

To ensure that the HDL files generated by Model Composer work correctly in hardware, you must close timing. To help accelerate this process, timing analysis has been integrated into Model Composer.

Timing analysis allows you to perform static timing analysis on the HDL files generated from Model Composer, either Post-Synthesis or Post-Implementation. It also provides a mechanism to correlate the results of running the Vivado® Timing Engine on either the Post-Synthesized netlist or the Post Implementation netlist with the Model Composer model in Simulink®. Thus, you do not have to leave the Simulink® modeling environment to close timing on the DSP sub-module of the design.

Invoking timing analysis on a compilation target (for example, HDL Netlist) results in a tabulated display of paths with columns showing information such as timing slack, path delay, etc. This is the Timing Analyzer table. You can sort the contents of the table using any of the column metrics such as slack, etc. Also, cross probing is enabled between the table entries and the Simulink model to accelerate finding and fixing timing failures in the model. Cross probing between the Timing Analyzer table and the Simulink model is accomplished by selecting/clicking a row in the table. The corresponding path in the model will be highlighted. The path is highlighted in red if the path corresponds to a timing violation; otherwise it is highlighted in green.

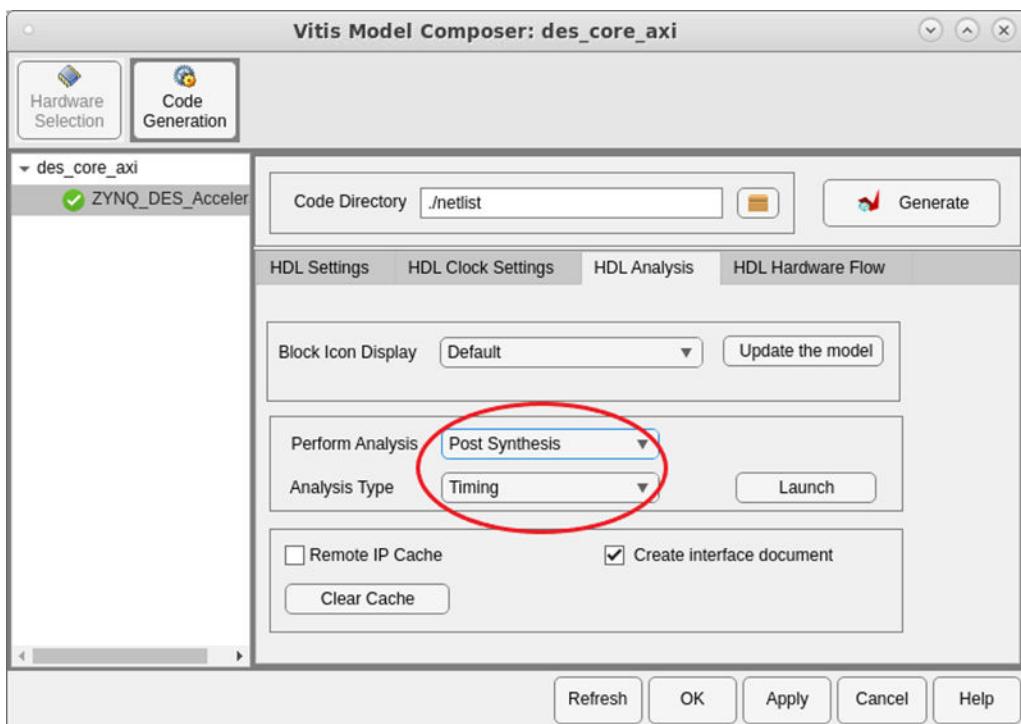
### Performing Timing Analysis

Timing analysis can be invoked whenever you generate any of the following compilation targets:

- IP catalog
- Hardware Co-Simulation
- Synthesized Checkpoint
- HDL Netlist

To perform timing analysis in Vitis Model Composer:

1. Double-click the **Vitis Model Composer Hub** block in the Simulink model.
2. Enter the following in the Vitis Model Composer Hub dialog box:
  - a. In the **HDL Settings** tab, specify a **Code Directory**.
  - b. In the **HDL Analysis** tab, set the **Perform Analysis** field to **Post Synthesis or Post Implementation** based on the runtime versus accuracy tradeoff. Post Synthesis timing will be less accurate but run faster, while Post Implementation timing will be more accurate but run slower.
  - c. In the **HDL Analysis** tab, set the **Analysis Type** field to **Timing**.

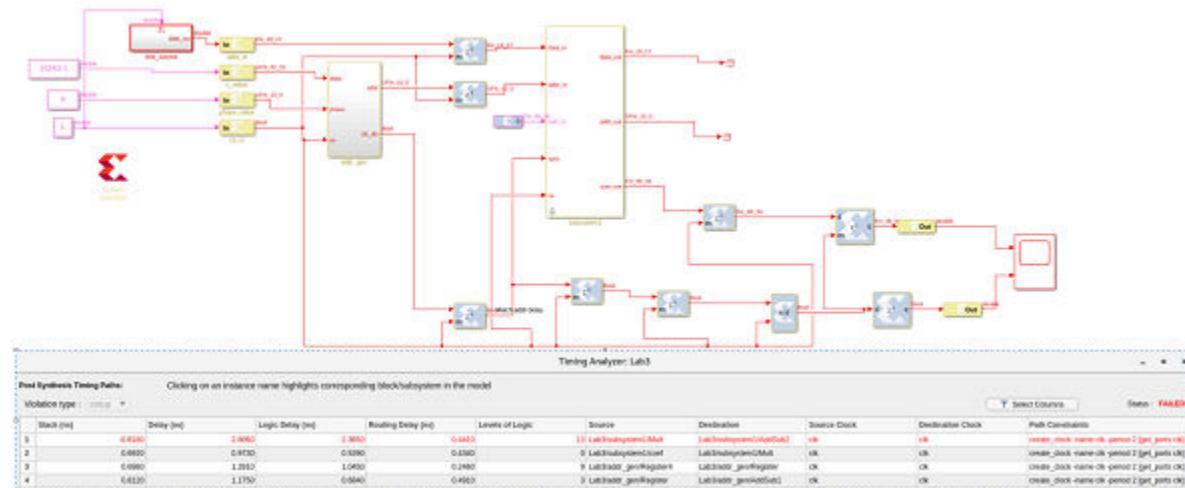


3. In the Model Composer Hub dialog box, click **Generate**.

When you generate, the following occurs:

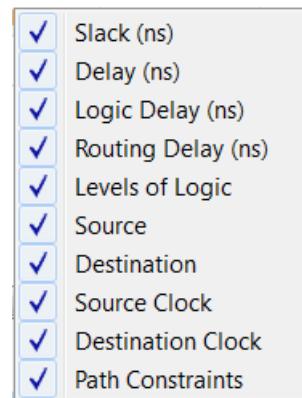
- a. Model Composer generates the required files for the selected compilation target. For timing analysis Model Composer invokes Vivado in the background for the design project, and passes design timing constraints to Vivado.

- b. Depending on your selection for **Perform Analysis (Post Synthesis or Post Implementation)**, the design runs in Vivado through synthesis or through implementation.
- c. After the Vivado tools run is completed, timing paths information is collected and saved in a specific file format from the Vivado timing database. At the end of the timing paths data collection the Vivado project is closed and control is passed to the MATLAB®/Model Composer process.
- d. Model Composer processes the timing information and displays a Timing Analyzer table with timing paths information (see below).



In the timing analyzer table:

- Only unique paths from the Simulink model are reported.
- The 50 paths with the lowest Slack values are displayed with the worst Slack at the top, and increasing Slack below.
- Paths with timing violations have a negative Slack and display in red.
- The display order can be sorted for any column's values by clicking the column head.
- To show/hide columns, click the **Select Columns** button and select/deselect the column name as required.



- For a design with multiple clock cycle constraints, the Timing Analyzer can identify multicycle path constraints, and show them in the **Path Constraints** column. In that case, the **Source Clock**, and **Destination Clock** columns display clock enable signals to reflect different sampling rates.

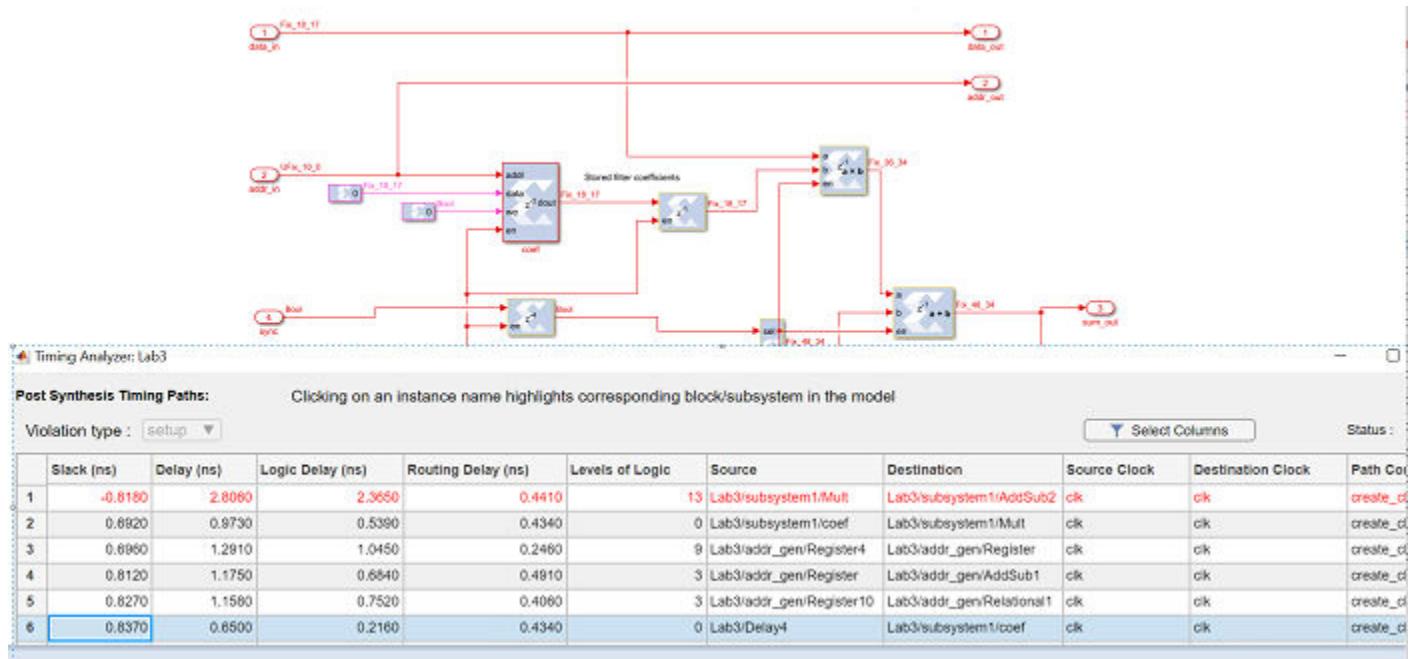
Source Clock	Destination Clock	Path Constraints
clk, ce_3	clk, ce_3	set_multicycle_path -setup 3 -hold 2
clk, ce_4	clk, ce_4	set_multicycle_path -setup 4 -hold 3
clk, ce_6	clk, ce_6	set_multicycle_path -setup 6 -hold 5
clk, ce_12	clk, ce_12	set_multicycle_path -setup 12 -hold 11
clk, ce_12	clk, ce_12	set_multicycle_path -setup 12 -hold 11
clk, ce_12	clk, ce_12	set_multicycle_path -setup 12 -hold 11

- You can cross probe from the table to the Simulink model by selecting a path in the table, which will highlight the corresponding HDL blocks in the Simulink model. See [Cross Probing from the Timing Analysis Results to the Model](#).

## Cross Probing from the Timing Analysis Results to the Model

You can cross probe from the Timing Analyzer table to the Simulink model by clicking any path (row) in the Timing Analyzer table, which highlights the corresponding HDL blocks in the model. This allows you to troubleshoot timing violations by analyzing the path on which they occur.

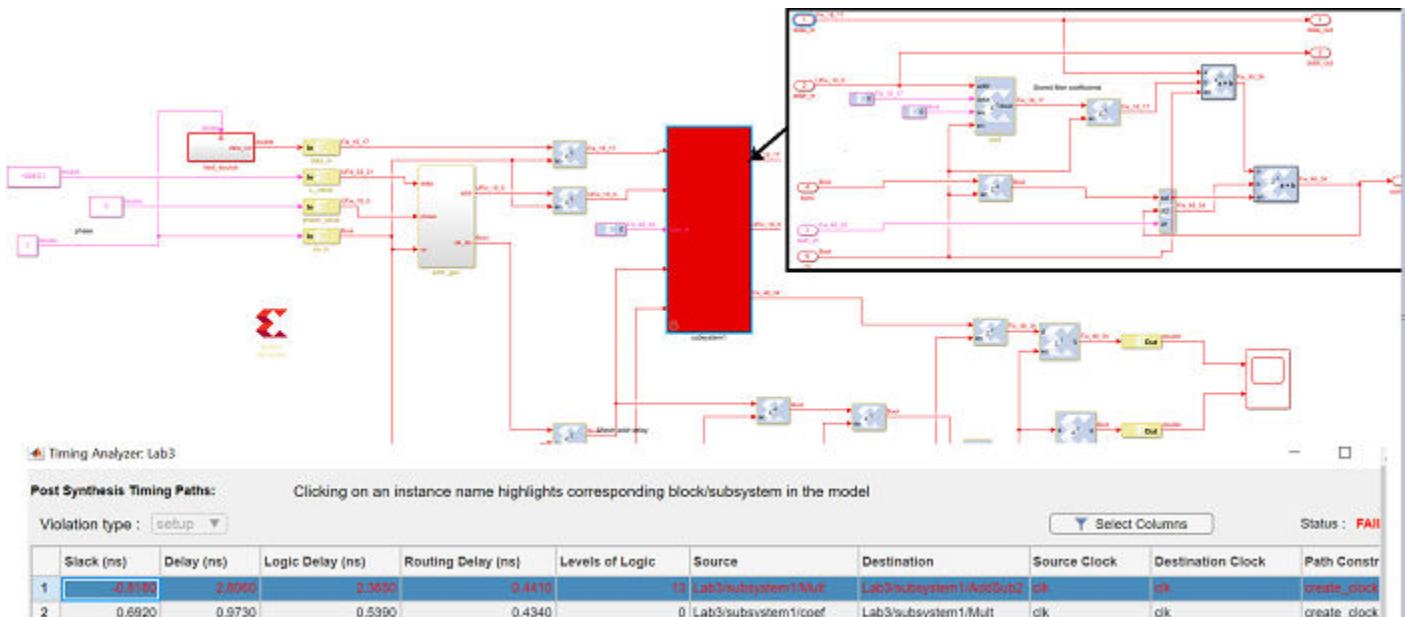
Figure 84: Timing Analyzer Table



When you cross probe, the following will display in the model:

- Blocks in a path with a timing violation are highlighted in red in the model, whereas blocks that belong to a path with no timing violation (that is, a path with a positive Slack value) are highlighted in green in the model.
- If blocks in a highlighted path are inside a subsystem, then the subsystem is highlighted in red so you may expand the subsystem to inspect the blocks underneath.

Figure 85: Cross Probing



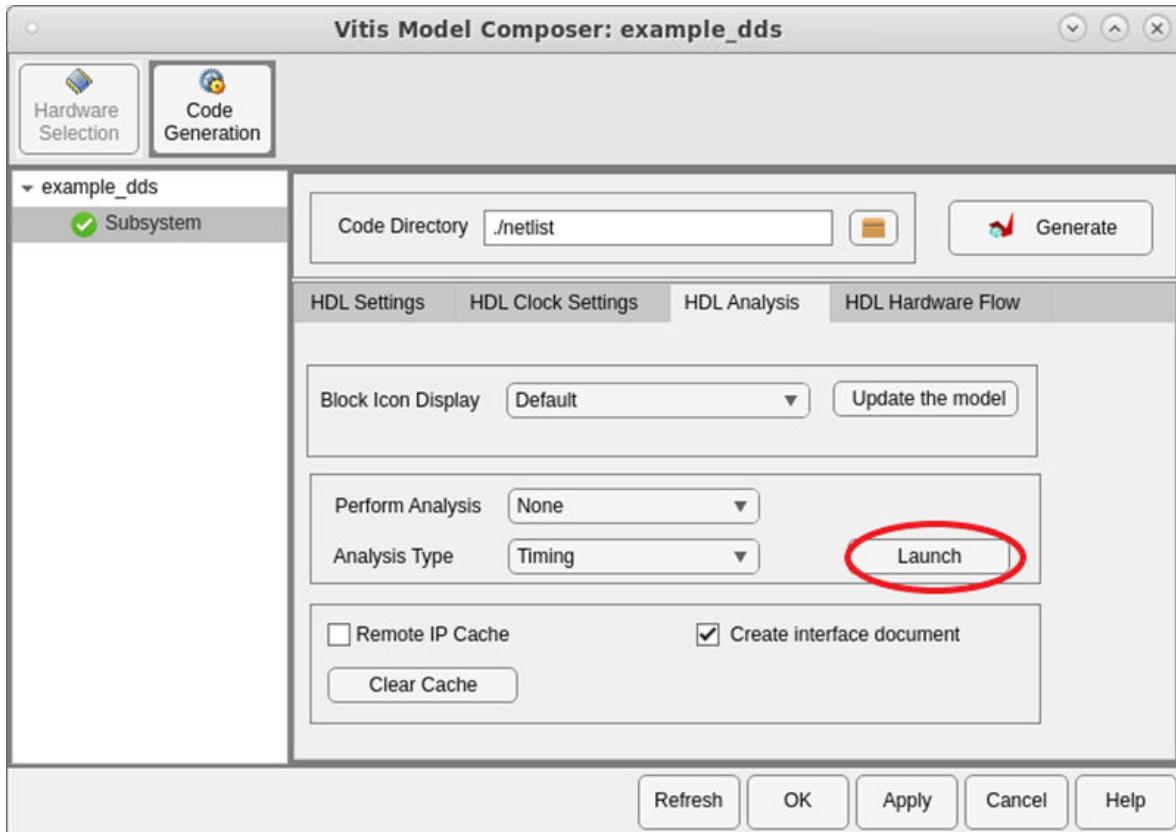
- When you select a path (row in the table) to cross probe, this normally highlights the destination block at the end of the path. That brings the subsystem containing the destination block to the front in the model. As a result, you may not be able to see the highlighted source block if the source block is in a different subsystem. If you want to see the source block, click the path in the **Source** column in the table. This will bring the subsystem containing the source block to the front of the model. Selecting the path in any other column will bring the subsystem containing the destination block to the front.

## Accessing Existing Timing Analysis Results

A **Launch** button is provided under the HDL Analysis tab of the Vitis Model Composer Hub dialog box to relaunch the Timing Analyzer table using the existing timing analysis results for the model. Ensure that the specified Code Directory is readable by the Timing Analyzer, and the Analysis Type field is set to **Timing**. This will only work if you already ran timing analysis on the Simulink model and haven't changed the Simulink model since the last run.

When you click the **Launch** button, the Timing Analyzer table will display the timing analysis results stored in the specified Code Directory, regardless of the option selected for Perform Analysis (Post Synthesis or Post Implementation).

Figure 86: Launch Button



You can also launch the Timing Analyzer table to display existing timing analysis results by entering this command at the MATLAB command prompt:

```
x1AnalyzeTiming(<mdl_hdle>, <netlist_dir>)
```

where `<mdl_hdle>` is the Simulink® model handle (the handle of the top level design), and `<netlist_dir>` is the **Code Directory** specified in the Model Composer Hub dialog box.

## Recommendations For Troubleshooting Timing Violations

The following are recommended for troubleshooting timing violations:

- For quicker timing analysis iterations, post-synthesis analysis is preferred over post-implementation analysis.
- After logic optimization during the Vivado Synthesis process the tool doesn't keep information about merged logic in the Vivado database. Merged and shared logic may make it difficult to accurately cross probe from Vivado timing paths to the Simulink model. Hence, it is recommended that you create a custom Vivado Synthesis strategy to control merged and shared logic.

For information about how to create a custom Synthesis strategy in Vivado, see this [Link](#) in the *Vivado Design Suite User Guide: Using the Vivado IDE* ([UG893](#)).

To control merged and shared logic in the Vivado IDE, make the following changes to the default Vivado Synthesis strategy.

1. Set these Synthesis options in Vivado IDE:
  - Select the Synthesis option `-keep_equivalent_registers`.
  - Set the Synthesis option `-resource_sharing` to the value `off`.
2. Save the new Synthesis strategy and exit Vivado IDE.
3. In Model Composer, select the new custom **Synthesis strategy** in the Model Composer Hub dialog box before generating the design.

## Resource Analysis in Model Composer

To ensure that the HDL files generated by Model Composer will fit into your target device, you may need to analyze the resources being used. To help accelerate this process, resource analysis has been integrated into Model Composer.

Resource analysis allows you to determine the number of look-up tables (LUTs), registers, DSP48s (DSPs), and block RAMs (BRAMs) used by your model. The analysis is performed either Post-Synthesis or Post-Implementation and provides a mechanism to correlate the resources used in the Vivado® tools with the Model Composer model in Simulink®. Thus, you do not have to leave the Simulink modeling environment to investigate and determine areas where excessive resources are being used in your design.

Invoking resource analysis on a compilation target (for example, IP catalog) results in a tabulated display of blocks, and hierarchies showing LUT, Register, DSP, and block RAM resource usage. This is the Resource Analysis table. You can sort the contents of the table using any of the column metrics such as DSPs, etc. Also, cross probing is enabled between the table entries and the Simulink model to accelerate finding and fixing excessive resource usage in the model. Cross probing between the Resource Analysis table, and the Simulink model is accomplished by selecting (clicking) a row in the table. The corresponding block, or hierarchy in the model is highlighted in yellow.

### Performing Resource Analysis

Resource analysis can be performed whenever you generate any of the following compilation targets:

- IP Catalog
- Hardware Co-Simulation
- Synthesized Checkpoint

- HDL Netlist

To perform resource analysis in Vitis Model Composer:

1. Double-click the Model Composer Hub block in the Simulink model.
2. Select the following in the Model Composer Hub dialog box dialog box:

a. In the **Hardware Selection** tab:

- i. Click the button next to the Select Hardware box to open the Device Chooser.
- ii. Specify the Part in which your design will be implemented.

**Note:** If you select a **Board** or **Platform** instead of a **Part**, the **Part** field will be populated with the name of the part on the selected **Board** or **Platform**.

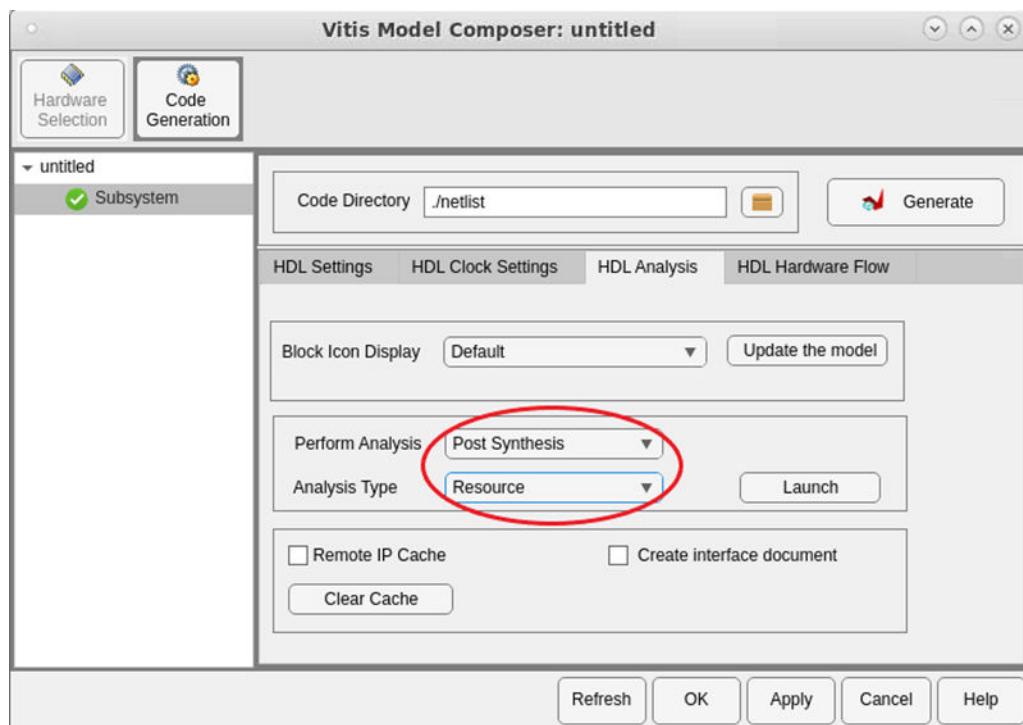
b. In the **Code Generation/HDL Settings** tab:

- i. Select one of the Compilation Types. Model Composer can perform resource analysis for any Compilation Type you select.
- ii. Specify a Code Directory.

c. In the **Code Generation/HDL Analysis** tab:

- i. Set the Perform Analysis field to **Post Synthesis** or **Post Implementation** based on the runtime versus accuracy tradeoff.
- ii. Set the Analysis type field to **Resource**.

Figure 87: Resource Analyzer



3. In the Model Composer Hub dialog box, click **Generate**.

When you generate, the following occurs:

- a. Model Composer generates the required files for the selected compilation target. For resource analysis Model Composer invokes Vivado in the background for the design project.
- b. Depending on your selection for **Perform analysis (Post Synthesis or Post Implementation)**, the design runs in Vivado through synthesis or through implementation.
- c. After the Vivado tools run is completed, resource utilization data is collected from the Vivado resource utilization database and saved in a specific file format under the target directory. At the end of the resource utilization data collection the Vivado project is closed and control is passed to the MATLAB/Model Composer process.
- d. Model Composer processes the resource utilization data and displays a Resource Analyzer table with resource utilization information (see below).

**Figure 88: Resource Analyzer**

The screenshot shows the 'Resource Analyzer' dialog box for a project named 'Lab6\_1'. The dialog has a toolbar at the top with icons for hierarchical/flat display, collapse all, expand all, and flatten list. The main area has two sections: 'Post Synthesis Resources:' and a table. The table lists resources categorized by name, with columns for BRAMs, DSPs, LUTs, and Registers. The table data is as follows:

Name	BRAMs (140)	DSPs (220)	LUTs (53200)	Registers (106400)
Lab6_1	2	0	569	641
DEScore	0	0	382	208
Start	0	0	0	1
round_datapath	0	0	176	80
Key Scheduler	0	0	168	58
DES_fsm	0	0	6	5
Data	0	0	32	64
DES transmit interface block	0	0	67	197
DES receive interface block	0	0	7	137
AXI FIFO	2	0	113	99

In the resource analyzer table:

- The header section of the dialog box indicates the Vivado design stage after which resource utilization data was collected from Vivado. This will be either **Post Synthesis** or **Post Implementation**.
- The local toolbar contains the following commands to change the display of resource counts:
  - Hierarchical/Flat Display: Toggles the display between a hierarchical tree and a flattened list.
  - Collapse All: Collapses the design hierarchy to display only the top-level objects.
  - Expand All: Expands the design hierarchy at all levels to display resources used by each subsystem and each block in the design.

- The number shown in each column heading indicates the total number of each type of resource available in the Xilinx device for which you are targeting your design. In the example below, the design is targeting a Kintex-7 FPGA.

Figure 89: Resource Analysis Report for Kintex-7

Name	BRAMs (445)	DSPs (840)	LUTs (203800)	Registers (407600)
Lab3	0.5000	1	153	273
subsystem1	0.5000	1	97	49
Register1	0	0	0	1
Register	0	0	0	48
Delay7	0	0	1	1
Delay4	0	0	0	20
Delay3	0	0	1	1
Delay2	0	0	0	48
addr_gen	0	0	54	105

- The example displays a hierarchical listing of each subsystem and block in the design, with the count of the following resource types:
  - BRAMs:** block RAM and FIFO primitives.block RAMs (BRAMs) are counted in this way.

Table 5: Number of BRAMs

Primitive Type	# BRAMs
RAMB36E	1
FIFO36E	1
RAMB18E	0.5
FIFO18E	0.5

Variations of Primitives (for example, RAM36E1 and RAM36E2) are all counted in the same way.

$$\text{Total BRAMs} = (\text{Number of RAMB36E}) + (\text{Number of FIFO36E}) + 0.5 \\ (\text{Number of RAMB18E} + \text{Number of FIFO18E})$$

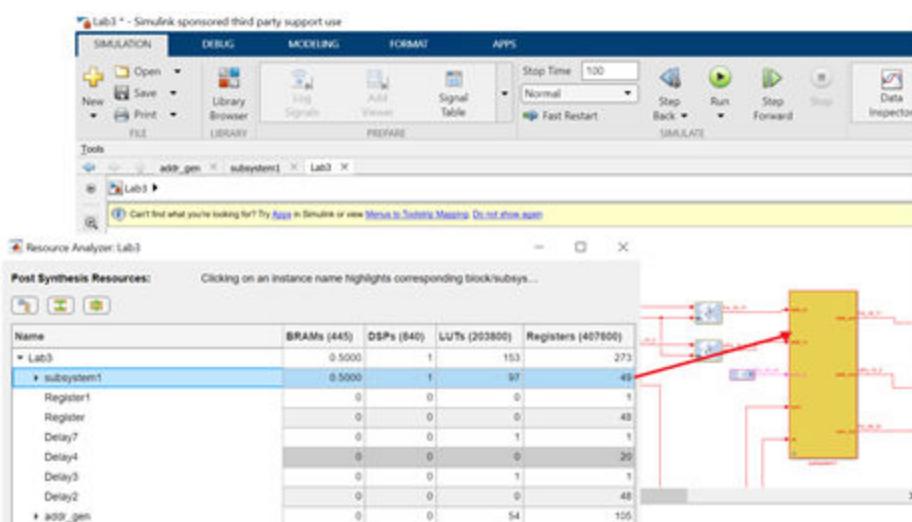
- DSPs:** DSP48 primitives (DSP48E, DSP48E1, DSP48E2) and DSP58
- Registers:** Registers and Flip-Flops. All primitive names that start with FD\* (FDCE, FDPE, FDRE, FDSE, etc.) and LD\* (LDCE, LDPE, etc.) are considered as **Registers**.
- LUTs:** All LUT types combined.
- The display order can be sorted for any column's values by clicking the column head.

- You can cross probe from the table to the Simulink model by selecting a row in the table, which will highlight the corresponding HDL blocks in the Simulink model. See [Cross Probing from the Resource Analysis Results to the Model](#).

## Cross Probing from the Resource Analysis Results to the Model

You can cross probe from the Resource Analyzer table to the Simulink® model by clicking a block or subsystem name in the Resource Analyzer table, which highlights the corresponding HDL block or subsystem in the model. The cross probing is useful to identify blocks and subsystems that are implemented using a particular type of resource.

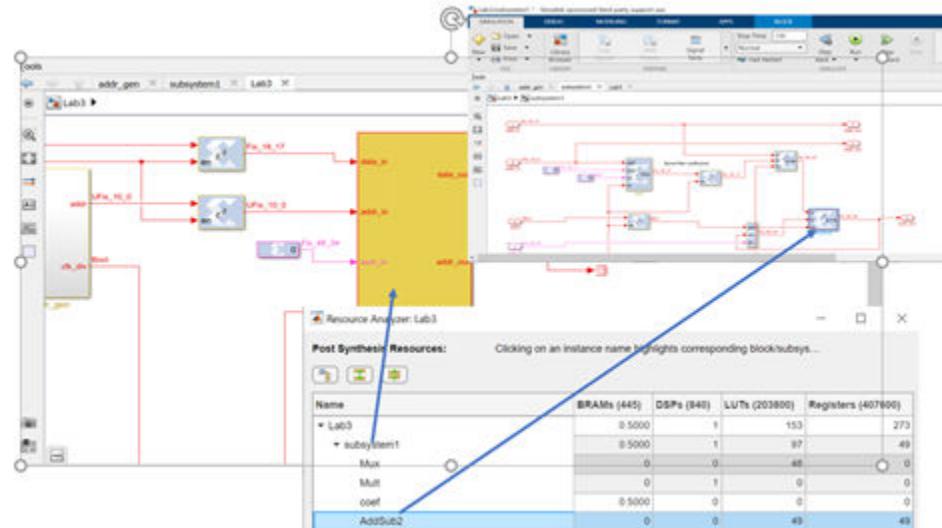
Figure 90: Resource Analyzer



When you cross probe, the following will display in the model:

- The block you have selected in the table will be highlighted in yellow and outlined in red.
- If the block or subsystem you have selected in the table is within an upper-level subsystem, then the parent subsystem is highlighted in red in addition to the underlying block.

Figure 91: Selected Subsystem

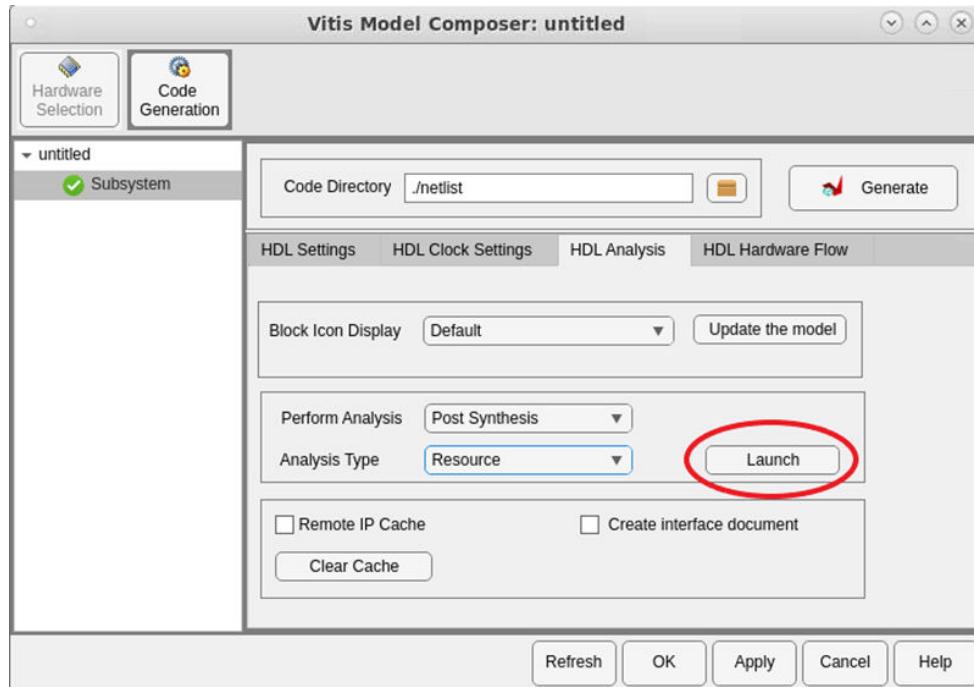


## Accessing Existing Resource Analysis Results

A **Launch** button is provided under the HDL Analysis tab of the Model Composer Hub block dialog box to launch the Resource Analyzer table using the existing resource utilization results for the model. Make sure the **Target directory** specified on the **Compilation** tab of the dialog box is readable by the Resource Analyzer, and the **Analyzer type** field is set to **Resource**. This will only work if you already ran analysis on the Simulink model and haven't changed the Simulink model since the last run.

When you click the **Launch** button, the Resource Analyzer table will display the resource utilization results stored in the **Target directory** specified on the **Compilation** tab, regardless of the option selected for **Perform analysis** (the **Post Synthesis** or **Post Implementation** option).

Figure 92: Launch Button



You can launch the Resource Analyzer table to display existing resource utilization results by entering the following command at the MATLAB® command prompt:

```
>> xlAnalyzeResource(get_param('model_name','handle'),'./netlist')
```

- `get_param('model_name','handle')` gives you the model handle.  
**Note:** `model_name` represents the name of the model.
- For the path to `netlist` directory, you can use an absolute path, or if you are using this API from the same directory where `netlist` directory is present, then you can use a relative path like `'./netlist'`.

## ***Recommendations for Optimizing Resource Analysis***

The following are recommended for using the Resource Analyzer to optimize resource utilization in the design:

- For quicker resource analysis iterations, post-synthesis analysis is preferred over post-implementation analysis.
- After logic optimization during the Vivado Synthesis process the tool does not keep information about merged logic in the Vivado database. Merged and shared logic may make it difficult to accurately cross probe from Vivado resource data to the Simulink model. Hence, it is recommended that you create a custom Vivado Synthesis strategy to control merged and shared logic.

For information about how to create a custom Synthesis strategy in Vivado IDE, see this [link](#) in the *Vivado Design Suite User Guide: Using the Vivado IDE* ([UG893](#)).

To control merged and shared logic in the Vivado IDE, make the following changes to the default Vivado Synthesis strategy.

1. In Vivado IDE:
  - . Select the Synthesis option `-keep_equivalent_registers`.
  - . Set the Synthesis option `-resource_sharing` to the value `off`.
2. Save the new Synthesis strategy and exit Vivado IDE.
3. In Vitis Model Composer, select the new custom **Synthesis Strategy** in the Model Composer Hub dialog box (HDL Settings tab) before generating the design.

---

## Using Hardware Co-Simulation

Model Composer provides hardware co-simulation, making it possible to incorporate a design running in an FPGA directly into a Simulink® simulation. This allows all (or a portion) of the Model Composer design that had been simulating in Simulink as sequential software to be executed in parallel on the FPGA, and can speed up simulation dramatically. Users of this flow can send larger data sets, or more test vectors, doing an exhaustive functional test of the implemented logic. This increased code coverage allows more corner cases to be verified to help identify design bugs in the logic. Data at the input to the compiled co-simulation block on the Simulink model is sent to the target FPGA, either as one transaction or a burst of transactions, executed for a given number of clock cycles in parallel, and read back to the model's co-simulation outputs.

Hardware co-simulation has two compilation types: burst or non-burst (standard). The burst mode provides much higher performance. Channels to each input of the compiled co-simulation target are opened and packets of data are sent to the open channel, followed by bursting to all of the remaining inputs. The FPGA design is executed in parallel for enough cycles to consume the data, and the target outputs are burst read in a channelized fashion. Bursting provides for less overhead to send and receive large amounts of data from the FPGA. However, burst mode is only supported through MATLAB® script-based hardware co-simulation of the Hardware Co-Simulation target and is not used within Simulink. Exhaustive data vectors can be scripted to test the functionality of the co-simulation target, and an example script is returned as part of the compilation. Non-burst mode has lower performance but allows a compiled co-simulation block to be used within Simulink in place of the original Model Composer design hierarchy.

**Note:** Hardware co-simulation does not support designs which contain multiple clocks.

Board support allows the JTAG-based physical interface to communicate with the co-simulation target: JTAG-based communication is available for most of the JTAG aware boards that exist as a project target in Vivado®. Boards from Xilinx partners are available and can be downloaded from the partner websites and installed as part of the Vivado Design Suite. Custom boards can also be created as detailed in Appendix A, Board Interface File, in the *Vivado Design Suite User Guide: System-Level Design Entry* ([UG895](#)). Setting up board awareness in Model Composer and the minimum tags needed in the `board.xml` file are detailed in the section [Specifying Board Support in Model Composer HDL Blockset](#).

Hardware Co-Simulation compilation targets automatically create a bitstream based on the selected communication interface and associate it to a block.

- If a board is supported for JTAG hardware co-simulation, the **Hardware Co-Simulation** option for **Compilation** is enabled in the Model Composer Hub block dialog box when you perform the procedure described in [Compiling a Model for Hardware Co-Simulation](#). If the **Hardware Co-Simulation** option is grayed out and disabled, you cannot perform JTAG hardware co-simulation on the board.

This support applies to the following types of boards:

*Table 6: Board Support*

Board Name	Display Name
zed	ZedBoard Zynq Evaluation and Development Kit
ac701	Artix-7 AC701 Evaluation Platform 1.0/1.1
kc705	Kintex-7 KC705 Evaluation Platform 1.0/1.1
kcu105	Kintex UltraScale KCU105 Evaluation Platform
vc707	VirTEX-7 VC707 Evaluation Platform
vc709	VirTEX-7 VC709 Evaluation Platform
vcu108	VirTEX UltraScale VCU108 Evaluation Platform
zc702	ZYNQ-7 ZC702 Evaluation Board
zc706	ZYNQ-7 ZC706 Evaluation Board

- Xilinx boards installed as part of your Vivado installation.
- Partner boards, which are available and can be downloaded from the partner websites and installed as part of the Vivado Design Suite.
- Custom boards, which can be created in the Vivado Design Suite as detailed in this [Link](#), in the *Vivado Design Suite User Guide: System-Level Design Entry* ([UG895](#)).

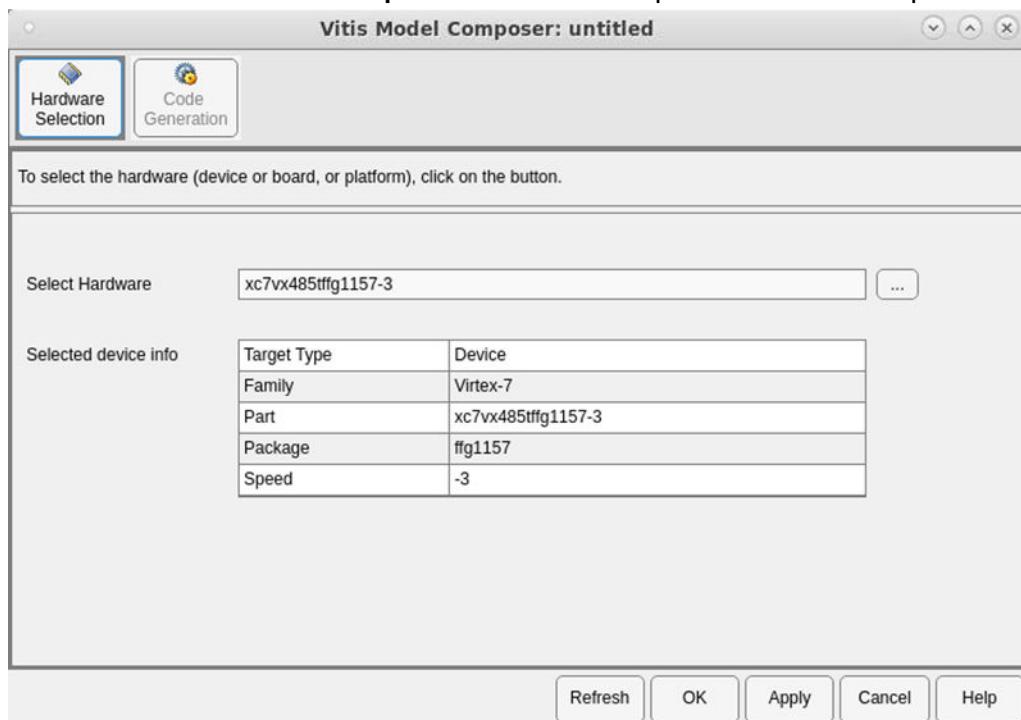
## Compiling a Model for Hardware Co-Simulation

The starting point for hardware co-simulation is the Model Composer model or subsystem you would like to run in hardware. A model can be co-simulated if it meets the requirements of the underlying hardware board. The model must include a Model Composer Hub block; this block defines how the model should be compiled into hardware.

For information on how to use the Model Composer Hub, see [Compiling and Simulating Using the Model Composer Hub](#).

To compile your Vitis Model Composer model for hardware co-simulation, perform the following:

1. Double-click the **Vitis Model Composer Hub** block to open the Model Composer Hub dialog



box.

2. In the **Hardware Selection** tab, click on the button next to the **Select Hardware** field to open the Device Chooser.
3. In the **Boards** tab, select a Board.

The boards appearing in the **Board** list are:

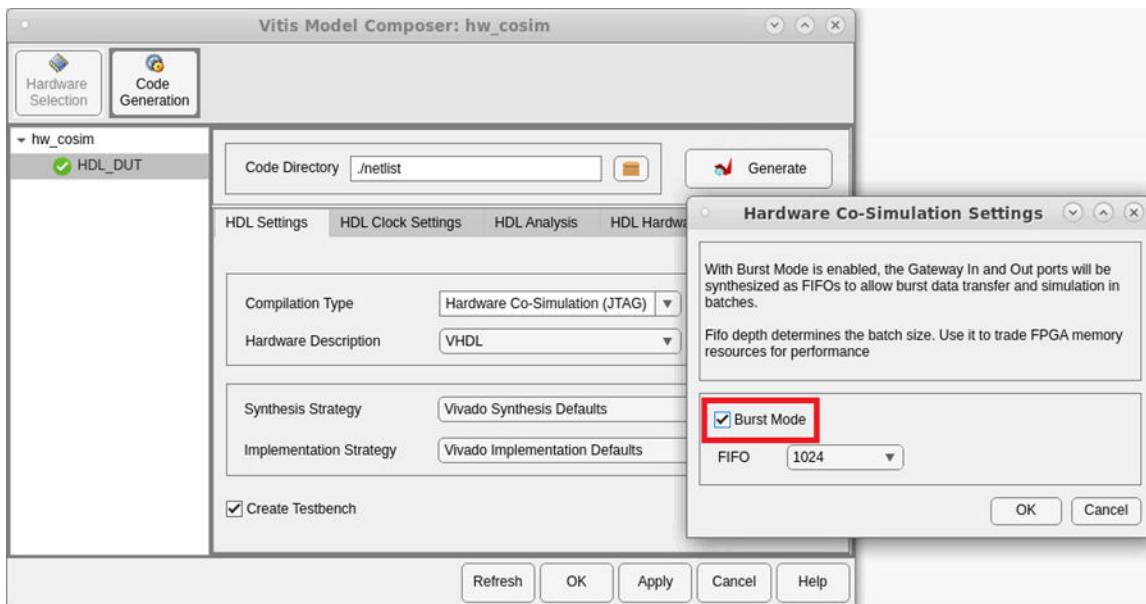
- All of the boards installed as part of Vivado.
- Any custom boards you have created in Vivado.
- Any Partner boards you have purchased and enabled in Vivado.

For a Partner board or a custom board to appear in the Board list, you must configure Vitis Model Composer to access the board files that describe the board. Board awareness in Model Composer is detailed in [Specifying Board Support in Model Composer HDL Blockset](#).

To compile for hardware co-simulation, you must select a Board. You cannot select a Part or Platform.

4. Click **OK** to close the Device Chooser.
5. In the Code Generation pane, select the desired HDL subsystem from the list on the left.
6. In the HDL Settings tab, select a Compilation Type of **Hardware Co-Simulation (JTAG)**.
7. If you will use burst mode for a faster hardware co-simulation run, click the button next to the Compilation Type field, select **Burst Mode**, and enter a FIFO depth for the burst mode operation. Then click **OK** to close the Hardware Co-Simulation Settings dialog box.

For a description of the burst mode, see [Burst Data Transfers for Hardware Co-Simulation](#).



**IMPORTANT!** To perform a burst mode hardware co-simulation, you must create a test bench by checking the **Create Testbench** box on the HDL Settings tab of the Vitis Model Composer Hub block.

8. If you want to create a test bench as part of the compilation, select the **Create Testbench** option on the HDL Settings tab. If you select **Create Testbench**, the compilation will automatically create an example testbench for you. You can also create your own test bench for hardware co-simulation (see [M-Code Access to Hardware Co-Simulation](#)).
9. Click the **Generate** button.

The code generator produces an FPGA configuration bitstream for your design that is suitable for hardware co-simulation. Model Composer not only generates the HDL and netlist files for your model during the compilation process, but it also runs the downstream tools necessary to produce an FPGA configuration file.

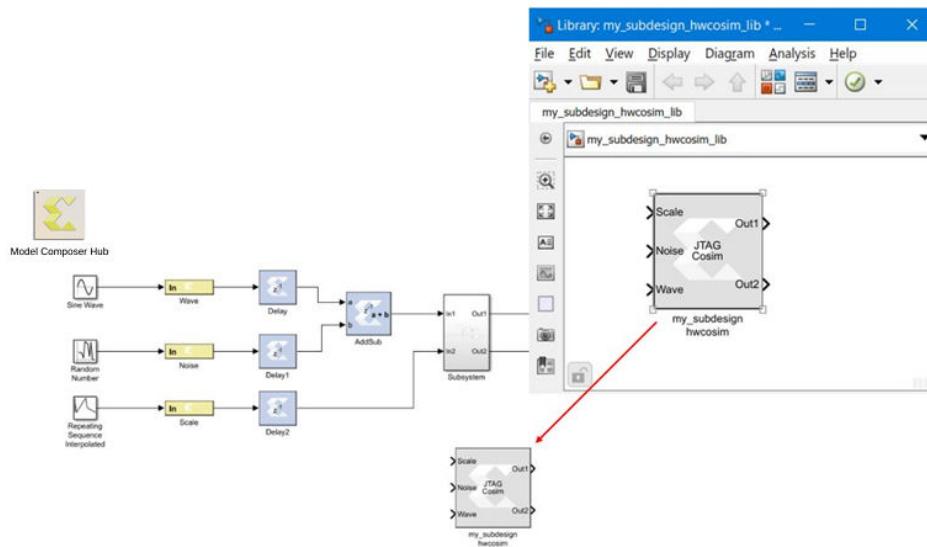
The configuration bitstream contains the hardware associated with your model, and also contains additional interfacing logic that allows Model Composer to communicate with your design using a physical interface between the board and the PC. This logic includes a memory map interface over which Model Composer can read and write values to the input and output ports on your design. It also includes any board-specific circuitry that is required for the target FPGA board to function correctly.

When the Compilation finishes the results are as follows:

- If you *have not selected* **Burst mode** in step 7 above (standard mode), a **JTAG Cosim** hardware co-simulation block will appear in a separate window. Drag (or Copy and Paste) the Hardware Cosim block into your Simulink model. The Hardware Cosim block will enable you to perform hardware co-simulation from within the Simulink window.

For a description of the hardware co-simulation block, see [Hardware Co-Simulation Blocks](#).

Figure 93: Hardware Co-Simulation Library Block



If you selected the **Create Testbench** option for compilation, an M-Code HWCosim example test bench will also be generated (see [M-Code Access to Hardware Co-Simulation](#)) by the compilation. You can use this test bench to perform hardware co-simulation, or customize this test bench to develop a test bench of your own.

- If you *have selected* **Burst mode** in step 7 above (burst mode), no hardware co-simulation block will appear. When you perform the burst mode co-simulation, you will use the MATLAB® M-code test bench placed in the target directory during compilation.
  - If you compiled the top-level design the test bench will be named:

```
<design_name>_hwcosim_test.m
```

- If you compiled a subsystem of the design the test bench will be named:

```
<design_name>_<sub_system>_hwcosim_test.m
```

The compilation has prepared the Simulink model for performing hardware co-simulation.

To perform the hardware co-simulation, proceed as follows:

- To perform the standard (non-burst mode) hardware co-simulation, see [Performing Standard Hardware Co-Simulation](#).
- To perform the burst mode hardware co-simulation, see [Performing Burst Mode Hardware Co-Simulation](#).

## Performing Standard Hardware Co-Simulation

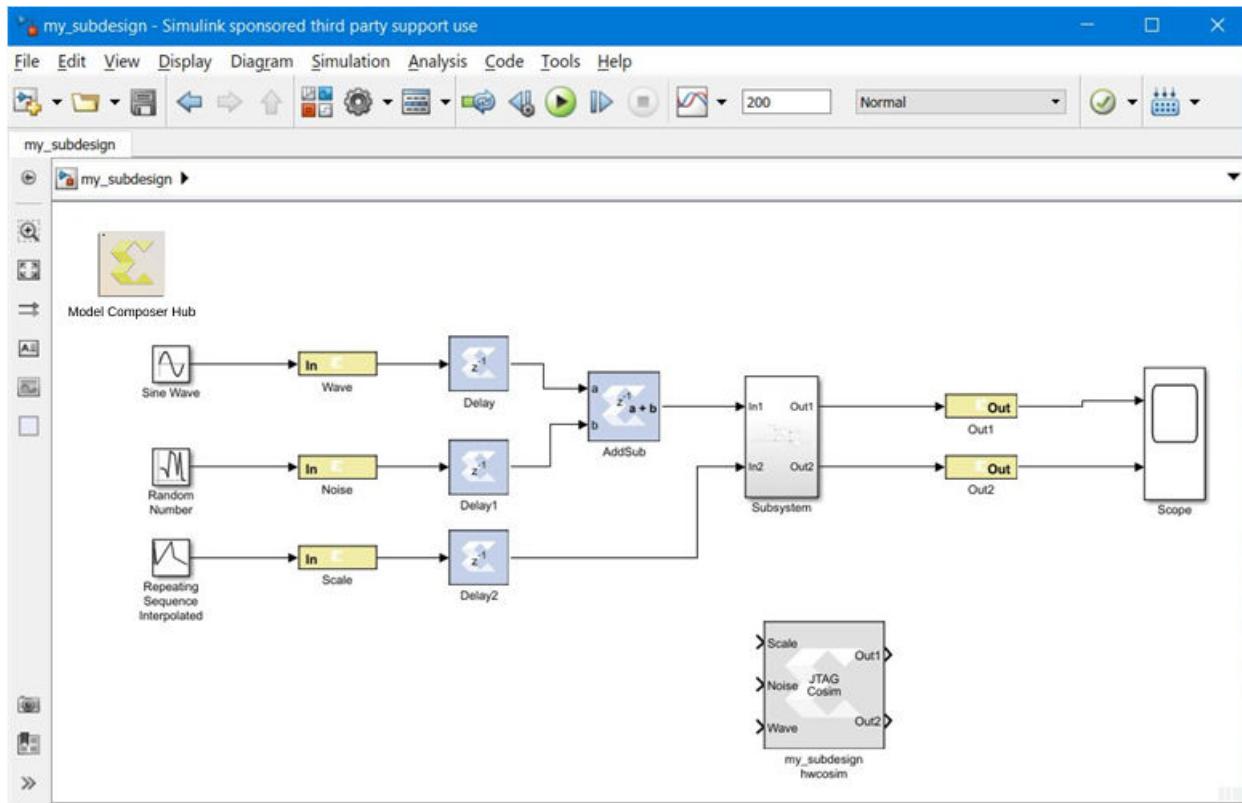
If you are performing the standard (non-burst mode) hardware co-simulation, your Simulink model will contain a JTAG hardware co-simulation block. This block was created automatically when Model Composer finished compiling your design into an FPGA bitstream (see [Compiling a Model for Hardware Co-Simulation](#)). The block is stored in a Simulink library with this file name:

```
<design_name>_hwcosim_lib.slx
```

The hardware co-simulation block was moved into your Simulink model at the end of the compilation procedure. In the following procedure, you will have to wire up this block in your Simulink model to perform hardware co-simulation.

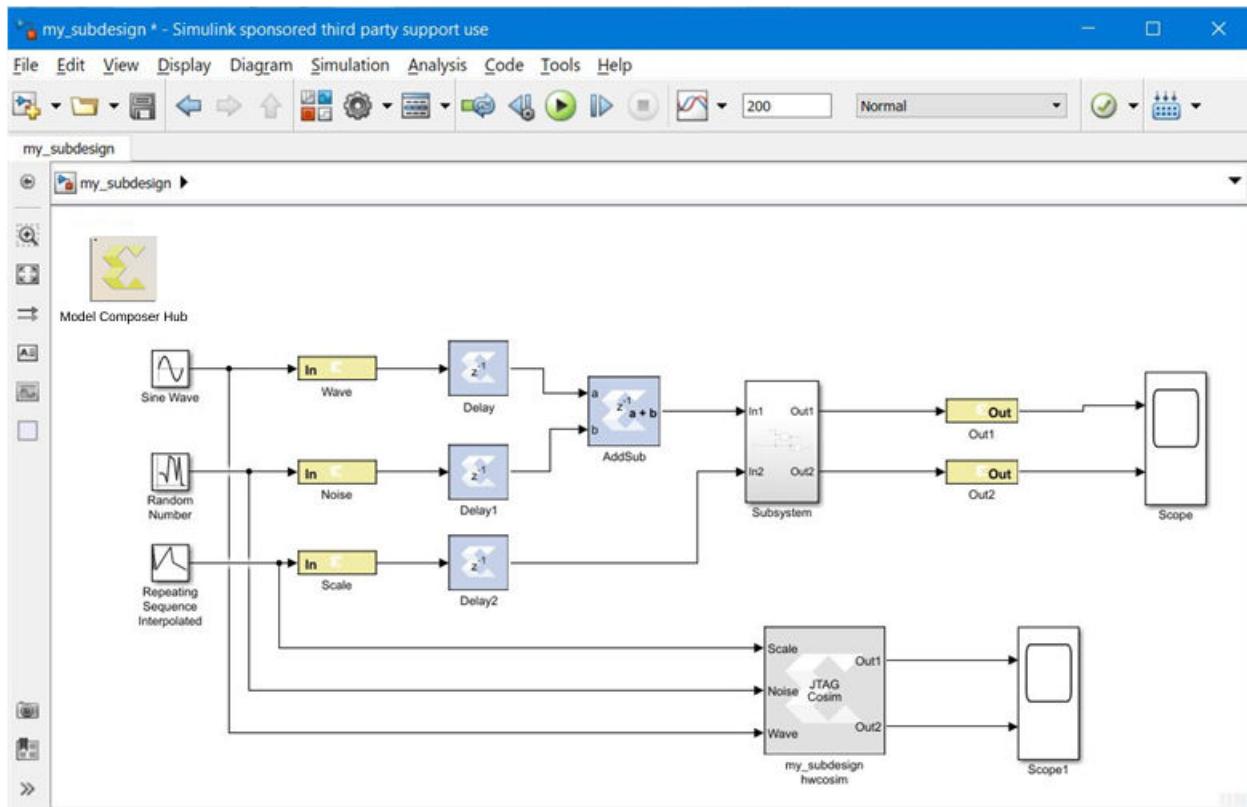
**Note:** If your board contains a Zynq® SoC device, you must install the Vitis™ unified software platform with the Vivado® Design Suite to perform hardware co-simulation.

Figure 94: Hardware Co-Simulation Block

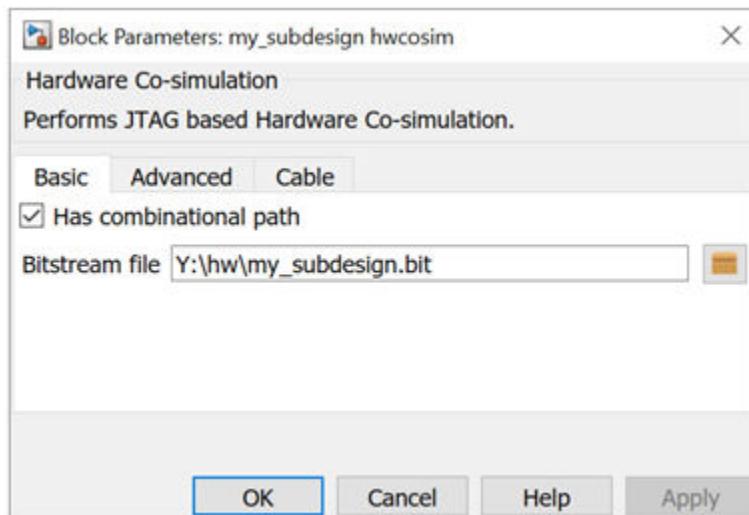


To perform the standard hardware co-simulation:

1. Connect the hardware co-simulation block to the Simulink blocks that supply its inputs and receive its outputs.



- Double-click the hardware co-simulation block to display the properties dialog box for the block.



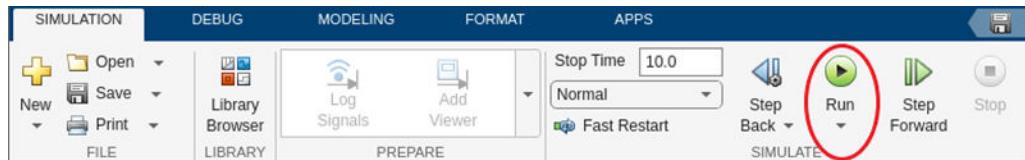
- Fill out the block parameters in the properties dialog box.

The properties are described in [Block Parameters for the JTAG Hardware Co-Simulation Block](#).

- To set up the board for performing JTAG hardware co-simulation, you should connect a cable to the board's JTAG port.

For a description of the setup procedure for a JTAG hardware co-simulation, using a KC705 board as an example, see [Setting Up a KC705 Board for JTAG Hardware Co-Simulation](#).

5. In the Simulink model, simulate the model and the hardware by clicking the **Run** button on the Simulation tab.



Running the simulation will simulate both the Model Composer design (or subsystem) in your Simulink model and the Xilinx device on your target board. You can then examine the results of the two simulations and compare the results to determine if the design implemented in hardware will operate as expected.

## Performing Burst Mode Hardware Co-Simulation

To perform the burst mode hardware co-simulation, you will execute the MATLAB M-code test bench that was generated automatically during compilation (see [Compiling a Model for Hardware Co-Simulation](#)).

This test bench resides in the **Target directory** specified when the design was compiled for the hardware co-simulation compilation target.

The test bench is named as follows:

- If you compiled the top-level design the test bench will be named:

```
<design_name>_hwcosim_test.m
```

- If you compiled a subsystem of the design the test bench will be named:

```
<design_name>_<sub_system>_hwcosim_test.m
```

**Note:** If your board contains a Zynq® SoC device, you must install the Vitis™ unified software platform with the Vivado® Design Suite to perform hardware co-simulation.

To perform burst mode hardware co-simulation, do the following:

1. Set up the board for performing JTAG hardware co-simulation.
  - Connect a cable to the board's JTAG port.  
For a description of the setup procedure for a JTAG hardware co-simulation, using a KC705 board as an example, see [Setting Up a KC705 Board for JTAG Hardware Co-Simulation](#).
2. Run the test bench script from the MATLAB console. To run the test bench script, you can open the MATLAB console, change directory to the **Target directory** and run the script by name.

The script runs the Simulink model to determine the stimulus data driven to the Xilinx Gateway In blocks (from the other Simulink source blocks or MATLAB variables), and captures the expected output produced by the Xilinx block design (BD), and exports the data to the **Target directory** as these separate data files:

```
<design_name>_<sub_system>_<port_name>.dat
```

The test bench then compares actual to expected outputs.

If the test fails this will be printed on the console, and the failing comparisons will be listed in this file:

```
<design_name>_<sub_system>_hwcosim_test.result
```

## M-Code Access to Hardware Co-Simulation

It is possible to programmatically control the hardware created through the Model Composer HDL hardware co-simulation flow using MATLAB M-code (M-Hwcosim). The M-Hwcosim interfaces allow for MATLAB objects that correspond to the hardware to be created in pure M-code, independent of the Simulink framework. These objects can then be used to read and write data into hardware. This capability is useful for providing a scripting interface to hardware co-simulation, allowing for the hardware to be used in a scripted test bench or deployed as hardware acceleration in M-code.

For more information on this subject, refer to [M-Code Access to Hardware Co-Simulation](#).

## Setting Up Your Hardware Board

The first step in performing hardware co-simulation is to set up your hardware board. The hardware setup for JTAG hardware co-simulation is as follows:

For JTAG-based hardware co-simulation, you will connect a cable to the board's JTAG port. Consult your board's documentation for the location of the board's JTAG port. Documentation for Xilinx boards can be downloaded from the [Boards and Kits](#) page on the Xilinx website.

For a description of the setup procedure for a JTAG hardware co-simulation, using a KC705 board as an example, see [Setting Up a KC705 Board for JTAG Hardware Co-Simulation](#).

### ***Setting Up a KC705 Board for JTAG Hardware Co-Simulation***

The following procedure describes how to set up the hardware required to run JTAG hardware co-simulation on a KC705 board.

For detailed information about the KC705 board, see the *KC705 Evaluation Board for the Kintex-7 FPGA User Guide* ([UG810](#)).

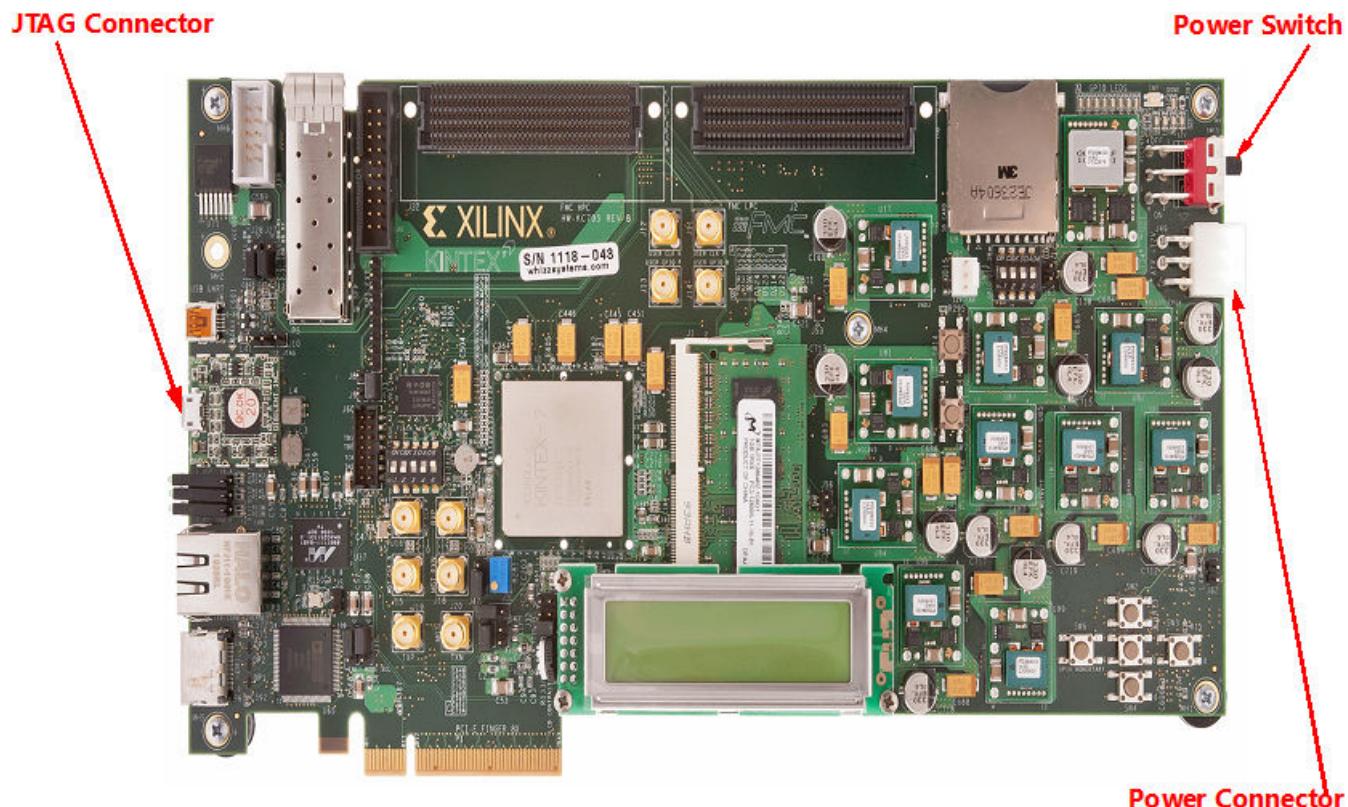
## Assemble the Required Hardware

1. Xilinx Kintex-7 KC705 board which includes the following:
  - a. Kintex-7 KC705 board
  - b. 12V Power Supply bundled with the KC705 kit
  - c. Micro USB-JTAG cable

## Set Up the KC705 Board

The figure below illustrates the KC705 components of interest in this JTAG setup procedure:

Figure 95: KC705 Board



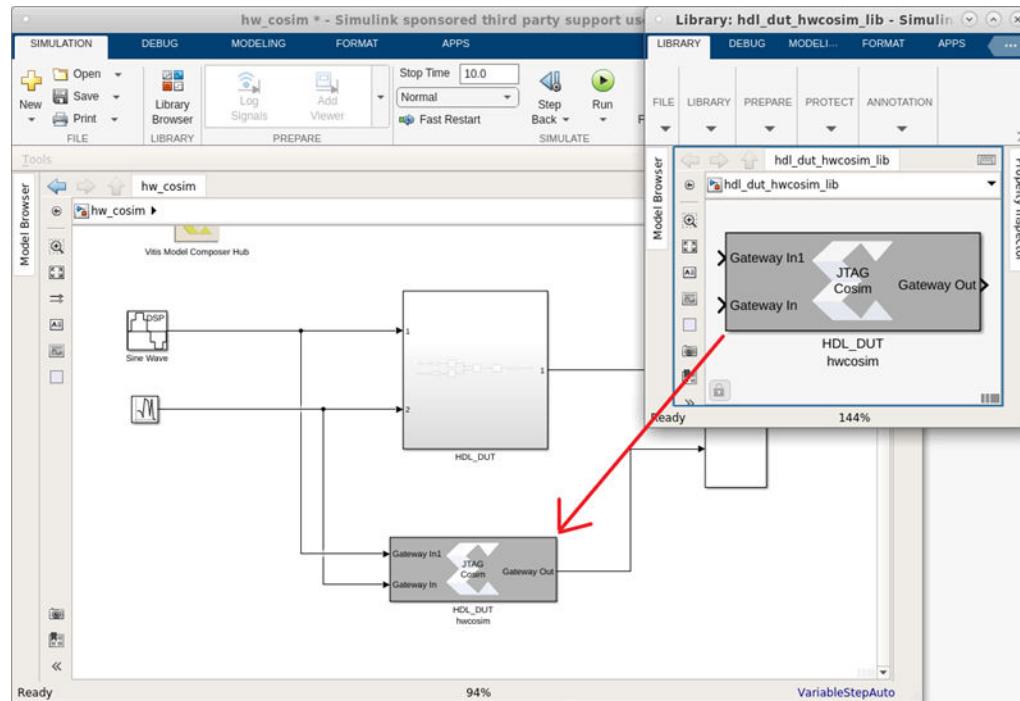
1. Position the KC705 board as shown above.
2. Make sure the power switch, located in the upper-right corner of the board, is in the OFF position.
3. Connect the AC power cord to the power supply brick. Plug the power supply adapter cable into the KC705 board. Plug in the power supply to AC power.
4. Connect the small end of the Micro USB-JTAG cable to the JTAG socket.
5. Connect the large end of the Micro USB-JTAG cable to a USB socket on your PC.

6. Turn the KC705 board Power switch ON.

## Hardware Co-Simulation Blocks

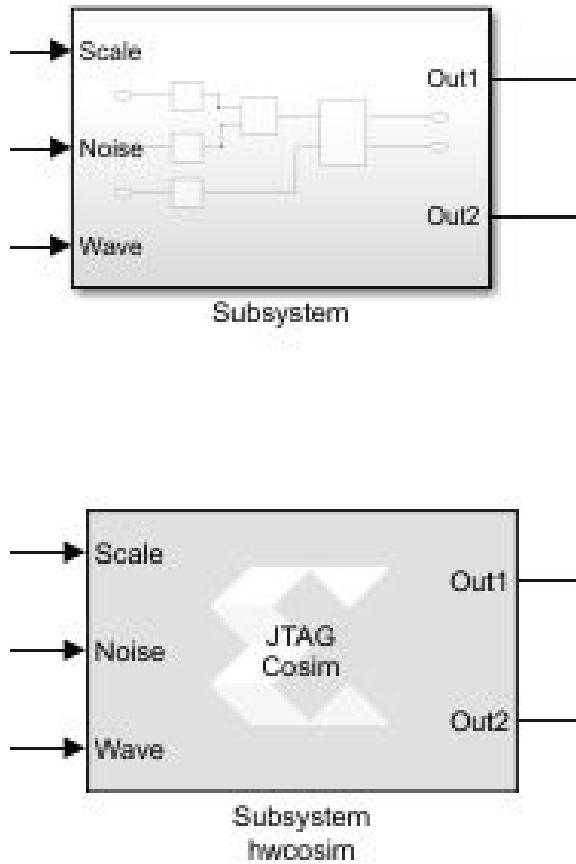
Model Composer automatically creates a new hardware co-simulation block once it has finished compiling your design into an FPGA bitstream. It also creates a Simulink library to store the hardware co-simulation block. At this point, you can copy the block out of the library and use it in your Model Composer design like any other Simulink or HDL blocks.

Figure 96: Hardware Co-Simulation Blocks



The hardware co-simulation block assumes the external interface of the model or Subsystem from which it is derived. The port names on the hardware co-simulation block match the ports names on the original Subsystem. The port types and rates also match the original design.

Figure 97: Port Names



Hardware co-simulation blocks are used in a Simulink design the same way other blocks are used. During simulation, a hardware co-simulation block interacts with the underlying FPGA board, automating tasks such as device configuration, data transfers, and clocking. A hardware co-simulation block consumes and produces the same types of signals that other Model Composer HDL blocks use. When a value is written to one of the block's input ports, the block sends the corresponding data to the appropriate location in hardware. Similarly, the block retrieves data from hardware when there is an event on an output port.

hardware co-simulation blocks may be driven by Xilinx® fixed-point signal types, Simulink fixed-point signal types, or Simulink doubles. Output ports assume a signal type that is appropriate for the block they drive. If an output port connects to an HDL block, the output port produces a Xilinx® fixed-point signal. Alternatively, the port produces a Simulink data type when the port drives a Simulink block directly.

**Note:** When Simulink data types are used as the block signal type, quantization of the input data is handled by rounding, and overflow is handled by saturation.

Like other HDL blocks, hardware co-simulation blocks provide parameter dialog boxes that allow them to be configured with different settings. The parameters that a hardware co-simulation block provides depend on the FPGA board the block is implemented for (i.e., different FPGA boards provide their own customized hardware co-simulation blocks).

## ***Block Parameters for the JTAG Hardware Co-Simulation Block***

The block parameters dialog box for the JTAG hardware co-simulation block can be invoked by double-clicking the block icon in your Simulink model.

Parameters specific to the block are as follows:

### **Basic tab**

**Has combinational path:** Select this if your circuit has any combinational paths. A combinational path is one in which a change propagates from input to output without any clock event. There is no latch, flip-flop, or register in the path. Enabling this option causes Model Composer to read the outputs immediately after writing inputs, before clocking the design. This ensures that value changes on combinational paths extending from the hardware co-simulation block into the Simulink Model get propagated correctly.

**Bitstream file:** Specify the FPGA configuration bitstream. By default this field contains the path to the bitstream generated by Model Composer during the last **Generate** triggered from the Model Composer Hub block.

### **Advanced tab**

**Skip device configuration:** When selected, the configuration bitstream will not be loaded into the FPGA or SoC. This option can be used if another program is configuring the device (for example, the Vivado Hardware Manager and the Vivado Logic Analyzer).

**Display Part Information:** This option toggles the display of the device part information string (for example, `xc7k325tffg900-2` for a Kintex device) in the center of the hardware co-simulation block.

### **Cable tab**

Cable Settings

- **Type:** Currently, **Auto Detect** is the only setting for this parameter. Model Composer will automatically detect the cable type.

## **Hardware Co-Simulation Clocking**

If you are performing a standard hardware co-simulation, you will have to select a clocking mode when you configure the co-simulation block included in your Simulink model.

## Clocking Modes

There are several ways in which a Model Composer hardware co-simulation block can be synchronized with its associated FPGA hardware. In single-step clock mode, the FPGA is in effect clocked from Simulink, whereas in free-running clock mode, the FPGA runs off an internal clock, and is sampled asynchronously when Simulink wakes up the hardware co-simulation block.

### Single-Step Clock

In single-step clock mode, the hardware is kept in lock step with the software simulation. This is achieved by providing a single clock pulse (or some number of clock pulses if the FPGA is over-clocked with respect to the input/output rates) to the hardware for each simulation cycle. In this mode, the hardware co-simulation block is bit-true and cycle-true to the original model.

Because the hardware co-simulation block is in effect producing the clock signal for the FPGA hardware only when Simulink awakes it, the overhead associated with the rest of the Simulink model's simulation, and the communication overhead (e.g. bus latency) between Simulink and the FPGA board can significantly limit the performance achieved by the hardware. As long as the amount of computation inside the FPGA is significant with respect to the communication overhead (e.g. the amount of logic is large, or the hardware is significantly over-clocked), the hardware will provide significant simulation speed-up.

### Free-Running Clock

In free-running clock mode, the hardware runs asynchronously relative to the software simulation. Unlike the single-step clock mode, where Simulink effectively generates the FPGA clock, in free-running mode, the hardware clock runs continuously inside the FPGA itself. In this mode, simulation is not bit and cycle true to the original model, because Simulink is only sampling the internal state of the hardware at the times when Simulink awakes the hardware co-simulation block. The FPGA port I/O is no longer synchronized with events in Simulink. When an event occurs on a Simulink port, the value is either read from or written to the corresponding port in hardware at that time. However, since an unknown number of clock cycles have elapsed in hardware between port events, the current state of the hardware cannot be reconciled to the original Model Composer model. For many streaming applications, this is in fact highly desirable, as it allows the FPGA to work at full speed, synchronizing only periodically to Simulink.

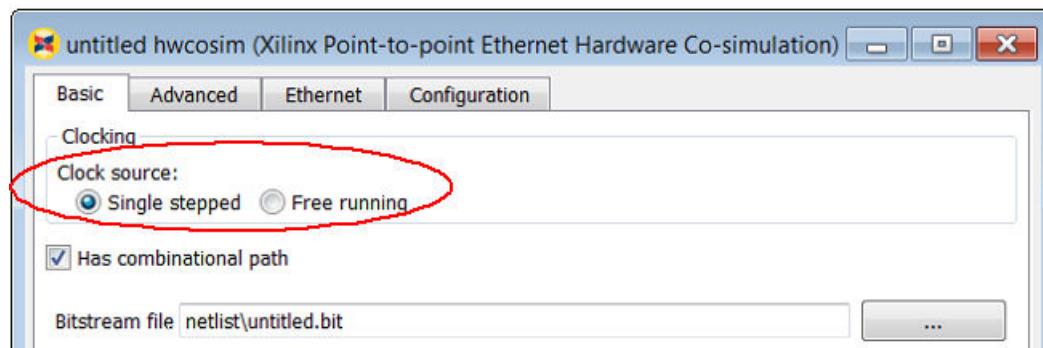
In free-running mode, you must build explicit synchronization mechanisms into the Model Composer model. A simple example is a status register, exposed as an output port on the hardware co-simulation block, which is set in hardware when a condition is met. The rest of the Model Composer model can poll the status register to determine the state of the hardware.

## Selecting the Clock Mode

Not every hardware board supports a free-running clock. However, for those that do, the parameters dialog box for the hardware co-simulation block provides a means to select the desired clocking mode. You may change the co-simulation clocking mode before simulation starts by selecting either the **Single stepped** or **Free running** radio button for **Clock Source** in the parameters dialog box.

**Note:** The clocking options available to a hardware co-simulation block depend on the FPGA board being used (i.e., some boards may not support a free-running clock source, in which case it is not available as a dialog box parameter).

Figure 98: Single Stepped Button



For a description of a way to programmatically turn on or off a free-running clock using M-Hardware Cosim, see the description of the Run operation under in [M-Hwcosim MATLAB Class](#).

## Burst Data Transfers for Hardware Co-Simulation

Hardware co-simulation (HWCosim) is a methodology by which a user can offload, either partially or whole, the most compute intensive portion of a model into the actual target FPGA platform. The host system provides the stimulus to the model via the co-simulation interface (typically JTAG) and post-processes the response. This methodology is useful for validating the correctness of the generated hardware design on the target platform itself, as well as for speeding up the simulation time during verification of the model in a hardware co-verification scenario.

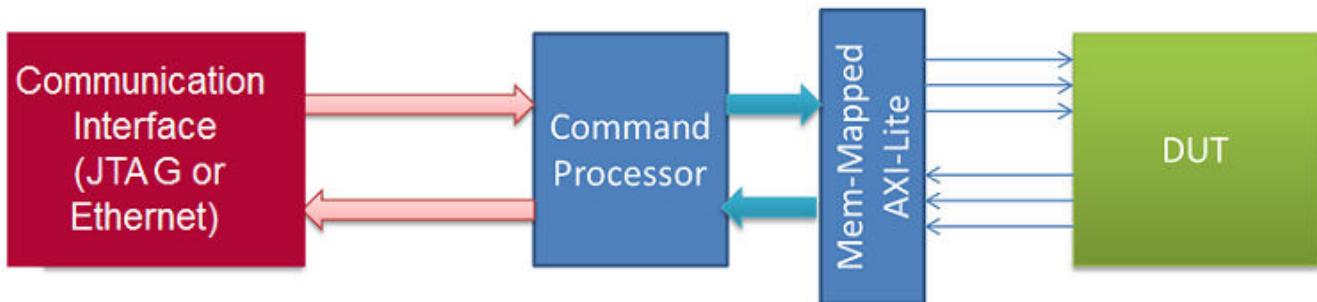
MATLAB/Simulink in conjunction with Model Composer currently supports two variants of HWCosim: GUI-based and MATLAB M-script based. The first is run under the control of the Simulink scheduler, and can only progress one clock cycle at a time, due to the potential for feedback loops in the model.

The second variant is MATLAB M-script based simulation under Model Composer control (M-HWCosim), which is commonly used in testbenches produced as collateral during the bitstream generation from the Model Composer Hub block. These testbenches are typically feedback-free and come with a-priori known input that can be transferred to the device in larger batches.

## Hardware Co-Simulation Overview

A high-level overview of hardware co-simulation (HWCosim) is given in the figure below. At the center of it is the device under test (DUT). The DUT is typically a piece of IP that is developed and tested within a Simulink test framework providing the stimulus and receiving (and potentially evaluating) the response. In order to allow for Simulink to communicate with the DUT it needs to be embedded into the HWCosim wrapper consisting of the following components:

Figure 99: Hardware Co-Simulation Flow

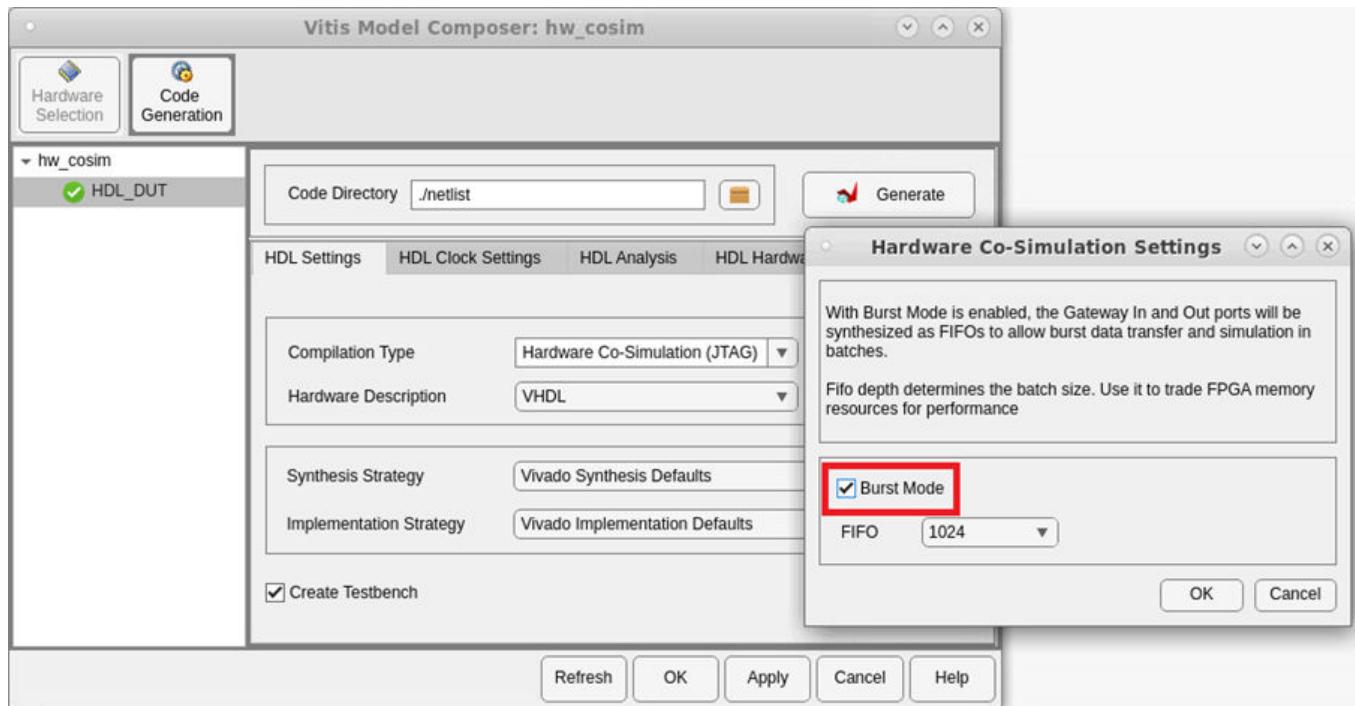


- **Communication interface (JTAG):** Used for communications with the host PC, receiving the command messages and sending responses.
- **Command processor:** Command messages are parsed and executed.
- **Memory-mapped AXI4-Lite register bank:** Use `write` commands to set up the stimulus data in the register map, which is driving the inputs to the DUT. Similarly, use `read` commands to query the memory-mapped DUT outputs. Finally, use a `run(x)` command to the memory-mapped clock control register to trigger exactly "x" clock pulses on the DUT's clock input. Alternatively, use `run(inf)` to start the free-running clock mode and `run(0)` to turn the clock off.

## Burst Data Transfer Mode

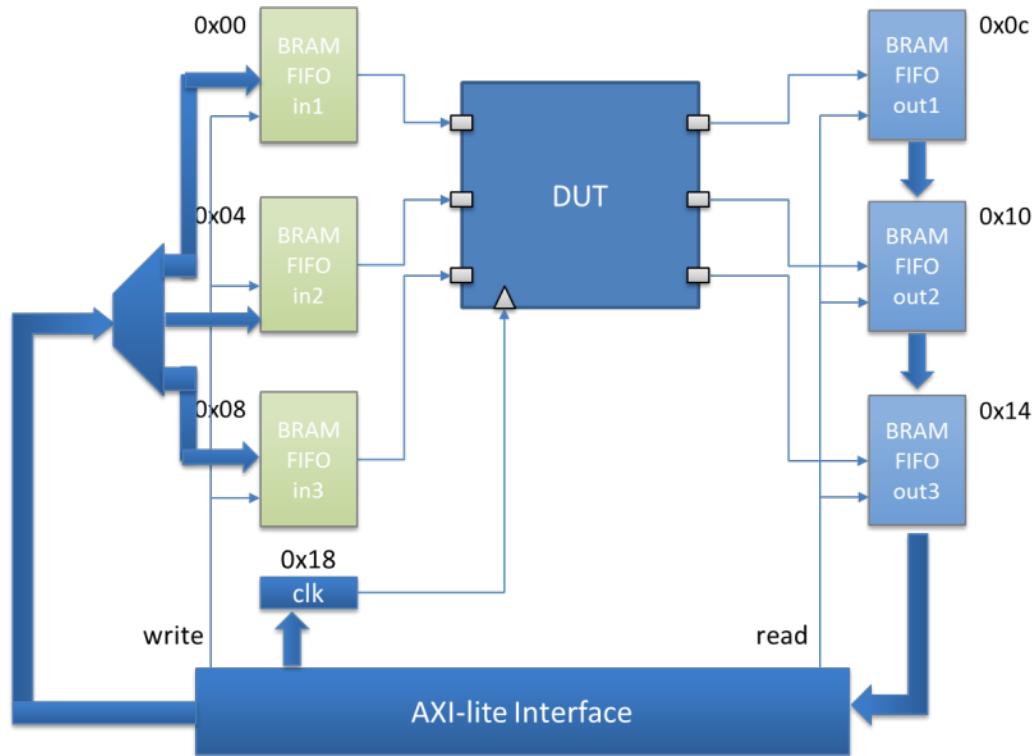
If you enable burst data transfer mode in the Model Composer Hub block (**Compilation→Settings→Burst mode**), the non-clock input and output registers will be replaced with "n"-entry FIFOs. You can select "n" (**FIFO depth**), which is useful for trading off performance versus FPGA block RAM resource use.

Figure 100: Burst Mode



Enabling **Burst mode** allows the M-HWCosim scheduler to "burst write" a time-sequence of "n" values into each input FIFO, run the clock for a number of cycles determined by the rate of input/output ports and the FIFO depths, and capture the resulting output in the output FIFOs. After the batch has been run, the scheduler proceeds to "burst read" the contents of the output FIFOs into a MATLAB array, where it can be checked against expected data.

Figure 101: Burst Mode Flow



This batch processing of time samples allows to better pack data into JTAG sequences or thereby significantly reducing overhead.

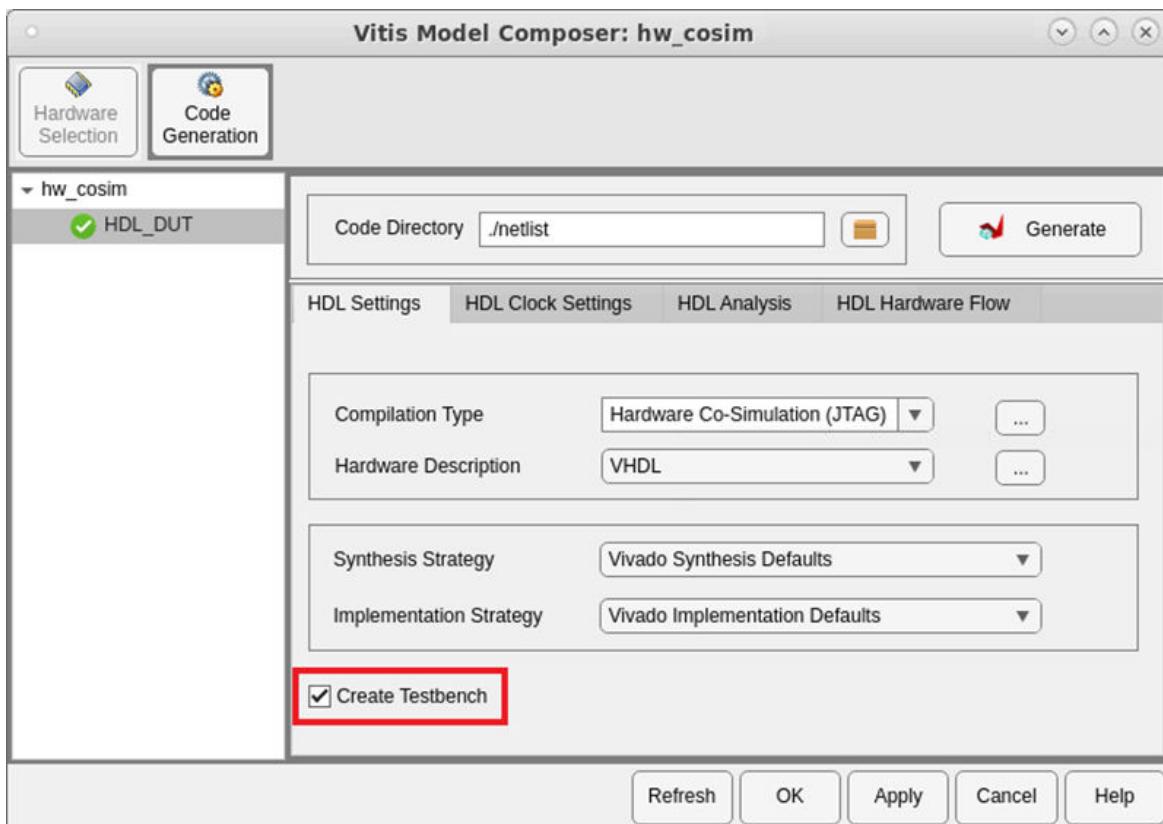
## How to Use Burst Data Transfer Mode

The simplest way for you to start using burst data transfer mode is via an automatically generated test bench script. Advanced users can make use of the HWCosim API exposed via the MATLAB Hwcosim objects that are shipped with Model Composer.

### Automatic Testbench Generation

Testbench generation is run alongside the hardware co-simulation compilation flow. You can enable the automatic creation of an M-HWCosim test bench script by enabling **Create Testbench** at the bottom of the HDL Settings tab.

Figure 102: Create Test Bench



The test generator will produce this M-script file in the Target Directory:

```
<design_name>_<sub_system>_hwcosim_test.m
```

You can run this script from the MATLAB® console. The script will also run the Simulink model to determine the stimulus data driven to the Xilinx® Gateway In blocks (from the other Simulink source blocks or MATLAB variables), while also capturing the expected output produced by the Xilinx® Block Design (BD) and exporting the data to the **Target directory** as these separate data files:

```
<design_name>_<sub_system>_<port_name>.dat
```

To run the test bench, you can open the MATLAB console, change directory to the Target Directory, and run the script by name. If the test fails this will be printed on the console, and the failing comparisons will be listed in this file:

```
<design_name>_<sub_system>_hwcosim_test.result
```

## Burst Mode Testbench Script

The following is a test bench generated for an example design as part of the compilation flow:

```
%% project3_burst_hwcosim_test
% project3_burst_hwcosim_test is an automatically generated example MCode
% function that can be used to open a hardware co-simulation (hwcosim)
target,
% load the bitstream, write data to the hwcosim target's input blocks, fetch
% the returned data, and verify that the test passed. The returned value of
% the test is the amount of time required to run the test in seconds.
% Fail / Pass is indicated as an error or displayed in the command window.

%%
% PLEASE NOTE that this file is automatically generated and gets re-created
% every time the Hardware Co-Simulation flow is run. If you modify any part
% of this script, please make sure you save it under a new name or in a
% different location.

%%
% The following sections exist in the example test function:
% Initialize Bursts
% Initialize Input Data & Golden Vectors
% Open and Simulate Target
% Release Target on Error
% Test Pass / Fail

function eta = project3_burst_hwcosim_test
eta = 0;

%%
% ncycles is the number of cycles to simulate for and should be adjusted if
% the generated testbench simulation vectors are substituted by user data.
ncycles = 10;

%%
% Initialize Input Data & Golden Vectors
% xlHwcosimTestbench is a utility function that reformats fixed-point HDL
Netlist
% testbench data vectors into a double-precision floating-point MATLAB
binary
% data array.
xlHwcosimTestbench('.', 'project3_burst');

%%
% The testbench data vectors are both stimulus data for each input port, as
% well as expected (golden) data for each output port, recorded during the
% Simulink simulation portion of the Hardware Co-Simulation flow.
% Data gets loaded from the data file ('<name>_<port>_hwcosim_test.dat')
% into the corresponding 'testdata-<port>' workspace variables using
% 'getfield(load('<name>_<port>_hwcosim_test.dat' ...)' commands.
%
% Alternatively, the workspace variables holding the stimulus and / or
golden
% data can be assigned other data (including dynamically generated data) to
% test the design with. If using alternative data assignment, please make
% sure to adjust the "ncycles" variable to the proper number of cycles, as
% well as to disable the "Test Pass / Fail" section if unused.
testdata_noise_x0 =
getfield(load('project3_burst_noise_x0_hwcosim_test.dat', '-mat'),
'velues');
testdata_scale = getfield(load('project3_burst_scale_hwcosim_test.dat', '-
```

```
mat'), 'values');
testdata_wave = getfield(load('project3_burst_wave_hwcosim_test.dat', '-mat'), 'values');
testdata_intout = getfield(load('project3_burst_intout_hwcosim_test.dat', '-mat'), 'values');
testdata_sigout = getfield(load('project3_burst_sigout_hwcosim_test.dat', '-mat'), 'values');

%%
% The 'result_<port>' workspace variables are arrays to receive the actual
% results
% of a Hardware Co-Simulation read from the FPGA. They will be compared to
the
% expected (golden) data at the end of the Co-Simulation.
result_intout = zeros(size(testdata_intout));
result_sigout = zeros(size(testdata_sigout));

%%
% project3_burst.hwc is the data structure containing the Hardware Co-
Simulation
% design information returned after netlisting the Simulink / System
% Generator model.
% Hwcosim(project) instantiates and returns a handle to the API shared
library object.
project = 'project3_burst.hwc';
h = Hwcosim(project);
try
    %% Open the Hardware Co-Simulation target and co-simulate the design
    open(h);
    cosim_t_start = tic;
    h('noise_x0') = testdata_noise_x0;
    h('scale') = testdata_scale;
    h('wave') = testdata_wave;
    run(h, ncycles);
    result_intout = h('intout');
    result_sigout = h('sigout');
    eta = toc(cosim_t_start);
    % Release the handle for the Hardware Co-Simulation target
    release(h);

    %% Release Target on Error
    catch err
        release(h);
        rethrow(err);
        error('Error running hardware co-simulation testbench. Please refer to
hwcosim.log for
details.');
    end

    %% Test Pass / Fail
    logfile = 'project3_burst_hwcosim_test.results';
    logfd = fopen(logfile, 'w');
    sim_ok = true;
    sim_ok = sim_ok & xlHwcosimCheckResult(logfd, 'intout', testdata_intout,
result_intout);
    sim_ok = sim_ok & xlHwcosimCheckResult(logfd, 'sigout', testdata_sigout,
result_sigout);
    fclose(logfd);
    if ~sim_ok
        error('Found errors in the simulation results. Please refer to

```

```
project3_burst_hwcosim_test.results for details.' );  
end  
disp(['Hardware Co-Simulation successful. Data matches the Simulink  
simulation and completed in  
' num2str(eta) ' seconds.']);
```

This script first defines the number of cycles (`ncycles`) to run in the simulation, prepares the test bench, and loads the stimulus data and expected output into MATLAB arrays. Then it creates an `Hwcosim` object instance with a handle (`h`), which loads the `HWCosim` API shared library. Inside the try-catch block it opens the instance, initializes the FPGA, and opens a connection to it.

Once the setup phase is complete, the code between the `tic` and `toc` timing commands executes the write-run-read commands. Please note that unlike in previous versions of `HWCosim`, this test bench does not require a for-loop to cycle through every clock cycle. This is due to the new smart cache layer which can buffer up nearly arbitrary size write commands in host memory before issuing smaller cycles of write-run-read batches to the hardware (during execution of the user-visible `run(h, ncycles)` command).

At the end of the execution phase the `HWCosim` instance is released and the test bench compares actual to expected outputs.

Comments in the test bench code will help you understand the flow of the hardware co-simulation and help you develop customized test bench scripts for your design.

---

## Importing HDL Modules

Sometimes it is important to add one or more existing HDL modules to a Model Composer design. The HDL Black Box block allows VHDL and Verilog to be brought into a design. The Black Box block behaves like other Model Composer HDL blocks - it is wired into the design, participates in simulations, and is compiled into hardware. When Model Composer compiles a Black Box block, it automatically connects the ports of the Black Box to the rest of the design. A Black Box can be configured to support either synchronous clock designs or multiple hardware clock designs based on the context and Model Composer Hub block settings.

The Black Box Interface	
<a href="#">Black Box HDL Requirements and Restrictions</a>	Details the requirements and restrictions for VHDL, Verilog, and EDIF associated with black boxes.
<a href="#">Black Box Configuration Wizard</a>	Describes how to use the Black Box Configuration Wizard.
<a href="#">Black Box Configuration M-Function</a>	Describes how to create a black box configuration M-function.

HDL Co-Simulation	
<a href="#">Configuring the HDL Simulator</a>	Explains how to configure the Vivado® simulator or Questa to co-simulate the HDL in the Black Box block.

[Co-Simulating Multiple Black Boxes](#)

Describes how to co-simulate several Black Box blocks in a single HDL simulator session.

## Black Box HDL Requirements and Restrictions

An HDL component associated with a black box must adhere to the following Model Composer requirements and restrictions:

- The entity name must not collide with any other entity name in the design.
- Bi-directional ports are supported in HDL black boxes, however they will not be displayed in the Model Composer as ports; they only appear in the generated HDL after netlisting.
- For Verilog black boxes, the module and port names must follow standard HDL naming conventions.
- Any port that is a clock or clock enable must be of type std\_logic. (For Verilog black boxes, ports must be of non-vector inputs, e.g., input clk.)
- Clock and clock enable ports in black box HDL should be expressed as follows: Clock and clock enables must appear as pairs (i.e., for every clock, there is a corresponding clock enable, and vice-versa). A black box may have more than one clock port and its behavior changes based on the context of the design.
  - In Synchronous single clock design context, a single clock source is used to drive each clock port. Only the clock enable rates differ.
  - In case of multiple independent hardware clock design context, two different clock sources is used to drive clock and clock enable pins.
- Each clock name (respectively, clock enable name) must contain the substring clk, for example my\_clk\_1 and my\_ce\_1.
- The name of a clock enable must be the same as that for the corresponding clock, but with ce substituted for clk. For example, if the clock is named src\_clk\_1, then the clock enable must be named src\_ce\_1.
- Falling-edge triggered output data cannot be used.
- Fixed-point binary values with negative indices (e.g., (5 downto -3)) are not supported.



**IMPORTANT!** It is not recommended to use the black box block to import encrypted RTLs which are generated for Vivado IP. As an alternative, try to import Vivado IPs using a DCP file.

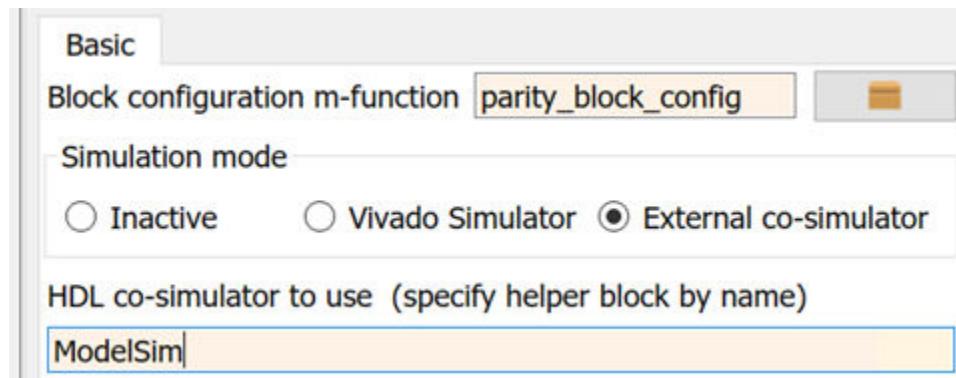
## Black Box Configuration M-Function

An imported module is represented in Model Composer by a Black Box block. Information about the imported module is conveyed to the black box by a configuration M-function. This function defines the interface, implementation, and the simulation behavior of the black box block it is associated with. The information a configuration M-function defines includes the following:

- Name of the top-level entity for the module
- VHDL or Verilog language selection
- Port descriptions
- Generics required by the module
- Synchronous single clock or asynchronous multiple independent clock configuration
- Clocking and sample rates
- Files associated with the module
- Whether the module has any combinational paths

The name of the configuration M-function associated with a black box is specified as a parameter in the dialog box (`parity_block_config.m`).

Figure 103: Parameter Dialog



Configuration M-functions use an object-based interface to specify black box information. This interface defines two objects, `SysgenBlockDescriptor` and `SysgenPortDescriptor`. When Model Composer invokes a configuration M-function, it passes the function a block descriptor:

```
function sample_block_config(this_block)
```

A `SysgenBlockDescriptor` object provides methods for specifying information about the black box. Ports on a block descriptor are defined separately using port descriptors.

## Language Selection

The black box can import VHDL and Verilog modules. `SysgenBlockDescriptor` provides a method, `setTopLevelLanguage`, that tells the black box what type of module you are importing. This method should be invoked once in the configuration M-function. The following code shows how to select between the VHDL and Verilog languages.

VHDL Module:

```
this_block.setTopLevelLanguage( 'VHDL' );
```

Verilog Module:

```
this_block.setTopLevelLanguage( 'Verilog' );
```

**Note:** The Configuration Wizard automatically selects the appropriate language when it generates a configuration M-function.

## ***Specifying the Top-Level Entity***

You must tell the black box the name of the top-level entity that is associated with it.

SysgenBlockDescriptor provides a method, `setEntityName`, which allows you to specify the name of the top-level entity.

**Note:** Use lower case text to specify the entity name.

For example, the following code specifies a top-level entity named `foo`.

```
this_block.setEntityName( 'foo' );
```

**Note:** The Configuration Wizard automatically sets the name of the top-level entity when it generates a configuration M-function.

## ***Defining Port Blocks***

The port interface of a black box is defined by the block's configuration M-function. Recall that black box ports are defined using port descriptors. A port descriptor provides methods for configuring various port attributes, including port width, data type, binary point, and sample rate.

### **Adding New Ports**

When defining a black box port interface, it is necessary to add input and output ports to the block descriptor. These ports correspond to the ports on the module you are importing. In your model, the black box block port interface is determined by the port names that are declared on the block descriptor object. SysgenBlockDescriptor provides methods for adding input and output ports:

Adding an input port:

```
this_block.addSimulinkInport( 'din' );
```

Adding an output port:

```
this_block.addSimulinkOutport( 'dout' );
```

The string parameter passed to methods `addSimulinkInport` and `addSimulinkOutport` specifies the port name. These names should match the corresponding port names in the imported module.

**Note:** Use lower case text to specify port names.

Adding a bidirectional port:

```
config_phase = this_block.getConfigPhaseString;
if (strcmpi(config_phase,'config_netlist_interface'))
    this_block.addInoutport('bidi');
    % Rate and type info should be added here as well
end
```

Bidirectional ports are supported only during the netlisting of a design and will not appear on the Model Composer diagram; they only appear in the generated HDL. As such, it is important to only add the bi-directional ports when Model Composer is generating the HDL. The if-end conditional statement is guarding the execution of the code to add-in the bi-directional port.

It is also possible to define both the input and output ports using a single method call. The `setSimulinkPorts` method accepts two parameters. The first parameter is a cell array of strings that define the input port names for the block. The second parameter is a cell array of strings that define the output port names for the block.

**Note:** The Configuration Wizard automatically sets the port names when it generates a configuration M-function.

## Obtaining a Port Object

Once a port has been added to a block descriptor, it is often necessary to configure individual attributes on the port. Before configuring the port, you must obtain a descriptor for the port you would like to configure. `SysgenBlockDescriptor` provides methods for accessing the port objects that are associated with it. For example, the following method retrieves the port named `din` on the `this_block` descriptor:

Accessing a `SysgenPortDescriptor` object:

```
din = this_block.port('din');
```

In the above code, an object `din` is created and assigned to the descriptor returned by the `port` function call.

`SysgenBlockDescriptor` also provides methods, `inport` and `outport`, that return a port object given a port index. A port index is the index of the port (in the order shown on the block interface) and is some value between 1 and the number of input/output ports on the block. These methods are useful when you need to iterate through the block's ports (e.g., for error checking).

## Configuring Port Types

SysgenPortDescriptor provides methods for configuring individual ports. For example, assume port dout is unsigned, 12 bits, with binary point at position 8. The code below shows one way in which this type can be defined.

```
dout = this_block.port('dout');
dout.setWidth(12);
dout.setBinPt(8);
dout.makeUnsigned();
```

The following also works:

```
dout = this_block.port('dout');
dout.setType('Ufix_12_8');
```

The first code segment sets the port attributes using individual method calls. The second code segment defines the signal type by specifying the signal type as a string. Both code segments are functionally equivalent.

The black box supports HDL modules with 1-bit ports that are declared using either single bit port (e.g., std\_logic) or vectors (e.g., std\_logic\_vector(0 downto 0)) notation. By default, Model Composer assumes ports to be declared as vectors. You may change the default behavior using the useHDLVector method of the descriptor. Setting this method to true tells Model Composer to interpret the port as a vector. A false value tells Model Composer to interpret the port as single bit.

```
dout.useHDLVector(true); % std_logic_vector
dout.useHDLVector(false); % std_logic
```

**Note:** The Configuration Wizard automatically sets the port types when it generates a configuration M-function.

## Configuring Bi-Directional Ports for Simulation

Bidirectional ports (or inout ports) are supported only during the generation of the HDL netlist, that is, bi-directional ports will not show up in the Model Composer diagram. By default, bi-directional ports will be driven with 'X' during simulation. It is possible to overwrite this behavior by associating a data file to the port. Be sure to guard this code because bi-directional ports can only be added to a block during the config\_netlist\_interface phase.

```
if (strcmpi(this_block.getConfigPhaseString, 'config_netlist_interface'))
    bidi_port = this_block.port('bidi');
    bidi_port.setGatewayFileName('bidi.dat');
end
```

In the above example, a text file, `bidi.dat`, is used during simulation to provide stimulation to the port. The data file should be a text file, where each line represents the signal driven on the port at each simulation cycle. For example, a 3-bit bi-directional port that is simulated for 4 cycles might have the following data file:

```
ZZZ
110
011
XXX
```

Simulation will return with an error if the specified data file cannot be found.

## Configuring Port Sample Rates

The Black Box block supports ports that have different sample rates. By default, the sample rate of an output port is the sample rate inherited from the input port (or ports, if the inputs run at the same sample rate). Sometimes, it is necessary to explicitly specify the sample rate of a port (e.g., if the output port rate is different than the block's input sample rate).

**Note:** When the inputs to a black box have different sample rates, you must specify the sample rates of every output port.

`SysgenPortDescriptor` provides a method called `setRate` that allows you to explicitly set the rate of a port.

**Note:** The rate parameter passed to the `setRate` method is not necessarily the Simulink® sample rate that the port runs at. Instead, it is a positive integer value that defines the ratio between the desired port sample period and the Simulink® system clock period defined by the Model Composer Hub block dialog box.

Assume you have a model in which the Simulink system period value for the model is defined as 2 sec. Also assume that the example `dout` port is assigned a rate of 3 by invoking the `setRate` method as follows:

```
dout.setRate( 3 );
```

A rate of 3 means that a new sample is generated on the `dout` port every 3 Simulink system periods. Because the Simulink system period is 2 sec, this means the Simulink sample rate of the port is  $3 \times 2 = 6$  sec.

**Note:** If your port is a non-sampled constant, you can define it in the configuration M-function using the `setConstant` method of `SysgenPortDescriptor`. You can also define a constant by passing `Inf` to the `setRate` method.

## Dynamic Output Ports

A useful feature of the black box is its ability to support dynamic output port types and rates. For example, it is often necessary to set an output port width based on the width of an input port. SysgenPortDescriptor provides member variables that allow you to determine the configuration of a port. You can set the type or rate of an output port by examining these member variables on the block's input ports.

For example, you can obtain the width and rate of a port (in this case `din`) as follows:

```
input_width = this_block.port('din').width;
input_rate = this_block.port('din').rate;
```

**Note:** A black box's configuration M-function is invoked at several different times when a model is compiled. The configuration function may be invoked before the data types and rates have been propagated to the black box.

The SysgenBlockDescriptor object provides Boolean member variables `inputTypesKnown` and `inputRatesKnown` that tell whether the port types and rates have been propagated to the block. If you are setting dynamic output port types or rates based on input port configurations, the configuration calls should be nested inside conditional statements that check that values of `inputTypesKnown` and `inputRatesKnown`.

The following code shows how to set the width of a dynamic output port `dout` to have the same width as input port `din`:

```
if (this_block.inputTypesKnown)
    dout.setWidth(this_block.port('din').width);
end
```

Setting dynamic rates works in a similar manner. The code below sets the sample rate of output port `dout` to be twice as slow as the sample rate of input port `din`:

```
if (this_block.inputRatesKnown)
    dout.setRate(this_block.port('din').rate*2);
end
```

## Black Box Clocking

In order to import a multirate module, you must tell Model Composer information about the module's clocking in the configuration M-function. Model Composer treats clock and clock enables differently than other types of ports. A clock port on an imported module must always be accompanied by a clock enable port (and vice versa). In other words, clock and clock enables must be defined as a pair, and exist as a pair in the imported module. This is true for both single rate and multirate designs.

Although clock and clock enables must exist as pairs, Model Composer drives all clock ports on your imported module with the FPGA system clock. The clock enable ports are driven by clock enable signals derived from the FPGA system clock.

SysgenBlockDescriptor provides a method, `addClkCEPair`, which allows you to define clock and clock enable information for a black box. This method accepts three parameters. The first parameter defines the name of the clock port (as it appears in the module). The second parameter defines the name of the clock enable port (also as it appears in the module).

The port names of a clock and clock enable pair must follow the naming conventions provided below:

- The clock port must contain the substring `clk`
- The clock enable must contain the substring `ce`
- The strings containing the substrings `clk` and `ce` must be the same (e.g. `my_clk_1` and `my_ce_1`).

The third parameter defines the rate relationship between the clock and the clock enable port. The rate parameter should not be thought of as a Simulink sample rate. Instead, this parameter tells Model Composer the relationship between the clock sample period, and the desired clock enable sample period. The rate parameter is an integer value that defines the ratio between the clock rate and the corresponding clock enable rate.

For example, assume you have a clock enable port named `ce_3` that would like to have a period three times larger than the system clock period. The following function call establishes this clock enable port:

```
addClkCEPair('clk_3','ce_3',3);
```

When Model Composer compiles a black box into hardware, it produces the appropriate clock enable signals for your module, and automatically wires them up to the appropriate clock enable ports.

## Combinational Paths

If the module you are importing has at least one combinational path (i.e., a change on any input can effect an output port without a clock event), you must indicate this in the configuration M-function. SysgenBlockDescriptor object provides a `tagAsCombinational` method that indicates your module has a combinational path. It should be invoked as follows in the configuration M-function:

```
this_block.tagAsCombinational;
```

## Specifying VHDL Generics and Verilog Parameters

You may specify a list of generics that get passed to the module when Model Composer compiles the model into HDL. Values assigned to these generics can be extracted from mask parameters and from propagated port information (e.g. port width, type, and rate). This flexible means of generic assignment allows you to support highly parametric modules that are customized based on the Simulink environment surrounding the black box.

The `addGeneric` method allows you to define the generics that should be passed to your module when the design is compiled into hardware. The following code shows how to set a VHDL Integer generic, `dout_width`, to a value of 12.

```
addGeneric('dout_width', 'Integer', '12');
```

It is also possible to set generic values based on port on propagated input port information (e.g. a generic specifying the width of a dynamic output port).

Because a black box's configuration M-function is invoked at several different times when a model is compiled, the configuration function may be invoked before the data types (or rates) have been propagated to the black box. If you are setting generic values based on input port types or rates, the `addGeneric` calls should be nested inside a conditional statement that checks the value of the `inputTypesKnown` or `inputRatesKnown` variables. For example, the width of the dout port can be set based on the value of din as follows:

```
if (this_block.inputTypesKnown)
    % set generics that depend on input port types
    this_block.addGeneric('dout_width', ...
    this_block.port('din').width);
end
```

Generic values can be configured based on mask parameters associated with a block box. `SysgenBlockDescriptor` provides a member variable, `blockName`, which is a string representation of the black box's name in Simulink. You may use this variable to gain access the black box associated with the particular configuration M-function. For example, assume a black box defines a parameter named `init_value`. A generic with name `init_value` can be set as follows:

```
simulink_block = this_block.blockName;
init_value = get_param(simulink_block, 'init_value');
this_block.addGeneric('init_value', 'String', init_value);
```

**Note:** You can add your own parameters (e.g. values that specify generic values) to the black box by doing the following:

- Copy a black box into a Simulink library or model.
- Break the link on the black box.
- Add the desired parameters to the black box dialog box.

## Black Box VHDL Library Support

This Black Box feature allows you to import VHDL modules that have predefined library dependencies. The following example illustrates how to do this import.

The VHDL module below is a 4-bit, Up counter with asynchronous clear (`async_counter.vhd`). It will be compiled into a library named `async_counter_lib`.

```
1 -- 4-bit, Up counter, with asynchronous clear
2 library ieee;
3 use ieee.std_logic_1164.all;
4 use ieee.std_logic_unsigned.all;
5 entity async_counter is
6 port(clk, clr : in std_logic;
7      ce: in std_logic := '1'; |
8      q : out std_logic_vector(3 downto 0));
9 end async_counter;
10 architecture archi of async_counter is
11 signal tmp: std_logic_vector(3 downto 0);
12 begin
13 process (clk, clr)
14 begin
15 if (clr='1') then
16     tmp <= "0000";
17 elsif (clk'event and clk='1') then
18     tmp <= tmp + 1;
19 end if;
20 end process;
21 q <= tmp;
22 end archi;
```

The VHDL module below is a 4-bit, Up counter with synchronous clear (`sync_counter.vhd`). It will be compiled into a library named `sync_counter_lib`.

```
1 -- 4-bit, Up counter, with synchronous clear
2 library ieee;
3 use ieee.std_logic_1164.all;
4 use ieee.std_logic_unsigned.all;
5
6 entity sync_counter is
7 port(clk, clr : in std_logic;
8      ce: in std_logic := '1'; |
9      q : out std_logic_vector(3 downto 0));
10 end sync_counter;
11 architecture archi of sync_counter is
12 signal tmp: std_logic_vector(3 downto 0);
13 begin
14 process (clk)
15 begin
16 if (clk'event and clk='1') then
17     if (clr='1') then
18         tmp <= "0000";
19     else
20         tmp <= tmp + 1;
21     end if;
22 end if;
23 end process;
24 q <= tmp;
25 end archi;
```

The VHDL module below is the top-level module that is used to instantiate the previous modules. This is the module that you need to point to when adding the BlackBox into your Model Composer model.

```
1   library ieee;
2   use ieee.std_logic_1164.all;
3   use ieee.std_logic_unsigned.all;
4   library sync_counter_lib;
5   use sync_counter_lib.all;
6   library async_counter_lib;
7   use async_counter_lib.all;
8
9
10  entity top_level is
11    port(clk, clr : in std_logic;
12          ce: in std_logic := '1';
13          q_sync : out std_logic_vector(3 downto 0);
14          q_async : out std_logic_vector(3 downto 0)
15          );
16  end top_level;
17
18  architecture structural of top_level is
19  component async_counter
20  port (
21      clk, clr, ce: in std_logic;
22      q: out std_logic_vector(3 downto 0));
23  end component;
24
25  component sync_counter
26  port (
27      clk, clr, ce: in std_logic;
28      q: out std_logic_vector(3 downto 0));
29  end component;
30
31 begin
32  counter_0: entity async_counter_lib.async_counter
33  port map (
34      ce => ce,
35      q => q_async,
36      clk => clk,
37      clr => clr
38  );
39  counter_1: entity sync_counter_lib.sync_counter
40  port map (
41      ce => ce,
42      q => q_sync,
43      clk => clk,
44      clr => clr
45  );
46  end structural;
```

Define libraries using "library" and "use" clauses

The VHDL is imported by first importing the top-level entity, `top_level`, using the Black Box.

Once the file is imported, the associated Black Box Configuration M-file needs to be modified as follows:

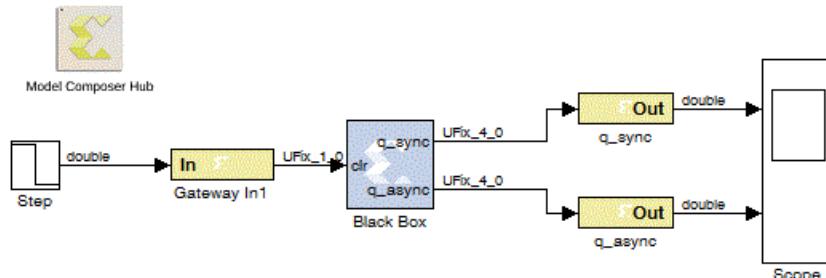
```
% Add additional source files as needed.  
% -----  
% | Add files in the order in which they should be compiled.  
% | If two files "a.vhd" and "b.vhd" contain the entities  
% | entity_a and entity_b, and entity_a contains a  
% | component of type entity_b, the correct sequence of  
% | addFile() calls would be:  
% |     this_block.addFile('b.vhd');  
% |     this_block.addFile('a.vhd');  
% | ----- Specifying library names by using  
%           "addFileToLibrary" command  
%  
%     this_block.addFile('');  
%     this_block.addFile('');  
this_block.addFile('top.vhd');  
this_block.addFileToLibrary('async_counter.vhd', 'async_counter_lib');  
this_block.addFileToLibrary('sync_counter.vhd', 'sync_counter_lib');
```



The interface function `addFileToLibrary` is used to specify a library name other than “work” and to instruct the tool to compile the associated HDL source to the specified library.

The Model Composer model should look similar to the following figure.

Figure 104: Model Composer Model with Black Box Support



The next step is to double-click the Model Composer Hub block and click the **Generate** button to generate the HDL netlist.

During the generation process, a Vivado IDE project (.xpr) is created and placed with the `hdl_netlist` folder under the `netlist` folder. If you double-click the Vivado IDE project and select the `Libraries` tab under the `Source` view, you will see not only a `work` library, but an `async_counter_lib` library and `sync_counter_lib` library as well.

## Error Checking

It is often necessary to perform error checking on the port types, rates, and mask parameters of a black box. `SysgenBlockDescriptor` provides a method, `setError`, that allows you to specify an error message that is reported to the user. The error message that a user sees is the string parameter passed to `setError`.

## Black Box API

### SysgenBlockDescriptor Member Variables

Type	Member	Description
String	entityName	Name of the entity or module.
String	blockName	Name of the black box block.
Integer	numSimulinkImports	Number of input ports on black box.
Integer	numSimulinkOutports	Number of output ports on the black box.
Boolean	inputTypesKnown	true if all input types are defined, and false otherwise.
Boolean	inputRatesKnown	true if all input rates are defined, and false otherwise.
Array of Doubles	inputRates	Array of sample periods for the input ports (indexed as in import(indx)). Sample period values are expressed as integer multiples of the Simulink System Period value specified by the Model Composer Hub block.
Boolean	error	true if an error has been detected, and false otherwise.
Cell Array of Strings	errorMessages	Array of all error messages for this block.

### SysgenBlockDescriptor Methods

Method	Description
setTopLevelLanguage(language)	Declares language for the top-level entity (or module) of the black box. The language should be VHDL or Verilog.
setEntityName(name)	Sets name of the entity or module.
addSimulinkImport(pname)	Adds an input port to the black box. pname defines the name the port should have.
addSimulinkOutport(pname)	Adds an output port to the black box. pname defines the name the port should have.
setSimulinkPorts(in,out)	Adds input and output ports to the black box. in (respectively, out) is a cell array whose element tell the names to use for the input (resp., output) ports.
addInoutport(pname)	Adds a bidirectional port to the black box. pname defines the name the port should have. Bidirectional ports can only be added during the config_netlist_interface phase of configuration.
tagAsCombinational()	Indicate that the block has a combinational path (i.e., direct feedthrough) from an input port to an output port.
addClkCEPair(clkPname, cePname, rate)	Defines a clock/clock enable port pair for the block. clkPname and cePname tell the names for the clock and clock enable ports respectively. rate, a double, tells the rate at which the port pair runs. The rate must be a positive integer. Note the clock (respectively, clock enable) name must contain the substring clk (resp., ce). The names must be parallel in the sense that the clock enable name is obtained from the clock name by replacing clk with ce.

Method	Description
port(name)	Returns the SysgenPortDescriptor that matches the specified name.
inport(indx)	Returns the SysgenPortDescriptor that describes a given input port. indx tells the index of the port to look for, and should be between 1 and numInputPorts.
outport(indx)	Returns the SysgenPortDescriptor that describes a given output port. indx tells the index of the port to look for, and should be between 1 and numOutputPorts.
addGeneric(identifier, value)	Defines a generic (or parameter if using Verilog) for the block. identifier is a string that tells the name of the generic. value can be a double or a string. The type of the generic is inferred from value's type. If value is an integral double (e.g., 4.0), the type of the generic is set to integer. For a non-integral double, the type is set to real. When value is a string containing only zeros and ones (e.g., `0101`), the type is set to bit_vector. For any other string value, the type is set to string.
addGeneric(identifier, type, value)	Explicitly specifies the name, type, and value for a generic (or parameter, if using Verilog) for the block. All three arguments are strings. identifier tells the name, type tells the type, and value tells the value.
addFile(fn)	Adds a file name to the list of files associated to this black box, fn is the file name. Ordinarily, HDL files are associated to black boxes, but any sorts of files are acceptable. VHDL file names should end in .vhd; Verilog file names should end in .v. The order in which file names are added is preserved, and becomes the order in which HDL files are compiled. File names can be absolute or relative. Relative file names are interpreted with respect to the location of the .mdl or library .mdl for the design.
getDeviceFamilyName()	Gets the name of the FPGA corresponding to the black box.
getConfigPhaseString	Returns the current configuration phase as a string. A valid return string includes: config_interface, config_rate_and_type, config_post_rate_and_type, config_simulation, config_netlist_interface, and config_netlist.
setSimulatorCompilationScript(script)	Overrides the default HDL co-simulation compilation script that the black box generates. script tells the name of the script to use. For example, this method can be used to short-circuit the compilation phase for repeated simulations where the HDL for the black box remains unchanged.
setError(message)	Indicates that an error has occurred, and records the error message. message gives the error message.
addDirectory(directoryName)	Adds the entire list of HDL files present in the specified directory to the Black Box flow. This is useful in case of the top level HDL file depends on other HDL files. This works fine in case of Simulation mode set to Vivado Simulator option.

## SysgenPortDescriptor Member Variables

Type	Member	Description
String	name	Tells the name of the port.
Integer	simulinkPortNumber	Tells the index of this port in Simulink®. Indexing starts with 1 (as in Simulink).

Type	Member	Description
Boolean	typeKnown	True if this port's type is known, and false otherwise.
String	type	Type of the port, such as UFix_<n>_<b>, Fix_<n>_<b>, or Bool.
Boolean	isBool	True if port type is Bool, and false otherwise.
Boolean	isSigned	True if type is signed, and false otherwise.
Boolean	isConstant	True if port is constant, and false otherwise.
Integer	width	Tells the port width.
Integer	binpt	Tells the binary point position, which must be an integer in the range 0..width.
Boolean	rateKnown	True if the rate is known, and false otherwise.
Double	rate	Tells the port sample time. Rates are positive integers expressed as MATLAB® doubles. A rate can also be infinity, indicating that the port outputs a constant.

## SysgenPortDescriptor Methods

Method	Description
setName(name)	Sets the HDL name to be used for this port.
setSimulinkPortNumber(num)	Sets the index associated with this port in Simulink®. num tells the index to assign. Indexing starts with 1 (as in Simulink).
setType(typeName)	Sets the type of this port to type. Type must be one of Bool, UFix_<n>_<b>, Fix_<n>_<b>, signed or unsigned. The last two choices leave the width and binary point position unchanged. XFloat_<exponent_bit_width>_<fraction_bit_width> is also supported. For example: <code>ap_return_port = this_block.port('ap_return');</code> <code>ap_return_port.setType('XFloat_30_2');</code>
setWidth(w)	Sets the width of this port to w.
setBinpt(bp)	Sets the binary point position of this port to bp.
makeBool()	Makes this port Boolean.
makeSigned()	Makes this port signed.
makeUnsigned()	Makes this port unsigned.
setConstant()	Makes this port constant
setGatewayFileName(filename)	Sets the dat file name that will be used in simulations and test-bench generation for this port. This function is only meant for use with bi-directional ports so that a hand written data file can be used during simulation. Setting this parameter for input or output ports is invalid and will be ignored.
setRate(rate)	Assigns the rate for this port. rate must be a positive integer expressed as a MATLAB® double or Inf for constants.

Method	Description
useHDLVector(s)	Tells whether a 1-bit port is represented as single-bit (ex: std_logic) or vector (ex: std_logic_vector(0 downto 0)).
HDLTypeIsVector()	Sets representation of the 1-bit port to std_logic_vector(0 downto 0).

## Multiple Independent Clock Support on Black Box

### ***Design Rule Checks on Port Connection***

When a black box is used in a multiple independent hardware clock design context, design rule checks (DRCs) for its port connections must be added in the configuration M-function. This helps to avoid invalid or incorrect port connection with different clock sources. You need to ensure all port signals are connected from/to a proper clocked-subsystem interface.

The utility `checkPortsOfSameClockDomain()` should be used to specify a list of ports from a particular clock domain and to group it together. The input arguments to this application programming interface (API) are 'SysgenBlockDescriptor' objects followed by the list of port names associated with a particular clock domain.

In the example shown below, the API puts out an error check, and verifies that the four ports are connected to the same subsystem clock domain.

```
checkPortsOfSameClockDomain (<block_descriptor>, '<port_name_1>',  
'<port_name_2>',  
'<port_name_3>', '<port_name_4>' );
```

### ***Configuring Port Sample Rates***

In multiple clock hardware designs, the clock period of the port interface should be computed using the connected "clocked subsystem domain". By default, "synchronous system clock" source is used by all the ports, but for asynchronous clock hardware designs, it is necessary to explicitly specify the clock sources of every port (e.g., if the output port clock is different than the block's input port clock).

**Note:** You must set the sample rate to '1.0' for all output ports of multiple independent clock black box designs; it automatically sets the output ports to the destination clock subsystem period.

SysgenPortDescriptor provides a method called `setRate` that you can use to explicitly set the rate of a port.

Example:

```
port('<port_name>').setRate(1.0)
```

## Black Box Clocking

In order to import a synchronous or asynchronous black box module, you must tell Model Composer information about the module's clocking in the configuration M-function. Model Composer treats clock and clock enables differently than other types of ports. A clock port on an imported module must always be accompanied by a clock enable port, and vice versa. In other words, clock and clock enables must be defined as a pair, and exist as a pair in the imported module. This is true for both single synchronous clock and multiple independent clock designs.

SysgenBlockDescriptor provides a method called addClkCEPair that you can use to define clock, clock enable, and its associated clock period by using clock sub-system domain. The clock domain information is not required for synchronous single clock designs.

The first parameter defines the name of the clock port (as it appears in the module). The second parameter defines the name of the clock enable port (also as it appears in the module).

The port names of a clock and clock enable pair must follow the naming conventions provided below:

- The clock port must contain the substring `clk`.
- The clock enable must contain the substring `ce`.
- The strings containing the substrings `clk` and `ce` must be the same, such as: `my_clk_1` and `my_ce_1`.

The third parameter defines the rate relationship between the clock and the clock-enable port. The rate parameter should not be thought of as a Simulink® sample rate. Instead, this parameter tells Model Composer the relationship between the clock sample period, and the desired clock enable sample period. The rate parameter is an integer value that defines the ratio between the clock rate and the corresponding clock enable rate.

For multiple independent clock designs, the fourth and fifth optional parameters are mandatory.

The fourth parameter holds a "Boolean" value, and it defines whether clock and clock enable pair is tied to ground. If you set it to `true`, both clock and clock enable would be tied to ground during simulation. Setting it to `false` would activate clock and clock enable rate transitions.

The fifth parameter defines the clock period for the corresponding clock-clock enable pair. The 'clockDomain' property of the black box "SysgenPortDescriptor" must be used to set the clock periods for multiple independent clock designs.

Example:

```
rate_data = this_block.port('<port_name>').rate;
clkDomain_data = this_block.port(<port_name>).clockDomain;
this_block.addClkCEPair('clk','ce',rate_data, false, clkDomain_data);
```

## HDL Co-Simulation

This topic describes how a mixed language/mixed flow design that includes Xilinx® HDL blocks, HDL modules, and a Simulink block design can be simulated in its entirety.

Model Composer simulates black boxes by automatically launching an HDL simulator, generating additional HDL as needed (analogous to an HDL test bench), compiling HDL, scheduling simulation events, and handling the exchange of data between the Simulink and the HDL simulator. This is called *HDL co-simulation*.

### **Configuring the HDL Simulator**

Black box HDL can be co-simulated with Simulink® using the Model Composer interface to either the Vivado® simulator or the Questa simulation software from Model Technology, Inc.

#### **Xilinx® Simulator**

To use the Xilinx simulator for co-simulating the HDL associated with the black box, select **Vivado Simulator** as the option for the **Simulation mode** parameter on the black box. The model is then ready to be simulated and the HDL co-simulation takes place automatically.

#### **Questa Simulator**

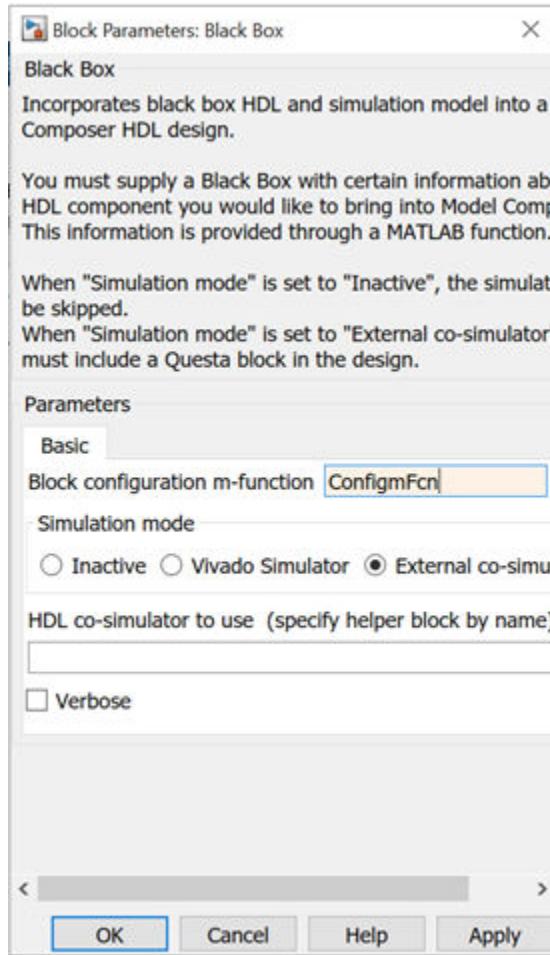
To use the Questa simulator by Model Technology, Inc., you must first add the Questa block that appears in the Tools library of the Xilinx HDL Blockset to your Simulink diagram.

*Figure 105: Questa Block*



For each black box that you wish to have co-simulated using the Questa simulator, you need to open its block parameterization dialog and set it to use the Questa session represented by the black box that was just added. You do this by making the following two settings:

1. Change the Simulation Mode field from Inactive to External co-simulator.
2. Enter the name of the Questa block (e.g., Questa) in the HDL co-simulator to use field.

**Figure 106: Black Box Parameters**

The block parameter dialog for the Questa block includes some parameters that you can use to control various options for the Questa session. See the block help page for details. The model is then ready to be simulated with these options, and the HDL co-simulation takes place automatically.

## ***Co-Simulating Multiple Black Boxes***

Model Composer allows many black boxes to share a common Questa co-simulation session. For example, many black boxes can be set to use the same Questa block. In this case, Model Composer automatically combines all black box HDL components into a single shared top-level co-simulation component, which is transparent to the user. However, only one Questa simulation license is needed to co-simulate several black boxes in the Simulink® simulation.

Multiple black boxes can also be co-simulated with the Vivado simulator by selecting **Vivado Simulator** as the option for **Simulation mode** on each black box.

## Black Box Configuration Wizard

Model Composer provides a configuration wizard that makes it easy to associate a VHDL or Verilog module to a Black Box block. The Configuration Wizard parses the VHDL or Verilog module that you are trying to import, and automatically constructs a configuration M-function based on its findings. Then, it associates the configuration M-function it produces to the Black Box block in your model. Whether or not you can use the configuration M-function as is depends on the complexity of the HDL you are importing. Sometimes the configuration M-function must be customized by hand to specify details the configuration wizard misses. Details on the construction of the configuration M-function can be found in the [Black Box Configuration M-Function](#) topic.

### Using the Configuration Wizard

The Black Box Configuration Wizard opens automatically when a new black box block is added to a model.

**Note:** Before running the Configuration Wizard, ensure the VHDL or Verilog you are importing meets the specified [Black Box HDL Requirements and Restrictions](#).

For the Configuration Wizard to find your module, the model must be saved in the same directory as the module you are trying to import.

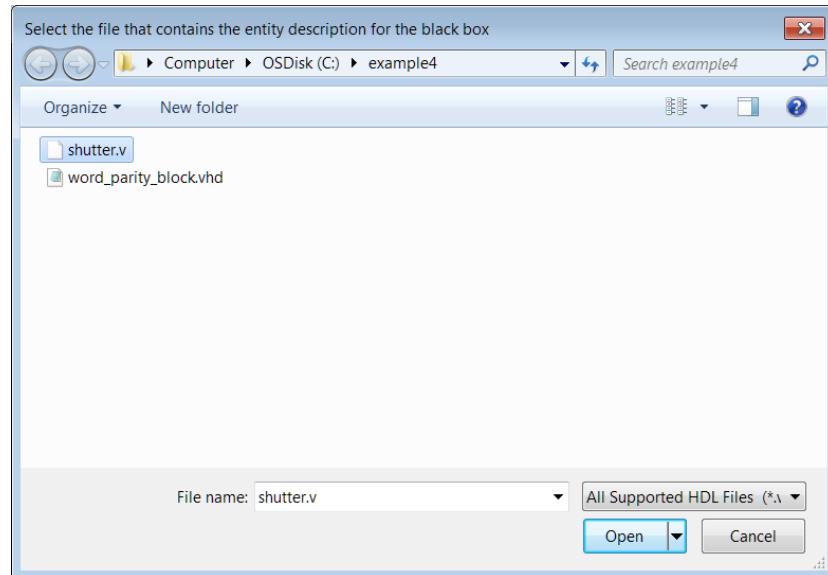
**Note:** The wizard only searches for .vhd and .v files in the same directory as the model. If the wizard does not find any files it issues a warning and the black box is not automatically configured. The warning looks like the following:

Figure 107: Warning



After searching the model's directory for .vhd and .v files, the Configuration Wizard opens a new window that lists the possible files that can be imported. An example screenshot is shown below:

## *Figure 108: Files to Import*



You can select the file you would like to import by selecting the file, and then pressing the **Open** button. At this point, the configuration wizard generates a configuration M-function, and associates it with the black box block.

**Note:** The configuration M-function is saved in the model's directory as `<module>_config.m`, where `<module>` is the name of the module that you are importing.

## ***Configuration Wizard Fine Points***

The configuration wizard automatically extracts certain information from the imported module when it is run, but some things must be specified by hand. These things are described below:

**Note:** The configuration function is annotated with comments that instruct you where to make these changes.

- If your model has a combinational path, you must call the `tagAsCombinational` method of the block's `SysgenBlockDescriptor` object. A multiple independent hardware clock design will not support a combinational path.
  - The Configuration Wizard only knows about the top-level entity that is being imported. There are typically other files that go along with this entity. These files must be added manually in the configuration M-function by invoking the `addFile` method for each additional file or by using the `addDirectory` method once (i.e., by keeping the dependent files in a separate directory).

- The Configuration Wizard automatically creates either a synchronous single clock black box descriptor or an asynchronous multiple clock black box descriptor.
    - In the case of single-rate black box, every port on the black box runs at the same rate. In most cases, this is acceptable. You may want to explicitly set port rates, which can result in a faster simulation time.
    - In the case of a multiple clock black box, the input port rate must be derived from the "source clock subsystem" and the output port rate must be set based on the "destination clock subsystem". In some cases, you may want to explicitly set port rates for a required configuration.
- 

## Compilation Types for HDL Library designs

There are different ways in which Model Composer can compile your design into an equivalent, often lower-level, representation. The way in which a design is compiled depends on settings in the Model Composer Hub block dialog box. The support of different compilation types provides you the freedom to choose a suitable representation for your design's environment. For example, an HDL Netlist or IP catalog is an appropriate target if your design is used as a component in a larger system.

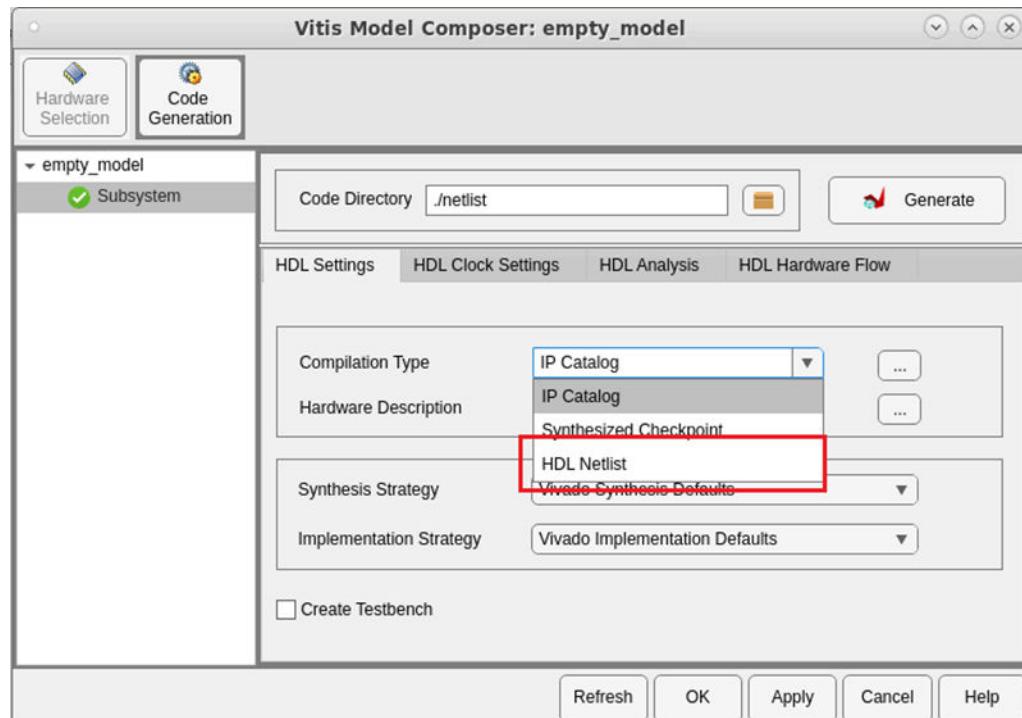
<a href="#">HDL Netlist Compilation</a>	Describes how to generate HDL files that implement the design.
<a href="#">Hardware Co-Simulation Compilation</a>	Describes how Model Composer can be configured to compile your design into FPGA hardware that can be used by Simulink® and Questa.
<a href="#">IP Catalog Compilation</a>	Describes how to package a Model Composer design as an IP core that can be added to the Vivado® IP catalog for use in another design. Model Composer uses the IP catalog compilation type as the default generation target.
<a href="#">Synthesized Checkpoint Compilation</a>	Describes how to generate a synthesized checkpoint file ( <code>synth_1.dcp</code> ) that can be used in a Vivado integrated design environment (IDE) project.

## HDL Netlist Compilation

The HDL Netlist compilation type produces HDL files that implement the design. More details regarding the HDL Netlist compilation flow can be found in the [Compilation Results](#) section.

As shown in the following figure, you can select **HDL Netlist** compilation by selecting it from the **Compilation Type** menu on the HDL Settings tab.

Figure 109: HDL Netlist



The HDL Netlist compilation can be performed for any of the boards or parts your Vivado tools support. In addition to accessing the Xilinx development boards installed as part of your Vivado installation, you can also specify Partner boards or custom boards (see [Specifying Board Support in Model Composer HDL Blockset](#)).

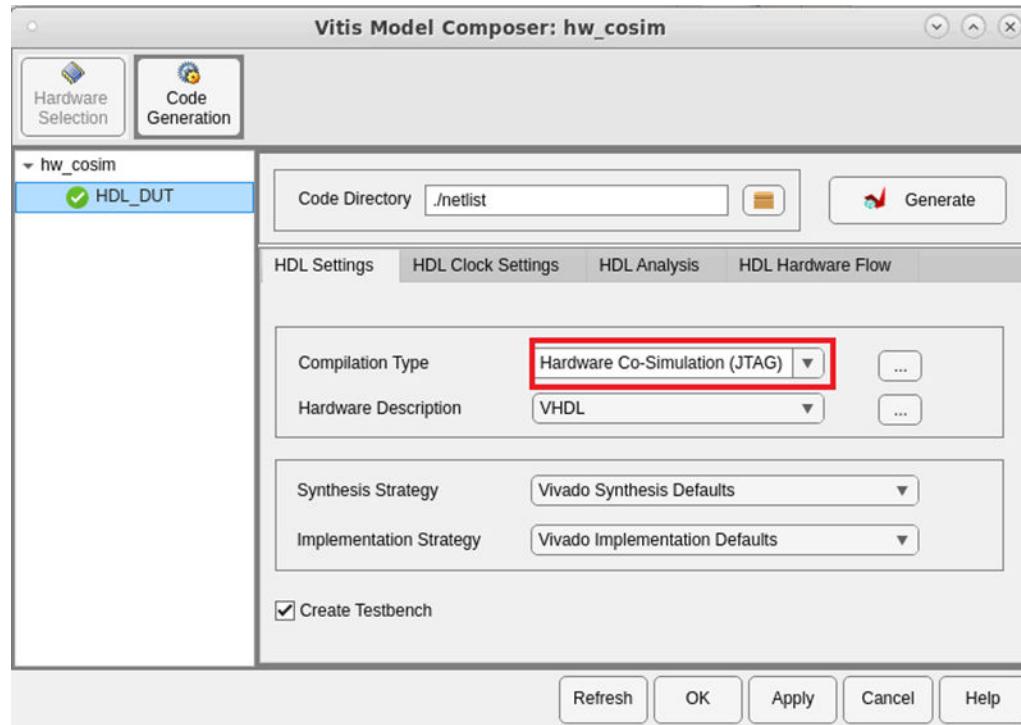
The files generated as part of an HDL Netlist compilation are placed in an `hdl_netlist` subdirectory under the directory you specified in the Code directory field. These files are described in the [Compilation Results](#) section.

## Hardware Co-Simulation Compilation

Model Composer can compile designs into FPGA hardware that can be used in the loop with Simulink® simulations. This capability is discussed in the topic [Using Hardware Co-Simulation](#).

As shown in the following figure, you can select **Hardware Co-Simulation** compilation by selecting it from the **Compilation Type** menu on the HDL Settings tab.

Figure 110: Hardware Co-Simulation



JTAG Hardware Co-Simulation is supported for all Xilinx development boards.

The Simulink library (`<design_name>_hwcosim_lib.slx`) generated as part of a Hardware Co-Simulation compilation is placed in the directory you specified in the **Code directory** field. This library, and the hardware co-simulation block stored in the library, are described in [Hardware Co-Simulation Blocks](#).

## IP Catalog Compilation

Model Composer uses the **IP Catalog** compilation type as the default generation target.

The IP Catalog compilation target allows you to package your Model Composer design into an IP module that can be included in the Vivado IP catalog. From there, the generated IP can be instantiated into another Vivado user design as a submodule.

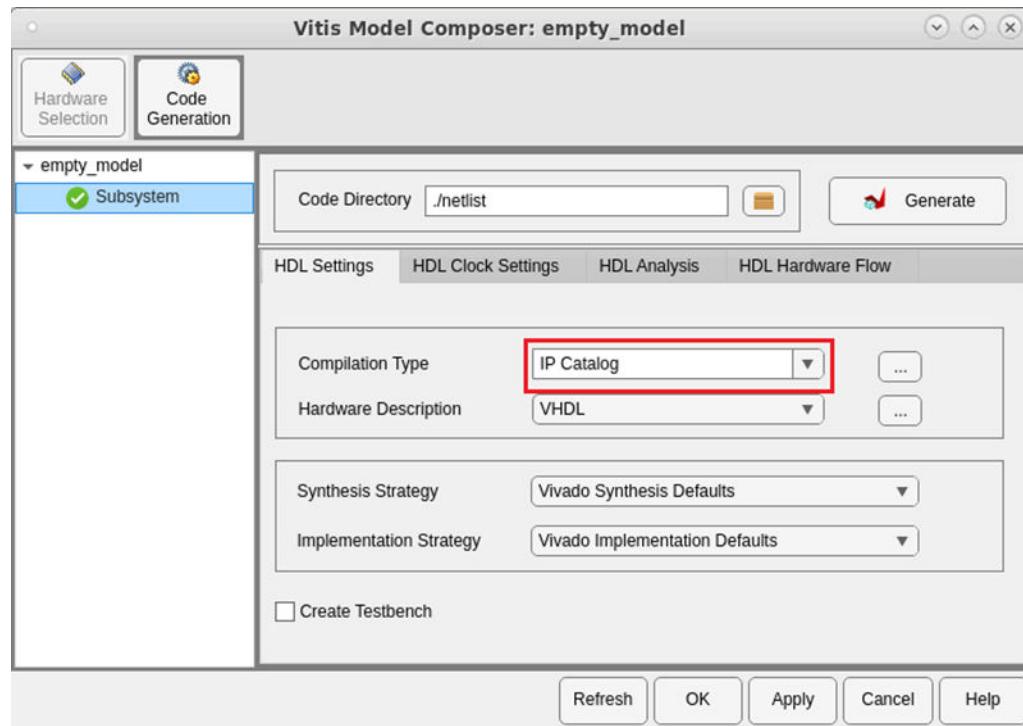
Model Composer first generates an HDL NetList based on the block design. If there are Vivado IP modules in the design, all the necessary IP files are copied into a subfolder named `IP`. Finally, all the RTL design files and Vivado IP design files are included into a ZIP file that is placed in a subfolder named `ip_catalog`.

### ***The IP Catalog Flow***

In a Model Composer design, double-click the Vitis Model Composer Hub block.

As shown below, you can select **IP Catalog** compilation by selecting it from the **Compilation Type** menu on the HDL Settings tab.

Figure 111: IP Catalog

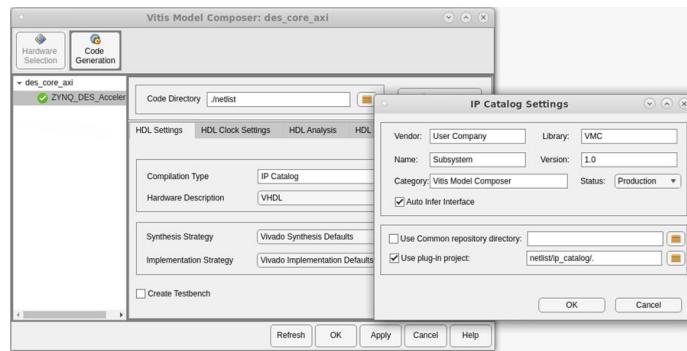


The **Board** and **Part** fields allow you to specify the board or part for which you are targeting the **IP Catalog** compilation. When you select a **Board**, the **Part** field automatically displays the name of the Xilinx device on the selected **Board**, and this part name cannot be changed.

The **IP Catalog** compilation can be performed for any of the boards or parts your Vivado tools support. In addition to accessing the Xilinx development boards installed as part of your Vivado installation, you can also specify Partner boards or custom boards (see [Specifying Board Support in Model Composer HDL Blockset](#)).

The **Code directory** field allows you to specify the location of the generated files.

The ... to the right of the **Compilation Type** field allows you to enter information about the module that will appear in the Vivado IP catalog.

**Figure 112: IP Catalog Settings**

The **Use common repository directory** field allows you to specify a directory referred to as the Common Repository. In an IP catalog compilation, the IP created is copied over to this location. If a Vivado user adds this Path as User Repository in the Vivado project's IP Settings, then all IPs that a Model Composer user has placed in this Common Repository will automatically be picked up by Vivado and can be used either in an IP integrator or an RTL flow.

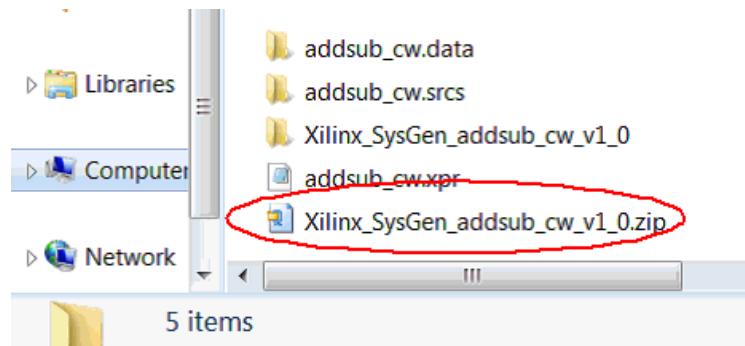
The **Use Plug-in project** field is used to specify a Vivado project containing an IP integrator Block Diagram (BD) that has been imported into Model Composer. For an example of a procedure that will need to have a Vivado project specified in this field, see [Tailor Fitting a Platform Based Accelerator Design in Model Composer](#).

Once you click the **Generate** button, the IP catalog flow starts. As shown below, **Compilation status** windows pop up and indicate the progress of the flow. Once the IP Catalog flow is finished, it will indicate **Generation Completed**. You can then click **Show Details**, to get more detailed information.

**Figure 113: Compilation Status**

Navigate to the specified Target directory, to find a folder named `ip_catalog`. This folder contains all the necessary files to form an IP from your Model Composer design. The ZIP file, circled below, contains all the files required to include the Model Composer design as IP in the Vivado IP catalog.

Figure 114: ZIP File



## Using AXI4 Interfaces

Selecting the **Auto Infer Interface** option in the IP Catalog: Settings dialog box ensures AXI4 interfaces are automatically inferred from the design Gateway In and Gateway Out ports. The **Auto Infer Interface** option groups signals into AXI4-Stream, AXI4-Lite and AXI4 interfaces based on the port names.

The **Auto Infer Interface** option will infer interfaces based on the following criteria:

- The Gateway In and Gateway Out port name suffix must exactly match the signal names in the AXI4 interface standard.
- The design must contain the minimum number of signals to be considered a valid AXI4 interface.

For example, if a design has two Gateway In ports named PortName\_tdata and PortName\_tvalid, and also a Gateway Out port named PortName\_tready, the **Auto Infer Interface** option infers these three ports into a single AXI4-Stream port named PortName. In this example.

- The port name suffixes are exact matches for the signals in an AXI4-Stream interface (TDATA, TREADY and TVALID).
- These three signals are the minimum signals required for an AXI4-Stream interface.

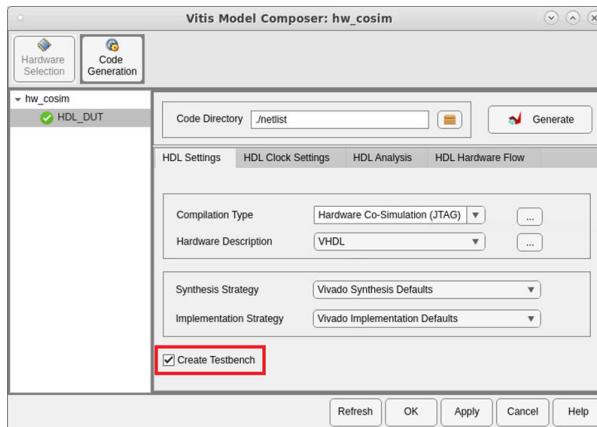
If optional AXI4 sideband signals are present, for example the TUSER signal is optional in the AXI4-Stream standard, and they are named using the same naming convention (for example, PortName\_tuser) they will be grouped into the same AXI4 Interface.

For more details on AXI4 interfaces, AXI4 interface signals names and the minimum required signals for an AXI4 interface, refer to the document *Vivado Design Suite: AXI Reference Guide (UG1037)*.

## Including a Testbench with the IP Module

To verify the functionality of the newly generated IP, it is important to include a test bench. As shown below, if you check **Create testbench**, a test bench is automatically created when you click the **Generate** button.

Figure 115: Create Testbench

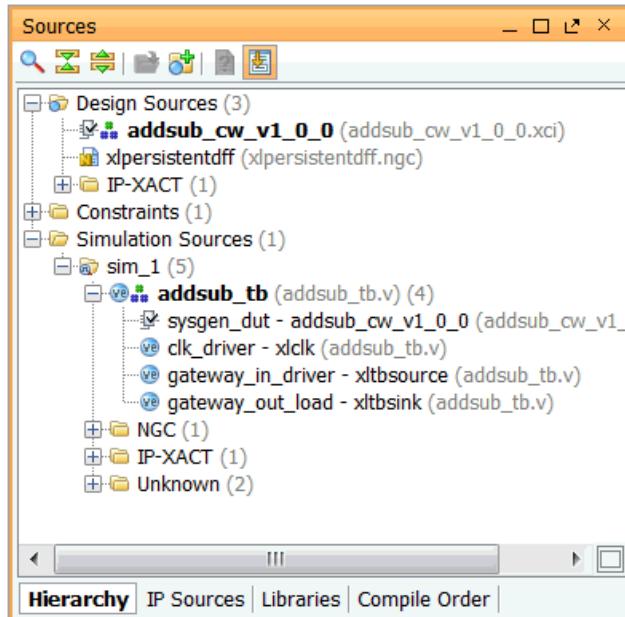


As shown below, when you include a test bench, you can verify the IP functionality by adding three more steps to the flow.

- **Step 1:** Add the new IP to the Vivado IP catalog. Refer to the document *Vivado Design Suite User Guide: Designing with IP* ([UG896](#)).
- **Step 2:** Create a new Vivado IDE project and add the IP as the top-level source.
- **Step 3:** Run simulation, synthesis and implementation to verify the functionality of the generated IP.

The following figure shows an open Vivado IDE project with the newly created IP as the top-level source.

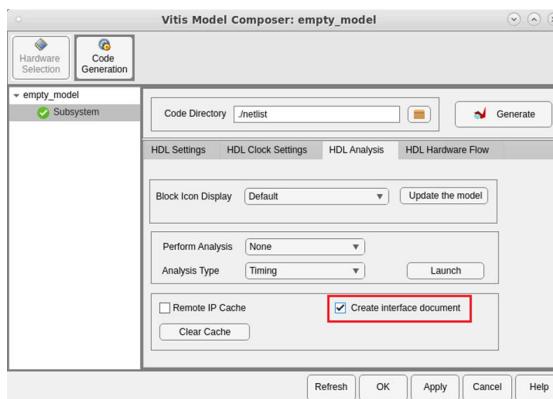
*Figure 116: New IP*



## ***Adding an Interface Document to the IP Module***

As shown below, check **Create interface document**, then click **Generate**, and Model Composer generates an interface document for the IP and packages this HTML document with the IP.

**Figure 117: Create Interface Document**



You can find a new folder, documentation, under the netlist folder. Right-click the new IP in the Vivado IDE, and click **Product guide**, to open one HTML file with interface information about this IP.

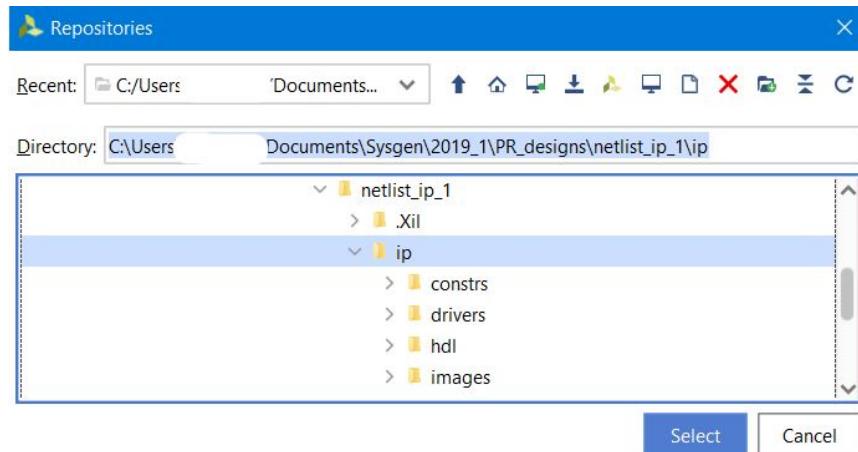
## Adding the Generated IP to the Vivado IP Catalog

To use the IP generated from Model Composer, you need to create a new project, or open an existing project that targets the same device as specified in Model Composer for creating the IP.

**Note:** The IP is only accessible in this project. For each new project where you use this IP, you need to perform the same steps.

Select **IP Catalog** in the Project Manager, and right-click an empty area in IP Catalog window. Select **Add Repository**, and add the directory that contains your new IP.

Figure 118: IP Catalog



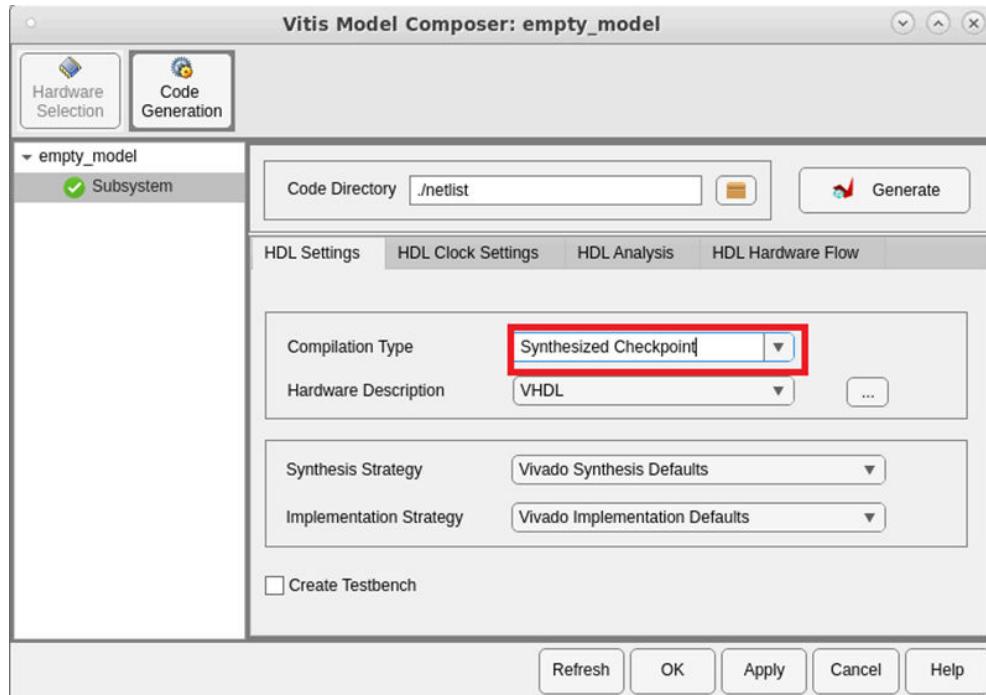
Once the IP is added to the IP catalog, you can include it in larger designs just as you would with any other IP in the IP catalog.

## Synthesized Checkpoint Compilation

Vivado tools provide design checkpoint files (.dcp) as a mechanism to save and restore a design at key steps in the design flow. Checkpoints are merely a snapshot of a design at a specific point in the flow. A Synthesized Checkpoint is a checkpoint file that is created in the out-of-context (OOC) mode after a design has been successfully synthesized.

When you select the **Synthesized Checkpoint** compilation target (see figure below), a synthesized checkpoint target file named <design\_name>.dcp is created, and placed in the **Code directory**. You can then use this <design\_name>.dcp file in any Vivado IDE project.

Figure 119: Synthesized Checkpoint



The Synthesized Checkpoint compilation can be performed for any of the boards or parts your Vivado tools support. In addition to accessing the Xilinx development boards installed as part of your Vivado installation, you can also specify partner boards or custom boards (see [Specifying Board Support in Model Composer HDL Blockset](#)).

## Creating Your Own Custom Compilation Target

Model Composer provides a custom compilation infrastructure to create your own custom compilation target. In addition to generating HDL from your Model Composer design, you can also create a compilation target plug-in that automates steps both before and after the HDL is generated. Details about how to create a custom compilation target can be found in the topic [Creating Custom Compilation Targets](#) topic.

---

## Creating Custom Compilation Targets

Model Composer provides a custom compilation infrastructure that allows you to create your own custom compilation targets. In addition to generating HDL from your Model Composer design, you can also create a compilation target plug-in that automates steps both before and after the Vivado® integrated design environment (IDE) project is created. In order to create a custom compilation target, you need to be familiar with the object-oriented programming concepts in the MATLAB® environment.

## xilinx\_compilation Base Class

The custom compilation infrastructure provides a base class named `xilinx_compilation`. From this base class, you can then create a subclass, and use its properties and override the member functions to implement your own functionality.

Figure 120: Base Class



## Creating a New Compilation Target

The following general procedure outlines how to create a new compilation target, and is followed by more specific examples.

### *Running the Helper Function*

Create a new custom compilation target by running the following helper function.

```
xilinx.environment.addCompilationTarget(target_name, directory_name)
```

For example, consider the following command:

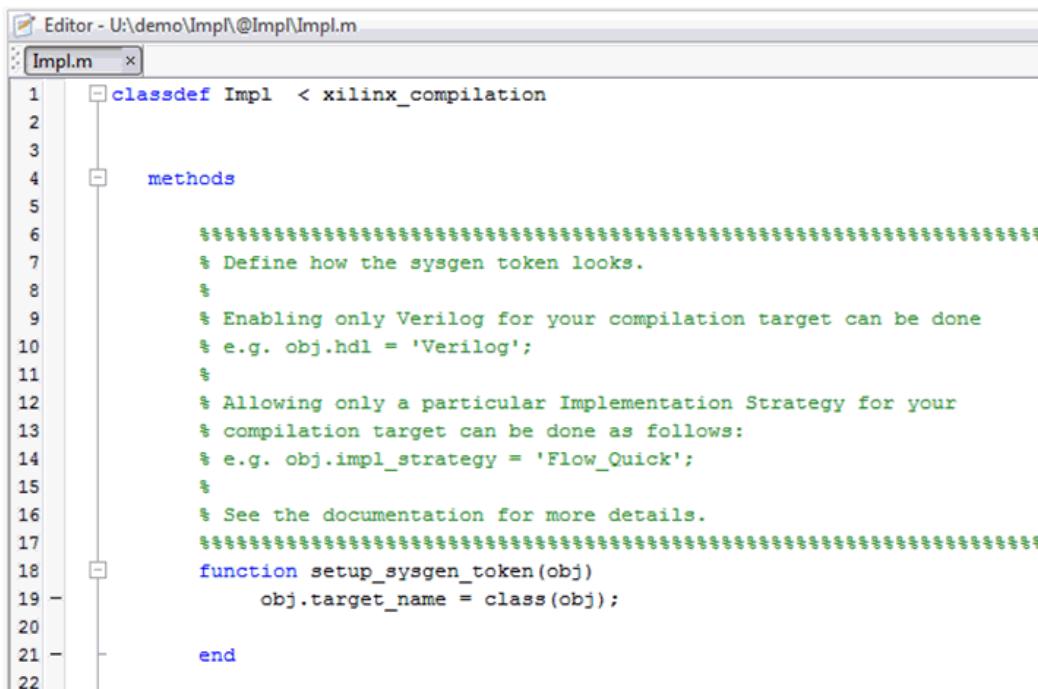
```
xilinx.environment.addCompilationTarget('Impl', 'U:\demo')
```

Figure 121: Helper Function



When you enter this command in the MATLAB Command Window as shown above, the following happens:

1. A folder is created named `Impl/@Impl` in `U:\demo`.
2. Inside the folder, a template class file `Impl` is created (`Impl.m`), which is derived from the base class `xilinx_compilation`. At this point, if no modifications are made to the file, the newly created `Impl` compilation target acts the same as the **HDL Netlist** compilation target. The content of the `Impl.m` file is shown in the following figure.



```
Editor - U:\demo\Impl\@Impl\Impl.m
Impl.m x
1 classdef Impl < xilinx_compilation
2
3
4     methods
5
6         % Define how the sysgen token looks.
7         %
8         % Enabling only Verilog for your compilation target can be done
9         % e.g. obj.hdl = 'Verilog';
10        %
11        %
12        % Allowing only a particular Implementation Strategy for your
13        % compilation target can be done as follows:
14        % e.g. obj.impl_strategy = 'Flow_Quick';
15        %
16        % See the documentation for more details.
17        %
18        function setup_sysgen_token(obj)
19            obj.target_name = class(obj);
20
21        end
22
```

3. The helper function then adds `U:\demo\Impl` to the MATLAB path, so that the new class `Impl` can be discovered by MATLAB.

**Note:** Be aware that the `target_name` cannot contain spaces. After the class is created, you can add spaces to the `target_name` property of the class.

## Modifying a Compilation Target

If modifications are made to a class file for a compilation target, you are required to call the following helper function. This helper function ensures that Model Composer detects the new class definition.

```
>> xilinx.environment.rehashCompilationTarget
```

## ***Adding an Existing Compilation Target***

You must add the path that contains the folder with the custom compilation target. As shown below, you can use the `addpath` functionality provided by MATLAB® to do this:

```
>>addpath('U:\demo\Impl');
```

When you use `addpath`, you must provide the absolute path, not the relative path.

## ***Saving a Custom Compilation Target***

You can use the `savepath` functionality in MATLAB® to save the custom compilation target. To do the save, you may need write permission to the MATLAB installation area.

## ***Removing a Custom Compilation Target***

To remove the custom compilation target, remove the path to the target from the MATLAB® Search Path.

# **Base Class Properties and APIs**

The `xilinx_compilation` base class resides in the following location:

```
<Vivado Install Path>/scripts/sysgen/matlab/@xilinx_compilation
```

## ***Vivado Project-Related Properties***

### **`top_level_module`**

You can use this property to set the top-level name of their choice. This parameter accepts a MATLAB® string.

## ***Vivado IDE Project Generation-Related Functions***

### **`pre_project_creation(design_info)`**

This function should be called before you create the Vivado® IDE project. Before the Model Composer Infrastructure creates the project, it has to know what files need to be added to the Vivado® IDE project, and what additional Tcl commands need to be run. There might be use-cases where the user wants to add some files to the project based on the top-level port interface of the Model Composer design. For this purpose, a structure that describes the port interface is passed into this function called `design_info`. `design_info` is described in detail in a later section.

**post\_project\_creation(design\_info)**

This function should be called at the end of Vivado IDE project creation. This is the last function to be called after the Project Generation script is run. This is a useful function for things like error parsing, generating reports, and opening the Vivado IDE project. A structure which describes the port interface is passed into this function called `design_info`. `design_info` is described in detail in a later section.

**add\_tcl\_command(string)**

This function adds the additional Tcl commands as a string. These Tcl commands will be issued after the Vivado IDE project is created. Use this command to create a bitstream once project creation occurs. The Tcl command can also be used to source a particular Tcl file. The commands are executed in the order in which they are received.

**add\_file(string)**

This function adds user-defined files to the Vivado IDE project. This application programming interface (API) function can also be used to add XDC constraint files to the Vivado IDE project. You should make sure that the order in which `add_file` is called, is hierarchical in nature. The top-module file must be added last.

**run\_synthesis()**

This function runs synthesis in the Vivado IDE project.

**run\_implementation()**

This function runs implementation in the Vivado IDE project.

**generate\_bitstream()**

This function generates a bitstream in the Vivado IDE project.

## ***Design Info***

`design_info` is a MATLAB® struct and its contents are shown below:

Figure 122: Design Info

The screenshot shows two tables of design information. The top table is for 'design\_info.ports.gateway\_in' and the bottom table is for 'design\_info'. Both tables have columns for Field, Value, Min, and Max.

Field	Value	Min	Max
ArithmeticType	'xISigned'		
BinaryPoint	14	14	14
DatFile	'adder_gateway_i...		
Direction	'in'		
IconText	'Gateway In'		
IsClock	0	0	0
Name	'gateway_in'		
Period	1	1	1
Type	'Fix_16_14'		
Width	16	16	16

Field	Value	Min	Max
ports	<1x1 struct>		
sim_time	10	10	10
target_dir	'/group/dspuser...'		
testbench	'on'		
top_level	'adder'		

## Examples of Creating Custom Compilation Targets

The following examples provide more detail on how you can create various kinds of customized targets.

### ***Example 1: Creating an Implementation Target***

1. Open a Model Composer model, then open the Model Composer Hub block. This populates with all the available compilation targets.
2. In the MATLAB® Command Window, modify the path as per your requirements, then enter the following command:

```
xilinx.environment.addCompilationTarget('Impl', 'U:\demo')
```

This provides a template derived class for you to edit.

3. In the MATLAB Command Window, enter the following command:

```
xilinx.environment.rehashCompilationTarget
```

This ensures that the new compilation target is picked up by the Model Composer Hub block.

4. Close and then re-open the Model Composer Hub block. You now see the compilation target, **Impl**.
5. At this point, selecting **Impl** does not perform any customized operations on the Model Composer Hub block. It is equivalent to an HDL Netlist compilation target.
6. Open U:\demo\Impl\@Impl\Impl.m in the MATLAB Editor.
7. Populate the `setup_sysgen_token()` function as per the requirements. Using this approach, you can control how the Model Composer Hub block should look, including the enabled/disabled fields when the user-defined custom compilation is selected.

```
#####
% Define how the sysgen token looks.
%
% Enabling only Verilog for your compilation target can be done
% e.g. obj.hdl = 'Verilog';
%
% Allowing only a particular Implementation Strategy for your
% compilation target can be done as follows:
% e.g. obj.impl_strategy = 'Flow_Quick';
%
% See the documentation for more details.
#####
function setup_sysgen_token(obj)
    obj.target_name = class(obj);
    obj.hdl = 'Verilog';
    obj.impl_strategy = 'Flow_Quick';
end
```

8. In the MATLAB Command Window, you should enter the following command:

```
xilinx.environment.rehashCompilationTarget
```

This ensures that the updated class definition of **Impl** is used.

9. Close and then re-open the Model Composer Hub block. Select **Impl** from the list of Compilation targets.
10. The Model Composer Hub block displays:
11. Observe that the **Hardware description language** field and the **Implementation strategy** field are fixed to what you set in the **Impl** class and are disabled for user modification.
12. All the user specified files and additional Tcl commands to be run are known before the Vivado® IDE project is created. The next step is to populate the `pre_project_creation()` function as indicated below:

```
#####
% Define how the Project should be generated. Adding tcl commands,
% files etc. should be done here.
%
% e.g. obj.add_tcl_command('launch_runs synth_1');
% e.g. obj.add_file('C:\work\myconstraints.xdc');
% e.g. obj.run_implementation()
%
% design_info is the struct that contains the information about the
% design and its interface. See documentation for more details
#####
function pre_project_creation(obj, design_info)
    obj.add_tcl_command('launch_runs synth_1');
    obj.add_tcl_command('wait_on_run synth_1');
    obj.run_implementation();
end
```

13. In the MATLAB Command Window, enter the following command:

```
xilinx.environment.rehashCompilationTarget
```

This ensures that the updated class definition of **Impl** is used.

14. Close and then re-open the Model Composer Hub block. Select **Impl** from the list of Compilation targets.

15. Click **Generate**. Once the process is finished, you can see the implementation results by opening up the Vivado IDE project.

## ***Example 2: Creating a Bitstream Target***

1. Open a Vitis Model Composer design.
2. In the MATLAB command Window, modify the path as per your requirements, similar to the first example, and then enter the following command:

```
xilinx.environment.addCompilationTarget('Bitstream', '.')
```

This provides a template derived class for the users to edit. The last field corresponds to the directory which contains the `board.xml` file.

3. In the MATLAB Command Window, enter the following command:

```
xilinx.environment.rehashCompilationTarget
```

This will ensure that the new compilation target is picked up by the Vitis Model Composer Hub block.

4. Close and then re-open the Vitis Model Composer Hub block.
5. You will now see the compilation target **Bitstream** on the Vitis Model Composer Hub block.
6. Open the `Bitstream.m` created in the '`./Bitstream/@Bitstream/Bitstream.m`'.
7. Download the following two files:



8. Inside the function `pre_project_creation()`, add the following lines to do the following:
  - a. Set the board as a KC705 board.
  - b. Add a new top-level file (`top.v`) to use the differential clock ports of KC705.
  - c. Add a new XDC file to give the location constraints for the clock, dip, and led ports.
  - d. Set the newly added module `top` as the top.
  - e. Run synthesis.
  - f. Run implementation.
  - g. Generate bitstream.

After you save the files to a location on your computer, you should give the full path to the files in the `add_file` API as per your path.

```
add_tcl_command(obj, 'set_property board xilinx.com:kintex7:kc705:1.1 [current_project]');
add_file(obj,
'/group/dspusers-xsj/umangp/rel/2013.4/cust_comp_test/
bitstream_example.xdc');
add_file(obj, '/group/dspusers-xsj/umangp/rel/2013.4/cust_comp_test/
top.v');
obj.top_level_module = 'top';
run_synthesis(obj);
run_implementation(obj);
generate_bitstream(obj);
```

9. In the MATLAB Command Window, enter the following command:

```
xilinx.environment.rehashCompilationTarget
```

This ensures that the new compilation target is picked up by the Vitis Model Composer Hub block.

10. Close and then re-open the Vitis Model Composer Hub block.
11. Select the **Bitstream** compilation target.
12. Click the **Generate** button.

13. After the generation is complete, you can find the bit file in the following directory:

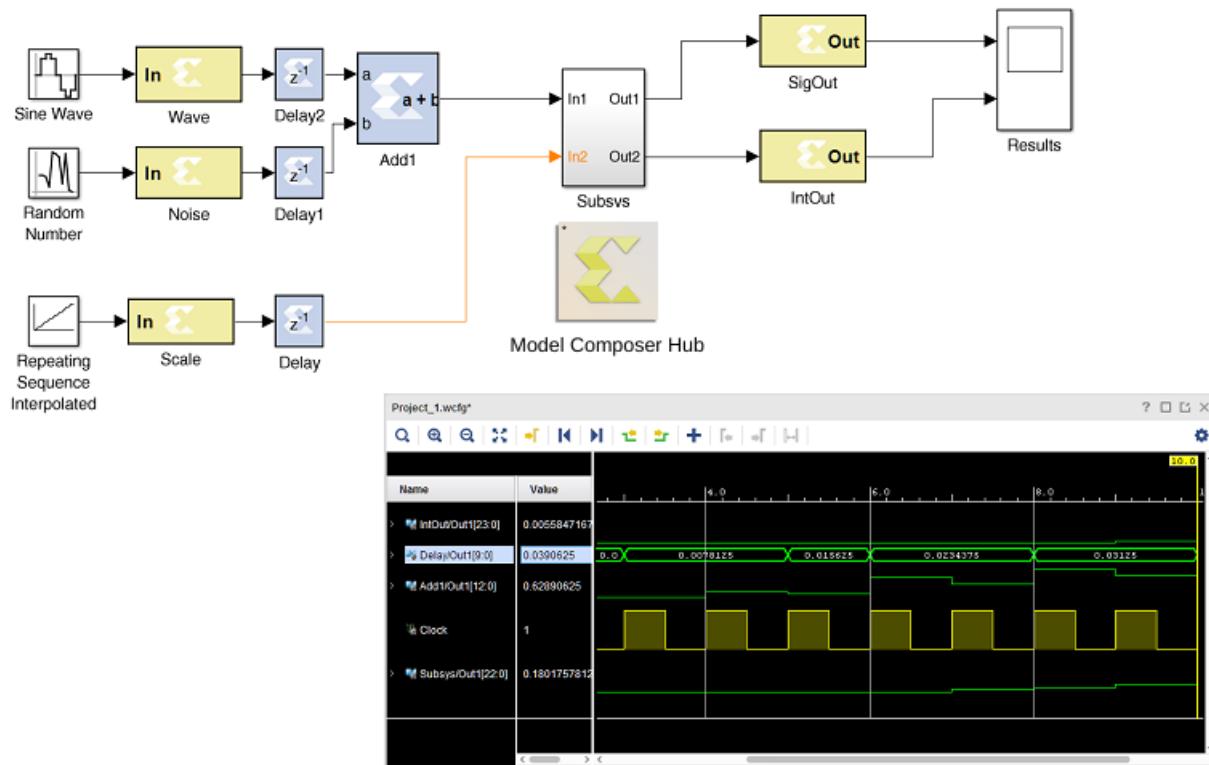
```
./<Target_directory>/Bitstream/bitstream_example.runs/impl_1/top.bit
```

## Xilinx Waveform Viewer

The Xilinx® Waveform Viewer displays a waveform diagram of selected signals in your Vitis Model Composer design. Waveforms can be displayed in the Waveform Viewer after running a Simulink simulation. Inputs and outputs of blocks in the HDL Blockset can be displayed in the Waveform Viewer.

In your design, you can select the signals that will be monitored in the Waveform Viewer. As you develop and troubleshoot your design, the waveforms for the signals you are monitoring will be updated in the Waveform Viewer each time you simulate the model.

Figure 123: Example Design in Waveform Viewer



The Xilinx Waveform Viewer used with Model Composer is also used by other tools in the Vivado® toolset. The Waveform Viewer is used to analyze a design and debug code in the Vivado simulator and to display data captured by the Integrated Logic Analyzer (ILA) for in-system debugging.

For information on using the Waveform Viewer to develop and troubleshoot your design, see this [link](#) in the *Vivado Design Suite User Guide: Logic Simulation (UG900)*.

## Waveform Viewer Files

The first time you open the Waveform Viewer for your Simulink model, Model Composer creates a `wavedata` directory in the directory containing your Simulink model.

**Note:** You will need write permission for the directory containing your Simulink model.

Data describing the display in the Waveform Viewer is stored in the following files in the `wavedata` directory:

- `<design_name>.wcfg` - This is the waveform configuration file. It contains the names of the signals you are monitoring in your design and how the waveforms for these signals will appear in the Waveform Viewer.
- `<design_name>.wdb` - This is the waveform database file. It contains the data necessary to draw the waveforms in the Waveform Viewer.

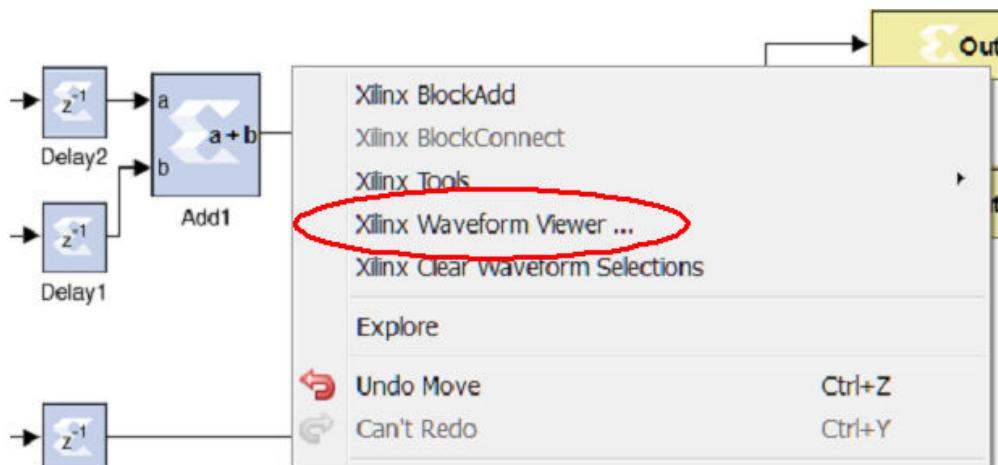
The names of the signals that are being monitored are stored in the Simulink model (SLX file). If the Simulink model cannot access the data in the `wavedata` directory (for example, if you moved the model's SLX file to a different directory and opened it in the new directory), you can display the monitored signals by opening the Waveform Viewer and simulating the design. The waveforms for the monitored signals will then appear in the Waveform Viewer.

## Opening the Xilinx Waveform Viewer

You can open the Waveform Viewer in either of the following ways:

- Opening from right-click menu:  
Right-click in your model and select **Xilinx Waveform Viewer**.

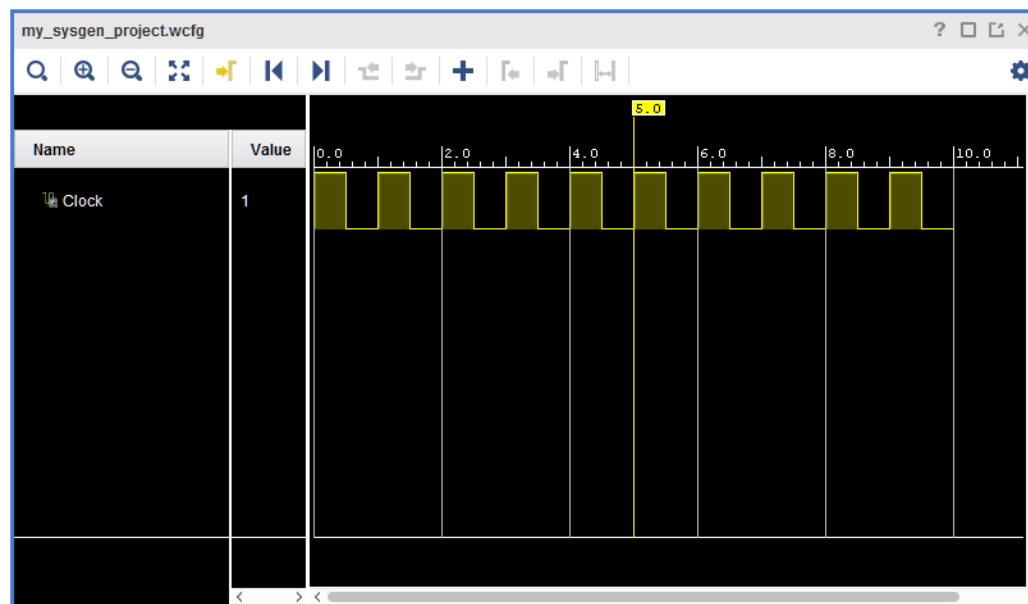
Figure 124: Xilinx Waveform Viewer



If you open it from the right-click menu, the Waveform Viewer opens with the following display:

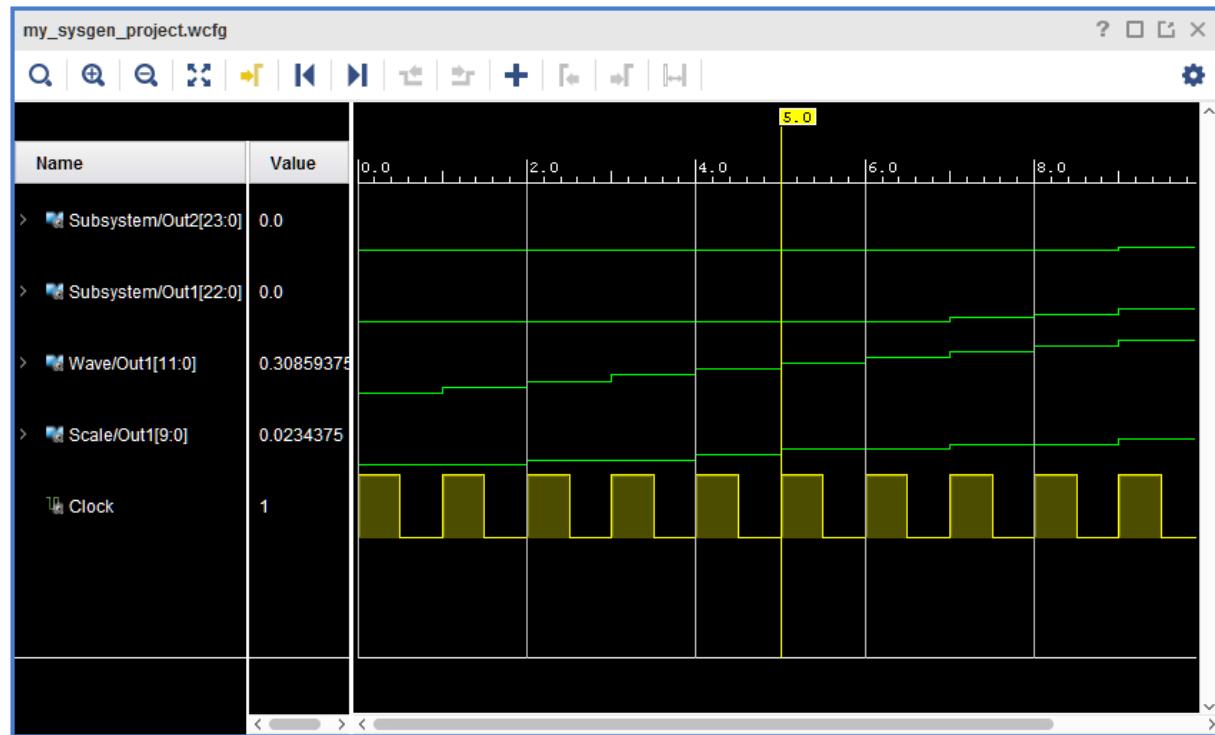
- If this is the first time you are opening the Waveform Viewer for this design, the Waveform Viewer opens displaying waveforms for the clock signals in your design, and no other waveforms. You can then add the signals in your design that you want monitored to the Waveform Viewer display (see [Adding Signals to the Waveform Viewer Display](#)).

Figure 125: Waveform Viewer Display



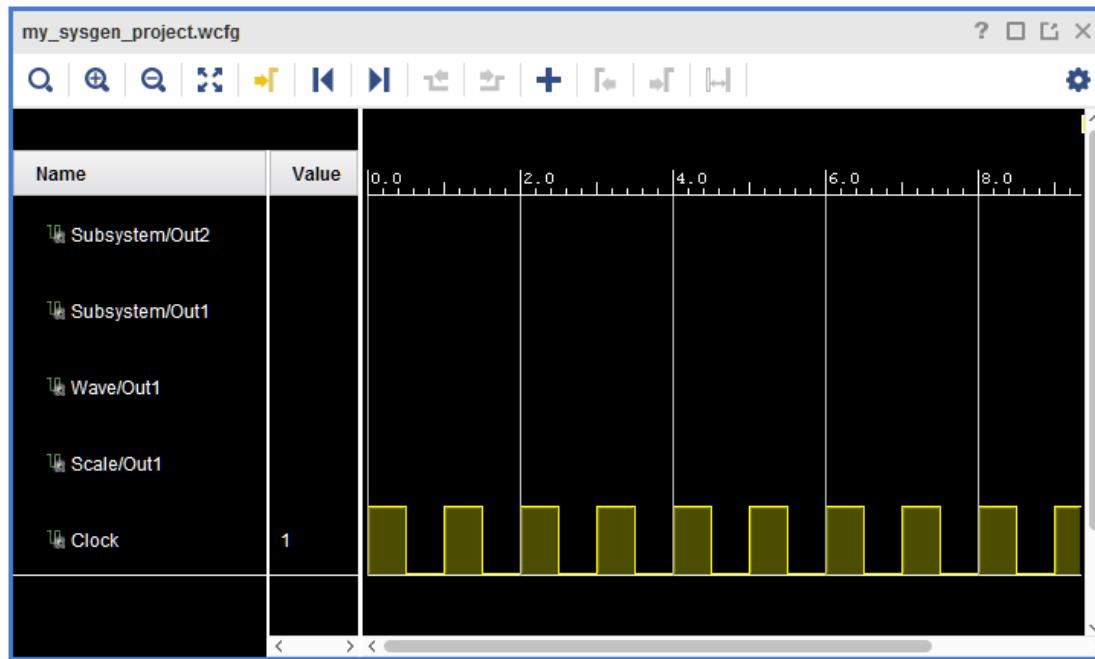
- If you have previously monitored signals in the Waveform Viewer for this design, and have saved the data, the Waveform Viewer opens displaying the signal names, and waveforms displayed when you last closed the Waveform Viewer.

Figure 126: Signals in Waveform Viewer



- If you have previously monitored signals in the Waveform Viewer for this design, but cannot access the saved data (for example, if you moved the model's SLX file to a different directory, and opened it in the new directory), the Waveform Viewer opens displaying the signal names for the signals monitored when you last saved the model. The Waveform Viewer will not show the waveforms for the monitored signals until you resimulate the model.

Figure 127: Waveform Viewer New Signals



- Opening after simulation:

If you have previously monitored signals in the Waveform Viewer for your design, the Waveform Viewer will open automatically when you simulate your model.

## Adding Signals to the Waveform Viewer Display

Inputs and outputs of blocks in the HDL Blockset can be displayed in the Waveform Viewer. The data necessary to draw each signal's waveform is not stored with the design; it is generated by simulation. You can only display a signal's waveform after you have added the signal to the Waveform Viewer and then simulated the model.

To add signals to the display in the Waveform Viewer:

- With the Waveform Viewer open, select a signal in the Model Composer model.

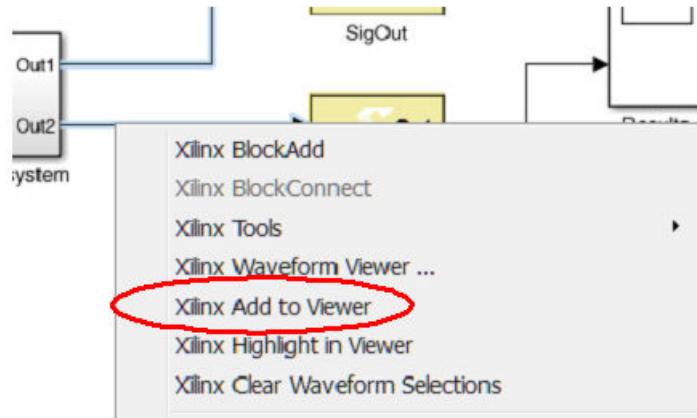
You can also select multiple signals by using **Shift** + click to select additional signals.

**Note:** For the Gateway In block, only the output signal can be displayed in the Waveform Viewer.

- Right-click one of the selected signals in the Model Composer model and select **Xilinx Add to Viewer** in the right-click menu.

**Note:** If you select a signal that is currently displayed in the Waveform Viewer, the **Xilinx Add to Viewer** entry will not appear in the right-click menu.

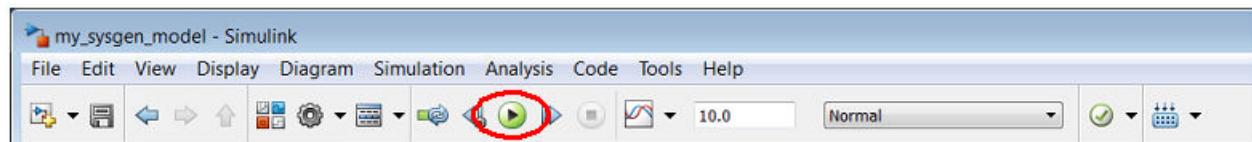
Figure 128: Xilinx Add to Viewer Command



The signal names of the selected signals appear in the Waveform Viewer.

3. Only the names of the added signals appear in the Waveform Viewer, because the Waveform Viewer does not have the data to draw the signal's waveform until you simulate the design.
4. Simulate the model.

Figure 129: Run Button



After the simulation is finished, the waveforms for the added signals are displayed in the Waveform Viewer.

## Deleting Signals From the Waveform Viewer Display

1. In the Waveform Viewer, select the signals to be deleted.  
Use **Shift+click** or **Ctrl+click** to select multiple signal names (**Ctrl+A** to select all).
2. Right-click one of the selected names and select **Delete** in the right-click menu.  
OR  
Press the **Delete** key.

The waveforms are deleted from the Waveform Viewer. Deleted waveforms are no longer monitored; if you resimulate the model the deleted waveforms will not appear in the Waveform Viewer.

## Cross Probing Between the Waveform Viewer and the Model

Cross probing helps you correlate the waveforms in the viewer to the wires in the Model Composer model.

You can cross probe signals between the Waveform Viewer, and the model in the following ways:

- To cross probe a signal from the Waveform Viewer to the Model Composer model, select one or more signal names in the Waveform Viewer. Use **Shift+click** or **Ctrl+click** to select multiple signal names (**Ctrl+A** to select all).

The selected signals are highlighted in orange in the Model Composer model.

To unhighlight a signal you have highlighted in the Model Composer model, **Ctrl+click** the signal name in the Waveform Viewer. The signal is unhighlighted in the Model Composer model.

- To cross probe a signal from the Model Composer model to the Waveform Viewer:
  1. With the Waveform Viewer open, select a signal in the Model Composer model.  
You can also select multiple signals by using **Shift+click** to select additional signals.
  2. Right-click one of the selected signals in the Model Composer model and select **Xilinx Highlight in Viewer** in the right-click menu.

**Note:** If you select a signal that is not currently displayed in the Waveform Viewer, the **Xilinx Highlight in Viewer** entry will not appear in the right-click menu.

Figure 130: Xilinx Highlight in Viewer



3. Observe that the signal names of the selected signals are highlighted in the Waveform Viewer.

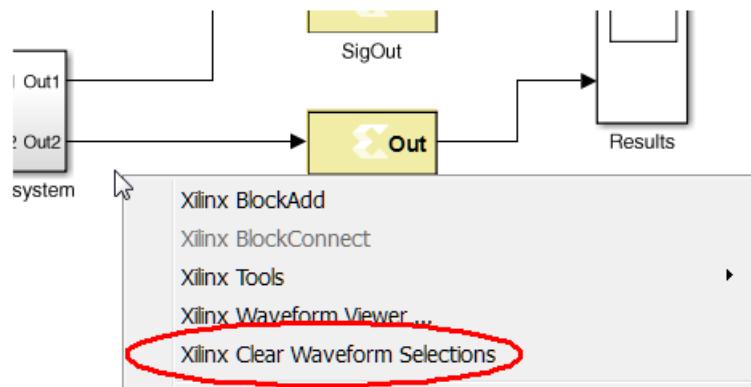
## Clearing the Waveform Viewer Display

To clear the waveform display, deleting all the waveforms currently displayed in the Waveform Viewer:

1. Right-click in the Model Composer model.
2. Select **Xilinx Clear Waveform Selections** in the right-click menu.

All of the signals currently displayed in the Waveform Viewer are deleted from the Waveform Viewer display, and the Waveform Viewer closes. The deleted waveforms are no longer monitored and the `wavedata` directory (which contains data describing the current display in the Waveform Viewer) is removed from the directory containing your Simulink model.

Figure 131: Xilinx Clear Waveform Selections



To open the Waveform Viewer again, right-click in your model and select **Xilinx Waveform Viewer** in the right-click menu. The Waveform Viewer opens displaying waveforms for the clock signals in your design, and no other waveforms.

## Customizing the Display and Analyzing Waveforms

The Waveform Viewer has many tools to customize how your waveforms are displayed and to analyze the waveforms. For information on using the Waveform Viewer to develop and troubleshoot your design, see this [link](#) in the *Vivado Design Suite User Guide: Logic Simulation (UG900)*.

## Tips for Working in the Waveform Viewer

The following tips will help you with your waveform analysis using the Model Composer model and the Waveform Viewer:

- Keep the Waveform Viewer open during a Model Composer session. Do not close the Waveform Viewer between each simulation.

- If you select a group of signals in the Waveform Viewer, all of the signals in the group will be cross-probed from the Waveform Viewer to the Model Composer model.
- To add multiple signals in your Model Composer model to the Waveform Viewer display, you can press and hold the left mouse button and drag the mouse to draw a box around the signals, selecting them. Then right-click one of the selected signals and select **Xilinx Add to Viewer** in the right-click menu. The selected signals will be added to the Waveform Viewer display.
- When naming an output signal for a block in your Model Composer model, avoid using the reserved characters shown in the table below. These are reserved characters in VHDL or Verilog. If your model does contain a signal with a reserved character, its name will be changed in the Waveform Viewer display according to the following mapping table.

Table 7: Reserved Characters

Reserved Character	Mapped To
(	#1
)	#2
[	#3
]	#4
.	#5
,	#6
:	#7
\	#8

## Closing the Waveform Viewer

To close the Waveform Viewer, select **File**→**Exit**. If you have not yet saved the waveform data, you will be prompted to save the data before the Waveform Viewer closes.

# HLS Library

## Introduction

Vitis™ Model Composer provides the HLS blockset in the Xilinx toolbox. This enables you to transform your algorithmic specifications to production-quality IP implementations using automatic optimizations and leveraging the high-level synthesis technology of Vitis HLS. Using the IP integrator in Vivado, you can then integrate the IP into a platform that, for example, may include a Zynq® device, DDR3 DRAM, and a software stack running on an Arm® processor.

The HLS library in the Xilinx Tool Box provides optimized blocks for use within the Simulink environment. These include basic functional blocks for expressing algorithms like Math, Linear Algebra, Logic, and Bit-wise operations and others.

The HLS library contains the following categories of elements.

**Table 8: HLS Block Library**

Library	Description
Logic and Bit Operations	Blocks that supports the compound logical operations and bit-wise operations.
Lookup Tables	Block set that performs a one dimensional lookup operation with an input index.
Math Functions	Blocks that implement mathematical functions.
Ports and Subsystems	Blocks that allow creation of subsystems and input/output ports.
Relational Operations	Block set to define some kind of relation between two entities (e.g., Numerical Equality and inequalities).
Signal Attributes	Includes block which helps to maintain the compatibility between input type and output type (e.g., Type casting).
Signal Operations	Blocks that support simple modifications to the time variable of the signal to generate new signals (e.g., Unit Delay).
Signal Routing	Blocks that supports the setup to track signal sources and destinations (e.g., Bus selector).
Sinks	Include blocks that receive physical signal output from other blocks.
Source	Include blocks that generate or import signal data.
Tools	Include blocks that controls the implementation/Interface of the Model.

For information on specific blocks in the Model Composer HLS library, see [HLS Blockset](#).

The HLS block library is compatible with the standard Simulink block library, and these blocks can be used together to create models that can be simulated in Simulink. However, only certain Simulink blocks are supported for code generation by Model Composer. The Simulink blocks compatible with output generation from Model Composer can be found in the HLS block library.

Model Composer also lets you create your own custom blocks from existing C/C++ code for use in models. Refer to [Importing C/C++ Code as Custom Blocks](#) for more information.

Your Model Composer design is bit-accurate with regard to the final implementation in hardware, though untimed. You can compile the design model into C++ code for synthesis in Vitis HLS, create HDL blocks, or create packaged IP to be used in Vivado.

To familiarize yourself with the Model Composer HLS library, the *Vitis Model Composer Tutorial* ([UG1498](#)) includes labs and data to walk you through the tool.

The rest of this document discusses the following topics:

- [Creating a Model Composer model using HLS block libraries](#).
- [Importing existing C-code into the Model Composer HLS block library for use in your models](#).
- [Compiling the model for use in downstream design tools](#).
- [Verifying your Model Composer model, C++, and RTL outputs](#).

---

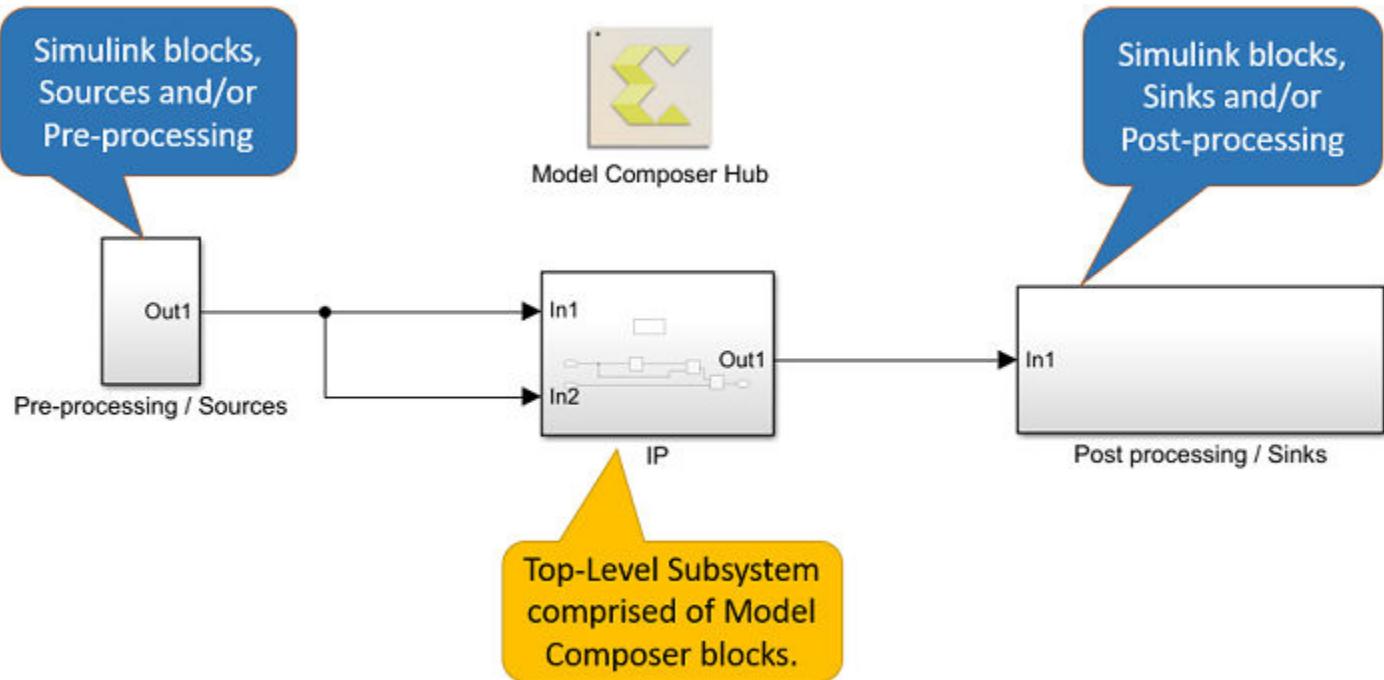
## Creating a Model Composer Design

As shown in the image below, a Model Composer design with HLS blocks includes the following elements:

1. Simulink® blocks that determine inputs, and provide source signals. These blocks are used in simulation of the design, but do not affect the output generated by Model Composer.
2. A top-level subsystem block, as described in [Creating a Top-Level Subsystem Module](#), that encapsulates the algorithm defined by the Model Composer model. This subsystem module can contain:
  - Blocks from the HLS library to define your algorithm, as listed in the HLS Library.
  - Custom imported functions as described in [Importing C/C++ Code as Custom Blocks](#).
  - An Interface Spec block that defines the hardware interfaces as described in [Defining the Interface Specification](#).
3. The Model Composer Hub block that controls throughput of the design, and output generation through a series of options as described in [Vitis Model Composer Hub](#).

4. The output signals, or sinks that process the output in Simulink. Again, these blocks are used during Simulink simulation as described in [Simulating and Verifying Your Design](#), but do not affect the output generated by Model Composer.

Figure 132: Elements of a Model Composer Design



## Creating a New Model

You create a new model by adding blocks from the Library Browser into the Simulink Editor. You then connect these blocks with signal lines to establish relationships between blocks. The Simulink Editor manages the connections with smart guides and smart signal routing to control the appearance of your model as you build it. You can add hierarchy to the model by encapsulating a group of blocks and signals as a subsystem within a single block. Model Composer provides a set of predefined blocks that you can combine to create a detailed model of your application.

In the Simulink start page, select **Blank Model** to open a new model.



**TIP:** You can also open an existing Model Composer template if any have been defined. Model templates are starting points to reuse settings and block configurations. To learn more about templates, see [Create a Template from a Model](#) in the Simulink documentation.

The Simulink start page also lists the recent models that you have opened on the left-hand column. You can open one of these recent models if you prefer.

The blank model opens, and you will create the Model Composer model by adding blocks, specifying block parameters, and using signal lines to connect the blocks to each other.



**IMPORTANT!** HLS Library only supports one sample time for the model, and does not support multi-time systems. All HLS Library blocks inherit the sample time from the source block of the model. See [What is Sample Time](#) for more information.

To save the model select **File** → **Save** from the main menu. The **Save As** dialog box is opened, with a file browser. Navigate to the appropriate folder or location, and enter a name for the model in the **File Name** field. Click **Save**. The model is saved with the file extension `.slx`.

Model Composer also includes example models based on HLS library which can be accessed from the *Model Composer Examples* section of the *Vitis Model Composer* documentation available from the **Help** menu in the tool, or by typing the `xmcOpenExamples` command from the MATLAB command prompt:

```
>> xmcOpenExamples
```

This command opens a window to specify the target directory for downloading the examples from the GitHub repository.

## Adding Blocks to a Model

You can add blocks to the current model by opening the Library Browser and dragging and dropping the block onto the design canvas of the Simulink Editor. Open the Library Browser by

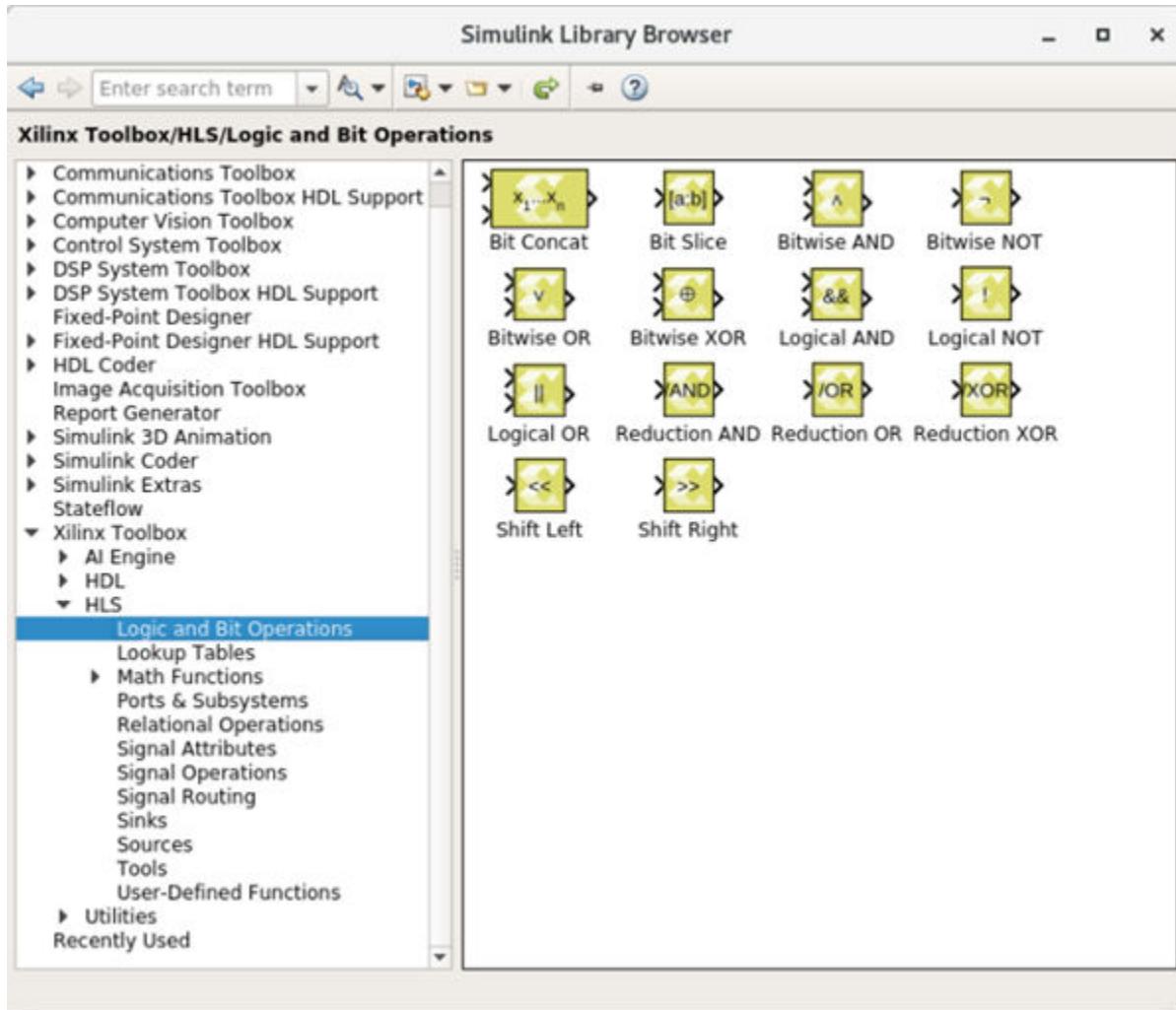
clicking the button on the **Simulation** tab. You will see the standard Simulink library of blocks, as well as the HLS library in the Xilinx Toolbox.



**TIP:** You can also open the Library browser by typing the `slLibraryBrowser` command from the command prompt.

The HLS blocks are organized into sub-categories based on functionality. The figure below shows the **HLS** → **Logic and Bit Operations** block library in the Library Browser.

Figure 133: Library Browser



Double-clicking a block in the Library Browser, opens the Block Parameter dialog box displaying the default values for the various parameters defined on the selected block. While the block is in the library, you can only view the parameters. To edit the parameters, you must add the block to the design canvas.

To get additional information about a block you can right-click a block in the Library Browser and select the **Help** command. Alternatively, you can double-click the block in the Library Browser and click the **Help** button from the block dialog box. The Help browser opens with specific information for the block.

When you drag and drop the block onto the canvas, the block is added to the model with the default parameter values defined.



**TIP:** You can also quickly add blocks to the current model by single-clicking on the design canvas of the Simulink Editor and typing the name of a block. Simulink displays possible matches from the libraries, and you can select and add the block of interest.

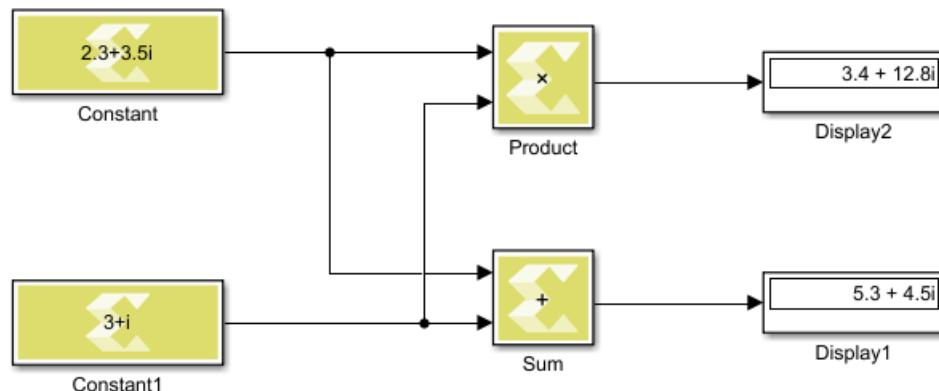
Simulink models contain both signals and parameters. Signals are represented by the lines connecting blocks. Parameters are coefficients that define key characteristics and behavior of a block.

## Connecting Blocks

You can connect the output ports on blocks to the input ports of other blocks with signal lines. Signal lines define the flow of data through the model. Signals can have several attributes:

- Data type: Defines the type of data carried by the signal. Values can range from integer, to floating point, to fixed point data types. See [Working with Data Types](#) for more information.
- Signal dimension: Defines the values as being scalar, vector, or matrices. See [Signal Dimensions](#) and [Matrices, Vectors, and Scalars](#) for more information.
- Complexity: Defines a value as being a complex or real number. See [Signal Values](#) for more information. The figure below shows complex numbers propagating through a model.

Figure 134: Complex Signal Values



To add a signal line, position the cursor over an input or output port of a Simulink block. The cursor changes to a cross hair (+). Left-click and drag the mouse away from the port. While holding down the mouse button, the connecting line appears as a dotted line as you move across the design canvas. The dotted line represents a signal that is not completely connected.

Release the mouse button when the cursor is over a second port to be connected. If you start with an input port, you can stop at an output port, or connect to another signal line; if you start at an output you can stop at an input. Simulink connects the ports with a signal line and an arrow indicating the direction of signal flow.

You can connect into an existing line by right-clicking and dragging the mouse. This creates a branching line connected to the existing signal line at the specified location. The branch line can connect to an input or output as appropriate to the connected signal.



**TIP:** You can also connect blocks by selecting them sequentially while holding the Ctrl key. This connects the output of the first block into the input of the second block. Keeping the Ctrl key pressed and selecting another block continues the connection chain.

Simulink updates the model when you run simulation by clicking **Run Simulation**. You can also update the model using the **Simulation** → **Update Diagram** menu command, or by typing **Ctrl+D** at any point in the design process. You will see the Data Types, Signal Dimensions and Sample Times from the source blocks propagate through the model.



**TIP:** You can use the **Display** → **Signals and Ports** menu command to enable the various data that you want displayed in your model, such as **Signal Dimensions** and **Port Data Types**.

You cannot specify sample times on HLS Library blocks, except for the Constant block from the Source library of the HLS library. Model Composer infers the sample time from the source blocks connected at the input of the model, and does not support multiple sample times in the Model Composer design.

By updating the diagram from time to time, you can see and fix potential design issues as you develop the model. This approach can make it easier to identify the sources of problems by limiting the scope to recent updates to the design. The **Update Diagram** is also faster than running simulation.

## Working with Data Types

Data types supported by HLS library blocks include the following:

**Table 9: Model Composer Data Types**

Name	Description
double	Double-precision floating point
single	Single-precision floating point
half*	Half-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*	Signed and unsigned fixed point
boolean	For this data type, Simulink represents real, nonzero numeric values as TRUE (1)



**IMPORTANT!** Data types marked with '\*' are specific to Model Composer HLS Library, and are not naturally supported by Simulink. While Simulink does support fixed point data types, you must have the Fixed-Point Designer™ product installed and licensed. In addition, the fixed point data type supported by Vitis Model Composer is not compatible with the fixed point data type supported by Simulink although it uses a similar notation.

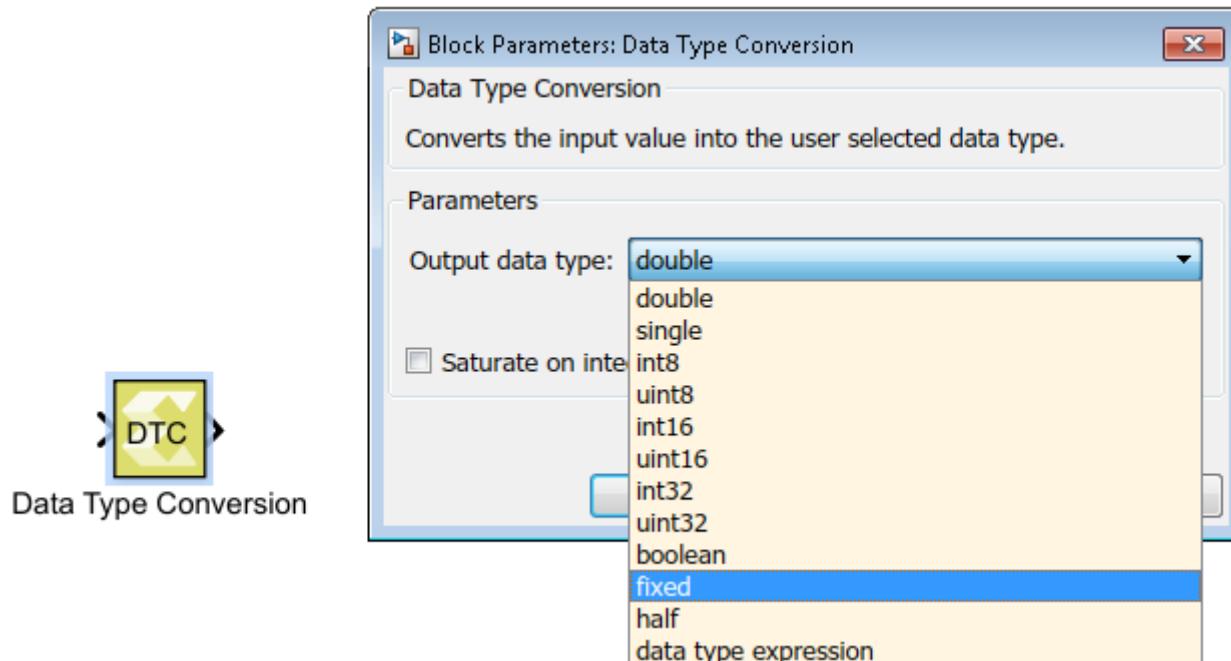
Notice in the preceding table there are some data types that are supported by Model Composer HLS Library that are not supported by default in Simulink. If you connect blocks from the HLS library, with `fixed` or `half` data types, to Simulink native blocks, you will see an error when running simulation in Simulink, or when using the **Update Diagram** command, or pressing **Ctrl + D**.

```
RelationalOperator does not accept signals of data type 'x_sfix16'.  
'ConstRE_or_IMpartBug/Relational Operator' only accepts numeric and  
enumerated data types.
```

This error indicates that Simulink could not cast the signal value from the Model Composer fixed data type to a double precision floating point data type.

In cases of mismatched data types, Model Composer recommends that you use a Data Type Conversion block to specify the behavior of the model, and indicate the conversion of one data type to another. The Data Type Conversion block (DTC) is found in the HLS Library under the Signal Attributes library.

Figure 135: Data Type Conversion Block



The DTC block lets you specify the **Output data type**, while the input data type is automatically determined by the signal connected to the input port. Using the DTC block, you can convert from single precision floating point to double precision for example, or from double precision to single precision.

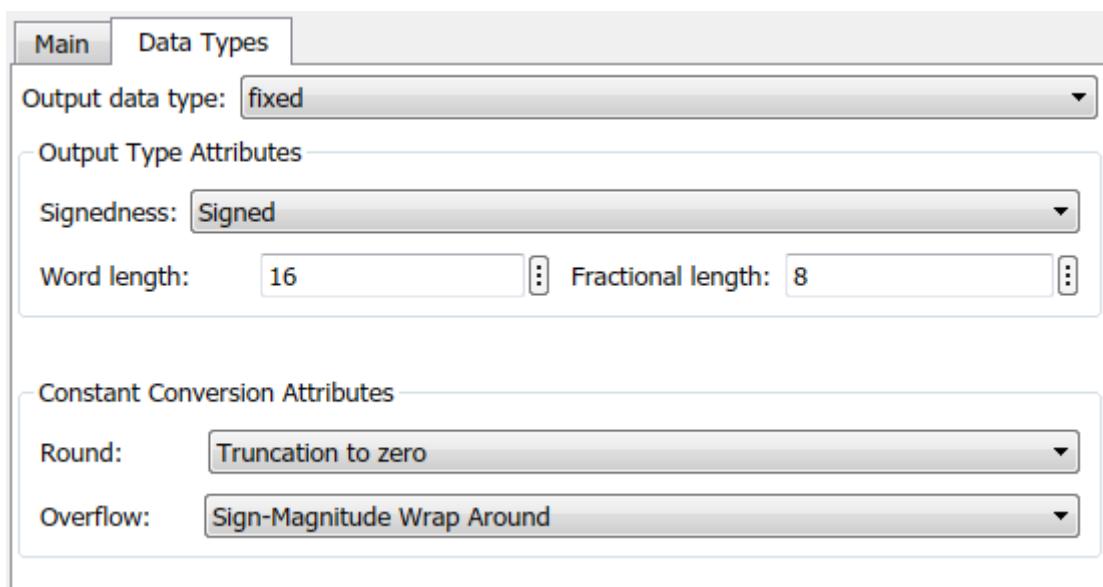


**IMPORTANT!** You must exercise caution when casting from a higher precision data type to a lower precision data type, as loss of precision can lead to rounding or truncation and loss of data can occur.

## Working with Fixed-Point Data Types

As indicated earlier, Simulink® provides support for fixed-point data types through the Fixed-Point Designer™ product. However, the format of the `fixed` data type supported by Model Composer and Simulink are not compatible.

Figure 136: Fixed-Point Data Type



The format used to display the Model Composer fixed-point data types is as follows: `x_ [ u / s ] fix[wl]_E[n][f]`

Where:

- `x_`: Is the prefix indicating the Xilinx fixed data type.
- `[ u / s ]`: Represents signed or unsigned data.
- `fix`: Indicates the fixed-point data type.
- `[wl]` Specifies the word length of the data.
- `E`: Prefix for the fractional portion of the fixed-point data type. Does not display if the fractional length is 0.

- n: Displays 'n' if the binary point is to the left of the right-most bit in the word; or displays no 'n' if the binary point is to the right of the right-most bit in the word.
- [f1]: Specifies the fractional length of the fixed-point data type, indicating the position of the binary point with respect to the right-most bit in the word.

For example, `x_sfix16_En6` represents a signed 16-bit fixed-point number, with 6-bits allocated to the right of the binary point.

Notice the fixed-point data type also lets you specify what happens in the case of data overflow, or the need to do rounding or truncation. For more information refer to [Data Type Conversion](#).

You must use a DTC block to convert the Model Composer fixed-point data type into the Simulink fixed-point data type. However, there is no direct conversion between Model Composer fixed-point and Simulink fixed-point data types, so you can use the following method:

1. Convert Model Composer fixed-point data type to the `double` data type using the DTC block from the HLS library in the Library Browser.
2. Convert the `double` data type to Simulink format fixed-point data type using the Simulink Data Type Conversion block from the Simulink Signal Attributes library in the Library Browser.
3. Match the signedness, word length, and fractional length between the two fixed-point data types.



**TIP:** Converting between the Model Composer fixed data type and the Simulink fixed data type is not recommended unless necessary for your design. You can convert from the Model Composer fixed-point data type to `double`, as shown in the first step, and this should be sufficient for most applications.

Although handling fixed-point data type in a design is more time consuming, the value of using fixed-point data types for applications targeted at implementation in an FPGA is worth the challenge. It is widely accepted that designing in floating point leads to higher power usage for the design. This is true for FPGAs where floating-point DSP blocks have been hardened onto the FPGA and users must implement a floating point solution using DSP blocks and additional device resources. Floating-point implementations require more FPGA resources than an equivalent fixed-point solution. With this higher resource usage comes higher power consumption and ultimately increased overall cost of implementing the design. For more information refer to the white paper *Reduce Power and Cost by Converting from Floating Point to Fixed Point* ([WP491](#)).

## Working with Half Data Types

Model Composer also supports a `half` precision floating point data type, which is 16 bits wide instead of 32 bits, because it consumes less real estate on the target device when implemented on the FPGA. This is an important consideration when designing in Model Composer. However, Simulink does not support the `half` data type, and this can lead to errors in simulation. The solution is to use the Model Composer DTC block to convert the `half` into the `single` data type supported by Simulink, for those portions of the design that are not in the Model Composer sub-module and will not be part of the generated output.

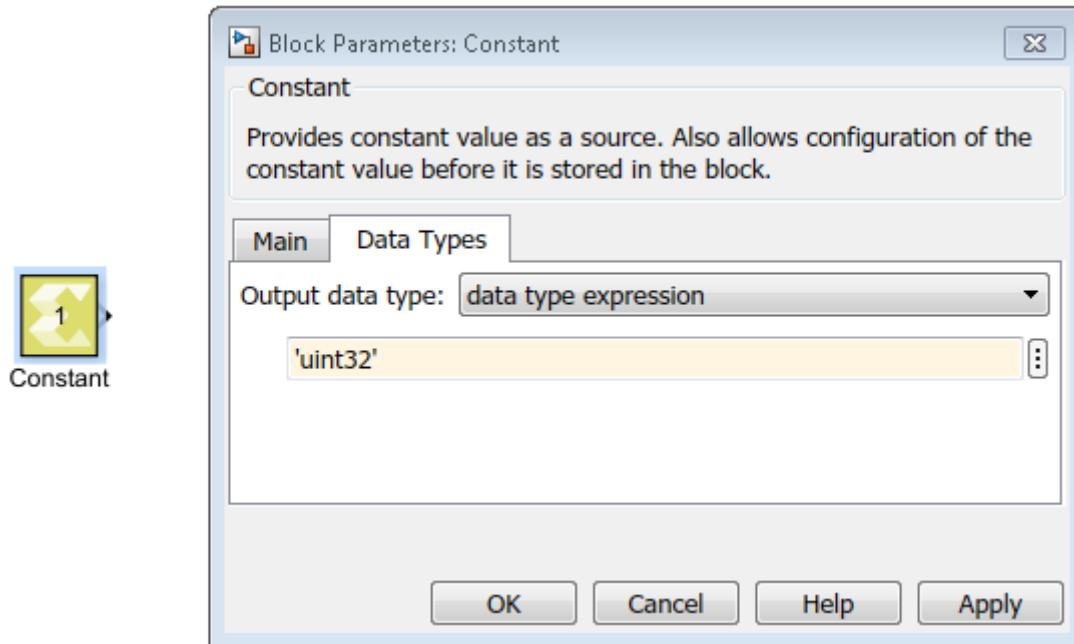
## Working with Data Type Expression

Model Composer lets you specify data types as an expression. Currently the following HLS library blocks support data type expression:

- Constant
- Data Type Conversion
- Gain
- Look-Up Table
- Reinterpret

To specify a data type expression open one of the block types that support it, and edit the data type and value. The following shows a data type expression being defined for the Constant block. The **Output data type** is specified as an expression, and a string is specified to indicate the data type value, in this case '`uint32`'.

Figure 137: Data Type Expression



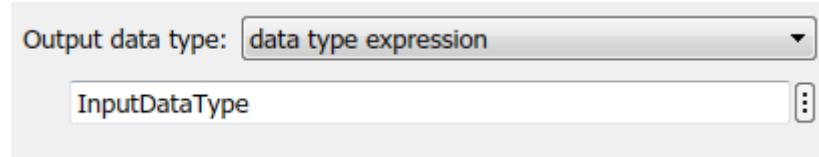
The data type value can be specified as a string representing any of the supported data types shown in the Model Composer Data Types table in the [Working with Data Types](#) section. The exception to this rule is for fixed point data types, which are not specified with the `fixed` string, but are defined according to the display format discussed under [Working with Fixed-Point Data Types](#) (e.g. `'x_sfix16_En8'`).

The real benefit of defining a data type as an expression is the ability to programmatically determine the data type value using a variable from the model. For instance, if you define a variable from the MATLAB® command line:

```
>> InputDataType = 'x_ufix8_En7';
```

You can use the variable in defining the data type expression.

Figure 138: Variable Data Type



You can specify variables from the MATLAB command line, or define variables within the model using the **Tools**→**Model Explorer** menu command, or simply pressing **Ctrl+H**. From the Model Explorer you can create, edit, and manage variables that the model or a block uses.



**TIP:** You can also enable the **View→Property Inspector** command to display the variables for currently selected objects.

## Managing Overflow

Sometimes the data type definition for a block will not support the incoming data value on a signal. In these cases, an overflow condition can occur if the value on the signal is too large or too small to be represented by the data type of the block. The two types of overflow that can occur are wrap overflow, and saturation overflow:

- **Wrap on Overflow:** This is the default overflow mechanism, and causes the bit value to wrap at the overflow point. For instance, when an arithmetic operation such as multiplying two numbers produces a result larger than the maximum value for the data type, effectively causing a wrap around.
- **Saturate on Overflow:** This is an overflow mechanism in which all operations such as addition and multiplication are limited to a fixed range between the minimum and maximum values supported by the data type. In essence, the value will reach the maximum or minimum value and stop.

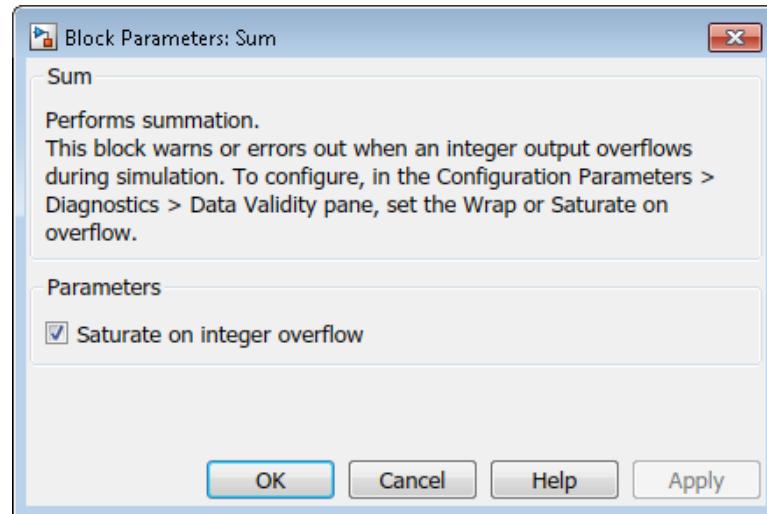
Wrapping is the default method for handling overflow, as it occurs naturally as the value overruns the data type. There is no checking required. However, the **Saturate on Overflow** option requires some additional logic in order to check the data value against the permitted maximum or minimum value to prevent wrapping. This additional logic consumes available resources on the target device.

### Saturate on Overflow

#### Saturate on Integer Overflow

Model Composer currently supports overflow detection of integer data values on signals. As previously indicated, the default overflow mechanism is to wrap on overflow. Specific blocks in the standard Simulink library of blocks and in the HLS library have an option to **Saturate on integer overflow**. This can be enabled on the Block Parameters dialog box. This parameter applies only if the output is an integer (int8, int16, int32, uint8, uint16, uint32). Refer to the Model Composer Block Library for information specific to a block.

Figure 139: Saturate on Integer Overflow

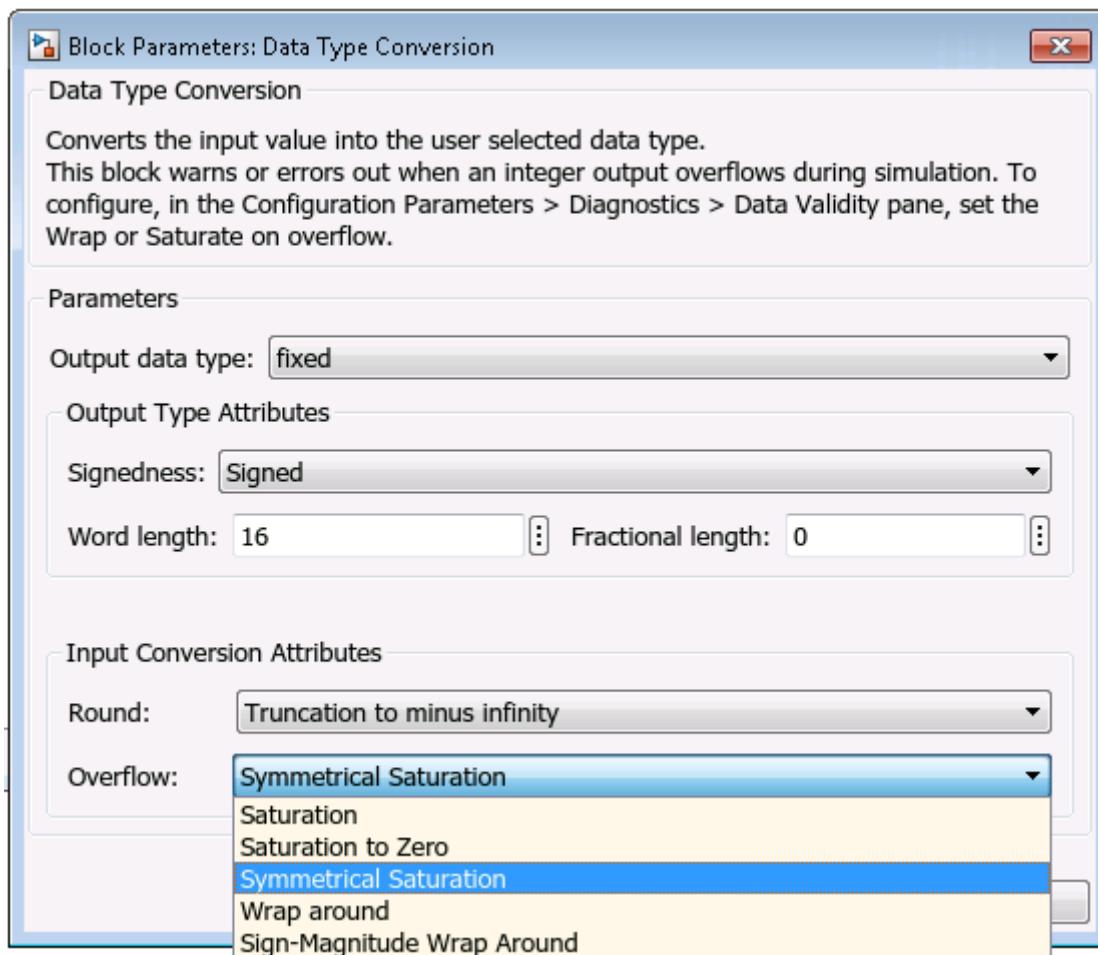


Saturate on integer overflow simply means that when the input value exceeds the range of values supported by the output, either too great or too small, the value simply sits at the max or min supported value. The value is saturated, and does not change.

### Saturate on Fixed-Point Overflow

For fixed-point data types, as supported on the Data Conversion Block (DTC) for example, the overflow modes offer more control than the Saturate on integer overflow option, as shown in the following figure.

Figure 140: Fixed-Point Overflow

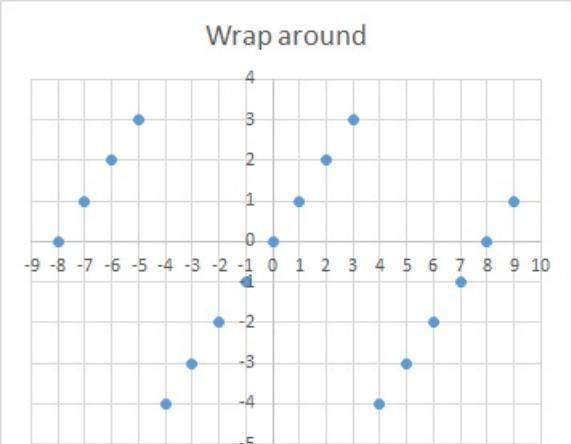
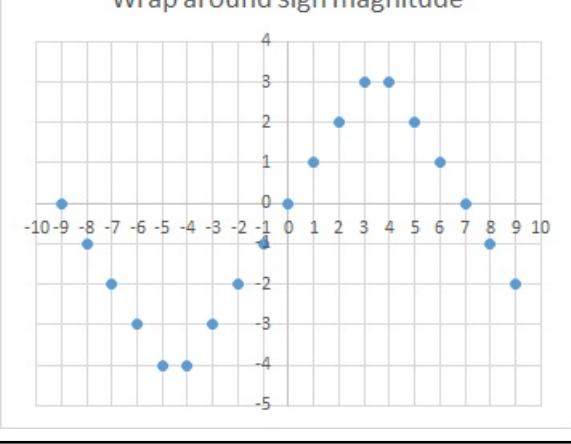


A description of the different fixed-point overflow modes is provided below, with a graph to illustrate the condition.

**Table 10: Fixed-Point Overflow Modes**

Mode	Description	Image																																
Saturation	When the input value overflows the output data type, the output value reaches saturation at the min or max value, and does not change.	<p style="text-align: center;"><b>Saturation</b></p> <table border="1"> <caption>Data for Saturation Mode</caption> <thead> <tr> <th>x</th> <th>y</th> </tr> </thead> <tbody> <tr><td>-7</td><td>-5</td></tr> <tr><td>-6</td><td>-5</td></tr> <tr><td>-5</td><td>-5</td></tr> <tr><td>-4</td><td>-5</td></tr> <tr><td>-3</td><td>-3</td></tr> <tr><td>-2</td><td>-2</td></tr> <tr><td>-1</td><td>-1</td></tr> <tr><td>0</td><td>0</td></tr> <tr><td>1</td><td>1</td></tr> <tr><td>2</td><td>2</td></tr> <tr><td>3</td><td>3</td></tr> <tr><td>4</td><td>3</td></tr> <tr><td>5</td><td>3</td></tr> <tr><td>6</td><td>3</td></tr> <tr><td>7</td><td>3</td></tr> </tbody> </table>	x	y	-7	-5	-6	-5	-5	-5	-4	-5	-3	-3	-2	-2	-1	-1	0	0	1	1	2	2	3	3	4	3	5	3	6	3	7	3
x	y																																	
-7	-5																																	
-6	-5																																	
-5	-5																																	
-4	-5																																	
-3	-3																																	
-2	-2																																	
-1	-1																																	
0	0																																	
1	1																																	
2	2																																	
3	3																																	
4	3																																	
5	3																																	
6	3																																	
7	3																																	
Saturation to Zero	When the input value overflows the output data type, the output value reaches saturation at the min or max value, and returns to zero.	<p style="text-align: center;"><b>Saturation to zero</b></p> <table border="1"> <caption>Data for Saturation to Zero Mode</caption> <thead> <tr> <th>x</th> <th>y</th> </tr> </thead> <tbody> <tr><td>-7</td><td>-5</td></tr> <tr><td>-6</td><td>-5</td></tr> <tr><td>-5</td><td>-5</td></tr> <tr><td>-4</td><td>-4</td></tr> <tr><td>-3</td><td>-3</td></tr> <tr><td>-2</td><td>-2</td></tr> <tr><td>-1</td><td>-1</td></tr> <tr><td>0</td><td>0</td></tr> <tr><td>1</td><td>1</td></tr> <tr><td>2</td><td>2</td></tr> <tr><td>3</td><td>3</td></tr> <tr><td>4</td><td>3</td></tr> <tr><td>5</td><td>3</td></tr> <tr><td>6</td><td>3</td></tr> <tr><td>7</td><td>3</td></tr> </tbody> </table>	x	y	-7	-5	-6	-5	-5	-5	-4	-4	-3	-3	-2	-2	-1	-1	0	0	1	1	2	2	3	3	4	3	5	3	6	3	7	3
x	y																																	
-7	-5																																	
-6	-5																																	
-5	-5																																	
-4	-4																																	
-3	-3																																	
-2	-2																																	
-1	-1																																	
0	0																																	
1	1																																	
2	2																																	
3	3																																	
4	3																																	
5	3																																	
6	3																																	
7	3																																	
Symmetrical Saturation	Like Saturation to Zero, except the min and max values are symmetrical, or equal in size though opposite in value.	<p style="text-align: center;"><b>Symmetrical saturation</b></p> <table border="1"> <caption>Data for Symmetrical Saturation Mode</caption> <thead> <tr> <th>x</th> <th>y</th> </tr> </thead> <tbody> <tr><td>-7</td><td>-4</td></tr> <tr><td>-6</td><td>-4</td></tr> <tr><td>-5</td><td>-4</td></tr> <tr><td>-4</td><td>-4</td></tr> <tr><td>-3</td><td>-3</td></tr> <tr><td>-2</td><td>-2</td></tr> <tr><td>-1</td><td>-1</td></tr> <tr><td>0</td><td>0</td></tr> <tr><td>1</td><td>1</td></tr> <tr><td>2</td><td>2</td></tr> <tr><td>3</td><td>3</td></tr> <tr><td>4</td><td>3</td></tr> <tr><td>5</td><td>3</td></tr> <tr><td>6</td><td>3</td></tr> <tr><td>7</td><td>3</td></tr> </tbody> </table>	x	y	-7	-4	-6	-4	-5	-4	-4	-4	-3	-3	-2	-2	-1	-1	0	0	1	1	2	2	3	3	4	3	5	3	6	3	7	3
x	y																																	
-7	-4																																	
-6	-4																																	
-5	-4																																	
-4	-4																																	
-3	-3																																	
-2	-2																																	
-1	-1																																	
0	0																																	
1	1																																	
2	2																																	
3	3																																	
4	3																																	
5	3																																	
6	3																																	
7	3																																	

Table 10: Fixed-Point Overflow Modes (cont'd)

Mode	Description	Image
Wrap around	When the input value exceeds the output data type, the output value is wrapped from the maximum value to the minimum value, or from the minimum value to the maximum value, thus cycling through the range of permitted values.	
Sign-Magnitude Wrap Around	When the input value exceeds the output data type, the output value reaches the maximum value, and then begins decreasing to return to the minimum value. In an underflow situation, the minimum value is reached, and begins increasing to return to the maximum value.	

## Configuring Overflow Warnings

In case of either wrap or saturate, you may want to know when overflow occurs. You can define how Simulink handles each of these overflow conditions in the model by clicking on the **Model**



**Configuration Parameters** command (  ) on the tool bar menu, or typing **Ctrl-E**. In the Configuration Parameters dialog box, under the **Diagnostics → Data Validity** tab, you can specify values for the **Wrap on Overflow** and **Saturate on Overflow** fields. Each of these fields can have one of the following settings:

- **none**: Simulink takes no special action to report or handle the overflow.
- **warning**: A message will be displayed in the diagnostic viewer. The next warning for the same block will be ignored, and simulation will continue.

- **error:** An error message will be displayed in the diagnostic viewer and the simulation will be terminated.



**TIP:** Help for this dialog box can be found under [Model Configuration Parameters: Data Validity Diagnostics](#).

## Creating a Top-Level Subsystem Module

In order to generate output from the Model Composer model the top-level of the Model Composer model must contain the Vitis Model Composer Hub block, as described in [Vitis Model Composer Hub](#), as well as a subsystem that encapsulates the application design. To generate output from the subsystem that is instantiated at the top-level of the design, only HLS Library blocks and a limited set of specific Simulink® blocks can appear in the subsystem. The HLS Library blocks define the functions to be compiled for the packaged IP or compiled C++ code. The top-level design can contain other blocks and subsystem modules that serve different purposes, such as simulation, but the primary application must be completely contained within the specified subsystem.



**TIP:** The specific Simulink blocks that are supported in the Model Composer subsystem also appear in the Model Composer block library. Refer to [Supported Simulink Blocks](#) for a complete list.

To create a subsystem from within a model, add one or more blocks to the model canvas, select the blocks, and turn the selected blocks into a subsystem:

1. Drag and drop blocks onto the model canvas in the Simulink Editor, as explained in [Adding Blocks to a Model](#).
2. Select one or more blocks, and right-click to use the **Create Subsystem from Selection** command.
3. Name the subsystem, giving it the same name you want to assign to the generated output application or IP.
4. Double-click the subsystem to open it in the Simulink Editor, and continue the design.

The Explorer bar and Model Browser in Simulink help you navigate your model:

- The Explorer bar lets you move up and down the hierarchy, or back and forth between different views in the Simulink Editor.
- The Model Browser provides a view of the **Model Hierarchy**, and lets you select and open different levels to quickly move through the hierarchy of the design.

# Importing C/C++ Code as Custom Blocks

## Introduction

Model Composer lets you import C or C++ code to create new blocks that can be added to a library for use in models along side other HLS Library blocks. This feature lets you build custom block libraries for use in Model Composer.



**TIP:** The import function example in the product showcases most of the capabilities of importing C/C++ code using a series of small examples. Type `xmcOpenExample('import_function')` in the MATLAB command window to open the example.

## Using the `xmcImportFunction` Command

Model Composer provides the `xmcImportFunction` command, for use from the MATLAB command line, to let you specify functions defined in source and header files to import into Model Composer, and create Model Composer blocks, or block library. The `xmcImportFunction` command uses the following syntax:

```
xmcImportFunction('libName', {'funcNames'}, 'hdrFile', {'srcFiles'},  
{'srchPaths'}, 'options')
```

Where:

- `libName`: A string that specifies the name of the Model Composer HLS library that the new block is added to. The library can be new, and will be created, or can be an existing library.
- `funcNames`: Specifies a list (cell array) of one or more function names defined in the source or header files to import as a Model Composer block. An empty set, {}, imports all functions defined in the specified header file (`hdrFile`). For functions inside namespaces, full namespace prefix needs to be given. For example, to import the function '`sinf`' in `hls_math`, the full function name '`hls::sinf`' needs to be specified.
- `hdrFile`: A string that specifies a header file (.h) which contains the function declarations, or definitions. This should be the full path to the header file if it is not residing inside the current working directory. For example, to import a function from `hls_math.h`, you need to specify the full path '`$XILINX_VIVADO/include/hls_math.h`'.



**IMPORTANT!** The function signature must be defined in the header file, and any Model Composer (XMC) pragmas must be specified as part of the function signature in the header file.

- `srcFiles`: Specifies a list of one or more source files to search for the function definitions. When used in a model, the header and source files, together with the main header file of the model, `headerFile`, will be compiled into the shared library for simulation, and copied into the Target Directory specified for output generation in the Model Composer Hub block, as described in [Vitis Model Composer Hub](#).

- `srchPaths`: Specifies a list of one or more search paths for header and source files. An empty set, {}, indicates no search path, in which case the code is looked for in the MATLAB current folder. Use '`$XILINX_VIVADO/include`' to include the HLS header files.

In addition, the `xmcImportFunction` command has the following options, which can follow the required arguments in any order:

- '`unlock`': Unlock an existing library if it is locked. The `xmcImportFunction` command can add blocks to an existing library, but it must be unlocked in order to do so.
- '`override`': Overwrite an existing block with the same name in the specified library.



**TIP:** The help for `xmcImportFunction` can be accessed from the MATLAB command line, using `help xmcImportFunction`, and provides the preceding information.

As an example, the following `simple.h` header file defines the `simple_add` function, with two double-precision floating point inputs and a pointer output. The function simply adds the two inputs and returns the sum as the output.

```
void simple_add(const double in1, const double in2, double *out) {  
    *out = in1 + in2;  
}
```

To import the `simple_add` function as a block in a Model Composer HLS library you can enter the following command at the MATLAB command prompt:

```
xmcImportFunction('SimpleLib',{'simple_add'},'simple.h',{},{})
```

Where:

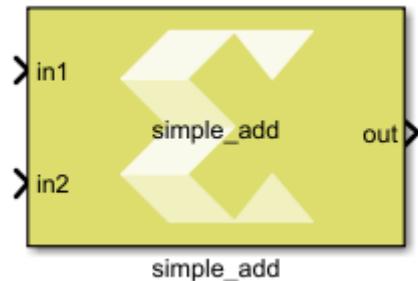
- `SimpleLib` is the name of the Model Composer HLS library to add the block to.
- `simple_add` is the function name to import.
- `simple.h` is the header file to look in.
- No C source files or search paths are specified. In this case, the function definition must be found in the specified header file, and only the MATLAB current folder will be searched for the specified files.



**TIP:** Model composer will give you a warning if you attempt to import a block with the same function name as a block that is already in the specified library.

When `xmcImportFunction` completes, the `SimpleLib` library model will open with the `simple_add` block created as shown below.

Figure 141: simple\_add Block



During simulation, the C/C++ code for the Library blocks will get compiled and a library file will get created and loaded. The library file will be cached to speed up initializing simulations on subsequent runs. You can change the source code underlying the library block without the need to re-import the block, or re-create the library, although the cached library file will be updated if you change the C/C++ source code.

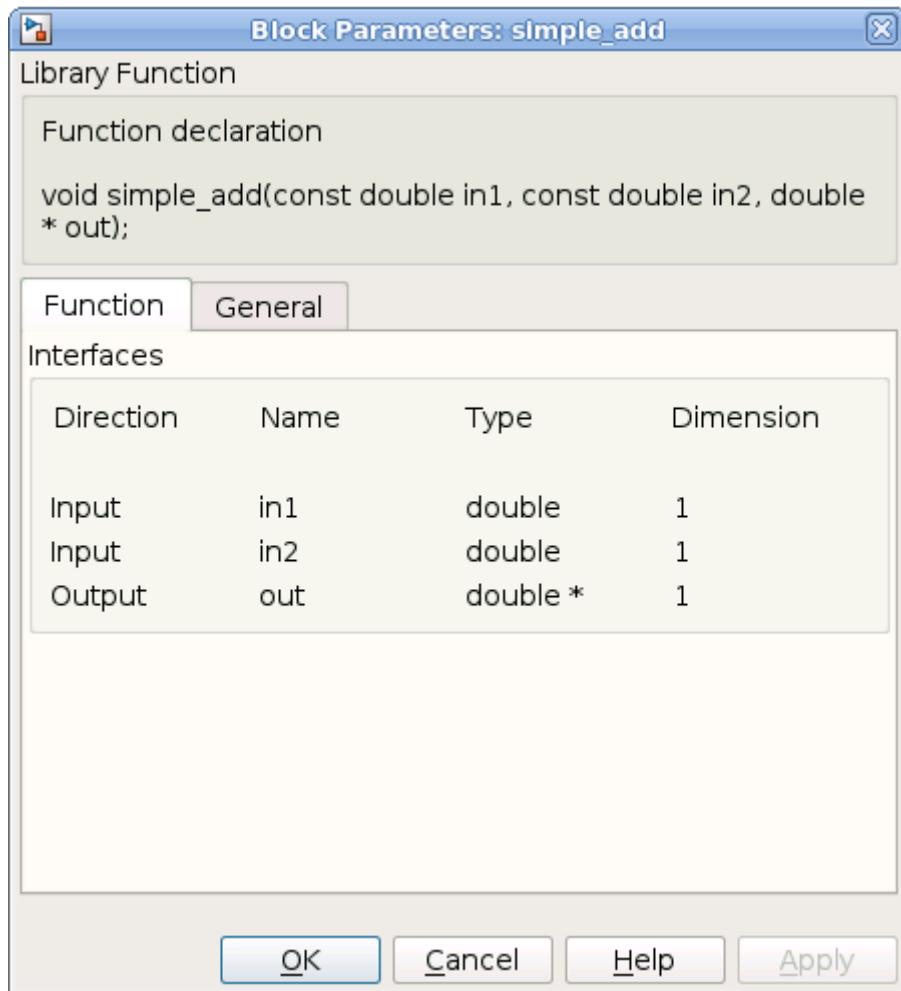
However, if you change the function signature, or the parameters to the function, then you will need to rerun the `xmcImportFunction` command to recreate the block. In this case, you will also need to use the `override` option to overwrite the existing block definition in your library.



**IMPORTANT!** You must rerun the `xmcImportFunction` command any time that you change the interface to an imported function, or the associated XMC pragmas. In this case, you should delete the block from your design and replace it with the newly generated block from the library. However, you can change the function content without the need to run `xmcImportFunction` again.

After the block symbol has been created, you can double-click on the symbol to see the parameters of the imported block. You can quickly review the parameters as shown in the following figure to ensure the function ports have been properly defined.

Figure 142: simple\_add Block Parameters



## Importing C/C++ into Model Composer

While Model Composer lets you import C or C++ functions to create a library of blocks, it does have specific requirements for the code to be properly recognized and processed. The function source can be defined in either a header file (.h), or in a C or C++ source file (.c, .cpp), but the header file must include the function signature.

You can import functions with function arguments that are real or complex types of scalar, vectors, or matrices, as well as using all the data types supported by Model Composer HLS Library, including fixed-point data types. Model Composer also lets you define functions as templates, with template variables defined by input signals, or as customization parameters to be specified when the block is added into the model or prior to simulating the model. Using function templates in your code lets you create a Model Composer block that supports different applications, and can increase the re-usability of your block library. Refer to [Defining Blocks Using Function Templates](#) for more information.



**IMPORTANT!** The function signature must be defined in the header file, and any Model Composer (XMC) pragmas must be specified as part of the function signature in the header file.

The `xmcImportFunction` command supports C++ functions using `std::complex<T>` or `hls::x_complex<T>` types. For more details, see the explanation in [Using Complex Types](#).

If the input of an imported function is a 1-D array, the tool can perform some automatic mappings between the input signal and the function argument. For example, if the function argument is `a[10]`, then the connected signal in Model Composer can be either a vector of size 10, or a row or column matrix of size  $1 \times 10$  or  $10 \times 1$ .

However, if all of the inputs and outputs of an imported function are scalar arguments, you can connect a vector signal, or a matrix signal to the input. In this case, the imported function processes each value of the vector, or matrix on the input signal as a separate value, and will combine those values into the vector, or matrix on the output signal. For example, a vector of size 10 connected to a scalar input, will have each element of the vector processed, and then returned to a vector of size 10 on the output signal.

You can import functions that do not have any inputs, and instead only generate outputs. This is known as a source block, and can have an output type of scalar, vector, complex, or matrix. You can also import source blocks with multiple outputs. The following example function has no input port, and `y` is the output:

```
#include <stdint.h>
#include <ap_fixed.h>

#pragma XMC OUTPORT y
#pragma XMC PARAMETER Limit
template <typename T>
void counter(T &y, int16_t Limit)
{
    static T count = 0;

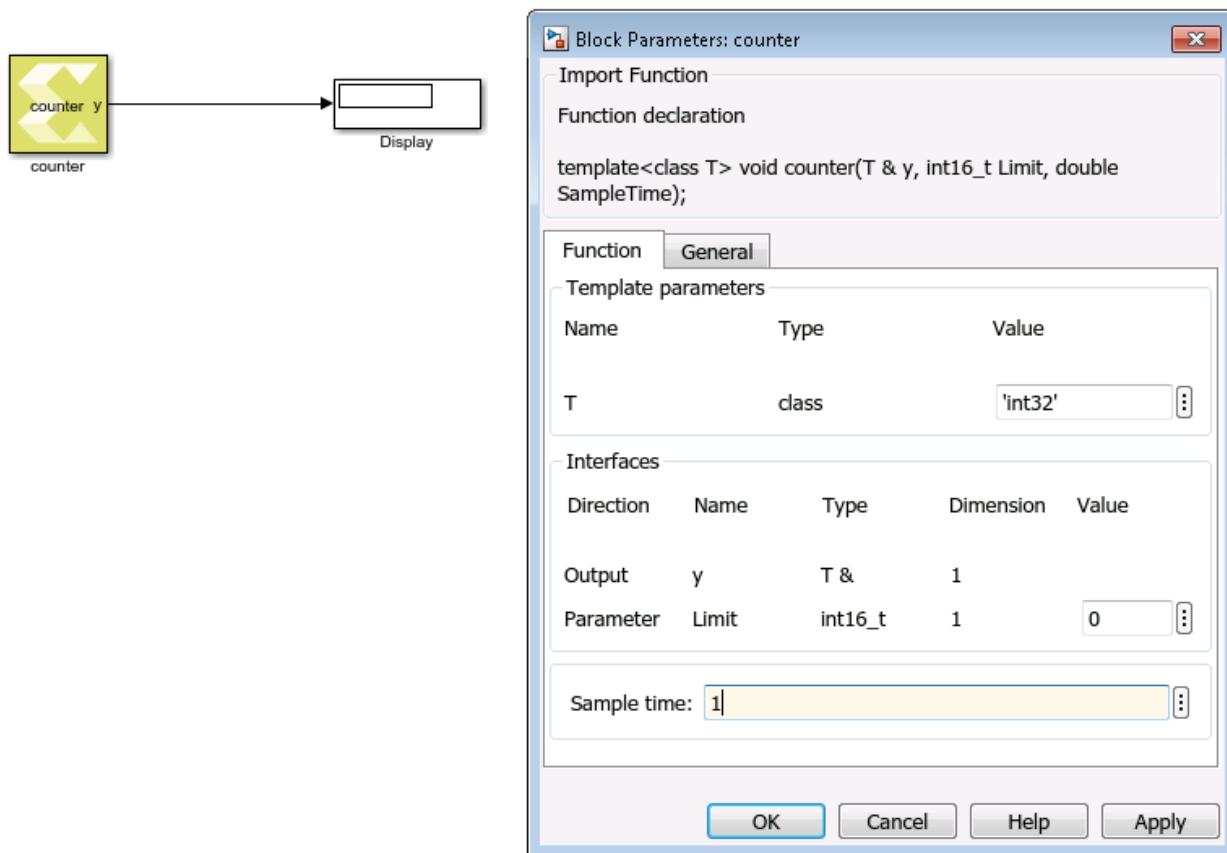
    count++;

    if (count > Limit)
        count = 0;
    y = count;
}
```



**TIP:** Because source blocks have no inputs, the `SampleTime` parameter is automatically added when the block is created with `xmcImportFunction` command, as shown in the Function declaration in the following image. The default value is -1 which means the sample time is inherited from the model. You can also explicitly specify the sample time by customizing the block when it is added to a model, as shown below.

Figure 143: Setting Sample Time for a Source Block



The direction of ports for the function arguments can be determined automatically by the `xmc ImportFunction` command, or manually specified by pragma with the function signature in the header file.

- Automatically determining input and output ports:
  - The `return` value of the function is always defined as an output, unless the `return` value is `void`.
  - A formal function argument declared with the `const` qualifier is defined as an input.
  - An argument declared with a reference, a pointer type, or an array type without a `const` qualifier is defined as an output.
  - Other arguments are defined as inputs by default (e.g., scalar read-by-value).
- Manually defining input and output ports:
  - You can specify which function arguments are defined as inputs and outputs by adding the `IMPORT` and `OUTPORT` pragmas into the header file immediately before the function declaration.
  - `#pragma XMC IMPORT <parameter_name> [ , <parameter_name>... ]`

- `#pragma XMC OUTPORT <parameter_name> [ , <parameter_name>... ]`

In the following example `in` is automatically defined as an input due to the presence of the `const` qualifier, and `out` is defined as an output. The imported block will also have a second output due to the integer `return` value of the function.

```
int func(const int in, int &out);
```

In the following function `in` is automatically defined as an input, and `out` as an output, however, there is no `return` value.

```
void func(const in[512], int out[512]);
```

In the following example the ports are manually identified using pragmas that have been added to the source code right before the function declaration. This is the only modification to the original C++ code needed to import the function into Model Composer. In this example the pragmas specify which parameter is the input to the block and which parameter is the output of the block.

```
#pragma XMC IMPORT din
#pragma XMC OUTPORT dout
void fir_sym (ap_fixed<17,3,AP_TRN,AP_WRAP> din[100],
              ap_fixed<17,3,AP_TRN,AP_WRAP> dout[100]);
```



**TIP:** *ap\_fixed* specifies a fixed-point number compatible with Vitis HLS.

Manually adding pragmas to the function signature in the header file to define the input and output parameters of the function is useful when your code does not use the `const` qualifier, and adding the `const` qualifier can require extensive editing of the source code when there is a hierarchy of functions. It also makes the designation of the inputs and outputs explicit in the code, which can make the relationship to the imported block more clear.

Some final things to consider when writing C or C++ code for importing into Model Composer:

- You should develop your source code to be portable between 32 bit and 64 bit architectures.
- Your source code can use Vitis HLS pragmas for resource and performance optimization, and Model Composer uses those pragmas but does not modify or add to them.
- If your code has static variables, the static variable will be shared across all instances of the blocks that import that function. If you do not want to share that variable across all instances you should copy and rename the function with the static variable and import a new library block using the `xmc ImportFunction` command.

- If you use C (.c) source files to model the library function (as opposed to C++ (.cpp) source files), the .h header file must include an `extern "C"` declaration for the downstream tools (such as Vitis HLS) to work properly. An example of how to declare the `extern "C"` in the header files is as follows:

```
// c_function.h:  
#ifndef __cplusplus  
extern 'C' {  
#endif  
void c_function(int in, int &out);  
#ifdef __cplusplus  
}  
#endif
```

## Using Complex Types

C++ code for Vitis HLS can use `std::complex<T>` or `hls::x_complex<T>` to model complex signals for `xmclImportFunction` blocks.

The code generated by Model Composer uses `std::complex` for representing complex signals. If your imported C/C++ block function is modeled with `hls::x_complex`, when generating the output code Model Composer will automatically insert `std::complex-to-hls::x_complex` adapters to convert the complex types for the block ports.

The C++ code must also include the required header file for the complex type declaration. For the `hls::x_complex` type, the `xmcImportFunction` command must also include '`$XILINX_VIVADO/include`' search path for the `hls_x_complex.h` header file. For example, the following imports the `complex_mult` function, and specifies the needed include path:

```
xmcImportFunction('my_lib', {'complex_mult'}, 'complex_mult.h', {},  
{'$XILINX_VIVADO/include'});
```

## Example Functions Using Complex Types

```
#include "hls_x_complex.h"  
hls::x_complex<double>  
complex_mult(hls::x_complex<double> in1, hls::x_complex<double> in2)  
{ return in1 * in2; }  
  
#include <complex>  
std::complex<double>  
complex_mult2(std::complex<double> in1, std::complex<double> in2)  
{ return in1 * in2; }  
  
#include <complex>  
void  
complex_mult3(std::complex<double> in1, std::complex<double> in2,  
std::complex<double> &out1)  
{ out1.real(in1.real() * in2.real() - in1.imag() * in2.imag());  
    out1.imag(in1.real() * in2.imag() + in1.imag() * in2.real()); }
```

## Defining Blocks Using Function Templates



**IMPORTANT!** To use template syntax, your function signature and definition should both be specified in a header file when running `xmcImportFunction`.

While it is common to write functions that accept only a predetermined data type, such as `int32`, in some cases you may want to create a block that accepts inputs of different sizes, or supports different data types, or create a block that accepts signals with different fixed-point lengths and fractional lengths. To do this you can use a function template that lets you create a block that accepts a variable signal size, data type, or data dimensions.

You can define blocks using function templates, as shown in the following example:

```
#include <stdint.h>
template <int ROWS, int COLS>
void simple_matrix_add(const int16_t in1[ROWS][COLS],
                      const int16_t in2[ROWS][COLS],
                      int16_t out[ROWS][COLS]) {
    for (int i = 0; i<ROWS; i++) {
        for (int j = 0; j<COLS; j++) {
            out[i][j] = in1[i][j] + in2[i][j];
        }
    }
}
```

The example uses the template parameters `ROWS` and `COLS`. The actual dimensions of the input and output arrays, `in1[ROWS][COLS]` for instance, are determined at simulation time by the dimensions of the input signals to the block. `ROWS` and `COLS` are template parameters used to define the dimensions of the function arguments, and also used in the body of the function, `i<ROWS` for example.

Use the command below to import the function into Model Composer:

```
xmcImportFunction('SimpleLib', {'simple_matrix_add'}, ...
    'template_example.h', {}, {}, 'unlock')
```



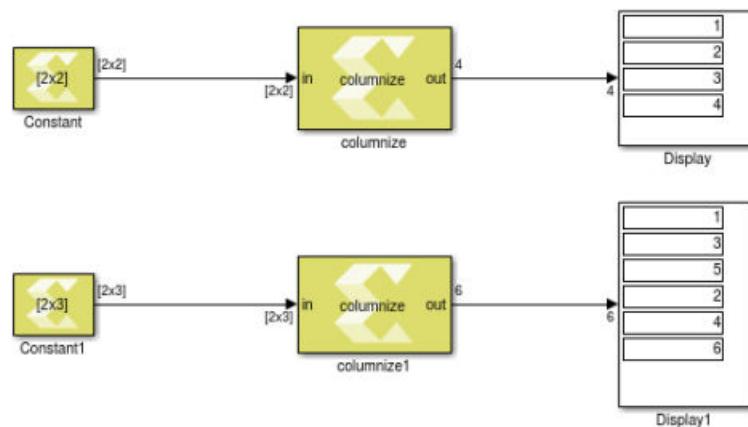
**TIP:** In the example above the ellipsis (...) is used to indicate a continuation of the command on the next line. Refer to [Continue Long Statements on Multiple Lines](#) in the MATLAB documentation for more information.

You can perform simple arithmetic operations using template parameters. For example, the following code multiplies the `ROWS` and `COLS` of the input matrix to define the output, as shown in the figure below.

```
#include <stdint.h>
#pragma XMC IMPORT in
#pragma XMC OUTPORT out
template<int ROWS,int COLS>
void columnize(const int16_t in[ROWS][COLS], int16_t out[ROWS*COLS]) {
    for (int i = 0; i<ROWS; i++) {
```

```
    for (int j = 0; j<COLS; j++) {  
        out[i*COLS+j] = in[i][j];  
    }  
}
```

Figure 144: Columnize Function



Other simple supported operations include +, -, \*, /, %, <<, and >>, using both the template parameters and integer constants. For example:

```
template<int M, int N>  
void func(const int in[M][N], int out[M*2][M*N]);  
  
template<int ROWS, int COLS>  
void func(array[2 * (ROWS + 1) + COLS + 3]);
```

You can also define a function template that uses a fixed-point data type of variable word length and integer length using function templates, as shown in the following example:

```
#include <stdint.h>  
#include <ap_fixed.h>  
#pragma XMC OUTPORT out  
template <int WordLen, int IntLen>  
void fixed_add(const ap_fixed<WordLen,IntLen> in1,  
               const ap_fixed<WordLen,IntLen> in2,  
               ap_fixed<WordLen+1,IntLen> &out) {  
    out = in1+in2;  
}
```

The example above uses the fixed point notations from Vitis HLS, which specifies the word length and the integer length. In Model Composer, as described in [Working with Data Types](#), you specify the word length and the fractional length. This requires you to use some care in connecting fixed point data types in Model Composer to the imported `fixed_add` block. For example, in the function above if `WordLen` is 16 and `IntLen` is 11, in Model Composer fixed point data type the word length is 16, and the fractional length is 5. For more information on fixed-point notation in Vitis HLS, refer to the *Vitis High-Level Synthesis User Guide* ([UG1399](#)).



**TIP:** As shown in the example above, simple arithmetic operations are also supported in the fixed point template parameter.

To import the `fixed_add` function and create a block in Model Composer, use the following command:

```
xmc ImportFunction('SimpleLib',{'fixed_add'},fixed_example.h',{},{'$XILINX_VIVADO/include'})
```

## Function Templates for Data Types

Function templates for data types are functions that can operate with generic data types. This lets you create library functions that can be adapted to support multiple data types without needing to replicate the code or block in the Model Composer HLS block library to support each type. The `xmc ImportFunction` command in Model Composer will create generic library blocks which the user of the block can connect to signals of any data types supported by the block.

The data type (`typename`) template parameters are resolved at simulation run time, when the code and simulation wrapper are generated. The parameters are replaced during simulation by the actual data types that are specified by the signals connecting to the library block. The resolved data types can only be the types that Model Composer supports as discussed in [Working with Data Types](#).

To import a block that accepts multiple data types, you use a function template. For example:

```
template <typename T>
T max(T x, T y) {
    return (x > y) ? x : y;
}
```

Or, in the case of a function with complex function arguments, the example would appear as follows:

```
#include <complex>
template <typename T>
void mult_by_two(std::complex< T > x, std::complex< T > *y)
{
    *Out = In1 * 2;
}
```

The determination of the type is made by Model Composer during simulation. The `typename` (or `class`) parameters are propagated from input signals on the block, or are customization parameters that must be defined by the user at simulation run time.



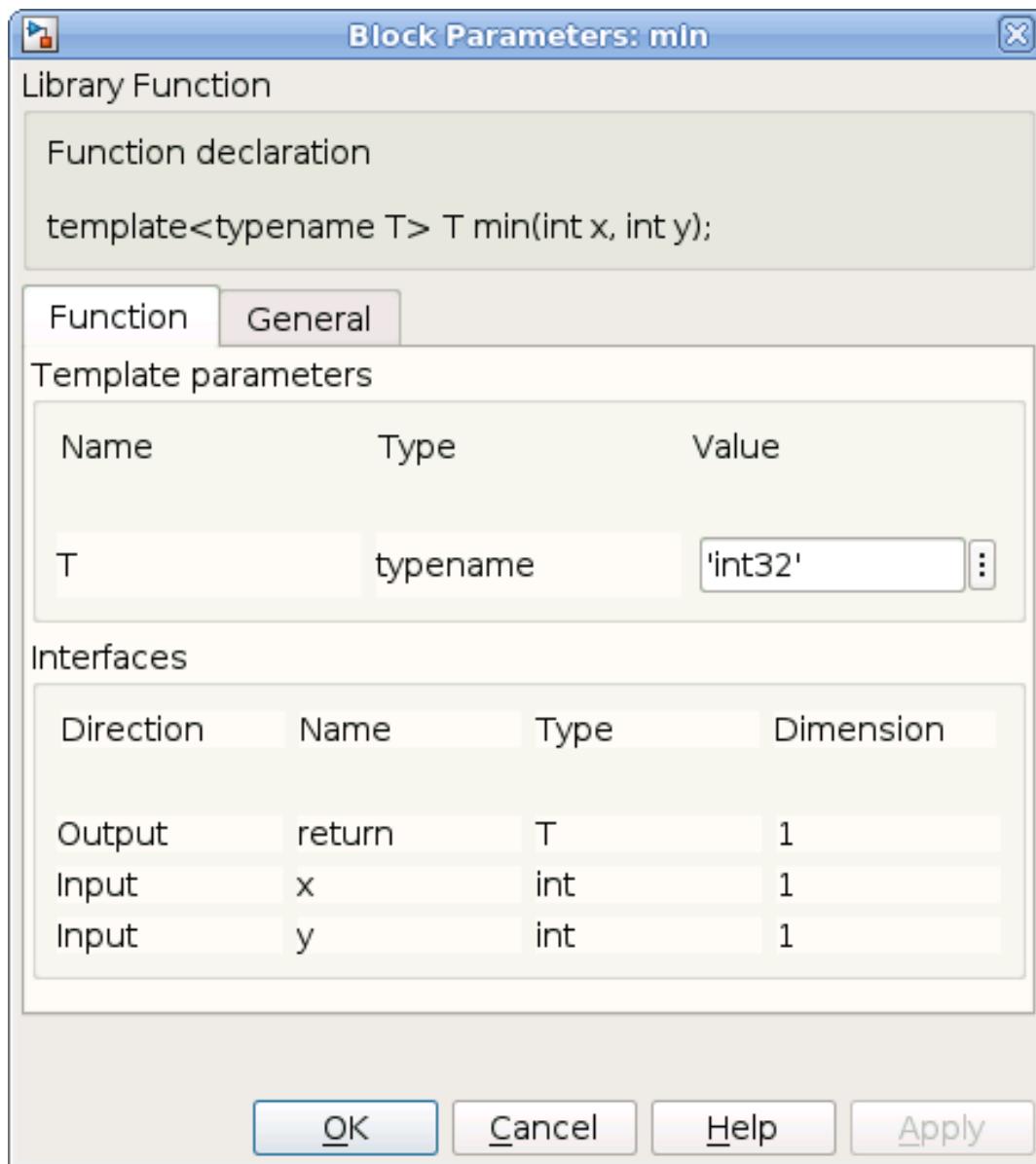
**IMPORTANT!** *The data type for a function or class cannot be propagated from an output.*

For example, the following function template specifies the parameter 'T' as a customization parameter. Because it is not associated with either input argument, 'x' or 'y', it must be specified by the user when the block is added to the model:

```
template <typename T>
T min(int x, int y) {
    return (x < y) ? x : y;
}
```

The Block Parameters dialog box for the generated Library Function block has an edit field to enter the template argument as shown in the following figure.

Figure 145: Library Function Block Parameters



In the template syntax, the data type template parameters for function or class can be specified with other template parameters. The order of specification is not important. For example:

```
template <typename T1, int ROWS, int COLS, int W, int I>
T1 func(T1 x[ROWS][COLS], ap_fixed<W, I> &y) {
...
}
```



**IMPORTANT!** In the example above, notice that the 'T1' template parameter is used to specify both the function return and the data type of the input 'x'. In this case, because it is a single template parameter, both arguments will resolve to the same data type that is propagated from the input signal to the block.

## SUPPORTED\_TYPES/UNSUPPORTED\_TYPES Pragma

When defining a data type (`typename`) template parameter (or `class`), you can also define the accepted data types for the variable by using either the `SUPPORTED_TYPES` or `UNSUPPORTED_TYPES` pragma as part of the function signature. This is shown in the following code example.

```
#pragma XMC IMPORT x
#pragma XMC IMPORT y
#pragma XMC SUPPORTED_TYPES T: int8, int16, int32, double, single, half
template <class T>
T max(T x, T y) {
    return (x > y) ? x : y;
}

#pragma XMC UNSUPPORTED_TYPES T: boolean
#pragma XMC IMPORT x, y
template <typename T>
T min(T x, T y) {
    return (x < y) ? x : y;
}
```

Model Composer supports an extensive list of data types as discussed in [Working with Data Types](#). To specify which of these data types the template parameter supports, you can either include the list of supported types, or the unsupported types. The `SUPPORTED_TYPES` and `UNSUPPORTED_TYPES` pragmas are simply two opposite views of the same thing:

- `SUPPORTED_TYPES`: Specifies a template parameter name (`param`), and the list of data types that are accepted by that parameter. This implies the exclusion of all types not listed.

```
#pragma XMC SUPPORTED_TYPES param: type1, type2, ...
```

- `UNSUPPORTED_TYPES`: Specifies a template parameter name (`param`), and the list of data types that are not accepted by that parameter. This implies the inclusion of all types not listed.

```
#pragma XMC UNSUPPORTED_TYPES param: type1, type2, ...
```

With the `SUPPORTED_TYPES` or `UNSUPPORTED_TYPES` pragma in place, Model Composer will check the type of input signal connected to the block to ensure that the data type is supported. Without the use of one of these pragmas, the data type template parameter will accept any of the data types supported by Model Composer.

## Function Template Specialization and Overloading

Specialization is supported for function templates in the `xmcImportFunction` command. Model Composer will create the library block for the generic function template, supporting multiple data types, but the block will also include any specialized functions to be used when connected to input signals with matching data types. Both the generic function, and any specialization functions are compiled into the block DLL. For example:

```
template <typename T>
T min(T x, T y) {
    return (x < y) ? x : y;
}

template <>
bool min<bool>(bool x, bool y) {
...
}
```

In this case, Model Composer will call the specialized boolean form of the `min` function when the block is connected to boolean signals.

Overloading of a function with the same number of input/output arguments is also supported by Model Composer. For example, the following defines two forms of the function:

```
int func(int x);
float func(float x);
```

You can also overload a function template as shown below:

```
template <typename T>
int func(int x, T y);

template <typename T>
float func(float x, T y);
```



**TIP:** Overloading functions with different numbers of input/output arguments or different argument dimensions is not supported, and must be defined as separate functions.

## Defining Customization Parameters

Template parameters can be used to define the port array sizing and data type, and the parameters are defined by the input signals on the block. Additional customization parameters can also be defined, which are not defined by input signals, and thus must be defined by the user using the Block Parameter dialog box sometime before simulation run time.

There are two methods to define customization parameters for a library function block:

- Using C/C++ function templates.

- Assigning the Model Composer (XMC) **PARAMETER** pragma to a function argument, defining it as not connecting to an input or output of the block, but rather as a customization parameter.

There are pros and cons to both methods, which are discussed below.

## Function Templates

The first method, defines a function template that uses template parameters for customization. A template parameter defines a customization parameter in Model Composer if its value is not determined by an input signal, or derived by the function as an output. You can use customization parameters to define the values, data types, or data dimensions of output ports, or for parameters in use in the function body.



**IMPORTANT!** *The template function signature and function definition must be defined in the C/C++ header file.*

The template parameter for the function argument is defined using standard function template syntax, but the template parameter is not assigned to an input argument in the function signature. When the block is instantiated into a model, Model Composer identifies template parameters whose values are not determined by input signals, and lets the user define the values for those customization parameters. Values can be defined for customization parameters in the model any time prior to simulation.

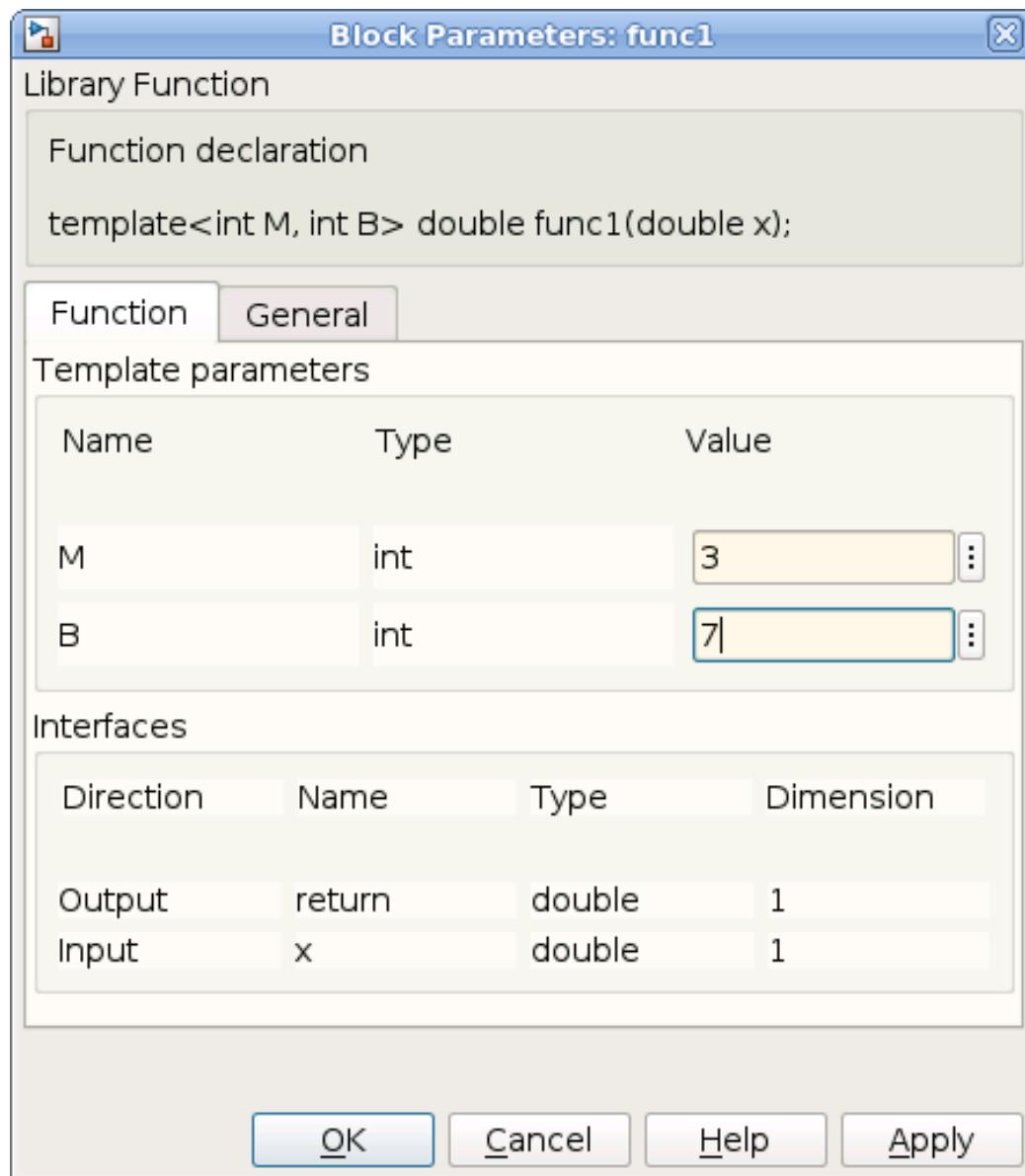
For function templates, the customization parameters can only be integer values to define the size or dimensions of a data type, or can only be scalar variables with definable data types. Model Composer defines a default value of 0 for integer parameters, and 'int32' for data type, or typename parameters.

In the function template example below, the template parameters 'M' and 'B' define customization parameters because the parameter values are not inherited from the input signal to the block. In this case, the parameters need to be customized by the user when the block is added to the model, or any time before simulation.

```
template <int M, int B>
double func1(double x) {
    return x * M + B;
}
```

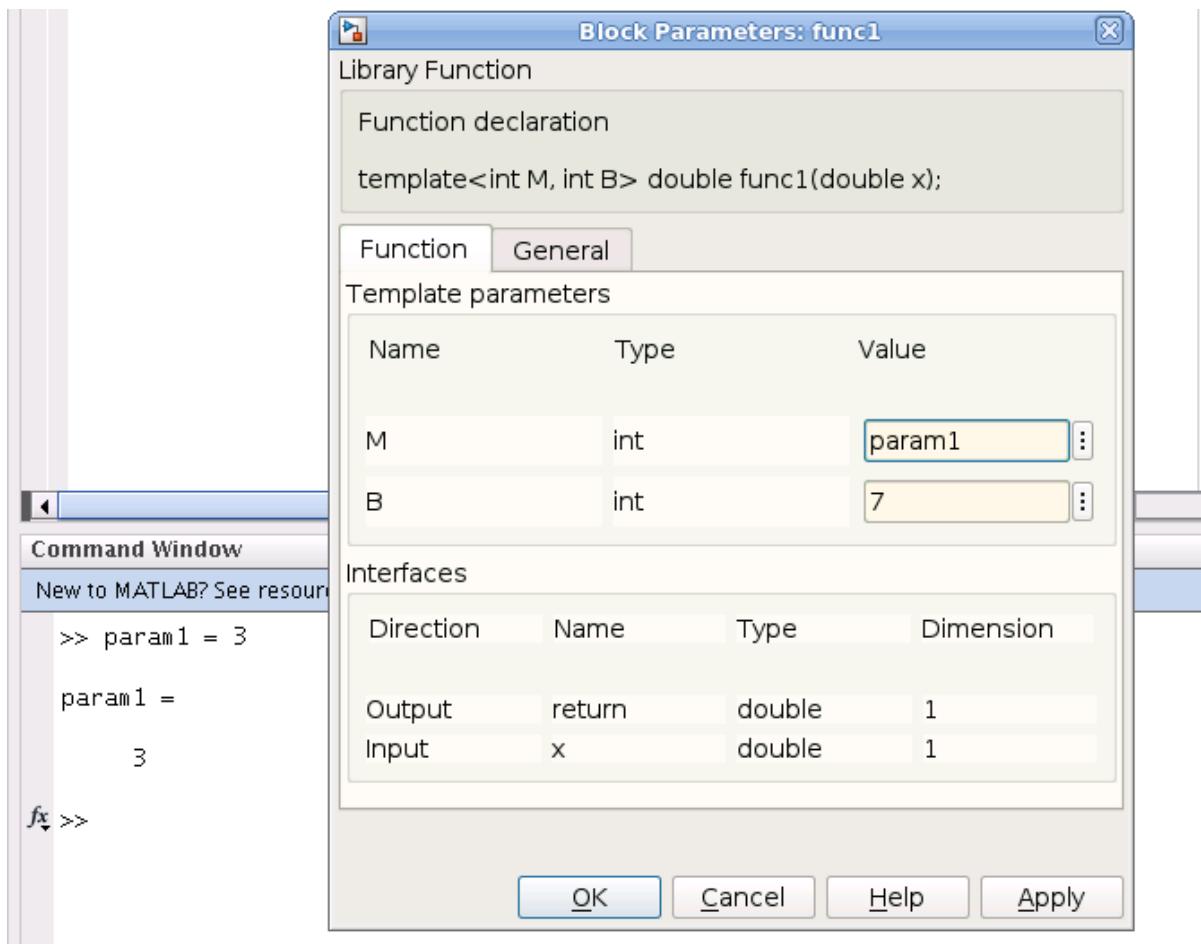
Customization parameters are displayed in the Block Parameters dialog box for the imported block as shown for the `func1` function below. Double click on a block in the model to open the **Block Parameters** dialog box, then enter the value for any editable parameters, such as 'M' and 'B' below.

Figure 146: Entering Parameter Values



Optionally, the user can also specify the name of a MATLAB workspace variable in the text field for the customization parameter, and have the value determined by Model Composer through the MATLAB variable. For example, the variable `param1` is defined in the MATLAB workspace, and used to define the value for 'M'.

Figure 147: Defining Parameters using Workspace Variables



## PARAMETER Pragma

The second method defines function arguments as customization parameters through the use of the Model Composer `PARAMETER` pragma.

To declare that a function argument is a customization parameter, you must add the `PARAMETER` pragma with the parameter name, or list of names, before the function signature in the header file. You can specify multiple parameters with one pragma, or have separate pragmas for each, as shown below.

```
#pragma XMC PARAMETER <name1>, <name2>
#pragma XMC PARAMETER <name3>
function declaration(<name1>, <name2>, <name3>)
```

When a function argument is declared a customization parameter by pragma, the `xmc ImportFunction` command will not create an input or output port on the block for that argument. It will be defined for use inside the function body only. When the block is added to a model, a customization field is added to the Block Parameter dialog box, and the user of the block can define values for the customization parameters.

Using the `PARAMETER` pragma on a function argument that is already driven by the input signal will be flagged as an error or a warning. In this case, the signal input propagation through the function will have higher precedence than the customization parameter.

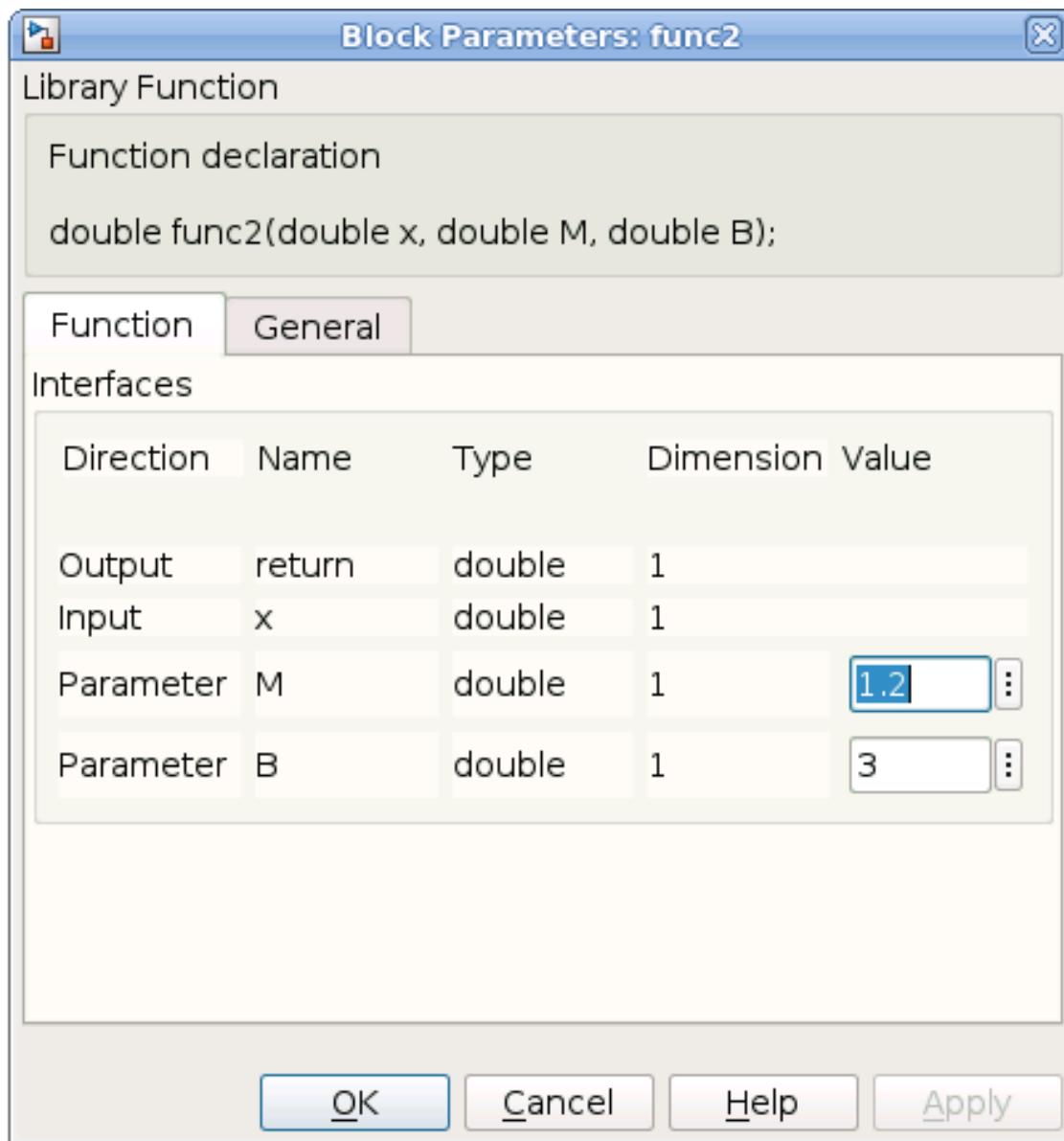
While the [function templates](#) method only supports scalar and integer type customization parameters, the `PARAMETER` pragma supports integer, floating point or fixed point data type for the parameters. The customization parameters also can be scalar, vector or a two-dimensional matrix. In addition, while the function template defines default values of 0 for integer types, and `int32` for the data type, the `PARAMETER` pragma lets you define default value for the parameters. Model Composers defines default values of 0 for all parameters that do not have user-defined defaults.

The example below uses the Model Composer `PARAMETER` pragma to define the customization parameters 'M' and 'B'.

```
#pragma XMC PARAMETER M, B
double func2(double x, double M = 1.2, double B = 3) {
    return x * M + B;
}
```

The 'M' and 'B' customization parameters also have default values assigned: `M=1.2, B=3`. The default values for the customization parameters are assigned to the arguments in the function signature, and are displayed in the **Block Parameters** dialog box when opened for edit, as shown below.

Figure 148: Customization Parameters with Defaults



**IMPORTANT!** If you define default values for the customization parameters of any argument, the C/C++ language requires that all arguments following that one must also have default values assigned, because the function can be called without arguments having default values. Therefore, you should add all customization parameters with default values at the end of the function argument list.

## Vector and Matrix Customization Parameters

The PARAMETER pragma method can also be used to specify customization parameters with vector and matrix dimensions, or values. In the following example the `coef` vector is defined by the pragma as a customization parameter:

```
#pragma XMC PARAMETER coef
#pragma XMC IMPORT din
#pragma XMC OUTPORT dout
#pragma XMC SUPPORTS_STREAMING
void FIR(ap_fixed<17, 3> din[100], ap_fixed<17, 3> dout[100],
ap_fixed<16, 2> coef[52]);
```

The constant array values of the customization parameter are entered in MATLAB expression format. Note that commas are optional:

- Vector parameter: [val1, val2, val3, ...]
- Matrix parameter (row-major order): [val11, val12, val13, ...; val21, val22, val23, ...; ...]

## Interface Output Types and Sizes

Customization parameters can also be used to directly set the data types and dimension size for output ports whose values are not determined by inputs to the function. In the function below, the template variables define the word length and fractional length of the `ap_fixed` data type and the array size.

```
template <typename T1, int N1, int W2, int I2, int N2>
void func(const T1 in[N1], ap_fixed<W2, I2> out[N2]) {
...
}
```

The template variables 'W2', 'I2' and 'N2' define customization parameters because the values must be set by the user rather than determined from the input arguments. However, Model Composer recognizes that the template variables 'T1' and 'N1' are specified on the input port, and so the data type (`typename`) and the size of the input vector are not customization parameters, but rather get defined by the input signal on the block.

To set the data type for output ports, or arguments used in the body of the function, the `typename` specified must be one of the Model Composer supported data types, including the signed or unsigned fixed data types.

*Table 11: Model Composer Supported Data Types*

Supported Typenames
'int8'
'uint8'
'int16'

Table 11: Model Composer Supported Data Types  
(cont'd)

Supported Typenames
'uint16'
'int32'
'uint32'
'double'
'single'
'x_half'
'boolean'
'x_sfix<n1>_En<n2>'
'x_ufix<n1>_En<n2>'

In the example function below, while the typename for 'T1' is determined by the input signal, you can set the typename for 'T2' in the **Block Parameters** dialog box on the mask, when the block is added to a model, or before simulation run time:

```
template <typename T1, int N1, typename T2, int N2>
void func(const T1 in[N1], T2 out[N2]) {
    ...
}
```

## Pragmas for xmcImportFunction

### XMC SUPPORTS\_STREAMING

The Model Composer SUPPORTS\_STREAMING pragma indicates that the array parameters of a function support streaming data. This means that each element of the array is accessed once in a strict sequential order and indicates to Model Composer to optimize the design for streaming data. There can be no random access to the non-scalar arguments of a function to which the SUPPORTS\_STREAMING pragma is applied.

The following example illustrates the difference between random access and sequential access. The transform\_matrix output array of the create\_transform\_matrix function is addressed in a random order. It accesses the last row of the transform\_matrix first, followed by the first and second row. This prevents the block from supporting streaming data.

```
void create_transform_matrix(const float angle, const float center_x,
                           const float center_y, float transform_matrix[3]
                           [3]) {
    float a = hls::cosf(angle);
    float b = hls::sinf(angle);

    transform_matrix[2][0] = 0;
    transform_matrix[2][1] = 0;
    transform_matrix[2][2] = 0;
```

```
    transform_matrix[0][0] = a;
    transform_matrix[0][1] = b;
    transform_matrix[0][2] = (1-a)*center_x-b*center_y;

    transform_matrix[1][0] = -b;
    transform_matrix[1][1] = a;
    transform_matrix[1][2] = b*center_x +(1-a)*center_y;
}
```

To change this function to support streaming data, it can be modified as depicted below to address the `transform_matrix` output array in a sequential manner:

```
#pragma XMC SUPPORTS_STREAMING
void create_transform_matrix(const float angle, const float center_x,
                           const float center_y, float transform_matrix[3]
                           [3]) {
    float a = hls::cosf(angle);
    float b = hls::sinf(angle);

    transform_matrix[0][0] = a;
    transform_matrix[0][1] = b;
    transform_matrix[0][2] = (1-a)*center_x-b*center_y;

    transform_matrix[1][0] = -b;
    transform_matrix[1][1] = a;
    transform_matrix[1][2] = b*center_x +(1-a)*center_y;

    transform_matrix[2][0] = 0;
    transform_matrix[2][1] = 0;
    transform_matrix[2][2] = 0;
}
```

As shown in the preceding example, to specify that an imported function supports streaming, simply add the `SUPPORTS_STREAMING` pragma in the C or C++ header file before the function declaration:

```
#pragma XMC SUPPORTS_STREAMING
```

If the function has array arguments that are accessed sequentially, but `SUPPORTS_STREAMING` is not specified, then a subsystem using that block will not be implemented in a streaming architecture. This means the performance of the function will not be optimized.



**IMPORTANT!** If your function accesses the array arguments in random order, you must not specify the `SUPPORTS_STREAMING` pragma or an error will be returned when generating output or verifying your design.

The following is an example of a function that accesses the array arguments in a strictly sequential order, supporting the streaming of data. This function flips the rows of an input image horizontally. The function accesses the input image in a sequential order and buffers two rows of the input image in a circular buffer. Once two full rows are buffered, the function writes the buffer content to the function argument in a sequential order. As such, this function supports streaming, and uses the SUPPORTS\_STREAMING pragma to specify it.

```
#ifndef _MY_FUNCS
#define _MY_FUNCS

#include <stdint.h>

#pragma XMC IMPORT in1
#pragma XMC OUTPORT out1
#pragma XMC SUPPORTS_STREAMING
#pragma XMC BUFFER_DEPTH 4+2*WIDTH
// This function reverses each of the rows of the input image.
template<int WIDTH, int HEIGHT>
void
flip(uint8_t in1[HEIGHT][WIDTH],
      uint8_t out1[HEIGHT][WIDTH])
{
#pragma HLS dataflow

    uint8_t buf[2][WIDTH];

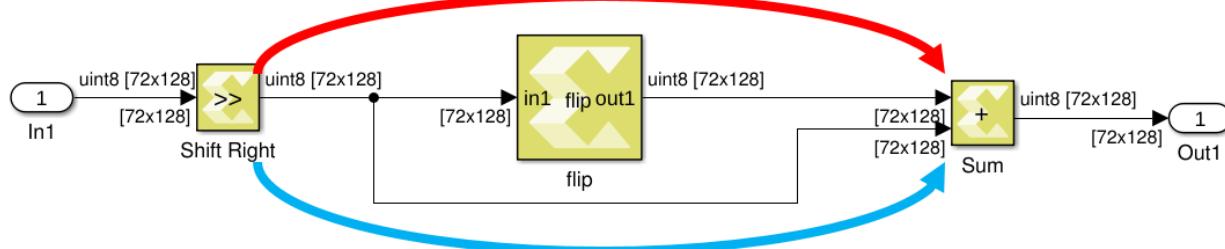
    int readBuf = 0;
    int writeBuf = 0;
    for (int row = 0; row < HEIGHT + 2; ++row) {
        for (int col = 0; col < WIDTH; ++col) {
#pragma HLS DEPENDENCE array inter false
#pragma HLS PIPELINE II=1
            if (row < HEIGHT) {
                buf[writeBuf][col] = in1[row][col];
                if (col == WIDTH-1) {
                    ++writeBuf;
                    writeBuf = (3 == writeBuf) ? 0 : writeBuf;
                }
            }
            if (row > 1) {
                out1[row - 2][col] = buf[readBuf][WIDTH- 1 - col];
                if (col == WIDTH-1) {
                    ++readBuf;
                    readBuf = (3 == readBuf) ? 0 : readBuf;
                }
            }
        }
    }
#endif
```

## XMC BUFFER\_DEPTH

The Model Composer `BUFFER_DEPTH` pragma provides information for properly sizing the buffers that connect the blocks in an implementation. These buffers are implemented as FIFOs in hardware. By default, Model Composer sets the depths of these buffers to 1. However, if your design has re-convergent paths (two paths converging into the same node) and the processing of data from the blocks of one path are not in lockstep with the processing of data from the other path, then a deadlock can occur. To avoid the deadlock the depth of one or more of the buffers on the paths can be increased to store the data. The following example illustrates this concept.

In the following diagram the `Sum` block consumes both the output signal of the `flip` block (red path), and the output of the `Shift Right` block (blue path). The `flip` block has been created with the `xmcImportFunction` command, and its source code is shown in the `flip` function previously described.

Figure 149: Buffer Depth



From the code for the `flip` block, you can see that the block needs to read 2 full rows before producing the first output. If the `BUFFER_DEPTH` pragma is not specified for the block, Model Composer sets the buffer sizes to 1 for the signals in the diagram. This results in deadlock, because the `flip` block reads 257 pixels from the input FIFO before producing the first output. However, by default, the parallel blue path feeding the second input of `Sum` has only enough storage for 1 pixel.



**TIP:** Vitis HLS provides some capability to detect deadlocks during C/RTL co-simulation. In case a deadlock is detected, the tool prints out messages showing which FIFOs are involved in the deadlock, to help identify FIFOs that may require a `BUFFER_DEPTH` of more than 1.

To change the default `BUFFER_DEPTH`, as shown in the `flip` function, place the pragma in the header file before the function declaration:

```
#pragma XMC BUFFER_DEPTH <depth>
```

Where `<depth>` specifies the buffer depth, and can be specified as a value or an expression.

By specifying `#pragma XMC BUFFER_DEPTH 4 + 2 * WIDTH` in the `flip` function, Model Composer can determine that there is an imbalance in processing among the re-convergent paths, and address this imbalance by setting the buffer depth for the second input to the `Sum` block (blue path) to match the buffer depth of the `flip` block.



**TIP:** Determining the minimal buffer depth may require a bit of trial and error because it also depends on the timing of the reads and writes into the FIFOs in the RTL code. In the `flip` function example, 256 (or  $2 * WIDTH$ ) was not sufficient `BUFFER_DEPTH`, but 260 (or  $4 + 2 * WIDTH$ ) prevented the deadlock.

## XMC THROUGHPUT\_FACTOR

The Model Composer `THROUGHPUT_FACTOR` pragma provides some control over the throughput of an `xmcImportFunction` block. You can add the `THROUGHPUT_FACTOR` pragma to your function header file, along with the `SUPPORTS_STREAMING` pragma as shown in the following example:

```
#pragma XMC THROUGHPUT_FACTOR TF_param: 1,2,4
#pragma XMC SUPPORTS_STREAMING
template<int ROWS, int COLS, int TF_param>
void DilationWrap(const uint8_t src[ROWS][COLS], uint8_t dst[ROWS][COLS])
```

The syntax of the pragma as shown in the prior example is:

```
#pragma XMC THROUGHPUT_FACTOR TF_param: 1,2,4
```

Where:

- The `TF_param` must be an `int` type template parameter, as is in the example above.
- It is optional, though recommended, to specify any specific throughput factors that are supported by the function. In the example above, `1,2,4` specifies the supported throughput factors in the pragma, expressed as positive integers, and must include the value 1. If you do not explicitly specify the throughput factors, the `TF_param` is assumed to be valid for any positive throughput factor up to the upper limit of 16 that is supported by Model Composer.

As discussed in [Controlling the Throughput of the Implementation](#), you specify the throughput factor for the model in the Model Composer Hub block. You can specify a throughput factor for the Hub block that divides evenly into one of the `THROUGHPUT_FACTOR` values on the `xmcImportFunction` block.



**IMPORTANT!** If the throughput factor of the Hub block does not match, or does not divide evenly into the `THROUGHPUT_FACTOR` specified by the `xmcImportFunction` block, then the throughput is reduced to 1 for the block function.

Please note the following requirements:

- `THROUGHPUT_FACTOR` pragma must be used on Template functions.
- `THROUGHPUT_FACTOR` pragma must be used with `SUPPORTS_STREAMING` pragma.

- Only one THROUGHPUT\_FACTOR pragma can be specified for an `xmcImportFunction` block.
- The block function will be called with actual arguments that have cyclic ARRAY\_RESHAPE directives with factor=TF (see example below). For more information on the ARRAY\_RESHAPE pragma, refer to [HLS Pragmas](#) in the *Vitis Unified Software Platform Documentation*.
- The read accesses from a non-scalar input argument of the function should be compliant with the requirements for streaming, and Vitis™ HLS should be able to combine groups of TF reads into 1 read of the reshaped array.
- The write accesses into a non-scalar output argument of the function should be compliant with the requirements for streaming, and Vitis™ HLS should be able to combine groups of TF writes into 1 write of the reshaped array.

The following is an example function specifying both SUPPORTS\_STREAMING and THROUGHPUT\_FACTOR pragmas:

```
#include <stdint.h>

#pragma XMC THROUGHPUT_FACTOR TF: 1, 2, 4, 8, 16
#pragma XMC SUPPORTS_STREAMING
template<int TF>
void mac(const int32_t In1[240], const int32_t In2[240], const int32_t
In3[240],
         int32_t Out1 [240])
{
    #pragma HLS ARRAY_RESHAPE variable=In1 cyclic factor=TF
    #pragma HLS ARRAY_RESHAPE variable=In2 cyclic factor=TF
    #pragma HLS ARRAY_RESHAPE variable=In3 cyclic factor=TF
    #pragma HLS ARRAY_RESHAPE variable=Out1 cyclic factor=TF

    for (uint32_t k0 = 0; k0 < 240 / TF; ++k0) {
        #pragma HLS pipeline II=1
        int32_t Product_in2m[TF];
        int32_t Sum_in2m[TF];
        int32_t Product_in1m[TF];
        int32_t Sum_outm[TF];
        for (uint32_t k1 = 0; k1 < TF; ++k1) {
            Product_in2m[k1] = In2[(k0 * TF + k1)];
        }
        for (uint32_t k1 = 0; k1 < TF; ++k1) {
            Sum_in2m[k1] = In3[(k0 * TF + k1)];
        }
        for (uint32_t k1 = 0; k1 < TF; ++k1) {
            Product_in1m[k1] = In1[(k0 * TF + k1)];
        }
        for (uint32_t k1 = 0; k1 < TF; ++k1) {
            int32_t Product_in2s;
            int32_t Sum_in2s;
            int32_t Product_in1s;
            int32_t Product_outs;
            int32_t Sum_outs;
            Product_in2s = Product_in2m[k1];
            Sum_in2s = Sum_in2m[k1];
            Product_in1s = Product_in1m[k1];
            Product_outs = Product_in1s * Product_in2s;
            Sum_outs = Product_outs + Sum_in2s;
            Sum_outm[k1] = Sum_outs;
        }
    }
}
```

```
        }
        for (uint32_t k1 = 0; k1 < TF; ++k1) {
            Out1[(k0 * TF + k1)] = Sum_outm[k1];
        }
    }
```

## Adding Your Library to Library Browser

To use the imported blocks in your library, you can simply open the Simulink model of your library, and copy blocks into a new Model Composer model. However, if you want to see your library listed in the Library Browser, and be able to drag and drop blocks from the library into new models, after running the `xmcImportFunction` command you must prepare your library using the following process.

1. Enable Library Browser parameter.
2. Save the library.
3. Create `slblocks.m` script for the library.
4. Add path to MATLAB, or add library to MATLAB path.
5. Refresh Library Browser.



**TIP:** Setting up the library using this process is only required for newly created libraries, rather than existing libraries which have already been setup.

To enable the library to be available in the Library Browser, you must turn on the `EnableLBRepository` parameter for the library. After importing a block into a new library using `xmcImportFunction`, with the library open, you must use the following command from the MATLAB command line prior to saving your library:

```
set_param(gcs, 'EnableLBRepository', 'on');
```

This parameter identifies the library as belonging to the Library Browser. However, that is just the first step. Save the library by using the **File** → **Save** command from the main menu, or by clicking on the button in the toolbar.

Libraries in the Library Browser also require the presence of a script in the same directory as the library model, called `slblocks.m`, that defines the metadata associated with the library. You can create this script by copying an existing script from another library, or copying it from the MATLAB installation, or by editing the following text and saving it as `slblocks.m`:

```
function blkStruct = slblocks
    % This function adds the library to the Library Browser
    % and caches it in the browser repository

    % Specify the name of the library
```

```
Browser.Library = 'newlib';
% Specify a name to display in the library Browser
Browser.Name = 'New Library';

blkStruct.Browser = Browser;
```

Notice the `Browser.Library` specifies the name of the library model minus the `.slx` file extension, and `Browser.Name` specifies the display name that will appear in Library Browser.

**Note:** Each library should appear in a separate directory, with the `<library>.slx` file and the `slblocks.m` script for that library.

After creating the library and the `slblocks.m` script, you need to either add the library location to the MATLAB path so that MATLAB can find it, or copy the library to a folder that is already on the MATLAB path. You can type `path` at the MATLAB command prompt to see the current path that MATLAB uses. You can also add the library directory to the MATLAB path using the following commands:

```
addpath ('library_folder')
savepath
```

Where:

- `'library_folder'`
- `savepath` is a string that saves the current search path to `pathdef.m`.



**TIP:** To remove a folder from the MATLAB path you can use the following command sequence:

```
rmpath ('library_folder')
savepath
```

Finally, to view the new library in the Library Browser, from the left side of the Library Browser window right-click and select the **Refresh Library Browser** command. This will load the library into the tool. You should now be able to view the imported blocks and drag and drop them into your models.

## Debugging Imported Blocks

Model Composer provides the ability to debug C/C++ code that has been imported as a block using the `xmcImportFunction` command, while simulating the entire design in Simulink®. In this case, the `xmcImportFunctionSettings` command can be used to set the debugging tool.

This feature lets you build the C/C++ function with debug information, and load it into Simulink for simulation. Once loaded, you can step into the C/C++ code of a specific imported block, and debug the function. The debugging environment lets you set debug break points in the C/C++ code, step through, and observe the intermediate results to verify the function in the context of the simulation. Debugging C/C++ code during Simulink simulation provides a natural flow. You can set desired input stimulus in Simulink, and observe the effect stepping through the code.

The debug flow in Model Composer uses the following steps:

1. Specify the debug tool using the `xmcImportFunctionSettings` command.
2. Launch the debugging tool.
3. Add a breakpoint in the imported function.
4. Attach to the MATLAB® process.
5. Start Simulink simulation.
6. Debug the imported function during simulation.

## ***Enable Debug Mode***

Debugging the C/C++ function requires the simulation model to be built in the debug mode, instead of being built for release. You will use the `xmcImportFunctionSettings` command to configure the build mode prior to launching simulation. To enable the debug build, use the following command:

```
xmcImportFunctionSettings('build', 'debug')
```

Refer to [xmclImportFunctionSettings Command Syntax](#) for more information on the command options. Enabling debug mode in Windows operating system causes Model Composer to return the following messages in the MATLAB® Command Window:

```
Imported C/C++ code will be built with MinGW compiler. You can use gdb to
debug your C/C++ code.
MATLAB process ID is 4656.
You can also get the process ID by typing "feature getpid" in the MATLAB
command window.
```

The information returned above can be used to launch the default debug tool, and connect to the MATLAB process, as described in the following sections.



**TIP:** You can restore the release build environment, using the 'release' value of the 'build' option:

```
xmcImportFunctionSettings('build', 'release')
```

## Launch the Debug Tool

After enabling the debug build mode, the `xmcImportFunctionSettings` command returns a link to the suggested debugging tool.

A third-party debugger is required for debugging with Model Composer. The default debugger is GDB for both the Linux and Windows operating systems.

## Setting a Breakpoint for the Imported Function

When the debugger is launched, you can set a breakpoint for the C/C++ imported function in the current model. This will break, or pause the Simulink simulation at the point it enters the imported function. This lets you perform further debugging actions, such as stepping through the function, printing variable values, or listing lines of code. Refer to the documentation for your debugging tool for more information on specific commands, and debugging techniques.



**TIP:** The following commands are provided for GDB, as it is the default debugger for Model Composer.

Setting a breakpoint uses the function name of the imported function:

```
(gdb) break <function_name>
```

Because simulation has not yet started, GDB will respond that no symbol table is loaded, and indicate that you can use the "file" command to specify break points. This simply means that you can also specify breakpoints based on the source file for the imported C/C++ function, and line number, specified as follows:

```
(gdb) break <file name>:<line num>
```

For example: `break func3_d.h:10`



**IMPORTANT!** Blocks created from function templates, as described in [Defining Blocks Using Function Templates](#), require the file name and line number to set breakpoints.

## Connecting Debug to the MATLAB Process

With the breakpoint established, you can link GDB to the MATLAB® process by using the GDB attach command, and specifying the process ID (PID) returned by the `xmcImportFunctionSettings` command when you set up the debug build mode, as previously discussed. Use the following command:

```
(gdb) attach <PID>
```



**IMPORTANT!** After it is attached to GDB, the MATLAB process will be suspended. You must use the `continue` command to have the process resume running after the `gdb` prompt is returned:

```
(gdb) continue
```

At this point you are ready to start the Simulink® simulation, and begin debugging your design.

## xmcImportFunctionSettings Command Syntax

The `xmcImportFunctionSettings` command sets options for the import function feature in Model Composer. Options are specified in the form of name/value pairs. The current options include:

- `build`: Specifies the build environment for Model Composer. Supported values include:
  - `release`: The default build mode. Generates the specified output, and lets you perform simulation.
  - `debug`: Provides integration into a third-party compiler to let you step through and observe the imported C/C++ function using standard debug features.
- `compiler`: Specifies the third-party compiler to use for debugging purposes. The supported values are:
  - `default`: Compile with GCC or MinGW compiler for debugging using GDB debugger. Note that GCC or MinGW, and GDB are included with the standard installation of Model Composer.
- `blocks`: Specifies the specific block or blocks that you want to observe during the debugging process. If the option is not specified, all imported function blocks in the current design are included for debugging. You can specify one or more blocks using the following command form:

```
xmcImportFunctionSettings('blocks', {'block1','block2', ...})
```

You can also unset the selection of the blocks using the following command:

```
xmcImportFunctionSettings('blocks', {})
```

You can use the MATLAB `gcb` command to get the block path for a specific block. The blocks must be specified as a list of blocks, even if only one block is specified. For example:

```
xmcImportFunctionSettings('blocks', {'xmc_optical_flow/Lucas-Kanade'})
```



**TIP:** The settings specified by `xmcImportFunctionSettings` remain set until you exit Model Composer, or change the options using `xmcImportFunctionSettings`.

**Note:** In earlier versions of Model Composer, there existed a set of Computer Vision libraries which have been removed from 2020.2 and subsequent releases. You can import these functions into Model Composer as a block using the `xmcImportFunction` feature. To do this, you need to write a wrapper file around the library function. Refer to the Model Composer HLS examples, Sobel Edge detection and Color Detection (from [GitHub](#)), to understand how to write a wrapper file and import it as a block into the Model Composer design.

For example: Type, `xmcOpenExample('color_detection')` in the MATLAB command window. You can get the latest version of Vision libraries from this [GitHub](#) repository.

---

# Generating Outputs

## Introduction



**IMPORTANT!** To generate output from the Model Composer HLS model, only HLS library blocks and a limited set of Simulink blocks can be used in the subsystem that is instantiated at the top-level of the design. The Simulink blocks compatible with output generation in Model Composer can be found in the HLS blockset. Refer to [Supported Simulink Blocks](#) for a complete list.

Model Composer automatically compiles designs into low-level representations. However, a Model Composer model requires the addition of the Model Composer Hub block to configure compilation and generate outputs. Model Composer can create three different types of output from the model, as defined by the **Target** setting of the Model Composer Hub block:

- [IP Catalog](#)
- [HLS C++ Code](#)

## Vitis Model Composer Hub

Control implementation of the model.

### Description

The Vitis Model Composer Hub block controls the behavior of the Vitis Model Composer tool.

You can specify the targeted design flow for the generated output, the directory path for the output, and the desired device and design clock frequency using the following tabs.

- The **Hardware Selection** pane helps with device or board selection.
- The **Code Generation** pane provides options to select the output flow by selecting subsystems and specifying Code directory. Different options will be displayed depending on if the subsystem is targeting HDL, HLS, or AIE.

## Library

AI Engine/Tools; HLS/Tools; Utilities/Code Generation.



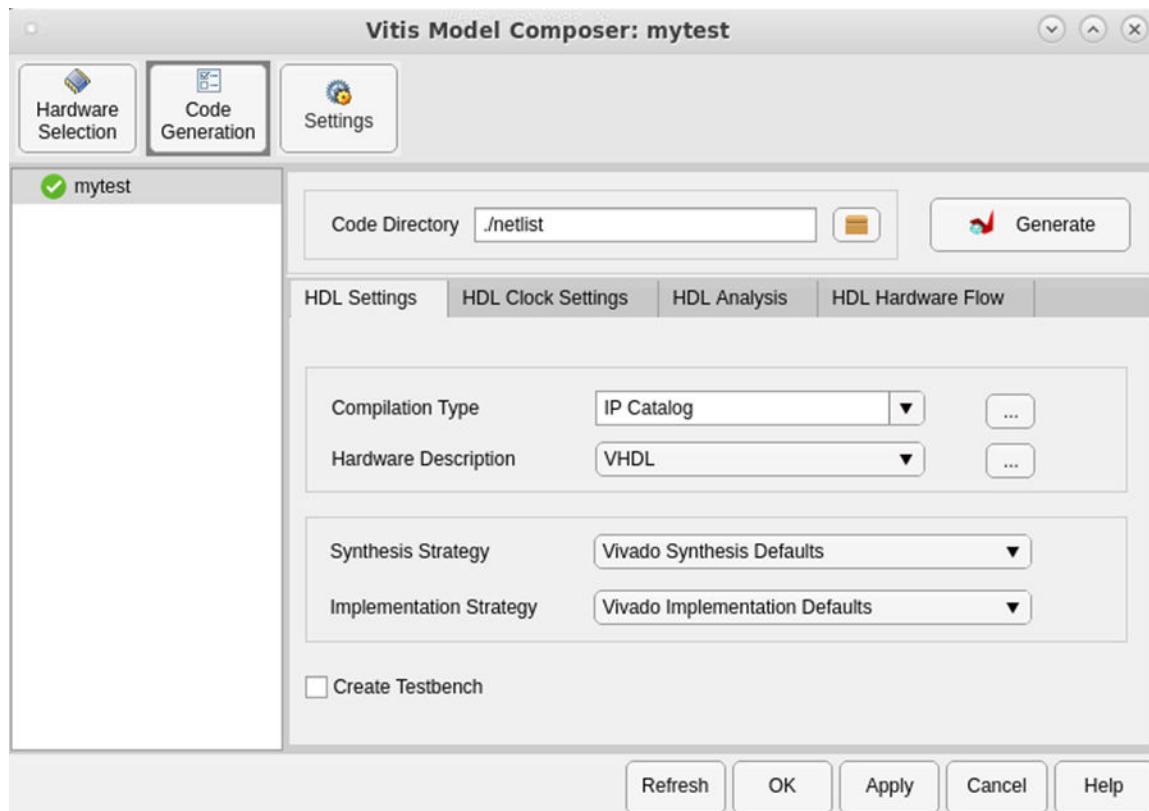
## Vitis Model Composer Hub

### Data Type Support

Data type support is not applicable to the Vitis Model Composer Hub block.

### Parameters

Figure 150: Vitis Model Composer Hub Block Parameters



The following section describes the configurable options available in each pane of the Vitis Model Composer Hub block.

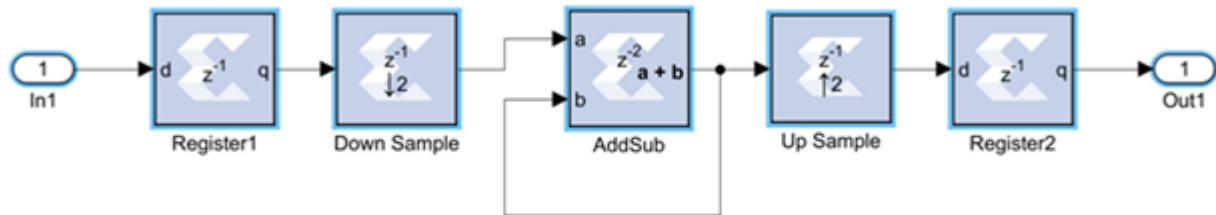
- **Hardware Selection:** Clicking the browse button (...) displays the Device Chooser dialog box. This allows you to select a part, board, or platform to which your design is targeted. Vitis Model Composer obtains board and device data from the Vivado database.
- **Code Generation:** Select the subsystem name for which to generate code from the list on the left. Different settings will display depending on the type of code generation (HDL, HLS, or AI Engine) to be performed.
- **AIE Settings:**
  - **AIE Compiler Options:** When enabled, this option provides control over compiler debug options, execution target options etc.
  - **Create Testbench:** When enabled, Vitis Model Composer generates the test vectors while generating the code.
  - **Run cycle-approximate AIE Simulation (SystemC) after code generation:** This option is only available if **Create testbench** is selected. When enabled, it runs the AIE simulation after code generation.
  - **Simulation timeout (cycles):** When enabled, it specifies the number of cycles for which AIE simulation is run. The default value is 50000.
  - **Plot AIE Simulation Output and Estimate Throughput:** When enabled, this option logs simulation data and allows visualization of the output of an AI Engine subsystem.
  - **Collect profiling statistics and enable 'printf' for debugging:** When enabled, this option allows profiling data to be collected for analysis.
  - **Collect data for Vitis Analyzer:** When enabled, this option provides a summary of the simulation results which can be viewed in the Vitis Analyzer.
  - **Open Vitis Analyzer:** Click to invoke the Vitis Analyzer tool. This option is only enabled after AI Engine Simulation has been ran at least once after enabling.
- **AIE Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the Create Testbench option in the AIE Settings panel.
  - **Generate Hardware Validation Code:** When enabled, Vitis Model Composer generates code to be used for hardware validation.
  - **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
  - **Target:** Specify the target for hardware validation flow.
  - **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.

- **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
- **Run hardware emulation after code generation:** When enabled, hardware emulation will run immediately after code generation.
- **HDL Settings:**
  - **Compilation Type:** Specifies the type of compilation result that should be produced when the code generator is invoked. The default compilation type is IP Catalog. When IP Catalog is selected, the Settings (...) button brings up a dialog box that allows you to add a description of the IP that will be placed in the IP catalog.
  - **Hardware Description:** Specifies the HDL language to be used for compilation of the design. The possibilities are VHDL and Verilog.
    - **VHDL library:** Specifies the name of VHDL work library for code generation. The default name is `xil_defaultlib`.
    - **Use STD\_LOGIC type for Boolean or 1 bit wide gateways:** If your design's Hardware Description Language (HDL) is VHDL, selecting this option will declare a Boolean or 1-bit port (Gateway In or Gateway Out) as a STD-LOGIC type. If this option is not selected, Vitis Model Composer will interpret Boolean or 1-bit ports as vectors.
- Note:** When you enable this option and try to run Generate code and Run behavioral simulation in Vivado, you may see a failure during the elaboration phase.
- **Synthesis strategy:** Choose a Synthesis strategy from the pre-defined strategies in the drop-down menu.
- **Implementation strategy:** Choose an Implementation strategy from the pre-defined strategies in the drop-down menu.
- **Create testbench:** This instructs Vitis Model Composer to create an HDL test bench. Simulating the test bench in an HDL simulator compares Simulink simulation results with ones obtained from the compiled version of the design. To construct test vectors, Vitis Model Composer simulates the design in Simulink, and saves the values seen at gateways. The top HDL file for the test bench is named `<name>_testbench.vhd/.v`, where `<name>` is a name derived from the portion of the design being tested.
- Note:** Testbench generation is not supported for designs that have gateways (Gateway In or Gateway Out) configured as an AXI4-Lite interface.
- **HDL Clock Settings:**
  - **Enable multiple clocks:** Must be enabled when the design has multiple clocks. This indicates to the code generation engine that the clock information for the various subsystems must be obtained from the respective clock tabs. If not enabled, then the design will be treated as a single clock design.

- **Number of clocks:** Defines the number of clocks in the design. The number of clock tabs that appear will be equivalent to the number of clocks. In each clock tab, you must select the subsystem and configure the clock settings of that subsystem.
- **FPGA clock period (ns):**

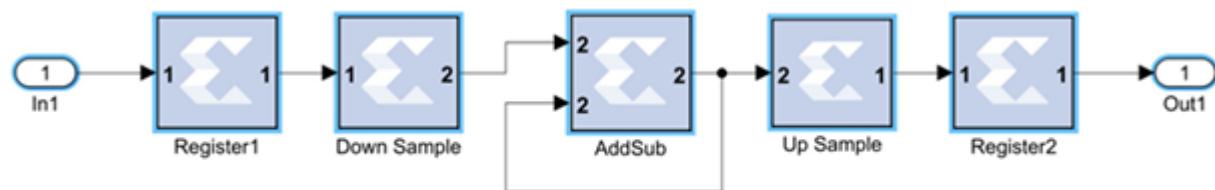
Defines the period in nanoseconds of the system clock. The value need not be an integer. The period is passed to the Xilinx implementation tools through a constraints file, where it is used as the global PERIOD constraint. Multicycle paths are constrained to integer multiples of this value.
- **Simulink system period (sec):** Defines the Simulink System Period, in units of seconds. The Simulink system period is the greatest common divisor of the sample periods that appear in the model. These sample periods are set explicitly in the block dialog boxes, inherited according to Simulink's propagation rules, or implied by a hardware oversampling rate in blocks with this option. In the final case, the implied sample time is in fact faster than the observable simulation sample time for the block in Simulink. In hardware, a block having an oversampling rate greater than one processes its inputs at a faster rate than the data. For example, a sequential multiplier block with an over-sampling rate of eight implies a (Simulink) sample period that is one eighth of the multiplier block's actual sample time in Simulink. This parameter can be modified only in a master block.
- **Clock pin location:** Defines the pin location for the hardware clock. This information is passed to the Xilinx implementation tools through a constraints file. This option should not be specified if the Vitis Model Composer design is to be included as part of a larger HDL design.
- **Provide clock enable clear pin:** This instructs Vitis Model Composer to provide a `ce_clr` port on the top-level clock wrapper. The `ce_clr` signal is used to reset the clock enable generation logic. The ability to reset clock enable generation logic allows designs to have dynamic control for specifying the beginning of data path sampling.
- **HDL Analysis:**
  - **Block icon display:** Specifies the type of information to be displayed on each block icon in the model after compilation is complete. The various display options are described below.
    - **Default:** Displays the default block icon information on each block in the model. A block's default icon is derived from the `xbsIndex` library.

Figure 151: Default Block Icon



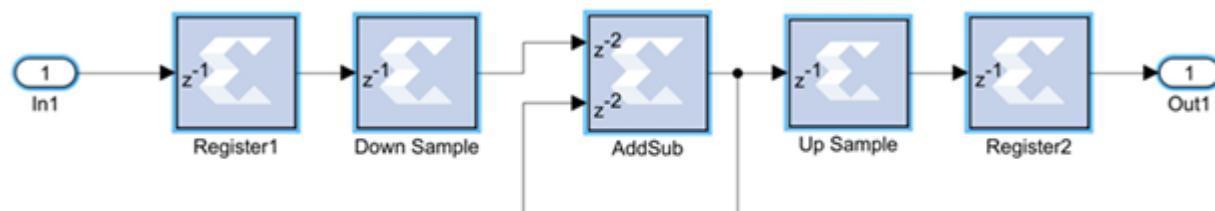
- **Normalized Sample Periods:** Displays the normalized sample periods for all the input and output ports on each block. For example, if the Simulink System Period is set to 4 and the sample period propagated to a block port is 4, then the normalized period that is displayed for the block port is 1; and if the period propagated to the block port is 8 then the sample period displayed would be 2 (a larger number indicates a slower rate).

Figure 152: Normalized Sample Periods Icon



- **Sample frequencies (MHz):** Displays sample frequencies for each block.
- **Pipeline stages:** Displays the latency information from the input ports of each block. The displayed pipeline stage might not be accurate for certain high-level blocks such as the FFT, RS Encoder/Decoder, Viterbi Decoder, etc. In this case the displayed pipeline information can be used to determine whether a block has a combinational path from the input to the output. For example, the Up Sample block in the following figure shows that it has a combinational path from the input to the output port.

Figure 153: Pipeline Stages



- **HDL port names:** Displays the HDL port name of each port on each block in the model.
- **Input data types:** Displays the data type of each input port on each block in the model.
- **Output data types:** Displays the data type of each output port on each block in the model.
- **Update the model:** Update the model to display the selected Block Icon type.
- **Perform Analysis:** Specifies whether an analysis (timing or resource) will or will not be performed on the Vitis Model Composer design when it is compiled. If **None** is selected, no timing analysis or resource analysis will be performed. If **Post Synthesis** is selected, the analysis will be performed after the design has been synthesized in the Vivado toolset. If **Post Implementation** is selected, the analysis will be performed after the design is implemented in the Vivado toolset.
- **Analysis Type:** Two selections are provided: Timing or Resource. After generation is completed, a Timing Analyzer table or Resource Analyzer table is launched.
- **Launch:** Launches the Timing Analyzer or Resource Analyzer table, depending on the selection of Analyzer type. This will only work if you already ran analysis on the Simulink model and haven't changed the Simulink model since the last run.
- **Remote IP cache:** If selected, your design will access an IP cache whenever a Vitis Model Composer compilation performs Vivado synthesis as part of the compilation. If the compilation generates an IP instance for synthesis, and the Vivado synthesis tool generates synthesis output products, the tools create an entry in the cache area. If a new customization of the IP is created which has identical properties, the tools will copy the synthesis outputs from the cache to the design's output directory instead of synthesizing the IP instance again. Accessing the disk cache speeds up the iterative design process. IP caching is described in HDL Library.
- **Create interface document:** When this check box is selected and the **Generate** button is activated for netlisting, Vitis Model Composer creates an HTM document that describes the design being netlisted. This document is placed in a `documentation` subfolder under the `netlist` folder.
- **Clear cache:** Clicking this button clears the remote IP cache. Clearing the cache saves disk space (the IP Cache can grow large, especially if your design uses many IP modules).
- **HDL Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the **Create Testbench** option in the HDL Settings panel. The HDL hardware flow is only supported for Versal® devices.
  - **Generate Hardware Validation Code:** When enabled, Vitis Model Composer generates code to be used for hardware validation.
  - **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
  - **Target:** Specify the target for hardware validation flow.

- **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
- **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
- **Generate (BOOT.BIN/SD card image) after code generation:** When enabled, a BOOT.BIN (for baremetal HW system) or SD card image (for Linux HW system) will be generated after code generation.
- **HLS Settings:**
  - **Target:** Select IP Catalog to export the design to the Vivado IP Catalog. After C/C++ code generation, Vitis High-Level Synthesis (HLS) is invoked to synthesize the C code and create a project that can be exported as an IP to the Vivado IP Catalog. Select HLS C++ code to compile the design model into C++ code.
  - **FPGA clock frequency:** Specifies the clock frequency in MHz for the targeted device. This frequency is passed to the downstream tool flow.
  - **Throughput factor:** Specifies the number of samples processed per clock to increase the throughput. A larger factor increases hardware resource usage. The throughput factor must be between 1 and 16.
  - **Create testbench and run (C simulation/RTL cosimulation):** If selected, Vitis Model Composer runs simulation and generates test vectors while generating code.
  - **Testbench stack size (MBytes):** This parameter prompts you to enter a larger stack size. When **Create and run testbench** is enabled, the **Testbench stack size** option specifies the size of the testbench stack frame during C simulation (CSIM). Occasionally, the default stack frame size of 10 MB allocate for execution of the testbench may be insufficient to run the test, due to large arrays allocated on the stack and/or deep nesting of subsystems. Typically when this happens, the test would fail with a segmentation fault and an associated error message. In such a case you can increase the size of the stack frame and rerun the test.
- **HLS Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the Create Testbench option in the HLS Settings panel. Generate Hardware Validation Code.

When enabled, Vitis Model Composer generates code to be used for hardware validation.

  - **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
  - **Target:** Specify the target for hardware validation flow.
  - **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
  - **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.

- **Generate (BOOT.BIN/SD card image) after code generation:** When enabled, a BOOT.BIN (for baremetal HW system) or SD card image (for Linux HW system) will be generated after code generation.
- **Code Generation:** Select a subsystem containing blocks from the AI Engine, HDL, or HLS blocksets and specify the corresponding Code Directory. The Code Directory can be specified by entering the complete directory path or using the Browse button to provide a path.
- **Settings:** Specify whether the Model Composer Hub block should treat your model as a legacy System Generator design.

## Controlling the Throughput of the Implementation

### *Introduction*

Throughput of a system is one of its most important design criteria. For example, if you are designing a system that processes High Definition video frames (1920x1080) at 30 frames per second, the required throughput of your application would be 62,208,000 pixels per second (1920x1080x30). If you process one pixel per clock (in hardware terminology this is called an initiation interval of one, or II=1), your device needs to be clocked at over 62.2 MHz. If your requirements change, and you need to process a 4K video frame at 60 frames per second, the required throughput of the application would be 497,664,000 pixels per second (3840x2160x60), and your device needs to be clocked at over 497 MHz.

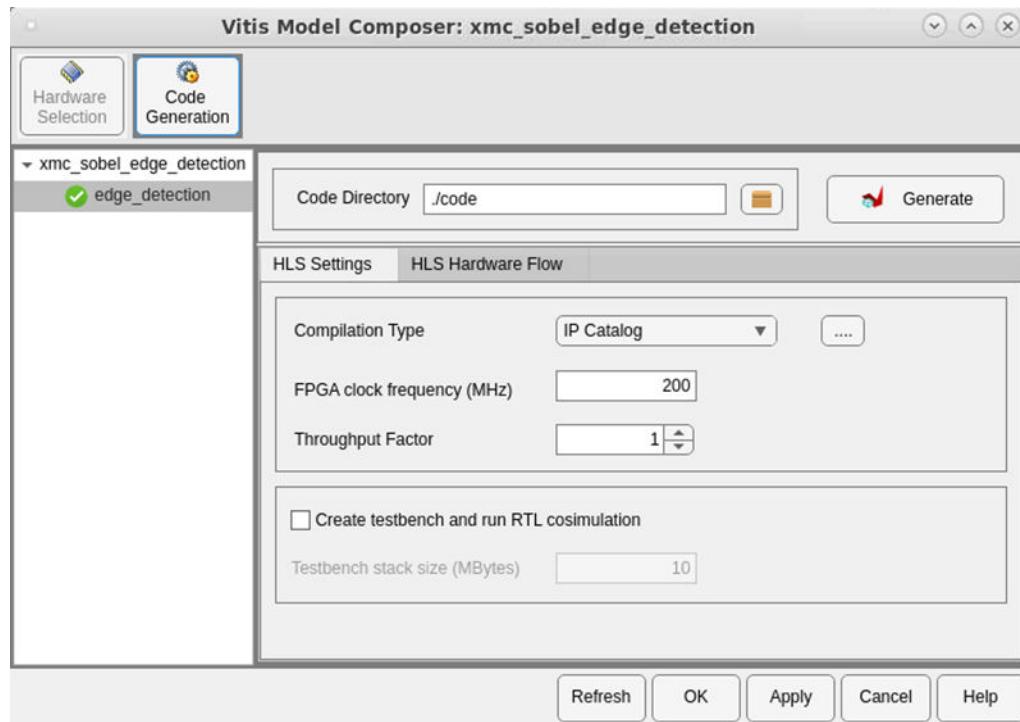
However, in practice you may not be able to achieve an initiation interval of one (II=1), therefore to achieve the desired throughput, you need to clock the device at even higher rates. In other applications, such as wireless communications, the clock frequencies needed to achieve a desired throughput could easily surpass the maximum clock frequency allowed for a device.

If you need to increase the throughput of your design, without increasing the clock frequency that your device is operating at (to operate at a clock frequency below the maximum allowed for a device, or to curtail power consumption), you can take advantage of the programmable logic nature of Xilinx FPGAs, and use parallelization techniques to process more samples per clock. Throughput control in Model Composer allows the user to do exactly that without making structural changes to their design in Simulink.

### ***Setting Throughput Factor from the Hub Block***

The Model Composer Hub block provides Throughput Factor to control the throughput of the generated code, or hardware design. The Throughput Factor specifies how many sample elements of the inputs are to be processed per clock cycle. By default, the Throughput Factor is set to 1. You can specify this factor by clicking on the **HLS Setting** tab of the Model Composer Hub block, as shown below:

Figure 154: Model Composer Hub - Throughput Factor



The Throughput Factor must be between 1 and 16. Specifying a value greater than 1 will create parallel logic to process the transactions, using more resources from the device, and increasing the HLS and Vivado Synthesis run time.

Code generation for designs with Throughput Factor > 1 imposes additional restrictions on the design. In case these restrictions are not met, Model Composer will return an error trying to explain the violation.

### **Restrictions on Using Throughput Control**

After you set the value of Throughput Factor, and click the **Generate** button on the Hub, it triggers the compilation of the subsystem. A Throughput Factor of more than 1 can be achieved only if the design complies with the following restrictions:

- The Throughput Factor must be between 1 and 16.
- The subsystem must have at least one non-scalar input port.
- All of the non-scalar ports of the subsystem must use either AXI4-Streaming or FIFO interfaces.
- For any vector signal within the subsystem, but not inside a Window Processing block kernel, the vector length must be a multiple of the Throughput Factor.
- For any matrix signal within the subsystem, but not inside a Window Processing block kernel, the number of columns must be a multiple of the Throughput Factor.

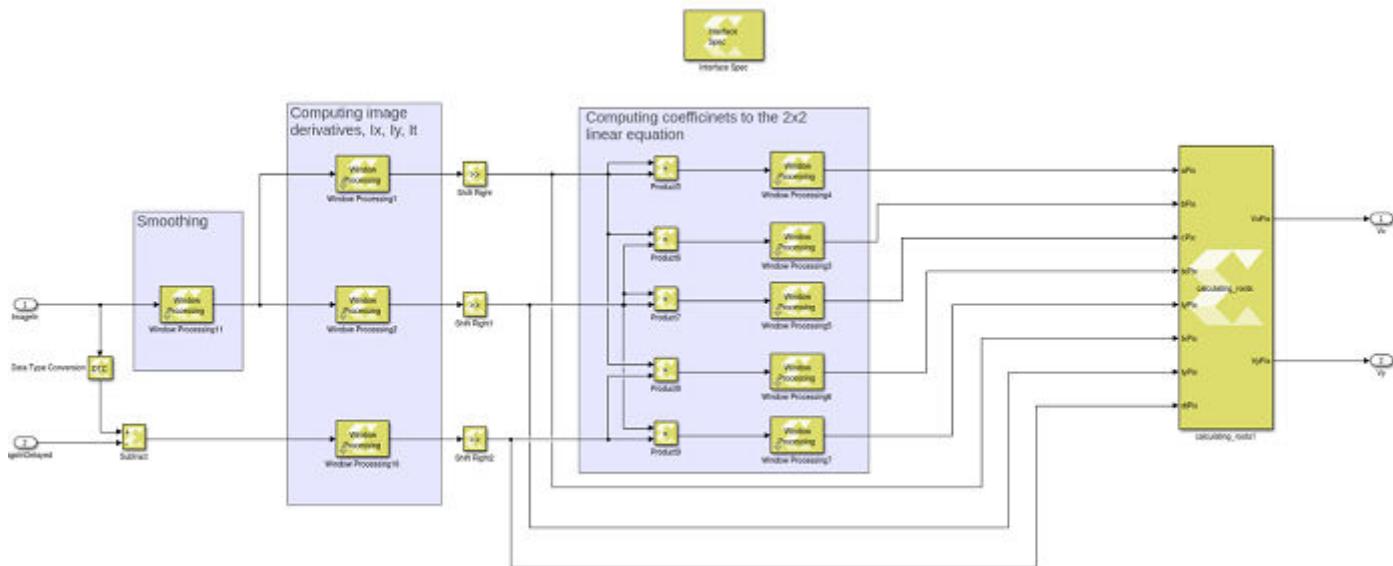
- Except for blocks inside a Window Processing block kernel, the subsystem must not include any of the following blocks:
  - look up
  - matrix multiply, QR inverse
  - transpose, hermitian
  - sum of elements and product of elements with floating point input
  - cumulative sum, reducing min, reducing max
  - if action subsystem
- For blocks created using `xmcImportFunction`, refer to [XMC THROUGHPUT\\_FACTOR](#).

In summary, if the specified Throughput Factor is >1, and the design complies with all above mentioned restrictions, Model Composer can generate models that process samples concurrently. In cases where the design does not meet these restrictions, Model Composer will not generate an output model.

## ***Understanding Throughput Control Through an Example***

The following section demonstrates the benefits of using the Throughput Control feature with the Optical flow example design found in the list of examples for Model Composer HLS library.

*Figure 155: Optical Flow Example*

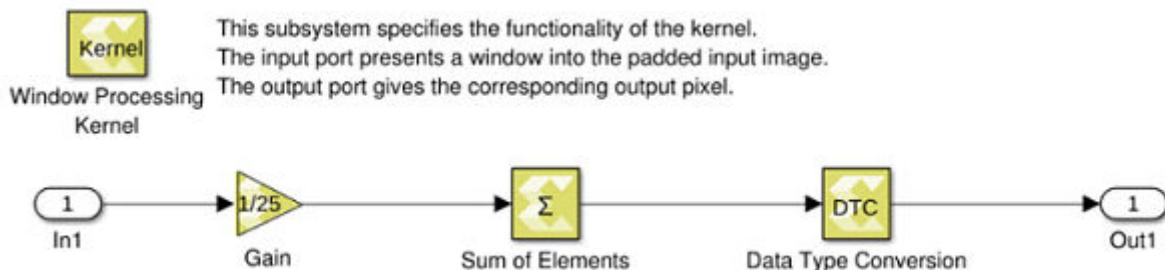


This design uses the following blocks:

- Data Type Conversion, Subtract, Right Shift, Product

- Window processing blocks, with Gain, Sum of Elements, and Data Type Conversion.
- An Import Function block with the `calculating_roots` function.

**Figure 156: Window Processing Kernel**



All these blocks follow the element-wise application pattern, and comply with the restrictions previously discussed.

---

**IMPORTANT!** Direct use of the Sum of Elements block in subsystems using Throughput Control is restricted. In this example, the 'Sum of Elements' block is used in the Window Processing block but not directly in the top-level subsystem.

---

With the default Throughput Factor=1, Model Composer generates the code shown below:

```
void
Lucas_Kanade(hls::stream< uint8_t >& ImageIn, hls::stream< uint8_t >&
              ImageInDelayed, hls::stream< float >& Vx, hls::stream< float >& Vy)
{
    #pragma HLS INTERFACE axis port=ImageIn
    #pragma HLS INTERFACE axis port=ImageInDelayed
    #pragma HLS INTERFACE axis port=Vx
    #pragma HLS INTERFACE axis port=Vy
    #pragma HLS INTERFACE s_axilite port=return
    #pragma HLS dataflow
```

The IP reads its inputs, the image and delayed image, over AXI4-Stream. These streams will use a data width of 8 bits (1 pixel). Similarly pixels of the output image are streamed over an AXI4-Stream interface of data width 8 bits.

If you set TF=4, you get the code shown below.

```
void
Lucas_Kanade(hls::stream< xmc::MultiScalar< uint8_t, 4 > >& ImageIn,
              hls::stream< xmc::MultiScalar< uint8_t, 4 > >& ImageInDelayed,
              hls::stream< xmc::MultiScalar< float, 4 > >& Vx,
              hls::stream< xmc::MultiScalar< float, 4 > >& Vy)
{
    #pragma HLS INTERFACE axis port=ImageIn
    #pragma HLS data_pack variable=ImageIn
    #pragma HLS INTERFACE axis port=ImageInDelayed
    #pragma HLS data_pack variable=ImageInDelayed
    #pragma HLS INTERFACE axis port=Vx
```

```
#pragma HLS data_pack variable=Vx
#pragma HLS INTERFACE axis port=Vy
#pragma HLS data_pack variable=Vy
#pragma HLS INTERFACE s_axilite port=return
#pragma HLS dataflow
```

This IP receives 4 pixels of the input image, and 4 pixels of the delayed input image, at the same time over AXI4-Stream that have data width of 32 bits. Inside the IP the logic has been duplicated so that 4 pixels are processed in parallel. The IP sends 4 pixels of the output image at a time over an AXI4-Stream, of data width 32 bits. Note that `xmc : :MultiScalar<T, N>` is a template struct defined in `xmcMultiScalar.h`. It is a struct that contains an array of N elements of type T.

The following table represents the Vitis HLS timing and resource estimates for optical flow design.

**Table 12: Optical Flow Design Timing/Resource Utilization Estimates**

	<b>Throughput factor = 1</b>	<b>Throughput factor = 4</b>	<b>Throughput factor = 8</b>
Clock Freq	300 MHz	300 MHz	300 MHz
Latency/II	41848/41834	10483/10469	5358/5344
BRAM_18k (Utilization %)	5	2	4
DSP48E (Utilization %)	2	9	19
FF (Utilization %)	8	30	59
LUT (Utilization %)	14	36	88

The second line in the table shows the initiation interval (II). At clock frequency of 300 MHz and Throughput Factors 4 and 8, the initiation interval of the design is reduced by a factor of approximately 4 and approximately 8 respectively, when compared with the initiation interval for Throughput Factor=1. Note that this comes at the cost of increasing resource utilization when the Throughput Factor increases.

For Throughput factor of one, the II is 41,848. The input to this design is a 200x200 pixel image frame and the value of II here indicates the number of clocks to process the entire frame. As such it takes slightly more than the duration of one clock cycle to process one pixel. As the Throughput Factor increases, the II to process one frame decreases, and the application processes more than one pixel per clock cycle.

## Defining the Interface Specification

Within the Simulink® environment, the inputs and outputs in your design are defined using "Inport" and "Outport" blocks. However, while moving from the software algorithm to an RTL implementation in hardware, these same input and output ports must be mapped to ports in the design interface, using a specific input-output (I/O) protocol, which typically operates with some real world delay. Part of developing your design is to specify how your design will communicate with other designs or IP in the system. You do this by specifying the interface to your design and choosing among a few standard I/O protocols.

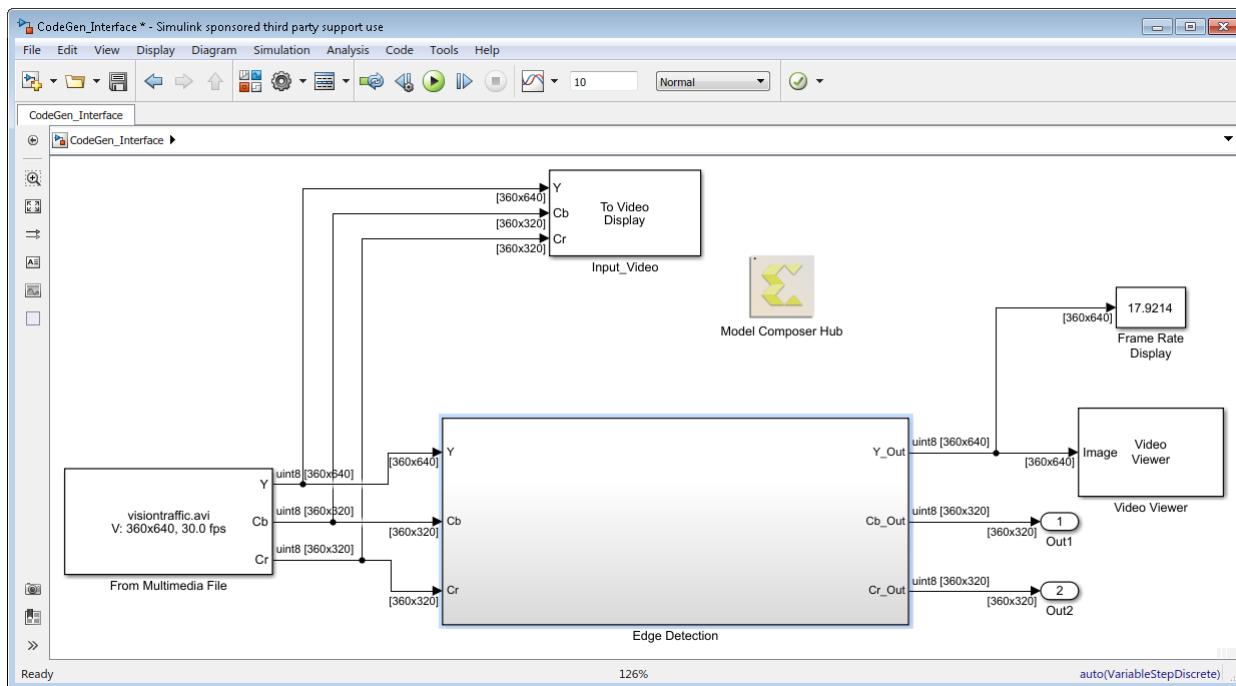
Model Composer requires the use of the Interface Specification (Interface Spec) block to define this I/O protocol.

Interface synthesis is supported only in the top-level subsystem module in the design, which Model Composer generates C++ code for. In the figure below, the Edge Detection module is the top-level subsystem module and the Interface Spec block must be instantiated inside that module.



**TIP:** Any Interface Spec blocks instantiated in other subsystem modules, or nested subsystem modules are ignored.

Figure 157: Top-Level Subsystem Module



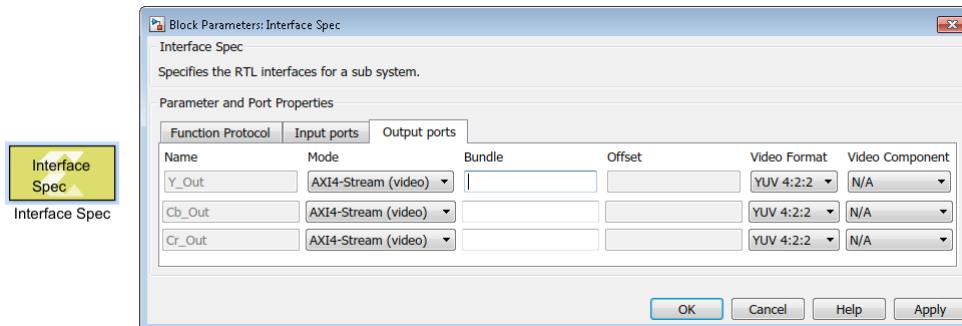
The Interface Spec block lets you control what interfaces should be used for the design. The Interface Spec affects only output code generation; it has no effect on Simulink simulation of your design. If you do not add an Interface Spec block to the subsystem module, Model Composer assigns default interfaces that may not be appropriate for the target platform or device. Therefore, it is recommended that you use the Interface Spec block to define the requirements of your subsystem module. The default function-level protocol is Handshake to specify control signals, and AXI4-Lite Slave for the function return. The default I/O protocol is AXI4-Lite Slave for scalar ports, and AXI4-Stream for non-scalar ports.

The Interface Spec block specifies how RTL ports are created from the function definition during interface synthesis. The ports in the RTL implementation are derived from the following.

- Any function-level protocol that defines control signals for the module.
- Function input and output arguments, and return values.
- Global variables accessed by the function but defined outside its scope.

**Note:** If a global variable is accessed, but all read and write operations are local to the subsystem, the resource is created in the design, and does not require the definition of a port.

Figure 158: Interface Spec Block



The Interface Spec block consists of 3 tabs defining the following information:

- **Function Protocol:** This is the block-level interface protocol which adds signal ports to the subsystem telling the IP when to start processing data. It is also used by the IP to indicate whether it accepts new data, or whether it has completed an operation, or whether it is idle.
- **Input Ports:** This tab automatically detects the input ports in your subsystem and lets you specify the interface protocol on those ports.
- **Output Ports:** This tab automatically detects the output ports on the subsystem module, and lets you specify the interface protocol.

**IMPORTANT!** The Interface Spec block has a current limitation of 8 input ports and 8 output ports on the subsystem module.

The Interface Specification displays and lets you configure the following features or parameters of the function or I/O port protocol.

**Table 13: Function Protocol Tab**

Attribute	Description
Mode	<p>Specifies a block-level protocol to add control signals to the subsystem module. The supported block-level protocols are:</p> <ul style="list-style-type: none"><li>• <b>AXI4-Lite Slave:</b> Implements the return port as an AXI4-Lite Slave interface, and adds the block-level control ports defined by the Handshake protocol. This is the default function protocol.</li><li>• <b>Handshake:</b> Defines a set of block-level control ports for the function to start processing input, and indicate when the design is <code>idle</code>, <code>done</code>, and <code>ready</code> for new input data.</li><li>• <b>No block-level I/O protocol:</b> No control ports are added to the subsystem.</li></ul>
Bundle	Only valid with the AXI4-Lite Slave mode. Indicates that multiple ports should be grouped into the same interface. The bundle is specified by a <code>&lt;name&gt;</code> that cannot contain spaces or special characters.

**Table 14: Input/Output Port Tabs**

Attribute	Description
Name	Displays the port name, which cannot be changed from here.

Table 14: Input/Output Port Tabs (cont'd)

Attribute	Description
Mode	<p>Specifies the port-level I/O protocols. The supported port-level protocols are:</p> <ul style="list-style-type: none"> <li><b>Default:</b> Uses AXI4-Lite Slave interface for scalar ports, or AXI4-Stream interface for non-scalar ports.</li> <li><b>AXI4-Stream:</b> Implements ports as an AXI4-Stream interface for high-speed streaming data.</li> <li><b>AXI4-Stream (video):</b> Implements ports as an AXI4-Stream interface, with the additional assignment of <b>Video Format</b> and <b>Video Component</b> attributes.</li> <li><b>AXI4-Lite Slave:</b> Implements the port as part of an AXI4-Lite Slave interface. All input or output ports with the same <b>Bundle</b> name are grouped into the same AXI4-Lite Slave interface.</li> <li><b>FIFO:</b> Implements the port with a standard FIFO interface, combining data input or output with associated active-low FIFO empty and full control signals.</li> </ul> <p><b>Note:</b> The FIFO interface is the most hardware-efficient approach for access to a memory element that is always sequential, that is, no random access is required. To read from non-sequential address locations, use the Block RAM interface.</p> <ul style="list-style-type: none"> <li><b>Constant:</b> The data applied to the input port remains stable during the function operation, but is not a constant value that can be optimized. This allows internal optimizations to remove unnecessary registers.</li> <li><b>Valid Port:</b> Implements a data port with an associated <code>valid</code> port to indicate when the data is valid for reading or writing.</li> <li><b>No protocol:</b> No protocol. Neither the input or output data signals have associated control ports to indicate when data is read or written.</li> <li><b>Block RAM:</b> Implements array arguments as a standard RAM interface. If you use the generated IP in Vivado IP integrator, the memory interface appears as a single port.</li> </ul>
Bundle	Used in conjunction with the AXI4-Stream (video) interfaces that have more than 1 color component. In this case there should be one port for each color component, and the ports should specify the same bundle <name> so they will be grouped into the same AXI4 Stream (video) interface. Also valid with the AXI4-Lite Slave mode. This parameter explicitly groups all interface ports with the same bundle <name> into the same AXI4-Lite Slave interface.
Offset	Only valid with the AXI4-Lite Slave mode. This parameter specifies an address offset associated with the port in the AXI4-Lite Slave address map. The offset is specified as a non-negative integer, with a default value of 0.
Video Format	Only valid with the AXI4-Stream (video) mode. This parameter specifies the color format for a video stream. Valid formats include: <ul style="list-style-type: none"> <li><b>YUV 4:2:2:</b> Video format based on brightness (luminance) and color (chrominance), with reduced color content.</li> <li><b>YUV 4:4:4:</b> Video format based on brightness (luminance) and color (chrominance), with full color content.</li> <li><b>RGB:</b> Video format based on separate Red, Blue, and Green color signals.</li> <li><b>Mono:</b> Specifies an audio format for your video.</li> </ul>

**Table 14: Input/Output Port Tabs (cont'd)**

Attribute	Description
Video Component	Only valid with the AXI4-Stream (video) mode. This parameter specifies the color component for a video format that uses more than one color component. Valid video components include: <ul style="list-style-type: none"><li>• <b>Y, U, V:</b> Specifies one component of the YUV video format.</li><li>• <b>R, G, B:</b> Specifies one component of the RGB video format.</li></ul>

The choice of port-level interface protocol should take into account the following considerations:

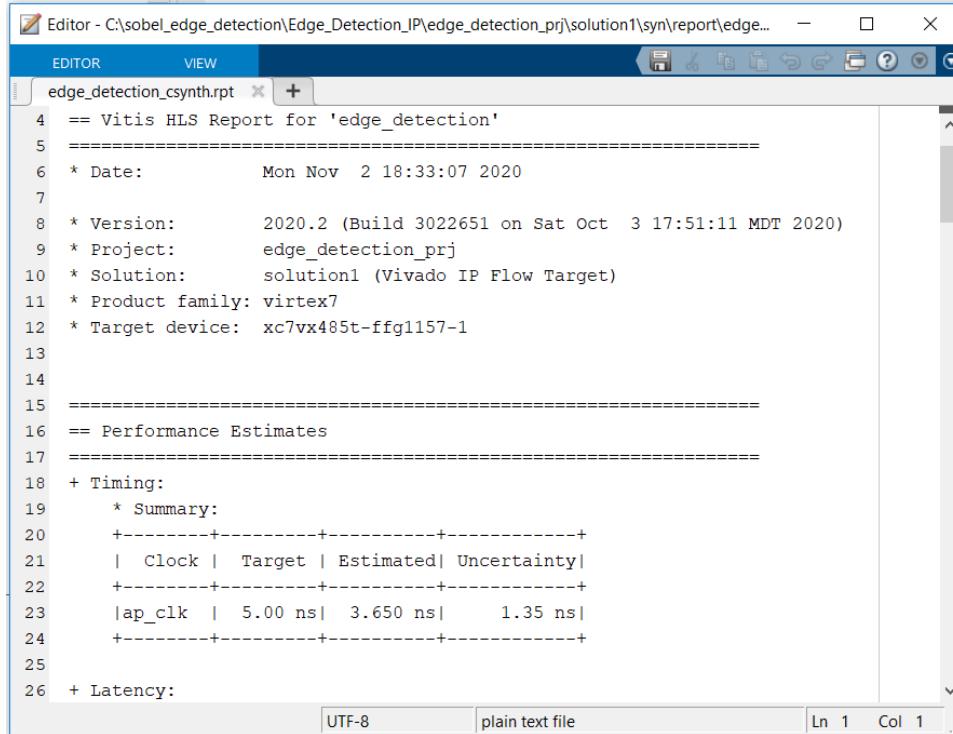
- Scalar ports can be implemented using any of the following protocols: Default, AXI4-Lite Slave, Constant, Valid Port, No protocol.
- Large array or matrix ports should use a streaming protocol such as AXI4-Stream, FIFO, or AXI4-Stream (video).
- Video signals can be transported over an AXI4-Stream (video) interface. In this case you also need to specify the video format YUV 4:2:2, YUV 4:4:4, RGB, or Mono. For video formats that have more than 1 color component, you also need to assign multiple ports to the same signal bundle, and you need to specify which port carries which color component. All of the ports that make up the video signal are implemented by a single AXI4-Stream interface that includes start-of frame and end-of-line sideband signals. For more information refer to *AXI4-Stream Video IP and System Design Guide* ([UG934](#)).

## Generating Packaged IP for Vivado

Model Composer can automatically generate packaged IP for use in Vivado IP catalog. When Model Composer generates output for the IP catalog, it first writes the C++ code as described in [Generating C++ Code](#), and then it synthesizes RTL code from the C++ code. This process begins when you set the **Target** in the Model Composer Hub block to **IP catalog**, hit **Apply** to confirm any changes, and click **Generate**.

Model Composer displays a transcript window of the process. When the process has concluded, the MATLAB® window displays the Synthesis Report for your review, as shown in the figure below. The Synthesis Report includes details on the estimated performance and resource utilization of the RTL design synthesized by Model Composer. You can review this report to see the estimates and review your model.

Figure 159: Synthesis Report



```
Editor - C:\sobel_edge_detection\Edge_Detection_IP\edge_detection_prj\solution1\syn\report\edge...
EDITOR      VIEW
edge_detection_csynth.rpt  [+]
4 == Vitis HLS Report for 'edge_detection'
5 =====
6 * Date:           Mon Nov  2 18:33:07 2020
7
8 * Version:        2020.2 (Build 3022651 on Sat Oct  3 17:51:11 MDT 2020)
9 * Project:        edge_detection_prj
10 * Solution:       solution1 (Vivado IP Flow Target)
11 * Product family: virtex7
12 * Target device:  xc7vx485t-ffg1157-1
13
14
15 =====
16 == Performance Estimates
17 =====
18 + Timing:
19   * Summary:
20   +-----+-----+-----+
21   | Clock | Target | Estimated| Uncertainty|
22   +-----+-----+-----+
23   |ap_clk | 5.00 ns| 3.650 ns|    1.35 ns|
24   +-----+-----+-----+
25
26 + Latency:
```

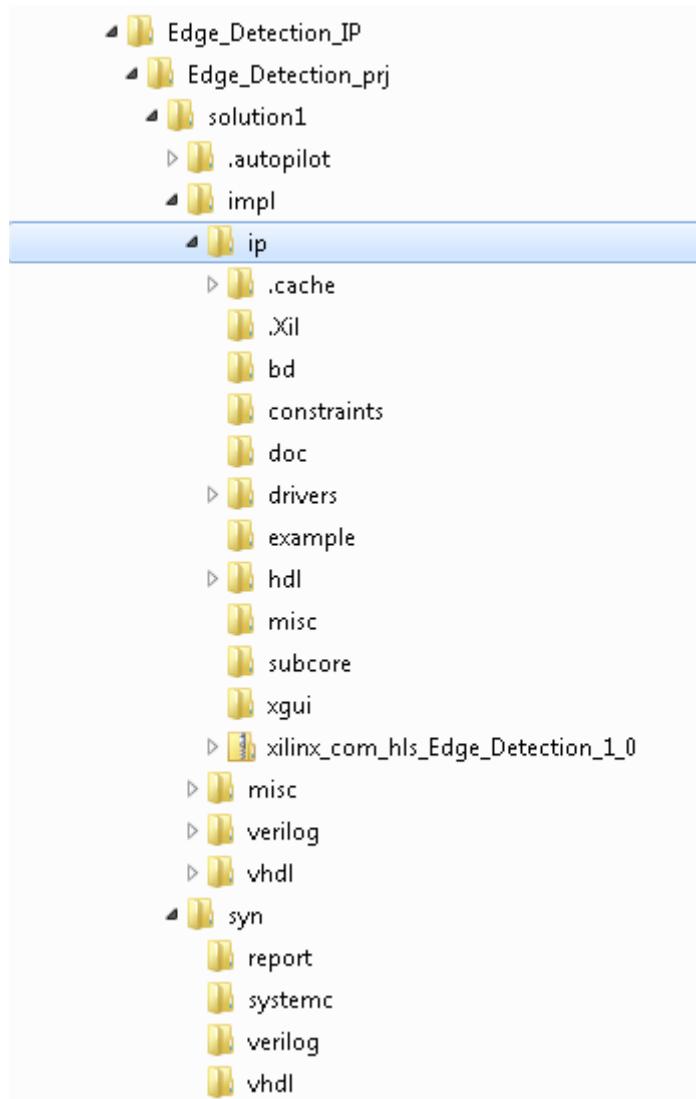
When Model Composer has completed synthesizing the RTL, it reports the message Exporting RTL as a Vivado IP to the transcript window, and launches Vivado to create and package the IP for the subsystem design.

Model Composer generates the following outputs from the algorithm:

- SystemC (IEEE 1666-2006, version 2.2)
- VHDL (IEEE 1076-2000)
- Verilog (IEEE 1364-2001)
- Report files created during synthesis, C/RTL co-simulation, and IP packaging.

When Model Composer has completed generating the packaged IP, it can be found in the project directory structure as shown in the following figure. The `Edge_Detection_IP` folder is the **Code Directory** specified by the Model Composer Hub. The `Edge_Detection_prj` folder is a project created by the `run_hls.tcl` script. The `solution1` folder is a Vitis HLS solution. For more information refer to the *Vitis High-Level Synthesis User Guide (UG1399)*. The `syn` and `impl` folders store the results of synthesis and implementation. The `ip` folder contains the packaged IP to add to the Vivado Design Suite IP catalog.

Figure 160: Packaged IP Folder

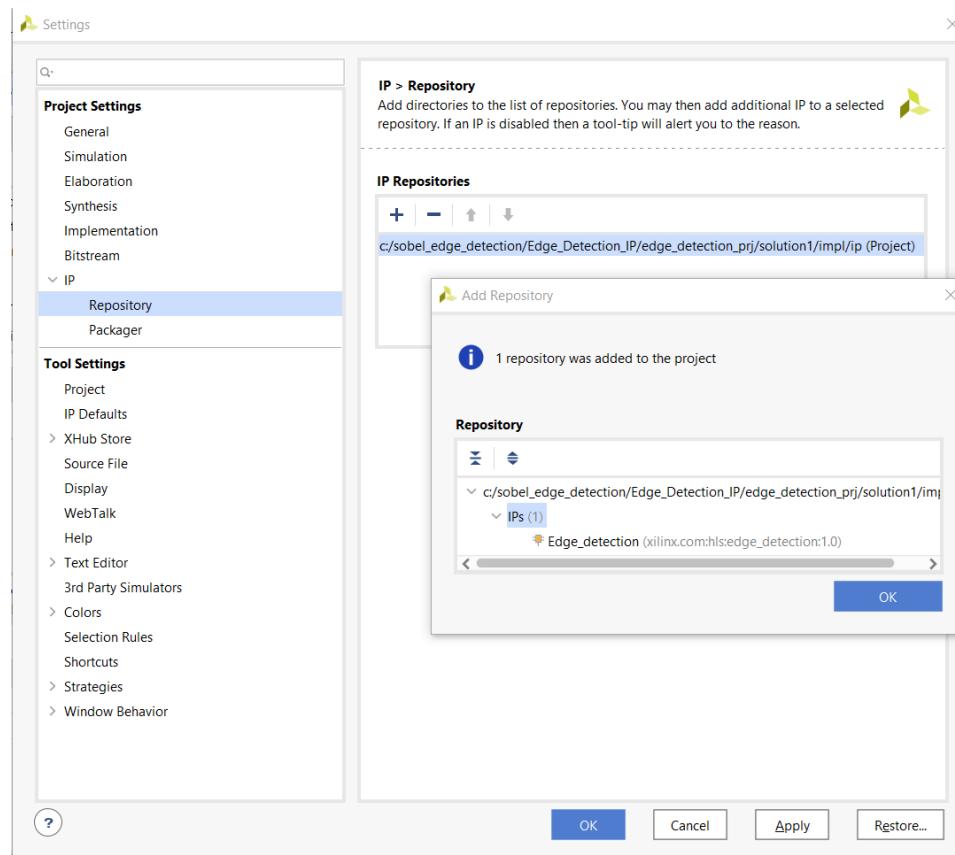


After Model Composer has generated the packaged IP, the `.zip` file archive in the `<project_name>/<solution_name>/impl/ip` folder can be imported into the Vivado IP catalog, and used in any Vivado Design Suite design, either as RTL IP, or in the IP integrator.

For Model Composer models that specify AXI4-Lite Slave interfaces through the Interface Specification block, as discussed in [Defining the Interface Specification](#), a set of software driver files is also created by Vitis HLS during the IP packaging process. These C driver files can be included in an SDK C project and used to access the AXI4-Lite Slave slave port. The software driver files are written to directory `<project_name>/<solution_name>/impl/ip/drivers` and are included in the packaged IP.

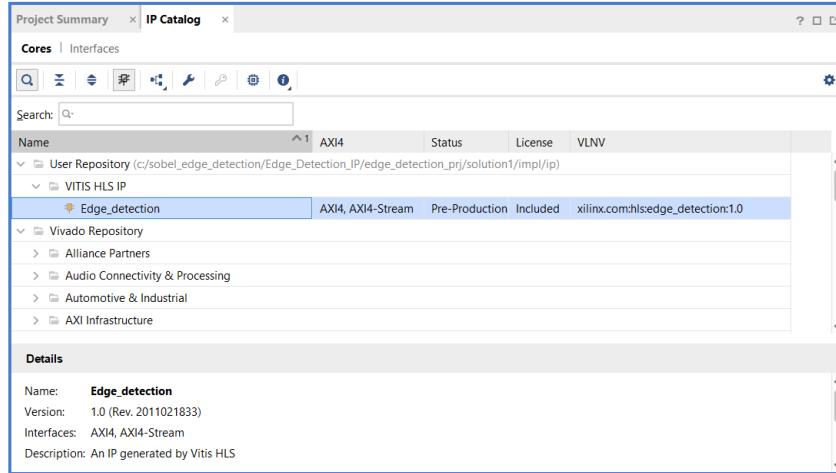
To add the IP into the Vivado IP catalog, from within the Vivado GUI, select the **Tools → Settings** command to open the Settings dialog box. Select the **IP → Repository** command, and add the Vitis HLS packaged IP as shown in the following figure.

Figure 161: Setting the IP Repository



After adding the path to the repository, the IP is added to the IP catalog as shown in the following figure. You can now use the IP in standard RTL designs, or in Vivado IP integrator block designs. For more information on working with IP and adding to the IP repository refer to the *Vivado Design Suite User Guide: Designing with IP (UG896)*.

Figure 162: IP Catalog



**IMPORTANT!** If you see the repository added to the IP catalog, but do not see the Vitis HLS packaged IP, it is possible the target part for the current project is not compatible with the device used when generating the Model Composer output. You can fix this by changing the part in the current project to the device specified by the Model Composer model.

## Generating C++ Code

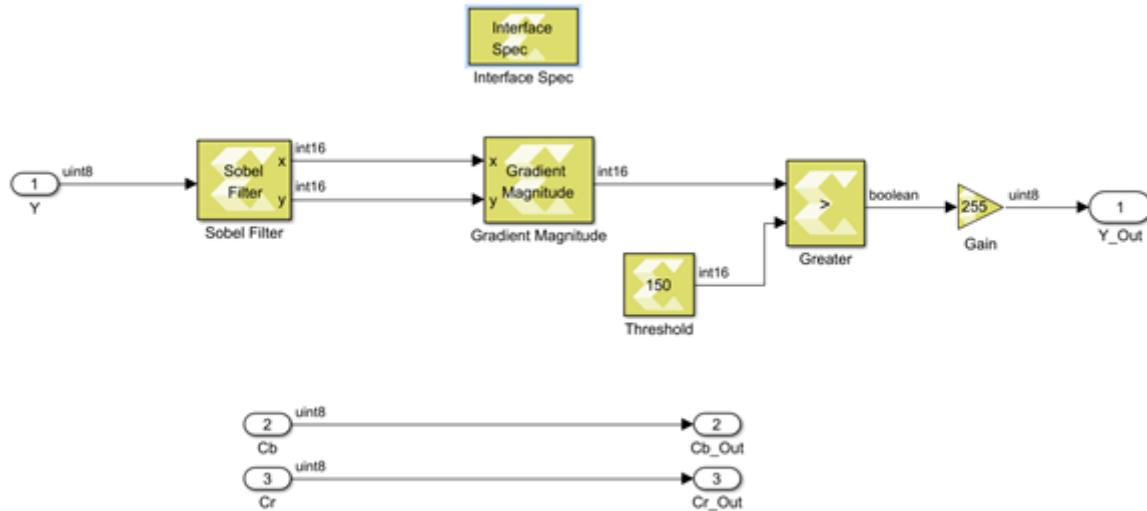
The following figure shows the HLS C++ Code output by Model Composer from the **Generate** command. The C++ code is output either as an intermediate step when generating a packaged IP for System Generator output, or as a specified output to let you optimize the C++ code using directives or pragmas in Vitis HLS.

Figure 163: C++ Output Files



The files generated by Model Composer reflect the contents and hierarchy of the subsystem that was compiled. In this case, the subsystem is the Edge Detection function described in the Model Composer section of the [Vitis Model Composer Tutorial \(UG1498\)](#). The following figure shows the contents of the Edge Detection subsystem.

Figure 164: Edge Detection Subsystem



X20082-111917

The `Edge_Detection.cpp` file specifies the following include files, which incorporate the code generated for the various Model Composer blocks used in the subsystem:

```
#include "Edge_Detection.h"
#include "GradMagnitude.h"
#include "SobelFilter.h"
```

The following shows the generated code for the Edge Detection subsystem. Notice the pragmas added to the function to specify the function protocol and the I/O port protocols for the function signature and return value. The pragmas help direct the solution synthesized by Vitis HLS, and result in higher performance in the implemented RTL.

```
Edge_Detection(hls::stream< ap_axiu<16, 1, 1, 1> >& Y,
               hls::stream< ap_axiu<16, 1, 1, 1> >& Y_Out)
{
    #pragma HLS INTERFACE s_axilite port=return
    #pragma HLS INTERFACE axis bundle=image_out port=Y_Out
    #pragma HLS INTERFACE axis bundle=input_vid port=Y
    #pragma HLS dataflow
    uint8_t core_Y[360][640];
    #pragma HLS stream variable=core_Y dim=2 depth=1
    uint8_t core_Cb[360][320];
    #pragma HLS stream variable=core_Cb dim=2 depth=1
    uint8_t core_Cr[360][320];
    #pragma HLS stream variable=core_Cr dim=2 depth=1
    uint8_t core_Y_Out[360][640];
    #pragma HLS stream variable=core_Y_Out dim=2 depth=1
    uint8_t core_Cb_Out[360][320];
    #pragma HLS stream variable=core_Cb_Out dim=2 depth=1
    uint8_t core_Cr_Out[360][320];
    #pragma HLS stream variable=core_Cr_Out dim=2 depth=1
    fourier::AxiVideoStreamAdapter< uint8_t >::readStreamVf0(Y,
        reinterpret_cast< uint8_t*>(core_Y), reinterpret_cast< uint8_t*>(core_Cb),
        reinterpret_cast< uint8_t*>(core_Cr), 360, 640);
```

```
Edge_Detection_core(core_Y, core_Cb, core_Cr, core_Y_Out, core_Cb_Out,
                     core_Cr_Out);
fourier::AxiVideoStreamAdapter< uint8_t >::writeStreamVf0(Y_Out,
    reinterpret_cast< uint8_t*>(core_Y_Out), reinterpret_cast<
    uint8_t*>(
        core_Cb_Out), reinterpret_cast< uint8_t*>(core_Cr_Out), 360, 640);
}
```

Finally, notice the `run_hls.tcl` file that is generated in the output folder. This is a Tcl script that can be used to run Vitis HLS on the generated output files to create a project and solution, synthesize the RTL from the C++ code, and export the design to the Model Composer HDL model. Each Vitis HLS project holds one set of C/C++ code and can contain multiple solutions. Each solution can have different constraints and optimization directives. For more information refer to the *Vitis High-Level Synthesis User Guide* ([UG1399](#)).

You can run the `run_hls.tcl` script from a Vitis HLS command prompt as follows:

1. Open the Vitis HLS Command Prompt:

- On Windows, use **Start** → **All Programs** → **Xilinx Design Tools** → **Vitis HLS 2022.1** → **Vitis HLS** → **Vitis HLS 2022.1 Command Prompt**.
- On Linux, open a new shell and source the `<install_dir>/Vitis_HLS/<version>/settings64.sh` script to configure the shell.

2. From the command prompt, change the directory to the parent folder of the **Code Directory** specified on the Model Composer Hub dialog box when you generated the output, as discussed at [Vitis Model Composer Hub](#). For example:

```
cd C:/Data
```

3. From the command prompt, launch the `run_hls.tcl` script that can be found in C:

```
vitis_hls -f ./code/run_hls.tcl
```

Vitis HLS launches to synthesize the RTL from the C++ code, generating a Vitis HLS project, and solution in the process. You can open the Vitis HLS project by going to the **Code directory** and entering the following name with the project name:

```
vitis_hls -p ./Edge_Detection_proj
```

This will open the Vitis HLS project in the GUI Mode.

## Model Composer Log File

To help you diagnose issues related to code generation, Model Composer generates a log file, `model_composer.log`, that is written to the **Code Directory** specified on the Model Composer Hub block.

By default, Model Composer generates code for the model using a streaming micro-architecture in which blocks run concurrently via task pipelining, or dataflow. However, in some cases this streaming micro-architecture is not achievable, because the model includes an `xmcImportFunction` block that does not support streaming for example. In this case, Model Composer generates code in which the blocks operate sequentially. The Model Composer log file includes information to help you identify when this condition occurs, and what some possible causes might be.

The log file also contains information related to which blocks are used in the Model Composer model.

If **Target** on the Model Composer Hub block is set to HLS C++ code, and **Create and run testbench** is selected, the `model_composer.log` file will contain the output from running the C++ verification.

If **Target** is set to **IP Catalog** or **System Generator**, information related to running Vitis HLS is provided. In these cases, more detailed information can be found in the `vitis_hls.log` file which can also be found in the directory specified in Target directory.

---

# Simulating and Verifying Your Design

## Introduction

Verification in Model Composer can be separated into two distinct processes:

- Verification of the algorithm in Simulink® to verify the functional correctness of the design.
- Verification of the Model Composer model, to confirm the equivalence of the simulation results in Simulink and the C++ and RTL outputs.

In high-level synthesis, running the compiled C program is referred to as C simulation. Executing the C++ algorithm generated by Model Composer simulates the function and verifies that the output from the code matches the output from the Simulink simulation to validate that the algorithm is functionally correct.

In C/RTL co-simulation, Vitis HLS uses the C test bench to simulate the C function prior to synthesis and to verify the RTL output. The verification process consists of three phases:

1. The C simulation is executed and the inputs to the top-level subsystem are saved as “input vectors”.
2. The input vectors are used in behavioral simulation of the RTL code for the top-level subsystem created by Vitis HLS. The outputs from the RTL are saved as “output vectors”.

3. The output vectors are applied to the C test bench as output from the top-level subsystem, to verify the results of the C-simulation match.

Vitis HLS uses this return value for both C simulation and C/RTL co-simulation to determine if the results are correct.

## Simulating in Simulink

Simulink can interactively simulate your model, and view the results on scopes and graphical displays. The Simulink model defines what data to input at the start of simulation, and defines what data to capture during simulation.

When defining the model, you define the input and output signals for the model. Input signals load data into the model for simulation, while output signals allow you to record simulation results. The kind of data you want to load impacts your choice of signal loading techniques. You can define input data as constant values, use source blocks, such as the Sine Wave block, import data from a spreadsheet, or use the output of a previous simulation. Refer to [Prepare Model Inputs and Outputs](#) in the Simulink documentation for more information on preparing for simulation in Simulink.

After the simulation is completed, you can analyze any logged data with MATLAB scripts and visualization tools like the Simulation Data Inspector within the MathWorks environment.

When you enable the **Create and execute testbench** check box, as discussed in [Vitis Model Composer Hub](#), Model Composer performs two tasks:

1. Automatically logs the test data, or stimulus, at the input of your design, and the simulation results as test vectors for later use as "golden" data for comparison during C/C++ and RTL co-simulation. This file is named `signals.stim`, and is added to the specified **Code Directory** when generating output.
2. Executes the generated test bench and verifies equivalence of the code using C-simulation and C/RTL co-simulation. This process is compute intensive, and can take considerable time.



---

**IMPORTANT!** If the model simulation time in Simulink is long, with significant amounts of data processed, the test bench execution will take an even longer time. Model Composer will generate an error if the simulation time becomes infinite.

---

## Managing the HLS Block Cache

Model Composer creates a cache entry when you simulate a model with an imported block created using `xmcImportFunction`. When you simulate the model again, unless you make any changes to the function, or supporting source files, Model Composer will use the cached entry for the block to initiate the simulation faster. You can manage the simulation cache in Model Composer using the following command from the MATLAB command prompt:

```
>> xmcSimCache
```

The usage for this command is as follows.

Table 15: **xmcSimCache** Command Usage

Command	Description
<code>xmcSimCache('enable')</code>	Enable the simulation cache. This is enabled by default.
<code>xmcSimCache('disable')</code>	Disable the simulation cache.
<code>xmcSimCache('isEnabled')</code>	Returns the state of the simulation cache.
<code>xmcSimCache('setLocation', &lt;dir&gt;)</code>	Specify a directory to use for the simulation cache. For example:  <code>xmcSimCache('setLocation', 'C:/temp')</code>
<code>xmcSimCache('setDefaultLocation')</code>	Restore the simulation cache to its default location.
<code>xmcSimCache('getLocation')</code>	Return the current location of the simulation cache.
<code>xmcSimCache('clear')</code>	Clear the entire simulation cache.
<code>xmcSimCache('clear', 'release', &lt;version&gt;)</code>	Clear simulation cache entries for the specified release version. For example:  <code>xmcSimCache('clear', 'release', '2017.4')</code>
<code>xmcSimCache('clear', 'days', &lt;number&gt;)</code>	Clear simulation cache entries older than or equal to the specified number of days. For example:  <code>xmcSimCache('clear', 'days', 30)</code>
<code>xmcSimCache('clear', 'id', &lt;vals&gt;)</code>	Clear simulation cache entries by the cache ID. For example:  <code>xmcSimCache('clear', 'id', {'12345678', 'abcdefg'})</code>

## Verifying the C++ Code

When generating the output using the Model Composer Hub block, you also have the ability to **Create and run C simulation**. When selecting this option, you are enabling the Model Composer verification flow. This causes Model Composer to generate a few more output files, including a makefile, the test bench, `tb.cpp`, and `signals.stim` as previously discussed. The purpose of the test bench is to apply input stimuli, generated during Simulink simulation, to the top-level function of the generated C++ or RTL code and compare that function's output against the output samples captured in the `signals.stim` file. Depending on the output generated, the verification flow runs simulation on the C++ or RTL outputs generated by Model Composer and looks for the same result as generated by Simulink.

When the **Target** on the Model Composer Hub block is HLS C++ code, the verification flow is as follows:

- The model is simulated in Simulink and the input and outputs are logged into the `signals.stim` binary file.

- Model Composer generates the C++ code and a test bench, `tb.cpp`, which contains a `main()` function.
- Model Composer launches simulation.
- It verifies that the output from the generated C++ code matches the output logged from the Simulink simulation, `signals.stim`.
- In case of a mismatch, the mismatched output signal name is reported, as well as the actual and expected values.
- The result is a Pass/Fail returned by Model Composer.

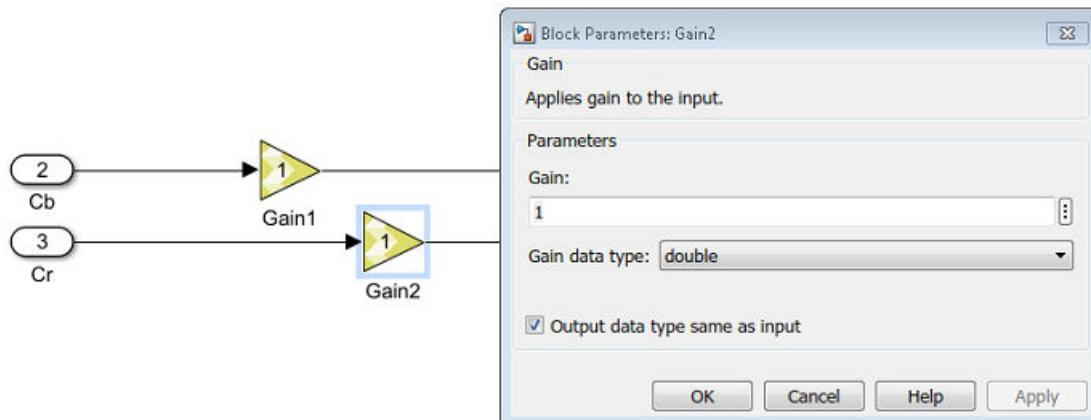


**IMPORTANT!** During simulation by Model Composer, you may receive the following error message:

Failed to find a XilinxLibrary block connected to input port.

This error simply means that there is an input in the subsystem that does not connect to a block from the HLS Library block set. This may be due to the presence of signals that you are simply passing through the subsystem for signal grouping, or improved readability. The recommended fix for this conditions is to connect the input to a Gain block from the Xilinx Toolbox → HLS → Math Functions → Math Operations block library, with the default value of 1, and Output data type same as input checked, as shown in the following figure.

Figure 165: Adding Gain to Unconnected Inputs



## Verifying the C/RTL Code

When the **Target** specified on the Block Parameters dialog box of the Model Composer Hub is either IP Catalog or System Generator, and the verification flow is enabled, Model Composer uses C/RTL co-simulation to verify the RTL output. Again, the objective is to verify that the results of the RTL simulation match the results of the Simulink simulation. In this case, the verification flow is as follows:

- The Model Composer model is simulated in Simulink to capture the test vectors in `signals.stim`.

- Model Composer generates the C/C++ code and the C test bench, `tb.cpp`.
- Model Composer runs the C-synthesis and generates the RTL output.
- Model Composer runs the C/RTL co-simulation. This step ensures the following:
  - That the C++ code generated by Model Composer is correct by comparing with the Simulink simulation, `signals.stim`.
  - That the RTL code generated by Model Composer is correct by comparing the output stimulus from RTL with C/C++ output.



**TIP:** After verification, Model Composer exports the RTL as an IP for Model Composer HDL model, or packages the IP for use in Vivado.

- The result is a separate Pass/Fail returned by Model Composer for both the C-simulation and the C/RTL co-simulation. If the C-simulation fails, the process stops before the C/RTL simulation is run.

---

## Select Target Device or Board

### Device Chooser Dialog Box

Choose the default part or platform board to use for the current project. The device resources that the design is synthesized against, and placed onto are determined by selecting the target part, board, or platform.

- **Parts tab:** Lists the available target parts for the current project.
- **Boards tab:** Lists the available target boards for the current project.
- **Platform tab:** Allows you to specify the path to a Xilinx® Platform File (`.xpfm`).



**IMPORTANT!** The devices and boards that are available are determined at the time the Vitis Model Composer tool is installed. You can also add uninstalled devices or boards. To learn more refer to Xilinx® Answer Record [60112](#).

The selection of target part or boards can be limited or filtered by specifying search patterns in one or more of the available search fields at the top of the Device Chooser dialog box.

For parts:

- **Category:** Choose devices according to Military, Automobile, or Commercial grade products.
- **Family:** Filter devices according to the available device families (such as Virtex, Kintex, or UltraScale).
- **Package:** Specify the type of package the device will have.

- **Speed:** Filter the device by a specific speed grade.
- **Temperature:** Filter the device by a specific temperature.

For boards:

- **Vendor:** Choose devices according to the available vendors of platform boards.
- **Name:** Filter devices according to the available display names.
- **Board Rev:** Specify the revision level of the board.

The target parts or boards that match the specified filters and/or search string appear in a table of results in the lower portion of the dialog box.

Choose a target part or board for the design, and click **OK**.

# AI Engine Library

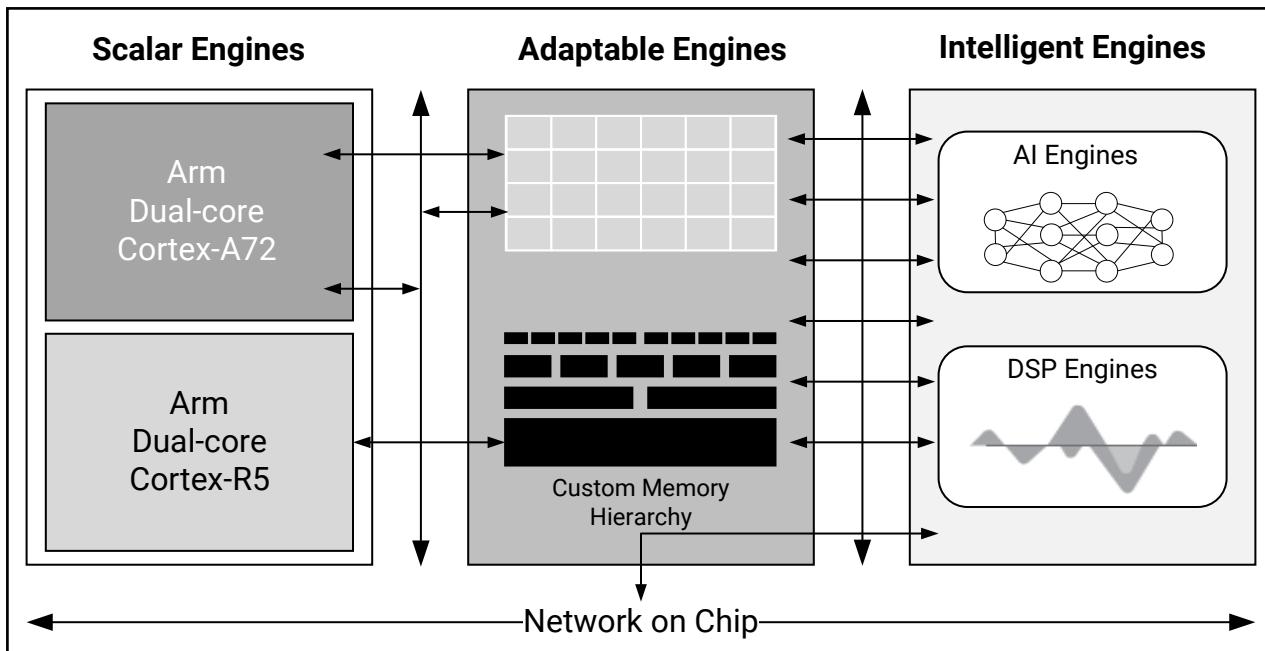
---

## Introduction

Versal® devices are the industry's first adaptive compute acceleration platform (ACAP), combining adaptable processing and acceleration engines with programmable logic and configurable connectivity to enable customized, heterogeneous hardware solutions for a wide variety of applications in Data Center, Automotive, 5G Wireless, Wired, and Defense. Versal ACAPs provide transformational features like an integrated silicon host interconnect shell and Intelligent Engines (AI and DSP), Adaptable Engines, and Scalar Engines, providing superior performance/watt over conventional FPGAs, CPUs, and GPUs.

Versal devices are built from a library of building blocks dedicated to processing, compute, acceleration, and connectivity. The following figure shows a top-level view of the Versal ACAP, that contains three major architectural areas: the Scalar Engines that include the Arm® processing system, the Adaptable Engines that include the programmable logic, and the Intelligent Engines that include the AI Engines and DSP Engines. The AI Engine along with Adaptable Engines (programmable logic) and Scalar Engines (processor subsystem) form a tightly integrated heterogeneous compute platform.

Figure 166: Xilinx Versal ACAP Overview



X24255-072120

## AI Engines

An AI Engine is an array of very-long instruction word (VLIW) processors with single instruction multiple data (SIMD) vector units that are highly optimized for compute-intensive applications, specifically digital signal processing (DSP), 5G wireless applications, and artificial intelligence (AI) technology such as machine learning (ML). They provide up to five times higher compute density for vector-based algorithms.

AI Engines provide multiple levels of parallelism including instruction-level and data-level parallelism:

- Instruction-level parallelism includes a scalar operation, up to two moves, two vector reads (loads), one vector write (store), and one vector instruction that can be executed—in total, a 7-way VLIW instruction per clock cycle.
- Data-level parallelism is achieved via vector-level operations where multiple sets of data can be operated on a per-clock-cycle basis.

Each AI Engine contains both a vector and scalar processor, dedicated program memory, local 32 KB data memory, and access to local memory in any of four neighboring directions (north, south, east, or west). It also has access to DMA engines and AXI4 interconnect switches to communicate via streams to other AI Engines or to the programmable logic (PL) or the DMA.

## Adaptable and Scalar Engines

Adaptable Engines are a combination of programmable logic blocks and memory, architected for flexible custom-compute and data movement. Scalar Engines, including Arm Cortex®-A72 and Cortex®-R5F processors, allow for complex control processing tasks.

Refer to the *Versal ACAP AI Engine Architecture Manual* ([AM009](#)) for specific details on the AI Engine array and interfaces.

Refer to the *Versal Architecture and Product Data Sheet: Overview* ([DS950](#)) for specific details on Compute and Acceleration Engines.

## AI Engine Kernels

An AI Engine kernel is a C/C++ program written using AI Engine vector data types and specialized intrinsic calls that target the VLIW vector processor. They are computational functions running on an AI Engine. These kernels form the fundamental building blocks of an AI Engine program which consists of dataflow graph specification. The AI Engine kernel code is compiled using the aiecompiler included in the Vitis™ software platform core development kit. The aiecompiler compiles the kernels to produce an ELF file that runs on the AI Engine processors.

## AI Engine Graphs

An AI Engine program consists of a dataflow graph specification written in C++. This specification can be compiled and executed using the aiecompiler. A static dataflow (SDF) graph application consists of nodes and edges where nodes represent compute kernel functions and edges represent data connections. Kernels in the application can be compiled to run on the AI Engine or in the PL region of the device.

---

## Vitis Model Composer for AI Engine Development

Vitis™ Model Composer enables the rapid simulation, exploration, and code generation of algorithms targeted for AI Engines from within the Simulink® environment. You can achieve this by importing AI Engines kernels and data-flow graphs into Model Composer as blocks and controlling the behavior of the kernels and graphs by configuring the block GUI parameters. Simulation results can be visualized by seamlessly connecting Simulink source and sink blocks with the Model Composer AI Engines blocks. Furthermore, the simulation results can be sent to the MATLAB® workspace for further analysis.

Refer to [Creating an AI Engine Design using Vitis Model Composer](#) for more information on importing AI Engine kernels and graphs as blocks.

Vitis™ Model Composer provides a set of AI Engine library blocks for use within the Simulink environment. These include:

- Blocks that support connection between the AI Engine and the Xilinx HDL blockset.
- Configurable AI Engine functions such as FIRs, FFTs, Mixers, and DDS.

**Note:** For more information on specific blocks refer to the Vitis™ Model Composer AI Engine Block library.

Connecting HLS kernel blocks, HDL library blocks, and AI Engine blocks, allows modeling and simulation of a heterogeneous platform which can be targeted to both programmable logic and AI Engines in Versal® ACAP devices.

In addition to simulation, you can also use the AI Engine Model Composer Hub to generate dataflow graphs. For more details on the AI Engine Model Composer Hub block, specific to AI Engine code generation, refer to [Code Generation](#).

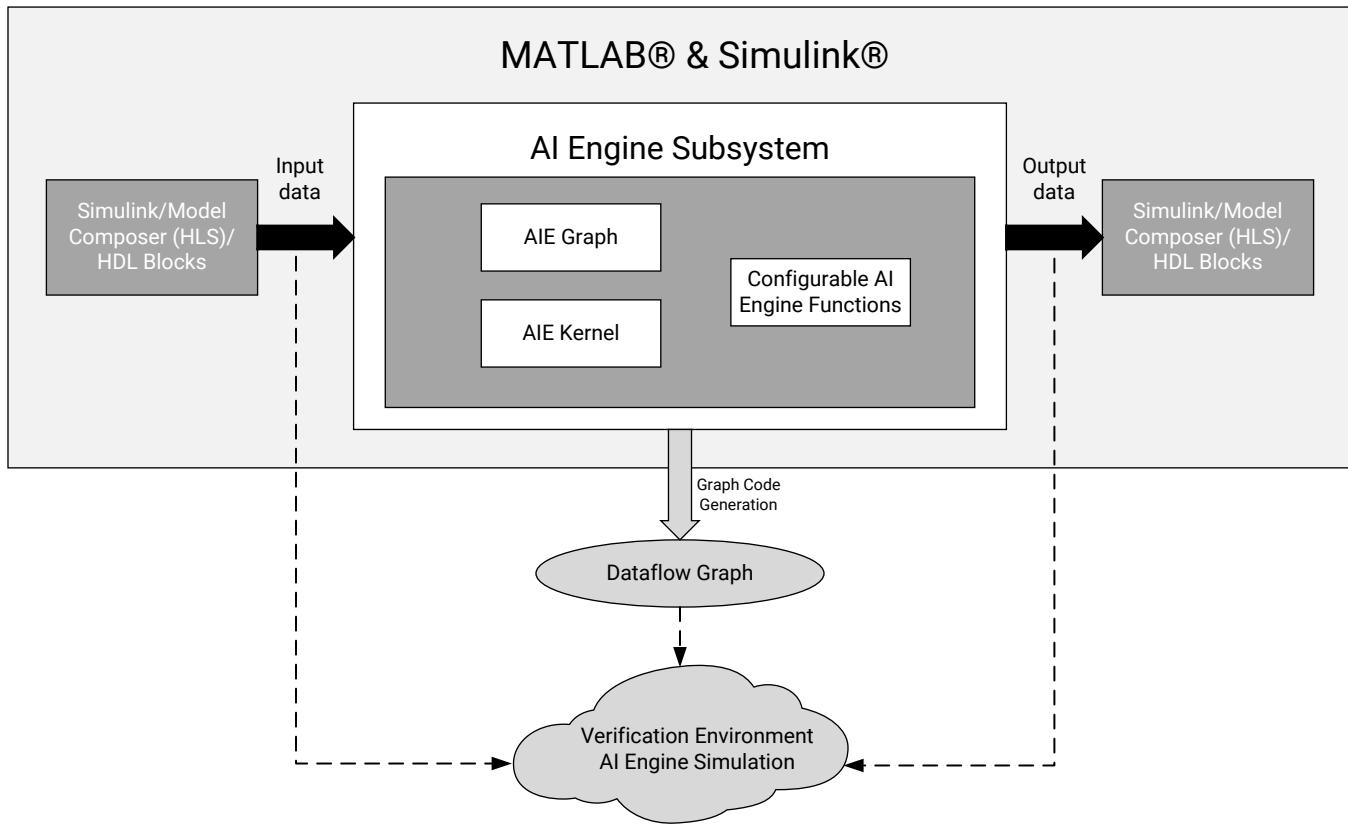
AI Engine Model composer allows you to verify the generated dataflow graph code using the AI Engine simulator. Based on verification requirements, you can choose to verify your algorithm from the Hub block.

The simulation results are compared against the reference design in the Simulink environment.

**Note:** Refer to [Simulation and Code Generation](#) for more details on simulator options and verification.

A typical AI Engine design flow is shown in the following diagram.

Figure 167: Typical AI Engine Design Flow



X25368-052521

To learn more about the AI Engine flow in Model Composer, refer to the *Vitis Model Composer Tutorial* ([UG1498](#)).

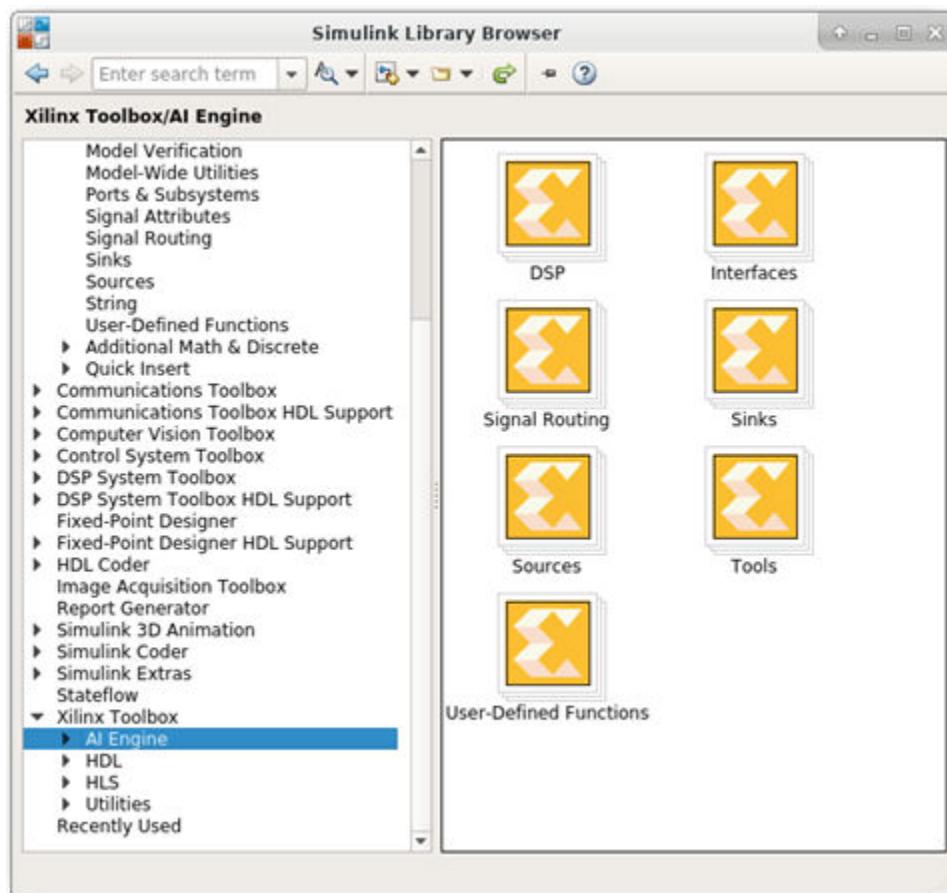
The remainder of this section discusses the following topics:

- [Creating an AI Engine Design using Vitis Model Composer](#)
- [Simulation and Code Generation](#)
- [Verification of AI Engine Code](#)

# Creating an AI Engine Design using Vitis Model Composer

As previously discussed, AI Engine kernels are functions that form the fundamental building blocks of the data-flow graph. Model Composer supports generating the AI Engine data-flow graph by importing the AI Engine kernel or sub-graph. The AI Engine library is available under Xilinx Toolbox in the Simulink library browser set as shown in the following figure.

Figure 168: Simulink Library Browser



## Preparing the Kernels

Kernels are declared as C/C++ functions that return void and can use special data types for arguments which are discussed in [Data Accessing Mechanisms](#). The kernels should be defined each in their own source file. This organization is recommended for reusability and faster compilation. Furthermore, the kernel source files should include all relevant header files to allow for independent compilation.



**IMPORTANT!** It is assumed that your kernel code is already developed. If you try to import bad kernel code, for example one that causes memory corruption, you may see undesirable outcomes including MATLAB crashing.

The topics in this section introduce some basics of AI Engine programming which are necessary to understand the Vitis Model Composer AI Engine design flow. Refer to *AI Engine Tools and Flows User Guide* ([UG1076](#)) for a high-level overview of the kernel and AI Engine programming models. Some insight is also provided on data access APIs to help you understand the configuration parameters of the AI Engine kernel blocks available in the library.

## Data Accessing Mechanisms

An AI Engine kernel can either consume or produce blocks of data, or, it can access and produce data streams in a sample-by-sample fashion. The data access APIs for both cases are described in the following sections.

### Window-Based Access

From the kernel perspective, incoming blocks of data is called an input window. Input windows are defined by the type of data contained within that window. The following example shows a declaration of an input window carrying complex integers where the real and imaginary parts are both 16 bits wide.

```
input_window_cint16 myInputWindow;
```

From the kernel perspective, outgoing blocks of data is called an output window. Again, these are defined by type. The following example shows a declaration of an output window carrying 32-bit integers.

```
output_window_int32 myOutputWindow;
```

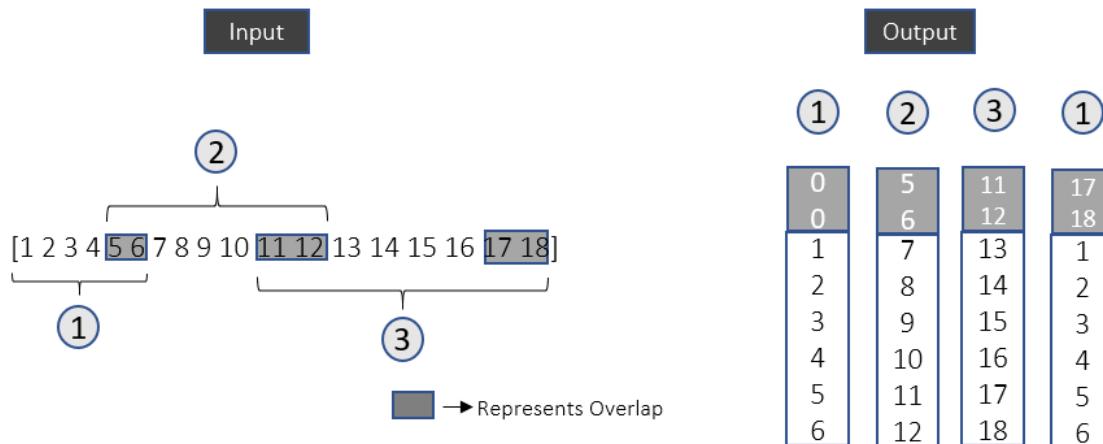
A kernel reads from its input windows and writes to its output windows. By default, the synchronization required to wait for an input window of data or provide an empty output window is performed before entering the kernel. There is no synchronization required within the kernel to read or write the individual elements of data. In other words, the kernel will not execute unless there is a full window available.

In some situations, if you are not consuming a windows worth of data on every invocation of a kernel, or if you are not producing a windows worth of data on every invocation, you can control the buffer synchronization by configuring the kernel port to be `async` in the Block Parameters dialog box of the kernel.

It is also possible to have overlap from one block of input to the next. This in general is required for certain algorithms such as filters. This overlap is referred to as 'Window Margin'. If a Window margin is specified, the kernel has access to a total number of samples equal to `window_size + margin_size`.

The behavior of the window margin can be demonstrated using the following example.

Figure 169: Simulation



Here, input is a vector of size 8 and this is fed to the kernel block which is configured to have a window size of 6 with and a window margin of 2, as shown in the previous figure. The kernel should have access to a total of 8 samples at every invocation. During the first simulation cycle, two 0's are prepended to the first 6 new values from the input data. For the subsequent simulation cycles, the kernel receives 8 values which includes 6 new values and 2 values from the previous cycle.

### Stream-Based Access

Kernels can access data streams in a sample-by-sample fashion using data access APIs. With a stream-based access model, kernels receive an input stream or an output stream of typed data as an argument. Each access to these streams is synchronized (i.e., reads stall if the data is not available in the stream and writes stall if the stream is unable to accept new data). There is also a direct stream communication channel between one AI Engine and the physically adjacent AI Engine, called a cascade.

The following example shows a declaration of input and output streams of type `cint16`.

```
input_stream_cint16 * myInputStream;
output_stream_cint16 * myOutputStream;
```

## Run-Time Parameter Specification

It is possible to modify the behavior of the AI Engine program or data-flow graph based on a dynamic condition or event using the run-time parameter. The modification could be in the data being processed, for example a modified mode of operation or a new coefficient table, or it could be in the control flow of the graph such as conditional execution or dynamically reconfiguring a graph. Either the kernels or the graphs can be defined to execute with parameters.

If an integer scalar value appears in the formal arguments of a kernel function, then that parameter becomes a run-time parameter. Run-time parameters are processed as ports alongside those created by streams and windows. Both scalar and array values can be passed as run-time parameters.

Consider the following example where a kernel function is defined with run-time parameters. Here, `select` is a scalar RTP port and `coefficients` is a vector RTP with 32 integers.

```
#ifndef RTP_KERNEL_H
#define RTP_KERNEL_H
void simple_param(input_window_cint16 * in,
                  output_window_cint16 *outw,
                  int select,
                  const int32 (&coefficients)[32]);
#endif
```

Two types of RTPs are supported:

- **Synchronous Parameters (or triggering parameters):** The kernel does not execute until the run-time parameter is written by a controlling processor. Upon a write, the kernel executes once, reading the new updated value. After completion, it is blocked from executing again until the parameter is updated. This allows for a different type of execution model from the normal streaming model, and can be useful for certain updating operations where blocking synchronization is important.
- **Asynchronous Parameters:** These parameters can be changed any time by a controlling processor such as Arm®. They are read each time a kernel is invoked without any specific synchronization. These types of parameters can be used, for example, to pass new filter coefficients to a filter kernel that changes infrequently.

## Importing AI Engine Code as a Block

Vitis Model Composer allows you import the AI Engine kernel from the AI Engine library. This allows you to create a block with an interface that has input and output ports equivalent to the arguments of an AI Engine kernel function, and also gives the flexibility to configure the kernel parameters using the Block Parameters dialog box. If you have a data-flow graph instead of an AI Engine kernel function, then Model Composer also allows you to import it into the Simulink environment from where it is possible to seamlessly connect the AI Engine graph block with AI Engine kernel block to build a complete system.

In summary, the entry point for using an AI Engine block set can be a kernel or a data flow sub-graph for which Vitis Model Composer generates a block with interfaces that match the function arguments of a kernel or a graph.

## Variable-Size Signals

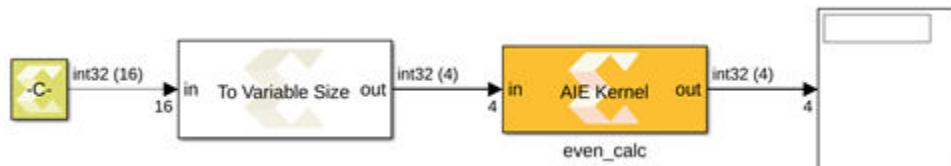
In Simulink, a signal whose size (the number of elements in a dimension) can change during Simulink simulation is called a variable-size signal. To understand the importance of variable-size signaling in the context of modeling an AI Engine design in Model Composer, consider a kernel that outputs even numbers from a set of input numbers.

```
void even_calc(input_window_int32 * in, output_stream_int32 * out) {  
    int32 val,temp;  
    for (unsigned i=0; i<4; i++) {  
        window_readincr(in,val);  
        if(val % 2 == 0) {  
            int32 temp = val;  
            writeincr(out,temp);  
        }  
    }  
}
```

Here, the input is a window of type `int32` and the output is a stream of similar type. If you try to model this in Simulink, you will observe that the number of data samples it produces may vary at each invocation.

Assume the input window size is 4 and the input given to the kernel is [1 -2 3 -4 5 -6 7 8 9 10 12 14 5 7 9 13].

Figure 170: Variable-Size Signals



To understand why the size of the output can vary dynamically, run the simulations in steps.

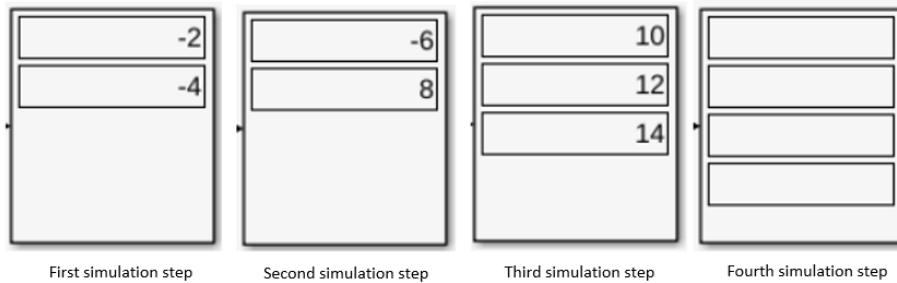
During the first simulation step, the AI Engine kernel consumes four values (i.e., 1, -2, 3, -4) and outputs two values ([ -2, -4]), which are the even numbers in the set [1, -2, 3, -4]. In the second simulation step, the kernel consumes the next set of window inputs (i.e., [ 5, -6, 7, 8]) the output is [-6, 8]. For the third set of inputs [9, 10, 12, 14], the output at the third simulation step is [10, 12, 14]. Similarly for the final set of inputs [5, 7, 9, 13], the output is empty because there are no even numbers to produce from the fourth input window.

In summary, the output size at the:

- First simulation step is 2.

- Second simulation step is 2.
- Third simulation step is 3.
- Fourth simulation step is 0.

Figure 171: Display Block - Simulation Steps



So, the kernel produces data samples of different sizes at every invocation and sometimes it does not produce any output. To model this behavior in Model Composer, you can use variable-size signals in Simulink. However, during a simulation, the number of dimensions cannot change. A variable-size signal always has an associated maximum signal size. In this case, it is 4.

The variable-size signal in Simulink is represented with a thicker signal line unlike the normal signal as highlighted in the previous figure. You can learn more about variable size signals at the following links:

- [MATLAB](#)
- [GitHub](#)

## Importing AI Engine Kernels

Vitis Model Composer supports importing C/C++ kernels functions. Function must have `void` as the return type. It also supports importing class kernels as well as templated kernels. Model Composer provides two AI Engine library blocks to import kernel functions of different types (class-based and non-class-based kernels):

- AIE Kernel
- AIE Class Kernel

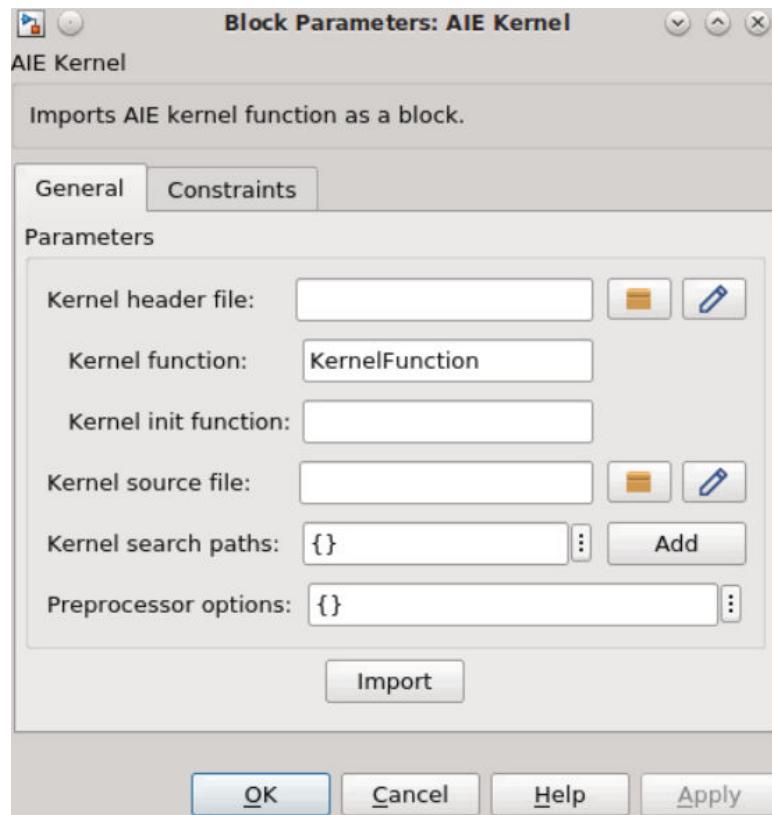
These are described in the following sections.

### Non-Class-Based Kernels

To Import a non-class-based AI Engine kernel as a block into Model Composer, you need to use an AIE Kernel block from the AI Engine Library as shown.

*Figure 172: AI Engine Kernel*

Double-clicking the block symbol displays the parameters of the AI Engine kernel block as shown in the following figure.

*Figure 173: Block Parameters Dialog Box: AIE Kernel*

The block mask parameters need to be updated in order to import the kernel function as a block. The following table provides details on the parameters and description for each parameter.

**Table 16: AIE Kernel: Parameters**

Parameter Name	Parameter Type	Criticality	Description
Kernel header file	String	Mandatory	Name of the header file that contains the kernel function declaration. The string could be just the file name, a relative path to the file, or an absolute path of the file. Use the <b>Browse</b> button to navigate to the file.
Kernel function	String	Mandatory	Name of the kernel function for which the block is to be created. This function should be declared in the kernel header file.
Kernel init function	String	Optional	Name of the initialization function used by the kernel function.
Kernel source file	String	Mandatory	Name of the source file that contains the kernel function definition. The string could be the file name, a relative path to the file or an absolute path of the file.
Kernel search paths	Vector of Strings	Optional	If the kernel header file or the kernel source file are not found using the value provided through Kernel header file or Kernel source file fields, respectively, then the paths provided through Kernel search paths are used to find the files.  This parameter allows the use of environment variables while specifying paths for the kernel header file and the kernel source file. The environment variable can be used in either \${ENV} or \$ENV format.
Preprocessor options		Optional	Optional preprocessor arguments for downstream compilation with specific preprocessor options.  The following two preprocessor option formats are accepted and multiple can be selected: -D<name> and D<name>=<definition> separated by a comma. That is, the optional argument must begin with -D and if the option <definition> value is not provided, it is assumed to be 1.

The block parameter window which appears after double-clicking on the AI Engine kernel block is same irrespective of whether the kernel is Window type or Stream type. But the function configuration parameters changes for Window and Stream type. To edit the code in the MATLAB editor, click **Edit** (immediately after the browse button).

### Importing Window-Based Kernels

As explained in [Data Accessing Mechanisms](#), the size of the input and output data blocks for window-based access depends on the specified window size. Vitis Model Composer supports the following windows-based input and output data types as interfaces to the AI Engine kernel block.

- `input_window_<Type>`
- `output_window_<Type>`

<Type>	Complexity	Signedness
int8	Real	Signed
int16	Real	Signed
int32	Real	Signed
int64	Real	Signed
uint8	Real	Unsigned

<Type>	Complexity	Signedness
uint16	Real	Unsigned
uint32	Real	Unsigned
uint64	Real	Unsigned
cint16	Complex	Signed
cint32	Complex	Signed
float	Real	N/A
cfloat	Complex	N/A

As an example, to import a simple kernel with a window-based interface, the following `simple.h` header file defines the `add_kernel` function with two input windows and one output window of type `int16`.

### Simple.h

```
#ifndef __ADD_KERNEL_H__
#define __ADD_KERNEL_H__

#include <adf.h>
#define NUM_SAMPLES 4
void add_kernel(input_window_int16 * in1, input_window_int16 * in2,
output_window_int16 * outw);

#endif
```

The kernel (`simple.cc`) is defined as follows. It processes a `sum` operation on `in1` and `in2` and produces output on `outw`.

```
#include "simple.h"
void add_kernel(input_window_int16 * in1, input_window_int16 * in2,
output_window_int16 * outw)
{
    int16 temp1,temp2,temp_out;
    for (unsigned i=0; i<NUM_SAMPLES; i++) {
        window_readincr(in1,temp1);
        window_readincr(in2,temp2);
        temp_out = temp1 + temp2;
        window_writeincr(outw,temp_out);
    }
}
```



**TIP:** Although not required, the following recommendations are useful for reusability and faster compilation.

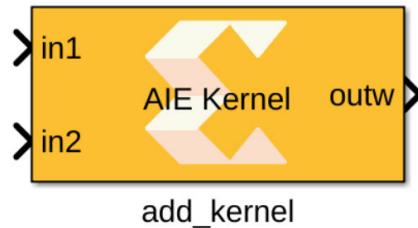
- Define each kernel in its own source file.
- Organize kernels by creating directories for header files and source files separately.
- Kernel source files should include all relevant header files to allow for independent compilation.

To import the `add_kernel` function as a block in a Model Composer design, double-click the **AIE Kernel** block and update parameters as follows:

- **Kernel header file:** kernels/include/simple.h
- **Kernel function:** add\_kernel
- **Kernel Init function:** Leave empty
- **Kernel source file:** kernels/source/simple.cc
- **Kernel search path:** Leave empty
- **Preprocessor options:** Leave empty

When you click the **Import** button in the Block Parameters dialog box, the tool parses the function signature in the header file and updates the AI Engine kernel block GUI interface as shown in the following figure.

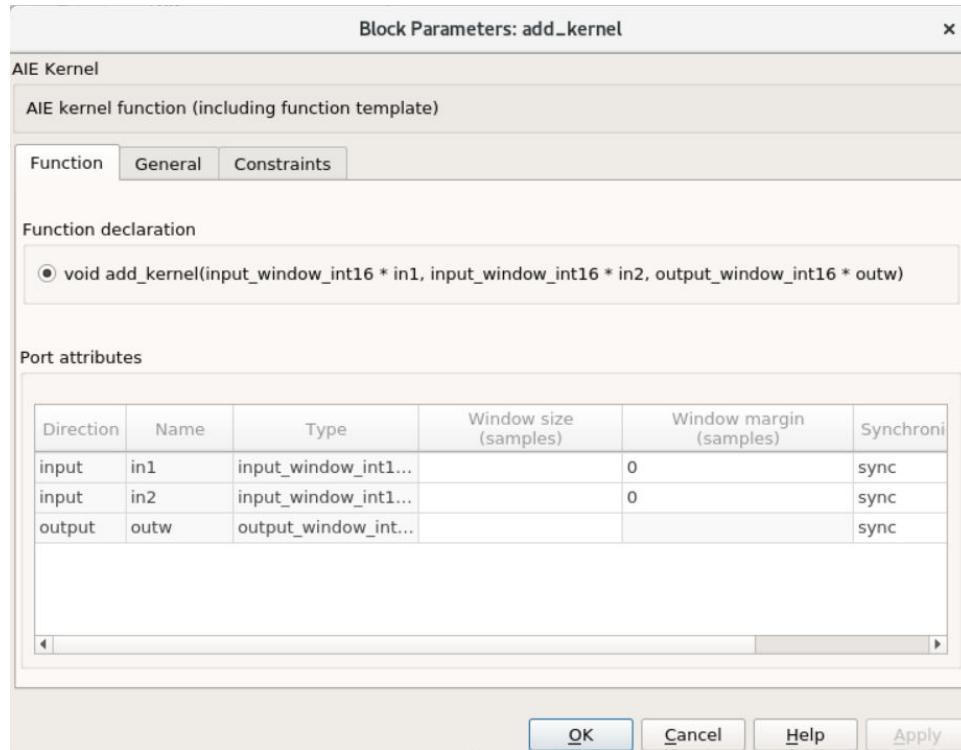
Figure 174: AIE Kernel Block (Updated)



After the AIE Kernel block is added to the Simulink editor, input and output ports are not present. But, after adding the kernel parameters in the Block Parameters dialog box, the block is updated with two input ports and one output port with block name matching the imported kernel function.

After a successful import, the Function tab displays automatically, providing user-editable configuration parameters. You can quickly review the function definition of the imported kernel function and the port names with directions.

Figure 175: Function Tab



Appropriate values should be entered in the Function tab for Window size and Window margin (see the previous figure).

## Setting the Window Margin Value

As explained in [Data Accessing Mechanisms](#), window margin is the overlapping input data samples. Model Composer accepts Window margin value in terms of the number of samples. The values given in the Window margin fields should be multiple of 32 bytes.

For example, if your input data type is `int16` which is 2 bytes. The minimum Window margin value that is accepted is 16 samples ( $16 \times 2$ ). The other values that are accepted can be 32, 48, 64 and so on.

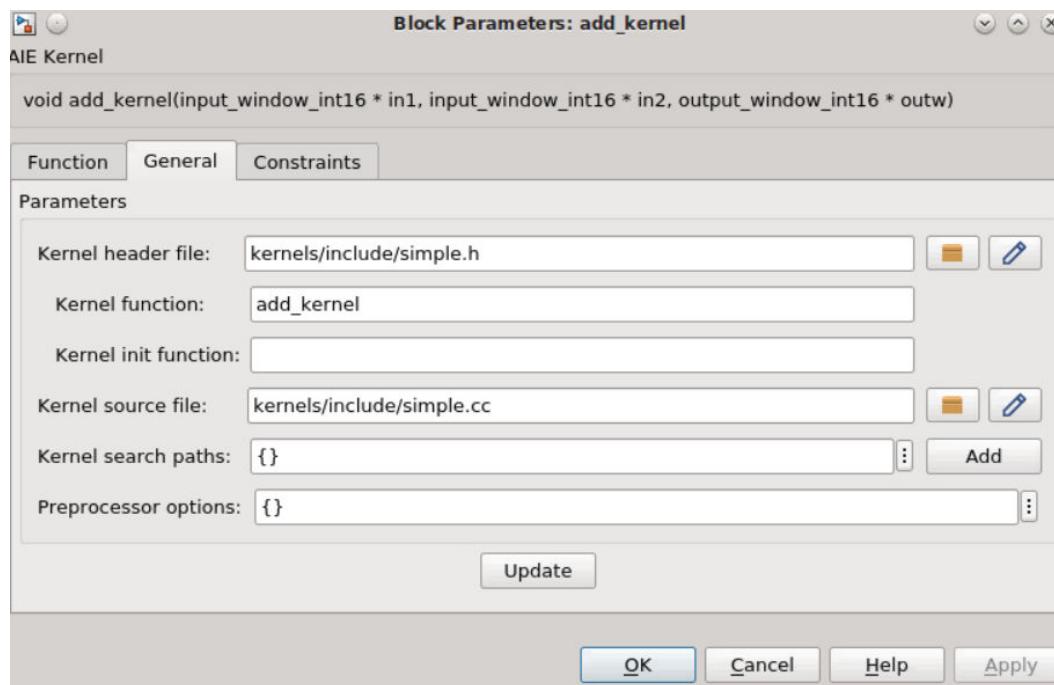
Another example. If your input is of type `c_int32` which is 8 bytes (real 4 bytes and 4 imaginary bytes). In this case the minimum window margin value that is accepted is 4. Because,  $4 \times 8$  bytes gives 32 bytes. The other values that are accepted can be 8, 12, 16, and so on.

The following table provides details on the parameters and description for each parameter.

**Table 17: Window Port Parameters**

Parameter Name	Criticality	Description
Window size	Mandatory	<ul style="list-style-type: none"><li>• Window size is required for each port (argument) of the kernel function.</li><li>• The value represents the number of samples (elements).</li><li>• The window size must be a positive integer value.</li><li>• Window size should be a multiple of 16 bytes.</li></ul>
Window margin	Mandatory	<ul style="list-style-type: none"><li>• Window margin is required for each input port (argument) of the kernel function.</li><li>• The value represents the number of samples (elements).</li><li>• The window margin must be a non-negative integer.</li><li>• The window margin should be a multiple of 32 bytes.</li></ul>
Synchronicity	Mandatory	<ul style="list-style-type: none"><li>• The Synchronicity value options available are <code>sync</code> and <code>async</code>.</li><li>• Port synchronicity is set to <code>sync</code> by default. You can optionally change it <code>async</code>.</li></ul>

After the successful import of kernel functions, the **Import** button label in the General tab changes to **Update** enabling further updates of block parameters. You can change the source code of the kernel function even after importing the block without requiring a re-import. However, if you change the function signature, or the parameters to the function, then you will need to click **Update** in the General tab to apply changes.

**Figure 176: General Tab**

## Importing Stream-Based Kernels

As explained in [Data Accessing Mechanisms](#), stream-based kernels access data streams in a sample-by-sample fashion. Vitis Model Composer supports the following stream-based input and output data types as interfaces to the AIE Kernel block.

- `input_stream_<TYPE>`
- `output_window_<TYPE>`

<Type>	Complexity	Signedness
int8	Real	Signed
int16	Real	Signed
int32	Real	Signed
int64	Real	Signed
uint8	Real	Unsigned
uint16	Real	Unsigned
uint32	Real	Unsigned
uint64	Real	Unsigned
cint16	Complex	Signed
cint32	Complex	Signed
float	Real	N/A
cfloat	Complex	N/A
accfloat	Real	N/A
caccfloat	Complex	N/A

As an example, to import a simple kernel with a stream-based interface, the following `simple.h` header file declares the `simple_comp` function with one input stream and one output stream.

```
#ifndef __COMPLEX_KERNEL_H__
#define __COMPLEX_KERNEL_H__
#include <adf.h>
void simple_comp(input_stream_cint16 * in, output_stream_cint16 * out);
#endif //__COMPLEX_KERNEL_H__
```

The function is defined in `simple.cc`.

```
#include "simple.h"
void simple_comp(input_stream_cint16 * in, output_stream_cint16 * out) {
    cint16 c1, c2;

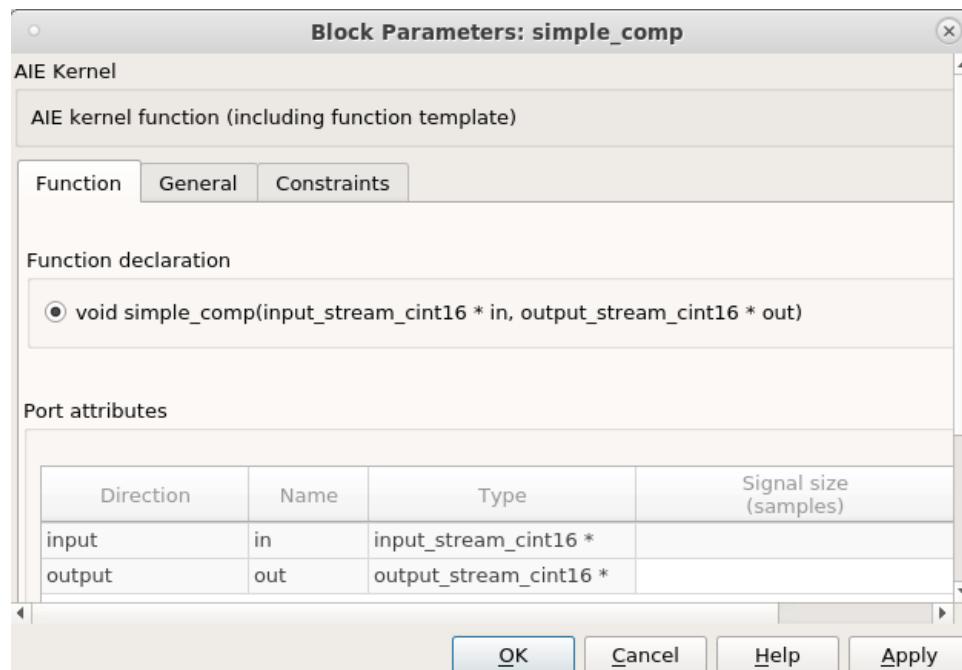
    for (unsigned i=0; i<NUM_SAMPLES; i++) {
        c1 = readincr(in);
        c2.real = c1.real+c1.imag;
        c2.imag = c1.real-c1.imag;
        writeincr(out, c2);
    }
}
```

**Note:** See the *AI Engine Tools and Flows User Guide* ([UG1076](#)) for details of the `readincr()` and `writeincr()` APIs.

Although, the function arguments for window-based and stream-based kernels are different, the procedure for importing the stream-based kernel is the same.

After a successful import, the Function tab GUI displays automatically. You can quickly review the function definition and ports as shown in the following figure.

Figure 177: Function Tab



The following table provides details on the parameters and a description for each parameter.

Table 18: Stream Port Parameters

Parameter Name	Description
Signal size	This parameter represents the size of the output signal and should be set to a value greater than or equal to the maximum number of samples that are produced during any invocation of the kernel.

In the General tab, the **Import** button changes to **Update**, enabling further updates of block parameters.

Model Composer also supports cascade stream connections between two AI Engine processors.

An AI Engine kernel can use incoming stream connections as follows:

- Input\_stream\_acc48

- Input\_stream\_cacc48

Similarly, a kernel can use the outgoing cascade stream connections as follows:

- output\_stream\_acc48
- output\_stream\_cacc48

In Model Composer, a cascade stream port is represented as a 48-bit fixed point signal ( $x\_sfix48$ ) that can be either complex or real.

Consider the following example, where a cascade output stream of one kernel is connected to the cascade input stream of another kernel.

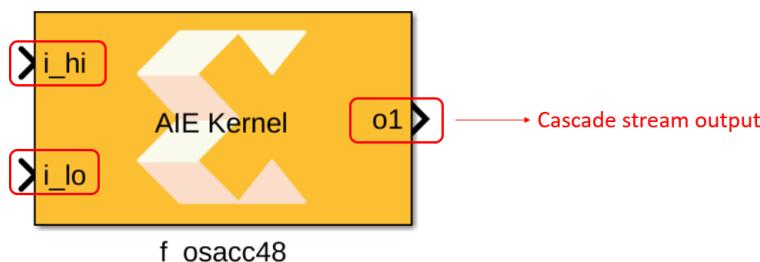
```
#ifndef __CASCADE_KERNELS_H__
#define __CASCADE_KERNELS_H__
void f_osacc48(input_window_int32 *i_hi,
                 input_window_int16 *i_lo,
                 output_stream_acc48 *o1);
#endif
```

The kernel function `f_osacc48` has two input windows: `i_hi` and `i_lo`, and one cascade stream output: `o1`.

**Note:** This kernel function includes both window-based ports and stream-based ports.

After importing this kernel function, the AIE Kernel block is as shown in the following figure.

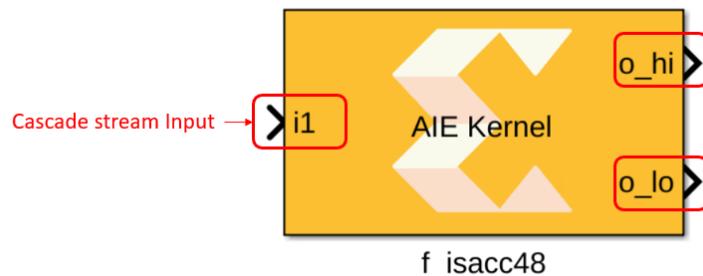
Figure 178: AIE Kernel after Import



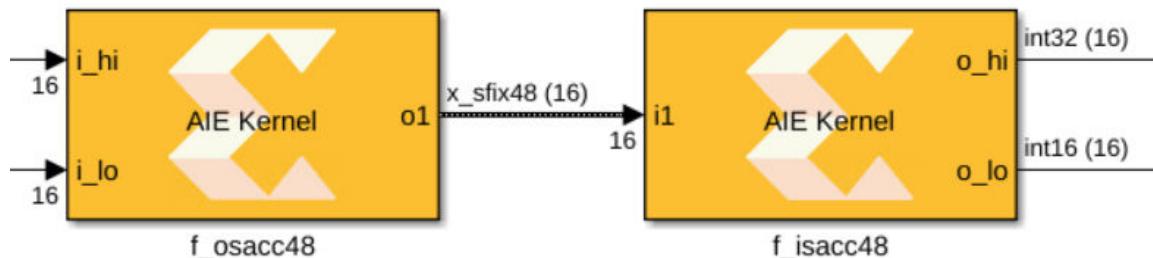
Consider another kernel function `f_isacc48`, which has one cascade stream input: `i1`, and two output windows: `o_hi` and `o_lo`.

```
#ifndef __CASCADE_KERNELS_H__
#define __CASCADE_KERNELS_H__
void f_isacc48(input_stream_acc48 *i1,
                output_window_int32 *o_hi,
                output_window_int16 *o_lo);
#endif
```

After importing the second kernel function, the AIE Kernel block is as shown in the following figure.

**Figure 179: AIE Kernel Block (Second Kernel Function)**

Now the two kernels can be connected to form a cascade connection using the cascade stream output of block `f_osacc48` and the cascade stream input of block `f_isacc48`. This is shown in the following figure.

**Figure 180: Connected Kernels (Cascade Connection)**

### Importing an AI Engine Kernel with Run-Time Parameters

Vitis Model Composer supports importing AI Engine kernels with run-time parameters in kernel functions alongside window and stream types. The following table lists the scalar data types that can be passed as run-time parameters.

<Type>	Complexity	Signedness
int8	Real	Signed
int16	Real	Signed
int32	Real	Signed
int64	Real	Signed
uint8	Real	Unsigned
uint16	Real	Unsigned
uint32	Real	Unsigned
uint64	Real	Unsigned
cint16	Complex	Signed
cint32	Complex	Signed
float	Real	N/A

<Type>	Complexity	Signedness
cfloat	Complex	N/A

Implicit ports are inferred for each parameter (scalar and vector data types) in the function argument. The following table describes the type of port inferred for each function argument.

Formal Parameter	Port Class
T	Input
Const T	Input
T &	Inout
Const T &	Input
Const T (&) [ .. ]	Input
T (&)[ .. ]	Inout

In the following example, the `simple_rtp` function has two real-time parameters. Notice the function argument `select` which is passed by value, and argument `weight` which is passed by reference.

```
#ifndef __RTP_KERNEL_H__
#define __RTP_KERNEL_H__

void simple_rtp(input_window_cint16 * in, output_window_cint16 * outw, int32
&weight, int32 select);

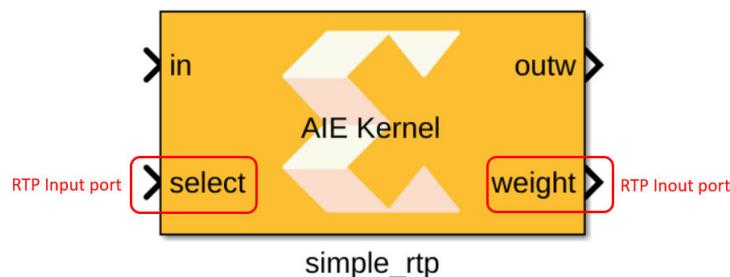
#endif //__RTP_KERNEL_H__
```

When imported for the above function, the AIE Kernel block looks as shown in the following figure. In Model Composer, the `inout` port appears as the `output` port on the AIE Kernel block.

**Note:** Model Composer ignores the `inout` RTP ports during code generation and only considers them for Simulink simulation. (i.e., they will not be read from the PS).

Because RTPs are used alongside the window and stream ports, the procedure for importing the kernel function remains the same. When the above kernel function with RTPs are imported, the AIE Kernel block looks as shown in the following figure.

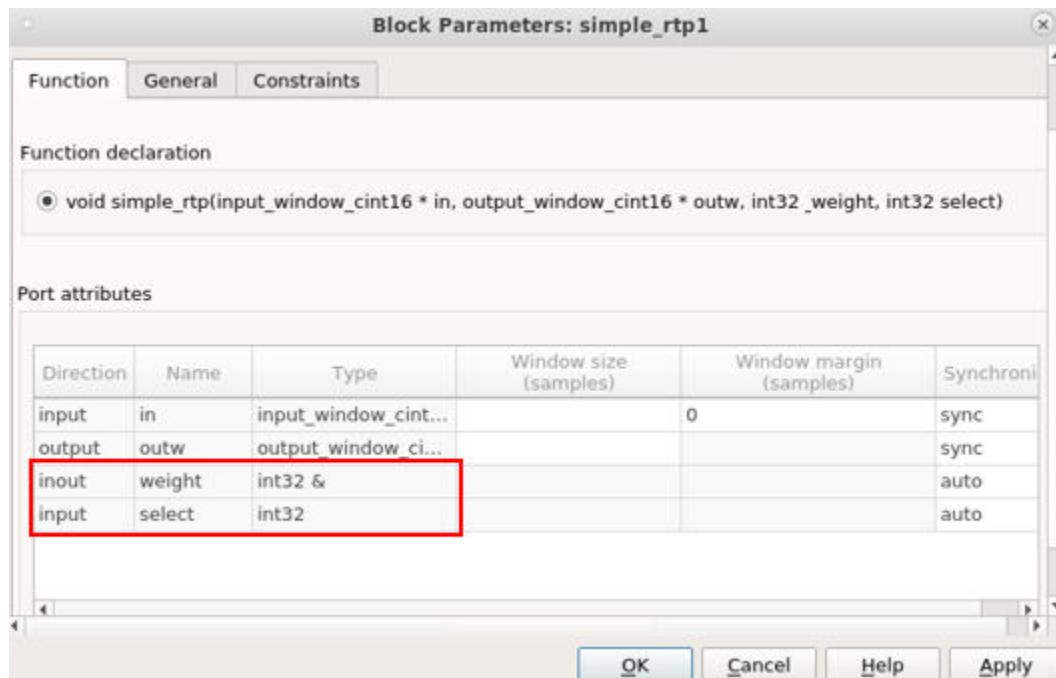
Figure 181: AIE Kernel (RTPs)



Notice that the AIE kernel block name (`simple_rtp`) is same as AI Engine kernel function name.

After a successful import, the Function tab displays automatically. You can quickly review the function definition and run-time parameter ports as shown.

Figure 182: Function Tab



Port synchronicity is the only parameter that is specific to RTPs. The following table provides details about the valid synchronicity of the Destination RTP input port with respect to the Source RTP inout port. The default port synchronicity is set to 'auto'.

Table 19: Valid Synchronicity

Source RTP Inout Port	Destination RTP input Port
auto	async
sync	auto
sync	sync
async	async

If the source RTP inout port is set to 'auto' then the destination RTP input port should be 'async'. Similarly for other combinations. Model Composer throws an appropriate error when you try to use any combination which is not specified in the previous table.

### Importing an AI Engine Kernel with Function Template

You may require a generic function that can be used for different datatypes. Using templates, you can pass a datatype as a parameter and Vitis Model Composer supports importing an AI Engine Kernel with a function template. To do this, use the same AIE Kernel block used earlier to import the ordinary C++ functions.

As an example to import the kernel function with templates, consider below header file `kernel.h`, containing the declaration of a function template. Here, the template has typename template parameter T, and a non-type (integral) template parameter N.

`kernel.h`

```
#ifndef _AIE_TEMP_KERNELS_H_
#define _AIE_TEMP_KERNELS_H_

#include <adf.h>
template<typename T, int N>
void myFunc(input_window<T> *i1,
            output_window<T> *o1
            );
#endif // ifndef _AIE_TEMP_KERNELS_H
```

The definition of the function template is in the source file `kernel.cpp` as shown below.

`kernel.cpp`

```
#include "kernel.h"

template<typename T, int N>
void
myFunc(input_window<T> *i1,
       output_window<T> *o1
       )
{
    for(int i = 0;i<8;i++)
    {
        T val = window_readincr(i1);
        val *= N;
        window_writeincr(o1, val);
    }
}
```

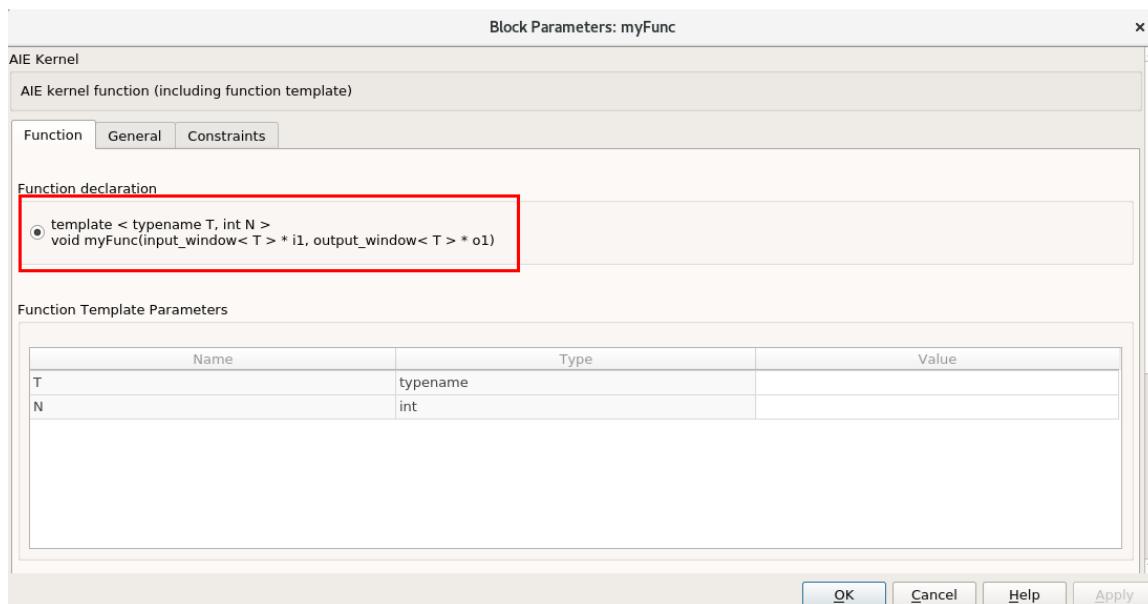
Notice the usage of the non-type template parameter 'N' in the kernel output computation. To import the template function as a block into Model Composer, double-click the AIE Kernel block and update the parameters as follows.

- **Kernel header file:** `kernels/include/kernel.h`
- **Kernel function:** `myFunc`
- **Kernel Init function:** Leave empty

- **Kernel source file:** kernels/source/kernel.cpp
- **Kernel search path:** Leave empty
- **Preprocessor options:** Leave empty

When you click the **Import** button in the Block Parameters dialog box, the **Function** tab displays automatically. Enter the values of a template type parameter 'T' and a template non-type parameter of integral type within the Function Template Parameters section as shown in the following figure. Double-click the appropriate editable field and enter the values. You can also review the declaration of the template function in the Function declaration section.

Figure 183: AIE Kernel: Function declaration Section

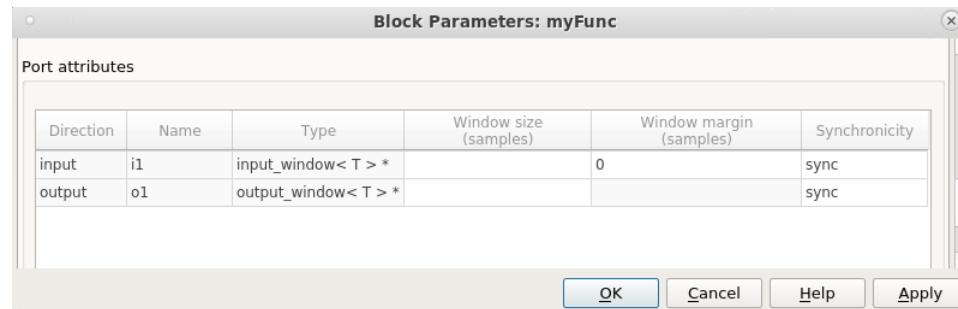


The following typenames are supported as type template parameters:

- int8, int16, int32, int64
- uint8, uint16, uint32, uint64
- float, double
- cint16, cint32, cfloat

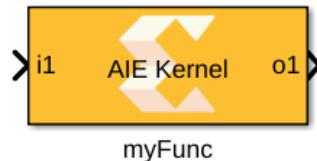
Scroll down to the Port attributes section in the Function tab and enter appropriate user-editable configuration parameters as shown.

Figure 184: AIE Kernel: Port attributes Section



After entering the appropriate values in the Function tab, click **Apply**. Notice the updated interface of the AIE kernel block GUI as shown in the following figure.

Figure 185: AIE Kernel: Updated



### Template Specialization

For cases where you want to override the default template implementation to handle a particular type in a different way, Vitis Model Composer supports template specialization. Consider the following example where a function `myFunc` has one specialized version declared to implement an `int16` datatype along with a generic template function.

#### kernel.cpp

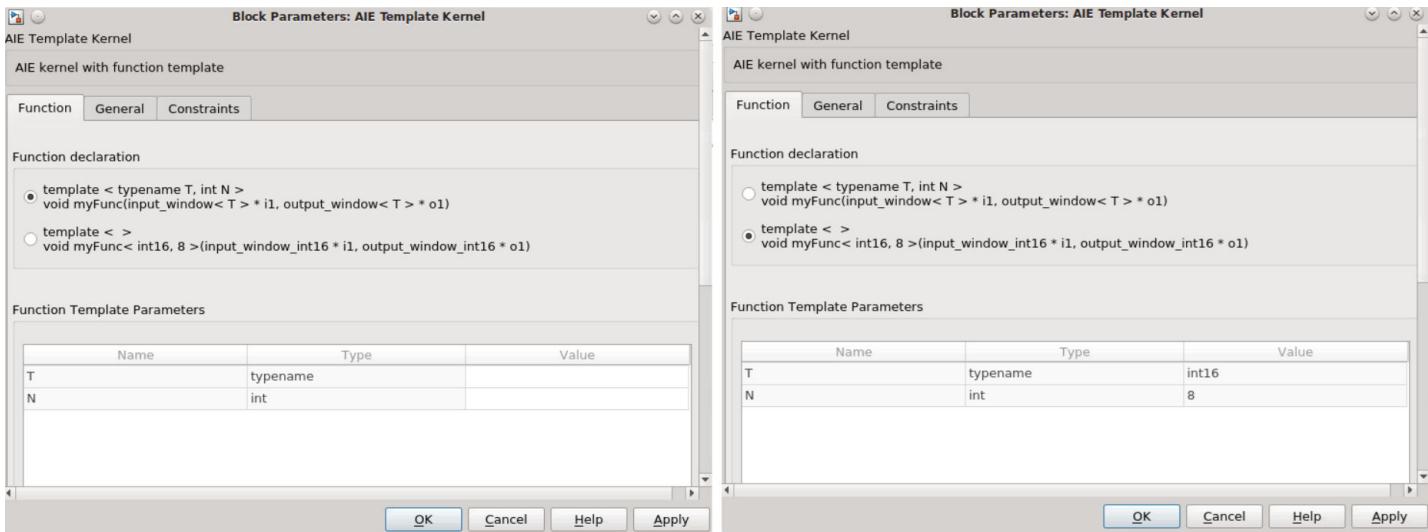
```
#ifndef _AIE_CLASS_KERNELS_H_
#define _AIE_CLASS_KERNELS_H_

#include <adf.h>
template<typename T, int N>
void myFunc(input_window<T> *i1,
            output_window<T> *o1
            );
template<>
void myFunc<int16, 8>(input_window<int16> *i1,
                      output_window<int16> *o1);

#endif
```

When you try to import the kernel `myFunc` as a block into Vitis Model Composer using the AIE Template Kernel block, the Function tab in the block GUI parameter looks as shown. If you select the function variant corresponding to the base template, the Function Template Parameters table shows the values corresponding to that. If you select the specialization variant instead, the table shows the values of the template parameters of that specialization. You cannot change these values.

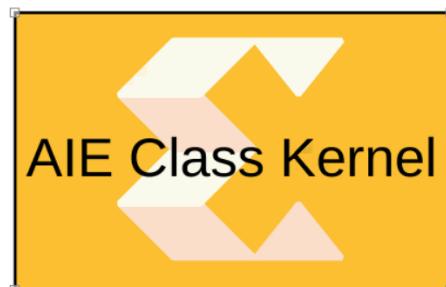
Figure 186: AIE Template Kernel: Functional declaration Options



## Class-Based Kernels

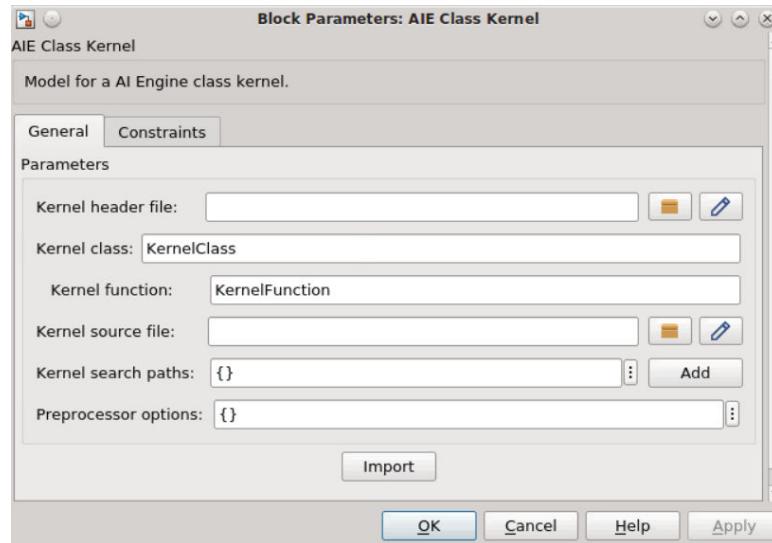
Vitis Model Composer supports importing the C++ kernel class to have constructor parameters for specifying parameter values. You need to use an AIE Class Kernel block from the AI Engine Library as shown.

Figure 187: AIE Class Kernel



## AIE Class Kernel

Double-clicking the block symbol displays the parameters of the AI Engine class kernel block as shown in the following figure.

**Figure 188: AIE Class Kernel: Block Parameters**

The block mask parameters need to be updated in order to import the kernel function as a block. The following table provides details on the parameters and description for each parameter.

**Table 20: AIE Class Kernel: Parameters**

Parameter Name	Parameter Type	Criticality	Description
Kernel header file	String	Mandatory	Name of the header file that contains the kernel class and registerKernelClass method declarations. The string could be just the file name, a relative path to the file or an absolute path of the file. Use the browse button to select the file. This field does not accept environmental variables.
Kernel class	String	Mandatory	Name of the kernel class which contains member variables and kernel member function.
Kernel function	String	Mandatory	Name of the kernel member function for which the block is to be created. This function should be registered using the registerKernelClass method in kernel header file.
Kernel source file	String	String	Name of the source file that contains the kernel member function definition and non-default constructor parameter values are specified. The string could be the file name, a relative path to the file or an absolute path of the file. This field does not accept environmental variables.
Kernel search paths	Vector of Strings	Optional	If the kernel header file or the kernel source file are not found using the value provided through the Kernel header file or Kernel source file fields, respectively, then the paths provided through Kernel search paths are used to find the files. This parameter allows use of environment variables while specifying paths for the kernel header file and the kernel source file. The environment variable can be used in either \${ENV} or \$ENV format.

Table 20: AIE Class Kernel: Parameters (cont'd)

Parameter Name	Parameter Type	Criticality	Description
Preprocessor options		Optional	Optional preprocessor arguments for downstream compilation with specific preprocessor options. The following two preprocessor option formats are accepted and multiple can be selected: -D<name> and -D<name>=<definition> separated by a comma. That is, the optional argument must begin with -D and if the the option <definition> value is not provided, it is assumed to be 1.

The AIE Class Kernel block supports all the kernel functions that a normal AI Engine kernel block can support and the Block Parameters dialog box which appears after double-clicking on the AI Engine class kernel block is the same irrespective of whether the kernel member function is Window-based or Stream-based. To edit the header file or source file, you can click the **Edit** button (immediately after the browse button).

### Kernel Class with Default Constructor

As an example, to import the C++ class kernel with the default constructor, consider the following `simple.h` header file that defines the kernel class `simple_class` with the default constructor.

```
simple.h

#include "adf.h"

class simple_class
{
private:
    int16 val;
    int16 numSamples;

public:
    simple_class();

    void mulBytwo(input_window_int16* in, output_window_int16* out);

    static void registerKernelClass()
    {
        REGISTER_FUNCTION(simple_class::mulBytwo);
    }
};
```



**RECOMMENDED:** It is highly recommended to define the body of the kernel and class constructors in `.cpp` file.

It is necessary to register the kernel function using the `registerKernelClass()` method. More than one class kernel can be declared in a header file and each class should contain separate `registerKernelClass()` methods. Only one function can be registered per class and Vitis Model Composer can import only functions that are registered using `REGISTER_FUNCTION()`.

The Kernel function is defined in `simple.cpp` as shown below.

#### `simple.cpp`

```
#include "simple.h"

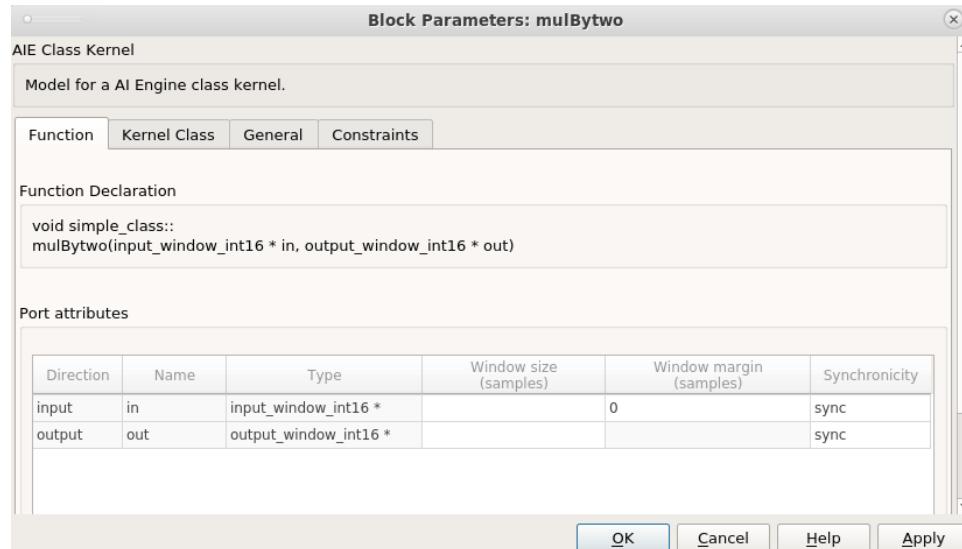
simple_class::Simple_class()
{
    val = 24;
    numSamples = 8;
}

void simple_class::mulBytwo(input_window_int16* in, output_window_int16*
out)
{
    for (int i=0; i<numSamples; i++)
    {
        int16 value = window_readincr(in);
        window_writeincr(out, (in*2)+val);
    }
}
```

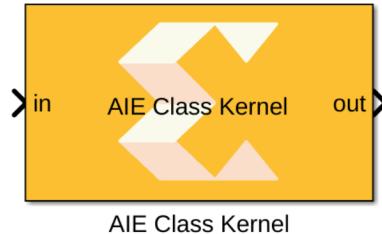
To import the `mulBytwo` function as a block in a Model Composer design, double click the AIE Class Kernel block and update the parameters as follows.

- **Kernel header file:** `kernels/include/simple.h`
- **Kernel class:** `simple_class`
- **Kernel function:** `mulBytwo`
- **Kernel source file:** `kernels/source/simple_kernel.cpp`
- **Kernel search path:** Leave empty
- **Preprocessor options:** Leave empty

Click the **Import** button in the Block Parameters dialog box. After successful import, the Function tab displays. This provides user-editable configuration parameters as shown in the following figure.

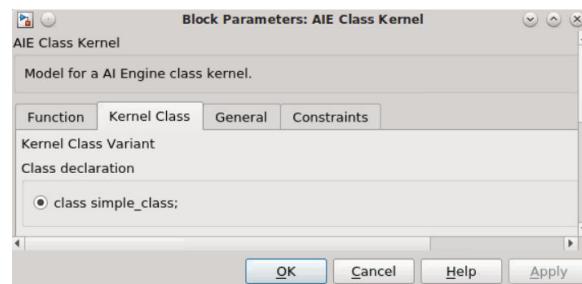
*Figure 189: AIE Class Kernel: Block Parameters*

After entering the appropriate values in the Function tab, click **Apply** to see the updated interface of the AIE Class Kernel block GUI as shown.

*Figure 190: AIE Class Kernel after Update*

You can quickly review the function declaration of the imported kernel function and the port names with directions, from the Function tab.

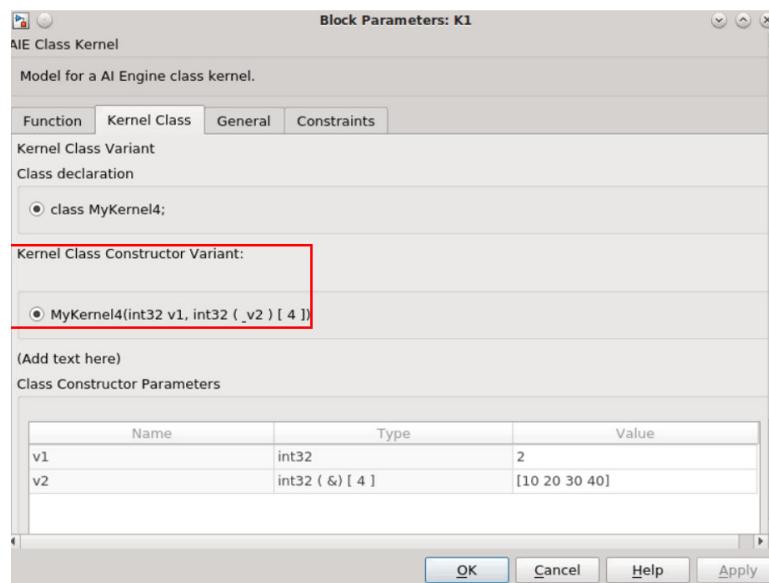
Click the **Kernel Class** tab to observe the class declaration as shown in the following figure.

*Figure 191: Kernel Class Tab: Class Declaration*

### Class Kernels with Parameterized Constructors

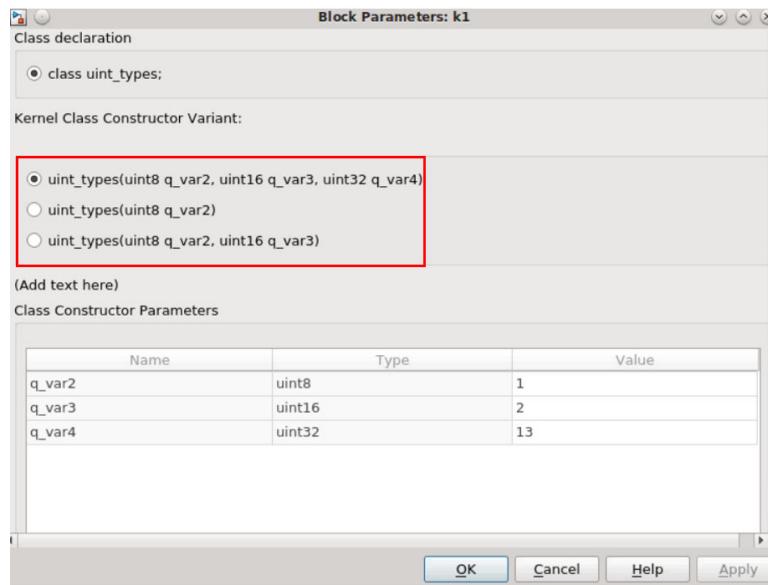
Default constructors do not take any arguments and have no parameters. However, it is possible to pass arguments to the constructors and Vitis Model Composer supports importing the class kernels with parameterized constructors. Both scalar and vector arguments can be passed to constructors. You can assign values to these parameters from the **Kernel Class** tab in the AI Engine Class Kernel block as shown in the following figure. You can also observe the parameterized constructor declaration in Kernel Class Constructor Variant section.

Figure 192: Kernel Class: Parameter Values



If you have multiple variants of Kernel Class Constructors, you can choose one of them and pass values to the constructor arguments accordingly.

Figure 193: Kernel Class: Multiple Values



### Constructor with Reference to an Array

Consider the following example that declares the constructor with reference to an array as argument.

#### fir.h

```
class FIR
{
private:
    int32 (&coeffs)[NUM_COEFFS];
    int32 tapDelayLine[NUM_COEFFECTS];
    uint32 numSamples;
public:
    FIR(int32(&coefficients)[NUM_COEFFECTS], uint32 samples);
    void filter(input_window_int32* in, output_window_int32* out);
    static void registerKernelClass()
    {
        REGISTER_FUNCTION(FIR::filter);
        REGISTER_PARAMETER(coeffs);
    }
};
```

#### fir.cpp

```
#include "fir.h"
FIR::FIR(int32(&coefficients)[NUM_COEFFECTS], uint32 samples)
: coeffs(coefficients)
{
    for (int i = 0; i < NUM_COEFFECTS; i++)
        tapDelayLine[i] = 0;
    numSamples = samples;
```

```
    }
void FIR::filter(input_window_int32* in, output_window_int32* out)
{
    ...
}
```

Here, member variable `coeffs` is an `int32 (&)[NUM_COEFFS]` data type. The constructor initializer `coeffs(coefficients)` initializes `coeffs` to the reference to an array allocated externally to the class object. To let the aiecompiler know that the `coeffs` member variable is intended to be allocated by the compiler, you must use `REGISTER_PARAMETER` to register an array reference member variable inside the `registerKernelClass()` method. The aiecompiler throws an appropriate error if the constructors with reference to an array are not registered.

### Kernel with Class Templates

You may require a class implementation that remains the same for all classes but the data types vary. Vitis Model Composer supports importing the kernels with class templates using the AIE Class Kernel block. Consider the following example which declares the class template in `kernel.h`.

```
kernel.h

#ifndef _AIE_CLASS_KERNELS_H_
#define _AIE_CLASS_KERNELS_H_
#include <adf.h>

template<typename T, int N>
class MyKernel {
    int m_count;
public:
    MyKernel();
    void myFunc(input_stream<T> *i1,
                output_stream<T> *o1,
                output_stream<int> *o2);

    static void registerKernelClass()
    {
        REGISTER_FUNCTION(MyKernel::myFunc);
    }
};

#endif
```

In this case, the default constructor initializer `m_count(N)` initializes `m_count` with template parameter `N` as shown in the following `kernel.cpp` code.

`kernel.cpp`

```
#include "kernel.h"

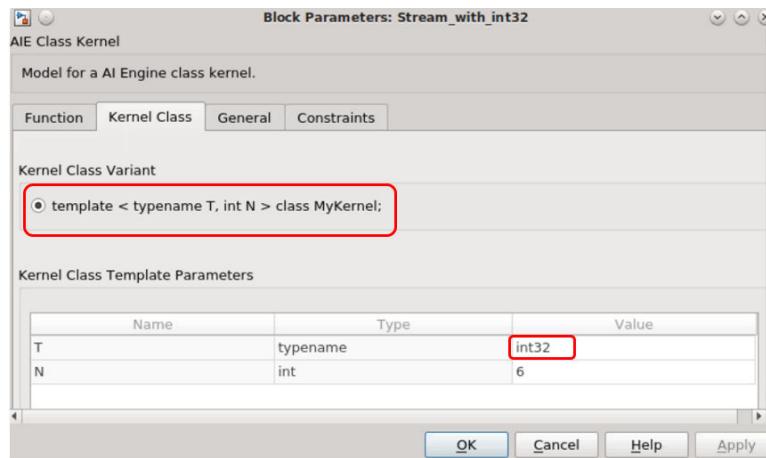
template<typename T, int N>
MyKernel<T,N>::MyKernel()
: m_count(N)
```

```
{  
}  
  
template<typename T, int N>  
void  
MyKernel<T,N>::myFunc( input_stream<T> *i1,  
                        output_stream<T> *o1,  
                        output_stream<int> *o2)  
{  
    put_ms(0, get_ss(0) * N);  
    ++m_count;  
    writeincr(o2, m_count);  
}
```

After successfully importing the kernel with class template using the AIE Class Kernel block, the Function tab displays. Here you can enter appropriate values in the user-editable configuration parameters. Click **Apply** to see the updated interface in the Block Parameters dialog box the AIE Class Kernel block.

Redirect to the **Kernel Class** tab in the Block Parameters dialog box to review the template class declaration from the kernel class variant. In the **Kernel Class** tab, you can enter the value of a template type parameter 'T' and a template non-type parameter of integral type as shown.

Figure 194: Kernel Class Template



### IMPORTANT!

1. Template type parameters can be any valid window, stream, or RTP datatypes.
2. Only a value that has an integral type is supported for template non-type parameters.
3. MATLAB variables can be used to specify non-type template parameters.

## Template Specialization

For cases when you need to override the default template implementation to handle a particular type in a different way, Vitis Model Composer supports template specialization. Consider the following example where a class `MyClass` has two different interfaces than the generic `MyClass`. One specialized version is declared to implement the `cint16` datatype and other version to implement the `uint32` datatype.

**template\_specialization.h**

```
#include <adf.h>
template<typename T,int N>
class MyClass
{
};

template<>
class MyClass<cint16,1> {
    int m_count;
    int16 var_1;
    int16 var_2;
    int16 var_3;
    uint16 var_4;
public:
    MyClass();
    MyClass(int16 q_var1,int16 q_var2,int16 q_var3,uint16 q_var4);
    MyClass(int16 q_var1,int16 q_var2);
    MyClass(int16 q_var1,int16 q_var2,int16 q_var3);

    void func_mem(input_stream<cint16> *i1,
                  output_stream<cint16> *o1,
                  output_stream<int> *o2);

    static void registerKernelClass()
    {
        REGISTER_FUNCTION(MyClass::func_mem);
    }
};

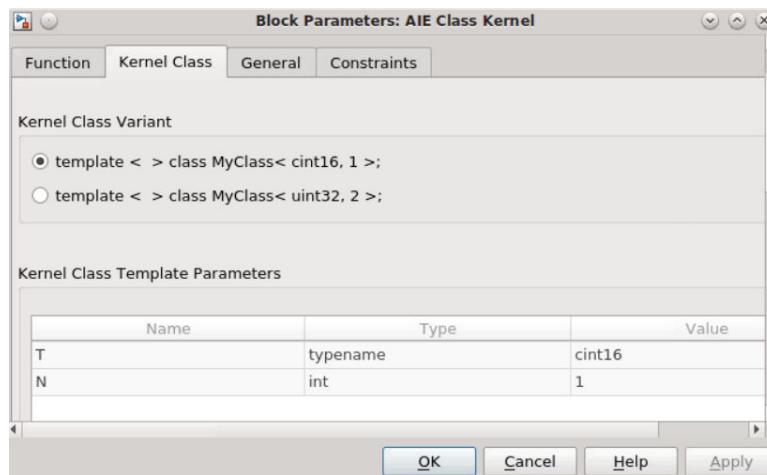
template<>
class MyClass<uint32,2> {
    int m_count;
    int16 var;
public:
    MyClass(uint32 q_var1);

    void func_mem(input_stream<uint32> *i1,
                  output_stream<uint32> *o1,
                  output_stream<int> *o2);

    static void registerKernelClass()
    {
        REGISTER_FUNCTION(MyClass::func_mem);
    }
};
```

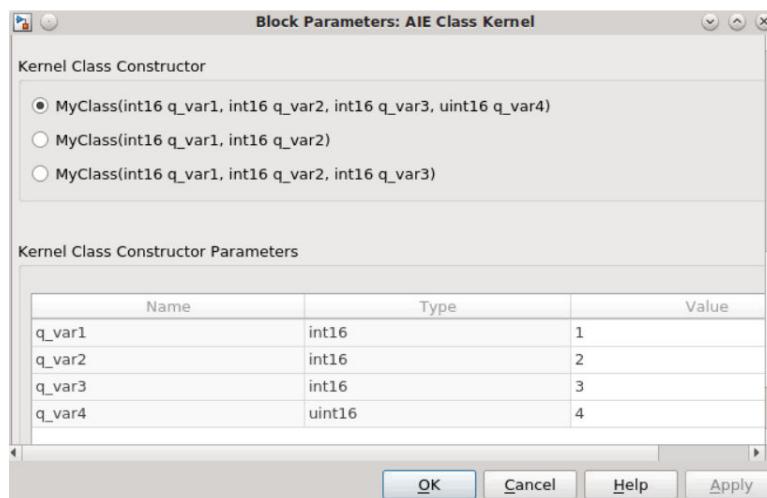
You can see that two functions are registered separately in two specialized classes. When you try to import the kernel `func_mem` as a block into Model Composer using the AIE Class kernel block, the **Kernel Class** tab in block GUI parameters looks as shown.

Figure 195: Class Variant



After selecting one of the Kernel Class Variants from the list, the Class Template Parameters update accordingly. The list of Kernel Class Constructors for the corresponding class variant, is updated and you can select from the list (see the following figure).

Figure 196: Kernel Class Constructors



**Note:** MATLAB variables can be used to specify the values of Kernel Class Constructor Parameters.

## Template Partial Specialization

For cases where you write a template that specializes one template parameter and still allows some parameterization, you can use the template partial specialization. Vitis Model Composer allows you to import the class kernels with partial specialization using the AIE Class Kernel block. Consider the following example where a class `class_a` is partially specialized with a non-type template parameter.

**partial\_specialization.h**

```
#include <adf.h>
template<typename T,int N>
class class_a
{
};

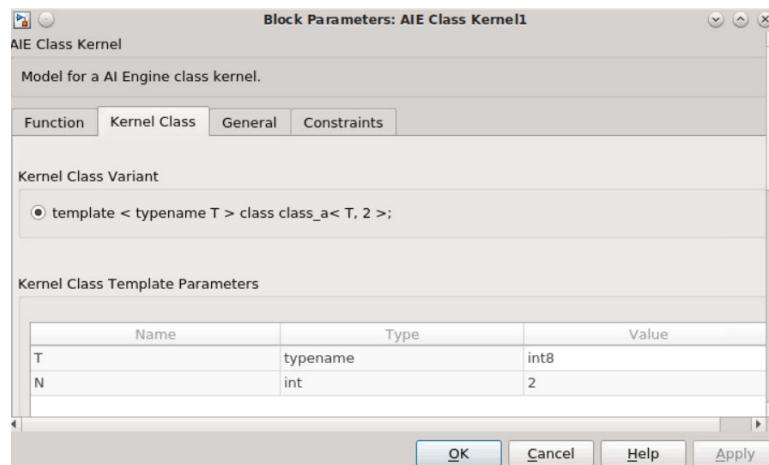
template<typename T>
class class_a<T,2> {
    int m_count;
    T var;
public:
    class_a(T q_var1);

    void func_mem(input_stream<T> *i1,
                  output_stream<T> *o1,
                  output_stream<int> *o2);

    static void registerKernelClass()
    {
        REGISTER_FUNCTION(class_a::func_mem);
    }
};
```

Notice that the function `func_mem` is registered in `registerKernelClass()` method. When you try to import the kernel function as a block into Model Composer using the AIE Class Kernel block, the Kernel Class tab in the Block Parameters dialog box looks as shown.

**Figure 197: Block Parameters: AIE Class Kernel**



Because the class is partially specialized with a non-type template parameter, you cannot edit the parameter 'N' from the Kernel Class Template Parameters. However, the value of the template type parameter can be modified to any valid datatype.

## Kernels with Namespaces

Vitis Model Composer supports importing kernels declared in a namespace. For both templated and non-templated kernels you need to qualify the kernel function with the namespace.

Consider the following examples where the non-templated kernel function is qualified with the namespace ns1 and templated kernel function is qualified with the namespace ns2.

### Kernel.h

```
namespace ns1 {  
void myFunc_1(input_stream<int32> * restrict i1,  
              output_stream<int32> * restrict o1);  
} // namespace ns1
```

### templateKernel.h

```
namespace ns2 {  
template<typename T,int size>  
void myFunc_2(input_stream<int32> * restrict i1,  
              output_stream<int32> * restrict o1);  
} // namespace ns2
```

To import the above functions using the AIE Kernel and AIE Template Kernel blocks, the Kernel function parameter in the Block Parameters dialog box should be updated as follows:

- **Kernel function:** ns1::myFunc\_1 (Non-templated function)
- **Kernel function:** ns2::myFunc\_2 (Templated function)

If you have a class kernel declared in a namespace, then only the kernel class field should be qualified, and not the kernel function.

For example, consider the following kernel class which is qualified with the namespace ns3.

```
class_kernel.h  
  
namespace ns3 {  
#include "adf.h"  
  
class simple_class  
{  
private:  
    int16 val;  
    int16 numSamples;  
  
public:  
    simple_class();
```

```
void func_q(input_window_int16* in, output_window_int16* out);

static void registerKernelClass()
{
    REGISTER_FUNCTION(simple_class::func_q);
}
};

} // namespace ns3
```

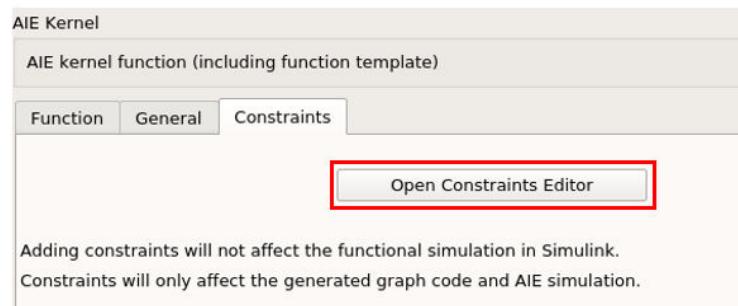
To Import the kernel function `func_q` as a block, the Kernel class and Kernel function parameters in the AIE Class Kernel block should be updated as follows:

- **Kernel class:** `ns3::simple_class`
- **Kernel function:** `func_q`

## Specifying Constraints

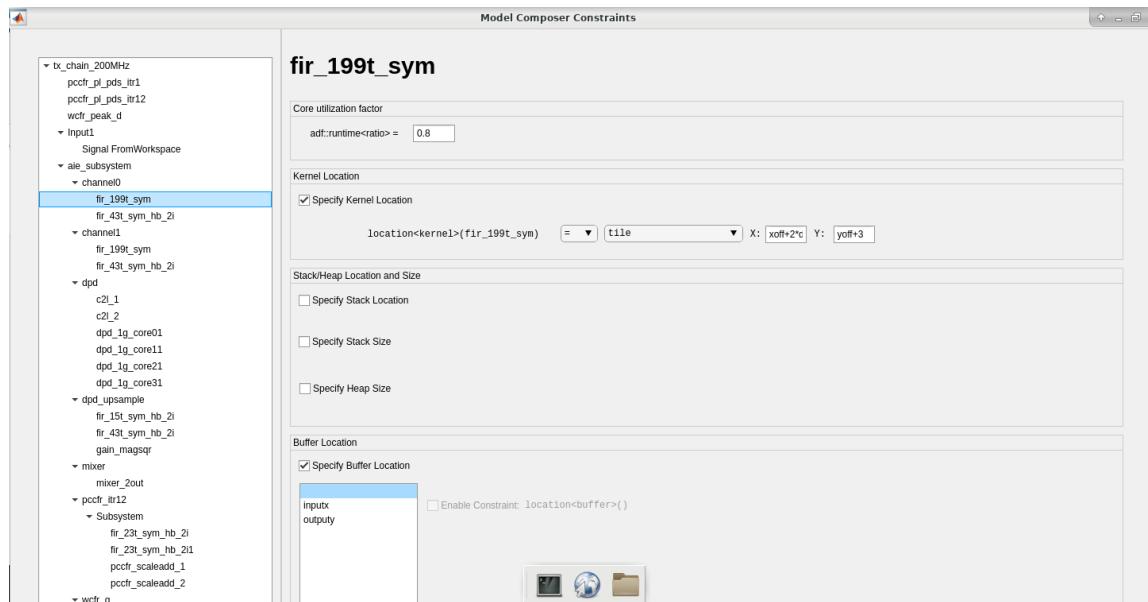
Constraints are user-defined properties for graph nodes which provide additional information to the compiler. Vitis Model Composer provides a mechanism to specify these constraints from within the kernel import or graph import blocks in the AI Engine library. During graph code generation, all these constraints automatically appear inside the graph code. The following figure shows the Constraints tab of the AIE Kernel block highlighting the Open Constraints Editor button in it.

Figure 198: Constraints Tab



Clicking **Open Constraints Editor** opens the Vitis Model Composer Constraints dialog box. Here you can specify various constraints such as core utilization factor, kernel location, buffer location, stack/heap location, and size as shown in the following figure.

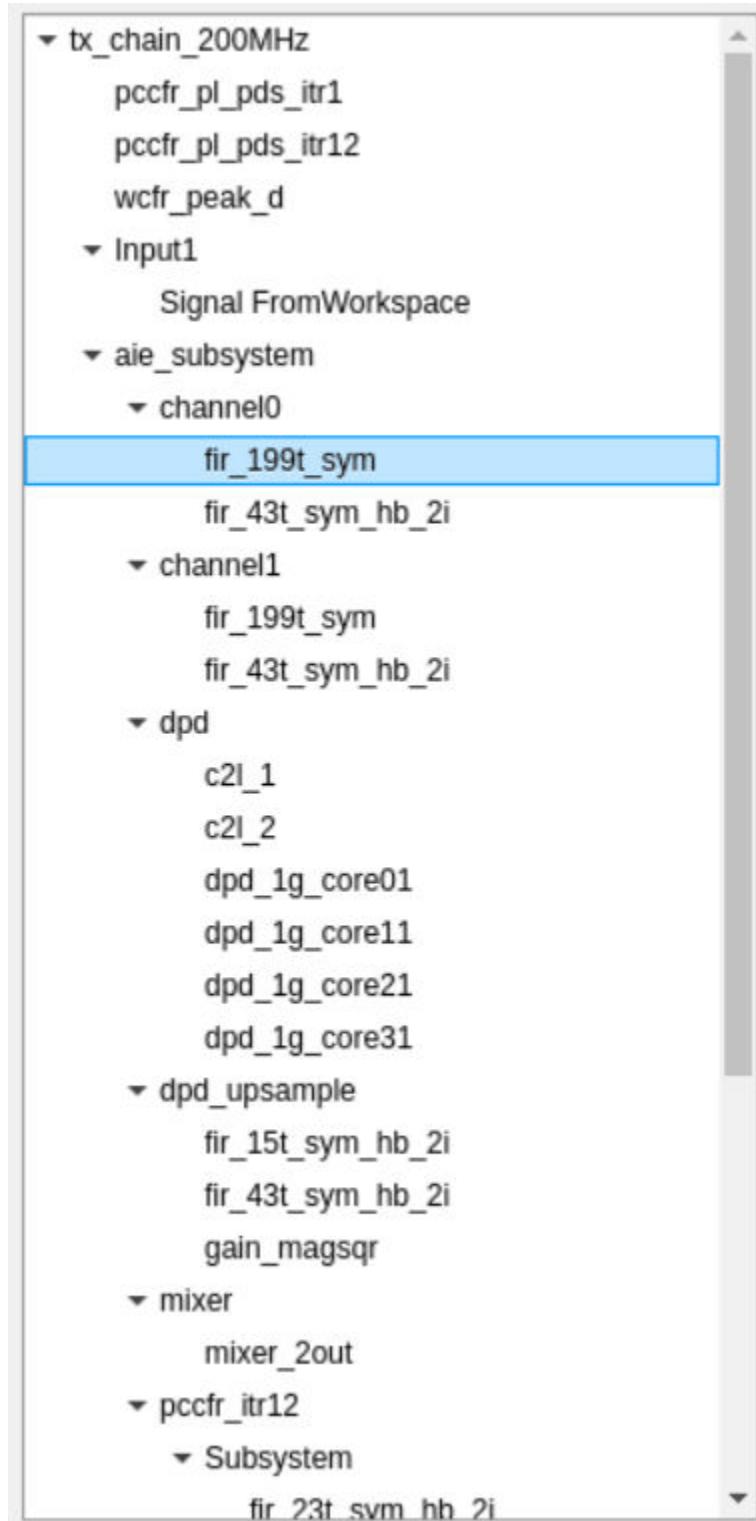
Figure 199: Model Composer Constraints Dialog Box



A similar constraints tab is available for all blocks in the Xilinx Toolbox/AI Engine/User-Defined Functions library and the constraint editor reflects the constraints available for that particular block. Adding these constraints will not affect Simulink simulation as they are only used for generating the graph code and AIE simulation.

When you open the constraints editor from any particular kernel/graph import block, the Model Composer Constraints dialog box allows you to specify the constraints for that particular kernel. However, you can switch between all the kernels/graphs available in your design from the navigation panel on the left side and specify the constraints accordingly as shown in the following figure. In this way, you can avoid opening each kernel/graph block separately to specify constraints.

Figure 200: Navigation Panel in Constraints Editor



The remainder of this section discusses the types of constraints that Vitis Model Composer supports.

### Core utilization factor (runtime<ratio>)

The core utilization factor ratio is specified as the ratio of the function run time compared to the cycle budget and must be between 0 and 1. The cycle budget is the number of instruction cycles a function can take to either consume data from its input or to produce a block of data on its output.

You can specify the core utilization factor in the Model Composer Constraints editor window as shown.



### Kernel Location

When building large graphs with multiple subgraphs, it is sometimes useful to control the exact mapping of kernels to AI Engines, either relative to other kernels or in an absolute sense. Specifying location constraints provides a powerful mechanism to create a robust, scalable, and predictable mapping of your graph onto the AI Engine array. It also reduces the choices for the mapper to try, which can considerably speed up the mapper.

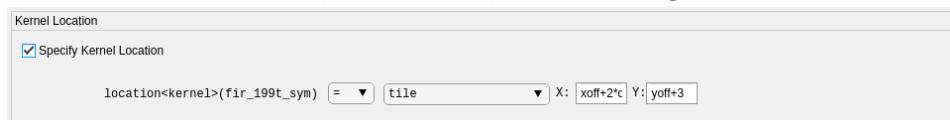
The kernel location constraint can be specified from the Model Composer Constraints editor window as shown.

- By default, the option **Specify Kernel Location** is deselected. Enable this to specify the constraint.



You can choose to either:

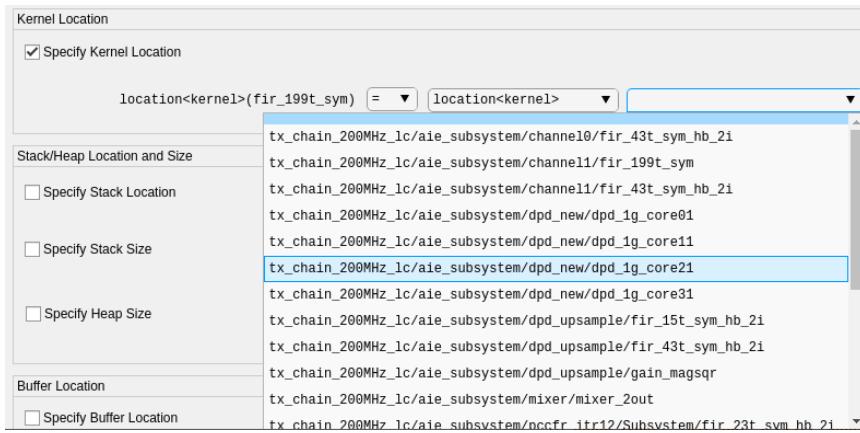
- Constrain a kernel to be placed on a specified AI Engine tile.



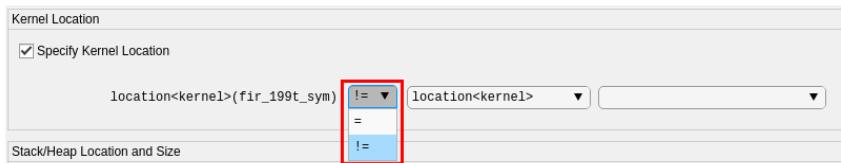
**IMPORTANT!** MATLAB variables can be used to specify the kernel locations.

Or

- Constrain two kernels to be placed relatively on the same AI Engine. This forces them to be sequenced in topological order and be able to share memory buffers without synchronization. As shown, you can select the kernel you want to place relatively on the AI Engine from the drop down.

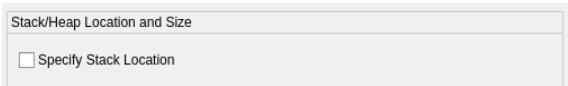


- Vitis Model Composer also supports specifying two kernels, say k1 and k2. These should not be mapped to the same AI Engine.



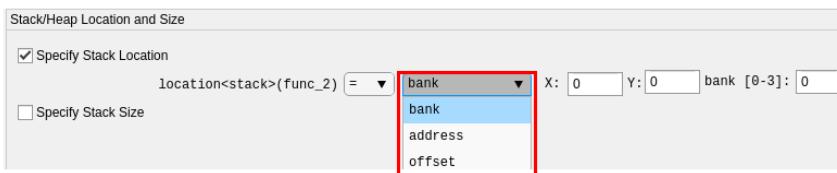
## Stack Location

The stack location constraint is used to specify the location of the system memory (stack and heap) of the AI Engine where the specified kernel is mapped. This provides the mechanism to constrain the location of the system memory with respect to other buffers used by that kernel. By default, the option **Specify Stack Location** is deselected. Enable this to specify the constraint.



You can specify the stack location by pointing to a:

- Specific data memory bank on an AI Engine tile. The bank ID is relative to the tile and can take values 0,1,2,3.
- Specific data memory address on an AI Engine tile. The offset address is relative to the tile starting at zero with a maximum value of 32768 (32K).
- Specific data memory address offset. The offset address is between 0 and 32768 (32K) and is relative to a tile allocated by the compiler.



Vitis Model Composer also supports specifying the stack location of the kernel where it should not be mapped to a particular bank, address, or offset.

### Stack Size

This constraint allows you to set the stack size for an individual kernel. By default the option **Specify Stack Size** is deselected. Enable this to specify the constraint. The default value is 1024.

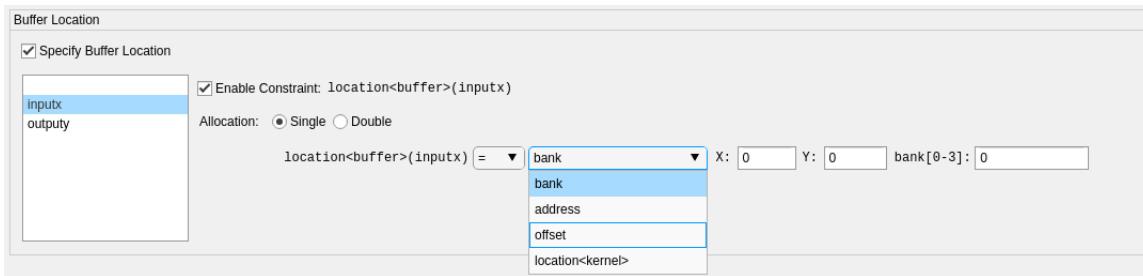


### Buffer Location

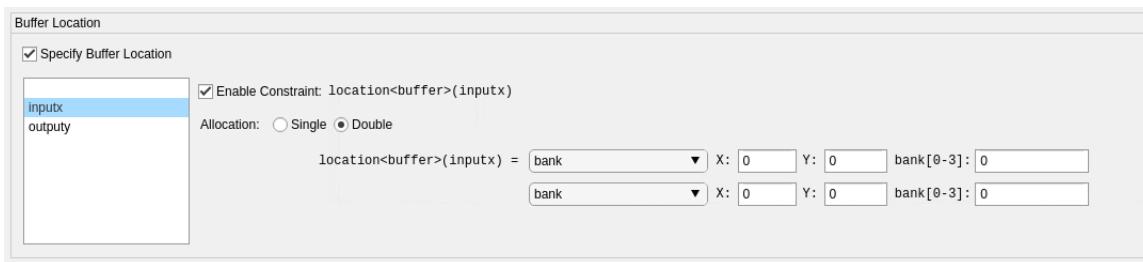
The AI Engine compiler attempts to automatically allocate buffers for windows, lookup tables, and run-time parameters in the most efficient manner possible. However, you might want to explicitly control their placement in memory. Similar to the kernels shown previously in this section, buffers inferred on a kernel port can also be constrained to be mapped to specific tiles, banks, or even address offsets using location constraints.



- By default, the option **Specify Buffer Location** is deselected. When you enable this option, the kernel ports that can be constrained are displayed. Buffer locations are only allowed on window kernel ports.
- You can click on each individual port and enable constraint as shown in the following figure.
- You can use the **Allocation** option to specify a single or double buffer constraint on a window port. By default, a window port is double buffered.
- For a single buffer allocation, you can choose to constrain the buffer location by pointing to a:
  - Specific data memory bank on an AI Engine tile. The bank ID is relative to the tile and can take values 0,1,2,3.
  - Specific data memory address on an AI Engine tile. The offset address is relative to the tile starting at zero with a maximum value of 32768 (32K).
  - Specific data memory address offset. The offset address is between 0 and 32768 (32K) and is relative to a tile allocated by the compiler.
  - Specific buffer location to be on the same bank as that of one or more other port buffers. This ensures that the buffer can be accessed by other kernel without requiring a DMA.



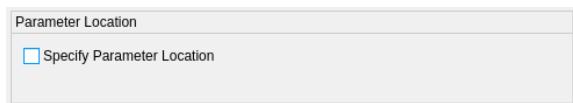
- You can constrain the location of double buffers attached to a port that are to be placed on a specific address or a bankid.



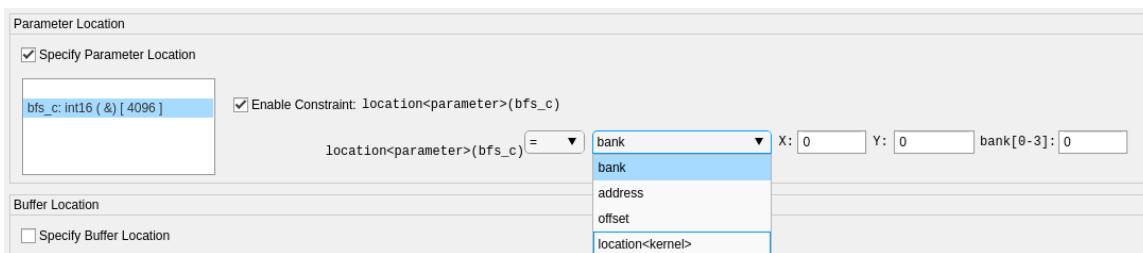
**IMPORTANT!** The non-collocation constraint (i.e., specifying where the buffer should not be mapped to) is allowed only for single buffer.

## Parameter Location

This constraint allows you to set the location of the parameter array declared within the graph.

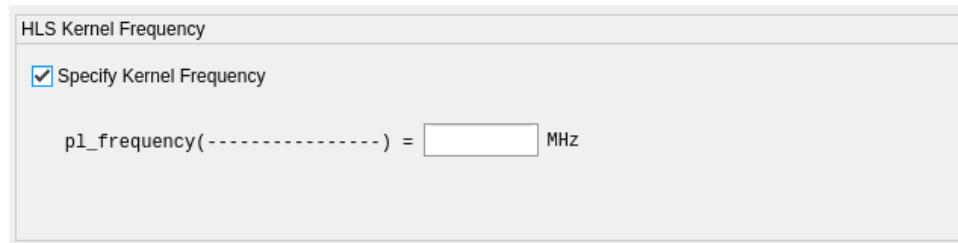


By default, the option **Specify Parameter Location** is deselected. When you enable this option, the parameters that can be constrained are displayed. You can click on each individual parameter and constrain the location of a parameter lookup table to be placed on specific address or a bankid. You can also constrain the parameter location to be on the same tile as that of some other kernel. This ensures that the buffer, or parameter array can be accessed by the other kernel without requiring a DMA.



### HLS Kernel Frequency

This constraint allows you to specify the clock frequency (in MHz) of the PL Kernel.



### Graph Bounding Box

This bounding box constraint specifies a rectangular bounding box for a graph to be placed in AI Engine tiles, between columns from `column_min` to `column_max` and rows from `row_min` to `row_max`. Multiple bounding box location constraints can be set to specify an irregular shape bounding region.



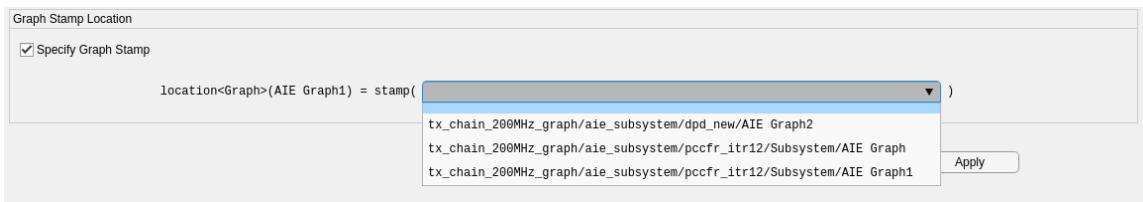
By default, the **Specify Bounding Box** option is deselected. Enable this to specify the boundary location of the graph. Further, you can also enable the **Specify Another Bounding Box** option to specify multiple bounding regions.

### Graph Stamp Location

The graph stamp location constraint can be used when the same graph has multiple instances that can be constrained to the same geometry in AI Engine. There are two main advantages of using this constraint:

- When the same graph is instantiated multiple times, the throughput should be same. Because of the differences in routing, throughput might not be the exactly identical. However, it will be much closer when stamping is used.
- The run time required will be significantly less because the AI Engine compiler only solves a reference graph instead of the entire design.

By default, the **Specify Graph Stamp** option is deselected. When you enable this, Model Composer allows you to select the graph from the drop down menu for which the graph (in lhs) can be stamped.



**Note:** Applying constraints on Xilinx Toolbox/AI Engine/DSP library blocks is not supported and the constraint editor does not show DSP library blocks in the drop-down menu.

**Note:** When you copy an AIE block, the constraints applied on the original block may not be properly copied.

## Importing AI Engine Graphs

As discussed in [AI Engine Graphs](#), a graph is a connection of different compute kernel functions. Unlike when importing kernels, where a kernel function is imported as a block into Model Composer, in this case, graph code is imported as a block. To import the graph as block into Vitis Model Composer, you need to select the AIE Graph block from the AI Engine library (shown in the following figure).

Figure 201: **AIE Graph**



Vitis Model Composer allows connection between the AIE Graph block and the AIE Kernel block so that the whole design can be simulated in the Simulink environment.



---

**IMPORTANT!** It is assumed that your kernel code is already developed and that the associated kernels are properly organized.

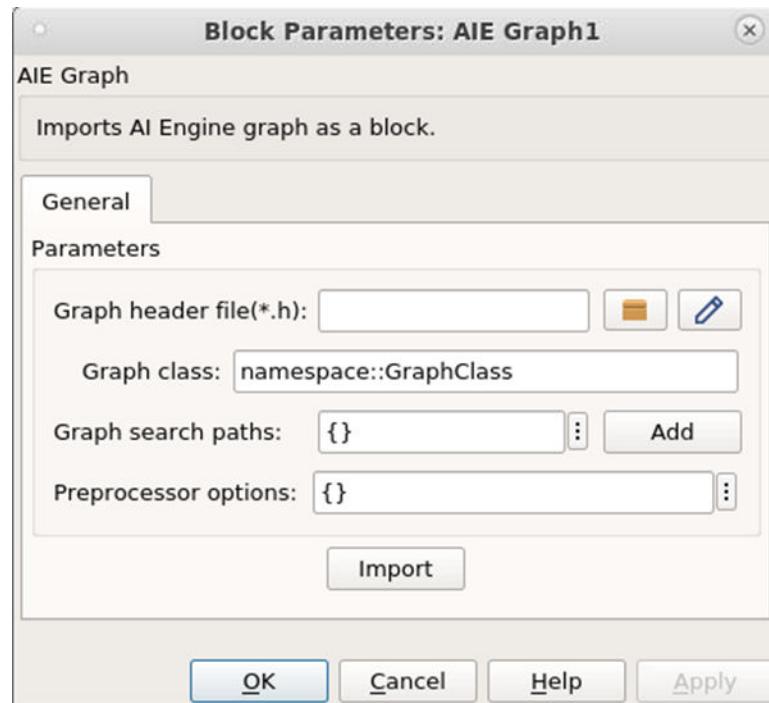
---

The AIE Graph block supports importing the AI Engine graph into Vitis Model Composer using the header file (\*.h).

## Using the Header File

To import the graph using the header file (.h), double-click the **AIE Graph** block. Specify the graph header file, class, search path, and preprocessor options as shown in the following figure.

Figure 202: AIE Graph Block Parameters Dialog Box



The following table provides further details including names and descriptions of each parameter.

Table 21: AIE Graph Block Parameters

Parameter Name	Parameter Type	Criticality	Description
Graph application file (*.h)	String	Mandatory	Specify the file (.h), where the application graph class is defined and the Adaptive Data Flow (ADF) header (adf.h), kernel function prototypes are included.
Graph class	String	Mandatory	Specify the name of the graph class.
Graph Search paths	Vector of strings	Mandatory	Specify search paths where header files, kernels, and other include files can be found and included for simulation. The search path \$XILINX_VITIS/adf/include (where adf.h is defined) is included by default and does not need to be specified.
Preprocessor options		Optional	Optional preprocessor arguments for downstream compilation with specific preprocessor options. The following preprocessor option formats are accepted and multiple can be selected: '-D<name>' and '-D<name>=<definition>'. That is, the optional argument must begin with the '-D' string and if the optional <definition> value is not provided, it is assumed to be 1.

```

graph.h

#ifndef __XMC_PROJ_H__
#define __XMC_PROJ_H__

#include <adf.h>
#include "simple.h"

class Proj_base : public adf::graph {
public:
    adf::kernel AIE_Kernel;

public:
    adf::input_port In1, In2;
    adf::output_port Out1, Out2;

    Proj_base() {
        // create kernel AIE_Kernel
        AIE_Kernel = adf::kernel::create(simple_comp_1);
        adf::source(AIE_Kernel) = "simple.cc";

        // create kernel constraints AIE_Kernel
        adf::runtime<ratio>( AIE_Kernel ) = 0.9;

        // create nets to specify connections
        adf::connect<adf::stream> net0 (In1, AIE_Kernel.in[0]);
        adf::connect<adf::stream> net1 (In2, AIE_Kernel.in[1]);
        adf::connect<adf::stream> net2 (AIE_Kernel.out[0], Out1);
        adf::connect<adf::stream> net3 (AIE_Kernel.out[1], Out2);
    }
};

class Proj : public adf::graph {
public:
    Proj_base mygraph;

public:
    adf::input_plio In1, In2;
    adf::output_plio Out1, Out2;

    Proj() {
        In1 = adf::input_plio::create("In1",
            adf::plio_32_bits,
            "./data/input/In1.txt");

        In2 = adf::input_plio::create("In2",
            adf::plio_32_bits,
            "./data/input/In2.txt");

        Out1 = adf::output_plio::create("Out1",
            adf::plio_32_bits,
            "Out1.txt");

        Out2 = adf::output_plio::create("Out2",
            adf::plio_32_bits,
            "Out2.txt");

        adf::connect<> (In1.out[0], mygraph.In1);
        adf::connect<> (In2.out[0], mygraph.In2);
        adf::connect<> (mygraph.Out1, Out1.in[0]);
    }
};

```

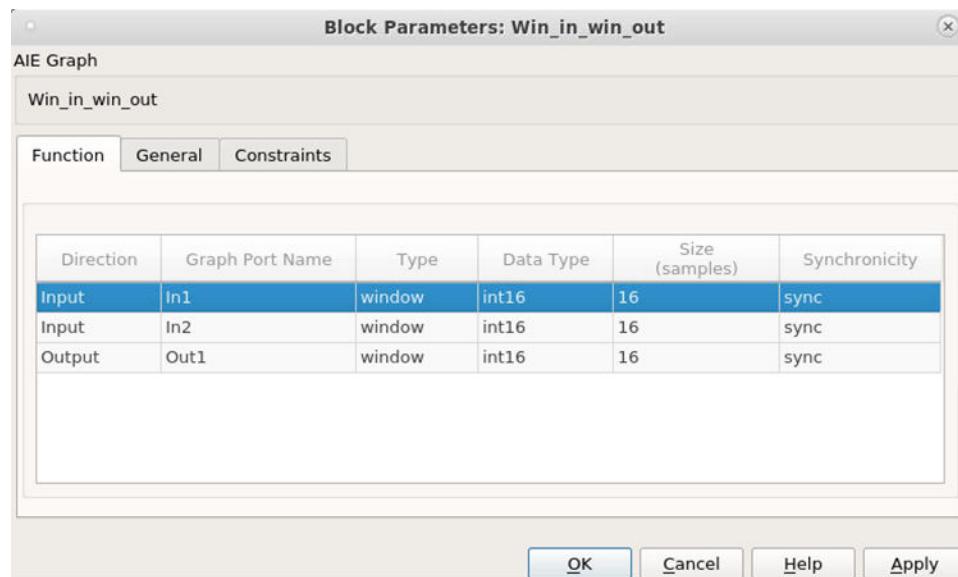
```
    adf::connect< > (mygraph.Out2, Out2.in[0]);  
}  
};  
  
#endif // __XMC_PROJ_H__
```

**Note:** It is not allowed to import the graph class that has PLIO attributes specified. Model Composer will throw an appropriate error if you try to do so. In this case, use the `Proj_base` class to import the graph.

When the GUI parameters are updated, click the **Import** button.

The Block Parameters dialog box updates as shown in the following figure. This contains the port direction and type.

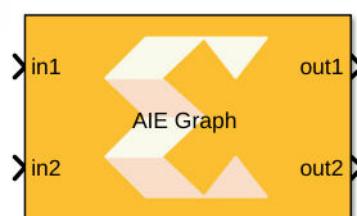
Figure 203: Block Parameters Dialog Box



Parameters such as the Graph Port Name, Data Type etc. are automatically updated from the graph code.

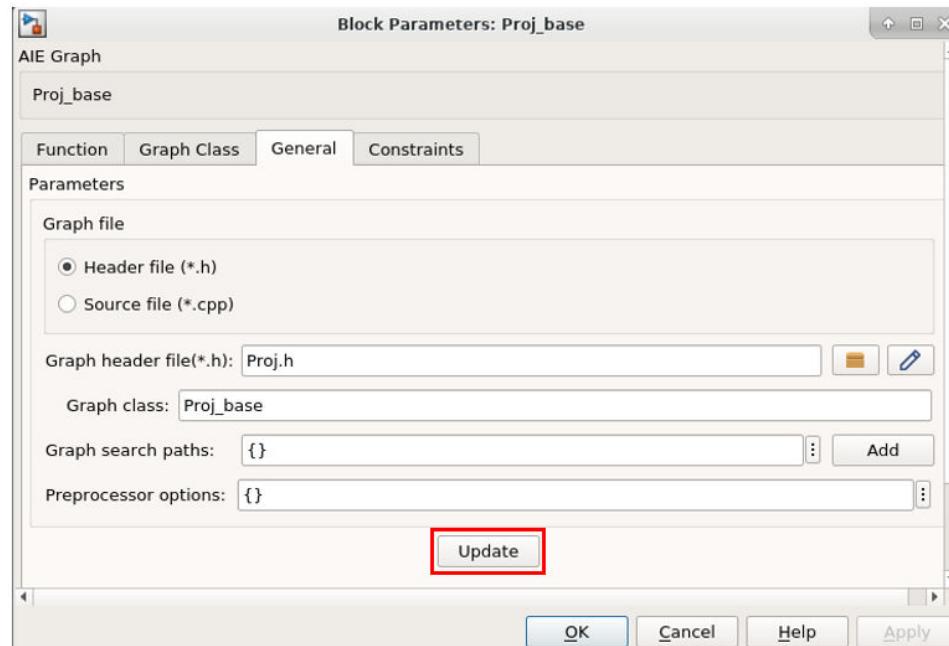
The AIE Graph block GUI interface with input and output ports is as shown in the following figure.

Figure 204: AIE Graph Block



In the General tab, the Import button changes to Update, enabling further update of block parameters.

Figure 205: Update Button



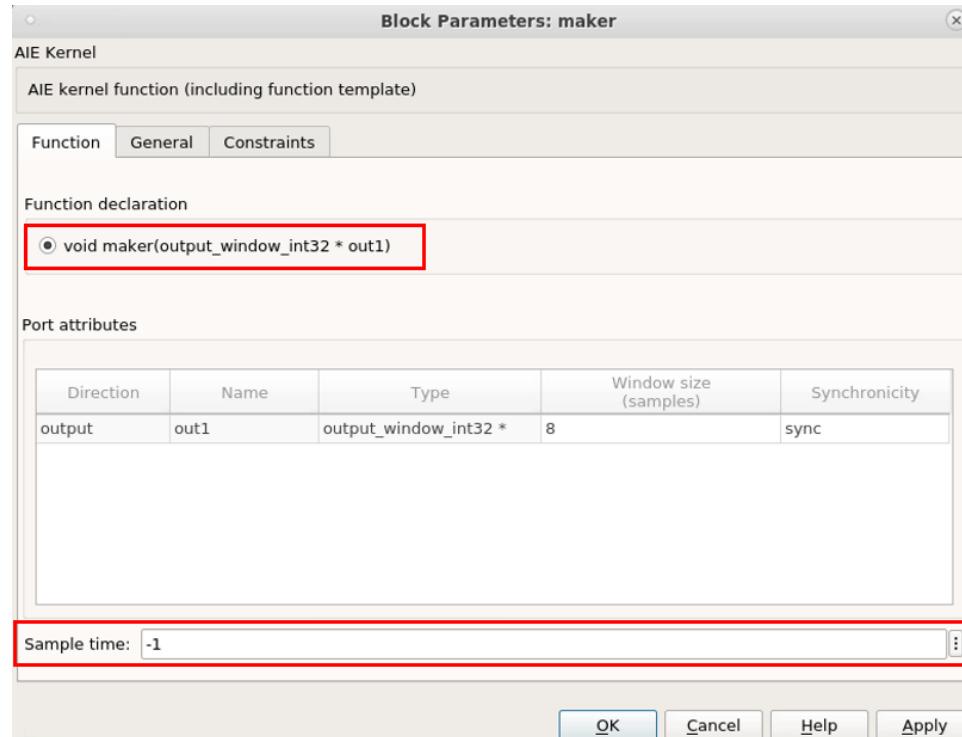
## Importing Kernels and Graphs as Source Blocks

Vitis Model Composer supports importing kernels and graphs as a source blocks (i.e., user-defined functions with no input ports) into the design. These source blocks have inherited sample time and work only when the model has at least one another block with a non-inherited sample time that Simulink can use for sample time propagation. This requires you to add a block (for example a Constant block) in the model and specify a valid sample time. Alternatively, you can explicitly specify the sample time for the imported source blocks similarly to the other source blocks such as Constant, RTP Source blocks etc. from Simulink and AI Engine libraries respectively.

The AIE Kernel, AIE Class Kernel and AIE Graph blocks from the AI Engine/User-Defined Functions library supports importing the code as a source block. When you try to import the kernel into the Vitis Model Composer that has only output ports, the tool identifies that as a source block and adds the Sample time parameter to the Function tab in Block Parameters dialog box as shown in the following figure.

**Note:** The Sample time parameter is not visible when the kernel code has at least one input port.

Figure 206: Block Parameters: maker



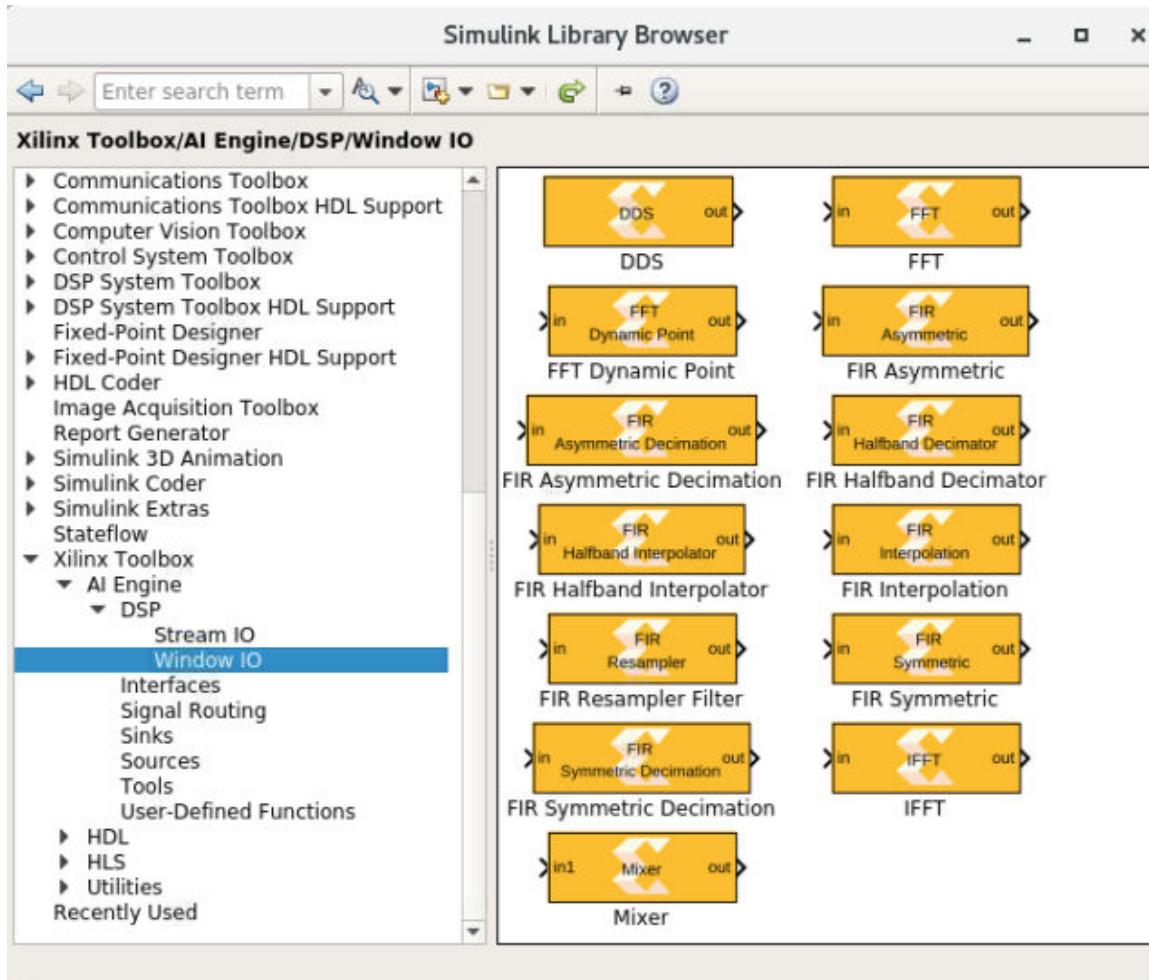
The default value of the Sample time is -1 which indicates the sample time is inherited. Valid sample time values must be positive, real scalar, or -1.

---

## AI Engine DSPLib

The Vitis™ DSP Library (DSPLib) is a library of commonly used DSP functions optimized for AI Engines. To facilitate the use of these functions in a design, Vitis™ Model Composer provides different DSPLib functions as blocks within the Xilinx Toolbox/AI Engine/DSP library. You can conveniently drag and drop one of these blocks into your model from the Simulink Library browser and configure the block.

Figure 207: Simulink Library Browser



Vitis Model Composer provides a copy of DSPLib functions which can be used as is. Optionally, you can download DSPLib functions from the online GitHub repository and use the MATLAB command `xmcLibraryPath` to set the path to the DSPLib library.

For more information on using the MATLAB utility, refer to [xmcLibraryPath](#).

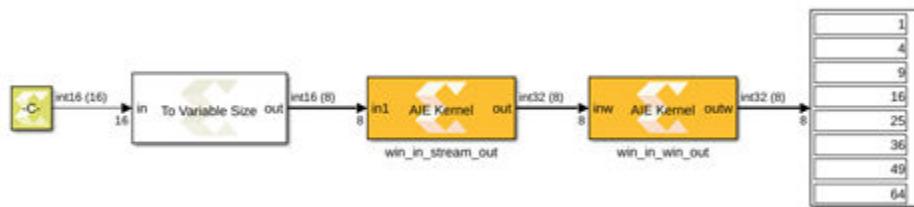
## Setting Signal Size to Avoid Buffer Overflow

The Signal Size field on the AI Engine import block masks only applies to kernels with stream or cascade outputs. Moreover, it has no implementation significance and it is only meaningful for simulation purposes in the Simulink environment. This section provides more in-depth knowledge of what Signal Size is and how to set it.

Start with a very simple kernel with window input and stream output. The kernel code is as follows:

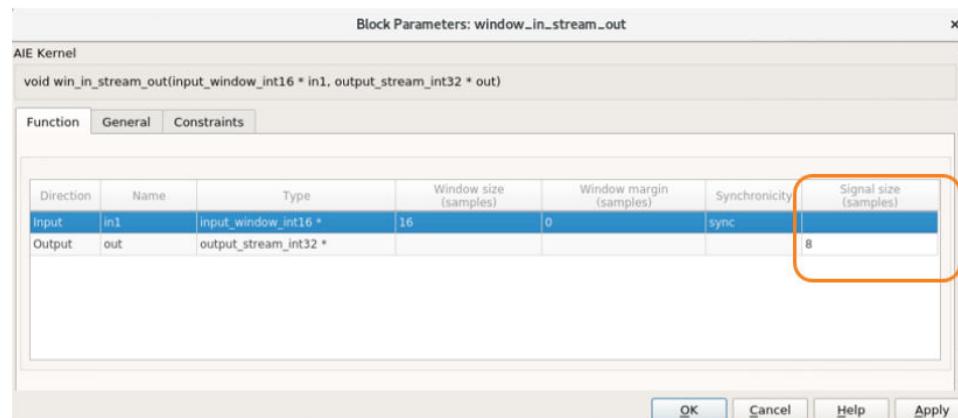
```
void win_in_stream_out(input_window_int16 * in1, output_stream_int32 * out) {  
    int16 val;  
    for (unsigned i=0; i<16; i++) {  
        window_readincr(in1, val);  
        int32 squaring = val * val;  
        writeincr(out, squaring);  
    }  
}
```

Figure 208: AIE Kernel: Window Input/Stream Output



This kernel expects a window of size 16 and at every invocation of this kernel, 16 output samples are generated. Import this kernel into Simulink using the AIE Kernel block. The mask for the block is shown in the following figure.

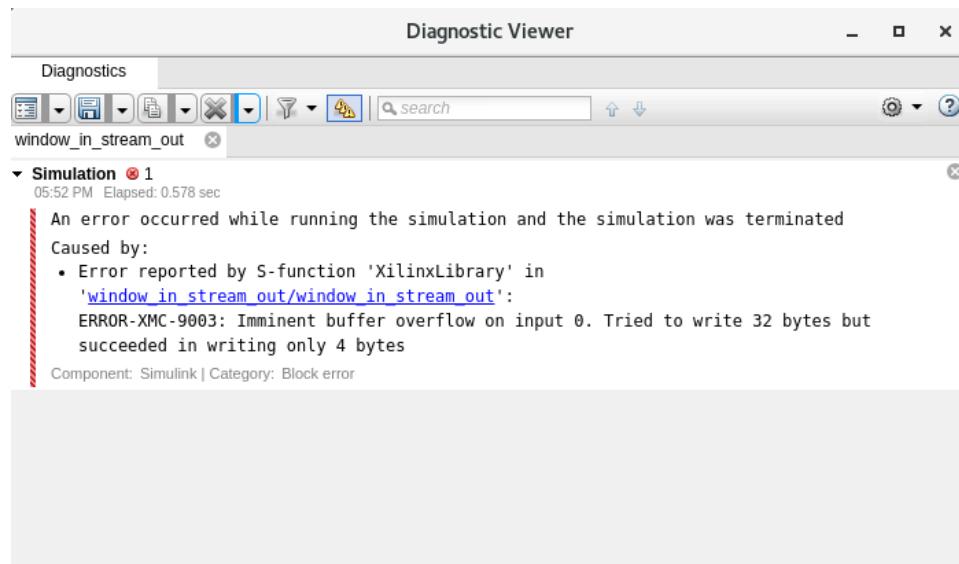
Figure 209: Block Parameters: window\_in\_stream\_out



Regardless of what value you set the signal size to, it does not affect the numerical output. For this example, you will generally set the signal size to 16 because every invocation of the kernel produces 16 samples. In this case, the output of this block will be a variable size signal of maximum size 16 (equal to the signal size) and each output will contain 16 samples. However, if for example you set the signal size to 32, the output of the block will be a variable size signal with a maximum size of 32, but each output will only contain 16 samples.

What if you set the signal size to a number smaller than 16, for example to 8? In this case, similar to the previous cases, the output will be a variable size signal of maximum size of 8. As mentioned previously, at each invocation of the kernel, the kernel produces 16 samples. Eight of these samples will be put out by the block. The other eight are stored in an internal buffer in the block. If you call the kernel too many times, eventually the internal buffer of the block will fill up and you will see a buffer overflow error as shown in the following figure.

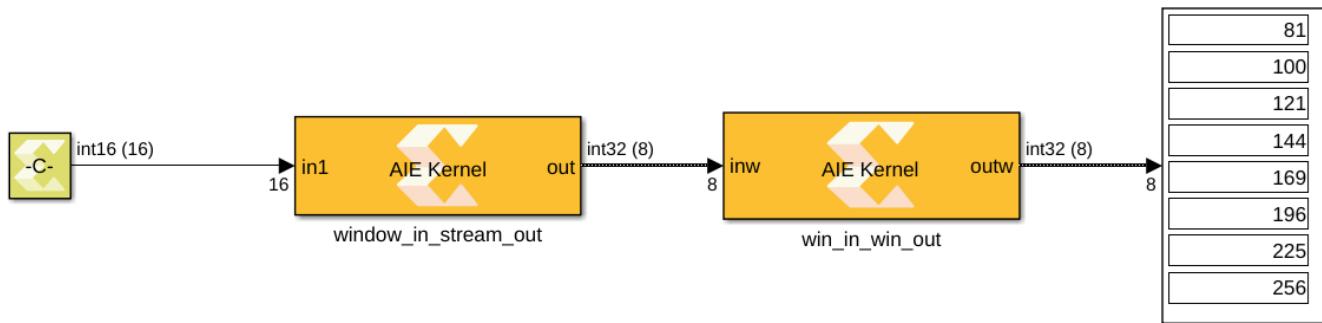
Figure 210: Buffer Overflow Error



This is a trivial example. You may contend that there is no reason to set the signal size to anything less than 16, and that is correct. Now examine a model with two AI Engine kernels. Connect the output of the kernel previously created to another AI Engine kernel with window input and window output. The code for this second kernel is as follows:

```
void win_in_win_out(input_window_int16 * inw, output_window_int16 * outw)
{
    int16 temp;
    for (unsigned i=0; i<8; i++) {
        window_readincr(inw,temp);
        window_writeincr(outw,temp);
    }
}
```

Figure 211: Two AIE Kernels



This kernel requires an input window of size 8 and produces a window size of 8. Now consider two scenarios. First consider a case in which the first block has the signal size set to 16. As mentioned previously, with a signal size of 16, the buffer for the first block will not overflow. But now examine the second block more closely. The second kernel upon receiving 16 samples, will get invoked twice. Each time, it produces eight samples for a total of 16 samples. However, since the output window size is 8, the block will produce eight samples and store the other eight in the internal buffer. Just like before, if you run this model for long enough, the buffer for the second block will overflow and simulation will stop.

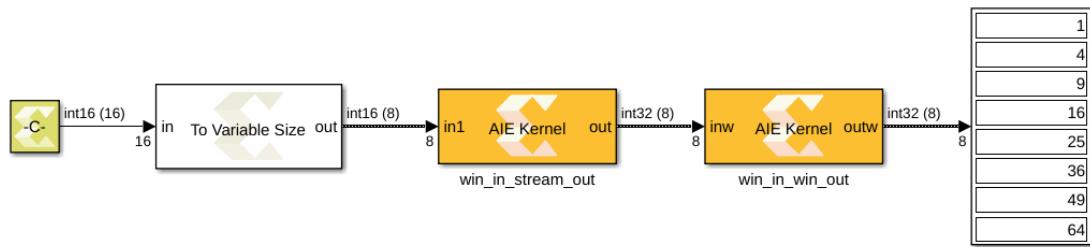
In another scenario, to avoid an overflow, you might set the signal size for the first block to 8. This will avoid an overflow in the second block. However as mentioned previously, now the buffer for the first block will overflow. So how can you get out of this situation?

The buffer overflows because you are feeding more data to the blocks than the blocks can process. If you reduce the rate, the kernels will be able to process any excess data in the buffers and as such prevent the overflow. Now look into this more carefully.

Assume the simulation has been running for a while and the first block's buffer is not empty. If you somehow stop feeding data to the first block, every time Simulink calls the first block, the kernel will not be invoked (there is no input data), but because there are samples in the buffer, the block will continue to produce samples (eight at a time) until the buffer empties out after which it will produce an empty variable size signal.

This information should help you avoid buffer overflow. Instead of stopping the input as suggested above, simply reduce the flow of the data into the first block. One way of doing this is to use a To Variable Size block from AI Engine/Tools and set the Output size on the block mask to a number smaller than the size of the input. The following figure depicts the same design shown above but with a To Variable Size block at its input.

Figure 212: Two AIE Kernels: Buffer Block Input



In this design, because fewer samples are being fed to the first block at any given call to the block, the buffers will not overflow. Note that the output of this model will be different from the model without the buffer block because the buffer block produces zero samples at time step zero.



**TIP:** If a block with stream output is connected to a block with window input, set the size of the signal for the producing block to the same size as the input window for the consuming block.



**TIP:** To avoid buffer overflow, reduce the rate you feed data to the system using a buffer block.

## Simulation and Code Generation

After a high level graphical design is created using the blocks available in the Vitis Model Composer AI Engine library, it should be simulated interactively in the Simulink environment. This process ensures the functional correctness of the design using the native Simulink functional simulator and displays the results on scopes and graphical displays. The compilation and execution times are generally short at this stage, which helps you to quickly verify the functionality and iterate over the design until the specification requirements are met. The functionally verified design can then be used to generate the dataflow graph using the Vitis Model Composer Hub block. The verification of the dataflow graph can be done using various execution targets which Vitis Model Composer supports to simulate your AI Engine application at different levels of abstraction, accuracy, and speed.

This section discusses following topics in detail:

- Running Simulink Simulation
- Code Generation
- Verifying the generated dataflow graph

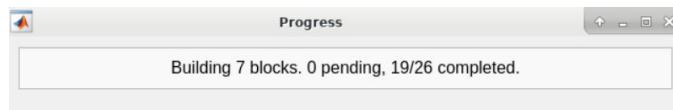
## Running Simulink Simulation

Simulation involves compiling the design and checking for any design rule violations, then executing the design to produce the outputs. You can define the inputs of the design using any Simulink source blocks and the output is analyzed either by logging the data to the workspace, or by visually viewing the results using a scope, spectrum analyzer, or display block.

Vitis Model Composer provides two MATLAB utilities `xmcVitisRead` and `xmcVitisWrite` to directly read/write data from/to the files that are formatted for AIE Simulator and/or x86 Simulator. For more information on using these utilities, refer to [AI Engine Utilities](#).

Clicking the **Simulate model** icon in the Simulink simulation tool bar, compiles all the kernels and graphs in the design. You can monitor the status from the Progress window, which displays after simulation begins (see the following figure).

Figure 213: Compilation Status



The Progress window displays only when you are compiling a design for the first time. When you simulate the model again, unless you make any changes to the imported kernel or graph, Model Composer will use the cached entry for the block to run the simulation faster. For example, assume you have three kernels (`add2`, `add3`, `add4`) in your design and you run the simulation for the first time. In that case, all the three kernels get compiled. When you change the `add3` kernel code and try to simulate again, only the changed `add3` kernel gets re-compiled and the cached entries for `add2` and `add4` are used for faster simulation.

To manage the simulation cache in Model Composer, use the commands described in [Managing the HLS Block Cache](#) from the MATLAB command prompt.

When simulation is complete, you can review the results by connecting any of the Simulink sink blocks to appropriate points in your design.

## Code Generation

When the design is functionally verified in Simulink, you can generate the dataflow graph from the design. It is necessary to encapsulate the AI Engine blocks into a subsystem. To understand more about creating a top-level subsystem, refer to [Creating a Top-Level Subsystem Module](#).



**IMPORTANT!** To generate output from the AI Engine model, only blocks from the Vitis Model Composer AI Engine library and a limited set of Simulink blocks can be used in the subsystem that is instantiated at the top-level of the design. Refer to [Connecting Source and Sink Blocks](#) for more details about the blocks that are supported inside the subsystem.

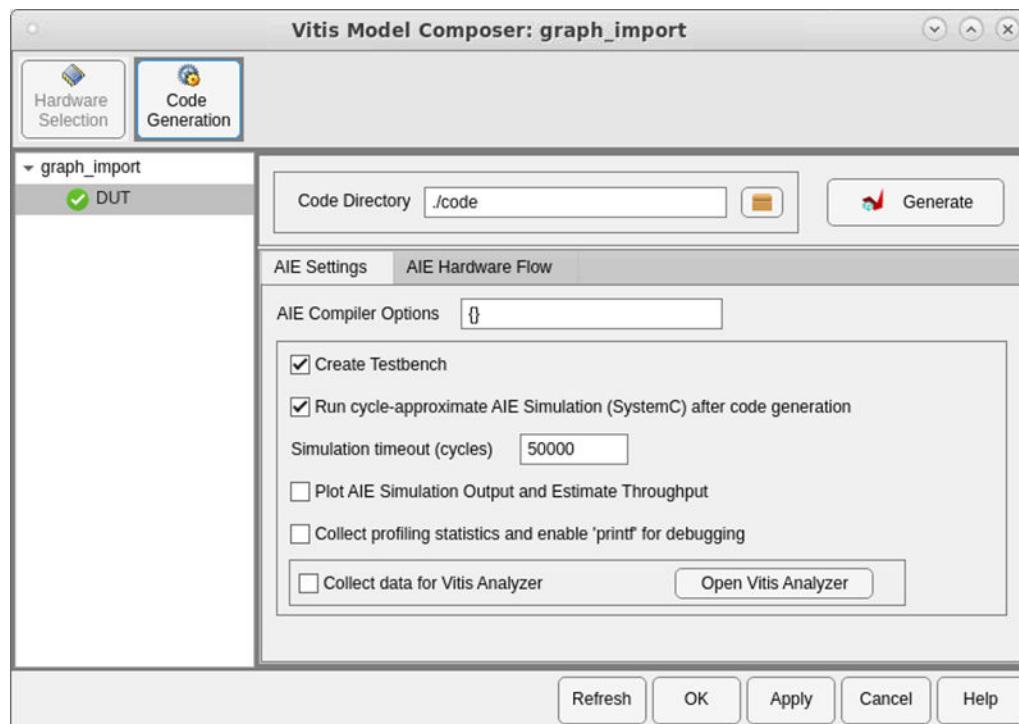
## Vitis Model Composer Hub Block for AI Engine Code Generation

Model Composer automatically generates AI Engine code (dataflow graph) from the subsystem that comprises blocks from the [AI Engine Blockset](#) library. However, an AI Engine model in Model Composer requires the addition of the Vitis Model Composer Hub block to configure compilation and generation of AI Engine output. In addition to the targets available in the Hub block which supports compilation of the design into low-level representations using blocks from the [library](#), it also supports an AI Engine compilation target.

This section discusses only the graph code generation from Model Composer. For running and verifying the generated AI Engines code, refer to [Verification of AI Engine Code](#).

The Model Composer Hub block settings specific to AI Engine compilation targets are shown in the following figure.

Figure 214: Model Composer Hub AI Engine Settings



Add the Hub block from the library, and configure the AI Engine subsystem and settings as shown in the previous figure. For more details about adding the Model Composer Hub block into the design and associated features, refer to [Vitis Model Composer Hub](#). Select the subsystem for which to generate code from the list on the left.

You can specify a cell array of AI Engine compiler options using the **AIE Compiler Options** edit button. This provides a method to control the compiler debug options, execution target options, file options and so on. Examples as follows:

- To control the debug option log-levels, you can specify the string `{ '--log-level=5' }` in the **AIE Compiler Options** field.
- For issues related to the stack size or heap size in the downstream AI Engine flows, you can increase the size by adding `--stacksize=<int>` and `--heapsize=<int>` in the AIE Compiler options field.

When the Code Directory, Subsystem and Hardware Target are specified, click **Generate** to create the dataflow graph.



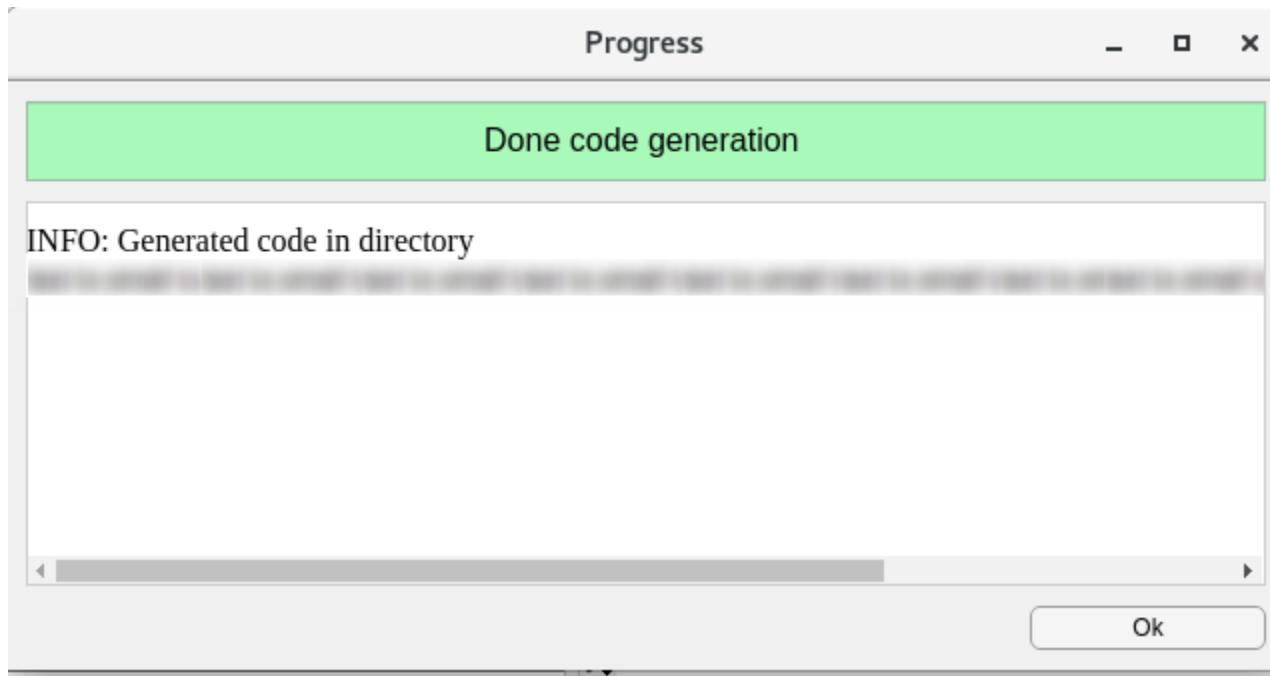
**IMPORTANT!** You can enable the **Create testbench** option to log the test data at input and output.

Further, you can enable the **Run AIE Simulation** option to verify the dataflow graph. For more information, refer to [Verification of AI Engine Code](#).

Once the code generation process is initiated, the Progress window may display (based on whether the imported kernel/graph code is pre-compiled or not). If the design was already compiled during the Simulink simulation phase, you may not see this window. However, Model Composer displays the progress of code generation in the Progress window.

When Vitis Model Composer has completed generating the code, it displays the status message **Done code generation** in the Progress window as shown in the following figure.

Figure 215: Done Code Generation



**TIP:** Model Composer runs the Simulink simulation every time you try to generate the code. You can choose to either run the simulation manually or click **Generate** which validates the subsystem by running a set of DRCs. If the DRC validation fails, then Model Composer returns an appropriate error and the code generation process stops.

## Output Directory

A new directory gets created with the name specified in the Code Directory field in the Model Composer Hub block. There are various sub-directories in the `code` directory but the `src_aie/` directory and the `Makefile` which are highlighted in figure below, are of interest for this section. The details about other sub-directories are explained in subsequent topics.

Figure 216: Target Directory

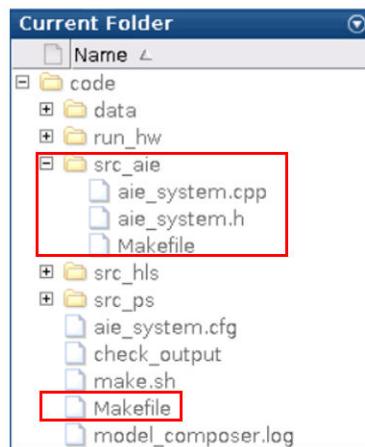
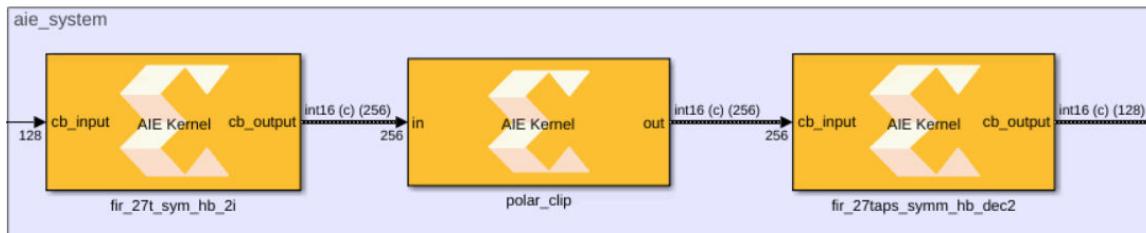


Table 22: File/Directory Descriptions

File/Directory	File/Sub-directory	Description
src_aie	Subsystem_Name.h	Header file that specifies the AI Engine dataflow graph.  <b>Note:</b> <code>Subsystem_Name</code> is a unique string derived from the top-level subsystem specified in the Model Composer model.
	Subsystem_Name.cpp	Test bench to simulate the dataflow graph specified in <code>Subsystem_Name.h</code> .
	Makefile	This file contains the <code>aiecompiler</code> options specified from Model Composer Hub block.
Makefile		This file contains the commands to compile and simulate the dataflow graph.  For more details on how to use the <code>Makefile</code> to run simulation from command line, refer to the section <a href="#">Running Simulation using the Makefile</a> .

The files generated by Vitis Model Composer in the `src_aie` directory reflect the contents and hierarchy of the subsystem that gets compiled. In this case, assume the subsystem is `aie_system` which is derived from the design in [Vitis Model Composer Tutorial \(UG1498\)](#). The following figure shows the interconnection of imported kernel functions as blocks, encapsulated as a subsystem.

**Figure 217: Block Interconnection**

The generated code for the subsystem `aie_system` is as follows.

**aie\_system.h**

```
#ifndef __XMC_AIE_SYSTEM_H__
#define __XMC_AIE_SYSTEM_H__

#include <adf.h>
#include "kernels/inc/hb_27_2i.h"
#include "kernels/inc/polar_clip.h"
#include "kernels/inc/hb_27_2d.h"

class Aie_system_base : public adf::graph {
public:
    adf::kernel fir_27t_sym_hb_2i_0;
    adf::kernel polar_clip_0;
    adf::kernel fir_27taps_symm_hb_dec2_0;

public:
    adf::input_port In1;
    adf::output_port Out1;

    Aie_system_base() {
        // create kernel fir_27t_sym_hb_2i_0
        fir_27t_sym_hb_2i_0 = adf::kernel::create(fir_27t_sym_hb_2i);
        adf::source(fir_27t_sym_hb_2i_0) = "kernels/src/hb_27_2i.cpp";

        // create kernel polar_clip_0
        polar_clip_0 = adf::kernel::create(polar_clip);
        adf::source(polar_clip_0) = "kernels/src/polar_clip.cpp";

        // create kernel fir_27taps_symm_hb_dec2_0
        fir_27taps_symm_hb_dec2_0 =
            adf::kernel::create(fir_27taps_symm_hb_dec2);
        adf::source(fir_27taps_symm_hb_dec2_0) = "kernels/src/hb_27_2d.cpp";

        // create kernel constraints fir_27t_sym_hb_2i_0
        adf::runtime<ratio>( fir_27t_sym_hb_2i_0 ) = 0.9;

        // create kernel constraints polar_clip_0
        adf::runtime<ratio>( polar_clip_0 ) = 0.9;

        // create kernel constraints fir_27taps_symm_hb_dec2_0
        adf::runtime<ratio>( fir_27taps_symm_hb_dec2_0 ) = 0.9;

        // create nets to specify connections
        adf::connect<adf::window<512,64>> net0 (In1,
fir_27t_sym_hb_2i_0.in[0]);
        adf::connect<adf::window<1024>, adf::stream> net1
```

```
(fir_27t_sym_sb_2i_0.out[0], polar_clip_0.in[0]);
    adf::connect<adf::stream, adf::window<1024,128>> net2
(polar_clip_0.out[0], fir_27taps_symm_sb_dec2_0.in[0]);
    adf::connect<adf::window<512>> net3
(fir_27taps_symm_sb_dec2_0.out[0], Out1);
}
};

class Aie_system : public adf::graph {
public:
    Aie_system_base mygraph;

public:
    adf::input_plio In1;
    adf::output_plio Out1;

    Aie_system() {
        In1 = adf::input_plio::create("In1",
            adf::plio_32_bits,
            "./data/input/In1.txt");

        Out1 = adf::output_plio::create("Out1",
            adf::plio_32_bits,
            "Out1.txt");

        adf::connect<>(In1.out[0], mygraph.In1);
        adf::connect<>(mygraph.Out1, Out1.in[0]);
    }
};

#endif // __XMC_AIE_SYSTEM_H__
```

Vitis Model Composer automatically generates the graph header file `aie_system.h` which contains the dataflow graph corresponding to the subsystem name specified in the Hub block. The connection between the AI Engine kernel or graph as well as the configuration parameters such as window size, window margin and so on, which are specified in the AI Engine kernel block, are automatically reflected in the generated graph code.

Vitis Model Composer also generates the `aie_system.cpp` file, which is a control program that has the `main()` function defined to initialize, run, and end the simulation using the control APIs.

#### `aie_system.cpp`

```
#include "aie_system.h"

// instantiate cardano dataflow graph
Aie_system mygraph;

// initialize and run the dataflow graph
#if defined(__AIESIM__) || defined(__X86SIM__)
int main(void) {
    mygraph.init();
    mygraph.run();
    mygraph.end();
    return 0;
}
#endif
```

## Limitations

- AI Engine code cannot be generated if a top-level subsystem's `output` port is connected to a synchronous run-time parameter port.
- The value of an input run-time parameter port can only be updated once at the beginning when running the generated graph.

## Stream FIFO Depth Specification

The AI Engine architecture uses streaming data extensively for communicating between two AI Engines, and for communicating between the AI Engine and the programmable logic (PL). This raises the potential for a resource deadlock when the data flow graph has reconvergent stream paths. If the pipeline depth of one path is longer than the other, the producer kernel can stall and might not be able to push data into the shorter path because of back pressure. At the same time, the consumer kernel is waiting to receive data on the longer path due to the lack of data. If the order of data production and consumption between two stream paths is different, a deadlock can happen even between two kernels that are directly connected with two stream paths.

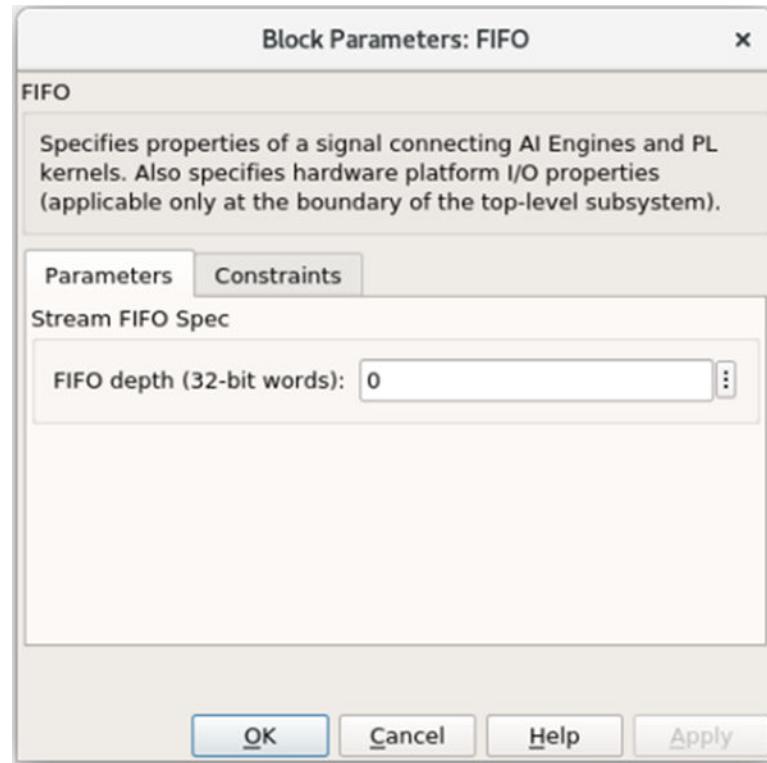
Vitis Model Composer supports adding a FIFO\_DEPTH between two AI Engine kernels or between an AI Engine and the programmable logic (PL) using the AIE FIFO block and automatically generates the graph code with `fifo_depth` constraint on a connection.

Figure 218: AIE FIFO



The AIE FIFO block specifies the FIFO depth on a particular path. Specifying the FIFO depth value can help avoid deadlock or stalling by creating more buffering in the paths. This block does not affect functional simulation and will only impact the generated graph code. You can set location constraints for the FIFO block using the Constraint manager. FIFOs can be either stream FIFOs, DMA FIFOs, or a combination of the two.

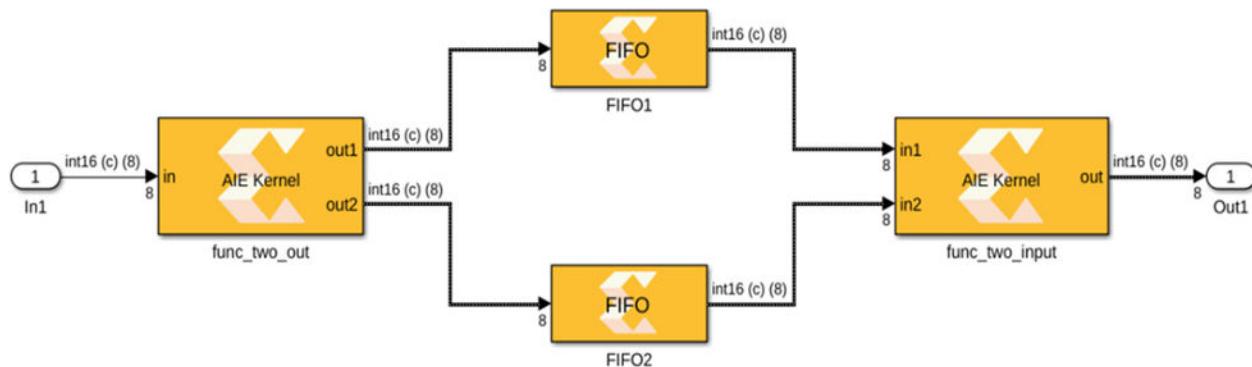
Figure 219: Block Parameters: AIE FIFO



- **Parameters:** Use this tab to specify FIFO depth.
- **Constraints:** Use this tab to set location constraints for the FIFO block using the Constraint manager.

Consider the following example where the AIE FIFO blocks are connected in two stream paths between AIE Kernel blocks.

Figure 220: AIE FIFO Blocks in Two Stream Paths



The FIFO depth value is specified as 0 by default and the corresponding information is reflected on the block symbol. For example, if values 2 and 4 are specified as parameters of the two FIFO blocks, the values will update as shown in the following figures.

Figure 221: AIE FIFO

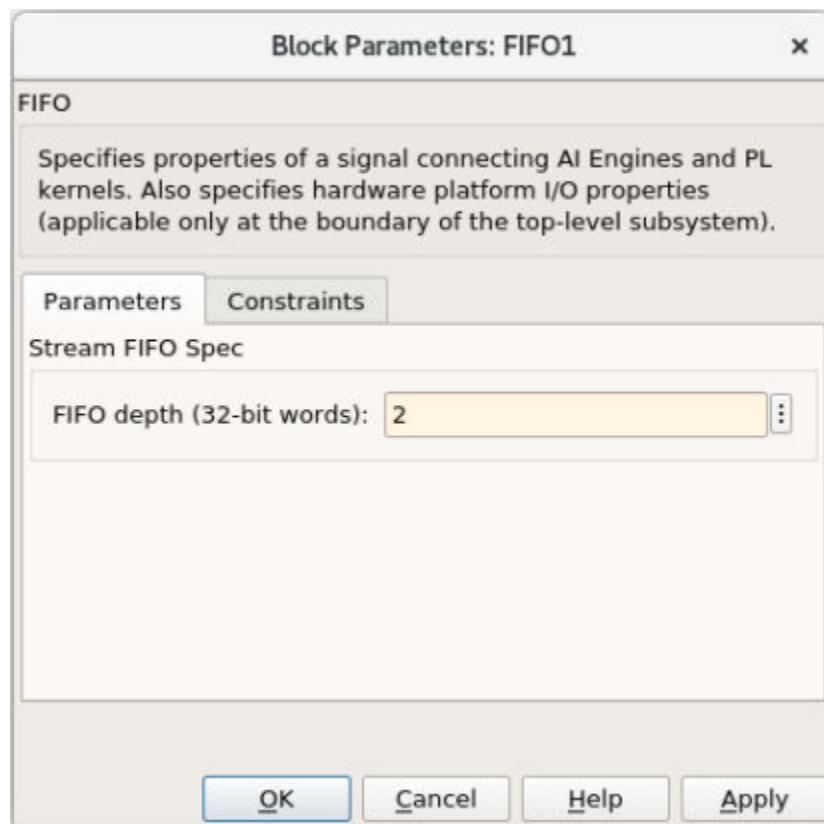


Figure 222: AIE FIFO

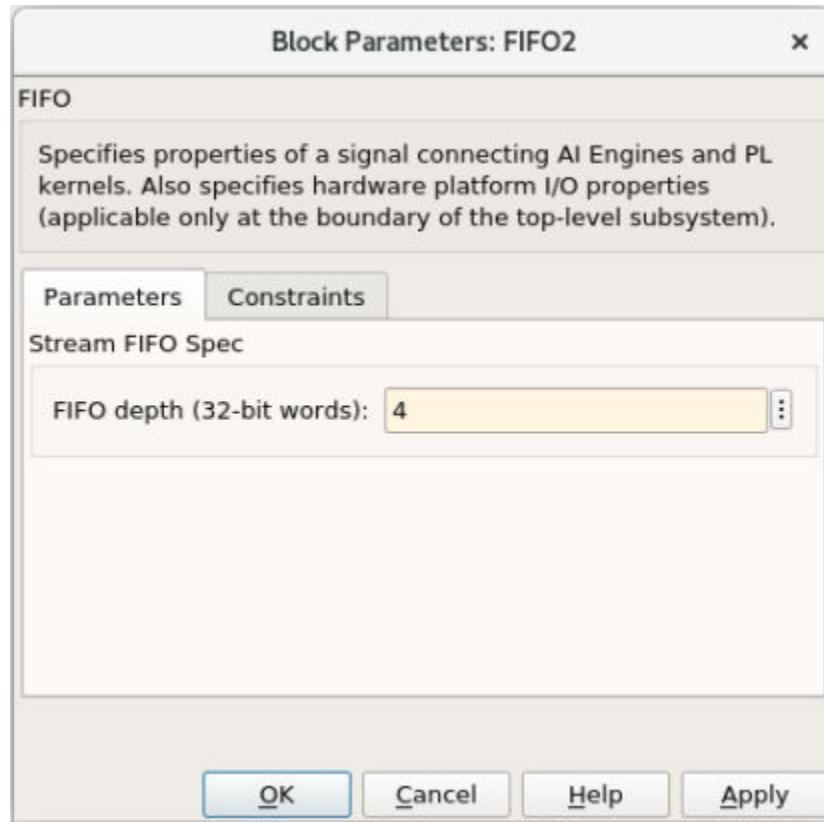
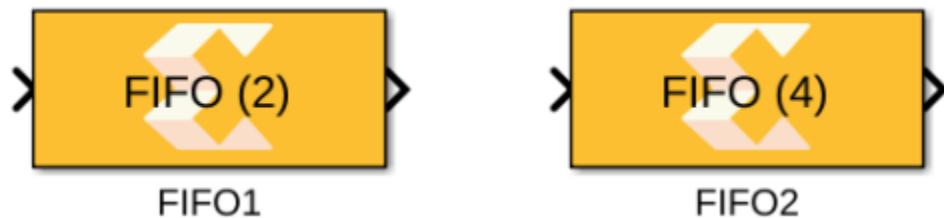


Figure 223: Block Symbol Updates



The stream FIFO values specified using the AIE Signal Spec block are automatically updated in the generated graph code (`graph.h`) with `fifo_depth` constraints as shown in the following code.

### Snippet of graph.h

```
// create nets to specify connections
adf::connect< adf::stream > net0 (In1, AIE_Kernel.in[0]);
adf::connect< adf::stream > net1 (AIE_Kernel.out[0],
AIE_Kernel1.in[0]);
adf::fifo_depth(net1) = 2;
adf::connect< adf::stream > net2 (AIE_Kernel.out[1],
AIE_Kernel1.in[1]);
adf::fifo_depth(net2) = 4;
adf::connect< adf::stream > net3 (AIE_Kernel1.out[0], Out1);
```

Notice the two `fifo_depth` constraints corresponding to the two stream paths in the design. Using this `fifo_depth` constraint on a connection is useful as it creates more buffering in paths with back pressure, and hence avoids any deadlock.



**IMPORTANT!** The AIE FIFO block can only be used in an AI Engine subsystem.

## PLIO Attributes

Typically, the AI Engine array runs at a higher clock frequency (between 1 GHz and 1.25 GHz) than the internal Programmable Logic. Within the AI Engine core the streaming data-width is 32-bit; whereas between the AI Engine interface tile and PL interface, it is 64-bit by default. To balance the throughput between AI Engine and internal programmable logic, it is desirable to pipeline enough data by choosing wider stream data paths for PL blocks. For example, to utilize an AI Engine array running at 32 bits / 1 GHz rate to its full potential, PL blocks may use 64 bits / 500 MHz rate or 128 bits / 250 MHz rate and so on. Such wider (> 32 bits) stream data is sequentialized automatically into 32-bit streams within the AI Engine interface tile.

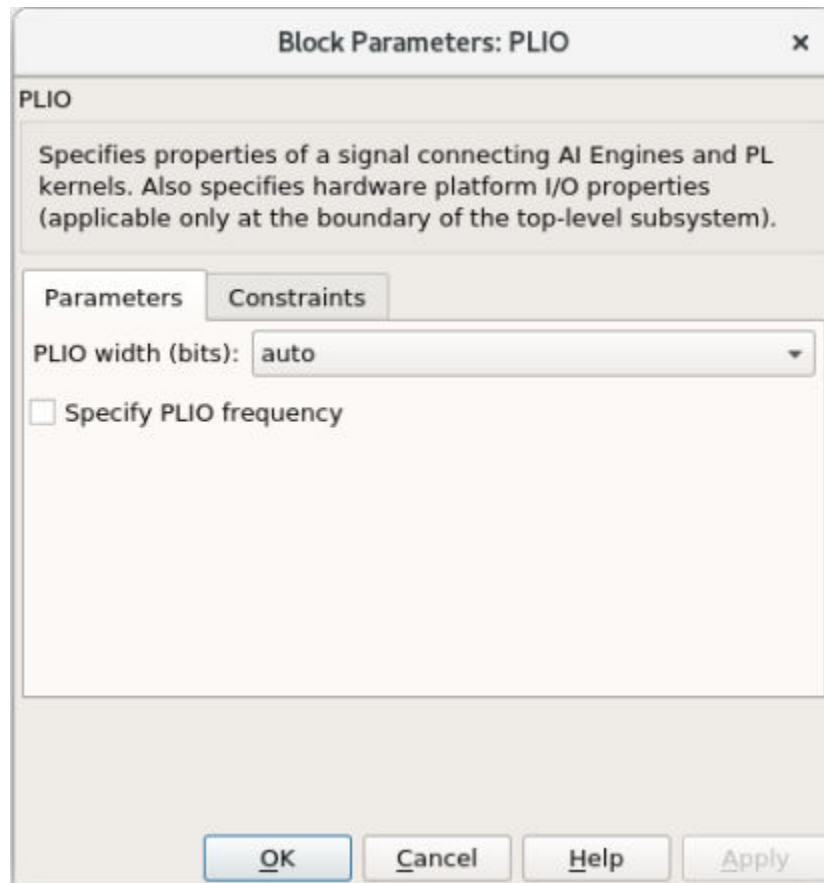
## Specifying PLIOs in Model Composer Designs

Model Composer supports specifying the PLIO width using the AIE PLIO block and making external stream connections that cross the AI Engine to PL boundary.

Figure 224: AIE Signal Spec

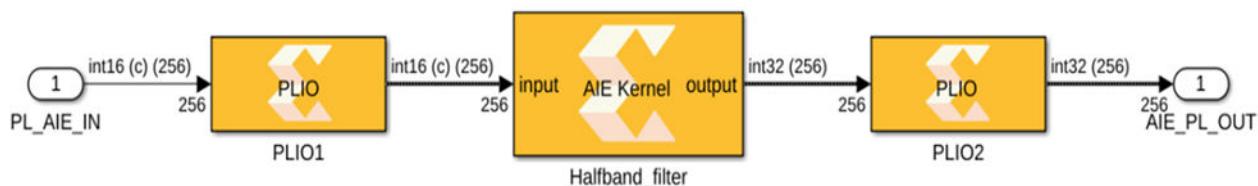


The AIE PLIO block supports specifying the Platform IO (PLIO) width. Specifying the PLIO width at the boundary of the AI Engine subsystem can affect the throughput of data between the AI Engine domain and the programmable logic (PL) domain. You can also set the constraints for the PLIO block using its constraint manager.

**Figure 225: Block Parameters: AIE PLIO**

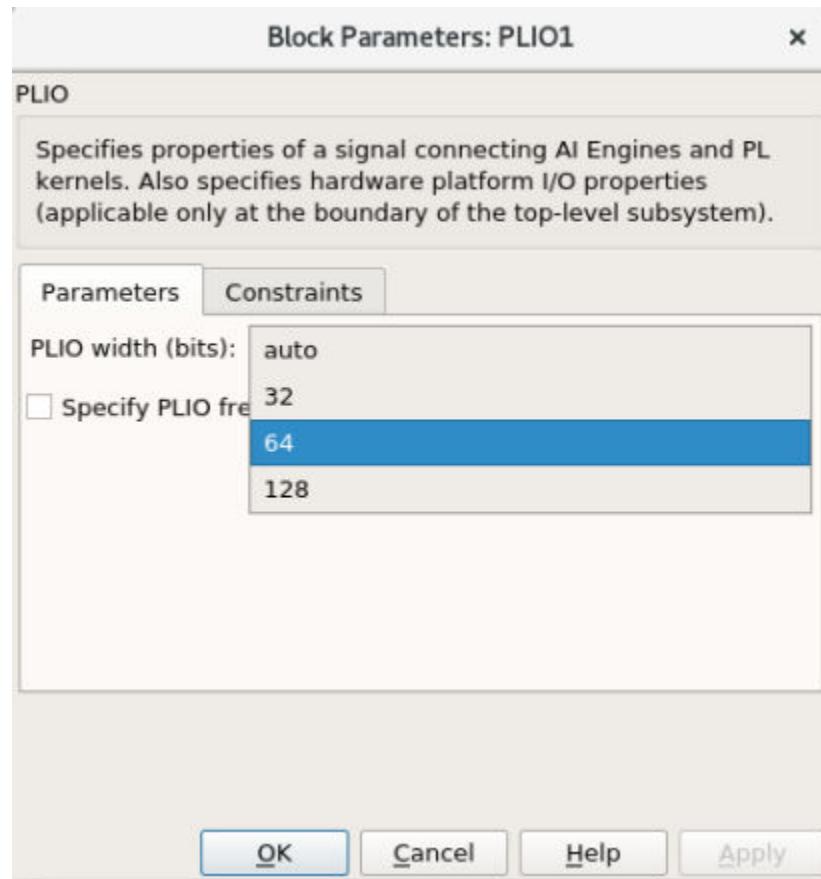
From the Parameters tab in the AIE Signal Spec block, you can select the available PLIO width options from the drop-down menu.

Consider following example where an AIE Signal Spec block is connected at the boundary of the AI Engine subsystem.

**Figure 226: AIE PLIO Block Connected to AI Engine Subsystem**

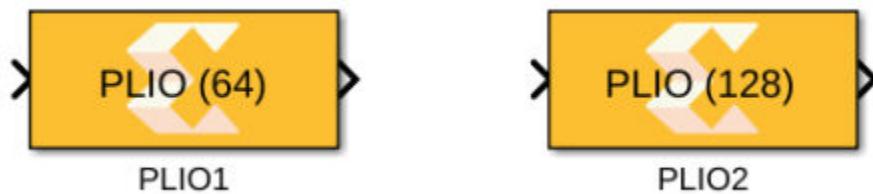
By default, the PLIO width is set to `auto`. Other available options are: `32`, `64`, and `128`.

Figure 227: Block Parameters: AIE PLIO Width



After the PLIO width is specified as 64 and 128 for the two AIE PLIO blocks in the example, the GUI updates as follows.

Figure 228: AIE Signal Spec Blocks Updated



The PLIO width specified using the AIE PLIO block is automatically updated in the generated graph code (`graph.cpp`) with PLIO constraints as shown in the following code.

**Note:** Adding the PLIO width does not impact the Simulink simulation, only the code generation.

### Snippet of graph.h

```
adf::input_plio PL_AIE_IN;
adf::output_plio AIE_PL_OUT;

Subsystem() {
    PL_AIE_IN = adf::input_plio::create("PL_AIE_IN",
        adf::plio_64_bits,
        "./data/input/PL_AIE_IN.txt");

    AIE_PL_OUT = adf::output_plio::create("AIE_PL_OUT",
        adf::plio_128_bits,
        "AIE_PL_OUT.txt");

    adf::connect<->(PL_AIE_IN.out[0], mygraph.PL_AIE_IN);
    adf::connect<->(mygraph.AIE_PL_OUT, AIE_PL_OUT.in[0]);
}
```

The PLIO attributes are used in a program to read input from a file or write output data to a file. You can see a connection with one 64-bit PLIO attribute declared for input and one 128-bit PLIO attribute declared for output.

### Data File Layout

When simulating PLIO with data files, the data should be organized to accommodate both the width of the PL block as well as the data type of the connecting port on the AI Engine block. Vitis Model Composer automatically generates the data file that accommodates to the specified PLIO width.

For example, a data file representing a 64-bit PL interface to an AI Engine kernel expecting `cint16` should be organized as four columns per row, where each column represents a 16-bit real or imaginary value.

PLIO Width	AIE Kernel Data Type	Dat File Layout
64-bit	cint16	0 0 0 0 1 1 1 1 2 2 2 2

This data file is in the output code directory.

### Specifying PLIO Frequency

The AI Engine always run at 1 GHz and can write (at most) two streams with a 32-bit data width per cycle. In contrast, an IP implemented in the PL can run at up to 500 MHz, while consuming a larger bit-width. In order to balance the throughput between the AI Engine and PL, and also ensure the processes do not create a bottleneck with respect to the total performance, it is required to match the rates between the two. Vitis Model Composer supports specifying the frequency of PL from Platform I/O tab in AIE Signal Spec block.

You can either adjust the PLIO frequency or the Width to match the rate between the AI Engine and PL. Consider an example of a 32-bit channel written to each cycle by the AI Engine at 1 GHz. In order for PL to match the rate of AI Engine, it has to consume twice the data at half the frequency or four times the data at a quarter of the frequency.

AI Engine		PL	
Frequency	Data per Cycle	Frequency	Data per Cycle
1 GHz	32 bit	500 MHz	64 bit
		256 MHz	128 bit

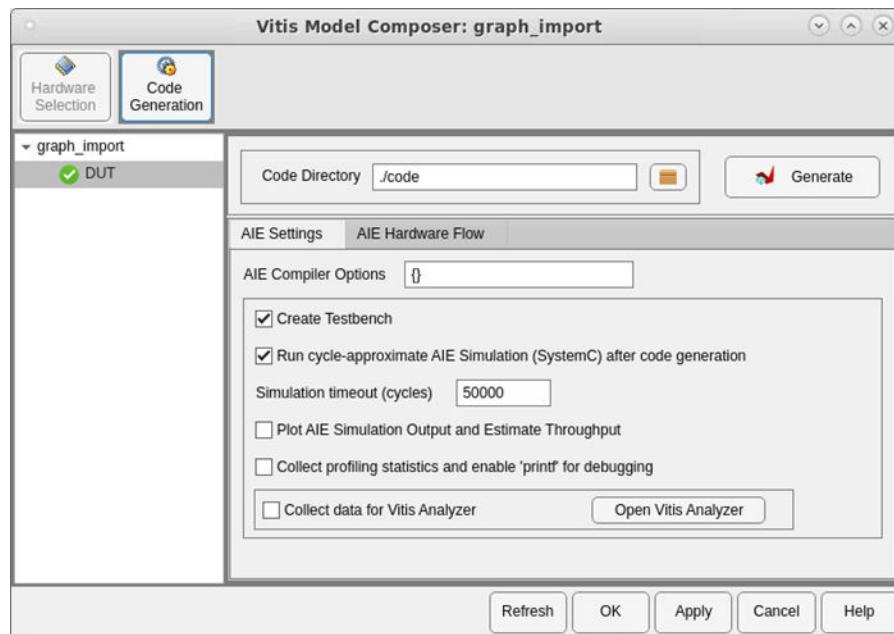
## Verification of AI Engine Code

The Versal® ACAP AIE simulator (`aiesimulator`) models the timing and resources of the AI Engine array accurately while using transaction-level, approximately timed SystemC models for NoC, DDR, PL, and PS. This allows accurate performance analysis of your AI Engine. Vitis Model Composer supports verification of the dataflow graph using this AIE simulator.

### Vitis Model Composer Hub Block for Verification

To verify the AI Engine design, you need to enable the **Create testbench** option on the Hub and then choose the simulator options available, as shown in the following figure.

Figure 229: Model Composer Hub: Testbench and Simulator Options



Enabling the **Create testbench** option only logs the test data, or stimulus at the input of your design, and the simulation results as test vectors for later use as "golden" results. By default, no simulator is selected and in order to verify the design, you need to select the **Run cycle-approximate AIE Simulation (SystemC) after code generation** option.

The Simulation timeout value limits the execution to the specified number of cycles. This is necessary because of the finite amount of input data - if the timeout value is not specified, the AI Engine kernels are invoked repeatedly forever (i.e., the graph runs infinitely). To avoid this situation, select the **Run cycle-approximate AIE Simulation (SystemC) after code generation** check box and specify the Simulation timeout value as shown in the following figure.

Figure 230: AIE Simulation: Timeout Value



The default timeout value is set to 50,000 cycles and this value is used to terminate the simulation after the specified number of clock cycles.

When only the **Create testbench** option is enabled, and the code is generated, the structure and contents of the target directory created by Model Composer consists of the following files (not a comprehensive list) in addition to the list mentioned in [Code Generation](#).

Table 23: Target Directory

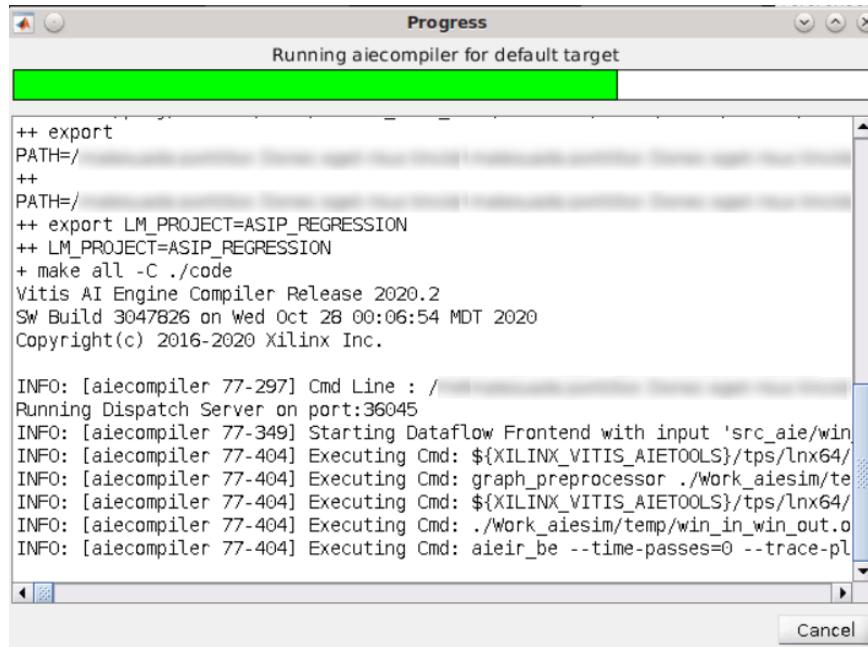
Directory/File	Sub-directory/File	Description
data/	input/	Contains files that capture the input stimuli from Simulink.
	reference_output/	Contains files that capture the simulation output from Simulink.

When the simulator option is enabled, the AI Engine code verification advances in three phases:

1. Compiling the AI Engine graph design.
2. Running simulation using the AI Engine simulator.
3. Verifying the simulation results by comparing the output with the golden reference output.

After clicking **Generate**, you can monitor the compilation, simulation, and verification progress of the AI Engine graph code from the Progress window (see the following figure).

Figure 231: Graph Code Progress



After successful compilation and simulation, Model Composer automatically compares the target output with the golden output and returns the following message in the Progress window (or in the corresponding simulation log files).

```
Comparing simulation results ...
Output data file : data/aiesimulator_output/Out1.txt.mod
reference data file : data/reference_output/Out1.txt
Simulation results MATCH.
*****
Test PASSED
Verification Complete
```

**Note:** In some scenarios, the simulator output produces fewer samples when compared with the golden output or vice-versa. In such cases, the test result will be still show as 'PASS.' This indicates that the first 'n' lines from the simulation output matches the first 'n' lines of the golden output and the results are partially matched. The .diff file in the corresponding simulator output captures any difference with the reference output.

Table 24: Target Directories

File Name/ Parent Directory	Filename/Sub-directory	Description
data/	aiesimulator_output/	Contains .txt files that captures the output of the AI Engine simulation. In addition to the actual output file, the .diff file is also generated to capture any difference from the golden result.

In addition to this, `aiecompiler` writes various configuration and binary files to the `Work_aiesim` directory. For more information on the structure and contents of the directory specific to the compilation, refer to the *AI Engine Tools and Flows User Guide (UG1076)*.

## Profiling Statistics and Event Tracing

You can obtain profiling data when you run your AIE simulation. Analyzing this data helps you gauge the efficiency of the kernels, the stall and active times associated with each AI Engine, and pinpoint AI Engine kernels whose performance may not be optimal. This also allows you to collect data on design latency, throughput, and bandwidth. In addition to this, you can do event trace using a formatted `printf` statement in the code for printing debug messages. To achieve this, you should enable the option **Collect profiling statistics and enable 'printf' for debugging** in the Model Composer Hub block.



**IMPORTANT!** Using this option generates a `run_summary` file which is written to the `aiesimulator_output` folder.



**IMPORTANT!** Enabling this option may slightly increase the overall AIE simulation time.

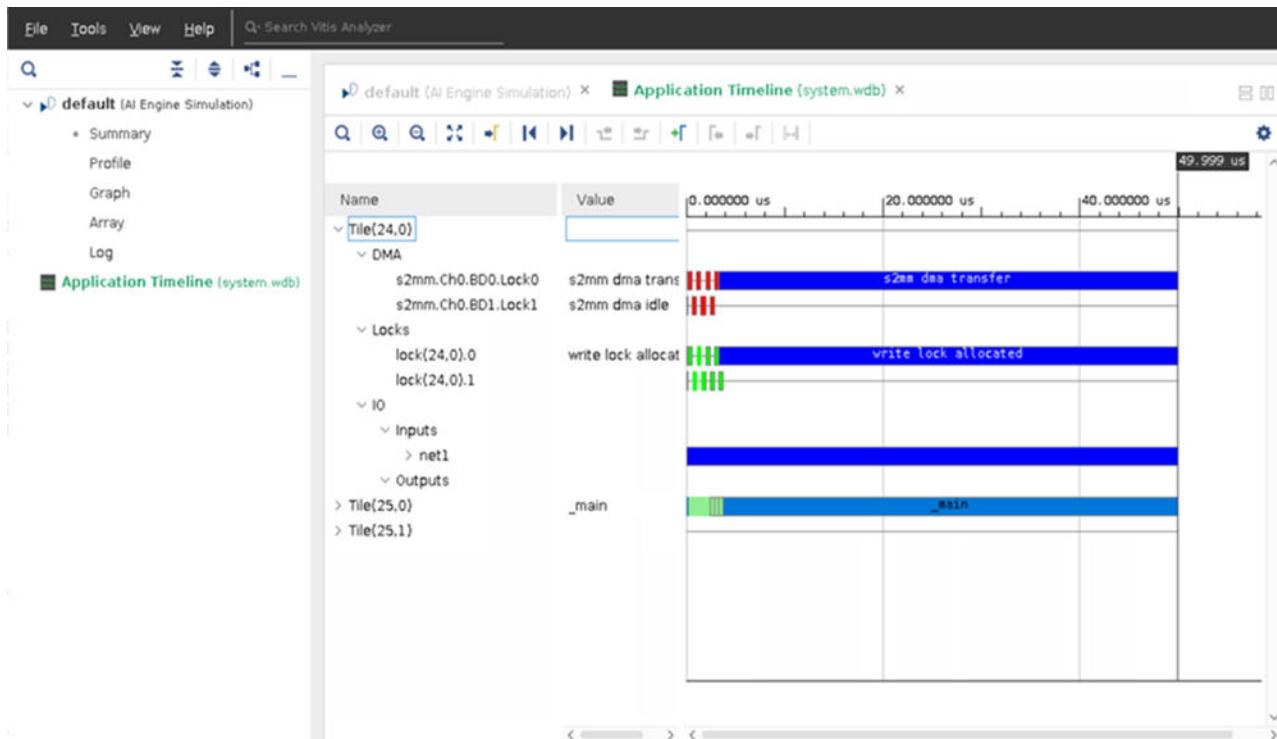
## Viewing Results in the Vitis Analyzer

The Vitis™ software platform analyzer is a utility that allows you to view and analyze the reports generated while building and running the application. It is intended to let you review reports generated by both the Vitis compiler when the application is built, and the Xilinx Runtime (XRT) library when the application is run. The Vitis analyzer can be used to view reports from Vitis integrated design environment (IDE).

During the simulation of the AI Engine graph, the `aiesimulator` writes a summary of the simulation results called `default.aierun_summary`. This can be viewed in the Vitis analyzer. The summary contains a collection of reports and diagrams reflecting the state of the AI Engine application.

Vitis Model Composer integrates the Vitis analyzer utility. This can be invoked by enabling the **Collect Data for Vitis Analyzer** option from within the Hub block, along with the AIE Simulation. When the simulation completes, Model Composer automatically reads the `system.wdb` file which is generated during the `aiesimulator` run and invokes the Application Timeline window in Vitis Analyzer as shown.

Figure 232: Application Timeline



From the report navigator you can view other available reports, such as Summary, Profile, Graph, Array, and Log.

**Note:** You can relaunch the Vitis Analyzer by clicking **Open Vitis Analyzer** as shown in the following figure. This option can be used to invoke the Vitis Analyzer tool, only when the AIE Simulation has been ran at least once after enabling the **Collect data for Vitis analyzer** option.



In Vitis Model Composer, you can launch Vitis analyzer from the MATLAB command window using the following command.

```
xmcOpenVitisAnalyzer('file')
```

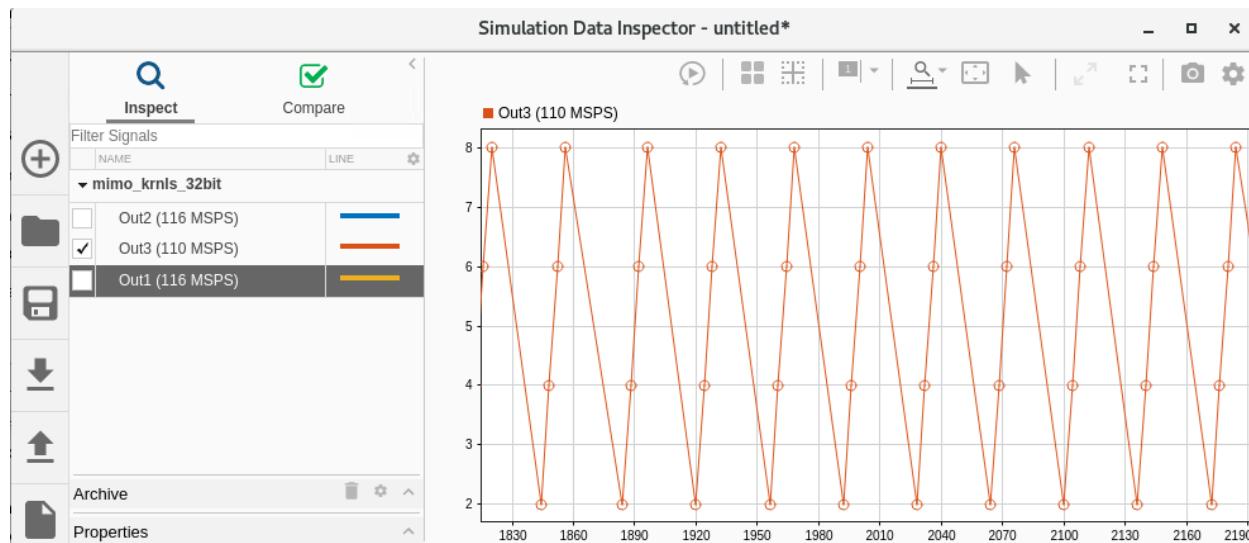
When this command is given without a <file> option, Model Composer looks up all `default.aierun_summary` and `system.wdb` files in the current target directory and invokes the Vitis analyzer to display the results in the summary page.

For more information on the Vitis analyzer, refer to the Using Vitis Analyzer topic in [Vitis Unified Software Platform Documentation](#).

## Plotting AIE Simulation Output Data and Calculating Throughput

Vitis Model Composer provides the capability to log the simulation data and visualize the output of an AI Engine subsystem by integrating the Simulink 'Simulation Data Inspector' feature. It also calculates the throughput for each output port of the AI Engine subsystem. To achieve this, enable the option **Plot AIE Simulation output and estimate the throughput** from the Hub block. When the AIE simulation completes, the tool automatically brings up the Simulation Data Inspector window reflecting the outputs of the AI Engine subsystem as shown in the following figure.

Figure 233: Simulation Data Inspector



The Simulation Data Inspector displays available data in the Inspect pane. To plot a signal, select the check box next to the signal. You can modify the layout and add different visualizations to analyze the simulation data. You can also get the throughput information for each port from the Inspect pane. If required, you can re-open the Simulation Data Inspector from the Simulink® Editor toolbar using the **Simulation Data Inspector** button.

For more information on using the Simulink Simulation Data Inspector, visit <https://in.mathworks.com/help/simulink/ug/populate-sdi-with-your-data.html>.



**IMPORTANT!** Model Composer can only plot the outputs of the AI Engine subsystem automatically.

## Running Simulation using the Makefile

If you want to edit the graph code, for example, to add or modify constraints, or explore the graph code by editing the kernel configuration parameters (like window size or window margin etc.), and re-compile. Vitis Model Composer generates a Makefile allowing you to easily accomplish this by running the following command.

```
make all
```

This command compiles an AI Engine graph using the default `aiecompiler` target and runs the simulation using `aiesimulator`. It also compares the output of the simulator with the golden output. This command also launches the Vitis analyzer, based on the option selected in the Hub block.

To do this, you need to source the `settings64.csh` or `settings64.sh` from `<MODEL_COMPOSER_INSTALLATION_DIRECTORY>/Model_Composer/<VERSION>`

When the code is generated without the **Create testbench** option checked, the `aiesimulator` settings in Makefile are as follows.

### Default aiesimulator Settings

```
#####
## aiesimulator settings
#####
AIE_SIM := aiesimulator
AIE_SIM_TIMEOUT := 50000
AIE_OUTPUT_DIR := $(DATA_DIR)/aiesimulator_output
AIESIM_FLAGS := --profile
LAUNCH_VITIS_ANALYZER :=
```

Observe the Timeout value is 50000 which is default and `LAUNCH_VITIS_ANALYZER` is not set to TRUE. To run simulation for different timeout values with the Vitis analyzer enabled, you may need to manually edit the Makefile as follows.

### Modified Settings

```
AIE_SIM_TIMEOUT := <Value>
LAUNCH_VITIS_ANALYZER := true
```

When the code is generated with the **Create testbench** option selected, and the simulator option is enabled, then the modifications done in the Model Composer Hub block for **Simulation Timeout** and **Collect Data for Vitis Analyzer** are automatically reflected in the Makefile.

# Hardware Validation Flow for AI Engines and PL

---

## Introduction

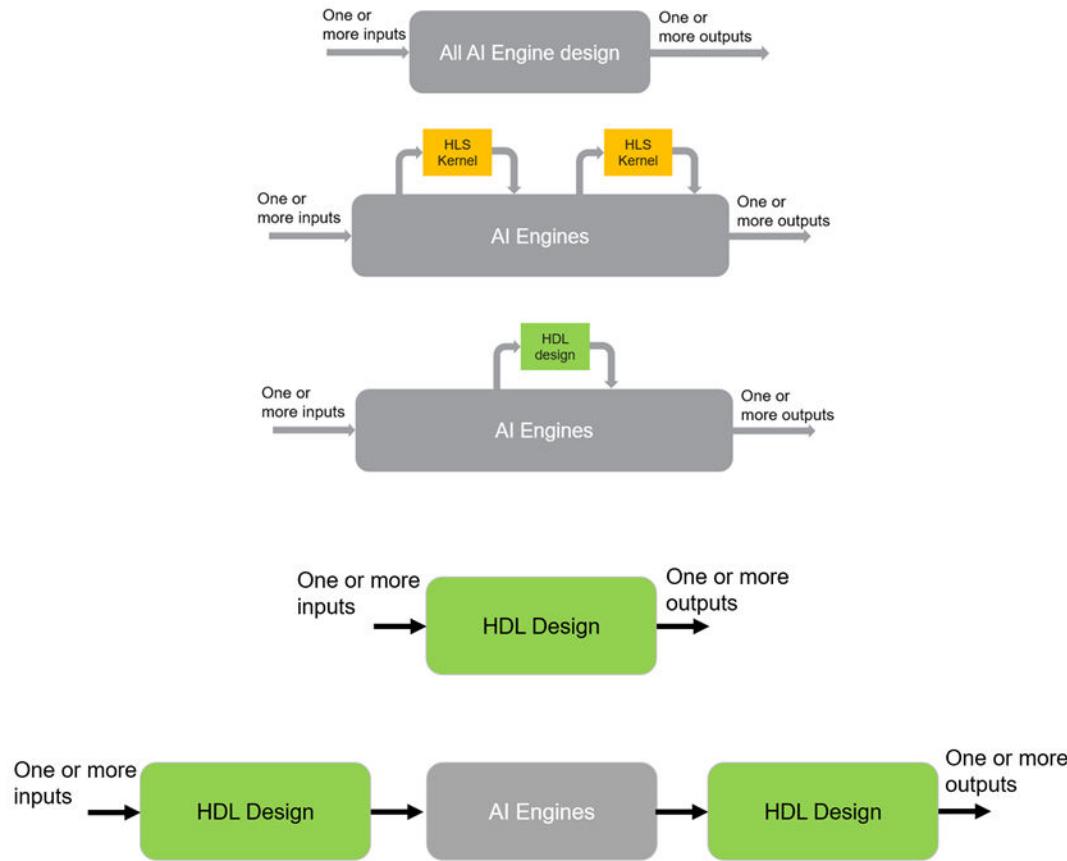
The hardware validation flow for AI Engines and PL in Vitis Model Composer provides a methodology to verify AI Engine- and PL-based applications on Xilinx hardware (Versal devices). Vitis Model Composer provides the option to generate a hardware image targeting a specific platform for the Simulink model. This hardware image can then be run on a board to verify whether the results from hardware match with the simulation output. This image can be either baremetal or Linux-based. This section covers the details of the Hardware Validation flow.

---

## High-Level Flow for Generating a Hardware Image

You can generate a hardware image for designs with only AI Engine blocks, designs with both PL and AI Engine blocks, or designs with only PL blocks. The following figure shows the topologies that are supported for Hardware Validation flow.

Figure 234: Supported Topologies for Hardware Validation Flow



**IMPORTANT!** Vitis Model Composer supports integration of blocks from the AI Engine library with the HDL library to generate a hardware image. However, to integrate with HLS C/C++ code, you should use the HLS Kernel block, and not other blocks from the HLS library.

To generate the hardware image from a Simulink design, you should have an expandable platform. This is a file with the .xp fm extension. For Xilinx hardware, such as VCK190, the platform files are shipped with Vitis. You can also create an expandable custom platform for a custom board and use it in Vitis Model Composer. For more information refer to [UG1393](#).

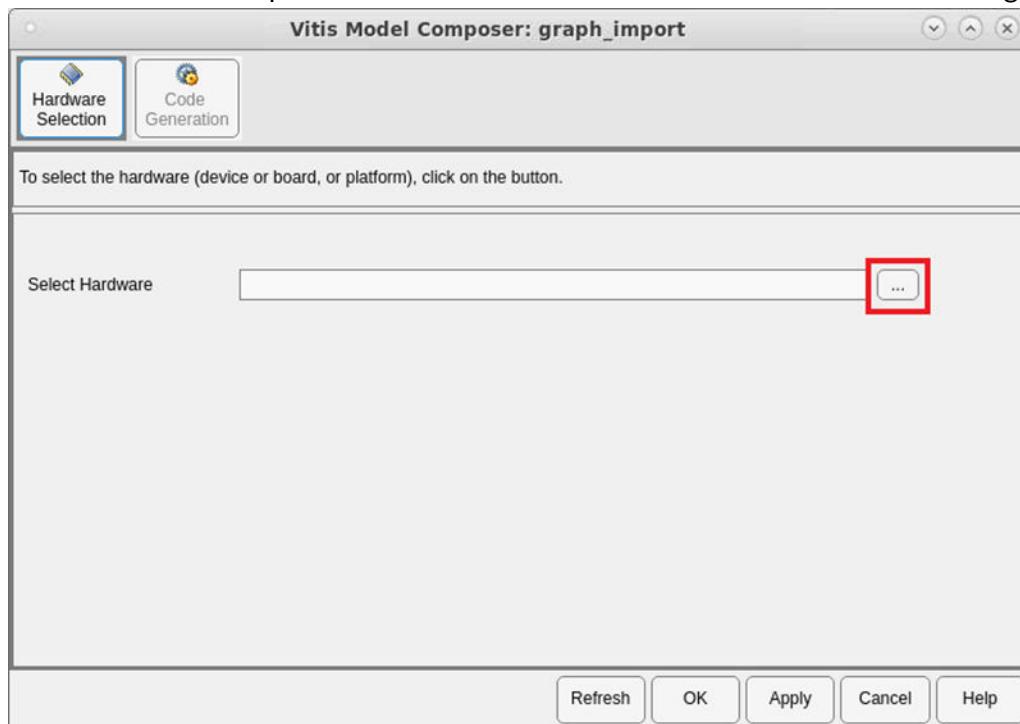
Using the Vitis Model Composer Hub block, you have a choice between creating a baremetal application or Linux-based application for either a hardware target or a hardware emulation target. In hardware emulation, Vivado simulator is used to simulate the PL portions of the design and QEMU is used to emulate the host code for the Arm processor. The advantage of hardware emulation is that there is no need for a hardware board. However, hardware emulation is only an emulation of the hardware and is, in general, slower than running the design in hardware.

As part of the creation of the hardware image, the input data samples that are fed into the design during simulation in Simulink are collected. Likewise, the output data samples from the design are also collected. The input and output data is packaged as part of the hardware image and downloaded to the hardware. The input data is fed into the design in hardware, the output data is collected and compared with the output data from simulation. This comparison is done by the processor in the device. Unless something is wrong, the result should match bit by bit with the result of the simulation because the simulation in Vitis Model Composer is bit-accurate. The hardware runs independently of Vitis Model Composer, and during the hardware run no information is communicated between Vitis Model Composer and the hardware.

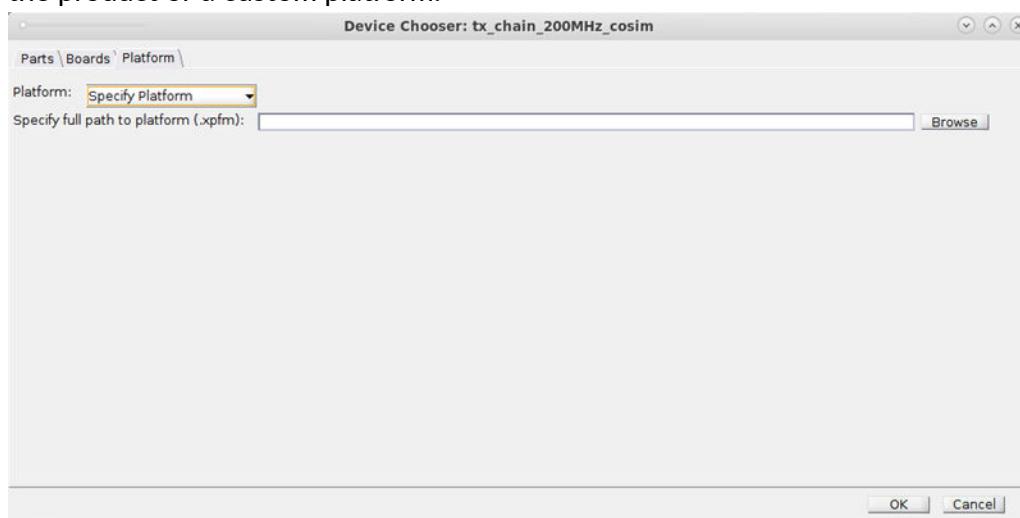
**Note:** For baremetal applications, the tool generates a `BOOT.BIN` image file. For Linux-based applications the tool generates an `sd_card.img` image file. In both cases, for hardware emulation, Vitis Model Composer triggers the emulation when image creation is complete. If you choose the hardware target, you can find the details of how to move the images to the VCK190 hardware board [here](#).

# Setting up the Tool to Generate an Image File for Hardware Validation Flow

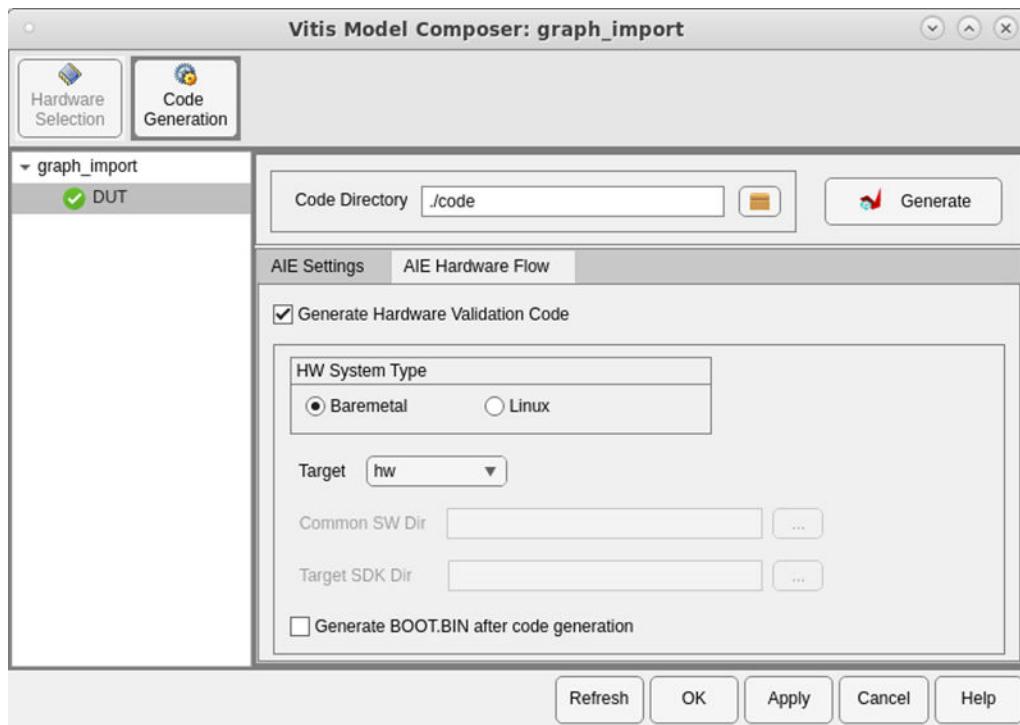
1. Choose a platform. In the Vitis Model Composer Hub block, select the **Hardware Selection** tab on the left and open the hardware selector menu as shown in the following figure.



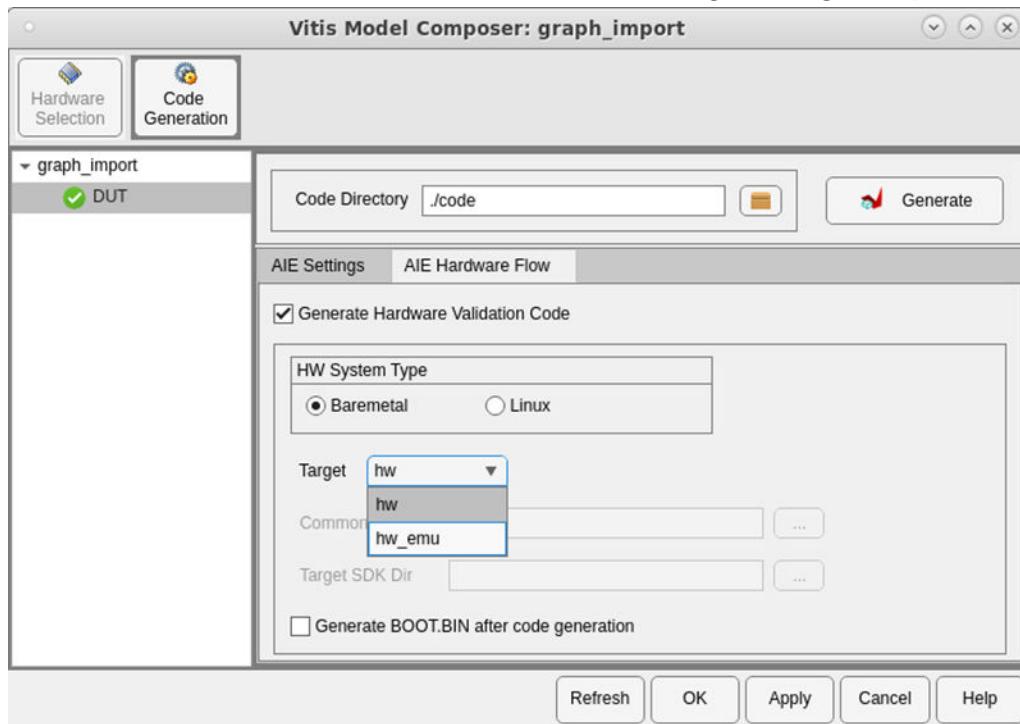
2. Select the **Platform** tab from the top and browse to select either a platform that ships with the product or a custom platform.



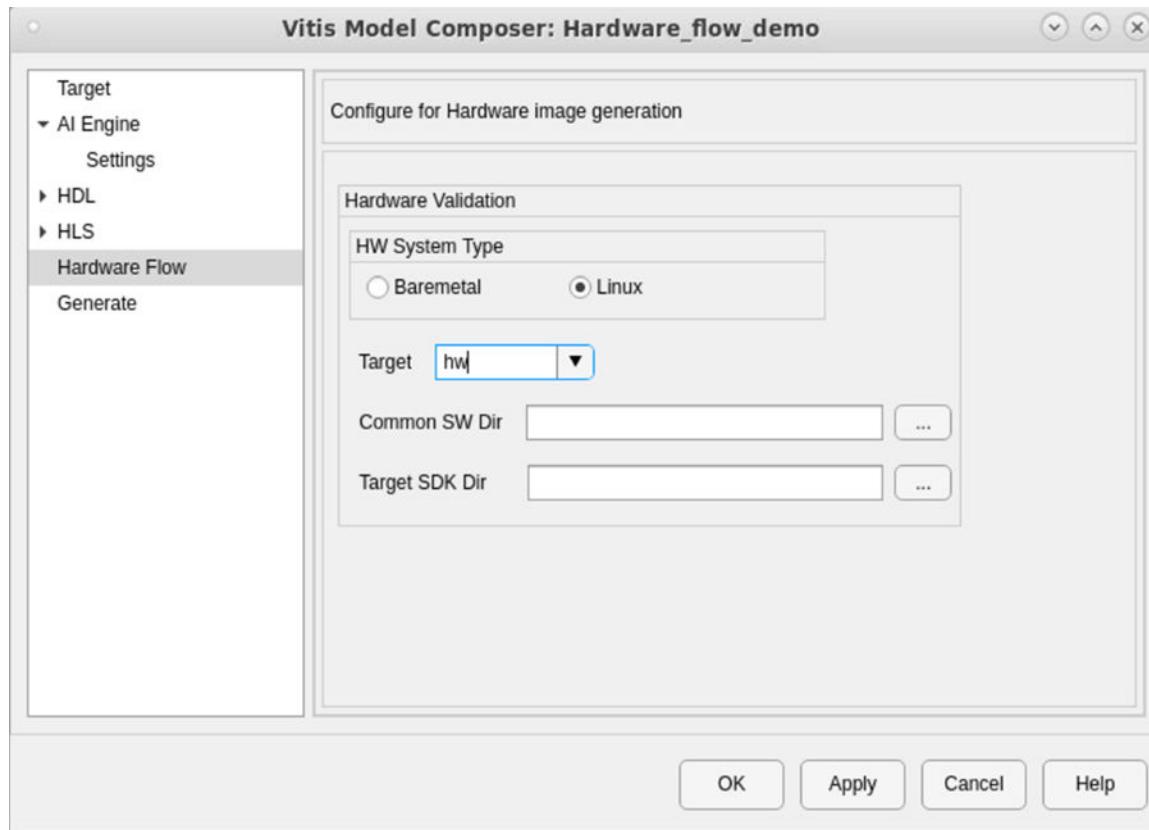
3. Select the subsystem containing HDL and/or AI Engine blocks for which to perform hardware validation. Select the **Hardware Flow** tab and the **Generate Hardware Validation Code** check box.



4. Under **HW System Type**, choose between **Baremetal** and **Linux**. For each selection, you can choose between hardware or hardware emulation using the **Target** drop-down menu.



**Note:** For Linux applications only, further information is required (see the following figure). This is a once-only action. Use the following steps to obtain the necessary information.



1. Click [here](#) to download the Versal common image. Unzip the download and specify the directory in the **Common SW Dir** field.
2. Switch to bash shell and source  `sdk.sh` in the common image directory. This will prompt for a target directory path for the SDK. Extracting the SDK will take about ten minutes. Specify the SDK directory in the **Target SDK Dir** field.
5. Click **Generate**. Depending on your settings and the complexity of your design, generation may take up to one hour. Subsequent generation can be much faster if changes to the design do not cause a change in the PL. For example if you simply increase the simulation time in Simulink (to collect more data), change the data source, or make modifications to the AI Engine kernel, the subsequent image generations will be faster.

# Generating the Hardware Image Outside the MATLAB Environment

When **Generate Hardware Validation Code** is selected from the Model Composer Hub block and the **Generate** button is clicked, the process can take some time, especially when the image is being built for the first time. This may stall that particular MATLAB session for any other work. To avoid this, you can generate the image outside of MATLAB such that the MATLAB session remains free for other work.

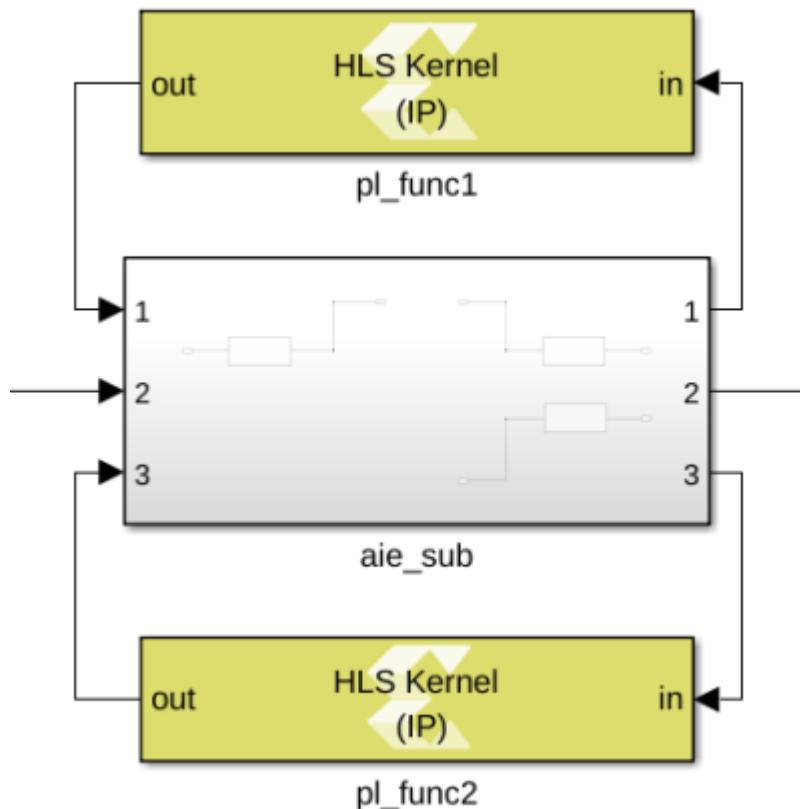
1. Open a Linux terminal and ensure the \$XILINX\_VITIS environment variable is set.

**Note:** Source the script `settings64.sh` from `<Model Composer Install directory>/Model_Composer/<Version>/settings64.sh` in order to setup the XILINX\_VITIS environment.

2. `cd` to the `<code-generation-directory>/run_hw` directory.
3. From the Linux terminal, run `./run_hw.sh`.

## Design Considerations

- For designs with HDL blocks, the HDL Netlist generation directory must be `./netlist`, and the sequence of code generation must be followed.
- Designs with HLS kernel blocks connected to other HLS kernel blocks are not currently supported. Designs with HLS kernel blocks connected to AIE DUT are supported; however, you can connect multiple HLS kernels to the AIE DUT. For example, consider the topology as shown in the following figure.



Here, two HLS kernels are connected to the different ports of the `aie_sub`. This is supported for the hardware validation flow.

- HLS kernels must have AXI input and output ports.
- You can only use HLS kernel blocks to import C/C++ code (for PL) and to connect with AI Engines. The blocks from the HLS library are not allowed to connect and co-simulate.

# Connecting AI Engine and Non-AI Engine Blocks

---

## AI Engine/Programmable Logic Integration

An AI Engine kernel written using specialized intrinsic and imported into Model Composer can be used as part of a larger Versal® ACAP system design. In addition to kernels operating on the AI Engines, you can specify kernels to run on the programmable logic (PL) region of the device. The PL kernels can be written using RTL or HLS C/C++ functions. The connection between AI Engine and the PL block is routed through a physical channel interface tile and conceptually the data width of the connections are 32 bits, 64 bits or 128 bits.

Model Composer allows connecting an AI Engine kernel to a HLS PL kernel only if the data types and complexities of these port matches. If the datatypes or complexities of the port of the AI Engine kernel and the port of the PL kernel do not match, an interface blocks should be used to reconcile the discrepancy.

This chapter discusses interconnecting HDL blocks or HLS C/C++ functions with AI Engine kernels:

- [Interconnecting AI Engine and HDL Blocks](#)
- [Interconnecting AI Engines and HLS Kernels](#)

## Interconnecting AI Engine and HDL Blocks

The HDL blockset in the Xilinx® toolbox contains the common DSP building blocks such as adders, multipliers, and registers. It also includes a set of complex DSP building blocks such as FFTs, filters and memories. Model Composer automatically compiles designs into low-level representations (i.e., RTL) which can be targeted to programmable logic. The Versal hardware allows for connecting AI Engine kernels and PL kernels. However, HDL and AI Engine domains are incompatible in at least two aspects:

- The HDL domain is cycle accurate, whereas the AI Engine domain is only bit accurate. A Model Composer HDL design may not be ready to accept input data or may not have a valid output and these are managed through `tvalid` and `tready` signals of AXI4-Streamports.

- The HDL domain accepts only scalar inputs, whereas AI Engine blocks work with variable sized vector signals.

In order to properly manage the sampling times across two domains and simulate the heterogeneous system with both PL (modeled with HDL blocks) and AI Engine, Vitis Model Composer provides interface blocks in the [Utilities](#) library to connect from AI Engine to HDL blocks and vice-versa.

- AIE to HDL - This block connects AI Engine to HDL blocks using an AXI4-Stream-like interface.
- HDL to AIE - This block connects HDL to AI Engine blocks using an AXI4-Stream-like interface.

You can find these blocks in `Xilinx Toolbox/Utilities/Connectors` library.

Figure 235: Connector Blocks



As discussed, AIE to HDL and HDL to AIE blocks have `tvalid` and `tready` ports as depicted in the previous figure. The gateway from the AI Engine to the HDL domain can accept a vector input but generates a scalar output, meaning that in Simulink, the HDL domain will run at a different rate than the AI Engine domain. For example, if the AI Engine domain is producing 16 samples at every clock, the HDL domain must run at least 16 times faster to process the data. However, in some cases, the HDL domain needs to run even faster because the HDL domain, being a cycle accurate domain, may not consume one sample per clock. For example, if the HDL domain consumes one sample every two clocks (known as an initiation interval of 2), for the earlier example, the HDL domain needs to run 32 times faster than the AI Engine domain.

The following sections discuss setting the block parameters of the AIE to HDL and HDL to AIE blocks and includes examples.

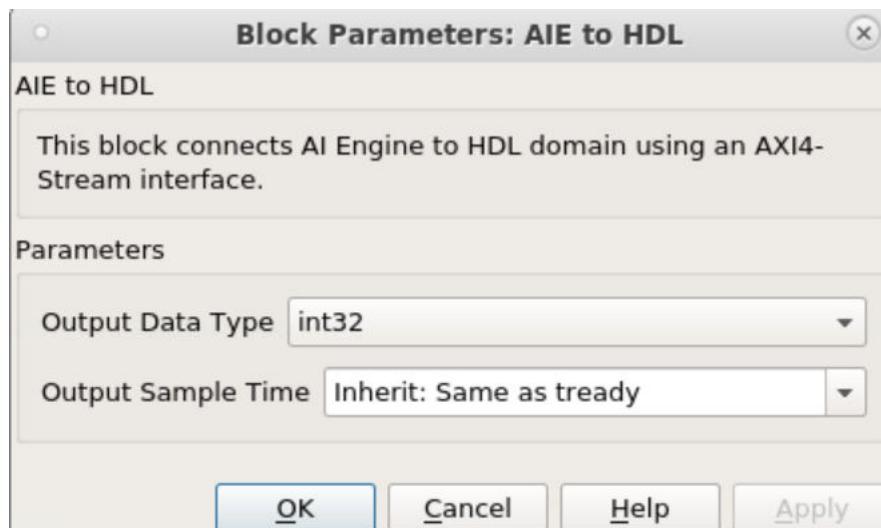
## AIE to HDL

The AIE to HDL block connects the output of AI Engine block with the input of HDL block. This block accepts variable size signal from AI Engine blocks along with the `tready` signal which indicates whether the HDL domain can accept the data. The input data type to this block is inherited from the input signal. Note that if the HDL domain `tready` signal stays low for a long time, eventually the internal buffers in the AIE to HDL block will overflow and the simulation stops. The bit width of the `tdata` output of the AIE to HDL block is limited to 32, 64, and 128 according hardware functionality.

Figure 236: AIE to HDL



Figure 237: AIE to HDL Parameters



## Setting the AIE to HDL Block

The following image depicts the components that are needed to connect an AI Engine subsystem to an HDL design. In setting this connection, you should consider certain input design criteria and set the parameters of the blocks accordingly. These input design criteria are:

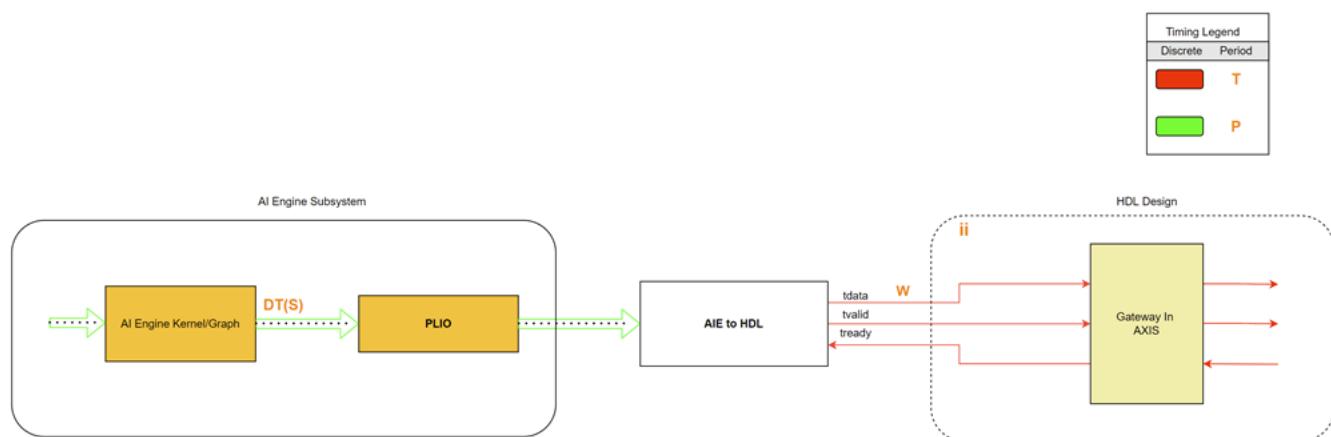
1. In the HDL design, the bit width of the `tdata` signal line ( $w$ ). This is the bit width of the data in the programmable logic.
2. HDL design sample time ( $T$ ). This sample time determines the target clock rate for which the HDL design will be clocked in hardware. For single clock designs, this will be the sample time set in the Gateway In AXIS block.

3. As mentioned previously, simulation in HDL domain is cycle-accurate. An HDL design may not be ready to accept a new sample at every cycle (the `tready` signal from the HDL design will be set to zero when the HDL design cannot accept new samples). This is referred as the initialization interval ( $II$ ) of the HDL design. For example, if an HDL design accepts a new sample every 10 cycles, the design would have an  $II$  of 10. A design that can accept a new sample at every clock cycle has an initiation interval of one.
- 4.
5. The number of samples in the output of the AI Engine kernel ( $S$ ).
6. The output data type of the AI Engine kernel ( $DT$ ).

Set  $P$  to be the period of the AI Engine subsystem. Note that all the inputs and outputs signals of the AI Engine subsystem must have the same period. Later a lower limit will be determined for  $P$ .

**Note:** The PLIO block is a pass-through block and only impacts code generation.

Figure 238: Setting the AIE to HDL Block



### Step 1: Set the PLIO bit width in the PLIO Block

Set the PLIO bit width to  $W$ .

### Step 2: Set Parameters of the AIE to HDL Block

- **Output Data Type:**

Set the **Output Data Type** such that the output bit width is  $W$ . If  $W$  is larger than the bit width of the input, the output should be unsigned, or else the output should have the same signedness of the input. Note that the input bit width cannot be larger than  $W$ .

- **Output Sample Time:**

Set the **Output Sample Time** to **Inherit: Same as tready** (this is equivalent of setting this to  $T$ ). Note that the bit rate into the block is:

$$\frac{S \times (\text{DT bit width})}{P}$$

and the output bit rate of the block is:

$$\frac{W}{T}$$

For the internal buffers of the block not to overflow, the input rate should be less than or equal to the output rate. However, the HDL design has an initialization interval of  $ii$ . As such,

$$\text{input rate} \leq \frac{\text{output rate}}{ii}$$

or

$$P \geq \frac{S \times T \times ii \times (\text{DT bit width})}{W}$$

### Step 3: Set parameters of the Gateway In AXI Stream block

- Set **Output data type** to  $W$ .
- Set **Sample Time** to  $T$ .

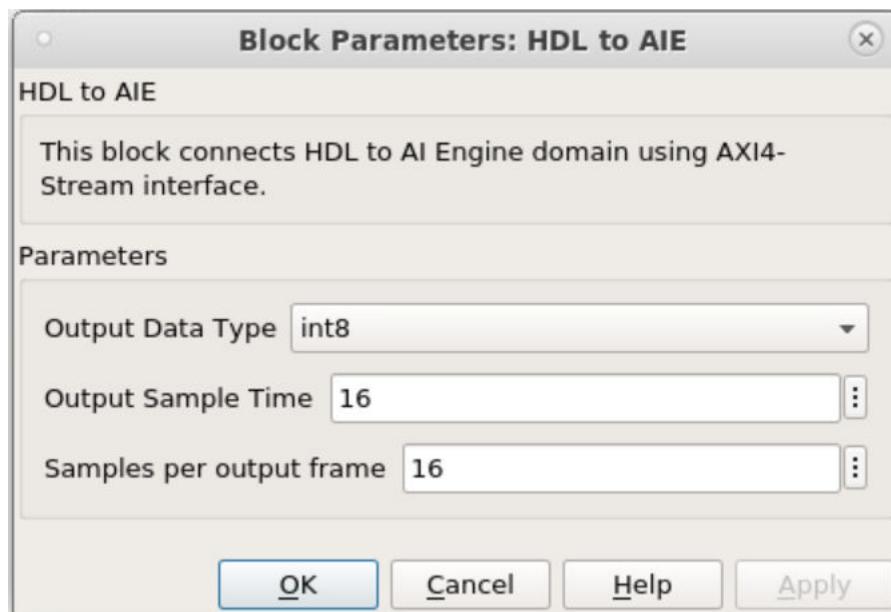
### HDL to AIE

The HDL to AIE block connects the output of the HDL block with the input of the AI Engine block. This block accepts `tdata` which is the primary input for the data and the `tvalid` signal that indicates the producer has valid data. Output from the HDL to AIE block is a variable size signal (`data`) to AI Engine blocks along with the `tready` signal which indicates that the block can accept a transfer. A transfer takes place when both `tvalid` and `tready` are asserted.

Figure 239: HDL to AIE



Figure 240: HDL to AIE Parameters



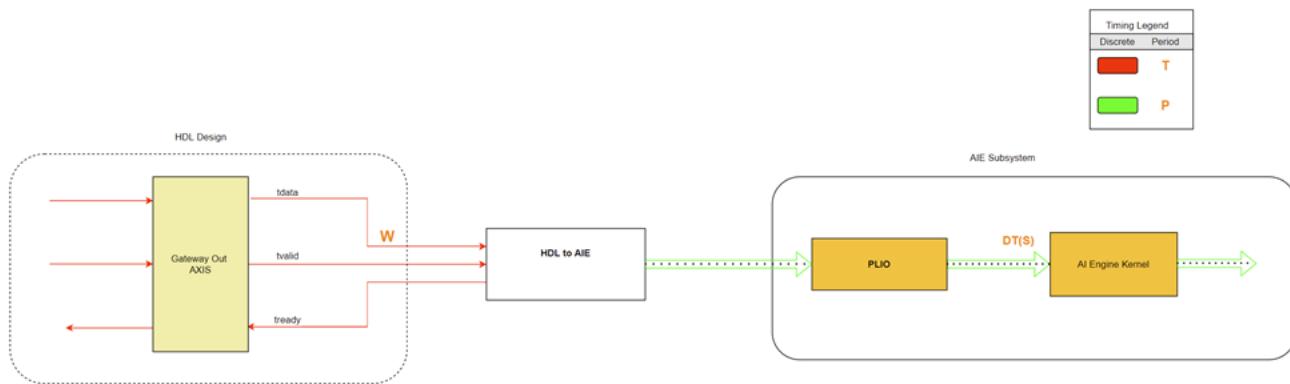
## Setting the HDL-AIE Block

The following image depicts the components that are needed to connect an HDL design to an AI Engine subsystem. In setting this connection, you should consider certain input design criteria and set the parameters of the blocks accordingly. These input design criteria are:

1. The bit width of the `tdata` signal line ( $w$ ). This is the bit width of the data in the programmable logic.
2. HDL design sample time ( $T$ ). This sample time determines the target clock rate for which the HDL design will be clocked in hardware.
3. The input data type to the AI Engine kernel block ( $DT$ ). This is determined by the AI Engine kernel.

4. The number of samples in the input to the AI Engine kernel block ( $S$ ). For an AI Engine kernel with a window input type this is typically the size of the input window. For an AI Engine kernel with a stream input, this is typically the number of samples the AI Engine kernel consumes at every invocation.
5. The period of all the input and output signals going into or out of the AI Engine subsystem ( $P$ ). All the input and output signals of the AI Engine subsystem must have the same period.

Figure 241: Setting the HDL to AIE Block



Considering the five design criteria above, set the parameters of the blocks as follows:

#### Step 1: Set the PLIO bit width in the PLIO block

Set the PLIO bit width to  $W$ .

#### Step 2: Set the parameters of the HDL to AIE block

- Set Output Data Type to  $DT$ .
- Set Output frame size to  $S$ .
- Set Output Sample Time to  $T \times (\text{bit width of } DT)/(W)$  if this input is driving the AI Engine subsystem period or to  $P/S$  if the period of the AI Engine subsystem ( $P$ ) is determined by another input to AI Engine subsystem.

#### Step 3: Set the Gateway Out AXIS block

Set the **Sample Period** parameter to the same value as in the corresponding Gateway In, AXI Stream block.

# Interconnecting AI Engines and HLS Kernels

## ***HLS Function versus HLS Kernel***

You can import an HLS function into your Model Composer design using the `xmc ImportFunction` command as described in [Importing C/C++ Code as Custom Blocks](#). You can simulate the block along with other blocks available in the Model Composer HLS library and generate HLS code from a system comprised of one or more imported HLS function blocks and other HLS blocks from the HLS library, except for HLS Kernel block. Model Composer can also import HLS kernels. This section describes HLS Kernels and how it is different from an HLS function.

## ***Behavior of HLS Functions on Blocking Calls***

An HLS function first and foremost is a function. It has a predetermined number of inputs and outputs and every time the function is invoked, it consumes the inputs and produces the predetermined number of outputs. If an HLS function imported using `xmc ImportFunction` hangs, (for example, if it has an infinite loop), Simulink will also hang, waiting indefinitely for the output from the imported block. This is because an imported HLS function using `xmc ImportFunction` runs on the same thread as Simulink. If the imported functions hangs, Simulink also hangs.

## **HLS Kernels are IPs**

When you import an HLS function into a design by itself, the HLS function will not operate as an IP with streaming ports. In Vitis Model Composer, you need to enclose the HLS function in a subsystem (perhaps along with other HLS blocks) and use the Interface Spec block to designate streaming ports for the design. You can then generate an HLS IP. Unlike an imported HLS function, an HLS Kernel is a proper HLS IP that can be used in the Vitis™ HLS and be synthesized directly. The following code snippet highlights the HLS kernel code with streaming interface.

`hls_kernel.cc`

```
void hls_kernel_blk(
    hls::stream<ap_axis<64, 0, 0, 0>> & in_sample1,
    hls::stream<ap_axis<64, 0, 0, 0>> & in_sample2,
    hls::stream<ap_axis<64, 0, 0, 0>> & out0_itrl1,
    hls::stream<ap_axis<64, 0, 0, 0>> & out1_itrl1
)
{
    #pragma HLS PIPELINE II=1
    #pragma HLS INTERFACE ap_ctrl_none port=return
    #pragma HLS INTERFACE axis register both port=out1_itrl1
    #pragma HLS INTERFACE axis register both port=out0_itrl1
    #pragma HLS INTERFACE axis register both port=in_sample1
    #pragma HLS INTERFACE axis register both port=in_sample2
```

```
ap_int64 in_samp0 ; // Iteration-1: 2 complex samples concatenated to  
64-bit  
    ap_int64 in_samp1 ; // Iteration-2: 2 complex samples concatenated to  
64-bit  
...
```

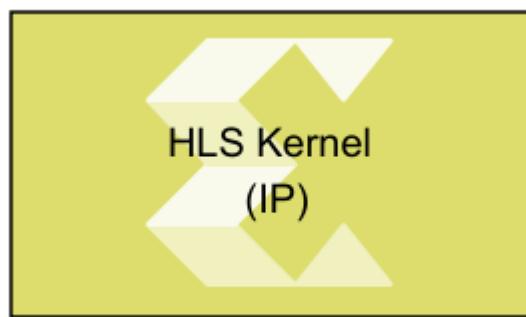
In this example, notice the function signature and also the HLS pragmas specifying the interface on the ports. This function has all the constructs required by the HLS IP. You can directly import the code above into Model Composer using the HLS Kernel block, and then simulate it.

An HLS Kernel block can accept variable size signals allowing it to connect to AI Engine blocks and also produces variable size output signals. Unlike a block that is imported using `xmcImportFunction`, the HLS Kernel block runs on a separate thread than Simulink and as such, the presence of a blocking read call in the HLS kernel code will not cause Simulink to hang when the input variable size signal is empty, instead the block will also produce an empty variable size output signal.

### ***Importing HLS Kernels***

To import the HLS kernel as a block into Model composer, you need to select it from the HLS/ User-Defined Functions library.

*Figure 242: HLS Kernel*



Double-click the block symbol to display the parameters of the HLS kernel block as shown in the following figure.

Figure 243: HLS Kernel Parameters



The block mask parameters need to be updated in order to import the HLS kernel as a block. The following table provides details on the parameters and descriptions for each parameter.

Table 25: Parameters

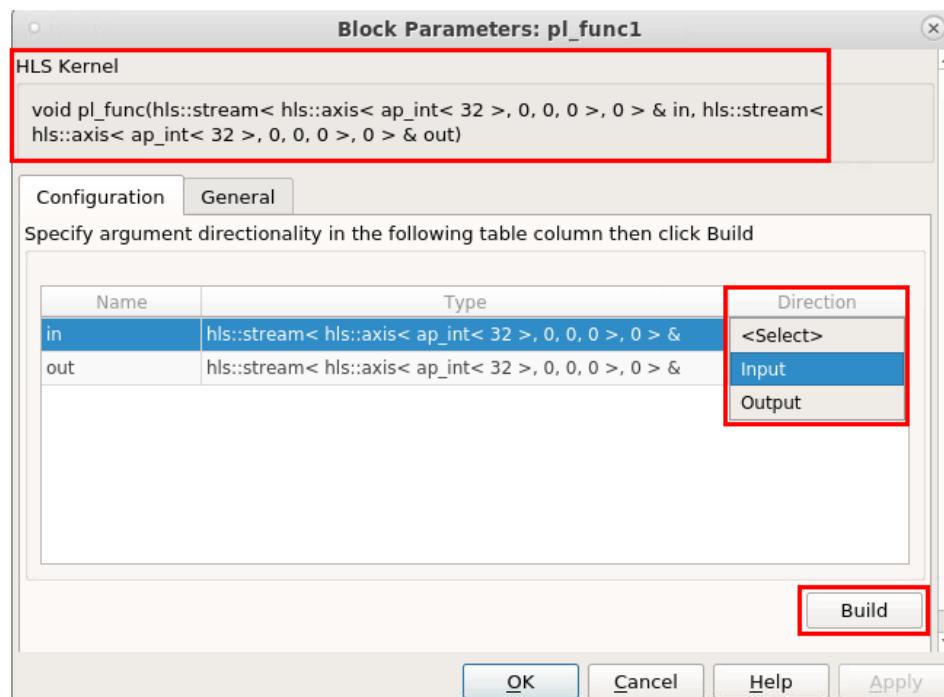
Parameter Name	Parameter Type	Criticality	Description
Kernel header file	String	Mandatory	The name of the HLS kernel header file that contains the function declaration. The string could be just the file name, a relative path to the file, or an absolute path of the file. Use the <b>Browse</b> button to select the file. If environment variables are used to specify the header file path, then an appropriate error is returned.
Kernel function	String	Mandatory	The name of the kernel function in C/C++ for which the HLS kernel block is to be created.
Kernel source file	String	Optional	The name of the source file that contains the kernel function implementation (definition). The string could be just the file name, a relative path to the file or the absolute path of the file. You can specify both the declaration and the definition of the function in the header file and leave this field empty. If environment variables are used to specify the source file path, an appropriate error is returned.

Table 25: Parameters (cont'd)

Parameter Name	Parameter Type	Criticality	Description
Kernel search paths	Vector of Strings	Optional	If the kernel header file or the kernel source file are not found using in the current folder, then the paths provided in Kernel search paths are used to locate the files. This parameter allows use of environment variables while specifying paths for the kernel header file and the kernel source file. The environment variable can be used in either \${ENV} or \$ENV format.
Preprocessor options		Optional	Optional preprocessor arguments for downstream compilation with specific preprocessor options. The following two preprocessor option formats will be accepted (multiple can be selected): -Dname and -Dname=definition. That is, the optional argument must begin with the -D string and if the option definition value is not provided, it is assumed to be 1.

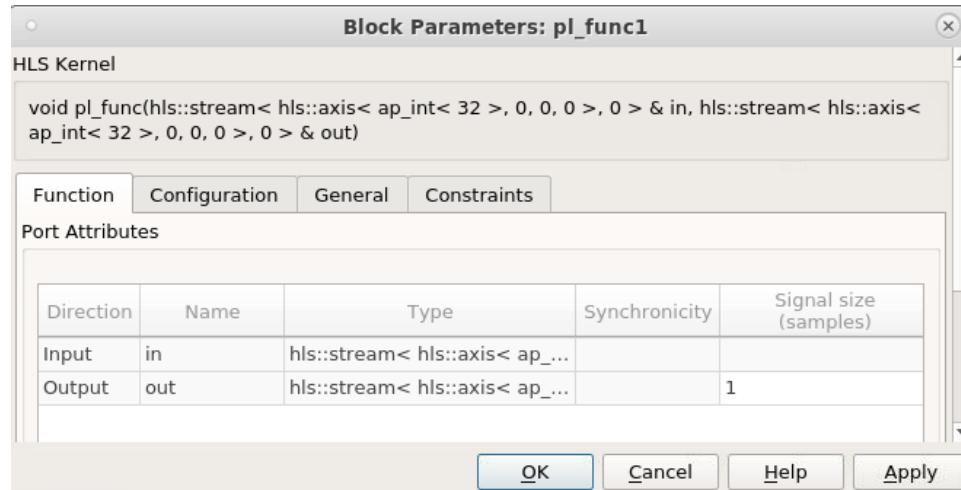
After successful import, the Function tab GUI displays automatically. You can quickly review the HLS Kernel definition and specify the directionality of the ports from the drop-down as shown in following figure.

Figure 244: Kernel Definition and Ports



When you click on the **Build** button after specifying the directionality of the ports, a new window opens as shown in the following figure. Don't forget to set the Signal size appropriately for stream signal types or else you may run into a memory overflow. For example, if at every invocation, the kernel produces 16 samples, set Signal Size to 16.

Figure 245: Kernel Definition and Ports (Post-Build)



## Importing Templated Functions

HLS kernel block supports importing a templated function as a block into Vitis Model Composer. Consider the HLS kernel with function template as depicted in the following code.

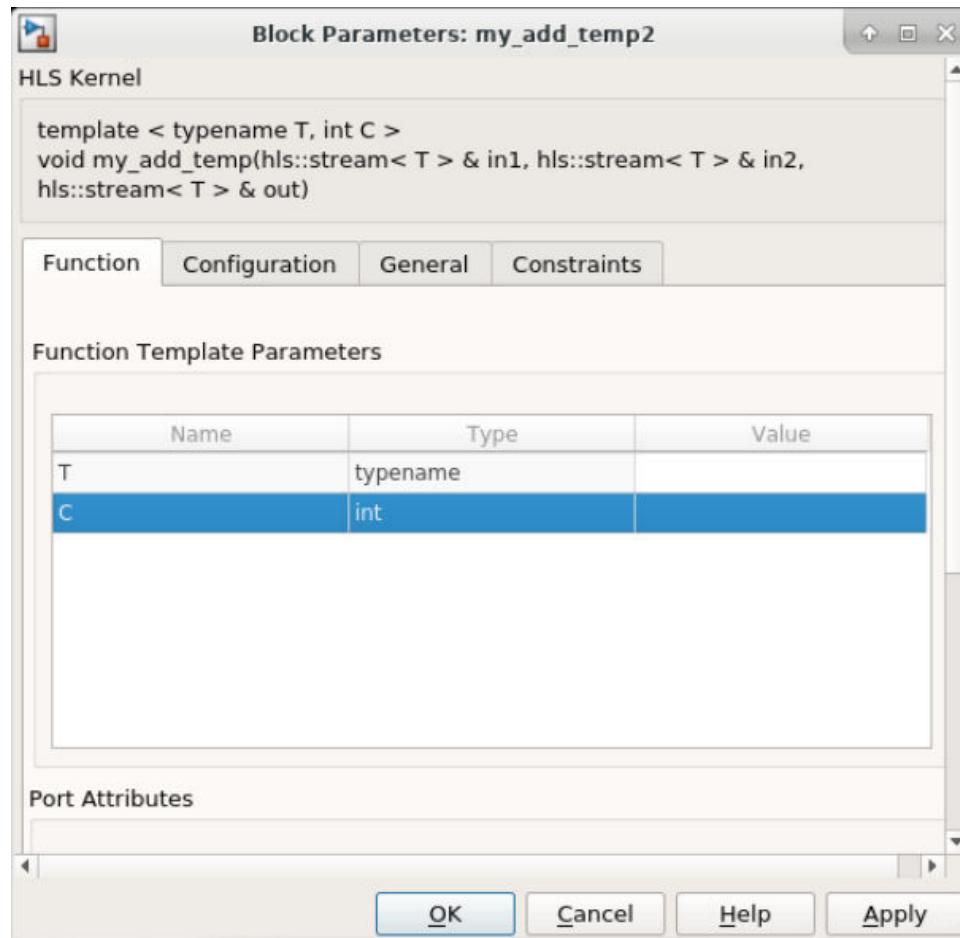
```
template <typename T, int C>
void my_add_temp(hls::stream<T> & in1, hls::stream<T> & in2, hls::stream<T> & out)
{
    T a, b, c;

    a = in1.read();
    b = in2.read();
    c = a + b * C;

    out.write(c);
}
```

After configuring the port directionalities and clicking **Build** as explained in the previous section, the following dialog box opens for setting the template values.

Figure 246: Block Parameters Dialog Box



You can enter the template values in the **Function Template Parameters** section click **Apply** then **OK**. This generates the HLS Kernel block with all the ports in the interface.

### ***Interconnect AI Engine and HLS Kernel Blocks***

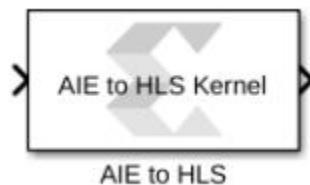
Connections between an output port of an AI Engine kernel and an input port of an HLS kernel use an AIE to HLS Kernel block. Connections between an output port of an HLS kernel and an input port of an AI Engine kernel use an HLS Kernel to AIE block. These blocks reformat the data to match the data type of the sink port. In this process no data (information) is lost; and it is simply adjusting the data type and the number of samples. For example, an interface block can reformat a signal carrying 64 int8 values to a signal carrying 16 int32 values. Use of these blocks are not mandatory if the data types between the HLS kernel block and the AI Engine blocks match.

These blocks are available in the Xilinx Toolbox/Utilities/Connectors library.

## AIE to HLS Kernel

The AIE to HLS Kernel block reformats a signal driven by an AI Engine Kernel block or an AI Engine kernel output port is of type `cint16` and the HLS kernel is of type graph block, so that the resulting signal matches the data type `ap_axis<64>`, you would use an AIE to HLS kernel block with parameter output type set to `ap_axis<64>`. This block reads `cint16` samples from its input and then packs pairs of subsequent `cint16` samples into `ap_axis<64>` samples to its output.

Figure 247: AIE to HLS Kernel Block



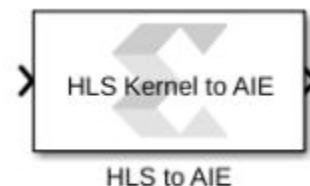
Double-click the block symbol to see the parameters of the AIE to HLS Kernel block. For more information refer to graph block, so that the resulting signal matches the data type and complexity required by the input of an HLS kernel block. For example, if the [AIE to HLS](#).

- **Output Type:** Possible values are: `ap_axis<32>`, `ap_axis<64>`, `ap_axis<128>`, `ap_axiu<32>`, `ap_axiu<64>`, `ap_axiu<128>`, `ap_int<32>`, `ap_int<64>`, `ap_uint<32>`, `ap_uint<64>`, int, long long, unsigned, unsigned long long.
- **Output Size:** The size of the output port. The output port is a variable sized signal whose maximum size is specified by the OutputSize parameter. Default Output Size is 1.

## HLS Kernel to AIE

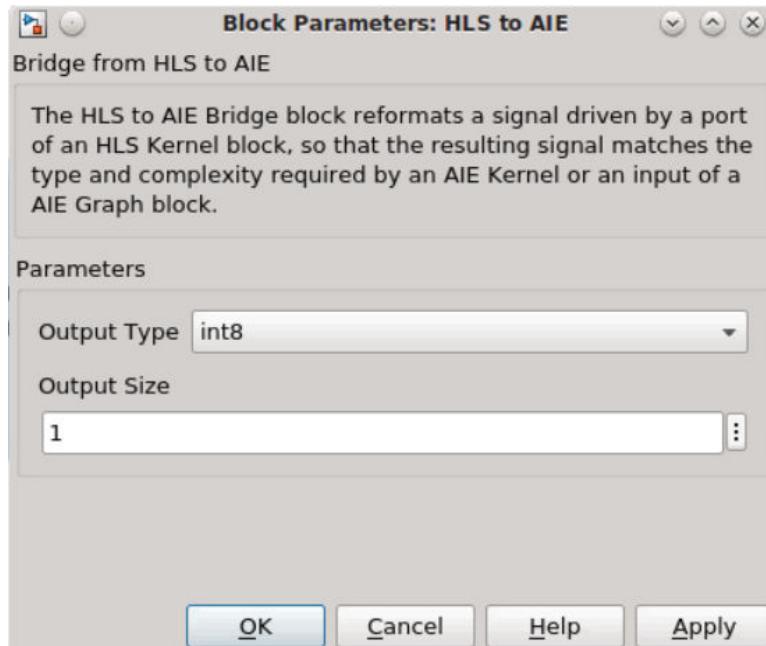
The HLS Kernel to AIE block reformats a signal driven by a port of an HLS kernel block, so that the resulting signal matches the data type and complexity required by an AI Engine kernel or an input of a AI Engine graph block. For example, if the data type of port of the HLS kernel block is `axiu<128>` and the data type of the port of the AI Engine is `uint32`, the HLS Kernel to AIE block reformats the input samples by unpacking each `axisu<128>` sample into four `uint32` samples. The output port of this block is a variable-size signal.

Figure 248: HLS Kernel to AIE Block



Double-click the block symbol to see the parameters of the HLS Kernel to AIE block. For more information refer to [HLS to AIE](#).

Figure 249: Block Parameters: HLS Kernel to AIE



- **Output Type:** Possible values are: int8, int16, int32, int64, uint8, uint16, uint32, uint64, cint16, cint32.
- **Output Size:** The size of the output port. The output port is a variable-sized signal whose maximum size is specified by the Output Size parameter. Default size is '1'.

---

## Connecting Source and Sink Blocks

The AI Engine library is compatible with the standard Simulink block library, and these blocks can be used together to create models that can be simulated in Simulink. However, only certain blocks which are designed to probe at different points in the design and debug are permitted inside a subsystem during code generation. Namely, Scope, Display, To Workspace blocks etc. In addition to these, the AI Engine library provides some sink blocks that can be connected to the variable-size signal output from the AIE Kernel or AIE Graph blocks.

Block	Description
To Fixed Size	Converts variable-size output to fixed size.
Variable Size Signal to Workspace	Logs the variable signal to workspace.

## To Fixed Size

The output ports of the AIE Kernel and AIE Graph blocks are variable-sized (vector) signals. There is a possibility that the kernel does not produce a fixed number of output samples in each simulation step. Many Simulink blocks do not accept variable-size signals as inputs and so this limits leveraging Simulink blocks in designs that use the AIE kernel and AIE Graph blocks.

Model Composer provides the To Fixed Size block which takes a variable-sized vector input and produces a fixed sized vector output.

Figure 250: To Fixed Size



The 'To Fixed Size' block takes a variable sized vector input and produces a fixed sized vector output. The output size is specified by the Output Size parameter. The block copies samples from the input to the output.

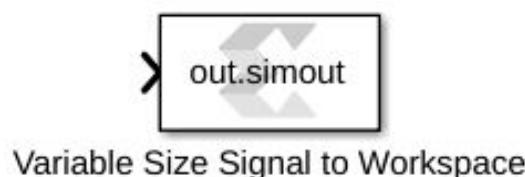
The input will be buffered till the number of samples reaches the Output Size. The buffered samples will then be transferred to the out port, and the valid port is set to true. When there are not enough samples buffered, the out port will be a vector of zeros, and the valid port is set to false.

The default value of the Output Size parameter is **Inherit: Same as input**. This block supports all the data types that are supported by Model Composer and the input can be real or complex.

## Variable Size Signal to Workspace

The output ports of AIE Kernel and AIE Graph blocks are variable-sized signals. Model Composer provides a Variable Size Signal to Workspace block in the AI Engine library to easily save the output into a workspace variable in MATLAB. The block will save only the valid samples of the input variable size signal, making analysis of the signal much easier.

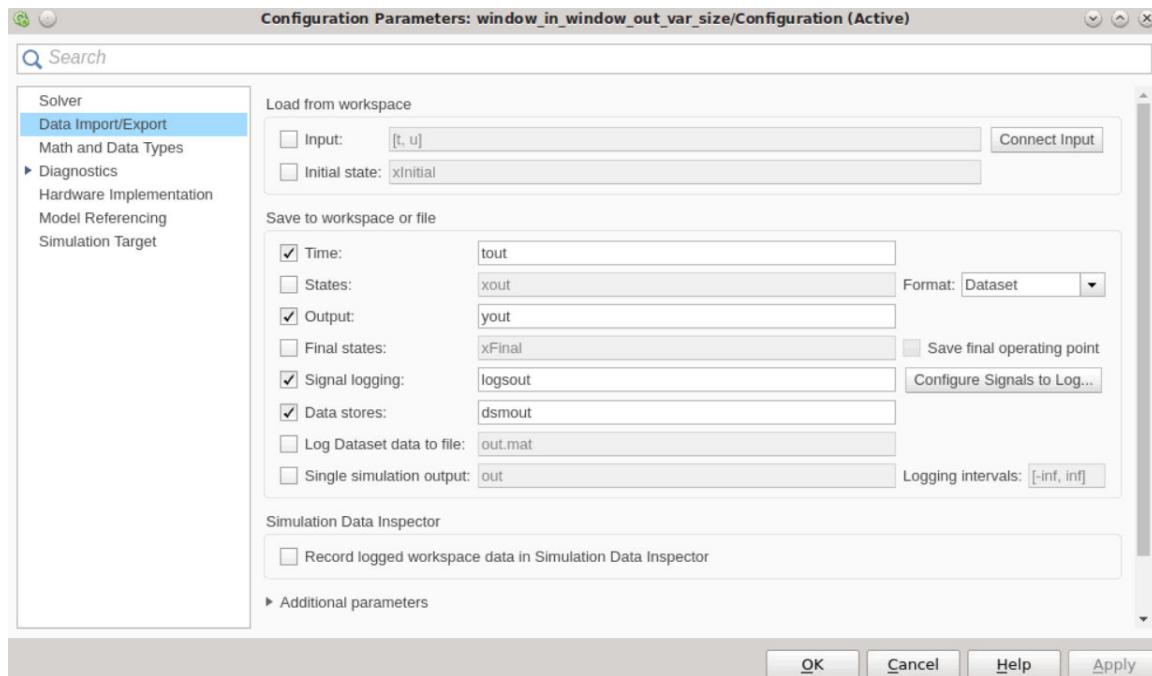
Figure 251: Variable Size Signal to Workspace



Within the block parameters, the default name for Variable name is set to 'simout'.

Because the Variable Size Signal to Workspace block is using the Simulink To Workspace block under the mask, settings that change the behavior of the To Workspace block will impact the Variable Size Signal to Workspace block as well. The block settings can be accessed from Model Settings (Ctrl-E).

Figure 252: Configuration Parameters



You can set the name of the output (default is `out`) from the settings window and you can also control whether the To Workspace block outputs the results in a structure called `out`. Regardless of whether the checkbox is selected or what name is chosen, this block will work in a similar way as the To workspace block.

If you toggle the Single simulation output check box from Model Settings, press Ctrl-D to refresh the text on the Variable Size Signal to Workspace block.



**IMPORTANT!** If there is an error in the simulation, the block creates an empty variable when Single simulation output is not checked from the Model Settings window. This behavior is consistent with the To Workspace block.

Connecting the AI Engine block to source blocks that generate or import signal data (Constant, Signal to Workspace block etc.) is supported.

# Xilinx Toolbox

## Xilinx Toolbox Block Description

### AI Engine Blocksets

Table 26: DSP

Block	Description
<b>Stream IO</b>	
DDS Stream	Implements the stream-based Direct Digital Synthesizer (DDS) targeted for AI Engines.
FFT Stream	Stream-based FFT implementation targeted for AI Engines.
FFT Dynamic Point Stream	FFT Dynamic Point Stream implementation targeted for AI Engines.
FIR Asymmetric Decimation Stream	Implements the stream-based FIR Asymmetric Decimation filter targeted for AI Engines.
FIR Asymmetric Stream	Implements the stream-based FIR Asymmetric filter targeted for AI Engines.
FIR Halfband Decimator Stream	Implements the stream-based FIR Halfband Decimator filter targeted for AI Engines.
FIR Halfband Interpolator Stream	Implements the stream-based FIR Halfband Interpolator filter targeted for AI Engines.
FIR Interpolation Stream	Implements the stream-based FIR Asymmetric Interpolation filter targeted for AI Engines.
FIR Symmetric Decimation Stream	Implements the stream-based FIR Symmetric Decimation filter targeted for AI Engines.
FIR Symmetric Stream	Implements the stream-based FIR Symmetric filter targeted for AI Engines.
IFFT Stream	Stream-based IFFT implementation targeted for AI Engines.
Mixer Stream	Implements the stream-based Mixer targeted for AI Engines.
Window Function Stream	Implements the Window Function Stream targeted for AI Engines.
<b>Window IO</b>	
DDS	Implements the Direct Digital Synthesizer (DDS) targeted for AI Engines.
FFT	Implements the FFT targeted for AI Engines which use rounding method and saturates the output samples on overflow.
FFT Dynamic Point	FFT Dynamic Point implementation targeted for AI Engines.
FIR Asymmetric	Implements the Single Rate Asymmetric FIR Filter targeted for AI Engines.
FIR Asymmetric Decimation	Implements the FIR Asymmetric Decimation filter targeted for AI Engines.

**Table 26: DSP (cont'd)**

<b>Block</b>	<b>Description</b>
FIR Halfband Decimator	Implements the FIR Halfband Decimator targeted for AI Engines.
FIR Halfband Interpolator	Implements the FIR Halfband Interpolator targeted for AI Engines.
FIR Interpolation	Implements the FIR Asymmetric Interpolation filter targeted for AI Engines.
FIR Resampler Filter	Implements the FIR Fractional Asymmetric Interpolation filter targeted for AI Engines.
FIR Symmetric	Implements the Single Rate Symmetric FIR Filter targeted for AI Engines.
FIR Symmetric Decimation	Implements the FIR Symmetric Decimation Filter targeted for AI Engines.
IFFT	Implements the Inverse FFT targeted for AI Engines which use the rounding method and saturates the output samples on overflow.
Mixer	Implements the Mixer targeted for AI Engines.
Window Function	Implements the Window Function targeted for AI Engines.

**Table 27: Interfaces**

<b>Block</b>	<b>Description</b>
FIFO	Allows specification of the FIFO depth on a particular path.
PLIO	Allows the Platform IO (PLIO) width to be specified.

**Table 28: Signal Routing**

<b>Block</b>	<b>Description</b>
Bus Creator	Create Signal Bus
Bus Selector	Select signals from incoming bus
From	Accept input from Goto block
Goto	Pass block input to From blocks

**Table 29: Sinks**

<b>Block</b>	<b>Description</b>
Display	Show value of input
Scope	Display signals generated during simulation
Stop Simulation	Stop simulation when input is nonzero
Terminator	Terminate unconnected output port
To File	Write data to file
To Workspace	Write data to workspace

**Table 30: Source**

Block	Description
RTP Source	Used as a source for the RTP input of an AI Engine block. When the RTP input is a scalar, the 'RTP Value' parameter should be a row vector. At each time step, the output is set to one of the elements of the vector starting with the first element. If an element of the vector is NaN, at the corresponding sampling time, the output will be an empty variable size signal.

**Table 31: User-Defined Functions**

Block	Description
AIE Class Kernel	Import class-based AI Engine kernels.
AIE Graph	Import an AI Engine graph.
AIE Kernel	Import an AI Engine kernel.

## HDL Blocksets

### Basic Element Blocks

**Table 32: Basic Element Blocks**

Block	Description
Absolute	The Xilinx Absolute block outputs the absolute value of the input.
Accumulator	The Xilinx Accumulator block implements an adder or subtractor-based scaling accumulator.
AddSub	The Xilinx AddSub block implements an adder/subtractor. The operation can be fixed (Addition or Subtraction) or changed dynamically under control of the sub mode signal.
CMult	The Xilinx CMult block implements a gain operator, with output equal to the product of its input by a constant value. This value can be a MATLAB expression that evaluates to a constant.
Convert	The Xilinx Convert block converts each input sample to a number of a desired arithmetic type. For example, a number can be converted to a signed (two's complement), or unsigned value.
Depuncture	The Xilinx Depuncture block allows you to insert an arbitrary symbol into your input data at the location specified by the depuncture code.
Divide	The Xilinx Divide block performs both fixed-point and floating-point division with the a input being the dividend and the b input the divisor. Both inputs must be of the same data type.
Down Sample	The Xilinx Down Sample block reduces the sample rate at the point where the block is placed in your design.
Exponential	This Xilinx Exponential block performs the exponential operation on the input. Currently, only the floating-point data type is supported.
Expression	The Xilinx Expression block performs a bitwise logical expression.
Mult	The Xilinx Mult block implements a multiplier. It computes the product of the data on its two input ports, producing the result on its output port.
MultAdd	The Xilinx MultAdd block performs both fixed-point and floating-point multiply and addition with the a and b inputs used for the multiplication and the c input for addition or subtraction.

Table 32: Basic Element Blocks (cont'd)

Block	Description
Mux	The Xilinx Mux block implements a multiplexer. The block has one select input (type unsigned), and a user-configurable number of data bus inputs, ranging from 2 to 1024.
Natural Logarithm	The Xilinx Natural Logarithm block produces the natural logarithm of the input.
Negate	The Xilinx Negate block computes the arithmetic negation of its input.
Parallel to Serial	The Parallel to Serial block takes an input word and splits it into N time-multiplexed output words where N is the ratio of number of input bits to output bits. The order of the output can be either least significant bit first or most significant bit first.
Puncture	The Xilinx Puncture block removes a set of user-specified bits from the input words of its data stream.
Reciprocal	The Xilinx Reciprocal block performs the reciprocal on the input. Currently, only the floating-point data type is supported.
Reciprocal SquareRoot	The Xilinx Reciprocal SquareRoot block performs the reciprocal squareroot on the input. Currently, only the floating-point data type is supported.
Reinterpret	The Xilinx Reinterpret block forces its output to a new type without any regard for retaining the numerical value represented by the input.
Relational	The Xilinx Relational block implements a comparator.
Requantize	The Xilinx Requantize block requantizes and scales its input signals.
Scale	The Xilinx Scale block scales its input by a power of two. The power can be either positive or negative. The block has one input and one output. The scale operation has the effect of moving the binary point without changing the bits in the container.
Serial to Parallel	The Serial to Parallel block takes a series of inputs of any size and creates a single output of a specified multiple of that size. The input series can be ordered either with the most significant word first or the least significant word first.
Shift	The Xilinx Shift block performs a left or right shift on the input signal. The result will have the same fixed-point container as that of the input.
Slice	The Xilinx Slice block allows you to slice off a sequence of bits from your input data and create a new data value. This value is presented as the output from the block. The output data type is unsigned with its binary point at zero.
SquareRoot	The Xilinx SquareRoot block performs the square root on the input. Currently, only the floating-point data type is supported.
Threshold	The Xilinx Threshold block tests the sign of the input number. If the input number is negative, the output of the block is -1; otherwise, the output is 1. The output is a signed fixed-point integer that is 2 bits long. The block has one input and one output.
Time Division Demultiplexer	The Xilinx Time Division Demultiplexer block accepts input serially and presents it to multiple outputs at a slower rate.
Time Division Multiplexer	The Xilinx Time Division Multiplexer block multiplexes values presented at input ports into a single faster rate output stream.
Up Sample	The Xilinx Up Sample block increases the sample rate at the point where the block is placed in your design. The output sample period is $l/n$ , where l is the input sample period, and n is the sampling rate.

## DSP Blocks

**Table 33: DSP Blocks**

Block	Description
Digital FIR Filter	The Xilinx Digital FIR Filter block allows you to generate highly parameterizable, area-efficient, high-performance single channel FIR filters.
DSP Macro 1.0	The Xilinx DSP macro block provides a device independent abstraction of the DSP48E1, DSP48E2, and DSP58 blocks. Using this block instead of using a technology-specific DSP slice helps makes the design more portable between Xilinx technologies.
DSP48E	The Xilinx DSP48E block is an efficient building block for DSP applications that use supported devices. The DSP48E combines an 18-bit by 25-bit signed multiplier with a 48-bit adder and programmable mux to select the adder's input.
DSP48E1	The Xilinx DSP48E1 block is an efficient building block for DSP applications that use 7 series devices. Enhancements to the DSP48E1 slice provide improved flexibility and utilization, improved efficiency of applications, reduced overall power consumption, and increased maximum frequency. The high performance allows designers to implement multiple slower operations in a single DSP48E1 slice using time-multiplexing methods.
DSP48E2	The Xilinx DSP48E2 block is an efficient building block for DSP applications that use UltraScale™ devices. DSP applications use many binary multipliers and accumulators that are best implemented in dedicated DSP resources. UltraScale™ devices have many dedicated low-power DSP slices, combining high speed with small size while retaining system design flexibility.
DSP58	The Xilinx DSP58 block is an efficient building block for DSP applications that use Versal® devices. DSP applications use many binary multipliers and accumulators that are best implemented in dedicated DSP resources. Versal® devices have many dedicated low-power DSP slices, combining high speed with small size while retaining system design flexibility.
DSPCPLX	The Xilinx DSPCPLX block is one of the advanced features provided by Versal® architecture DSP, which is the optimized solution to deal with 18x18 complex multiplication followed by 58 + 58 accumulation operation.
FFT	The Xilinx FFT (Fast Fourier Transform) block takes a block of time domain waveform data and computes the frequency of the sinusoid signals that make up the waveform.
Inverse FFT	The Xilinx Inverter FFT block performs a fast inverse (or backward) Fourier transform (IDFT), which undoes the process of Discrete Fourier Transform (DFT). The Inverter FFT maps the signal back from the frequency domain into the time domain.
Product	The Xilinx Product block implements a scalar or complex multiplier. It computes the product of the data on its two input channels, producing the result on its output channel. For complex multiplication the input and output have two components: real and imaginary.
Sine Wave	The Xilinx Sine Wave block generates a sine wave, using simulation time as the time source.
CIC Compiler 4.0	The Xilinx CIC Compiler provides the ability to design and implement AXI4-Stream-compliant Cascaded Integrator-Comb (CIC) filters for a variety of Xilinx FPGA devices.
Complex Multiplier 6.0	The Complex Multiplier block implements AXI4-Stream compliant, high-performance, optimized complex multipliers for devices based on user-specified options.
Convolution Encoder 9.0	The Xilinx Convolution Encoder block implements an encoder for convolution codes. Ordinarily used in tandem with a Viterbi decoder, this block performs forward error correction (FEC) in digital communication systems. This block adheres to the AMBA AXI4-Stream standard.

Table 33: DSP Blocks (cont'd)

Block	Description
CORDIC 6.0	The Xilinx CORDIC block implements a generalized coordinate rotational digital computer (CORDIC) algorithm and is AXI compliant.
DDS Compiler 6.0	The Xilinx DDS (Direct Digital Synthesizer) Compiler block implements high performance, optimized Phase Generation, and Phase to Sinusoid circuits with AXI4-Stream compliant interfaces for supported devices.
Divider Generator 5.1	The Xilinx Divider Generator block creates a circuit for integer division based on Radix-2 non-restoring division, or High-Radix division with prescaling.
Fast Fourier Transform 9.1	The Xilinx Fast Fourier Transform block implements the Cooley-Tukey FFT algorithm, a computationally efficient method for calculating the Discrete Fourier Transform (DFT). In addition, the block provides an AXI4-Stream-compliant interface.
FIR Compiler 7.2	This Xilinx FIR Compiler block provides users with a way to generate highly parameterizable, area-efficient, high-performance FIR filters with an AXI4-Stream-compliant interface.
Interleaver/De-interleaver 8.0	The Xilinx Interleaver Deinterleaver block implements an interleaver or a deinterleaver using an AXI4-compliant block interface. An interleaver is a device that rearranges the order of a sequence of input symbols. The term symbol is used to describe a collection of bits. In some applications, a symbol is a single bit. In others, a symbol is a bus.
Reed-Solomon Decoder 9.0	The Reed-Solomon (RS) codes are block-based error correcting codes with a wide range of applications in digital communications and storage.
Reed-Solomon Encoder 9.0	The Reed-Solomon (RS) codes are block-based error correcting codes with a wide range of applications in digital communications and storage. This block adheres to the AMBA® AXI4-Stream standard.
Viterbi Decoder 9.1	Data encoded with a convolution encoder can be decoded using the Xilinx Viterbi decoder block. This block adheres to the AMBA® AXI4-Stream standard.

## Interface Blocks

Table 34: Interface Blocks

Block	Description
Gateway In	The Xilinx Gateway In blocks are the inputs into the Xilinx portion of your Simulink design. These blocks convert Simulink integer, double, and fixed-point data types into the Model Composer fixed-point type. Each block defines a top-level input port or interface in the HDL design generated by Model Composer.
Gateway In AXI Stream	A utility block that makes connecting between HDL and AI Engine domains easier by combining three HDL gateway blocks into one block. It is primarily used with the AIE to HDL block.
Gateway Out	Xilinx Gateway Out blocks are the outputs from the Xilinx portion of your Simulink design. This block converts the Model Composer fixed-point or floating-point data type into a Simulink integer, single, double, or fixed-point data type.
Gateway Out AXI Stream	A utility block that makes connecting between HDL and AI Engine domains easier by combining three HDL gateway blocks into one block. It is primarily used with the HDL to AIE block.

## Logic and Bit Operation Blocks

**Table 35: Logic and Bit Operation Blocks**

Block	Description
Assert	The Xilinx Assert block is used to assert a rate and/or a type on a signal. This block has no cost in hardware and can be used to resolve rates and/or types in situations where designer intervention is required.
BitBasher	The Xilinx BitBasher block performs slicing, concatenation, and augmentation of inputs attached to the block.
Concat	The Xilinx Concat block performs a concatenation of n bit vectors represented by unsigned integer numbers, for example, n unsigned numbers with binary points at position zero.
Inverter	The Xilinx Inverter block calculates the bitwise logical complement of a fixed-point number. The block is implemented as a synthesizable VHDL module.
Logical	The Xilinx Logical block performs bitwise logical operations on fixed-point numbers. Operands are zero padded and sign extended as necessary to make binary point positions coincide; then the logical operation is performed and the result is delivered at the output port.

## Memory Blocks

**Table 36: Memory Blocks**

Block	Description
Addressable Shift Register	The Xilinx Addressable Shift Register block is a variable-length shift register in which any register in the delay chain can be addressed and driven onto the output data port.
Delay	The Xilinx Delay block implements a fixed delay of L cycles.
Dual Port RAM	The Xilinx Dual Port RAM block implements a random access memory (RAM). Dual ports enable simultaneous access to the memory space at different sample rates using multiple data widths.
FIFO	The Xilinx FIFO block implements an FIFO memory queue.
LFSR	The Xilinx LFSR block implements a Linear Feedback Shift Register (LFSR). This block supports both the Galois and Fibonacci structures using either the XOR or XNOR gate and allows a re-loadable input to change the current value of the register at any time. The LFSR output and re-loadable input can be configured as either serial or parallel ports.
Register	The Xilinx Register block models a D flip-flop-based register, having a latency of one sample period.
ROM	The Xilinx ROM block is a single port read-only memory (ROM).
Single Port RAM	The Xilinx Single Port RAM block implements a random access memory (RAM) with one data input and one data output port.
AXI FIFO	The Xilinx AXI FIFO block implements a FIFO memory queue with an AXI-compatible block interface.

## Signal Routing Blocks

*Table 37: Signal Routing Blocks*

Block	Description
Bus Creator	This block creates buses from input signals
Bus Selector	This block selects signals from incoming buses
From	This block accepts inputs from the Goto block
Goto	This block passes block inputs to the From blocks

## Source Blocks

*Table 38: Source Blocks*

Block	Description
Constant	The Xilinx Constant block generates a constant that can be a fixed-point value, a Boolean value, or a DSP48 instruction. This block is similar to the Simulink constant block, but can be used to directly drive the inputs on Xilinx blocks.
Counter	The Xilinx Counter block implements a free-running or count-limited type of an up, down, or up/down counter. The counter output can be specified as a signed or unsigned fixed-point number.
Opemode	The Xilinx Opemode block generates a constant that is a DSP48E, DSP48E1, or DSP48E2 instruction. It is a 15-bit instruction for DSP48E, a 20-bit instruction for DSP48E1, and a 22-bit instruction for DSP48E2. The instruction consists of the opemode, carry-in, carry-in select, alumode, and (for DSP48E1 and DSP48E2) the inmode bits.
Reset Generator	The Xilinx Reset Generator block captures the user's reset signal that is running at the system samplerate, and produces one or more downsampled reset signal(s) running at the rates specified on the block.

## SSR Blocks

*Table 39: SSR Blocks*

Block	Description
Vector Absolute	The Vector Absolute block outputs the absolute value of the input of vector type.
Vector AddSub Fabric	The Vector Adder/Subtracter Fabric block supports the Addition/Subtraction operation for inputs of vector type.
Vector Assert	The Vector Assert block asserts a user-defined sample rate and/or type on Vector inputs.
Vector Concat	The Vector Concat block concatenates two or more inputs of type vector. The output is cast to an unsigned value with the binary point at zero.
Vector Convert	The Vector Convert block supports Data Type Conversion feature for vector type inputs.
Vector Down Sample	The Vector Down Sample block down samples input vector data.
Vector Logical	The Vector Logical block supports logical operation for vector type inputs.
Vector Mux	The Vector Multiplexer block supports the Multiplexing feature for input of vector types.

Table 39: SSR Blocks (cont'd)

Block	Description
Vector Real Mult	The Vector Real Multiplier block supports the multiplication feature for vector type inputs.
Vector Reinterpret	The Vector Reinterpret block changes the vector input signal type without altering the binary representation.
Vector Relational	The Vector Relational block implements comparator for vector inputs.
Vector Slice	The Vector Slice block extracts a given range of bits from each sample of input vector and presents it at the output.
Vector Up Sample	The Vector Up Sample block up samples input vector data. Inserted values can be zeros or copies of the most recent input sample.
Vector Complex Mult	The Vector Complex Multiplier block supports multiplication of two complex input vectors.
Vector DDS	The Vector DDS block generates Real and Imaginary vector output signals of desired frequency.
Vector FFT	The Vector FFT block supports the FFT operation for vector type inputs.
Vector FIR	The Vector FIR block supports FIR filtering for vector type inputs.
Scalar2Vector	The Scalar2Vector block converts scalar type input to vector type output.
Vector Real Gateway In	The Vector Real Gateway In block converts vector inputs of type Simulink® integer, single,double, and fixed-point to Xilinx® fixed-point or floating-point data type.
Vector Real Gateway Out	The Vector Real Gateway Out block converts Xilinx® fixed-point or floating-point type vector inputs into vector outputs of type Simulink® integer, single, double, or fixed-point.
Vector2Scalar	The Vector2Scalar block converts vector type input to scalar type output.
Vector Delay	The Vector Delay block supports delay operation on vector type inputs.
Vector Delay Delta	The Vector Delay Delta Block delays each vector element differently based on the given latency and delay latency values.
Vector Register	The Vector Register block supports vector type inputs.
Vector Constant	The Vector Constant Block generates vector constant values.

## Tools Blocks

Table 40: Tools Blocks

Block	Description
System Generator	<p><b>IMPORTANT!</b> The System Generator token will be removed in a future release of Vitis Model Composer. Please consider updating your model to use the <a href="#">Vitis Model Composer Hub</a> block.</p> <p>The System Generator token serves as a control panel for controlling system and simulation parameters, and it is also used to invoke the code generator for netlisting. Every Simulink model containing any element from the HDL Blockset must contain at least one System Generator token. Once a System Generator token is added to a model, it is possible to specify how code generation and simulation should be handled.</p>
Clock Enable Probe	The Xilinx Clock Enable (CE) Probe provides a mechanism for extracting derived clock enable signals from Xilinx signals in Model Composer models.

**Table 40: Tools Blocks (cont'd)**

Block	Description
Clock Probe	The Xilinx Clock Probe generates a double-precision representation of a clock signal with a period equal to the Simulink system period.
FDATool	The Xilinx FDATool block provides an interface to the FDATool software available as part of the MATLAB Signal Processing Toolbox.
Indeterminate Probe	The output of the Xilinx Indeterminate Probe indicates whether the input data is indeterminate (MATLAB value NaN). An indeterminate data value corresponds to a VHDL indeterminate logic data value of 'X'.
Questa	The HDL Black Box block provides a way to incorporate existing HDL files into a model. When the model is simulated, co-simulation can be used to allow black boxes to participate. The Questa HDL co-simulation block configures and controls co-simulation for one or several black boxes.
Sample Time	The Sample Time block reports the normalized sample period of its input. A signal's normalized sample period is not equivalent to its Simulink absolute sample period. In hardware, this block is implemented as a constant.
Vitis Model Composer Hub	The Vitis Model Composer Hub block controls the behavior of the Vitis Model Composer tool.

## User-Defined Functions Blocks

**Table 41: User-Defined Functions Blocks**

Block	Description
Black Box	The HDL Black Box block provides a way to incorporate hardware description language (HDL) models into Model Composer.
MCode	The Xilinx MCode block is a container for executing a user-supplied MATLAB® function within Simulink. A parameter on the block specifies the M-function name. The block executes the M-code to calculate block outputs during a Simulink simulation. The same code is translated in a straightforward way into equivalent behavioral VHDL/Verilog when hardware is generated.
Vitis HLS	The Xilinx Vitis™ HLS block allows the functionality of a Vitis HLS design to be included in a Model Composer design. The Vitis HLS design can include C, C++, and System C design sources.

## HLS Blocksets

**Table 42: Logic and Bit Operations**

Block	Description
Bit Concat	Perform bitwise concatenation of input values into a single output value
Bit Slice	Extract a range of bits from a value
Bitwise AND	Perform element and bitwise Boolean AND operation on the inputs
Bitwise NOT	Perform element and bitwise Boolean NOT operation on the input
Bitwise OR	Perform element and bitwise Boolean OR operation on the inputs
Bitwise XOR	Perform element and bitwise Boolean XOR operation on the inputs
Logical AND	Performs element-wise logical AND operation on inputs

**Table 42: Logic and Bit Operations (cont'd)**

Block	Description
Logical NOT	Performs element-wise logical NOT operation on the input
Logical OR	Performs element-wise logical OR operation on inputs
Reduction AND	Compute bitwise AND of the elements of the input over all dimensions or over a specified dimension
Reduction OR	Compute bitwise OR of the elements of the input over all dimensions or over a specified dimension
Reduction XOR	Compute bitwise XOR of the elements of the input over all dimensions or over a specified dimension
Shift Left	Perform logical shift left of input over a constant number of bit positions specified by a non-negative integer mask parameter
Shift Right	Perform logical shift right of input over a constant number of bit positions specified by a non-negative integer mask parameter

**Table 43: Lookup Tables**

Block	Description
Lookup Table	Perform one-dimensional lookup operation with an input index

**Table 44: Math Functions / Math Operations**

Block	Description
Abs	Compute element-wise absolute value of input signal
atan	Compute element-wise inverse tangent of input signal
atan2	Compute element-wise four-quadrant inverse tangent of input signal
Complex to Polar	Element-wise conversion of complex input signals into magnitude and radiant phase angle
Complex to Real-Imag	Output real and imaginary parts of complex input signal
Conjugate	Apply element-wise complex conjugate operation to the input signal
Cosine	Element-wise computation of the cosine function for a given argument
cosh	Element-wise computation of the hyperbolic cosine for a given argument
Cumulative Sum	Compute the cumulative sum along the specified dimension of the input
Divide	Perform element-wise division
Exp	Perform an element-wise exponential value of the input
Gain	Multiply the input signal with a constant gain factor.
Log	Compute element-wise natural logarithm of input
Log10	Compute element wise base 10 logarithm of input
Max	Computes the maximum value of an input or element-wise maximum value of multiple inputs.
Min	Computes the minimum value of an input or element-wise minimum value of multiple inputs.
Modulus	Perform element-wise modulus operation on the input signals
Negate	Perform element-wise unary minus operation on the input data

**Table 44: Math Functions / Math Operations (cont'd)**

Block	Description
Polar to Complex	Element-wise conversion of real magnitude and angle representation signals into a complex signal
Pow	Compute the element-wise power function
Product	Compute element-wise product of the input signals
Product of Elements	Multiply the elements of the input signal
Real-Imag to Complex	Convert real and/or imaginary inputs to complex signal
Reciprocal	Perform element-wise computation of the reciprocal for a given argument
Reciprocal Sqrt	Perform element-wise computation of the reciprocal square root for a given argument
Remainder	Perform element-wise division on the input signal, and the output is the remainder after the division
Reshape Row-Major	Changes the input dimensions in row-major order.
Signum	Perform an element-wise signum function (sign extraction)
Sine	Element-wise computation of the sine function for the given input
sinh	Element-wise computation of the hyperbolic sine for a given argument
Sqrt	Element-wise computation of the square root for a given argument
Subtract	Perform an element-wise subtraction
Sum	Performs element-wise addition of two input signals
Sum of Elements	Perform element-wise addition on the input, column-wise, row-wise, or in all-dimensions
Tangent	Perform an element-wise computation of the tangent function for the given argument

**Table 45: Math Functions / Matrices and Linear Algebra**

Block	Description
Hermitian	Perform element-wise conjugate transpose operation on the input signal
Matrix Multiply	Compute matrix product of two input signals
QR Inverse	Compute the inverse of a matrix using QR factorization
Submatrix	Select a subset of elements (submatrix) from matrix input
Transpose	Perform an element-wise transpose operation on the input signal

**Table 46: Ports and Subsystems**

Block	Description
If	Model if-else control flow
In1	Create input port for subsystem or external input
Out1	Create output port for subsystem or external output
Action Port	Implement Action subsystems used in if and switch control flow statements
Window Processing	Assemble an output matrix by applying the kernel subsystem to submatrices (windows) of the input matrix in row-major order

**Table 47: Relational Operations**

Block	Description
Equals	Perform element-wise equal to relational operation on the inputs
Greater	Perform element-wise greater than relational operation on the inputs
Greater Equals	Perform element-wise greater than or equal relational operation on the inputs
Lesser	Perform element-wise less than relational operation on the inputs
Lesser Equals	Perform element-wise less than or equal relational operation on the inputs
Not Equals	Perform element-wise not equal to relational operation on the inputs

**Table 48: Signal Attributes**

Block	Description
Data Type Conversion	Convert the input to the data type of the output
Reinterpret	Element-wise reinterpretation of the input type into a compatible output type with the same bit width

**Table 49: Signal Operations**

Block	Description
Delay	Delay input signal by specified number of samples
Unit Delay	Provides a delay of one sample period

**Table 50: Signal Routing**

Block	Description
Bus Creator	Create Signal Bus
Bus Selector	Select signals from incoming bus
Conditional	Pass through input T when control input satisfies a selected criterion; otherwise, pass through input F
Demux	Separates a vector input into a number of scalar and vector outputs
From	Accept input from Goto block
Goto	Pass block input to From blocks
Merge	Combine multiple signals into single signal
Mux	Combines scalar and vector inputs into a larger vector output

**Table 51: Sinks**

Block	Description
Display	Show value of input
Scope	Display signals generated during simulation
Stop Simulation	Stop simulation when input is nonzero
Terminator	Terminate unconnected output port

**Table 51: Sinks (cont'd)**

Block	Description
To File	Write data to file
To Workspace	Write data to workspace

**Table 52: Source**

Block	Description
Constant	Generates the constant specified by the <b>Constant Value</b> parameter

**Table 53: Tools**

Block	Description
DocBlock	Create text that documents model and save text with model
Interface Spec	Specify the RTL interfaces for a subsystem
Vitis Model Composer Hub	Control implementation of the model

**Table 54: User-Defined Functions**

Block	Description
DocBlock	Create text that documents model and save text with model
HLS Kernel	Import an HLS kernel code with a streaming interface.

## Utilities

**Table 55: Code Generation**

Block	Description
Vitis Model Composer Hub	Control implementation of the model.
System Generator	<p><b>IMPORTANT!</b> The System Generator token will be removed in a future release of Vitis Model Composer. Please consider updating your model to use the <a href="#">Vitis Model Composer Hub</a> block.</p> <p>The System Generator token serves as a control panel for controlling system and simulation parameters, and it is also used to invoke the code generator for netlisting. Every Simulink model containing any element from the HDL Blockset must contain at least one System Generator token. Once a System Generator token is added to a model, it is possible to specify how code generation and simulation should be handled.</p>

**Table 56: Connectors**

<b>Block</b>	<b>Description</b>
AIE to HDL	Connect the input port of an HDL block with the output port of an AI Engine kernel or AI Engine graph block using an AXI4-Stream interface.
AIE to HLS	Connect an input port of an HLS kernel block to the output port of an AI Engine block in cases where the data type or complexity of the ports involved do not match.
HDL to AIE	Connect the output ports of HDL blocks to the input ports of AI Engine blocks using the AXI4-Stream protocol.
HLS to AIE	Connect an input port of an AI Engine Kernel or AI Engine Graph block to an output port of an HLS Kernel block in cases where the datatype or complexities of the ports involved does not match.

**Table 57: Ports & Subsystems**

<b>Block</b>	<b>Description</b>
In1	Create input port for subsystem or external input
Out1	Create output port for subsystem or external output
Subsystem	

**Table 58: Signal Routing**

<b>Block</b>	<b>Description</b>
Bus Creator	Create Signal Bus
Bus Selector	Select signals from incoming bus
From	Accept input from Goto block
Goto	Pass block input to From blocks

**Table 59: Sinks**

<b>Block</b>	<b>Description</b>
Display	Show value of input
Scope	Display signals generated during simulation
Stop Simulation	Stop simulation when input is nonzero
Terminator	Terminate unconnected output port
To File	Write data to file
To Workspace	Write data to workspace

**Table 60: Tools**

<b>Block</b>	<b>Description</b>
DocBlock	Create text that documents model and save text with model

Table 60: Tools (cont'd)

Block	Description
To Fixed Size	Takes a variable size vector as an input and produces a fixed size vector as output.
To Variable Size	Takes a fixed sized vector input and produces a variable sized vector output. The maximum size of the output vector is specified by the Output Size parameter. If there is not enough samples to pack the output, the output will be an empty variable size signal.
Variable Size Signal to Workspace	Save variable size signal data from your Simulink® simulation to the MATLAB® workspace.

## HDL Blockset

### Common Options in Block Parameter Dialog Boxes

Each Xilinx® block has several controls and configurable parameters, seen in its Block Parameters dialog box. This dialog box can be accessed by double-clicking on the block. Many of these parameters are specific to the block. Block-specific parameters are described in the documentation for the block.

The remaining controls and parameters are common to most blocks. These common controls and parameters are described below.

Each dialog box contains four buttons: **OK**, **Cancel**, **Help**, and **Apply**. **Apply** applies configuration changes to the block, leaving the box open on the screen. **Help** displays HTML help for the block. **Cancel** closes the box without saving changes. **OK** applies changes and closes the box.

#### Precision

The fundamental computational mode in the Xilinx blockset is arbitrary precision fixed-point arithmetic. Most blocks give you the option of choosing the precision, for example, the number of bits and binary point position.

By default, the output of Xilinx blocks is *full* precision; that is, sufficient precision to represent the result without error. Most blocks have a *User-Defined* precision option that fixes the number of total and fractional bits.

#### Arithmetic type

In the **Arithmetic Type** field of the Block Parameters dialog box, you can choose unsigned or signed (two's complement) as the data type of the output signal.

## Number of bits

Fixed-point numbers are stored in data types characterized by their word size as specified by Number of bits, Binary point, and Arithmetic type parameters. The maximum number of bits supported is 4096.

## Binary point

The binary point is the means by which fixed-point numbers are scaled. The Binary point parameter indicates the number of bits to the right of the binary point (for example, the size of the fraction) for the output port. The binary point position must be between zero and the specified number of bits.

## Overflow and Quantization

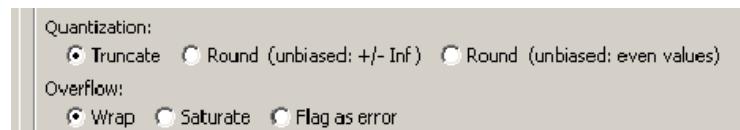
When user-defined precision is selected, errors can result from overflow or quantization. Overflow errors occur when a value lies outside the representable range. Quantization errors occur when the number of fractional bits is insufficient to represent the fractional portion of a value.

The Xilinx fixed-point data type supports several options for user-defined precision. For overflow the options are to **Saturate** to the largest positive/smallest negative value, to **Wrap** (for example, to discard bits to the left of the most significant representable bit), or to **Flag as error** (an overflow as a Simulink® error) during simulation. **Flag as error** is a simulation only feature. The hardware generated is the same as when **Wrap** is selected.

For quantization, the options are to **Round** to the nearest representable value (or to the value furthest from zero if there are two equidistant nearest representable values), or to **Truncate** (for example, to discard bits to the right of the least significant representable bit).

The following is an image showing the Quantization and Overflow options.

Figure 253: Quantization and Overflow Options



**Round (unbiased: +/- inf)** also known as "Symmetric Round (towards +/- inf)" or "Symmetric Round (away from zero)". This is similar to the MATLAB® `round()` function. This method rounds the value to the nearest desired bit away from zero and when there is a value at the midpoint between two possible rounded values, the one with the larger magnitude is selected. For example, to round 01.0110 to a Fix\_4\_2, this yields 01.10, because 01.0110 is exactly between 01.01 and 01.10 and the latter is further from zero.

**Round (unbiased: even values)** also known as "Convergent Round (toward even)" or "Unbiased Rounding". Symmetric rounding is biased because it rounds all ambiguous midpoints away from zero which means the average magnitude of the rounded results is larger than the average magnitude of the raw results. Convergent rounding removes this by alternating between a symmetric round toward zero and symmetric round away from zero. That is, midpoints are rounded toward the nearest even number. For example, to round 01.0110 to a Fix\_4\_2, this yields 01.10, because 01.0110 is exactly between 01.01 and 01.10 and the latter is even. To round 01.1010 to a Fix\_4\_2, this yields 01.10, because 01.1010 is exactly between 01.10 and 01.11 and the former is even.

It is important to realize that whatever option is selected, the generated HDL model and Simulink model behave identically.

## Latency

Many elements in the Xilinx blockset have a latency option. This defines the number of sample periods by which the block's output is delayed. One sample period might correspond to multiple clock cycles in the corresponding FPGA implementation (for example, when the hardware is over-clocked with respect to the Simulink model). Model Composer does not perform extensive pipelining; additional latency is usually implemented as a shift register on the output of the block.

## Provide Synchronous Reset Port

Selecting the **Provide Synchronous Reset Port** option activates an optional reset (`rst`) pin on the block.

When the reset signal is asserted the block goes back to its initial state. Reset signal has precedence over the optional enable signal available on the block. The reset signal has to run at a multiple of the block's sample rate. The signal driving the reset port must be Boolean.

## Provide Enable Port

Selecting the **Provide Enable Port** option activates an optional enable (`en`) pin on the block. When the enable signal is not asserted the block holds its current state until the enable signal is asserted again or the reset signal is asserted. Reset signal has precedence over the enable signal. The enable signal has to run at a multiple of the block's sample rate. The signal driving the enable port must be Boolean.

## Sample Period

Data streams are processed at a specific sample rate as they flow through Simulink. Typically, each block detects the input sample rate and produces the correct sample rate on its output. Xilinx blocks Up Sample and Down Sample provide a means to increase or decrease sample rates.

### Specify Explicit Sample Period

If you select **Specify explicit sample period** rather than the default, you can set the sample period required for all the block outputs. This is useful when implementing features such as feedback loops in your design. In a feedback loop, it is not possible for Model Composer to determine a default sample rate, because the loop makes an input sample rate depend on a yet-to-be-determined output sample rate. Model Composer under these circumstances requires you to supply a hint to establish sample periods throughout a loop.

### Use Behavioral HDL (otherwise use core)

When this checkbox is checked, the behavioral HDL generated by the M-code simulation is used instead of the structural HDL from the cores.

The M-code simulation creates the C simulation and this C simulation creates behavioral HDL. When this option is selected, it is this behavioral HDL that is used for further synthesis. When this option is not selected, the structural HDL generated from the cores and HDL templates (corresponding to each of the blocks in the model) is used instead for synthesis. Cores are generated for each block in a design once and cached for future netlisting. This capability ensures the fastest possible netlist generation while guaranteeing that the cores are available for downstream synthesis and place and route tools.

### Use XtremeDSP Slice

This field specifies that if possible, use the XtremeDSP slice (DSP48 type element) in the target device. Otherwise, CLB logic are used for the multipliers.

### Display shortened port names

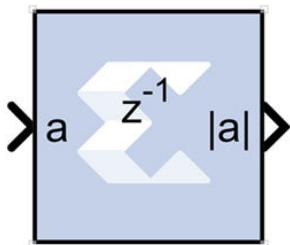
AXI4-Stream signal names have been shortened (by default) to improve readability on the block. Name shortening is purely cosmetic and when netlisting occurs, the AXI4-Stream name is used. For example, a shortened master signal on an AXI4-Stream interface might be `data_tvalid`. When you uncheck **Display shortened port names**, the name becomes `m_axis_data_tvalid`.

## Block Reference Pages

Following is an alphabetic listing of the blocks in the HDL blockset, with descriptions of each of the blocks.

## Absolute

The Xilinx Absolute block outputs the absolute value of the input.



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**
  - **Precision:** This parameter allows you to specify the output precision for fixed-point arithmetic. Floating point arithmetic output will always be **Full** precision.
    - **Full:** The block uses sufficient precision to represent the result without error.
    - **User Defined:** If you do not need full precision, this option allows you to specify a reduced number of total bits and/or fractional bits.
  - **Fixed-point Output Type:**
    - **Arithmetic type:**
      - **Signed (2's comp):** The output is a Signed (2's complement) number.
      - **Unsigned:** The output is an Unsigned number.
  - **Fixed-point Precision:**
    - **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
    - **Binary point:** Position of the binary point. in the fixed-point output.
    - **Quantization:** Refer to the section [Overflow and Quantization](#).
    - **Overflow:** Refer to the section [Overflow and Quantization](#).

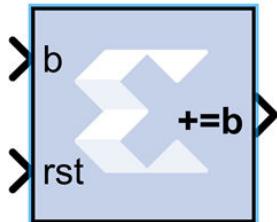
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

## Accumulator

The Xilinx® Accumulator block implements an adder or subtractor-based scaling accumulator.



The block's current input is accumulated with a scaled current stored value. The scale factor is a block parameter.

### Block Interface

The block has an input  $b$  and an output  $q$ . The output must have the same width as the input data. The output will have the same arithmetic type and binary point position as the input. The output  $q$  is calculated as follows:

$$q(n) = \begin{cases} 0 & \text{if } rst=1 \\ q(n-1) \times \text{FeedbackScaling} + b(n-1) & \text{otherwise} \end{cases}$$

A subtractor-based accumulator replaces addition of the current input  $b(n)$  with subtraction.

### Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows:

- **Operation:** This determines whether the block is adder- or subtractor-based.
- **Fixed-Point Output Precision:**
  - **Number of bits:** specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
  - **Overflow:** Refer to the section [Overflow and Quantization](#).
- **Feedback scaling:** Specifies the feedback scale factor to be one of the following:  
1, 1/2, 1/4, 1/8, 1/16, 1/32, 1/64, 1/128, or 1/256.
- **Optional Ports:**

- **Provide synchronous reset port:** Activates an optional reset (rst) pin on the block. When the reset signal is asserted, the block goes back to its initial state. However, when a floating point accumulator is used, the output will be NAN during reset. The reset signal has precedence over the optional enable signal available on the block. The reset signal must run at a multiple of the block's sample rate. The signal driving the reset port must be Boolean.
- **Bypass Option on Reset:**
  - **Reinitialize with input 'b':** When selected, the output of the accumulator is reset to the data on input port b. When not selected, the output of the accumulator is reset to zero. This option is available only when the block has a reset port. Using this option has clock speed implications if the accumulator is in a multirate system. In this case the accumulator is forced to run at the system rate because the clock enable (CE) signal driving the accumulator runs at the system rate, and the reset to input operation is a function of the CE signal.
- **Internal Precision tab:** Parameters specific to the Internal Precision tab are as follows:
  - **Floating Point Precision:**
    - **Input MSB Max:** The Most Significant Bit of the largest number that can be accepted.
    - **Output MSB Max:** The MSB of the largest result. It can be up to 54 bits greater than the Input MSB.
    - **Output LSB Min:** The Least Significant Bit of the smallest number that can be accepted. It is also the LSB of the accumulated result.
  - **Implementation tab:** Parameters specific to the Implementation tab are as follows:
    - **Use behavioral HDL (otherwise use core):** The block is implemented using behavioral HDL. This gives the downstream logic synthesis tool maximum freedom to optimize for performance or area.
    - **Implement using:** Core logic can be implemented in **Fabric** or in a **DSP48**, if a DSP48 is available in the target device. The default is **Fabric**.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

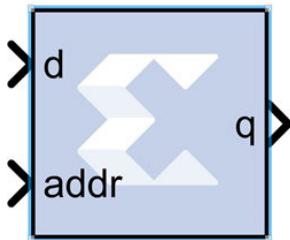
The Accumulator block always has a latency of 1.

## LogiCORE Documentation

[Accumulator LogiCORE IP Product Guide \(PG119\)](#)

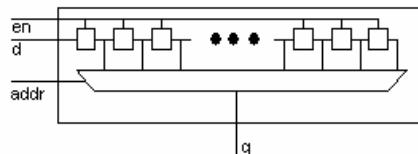
## Addressable Shift Register

The Xilinx Addressable Shift Register block is a variable-length shift register in which any register in the delay chain can be addressed and driven onto the output data port.



The block operation is most easily thought of as a chain of registers, where each register output drives an input to a multiplexer, as shown below. The multiplexer select line is driven by the address port (`addr`). The output data port is shown below as `q`.

Figure 254: Output Data Port



The Addressable Shift Register has a maximum depth of 1024 and a minimum depth of 2. The address input port, therefore, can be between 1 and 10 bits (inclusive). The data input port width must be between 1 and 255 bits (inclusive) when this block is implemented with the Xilinx LogiCORE (for example, when **Use behavioral HDL (otherwise use core)** is unchecked).

In hardware, the address port is asynchronous relative to the output port. In the block S-function, the address port is therefore given priority over the input data port, for example, on each successive cycle, the addressed data value is read from the register and driven to the output before the shift operation occurs. This order is needed in the Simulink® software model to guarantee one clock cycle of latency between the data port and the first register of the delay chain. (If the shift operation were to come first, followed by the read, then there would be no delay, and the hardware would be incorrect.)

## Block Interface

The block interface (inputs and outputs as seen on the Addressable Shift Register icon) are as follows:

Table 61: Input Signals

Signal	Description
d	data input
addr	address
en	enable signal (optional)

**Table 62: Output Signals**

Signal	Description
q	data output

### Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to this block are as follows:
  - **Infer maximum latency (depth) using address port width:** You can choose to allow the block to automatically determine the depth or maximum latency of the shift-register-based on the bit-width of the address port.
  - **Maximum latency (depth):** In the case that the maximum latency is not inferred (previous option), the maximum latency can be set explicitly.
  - **Initial value vector:** Specifies the initial register values. When the vector is longer than the shift register depth, the vector's trailing elements are discarded. When the shift register is deeper than the vector length, the shift register's trailing registers are initialized to zero.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

- **Implementation tab:** Parameters specific to this block are as follows:
  - **Optimization:** You can choose to optimize for **Resource** (minimum area) or for **Speed** (maximum performance).

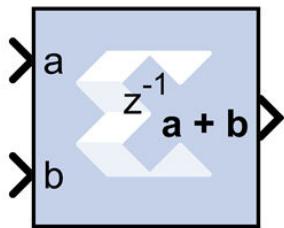
### LogiCORE Documentation

*RAM-Based Shift Register LogiCORE IP Product Guide* ([PG122](#))

*Floating-Point Operator LogiCORE IP Product Guide* ([PG060](#))

## AddSub

The Xilinx AddSub block implements an adder/subtractor. The operation can be fixed (Addition or Subtraction) or changed dynamically under control of the sub mode signal.



## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

- **Basic tab:** Parameters specific to the Basic tab are as follows:
  - **Operation:** Specifies the block operation to be Addition, Subtraction, or Addition/Subtraction. When Addition/Subtraction is selected, the block operation is determined by the sub input port, which must be driven by a Boolean signal. When the sub input is 1, the block performs subtraction. Otherwise, it performs addition.
  - **Provide carry-in port:** When selected, allows access to the carry-in port, cin.
  - **Provide carry-out port:** When selected, allows access to the carry-out port, cout. The carry-out port is available only when **User defined** precision is selected, the inputs and output are unsigned, and the number of output integer bits equals x, where x = max (integer bits a, integer bits b).
  - **Latency:** The **Latency** value defines the number of sample periods by which the block's output is delayed. One sample period might correspond to multiple clock cycles in the corresponding FPGA implementation (for example, when the hardware is over-clocked with respect to the Simulink model). Model Composer will not perform extensive pipelining unless you select the **Pipeline for maximum performance** option (on the Implementation tab, described below); additional latency is usually implemented as a shift register on the output of the block.
- **Output tab:**
  - **Precision:**

This parameter allows you to specify the output precision for fixed-point arithmetic. Floating point arithmetic output will always be **Full** precision.

    - **Full:** The block uses sufficient precision to represent the result without error.
    - **User Defined:** If you do not need full precision, this option allows you to specify a reduced number of total bits and/or fractional bits.
  - **Fixed-point Output Type:**
    - **Arithmetic Type:**

- **Signed (2's comp):** The output is a Signed (2's complement) number.
- **Unsigned:** The output is an Unsigned number.
- **Fixed -point Precision:**
  - **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
  - **Binary point:** Position of the binary point in the fixed-point output.
- **Quantization:** Refer to the section [Overflow and Quantization](#).
- **Overflow:** Refer to the section [Overflow and Quantization](#).
- **Implementation tab:**

Parameters specific to the Implementation tab are as follows:

- **Use behavioral HDL (otherwise use core):** The block is implemented using behavioral HDL. This gives the downstream logic synthesis tool maximum freedom to optimize for performance or area.

**Note:** For Floating-point operations, the block always uses the Floating-point Operator core.

- **Core Parameters:**

- **Pipeline for maximum performance:**

The XILINX LogiCORE can be internally pipelined to optimize for speed instead of area. Selecting this option puts all user defined latency into the core until the maximum allowable latency is reached. If the **Pipeline for maximum performance** option is not selected and latency is greater than zero, a single output register is put in the core and additional latency is added on the output of the core.

The **Pipeline for maximum performance** option adds the pipeline registers throughout the block, so that the latency is distributed, instead of adding it only at the end. This helps to meet tight timing constraints in the design.

- **Implement using:** Core logic can be implemented in **Fabric**, or in a **DSP48**, if a DSP48 is available in the target device. The default is **Fabric**.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

*Adder/Subtractor LogiCORE IP Product Guide* ([PG120](#))

*Floating-Point Operator LogiCORE IP Product Guide* ([PG060](#))

## Assert

The Xilinx Assert block is used to assert a rate and/or a type on a signal. This block has no cost in hardware and can be used to resolve rates and/or types in situations where designer intervention is required.



### Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Parameters specific to this block are as follows:

- **Type:**
  - **Assert type:** Specifies whether or not the block will assert that the type at its input is the same as the type specified. If the types are not the same, an error message is reported. This block is listed in the following Xilinx Blockset libraries: Floating-Point and Index.
  - **Specify type:** Specifies whether or not the type to assert is provided from a signal connected to an input port named `type` or whether it is specified explicitly from parameters in the Assert block dialog box.
  - **Output Type:** Specifies the data type of the output. Can be **Boolean**, **Fixed-point**, or **Floating-point**.
  - **Arithmetic Type:** If the Output Type is specified as Fixed-point, you can select **Signed (2's comp)** or **Unsigned** as the Arithmetic Type.
    - **Fixed-point Precision:**
      - **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
      - **Binary point:** Position of the binary point in the fixed-point output.
    - **Floating-point Precision:**
      - **Single:** Specifies single precision (32 bits).
      - **Double:** Specifies double precision (64 bits).
      - **Custom:** Activates the field below so you can specify the Exponent width and the Fraction width.

- **Exponent width:** Specify the exponent width.
- **Fraction width:** Specify the fraction width.
- **Rate:**
  - **Assert rate:** specifies whether or not the block will assert that the rate at its input is the same as the rate specified. If the rates are not the same, an error message is reported.
  - **Specify rate:** Specifies whether or not the initial rate to assert is provided from a signal connected to an input port named `rate`, or whether it is specified **Explicitly** from the **Sample rate** parameter in the Assert block dialog box.
- **Provide output port:** Specifies whether or not the block will feature an output port. The type and/or rate of the signal presented on the output port is the type and/or rate specified for assertion.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

The **Output type** parameter in this block uses the same description as the Arithmetic Type described in the topic [Common Options in Block Parameter Dialog Boxes](#).

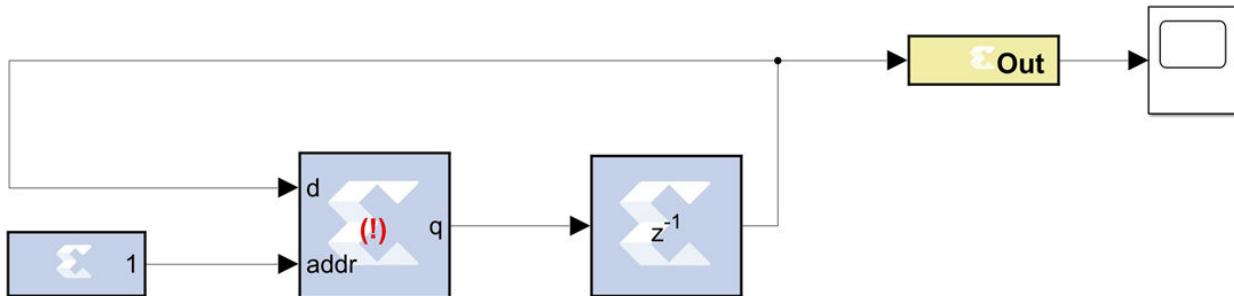
The Assert block does not use a Xilinx LogicCORE™ and does not use resources when implemented in hardware.

### Using the Assert Block to Resolve Rates and Types

In cases where the simulation engine cannot resolve rates or types, the Assert block can be used to force a particular type or rate. In general this might be necessary when using components that use feedback and act as a signal source. For example, the circuit below requires an Assert block to force the rate and type of an SRL16. In this case, you can use an Assert block to 'seed' the rate which is then propagated back to the SRL16 input through the SRL16 and back to the Assert block. The design below fails with the following message when the Assert block is not used.

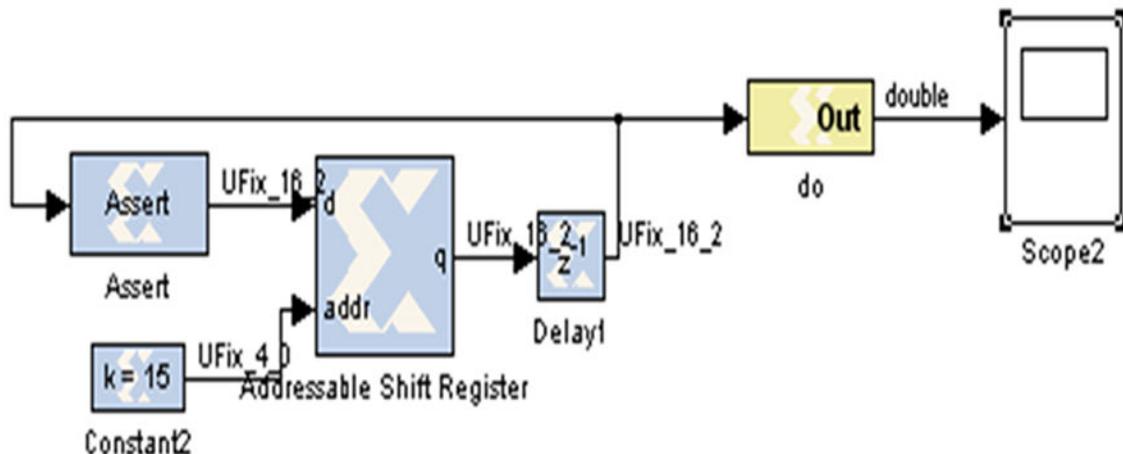
The data types could not be established for the feedback paths through this block. You might need to add Assert blocks to instruct the system how to resolve types.

Figure 255: Addressable Shift Register



To resolve this error, an Assert block is introduced in the feedback path as shown below:

Figure 256: Addressable Shift Register with Assert Block

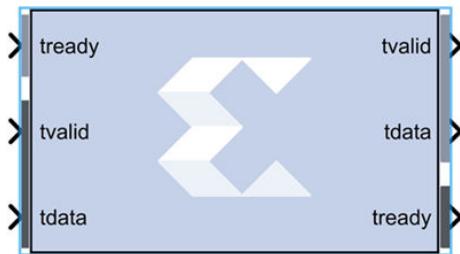


In the example, the Assert block is required to resolve the type, but the rate could have been determined by assigning a rate to the Constant clock. The decision whether to use Constant blocks or Assert blocks to force rates is arbitrary and can be determined on a case by case basis.

Model Composer now resolves rates and types deterministically, however in some cases, the use of Assert blocks might be necessary for some Model Composer HDL components, even if they are resolvable. These blocks might include Black Box components and certain IP blocks.

## AXI FIFO

The Xilinx AXI FIFO block implements a FIFO memory queue with an AXI-compatible block interface.



## Block Interface

- **Write Channel:**
  - **tready:** Indicates that the slave can accept a transfer in the current cycle.
  - **tvalid:** Indicates that the master is driving a valid transfer. A transfer takes place when both tvalid and tready are asserted.
  - **tdata:** The primary input data channel.
- **Read Channel:**
  - **tdata:** The primary output for the data.
  - **tready:** Indicates that the slave can accept a transfer in the current cycle.
  - **tvalid:** Indicates that the slave is accepting a valid transfer. A transfer takes place when both tvalid and tready are asserted.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows.

- **Data Port Parameters:**

- **FIFO depth:** Specifies the number of words that can be stored. Range 16-128K.
    - **Actual FIFO depth:** A report field that indicates the actual FIFO depth. The actual depth of the FIFO depends on its implementation and the features that influence its implementation.

- **Optional Ports:**

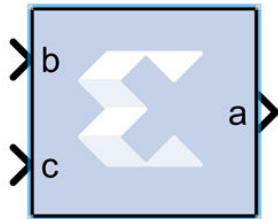
- **TDATA:** The primary payload that is used to provide the data that is passing across the interface. The width of the data payload is an integer number of bytes.
    - **TDEST:** Provides routing information for the data stream.

- **TSTRB:** The byte qualifier that indicates whether the content of the associated byte of TDATA is processed as a data byte or a position byte. For a 64-bit DATA, bit 0 corresponds to the least significant byte on DATA, and bit 7 corresponds to the most significant byte. For example:
  - STROBE[0] = 1b, DATA[7:0] is valid
  - STROBE[7] = 0b, DATA[63:56] is not valid
- **TREADY:** Indicates that the slave can accept a transfer in the current cycle.
- **TID:** The data stream identifier that indicates different streams of data.
- **TUSER:** The user-defined sideband information that can be transmitted alongside the data stream.
- **TKEEP:** The byte qualifier that indicates whether the content of the associated byte of TDATA is processed as part of the data stream. Associated bytes that have the TKEEP byte qualifier de-asserted are null bytes and can be removed from the data stream. For a 64-bit DATA, bit 0 corresponds to the least significant byte on DATA, and bit 7 corresponds to the most significant byte. For example:
  - KEEP[0] = 1b, DATA[7:0] is a NULL byte
  - KEEP [7] = 0b, DATA[63:56] is not a NULL byte
- **TLAST:** Indicates the boundary of a packet.
- **arestn:** Adds arestn (global reset) port to the block.
- **Data Threshold Parameters:**
  - **Provide FIFO occupancy DATA counts:** Adds data\_count port to the block. This port indicates the number of words written into the FIFO. The count is guaranteed to never under-report the number of words in the FIFO, to ensure the user never overflows the FIFO. The exception to this behavior is when a write operation occurs at the rising edge of write clock; that write operation will only be reflected on WR\_DATA\_COUNT at the next rising clock edge.
- **Implementation tab: FIFO Options**
  - **FIFO implementation type:** Specifies how the FIFO is implemented in the FPGA. Possible options are: Common Clock block RAM and Common Clock Distributed RAM. The XPM\_FIFO\_AXIS macro will be inferred or implemented when the design is compiled. For information on the XPM\_FIFO\_AXIS Xilinx Parameterized Macro (XPM), refer to *UltraScale Architecture Libraries Guide (UG974)*.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## BitBasher

The Xilinx BitBasher block performs slicing, concatenation and augmentation of inputs attached to the block.



The operation to be performed is described using Verilog syntax which is detailed in this document. The block can have up to four output ports. The number of output ports is equal to the number of expressions. The block does not cost anything in hardware.

### Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **BitBasher Expression:** Bitwise manipulation expression based on Verilog Syntax. Multiple expressions (limited to a maximum of 4) can be specified using new line as a separator between expressions.
- **Output Type tab:**
  - **Output:** This refers to the port on which the data type is specified.
  - **Output type:** Arithmetic type to be forced onto the corresponding output.
  - **Binary Point:** Binary point location to be forced onto the corresponding output.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

### Supported Verilog Constructs

The BitBasher block only supports a subset of Verilog expression constructs that perform bitwise manipulations including slice, concatenation, and repeat operators. All specified expressions must adhere to the following template expression:

```
output_var = {bitbasher_expr}
```

**bitbasher\_expr:** A slice, concat or repeat expression based on Verilog syntax or simply an input port identifier.

**output\_var:** The output port identifier. An output port with the name output\_var will appear on the block and will hold the result of the wire expression bitbasher\_expr.

## Concat

```
output_var = {bitbasher_expr1, bitbasher_expr2, bitbasher_expr3}
```

The concat syntax is supported as shown above. Each of bitbasher\_exprN could either be an expression or simply an input port identifier.

The following are some examples of this construct:

```
a1 = {b,c,d,e,f,g}
a2 = {e}
a3 = {b,{f,c,d},e}
```

## Slice

```
output_var = {port_identifier[bound1:bound2]}(1)
output_var = {port_identifier[bitN]}(2)
```

**port\_identifier:** The input port from which the bits are extracted.

**bound1, bound2:** Non-negative integers that lie between 0 and (bit-width of port\_identifier – 1)

**bitN:** Non-negative integers that lie between 0 and (bit-width of port\_identifier – 1)

As shown above, there are two schemes to extract bits from the input ports. If a range of consecutive bits need to be extracted, then the expression of the following form should be used.

```
output_var = {port_identifier[bound1:bound2]}(1)
```

If only one bit is to be extracted, then the alternative form should be used.

```
output_var = {port_identifier[bitN]}(2)
```

The following are some examples of this construct:

```
a1 = {b[7:3]}
```

a1 holds bits 7 through 3 of input b in the same order in which they appear in bit b (for example, if b is 110110110 then a1 is 10110).

```
a2 = {b[3:7]}
```

a<sub>2</sub> holds bits 7 through 3 of input b in the reverse order in which they appear in bit b (for example, if b is 110100110 then a<sub>2</sub> is 00101).

```
a3 = {b[5]}
```

a<sub>3</sub> holds bit 5 of input b.

```
a4 = {b[7:5], c[3:9], {d, e}}
```

The above expression makes use of a combination of slice and concat constructs. Bits 7 through 5 of input b, bits 3 through 9 of input c and all the bits of d and e are concatenated.

## Repeat

```
output_var = {N{bitbasher_expr}}
```

N: A positive integer that represents the repeat factor in the expression

The following are some examples of this construct:

```
a1 = {4{b[7:3]}}
```

The above expression is equivalent to a<sub>1</sub> = {b[7:3], b[7:3], b[7:3], b[7:3]}.

```
a2 = {b[7:3], 2{c, d}}
```

The above expression is equivalent to a<sub>2</sub> = {b[7:3], c, d, c, d}.

## Constants

Binary Constant: N'bbin\_const

Octal Constant: N'octal\_const

Decimal Constant: N'decimal\_const

Hexadecimal Constant: N'hexadecimal\_const

N: A positive integer that represents the number of bits that are used to represent the constant

bin\_const: A legal binary number string made up of 0 and 1

octal\_const: A legal octal number string made up of 0, 1, 2, 3, 4, 5, 6 and 7

decimal\_const: A legal decimal number string made up of 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9

hexadecimal\_const: A legal binary number string made up of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, a, b, c, d, e and f

A constant can only be used to augment expressions already derived from input ports. In other words, a BitBasher block cannot be used to simply source constant like the [Constant](#) block.

The following examples make use of this construct:

```
a1 = {4'b1100, e}
```

if e were 110110110 then a1 would be 1100110110110.

```
a1 = {4'hb, e}
```

if e were 110110110 then a1 would be 1101110110110.

```
a1 = {4'o10, e}
```

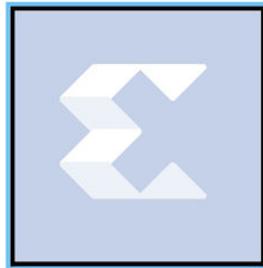
if e were 110110110 then a1 would be 1000110110110.

## Limitations

- Does not support masked parameterization on the bitbasher expressions.
- An expression cannot contain only constants, that is, each expression must include at least one input port.

## Black Box

The Model Composer Black Box block provides a way to incorporate hardware description language (HDL) models into Model Composer.



The block is used to specify both the simulation behavior in Simulink and the implementation files to be used during code generation with Model Composer. A black box's ports produce and consume the same sorts of signals as other HDL blocks. When a black box is translated into hardware, the associated HDL entity is automatically incorporated and wired to other blocks in the resulting design.

The black box can be used to incorporate either VHDL or Verilog into a Simulink model. Black box HDL can be co-simulated with Simulink using the Model Composer interface to the Vivado® simulator.

In addition to incorporating HDL into a Model Composer model, the black box can be used to define the implementation associated with an external simulation model.

## Requirements on HDL for Black Boxes

Every HDL component associated with a black box must adhere to the following Model Composer requirements and conventions:

- The entity name must not collide with any entity name that is reserved by Model Composer (e.g., xlfir, xlregister).
- Bi-directional ports are supported in HDL black boxes; however they will not be displayed in the Model Composer as ports, they will only appear in the generated HDL after netlisting.
- For a Verilog Black Box, the module and port names must be lower case, and follow standard Verilog naming conventions.
- For a VHDL Black Box, the supported port data types are std\_logic, std\_logic\_vector, signed, unsigned, boolean, sfixed, ufixed, float32 and float64.
- Top level ports should be ordered most significant bit down to least significant bit, as in std\_logic\_vector(7 downto 0), and not std\_logic\_vector(0 to 7).
- Top level ports with signed binary types in Verilog RTL are not supported (for example, 18 ' sb1010). Only unsigned binary types are supported.
- Clock and clock enable ports must be named according to the conventions described below.
  - Any port that is a clock or clock enable must be of type std\_logic. For Verilog black boxes, such ports must be non-vector inputs, e.g., input clk.
  - Clock and clock enable ports on a black box are not treated like other ports. When a black box is translated into hardware, Model Composer drives the clock and clock enable ports with signals whose rates can be specified according to the block's configuration and the sample rates that drive it in Simulink.
  - Falling-edge triggered output data cannot be used.



**IMPORTANT!** Model Composer does not import .dcp files as an IP for blackbox flows.

To understand how clocks work for black boxes, it helps to understand how Model Composer handles Timing and Clocking. In general, to produce multiple rates in hardware, Model Composer uses a single clock along with multiple clock enables, one enable for each rate. The enables activate different portions of hardware at the appropriate times. Each clock enable rate is related to a corresponding sample period in Simulink. Every HDL block that requires a clock has at least one clock and clock enable port in its HDL counterpart. Blocks having multiple rates have additional clock and clock enable ports.

Clocks for black boxes work like those for other HDL blocks. The black box HDL must have a separate clock and clock enable port for each associated sample rate in Simulink. Clock and clock enable ports in black box HDL should be expressed as follows:

- Clock and clock enables must appear as pairs (for every clock, there is a corresponding clock enable, and vice-versa). Although a black box can have more than one clock port, a single clock source is used to drive each clock port. Only the clock enable rates differ.
- Each clock name (respectively, clock enable name) must contain the substring clk (resp., ce).
- The name of a clock enable must be the same as that for the corresponding clock, but with ce substituted for clk. For example, if the clock is named src\_clk\_1, then the clock enable must be named src\_ce\_1.

Clock and clock enable ports are not visible on the black box block icon. A work around is required to make the top-level HDL clock enable port visible in Model Composer; the work around is to add a separate enable port to the top-level HDL and AND this signal with the actual clock enable signal.

### The Black Box Configuration Wizard

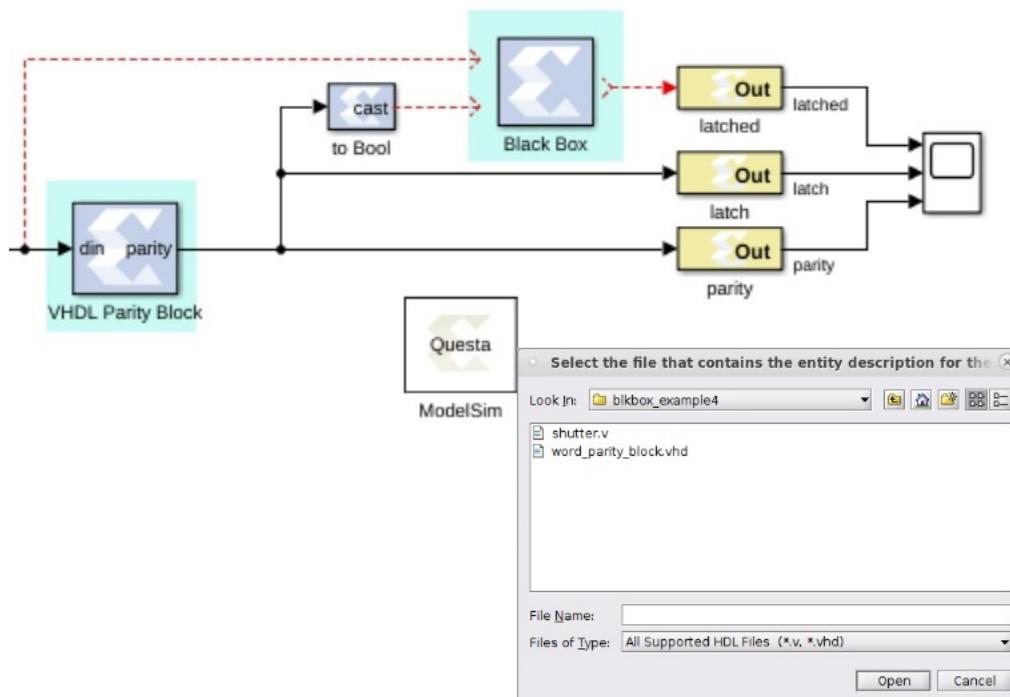
The Back Box Configuration Wizard is a tool that makes it easy to associate a Verilog or VHDL component to a black box. The Black Box Configuration Wizard is invoked whenever a black box is added to a model.



**IMPORTANT!** To use the wizard, copy the .v or .vhdl file that defines the HDL component for a black box into the directory that contains the model.

When a new black box is added to a model, the Configuration Wizard opens automatically. An example is shown in the figure below.

Figure 257: Black Box Configuration Wizard Example



From this wizard choose the HDL file that should be associated to the black box, then press the **Open** button. The wizard generates a configuration M-function (described below) for the black box, and associates the function with the block. The configuration M-function produced by the wizard can usually be used without change, but occasionally the function must be tailored by hand. Whether the configuration M-function needs to be modified depends on how complex the HDL is.

### The Black Box Configuration M-Function

A black box must describe its interface (e.g., ports and generics) and its implementation to Model Composer. It does this through the definition of a MATLAB M-function (or p-function) called the block's configuration. The name of this function must be specified in the block parameter dialog box under the Block Configuration parameter.

The configuration M-function does the following:

- It specifies the top-level entity name of the HDL component that should be associated with the black box.
- It selects the language (for example, VHDL or Verilog).
- It describes ports, including type, direction, bit width, binary point position, name, and sample rate. Ports can be static or dynamic. Static ports do not change; dynamic ports change in response to changes in the design. For example, a dynamic port might vary its width and type to suit the signal that drives it.
- It defines any necessary port type and data rate checking.
- It defines any generics required by the black box HDL.
- It specifies the black box HDL and other files (e.g., EDIF) that are associated with the block.
- It defines the clocks and clock enables for the block (see the following topic on clock conventions).
- It declares whether the HDL has any combinational feed-through paths.

Model Composer provides an object-based interface for configuring black boxes consisting of two types of objects: `BlockDescriptors`, used to define entity characteristics, and `PortDescriptors`, used to define port characteristics. This interface is used to provide Model Composer information in the configuration M-function for black box about the block's interface, simulation model, and implementation.

If the HDL for a black box has at least one combinational path (for example, a direct feed-through from an input to an output port), the block must be tagged as combinational in its configuration M-function using the `tagAsCombinational` method. A black box can be a mixture (for example, some paths can be combinational while others are not).



**IMPORTANT!** It is essential that a block containing a combinational path be tagged as such. Doing so allows Model Composer to identify such blocks to the Simulink simulator. If this is not done, simulation results are incorrect.

The configuration M-function for a black box is invoked several times when a model is compiled. The function typically includes code that depends on the block's input ports. For example, sometimes it is necessary to set the data type and/or rate of an output port based on the attributes on an input port. It is sometimes also necessary to check the type and rate on an input port. At certain times when the function is invoked, Simulink might not yet know enough for such code to be executed.

To avoid the problems that arise when information is not yet known (in particular, exceptions), `BlockDescriptor` members `inputTypesKnown` and `inputRatesKnown` can be used. These are used to determine if Simulink is able, at the moment, to provide information about the input port types and rates respectively. The following code illustrates this point.

```
if (this_block.inputTypesKnown)
% set dynamic output port types
    % set generics that depend on input port types
    % check types of input ports
end
```

If all input rates are known, this code sets types for dynamic output ports, sets generics that depend on input port types, and verifies input port types are appropriate. Avoid the mistake of including code in these conditional blocks (e.g., a variable definition) that is needed by code outside of the conditional block.

Note that the code shown above uses an object named `this_block`. Every black box configuration M-function automatically makes `this_block` available through an input argument. In MATLAB, `this_block` is the object that represents the black box, and is used inside the configuration M-function to test and configure the black box. Every `this_block` object is an instance of the `SysgenBlockDescriptor` MATLAB class. The methods that can be applied to `this_block` are specified in Appendix A. A good way to generate example configuration M-function is to run the Configuration Wizard (described below) on simple VHDL entities.

## Sample Periods

The output ports, clocks, and clock enables on a black box must be assigned sample periods in the configuration M-function. If these periods are dynamic, or the black box needs to check rates, then the function must obtain the input port sample periods. Sample periods in the black box are expressed as integer multiples of the system rate as specified by the Simulink system period field on the HDL Clock Settings tab of the Model Composer Hub block. For example, if the Simulink System Period is 1/8, and a black box input port runs at the system rate (for example, at 1/8), then the configuration M-function sees 1 reported as the port's rate. Likewise, if the Simulink System Period is specified as  $\pi$ , and an output port should run four times as fast as the system rate (for example, at  $4\pi$ ), then the configuration M-function should set the rate on the output port to 4. The appropriate rate for constant ports is Inf.

As an example of how to set the output rate on each output port, consider the following code segment:

```
block.outport(1).setRate(theInputRate);  
block.outport(2).setRate(theInputRate*5);  
block.outport(3).setRate(theInputRate*5);
```

The first line sets the first output port to the same rate as the input port. The next two lines set the output rate to 5 times the rate of the input.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Block Configuration M-Function:** Specifies the name of the configuration M-function that is associated to the black box. Ordinarily the file containing the function is stored in the directory containing the model, but it can be stored anywhere on the MATLAB path. Note that MATLAB limits all function names (including those for configuration M-functions) to 63 characters. Do not include the file extension (".*m*" or ".*p*") in the edit box.
  - **Simulation Mode:** Tells the mode (Inactive, Vivado Simulator, or External co-simulator) to use for simulation. When the mode is Inactive, the black box ignores all input data and writes zeroes to its output ports. Usually for this mode the black box should be coupled using a Variant Subsystem. For more information, see Variant Subsystems and Model Composer in the *Vitis Model Composer User Guide* ([UG1483](#)).

Model Composer supports the Questa simulator from Mentor Graphics®, Inc. for HDL co-simulation. For co-simulation of Verilog black boxes, a mixed mode license is required. This is necessary because the portion of the design that Model Composer writes is VHDL.

**Note:** When you use the Questa simulator, the Default Radix used is Binary.

Usually the co-simulator block for a black box is stored in the same Subsystem that contains the black box, but it is possible to store the block elsewhere. The path to a co-simulation block can be absolute, or can be relative to the Subsystem containing the black box (e.g., "../Questa"). When simulating, each co-simulator block uses one license. To avoid running out of licenses, several black boxes can share the same co-simulation block. Model Composer automatically generates and uses the additional VHDL needed to allow multiple blocks to be combined into a single Questa simulation.

## Data Type Translation for HDL Co-Simulation

During co-simulation, ports in Model Composer drive ports in the HDL simulator, and vice-versa. Types of signals in the tools are not identical, and must be translated. The rules used for translation are the following.

- A signal in Model Composer can be Boolean, unsigned or signed fixed point. Fixed-point signals can have indeterminate values, but Boolean signals cannot. If the signal's value is indeterminate in Model Composer, then all bits of the HDL signal become 'X', otherwise the bits become 0's and 1's that represent the signal's value.
- To bring HDL signals back into Model Composer, standard logic types are translated into Booleans and fixed-point values as instructed by the black box configuration M-function. When there is a width mismatch, an error is reported. Indeterminate signals of all varieties (weak high, weak low, etc.) are translated to Model Composer indeterminates. Any signal that is partially indeterminate in HDL simulation (e.g., a bit vector in which only the topmost bit is indeterminate) becomes entirely indeterminate in Model Composer.
- HDL to Model Composer translations can be tailored by adding a custom simulation-only top-level wrapper to the VHDL component. Such a wrapper might, for example, translate every weak low signal to 0 or every indeterminate signal to 0 or 1 before it is returned to Model Composer.

## Example

The following is an example VHDL entity that can be associated to a HDL black box.

```
library IEEE;
use IEEE.std_logic_1164.all;
use IEEE.numeric_std.all;
entity word_parity_block is
    generic (width : integer := 8);
    port (din : in std_logic_vector(width-1 downto 0);
          parity : out std_logic);
end word_parity_block;
architecture behavior of word_parity_block is
begin
    WORD_PARITY_Process : process (din)
        variable partial_parity : std_logic := '0';
    begin
        partial_parity := '0';
        XOR_BIT_LOOP: for N in din'range loop
            partial_parity := partial_parity xor din(N);
        end loop; -- N
        parity <= partial_parity after 1 ns ;
    end process WORD_PARITY_Process;
end behavior;
```

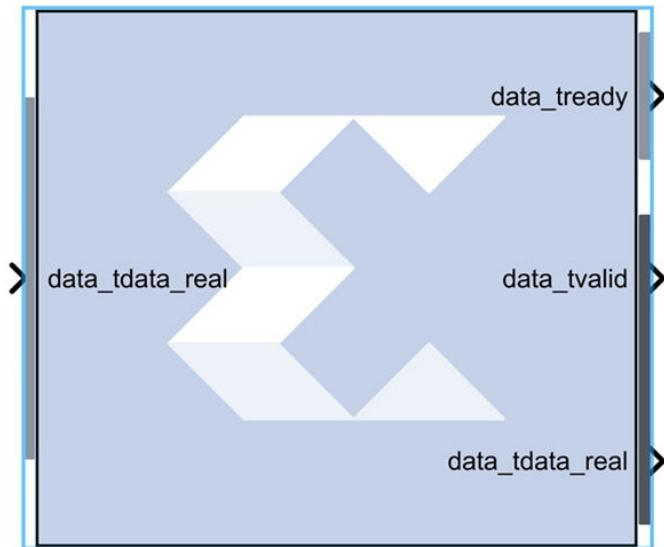
The following is an example configuration M-function. It makes the VHDL shown above available inside a HDL black box.

```
function word_parity_block_config(this_block)
this_block.setTopLevelLanguage('VHDL');
    this_block.setEntityName('word_parity_block');
    this_block.tagAsCombinational;
    this_block.addSimulinkInport('din');
    this_block.addSimulinkOutport('parity');
    parity = this_block.port('parity');
    parity.setWidth(1);
    parity.useHDLVector(false);
% -----
    if (this_block.inputTypesKnown)
        this_block.addGeneric('width',
```

```
this_block.port('din').width);
end % if(inputTypesKnown)
% -----
% -----
if (this_block.inputRatesKnown)
din = this_block.port('din');
parity.setRate(din.rate);
end % if(inputRatesKnown)
% -----
this_block.addFile('word_parity_block.vhd');
return;
```

## CIC Compiler 4.0

The Xilinx CIC Compiler provides the ability to design and implement AXI4-Stream-compliant Cascaded Integrator-Comb (CIC) filters for a variety of Xilinx FPGA devices.



CIC filters, also known as Hogenauer filters, are multi-rate filters often used for implementing large sample rate changes in digital systems. They are typically employed in applications that have a large excess sample rate. That is, the system sample rate is much larger than the bandwidth occupied by the processed signal as in digital down converters (DDCs) and digital up converters (DUCs). Implementations of CIC filters have structures that use only adders, subtractors, and delay elements. These structures make CIC filters appealing for their hardware-efficient implementations of multi-rate filtering.

### Sample Rates and the CIC Compiler Block

The CIC Compiler block must always run at the system rate because the CIC Compiler block has a programmable rate change option and Simulink® cannot inherently support it. You should use the "ready" output signal to indicate to downstream blocks when a new sample is available at the output of the CIC Compiler block.

The CIC will downsample the data, but the sample rate will remain at the clock rate. If you look at the output of the CIC Compiler block, you will see each output data repeated R times for a rate change of R while the `data_tvalid` signal pulses once every R cycles. The downstream blocks can be clocked at lower-than-system rates without any problems as long as the clock is never slower than the rate change R.

There are several different ways this can be handled. You can leave the entire design running at the system rate then use registers with enables, or enables on other blocks to capture data at the correct time. Or alternatively, you can use a downsample block corresponding to the lowest rate change R, then again use enable signals to handle the cases when there are larger rate changes.

If there are not many required rate changes, you can use MUX blocks and use a different downsample block for each different rate change. This might be the case if the downstream blocks are different depending on the rate change, basically creating different paths for each rate. Using enables as described above will probably be the most efficient method.

If you are not using the CIC Compiler block in a programmable mode, you can place an up/down sample block after the CIC Compiler to correctly pass on the sample rate to downstream blocks that will inherit the rate and build the proper CE circuitry to automatically enable those downstream blocks at the new rate.

## Block Parameters

- **Filter Specification tab:** Parameters specific to the Filter Specification tab are as follows.
  - **Filter Specification:**
    - **Filter Type:** The CIC core supports both interpolation and decimation architectures. When the filter type is selected as decimator the input sample stream is down-sampled by the factor R. When an interpolator is selected the input sample is up-sampled by R.
    - **Number of Stages:** Number of integrator and comb stages. If N stages are specified, there are N integrators and N comb stages in the filter. The valid range for this parameter is 3 to 6.
    - **Differential Delay:** Number of unit delays employed in each comb filter in the comb section of either a decimator or interpolator. The valid range of this parameter is 1 or 2.
    - **Number of Channels:** Number of channels to support in implementation. The valid range of this parameter is 1 to 16.
  - **Sample Rate Change Specification:**
    - **Sample Rate Changes:** Option to select between Fixed or Programmable.
    - **Fixed or Initial Rate(ir):** Specifies initial or fixed sample rate change value for the CIC. The valid range for this parameter is 4 to 8192.

- **Minimum Rate:** The minimum rate change value for programmable rate change. The valid range for this parameter is 4 to fixed rate (ir).
  - **Maximum Rate:** The maximum rate change value for programmable rate change. The valid range for this parameter is fixed rate (ir) to 8192.
- **Hardware Oversampling Specification:**
    - **Select format:** Choose Maximum\_Possible, Sample\_Period, or Hardware Oversampling Rate. Selects which method is used to specify the hardware oversampling rate. This value directly affects the level of parallelism of the block implementation and resources used. When “Maximum Possible” is selected, the block uses the maximum oversampling given the sample period of the signal connected to the Data field of the s\_axis\_data\_tdata port. When you select “Hardware Oversampling Rate”, you can specify the oversampling rate. When “Sample Period” is selected, the block clock is connected to the system clock and the value specified for the Sample Period parameter sets the input sample rate the block supports. The Sample Period parameter also determines the hardware oversampling rate of the block. When “Sample Period” is selected, the block is forced to use the s\_axis\_data\_tvalid control port.
    - **Sample period:** Integer number of clock cycles between input samples. When the multiple channels have been specified, this value should be the integer number of clock cycles between the time division multiplexed input sample data stream.
    - **Hardware Oversampling Rate:** Enter the hardware oversampling rate if you select **Hardware\_Oversampling\_Rate** as the format.
- **Implementation tab:**
    - **Numerical Precision:**
      - **Quantization:** Can be specified as Full\_Precision or Truncation.  
*Note:* Truncation occurs at the output stage only.
      - **Output Data Width:** Can be specified up to 48 bits for the Truncation option above.
    - **Optional:**
      - **Use Xtreme DSP slice:** This field specifies that if possible, use the XtremeDSP slice (DSP48 type element) in the target device.
      - **Use Streaming Interface:** Specifies whether or not to use a streaming interface for multiple channel implementations.
    - **Control Options:**
      - **ACLKEN:** Specifies if the block has a clock enable port (the equivalent of selecting the Has ACLKEN option in the CORE Generator GUI).
      - **ARESETn:** Specifies that the block has a reset port. Active-Low synchronous clear. A minimum ARESETn pulse of two cycles is required.

- **Has TREADY:** Specifies if the block has a TREADY port for the Data Output Channel (the equivalent of selecting the Has\_DOUT\_TREADY option in the CORE Generator GUI).

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

### LogiCORE Documentation

*CIC Compiler LogiCORE IP Product Guide (PG140)*

## Clock Enable Probe

The Xilinx Clock Enable (CE) Probe provides a mechanism for extracting derived clock enable signals from Xilinx signals in Model Composer models.



The probe accepts any Xilinx signal type as input, and produces a Bool output signal. The Bool output can be used at any point in the design where Bools are acceptable. The probe output is a cyclical pulse that mimics the behavior of an ideal clock enable signal used in the hardware implementation of a multirate circuit. The frequency of the pulse is derived from the input signal's sample period. The enable pulse is asserted at the end of the input signal's sample period for the duration of one Simulink® system period. For signals with a sample period equal to the Simulink system period, the block's output is always one.

Shown below is an example model with an attached analysis scope that demonstrates the usage and behavior of the Clock Enable Probe. The Simulink system sample period for the model is specified in the Model Composer Hub block as 1.0 seconds. In addition to the Simulink system period, the model has three other sample periods defined by the Down Sample blocks. Clock Enable Probes are placed after each Down Sample block and extract the derived clock enable signal. The probe outputs are run to output gateways and then to the scope for analysis. Also included in the model is CLK probe that produces a Double representation of the hardware system clock. The scope output shows the output from the four Clock Enable probes in addition to the CLK probe output.

Figure 258: Example Model with Attached Analysis Scope

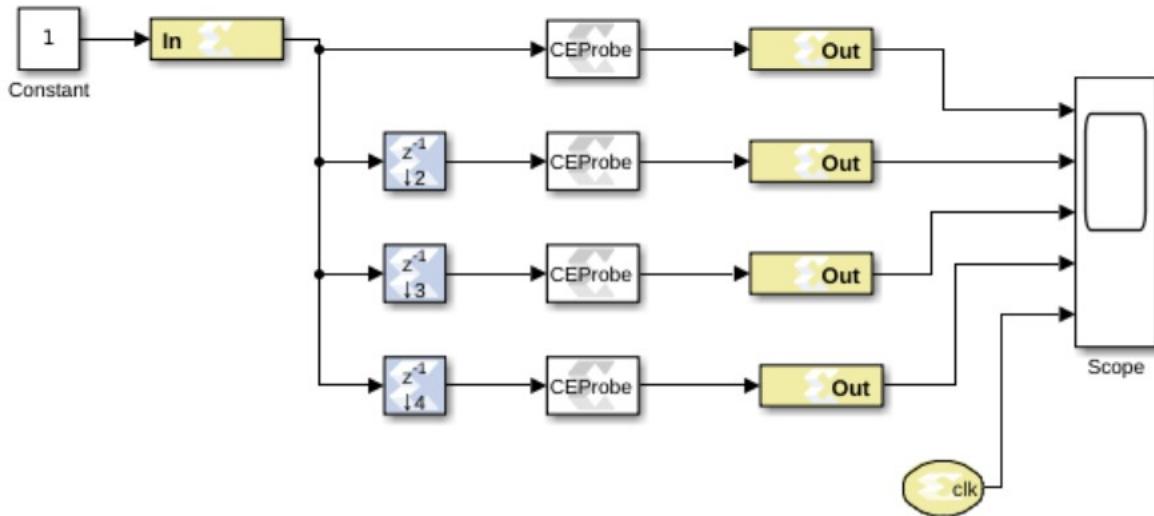
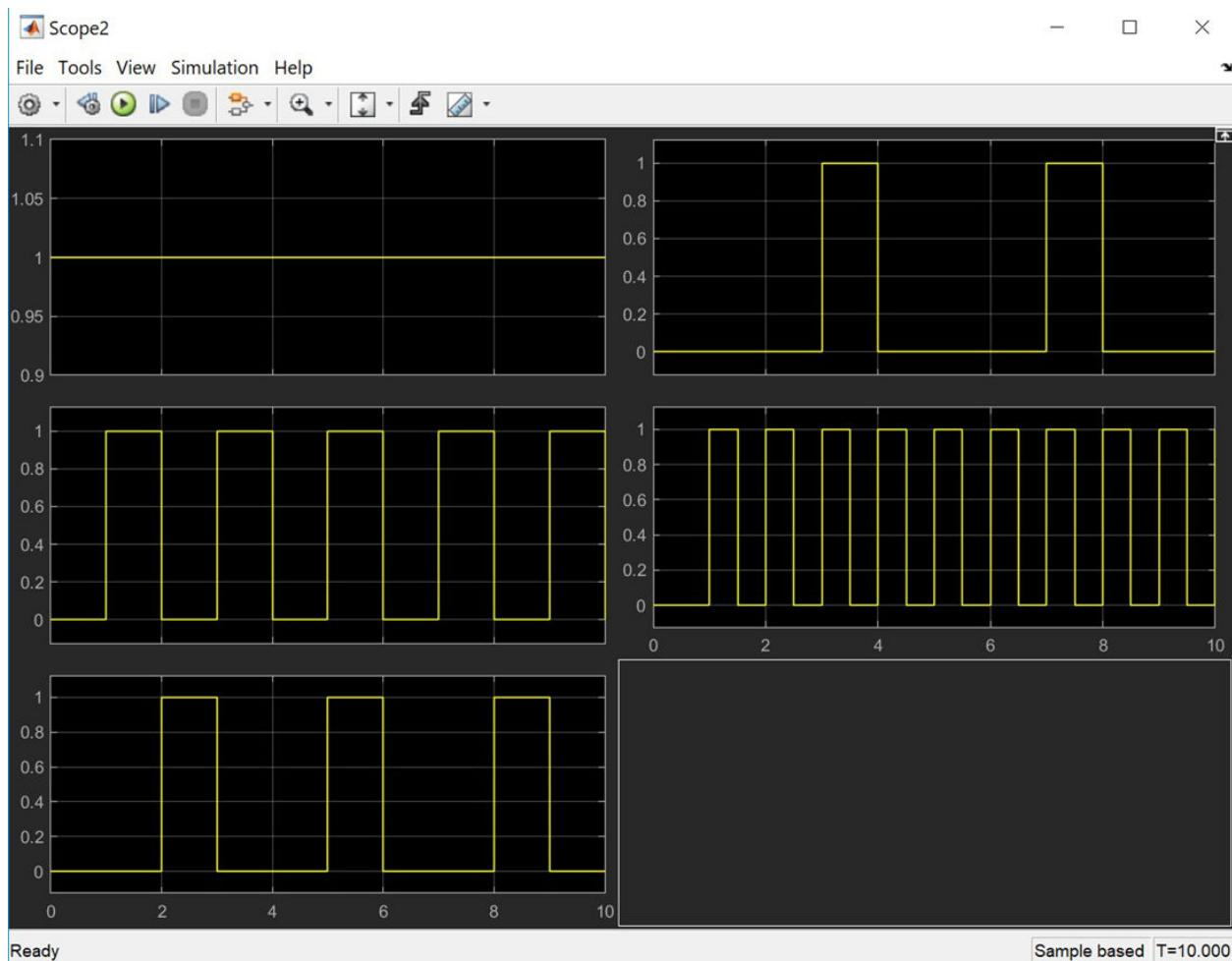


Figure 259: Analysis Scope Output

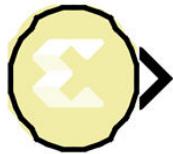


## Options

- **Use clock enable signal without Multi-Cycle path constraints:** Used to disable multi-cycle path constraints on the generated signal from the Clock Enable Probe block. This is typically applied when the signal generated is used as separate timing signal that is not clock-enable related.

## Clock Probe

The Xilinx Clock Probe generates a double-precision representation of a clock signal with a period equal to the Simulink® system period.

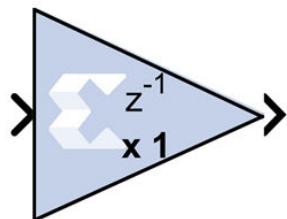


The output clock signal has a 50/50 duty cycle with the clock asserted at the start of the Simulink sample period. The Clock Probe's double output is useful only for analysis, and cannot be translated into hardware.

There are no parameters for this block.

## CMult

The Xilinx CMult block implements a gain operator, with output equal to the product of its input by a constant value. This value can be a MATLAB® expression that evaluates to a constant.



## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows:

- **Constant Type:**
  - **Fixed-point:** Use fixed-point data type.
  - **Floating-point:** Use floating-point data type. Can be a constant or an expression. If the constant cannot be expressed exactly in the specified fixed-point type, its value is rounded and saturated as needed.
- **Fixed-point Precision:**
  - **Number of bits:** Specifies the bit location of the binary point of the constant, where bit zero is the least significant bit.
  - **Binary point:** Position of the binary point.
- **Floating-point Precision:**
  - **Single:** Specifies single precision (32 bits)
  - **Double:** Specifies double precision (64 bits)
  - **Custom:** Activates the field below so you can specify the Exponent width and the Fraction width.
  - **Exponent width:** Specify the exponent width.
  - **Fraction width:** Specify the fraction width.
- **Output tab:**
  - **Precision:** This parameter allows you to specify the output precision for fixed-point arithmetic. Floating point arithmetic output will always be Full precision.
    - **Full:** The block uses sufficient precision to represent the result without error.
    - **User Defined:** If you do not need full precision, this option allows you to specify a reduced number of total bits and/or fractional bits.
  - **Fixed-point Output Type:**
    - **Arithmetic type:**
      - **Signed (2's comp):** The output is a Signed (2's complement) number.
      - **Unsigned:** The output is an Unsigned number.
    - **Fixed-point Precision:**
      - **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
      - **Binary point:** Position of the binary point in the fixed-point output.

- **Quantization:**

Refer to the section [Overflow and Quantization](#).

- **Overflow:**

Refer to the section [Overflow and Quantization](#).

- **Implementation tab:**

Parameters specific to the Implementation tab are as follows.

- **Use behavioral HDL description (otherwise use core):** When selected, Model Composer uses behavioral HDL, otherwise it uses the Xilinx LogiCORE™ Multiplier. When this option is not selected (false) Model Composer internally uses the behavioral HDL model for simulation if any of the following conditions are true:

- The constant value is 0 (or is truncated to 0).
- The constant value is less than 0 and its bit width is 1.
- The bit width of the constant or the input is less than 1 or is greater than 64.
- The bit width of the input data is 1 and its data type is xlFix.

- **Core Parameters:**

- **Implement using:** Specifies whether to use distributed RAM or block RAM.
- **Test for optimum pipelining:** Checks if the Latency provided is at least equal to the optimum pipeline length supported for the given configuration of the block. Latency values that pass this test imply that the core produced is optimized for speed.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

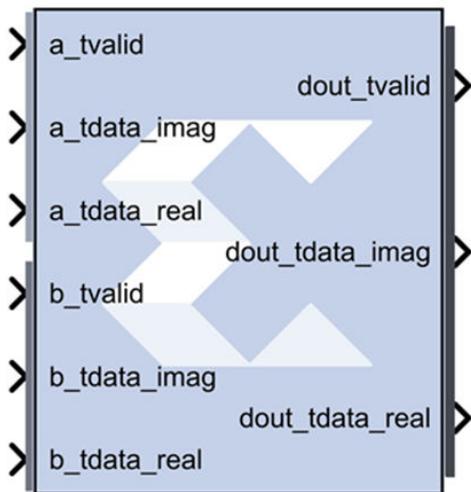
## LogiCORE Documentation

[LogiCORE IP Multiplier v12.0](#)

[LogiCORE IP Floating-Point Operator v7.1](#)

## Complex Multiplier 6.0

The Complex Multiplier block implements AXI4-Stream compliant, high-performance, optimized complex multipliers for devices based on user-specified options.



The two multiplicand inputs and optional rounding bit are input on independent AXI4-Stream channels as slave interfaces and the resulting product output using an AXI4-Stream master interface.

Within each channel, operands, and the results are represented in signed two's complement format. The operand widths. and the result width are parameterizable.

## Block Parameters

- Basic tab:

Parameters specific to the Basic tab are:

- Channel A Options:

- Has TLAST: Adds a tlast input port to the A channel of the block.
- Has TUSER: Adds a tuser input port to the A channel of the block.
- TUSER Width: User defined, maximum Limit range (1, 256).

- Channel B Options:

- Has TLAST: Adds a tlast input port to the B channel of the block.
- Has TUSER: Adds a tuser input port to the B channel of the block.
- TUSER Width: User defined. maximum Limit range (1, 256).

- Multiplier Construction Options:

- Use\_Mults: Use embedded multipliers/XtremeDSP slices.
- Use\_LUTs: Use LUTs in the fabric to construct multipliers.

- **Optimization Goal:** Only available if Use\_Mults is selected.
  - **Resources:** Uses the 3-real-multiplier structure. However, a 4-real-multiplier structure is used when the 3- I- multiplier structure uses more multiplier resources.
  - **Performance:** Always uses the 4-real multiplier structure to allow the best frequency performance to be achieved.
- **Flow Control Options:**
  - **Blocking:** Selects “Blocking” mode. In this mode, the lack of data on one input channel does block the execution of an operation if data is received on another input channel.
  - **NonBlocking:** Selects “Non-Blocking” mode. In this mode, the lack of data on one input channel does not block the execution of an operation if data is received on another input channel.
- **Page 2 tab:**
  - **Output Product Range:**

Select the output bit width. The values are automatically set to provide the full-precision product when the A and B operand widths are set. The output is sign-extended if required.

The natural output width for complex multiplication is (APortWidth + BPortWidth + 1). When the Output Width is set to be less than this, the most significant bits of the result are those output; the remaining bits will either be truncated or rounded according to Output Rounding option selected. That is to say, the output MSB is now fixed at (APortWidth + BPortWidth). For details please refer to the document [LogiCORE IP Complex Multiplier v6.0 Product Guide](#).
  - **Output Rounding:** If rounding is required, the Output LSB must be greater than zero.
    - **Truncate:** Truncate the output.
    - **Random\_Rounding:** When this option is selected, a `ctrl_tvalid` and `ctrl_tdata` input port is added to the block. Bit 0 of `ctrl_tdata` input determines the particular type of rounding for the operation. For details, refer to the Rounding section of the [Complex Multiplier LogiCORE IP Product Guide \(PG104\)](#).
  - **Channel CTRL Options:** The following options are activated when Random Rounding is selected.
    - **Has TLAST:** Adds a `ctrl_tlast` input port to the block.
    - **Has TUSER:** Adds a `ctrl_tuser` input port to the block.
    - **TUSER Width:** Specifies the bit width of the `ctrl_tuser` input port.
    - **Output TLAST Behavior:** Determines the behavior of the `dout_tlast` output port.

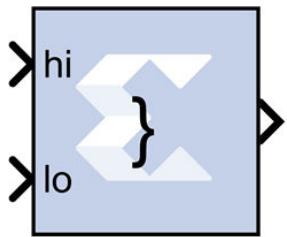
- **Null:** Output is null.
- **Pass\_A\_TLAST:** Pass the value of the a\_tlast input port to the dout\_tlast output port.
- **Pass\_B\_TLAST:** Pass the value of the b\_tlast input port to the dout\_tlast output port.
- **Pass CTRL\_TLAST:** Pass the value of the ctrl\_tlast input port to the dout\_tlast output port.
- **OR\_all\_TLASTS:** Pass the logical OR of all the present TLAST input ports.
- **AND\_all\_TLASTS:** Pass the logical AND of all the present TLAST input ports.
- **Core Latency:**
  - **Latency Configuration:**
    - **Automatic:** Block latency is automatically determined by Model Composer by pipelining the underlying LogiCORE™ for maximum performance.
    - **Manual:** You can adjust the block latency specifying the minimum block latency.
    - **Minimum Latency:** Entry field for manually specifying the minimum block latency.
  - **Control Signals:**
    - **ACLKEN:** Enables the clock enable (`aclk_en`) pin on the core. All registers in the core are enabled by this control signal.
    - **ARESETn:** Active-Low synchronous clear input that always takes priority over ACLKEN. A minimum ARESETn active pulse of two cycles is required, since the signal is internally registered for performance. A pulse of one cycle resets the core, but the response to the pulse is not in the cycle immediately following.
- **Advanced tab:** Block Icon Display
  - **Display shortened port names:** On by default. For example, when unchecked, `dout_tvalid` becomes `m_axis_dout_tvalid`.

## LogiCORE Documentation

Complex Multiplier LogiCORE IP Product Guide ([PG104](#))

## Concat

The Xilinx Concat block performs a concatenation of n bit vectors represented by unsigned integer numbers, for example, n unsigned numbers with binary points at position zero.



The Xilinx [Reinterpret](#) block provides capabilities that can extend the functionality of the Concat block.

### Block Interface

The block has  $n$  input ports, where  $n$  is some value between 2 and 1024, inclusively, and one output port. The first and last input ports are labeled `hi` and `low`, respectively. Input ports between these two ports are not labeled. The input to the `hi` port will occupy the most significant bits of the output and the input to the `lo` port will occupy the least significant bits of the output.

### Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Parameters specific to this block are as follows:

- Number of Inputs: specifies number of inputs, between 2 and 1024, inclusively, to concatenate together.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

The Concat block does not use a Xilinx LogiCORE.

## Constant

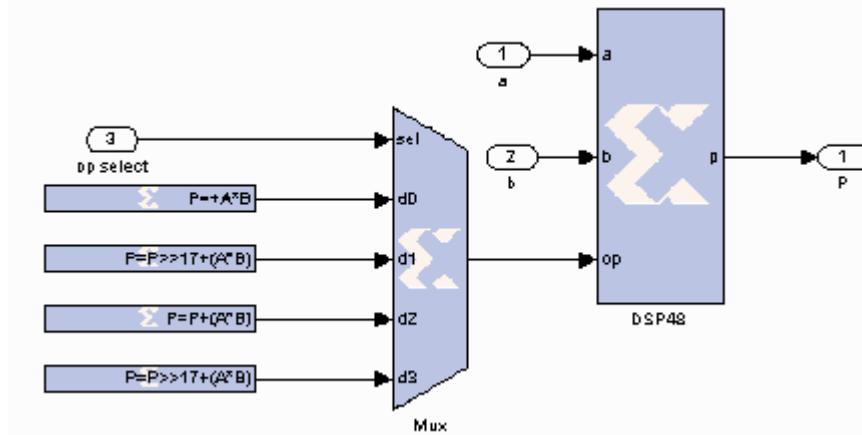
The Xilinx Constant block generates a constant that can be a fixed-point value, or a Boolean value. This block is similar to the Simulink® constant block, but can be used to directly drive the inputs on HDL blocks.



## DSP48 Instruction Mode

The constant block, when set to create a DSP48 instruction, is useful for generating DSP48 control sequences. The following figure shows an example. The example implements a 35x35-bit multiplier using a sequence of four instructions in a DSP48 block. The constant blocks supply the desired instructions to a multiplexer that selects each instruction in the desired sequence.

**Figure 260: Example of Constant Block Creating a DSP48 Instruction**



## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows:

- **Constant Value:**

Specifies the value of the constant. When changed, the new value appears on the block icon. If the constant data type is specified as fixed-point and cannot be expressed exactly in the specified fixed-point type, its value is rounded and saturated as needed. A positive value is implemented as an unsigned number, a negative value as signed.

- **Output Type:** Specifies the data type of the output. Can be Boolean, Fixed-point, or Floating-point.

- **Arithmetic Type:** If the Output Type is specified as Fixed-point, you can select **Signed (2's comp)**, **Unsigned**, or **DSP48 instruction** as the Arithmetic Type.

- **Fixed-point Precision:**

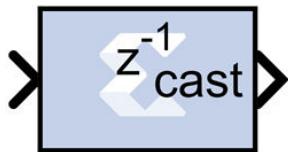
- **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.

- **Binary point:** Position of the binary point in the fixed-point output.
- **Floating-point Precision:**
  - **Single:** Specifies single precision (32 bits).
  - **Double:** Specifies double precision (64 bits)
  - **Custom:** Activates the field below so you can specify the Exponent width and the Fraction width.
  - **Exponent width:** Specifies the exponent width.
  - **Fraction width:** Specifies the fraction width.
- **Sample Period:**
  - **Sampled Constant:** Allows a sample period to be associated with the constant output and inherited by blocks that the constant block drives. (This is useful mainly because the blocks eventually target hardware and the Simulink sample periods are used to establish hardware clock periods.)
- **DSP48 tab:**
  - **DSP48 Instruction:** The use of this block for DSP48 instructions is deprecated. Please use the Opmode block.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Convert

The Xilinx Convert block converts each input sample to a number of a desired arithmetic type. For example, a number can be converted to a signed (two's complement) or unsigned value.



### Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

- **Basic tab:** Parameters specific to the Basic Tab are as follows.
  - **Output Type:** Specify the output data type.

- Boolean
- Fixed-point
- Floating-point
- **Arithmetic Type:** If the Output Type is specified as Fixed-point, you can select Signed (2's comp) or Unsigned.
- **Fixed-point Precision:**
  - **Number of bits:** Specifies the bit location of the binary point, where bit zero is the least significant bit.
  - **Binary point:** Specifies the bit location of the binary point.
- **Floating-point Precision:**
  - **Single:** Specifies single precision (32 bits).
  - **Double:** Specifies double precision (64 bits).
  - **Custom:** Activates the field below so you can specify the Exponent width and the Fraction width.
  - **Exponent width:** Specify the exponent width.
  - **Fraction width:** Specify the fraction width.
- **Quantization:**

Quantization errors occur when the number of fractional bits is insufficient to represent the fractional portion of a value. The options are to **Truncate** (for example, to discard bits to the right of the least significant representable bit), or to **Round (unbiased: +/- inf)** or **Round (unbiased: even values)**.

**Round (unbiased: +/- inf)** also known as "Symmetric Round (towards +/- inf)" or "Symmetric Round (away from zero)". This is similar to the MATLAB `round( )` function. This method rounds the value to the nearest desired bit away from zero and when there is a value at the midpoint between two possible rounded values, the one with the larger magnitude is selected. For example, to round 01.0110 to a Fix\_4\_2, this yields 01.10, since 01.0110 is exactly between 01.01 and 01.10 and the latter is further from zero.

**Round (unbiased: even values)** also known as "Convergent Round (toward even)" or "Unbiased Rounding". Symmetric rounding is biased because it rounds all ambiguous midpoints away from zero which means the average magnitude of the rounded results is larger than the average magnitude of the raw results. Convergent rounding removes this by alternating between a symmetric round toward zero and symmetric round away from zero. That is, midpoints are rounded toward the nearest even number. For example, to round 01.0110 to a Fix\_4\_2, this yields 01.10, since 01.0110 is exactly between 01.01 and 01.10 and the latter is even. To round 01.1010 to a Fix\_4\_2, this yields 01.10, since 01.1010 is exactly between 01.10 and 01.11 and the former is even.

- **Overflow:**

Overflow errors occur when a value lies outside the representable range. For overflow the options are to **Saturate** to the largest positive/smallest negative value, to **Wrap** (for example, to discard bits to the left of the most significant representable bit), or to **Flag as error** (an overflow as a Simulink error) during simulation. **Flag as error** is a simulation only feature. The hardware generated is the same as when **Wrap** is selected.

- **Optional Ports:**

Provide enable port activates an optional enable (en) pin on the block. When the enable signal is not asserted the block holds its current state until the enable signal is asserted again or the reset signal is asserted.

- **Latency:**

The Latency value defines the number of sample periods by which the block's output is delayed. One sample period might correspond to multiple clock cycles in the corresponding FPGA implementation (for example, when the hardware is over-clocked with respect to the Simulink® model). Model Composer will not perform extensive pipelining unless you select the **Pipeline for maximum performance** option (described below); additional latency is usually implemented as a shift register on the output of the block.

- **Implementation tab:** Parameters specific to the Implementation tab are as follows.

- **Performance Parameters:**

**Pipeline for maximum performance:** The XILINX LogiCORE can be internally pipelined to optimize for speed instead of area. Selecting this option puts all user defined latency into the core until the maximum allowable latency is reached. If the **Pipeline for maximum performance** option is not selected and latency is greater than zero, a single output register is put in the core and additional latency is added on the output of the core.

The **Pipeline for maximum performance** option adds the pipeline registers throughout the block, so that the latency is distributed, instead of adding it only at the end. This helps to meet tight timing constraints in the design.

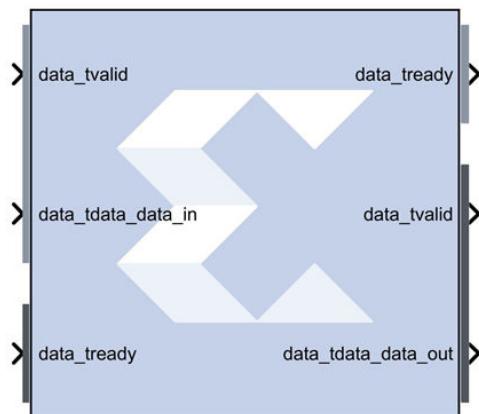
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

### LogiCORE Documentation

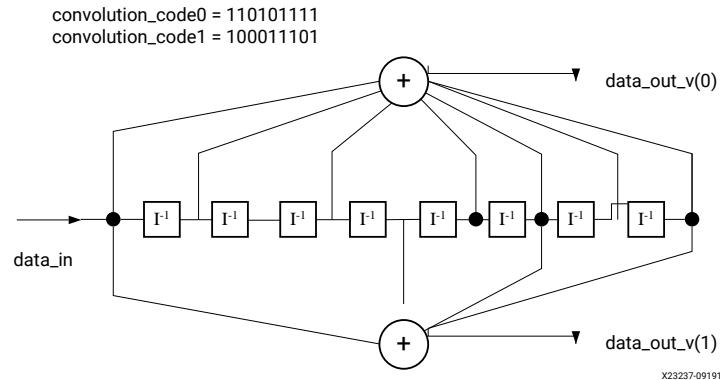
*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

## Convolution Encoder 9.0

The Xilinx® Convolution Encoder block implements an encoder for convolution codes. Ordinarily used in tandem with a Viterbi decoder, this block performs forward error correction (FEC) in digital communication systems. This block adheres to the AMBA® AXI4-Stream standard.

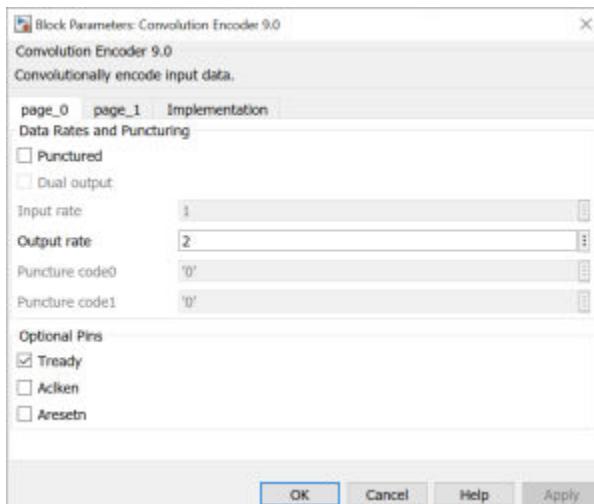


Values are encoded using a linear feed forward shift register which computes modulo-two sums over a sliding window of input data, as shown in the figure below. The length of the shift register is specified by the constraint length. The convolution codes specify which bits in the data window contribute to the modulo-two sum. Resetting the block will set the shift register to zero. The encoder rate is the ratio of input to output bit length; thus, for example a rate 1/2 encoder outputs two bits for each input bit. Similarly, a rate 1/3 encoder outputs three bits for each input bit.

**Figure 261: Linear Feed Forward Shift Register**

## Block Parameters

The following figure shows the Block Parameters dialog box.

**Figure 262: Block Parameter Dialog Box**

- **page\_0 tab:**

Parameters specific to the page\_0 tab are as follows.

- **Data Rates and Puncturing:**

- **Punctured:** Determines whether the block is punctured.
    - **Dual Output:** Specifies a dual-channel punctured block.
    - **Input Rate:** Punctured: Only the input rate can be modified. Its value can range from 2 to 12, resulting in a rate n/m encoder where n is the input rate and n< m < 2n.

- **Output Rate:** Not Punctured: Only the output rate can be modified. Its value can be integer values from 2 to 7, resulting in a rate 1/2 or rate 1/7 encoder, respectively
  - **Puncture Code0 and Code1:** The two puncture pattern codes are used to remove bits from the encoded data prior to output. The length of each puncture code must be equal to the puncture input rate, and the total number of bits set to 1 in the two codes must equal the puncture output rate ( $m$ ) for the codes to be valid. A 0 in any position indicates that the output bit from the encoder is not transmitted. See the associated LogiCORE™ data sheet for an example.
- **Optional Pins:**
    - **Tready:** Adds a `tready` pin to the block. Indicates that the slave can accept a transfer in the current cycle.
    - **Aclken:** Adds a `aclken` pin to the block. This signal carries the clock enable and must be of type `Bool`.
    - **Aresetn:** Adds a `aresetn` pin to the block. This signal resets the block and must be of type `Bool`. The signal must be asserted for at least 2 clock cycles, however, it does not have to be asserted before the decoder can start decoding. If this pin is not selected, Model Composer ties this pin to inactive (high) on the core.
  - **page\_1 tab:** Parameters specific to the page\_1 tab are as follows.
    - **Radix:**
      - **Convolution code radix:** Select Binary, Octal, or Decimal.
    - **Convolution:**
      - **Constraint length:** Equals  $n+1$ , where  $n$  is the length of the constraint register in the encoder.
      - **Convolution code:** Array of binary convolution codes. Output rate is derived from the array length. Between 2 and 7 (inclusive) codes can be entered.

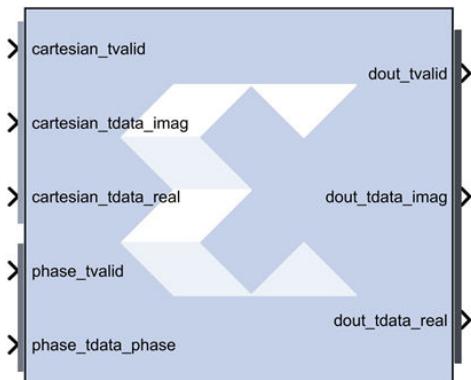
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

*Convolutional Encoder LogiCORE IP Product Guide (PG026)*

## CORDIC 6.0

The Xilinx CORDIC block implements a generalized coordinate rotational digital computer (CORDIC) algorithm and is AXI compliant.



The CORDIC core implements the following equation types:

- Rotate
- Translate
- Sin\_and\_Cos
- Sinh\_and\_Cosh
- Arc\_Tan
- Arc\_Tanh
- Square\_Root

Two architectural configurations are available for the CORDIC core:

- A word serial implementation with multiple-cycle throughput, but occupying a small silicon area.
- A fully parallel configuration with single-cycle data throughput at the expense of silicon area.

A coarse rotation is performed to rotate the input sample from the full circle into the first quadrant. (The coarse rotation stage is required as the CORDIC algorithm is only valid over the first quadrant). An inverse coarse rotation stage rotates the output sample into the correct quadrant.

The CORDIC algorithm introduces a scale factor to the amplitude of the result, and the CORDIC core provides the option of automatically compensating for the CORDIC scale factor.

## Changes from CORDIC 4.0 to CORDIC 6.0

AXI compliant

- The CORDIC 6.0 block is AXI compliant.

Ports Renamed

- `en` to `aclken`

- `rst` to `aresetn`
- `rdy` maps to `dout_tready`.
- `cartesian_tready` and `phase_tready` are automatically added when their respective channels are added.
- `x_in` to `cartesian_tdata_real`
- `y_in` to `cartesian_tdata_imag`
- `phase_in` to `phase_tdata_phase`
- `x_out` to `dout_tdata_real`
- `y_out` to `dout_tdata_imag`
- `phase_out` to `dout_tdata_phase`

### Port Changes

- The data output ports are not optional in CORDIC 6.0. The data output ports are selected based on the Function selected.
- A fully parallel configuration with single-cycle data throughput at the expense. There are separate `tuser`, `tlast`, and `tready` ports for the Cartesian and Phase input channels.
- The `dout_tlast` output port can be configured to provide `tlast` from the Cartesian input channel, from the Phase input channel, or the AND and or the OR of all `tlasts`.

### Optimization

- When you select **Blocking** mode for the AXI behavior, you can then select whether the core is configured for minimum **Resources** or maximum **Performance**.

### Displaying Port Names on the Block Icon

- You can select **Display shortened port names** to trim the length of the AXI port names on the block icon.

### Block Parameters

- **Page 1 tab:**
  - **Functional selection:**
    - **Rotate:** When selected, the input vector, (real, imag), is rotated by the input angle using the CORDIC algorithm. This generates the scaled output vector,  $Z_i * (\text{real}', \text{imag}')$ .
    - **Translate:** When selected, the input vector (real, imag) is rotated using the CORDIC algorithm until the imag component is zero. This generates the scaled output magnitude,  $Z_i * \text{Mag}(\text{real}, \text{imag})$ , and the output phase,  $\text{Atan}(\text{imag}/\text{real})$ .
    - **Sin\_and\_Cos:** When selected, the unit vector is rotated, using the CORDIC algorithm, by input angle. This generates the output vector ( $\text{Cos}()$ ,  $\text{Sin}()$ ).

- **Sinh\_and\_Cosh:** When selected, the CORDIC algorithm is used to move the vector (1,0) through hyperbolic angle  $p$  along the hyperbolic curve. The hyperbolic angle represents the log of the area under the vector (real, imag) and is unrelated to a trigonometric angle. This generates the output vector ( $\text{Cosh}(p)$ ,  $\text{Sinh}(p)$ ).
- **Arc\_Tan:** When selected, the input vector (real, imag) is rotated (using the CORDIC algorithm) until the imag component is zero. This generates the output angle,  $\text{Atan}(\text{imag}/\text{real})$ .
- **Arc\_Tanh:** When selected, the CORDIC algorithm is used to move the input vector (real, imag) along the hyperbolic curve until the imag component reaches zero. This generates the hyperbolic “angle,”  $\text{Atanh}(\text{imag}/\text{real})$ . The hyperbolic angle represents the log of the area under the vector (real, imag) and is unrelated to a trigonometric angle.
- **Square\_Root:** When selected a simplified CORDIC algorithm is used to calculate the positive square root of the input.
- **Architectural configuration:** Configuration:
  - **Word\_Serial:** Select for a hardware result with a small area.
  - **Parallel:** Select for a hardware result with high throughput.
- **Pipelining mode:**
  - **No\_Pipelining:** The CORDIC core is implemented without pipelining.
  - **Optimal:** The CORDIC core is implemented with as many stages of pipelining as possible without using any additional LUTs.
  - **Maximum:** The CORDIC core is implemented with a pipeline after every shift-add sub stage.
- **Data format:**
  - **SignedFraction:** Default setting. The real and imag inputs and outputs are expressed as fixed-point 2’s complement numbers with an integer width of 2-bits.
  - **UnsignedFraction:** Available only for Square Root functional configuration. The real and imag inputs and outputs are expressed as unsigned fixed-point numbers with an integer width of 1-bit.
  - **UnsignedInteger:** Available only for Square Root functional configuration. The real and imag inputs and outputs are expressed as unsigned integers.
- **Phase format:**
  - **Radians:** The phase is expressed as a fixed-point 2’s complement number with an integer width of 3-bits, in radian units.
  - **Scaled\_Radians:** The phase is expressed as fixed-point 2’s complement number with an integer width of 3-bits, with pi-radian units. One scaled-radian equals  $\text{Pi} * 1$  radians.

- **Input/Output Options:**

- **Input width:** Controls the width of the input ports `cartesian_tdata_real`, `cartesian_tdata_imag`, and `phase_tdata_phase`. The Input width range 8 to 48 bits.
- **Output width:** Controls the width of the output ports `dout_tdata_real`, `dout_tdata_imag`, and `dout_tdata_phase`. The Output width range 8 to 48 bits.

- **Round mode:**

- **Truncate:** The real, imag, and phase outputs are truncated.
- **Round\_Pos\_Inf:** The real, imag, and phase outputs are rounded (1/2 rounded up).
- **Round\_Pos\_Neg\_Inf:** The real, imag, and phase outputs are rounded (1/2 rounded up, -1/2 rounded down).
- **Nearest\_Even:** The real, imag, and phase outputs are rounded toward the nearest even number (1/2 rounded down and 3/2 is rounded up).

- **Page 2 tab:**

- **Advanced Configuration Parameters:**

- **Iterations:** Controls the number of internal add-sub iterations to perform. When set to zero, the number of iterations performed is determined automatically based on the required accuracy of the output.
- **Precision:** Configures the internal precision of the add-sub iterations. When set to zero, internal precision is determined automatically based on the required accuracy of the output and the number of internal iterations.
- **Compensation scaling:** Controls the compensation scaling module used to compensate for CORDIC magnitude scaling. CORDIC magnitude scaling affects the Vector Rotation and Vector Translation functional configurations, and does not affect the SinCos, SinhCosh, ArcTan, ArcTanh and Square Root functional configurations. For the latter configurations, compensation scaling is set to No Scale Compensation.

- **Coarse rotation:**

Controls the instantiation of the coarse rotation module. Instantiation of the coarse rotation module is the default for the following functional configurations: Vector rotation, Vector translation, Sin and Cos, and Arc Tan. If Coarse Rotation is turned off for these functions then the input/output range is limited to the first quadrant (-Pi/4 to + Pi/4).

Coarse rotation is not required for the Sinh and Cosh, Arctanh, and Square Root configurations. The standard CORDIC algorithm operates over the first quadrant. Coarse Rotation extends the CORDIC operational range to the full circle by rotating the input sample into the first quadrant and inverse rotating the output sample back into the appropriate quadrant.

- **Optional ports:**

- **Standard:**

- **aclken:** When this signal is not asserted, the block holds its current state until the signal is asserted again or the aresetn signal is asserted. The aresetn signal has precedence over this clock enable signal. This signal has to run at a multiple of the blocks sample rate. The signal driving this port must be Boolean.
    - **aresetn:** When this signal is asserted, the block goes back to its initial state. This reset signal has precedence over the optional aclken signal available on the block. The reset signal has to run at a multiple of the block's sample rate. The signal driving this port must be Boolean.
    - **tready:** Adds `dout_tready` port if Blocking mode is activated.

- **Cartesian:**

- **tlast:** Adds a tlast input port to the Cartesian input channel.
    - **tuser:** Adds a tuser input port to the Cartesian input channel.
    - **tuser width:** Specifies the bit width of the Cartesian tuser input port.

- **Phase:**

- **tlast:** Adds a tlast input port to the Phase input channel.
    - **tuser:** Adds a tuser input port to the Phase input channel.
    - **tuser width:** Specifies the bit width of the Phase tuser input port.

- **Tlast behavior:**

- **Null:** Data output port.
    - **Pass\_Cartesian\_TLAST:** Data output port.
    - **Pass\_Phase\_TLAST:** Data output port.
    - **OR\_all\_TLASTS:** Pass the logical OR of all the present TLAST input ports.
    - **AND\_all\_TLASTS:** Pass the logical AND of all the present TLAST input ports

- **Flow control:**

- **AXI behavior:**

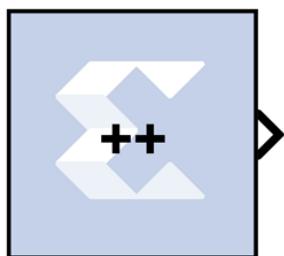
- **NonBlocking:** Selects “Non-Blocking” mode. In this mode, the lack of data on one input channel does not block the execution of an operation if data is received on another input channel.
- **Blocking:** Selects “Blocking” mode. In this mode, the lack of data on one input channel does block the execution of an operation if data is received on another input channel.
- **Optimization:** When NonBlocking mode is selected, the following optimization options are activated:
  - **Resources:** Core is configured for minimum resources.
  - **Performance:** Core is configured for maximum performance.
- **Implementation tab:**
  - **Block Icon Display:**
    - **Display shortened port names:** This option is ON by default. When unselected, the full AXI name of each port is displayed on the block icon.

## LogiCORE Documentation

CORDIC LogiCORE IP Product Guide ([PG105](#))

## Counter

The Xilinx Counter block implements a free-running or count-limited type of an up, down, or up/down counter. The counter output can be specified as a signed or unsigned fixed-point number.



Free-running counters are the least expensive in FPGA hardware. The free-running up, down, or up/down counter can also be configured to load the output of the counter with a value on the input `din` port by selecting the **Provide Load Pin** option in the Block Parameters dialog box.

$$out(n) = \begin{cases} \text{InitialValue} & \text{if } n=0 \\ (out(n-1)+Step)mod2^N & \text{otherwise} \end{cases}$$

The output for a free-running up counter is calculated as follows:

$$out(n) = \begin{cases} InitialValue & if\ n=0 \\ din(n-1) & if\ load(n-1)=1 \\ (out(n-1)+Step)mod2^N & otherwise \end{cases}$$

Here N denotes the number of bits in the counter. The free-running down counter calculations replace addition with subtraction.

For the free-running up/down counter, the counter performs addition when input up port is 1 or subtraction when the input up port is 0.

A count-limited counter is implemented by combining a free-running counter with a comparator. Count limited counters are limited to only 64 bits of output precision. Count limited types of a counter can be configured to step between the initial and ending values, provided the step value evenly divides the difference between the initial and ending values.

The output for a count limited up counter is calculated as follows:

$$out(n) = \begin{cases} InitialValue & if\ n=0\ or\ out(n-1)=CountLimit \\ (out(n-1)+Step)mod2^N & otherwise \end{cases}$$

The count-limited down counter calculation replaces addition with subtraction. For the count limited up/down counter, the counter performs addition when input up port is 1 or subtraction when input up port is 0.

The output for a free-running up counter with load capability is calculated as follows:

$$out(n) = \begin{cases} StartCount & if\ n=0\ or\ rst(n)=1 \\ din & if\ rst(n)=0\ and\ load(n)=1 \\ (out(n-1)+CountByValue)mod2^N & otherwise \end{cases}$$

Here N denotes the number of bits in the counter. The down counter calculations replace addition by subtraction.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows:

- **Counter type:** Specifies the counter to be a count-limited or free-running counter.
- **Count to value:** Specifies the ending value, the number at which the count-limited counter resets. A value of `Inf` denotes the largest representable output in the specified precision. This cannot be the same as the initial value.

- **Count direction:** Specifies the direction of the count (up or down) or provides an optional input port up (when up/down is selected) for specifying the direction of the counter.
- **Initial value:** Specifies the initial value to be the output of the counter.
- **Step:** Specifies the increment or decrement value.
- **Output type:** Specifies the block output to be either Signed or Unsigned.
- **Number of bits:** Specifies the number of bits in the block output.
- **Binary point:** Specifies the location of the binary point in the block output.
- **Provide load port:** When checked, the block operates as a free-running load counter with explicit load and din port. The load capability is available only for the free-running counter.
- **Provide Synchronous reset port:** Activates an optional reset (rst) pin on the block. When the reset signal is asserted the block goes back to its initial state. Reset signal has precedence over the optional enable signal available on the block. The reset signal has to run at a multiple of the block's sample rate. The signal driving the reset port must be Boolean.
- **Implementation tab:**

Parameters specific to the Implementation tab are as follows.

- **Implementation Details:**
  - **Use behavioral HDL (otherwise use core):** The block is implemented using behavioral HDL. This gives the downstream logic synthesis tool maximum freedom to optimize for performance or area.
- **Core Parameters:**
  - **Implement using:** Core logic can be implemented in **Fabric** or in a **DSP48**, if a DSP48 is available in the target device. The default is **Fabric**.

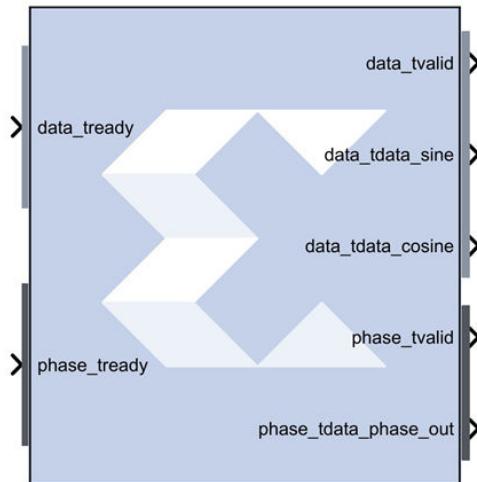
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

[Binary Counter LogiCORE IP Product Guide \(PG121\)](#)

## DDS Compiler 6.0

The Xilinx DDS (Direct Digital Synthesizer) Compiler block implements high performance, optimized Phase Generation and Phase to Sinusoid circuits with AXI4-Stream compliant interfaces for supported devices.

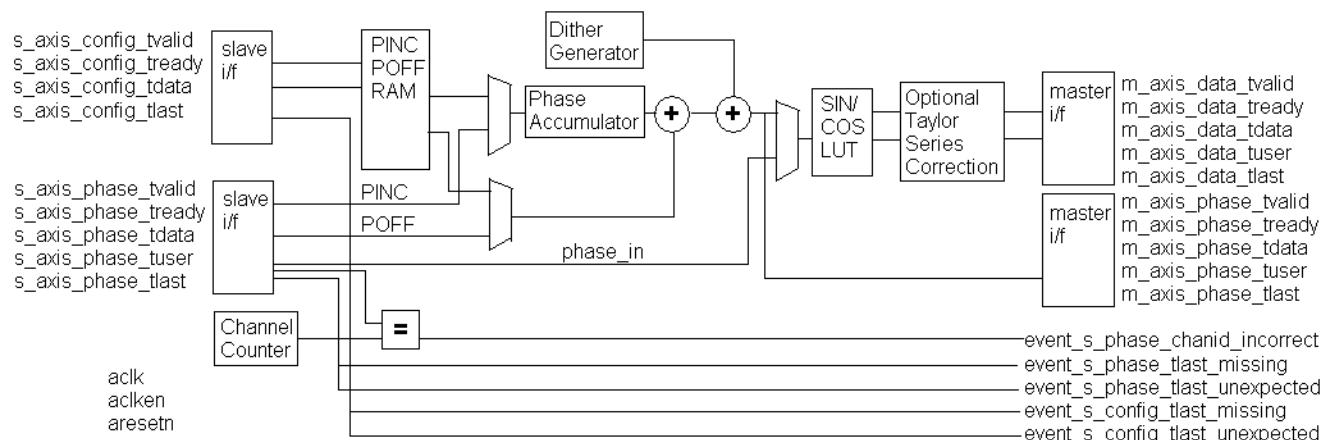


The core sources sinusoidal waveforms for use in many applications. A DDS consists of a Phase Generator and a SIN/COS Lookup Table (phase to sinusoid conversion). These parts are available individually or combined using this core.

## Architecture Overview

To understand the DDS Compiler, it is necessary to know how the block is implemented in FPGA hardware. The following is a block diagram of the DDS Compiler core. The core consist of two main parts, a Phase Generator part and a SIN/COS LUT part. These parts can be used independently or together with an optional dither generator to create a DDS capability. A time-division multi-channel capability is supported with independently configurable phase increment and offset parameters.

*Figure 263: DDS Compiler Block Diagram*



### Phase Generator

The Phase Generator consists of an accumulator followed by an optional adder to provide addition of phase offset. When the core is customized the phase increment and offset can be independently configured to be either Fixed, Programmable (using the CONFIG channel) or Streaming (using the input PHASE channel).

When set to fixed the DDS output frequency is set when the core is customized and cannot be adjusted once the core is embedded in a design.

When set to programmable, the CONFIG channel TDATA field will have a subfield for the input in question (PINC or POFF) or both if both have been selected to be programmable. If neither PINC nor POFF is set to programmable, there is no CONFIG channel.

When set to streaming, the input PHASE channel TDATA port (`s_axis_phase_tdata`) will have a subfield for the input in question (PINC or POFF) or both if both have been selected to be streaming. If neither PINC nor POFF is set to streaming, and the DDS is configured to have a Phase Generator then there is no input PHASE channel. Note that when the DDS is configured to be a SIN/COS Lookup only, the PHASE\_IN field is input using the input PHASE channel TDATA port.

### SIN/COS LUT

When configured as a SIN/COS Lookup only, the Phase Generator is not implemented, and the PHASE\_IN signal is input using the input PHASE channel, and transformed into the SINE and COSINE outputs using a look-up table.

Efficient memory usage is achieved by exploiting the symmetry of sinusoid waveforms. The core can be configured for SINE only output, COSINE only output or both (quadrature) output. Each output can be configured independently to be negated. Precision can be increased using optional Taylor Series Correction. This exploits XtremeDSP slices on FPGA families that support them to achieve high SFDR with high speed operation.

### **AXI Ports that are Unique to this Block**

Depending on the Configuration Options and Phase Increment Programmability/Phase Offset Programmability options selected, different subfield-ports for the PHASE channel or the CONFIG channel (or both channels) are available on the block, as described in the table below.

Configuration Options	Phase Increment Programmability		Phase Offset Programmability	
	Option Selected	Available Port	Option Selected	Available Port
Phase_Generator_only Phase_Generator_and_SIN_COS_LUT	Programmable	<code>s_axis_config_tdata_pinc</code>	Programmable	<code>s_axis_config_tdata_poff</code>
	Streaming	<code>s_axis_phase_tdata_pinc</code>	Streaming	<code>s_axis_phase_tdata_poff</code>
	Fixed	NA	Fixed	NA
SIN_COS_LUT_only	In this configuration, input port <code>s_axis_phase_tdata_phase_in</code> are available			

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows.

- **Configuration Options:** This parameter allows for two parts of the DDS to be instantiated separately or instantiated together. Select one of the following.
  - Phase\_Generator\_and\_SIN\_COS\_LUT
  - Phase\_Generator\_only
  - SIN\_COS\_LUT\_only
- **System Requirements:**
  - **System Clock (MHz):** Specifies the frequency at which the block is clocked for the purposes of making architectural decisions and calculating phase increment from the specified output frequency. This is a fixed ratio off the System Clock.
  - **Number of Channels:** The channels are time-multiplexed in the DDS which affects the effective clock per channel. The DDS can support 1 to 16 time-multiplexed channels.
  - **Mode of Operation:**
    - **Standard:** The output frequency of the DDS waveform is a function of the system clock frequency, the phase width in the phase accumulator and the phase increment value.
    - **Rasterized:** The DDS does not truncate the accumulated phase. Rasterized operation is intended for configurations where the desired frequency is a rational fraction of the system clock (output frequency = system frequency \* N/M, where 0 < N < M). Values of M from 9 to 16384 are supported.

**Note:** Refer to the document *DDS Compiler LogiCORE IP Product Guide* ([PG141](#)) for a detailed explanation of these modes.

- **Parameter Selection:** Select **System\_Parameters** or **Hardware\_Parameters**
- **System Parameters:**
  - **Spurious Free Dynamic Range (dB):** The targeted purity of the tone produced by the DDS. This sets the output width as well as internal bus widths and various implementation decisions.
  - **Frequency Resolution (Hz):** This sets the precision of the PINC and POFF values. Very precise values will require larger accumulators. Less precise values will cost less in hardware resource.

- **Noise Shaping:** Select one: **None**, **Phase\_Dithering**, **Taylor\_Series\_Corrected**, or **Auto**.

If the Configuration Options selection is **SIN\_COS\_LUT\_only**, then **None** and **Taylor\_Series\_Corrected** are the only valid options for Noise Shaping. If **Phase\_Generator\_Only** is selected, then **None** is the only valid choice for Noise Shaping.

- **Hardware Parameters:**

- **Phase Width:** Equivalent to frequency resolution, this sets the width of the internal phase calculations.
- **Output Width:** Broadly equivalent to SFDR, this sets the output precision and the minimum Phase Width allowable. However, the output accuracy is also affected by the choice of Noise Shaping.

- **Output Selection:**

- **Sine\_and\_Cosine:** Place both a Sine and Cosine output port on the block.
- **Sine:** Place only a Sine output port on the block.
- **Cosine:** Place only a Cosine output port on the block.
  - **Polarity:**
    - **Negative Sine:** Negates the `sine` output.
    - **Negative Cosine:** Negates the `cosine` output.

- **Amplitude Mode:**

- **Full\_Range:** Selects the maximum possible amplitude.
- **Unit\_Circle:** Selects an exact power-of-two amplitude, which is about one half the Full\_Range amplitude.

- **Implementation tab:**

- **Implementation Options:**

- **Memory Type:** Select between **Auto**, **Distributed\_ROM**, or **Block\_ROM**.
- **Optimization Goal:** Select between **Auto**, **Area**, or **Speed**.
- **DSP48 Use:** Select between **Minimal**, or **Maximal**. When set to Maximal, XtremeDSP slices are used to achieve to maximum performance.

- **Latency Options:**

- **Auto:** The DDS is fully pipelined for optimal performance.
- **Configurable:** Allows you to select less pipeline stages in the **Latency** pulldown menu below. This generally results in less resources consumed.

- **Control Signals:**

- **Has phase out:** When checked the DDS will have the `phase_output` port. This is an output of the Phase\_Generator half of the DDS, so it precedes the sine and cosine outputs by the latency of the sine/cosine lookup table.
- **ACLKEN:** Enables the clock enable (`aclk_en`) pin on the core. All registers in the core are enabled by this control signal.
- **ARESETn:** Active-low synchronous clear input that always takes priority over ACLKEN. A minimum ARESETn active pulse of two cycles is required, since the signal is internally registered for performance. A pulse of one cycle resets the core, but the response to the pulse is not in the cycle immediately following.

- **Explicit Sample Period:**

- **Use explicit period:** When checked, the DDS Compiler block uses the explicit sample period that is specified in the dialog entry box below.

- **AXI Channel Options tab:**

- **AXI Channel Options:**

- **TLAST:**

Enabled when there is more than one DDS channel (as opposed to AXI channel), as TLAST is used to denote the transfer of the last time-division multiplied channel of the DDS. Options are as follows.

- **Not\_Required:** In this mode, no TLAST appears on the input PHASE channel nor on the output channels.
- **Vector\_Framing:** In this mode, TLAST on the input PHASE channel and output channels denotes the last.
- **Packet\_Framing:** In this mode, TLAST is conveyed from the input PHASE channel to the output channels with the same latency as TDATa. The DDS does not use or interpret the TLAST signal in this mode. This mode is intended as a service to ease system design for cases where signals must accompany the datastream, but which have no application in the DDS.
- **Config\_Triggered:** This is an enhanced variant of the Vector Framing option. In this option, the TLAST on the input PHASE channel can trigger the adoption of new configuration data from the CONFIG channel when there is new configuration data available. This allows the re-configuration to be synchronized with the cycle of time-division-multiplexed DDS channels.

- **TREADY:**

- **Output TREADY:** When selected, the output channels will have a TREADY and hence support the full AXI handshake protocol with inherent back-pressure. If there is an input PHASE channel, its TREADY is also determined by this control, so that the datapath from input PHASE channel to output channels as a whole supports backpressure or not.
- **TUSER Options:** Select one of the following options for the **Input**, **DATA Output**, and **PHASE Output**.
  - **Not\_Required:** Neither of the above uses is required; the channel in question will not have a TUSER field.
  - **Chan\_ID\_Field:** In this mode, the TUSER field identifies the time-division-multiplexed channel for the transfer.
  - **User\_Field:** In this mode, the block ignores the content of the TUSER field, but passes the content untouched from the input PHASE channel to the output channels.
  - **User and Chan\_ID\_Field:** In this mode, the TUSER field has both a `user` field and a `chan_id` field, with the `chan_id` field in the least significant bits. The minimal number of bits required to describe the channel will determine the width of the `chan_id` field. For example, 7 channels will require 3 bits.
  - **User Field Width:** This field determines the width of the bit field which is conveyed from input to output untouched by the DDS.
- **Config Channel Options:**
  - **Synchronization Mode:**
    - **On\_Vector:** In this mode, the re-configuration data is applied when the channel starts a new cycle of time-division-multiplexed channels.
    - **On\_Packet:** In this mode, available when TLAST is set to Packet Framing, the TLAST channel will trigger the re-configuration. This mode is targeted at the case where it is to be associated with the packets implied by the input TLAST indicator.
- **Output Frequency tab:**
  - **Phase Increment Programmability:**

Specifies the phase increment to be **Fixed**, **Programmable** or **Streaming**. The choice of Programmable adds channel, data, and we input ports to the block.

The following fields are activated when Phase\_Generator\_and\_SIN\_COS\_LUT is selected as the Configuration Options field on the Basic tab, the Parameter Selection on the Basic tab is set to Hardware Parameters and Phase Increment Programmability field on the Phase Offset Angles tab is set to **Fixed** or **Programmable**.

- **Output frequencies (MHz):** For each channel, an independent frequency can be entered into an array. This field is activated when Parameter Selection on the Basic tab is set to **System Parameters** and Phase Increment Programmability is **Fixed** or **Programmable**.
- **Phase Angle Increment Values:** This field is activated when Phase\_Generator\_and\_SIN\_COS\_LUT is selected as the Configuration Options field on the Basic tab, the Parameter Selection on the Basic tab is set to **Hardware Parameters** and Phase Increment Programmability field on the Phase Offset Angles tab is set to **Fixed** or **Programmable**. Values must be entered in binary. The range is 0 to the weight of the accumulator, for example, 2Phase\_Width-1.
- **Phase Offset Angles tab:**
  - **Phase Offset Programmability:** Specifies the phase offset to be **None**, **Fixed**, **Programmable** or **Streaming**. The choice of Fixed or Programmable adds the channel, data, and we input ports to the block.
  - **Phase Offset Angles (x2pi radians):** For each channel, an independent offset can be entered into an array. The entered values are multiplied by  $2\pi$  radians. This field is activated when Parameter Selection on the Basic tab is set to System Parameters and Phase Increment Programmability is **Fixed** or **Programmable**.
  - **Phase Angle Offset Values:** For each channel, an independent offset can be entered into an array. The entered values are multiplied by  $2\pi$  radians. This field is activated when Parameter Selection on the Basic tab is set to Hardware Parameters and Phase Increment Programmability is Fixed or Programmable.
- **Advanced tab:** Block Icon Display
  - **Display shortened port names:** This option is ON by default. When unselected, the full AXI name of each port is displayed on the block.

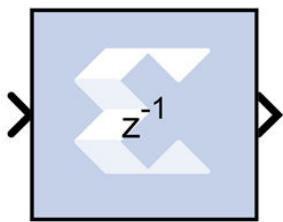
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

*DDS Compiler LogiCORE IP Product Guide ([PG141](#))*

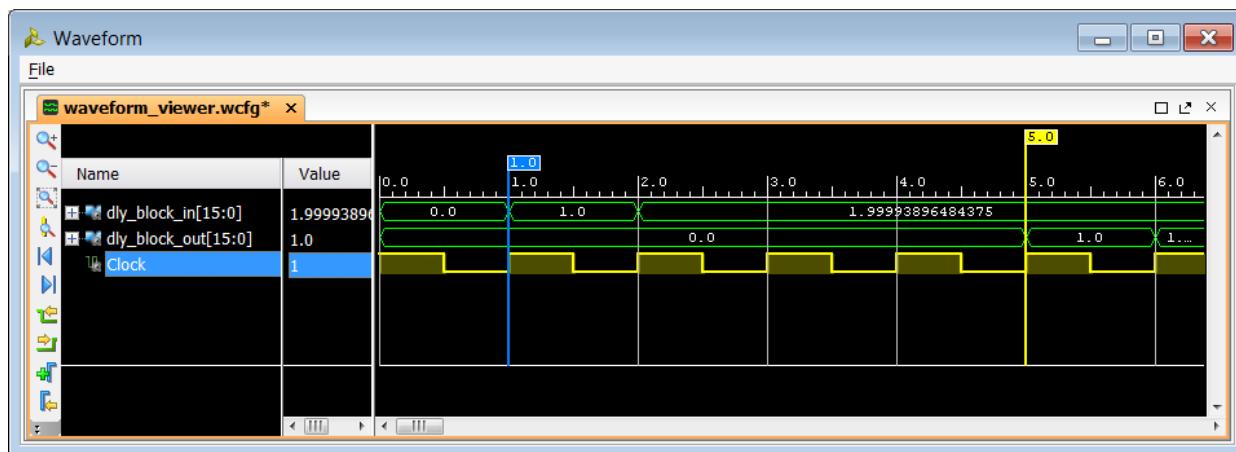
## Delay

The Xilinx Delay block implements a fixed delay of L cycles.



The delay value is displayed on the block in the form  $z^{-L}$ , which is the Z-transform of the block's transfer function. Any data provided to the input of the block will appear at the output after L cycles. The rate and type of the data of the output is inherited from the input. This block is used mainly for matching pipeline delays in other portions of the circuit. The delay block differs from the register block in that the register allows a latency of only 1 cycle and contains an initial value parameter. The delay block supports a specified latency but no initial value other than zeros. The following figure shows the Delay block behavior when L=4 and Period=1s.

Figure 264: Delay Block Behavior



For delays that need to be adjusted during run-time, you should use the Addressable Shift Register block. Delays that are not an integer number of clock cycles are not supported and such delays should not be used in synchronous design (with a few rare exceptions).

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows:

- **Provide synchronous reset port:** this option activates an optional reset (rst) pin on the block. When the reset signal is asserted the block goes back to its initial state. Reset signal has precedence over the optional enable signal available on the block. The reset signal has to run at a multiple of the block's sample rate. The signal driving the reset port must be Boolean.
- **Provide enable port:** this option activates an optional enable (en) pin on the block. When the enable signal is not asserted the block holds its current state until the enable signal is asserted again or the reset signal is asserted. Reset signal has precedence over the enable signal. The enable signal has to run at a multiple of the block's sample rate. The signal driving the enable port must be Boolean.
- **Latency:** Latency is the number of cycles of delay. The latency can be zero, provided that the **Provide enable port** checkbox is not checked. The latency must be a non-negative integer. If the latency is zero, the delay block collapses to a wire during logic synthesis. If the latency is set to L=1, the block will generally be synthesized as a flip-flop (or multiple flip-flops if the data width is greater than 1).
- **Implementation tab:**

Parameters specific to the Implementation tab are as follows:

- **Implement using behavioral HDL:** Uses behavioral HDL as the implementation. This allows the downstream logic synthesis tool to choose the best implementation.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

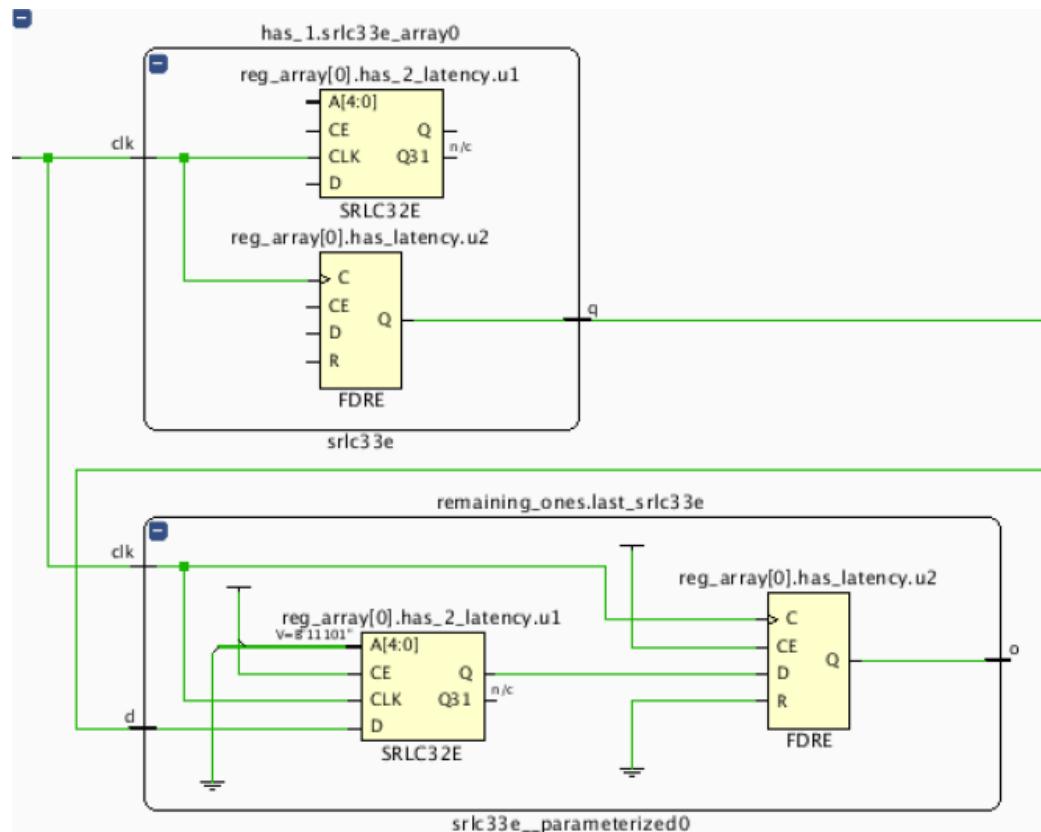
## Logic Synthesis using Behavioral HDL

This setting is recommended if you are using Synplify Pro as the downstream logic synthesis tool. The logic synthesis tool will implement the delay as it desires, performing optimizations such as moving parts of the delay line back or forward into blockRAMs, DSP48s, or embedded IOB flip-flops; employing the dedicated SRL cascade outputs for long delay lines based on the architecture selected; and using flip-flops to terminate either or both ends of the delay line based on path delays. Using this setting also allows the logic synthesis tool, if sophisticated enough, to perform retiming by moving portions of the delay line back into combinational logic clouds.

## Logic Synthesis using Structural HDL

If you do not check the box **Implement using behavioral HDL**, then structural HDL is used. This is the default setting and results in a known, but less-flexible, implementation which is often better for use with Vivado synthesis. In general, this setting produces structural HDL comprising an SRL (Shift-Register LUT) delay of (L-1) cycles followed by a flip-flop, with the SRL and the flip-flop getting packed into the same slice. For a latency greater than L=33, multiple SRL/flip-flop sets are cascaded, albeit without using the dedicated cascade routes. For example, the following is the synthesis result for a 1-bit wide delay block with a latency of L=64:

Figure 265: 1-Bit Wide Delay Block with a Latency of L=64

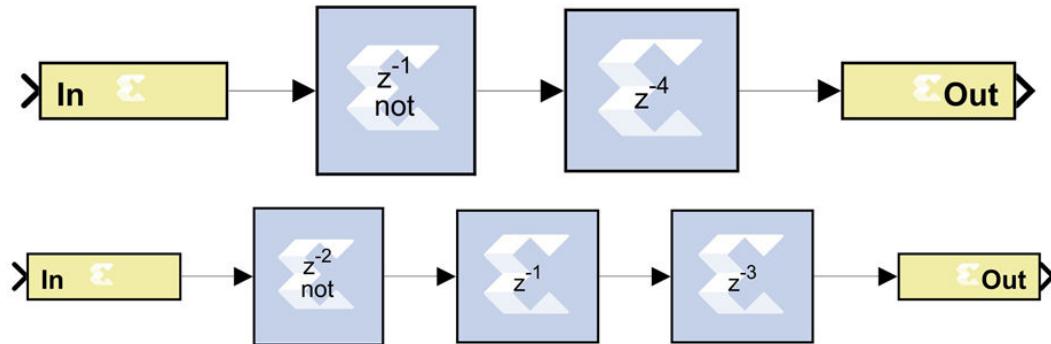


The first SRL provides a delay of 32 cycles and the associated flip-flop adds another cycle of delay. The second SRL provides a delay of 30 cycles; this is evident because the address is set to  $\{A4, A3, A2, A1, A0\} = 11101$  (binary) = 29, and the latency through an SRL is the value of the address plus one. The last flip-flop adds a cycle of delay, making the grand total  $L=32+1+30+1=64$  cycles.

The SRL is an efficient way of implementing delays in the Xilinx architecture. An SRL and its associated flip-flop that comprise a single logic cell can implement 33 cycles of delay whereas a delay line consisting only of flip-flops can implement only one cycle of delay per logic cell.

The SRL has a setup time that is longer than that of a flip-flop. Therefore, for very fast designs with a combinational path preceding the delay block, it can be advantageous, when using the structural HDL setting, to precede the delay block with an additional delay block with a latency of  $L=1$ . This ensures that the critical path is not burdened with the long setup time of the SRL. An example is shown below.

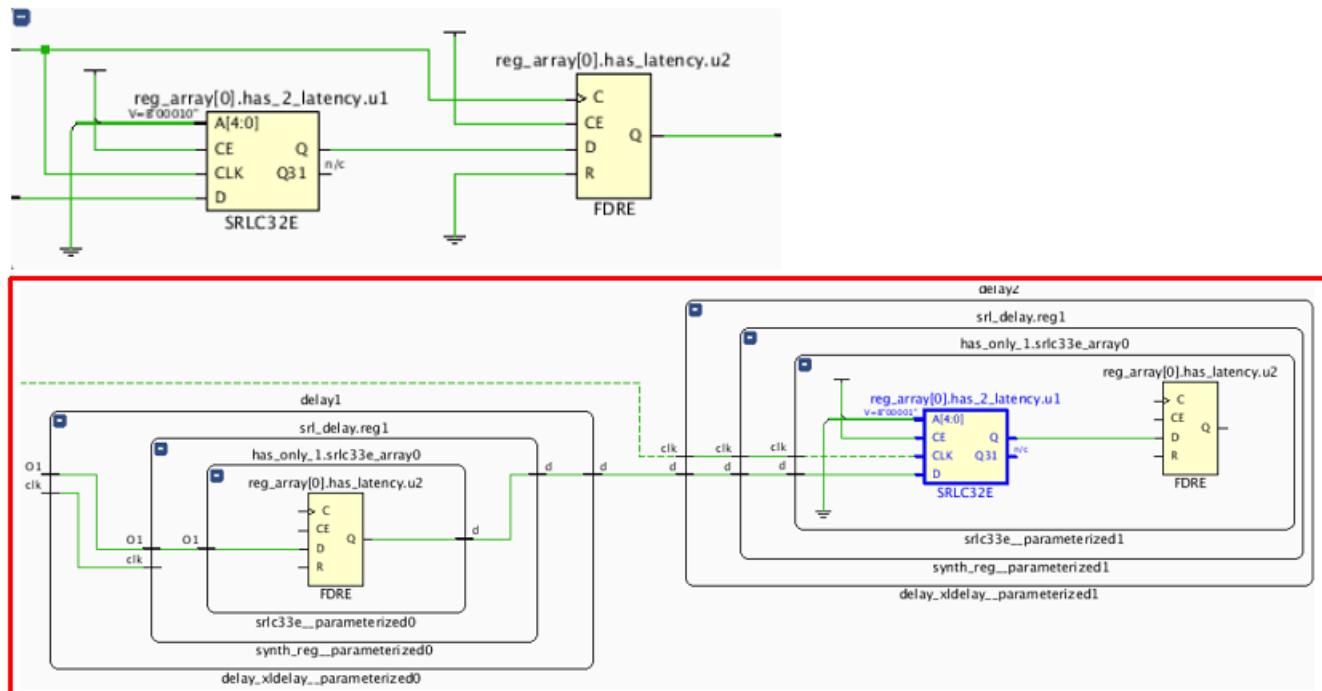
**Figure 266: Delay Block with an Additional Delay Block with a Latency**



In the example, the two designs are logically equivalent, but the bottom one will have a faster hardware implementation. The bottom design will have the combinational path formed by Inverter1 terminated by a flip-flop, which has a shorter setup time than an SRL.

The synthesis results of both designs are shown below, with the faster design highlighted in red:

**Figure 267: Synthesis Results**

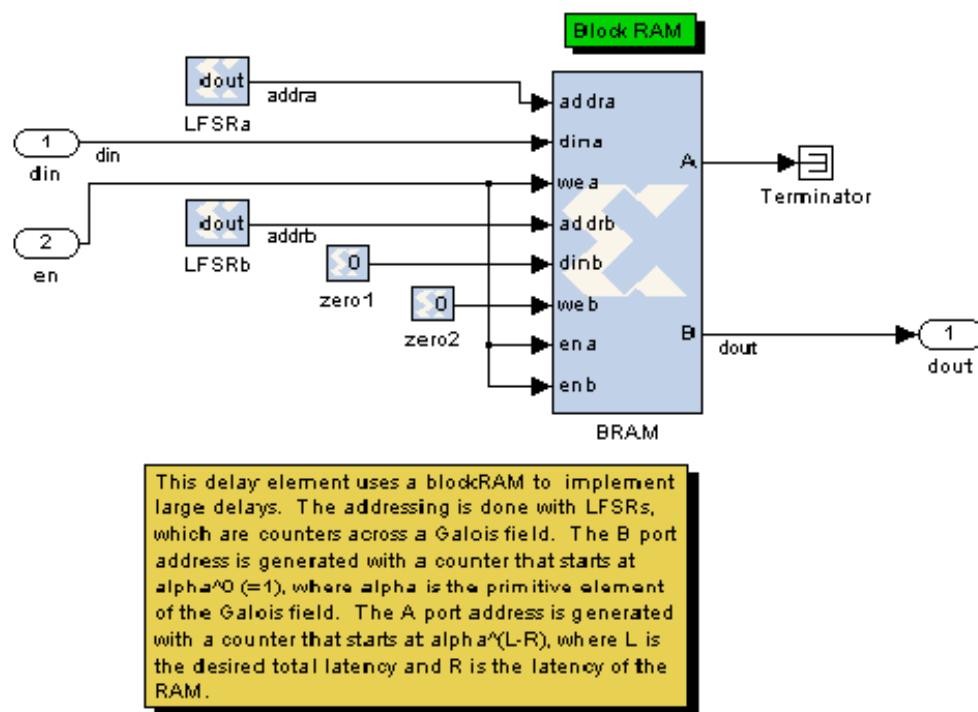


Note that an equivalent to the faster design results from setting the latency of Inverter1 to 1 and eliminating Delay1. This, however, is not equivalent to setting the latency of Inverter1 to 4 and eliminating the delay blocks; this would yield a synthesis equivalent to the upper (slower) design.

## Implementing Long Delays

For very long delays, of, say, greater than 128 cycles, especially when coupled with larger bus widths, it might be better to use a block-RAM-based delay block. The delay block is implemented using SRLs, which are part of the general fabric in the Xilinx. Very long delays should be implemented in the embedded block RAMs to save fabric. Such a delay exploits the dual-port nature of the blockRAM and can be implemented with a fixed or run-time-variable delay. Such a block is basically a block RAM with some associated address counters. The model below shows a novel way of implementing a long delay using LFSRs (linear feedback shift registers) for the address counters in order to make the design faster, but conventional counters can be used as well. The difference in value between the counters (minus the RAM latency) is the latency L of the delay line.

Figure 268: Novel Use of Long Delay LFSRs



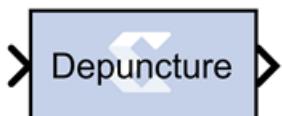
## Re-settable Delays and Initial Values

If a delay line absolutely must be re-settable to zero, this can be done by using a string of L register blocks to implement the delay or by creating a circuit that forces the output to be zero while the delay line is “flushed”.

The delay block does not support initial values, but the Addressable Shift Register block does. This block, when used with a fixed address, is generally equivalent to the delay block and will synthesize to an SRL-based delay line. The initial values pertain to initialization only and not to a reset. If using the addressable shift register in “structural HDL mode” (e.g., the **Use behavioral HDL** checkbox is not selected) then the delay line will not be terminated with a flip-flop, making it significantly slower. This can be remedied by using behavioral mode or by putting a Register or Delay block after the addressable shift register.

## Depuncture

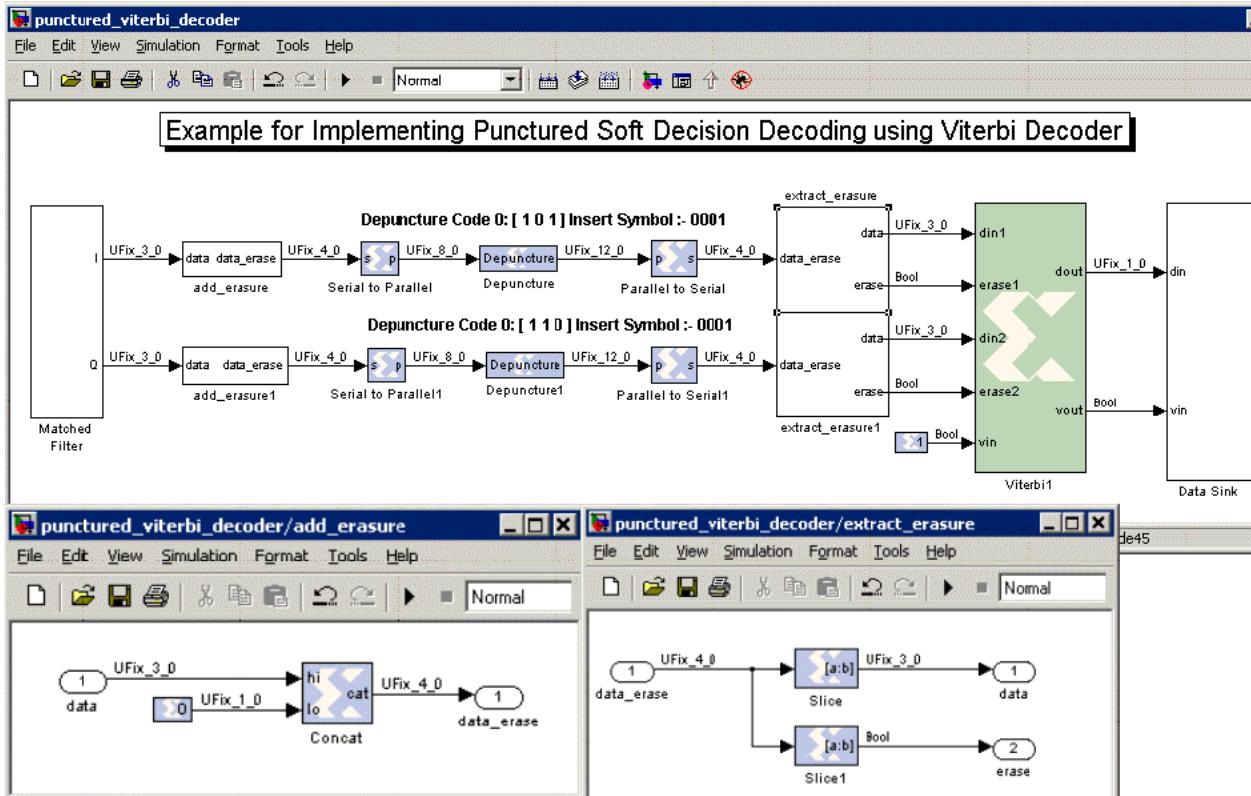
The Xilinx Depuncture block allows you to insert an arbitrary symbol into your input data at the location specified by the depuncture code.



The Xilinx Depuncture block accepts data of type `UFixN_0` where N equals the length of insert string x (the number of ones in the depuncture code) and produces output data of type `UFixK_0` where K equals the length of insert string multiplied by the length of the depuncture code.

The Xilinx Depuncture block can be used to decode a range of punctured convolution codes. The following diagram illustrates an application of this block to implement soft decision Viterbi decoding of punctured convolution codes.

Figure 269: Soft Decision Viterbi Decoding

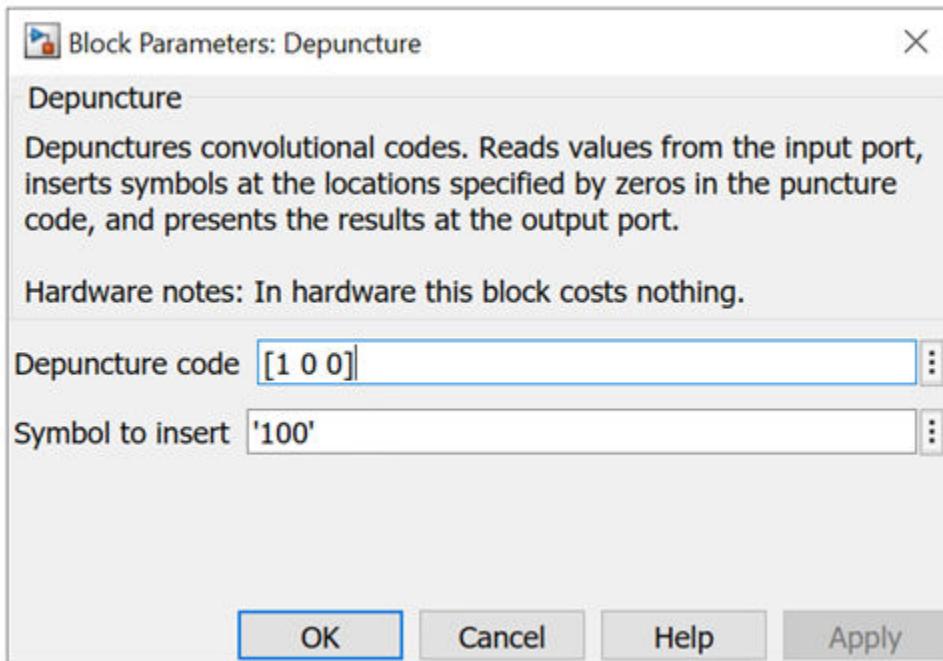


The previous diagram shows a matched filter block connected to a add\_erasure Subsystem which attaches a 0 to the input data to mark it as a non-erasure signal. The output from the add\_erasure subsystem is then passed to a serial to parallel block. The serial to parallel block concatenates two continuous soft inputs and presents it as a 8-bit word to the depuncture block. The depuncture block inserts the symbol '0001' after the 4-bits from the MSB for code 0 ([1 0 1]) and 8-bits from the MSB for code 1 ([1 1 0]) to form a 12-bit word. The output of the depuncture block is serialized as 4-bit words using the parallel to serial block. The extract\_erasure Subsystem takes the input 4-bit word and extracts 3-bits from the MSB to form a soft decision input data word and 1-bit from the LSB to form the erasure signal for the Viterbi decoder.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Figure 270: Block Parameters Dialog Box



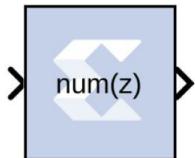
Parameters specific to the Xilinx Depuncture block are:

- **Depuncture code:** Specifies the depuncture pattern for inserting the string to the input.
- **Symbol to insert:** Specifies the binary word to be inserted in the depuncture code.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Digital FIR Filter

The Xilinx Digital FIR Filter block allows you to generate highly parameterizable, area-efficient, high-performance single channel FIR filters.



The Digital FIR filter block supports single channel, simple rate, integer decimation, and interpolation and fractional decimation and interpolation filter types.

To specify the coefficient vector for the FIR Filter generated by this block, you can either enter the coefficient vector directly into the Digital FIR Filter Block Parameters dialog box, or open an interface to the [FDATool](#) block and specify the coefficient vector in that interface.

The Digital FIR Filter block is ideal for generating simple, single channel FIR filters. If your FIR filter implementation will use more complicated filter features such as multiple channels or multiple path core configuration, an AXI4-Stream-compliant interface, or functions such as reloading co-efficient, channel pattern support, or other HDL-based GUI parameters, use the Xilinx [FIR Compiler 7.2](#) block in your design instead of the Digital FIR Filter block.

In the Vivado® design flow, the Digital FIR filter block is inferred as "LogiCORE™ IP FIR Compiler v7.2" for code generation. Refer to the document [LogiCORE IP FIR Compiler v7.2](#) for details on this LogicCore IP.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Parameters specific to the Xilinx Digital FIR Filter block areas follows.

- **Coefficient Vector:**

- **Use FDA Tool as Coefficient Source:** If selected, the Coefficient Vector will be determined by the settings in the Filter Design and Analysis Tool (FDA Tool). To use the FDA Tool as your coefficient source, you must click the [FDATool](#) button and configure the Block Parameters dialog box that appears, to describe your FIR filter.

**Note:** Because the FDATool functionality is integrated into the Digital FIR Filter block itself, you do not have to enter a separate FDATool block into your design to use the FDATool as your coefficient source.

The FDA Tool is a user interface for designing and analyzing filters quickly. FDATool enables you to design digital FIR filters by setting filter specifications, by importing filters from your MATLAB® workspace, or by adding, moving or deleting poles and zeroes. FDA Tool also provides tools for analyzing filters, such as magnitude and phase response and pole-zero plots (see [FDATool](#)).

- **Edit Box:**

The edit box is enabled for you to specify the Coefficient Vector when the **Use FDA Tool as Coefficient Source** option is disabled. The edit box specifies the vector coefficients of the filter's transfer function. Filter coefficients must be specified as a single MATLAB row vector. Filter structure must be Direct Form, and the input must be a scalar.

The number of taps is inferred from the length of the MATLAB row vector. If multiple coefficient sets are specified, then each set is appended to the previous set in the vector.

- **FDATool:** This button is enabled if the **Use FDA Tool as Coefficient Source** option is enabled. Click this button to open a Block Parameters dialog box for the FDA Tool, and enter your filter specifications in this dialog box. To understand how to use this dialog box to describe your FIR filter, see [FDATool](#).
- **Coefficient Precision:**
  - **Optimal Values:** If selected, the Coefficient Width and Coefficient Fractional Bits will be set automatically to their optimum values. The values are calculated using the dynamic range of filter response between pass band and stop band signals. These values ensure the minimum hardware will be used for the required filter response when the design is implemented in the Xilinx FPGA or SoC.
  - **Coefficient Width:** Specifies the number of bits used to represent the coefficients.
  - **Coefficient Fractional Bits:** Specifies the binary point location in the coefficients datapath options.
  - **Interpolation Rate:** Specifies the interpolation rate of the filter. Any value greater than 1 is applicable to all Interpolation filter types and Decimation filter types for Fractional Rate Change implementations. The value provided in this field defines the upsampling factor, or P for Fixed Fractional Rate (P/Q) resampling filter implementations.
  - **Decimation Rate:** Specifies the decimation rate of the filter. Any value greater than 1 is applicable to the all Decimation and Interpolation filter types for Fractional Rate Change implementations. The value provided in this field defines the downsampling factor, or Q for Fixed Fractional Rate (P/Q) resampling filter implementations.

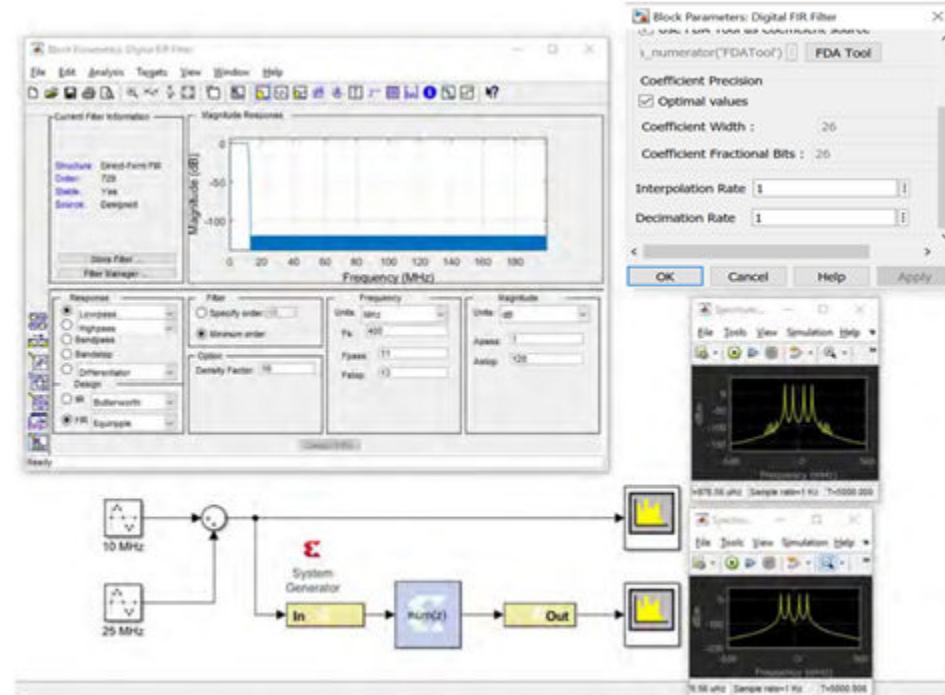
## Example

A simple filter design is shown below which uses the Digital FIR Filter block to implement a single rate low pass filter. Because **Use FDA Tool as Coefficient source** is enabled in the block parameters dialog box for the Digital FIR Filter block, the FDA Tool (invoked by clicking the **FDA Tool** button) is used to generate the filter coefficient for the following specification:

- **Fs** (sample frequency) = 400 MHz
- **Fpass** = 11 MHz
- **Fstop** = 13 MHz
- **Apass** = 1 dB
- **Astop** = 120 dB

For **Coefficient precision**, the **Optimal values** selection is enabled for the filter **Coefficient Width** parameter. Therefore, an optimized filter coefficient width will be computed automatically, for minimum hardware usage and better filter response.

Figure 271: Digital FIR Filter Example

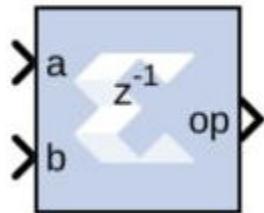


## LogiCORE Documentation

[LogiCORE IP FIR Compiler v7.2](#)

## Divide

The Xilinx Divide block performs both fixed-point and floating-point division with the  $a$  input being the dividend and the  $b$  input the divisor. Both inputs must be of the same data type.



### Block Parameters

- **Basic tab:** Parameters specific to the Basic tab are as follows
  - **AXI Interface:**

- **Flow Control:**

- **Blocking:** Selects “Blocking” mode. In this mode, the lack of data on one input channel does block the execution of an operation if data is received on another input channel.
- **NonBlocking:** Selects “Non-Blocking” mode. In this mode, the lack of data on one input channel does not block the execution of an operation if data is received on another input channel.

- **Fixed-point Options:**

- **Algorithm Type:**

- **Radix2:** This is non-restoring integer division using integer operands and allows a remainder to be generated. This option is recommended for operand widths less than 16 bits. This option supports both unsigned (two's complement) and signed divisor and dividend inputs.
  - **High\_Radix:** This option is recommended for operand widths greater than 16 bits, though the implementation requires the use of DSP48 (or variant) primitives. This option only supports signed (two's complement) divisor and dividend inputs.
  - **LutMult:** A simple lookup estimate of the reciprocal of the divisor followed by a multiplier. Only remainder output type is supported because of the bias required in the reciprocal estimate. This bias would introduce an offset (error) if used to create a fractional output. This is recommended for operand widths less than or equal to 12 bits. This implementation uses DSP slices, block RAM, and a small number of FPGA logic primitives (registers and LUTs). For operand widths where either Radix2 or the LUTMult options are possible, the LUTMult solution offers a solution using fewer FPGA logic resources because of the use of DSP and block RAM primitives. Supports unsigned or two's complement signed numbers.

- **Output Fractional width:** For Fixed-point division, this entry determines the number of bits in the fractional part of the output.

- **Optional Ports:**

- **Dividend Channel Ports:**

- **Has TLAST:** Adds a TLAST port to the Input channel.
    - **Has TUSER:** Adds a TUSER port to the Input channel.

- **Divisor Channel Ports:**

- **Has TLAST:** Adds a TLAST port to the Input channel.
    - **Has TUSER:** Adds a TUSER port to the Input channel.

- **Control Options:**

- **Provide enable port:** Adds an enable port to the block interface.
- **Has Result TREADY:** Adds a TREADY port to the Result channel.
- **Output TLAST behavior:** Determines the behavior of the result\_tlast output port.
  - **Pass\_A\_TLAST:** Pass the value of the a\_tlast input port to the dout\_tlast output port.
  - **Pass\_B\_TLAST:** Pass the value of the b\_tlast input port to the dout\_tlast output port.
  - **OR\_all\_TLASTS:** Pass the logical OR of all the present TLAST input ports.
  - **AND\_all\_TLASTS:** Pass the logical AND of all the present TLAST input ports.
- **Exception Signals:**
  - **UNDERFLOW:** Adds an output port that serves as an underflow flag.
  - **OVERFLOW:** Adds an output port that serves as an overflow flag.
  - **INVALID\_OP:** Adds an output port that serves as an invalid operation flag.
  - **DIVIDE\_BY\_ZERO:** Adds an output port that serves as a divide-by-zero flag.

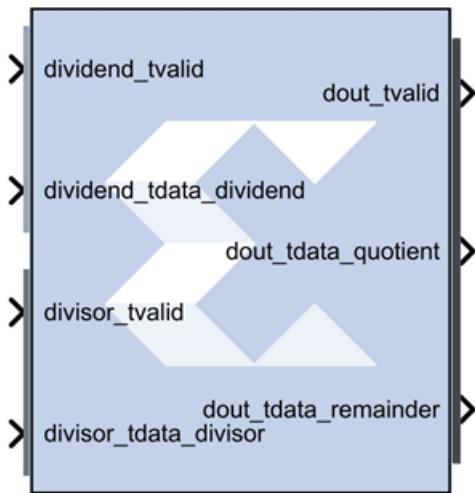
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

### LogiCORE Documentation

*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

## Divider Generator 5.1

The Xilinx Divider Generator block creates a circuit for integer division based on Radix-2 non-restoring division, or High-Radix division with prescaling.



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

- **Common Options:**

- **Algorithm Type:**

- **Radix-2** non-restoring integer division using integer operands, allows a remainder to be generated. This is recommended for operand widths less than around 16 bits. This option supports both unsigned and signed (2's complement) divisor and dividend inputs.
      - **High\_Radix** division with prescaling. This is recommended for operand widths greater than 16 bits, though the implementation requires the use of DSP48 (or variant) primitives. This option only supports signed (2's complement) divisor and dividend inputs.
      - **LutMult** A simple lookup estimate of the reciprocal of the divisor followed by a multiplier. Only the remainder output type is supported because of the bias required in the reciprocal estimate. This bias would introduce an offset (error) if used to create a fractional output. This is recommended for operand widths less than or equal to 12 bits. This implementation uses DSP slices, block RAM, and a small number of FPGA logic primitives (registers and LUTs). For operand widths where either Radix2 or the LUTMult options are possible, the LUTMult offers a solution using fewer FPGA logic resources because of the use of DSP and block RAM primitives. Supports unsigned or two's complement signed numbers.

- **Output channel:**

- **Remainder type:**

- **Remainder:** Only supported for Radix 2.
- **Fractional:** Determines the number of bits in the fractional port output.
- **Fractional width:** If Fractional Remainder type is selected, this entry determines the number of bits in the fractional port output.
- **Radix2 Options:**
  - **Radix2 throughput:** Determines the interval in clocks between new data being input (and output). Choices are 1, 2, 4, and 8.
- **High Radix Options:**
  - **Detect divide by zero:** Determines if the core shall have a division-by-zero indication output port.
- **AXI Interface:**
  - **AXI behavior:**
    - **NonBlocking:** Performs an action only when a control packet and a data packet are presented to the block at the same time.
    - **Blocking:** Preforms an action when a data packet is presented to the block. The block uses the previous control information.
  - **AXI Implementation emphasis:**
    - **Resources:** Automatic (fully pipelined) or Manual (determined by following field).
    - **Performance:** Implementation decisions target the highest speed.
- **Latency Options:**
  - **Latency configuration:** Automatic (fully pipelined) or Manual (determined by following field).
  - **Latency:** This field determines the exact latency from input to output in terms of clock enabled clock cycles.
- **Optional ports tab:**
  - **Optional Ports:**
    - **Divided Channel Ports:**
      - **Has TUSER:** Adds a tuser input port to the dividend channel.
      - **Has TLAST:** Adds a tlslast output port to the dividend channel.
    - **Divisor Channel Ports:**

- **Has TUSER:** Adds a tuser input port to the divisor channel.
- **Has TLAST:** Adds a tlast output port to the divisor channel.
- **ACLKEN:** Specifies that the block has a clock enable port (the equivalent of selecting the Has ACLKEN option in the CORE Generator GUI).
- **ARESETn:** Specifies that the block has a reset port. Active-Low synchronous clear. A minimum ARESETn pulse of two cycles is required.
- **m\_axis\_dout\_tready:** Specifies that the block has a dout\_tready output port.
- **Input TLAST combination for output:** Determines the behavior of the dout\_tlast output port.
  - **Null:** Output is null.
  - **Pass\_Dividend\_TLAST:** Pass the value of the dividend\_tlast input port to the dout\_tlast output port.
  - **Pass Divisor\_TLAST:** Pass the value of the divisor\_tlast input port to the dout\_tlast output port.
  - **OR\_all\_TLASTS:** Pass the logical OR of all the present TLAST input ports.
  - **AND\_all\_TLASTS:** Pass the logical AND of all the present TLAST input ports.

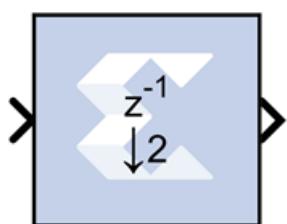
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

*Divider Generator LogiCORE IP Product Guide (PG151)*

## Down Sample

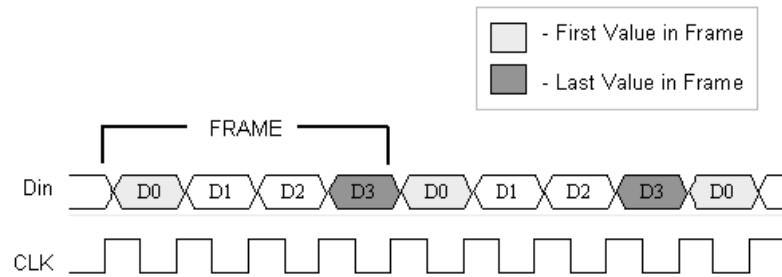
The Xilinx Down Sample block reduces the sample rate at the point where the block is placed in your design.



The input signal is sampled at even intervals, at either the beginning (first value), or end (last value) of a frame. The sampled value is presented on the output port and held until the next sample is taken.

A Down Sample frame consists of  $I$  input samples, where  $I$  is sampling rate. An example frame for a Down Sample block configured with a sampling rate of 4 is shown below.

**Figure 272: Down Sample Block Example**

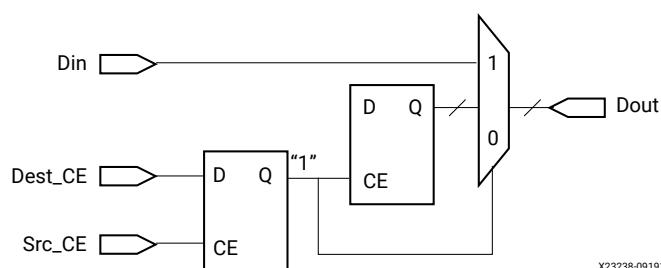


The Down Sample block is realized in hardware using one of three possible implementations that vary in terms of implementation efficiency. The block receives two clock enable signals in hardware, Src\_CE, and Dest\_CE. Src\_CE is the faster clock enable signal and corresponds to the input data stream rate. Dest\_CE is the slower clock enable, corresponding to the output stream rate, for example, down sampled data. These enable signals control the register sampling in hardware.

### Zero Latency Down Sample

The zero latency Down Sample block must be configured to sample the first value of the frame. The first sample in the input frame passes through the mux to the output port. A register samples this value during the first sample duration and the mux switches to the register output at the start of the second sample of the frame. The result is that the first sample in a frame is present on the output port for the entire frame duration. This is the least efficient hardware implementation as the mux introduces a combinational path from Din to Dout. A single bit register adjusts the timing of the destination clock enable, so that it is asserted at the start of the sample period, instead of the end. The hardware implementation is shown below:

**Figure 273: Down Sample with Zero Latency Example**

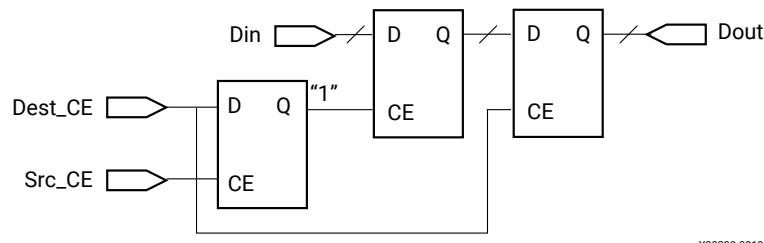


## Down Sample with Latency

If the Down Sample block is configured with latency greater than zero, a more efficient implementation is used. One of two implementations is selected depending on whether the Down Sample block is set to sample the first or last value in a frame.

If the block samples the first value in a frame, two registers are required to correctly sample the input stream. The first register is enabled by the adjusted clock enable signal so that it samples the input at the start of the input frame. The second register samples the contents of the first register at the end of the sample period to ensure output data is aligned correctly.

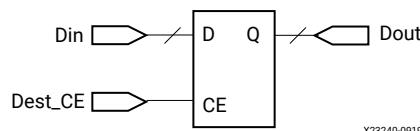
*Figure 274: Down Sample with Latency Example*



X23239-091919

If the block samples the last value in a frame, a register samples the data input data at the end of the frame. The sampled value is presented for the duration of the next frame. The most efficient implementation is when the Down Sample block is configured to sample the last value of the frame.

*Figure 275: Sampling Last Value*



X23240-091919

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**
  - **Sampling Rate (number of input samples per output sample):** Must be an integer greater or equal to 2. This is the ratio of the output sample period to the input, and is essentially a sample rate divider. For example, a ratio of 2 indicates a 2:1 division of the input sample rate. If a non-integer ratio is desired, the Up Sample block can be used in combination with the Down Sample block.
  - **Sample:** The Down Sample block can sample either the first or last value of a frame. This parameter will determine which of these two values is sampled.

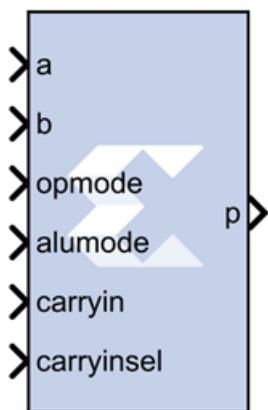
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

### Xilinx LogiCORE

The Down Sample block does not use a Xilinx LogiCORE.

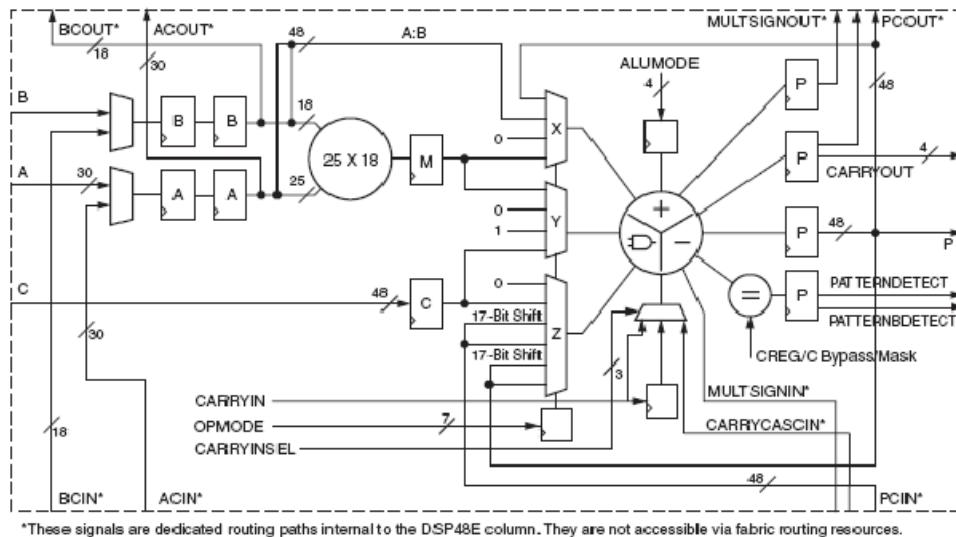
## DSP48E

The Xilinx DSP48E block is an efficient building block for DSP applications that use supported devices. The DSP48E combines an 18-bit by 25-bit signed multiplier with a 48-bit adder and programmable mux to select the adder's input.



Operations can be selected dynamically. Optional input and multiplier pipeline registers can be selected as well as registers for the `alumode`, `carryin` and `opmode` ports. The DSP48E block can also target devices that do not contain the DSP48E hardware primitive if the **Use synthesizable** model option is selected on the Implementation tab.

Figure 276: DSP48E



\*These signals are dedicated routing paths internal to the DSP48E column. They are not accessible via fabric routing resources.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**
  - **A or ACIN input:** Specifies if the A input should be taken directly from the a port or from the cascaded acin port. The acin port can only be connected to another DSP48 block.
  - **B or BCIN input:** Specifies if the B input should be taken directly from the b port or from the cascaded bcin port. The bcin port can only be connected to another DSP48 block.
- **Pattern Detection:**
  - **Reset p register on pattern detection:** If selected and the pattern is detected, reset the p register on the next cycle
  - **Pattern Input:**
    - **Pattern Input from c port:** When selected, the pattern used in pattern detection is read from the c port.
    - **Using Pattern Attribute (48bit hex value):** Value is used in pattern detection logic which is best described as an equality check on the output of the adder/subtractor/logic unit.
    - **Pattern attribute:** A 48-bit value that is used in the pattern detector.
  - **Mask Input:**
    - **Mask input from c port:** When selected, the mask used in pattern detection is read from the c port.

- **Using Mask Attribute (48 bit hex value):** When selected, the mask used in pattern detection is specified in the Mask attribute field of the block parameters.
- **Mask attribute:** A 48-bit value used to mask out certain bits during a pattern detection. A value of 0 passes the bit, and a value of 1 masks out the bit.
- **Select rounding mask:** Selects special masks that can be used for symmetric or convergent rounding in the pattern detector. The choices are **Select mask**, **Mode1**, and **Mode2**.
- **Optional Ports tab:**
  - **Input Ports:**
    - **Consolidate control port:** When selected, combines the `opmode`, `alumode`, `carry_in` and `carry_in_sel` ports into one 15-bit port. Bits 0 to 6 are the `opmode`, bits 7 to 10 are the `alumode` port, bit 11 is the `carry_in` port, and bits 12 to 14 are the `carry_in_sel` port. This option should be used when the Opmode block is used to generate a DSP48E instruction.
    - **Provide c port:** When selected, the `c` port is made available. Otherwise, the `c` port is tied to '0'.
    - **Provide global reset port:** When selected, the port `rst` is made available. This port is connected to all available reset ports based on the pipeline selections.
    - **Provide global enable port:** When selected, the optional `en` port is made available. This port is connected to all available enable ports based on the pipeline selections.
  - **Cascadable Ports:**
    - **Provide pcin port:** When selected, the `pcin` port is exposed. The `pcin` port must be connected to the `pcout` port of another DSP48 block.
    - **Provide carry cascade in port:** When selected, the carry cascade in port is exposed. This port can only be connected to a carry cascade out port on another DSP48E block.
    - **Provide multiplier sign cascade in port:** When selected, the multiplier sign cascade in port (`multsigncascin`) is exposed. This port can only be connected to a multiplier sign cascade out port of another DSP48E block.
  - **Output Ports:**
    - **Provide carryout port:** When selected, the `carryout` output port is made available. When the mode of operation for the adder/subtractor is set to one 48-bit adder, the `carryout` port is 1-bit wide. When the mode of operation is set to two 24 bit adders, the `carryout` port is 2 bits wide. The MSB corresponds to the second adder's `carryout` and the LSB corresponds to the first adder's `carryout`. When the mode of operation is set to four 12 bit adders, the `carryout` port is 4 bits wide with the bits corresponding to the addition of the 48 bit input split into 4 12-bit sections.

- **Provide pattern detect port:** When selected, the pattern detection output port is provided. When the pattern, either from the mask or the c register, is matched the pattern detection port is set to '1'.
- **Provide pattern bar detect port:** When selected, the pattern bar detection (`patternbdetect`) output port is provided. When the inverse of the pattern, either from the mask or the c register, is matched the pattern bar detection port is set to '1'.
- **Provide overflow port:** When selected, the overflow output port is provided. This port indicates when the operation in the DSP48E has overflowed beyond the bit P[N] where N is between 1 and 46. N is determined by the number of 1s in the mask whether set by the GUI mask field or the c port input.
- **Provide underflow port:** When selected, the underflow output port is provided. This port indicates when the operation in the DSP48E has underflowed. Underflow occurs when the number goes below -P[N] where N is determined by the number of 1s in the mask whether set by the GUI mask field or the c port input.
- **Cascadable Ports:**
  - **Provide ACOUT port:** When selected, the `acout` output port is made available. The `acout` port must be connected to the `acin` port of another DSP48E block.
  - **Provide BCOUT port:** When selected, the `bcout` output port is made available. The `bcout` port must be connected to the `bcin` port of another DSP48E block.
  - **Provide PCOUT port:** When selected, the `pcout` output port is made available. The `pcout` port must be connected to the `pcin` port of another DSP48 block.
  - **Provide multiplier sign cascade out port:** When selected, the multiplier sign cascade out port (`multsigncascout`) is made available. This port can only be connected to the multiplier sign cascade in port of another DSP48E block and is used to support 96-bit accumulators/adders and subtractors which are built from two DSP48Es.
  - **Provide carry cascade out port:** When selected, the carry cascade out port (`carrycascout`) is made available. This port can only be connected to the carry cascade in port of another DSP48E block.
- **Pipelining tab:**
  - **Pipeline Options:**
    - **Length of a/acin pipeline:** Specifies the length of the pipeline on input register A. A pipeline of length 0 removes the register on the input.
    - **Length of b/bCIN pipeline:** Specifies the length of the pipeline for the `b` input whether it is read from `b` or `bcin`.
    - **Length of acout pipeline:** Specifies the length of the pipeline between the `a/acin` input and the `acout` output port. A pipeline of length 0 removes the register from the `acout` pipeline length. Must be less than or equal to the length of the `a/acin` pipeline.

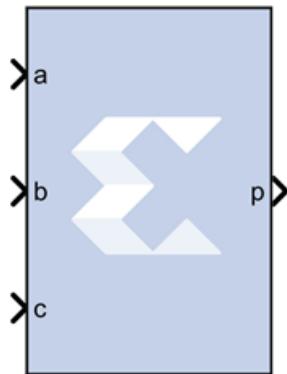
- **Length of bcout pipeline:** Specifies the length of the pipeline between the `b/bcin` input and the `bcout` output port. A pipeline of length 0 removes the register from the `bcout` pipeline length. Must be less than or equal to the length of the `b/bcin` pipeline.
  - **Pipeline c:** Indicates whether the input from the `c` port should be registered.
  - **Pipeline p:** Indicates whether the outputs `p` and `pcout` should be registered.
  - **Pipeline multiplier:** indicates whether the internal multiplier should register its output.
  - **Pipeline opmode:** Indicates whether the `opmode` port should be registered.
  - **Pipeline alumode:** Indicates whether the `alumode` port should be registered.
  - **Pipeline carry in:** Indicates whether the carry in port should be registered.
  - **Pipeline carry in select:** Indicates whether the carry in select port should be registered.
- **Reset/Enable Ports tab:**
    - **Reset port for a/acin:** When selected, a port `rst_a` is made available. This resets the pipeline register for port `a` when set to '1'.
    - **Reset port for b/bcin:** When selected, a port `rst_b` is made available. This resets the pipeline register for port `b` when set to '1'.
    - **Reset port for c:** When selected, a port `rst_c` is made available. This resets the pipeline register for port `c` when set to '1'.
    - **Reset port for multiplier:** when selected, a port `rst_m` is made available. This resets the pipeline register for the internal multiplier when set to '1'.
    - **Reset port for P:** When selected, a port `rst_p` is made available. This resets the output register when set to '1'.
    - **Reset port for carry in:** When selected, a port `rst_carryin` is made available. This resets the pipeline register for carry in when set to '1'.
    - **Reset port for alumode:** When selected, a port `rst_alumode` is made available. This resets the pipeline register for the `alumode` port when set to '1'.
    - **Reset port for controls (opmode and carry\_in\_sel):** When selected, a port `rst_ctrl` is made available. This resets the pipeline register for the `opmode` register (if available) and the `carry_in_sel` register (if available) when set to '1'.
    - **Enable port for first a/acin register:** When selected, an enable port `ce_a1` for the first `a` pipeline register is made available.
    - **Enable port for second a/acin register:** When selected, an enable port `ce_a2` for the second `a` pipeline register is made available.

- **Enable port for first b/bcin register:** When selected, an enable port `ce_b1` for the first b pipeline register is made available.
  - **Enable port for second b/bcin register:** When selected, an enable port `ce_b2` for the second b pipeline register is made available.
  - **Enable port for c:** When selected, an enable port `ce_c` for the port C register is made available.
  - **Enable port for multiplier:** When selected, an enable port `ce_m` for the multiplier register is made available.
  - **Enable port for p:** When selected, an enable port `ce_p` for the port P output register is made available.
  - **Enable port for carry in:** When selected, an enable port `ce_carry_in` for the carry in register is made available.
  - **Enable port for alumode:** When selected, an enable port `ce_alumode` for the alumode register is made available.
  - **Enable port for multiplier carry in:** When selected, an enable port `mult_carry_in` for the multiplier register is made available.
  - **Enable port for controls (opmode and carry\_in\_sel):** When selected, the enable port `ce_ctrl` is made available. The port `ce_ctrl` controls the opmode and carry in select registers.
- **Implementation tab:**
    - **Use synthesizable model:** When selected, the DSP48E is implemented from an RTL description which might not map directly to the DSP48E hardware. This is useful if a design using the DSP48E block is targeted at device families that do not contain DSP48E hardware primitives.
    - **Mode of operation for the adder/subtractor:** This mode can be used to implement small add-subtract functions at high speed and lower power with less logic utilization. The adder and subtracter in the adder/subtracted/logic unit can also be split into two 24-bit fields or four 12-bit fields. This is achieved by setting the mode of operation to "Two 24-bit adders" or "Four 12-bit adders".
    - **Use adder only:** When selected, the block is optimized in hardware for maximum performance without using the multiplier. If an instruction using the multiplier is encountered in simulation, an error is reported.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## DSP Macro 1.0

The Xilinx DSP macro block provides a device independent abstraction of the DSP48E1, DSP48E2, and DSP58 blocks. Using this block instead of using a technology-specific DSP slice helps makes the design more portable between Xilinx technologies.



The DSP Macro provides a simplified interface to the XtremeDSP slice by the abstraction of all opmode, subtract, alumode, and inmode controls to a single SEL port. Further, all CE and RST controls are grouped to a single CE and SCLR port respectively. This abstraction enhances portability of HDL between device families.

You can specify 1 to 64 instructions which are translated into the various control signals for the XtremeDSP slice of the target device. The instructions are stored in a ROM from which the appropriate instruction is selected using the SEL port.

## Block Parameters

- **Instruction tab:**

The Instruction tab is used to define the operations that the LogiCORE™ is to implement. Each instruction can be entered on a new line, or in a comma delimited list, and are enumerated from the top down. You can specify a maximum of 64 instructions.

Refer to the topic Instructions page of the *DSP Macro LogiCORE IP Product Guide (PG323)* for details on all the parameters on this tab.

- **Pipeline Options tab:**

The Pipeline Options tab is used to define the pipeline depth of the various input paths.

- **Pipeline Options:**

Specifies the pipeline method to be used; **Automatic**, **By Tier**, or **Expert**.

- **Custom Pipeline options:**

Used to specify the pipeline depth of the various input paths.

- **Tier 1 to 6:** When **By Tier** is selected for Pipeline Options these parameters are used to enable/disable the registers across all the input paths for a given pipeline stage. The following restrictions are enforced:
  - When P has been specified in an expression tier, 6 will be forced as asynchronous feedback is not supported.
- **Individual registers:**

When you select **Expert** for the Pipeline Options, these parameters are used to enable/disable individual register stages. The following restrictions are enforced:

- The P register is forced when P is specified in an expression. Asynchronous feedback is not supported.

Refer to the topic *Detailed Pipeline Implementation of the DSP Macro LogiCORE IP Product Guide* (PG323) for details on all the parameters on this tab.

- **Implementation tab:**

The Implementation tab is used to define implementation options.

- **Output Port Properties:**

- **Precision:** Specifies the precision of the P output port.
  - **Full:** The bit width of the output port P is set to the full XtremeDSP Slice width of 48 bits.
  - **User Defined:** The output width of P can be set to any value up to 48 bits. When set to less than 48 bits, the output is truncated (LSBs removed).
- **Width:** Specifies the User Defined output width of the P output port
- **Binary Point:** Specifies the placement of the binary point of the P output port.

- **Additional ports:**

- **Use ACOUT:** Use the optional cascade A output port.
- **Use CARRYOUT:** Use the optional carryout output port.
- **Use BCOUT:** Use the optional cascade B output port.
- **Use CARRYCASOUT:** Use the optional cascade carryout output port.
- **Use PCOUT:** Use the optional cascade P output port.

- **Control ports:**

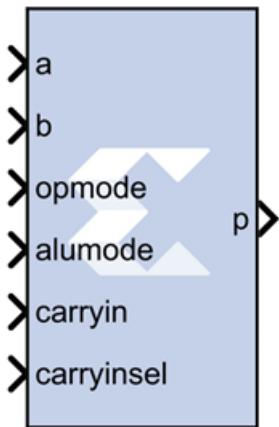
Refer to the topic *Implementation Page of the DSP Macro LogiCORE IP Product Guide* (PG323) for details on all the parameters on this tab.

## LogiCORE Documentation

DSP Macro LogiCORE IP Product Guide (PG323)

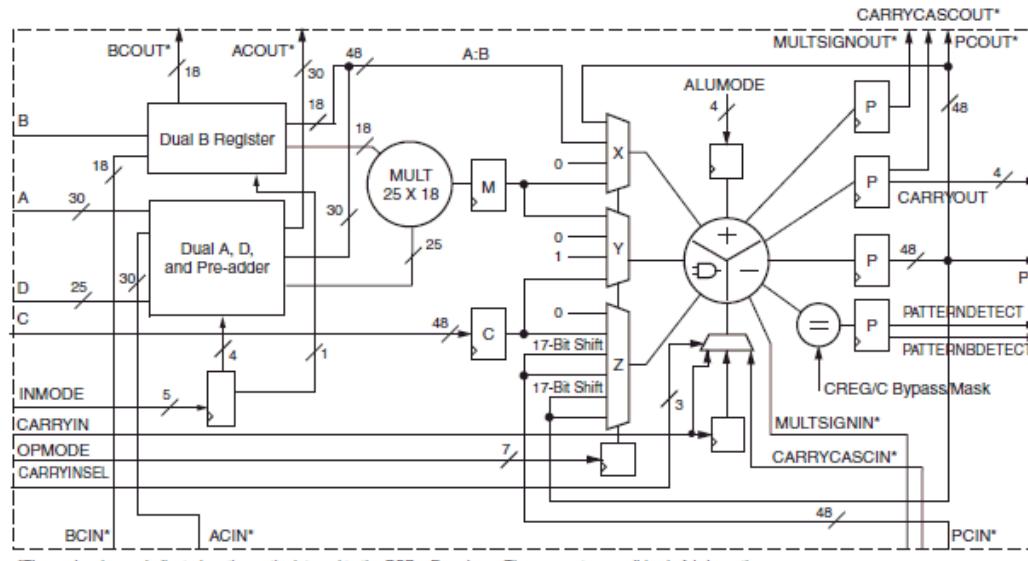
## DSP48E1

The Xilinx DSP48E1 block is an efficient building block for DSP applications that use Xilinx Virtex®-7 series devices. Enhancements to the DSP48E1 slice provide improved flexibility and utilization, improved efficiency of applications, reduced overall power consumption, and increased maximum frequency. The high performance allows designers to implement multiple slower operations in a single DSP48E1 slice using time-multiplexing methods.



The DSP48E1 slice supports many independent functions. These functions include multiply, multiply accumulate (MACC), multiply add, three-input add, barrel shift, wide-bus multiplexing, magnitude comparator, bit-wise logic functions, pattern detect, and wide counter. The architecture also supports cascading multiple DSP48E1 slices to form wide math functions, DSP filters, and complex arithmetic without the use of general FPGA.

Figure 277: DSP48E1



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows.

- **Input configuration:**

- **A or ACIN input:** Specifies if the A input should be taken directly from the a port or from the cascaded acin port. The acin port can only be connected to another DSP48 block.
- **B or BCIN input:** Specifies if the B input should be taken directly from the b port or from the cascaded bcin port. The bcin port can only be connected to another DSP48 block.

**Note:** If the input to the block is NaN, you will see a behavioral simulation mismatch.

- **DSP48E1 data-path configuration:**

- **SIMD Mode of Adder/Subtractor/Accumulator:** This mode can be used to implement small add-subtract functions at high speed and lower power with less logic utilization. The adder and subtractor in the adder/subtractor/logic unit can also be split into two 24-bit units or four 12-bit units.
- **Do not use multiplier:** When selected, the block is optimized in hardware for maximum performance without using the multiplier. If an instruction using the multiplier is encountered in simulation, an error is reported.

- **Use dynamic multiplier mode:** When selected, it instructs the block to use the dynamic multiplier mode. This indicates that the block is switching between A\*B and A:B operations on the fly and therefore needs to get the worst-case timing of the two paths.
- **Use Padder:** Use the 25-bit D data input to the pre-adder or alternative input to the multiplier. The pre-adder implements D + A as determined by the INMODE3 signal.
- **Pattern Detection:**
  - **Reset p register on pattern detection:** If selected and the pattern is detected, reset the p register on the next cycle
- **Pattern Input:**
  - **Pattern Input from c port:** When selected, the pattern used in pattern detection is read from the c port.
  - **Pattern Input:**
    - **Pattern Input from c port:** When selected, the pattern used in pattern detection is read from the c port.
    - **Using Pattern Attribute (48bit hex value):** Value is used in pattern detection logic which is best described as an equality check on the output of the adder/subtractor/logic unit
    - **Pattern attribute:** A 48-bit value that is used in the pattern detector.
- **Mask Input:**
  - **Mask input from c port:** When selected, the mask used in pattern detection is read from the c port.
  - **Using Mask Attribute (48 bit hex value):** Enter a 48-bit value used to mask out certain bits during pattern detection.
  - **MODE1:** Selects rounding\_mode 1.
  - **MODE2:** Selects rounding\_mode 2.
- **Optional Ports tab:**

Parameters specific to the Optional Ports tab are:

  - **Input Ports:**
    - **Consolidate control port:** When selected, combines the opmode, alumode, carry\_in, carry\_in\_sel, and inmode ports into one 20-bit port. Bits 0 to 6 are the opmode, bits 7 to 10 are the alumode port, bit 11 is the carry\_in port, bits 12 to 14 are the carry\_in\_sel port, and bits 15-19 are the inmode bits. This option should be used when the Opmode block is used to generate a DSP48 instruction.

- **Provide c port:** When selected, the c port is made available. Otherwise, the c port is tied to '0'.
- **Provide global reset port:** When selected, the port rst is made available. This port is connected to all available reset ports based on the pipeline selections.
- **Provide global enable port:** When selected, the optional en port is made available. This port is connected to all available enable ports based on the pipeline selections.
- **Provide pcin port:** When selected, the pcin port is exposed. The pcin port must be connected to the pcout port of another DSP48 block.
- **Provide carry cascade in port:** When selected, the carry cascade in port is exposed. This port can only be connected to a carry cascade out port on another DSP48E block.
- **Provide multiplier sign cascade in port:** When selected, the multiplier sign cascade in port (multsigncascin) is exposed. This port can only be connected to a multiplier sign cascade out port of another DSP48E block.
- **Provide carryout port:** When selected, the carryout output port is made available. When the mode of operation for the adder/subtractor is set to one 48-bit adder, the carryout port is 1-bit wide. When the mode of operation is set to two 24 bit adders, the carryout port is 2 bits wide. The MSB corresponds to the second adder's carryout and the LSB corresponds to the first adder's carryout. When the mode of operation is set to four 12 bit adders, the carryout port is 4 bits wide with the bits corresponding to the addition of the 48 bit input split into 4 12-bit sections.
- **Provide pattern detect port:** When selected, the pattern detection output port is provided. When the pattern, either from the mask or the c register, is matched the pattern detection port is set to '1'.
- **Provide pattern bar detect port:** When selected, the pattern bar detection (patternbdetect) output port is provided. When the inverse of the pattern, either from the mask or the c register, is matched the pattern bar detection port is set to '1'.
- **Provide overflow port:** When selected, the overflow output port is provided. This port indicates when the operation in the DSP48E has overflowed beyond the bit P[N] where N is between 1 and 46. N is determined by the number of 1s in the mask whether set by the GUI mask field or the c port input.
- **Provide underflow port:** When selected, the underflow output port is provided. This port indicates when the operation in the DSP48E has underflowed. Underflow occurs when the number goes below -P[N] where N is determined by the number of 1s in the mask whether set by the GUI mask field or the c port input.
- **Provide acout port:** When selected, the acout output port is made available. The acout port must be connected to the acin port of another DSP48E block.
- **Provide bcout port:** When selected, the bcout output port is made available. The bcout port must be connected to the bcin port of another DSP48E block.

- **Provide pcout port:** When selected, the `pcout` output port is made available. The `pcout` port must be connected to the `pcin` port of another DSP48 block.
- **Provide multiplier sign cascade out port:** When selected, the multiplier sign cascade out port (`multsigncascout`) is made available. This port can only be connected to the multiplier sign cascade in port of another DSP48E block and is used to support 96-bit accumulators/adders and subtracters which are built from two DSP48Es.
- **Provide carry cascade out port:** When selected, the carry cascade out port (`carrycascout`) is made available. This port can only be connected to the carry cascade in port of another DSP48E block.
- **Pipelining tab:**

Parameters specific to the Pipelining tab are as follows:

  - **Length of a/acin pipeline:** Specifies the length of the pipeline on input register A. A pipeline of length 0 removes the register on the input.
  - **Length of b/bcin pipeline:** Specifies the length of the pipeline for the b input whether it is read from `b` or `bcin`.
  - **Length of acout pipeline:** Specifies the length of the pipeline between the `a/acin` input and the `acout` output port. A pipeline of length 0 removes the register from the `acout` pipeline length. Must be less than or equal to the length of the `a/acin` pipeline.
  - **Length of bcout pipeline:** Specifies the length of the pipeline between the `b/bcin` input and the `bcout` output port. A pipeline of length 0 removes the register from the `bcout` pipeline length. Must be less than or equal to the length of the `b/bcin` pipeline.
  - **Pipeline c:** Indicates whether the input from the `c` port should be registered.
  - **Pipeline p:** Indicates whether the outputs `p` and `pcout` should be registered.
  - **Pipeline multiplier:** Indicates whether the internal multiplier should register its output.
  - **Pipeline opmode:** Indicates whether the `opmode` port should be registered.
  - **Pipeline alumode:** Indicates whether the `alumode` port should be registered.
  - **Pipeline carry in:** Indicates whether the `carry in` port should be registered.
  - **Pipeline carry in select:** Indicates whether the `carry in select` port should be registered.
  - **Pipeline preadder input register d:** Indicates to add a pipeline register to the `d` input.
  - **Pipeline preadder output register ad:** Indicates to add a pipeline register to the `ad` output.
  - **Pipeline INMODE register:** Indicates to add a pipeline register to the `INMODE` input.
- **Reset/Enable Ports tab:** Parameters specific to the Reset/Enable tab are as follows.

- **Provide Reset Ports:**

- **Reset port for a/acin:** When selected, a port `rst_a` is made available. This resets the pipeline register for port a when set to '1'.
- **Reset port for b/bcin:** When selected, a port `rst_b` is made available. This resets the pipeline register for port b when set to '1'.
- **Reset port for c:** When selected, a port `rst_c` is made available. This resets the pipeline register for port c when set to '1'.
- **Reset port for multiplier:** When selected, a port `rst_m` is made available. This resets the pipeline register for the internal multiplier when set to '1'.
- **Reset port for P:** When selected, a port `rst_p` is made available. This resets the output register when set to '1'.
- **Reset port for carry in:** When selected, a port `rst_carryin` is made available. This resets the pipeline register for carry in when set to '1'.
- **Reset port for alumode:** When selected, a port `rst_alumode` is made available. This resets the pipeline register for the alumode port when set to '1'.
- **Reset port for controls (opmode and carry\_in\_sel):** When selected, a port `rst_ctrl` is made available. This resets the pipeline register for the opmode register (if available) and the carry\_in\_sel register (if available) when set to '1'.
- **Reset port for d and ad:** When selected, ports `rst_d` and `rst_ad` are made available. This resets the pipeline register for these ports when set to '1'.
- **Reset port for INMODE:** When selected, a port `rst_inmode` is made available. This resets the pipeline register for the inmode port when set to '1'.

- **Provide Enable Ports:**

- **Enable port for first a/acin register:** When selected, an enable port `ce_a1` for the first a pipeline register is made available.
- **Enable port for second a/acin register:** When selected, an enable port `ce_a2` for the second a pipeline register is made available.
- **Enable port for first b/bcin register:** When selected, an enable port `ce_b1` for the first b pipeline register is made available.
- **Enable port for second b/bcin register:** When selected, an enable port `ce_b2` for the second b pipeline register is made available.
- **Enable port for c:** When selected, an enable port `ce_c` for the port C register is made available.
- **Enable port for multiplier:** When selected, an enable port `ce_m` for the multiplier register is made available.

- **Enable port for p:** When selected, an enable port `ce_p` for the port P output register is made available.
  - **Enable port for carry in:** When selected, an enable port `ce_carry_in` for the carry in register is made available.
  - **Enable port for alumode:** When selected, an enable port `ce_alumode` for the alumode register is made available.
  - **Enable port for multiplier carry in:** When selected, an enable port `mult_carry_in` for the multiplier register is made available.
  - **Enable port for controls (opmode and carry\_in\_sel):** When selected, the enable port `ce_ctrl` is made available. The port `ce_ctrl` controls the opmode and carry in select registers.
  - **Enable port for d:** When selected, an enable port is added input register d.
  - **Enable port for ad:** When selected, an enable port is add for the preadder output register ad.
  - **Enable port for INMODE:** When selected, an enable port is added for the INMODE register.
- **Implementation tab:**

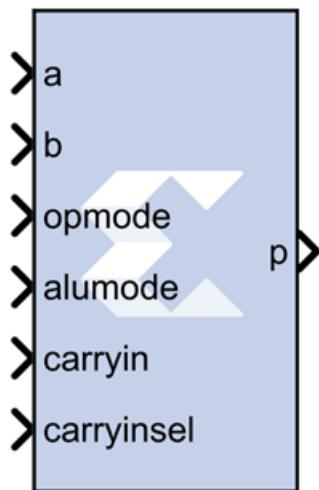
Parameters specific to the Implementation tab are as follows.

- **Use synthesizable model:** When selected, the DSP48E is implemented from an RTL description which might not map directly to the DSP48E hardware. This is useful if a design using the DSP48E block is targeted at device families that do not contain DSP48E hardware primitives.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## DSP48E2

The Xilinx DSP48E2 block is an efficient building block for DSP applications that use UltraScale devices. DSP applications use many binary multipliers and accumulators that are best implemented in dedicated DSP resources. UltraScale devices have many dedicated low-power DSP slices, combining high speed with small size while retaining system design flexibility.

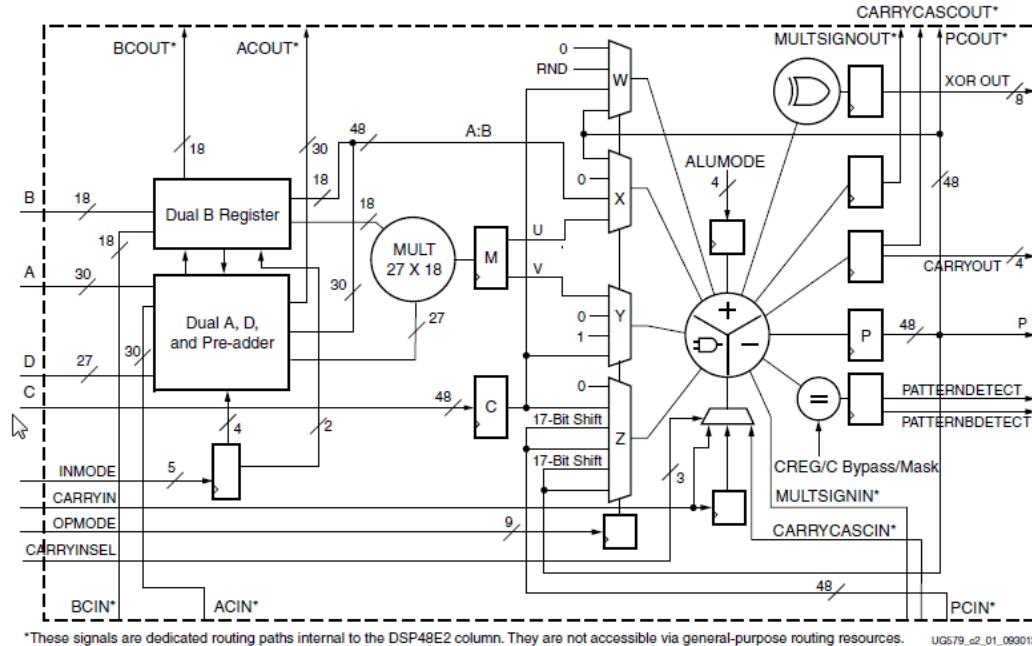


The DSP48E2 slice is effectively a superset of the DSP48E1 slice with these differences:

- Wider functionality
- More flexibility in the pre-adder
- Added fourth operand to ALU with WMUX
- Wide XOR of the X, Y, and Z multiplexers
- Additional unique features

Refer to the document titled *UltraScale Architecture DSP Slice User Guide* ([UG579](#)) for a detailed description of the DSP48E2 features.

Figure 278: DSP48E2



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Input configuration:**
    - **A or ACIN input:** Specifies if the A input should be taken directly from the a port or from the cascaded acin port. The acin port can only be connected to another DSP48 block.
    - **B or BCIN input:** Specifies if the B input should be taken directly from the b port or from the cascaded bcin port. The bcin port can only be connected to another DSP48 block.
  - Note:** If the input to the block is NaN, you will see a behavioral simulation mismatch.
- **DSP48E2 data-path configuration:**
  - **SIMD Mode of Adder/Subtractor/Accumulator:** This mode can be used to implement small add-subtract functions at high speed and lower power with less logic utilization. The adder and subtractor in the adder/subtracted/logic unit can also be split into two 24-bit units or four 12-bit units.
  - **Do not use multiplier:** When selected, the block is optimized in hardware for maximum performance without using the multiplier. If an instruction using the multiplier is encountered in simulation, an error is reported.

- **Use dynamic multiplier mode:** When selected, it instructs the block to use the dynamic multiplier mode. This indicates that the block is switching between A\*B and A:B operations on the fly and therefore needs to get the worst-case timing of the two paths.
- **Preadder configuration:** Use the 25-bit D data input to the pre-adder or alternative input to the multiplier. The pre-adder implements D + A as determined by the INMODE3 signal.
  - **PREADDINSEL Select preadder input:** Selects the input to be added with D in the preadder.
  - **AMULTSEL Select A multiplexer output:** Selects the input to the 27-bit A input of the multiplier. In the 7 series primitive DSP48E1 the attribute is called USE\_DPORT, but has been renamed due to new pre-adder flexibility enhancements (default AMULTSEL = A is equivalent to USE\_DPORT=False).
  - **BMULTSEL Select B multiplexer output:** Selects the input to the 18-bit B input of the multiplier.
  - **Enable D Port:** Automatically enabled when AD is selected above.
- **Pattern Detection:**
  - **Reset p register on pattern detection:** If selected and the pattern is detected, reset the p register on the next cycle.
  - **AUTO RESET PRIORITY:** When enabled by selecting the option above, select RESET (the default) or CEP (clock enabled for the P (output) register).
- **Pattern Input:**
  - **Pattern Input from c port:** When selected, the pattern used in pattern detection is read from the c port.
  - **Using Pattern Attribute (48bit hex value):** Value is used in pattern detection logic which is best described as an equality check on the output of the adder/subtractor/logic unit.
  - **Pattern Attribute (48bit hex value):** Enter a 48-bit value that is used in the pattern detector.
- **Mask Input:**
  - **Mask input from c port:** When selected, the mask used in pattern detection is read from the c port.
  - **Using Mask Attribute (48 bit hex value):** Enter a 48-bit value used to mask out certain bits during pattern detection.
  - **MODE1:** Selects rounding\_mode 1 (C-bar left shifted by 1).
  - **MODE2:** Selects rounding\_mode 2 (C-bar left shifted by 2).
- **Wide Xor tab:** Parameters specific to the Wide Xor tab are as follows.

- **Use Wide XOR:** This is a new feature in the DSP48E2 slice giving the ability to perform a 96-bit wide XOR function.
- **XORSIMD Select Wide XOR SIMD:** The XORSIMD attribute is used to select the width of the XOR function. Select either XOR12 (the default), XOR24, XOR48, or XOR96.
- **Optional Ports tab:** Parameters specific to the Optional Ports tab are as follows.
  - **Input Ports:**
    - **Consolidate control port:** When selected, combines the `opmode`, `alumode`, `carry_in`, `carry_in_sel`, and `inmode` ports into one 20-bit port. Bits 0 to 6 are the `opmode`, bits 7 to 10 are the `alumode` port, bit 11 is the `carry_in` port, bits 12 to 14 are the `carry_in_sel` port, and bits 15-19 are the `inmode` bits. This option should be used when the Opmode block is used to generate a DSP48 instruction.
    - **Provide c port:** When selected, the `c` port is made available. Otherwise, the `c` port is tied to '0'.
    - **Provide global reset port:** When selected, the port `rst` is made available. This port is connected to all available reset ports based on the pipeline selections.
    - **Provide global enable port:** When selected, the optional `en` port is made available. This port is connected to all available enable ports based on the pipeline selections.
  - **Cascadable Ports:**
    - **Provide pcin port:** When selected, the `pcin` port is exposed. The `pcin` port must be connected to the `pcout` port of another DSP48 block.
    - **Provide carry cascade in port:** When selected, the carry cascade in port is exposed. This port can only be connected to a carry cascade out port on another DSP48E block.
    - **Provide multiplier sign cascade in port:** When selected, the multiplier sign cascade in port (`multsigncascin`) is exposed. This port can only be connected to a multiplier sign cascade out port of another DSP48E block.
  - **Output Ports:**
    - **Provide carryout port:** When selected, the `carryout` output port is made available. When the mode of operation for the adder/subtractor is set to one 48-bit adder, the `carryout` port is 1-bit wide. When the mode of operation is set to two 24 bit adders, the `carryout` port is 2 bits wide. The MSB corresponds to the second adder's `carryout` and the LSB corresponds to the first adder's `carryout`. When the mode of operation is set to four 12 bit adders, the `carryout` port is 4 bits wide with the bits corresponding to the addition of the 48 bit input split into 4 12-bit sections.
    - **Provide pattern detect port:** When selected, the pattern detection output port is provided. When the pattern, either from the mask or the `c` register, is matched the pattern detection port is set to '1'.

- **Provide pattern bar detect port:** When selected, the pattern bar detection (`patternbdetect`) output port is provided. When the inverse of the pattern, either from the mask or the `c` register, is matched the pattern bar detection port is set to '1'.
  - **Provide overflow port:** When selected, the overflow output port is provided. This port indicates when the operation in the DSP48E has overflowed beyond the bit  $P[N]$  where  $N$  is between 1 and 46.  $N$  is determined by the number of 1s in the mask whether set by the GUI mask field or the `c` port input.
  - **Provide underflow port:** When selected, the underflow output port is provided. This port indicates when the operation in the DSP48E has underflowed. Underflow occurs when the number goes below  $-P[N]$  where  $N$  is determined by the number of 1s in the mask whether set by the GUI mask field or the `c` port input.
- **Cascadable Ports:**
    - **Provide acout port:** When selected, the `acout` output port is made available. The `acout` port must be connected to the `acin` port of another DSP48E block.
    - **Provide bcout port:** When selected, the `bcout` output port is made available. The `bcout` port must be connected to the `bcin` port of another DSP48E block.
    - **Provide pcout port:** When selected, the `pcout` output port is made available. The `pcout` port must be connected to the `pcin` port of another DSP48 block.
    - **Provide multiplier sign cascade out port:** When selected, the multiplier sign cascade out port (`multsigncascout`) is made available. This port can only be connected to the multiplier sign cascade in port of another DSP48E block and is used to support 96-bit accumulators/adders and subtracters which are built from two DSP48Es.
    - **Provide carry cascade out port:** When selected, the carry cascade out port (`carrycascout`) is made available. This port can only be connected to the carry cascade in port of another DSP48E block.
  - **Pipelining tab:**

Parameters specific to the Pipelining tab are as follows.

    - **Length of a/acin pipeline:** Specifies the length of the pipeline on input register A. A pipeline of length 0 removes the register on the input.
    - **Length of b/bcin pipeline:** Specifies the length of the pipeline for the b input whether it is read from `b` or `bcin`.
    - **Length of acout pipeline:** Specifies the length of the pipeline between the `a/acin` input and the `acout` output port. A pipeline of length 0 removes the register from the `acout` pipeline length. Must be less than or equal to the length of the `a/acin` pipeline.
    - **Length of bcout pipeline:** Specifies the length of the pipeline between the `b/bcin` input and the `bcout` output port. A pipeline of length 0 removes the register from the `bcout` pipeline length. Must be less than or equal to the length of the `b/bcin` pipeline.

- **Pipeline c:** Indicates whether the input from the c port should be registered.
- **Pipeline p:** Indicates whether the outputs p and pcout should be registered.
- **Pipeline multiplier:** Indicates whether the internal multiplier should register its output.
- **Pipeline opmode:** Indicates whether the opmode port should be registered.
- **Pipeline alumode:** Indicates whether the alumode port should be registered.
- **Pipeline carry in:** Indicates whether the carry in port should be registered.
- **Pipeline carry in select:** Indicates whether the carry in select port should be registered.
- **Pipeline preadder input register d:** Indicates to add a pipeline register to the d input.
- **Pipeline preadder output register ad:** Indicates to add a pipeline register to the ad output.
- **Pipeline INMODE register:** Indicates to add a pipeline register to the INMODE input.
- **Reset/Enable Ports tab:** Parameters specific to the Reset/Enable tab are as follows.
  - **Provide Reset Ports:**
    - **Reset port for a/acin:** When selected, a port `rst_a` is made available. This resets the pipeline register for port a when set to '1'.
    - **Reset port for b/bcin:** When selected, a port `rst_b` is made available. This resets the pipeline register for port b when set to '1'.
    - **Reset port for c:** When selected, a port `rst_c` is made available. This resets the pipeline register for port c when set to '1'.
    - **Reset port for multiplier:** When selected, a port `rst_m` is made available. This resets the pipeline register for the internal multiplier when set to '1'.
    - **Reset port for P:** When selected, a port `rst_p` is made available. This resets the output register when set to '1'.
    - **Reset port for carry in:** When selected, a port `rst_carryin` is made available. This resets the pipeline register for carry in when set to '1'.
    - **Reset port for alumode:** When selected, a port `rst_alumode` is made available. This resets the pipeline register for the alumode port when set to '1'.
    - **Reset port for controls (opmode and carry\_in\_sel):** When selected, a port `rst_ctrl` is made available. This resets the pipeline register for the opmode register (if available) and the carry\_in\_sel register (if available) when set to '1'.
    - **Reset port for d and ad:** When selected, a port `rst_a` and `rst_ad` is made available. This resets the pipeline register for ports when set to '1'.

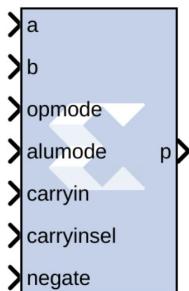
- **Reset port for INMODE:** When selected, a port `rst_inmode` is made available. This resets the pipeline register for the `inmode` port when set to '1'.
- **Provide Enable Ports:**
  - **Enable port for first a/acin register:** When selected, an enable port `ce_a1` for the first a pipeline register is made available.
  - **Enable port for second a/acin register:** When selected, an enable port `ce_a2` for the second a pipeline register is made available.
  - **Enable port for first b/bcin register:** When selected, an enable port `ce_b1` for the first b pipeline register is made available.
  - **Enable port for second b/bcin register:** When selected, an enable port `ce_b2` for the second b pipeline register is made available.
  - **Enable port for c:** When selected, an enable port `ce_c` for the port C register is made available.
  - **Enable port for multiplier:** When selected, an enable port `ce_m` for the multiplier register is made available.
  - **Enable port for p:** When selected, an enable port `ce_p` for the port P output register is made available.
  - **Enable port for carry in:** When selected, an enable port `ce_carry_in` for the carry in register is made available.
  - **Enable port for alumode:** When selected, an enable port `ce_alumode` for the alumode register is made available.
  - **Enable port for multiplier carry in:** When selected, an enable port `mult_carry_in` for the multiplier register is made available.
  - **Enable port for controls (opmode and carry\_in\_sel):** When selected, the enable port `ce_ctrl` is made available. The port `ce_ctrl` controls the opmode and carry in select registers.
  - **Enable port for d:** When selected, an enable port is added input register d.
  - **Enable port for ad:** When selected, an enable port is add for the preadder output register ad.
  - **Enable port for INMODE:** When selected, an enable port is added for the INMODE register.
- **Inversion Options tab:** When a checkbox is selected on this tab, the specified signal is inverted.
- **Implementation tab:** Parameters specific to the Implementation tab are as follows.

- **Use synthesizable model:** When selected, the DSP48E2 is implemented from an RTL description which might not map directly to the DSP48E2 hardware. This is useful if a design using the DSP48E2 block is targeted at device families that do not contain DSP48E2 hardware primitives.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## DSP58

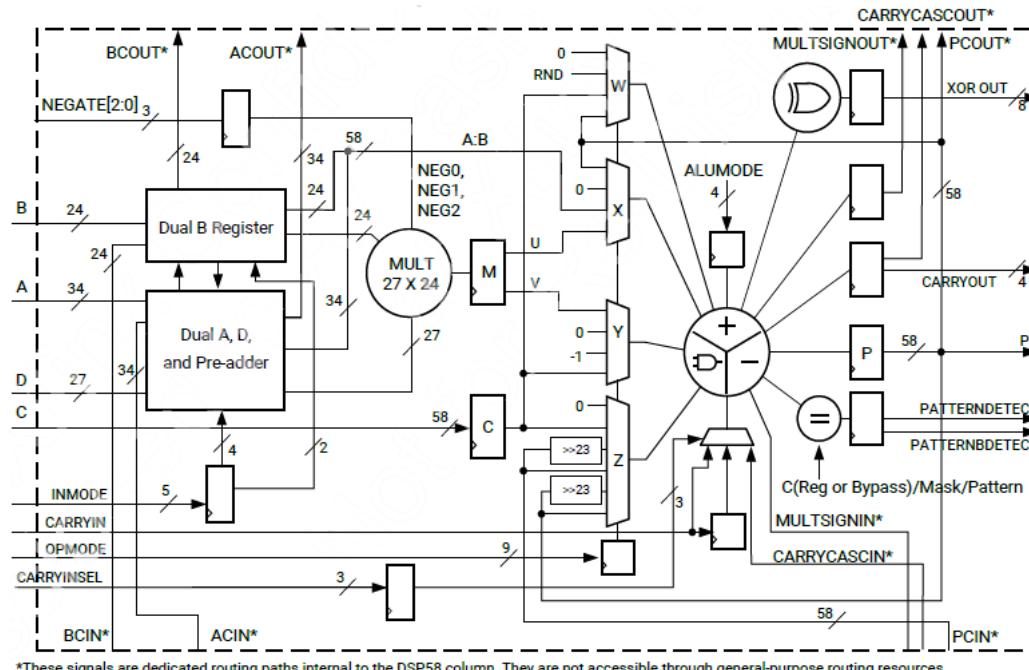
The Xilinx DSP58 block is an efficient building block for DSP applications that use Versal® devices. DSP applications use many binary multipliers and accumulators that are best implemented in dedicated DSP resources. Versal® devices have many dedicated low-power DSP slices, combining high speed with small size while retaining system design flexibility.



The DSP58 slice is effectively a super-set of the DSP48E2 slice with these differences. The DSP58 has the following.

- Wider functionality
- More flexibility in the pre-adder
- New optional negate import
- More XOR operations
- Additional unique features

Figure 279: DSP58



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

- **Input Configuration:**

- **A or ACIN input:** Specifies if the A input should be taken directly from the `a` port or from the cascaded `acin` port. The `acin` port can only be connected to another DSP58 block.
- **B or BCIN input:** Specifies if the B input should be taken directly from the `b` port or from the cascaded `bcin` port. The `bcin` port can only be connected to another DSP58 block.

**Note:** If the input to the block is NaN, you will see a behavioral simulation mismatch.

- **DSP58 Data-Path Configuration:**

- **SIMD Mode of Adder/Subtractor/Accumulator:** This mode can be used to implement small add-subtract functions at high speed and lower power with less logic utilization. The adder and subtracter in the adder/subtracted/logic unit can also be split into two 24-bit units or four 12-bit units.
- **Mode of Multiplier:** This option is disabled in the current release

- **Do not use multiplier:** When this is selected, the DSP58 block is optimized in hardware for maximum performance without using the multiplier. If an instruction using the multiplier is encountered in simulation, an error is reported.
- **Use dynamic multiplier mode:** When this is selected, it instructs the DSP58 block to use the dynamic multiplier mode. This indicates that the block is switching between  $A^*B$  and  $A:B$  operations on the fly, and therefore needs to get the worst-case timing of the two paths.
- **Preadder Configuration:** Use the 27-bit D data input to the pre-adder or alternative input to the multiplier. The pre-adder implements  $D + A$  as determined by the INMODE3 signal.
  - **PREADDINSEL Select preadder input:** Selects the input to be added with D in the pre-adder.
  - **AMULTSEL Select A multiplexer output:** Selects the input to the 27-bit A input of the multiplier. In the 7 series primitive, DSP48E1 the attribute is called USE\_DPORT, but has been renamed due to new pre-adder flexibility enhancements (default AMULTSEL = A is equivalent to USE\_DPORT=FALSE).
  - **BMULTSEL Select B multiplexer output:** Selects the input to the 18-bit B input of the multiplier.
  - **Enable D Port:** Automatically enabled when AD is selected.
- **Pattern Detection:**
  - **Reset p register on pattern detection:** If selected and the pattern is detected, reset the p register on the next cycle
  - **AUTO RESET PRIORITY:** When enabled by selecting the option above, select RESET (the default) or CEP (clock enabled for the P (output) register).
- **Pattern Input:**
  - **Pattern Input from c port:** When selected, the pattern used in pattern detection is read from the c port.
  - **Using Pattern Attribute (58bit hex value):** Value is used in pattern detection logic, which is best described as an equality check on the output of the adder/subtractor/logic unit.
  - **Pattern attribute:** A 58-bit value that is used in the pattern detector.
- **Mask Input:**
  - **Mask input from c port:** When selected, the mask used in pattern detection is read from the c port.
  - **Using Mask Attribute (58 bit hex value):** A 58-bit value used to mask out certain bits during pattern detection.
  - **MODE1:** Selects rounding\_mode 1 (C-bar left shifted by 1).

- **MODE2:** Selects rounding\_mode 2 (C-bar left shifted by 2).
- **Wide Xor tab:** Parameters specific to the Wide Xor tab are as follows.
  - **Use Wide XOR:** Use this feature to perform a 116 bit XOR function.
  - **XORSIMD Select Wide XOR SIMD:** Use the XORSIMD attribute to select the width of the XOR function. Select either XOR12 (the default), XOR22, XOR24, XOR34, XOR58, or XOR116).
- **Optional Ports tab:**
  - **Input Ports :**
    - **Consolidate control port:** When selected, combines the `opmode`, `alumode`, `carry_in`, `carry_in_sel`, `inmode`, and `negate` ports into one 25-bit port. Bits 0 to 8 are the `opmode`, bits 9 to 12 are the `alumode` port, bit 13 is the `carry_in` port, and bits 14 to 16 are the `carry_in_sel` port, bits 17 to 21 are the `inmode` port, and bits 22 to 24 are the `negate` port. This option should be used when the Opmode block is used to generate a DSP58 instruction.
    - **Provide c port:** When selected, the `c` port is made available. Otherwise, the `c` port is tied to '0'.
    - **Provide global reset port:** When selected, the port `rst` is made available. This port is connected to all available reset ports based on the pipeline selections.
    - **Provide global enable port:** When selected, the optional `en` port is made available. This port is connected to all available enable ports based on the pipeline selections.
  - **Cascadable Ports:**
    - **Provide pcin port:** When selected, the `pcin` port is exposed. The `pcin` port must be connected to the `pcout` port of another DSP58 block.
    - **Provide carry cascade in port:** When selected, the carry cascade in port is exposed. This port can only be connected to a carry cascade out port on another DSP58 block.
    - **Provide multiplier sign cascade in port:** When selected, the multiplier sign cascade in port (`multsigncascin`) is exposed. This port can only be connected to a multiplier sign cascade out port of another DSP58 block.
  - **Output Ports:**
    - **Provide carryout port:** When selected, the `carryout` output port is made available. When the mode of operation for the adder/subtractor is set to one 58-bit adder, the `carryout` port is 1-bit wide. When the mode of operation is set to two 24 bit adders, the `carryout` port is 2 bits wide. The MSB corresponds to the second adder's `carryout` and the LSB corresponds to the first adder's `carryout`. When the mode of operation is set to four 12 bit adders, the `carryout` port is 4 bits wide with the bits corresponding to the addition of the 48 bit input split into four 12-bit sections.

- **Provide pattern detect port:** When selected, the pattern detection output port is provided. When the pattern, either from the mask or the c register, is matched the pattern detection port is set to '1'.
- **Provide pattern bar detect port:** When selected, the pattern bar detection (`patternbdetect`) output port is provided. When the inverse of the pattern, either from the mask or the c register, is matched the pattern bar detection port is set to '1'.
- **Provide overflow port:** When selected, the overflow output port is provided. This port indicates when the operation in the DSP58 has overflowed beyond the bit P[N] where N is between 1 and 46. N is determined by the number of 1s in the mask whether set by the GUI mask field or the `c` port input.
- **Provide underflow port:** When selected, the underflow output port is provided. This port indicates when the operation in the DSP58 has underflowed. Underflow occurs when the number goes below -P[N] where N is determined by the number of 1s in the mask whether set by the GUI mask field or the `c` port input.
- **Cascadable Ports:**
  - **Provide ACOUT port:** When selected, the `acout` output port is made available. The `acout` port must be connected to the `acin` port of another DSP58 block.
  - **Provide BCOUT port:** When selected, the `bcout` output port is made available. The `bcout` port must be connected to the `bcin` port of another DSP58 block.
  - **Provide PCOUT port:** When selected, the `pcout` output port is made available. The `pcout` port must be connected to the `pcin` port of another DSP58 block.
  - **Provide multiplier sign cascade out port:** When selected, the multiplier sign cascade out port (`multsigncasout`) is made available. This port can only be connected to the multiplier sign cascade in port of another DSP58 block and is used to support 96-bit accumulators/adders and subtracters which are built from two DSP58s.
  - **Provide carry cascade out port:** When selected, the carry cascade out port (`carrycasout`) is made available. This port can only be connected to the carry cascade in port of another DSP58 block.
- **Pipelining tab:**
  - **Pipeline Options:**
    - **Length of a/acin pipeline:** Specifies the length of the pipeline on input register A. A pipeline of length 0 removes the register on the input.
    - **Length of b/bCIN pipeline:** Specifies the length of the pipeline for the `b` input whether it is read from `b` or `bcin`.
    - **Length of acout pipeline:** Specifies the length of the pipeline between the `a/acin` input and the `acout` output port. A pipeline of length 0 removes the register from the `acout` pipeline length. Must be less than or equal to the length of the `a/acin` pipeline.

- **Length of bcout pipeline:** Specifies the length of the pipeline between the `b/bcin` input and the `bcout` output port. A pipeline of length 0 removes the register from the `bcout` pipeline length. Must be less than or equal to the length of the `b/bcin` pipeline.
  - **Pipeline c:** Indicates whether the input from the `c` port should be registered.
  - **Pipeline p:** Indicates whether the outputs `p` and `pcout` should be registered.
  - **Pipeline multiplier:** indicates whether the internal multiplier should register its output.
  - **Pipeline opmode:** Indicates whether the `opmode` port should be registered.
  - **Pipeline alumode:** Indicates whether the `alumode` port should be registered.
  - **Pipeline carry in:** Indicates whether the `carry in` port should be registered.
  - **Pipeline carry in select:** Indicates whether the `carry in select` port should be registered.
  - **Pipeline preadder input register d:** Indicates to add a pipeline register to the `d` input.
  - **Pipeline preadder output register ad:** Indicates to add a pipeline register to the `ad` output.
  - **Pipeline INMODE register:** Indicates to add a pipeline register to the `INMODE` input.
- **Reset/Enable Ports tab:**
    - **Provide Reset Ports:**
      - **Reset port for a/acin:** When selected, a port `rst_a` is made available. This resets the pipeline register for port `a` when set to '1'.
      - **Reset port for b/bcin:** When selected, a port `rst_b` is made available. This resets the pipeline register for port `b` when set to '1'.
      - **Reset port for c:** When selected, a port `rst_c` is made available. This resets the pipeline register for port `c` when set to '1'.
      - **Reset port for multiplier:** when selected, a port `rst_m` is made available. This resets the pipeline register for the internal multiplier when set to '1'.
      - **Reset port for P:** When selected, a port `rst_p` is made available. This resets the output register when set to '1'.
      - **Reset port for carry in:** When selected, a port `rst_carryin` is made available. This resets the pipeline register for `carry in` when set to '1'.
      - **Reset port for alumode:** When selected, a port `rst_alumode` is made available. This resets the pipeline register for the `alumode` port when set to '1'.
      - **Reset port for controls (opmode and carry\_in\_sel):** When selected, a port `rst_ctrl` is made available. This resets the pipeline register for the `opmode` register (if available) and the `carry_in_sel` register (if available) when set to '1'.

- **Provide Enable Ports:**

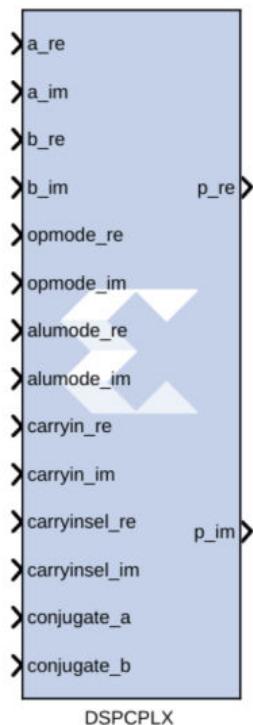
- **Enable port for first a/acin register:** When selected, an enable port `ce_a1` for the first a pipeline register is made available.
  - **Enable port for second a/acin register:** When selected, an enable port `ce_a2` for the second a pipeline register is made available.
  - **Enable port for first b/bcin register:** When selected, an enable port `ce_b1` for the first b pipeline register is made available.
  - **Enable port for second b/bcin register:** When selected, an enable port `ce_b2` for the second b pipeline register is made available.
  - **Enable port for c:** When selected, an enable port `ce_c` for the port C register is made available.
  - **Enable port for multiplier:** When selected, an enable port `ce_m` for the multiplier register is made available.
  - **Enable port for p:** When selected, an enable port `ce_p` for the port P output register is made available.
  - **Enable port for carry in:** When selected, an enable port `ce_carry_in` for the carry in register is made available.
  - **Enable port for alumode:** When selected, an enable port `ce_alumode` for the alumode register is made available.
  - **Enable port for multiplier carry in:** When selected, an enable port `mult_carry_in` for the multiplier register is made available.
  - **Enable port for controls (opmode and carry\_in\_sel):** When selected, the enable port `ce_ctrl` is made available. The port `ce_ctrl` controls the opmode and carry in select registers.
  - **Enable port for d:** When selected, an enable port is added input register d.
  - **Enable port for ad:** When selected, an enable port is add for the preadder output register ad.
  - **Enable port for INMODE:** When selected, an enable port is added for the INMODE register.
- **Inversion Options tab:** When a checkbox is selected under this tab, the specified signal is inverted.
  - **Implementation tab:**

- **Use synthesizable model:** When selected, the DSP58 is implemented from an RTL description which might not map directly to the DSP58 hardware. This is useful if a design using the DSP58 block is targeted at device families that do not contain DSP58 hardware primitives.
- **Mode of operation for the adder/subtractor:** This mode can be used to implement small add-subtract functions at high speed and lower power with less logic utilization. The adder and subtractor in the adder/subtracted/logic unit can also be split into two 24-bit fields or four 12-bit fields. This is achieved by setting the mode of operation to "Two 24-bit adders" or "Four 12-bit adders".

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

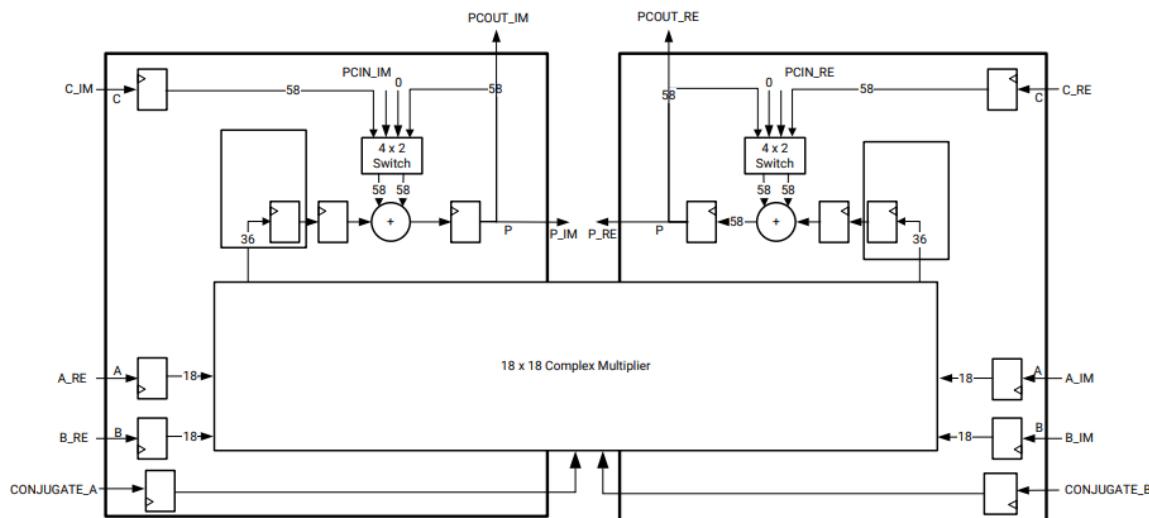
## DSPCPLX

The Xilinx DSPCPLX block is one of the advanced features provided by Versal® architecture DSP, which is the optimized solution to deal with 18x18 complex multiplication followed by 58 + 58 accumulation operation.



Versal architecture DSP supports an 18-bit complex multiplier with two back-to-back DSP58s in the same tile pair together. The two DSP58s with their DSP\_MODE attributes set to CINT18 form one complex arithmetic unit. The right DSP58 computes the real result P\_RE and left computes the imaginary result P\_IM. The following figure shows the unisim DSPCPLX primitive which is used to develop this feature.

Figure 280: Unisim DSPCPLX Primitive



## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

- **Basic tab:** Parameters specific to the Basic tab are as follows:
  - **Input Configuration:**
    - **A or ACIN input:** Specifies if the A input should be taken directly from the `a_re`, `a_im` ports or from the cascaded `acin_re`, `acin_im` ports. The `acin_re` and `acin_im` ports can only be connected to another DSPCPLX block.
    - **B or BCIN input:** Specifies if the B input should be taken directly from the `b_re`, `b_im` ports or from the cascaded `bcin_re`, `bcin_im` ports. The `bcin_re` and `bcin_im` ports can only be connected to another DSPCPLX block.
  - **Pattern Detection on Real Output:**
    - **Reset p\_re register on pattern detection:** If selected and the `pattern_re` is detected, reset the `p_re` register on the next cycle
    - **AUTO RESET PRIORITY RE:** When enabled by selecting the option above, select RESET (the default) or CEP (clock enabled for the P\_RE (output) register).

- **Pattern Input RE:**
  - **Pattern Input from c\_re port:** When selected, the `pattern_re` used in pattern detection on Real Output is read from the `c_re` port.
  - **Using Pattern Attribute RE (58-bit hex value):** Value is used in pattern detection logic which is best described as an equality check on the output of the adder/subtractor/logic unit.
  - **Pattern attribute RE:** Enter a 58-bit value that is used in the pattern detector.
- **Mask Input RE:**
  - **Mask input from c\_re port:** When selected, the `mask_re` used in pattern detection is read from the `c_re` port.
  - **Using Mask Attribute RE (58-bit hex value):** Enter a 58-bit value used to mask out certain bits during pattern detection on Real Output.
  - **MODE1:** Selects rounding\_mode 1 (C\_RE-bar left shifted by 1).
  - **MODE2:** Selects rounding\_mode 2 (C\_RE-bar left shifted by 2).
- **Pattern Detection on Imaginary Output:**
  - **Reset p\_im register on pattern detection:** If selected and the `pattern_im` is detected, reset the `p_im` register on the next cycle.
  - **AUTO RESET PRIORITY IM:** When enabled by selecting the option above, select RESET (the default) or CEP (clock enabled for the P\_IM (output) register).
- **Mask Input IM:**
  - **Mask input from c\_im port:** When selected, the `mask_im` used in pattern detection on Imaginary Output is read from the `c_im` port.
  - **Using Mask Attribute RE (58-bit hex value):** Enter a 58-bit value used to mask out certain bits during pattern detection on Imaginary Output.
  - **MODE1:** Selects rounding\_mode 1 (C\_IM-bar left shifted by 1).
  - **MODE2:** Selects rounding\_mode 2 (C\_IM-bar left shifted by 2).
- **Optional Ports tab:** Parameters specific to the Optional Ports tab are as follows:
  - **Input Ports:**

- **Consolidate control port:** When selected, combines the `opmode`, `alumode`, `carry_in`, `carry_in_sel`, `inmode` and `conjugate` ports into one 18-bit port. Bits 0 to 8 are the `opmode`, bits 9 to 12 are the `alumode` port, bit 13 is the `carry_in` port, bits 14 to 16 are the `carry_in_sel` port, bit 17 is the `Conjugate_A` input port and bit 18 is the `Conjugate_B` port. This option should be used when the Opmode block is used to generate a DSPCPLX instruction.

**Note:** Enabling this option will drive both the left and right DSP58 tiles with the same configuration.

- **Provide c port:** When selected, the `c_re` and `c_im` ports are made available. Otherwise, the `c_re` and `c_im` ports are tied to '0'.
- **Provide global reset port:** When selected, the port `rst_all` is made available. This port is connected to all available reset ports based on the pipeline selections.
- **Provide global enable port:** When selected, the optional `en_all` port is made available. This port is connected to all available enable ports based on the pipeline selections.
- **Cascadable Ports:**
  - **Provide pcin port:** When selected, the `pcin_re` and `pcin_im` ports are exposed. The `pcin_re` and `pcin_im` ports must be connected to the `pcout_re` and `pcout_im` ports of another DSPCPLX block respectively.
  - **Provide carry cascade in port:** When selected, the `carrycascin_re` and `carrycascin_im` ports are exposed. These ports can only be connected to a carry cascade out ports of another DSPCPLX block.
  - **Provide multiplier sign cascade in port:** When selected, the `multsignin_re` and `multsignin_im` ports are exposed. These ports can only be connected to a multiplier sign cascade out ports of another DSPCPLX block.
- **Output Ports:**
  - **Provide carryout port:** When selected, the `carryout_re` and `carryout_im` output ports are made available.
  - **Provide pattern detect port:** When selected, the `patterndetect_re` and `patterndetect_out` ports are provided. When the `pattern_re/pattern_im`, either from the `mask_re/mask_im` or the `c_re/c_im` register is matched, the respective `patterndetect_re/patterndetect_im` port is set to '1'.
  - **Provide pattern bar detect port:** When selected, the `patternbdetect_re` and `patternbdetect_im` ports are provided. When the inverse of the `pattern_re/pattern_im`, either from the `mask_re/mask_im` or the `c_re/c_im` register is matched, the `patternbdetect_re/patternbdetect_im` port is set to '1'.

- **Provide overflow port:** When selected, the `overflow_re` and `overflow_im` ports are provided. These ports indicate when the operation in the DSPCPLX has overflowed beyond the bit `P_RE[N]/P_IM[N]` where N is between 0 and 56. N is determined by the number of 1s in the `mask_re/mask_im` whether set by the GUI mask field or the `c_re/c_im` port input.
- **Provide underflow port:** When selected, the `underflow_re` and `underflow_im` ports are provided. These ports indicate when the operation in the DSPCPLX has underflowed. Underflow occurs when the number goes below `-P_RE[N]/P_IM[N]`, where N is determined by the number of 1s in the `mask_re/mask_im` whether set by the GUI mask field or the `c_re/c_im` port input.
- **Cascadable Ports:**
  - **Provide acout port:** When selected, the `acout_re` and `acout_im` output ports are made available. The `acout_re/acout_im` port must be connected to the `acin_re/acin_im` port of another DSPCPLX block.
  - **Provide bcout port:** When selected, the `bcout_re` and `bcout_im` output ports are made available. The `bcout_re/bcout_im` port must be connected to the `bcin_re/bcin_im` port of another DSPCPLX block.
  - **Provide pcout port:** When selected, the `pcout_re` and `pcout_im` output ports are made available. The `pcout_re/pcout_im` port must be connected to the `pcin_re/pcin_im` port of another DSPCPLX block.
  - **Provide multiplier sign cascade out port:** When selected, the `multsignout_re` and `multsignout_im` ports are made available. These ports can only be connected to the `multsignin_re` and `multsignin_im` ports of another DSPCPLX block respectively and is used to support 116-bit accumulators/adders and subtracters which are built from two DSPCPLXs.
  - **Provide carry cascade out port:** When selected, the `carrycasout_re` and `carrycasout_im` ports are made available. These ports can only be connected to the `carrycasin_re` and `carrycasin_im` ports of another DSPCPLX block respectively.
- **Pipelining tab:** Parameters specific to the Pipelining tab are as follows:
  - **Length of a\_re/acin\_re pipeline:** Specifies the length of the pipeline on input register A\_RE. The pipeline of length 0 removes the register on the input.
  - **Length of a\_im/acin\_im pipeline:** Specifies the length of the pipeline on input register A\_IM. The pipeline of length 0 removes the register on the input.
  - **Length of b\_re/bcin\_re pipeline:** Specifies the length of the pipeline for the `b_re` input and whether it is read from `b_re` or `bcin_re`.
  - **Length of b\_im/bcin\_im pipeline:** Specifies the length of the pipeline for the `b_im` input and whether it is read from `b_im` or `bcin_im`.

- **Length of acout\_re pipeline:** Specifies the length of the pipeline between the `a_re/` `acin_re` input and the `acout_re` output port. The pipeline of length 0 removes the register from the `acout_re` pipeline length. Must be less than or equal to the length of the `a_re/``acin_re` pipeline.
- **Length of acout\_im pipeline:** Specifies the length of the pipeline between the `a_im/` `acin_im` input and the `acout_im` output port. The pipeline of length 0 removes the register from the `acout_im` pipeline length. Must be less than or equal to the length of the `a_im/``acin_im` pipeline.
- **Length of bcout\_re pipeline:** Specifies the length of the pipeline between the `b_re/` `bcin_re` input and the `bcout_re` output port. The pipeline of length 0 removes the register from the `bcout_re` pipeline length. Must be less than or equal to the length of the `b_re/``bcin_re` pipeline.
- **Length of bcout\_im pipeline:** Specifies the length of the pipeline between the `b_im/` `bcin_im` input and the `bcout_im` output port. The pipeline of length 0 removes the register from the `bcout_im` pipeline length. Must be less than or equal to the length of the `b_im/``bcin_im` pipeline.
- **Pipeline c\_re:** Indicates whether the input from the `c_re` port should be registered.
- **Pipeline c\_im:** Indicates whether the input from the `c_im` port should be registered.
- **Pipeline p\_re:** Indicates whether the outputs `p_re` and `pcout_re` should be registered.
- **Pipeline p\_im:** Indicates whether the outputs `p_im` and `pcout_im` should be registered.
- **Pipeline multiplier\_re:** Indicates whether the internal `multiplier_re` should register its output.
- **Pipeline multiplier\_im:** Indicates whether the internal `multiplier_im` should register its output.
- **Pipeline opmode\_re:** Indicates whether the `opmode_re` port should be registered.
- **Pipeline opmode\_im:** Indicates whether the `opmode_im` port should be registered.
- **Pipeline alumode\_re:** Indicates whether the `alumode_re` port should be registered.
- **Pipeline alumode\_im:** Indicates whether the `alumode_im` port should be registered.
- **Pipeline carry in Re:** Indicates whether the `carryin_re` port should be registered.
- **Pipeline carry in Im:** Indicates whether the `carryin_im` port should be registered.
- **Pipeline carry in select Re:** Indicates whether the `carryinsel_re` port should be registered.
- **Pipeline carry in select Im:** Indicates whether the `carryinsel_im` port should be registered.

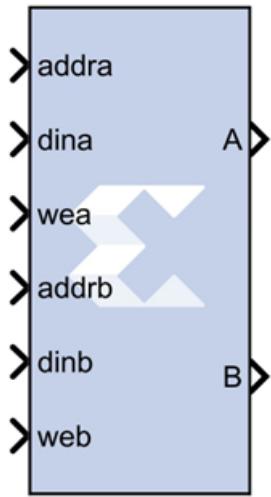
- **Pipeline preadder output register ad:** Indicates to add a pipeline register to the `ad` output.
- **Pipeline Conjugate register A:** Indicates to add a pipeline register to the `Conjugate_A` input.
- **Pipeline Conjugate register B:** Indicates to add a pipeline register to the `Conjugate_B` input.
- **Reset/Enable Ports tab:** Parameters specific to the Reset/Enable tab are as follows:
  - **Provide Reset Ports:**
    - **Reset port for a/acin:** When selected, `rst_a_re` and `rst_a_im` ports are made available. This resets the pipeline registers for port `a_re`, `a_im` when set to '1'.
    - **Reset port for b/bcin:** When selected, `rst_b_re` and `rst_b_im` are made available. This resets the pipeline registers for port `b_re`, `b_im` when set to '1'.
    - **Reset port for c:** When selected, `rst_c_re` and `rst_c_im` are made available. This resets the pipeline registers for port `c_re`, `c_im` when set to '1'.
    - **Reset port for multiplier:** When selected, `rst_m_re` and `rst_m_im` are made available. This resets the pipeline registers for internal multiplier respectively when set to '1'.
    - **Reset port for P:** When selected, `rst_p_re` and `rst_p_im` are made available. This resets the output `p_re` and `p_im` registers when set to '1'.
    - **Reset port for carry in:** When selected, `rst_allcarryin_re` and `rst_allcarryin_im` are made available. This resets the pipeline registers for `carryin_re` and `carryin_im` port when set to '1'.
    - **Reset port for alumode:** When selected, `rst_alumode_re` and `rst_alumode_im` are made available. This resets the pipeline register for the `alumode_re` and `alumode_im` port when set to '1'.
    - **Reset port for controls (opmode and carry\_in\_sel):** When selected, a port `rst_ctrl_re` and `rst_ctrl_im` are made available. This resets the pipeline register for the `opmode_re/opmode_im` register (if available) and the `carryinsel_re/carryinsel_im` register (if available) when set to '1'.
    - **Reset port for ad:** When selected, port `rst_ad` is made available. This resets the pipeline `ad` register for ports when set to '1'.
    - **Reset port for Conjugate\_a:** When selected, port `rst_conjugate_a` is made available. This resets the pipeline register for the `Conjugate_a` port when set to '1'.
    - **Reset port for Conjugate\_b:** When selected, port `rst_conjugate_b` is made available. This resets the pipeline register for the `Conjugate_b` port when set to '1'.
  - **Provide Enable Ports:**

- **Enable port for first a/acin register:** When selected, enable ports `cea1_re` and `cea1_im` for the first `a_re` and `a_im` pipeline register are made available.
  - **Enable port for second a/acin register:** When selected, enable ports `cea2_re` and `cea2_im` for the second `a_re` and `a_im` pipeline registers are made available.
  - **Enable port for first b/bcin register:** When selected, enable ports `ceb1_re` and `ceb1_im` for the first `b_re` and `b_im` pipeline registers are made available.
  - **Enable port for second b/bcin register:** When selected, enable ports `ceb2_re` and `ceb2_im` for the second `b_re` and `b_im` pipeline registers are made available.
  - **Enable port for c:** When selected, enable ports `cec_re` and `cec_im` for the port `C_re` and `C_im` registers are made available.
  - **Enable port for multiplier:** When selected, enable ports `cem_re` and `cem_im` for the Real and Imaginary multiplier registers are made available.
  - **Enable port for p:** When selected, enable ports `cep_re` and `cep_im` for the port `P_re` and `P_im` output registers are made available.
  - **Enable port for carry in:** When selected, enable ports `cecarryin_re` and `cecarryin_im` for the Real and Imaginary carry in registers are made available.
  - **Enable port for alumode:** When selected, enable ports `cealumode_re` and `cealumode_im` for the Real and Imaginary alumode registers are made available.
  - **Enable port for controls (opmode and carry\_in\_sel):** When selected, enable ports `cectrl_re` and `cectrl_im` are made available. The ports `cectrl_re` and `cectrl_im` controls the Real and Imaginary opmode and carry in select registers.
  - **Enable port for ad:** When selected, an `enable` port is created for the preadder output register `ad`.
  - **Enable port for Conjugate\_a:** When selected, an enable port `conjugate_a` is added for the `Conjugate_A` register.
  - **Enable port for Conjugate\_b:** When selected, an enable port `conjugate_b` is added for the `Conjugate_B` register.
- **Inversion Options tab:** When the checkbox is selected on this tab, the specified signal is inverted.
  - **Implementation tab:** Parameters specific to the Implementation tab are as follows.
    - **Use synthesizable model:** When selected, the DSPCPLX is implemented from an RTL description which might not map directly to the DSP58 hardware. This is useful if a design using the DSPCPLX block is targeted at device families that do not contain DSP58 hardware primitives.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Dual Port RAM

The Xilinx Dual Port RAM block implements a random access memory (RAM). Dual ports enable simultaneous access to the memory space at different sample rates using multiple data widths.



### Block Interface

The block has two independent sets of ports for simultaneous reading and writing. Independent address, data, and write enable ports allow shared access to a single memory space. By default, each port set has one output port and three input ports for address, input data, and write enable. Optionally, you can also add a port enable and synchronous reset signal to each input port set.

A dual-port RAM can be implemented using either distributed memory, block RAM, or UltraRAM resources in the FPGA.

#### Form Factors

The Dual Port RAM block also supports various Form Factors (FF). Form factor is defined as:

$$FF = W_B / W_A$$

where  $W_B$  is data width of Port B and  $W_A$  is Data Width of Port A.

The Depth of port B ( $D_B$ ) is inferred from the specified form factor as follows:

$$D_B = D_A / FF$$

The data input ports on Port A and B can have different arithmetic type and binary point position for a form factor of 1. For form factors greater than 1, the data input ports on Port A and Port B should have an unsigned arithmetic type with binary point at 0. The output ports, labeled A and B, have the same types as the corresponding input data ports.

The location in the memory block can be accessed for reading or writing by providing the valid address on each individual address port. A valid address is an unsigned integer from 0 to  $d-1$ , where  $d$  denotes the RAM depth (number of words in the RAM) for the particular port. An attempt to read past the end of the memory is caught as an error in simulation. When the dual-port RAM is implemented in distributed memory or block RAM, the initial RAM contents can be specified through a block parameter. Each write enable port must be a boolean value. When the WE port is 1, the value on the data input is written to the location indicated by the address line.

#### Write Mode

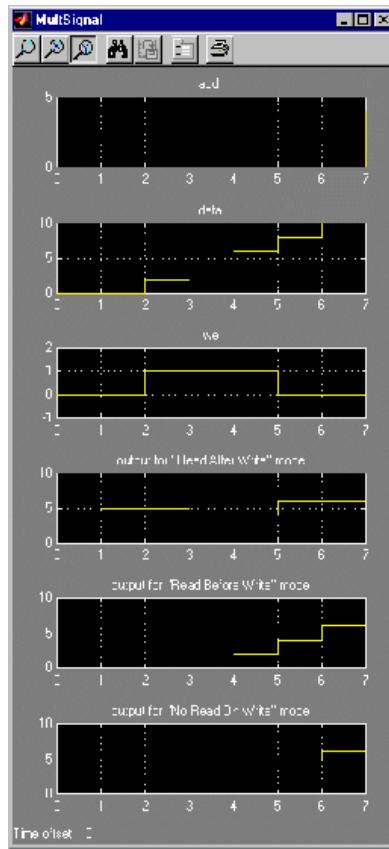
When the Dual Port RAM block is implemented in block RAM, you can set the write mode for the block in the block parameters dialog box.

The output during a write operation depends on the write mode. When the WE is 0, the output port has the value at the location specified by the address line. During a write operation (WE asserted), the data presented on the input data port is stored in memory at the location selected by the port's address input. During a write cycle, you can configure the behavior of each data out port A and B to one of the following choices:

- **Read after write**
- **Read before write**
- **No read on write**

The write modes can be described with the help of the figure below. In the figure, the memory has been set to an initial value of 5 and the address bit is specified as 4. When using **No read on write** mode, the output is unaffected by the address line and the output is the same as the last output when the WE was 0. For the other two modes, the output is obtained from the location specified by the address line, and hence is the value of the location being written to. This means that the output can be the old value which corresponds to **Read after write**.

Figure 281: Write Mode Output



**Collision Behavior:** The result of simultaneous access to both ports is described below.

**Read-Read Collisions:** If both ports read simultaneously from the same memory cell, the read operation is successful.

**Write-Write Collisions:** If both ports try to write simultaneously to the same memory cell, both outputs are marked as invalid (nan).

**Write-Read Collisions:** This collision occurs when one port writes and the other reads from the same memory cell. While the memory contents are not corrupted, the validity of the output data on the read port depends on the Write Mode of the write port.

- If the write port is in **Read before write** mode, the other port can reliably read the old memory contents.
- If the write port is in **Read after write** or **No read on write**, data on the output of the read port is invalid (nan).

You can set the Write Mode of each port using the Advanced tab of the block parameters dialog box.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Depth:** Specifies the number of words in the memory for Port A, which must be a positive integer. The Port B depth is inferred from the form factor specified by the input data widths.
  - **Initial value vector:** For distributed memory or block RAM, specifies the initial memory contents. The size and precision of the elements of the initial value vector are based on the data format specified for Port A. When the vector is longer than the RAM, the vector's trailing elements are discarded. When the RAM is longer than the vector, the RAM's trailing words are set to zero. The initial value vector is saturated and rounded according to the precision specified on the data port A of RAM.

**Note:** UltraRAM memory is initialized to all 0's during power up or device reset. If implemented in UltraRAM, the Single Port RAM block cannot be initialized to user defined values.

- **Memory Type:** Option to select whether the dual port RAM will be implemented in **Distributed memory**, **Block RAM**, or **UltraRAM**. The distributed dual port RAM is always set to use port A in Read Before Write mode and port B in read-only mode.

Depending on your selection for **Memory Type**, the dual-port RAM will be inferred or implemented in this way when the design is compiled:

- If the block will be implemented in **Distributed memory**, the Distributed Memory Generator v8.0 LogiCORE IP will be inferred or implemented when the design is compiled. This LogiCORE IP is described in the *Distributed Memory Generator LogiCORE IP Product Guide* ([PG063](#)).
- If the block will be implemented in block RAM or UltraRAM, the XPM\_MEMORY\_TDPRAM (True Dual Port RAM) macro will be inferred or implemented when the design is compiled. For information on the XPM\_MEMORY\_TDPRAM Xilinx Parameterized Macro (XPM), refer to *UltraScale Architecture Libraries Guide* ([UG974](#)).
- **Initial value for port A output Register:** Specifies the initial value for port A output register. The initial value is saturated and rounded according to the precision specified on the data port A of RAM.
- **Initial value for port B output register:** Specifies the initial value for port B output register. The initial value is saturated and rounded according to the precision specified on the data port B of RAM.
- **Provide synchronous reset port for port A output register:** When selected, allows access to the reset port available on the port A output register of the block RAM or UltraRAM. The reset port is available only when the latency of the Block RAM or UltraRAM is greater than or equal to 1.

- **Provide synchronous reset port for port B output register:** When selected, allows access to the reset port available on the port B output register of the Block RAM or UltraRAM. The reset port is available only when the latency of the Block RAM or UltraRAM is greater than or equal to 1.
- **Provide enable port for port A:** When selected, allows access to the enable port for port A. The enable port is available only when the latency of the block is greater than or equal to 1.
- **Provide enable port for port B:** When selected, allows access to the enable port for port B. The enable port is available only when the latency of the block is greater than or equal to 1.
- **Advanced tab:** Parameters specific to the Advanced tab are as follows.
  - **Write Modes:**
    - **Port A or Port B:** When the Dual Port RAM block is implemented in block RAM, specifies memory behavior for port A or port B when WE is asserted. Supported modes are: **Read after write**, **Read before write**, and **No read on write**. **Read after write** indicates the output value reflects the state of the memory after the write operation. **Read before write** indicates the output value reflects the state of the memory before the write operation. **No read on write** indicates that the output value remains unchanged irrespective of change of address or state of the memory. There are device specific restrictions on the applicability of these modes. Also refer to the Write Mode topic above for more information.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

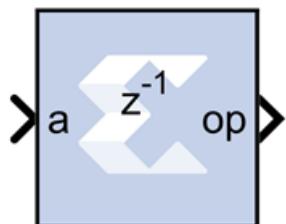
## LogiCORE and XPM Documentation

*Distributed Memory Generator LogiCORE IP Product Guide (PG063)* (Distributed Memory)

*UltraScale Architecture Memory Resources User Guide (UG573)* - XPM\_MEMORY\_TDPRAM Macro (UltraRAM)

## Exponential

This Xilinx Exponential block performs the exponential operation on the input. Currently, only the floating-point data type is supported.



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **AXI Interface:**
    - **Flow Control:**
      - **Blocking:** Selects “Blocking” mode. In this mode, the lack of data on one input channel does block the execution of an operation if data is received on another input channel.
      - **NonBlocking:** Selects “Non-Blocking” mode. In this mode, the lack of data on one input channel does not block the execution of an operation if data is received on another input channel.
    - **Optimize Goal:** When NonBlocking mode is selected, the following optimization options are activated.
      - **Resources:** Block is configured for minimum resources.
      - **Performance:** Block is configured for maximum performance.
  - **Block Memory Usage:**
    - **BMG Usage:**
      - **No Usage:** Do not use Block Memory.
      - **Full Usage:** Make full use of Block Memory.
  - **Latency Specification:**
    - **Latency:** This defines the number of sample periods by which the block's output is delayed.
- **Optional Ports tab:** Parameters specific to the Optional Ports tab are as follows.
  - **Input Channel Ports:**
    - **Has TLAST:** Adds a tlast port to the input channel.
    - **Has TUSER:** Adds a tuser port to the input channel.
  - **Control Options:**
    - **Provide enable port:** Add an enable port to the block interface.
    - **Has Result TREADY:** Add a TREADY port to the result channel.

- **Exception Signals:**
  - **UNDERFLOW:** Add an output port that serves as an underflow flag.
  - **OVERFLOW:** Add an output port that serves as an overflow flag.

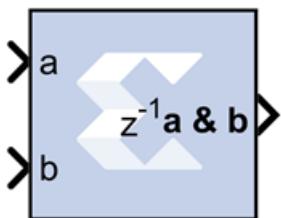
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

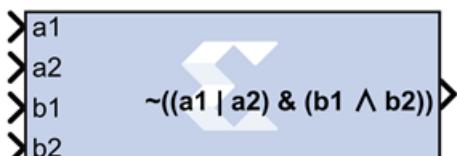
*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

## Expression

The Xilinx Expression block performs a bitwise logical expression.



The expression is specified with operators described in the table below. The number of input ports is inferred from the expression. The input port labels are identified from the expression, and the block is subsequently labeled accordingly. For example, the expression:  $\sim((a1 \mid a2) \& (b1 \wedge b2))$  results in the following block with 4 input ports labeled 'a1', 'a2', 'b1', and 'b2'.



The expression is parsed and an equivalent statement is written in VHDL (or Verilog). Shown below, in decreasing order of precedence, are the operators that can be used in the Expression block.

Operator	Symbol
Precedence	()
NOT	$\sim$
AND	$\&$
OR	$\mid$

Operator	Symbol
XOR	$\wedge$

## Block Parameters

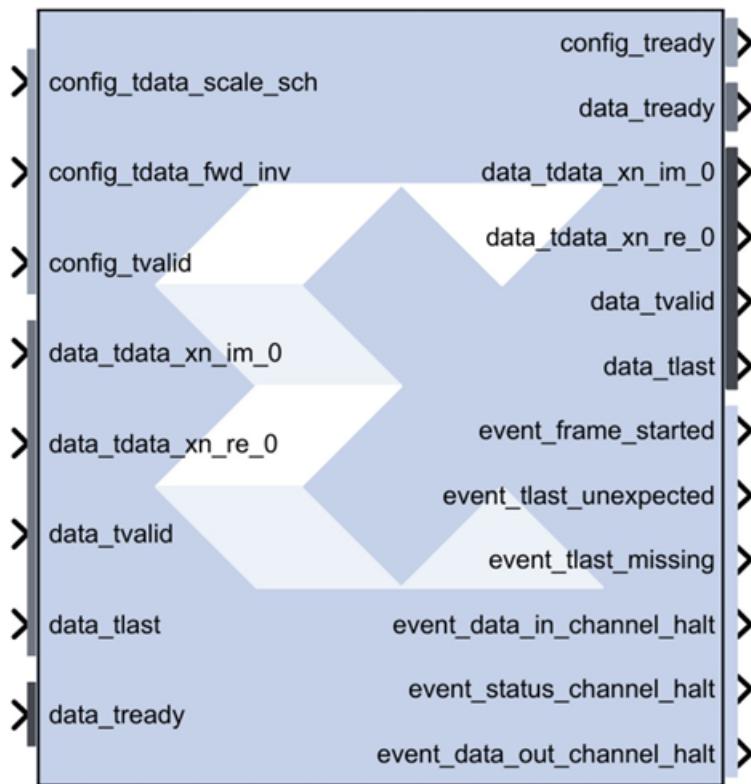
The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Expression:** Bitwise logical expression.
  - **Align Binary Point:** Specifies that the block must align binary points automatically. If not selected, all inputs must have the same binary point position.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Fast Fourier Transform 9.1

The Xilinx Fast Fourier Transform block implements the Cooley-Tukey FFT algorithm, a computationally efficient method for calculating the Discrete Fourier Transform (DFT). In addition, the block provides an AXI4-Stream-compliant interface.



The FFT computes an N-point forward DFT or inverse DFT (IDFT) where,  $N = 2^m$ ,  $m = 3 - 16$ . For fixed-point inputs, the input data is a vector of N complex values represented as dual  $b_x$ -bit two's complement numbers, that is,  $b_x$  bits for each of the real and imaginary components of the data sample, where  $b_x$  is in the range 8 to 34 bit, inclusive. Similarly, the phase factors  $b_w$  can be 8 to 34 bits wide.

For single-precision floating-point inputs, the input data is a vector of N complex values represented as dual 32-bit floating-point numbers with the phase factors represented as 24- or 25-bit fixed-point numbers.

## Theory of Operation

The FFT is a computationally efficient algorithm for computing a Discrete Fourier Transform (DFT) of sample sizes that are a positive integer power of 2. The DFT of a sequence is defined as:

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-jnk2\pi/N} \quad k=0, \dots, N-1$$

where  $N$  is the transform length and  $j$  is the square root of -1. The inverse DFT (IDFT) is defined as:

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) e^{-jnk^2/N} \quad n=0, \dots, N-1$$

### AXI Ports that are Unique to this Block

This System Generator block exposes the AXI CONFIG channel as a group of separate ports based on sub-field names. The sub-field ports are described as follows:

Configuration Channel Input Signals:

<code>config_tdata_scale_sch</code>	A sub-field port that represents the Scaling Schedule field in the Configuration Channel vector. Refer to the document <i>Fast Fourier Transform LogiCORE IP Product Guide</i> ( <a href="#">PG109</a> ) for an explanation of the bits in this field.
<code>config_tdata_fwd_inv</code>	A sub-field port that represents the <b>Forward Inverse</b> field in the Configuration Channel vector. Refer to the document <i>Fast Fourier Transform LogiCORE IP Product Guide</i> ( <a href="#">PG109</a> ) for an explanation of the bits in this field.
<code>config_tdata_nfft</code>	A sub-field port that represents the <b>Transform Size (NFFT)</b> field in the Configuration Channel vector. Refer to the document <i>Fast Fourier Transform LogiCORE IP Product Guide</i> ( <a href="#">PG109</a> ) for an explanation of the bits in this field.
<code>config_tdata_cp_len</code>	A sub-field port that represents the <b>Cyclic Prefix Length (CP_LEN)</b> field in the Configuration Channel vector. Refer to the document <i>Fast Fourier Transform LogiCORE IP Product Guide</i> ( <a href="#">PG109</a> ) for an explanation of the bits in this field.

This HDL block exposes the AXI DATA channel as separate ports based on the real and imaginary sub-field names. The sub-field ports are described as follows:

DATA Channel Input Signals:

<code>data_tdata_xn_im</code>	Represents the imaginary component of the Data Channel. The signal driving <code>xn_im</code> can be a signed data type of width S with binary point at S-1, where S is a value between 8 and 34, inclusive. eg: Fix_8_7, Fix_34_33. Both <code>xn_re</code> and <code>xn_im</code> signals must have the same data type. Refer to the document <i>Fast Fourier Transform LogiCORE IP Product Guide</i> ( <a href="#">PG109</a> ) for an explanation of the bits in this field.
<code>data_tdata_xn_re</code>	Represents the real component of the Data Channel. The signal driving <code>xn_re</code> can be a signed data type of width S with binary point at S-1, where S is a value between 8 and 34, inclusive. eg: Fix_8_7, Fix_34_33. Both <code>xn_re</code> and <code>xn_im</code> signals must have the same data type. Refer to the document <i>Fast Fourier Transform LogiCORE IP Product Guide</i> ( <a href="#">PG109</a> ) for an explanation of the bits in this field.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to the Basic tab are as follows.

- **Transform Length:**

- **Transform\_length:** One of  $N = 2^{(3..16)} = 8 - 65536$ .

- **Architecture Configuration:**

- **Target Clock Frequency(MHz):** Enter the target clock frequency.

- **Target Data Throughput(MSPS):** Enter the target throughput.

- **Architecture Choice:** Choose one of the following.

- `automatically_select`
    - `pipelined_streaming_io`
    - `radix_4_burst_io`
    - `radix_2_burst_io`
    - `radix_2_lite_burst_io`

- **Transform Length Options:**

- **Run Time Configurable Transform Length:** The transform length can be set through the `nfft` port if this option is selected. Valid settings and the corresponding transform sizes are provided in the section titled **Transform Size** in the associated document *Fast Fourier Transform LogiCORE IP Product Guide* ([PG109](#)).

- **Advanced tab:** Parameters specific to the Advanced tab are as follows.

- **Precision Options:**

- **Phase Factor Width:** Choose a value between 8 and 34, inclusive to be used as bit widths for phase factors.

- **Scaling Options:** Select between **Unscaled**, **Scaled**, and **Block Floating Point** output data types.

- **Rounding Modes:**

- **Truncation:** To be applied at the output of each rank.

- **Convergent Rounding:** To be applied at the output of each rank.

- **Control Signals:**

- **ACLKEN:** Enables the clock enable (aclken) pin on the core. All registers in the core are enabled by this control signal.
- **ARESETn:** Active-low synchronous clear input that always takes priority over ACLKEN. A minimum ARESETn active pulse of two cycles is required, since the signal is internally registered for performance. A pulse of one cycle resets the core, but the response to the pulse is not in the cycle immediately following.

- **Output Ordering:**

- **Cyclic Prefix Insertion:**

Cyclic prefix insertion takes a section of the output of the FFT and prefixes it to the beginning of the transform. The resultant output data consists of the cyclic prefix (a copy of the end of the output data) followed by the complete output data, all in natural order. Cyclic prefix insertion is only available when output ordering is Natural Order.

When cyclic prefix insertion is used, the length of the cyclic prefix can be set frame-by-frame without interrupting frame processing. The cyclic prefix length can be any number of samples from zero to one less than the point size. The cyclic prefix length is set by the CP\_LEN field in the Configuration channel. For example, when N = 1024, the cyclic prefix length can be from 0 to 1023 samples, and a CP\_LEN value of 0010010110 produces a cyclic prefix consisting of the last 150 samples of the output data.

- **Output ordering:** Choose between **Bit/Digit Reversed Order** or **Natural Order** output.
- **Throttle Schemes:** Select the tradeoff between performance and data timing requirements.

- **Real Time:** This mode typically gives a smaller and faster design, but has strict constraints on when data must be provided and consumed.
  - **Non Real Time:** This mode has no such constraints, but the design might be larger and slower.

- **Optional Output Fields:**

- **XK\_INDEX:** The XK\_INDEX field (if present in the Data Output channel) gives the sample number of the XK\_RE/XK\_IM data being presented at the same time. In the case of natural order outputs, XK\_INDEX increments from 0 to (point size) -1. When bit reversed outputs are used, XK\_INDEX covers the same range of numbers, but in a bit (or digit) reversed manner.

- **OVFLO:**

The Overflow (OVFLO) field in the Data Output and Status channels is only available when the Scaled arithmetic is used. OVFLO is driven High during unloading if any point in the data frame overflowed.

For a multichannel core, there is a separate OVFL0 field for each channel. When an overflow occurs in the core, the data is wrapped rather than saturated, resulting in the transformed data becoming unusable for most applications.

- **Block Icon Display:**
  - **Display shortened port names:** On by default. When unchecked, **data\_tvalid**, for example, becomes **m\_axis\_data\_tvalid**.
- **Implementation tab:** Parameters specific to the Implementation tab are as follows.
  - **Memory Options:**
    - **Data:** Option to choose between **Block RAM** and **Distributed RAM**. This option is available only for sample points 8 through 1024. This option is not available for Pipelined Streaming I/O implementation.
    - **Phase Factors:** Choose between **Block RAM** and **Distributed RAM**. This option is available only for sample points 8 till 1024. This option is not available for Pipelined Streaming I/O implementation.
    - **Number Of Stages Using Block RAM:** Store data and phase factor in **Block RAM** and partially in **Distributed RAM**. This option is available only for the Pipelined Streaming I/O implementation.
    - **Reorder Buffer:** Choose between **Block RAM** and **Distributed RAM** up to 1024 points transform size.
    - **Hybrid Memories:** Click check box to **Optimize Block RAM Count Using Hybrid Memories**.
  - **Optimize Options:**
    - **Complex Multipliers:** Choose one of the following.
      - Use CLB logic
      - Use 3-multiplier structure (resource optimization)
      - Use 4-multiplier structure (performance optimization)
    - **Butterfly Arithmetic:** Choose one of the following:
      - Use CLB logic
      - Use XTremeDSP Slices

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Block Timing

To better understand the FFT blocks control behavior and timing, please consult the core data sheet.

## LogiCORE Documentation

*Fast Fourier Transform LogiCORE IP Product Guide (PG109)*

*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

## FDATool

The Xilinx FDATool block provides an interface to the FDATool software available as part of the MATLAB® Signal Processing Toolbox.



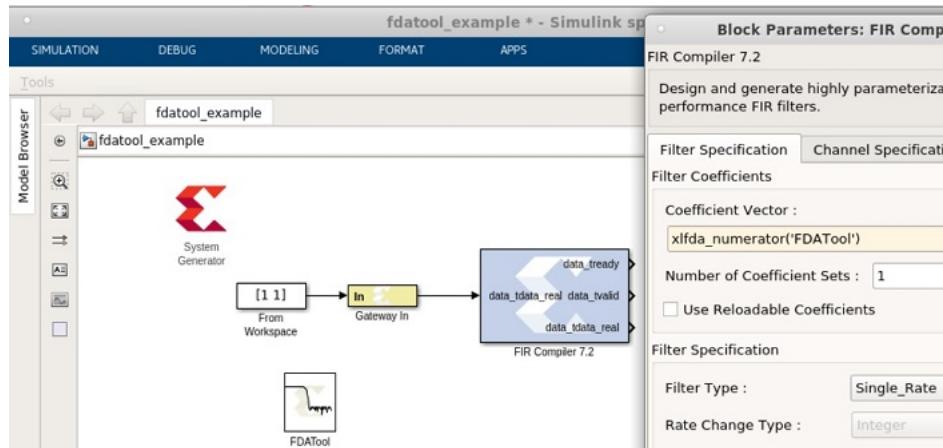
The block does not function properly and should not be used if the Signal Processing Toolbox is not installed. This block provides a means of defining an FDATool object and storing it as part of a Model Composer model. FDATool provides a powerful means for defining digital filters with a graphical user interface.

### Example of Use

Copy an FDATool block into a Subsystem where you would like to define a filter. Double-clicking the block icon opens up an FDATool session and graphical user interface. The filter is stored in an data structure internal to the FDATool interface block, and the coefficients can be extracted using MATLAB® helper functions provided as part of Model Composer. The function call `xlfda_numerator('FDATool')` returns the numerator of the transfer function (e.g., the impulse response of a finite impulse response filter) of the FDATool block named 'FDATool'. Similarly, the helper function `xlfda_denominator('FDATool')` retrieves the denominator for a non-FIR filter.

A typical use of the FDATool block is as a companion to an FIR filter block, where the Coefficients field of the filter block is set to `xlfda_numerator('FDATool')`. An example is shown in the following diagram:

Figure 282: FDATool Example



Note that `xlfda_numerator()` can equally well be used to initialize a memory block or a 'coefficient' variable for a masked Subsystem containing an FIR filter.

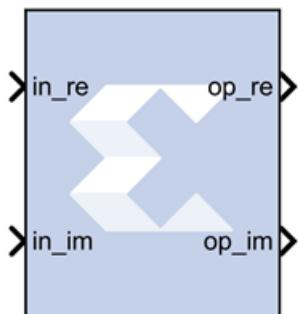
This block does not use any hardware resources.

### FDATool Interface

Double-clicking the icon in your Simulink model opens up an FDATool session and its graphical user interface. Upon closing the FDATool session, the underlying FDATool object is stored in the `UserParam` parameter of the Xilinx FDATool block. Use the `xlfda_numerator()` helper function and `get_param()` to extract information from the object as desired.

## FFT

The Xilinx FFT (Fast Fourier Transform) block takes a block of time domain waveform data and computes the frequency of the sinusoid signals that make up the waveform.



FFT is a fast implementation of the discrete Fourier transform. The data of the time domain signal is sampled at discrete intervals. The sampling frequency is twice the maximum frequency that can be resolved by the FFT, based on the Nyquist theorem. If a signal is sampled at 1 kHz, the highest frequency that can be resolved by the FFT is 500 Hz.

$$f_s = f_{\max}/2$$

where  $f_{\max}$  = maximum resolvable frequency and  $f_s$  = sampling frequency.

The duration of the data sample is inversely proportional to the frequency resolution of the FFT. The longer the sample duration, the higher the number of data points, and the finer the frequency resolution. If a signal sampled at  $f_s$  for twice the duration, the difference between successive frequency  $d_f$  is halved, resulting in an FFT with finer frequency resolution.

$$d_f = 1/T$$

where  $d_f$  = frequency resolution of the FFT, and  $T$  = total sampling time.

The number of samples taken over time  $T$  is  $N$ , so sampling frequency is  $N/T$  samples/sec.

## Description

FFT is a computationally efficient implementation of the Discrete Fourier Transform (DFT). A DFT is a collection of data points detailing the correlation between the time domain signal and sinusoids at discrete frequencies.

The DFT is defined by the following equation:

$$X(k) = \sum_{n=0}^{N-1} x[n] e^{-j \frac{2\pi}{N} nk} \text{ for } k=0,1,2, \dots, N-1$$

where  $N$  is the transform length,  $k$  is used to denote the frequency domain ordinal, and  $n$  is used to represent the time-domain ordinal.

The FFT block is ideal for implementing simple Fourier transforms. If your FFT implementation will use more complicated transform features such as an AXI4-Stream-compliant interface, a real time throttle scheme, Radix-4 Burst I/O, or Radix-2 Lite Burst I/O, use the Xilinx [Fast Fourier Transform 9.1](#) block in your design instead of the FFT block.

In the Vivado® design flow, the FFT block is inferred as "LogiCORE IP Fast Fourier Transform v9.1" for code generation. Refer to the document [LogiCORE IP Fast Fourier Transform v9.1](#) for details on this LogicCore IP.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Parameters specific to the Xilinx FFT block are as follows.

- **Transform Length:** Select the desired point size ranging from 8 to 65536.
- **Scale Result by FFT length:** If selected, data is scaled between FFT stages using a scaling schedule determined by the **Transform Length** setting. If not selected, data is unscaled, and all integer bit growth is carried to the output.
- **Natural Order:** If selected, the output of the FFT block will be ordered in natural order. If not selected, the output of the FFT block will be ordered in bit/digit reversed order.
- **Optimize for:** Directs the block to be optimized for either speed (**Performance**) or area (**Resources**) in the generated hardware.

**Note:** If **Resources** is selected and the input sample period is 8 times slower than the system sample period, the block implements Radix-2 Burst I/O architecture. Otherwise, Pipeline Streaming I/O architecture will be used.

- **Optional Port:**

- **Provide start frame port:** Adds `start_frame_in` and `start_frame_out` ports to the block. The signals on these ports can be used to synchronize frames at the input and output of the FFT block. See [Adding Start Frame Ports to Synchronize Frames](#) for a description of the operation of these two ports.

## Context Based Pipeline vs. Radix Implementation

Pipelined Streaming I/O and Radix-2 Burst I/O architectures are supported by the FFT block. Radix-4 Burst I/O architecture is implemented when you select **Optimize for: Resources** block parameter and the sample rate of the inputs is 8 times slower than the system rate. In all other configurations Pipelined Streaming I/O architecture is implemented by default.

## Input Data Type Support

The FFT block accepts inputs of varying bit widths with changeable binary point location, such as `Fix_16_0` or `Fix_30_10`, etc. in unscaled block configuration. For the scaled configuration, the input is supported in the same format as the [Fast Fourier Transform 9.1](#) block. The [Fast Fourier Transform 9.1](#) block accepts input values only in the normalized form in the format of `Fix_x_[x-1]` (for example, `Fix_16_15`), so the inputs are 2's complement with a single sign/integer bit.

## Latency Value Displayed on the Block

The latency value depends on parameters selected by the user, and the corresponding latency value is displayed on the FFT block icon in the Simulink model.

## Automatic Fixed Point and Floating Point Support

Signed fixed point and floating point data types are supported.

For floating point input, either scaled or unscaled data can be selected in the FFT block parameters. In the [Fast Fourier Transform 9.1](#) block, the floating point data type is accepted only when the scaled configuration is selected by the user.

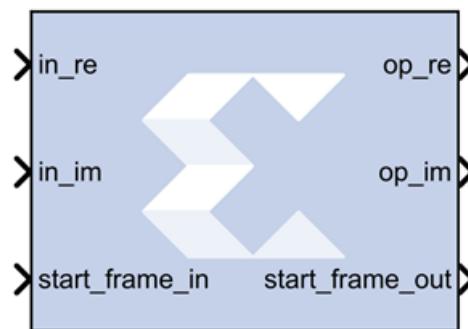
## Handling Overflow for Scaled Configuration

The FFT block uses a conservative schedule to avoid overflow scenarios. This schedule sets the scaling value for the corresponding FFT stages in a way that makes sure no overflow occurs.

## Adding Start Frame Ports to Synchronize Frames

Selecting **Provide start frame port** in the FFT block properties dialog box adds `start_frame_in` and `start_frame_out` ports at the input and output of the FFT block. These ports are used to synchronize frames at the input and output of the FFT block.

*Figure 283: Adding Start Frame Ports*



You must provide a valid input at the `start_frame_in` port. When the `start_frame_in` signal is asserted, an impulse is generated at the start of every frame to signal the FFT block to start processing the frame. The frame size is the **Transform Length** entered in the block parameters dialog box.

The `start_frame_out` port provides the information as to when the output frames start. An impulse at the start of every frame on the output side helps in tracking the block behavior.

The FFT block has a frame alignment requirement and these ports help the block operate in accordance with this requirement.

The figure below shows that as soon as the output is processed by the FFT block the `start_frame_out` signal becomes High (1).

Figure 284: Output

re_data_out	000280	000000	000280
img_data_out	000280	000000	000280
start_frame_out	1	0	1

The following apply to the **Provide start frame port** option and the start frame ports added to the FFT block when the option is enabled:

- The **Provide start frame port** option selection is valid only for Pipelined Streaming I/O architecture. See [Context Based Pipeline vs. Radix Implementation](#) for a description of the conditions under which Pipelined Streaming I/O architecture is implemented.
- The option is valid only for input of type fixed point.
- Verilog is supported for netlist generation currently, when the **Provide start frame port** option is selected.

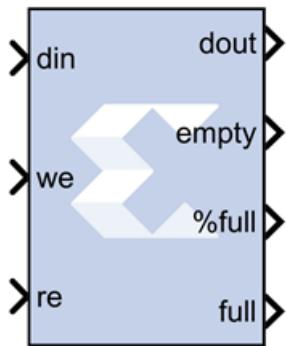
**Note:** The first sample input to the FFT block may be ignored and users are advised to drive the input data accordingly.

## LogiCORE Documentation

[LogiCORE IP Fast Fourier Transform v9.1](#)

## FIFO

The Xilinx FIFO block implements an FIFO memory queue.



Values presented at the module's data-input port are written to the next available empty memory location when the write-enable input is one. By asserting the read-enable input port, data can be read out of the FIFO using the data output port (`dout`) in the order in which they were written. The FIFO can be implemented using block RAM, distributed RAM, SRL, or built-in FIFO.

The `full` output port is asserted to one when no unused locations remain in the module's internal memory. The `percent_full` output port indicates the percentage of the FIFO that is full, represented with user-specified precision. When the `empty` output port is asserted the FIFO is empty.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows.

- **FIFO Implementation:**

- **Memory Type:**

This block implements FIFOs built from block RAM, distributed RAM, shift registers, or the 7 series built-in FIFOs. Memory primitives are arranged in an optimal configuration based on the selected width and depth of the FIFO. The following table provides best-use recommendations for specific design requirements.

*Table 63: Memory Type*

	Independent Clocks	Common Clock	Small Buffering	Medium-Large Buffering	High Performance	Minimal Resources
7 series, with Built-In FIFO	X	X		X	X	X
Block RAM	X	X		X	X	X
Shift Register		X	X		X	
Distributed RAM	X	X	X		X	

- **Performance Options:**

- **Standard FIFO:** FIFO will operate in Standard Mode.
- **First Word Fall Through:** FIFO will operate in First-Word Fall-Through (FWFT) mode. The First-Word Fall-Through feature provides the ability to look-ahead to the next word available from the FIFO without issuing a read operation. When data is available in the FIFO, the first word falls through the FIFO and appears automatically on the output. FWFT is useful in applications that require low-latency access to data and to applications that require throttling based on the contents of the data that are read. FWFT support is included in FIFOs created with block RAM, distributed RAM, or built-in FIFOs in 7 series devices.

- **Implementation Options:**

- **Use Embedded Registers (when possible):** In 7 series FPGA block RAM and FIFO macros, embedded output registers are available to increase performance and add a pipeline register to the macros. This feature can be leveraged to add one additional cycle of latency to the FIFO core (DOUT bus and VALID outputs) or implement the output registers for FWFT FIFOs. The embedded registers available in 7 series FPGAs can be reset (DOUT) to a default or user programmed value for common clock built-in FIFOs. See the topic 'Embedded Registers in block RAM and FIFO Macros' in the *FIFO Generator LogiCORE IP Product Guide* ([PG057](#)).
- **Depth:** Specifies the number of words that can be stored. Range 16-4M.
- **Specify custom dout width:** Allows specification of asymmetric data widths for input and output. When this option is enabled, the input `din` must be of type Unsigned int.
  - **Dout Width:** Specifies the custom width of `dout`. The default value is 32. The ratio between width of `din` and `dout` should be one of 1:1, 1:2, 1:4, 1:8, 2:1, 4:1, or 8:1.

For example, if the width of the `din` is 32. Then the `dout` can be 4, 8, 16, 32, 64, 128, or 256.



**IMPORTANT!** Asymmetric data-widths are supported only for Versal devices with Block RAM configuration.

---



**IMPORTANT!** The total size of the memory (depth\*width) should not exceed 150M.

---

- **Bits of precision to use for %full signal:** Specifies the bit width of the %full port. The binary point for this unsigned output is always at the top of the word. Thus, if for example precision is set to one, the output can take two values: 0.0 and 0.5, the latter indicating the FIFO is at least 50% full.

- **Optional Ports:**

- **Provide reset port:** Add a reset port to the block.

- **Reset Latency:** Creates a latency on the reset by adding registers. The default is 1.

**Note:** For UltraScale™ devices, after the reset gets asserted, the FIFO will remain disable for the next 20 cycles. During this 20 cycle period, all read and write operations are ignored.

- **Provide enable port:** Add enable port to the block.

- **Provide data count port:** Add data count port to the block. Provides the number of words in the FIFO.

- **Provide percent full port:** Add a percent full output port to the block. Indicates the percentage of the FIFO that is full using the user-specified precision. This optional port is turned on by default for backward compatibility reasons.

- **Provide almost empty port:** Add almost empty (ae) port to the block.
- **Provide almost full port:** Add almost efull (af) port to the block.

Following are some general guidelines to use Reset, Write enable, Read enable for the 'built-in FIFO' Memory type:

- **7 series devices:** Without Reset port, it is required to run at least 8 clock cycles latency before asserting WE/RE signals. With Reset port, it is required to run Reset signal ON for at least three clock cycles. During this time no WE or RE signals should be asserted. To be consistent across all built-in FIFO configurations, it is recommended to give reset pulse of at least five clock cycles.

After Reset de-assertion, run at least 30 clock cycles (reset duration +30 clock cycles duration is defined as a no access zone) before asserting WE/RE signals.

- **UltraScale devices:** The built-in FIFO requires a reset pulse of at least one clock cycle.
- **Versal Devices:** Read enable (`rd_en`) and Write enable (`wr_en`) signals can be made high only when `rd_rst_busy` and `wr_rst_busy` signals are low.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

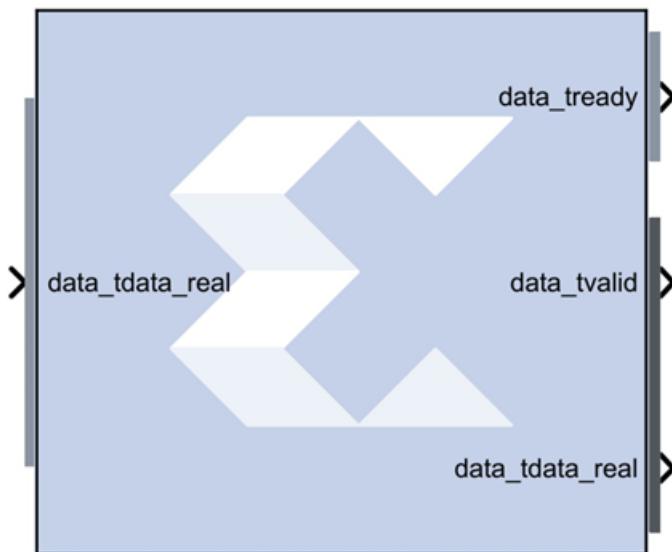
## LogiCORE Documentation

*FIFO Generator LogiCORE IP Product Guide (PG057)*

*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

## FIR Compiler 7.2

The Xilinx FIR Compiler block provides users with a way to generate highly parameterizable, area-efficient, high-performance FIR filters with an AXI4-Stream-compliant interface.



### AXI Ports that are Unique to this Block

This block exposes the AXI CONFIG channel as a group of separate ports based on sub-field names. The sub-field ports are described as follows:

Configuration Channel Input Signals:

config_tdata_fsel	A sub-field port that represents the <b>fsel</b> field in the Configuration Channel vector. <b>fsel</b> is used to select the active filter set. This port is exposed when the number of coefficient sets is greater than one. Refer to the <a href="#">FIR Compiler V7.2 Product Guide</a> for an explanation of the bits in this field.
-------------------	---

### Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Filter Specification tab:**

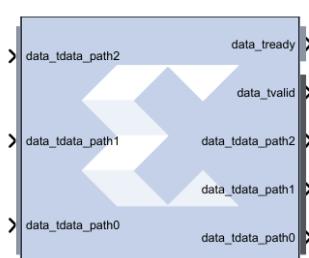
Parameters specific to the Filter Specification tab are as follows.

- **Filter Coefficients:**

- **Coefficient Vector:** Specifies the coefficient vector as a single MATLAB® row vector. The number of taps is inferred from the length of the MATLAB® row vector. If multiple coefficient sets are specified, then each set is appended to the previous set in the vector. It is possible to enter these coefficients using the [FDATool](#) block as well.
    - **Number of Coefficients Sets:** The number of sets of filter coefficients to be implemented. The value specified must divide without remainder into the number of coefficients.

- **Use Reloadable Coefficients:** Check to add the coefficient reload ports to the block. The set of data loaded into the reload channel will not take action until triggered by a re-configuration synchronization event. Refer to the [FIR Compiler V7.2 Product Guide](#) for a more detailed explanation of the RELOAD Channel interface timing. This block supports the `xlGetReloadOrder` function. See the Model Composer Utility function `xlGetReloadOrder` for details.
- **Filter Specification:**
  - **Filter Type:**
    - **Single\_Rate:** The data rate of the input and the output are the same.
    - **Interpolation:** The data rate of the output is faster than the input by a factor specified by the Interpolation Rate Value.
    - **Decimation:** The data rate of the output is slower than the input by a factor specified in the Decimation Rate Value.
    - **Hilbert:** Filter uses the Hilbert Transform.
    - **Interpolated:** An interpolated FIR filter has a similar architecture to a conventional FIR filter, but with the unit delay operator replaced by  $k-1$  units of delay.  $k$  is referred to as the zero-packing factor. The interpolated FIR should not be confused with an interpolation filter. Interpolated filters are single-rate systems employed to produce efficient realizations of narrow-band filters and, with some minor enhancements, wide-band filters can be accommodated. The data rate of the input and the output are the same.
  - **Rate Change Type:** This field is applicable to Interpolation and Decimation filter types. Used to specify an **Integer** or **Fixed\_Fractional** rate change.
  - **Interpolation Rate Value:** This field is applicable to all Interpolation filter types and Decimation filter types for Fractional Rate Change implementations. The value provided in this field defines the up-sampling factor, or  $P$  for Fixed Fractional Rate ( $P/Q$ ) resampling filter implementations.
  - **Decimation Rate Value:** This field is applicable to the all Decimation and Interpolation filter types for Fractional Rate Change implementations. The value provided in this field defines the down-sampling factor, or  $Q$  for Fixed Fractional Rate ( $P/Q$ ) resampling filter implementations.
- **Channel Specification tab:** Parameters specific to the Channel Specification tab are as follows.
  - **Interleaved Channel Specification:**
    - **Channel Sequence:** Select Basic or Advanced. See the [FIR Compiler LogiCORE IP Product Guide \(PG149\)](#) for an explanation of the advanced channel specification feature.

- **Number of Channels:** The number of data channels to be processed by the FIR Compiler block. The multiple channel data is passed to the core in a time-multiplexed manner. A maximum of 64 channels is supported.
- **Sequence ID List:** A comma delimited list that specifies which channel sequences are implemented.
- **Parallel Channel Specification:**
  - **Number of Paths:** Specifies the number of parallel data paths the filter is to process. As shown below, when more than one path is specified, the data\_tdata input port is divided into sub-ports that represent each parallel path.



- **Hardware Oversampling Specification:**
  - **Select format:**
    - **Maximum\_Possible:** Specifies that oversampling be automatically determined based on the din sample rate.
    - **Input\_Sample\_Period/Output\_Sample\_Period:** Activates the Sample period. Enter the Sample Period specification. Selecting this option exposes the s\_axis\_data\_tvalid port (called ND port on earlier versions of the core). With this port exposed, no input handshake abstraction and no rate-propagation takes place.
    - **Hardware Oversampling Rate:** Activates the Hardware Oversampling Rate. Enter the Hardware Oversampling Rate specification below.
  - **Hardware Oversampling Rate:** The hardware oversampling rate determines the degree of parallelism. A rate of one produces a fully parallel filter. A rate of n (resp., n+1) for an n-bit input signal produces a fully serial implementation for a non-symmetric (resp., symmetric) impulse response. Intermediate values produce implementations with intermediate levels of parallelism.
  - **Implementation tab:** Parameters specific to the Implementation tab are as follows.
    - **Coefficient Options:**
      - **Coefficient Type:** Specify Signed or Unsigned.
      - **Quantization:** Specifies the quantization method to be used for quantizing the coefficients. This can be set to one of the following:

- Integer\_Coefficients
  - Quantize\_Only
  - Maximize\_Dynamic\_Range
  - Normalize\_to\_Centre\_Coefficient
- **Coefficient Width:** Specifies the number of bits used to represent the coefficients.
  - **Best Precision Fractional Bits:** When selected, the coefficient fractional width is automatically set to maximize the precision of the specified filter coefficients.
  - **Coefficient Fractional Bits:** Specifies the binary point location in the coefficients datapath options.
  - **Coefficients Structure:** Specifies the coefficient structure. Depending on the coefficient structure, optimizations are made in the core to reduce the amount of hardware required to implement a particular filter configuration. The selected structure can be any of the following.
    - Inferred
    - Non-Symmetric
    - Symmetric
    - Negative\_Symmetric
    - Half\_Band
    - Hilbert

The vector of coefficients specified must match the structure specified unless Inferred from coefficients is selected in which case the structure is determined automatically from these coefficients.

- **Datapath Options:**

- **Output Rounding Mode:** Choose one of the following.
  - Full\_Precision
  - Truncate\_LSBs
  - Non\_Symmetric\_Rounding\_Down
  - Non\_Symmetric\_Rounding\_Up
  - Symmetric\_Rounding\_to\_Zero
  - Symmetric\_Rounding\_to\_Infinity
  - Convergent\_Rounding\_to\_Even
  - Convergent\_Rounding\_to\_Odd

- **Output Width:** Specify the output width. Edit box activated only if the Rounding mode is set to a value other than Full\_Precision.
  - **Detailed Implementation tab:** Parameters specific to the Detailed Implementation tab are as follows.
    - **Filter Architecture:** The following two filter architectures are supported.
      - Systolic\_Multiply\_Accumulate
      - Transpose\_Multiply\_Accumulate
- Note:** When selecting the Transpose Multiply-Accumulate architecture, these limitations apply:
- Symmetry is not exploited. If the **Coefficient Vector** specified on the Filter Specification tab is detected as symmetric, the FIR Compiler 7.2 block parameters dialog box will not allow you to select Transpose Multiply Accumulate.
  - Multiple interleaved channels are not supported.

- **Optimization Options:**

Specifies if the core is required to operate at maximum possible speed (“Speed” option) or minimum area (“Area” option). The “Area” option is the recommended default and will normally achieve the best speed and area for the design, however in certain configurations, the “Speed” setting might be required to improve performance at the expense of overall resource usage (this setting normally adds pipeline registers in critical paths).

- **Goal:**
  - Area
  - Speed
  - Custom
- **List:** A comma delimited list that specifies which optimizations are implemented by the block. The optimizations are as follows.
  - **Data\_Path\_Fanout:** Adds additional pipeline registers on the data memory outputs to minimize fan-out. Useful when implementing large data width filters requiring multiple DSP slices per multiply-add unit.
  - **Pre-Adder\_Pipeline:** Pipelines the pre-adder when implemented using fabric resources. This may occur when a large coefficient width is specified.
  - **Coefficient\_Fanout:** Adds additional pipeline registers on the coefficient memory outputs to minimize fan-out. Useful for Parallel channels or large coefficient width filters requiring multiple DSP slices per multiply-add unit.
  - **Control\_Path\_Fanout:** Adds additional pipeline registers to control logic when Parallel channels have been specified.

- **Control\_Column\_Fanout:** Adds additional pipeline registers to control logic when multiple DSP columns are required to implement the filter.
- **Control\_Broadcast\_Fanout:** Adds additional pipeline registers to control logic for fully parallel (one clock cycle per channel per input sample) symmetric filter implementations.
- **Control\_LUT\_Pipeline:** Pipelines the Look-up tables required to implement the control logic for Advanced Channel sequences.
- **No\_BRAM\_Read\_First\_Mode:** Specifies that Block RAM READ-FIRST mode should not be used.
- **Increased speed:** Multiple DSP slice columns are required for non-symmetric filter implementations.
- **Other:** Miscellaneous optimizations.

**Note:** All optimizations may be specified but are only implemented when relevant to the core configuration.

- **Memory Options:** The memory type for MAC implementations can either be user-selected or chosen automatically to suit the best implementation options. Note that a choice of "Distributed" might result in a shift register implementation where appropriate to the filter structure. Forcing the RAM selection to be either Block or Distributed should be used with caution, as inappropriate use can lead to inefficient resource usage - the default Automatic mode is recommended for most applications.
  - **Data Buffer Type:** Specifies the type of memory used to store data samples.
  - **Coefficient Buffer Type:** Specifies the type of memory used to store the coefficients.
  - **Input Buffer Type:** Specifies the type of memory to be used to implement the data input buffer, where present.
  - **Output Buffer type:** Specifies the type of memory to be used to implement the data output buffer, where present.
  - **Preference for other storage:** Specifies the type of memory to be used to implement general storage in the datapath.
- **DSP Slice Column Options:**
  - **Multi-Column Support:** For device families with DSP slices, implementations of large high speed filters might require chaining of DSP slice elements across multiple columns. Where applicable (the feature is only enabled for multi-column devices), you can select the method of folding the filter structure across the multiple-columns, which can be Automatic (based on the selected device for the project) or Custom (you select the length of the first and subsequent columns).
  - **Column Configuration:** Specifies the individual column lengths in a comma delimited list. (See the data sheet for a more detailed explanation.)

- **Inter-Column Pipe Length:** Pipeline stages are required to connect between the columns, with the level of pipelining required being depending on the required system clock rate, the chosen device and other system-level parameters. The choice of this parameter is always left for you to specify.
- **Interface tab:**
  - **Data Channel Options:**
    - **TLAST:** TLAST can either be Not\_Required, in which case the block will not have the port, or Vector\_Framing, where TLAST is expected to denote the last sample of an interleaved cycle of data channels, or Packet\_Framing, where the block does not interpret TLAST, but passes the signal to the output DATA channel TLAST with the same latency as the datapath.
    - **Output TREADY:** This field enables the `data_tready` port. With this port enabled, the block will support back-pressure. Without the port, back-pressure is not supported, but resources are saved and performance is likely to be higher.
    - **Input FIFO:** Selects a FIFO interface for the S\_AXIS\_DATA channel. When the FIFO has been selected, data can be transferred in a continuous burst up to the size of the FIFO (default 16) or, if greater, the number of interleaved data channels. The FIFO requires additional FPGA logic resources.
    - **TUSER:** Select one of the following options for the Input and the Output.
      - **Not\_Required:** Neither of the uses is required; the channel in question will not have a TUSER field.
      - **User\_Field:** In this mode, the block ignores the content of the TUSER field, but passes the content untouched from the input channel to the output channels.
      - **Chan\_ID\_Field:** In this mode, the TUSER field identifies the time-division-multiplexed channel for the transfer.
      - **User and Chan\_ID\_Field:** In this mode, the TUSER field will have both a user field and a chan\_id field, with the chan\_id field in the least significant bits. The minimal number of bits required to describe the channel will determine the width of the chan\_id field, e.g. 7 channels will require 3 bits.
- **Configuration Channel Options:**
  - **Synchronization Mode:**
    - **On\_Vector:** Configuration packets, when available, are consumed and their contents applied when the first sample of an interleaved data channel sequence is processed by the block. When the block is configured to process a single data channel configuration packets are consumed every processing cycle of the block.

- **On\_Packet:** Further qualifies the consumption of configuration packets. Packets will only be consumed once the block has received a transaction on the s\_axis\_data channel where s\_axis\_data\_tlast has been asserted.
- **Configuration Method:**
  - **Single:** A single coefficient set is used to process all interleaved data channels.
  - **By\_Channel:** A unique coefficient set is specified for each interleaved data channel.
- **Reload Channel Options:**
  - **Reload Slots:** Specifies the number of coefficient sets that can be loaded in advance. Reloaded coefficients are only applied to the block once the configuration packet has been consumed (Range 1 to 256).
- **Control Options:**
  - **ACLKEN:** Active-high clock enable. Available for MAC-based FIR implementations.
  - **ARESETn (active low):** Active-low synchronous clear input that always takes priority over ACLKEN. A minimum ARESETn active pulse of two cycles is required, since the signal is internally registered for performance. A pulse of one cycle resets the control and datapath of the core, but the response to the pulse is not in the cycle immediately following.
- **Advanced tab:**
  - **Block Icon Display:**
    - **Display shortened port names:**

On by default. When unchecked, data\_tvalid, for example, becomes m\_axis\_data\_tvalid.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

*FIR Compiler LogiCORE IP Product Guide (PG149)*

## Gateway In

The Xilinx Gateway In blocks are the inputs into the HDL portion of your Simulink® design. These blocks convert Simulink® integer, double, and fixed-point data types into the Model Composer fixed-point type. Each block defines a top-level input port or interface in the HDL design generated by Model Composer.



## Conversion of Simulink Data to Model Composer Data

A number of different Simulink data types are supported on the input of Gateway In. The data types supported include int8, uint8, int16, uint16, int32, uint32, single, double, and Simulink fixed point data type (if Simulink fixed point data type license is available). In all cases the input data is converted to a double internal to gateway and then converted to target data type as specified on the Gateway In block (Fixed Point, Floating Point or Boolean). When converting to Fixed point from the internal double representation, the Quantization and Overflow is further handled as specified in the Block GUI. For overflow, the options are to saturate to the largest positive/smallest negative value, to wrap (for example, to discard bits to the left of the most significant representable bit), or to flag an overflow as a Simulink error during simulation. For quantization, the options are to round to the nearest representable value (or to the value furthest from zero if there are two equidistant nearest representable values), or to truncate (for example, to discard bits to the right of the least significant representable bit). It is important to realize that conversion, overflow and quantization do not take place in hardware, they take place only in the simulation model of the block.

## Gateway Blocks

As listed below, the Xilinx Gateway In block is used to provide a number of functions:

- Converting data from Simulink integer, double and fixed-point type to the Model Composer fixed-point type during simulation in Simulink.
- Defining top-level input ports or interface in the HDL design generated by Model Composer.
- Defining test bench stimuli when the **Create Testbench** box is checked in the Model Composer Hub block. In this case, during HDL code generation, the inputs to the block that occur during Simulink simulation are logged as a logic vector in a data file. During HDL simulation, an entity that is inserted in the top level test bench checks this vector and the corresponding vectors produced by Gateway Out blocks against expected results.
- Naming the corresponding port in the top level HDL entity.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows.

- **Output Type:**

Specifies the output data type. Can be **Boolean**, **Fixed-point**, or **Floating-point**.

- **Arithmetic Type:** If the Output Type is specified as Fixed-point, you can select **Signed (2's comp)** or **Unsigned** as the Arithmetic Type.

- **Fixed-point Precision:**

- **Number of bits:** Specifies the total number of bits, including the binary point bit width.
- **Binary point:** Specifies the bit location of the binary point, where bit zero is the least significant bit.

- **Floating-point Precision:**

- **Single:** Specifies single precision (32 bits).
- **Double:** Specifies double precision (64 bits).
- **Custom:** Activates the field below so you can specify the Exponent width and the Fraction width.
- **Exponent width:** Specify the exponent width.
- **Fraction width:** Specify the fraction width.

- **Quantization:**

Quantization errors occur when the number of fractional bits is insufficient to represent the fractional portion of a value. The options are to **Truncate** (for example, to discard bits to the right of the least significant representable bit), or to **Round(unbiased: +/- inf)** or **Round (unbiased: even values)**.

- **Round(unbiased: +/- inf):**

Also known as "Symmetric Round (towards +/- inf)" or "Symmetric Round (away from zero)". This is similar to the MATLAB® `round()` function. This method rounds the value to the nearest desired bit away from zero and when there is a value at the midpoint between two possible rounded values, the one with the larger magnitude is selected. For example, to round 01.0110 to a Fix\_4\_2, this yields 01.10, since 01.0110 is exactly between 01.01 and 01.10, and the latter is further from zero.

- **Overflow:**

Overflow errors occur when a value lies outside the representable range. For overflow the options are to **Saturate** to the largest positive/smallest negative value, to **Wrap** (for example, to discard bits to the left of the most significant representable bit), or to **Flag as error** (an overflow as a Simulink® error) during simulation. **Flag as error** is a simulation only feature. The hardware generated is the same as when **Wrap** is selected.

- **Implementation tab:**

Parameters specific to the Implementation tab are as follows.

- **Interface Options:**

- **Interface:**

- **None:** Implies that during HDL Netlist generation, this Gateway In will be translated as an Input Port at the top level.
    - **AXI4-Lite:** Implies that during HDL Netlist generation, an AXI4-Lite interface will be created and this Gateway In will be mapped to one of the registers within the AXI4-Lite interface.

- **Auto assign address offset:**

If the Gateway In is configured to be an AXI4-Lite interface, this option allows an address offset to be automatically assigned to the register within the AXI4-Lite interface that the Gateway In is mapped to.

- **Address offset:** If Auto assign address offset is not checked, then this entry box allows you to explicitly specify an address offset to use. Must be a multiple of 4.
  - **Interface Name:** If the Gateway In is configured to be an AXI4-Lite interface, assigns a unique name to this interface. This name can be used to differentiate between multiple AXI4-Lite interfaces in the design. When using the IP Catalog flow, you can expect to see an interface in the IP that Model Composer creates with the name <design\_name>\_<interface\_name>\_s\_axi.



**IMPORTANT!** The **Interface Name** must be composed of alphanumeric characters (lowercase alphabetic) or an underscore (\_) only, and must begin with a lowercase alphabetic character. axi4\_lite1 is acceptable, 1Axi4-Lite is not.

---

- **Description:** Additional designer comments about this Gateway In that is captured in the interface documentation.

- **Constraints:**

- **IOB Timing Constraint:** In hardware, a Gateway In is realized as a set of input/output buffers (IOBs). There are two constraint options: None, and Data Rate.

If None is selected, no timing constraints for the IOBs are put in the user constraint file produced by Model Composer. This means the paths from the IOBs to synchronous elements are not constrained.

If Data Rate is selected, the IOBs are constrained at the data rate at which the IOBs operate. The rate is determined by System Clock Period provided on the Model Composer Hub block and the sample rate of the Gateway relative to the other sample periods in the design.

- **Specify IOB location constraints:** Checking this option allows IOB location constraints and I/O standards to be specified.
- **IOB pad locations, e.g. {'MSB', ..., 'LSB'}:** IOB pin locations can be specified as a cell array of strings in this edit box. The locations are package-specific.
- **IO Standards, e.g. {'MSB', ..., 'LSB'}:** I/O standards can be specified as a cell array of strings in this edit box. The locations are package-specific.

## Gateway In AXI Stream



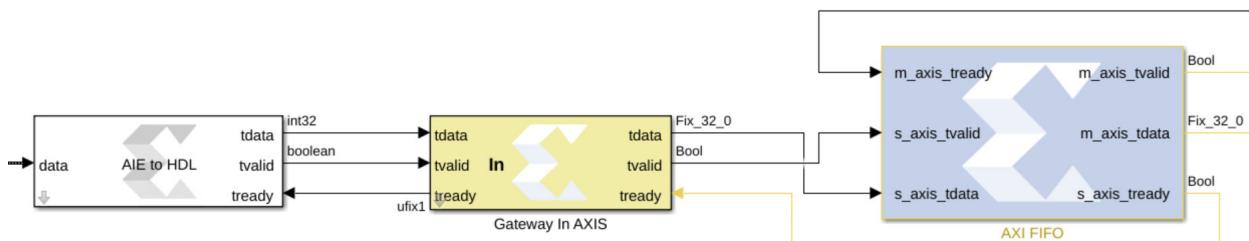
### Library

HDL/Interfaces

### Description

This is a utility block that makes connecting between HDL and AI Engine domains easier by combining three HDL gateway blocks into one block. It is primarily used with the AIE to HDL block. Note that the block name will be used as the AXIS name. The following figure shows how the block is used.

Figure 285: **Gateway In AXI Usage**



### Parameters

- **Output Data Type:** The output data type of the block. The output data type should match the receiving HDL design input.

- **Sample Time:** The output sample time. Refer to the AIE to HDL block help to learn more how to set this parameter.

## Gateway Out

Xilinx Gateway Out blocks are the outputs from the HDL portion of your Simulink® design. This block converts the Model Composer fixed-point or floating-point data type into a Simulink integer, single, double or fixed-point data type.



According to its configuration, the Gateway Out block can either define an output port for the top level of the HDL design generated by Model Composer, or be used simply as a test point that is trimmed from the hardware representation.

### Gateway Blocks

As listed below, the Xilinx Gateway Out block is used to provide the following functions:

- Convert data from a Model Composer fixed-point or floating-point data type into a Simulink integer, single, double, or fixed-point data type.
- Define I/O ports for the top level of the HDL design generated by Model Composer. A Gateway Out block defines a top-level output port.
- Define test bench result vectors when the Model Composer **Create Testbench** box is checked. In this case, during HDL code generation, the outputs from the block that occur during Simulink simulation are logged as logic vectors in a data file. For each top level port, an HDL component is inserted in the top-level test bench that checks this vector against expected results during HDL simulation.
- Name the corresponding output port on the top-level HDL entity.

### Block Parameters

- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Propagate data type to output:** This option is useful when you instantiate a Model Composer design as a sub-system into a Simulink design. Instead of using a Simulink double as the output data type by default, the Model Composer data type is propagated to an appropriate Simulink data type according to the following table:

Table 64: Propagate Data Type Output

Model Composer Data Type	Simulink Data Type
XFloat_8_24	single

**Table 64: Propagate Data Type Output (cont'd)**

Model Composer Data Type	Simulink Data Type
XFloat_11_53	double
Custom floating-point precision data type exponent width and fraction width less than those for single precision	single
Custom floating-point precision data type with exponent width or fraction width greater than that for single precision	double
XFix_<width>_<binpt>	sfix<width>_EN<binpt>
UFix_<width>_<binpt>	ufix<width>_EN<binpt>
XFix_<width>_0 where width is 8, 16 or 32	int<width> where width is 8, 16 or 32
UFix_<width>_0 where width is 8, 16 or 32	uint<width> where width is 8, 16 or 32
XFix_<width>_0 where width is other than 8, 16 or 32	sfix<width>
UFix_<width>_0 where width is other than 8, 16 or 32	ufix<width>

- Translate into Output Port:** Having this box unchecked prevents the gateway from becoming an actual output port when translated into hardware. This checkbox is on by default, enabling the output port. When this option is not selected, the Gateway Out block is used only during debugging, where its purpose is to communicate with Simulink Sink blocks for probing portions of the design. In this case, the Gateway Out block will turn gray in color, indicating that the gateway will not be translated into an output port.
- Implementation tab:** Parameters specific to the Implementation tab are as follows.
  - Interface Options:**
    - Interface:**
      - None:** During HDL Netlist generation, this Gateway Out will be translated as an Output Port at the top level.
      - AXI4-Lite:** During HDL Netlist Generation, an AXI4-Lite interface will be created and the Gateway Out will be mapped to one of the registers within the AXI4-Lite interface.
      - Interrupt:** During an IP Catalog Generation, this Gateway Out will be tagged as an Interrupt output port when the Model Composer design is packaged into an IP module that can be included in the Vivado® IP catalog.
    - Auto assign address offset:** If a Gateway Out is configured to be an AXI4-Lite interface, this option allows an address offset to be automatically assigned to the register within the AXI4-Lite interface that the Gateway Out is mapped to.
    - Address offset:** If Auto assign address offset is not checked, then this entry box allows you to explicitly specify a address offset to use. Must be a multiple of 4.

- **Interface Name:** If the Gateway Out is configured to be an AXI4-Lite interface, assigns a unique name to this interface. This name can be used to differentiate between multiple AXI4-Lite interfaces in the design. When using the IP Catalog flow, you can expect to see an interface in the IP that Model Composer creates with the name <design\_name>\_<interface\_name>\_s\_axi.



**IMPORTANT!** The **Interface Name** must be composed of alphanumeric characters (lowercase alphabetic) or an underscore (\_) only, and must begin with a lowercase alphabetic character. axi4\_lite1 is acceptable, 1Ax4-Lite is not.

- **Description:** Additional designer comments about this Gateway Out that is captured in the interface documentation.
- **Constraints:**

- **IOB Timing Constraint:** In hardware, a Gateway Out is realized as a set of input/output buffers (IOBs). There are three ways to constrain the timing on IOBs. They are None, Data Rate, and Data Rate, Set 'FAST' Attribute.

If **None** is selected, no timing constraints for the IOBs are put in the user constraint file produced by Model Composer. This means the paths from the IOBs to synchronous elements are not constrained.

If **Data Rate** is selected, the IOBs are constrained at the data rate at which the IOBs operate. The rate is determined by System Clock Period provided on the Model Composer Hub block and the sample rate of the Gateway relative to the other sample periods in the design. For example, the following OFFSET = OUT constraints are generated for a Gateway Out named 'Dout' that is running at the system period of 10 ns:

```
# Offset out constraints
NET "Dout(0)" OFFSET = OUT : 10.0 : AFTER "clk";
NET "Dout(1)" OFFSET = OUT : 10.0 : AFTER "clk";
NET "Dout(2)" OFFSET = OUT : 10.0 : AFTER "clk";
```

If **Data Rate, Set 'FAST' Attribute** is selected, the OFFSET = OUT constraints described above are produced. In addition, a FAST slew rate attribute is generated for each IOB. This reduces delay but increases noise and power consumption. For the previous example, the following additional attributes are added to the constraints file.

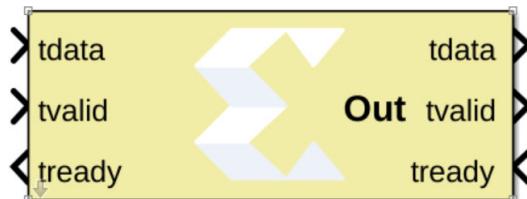
```
NET "Dout(0)" FAST;
NET "Dout(1)" FAST;
NET "Dout(2)" FAST;
```

- **Specify IOB Location Constraints:** Checking this option allows IOB location constraints to be specified.

- **IOB Pad Locations, e.g. {'MSB', ..., 'LSB'}:** IOB pin locations can be specified as a cell array of strings in this edit box. The locations are package-specific.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Gateway Out AXI Stream



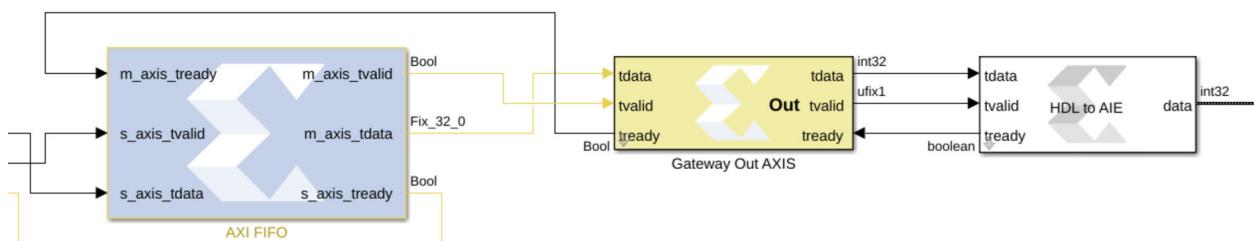
### Library

HDL/Interfaces

### Description

This is a utility block that makes connecting between HDL and AI Engine domains easier by combining three HDL gateway blocks into one block. It is primarily used with the HDL to AIE block. Note that the block name will be used as the AXIS name. The following figure shows an example of how the block gets connected.

Figure 286: **Gateway out AXI Usage**

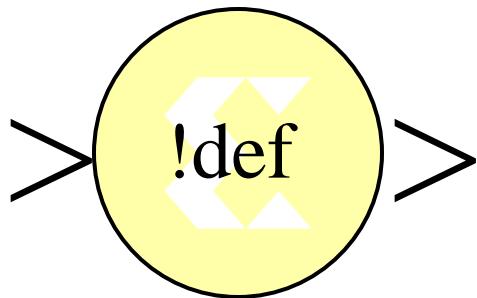


### Parameters

- **Sample Time:** The sample time of the `tready` signal on the input side. In general, this parameter should match the sample time of your HDL design.

## Indeterminate Probe

The output of the Xilinx Indeterminate Probe indicates whether the input data is indeterminate (MATLAB value NaN). An indeterminate data value corresponds to a VHDL indeterminate logic data value of 'X'.

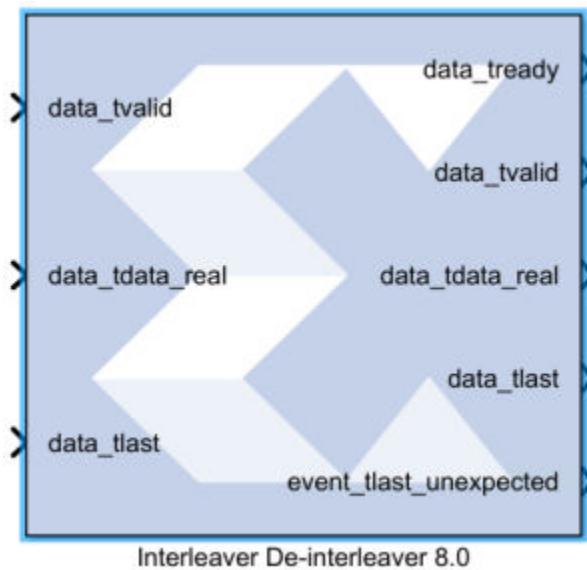


The probe accepts any Xilinx signal as input and produces a double signal as output. Indeterminate data on the probe input will result in an assertion of the output signal indicated by a value one. Otherwise, the probe output is zero.

## Interleaver/De-interleaver 8.0

**Note:** This block goes into the FPGA fabric and is a Licensed Core. Please visit the Xilinx web site to purchase the appropriate core license.

The Xilinx Interleaver Deinterleaver block implements an interleaver or a deinterleaver using an AXI4-compliant block interface. An interleaver is a device that rearranges the order of a sequence of input symbols. The term symbol is used to describe a collection of bits. In some applications, a symbol is a single bit. In others, a symbol is a bus.



The classic use of interleaving is to randomize the location of errors introduced in signal transmission. Interleaving spreads a burst of errors out so that error correction circuits have a better chance of correcting the data.

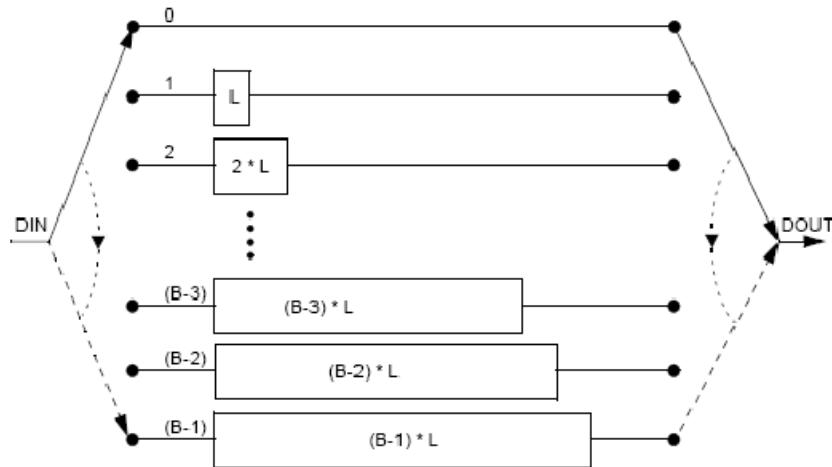
If a particular interleaver is used at the transmit end of a channel, the inverse of that interleaver must be used at the receive end to recover the original data. The inverse interleaver is referred to as a de-interleaver.

Two types of interleaver/de-interleavers can be generated with this LogiCORE™: Forney Convolutional and Rectangular Block. Although they both perform the general interleaving function of rearranging symbols, the way in which the symbols are rearranged and their methods of operation are entirely different. For very large interleavers, it might be preferable to store the data symbols in external memory. The core provides an option to store data symbols in internal FPGA RAM or in external RAM.

### Forney Convolutional Operation

The figure below, shows the operation of a Forney Convolutional Interleaver. The core operates as a series of delay line shift registers. Input symbols are presented to the input commutator arm on DIN. Output symbols are extracted from the output commutator arm on DOUT. DIN and DOUT are fields in the AXI Data Input and Data Output channels, respectively. Output symbols are extracted from the output commutator arm on DOUT. Both commutator arms start at branch 0 and advance to the next branch after the next rising clock edge. After the last branch (B-1) has been reached, the commutator arms both rotate back to branch 0 and the process is repeated.

Figure 287: Interleaver

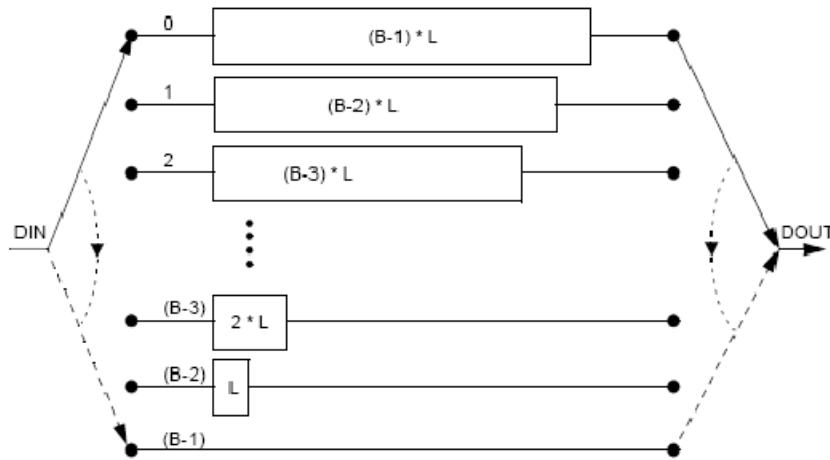


In the figure above, the branches increase in length by a uniform amount,  $L$ . The core allows interleavers to be specified in this way, or the branch lengths can be passed in using a file, allowing each branch to be any length.

Although branch 0 appears to be a zero-delay connection, there will still be a delay of a number of clock cycles between DIN and DOUT because of the fundamental latency of the core. For clarity, this is not illustrated in the figure.

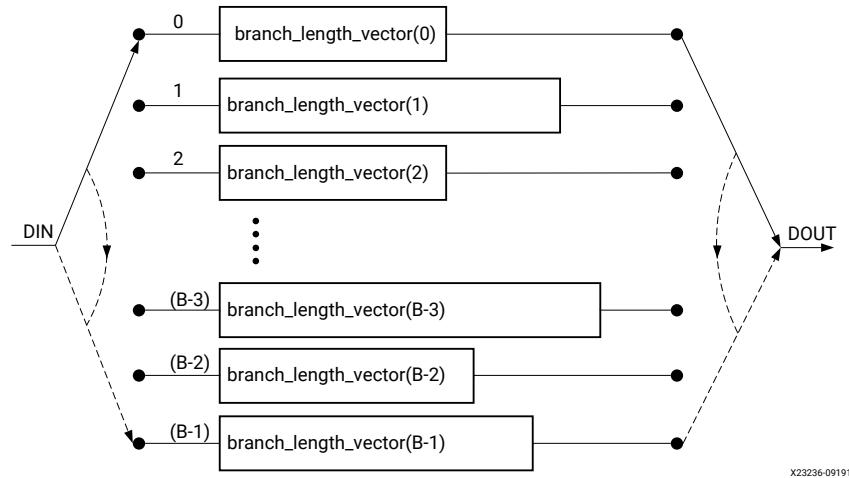
The only difference between an interleaver and a de-interleaver is that branch 0 is the longest in the de-interleaver and the branch length is decremented by  $L$  rather than incremented. Branch (B-1) has length 0. This is illustrated in the figure below:

Figure 288: De-interleaver



If a file is used to specify the branch lengths, as shown below, it is arbitrary whether the resulting core is called an interleaver or de-interleaver. All that matters is that one must be the inverse of the other. If a file is used, each branch length is individually controllable. This is illustrated in the figure below. For the file syntax, please consult the LogiCORE product specification.

*Figure 289: Interleaver/De-Interleaver*



The reset pin (`aresetn`) sets the commutator arms to branch 0, but does not clear the branches of data.

### Configuration Swapping

It is possible for the core to store a number of pre-defined configurations. Each configuration can have a different number of branches and branch length constant. It is even possible for each configuration to have every individual branch length defined by file.

The configuration can be changed at any time by sending a new `CONFIG_SEL` value on the AXI Control Channel. This value takes effect when the next block starts. The core assumes all configurations are either for an interleaver or de-interleaver, depending on what was selected in the GUI. It is possible to switch between interleaving and de-interleaving by defining the individual branch lengths for every branch of each configuration. The details for each configuration are specified in a COE file.

For details, please consult the Configuration Swapping section of the *Interleaver/De-Interleaver LogiCORE IP Product Guide* ([PG049](#)).

## Rectangular Block Operation

The Rectangular Block Interleaver works by writing the input data symbols into a rectangular memory array in a certain order and then reading them out in a different, mixed-up order. The input symbols must be grouped into blocks. Unlike the Convolutional Interleaver, where symbols can be continuously input, the Rectangular Block Interleaver inputs one block of symbols and then outputs that same block with the symbols rearranged. No new inputs can be accepted while the interleaved symbols from the previous block are being output.

The rectangular memory array is composed of a number of rows and columns as shown in the following table.

Row\Column	0	1	...	(C-2)	(C-1)
0					
1					
..					
(R-2)					
(R-1)					

The Rectangular Block Interleaver operates as follows:

1. All the input symbols in an entire block are written row-wise, left to right, starting with the top row.
2. Inter-row permutations are performed if required.
3. Inter-column permutations are performed if required.
4. The entire block is read column-wise, top to bottom, starting with the left column.

The Rectangular Block De-interleaver operates in the reverse way:

1. All the input symbols in an entire block are written column-wise, top to bottom, starting with the left column.
2. Inter-row permutations are performed if required.
3. Inter-column permutations are performed if required.
4. The entire block is read row-wise, left to right, starting with the top row.

Refer to the *Interleaver/De-Interleaver LogiCORE IP Product Guide (PG049)* for examples and more detailed information on the Rectangular Block Interleaver.

## AXI Interface

The AXI SID v7.1 has the following interfaces:

- A non AXI-channel interface for ACLK, ACLKEN and ARESETn
- A non AXI-channel interface for external memory (if enabled)

- A non AXI-channel interface for miscellaneous events
  - event\_tlast\_unexpected
  - event\_tlast\_missing (available only in Rectangular mode)
  - event\_halted (optional, available when Master channel TREADY is enabled)
  - event\_col\_valid (optional)
  - event\_col\_sel\_valid (optional)
  - event\_row\_valid (optional)
  - event\_row\_sel\_valid (optional)
  - event\_block\_size\_valid (optional)
- An AXI slave channel to receive configuration information (s\_axis\_ctrl) consisting of:
  - s\_axis\_ctrl\_tvalid
  - s\_axis\_ctrl\_tready
  - s\_axis\_ctrl\_tdata

The control channel is only enabled when the core is configured in such a way to require it.

- An AXI slave channel to receive the data to be interleaved (s\_axis\_data) consisting of:
  - s\_axis\_data\_tvalid (This is the equivalent of ND pin of SID v6.0 block; No longer optional)
  - s\_axis\_data\_tready
  - s\_axis\_data\_tdata
  - s\_axis\_data\_tlast
- An AXI master channel to send the data that has been interleaved (m\_axis\_data) consisting of:
  - m\_axis\_data\_tvalid
  - m\_axis\_data\_tready
  - m\_axis\_data\_tdata
  - m\_axis\_data\_tuser
  - m\_axis\_data\_tlast

### **AXI Ports that are Unique to this Block**

This HDL block exposes the AXI Control and Data channels as a group of separate ports based on the following sub-field names.

**Note:** Refer to the document [LogiCORE IP Interleaver/De-interleaver v8.0](#) for an explanation of the bits in the specified sub-field name.

- **Control Channel Input Signals:**

- **s\_axis\_ctrl\_tdata\_config\_sel:**

A sub-field port that represents the CONFIG\_SEL field in the Control Channel vector.  
Available when in Forney mode and Number of configurations is greater than one.

- **s\_axis\_ctrl\_tdata\_row:**

A sub-field port that represents the ROW field in the Control Channel vector. Available when in Rectangular mode and Row type is Variable.

- **s\_axis\_ctrl\_tdata\_row\_sel:**

A sub-field port that represents the ROW\_SEL field in the Control Channel vector.  
Available when in Rectangular mode and Row type is Selectable.

- **s\_axis\_ctrl\_tdata\_col:** A sub-field port that represents the COL field in the Control Channel vector. Available when in Rectangular mode and Column type is Variable.

- **s\_axis\_ctrl\_tdata\_col\_sel:**

A sub-field port that represents the COL\_SEL field in the Control Channel vector. Available when in Rectangular mode and Column type is Selectable.

- **s\_axis\_ctrl\_tdata\_block\_size:** A sub-field port that represents the COL field in the Control Channel vector. Available when in Rectangular mode and Block Size type is Variable.

- **DATA Channel Input Signals:**

- **s\_axis\_data\_tdata\_din:**

Represents the DIN field of the Input Data Channel.

- **DATA Channel Output Signals:**

- **m\_axis\_data\_tdata\_dout:**

Represents the DOUT field of the Output Data Channel.

- **TUSER Channel Output Signals:**

- **m\_axis\_data\_tuser\_fdo:** Represents the FDO field of the Output TUSER Channel. Available when in Forney mode and Optional FDO pin has been selected on the GUI.

- **m\_axis\_data\_tuser\_rdy:** Represents the RDY field of the Output TUSER Channel. Available when in Forney mode and Optional RDY pin has been selected on the GUI.

- **m\_axis\_data\_tuser\_block\_start:** Represents the BLOCK\_START field of the Output TUSER Channel. Available when in Rectangular mode and Optional BLOCK\_START pin has been selected on the GUI.
- **m\_axis\_data\_tuser\_block\_end:** Represents the BLOCK\_END field of the Output TUSER Channel. Available when in Rectangular mode and Optional BLOCK\_END pin has been selected on the GUI.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

- **Basic tab:** Parameters specific to the Basic Parameters tab are as follows.
  - **Memory Style:** Select **Distributed** if all the Block Memories are required elsewhere in the design; select **Block** to use Block Memory where ever possible; select **Automatic** and let Model Composer use the most appropriate style of memory for each case, based on the required memory depth.
  - **Symbol Width:** This is the number of bits in the symbols to be processed.
  - **Type:** Select **Forney Convolutional** or **Rectangular Block**.
  - **Mode:** Select **Interleaver** or **Deinterleaver**
  - **Symbol memory:** Specifies whether or not the data symbols are stored in Internal FPGA RAM or in External RAM.
- **Forney tab:** Parameters specific to the Forney Parameters tab are as follows.
  - **Dimensions:**
    - **Number of branches:** 1 to 256 (inclusive)
  - **Architecture:**
    - **ROM-based:** Look-up table ROMs are used to compute some of the internal results in the block.
    - **Logic-based:** Logic circuits are used to compute some of the internal results in the block.
  - Which option is best depends on the other core parameters. You should try both options to determine the best results. This parameter has no effect on the block behavior.
  - **Configurations:**
    - **Number of configurations:** If greater than 1, the block is generated with CONFIG\_SEL and NEW\_CONFIG inputs. The parameters for each configuration are defined in a COE file. The number of parameters defined must exactly match the number of configurations specified.

- **Length of Branches:** Branch length descriptions for Forney SID.
  - **constant\_difference\_between\_consecutive\_branches:** Specified by the Value parameter.
  - **use\_coe\_file\_to\_define\_branch\_lengths:** Location of file is specified by the COE File parameter.
  - **coe\_fileDefines\_individual\_branch\_lengths\_for\_every\_branch\_in\_each\_configuration:** Location of file is specified by the COE File parameter.
  - **coe\_fileDefines\_branch\_length\_constant\_for\_each\_configuration:** Location of file is specified by the COE File parameter.
  - **Value:** 1 to MAX (inclusive). MAX depends on the number of branches and size of block input. Branch length must be an array of either length one or number of branches. If the array size is one, the value is used as a constant difference between consecutive branches. Otherwise, each branch has a unique length.
  - **COE File:** The branch lengths are specified from a file
- **Rectangular Parameters #1 Tab:** Parameters specific to the Rectangular Parameters #1 tab are as follows.
  - **Number of Rows:**
    - **Value:** This parameter is relevant only when the Constant row type is selected. The number of rows is fixed at this value.
    - **Row Port Width:** This parameter is relevant only when the Variable row type is selected. It sets the width of the ROW input bus. The smallest possible value should be used to keep the underlying LogiCORE as small as possible.
    - **Minimum Number of Rows:** This parameter is relevant only when the Variable row type is selected. In this case, the core has to potentially cope with a wide range of possible values for the number of rows. If the smallest value that will actually occur is known, then the amount of logic in the LogiCORE can sometimes be reduced. The largest possible value should be used for this parameter to keep the core as small as possible.
    - **Number of Values:** This parameter is relevant only when you select the **Selectable** row type. This parameter defines how many valid selection values have been defined in the COE file. You should only add the number of select values you need.
  - **Row Type:**
    - **Constant:** The number of rows is always equal to the Row Constant Value parameter.
    - **Variable:** The number of rows is sampled from the ROW input at the start of each new block. Row permutations are not supported for the variable row type.
    - **Selectable:** ROW\_SEL is sampled at the start of each new block. This value is then used to select from one of the possible values for the number of rows provided in the COE file.

- **Number of Columns:**

- **Value:** This parameter is relevant only when you select the **Constant** column type is selected. The number of columns is fixed at this value.
- **COL Port Width:** This parameter is relevant only when you select the **Variable** column type. It sets the width of the COL input bus. The smallest possible value should be used to keep the underlying LogiCORE™ as small as possible.
- **Minimum Number of Columns:** This parameter is relevant only when you select the **Variable** column type is selected. In this case, the core has to potentially cope with a wide range of possible values for the number of columns. If the smallest value that will actually occur is known, then the amount of logic in the LogiCORE can sometimes be reduced. The largest possible value should be used for this parameter to keep the core as small as possible.
- **Number of Values:** This parameter is relevant only when you select the **Selectable** column type. This parameter defines how many valid selection values have been defined in the COE file. You should only add the number of select values you need.

- **Column Type:**

- **Constant:** The number of columns is always equal to the Column Constant Value parameter.
- **Variable:** The number of columns is sampled from the COL input at the start of each new block. Column permutations are not supported for the variable column type.
- **Selectable:** COL\_SEL is sampled at the start of each new block. This value is then used to select from one of the possible values for the number of columns provided in the COE file.
- **Rectangular Parameters #2 Tab:** Parameters specific to the Rectangular Parameters #2 tab are as follows.
  - **Permutations Configuration:**
    - **Row permutations:**
      - **None:** This tells Model Composer that row permutations are not to be performed.
      - **Use COE file:** This tells Model Composer that a row permute vector exists in the COE file, and that row permutations are to be performed. Remember this is possible only for un-pruned interleaver/deinterleavers.
    - **Column permutations:**
      - **None:** This tells Model Composer that column permutations are not to be performed
      - **Use COE file:** This tells Model Composer that a column permute vector exists in the COE file, and that column permutations are to be performed. Remember this is possible only for un-pruned interleaver/deinterleavers.

- **COE File:** Specify the pathname to the COE file.
- **Block Size:**
  - **Value:** This parameter is relevant only when you select the Constant block size type. The block size is fixed at this value.
  - **BLOCK\_SIZE Port Width:** This parameter is relevant only if the Variable block size type is selected. It sets the width of the BLOCK\_SIZE input bus. The smallest possible value should be used to keep the core as small as possible.
- **Block Size Type:**
  - **Constant:** The block size never changes. The block can be pruned (block size < row \* col). The block size must be chosen so that the last symbol is on the last row. An un-pruned interleaver will use a smaller quantity of FPGA resources than a pruned one, so pruning should be used only if necessary.
  - **Rows\*Columns:**

If the number of rows and columns is constant, selecting this option has the same effect as setting the block size type to constant and entering a value of rows \* columns for the block size.

If the number of rows or columns is not constant, selecting this option means the core will calculate the block size automatically whenever a new row or column value is sampled. Pruning is impossible with this block size type.
- **Variable:**

Block size is sampled from the BLOCK\_SIZE input at the beginning of every block. The value sampled on BLOCK\_SIZE must be such that the last symbol falls on the last row, as previously described.

If the block size is already available external to the core, selecting this option is usually more efficient than selecting “rows \* columns” for the block size type. Row and column permutations are not supported for the Variable block size type.
- **Port Parameters #1 tab:** Parameters specific to the Port Parameters tab are as follows.
  - **Control Signals:**
    - **ACLKEN:** When ACLKEN is de-asserted (Low), all the synchronous inputs are ignored and the block remains in its current state.
    - **ARESETn (Active-Low):** The Active-Low synchronous clear input always takes priority over ACLKEN.
  - **Status Signals:**

- **COL\_VALID:** This optional output is available when a variable number of columns is selected. If an illegal value is sampled on the `s_axis_ctrl_tdata_col` input, `event_col_valid` will go Low a predefined number of clock cycles later.
  - **COL\_SEL\_VALID:** This optional output (`event_col_sel_valid`) is available when a selectable number of columns is chosen. The event pins are `event_col_valid`, `event_col_sel_valid`, `event_row_valid`, `event_row_sel_valid`, `event_block_size_valid` (in the same order as in the options on the GUI).
  - **ROW\_VALID:** This optional output is available when a selectable number of rows is chosen.
  - **ROW\_SEL\_VALID:** This optional output is available when a selectable number of rows is chosen.
  - **BLOCK\_SIZE\_VALID:** This optional output is available when the block size is not constant, that is, if the block size type is either Variable or equal to Rows \* Columns.
- **Port Parameters #2 tab:** Parameters specific to the Port Parameters #2 tab are as follows.
    - **Data Output Channel Options:**
      - **TREADY:** TREADY for the Data Input Channel. Used by the Symbol Interleaver/De-interleaver to signal that it is ready to accept data.
      - **FDO:** Adds a `data_tuser_fdo` (First Data Out) output port.
      - **RDY:** Adds a `data_tuser_rdy` output port.
      - **BLOCK\_START:** Adds a `data_tuser_block_start` output port.
      - **BLOCK\_END:** Adds a `data_tuser_block_end` output port.
    - **Pipelining:**
      - **Pipelining:** Pipelines the underlying LogiCORE for Minimum, Medium, or Maximum performance.

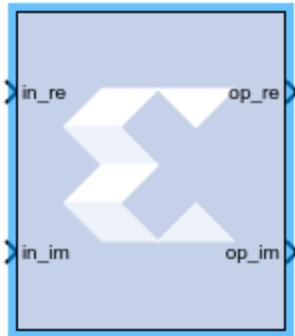
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

[LogiCORE IP Interleaver/De-interleaver v8.0](#)

## Inverse FFT

The Xilinx Inverse FFT block performs a fast inverse (or backward) Fourier transform (IDFT), which undoes the process of Discrete Fourier Transform (DFT). The Inverse FFT maps the signal back from the frequency domain into the time domain.



The IDFT of a sequence  $\{F_n\}$  can be defined as:

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X[k] e^{\frac{2\pi j}{N} nk} \quad \text{for } n=0, 1, 2, \dots, N-1$$

where  $N$  is the transform length,  $k$  is used to denote the frequency domain ordinal, and  $n$  is used to represent the time-domain ordinal.

The Inverse FFT (IFFT) is computed by conjugating the phase factors of the corresponding forward FFT.

The Inverse FFT block is ideal for implementing simple inverse Fourier transforms. If your Inverse FFT implementation will use more complicated transform features such as an AXI4-Stream-compliant interface, a real time throttle scheme, Radix-4 Burst I/O, or Radix-2 Lite Burst I/O, use the Xilinx [Fast Fourier Transform 9.1](#) block in your design instead of the Inverse FFT block.

In the Vivado® design flow, the Inverse FFT block is inferred as "LogiCORE™ IP Fast Fourier Transform v9.1" for code generation. Refer to the document [LogiCORE IP Fast Fourier Transform v9.1](#) for details on this LogicCore IP.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Parameters specific to the Xilinx Inverse FFT block are:

- **Transform Length:** Select the desired point size ranging from 8 to 65536.

- **Scale Result by FFT length:** If selected, data is scaled between IFFT stages using a scaling schedule determined by the Transform Length setting. If not selected, data is unscaled, and all integer bit growth is carried to the output.
- **Natural Order:** If selected, the output of the Inverse FFT block will be ordered in natural order. If not selected, the output of the Inverse FFT block will be ordered in bit/digit reversed order.
- **Optimize for:** Directs the block to be optimized for either speed (Performance) or area (Resources) in the generated hardware.

**Note:** If you selected **Resources** and the input sample period is 8 times slower than the system sample period, the block implements Radix-2 Burst I/O architecture. Otherwise, Pipeline Streaming I/O architecture is used.

- **Optional Port:**

- **Provide start frame port:** Adds `start_frame_in` and `start_frame_out` ports to the block. The signals on these ports can be used to synchronize frames at the input and output of the Inverse FFT block. See [Adding Start Frame Ports to Synchronize Frames](#) for a description of the operation of these two ports.

## Context Based Pipeline vs. Radix Implementation

Pipelined Streaming I/O and Radix-2 Burst I/O architectures are supported by the Inverse FFT block. Radix-4 Burst I/O architecture is implemented when the **Optimize for: Resources** block parameter is selected and the sample rate of the inputs is 8 times slower than the system rate. In all other configurations Pipelined Streaming I/O architecture is implemented by default.

## Input Data Type Support

The Inverse FFT block accepts inputs of varying bit widths with changeable binary point location, such as Fix\_16\_0 or Fix\_30\_10, etc. in unscaled block configuration. For the scaled configuration, the input is supported in the same format as the [Fast Fourier Transform 9.1](#) block. The [Fast Fourier Transform 9.1](#) block accepts input values only in the normalized form in the format of Fix\_x\_[x-1] (for example, Fix\_16\_15), so the inputs are 2's complement with a single sign/integer bit.

## Latency Value Displayed on the Block

The latency value depends on parameters selected by the user, and the corresponding latency value is displayed on the Inverse FFT block icon in the Simulink model.

## Automatic Fixed Point and Floating Point Support

Signed fixed point and floating point data types are supported.

For floating point input, either scaled or unscaled data can be selected in the Inverse FFT block parameters. In the [Fast Fourier Transform 9.1](#) block, the floating point data type is accepted only when the scaled configuration is selected by the user.

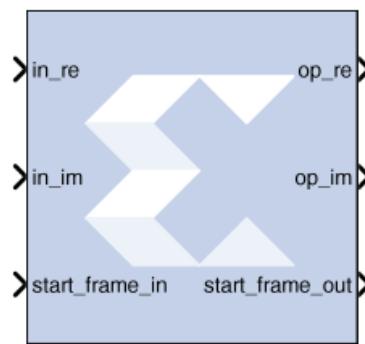
### Handling Overflow for Scaled Configuration

The Inverse FFT block uses a conservative schedule to avoid overflow scenarios. This schedule sets the scaling value for the corresponding FFT stages in a way that makes sure no overflow occurs.

### Adding Start Frame Ports to Synchronize Frames

Selecting **Provide start frame port** in the Inverse FFT block properties dialog box adds `start_frame_in` and `start_frame_out` ports at the input and output of the Inverse FFT block. These ports are used to synchronize frames at the input and output of the Inverse FFT block.

*Figure 290: Adding Start Frame Ports*



You must provide a valid input at the `start_frame_in` port. When the `start_frame_in` signal is asserted, an impulse is generated at the start of every frame to signal the Inverse FFT block to start processing the frame. The frame size is the Transform Length entered in the block parameters dialog box.

The `start_frame_out` port provides the information as to when the output frames start. An impulse at the start of every frame on the output side helps in tracking the block behavior.

The Inverse FFT block has a frame alignment requirement and these ports help the block operate in accordance with this requirement.

The figure below shows that as soon as the output is processed by the Inverse FFT block the `start_frame_out` signal becomes High (1).

Figure 291: Output

re_data_out	000280	000000	000280
img_data_out	000280	000000	000280
start_frame_out	1	0	1

The following apply to the **Provide start frame port** option and the start frame ports added to the FFT block when the option is enabled:

- The **Provide start frame port** option selection is valid only for Pipelined Streaming I/O architecture. See [Context Based Pipeline vs. Radix Implementation](#) for a description of the conditions under which Pipelined Streaming I/O architecture is implemented.
- The option is valid only for input of type fixed point.
- Verilog is supported for netlist generation currently, when the **Provide start frame port** option is selected.

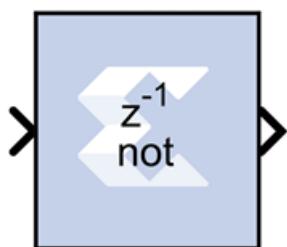
**Note:** The first sample input to the Inverse FFT block may be ignored and users are advised to drive the input data accordingly.

## LogiCORE Documentation

[LogiCORE IP Fast Fourier Transform v9.1](#)

## Inverter

The Xilinx Inverter block calculates the bitwise logical complement of a fixed-point number. The block is implemented as a synthesizable VHDL module.



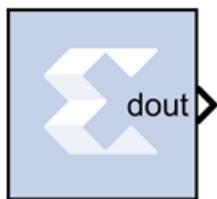
### Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LFSR

The Xilinx LFSR block implements a Linear Feedback Shift Register (LFSR). This block supports both the Galois and Fibonacci structures using either the XOR or XNOR gate and allows a re-loadable input to change the current value of the register at any time. The LFSR output and re-loadable input can be configured as either serial or parallel ports.



### Block Interface

Table 65: Block Interface

Port Name	Port Description	Port Type
din	Data input for re-loadable seed	Optional serial or parallel input
load	Load signal for din	Optional boolean input
rst	Reset signal	Optional boolean input
en	Enable signal	Optional boolean input
dout	Data output of LFSR	Required serial or parallel output

As shown in the table above, there can be between 0 and 4 block input ports and exactly one output port. If the configuration selected requires 0 inputs, the LFSR is set up to start at a specified initial seed value and will step through a repeatable sequence of states determined by the LFSR structure type, gate type, and initial seed.

The optional `din` and `load` ports provide the ability to change the current value of the LFSR at runtime. After the load completes, the LFSR behaves as with the 0 input case, and starts up a new sequence based upon the newly loaded seed, and the statically configured LFSR options for structure and gate type.

The optional `rst` port will reload the statically specified initial seed of the LFSR and continue on as before after the `rst` signal goes low. And when the optional `en` port goes low, the LFSR will remain at its current value with no change until the `en` port goes high again.

### Block Parameters

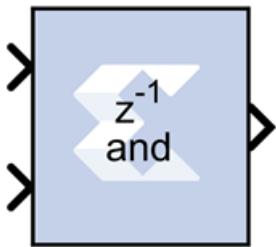
The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to the Basic tab are as follows:
  - **Type:** Fibonacci or Galois. This field specifies the structure of the feedback. Fibonacci has one XOR (or XNOR) gate at the beginning of the register chain that XORs (or XNORs) the taps together with the result going into the first register. Galois has one XOR (or XNOR) gate for each tap and gates the last register in the chains output with the input to the register at that tap.
  - **Gate type:** XOR or XNOR. This field specifies the gate used by the feedback signals.
  - **Number of bits in LFSR:** This field specifies the number of registers in the LFSR chain. As a result, this number specifies the size of the input and output when selected to be parallel.
  - **Feedback polynomial:** This field specifies the tap points of the feedback chain and the value must be entered in hex with single quotes. The lsb of this polynomial always must be set to 1 and the msb is an implied 1 and is not specified in the hex input. Please see the Xilinx application note titled [Efficient Shift Registers, LFSR Counters, and Long Pseudo-Random Sequence Generators](#) for more information on how to specify this equation and for optimal settings for the maximum repeating sequence.
  - **Initial value:** This field specifies the initial seed value where the LFSR begins its repeating sequence. The initial value might not be all zeroes when choosing the XOR gate type and might not be all ones when choosing XNOR, as those values will stall the LFSR.
- **Advanced tab:** Parameters specific to the Advanced tab are as follows:
  - **Use reloadable seed value :** This field specifies whether or not an input is needed to reload a dynamic LFSR seed value at run time.
  - **Parallel input:** This field specifies whether the reloadable input seed is shifted in one bit at a time or if it happens in parallel.
  - **Parallel output:** This field specifies whether all of the bits in the LFSR chain are connected to the output or just the last register in the chain (serial or parallel).

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Logical

The Xilinx Logical block performs bitwise logical operations on fixed-point numbers. Operands are zero padded and sign extended as necessary to make binary point positions coincide; then the logical operation is performed and the result is delivered at the output port.



In hardware this block is implemented as synthesizable VHDL. If you build a tree of logical gates, this synthesizable implementation is best as it facilitates logic collapsing in synthesis and mapping.

## Block Parameters

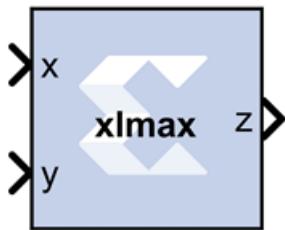
The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to the Basic tab are as follows:
  - **Logical function:** Specifies one of the following bitwise logical operators: AND, NAND, OR, NOR, XOR, XNOR.
  - **Number of inputs:** Specifies the number of inputs (1 - 1024).
  - **Logical Reduction Operation:** When the number of inputs is specified as 1, a unary logical reduction operation performs a bit-wise operation on the single operand to produce a single bit result. The first step of the operation applies the logical operator between the least significant bit of the operand and the next most significant bit. The second and subsequent steps apply the operator between the one-bit result of the prior step and the next bit of the operand using the same logical operator. The logical reduction operator implements the same functionality as that of the logical reduction operation in HDLs. The output of the logical reduction operation is always Boolean.
- **Output Type tab:** Parameters specific to the Output Type tab are as follows.
  - **Align binary point:** Specifies that the block must align binary points automatically. If not selected, all inputs must have the same binary point position.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## MCode

The Xilinx MCode block is a container for executing a user-supplied MATLAB function within Simulink. A parameter on the block specifies the M-function name. The block executes the M-code to calculate block outputs during a Simulink simulation. The same code is translated in a straightforward way into equivalent behavioral VHDL/Verilog when hardware is generated.



The block's Simulink® interface is derived from the MATLAB function signature, and from block mask parameters. There is one input port for each parameter to the function, and one output port for each value the function returns. Port names and ordering correspond to the names and ordering of parameters and return values.

The MCode block supports a limited subset of the MATLAB language that is useful for implementing arithmetic functions, finite state machines, and control logic.

The MCode block has the following three primary coding guidelines that must be followed:

- All block inputs and outputs must be of Xilinx fixed-point type.
- The block must have at least one output port.
- The code for the block must exist on the MATLAB path or in the same directory as the directory as the model that uses the block.

The example described below consists of a function `xlmax` which returns the maximum of its inputs. The second illustrates how to do simple arithmetic. The third shows how to build a finite state machine.

### Configuring an MCode Block

The **MATLAB Function** parameter of an MCode block specifies the name of the block's M- code function. This function must exist in one of the three locations at the time this parameter is set. The three possible locations are:

- The directory where the model file is located.
- A subdirectory of the model directory named `private`.
- A directory in the MATLAB path.

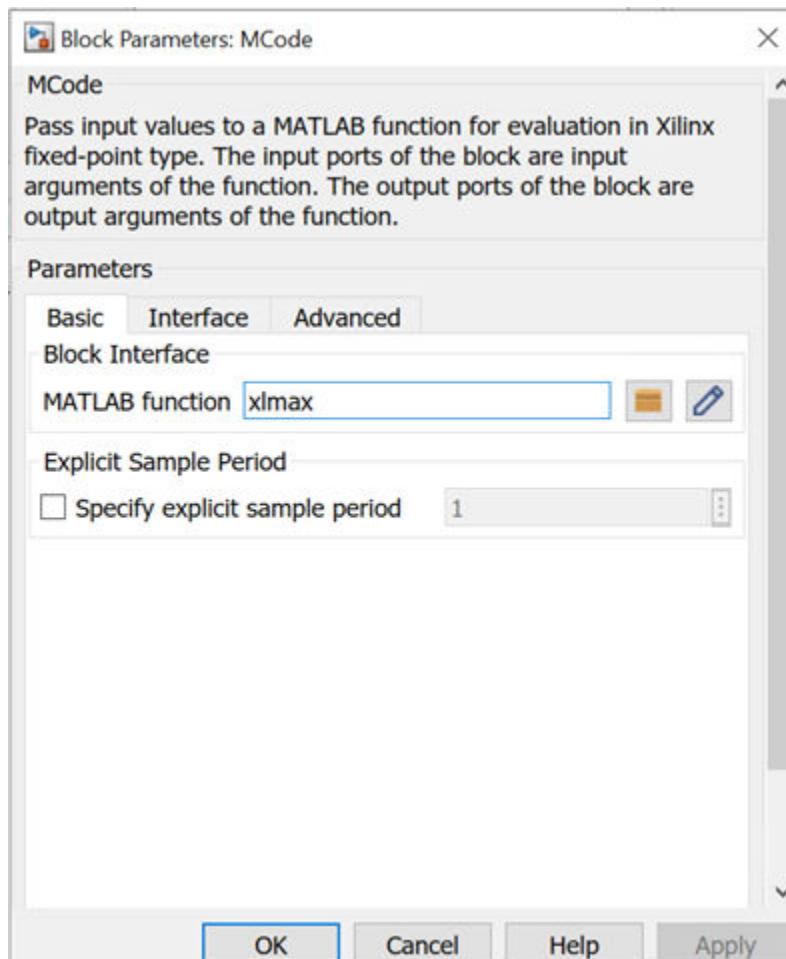
The block icon displays the name of the M-function. To illustrate these ideas, consider the file `xlmax.m` containing function `xlmax`:

```
function z = xlmax(x, y)
if x > y
    z = x;
else
    z = y;
end
```

An MCode block based on the function `xlmax` will have input ports `x` and `y` and output port `z`.

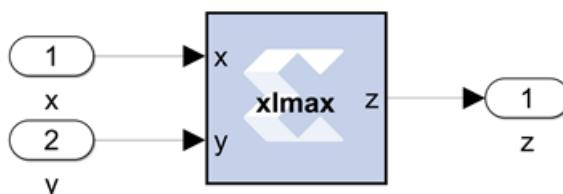
The following figure shows how to set up an MCode block to use function `xlmax`.

Figure 292: `xlmax` function



Once the model is compiled, the `xlmax` MCode block will appear like the block illustrated below.

Figure 293: `xlmax` MCode block



## MATLAB Language Support

The MCode block supports the following MATLAB language constructs:

- Assignment statements
- Simple and compound `if/else/elseif end` statements
- `switch statements`
- Arithmetic expressions involving only addition and subtraction
- Addition
- Subtraction
- Multiplication
- Division by a power of two
- Relational operators:

<code>&lt;</code>	Less than
<code>&lt;=</code>	Less than or equal to
<code>&gt;</code>	Greater than
<code>&gt;=</code>	Greater than or equal to
<code>==</code>	Equal to
<code>~=</code>	Not equal to

- Logical operators:

<code>&amp;</code>	And
<code> </code>	Or
<code>~</code>	Not

The MCode block supports the following MATLAB functions.

- Type conversion. The only supported data type is `xfix`, the Xilinx fixed-point type. The `xfix()` type conversion function is used to convert to this type. The conversion is done implicitly for integers but must be done explicitly for floating point constants. All values must be scalar; arrays are not supported.
- Functions that return `xfix` properties:

<code>xl_nbits()</code>	Returns number of bits
<code>xl_binpt()</code>	Returns binary point position
<code>xl_arith()</code>	Returns arithmetic type

- Bit-wise logical functions:

<code>xl_and()</code>	Bit-wise and
<code>xl_or()</code>	Bit-wise or
<code>xl_xor()</code>	Bit-wise xor
<code>xl_not()</code>	Bit-wise not

- Shift functions: `xl_lsh()` and `xl_rsh()`
- Slice function: `xl_slice()`
- Concatenate function: `xl_concat()`
- Reinterpret function: `xl_force()`
- Internal state variables: `xl_state()`
- MATLAB Functions:

<code>disp()</code>	Displays variable values
<code>error()</code>	Displays message and abort function
<code>isnan()</code>	Tests whether a number is NaN
<code>NaN()</code>	Returns Not-a-Number
<code>num2str()</code>	Converts a number to string
<code>ones(1,N)</code>	Returns 1-by-N vector of ones
<code>pi()</code>	Returns pi
<code>zeros(1,N)</code>	Returns 1-by-N vector of zeros

- Data Types :**

There are three kinds of `xfix` data types: unsigned fixed-point (`xlUnsigned`), signed fixed-point(`xlSigned`), and boolean (`xlBoolean`). Arithmetic operations on these data types produce signed and unsigned fixed-point values. Relational operators produce a boolean result. Relational operands can be any `xfix` type, provided the mixture of types makes sense. Boolean variables can be compared to boolean variables, but not to fixed-point numbers; boolean variables are incompatible with arithmetic operators. Logical operators can only be applied to boolean variables. Every operation is performed in full precision, for example, with the minimum precision needed to guarantee that no information is lost.

- Literal Constants:** Integer, floating-point, and boolean literals are supported. Integer literals are automatically converted to `xfix` values of appropriate width having a binary point position at zero. Floating-point literals must be converted to the `xfix` type explicitly with the `xfix()` conversion function. The predefined MATLAB values `true` and `false` are automatically converted to boolean literals.
- Assignment:** The left-hand side of an assignment can only contain one variable. A variable can be assigned more than once.
- Control Flow:**

The conditional expression of an `if` statement must evaluate to a boolean. Switch statements can contain a `case` clause and an `otherwise` clause. The types of a switch selector and its cases must be compatible; thus, the selector can be boolean provided its cases are. All cases in a `switch` must be constant; equivalently, no `case` can depend on an input value.

When the same variable is assigned in several branches of a control statement, the types being assigned must be compatible. For example,

```
if (u > v)
    x = a;
else
    x = b;
end
```

is acceptable only if `a` and `b` are both boolean or both arithmetic.

- **Constant Expressions:**

An expression is constant provided its value does not depend on the value of any input argument. Thus, for example, the variable `c` defined by

```
a = 1;
b = a + 2;
c = xfix({xlSigned, 10, 2}, b + 3.345);
```

can be used in any context that demands a constant.

- **xfix() Conversion:**

The `xfix()` conversion function converts a `double` to an `xfix`, or changes one `xfix` into another having different characteristics. A call on the conversion function looks like the following

```
x = xfix(type_spec, value)
```

Here `x` is the variable that receives the `xfix`. `type_spec` is a cell array that specifies the type of `xfix` to create, and `value` is the value being operated on. The `value` can be floating point or `xfix` type. The `type_spec` cell array is defined using curly braces in the usual MATLAB method. For example,

```
xfix({xlSigned, 20, 16, xlRound, xlWrap}, 3.1415926)
```

returns an `xfix` approximation to `pi`. The approximation is signed, occupies 20 bits (16 fractional), quantizes by rounding, and wraps on overflow.

The `type_spec` consists of 1, 3, or 5 elements. Some elements can be omitted. When elements are omitted, default element settings are used. The elements specify the following properties (in the order presented): data type, width, binary point position, quantization mode, and overflow mode. The data type can be `xlBoolean`, `xlUnsigned`, or `xlSigned`. When the type is `xlBoolean`, additional elements are not needed (and must not be supplied). For other types, width and binary point position must be supplied. The quantization and overflow modes are

optional, but when one is specified, the other must be as well. Three values are possible for quantization: `xlTruncate`, `xlRound`, and `xlRoundBanker`. The default is `xlTruncate`. Similarly, three values are possible for overflow: `xlWrap`, `xlSaturate`, and `xlThrowOverflow`. For `xlThrowOverflow`, if an overflow occurs during simulation, an exception occurs.

All values in a `type_spec` must be known at compilation time; equivalently, no `type_spec` value can depend on an input to the function.

The following is a more elaborate example of an `xfixed()` conversion:

```
width = 10, binpt = 4;
z = xfixed({xlUnsigned, width, binpt}, x + y);
```

This assignment to `x` is the result of converting `x + y` to an unsigned fixed-point number that is 10 bits wide with 4 fractional bits using `xlTruncate` for quantization and `xlWrap` for overflow.

If several `xfixed()` calls need the same `type_spec` value, you can assign the `type_spec` to a variable, then use the variable for `xfixed()`

calls. For example, the following is allowed:

```
proto = {xlSigned, 10, 4};
x = xfixed(proto, a);
y = xfixed(proto, b);
```

- **xfixed Properties: `xl_arith`, `xl_nb_bits`, and `xl_binpt`:**

Each `xfixed` number has three properties: the arithmetic type, the bit width, and the binary point position. The MCode blocks provide three functions to get these properties of a fixed-point number. The results of these functions are constants and are evaluated when Simulink compiles the model.

Function `a = xl_arith(x)` returns the arithmetic type of the input number `x`. The return value is either 1, 2, or 3 for `xlUnsigned`, `xlSigned`, or `xlBoolean` respectively.

Function `n = xl_nb_bits(x)` returns the width of the input number `x`.

Function `b = xl_binpt(x)` returns the binary point position of the input number `x`.

- **Bit-wise Operators: `xl_or`, `xl_and`, `xl_xor`, and `xl_not` :**

The MCode block provides four built-in functions for bit-wise logical operations: `xl_or`, `xl_and`, `xl_xor`, and `xl_not`.

Function `xl_or`, `xl_and`, and `xl_xor` perform bit-wise logical or, and, and xor operations respectively. Each function is in the form of

```
x = xl_op(a, b, ).
```

Each function takes at least two fixed-point numbers and returns a fixed-point number. All the input arguments are aligned at the binary point position.

Function `xl_not` performs a bit-wise logical not operation. It is in the form of `x = xl_not(a)`. It only takes one `xfix` number as its input argument and returns a fixed-point number.

The following are some examples of these function calls:

```
X = xl_and(a, b);
Y = xl_or(a, b, c);
Z = xl_xor(a, b, c, d);
N = xl_not(x);
```

- **Shift Operators: `xl_lsh`, and `xl_rsh`:**

Functions `xl_lsh` and `xl_rsh` allow you to shift a sequence of bits of a fixed-point number. The function is in the form:

`x = xl_lsh(a, n)` and `x = xl_rsh(a, n)` where `a` is a `xfix` value and `n` is the number of bits to shift.

Left or right shift the fixed-point number by `n` number of bits. The right shift (`xl_rsh`) moves the fixed-point number toward the least significant bit. The left shift (`xl_lsh`) function moves the fixed-point number toward the most significant bit. Both shift functions are a full precision shift. No bits are discarded and the precision of the output is adjusted as needed to accommodate the shifted position of the binary point.

Here are some examples:

```
% left shift a 5 bits
a = xfix({xlSigned, 20, 16, xlRound, xlWrap}, 3.1415926)
b = xl_rsh(a, 5);
```

The output `b` is of type `xlSigned` with 21 bits and the binary point located at bit 21.

- **Slice Function: `xl_slice`:**

Function `xl_slice` allows you to access a sequence of bits of a fixed-point number. The function is in the form:

```
x = xl_slice(a, from_bit, to_bit).
```

Each bit of a fixed-point number is consecutively indexed from zero for the LSB up to the MSB. For example, given an 8-bit wide number with binary point position at zero, the LSB is indexed as 0 and the MSB is indexed as 7. The block will throw an error if the `from_bit` or `to_bit` arguments are out of the bit index range of the input number. The result of the function call is an unsigned fixed-point number with zero binary point position.

Here are some examples:

```
% slice 7 bits from bit 10 to bit 4
b = xl_slice(a, 10, 4);
% to get MSB
c = xl_slice(a, xl_nbBits(a)-1, xl_nbBits(a)-1);
```

- **Concatenate Function: `xl_concat`:**

Function `x = xl_concat(hi, mid, ..., low)` concatenates two or more fixed-point numbers to form a single fixed-point number. The first input argument occupies the most significant bits, and the last input argument occupies the least significant bits. The output is an unsigned fixed-point number with binary point position at zero.

- **Reinterpret Function: `xl_force`:**

Function `x = xl_force(a, arith, binpt)` forces the output to a new type with `arith` as its new arithmetic type and `binpt` as its new binary point position. The `arith` argument can be one of `xlUnsigned`, `xlSigned`, or `xlBoolean`. The `binpt` argument must be from 0 to the bit width inclusively. Otherwise, the block will throw an error.

- **State Variables: `xl_state`:**

An MCode block can have internal state variables that hold their values from one simulation step to the next. A state variable is declared with the MATLAB keyword `persistent` and must be initially assigned with an `xl_state` function call.

The following code models a 4-bit accumulator:

```
function q = accum(din, rst)
    init = 0;

    persistent s, s = xl_state(init, {xlSigned, 4, 0});
    q = s;
    if rst
        s = init;
    else
        s = s + din;
    end
```

The state variable `s` is declared as persistent, and the first assignment to `s` is the result of the `xl_state` invocation. The `xl_state` function takes two arguments. The first is the initial value and must be a constant. The second is the precision of the state variable. It can be a type cell array as described in the `xfix` function call. It can also be an `xfix` number. In the above code, if `s = xl_state(init, din)`, then state variable `s` will use `din` as the precision. The `xl_state` function must be assigned to a persistent variable.

The `xl_state` function behaves in the following way:

1. In the first cycle of simulation, the `xl_state` function initializes the state variable with the specified precision.
2. In the following cycles of simulation, the `xl_state` function retrieves the state value left from the last clock cycle and assigns the value to the corresponding variable with the specified precision.

`v = xl_state(init, precision)` returns the value of a state variable. The first input argument `init` is the initial value, the second argument `precision` is the precision for this state variable. The argument `precision` can be a cell array in the form of `{type, nbits, binpt}` or `{type, nbits, binpt, quantization, overflow}`. The `precision` argument can also be an `xfix` number.

`v = xl_state(init, precision, maxlen)` returns a vector object. The vector is initialized with `init` and will have `maxlen` for the maximum length it can be. The vector is initialized with `init`. For example, `v = xl_state(zeros(1, 8), prec, 8)` creates a vector of 8 zeros, `v = xl_state([], prec, 8)` creates an empty vector with 8 as maximum length, `v = xl_state(0, prec, 8)` creates a vector of one zero as content and with 8 as the maximum length.

Conceptually, a vector state variable is a double ended queue. It has two ends, the front which is the element at address 0 and the back which is the element at length - 1.

Methods available for vector are:

<code>val = v(idx);</code>	Returns the value of element at address <code>idx</code> .
<code>v(idx) = val;</code>	Assigns the element at address <code>idx</code> with <code>val</code> .
<code>f = v.front;</code>	Returns the value of the front end. An error is thrown if the vector is empty.
<code>v.push_front(val);</code>	Pushes <code>val</code> to the front and then increases the vector length by 1. An error is thrown if the vector is full.
<code>v.pop_front;</code>	Pops one element from the front and decreases the vector length by 1. An error is thrown if the vector is empty.
<code>b = v.back;</code>	Returns the value of the back end. An error is thrown if the vector is empty.
<code>v.push_back(val);</code>	Pushes <code>val</code> to the back and the increases the vector length by 1. An error is thrown if the vector is full.
<code>v.pop_back;</code>	Pops one element from the back and decreases the vector length by 1. An error is thrown if the vector is empty.

<code>v.push_front_pop_back(val);</code>	Pushes val to the front and pops one element out from the back. It's a shift operation. The length of the vector is unchanged. The vector cannot be empty to perform this operation.
<code>full = v.full;</code>	Returns <code>true</code> if the vector is full, otherwise, <code>false</code> .
<code>empty = v.empty;</code>	Returns <code>true</code> if the vector is empty, otherwise, <code>false</code> .
<code>len = v.length;</code>	Returns the number of elements in the vector.

A method of a vector that queries a state variable is called a *query method*. It has a return value. The following methods are query method: `v(idx)`, `v.front`, `v.back`, `v.full`, `v.empty`, `v.length`, `v maxlen`. A method of a vector that changes a state variable is called an *update method*. An update method does not return any value. The following methods are update methods: `v(idx) = val`, `v.push_front(val)`, `v.pop_front`, `v.push_back(val)`, `v.pop_back`, and `v.push_front_pop_back(val)`. All query methods of a vector must be invoked before any update method is invocation during any simulation cycle. An error is thrown during model compilation if this rule is broken.

The MCode block can map a vector state variable into a vector of registers, a delay line, an addressable shift register, a single port ROM, or a single port RAM based on the usage of the state variable. The `xl_state` function can also be used to convert a MATLAB 1-D array into a zero-indexed constant array. If the MCode block cannot map a vector state variable into an FPGA, an error message is issued during model netlist time. The following are examples of using vector state variables.

### Delay Line

The state variable in the following function is mapped into a delay line.

```
function q = delay(d, lat)
    persistent r, r = xl_state(zeros(1, lat), d, lat);
    q = r.back;
    r.push_front_pop_back(d);
```

### Line of Registers

The state variable in the following function is mapped into a line of registers.

```
function s = sum4(d)
    persistent r, r = xl_state(zeros(1, 4), d);
    S = r(0) + r(1) + r(2) + r(3);
    r.push_front_pop_back(d);
```

### Vector of Constants

The state variable in the following function is mapped into a vector of constants.

```
function s = myadd(a, b, c, d, nbits, binpt)
    p = {xlSigned, nbits, binpt, xlRound, xlSaturate};
    persistent coef, coef = xl_state([3, 7, 3.5, 6.7], p);
    s = a*coef(0) + b*coef(1) + c*coef(2) + d*coef(3);
```

### Addressable Shift Register

The state variable in the following function is mapped into an addressable shift register.

```
function q = addrsr(d, addr, en, depth)
    persistent r, r = xl_state(zeros(1, depth), d);
    q = r(addr);
    if en
        r.push_front_pop_back(d);
    end
```

### Single Port ROM

The state variable in the following function is mapped into a single port ROM.

```
function q = addrsr(contents, addr, arith, nbits, binpt)
    proto = {arith, nbits, binpt};
    persistent mem, mem = xl_state(contents, proto);
    q = mem(addr);
```

- **Single Port RAM:**

The state variable in the following function is mapped to a single port RAM in fabric (Distributed RAM).

```
function dout = ram(addr, we, din, depth, nbits, binpt)
    proto = {xlSigned, nbits, binpt};
    persistent mem, mem = xl_state(zeros(1, depth), proto);
    dout = mem(addr);
    if we
        mem(addr) = din;
    end
```

The state variable in the following function is mapped to BlockRAM as a single port RAM.

```
function dout = ram(addr, we, din, depth, nbits, binpt, ram_enable)
    proto = {xlSigned, nbits, binpt};
    persistent mem, mem = xl_state(zeros(1, depth), proto);
    persistent dout_temp, dout_temp = xl_state(0, proto);
    dout = dout_temp;
```

```
dout_temp = mem(addr);
if we
    mem(addr) = din;
end
```

## MATLAB Functions

- **disp()**:

Displays the expression value. In order to see the printing on the MATLAB console, the option **Enable printing with disp** must be checked on the **Advanced** tab of the MCode block parameters dialog box. The argument can be a string, an `xfix` number, or an MCode state variable. If the argument is an `xfix` number, it will print the type, binary value, and double precision value. For example, if variable `x` is assigned with `xfix({x1Signed, 10, 7}, 2.75)`, the `disp(x)` will print the following line:

```
type: Fix_10_7, binary: 010.1100000, double: 2.75
```

If the argument is a vector state variable, `disp()` will print out the type, maximum length, current length, and the binary and double values of all the elements. For each simulation step, when **Enable printing with disp** is on and when a `disp()` function is invoked, a title line is printed for the corresponding block. The title line includes the block name, Simulink simulation time, and FPGA clock number.

The following MCode function shows several examples of using the `disp()` function.

```
function x = testdisp(a, b)
persistent dly, dly = xl_state(zeros(1, 8), a);
persistent rom, rom = xl_state([3, 2, 1, 0], a);
disp('Hello World!');
disp(['num2str(dly) is ', num2str(dly)]);
disp('disp(dly) is ');
disp(dly);
disp('disp(rom) is ');
disp(rom);
a2 = dly.back;
dly.push_front_pop_back(a);
x = a + b;
disp(['a = ', num2str(a), ', ', ...
'b = ', num2str(b), ', ', ...
'x = ', num2str(x)]);
disp(num2str(true));
disp('disp(10) is ');
disp(10);
disp('disp(-10) is ');
disp(-10);
disp('disp(a) is ');
disp(a);
disp('disp(a == b)');
disp(a==b);
```

The following lines are the result for the first simulation step.

```
xlmcode_testdisp/MCode (Simulink time: 0.000000, FPGA clock: 0)
Hello World!
num2str(dly) is [0.000000, 0.000000, 0.000000, 0.000000, 0.000000,
0.000000,
0.000000, 0.000000]
disp(dly) is
type: Fix_11_7,
 maxlen: 8,
 length: 8,
0: binary 0000.0000000, double 0.000000,
1: binary 0000.0000000, double 0.000000,
2: binary 0000.0000000, double 0.000000,
3: binary 0000.0000000, double 0.000000,
4: binary 0000.0000000, double 0.000000,
5: binary 0000.0000000, double 0.000000,
6: binary 0000.0000000, double 0.000000,
7: binary 0000.0000000, double 0.000000,
disp(rom) is
type: Fix_11_7,
 maxlen: 4,
 length: 4,
0: binary 0011.0000000, double 3.0,
1: binary 0010.0000000, double 2.0,
2: binary 0001.0000000, double 1.0,
3: binary 0000.0000000, double 0.0,
a = 0.000000, b = 0.000000, x = 0.000000
1
disp(10) is
type: UFix_4_0, binary: 1010, double: 10.0
disp(-10) is
type: Fix_5_0, binary: 10110, double: -10.0
disp(a) is
type: Fix_11_7, binary: 0000.0000000, double: 0.000000
disp(a == b)
type: Bool, binary: 1, double: 1
```

- **error()**:

Displays message and abort function. See MATLAB help on this function for more detailed information. Message formatting is not supported by the MCode block. For example:

```
if latency <= 0
    error('latency must be a positive');
end
```

- **isnan()**:

Returns true for Not-a-Number. `isnan(X)` returns true when `X` is Not-a-Number. `X` must be a scalar value of double or Xilinx fixed-point number. This function is not supported for vectors or matrices. For example:

```
if isnan(incr) & incr == 1
    cnt = cnt + 1;
end
```

- **NaN()**:

The `NaN()` function generates an IEEE arithmetic representation for Not-a-Number. A NaN is obtained as a result of mathematically undefined operations like  $0.0/0.0$  and  $\inf-\inf$ . `NaN(1,N)` generates a 1-by-N vector of NaN values. Here are examples of using NaN.

```
if x < 0
    z = NaN;
else
    z = x + y;
end
```

- **num2Str()**:

Converts a number to a string. `num2str(X)` converts the `X` into a string. `X` can be a scalar value of double, a Xilinx fixed-point number, or a vector state variable. The default number of digits is based on the magnitude of the elements of `X`. Here's an example of `num2str`:

```
if opcode <= 0 | opcode >= 10
    error(['opcode is out of range: ', num2str(opcode)]);
end
```

- **ones()**:

The `ones()` function generates a specified number of one values. `ones(1,N)` generates a 1-by-N vector of ones. `ones(M,N)` where M must be 1. It's usually used with `xl_state()` function call. For example, the following line creates a 1-by-4 vector state variable initialized to [1, 1, 1, 1].

```
ersistent m, m = xl_state(ones(1, 4), proto)
```

- **zeros()**:

The `zeros()` function generates a specified number of zero values. `zeros(1,N)` generates a 1-by-N vector of zeros. `zero(M,N)` where M must be 1. It's usually used with `xl_state()` function call. For example, the following line creates a 1-by-4 vector state variable initialized to [0, 0, 0, 0].

```
ersistent m, m = xl_state(zeros(1, 4), proto)
```

- **FOR Loop:**

FOR statement is fully unrolled. The following function sums  $n$  samples.

```
function q = sum(din, n)
persistent regs, regs = xl_state(zeros(1, 4), din);
q = reg(0);
for i = 1:n-1
    q = q + reg(i);
end
regs.push_front_pop_back(din);
```

The following function does a bit reverse.

```
function q = bitreverse(d)
q = xl_slice(d, 0, 0);
for i = 1:xl_nbBits(d)-1
    q = xl_concat(q, xl_slice(d, i, i));
end
```

- **Variable Availability :**

MATLAB code is sequential (for example, statements are executed in order). The MCode block requires that every possible execution path assigns a value to a variable before it is used (except as a left-hand side of an assignment). When this is the case, the variable is *available* for use. The MCode block will throw an error if its M-code function accesses unavailable variables.

Consider the following M-code:

```
function [x, y, z] = test1(a, b)
x = a;
if a>b
    x = a + b; y = a;
end
switch a
case 0
    z = a + b;
case 1
    z = a - b;
end
```

Here  $a$ ,  $b$ , and  $x$  are available, but  $y$  and  $z$  are not. Variable  $y$  is not available because the **if** statement has no **else**, and variable  $z$  is not available because the **switch** statement has no **otherwise** part.

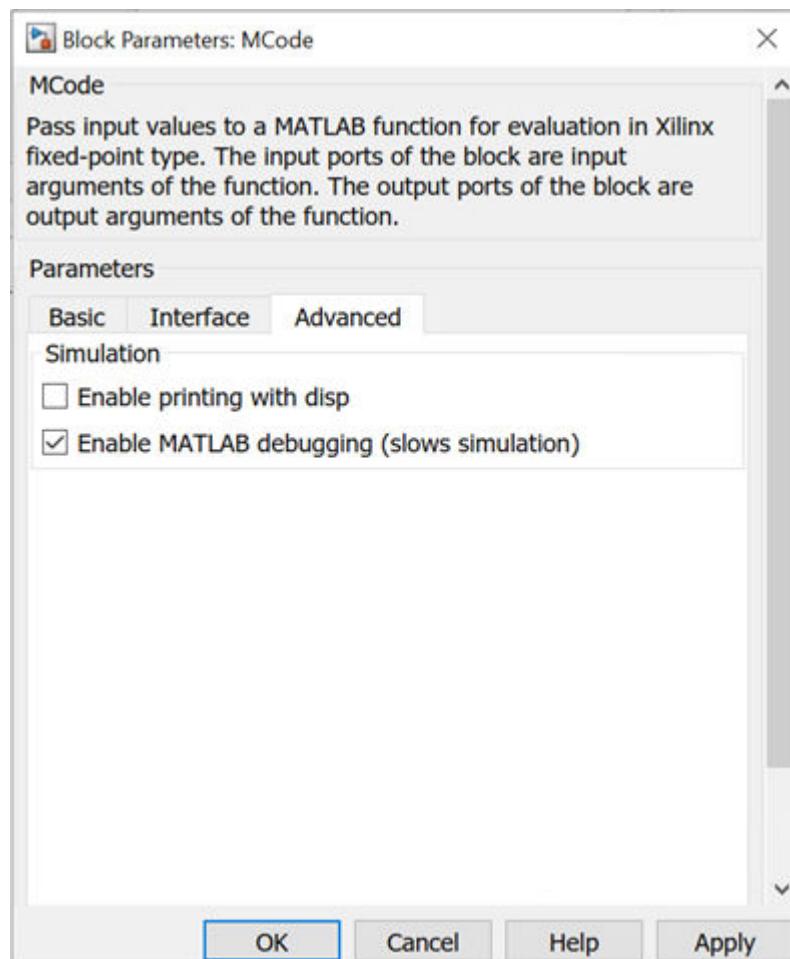
- **Debug MCode:**

There are two ways to debug your MCode. One is to insert `disp()` functions in your code and enable printing; the other is to use the MATLAB debugger. For usage of the `disp()` function, see the `disp()` section in this topic.

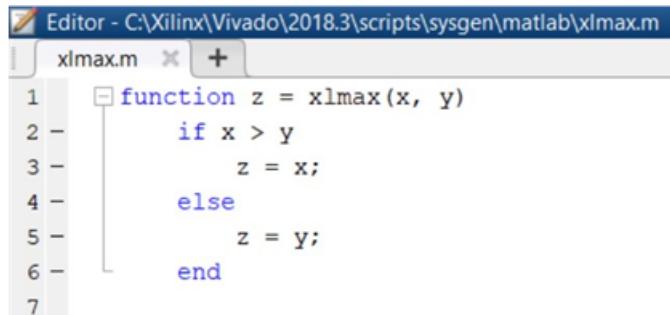
If you want to use the MATLAB debugger, you need to check the **Enable MATLAB debugging** option on the **Advanced** tab of the MCode block parameters dialog box. Then you can open your MATLAB function with the MATLAB editor, set break points, and debug your M-function. Just be aware that every time you modify your script, you need to execute a `clear functions` command in the MATLAB console.

To start debugging your M-function, you need to first check the **Enable MATLAB debugging** check box on the **Advanced** tab of the MCode block parameters dialog, then click the **OK** or **Apply** button.

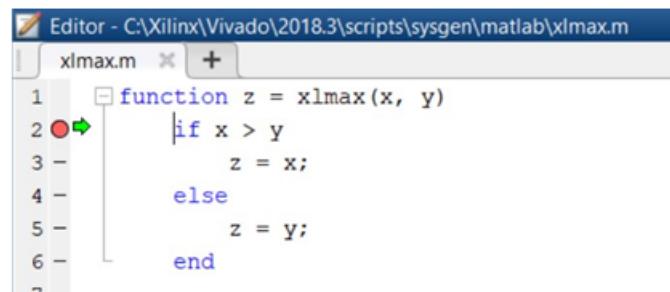
Figure 294: **Enable MATLAB Debugging**



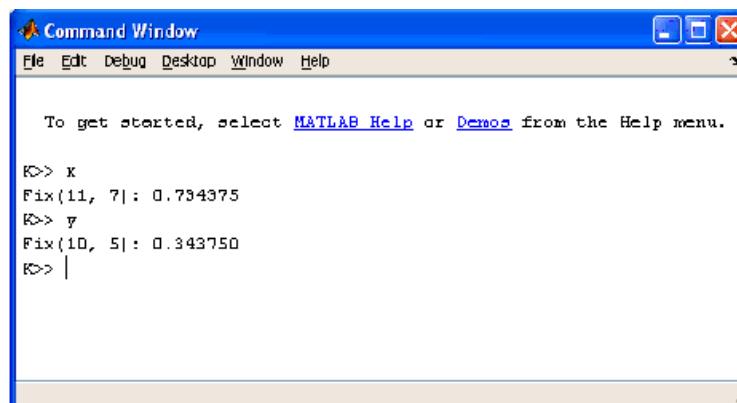
Now you can edit the M-file with the MATLAB editor and set break points as needed.

**Figure 295: Set Break Points**

During the Simulink simulation, the MATLAB debugger will stop at the break points you set when the break points are reached.

**Figure 296: Stopping at Break Point**

When debugging, you can also examine the values of the variables by typing the variable names in the MATLAB console.

**Figure 297: Examining Variable**

There is one special case to consider when the function for an MCode block is executed from the MATLAB debugger. A `switch/case` expression inside an MCode block must be type `xfix`, however, executing a `switch/case` expression from the MATLAB console requires that the expression be a `double` or `char`. To facilitate execution in the MATLAB console, a call to `double()` must be added. For example, consider the following:

```
switch i
  case 0
    x = 1
  case 1
    x = 2
end
```

where `i` is type `xfix`. To run from the console this code must changed to

```
switch double(i)
  case 0
    x = 1
  case 1
    x = 2
end
```

The `double()` function call only has an effect when the M code is run from the console. The MCode block ignores the `double()` call.

- **Passing Parameters:**

It is possible to use the same M-function in different MCode blocks, passing different parameters to the M-function so that each block can behave differently. This is achieved by binding input arguments to some values. To bind the input arguments, select the **Interface** tab on the block GUI. After you bind those arguments to some values, these M-function arguments will not be shown as input ports of the MCode block.

Consider for example, the following M-function:

```
function dout = xl_sconvert(din, nbits, binpt)
proto = {xlSigned, nbits, binpt};
dout = xfix(proto, din);
```

The following figures shows how the bindings are set for the `din` input of two separate `xl_sconvert` blocks.

Figure 298: din Bindings, Example 1

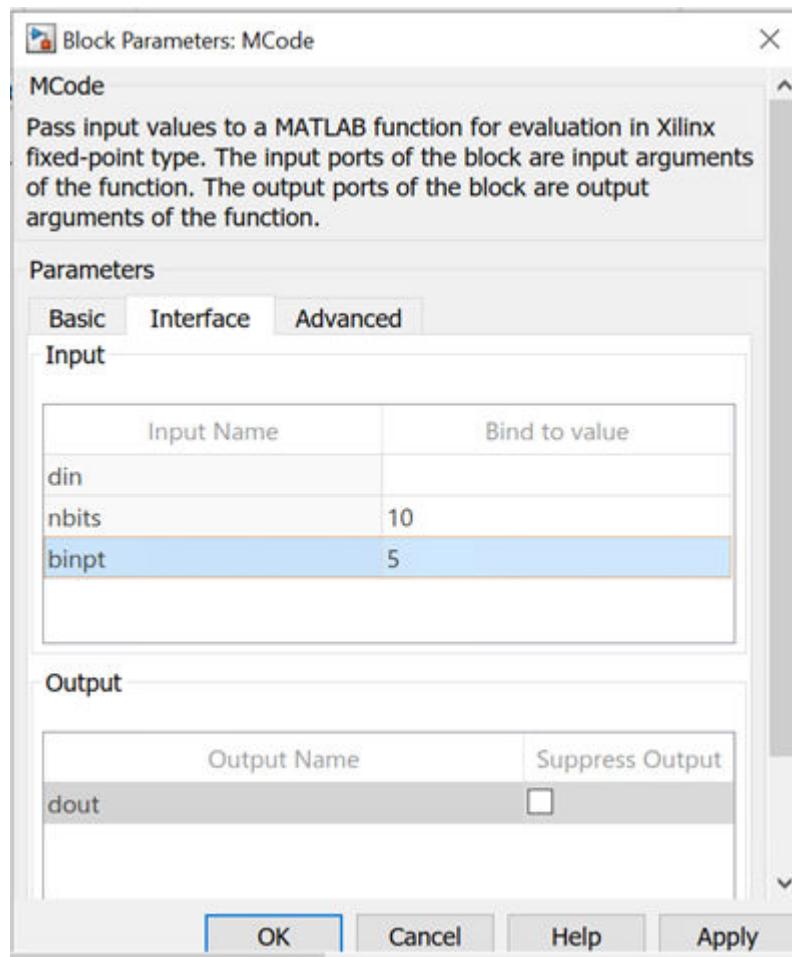
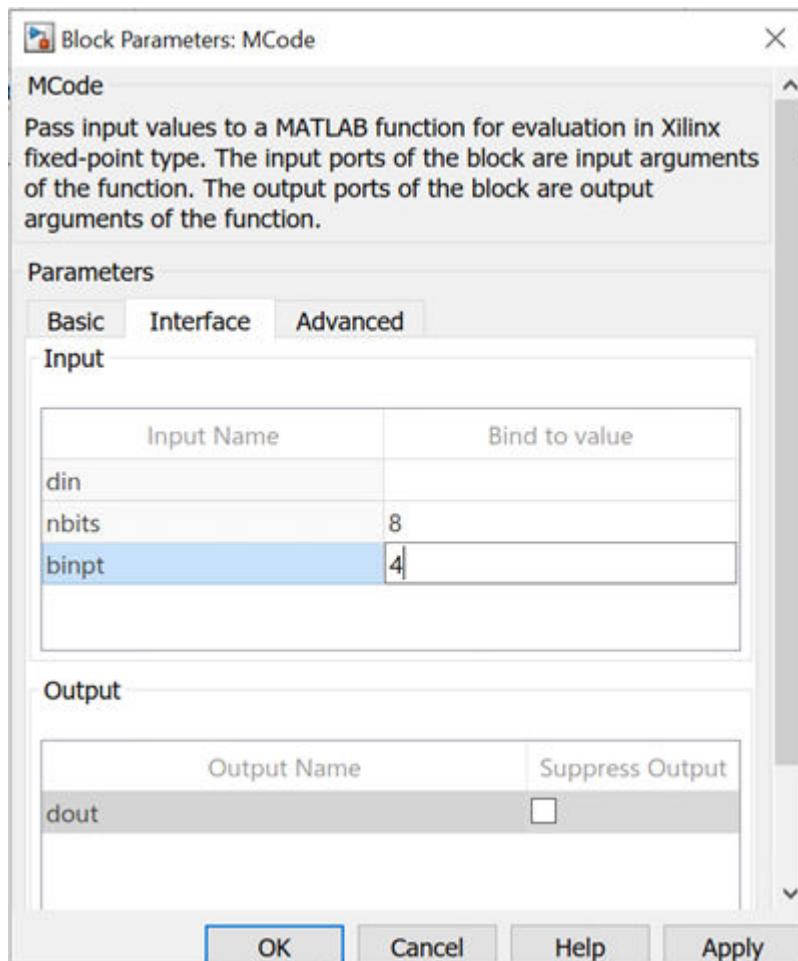
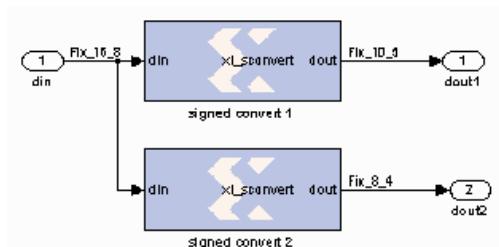


Figure 299: din Bindings, Example 2



The following figure shows the block diagram after the model is compiled.

Figure 300: Block Diagram



The parameters can only be of type double or they can be logical numbers.

- **Optional Input Ports:**

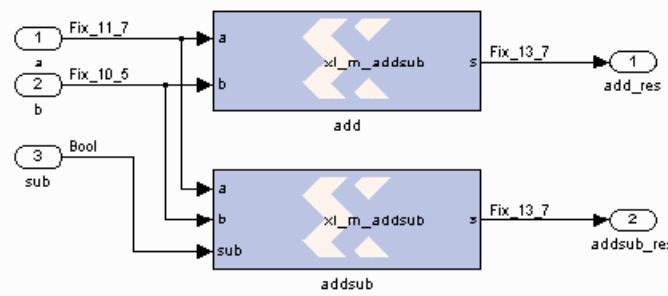
The parameter passing mechanism allows the MCode block to have optional input ports.  
Consider for example, the following M-function:

```
function s = xl_m_addsub(a, b, sub)
if sub
    s = a - b;
else
    s = a + b;
end
```

If `sub` is set to be `false`, the MCode block that uses this M-function will have two input ports `a` and `b` and will perform full precision addition. If it is set to an empty cell array {}, the block will have three input ports `a`, `b`, and `sub` and will perform full precision addition or subtraction based on the value of input port `sub`.

The following figure shows the block diagram of two blocks using the same `xl_m_addsub` function, one having two input ports and one having three input ports.

**Figure 301: Two Blocks Using Same `xl_m_addsub` Function**



- **Constructing a State Machine:**

There are two ways to build a state machine using an MCode block. One way is to specify a stateless transition function using a MATLAB function and pair an MCode block with one or more state register blocks. Usually the MCode block drives a register with the value representing the next state, and the register feeds back the current state into the MCode block. For this to work, the precision of the state output from the MCode block must be static, that is, independent of any inputs to the block. Occasionally you might find you need to use `xfix()` conversions to force static precision. The following code illustrates this:

```
function nextstate = fsm1(currentstate, din)
    % some other code
    nextstate = currentstate;
    switch currentstate
        case 0, if din==1, nextstate = 1; end
    end
    % a xfix call should be used at the end
    nextstate = xfix({xlUnsigned, 2, 0}, nextstate);
```

Another way is to use state variables. The above function can be re-written as follows:

```
function currentstate = fsm1(din)
    persistent state, state=xl_state(0,{xlUnsigned,2,0});
    currentstate = state;
    switch double(state)
        case 0, if din==1; state = 1; end
    end
```

- **Reset and Enable Signals for State Variables:**

The MCode block can automatically infer register reset and enable signals for state variables when conditional assignments to the variables contain two or fewer branches.

For example, the following M-code infers an enable signal for conditional assignment of persistent state variable `r1`:

```
function myFn = aFn(en, a)
    persistent r1, r1 = xl_state(0, {xlUnsigned, 2, 0});
    myFn = r1;
    if en
        r1 = r1 + a
    else
        r1 = r1
    end
```

There are two branches in the conditional assignment to persistent state variable `r1`. A register is used to perform the conditional assignment. The input of the register is connected to `r1 + a`, the output of the register is `r1`. The register's enable signal is inferred; the enable signal is connected to `en`, when `en` is asserted. Persistent state variable `r1` is assigned to `r1 + a` when `en` evaluates to `false`, the enable signal on the register is de-asserted resulting in the assignment of `r1` to `r1`.

The following M-code will also infer an enable signal on the register used to perform the conditional assignment:

```
function myFn = aFn(en, a)
    persistent r1, r1 = xl_state(0, {xlUnsigned, 2, 0});
    myFn = r1;
    if en
        r1 = r1 + a
    end
```

An enable is inferred instead of a reset because the conditional assignment of persistent state variable `r1` is to a non-constant value, `r1 + a`.

If there were three branches in the conditional assignment of persistent state variable `r1`, the enable signal would not be inferred. The following M-code illustrates the case where there are three branches in the conditional assignment of persistent state variable `r1` and the enable signal is not inferred:

```
function myFn = aFn(en, en2, a, b)
    persistent r1, r1 = xl_state(0, {xlUnsigned, 2, 0});
    if en
        r1 = r1 + a
    elseif en2
        r1 = r1 + b
    else
        r1 = r1
    end
```

The reset signal can be inferred if a persistent state variable is conditionally assigned to a constant; the reset is synchronous. Consider the following M-code example which infers a reset signal for the assignment of persistent state variable `r1` to `init`, a constant, when `rst` evaluates to true and `r1 + 1` otherwise:

```
function myFn = aFn(rst)
    persistent r1, r1 = xl_state(0, {xlUnsigned, 4, 0});
    myFn = r1;
    init = 7;
    if (rst)
        r1 = init
    else
        r1 = r1 + 1
    end
```

The M-code example above which infers reset can also be written as:

```
function myFn = aFn(rst)
    persistent r1, r1 = xl_state(0, {xlUnsigned, 4, 0});
    init = 1;
    myFn = r1;
    r1 = r1 +1
    if (rst)
        r1 = init
    end
```

In both code examples above, the reset signal of the register containing persistent state variable `r1` is assigned to `rst`. When `rst` evaluates to `true`, the register's reset input is asserted and the persistent state variable is assigned to constant `init`. When `rst` evaluates to `false`, the register's reset input is de-asserted and persistent state variable `r1` is assigned to `r1 + 1`. Again, if the conditional assignment of a persistent state variable contains three or more branches, a reset signal is not inferred on the persistent state variable's register.

It is possible to infer reset and enable signals on the register of a single persistent state variable. The following M-code example illustrates simultaneous inference of reset and enable signals for the persistent state variable `r1`:

```
function myFn = aFn(rst,en)
persistent r1, r1 = xl_state(0, {xlUnsigned, 4, 0});
myFn = r1;
init = 0;
if rst
    r1 = init
else
    if en
        r1 = r1 + 1
    end
end
```

The reset input for the register of persistent state variable `r1` is connected to `rst`; when `rst` evaluates to `true`, the register's reset input is asserted and `r1` is assigned to `init`. The enable input of the register is connected to `en`; when `en` evaluates to `true`, the register's enable input is asserted and `r1` is assigned to `r1 + 1`. It is important to note that an inferred reset signal takes precedence over an inferred enable signal regardless of the order of the conditional assignment statements. Consider the second code example above; if both `rst` and `en` evaluate to `true`, persistent state variable `r1` would be assigned to `init`.

Inference of reset and enable signals also works for conditional assignment of persistent state variables using switch statements, provided the switch statements contain two or less branches.

The MCode block performs dead code elimination and constant propagation compiler optimizations when generating code for the FPGA. This can result in the inference of reset and/or enable signals in conditional assignment of persistent state variables, when one of the branches is never executed. For this to occur, the conditional must contain two branches that are executed after dead code is eliminated, and constant propagation is performed.

- **Inferring Registers:**

Registers are inferred in hardware by using persistent variables, however, the right coding style must be used. Consider the two code segments in the following function:

```
function [out1, out2] = persistent_test02(in1, in2)
persistent ff1, ff1 = xl_state(0, {xlUnsigned, 2, 0});
persistent ff2, ff2 = xl_state(0, {xlUnsigned, 2, 0});
%code segment 1
out1 = ff1; %these two statements infer a register for ff1
ff1 = in1;
%code segment 2
ff2 = in2; %these two statements do NOT infer a register for ff2
out2 = ff2;
end
```

In code segment 1, the value of persistent variable ff1 is assigned to out1. Since ff1 is persistent, it is assumed that its current value was assigned in the previous cycle. In the next statement, the value of in1 is assigned to ff1 so it can be saved for the next cycle. This infers a register for ff1.

In code segment 2, the value of in2 is first assigned to persistent variable ff2, then assigned to out2. These two statements can be completed in one cycle, so a register is not inferred. If you need to insert delay into combinational logic, refer to the next topic.

- **Pipelining Combinational Logic:**

The generated FPGA bitstream for an MCode block might contain many levels of combinational logic and hence a large critical path delay. To allow a downstream logic synthesis tool to automatically pipeline the combinational logic, you can add delay blocks before the MCode block inputs or after the MCode block outputs. These delay blocks should have the parameter **Implement using behavioral HDL** set, which instructs the code generator to implement delay with synthesizable HDL. You can then instruct the downstream logic synthesis tool to implement register re-timing or register balancing. As an alternative approach, you can use the vector state variables to model delays.

- **Shift Operations with Multiplication and Division:**

The MCode block can detect when a number is multiplied or divided by constants that are powers of two. If detected, the MCode block will perform a shift operation. For example, multiplying by 4 is equivalent to left shifting 2 bits and dividing by 8 is equivalent to right shifting 3 bits. A shift is implemented by adjusting the binary point, expanding the `xfix` container as needed. For example, a `Fix_8_4` number multiplied by 4 will result in a `Fix_8_2` number, and a `Fix_8_4` number multiplied by 64 will result in a `Fix_10_0` number.

- **Using the `xl_state` Function with Rounding Mode:**

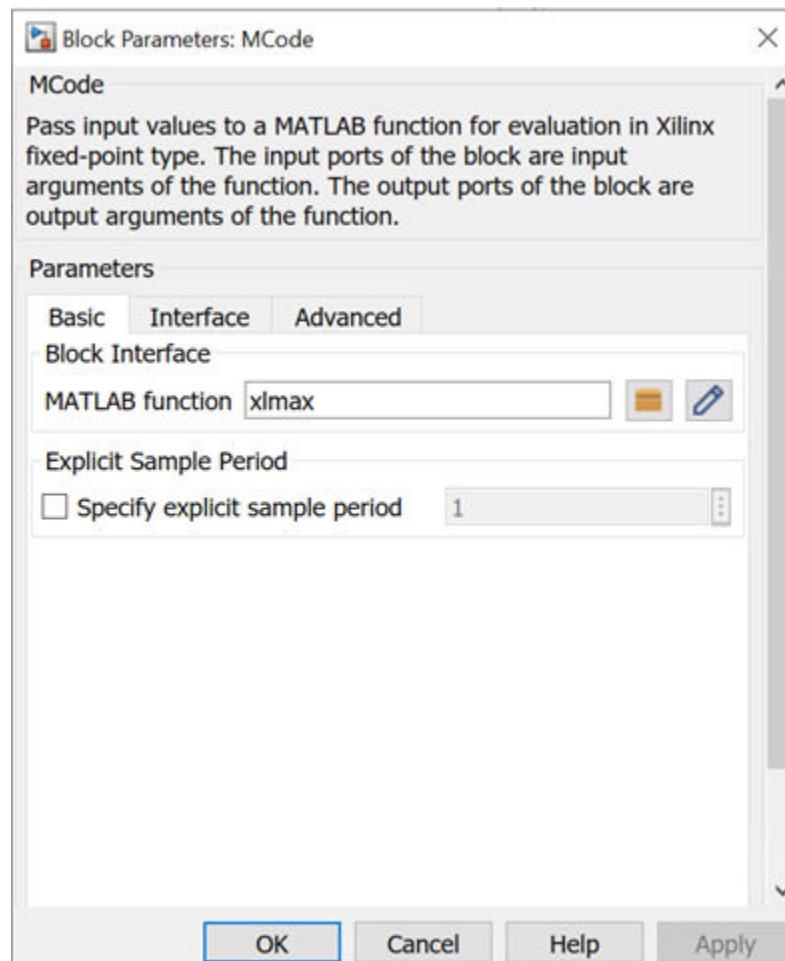
The `xl_state` function call creates an `xfix` container for the state variable. The container's precision is specified by the second argument passed to the `xl_state` function call. If precision uses `xlRound` for its rounding mode, hardware resources are added to accomplish the rounding. If rounding the initial value is all that is required, an `xfix` call to round a constant does not require additional hardware resources. The rounded value can then be passed to the `xl_state` function. For example:

```
init = xfix({xlSigned,8,5,xlRound,xlWrap}, 3.14159);
persistent s, s = xl_state(init, {xlSigned, 8, 5});
```

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the block icon in a Simulink® model.

Figure 302: Block Parameters

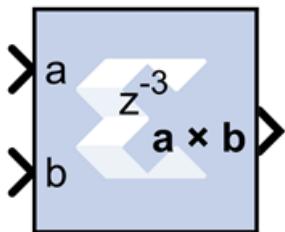


As described earlier in this topic, the **MATLAB function** parameter on an MCode block tells the name of the block's function, and the **Interface** tab specifies a list of constant inputs and their values.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Mult

The Xilinx Mult block implements a multiplier. It computes the product of the data on its two input ports, producing the result on its output port.



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to the Basic tab are as follows.

- **Precision:**

This parameter allows you to specify the output precision for fixed-point arithmetic. Floating point output always has **Full** precision.

- **Full:** The block uses sufficient precision to represent the result without error.
  - **User Defined:** If you do not need full precision, this option allows you to specify a reduced number of total bits and/or fractional bits.

- **Fixed-point output type:**

- **Arithmetic Type:**

- **Signed (2's comp):** The output is a Signed (2's complement) number.
    - **Unsigned:** The output is an Unsigned number.
    - **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
    - **Binary point:** Position of the binary point in the fixed-point output.

- **Quantization:**

Refer to the Overflow and Quantization section in the [Common Options in Block Parameter Dialog Boxes](#) topic.

- **Overflow:**

Refer to the Overflow and Quantization section in the [Common Options in Block Parameter Dialog Boxes](#) topic.

- **Optional Port:** Provide enable port

- **Latency:** This defines the number of sample periods by which the block's output is delayed.

**Note:** Only when latency of the Mult block is set to 4 in Model Composer, are all three pipeline stages used in the generated Multiplier IP.

- **Implementation tab:** Parameters specific to the Implementation tab are as follows.

- **Use behavioral HDL (otherwise use core):**

The block is implemented using behavioral HDL. This gives the downstream logic synthesis tool maximum freedom to optimize for performance or area.

**Note:** For Floating-point operations, the block always uses the Floating-point Operator core.

- **Core Parameters:**

- **Optimize for Speed|Area:** Directs the block to be optimized for either Speed or Area.
- **Use embedded multipliers:** This field specifies that if possible, use the XtremeDSP slice (DSP48 type embedded multiplier) in the target device.
- **Test for optimum pipelining:** Checks if the Latency provided is at least equal to the optimum pipeline length. Latency values that pass this test imply that the core produced is optimized for speed.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

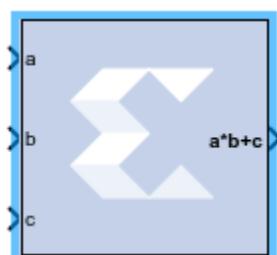
## LogiCORE™ Documentation

*Multiplier LogiCORE IP Product Guide (PG108)*

*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

## MultAdd

The Xilinx MultAdd block performs both fixed-point and floating-point multiply and addition with the a and b inputs used for the multiplication and the c input for addition or subtraction.



If the MultAdd inputs are floating point, then inputs a,b, and c must be of the same data type. If the inputs are fixed point, then the port c binary point must be aligned to the sum of the port a and port b binary points.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Operation:**
    - **Addition:** Specifies that an addition will be performed after multiplication.
    - **Subtraction:** Specifies that a subtraction will be performed after multiplication.
    - **Addition or subtraction:** Adds a `subtract` port to the block, which controls whether the operation following multiplication is addition or subtraction (`subtract` High = subtraction, `subtract` Low = addition).
  - **Optional Ports:**
    - **Provide enable port:** Adds an active-High enable port to the block interface.
    - **Latency:** This defines the number of sample periods by which the block's output is delayed. The latency values you can set depend on whether you are performing fixed point or floating point arithmetic:
      - For fixed point arithmetic, you can only specify a latency of **0** (for no latency) or **-1** (for maximum/optimal latency). If you have added an enable port to the block interface, you can only specify a latency of **-1** for fixed point arithmetic.
      - For floating point arithmetic, you can only specify a latency of **0** (for no latency) or a positive integer. If you have added an enable port to the block interface, you can only specify a positive integer for floating point arithmetic.

See the *Multiply Adder LogiCORE IP Product Guide* ([PG192](#)) for details on latency in the block.

- **Output tab:**

Parameters specific to the Output tab are as follows.

- **Precision:** This parameter allows you to specify the output precision for fixed-point arithmetic. Floating point arithmetic output will always be **Full** precision.
  - **Full:** The block uses sufficient precision to represent the result without error.
  - **User Defined:** If you do not need full precision, this option allows you to specify a reduced number of total bits and/or fractional bits.
- **Fixed-point Output Type:** Arithmetic type
  - **Signed (2's comp):** The output is a Signed (2's complement) number.
  - **Unsigned:** The output is an Unsigned number.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

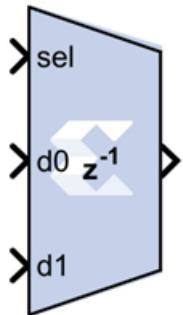
### LogiCORE Documentation

*Multiply Adder LogiCORE IP Product Guide ([PG192](#))*

*Floating-Point Operator LogiCORE IP Product Guide ([PG060](#))*

## Mux

The Xilinx Mux block implements a multiplexer. The block has one select input (type unsigned) and a user-configurable number of data bus inputs, ranging from 2 to 32.



### Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**
  - **Number of inputs:** specify a number between 2 and 32.
  - **Optional Ports:** Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).
- **Output tab:**
  - **Precision:** This parameter allows you to specify the output precision for fixed-point arithmetic. Floating point arithmetic output will always be **Full** precision.
    - **Full:** The block uses sufficient precision to represent the result without error.
    - **User Defined:** If you do not need full precision, this option allows you to specify a reduced number of total bits and/or fractional bits.

- **Fixed-point output type:**
  - **Arithmetic type:**
    - **Signed (2's comp):** The output is a Signed (2's complement) number.
    - **Unsigned:** The output is an Unsigned number.
  - **Number of bits:** Specifies the bit location of the binary point of the output number where bit zero is the least significant bit.
  - **Binary point:** Position of the binary point. in the fixed-point output.

- **Quantization:**

Refer to the section Overflow and Quantization in the topic [Common Options in Block Parameter Dialog Boxes](#).

- **Overflow:**

Refer to the section Overflow and Quantization in the topic [Common Options in Block Parameter Dialog Boxes](#).

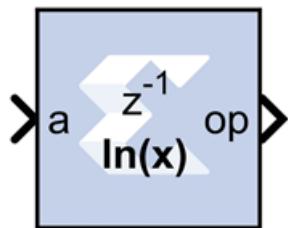
Parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

### LogiCORE Documentation

*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

## Natural Logarithm

The Xilinx Natural Logarithm block produces the natural logarithm of the input.



### Block Parameters Dialog Box

- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Flow Control Options:**

- **Blocking:** In this mode, the block waits for data on the input, as indicated by TREADY, which allows back-pressure.
- **NonBlocking:** In this mode, the block operates every cycle in which the input is valid, no back-pressure.
- **Optional Ports tab:**

Parameters specific to the Optional Ports tab are as follows.

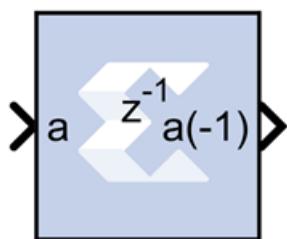
- **Input Channel Ports:**
  - **Has TLAST:** Adds a tlast input port to the block.
  - **Has TUSER:** Adds a tuser input port to the block.
- **Control Options:**
  - **Provide enable port:** Adds an enable port to the block interface.
  - **Has Result TREADY:** Adds a TREADY port to the output channel.
- **Exception Signals::**
  - **INVALID\_OP:** Adds an output port that serves as an invalid operation flag.
  - **DIVIDE\_BY\_ZERO:** Adds an output port that serves as a divide-by-zero flag.

## LogiCORE Documentation

Floating-Point Operator LogiCORE IP Product Guide ([PG060](#))

## Negate

The Xilinx Negate block computes the arithmetic negation of its input.



## Block Parameters

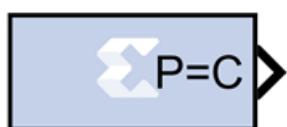
The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Precision:** This parameter allows you to specify the output precision for fixed-point arithmetic. Floating point output always has **Full** precision.
    - **Full:** The block uses sufficient precision to represent the result without error.
    - **User Defined:** If you do not need full precision, this option allows you to specify a reduced number of total bits and/or fractional bits.
  - **Fixed-Point Output Type:** Arithmetic Type
  - **Signed (2's comp):** The output is a Signed (2's complement) number.
  - **Unsigned:** The output is an Unsigned number.
- **Fixed-point Precision:**
  - **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
  - **Binary point:** Position of the binary point in the fixed-point output.
- **Quantization:** Refer to the section Overflow and Quantization in the topic [Common Options in Block Parameter Dialog Boxes](#).
- **Overflow:** Refer to the section Overflow and Quantization in the topic [Common Options in Block Parameter Dialog Boxes](#).
- **Optional Port:** Provide enable port
- **Latency:** This defines the number of sample periods by which the block's output is delayed.

Parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

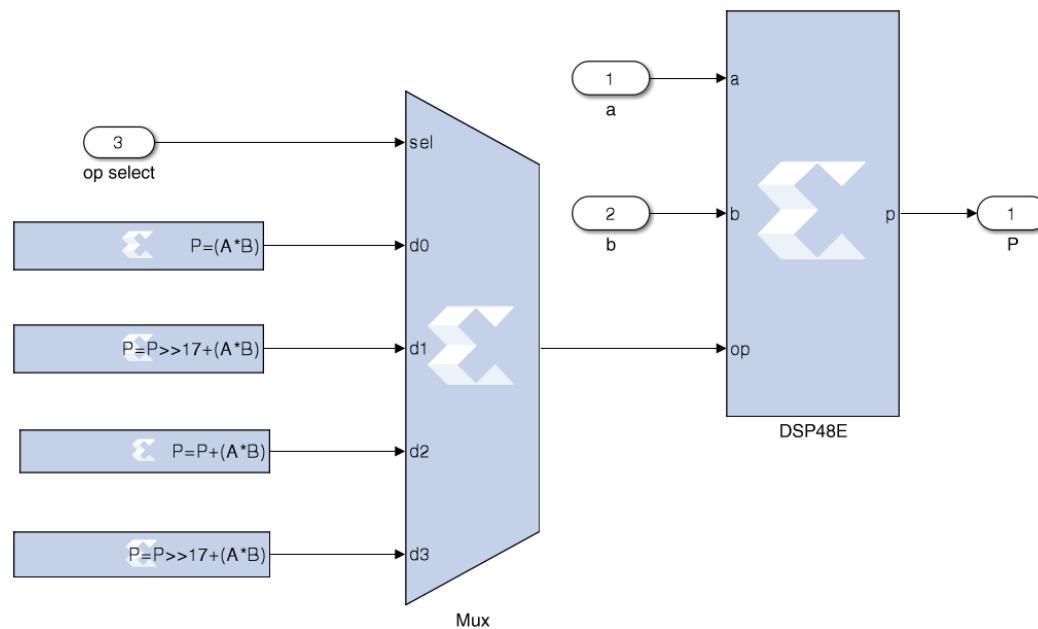
## Opmode

The Xilinx Opmode block generates a constant that is a DSP48E, DSP48E1, DSP48E2, DSP58, or DSPCPLX instruction. It is a 15-bit instruction for DSP48E, a 20-bit instruction for DSP48E1, and a 22-bit instruction for DSP48E2. The instruction consists of the opmode, carry-in, carry-in select, alumode, and (for DSP48E1 and DSP48E2) the inmode bits.



The Opmode block is useful for generating DSP48E, DSP48E1, DSP48E2, DSP58, or DSPCPLX control sequences. The figure below shows an example. The example implements a 35x35-bit multiplier using a sequence of four instructions in a DSP48E block. The Opmode blocks supply the desired instructions to a multiplexer that selects each instruction in the desired sequence.

Figure 303: DSP48E Block



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Opmode tab:**

Parameters specific to the Opmode tab are as follows.

- **Instruction:**

- **Device:** Specifies whether to generate an instruction for the DSP48E, DSP48E1, DSP48E2, DSP58, or DSPCPLX device.

- **DSP Instruction:**

- **Operation:** Displays the instruction that is generated by the block. This instruction is also displayed on the block in the Simulink model.
- **Operation select:** Selects the instruction.
- **Padder output:** Allows you to select the equation for the DSP48E1 Padder.
- **DSP Primitive Configuration:**

- **Multiplier Output:** Allows you to select the Multiplier Output of DSP58 to be normal or negated.
- **Preadder/Mult Function:** Allows you to select the function performed by the DSP48E2 Preadder/Multiplier.
- **PREADDINSEL:** Displays the setting of the PREADDINSEL static control bits that are part of the instruction generated by the Opmode block. In the DSP48E2 slice, the PREADDINSEL setting (A or B) selects the input to be added with the D input in the pre-adder.
- **AMULTSEL:** Displays the setting of the AMULTSEL static control bits that are part of the instruction generated by the Opmode block. In the DSP48E2 slice, the AMULTSEL setting (A or AD) selects the input to the 27-bit A input of the multiplier.
- **BMULTSEL:** Displays the setting of the BMULTSEL static control bits that are part of the instruction generated by the Opmode block. In the DSP48E2 slice, the BMULTSEL setting (B or AD) selects the input to the 18-bit B input of the multiplier.
- **A register configuration:** Allows you to select the A register configuration for the DSP48E2. Select either A1 or A2.
- **B register configuration:** Allows you to select the B register configuration for the DSP48E1 or DSP48E2. Select either B1 or B2.

- **Custom Instruction:**

**Note:** The Custom Instruction field is activated when you select “Custom” in the **Operation select** field.

- **Instruction:** Allows you to select the instruction for the DSP48E, DSP48E1, or DSP48E2.
- **Z mux:** Specifies the 'Z' source to the add/sub/logic unit to be one of {'0', 'C', 'PCIN', 'P'C', 'PCIN>>17', P>>17'}.
- **XY muxes:** Specifies the 'XY' source to the DSP48's adder to be one of {'0'P', 'A:B', 'A\*B', 'C', 'P+C', 'A:B+C' }. 'A:B' implies that A is concatenated with B to produce a value to be used as an input to the add/sub/logic unit.
- **W mux:** Specifies the 'W' source to the DSP48E2's adder to be one of {'0'P', 'RND', 'C' }.
- **Carry input:** Specifies the 'carry' source to the DSP48's add/sub/logic unit to be one of {'0', '1', 'CIN', 'Round PCIN towards infinity', 'Round PCIN towards zero', 'Round P towards infinity', 'Round P towards zero', 'Larger add/sub/acc (parallel operation)', 'Larger add/sub/acc (sequential operation)', 'Round A\*B' }.

For a description of any of the Custom Instruction options, see the following manuals:

- DSP48E: Virtex-5 FPGA XtremeDSP Design Considerations ([UG193](#))
- DSP48E1: 7 Series DSP48E1 Slice User Guide ([UG479](#))
- DSP48E2: UltraScale Architecture DSP Slice User Guide ([UG579](#))
- Versal ACAP DSP Engine Architecture Manual ([AM004](#))

## Xilinx LogiCORE

The Opemode block does not use a Xilinx LogiCORE.

## DSP48E Control Instruction Format

*Table 66: DSP48E Instruction*

Operation select	Notes
C + A*B	
PCIN + A*B	
P + A*B	
A*B	
C + A:B	
C - A:B	
C	
Custom	Use equation described in the Custom Instruction Field.

*Table 67: DSP48E Custom Instruction*

Instruction Field Name	Location	Mnemonic	Notes
XY muxes	op[3:0]	0	0
		P	DSP48 output register
		A:B	Concat inputs A and B (A is MSB)
		A*B	Multiplication of inputs A and B
		C	DSP48 input C
		P+C	DSP48 input C plus P
		A:B+C	Concat inputs A and B plus C register

Table 67: DSP48E Custom Instruction (cont'd)

Instruction Field Name	Location	Mnemonic	Notes
Z mux	op[6:4]	0	0
		PCIN	DSP48 cascaded input from PCOUT
		P	DSP48 output register
		C	DSP48 C input
		PCIN>>17	Cascaded input downshifted by 17
		P>>17	DSP48 output register downshifted by 17
Alumode	op[10:7]	X+Z	Add
		Z-X	Subtract
Carry input	op[14:12]	0 or 1	Set carry in to 0 or 1
		CIN	Select cin as source. This adds a CIN port to the Opmode block whose value is inserted into the mnemonic at bit location 11.
		Round PCIN toward infinity	
		Round PCIN toward zero	
		Round P toward infinity	
		Round P toward zero	
		Larger add/sub/acc (parallel operation)	
		Larger add/sub/acc (sequential operation)	
		Round A*B	

## DSP48E1 Control Instruction Format

Table 68: DSP48E1 Instruction

Operation select	Notes
C + A*B	
PCIN + A*B	
P + A*B	
A* B	
C + A:B	
C - A:B	
C	
Custom	Use equation described in the Custom Instruction Field.

Preadder output	Notes
Zero	

<b>Preadder output</b>	<b>Notes</b>
A2	
A1	
D + A2	
D + A1	
D	
-A2	
-A1	
D - A2	
D - A1	

<b>B register configuration</b>	<b>Notes</b>
B1	
B2	

*Table 69: DSP48E1 Custom Instruction*

<b>Instruction Field Name</b>	<b>Location</b>	<b>Mnemonic</b>	<b>Notes</b>
Instruction		X + Z	
		X +NOT(Z)	
		NOT(X+Z)	
		Z - X	
		X XOR Z	
		X XNOR Z	
		X AND Z	
		X OR Z	
		X AND NOT(Z)	
		X OR NOT (Z)	
Z mux	op[6:4]	X NAND Z	
		0	0
		PCIN	DSP48 cascaded input from PCOUT
		P	DSP48 output register
		C	DSP48 C input
		PCIN>>17	Cascaded input downshifted by 17
Operand: (Alumode)	op[10:7]	P>>17	DSP48 output register downshifted by 17
		X+Z	Add
		Z-X	Subtract

Table 69: DSP48E1 Custom Instruction (cont'd)

Instruction Field Name	Location	Mnemonic	Notes
XY muxes	op[3:0]	0	0
		P	DSP48 output register
		A:B	Concat inputs A and B (A is MSB)
		A*B	Multiplication of inputs A and B
		C	DSP48 input C
		P+C	DSP48 input C plus P
		A:B+C	Concat inputs A and B plus C register
Carry input	op[14:12]	0 or 1	Set carry in to 0 or 1
		CIN	Select cin as source. This adds a CIN port to the Opmode block whose value is inserted into the mnemonic at bit location 11.
		Round PCIN toward infinity	
		Round PCIN toward zero	
		Round P toward infinity	
		Round P toward zero	
		Larger add/sub/acc (parallel operation)	
		Larger add/sub/acc (sequential operation)	
		Round A*B	

## DSP48E2 Control Instruction Format

Table 70: DSP48E2 Instruction

Operation select	Notes
C + A*B	
PCIN + A*B	
P + A*B	
A* B	
C + A:B	
C - A:B	
C	
Custom	Use equation described in the Custom Instruction Field.

Preadder/Mult Function	Notes
Zero	
A*B	

<b>Preadder/Mult Function</b>	<b>Notes</b>
(D+A)*B	
(D-A)*B	
(D+A)**2	
(D-A)**2	
D**2	
A**2	
-(A**2)	
(D+A)*A	
(D-A)*A	
(D+B)*A	
(D-B)*A	
D*A	
B*A	
-B*A	
(D+B)**2	
(D-B)**2	
B**2	
-(B**2)	
(D+B)*B	
(D-B)*B	

<b>A register configuration</b>	<b>Notes</b>
A1	
A2	

<b>B register configuration</b>	<b>Notes</b>
B1	
B2	

Table 71: DSP48E2 Custom Instruction

Instruction Field Name	Location	Mnemonic	Notes
XY muxes	op[3:0]	0	0
		P	DSP48 output register
		A:B	Concat inputs A and B (A is MSB)
		A*B	Multiplication of inputs A and B
		C	DSP48 input C
		P+C	DSP48 input C plus P
		A:B+C	Concat inputs A and B plus C register
Z mux	op[6:4]	0	0
		PCIN	DSP48 cascaded input from PCOUT
		P	DSP48 output register
		C	DSP48 C input
		PCIN>>17	Cascaded input downshifted by 17
		P>>17	DSP48 output register downshifted by 17
W mux	op[8:7]	0	
		P	DSP48 output register
		RND	Rounding Constant into W mux
		C	DSP48 input C
ALU mode (Instruction)	op[12:9]	X + W + Z	
		X +W + NOT(Z)	
		NOT(X + W + Z)	
		Z - (X+W)	
		X XOR Z	
		X XNOR Z	
		X AND Z	
		X OR Z	
		X AND NOT(Z)	
		X OR NOT (Z)	
		X NAND Z	
		X NOR Z	
		NOT (X) OR Z	
		NOT (X) AND Z	
		X XOR Y XOR Z	

Table 71: DSP48E2 Custom Instruction (cont'd)

Instruction Field Name	Location	Mnemonic	Notes
Carry input	op[16:13]	0 or 1	Set carry in to 0 or 1
		CIN	Select CIN as source. This adds a CIN port to the Opmode block whose value is inserted into the mnemonic at bit location 11.
		Round PCIN toward infinity	
		Round PCIN toward zero	
		Round P toward infinity	
		Round P toward zero	
		Larger add/sub/acc (parallel operation)	
		Larger add/sub/acc (sequential operation)	
		Round A*B	
Pre-Adder/Mult Function	op[21:17]	Zero	
		A * B	
		(D + A) * B	
		(D - A) * B	
		(D + A)**2	
		(D - A)**2	
		D**2	
		A**2	
		-(A**2)	
		(D + A) * A	
		(D - A) * A	
		(D + B) * A	
		(D - B) * A	
		D * A	
		B * A	
		-B * A	
		(D + B)**2	
		(D - B)**2	
		B**2	
		-(B**2)	
		(D + B) * B	
		(D - B) * B	

### DSPCPLX Control Instruction Format

The OpMode block, when configured with a DSPCPLX device, outputs 18-bit wide data to drive the consolidated control port of the DSPCPLX block. The DSPCPLX block internally feeds the same setting to respective individual Real and Imaginary control input ports.

*Table 72: DSPCPLX Instruction*

Operation Select	Notes
A*B	
Custom	Use the equation described in the Custom Instruction Field.

*Table 73: DSPCPLX Custom Instruction*

Instruction Field Name	Location	Mnemonic	Notes
XY Muxes	op[3:0]	A*B	Multiplication of inputs A and B
Z mux	op[6:4]	0	0
		PCIN	DSPCPLX cascaded input from PCOUT
		P	DSPCPLX output register
		C	DSPCPLX C input
W mux	op[8:7]	0	
		RND	Rounding constant into W mux
ALU mode (Instruction)	op[12:9]	X + W + Z	
		X + W + NOT(Z)	
Carry input	op[16:13]	0 or 1	Set carry in to 0 or 1
		CIN	Select CIN as source. This adds a CIN port to the Opemode block whose value is inserted into the mnemonic at bit location 11.
Conjugate A Input	op[17]	0 or 1	Select to complex conjugate the input A value
Conjugate B Input	op[18]	0 or 1	Select to complex conjugate the input B value

### DSP58 Control Instruction Format

*Table 74: DSP58 Instruction*

Operation select	Notes
C + A*B	
PCIN + A*B	
P + A*B	
A* B	
C + A:B	
C - A:B	
C	

Table 74: DSP58 Instruction (cont'd)

Operation select	Notes
Custom	Use equation described in the Custom Instruction Field.

Preadder/Mult Function	Notes
Zero	
$\pm A \times B$	
$\pm(D \pm A) \times B$	
$\pm(D \pm A)^{**2}$	
$\pm(D)^{**2}$	
$\pm(A)^{**2}$	
$\pm(D \pm A) \times A$	
$\pm(D \pm B) \times A$	
$\pm D \times A$	
$\pm(D \pm B)^{**2}$	
$\pm(B)^{**2}$	
$\pm(D \pm B) \times B$	

A register configuration	Notes
A1	
A2	

B register configuration	Notes
B1	
B2	

Table 75: DSP58 Custom Instruction

Instruction Field Name	Location	Mnemonic	Notes
XY muxes	op[3:0]	0	0
		P	DSP58 output register
		A:B	Concat inputs A and B (A is MSB)
		A*B	Multiplication of inputs A and B
		C	DSP58 input C
		P+C	DSP58 input C plus P
		A:B+C	Concat inputs A and B plus C register

Table 75: DSP58 Custom Instruction (cont'd)

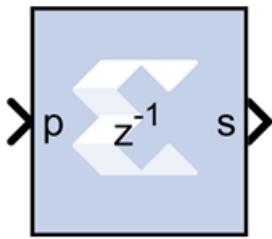
Instruction Field Name	Location	Mnemonic	Notes
Z mux	op[6:4]	0	0
		PCIN	DSP58 cascaded input from PCOUT
		P	DSP58 output register
		C	DSP58 C input
		PCIN>>23	Cascaded input downshifted by 23
		P>>23	DSP58 output register downshifted by 23
W mux	op[8:7]	0	
		P	DSP58 output register
		RND	Rounding Constant into W mux
		C	DSP58 input C
ALU mode (Instruction)	op[12:9]	X + W + Z	
		X +W + NOT(Z)	
		NOT(X + W + Z)	
		Z - (X+W)	
		X XOR Z	
		X XNOR Z	
		X AND Z	
		X OR Z	
		X AND NOT(Z)	
		X OR NOT (Z)	
		X NAND Z	
		X NOR Z	
		NOT (X) OR Z	
		NOT (X) AND Z	
		X XOR Y XOR Z	

Table 75: DSP58 Custom Instruction (cont'd)

Instruction Field Name	Location	Mnemonic	Notes
Carry input	op[16:13]	0 or 1	Set carry in to 0 or 1
		CIN	Select CIN as source. This adds a CIN port to the Opmode block whose value is inserted into the mnemonic at bit location 11.
		Round PCIN toward infinity	
		Round PCIN toward zero	
		Round P toward infinity	
		Round P toward zero	
		Larger add/sub/acc (parallel operation)	
		Larger add/sub/acc (sequential operation)	
		Round A*B	
Pre-Adder/Mult Function	op[21:17]	Zero	
		$\pm A*B$	
		$\pm(D \pm A)*B$	
		$\pm(D \pm A)^{**2}$	
		$\pm(D)^{**2}$	
		$\pm(A)^{**2}$	
		$\pm(D \pm A)*A$	
		$\pm(D \pm B)*A$	
		$\pm D*A$	
		$\pm(D \pm B)^{**2}$	
		$\pm(B)^{**2}$	
		$\pm(D \pm B)*B$	
Negate	op[24:22]	0 or 1	Select Negate to negate the Multiplier output

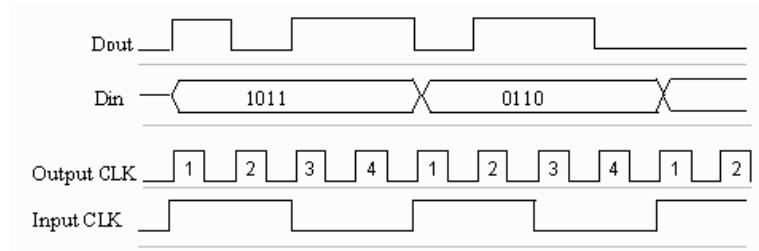
## Parallel to Serial

The Parallel to Serial block takes an input word and splits it into N time-multiplexed output words where N is the ratio of number of input bits to output bits. The order of the output can be either least significant bit first or most significant bit first.



The following waveform illustrates the block's behavior:

Figure 304: Block Behavior



This example illustrates the case where the input width is 4, output word size is 1, and the block is configured to output the most significant word first.

## Block Interface

The Parallel to Serial block has one input and one output port. The input port can be any size. The output port size is indicated on the Block Parameters dialog box.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

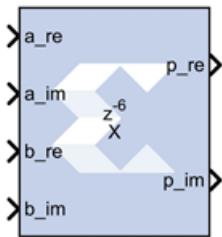
- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Output order:** Most significant word first or least significant word first.
  - **Type:** Signed or unsigned.
  - **Number of bits:** Output width. Must divide Number of Input Bits evenly.
  - **Binary Point:** Binary point location.

The minimum latency of this block is 0.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Product

The Xilinx Product block implements a scalar or complex multiplier. It computes the product of the data on its two input channels, producing the result on its output channel. For complex multiplication the input and output have two components: real and imaginary.



The Product block is ideal for generating a simple scalar or complex multiplier. If your implementation will use more complicated features such as AXI4 ports or a user-specified precision, use the Xilinx [Complex Multiplier 6.0](#) block (if you are configuring a complex multiplier) or Xilinx [Mult](#) block (if you are configuring a scalar multiplier) in your design instead of the Product block.

In the Vivado® design flow, the Product block is inferred as "LogiCORE™ IP Complex Multiplier" (if you have configured the Product block for complex multiplication) or "LogiCORE IP Multiplier" (if you have configured the Product block for scalar multiplication) for code generation. Refer to the [LogiCORE IP Complex Multiplier v6.0 Product Guide](#) or the [LogiCORE IP Multiplier v12.0 Product Guide](#) for details about these LogiCORE IP.

### Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Parameters specific to the block are as follows.

- **Complex Multiplication:** Specifies mode of operation: scalar multiplier (**Complex Multiplication** deselected) or complex multiplier (**Complex Multiplication** selected).
- **Optimize for:** Specifies whether your design will be optimized for **Performance** or for **Resources** when it is implemented in the Xilinx FPGA or SoC device.

Based on the settings for **Complex Multiplication** and **Optimize for**, and rate and type propagation (from the input data width), the latency value of the block will be derived automatically for a fully pipelined circuit. This latency value will be displayed on the block in the Simulink model.

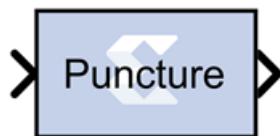
## LogiCORE Documentation

[LogiCORE IP Complex Multiplier v6.0](#)

[LogiCORE IP Multiplier v12.0](#)

## Puncture

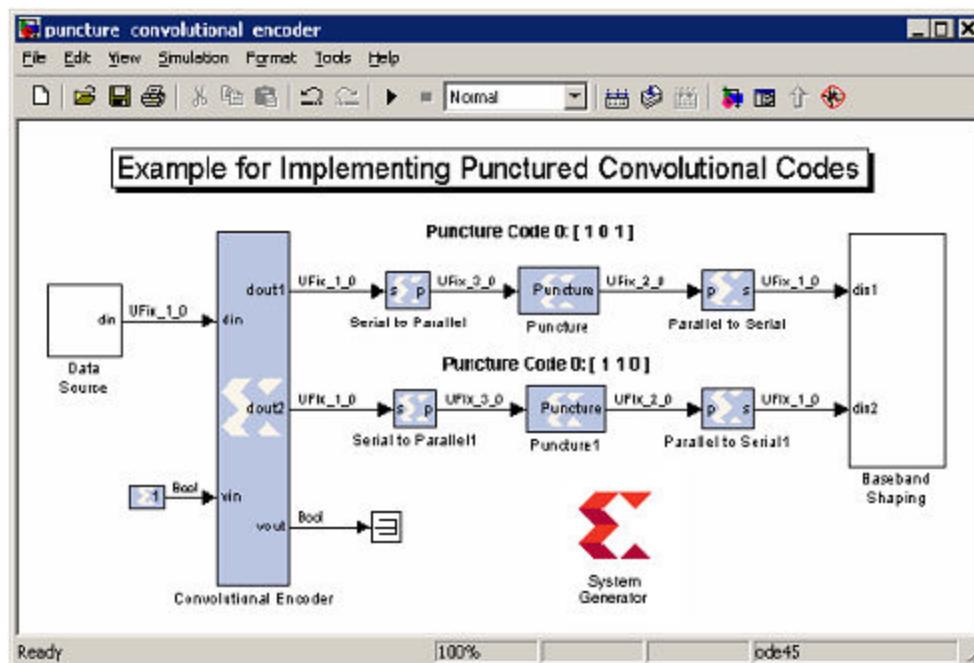
The Xilinx Puncture block removes a set of user-specified bits from the input words of its data stream.



Based on the Puncture Code parameter, a binary vector that specifies which bits to remove, it converts input data of type `UFixN_0` (where N is equal to the length of the puncture code) into output data of type `UFixK_0` (where K is equal to the number of ones in the puncture code). The output rate is identical to the input rate.

This block is commonly used in conjunction with a convolution encoder to implement punctured convolution codes as shown in the figure below.

*Figure 305: Implementing Punctured Convolution Codes*



The system shown implements a rate  $\frac{1}{2}$  convolution encoder whose outputs are punctured to produce four output bits for each three input bits. The top puncture block removes the center bit for code 0 ([1 0 1]) and bottom puncture block removes the least significant bit for code 1 ([1 1 0]), producing a 2-bit punctured output. These data streams are serialized into 1-bit in-phase and quadrature data streams for baseband shaping.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Parameters specific to the block are as follows:

- **Puncture Code:** The puncture pattern represented as a bit vector, where a zero in position  $i$  indicates bit  $i$  is to be removed.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Questa

The HDL [Black Box](#) block provides a way to incorporate existing HDL files into a model. When the model is simulated, co-simulation can be used to allow black boxes to participate. The Questa HDL co-simulation block configures and controls co-simulation for one or several black boxes.



During a simulation, each Questa block spawns one copy of Questa, and therefore uses one Questa license. If licenses are scarce, several black boxes can share the same block.

In detail, the Questa block does the following:

- Constructs the additional VHDL and Verilog needed to allow black box HDL to be simulated inside Questa.
- Spawns a Questa session when a Simulink simulation starts.
- Mediates the communication between Simulink and Questa.
- Reports if errors are detected when black box HDL is compiled.
- Terminates Questa, if appropriate, when the simulation is complete.

**Note:** The Questa block only supports symbolic radix in the Questa tool. In symbolic radix, Questa displays the actual values of an enumerated type, and also converts an object's value to an appropriate representation for other radix forms. Please refer to the Questa documentation for more information on symbolic radix.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

- **Basic tab:** Parameters specific to the Basic tab are as follows:

- **Run co-simulation in directory:**

Questa is started in the directory named by this field. The directory is created if necessary. All black box files are copied into this directory, as are the auxiliary files Model Composer produces for co-simulation. Existing files are overwritten silently. The directory can be specified as an absolute or relative path. Relative paths are interpreted with respect to the directory in which the Simulink .mdl file resides.

- **Open waveform viewer:**

When this checkbox is selected, the Questa waveform window opens automatically, displaying a standard set of signals. The signals include all inputs and outputs of all black boxes and all clock and clock enable signals supplied by Model Composer. The signal display can be customized with an auxiliary tcl script. To specify the script, select **Add Custom Scripts** and enter the script name (e.g., myscript.do) in the **Script to Run After vsim** field.

- **Leave Questa open at end of simulation:**

When this checkbox is selected, the Questa session is left open after the Simulink simulation has finished.

- **Skip compilation (use previous results):**

When this checkbox is selected, the Questa compilation phase is skipped in its entirety for all black boxes that are using the Questa block for HDL co-simulation. To select this option is to assert that: (1) underneath the directory in which Questa will run, there exists a Questa work directory, and (2) that the work directory contains up-to-date Questa compilation results for all black box HDL. Selecting this option can greatly reduce the time required to start-up the simulation, however, if it is selected when inappropriate, the simulation can fail to run or run but produce false results.

- **Advanced tab:** Parameters specific to the Advanced tab are as follows:

- **Include Unisim Libraries:** Selecting this check box enables the following path option in order to provide the path of the precompiled Unisim Library.

- **Path:** This parameter represents the actual path of the precompiled Unisim Library.
- **Enable Unisim Library for Verilog:** Selecting this check box ensures that Questa includes the Verilog UniSim library during simulation.

**Note:** The Verilog unisim library must be mapped to UNISIMS\_VER in Questa. In addition, selecting this check box ensures that the `g1b1.v` module is compiled and invoked during simulation.

- **Add custom scripts:**

The term “script” refers to a Tcl macro file (DO file) executed by Questa. Selecting this check box activates the fields **Script to Run Before Starting Compilation**, **Script to Run in Place of "vsim"**, and **Script to Run after "vsim"**. The DO file scripts named in these fields are not run unless this checkbox is selected.

- **Script to run before starting compilation:**

Enter the name of a Tcl macro file (DO file) that is to be executed by Questa before compiling black box HDL files.

**Note:** For information on how to write a Questa macro file (DO file) refer to the **Tcl and macros (DO files)** section in the *Vitis Model Composer User Guide* ([UG1483](#)).

- **Script to run in place of "vsim":**

Questa uses the Tcl (tool command language) as the scripting language for controlling and extending the tool. Enter the name of a Questa Tcl macro file (DO file) that is to be executed by the Questa `do` command at the point when Model Composer would ordinarily instruct Questa to begin a simulation. To start the simulation after the macro file starts executing, you must place a `vsim` command inside the macro file.

Normally, if this parameter is left blank, or Add custom scripts is not selected, then Model Composer instructs Questa to execute the default command `vsim $toplevel -title {Model Composer Co-Simulation (from block $blockname)}`. Here `$toplevel` is the name of the top level entity for simulation (e.g., `work.my_model_mti_block`) and `$blockname` is the name of the Questa block in the Simulink model associated with the current co-simulation. To avoid problems, certain characters in the block name (e.g., newlines) are sanitized.

If this parameter is not blank and **Add custom scripts** is selected, then Model Composer instead instructs Questa to execute `do $* $toplevel $blockname`. Here `$toplevel` and `$blockname` are as above and `$*` represents the literal text entered in the field. If, for example the literal text is '`foo . do`', then Questa executes `foo . do`. This macro file can then reference `$toplevel` and `$blockname` as `$1` and `$2`, respectively. Thus, the command `vsim $1` inside of the macro file `foo . do` runs `vsim` on `topLevel`.

- **Script to run after "vsim":**

Enter the name of a Tcl macro file (DO file) that is to be executed by Questa after all the HDL for black boxes has been successfully compiled, and after the Questa simulation has completed successfully. If the **Open Waveform Viewer** checkbox has been selected, Model Composer issues all commands it ordinarily uses to open and customize the waveform viewer before running this script. This allows you to customize the waveform viewer as desired (either by adding signals to the default viewer or by creating a fully custom viewer). The black box tutorial includes an example that customizes the waveform viewer.

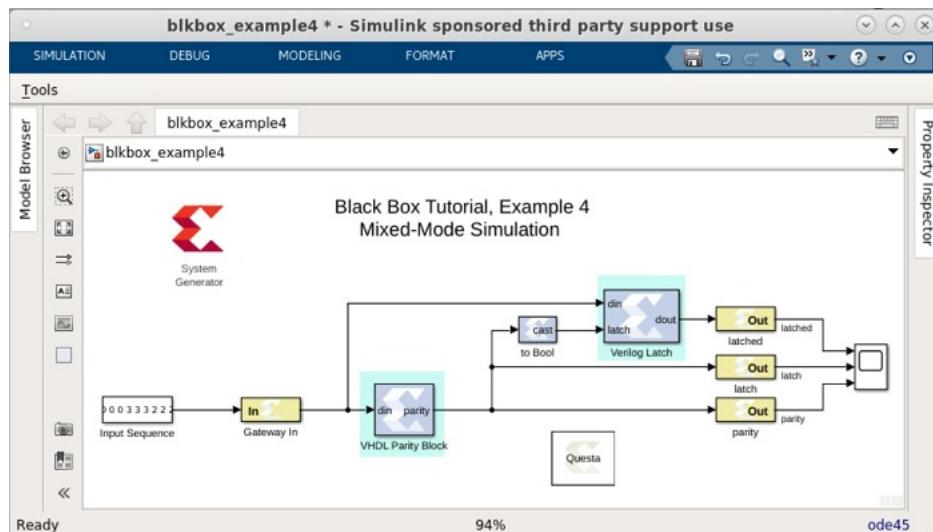
It is often convenient to use relative paths in a custom script. Relative paths are interpreted with respect to the directory that contains the model's MDL file. A relative path in the Run co-simulation in directory field is also interpreted with respect to the directory that contains the model's MDL file. Thus, for example, if Run co-Simulation in directory specifies `./questa` as the directory in which Questa should run, the relative path `../foo.do` in a script definition field refers to a file named `foo.do` in the directory that contains the `.mdl`.

## Fine Points

The time scale in Questa matches that in Simulink. For example, one second of Simulink simulation time corresponds to one second of Questa simulation time. This makes it easy to compare times at which events occur in the two settings. The typically large Simulink time scale is also useful because it allows Model Composer to schedule events without running into problems related to the timing characteristics of the HDL model. You need not worry too much about the details of Model Composer event scheduling in co-simulation models.

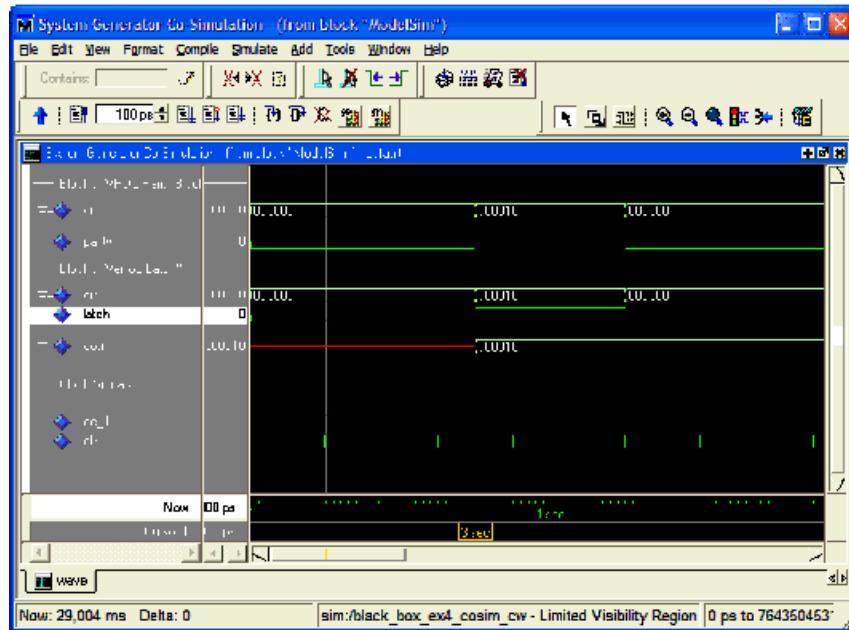
The following example is offered to illustrate the broader points.

*Figure 306: Example Model*



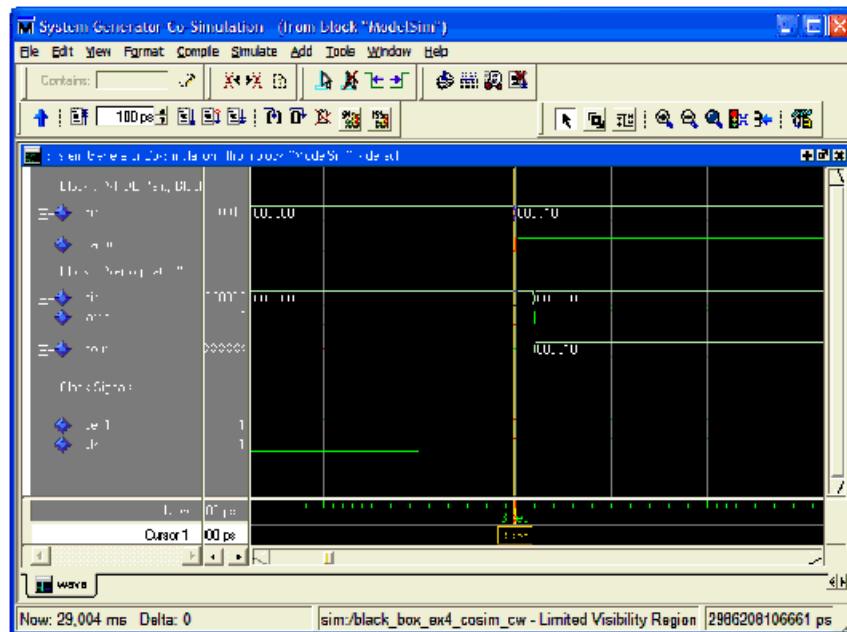
When the above model is run, the following waveforms are displayed by Questa:

Figure 307: Example Time Scale



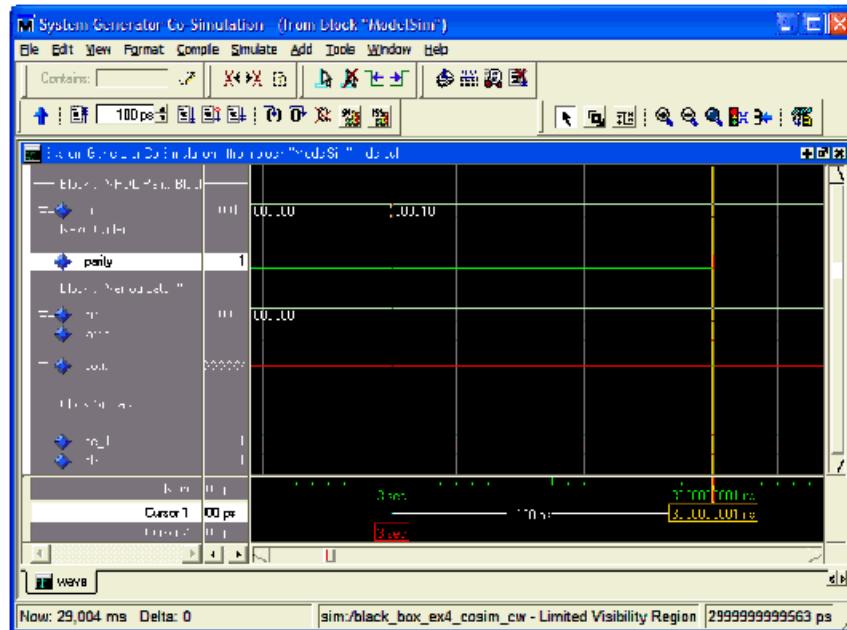
At the time scale presented here (the above shows a time interval of six seconds), the rising clock edge at three seconds and the corresponding transmission of data through each of the two black boxes appear simultaneous, much as they do in the Simulink simulation. Looking at the model, however, it is clear that the output of the first black box feeds the second black box. Both of the black boxes in this model have combinational feed-throughs, for example, changes on inputs translate into immediate changes on outputs. Zooming in toward the three second event reveals how Model Composer has resolved the dependencies. Note the displayed time interval has shrunk to ~20 ms.

Figure 308: Resolved Dependencies



The above figure reveals that Model Composer has shifted the rising clock edge so it occurs before the input value is collected from Simulink and presented to the first of the black boxes. It then allows the value to propagate through the first black box and presents the result to the second at a slightly later time. Zooming in still further shows that the HDL model for the first black box includes a propagation delay which Model Composer has effectively abstracted away through the use of large time scales. The actual delay through the first black box (exactly 1 ns) can be seen in the figure below.

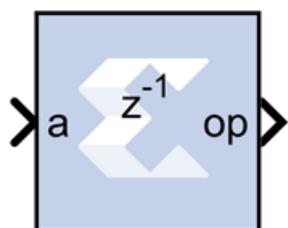
Figure 309: Delay Through the First Black Box



In propagating data through black box components, Model Composer allocates 1/ 1000 of the system clock period down to 1us, then shrinks the allocation to 1/100 of the system clock period down to 5 ns, and below that threshold resorts to delta-delay stepping, for example, issuing "run 0 ns" commands to Questa. If the HDL includes timing information (e.g., transport delays) and the Simulink System Period is set too low, then the simulation results are incorrect. The above model begins to fail when the Simulink system period setting is reduced below 5e-7, which is the point at which Model Composer resorts to delta-delay stepping of the black boxes for data propagation.

## Reciprocal

The Xilinx Reciprocal block performs the reciprocal on the input. Currently, only the floating-point data type is supported.



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

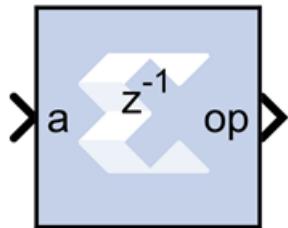
- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Flow Control:**
    - **Blocking:** Selects “Blocking” mode. In this mode, the lack of data on one input channel does block the execution of an operation if data is received on another input channel.
    - **NonBlocking:** Selects “Non-Blocking” mode. In this mode, the lack of data on one input channel does not block the execution of an operation if data is received on another input channel.
  - **Optional ports:**
    - **Input Channel Ports:**
      - **Has TLAST:** Adds a TLAST port to the Input channel.
      - **Has TUSER:** Adds a TUSER port to the Input channel.
      - **Provide enable port:** Adds an enable port to the block interface.
      - **Has Result TREADY:** Adds a TREADY port to the Result channel.
    - **Exception Signals:**
      - **UNDERFLOW:** Adds an output port that serves as an underflow flag.
      - **DIVIDE\_BY\_ZERO:** Adds an output port that serves as a divide-by-zero flag.

## LogiCORE Documentation

Floating-Point Operator LogiCORE IP Product Guide ([PG060](#))

## Reciprocal SquareRoot

The Xilinx Reciprocal SquareRoot block performs the reciprocal squareroot on the input. Currently, only the floating-point data type is supported.



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows.

- **Flow Control:**

- **Blocking:** Selects Blocking mode. In this mode, the lack of data on one input channel does block the execution of an operation if data is received on another input channel.
- **NonBlocking:** Selects Non-Blocking mode. In this mode, the lack of data on one input channel does not block the execution of an operation if data is received on another input channel.

- **Optional ports:**

- **Input Channel Ports:**

- **Has TLAST:** Adds a TLAST port to the Input channel.
- **Has TUSER:** Adds a TUSER port to the Input channel.
- **Provide enable port:** Adds an enable port to the block interface.
- **Has Result TREADY:** Adds a TREADY port to the Result channel.

- **Exception Signals:**

- **INVALID\_OP:** Adds an output port that serves as an invalid operation flag.
- **DIVIDE\_BY\_ZERO:** Adds an output port that serves as a divide-by-zero flag.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

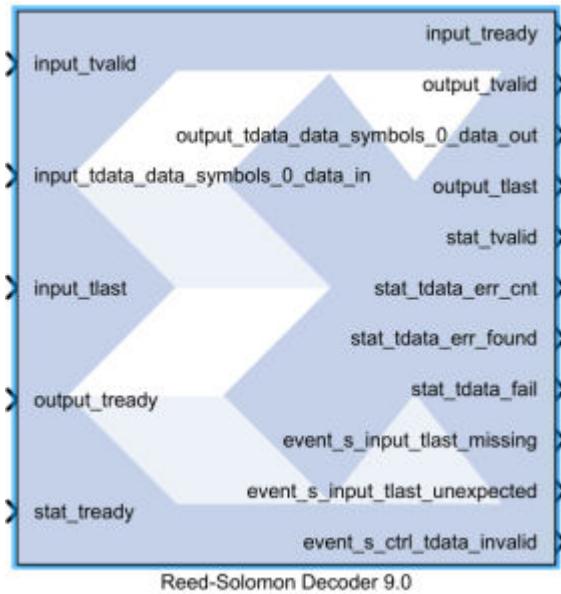
## LogiCORE Documentation

*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

## Reed-Solomon Decoder 9.0

**Note:** This block goes into the FPGA fabric and is a Licensed Core. Please visit the Xilinx web site to purchase the appropriate core license.

The Reed-Solomon (RS) codes are block-based error correcting codes with a wide range of applications in digital communications and storage.



They are used to correct errors in many systems such as digital storage devices, wireless/ mobile communications, and digital video broadcasting.

The Reed-Solomon decoder processes blocks generated by a Reed-Solomon encoder, attempting to correct errors, and recover information symbols. The number and type of errors that can be corrected depend on the characteristics of the code.

Reed-Solomon codes are Bose-Chaudhuri-Hocquenghem (BCH) codes, which in turn are linear block codes. An  $(n,k)$  linear block code is a  $k$ -dimensional sub-space of an  $n$ -dimensional vector space over a finite field. Elements of the field are called *symbols*. For a Reed-Solomon code,  $n$  ordinarily is  $2^s - 1$ , where  $s$  is the width in bits of each symbol. When the code is *shortened*,  $n$  is smaller. The decoder handles both full length and shortened codes. It is also able to handle *erasures*, that is, symbols that are known with high probability to contain errors.

When the decoder processes a block, there are three possibilities:

1. The information symbols are recovered. This is the case provided  $2p + r \leq n - k$ , where  $p$  is the number of errors, and  $r$  is the number of erasures.
2. The decoder reports it is unable to recover the information symbols.
3. The decoder fails to recover the information symbols but does not report an error.

The probability of each possibility depends on the code and the nature of the communications channel. Simulink® provides excellent tools for modeling channels and estimating these probabilities.

## Block Interface Channels and Pins

This Xilinx Reed-Solomon Decoder block is AXI4 compliant. The following describes the standard AXI channels and pins on the interface:

- **input Channel:**

- `input_tvalid`: TVALID for the input channel.
- `input_tdata_erase`: Added to the channel when you select **Erase** on the Optional Pins tab. It indicates the symbol currently presented on `data_in` should be treated as an erasure. The signal driving this pin must be `Bool`.
- `input_tdata_data_in`: Presents blocks of `n` symbols to be decoded. This signal must have type `UFIX_s_0`, where `s` is the width in bits of each symbol.
- `input_tlast`: Marks the last symbol of the input block. Only used to generate event outputs. Can be tied low or high if event outputs are not used.
- `input_tready`: TREADY for the input channel.
- `input_tuser_mark_in`: marker bits for tagging data on `data_in`. Added to the channel when you select **Marker Bits** from the Optional Pins tab.

- **output Channel:**

- `output_tready`: TREADY for the output channel.
- `output_tvalid`: TVALID for the output channel.
- `output_tdata_data_out`: Produces the information and parity symbols resulting from decoding. The type of `data_out` is the same as that for `data_in`.
- `output_tlast`: Goes high when the last symbol of the last block is on `tdata_data_out`. `output_tlast` produces a signal of type `UFIX_1_0`.
- `output_tuser_mark_out`: `mark_in` tagging bits delayed by the latency of the LogiCORE™. Added to the channel when you select **Marker Bits** on the Optional Pins tab.
- `output_tdata_info`: Added to the channel when you select **Info** on the Optional Pins tab. The signal marks the last information symbol of a block on `tdata_data_out`.
- `output_tdata_data_d1`: Added to the channel when you select **Original Delayed Data** on the Optional Pins tab. The signal marks the last information symbol of a block on `tdata_data_out`.

- **stat Channel:**

- `stat_tready`: TREADY for the stat channel.
- `stat_tvalid`: TVALID for the stat channel. You should tie this signal high if the downstream slave is always able to accept data or if the stat channel is not used.
- `stat_tdata_err_cnt`: Presents a value at the time `data_out` presents the last symbol of the block. The value is the number of errors that were corrected. `err_cnt` must have type `UFIX_b_0` where `b` is the number of bits needed to represent `n-k`.

- **stat\_tdata\_err\_found:** presents a value at the time `output_tdata_data_out` presents the last symbol of the block. The value 1 if the decoder detected any errors or erasures during decoding. `err_found` must have type `UFIX_1_0`.
- **stat\_tdata\_fail:** Presents a value at the time `output_tdata_data_out` presents the last symbol of the block. The value is 1 if the decoder was unable to recover the information symbols, and 0 otherwise. This signal must be of type `UFIX_1_0`.
- **stat\_tdata\_erase\_cnt:** Only available when erasure decoding is enabled. Presents a value at the time presents the last symbol of the block. The value is the number of erasures that were corrected. This signal must be of type `UFIX_b_0` where `b` is the number of bits needed to represent `n`. Added to the channel when you select **Erase** from the Optional Pins tab.
- **stat\_tdata\_bit\_err\_1\_to\_0:** Number of bits received as 1 but corrected to 0. Added to the channel when you select **Error Statistics** from the Optional Pins tab. The element width is the number of binary bits required to represent  $((n-k) * \text{Symbol\_Width})$ .
- **stat\_tdata\_bit\_err\_0\_to\_1:** Number of bits received as 0 but corrected to 1. Added to the channel when you select **Error Statistics** from the Optional Pins tab. The element width is the number of binary bits required to represent  $((n-k) * \text{Symbol\_Width})$ .
- **stat\_tlast:** Added when Number of Channels parameter is greater than 1. Indicates that status information for the last channel is present on `output_tdata`.
- **event Channel:**
  - **event\_s\_input\_tlast\_missing:** This output flag indicates that the `input_tlast` was not asserted when expected. You should leave this pin unconnected if it is not required.
  - **event\_s\_input\_tlast\_unexpected:** This output flag indicates that the `input_tlast` was asserted when not expected. You should leave this pin unconnected if it is not required.
  - **event\_s\_ctrl\_tdata\_invalid:** This output flag indicates that values provided on `ctrl_tdata` were illegal. The block must be reset if this is asserted. You should leave this pin unconnected if it is not required.
- **ctrl Channel:** This channel is only present when variable block length, number of check symbols or puncture is selected as a block parameter.
  - **ctrl\_tready:** TREADY for the ctrl channel.
  - **ctrl\_tvalid\_r\_in:** TVALID for the ctrl channel.
  - **ctrl\_tdata:** This input contains the block length, the number of check symbols and puncture select, if applicable.
- **Other Optional Pins:**

- `aresetn`:

Resets the decoder. This pin is added to the block when you specify **Synchronous Reset** on the Optional Pins tab. The signal driving `rst` must be `Bool`.

`aresetn` must be asserted high for at least 1 sample period before the decoder can start decoding code symbols.

- `aclken`: Carries the clock enable signal for the decoder. The signal driving `aclken` must be `Bool`. Added to the block when you select the optional pin **Clock Enable**.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Attributes 1 tab:** Parameters specific to the Attributes 1 tab are as follows.
  - **Code Block Specification:**
    - **Code specification:** Specifies the type of RS Decoder desired. The choices are as follows.
      - **Custom:** Allows you to set all the block parameters.
      - **DVB:** Implements DVB (Digital Video Broadcasting) standard (204, 188) shortened RS code.
      - **ATSC:** Implements ATSC (Advanced Television Systems Committee) standard (207, 187) shortened RS code.
      - **G.709:** Implements G.709 Optical Transport Network standard.
      - **CCSDS:** Implements CCSDS (Consultative Committee for Space Data Systems) standard (255, 223) full length RS code.
      - **IESS-308 (All):** Implements IESS-308 (INTELSAT Earth Station Standard) specification (all) shortened RS code.
      - **IESS-308 (126):** Implements IESS-308 (INTELSAT Earth Station Standard) specification (126, 112) shortened RS code.
      - **IESS-308 (194):** Implements IESS-308 specification (194, 178) shortened RS code.
      - **IESS-308 (208):** Implements IESS-308 specification (208, 192) shortened RS code.
      - **IESS-308 (219):** Implements IESS-308 specification (219, 201) shortened RS code.
      - **IESS-308 (225):** Implements IESS-308 specification (225, 205) shortened RS code.
      - **IEEE-802.16:** Implements IEEE-802.16 specification (255, 239) full length RS code.

- **Symbol width:** Tells the width in bits for symbols in the code. The encoder support widths from 3 to 12 (default 8).
- **Field polynomial:** Specifies the polynomial from which the symbol field is derived. It must be specified as a decimal number. This polynomial must be primitive. A value of zero indicates the default polynomial should be used. Default polynomials are listed in the table below.

*Table 76: Field Polynomials*

Symbol Width	Default Polynomials	Array Representation
3	$x^3 + x + 1$	11
4	$x^4 + x + 1$	19
5	$x^5 + x^2 + 1$	37
6	$x^6 + x + 1$	67
7	$x^7 + x^3 + 1$	137
8	$x^8 + x^4 + x^3 + x^2 + 1$	285
9	$x^9 + x^4 + 1$	529
10	$x^{10} + x^3 + 1$	1033
11	$x^{11} + x^2 + 1$	2053
12	$x^{12} + x^6 + x^4 + x + 1$	4179

- **Scaling Factor (h):** (represented in the previous formula as h) specifies the scaling factor for the code. Ordinarily, h is 1, but can be as large as  $2^S - 1$  where s is the symbol width. The value must be chosen so that  $\alpha^h$  is primitive. That is, h must be relatively prime to  $2^S - 1$ .
- **Generator Start:** specifies the first root r of the generator polynomial. The generator polynomial g(x), is given by:

$$g(x) = \prod_{j=0}^{n-k-1} (x - \alpha^{h(r+j)})$$

where  $\alpha$  is a primitive element of the symbol field, and the scaling factor is described below.

- **Variable Block Length:** When checked, the block is given a `ctrl` input channel.
- **Symbols Per Block(n):** Tells the number of symbols in the blocks the encoder produces. Acceptable numbers range from 3 to  $2^S - 1$ , where s denotes the symbol width.
- **Data Symbols(k):** Tells the number of information symbols each block contains. Acceptable values range from  $\max(n - 256, 1)$  to  $n - 2$ .
- **Variable Check Symbol Options:**

- **Variable Number of Check Symbols (r):**
- **Define Supported R\_IN Values:**

If only a subset of the possible values that could be sampled on R\_IN is actually required, then it is possible to reduce the size of the core slightly. For example, for the Intelsat standard, the R\_IN input is 5 bits wide but only requires r values of 14, 16, 18, and 20. The core size can be slightly reduced by defining only these four values to be supported. If any other value is sampled on R\_IN, the core will not decode the data correctly.

- **Number of Supported R\_IN Values:** Specify the number of supported R\_IN values.
- **Supported R\_IN Definition File:** This is a COE file that defines the R values to be supported. It has the following format: radix=10; legal\_r\_vector=14,16,18,20; The number of elements in the legal\_r\_vector must equal the specified **Number of Supported R\_IN Values**.
- **Attributes 2 tab:**
  - **Implementation:**
    - **State Machine:**
      - **Self Recovering:** When checked, the block synchronously resets itself if it enters an illegal state.
      - **Memory Style:** Select between **Distributed**, **Block** and **Automatic** memory choices.
      - **Number Of Channels:** Specifies the number of separate time division multiplexed channels to be processed by the encoder. The encoder supports up to 128 channels.
      - **Output check symbols:** If selected, then the entire n symbols of each block are output on the output channel. If not selected, then only the k information symbols are output.
      - **Puncture Options:**
        - **Number of Puncture Patterns:** Specifies how many puncture patterns the LogiCORE needs to handle. It is set to 0 if puncturing is not required.
        - **Puncture Definition File:** Specifies the pathname of the puncture definition file that is used to define the puncture patterns.
  - A relative pathname can be specified for a COE file in the current working directory. For example, the syntax is [cwd '/ieee802\_16d\_puncturing.coe'].
  - **Optional pins tab:**
    - **Clock Enable:** Adds a aclken pin to the block. This signal carries the clock enable and must be of type Bool.

- **Info:** Adds the `output_tdata_info` pin. Marks the last information symbol of a block on `tdata_data_out`.
- **Synchronous Reset:** Adds a `aresetn` pin to the block. This signal resets the block and must be of type Bool. The signal must be asserted for at least 2 clock cycles, however, it does not have to be asserted before the decoder can start decoding.
- **Original Delayed Data:** When checked, the block is given a `tdata_data_del` output. Indicates that a DAT\_DEL field is in the `output_tdata` output.
- **Erase:** When checked, the block is given an `input_tdata_erase` input pin.
- **Error Statistics:** adds the following error statistics outputs:
  - **bit\_err\_0\_to\_1:** Number of bits received as 1 but corrected to 0.
  - **bit\_err\_1\_to\_0:** Number of bits received as 0 but corrected to 1.
- **Marker Bits:** Adds the following pins to the block:
  - **input\_tuser\_mark\_in:** Carries marker bits for tagging data on `input_tdata_data_in`.
  - **output\_tuser\_mark\_out:** Mark\_in tagging bits delayed by the latency of the LogiCORE.
- **Number of Marker Bits:** Specifies the number of marker bits.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

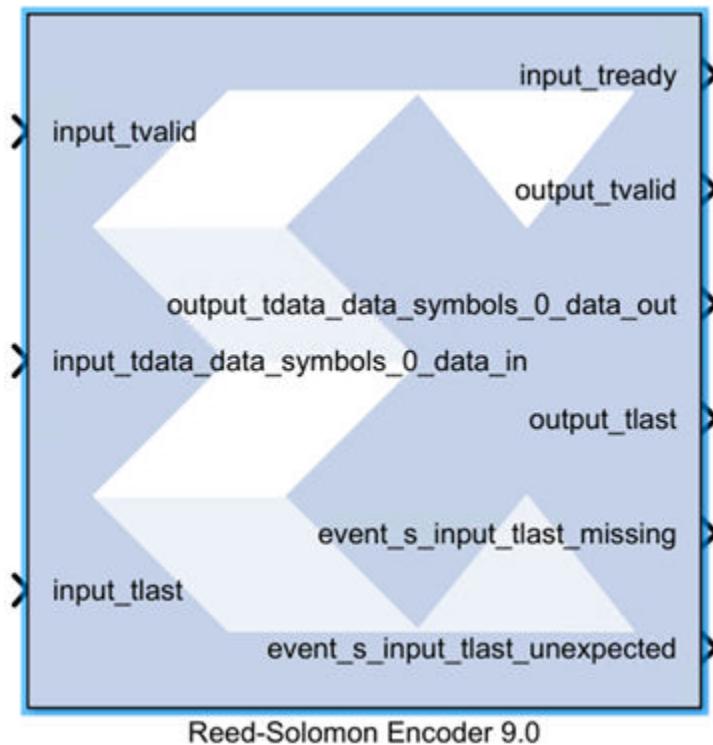
## LogiCORE Documentation

*Reed-Solomon Decoder LogiCORE IP Product Guide (PG107)*

## Reed-Solomon Encoder 9.0

**Note:** This block goes into the FPGA fabric and is a Licensed Core. Please visit the Xilinx web site to purchase the appropriate core license.

The Reed-Solomon (RS) codes are block-based error correcting codes with a wide range of applications in digital communications and storage. This block adheres to the AMBA® AXI4-Stream standard.



Reed-Solomon Encoder 9.0

They are used to correct errors in many systems such as digital storage devices, wireless or mobile communications, and digital video broadcasting.

The Reed-Solomon encoder augments data blocks with redundant symbols so that errors introduced during transmission can be corrected. Errors can occur for a number of reasons (noise or interference, scratches on a CD, etc.). The Reed-Solomon decoder attempts to correct errors and recover the original data. The number and type of errors that can be corrected depends on the characteristics of the code.

A typical system is shown below:

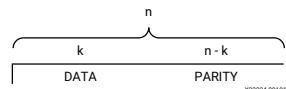
Figure 310: Typical System



Reed-Solomon codes are Bose-Chaudhuri-Hocquenghem (BCH) codes, which in turn are linear block codes. An  $(n, k)$  linear block code is a  $k$ -dimensional sub space of an  $n$ -dimensional vector space over a finite field. Elements of the field are called symbols. For a Reed-Solomon code,  $n$  ordinarily is  $2^s - 1$ , where  $s$  is the width in bits of each symbol. When the code is shortened,  $n$  is smaller. The encoder handles both full length and shortened codes.

The encoder is systematic. This means it constructs code blocks of length  $n$  from information blocks of length  $k$  by adjoining  $n-k$  parity symbols.

Figure 311: Systematic Encoder



A Reed-Solomon code is characterized by its field and generator polynomials. The field polynomial is used to construct the symbol field, and the generator polynomial is used to calculate parity symbols. The encoder allows both polynomials to be configured. The generator polynomial has the form:

$$g(x) = (x - \alpha^j)(x - \alpha^{j+1} \dots (x - \alpha^{i+n-k-1})$$

where  $\alpha$  is a primitive element of the finite field having  $n + 1$  elements.

### Block Interface Channels and Pins

The Xilinx Reed-Solomon Decoder 9.0 block is AXI4 compliant. The following describes the standard AXI channels and pins on the interface:

- **input Channel:**

- `input_tvalid`: TVALID for the input channel.
- `input_tdata_data_in`: Presents blocks of  $n$  symbols to be decoded. This signal must have type `UFIX_S_0`, where  $s$  is the width in bits of each symbol.
- `input_tlast`: Marks the last symbol of the input block. Only used to generate event outputs. Can be tied low or high if event outputs are not used.
- `input_tready`: TREADY for the input channel.
- `input_tuser_marker`: Marker bits for tagging data on `input_tdata_data_in`. Added to the channel when you select **Marker Bits** from the Detailed Implementation tab.

- **output Channel:**

- `output_tready`: TREADY for the output channel. Added to the channel when you select **Output TREADY** from the Optional Pins tab.
- `output_tvalid`: TVALID for the output channel.
- `output_tdata_data_out`: Produces the information and parity symbols resulting from decoding. The type of `data_out` is the same as that for `data_in`.
- `output_tlast`: Goes high when the last symbol of the last block is on `tdata_data_out`. `output_tlast` produces a signal of type `UFIX_1_0`.
- `output_tuser_marker`: This pin is available when user selects "Marker Bits" from the Detailed Implementation tab.

- **event Channel:**

- **event\_s\_input\_tlast\_missing:** This output flag indicates that the `input_tlast` was not asserted when expected. You should leave this pin unconnected if it is not required.
- **event\_s\_input\_tlast\_unexpected:** This output flag indicates that the `input_tlast` was asserted when not expected. You should leave this pin unconnected if it is not required.
- **event\_s\_ctrl\_tdata\_invalid:** This output flag indicates that values provided on `ctrl_tdata` were illegal. This pin is available when "Variable Block Length" or "Variable Number of Check Symbols" are selected on the GUI.
- **ctrl Channel:** This channel is only present when variable block length or number of check symbols is selected as a block parameter.
  - `ctrl_tvalid`: TVALID for the ctrl channel.
  - `ctrl_tdata_n_in`: This signal is only present if "Variable Block Length" is selected in the GUI. This allows the block length to be changed every block. The `ctrl_tdata_n_in` signal must have type `UFIX_s_0`, where `s` is the width in bits of each symbol. Unless there is an `R_IN` field, the number of check symbols is fixed, so varying `n` automatically varies `k`.
  - `ctrl_tdata_r_in`: This field is only present if "Variable Number of Check Symbols" is selected in the GUI. It allows the number of check symbols to be changed every block. The new block's length, `r_block`, is set to `ctrl_tdata_r_in` sampled. The `ctrl_tdata_r_in` signal must have type `UFIX_p_0`, where `p` is the number of bits required to represent the parity bits (`n-k`) in the default code word, `n` being the "Symbols Per Block" and `k` being "Data Symbols". Selecting this input significantly increases the size of the core.

## Other Optional Pins

- `aresetn`: Resets the encoder. This pin is added to the block when you specify **ARESETn** on the Detailed Implementation tab. The signal driving `ARESETn` must be `Bool`. `aresetn` must be asserted low for at least 2 clock periods and at least 1 sample period before the decoder can start decoding code symbols.
- `aclken`: Carries the clock enable signal for the encoder. The signal driving `aclken` must be `Bool`. Added to the block when you select the optional pin **ACLKEN**.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Attributes:** Parameters specific to the Attributes tab are as follows.

- **Code Block Specification:**

- **Code specification:** specifies the encoder type desired. The choices are:
  - **Custom:** Allows you to set all the block parameters.
  - **DVB:** Implements DVB (Digital Video Broadcasting) standard (204, 188) shortened RS code.
  - **ATSC:** Implements ATSC (Advanced Television Systems Committee) standard (207, 187) shortened RS code
  - **G\_709:** Implements G.709 Optical Transport Network standard.
  - **ETSI\_BRAN:** Implements the ETSI Project standard for Broadband Radio Access Networks (BRAN).
  - **CCSDS:** Implements CCSDS (Consultative Committee for Space Data Systems) standard (255, 223) full length RS code.
  - **ITU\_J\_83\_Annex\_B:** Implements International Telecommunication Union (ITU)-J.83 Annex B specification (128, 122) extended RS code.
  - **IESS-308 (126):** Implements IECC-308 (INTELSAT Earth Station Standard) specification (126, 112) shortened RS code.
  - **IESS-308 (194):** Implements IECC-308 specification (194, 178) shortened RS code.
  - **IESS-308 (208):** Implements IECC-308 specification (208, 192) shortened RS code.
  - **IESS-308 (219):** Implements IECC-308 specification (219, 201) shortened RS code.
  - **IESS-308 (225):** Implements IECC-308 specification (225, 205) shortened RS code.
- **Variable Number of Check Symbols (r):** False, true. When checked, the `ctrl_tdata_r_in` and `ctrl_tdata_n_in` pins become available on the block.
- **Variable Block Length:** False, true. When checked, the `ctrl_tdata_n_in` pin becomes available on the block.
- **Symbol width:** Tells the width in bits for symbols in the code. The encoder supports widths from 3 to 12 and the default value is 8.
- **Field polynomial:** specifies the polynomial from which the symbol field is derived. It must be specified as a decimal number. This polynomial must be primitive. A value of zero indicates the default polynomial should be used. Default polynomials are listed in the table below.

**Table 77: Field Polynomials**

Symbol Width	Default Polynomials	Array Representation
3	$x^3 + x + 1$	11

Table 77: Field Polynomials (cont'd)

Symbol Width	Default Polynomials	Array Representation
4	$x^4 + x + 1$	19
5	$x^5 + x^2 + 1$	37
6	$x^6 + x + 1$	67
7	$x^7 + x^3 + 1$	137
8	$x^8 + x^4 + x^3 + x^2 + 1$	285
9	$x^9 + x^4 + 1$	529
10	$x^{10} + x^3 + 1$	1033
11	$x^{11} + x^2 + 1$	2053
12	$x^{12} + x^6 + x^4 + x + 1$	4179

- **Scaling Factor (h):** (represented in the previous formula as h) specifies the scaling factor for the code. Ordinarily, h is 1, but can be as large as  $2^S - 1$  where s is the symbol width. The value must be chosen so that  $a^h$  is primitive. That is, h must be relatively prime to  $2^S - 1$ .
- **Generator Start:** Specifies the first root r of the generator polynomial. The generator polynomial g(x), is given by:

$$g(x) = \prod_{j=0}^{n-k-1} (x - \alpha^{h(r+j)})$$

where  $\alpha$  is a primitive element of the symbol field, and the scaling factor is described below.

- **Symbols Per Block(n):** Tells the number of symbols in the blocks the encoder produces. Acceptable numbers range from 3 to  $2^S - 1$ , where s denotes the symbol width.
- **Data Symbols(k):** Tells the number of information symbols each block contains. Acceptable values range from  $\max(n - 256, 1)$  to n - 2.
- **Detailed Implementation tab:**
  - **Implementation:**
    - **Check Symbol Generator Optimization:** This option is available when "Variable Number of Check Symbols" option is selected on the GUI.
    - **Fixed Architecture:** The check symbol generator is implemented using a highly efficient fixed architecture.
    - **Area:** The check symbol generator implementation is optimized for area and speed efficiency. The range of input, `ctrl_tdata_n_in`, is reduced.
    - **Flexibility:** The check symbol generator implementation is optimized to maximize the range of input of `ctrl_tdata_n_in`.

- **Memory Style:** Select between **Distributed**, **Block** and **Automatic** memory choices. This option is available only for CCSDS codes.
  - **Number Of Channels:** Specifies the number of separate time division multiplexed channels to be processed by the encoder. The encoder supports up to 128 channels.
- **Optional Pins:**
- **ACLKEN:** Adds a **aclken** pin to the block. This signal carries the clock enable and must be of type **Bool**.
  - **Output TREADY:** When selected, the output channels will have a TREADY and hence support the AXI4 handshake protocol with inherent back-pressure.
  - **ARESETn:** Adds a **aresetn** pin to the block. This signal resets the block and must be of type **Bool**. **aresetn** must be asserted low for at least 2 clock periods and at least 1 sample period before the decoder can start decoding code symbols.
  - **Info bit:** Adds the **output\_tdata\_info** pin. Marks the last information symbol of a block on **tdata\_data\_out**.
  - **Marker Bits:** Adds the following pins to the block:
    - **input\_tuser\_user:** Carries marker bits for tagging data on **input\_tdata\_data\_in**.
    - **output\_tuser\_user:** **mark\_in** tagging bits delayed by the latency of the LogiCORE.
  - **Number of Marker Bits:** Specifies the number of marker bits.

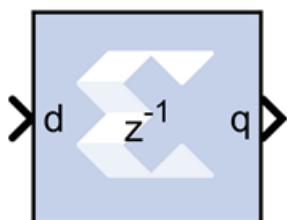
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

*Reed-Solomon Encoder LogiCORE IP Product Guide (PG025)*

## Register

The Xilinx Register block models a D flip-flop-based register, having latency of one sample period.



## Block Interface

The block has one input port for the data and an optional input reset port. The initial output value is specified by you in the block parameters dialog box (below). Data presented at the input will appear at the output after one sample period. Upon reset, the register assumes the initial value specified in the parameters dialog box.

The Register block differs from the Xilinx Delay block by providing an optional reset port and a user specifiable initial value.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows.

- **Initial value:** specifies the initial value in the register.
- **Optional Ports:**

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Xilinx LogiCORE

The Register block is implemented as a synthesizable VHDL module. It does not use a Xilinx LogiCORE™.

## Reinterpret

The Xilinx Reinterpret block forces its output to a new type without any regard for retaining the numerical value represented by the input.



The binary representation is passed through unchanged, so in hardware this block consumes no resources. The number of bits in the output will always be the same as the number of bits in the input.

The block allows for unsigned data to be reinterpreted as signed data, or, conversely, for signed data to be reinterpreted as unsigned. It also allows for the reinterpretation of the data's scaling, through the repositioning of the binary point within the data. The Xilinx Scale block provides an analogous capability.

An example of this block's use is as follows: if the input type is 6 bits wide and signed, with 2 fractional bits and the output type is forced to be unsigned with 0 fractional bits, then an input of -2.0 (1110.00 in binary, two's complement) would be translated into an output of 56 (111000 in binary).

This block can be particularly useful in applications that combine it with the Xilinx Slice block or the Xilinx Concat block. To illustrate the block's use, consider the following scenario:

Given two signals, one carrying signed data and the other carrying two unsigned bits (a UFix\_2\_0), you should design a system that concatenates the two bits from the second signal onto the tail (least significant bits) of the signed signal.

You can do so using two Reinterpret blocks and one Concat block. The first Reinterpret block is used to force the signed input signal to be treated as an unsigned value with its binary point at zero. The result is then fed through the Concat block along with the other signal's UFix\_2\_0. The Concat operation is then followed by a second Reinterpret that forces the output of the Concat block back into a signed interpretation with the binary point appropriately repositioned.

Though three blocks are required in this construction, the hardware implementation is realized as simply a bus concatenation, which has no cost in hardware.

## Block Parameters

Parameters specific to the block are as follows.

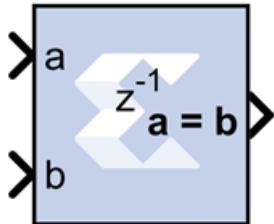
- **Force Arithmetic Type:** When checked, the Output Arithmetic Type parameter can be set and the output type is forced to the arithmetic type chosen according to the setting of the Output Arithmetic Type parameter. When unchecked, the arithmetic type of the output is unchanged from the arithmetic type of the input.
- **Output Arithmetic Type:** The arithmetic type (unsigned or signed, 2's complement, Floating-point) to which the output is to be forced.
- **Force Binary Point:** When checked, the Output Binary Point parameter can be set and the binary point position of the output is forced to the position supplied in the Output Binary Point parameter. When unchecked, the arithmetic type of the output is unchanged from the arithmetic type of the input.
- **Output Binary Point:** The position to which the output's binary point is to be forced. The supplied value must be an integer between zero and the number of bits in the input (inclusive).

## LogiCORE Documentation

[LogiCORE IP Floating-Point Operator v7.1](#)

# Relational

The Xilinx Relational block implements a comparator.



The supported comparisons are the following:

- equal-to ( $a = b$ )
- not-equal-to ( $a \neq b$ )
- less-than ( $a < b$ )
- greater-than ( $a > b$ )
- less-than-or-equal-to ( $a \leq b$ )
- greater-than-or-equal-to ( $a \geq b$ )
- The output of the block is a `Bool`.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

The only parameter specific to the Relational block is:

- **Comparison:** specifies the comparison operation computed by the block.

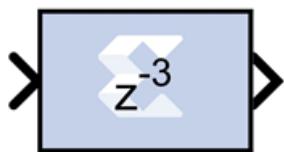
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

[LogiCORE IP Floating-Point Operator v7.1](#)

# Requantize

The Xilinx Requantize block requantizes and scales its input signals.



The Xilinx Requantize block requantizes each input sample to a number of a desired fixed point precision output. For example, a fixed point signed (two's complement) or unsigned number can be requantized to an output with lesser or greater number of bits and realign its binary point precision.

This block also scales its input by a power of two. The power can be either positive or negative. The scale operation has the effect of moving the binary point without changing the bits in the container.

The Requantize block is used to requantize and scale its input signals. If you are only performing one of these operations, but not both, you can use a different block in the HDL blockset to perform that operation.

- To requantize your input without scaling, use the [Convert](#) block in the HDL blockset.
- To scale your input without requantizing, use the [Scale](#) block in the HDL blockset.

## Quantization

Quantization errors occur when the number of fractional bits is insufficient to represent the fractional portion of a value. This block uses symmetric round during quantization for any insufficient input data.

Round (unbiased: +/- inf) is also known as "Symmetric Round (towards +/- inf)" or "Symmetric Round (away from zero)". This is similar to the MATLAB `round()` function. This method rounds the value to the nearest desired bit away from zero. When there is a value at the midpoint between two possible rounded values, the one with the larger magnitude is selected. For example, to round 01.0110 to a Fix\_4\_2, this yields 01.10, since 01.0110 is halfway between 01.01 and 01.10, and 01.10 is further from zero.

## Overflow

Overflow errors occur when a value lies outside the representable range. In case of data overflow this block saturates the data to the largest positive/smallest negative value.

## Block Parameters

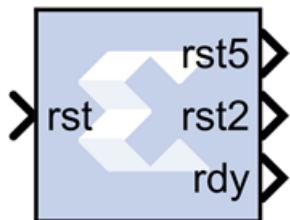
The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

Parameters specific to the block are as follows.

- **Scale factor s (scale output by  $2^s$ ):** The scale factor can be a positive or negative integer. The output of the block is  $i * 2^k$ , where  $i$  is the input value and  $k$  is the scale factor. The effect of scaling is to move the binary point, which in hardware has no cost (a shift, on the other hand, might add logic).
- **Fixed-point Precision:**
  - **Number of bits:** Specifies the total number of bits, including the binary point bit width.
  - **Binary point:** Specifies the bit location of the binary point. Bit zero is the Least Significant Bit.

## Reset Generator

The Reset Generator block captures the user's reset signal that is running at the system sample rate, and produces one or more downsampled reset signal(s) running at the rates specified on the block.

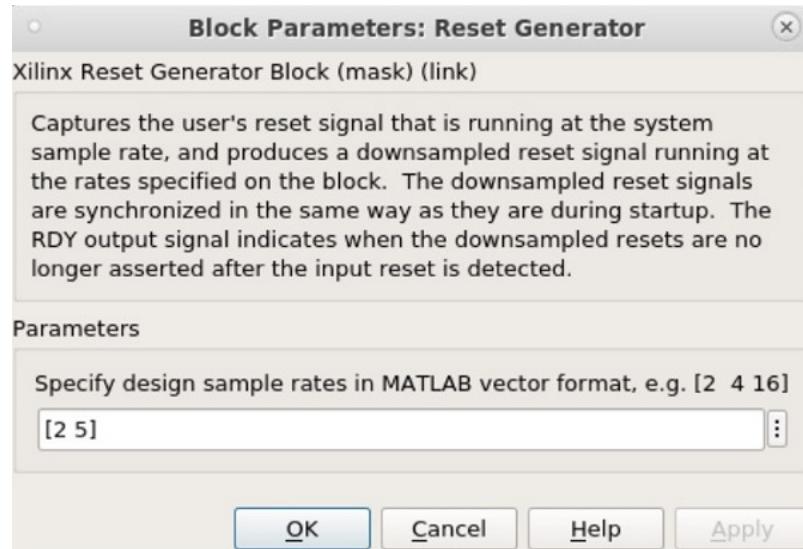


The downsampled reset signals are synchronized in the same way as they are during startup. The RDY output signal indicates when the downsampled resets are no longer asserted after the input reset is detected.

### Block Parameters Dialog Box

The block parameters dialog box shown below can be invoked by double-clicking the icon in your Simulink® model.

Figure 312: Block Parameters



You specify the design sample rates in MATLAB® vector format as shown above. Any number of outputs can be specified.

## ROM

The Xilinx ROM block is a single port read-only memory (ROM).



Values are stored by word and all words have the same arithmetic type, width, and binary point position. Each word is associated with exactly one address. An address can be any unsigned fixed-point integer from 0 to  $d-1$ , where  $d$  denotes the ROM depth (number of words). The memory contents are specified through a block parameter. The block has one input port for the memory address and one output port for data out. The address port must be an unsigned fixed-point integer. The block has two possible Xilinx LogiCORE™ implementations, using either distributed or block memory.

For the block memory, the address width must be equal to  $\text{ceil}(\log_2(d))$  where  $d$  denotes the memory depth. The maximum width of data words in the block memory depends on the depth specified; the maximum depth is depends on the device family targeted.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows.

- **Depth:** Specifies the number of words stored; must be a positive integer.
- **Initial value vector:** Specifies the initial value. When the vector is longer than the ROM depth, the vector's trailing elements are discarded. When the ROM is deeper than the vector length, the ROM's trailing words are set to zero. The initial value vector is saturated or rounded according to the data precision specified for the ROM.
- **Memory Type:** Specifies whether the ROM will be implemented using Distributed ROM or Block ROM. Depending on your selection, the ROM will be inferred or implemented as follows when the design is compiled:
  - If the block will be implemented in Distributed memory, the Distributed Memory Generator v8.0 LogiCORE IP will be inferred or implemented when the design is compiled. This is described in *Distributed Memory Generator LogiCORE IP Product Guide (PG063)*.
  - If the block will be implemented in block RAM, the XPM\_MEMORY\_SPROM (Single Port ROM) macro will be inferred or implemented when the design is compiled. For information on the XPM\_MEMORY\_SPROM Xilinx Parameterized Macro (XPM), refer to *UltraScale Architecture Libraries Guide (UG974)*.
- **Optional Ports:**
  - **Provide reset port for output register:** When selected, allows access to the reset port available on the output register of the Block ROM. The reset port is available only when the latency of the Block ROM is set to 1.
  - **Initial value for output register:** Specifies the initial value for output register. The initial value is saturated and rounded according to the data precision specified for the ROM.
- **Output tab:** Parameters specific to the Output tab are as follows.
  - **Output Type:** Specify the data type of the output.
    - Boolean
    - Fixed-point
    - Floating-point
  - **Arithmetic Type:** If the Output Type is specified as Fixed-point, you can select **Signed (2's comp)** or **Unsigned** as the Arithmetic Type.

- **Fixed-point Precision:**
  - **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
  - **Binary point:** Position of the binary point. in the fixed-point output.
- **Floating-point Precision:**
  - **Single:** Specifies single precision (32 bits).
  - **Double:** Specifies double precision (64 bits).
  - **Custom:** Activates the field below so you can specify the Exponent width and the Fraction width.
- **Exponent width:** Specify the exponent width.
- **Fraction width:** Specify the fraction width.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

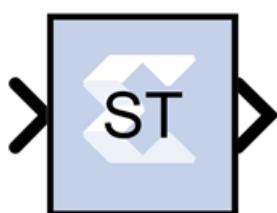
## LogiCORE Documentation

*Distributed Memory Generator LogiCORE IP Product Guide (PG063)*

*UltraScale Architecture Memory Resources User Guide (UG573) - XPM\_MEMORY\_SPROM Macro (UltraRAM)*

## Sample Time

The Sample Time block reports the normalized sample period of its input. A signal's normalized sample period is not equivalent to its Simulink absolute sample period. In hardware, this block is implemented as a constant.



## Scalar2Vector

The Scalar2Vector block converts scalar type input to vector type output.

## Description

The Xilinx® Scalar2Vector block slices the binary value of the input scalar based on the Width parameter to produce a vector output. For example, if the input is 3720 ( binary value 111 010 001 000 ) of type `Ufix_12_0`, SSR is 4, and the Width parameter value is 3, then this block slices the input binary value into 4 groups, each of 3 bits, so that it produces the output [0 1 2 7].

## Data Type Support

The input must be a Boolean or unsigned fixed-point signal. The output type is normally unsigned with binary point at zero, but can be Boolean when the Width parameter is 1.



## Block Parameters

Width: This parameter defines the number of bits for each element of output vector. This parameter is decided by:

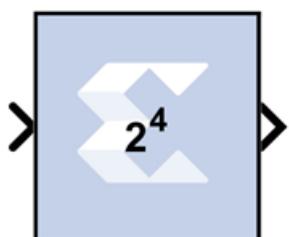
$$\text{Width} = \text{Input data width (bits)}/\text{SSR}$$

This formula must be satisfied when setting up the block parameters.

Super Sample Rate (SSR): This configurable GUI parameter is primarily used to control the processing of multiple data samples on every sample period. This block enables 1-D vector support for the primary block operation.

## Scale

The Xilinx Scale block scales its input by a power of two. The power can be either positive or negative. The block has one input and one output. The scale operation has the effect of moving the binary point without changing the bits in the container



## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

The only parameter that is specific to the Scale block is Scale factor s. It can be a positive or negative integer. The output of the block is  $i \cdot 2^k$ , where i is the input value and k is the scale factor. The effect of scaling is to move the binary point, which in hardware has no cost (a shift, on the other hand, might add logic).

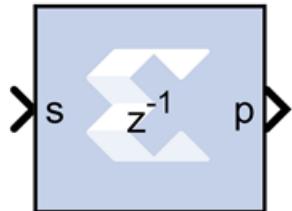
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Xilinx LogiCORE

The Scale block does not use a Xilinx LogiCORE.

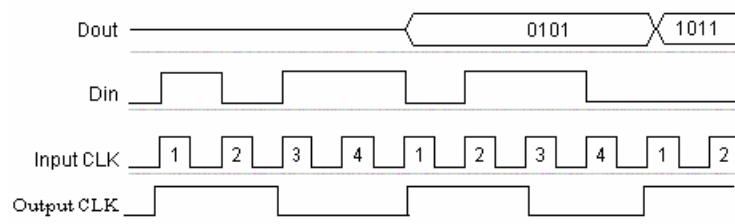
## Serial to Parallel

The Serial to Parallel block takes a series of inputs of any size and creates a single output of a specified multiple of that size. The input series can be ordered either with the most significant word first or the least significant word first.



The following waveform illustrates the block's behavior:

Figure 313: Serial to Parallel Behavior



This example illustrates the case where the input width is 1, output width is 4, word size is 1 bit, and the block is configured for most significant word first.

## Block Interface

The Serial to Parallel block has one input and one output port. The input port can be any size. The output port size is indicated on the Block Parameters dialog box.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

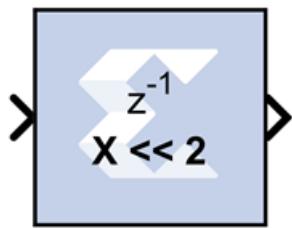
- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Input order:** Least or most significant word first.
  - **Arithmetic type:** Signed or unsigned output.
  - **Number of bits:** Output width which must be a multiple of the number of input bits.
  - **Binary point:** Output binary point location

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

An error is reported when the number of output bits cannot be divided evenly by the number of input bits. The minimum latency for this block is zero.

## Shift

The Xilinx Shift block performs a left or right shift on the input signal. The result will have the same fixed-point container as that of the input.



## Block Parameters

Parameters specific to the Shift block are:

- **Shift direction:** Specifies a direction, Left or Right. The Right shift moves the input toward the least significant bit within its container, with appropriate sign extension. Bits shifted out of the container are discarded. The Left shift moves the input toward the most significant bit within its container with zero padding of the least significant bits. Bits shifted out of the container are discarded.

- **Number of bits:** Specifies how many bits are shifted. If the number is negative, direction selected with Shift direction is reversed.

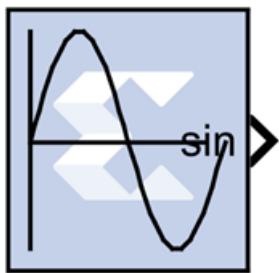
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Xilinx LogiCORE

The Shift block does not use a Xilinx LogiCORE™.

## Sine Wave

The Xilinx Sine Wave block generates a sine wave, using simulation time as the time source.



The Xilinx Sine Wave block outputs a sinusoidal waveform. Outputs from the block can be a sine wave, a cosine wave, or both. When implemented in a Xilinx FPGA or SoC, the Sine Wave block optimizes the block parameters for your target device.

The output of the Sine Wave block is determined by this equation:

$$y = \sin(2\pi(k+o)/p)$$

where

$p$  = number of time samples per sine wave period

$k$  = repeating integer value that ranges from 0 to  $p-1$

$o$  = offset (phase shift) of the signal

In this block, Model Composer sets  $k$  equal to 0 at the first time step and computes the block output, using the formula above. At the next time step, Simulink increments  $k$  and re-computes the output of the block. When  $k$  reaches  $p$ , Simulink resets  $k$  to 0 before computing the block output. This process continues until the end of the simulation.

The output characteristic of the Sine Wave block is determined by:

$$\text{Samples per period} = 2\pi / (\text{Frequency} * \text{Sample Time})$$

Number of offset samples = Phase Offset \* Samples per period /  $2\pi$

The Sine Wave block is ideal for generating simple sine and cosine waves. If your sine wave implementation will use more complicated features such as a phase generator, multiple channel support, or AXI4 ports, use the Xilinx [DDS Compiler 6.0](#) block in your design instead of the Sine Wave block.

In the Vivado design flow, the Sine Wave block is inferred as "LogicCore IP DDS Compiler v6.0" for code generation.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Parameters specific to the block are as follows:

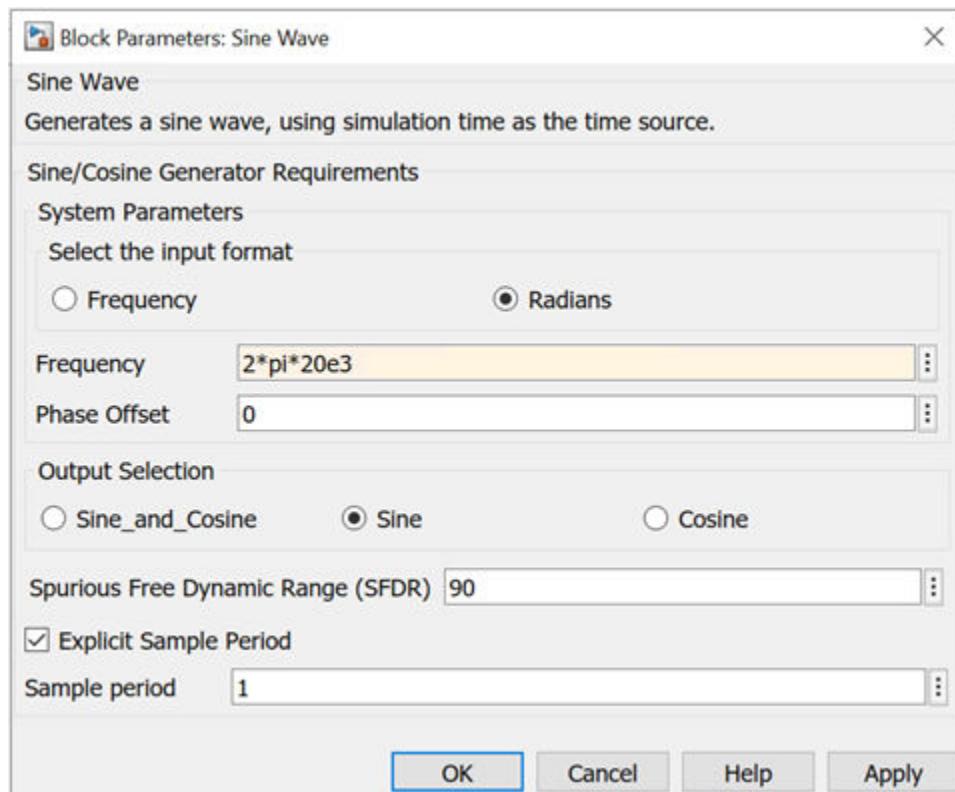
- **System Parameters:**
  - **Select the input format:** Specifies whether the frequency and phase offset inputs are entered as a **Frequency (Hz)** or an angular velocity (**Radians**) value.
  - **Frequency:** Specifies the frequency, either in Hertz or radians. The default is 1.
  - **Phase Offset:** Specifies the phase shift, either in Hertz or radians. The default is 0.
- **Output Selection:**
  - **Sine\_and\_Cosine:** Places both a sine and cosine output port on the block.
  - **Sine:** Places only a sine output port on the block.
  - **Cosine:** Places only a cosine output port on the block.
- **Spurious Free Dynamic Range (SFDR):** Specifies the precision of the output produced by the Sine Wave block. This sets the output width as well as internal bus widths, and controls various implementation decisions.
- **Explicit Sample Period:** If checked, the Sine Wave block uses the explicit sample time specified in the **Sample Period** box below. If not checked, the Model Composer base period will be used as block sample time.
- **Sample Period:** If **Explicit Sample Period**

## Example

A simple use case of generating sinusoidal signal using Sine Wave block is shown below.

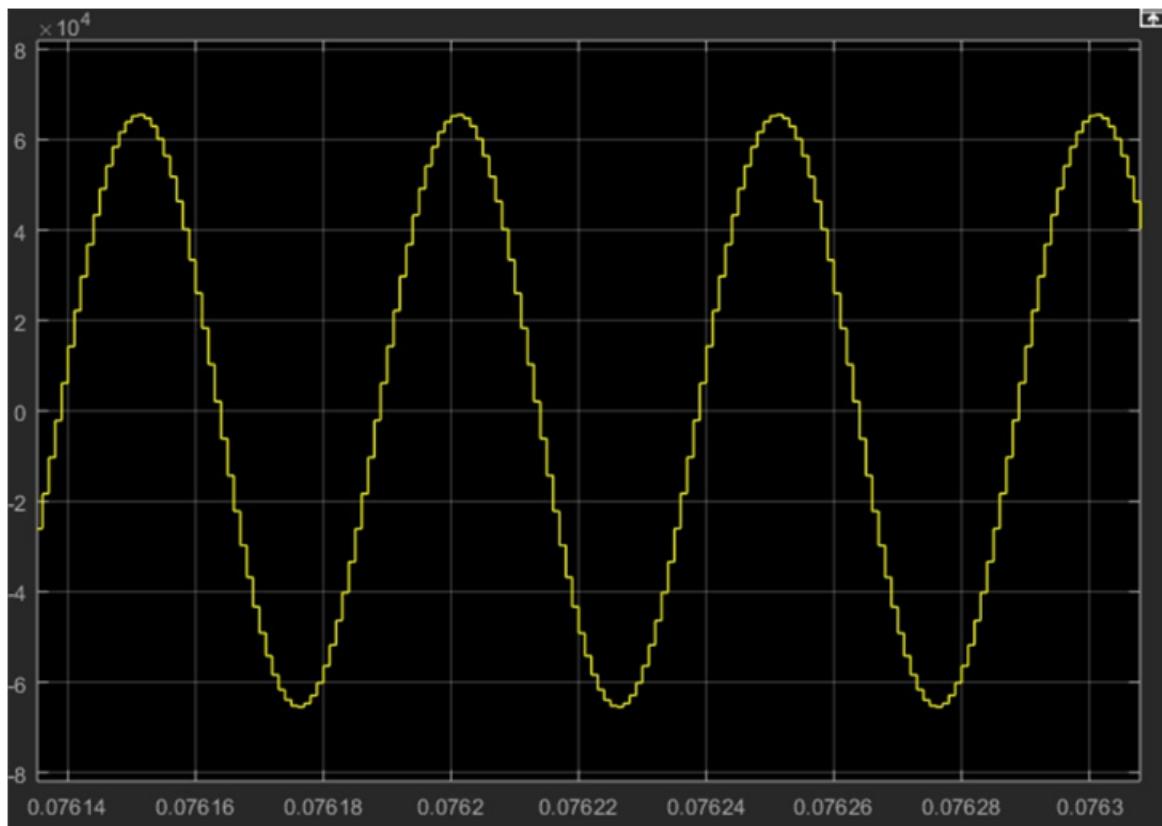
To generate a 20 KHz sine wave with  $\pi/2$  phase offset in a system running at sample period of  $(1/1e6)$  or 1 MHz, use the following specification on the Sine Wave block.

Figure 314: Sine Wave Specifications



These settings generate this sine wave:

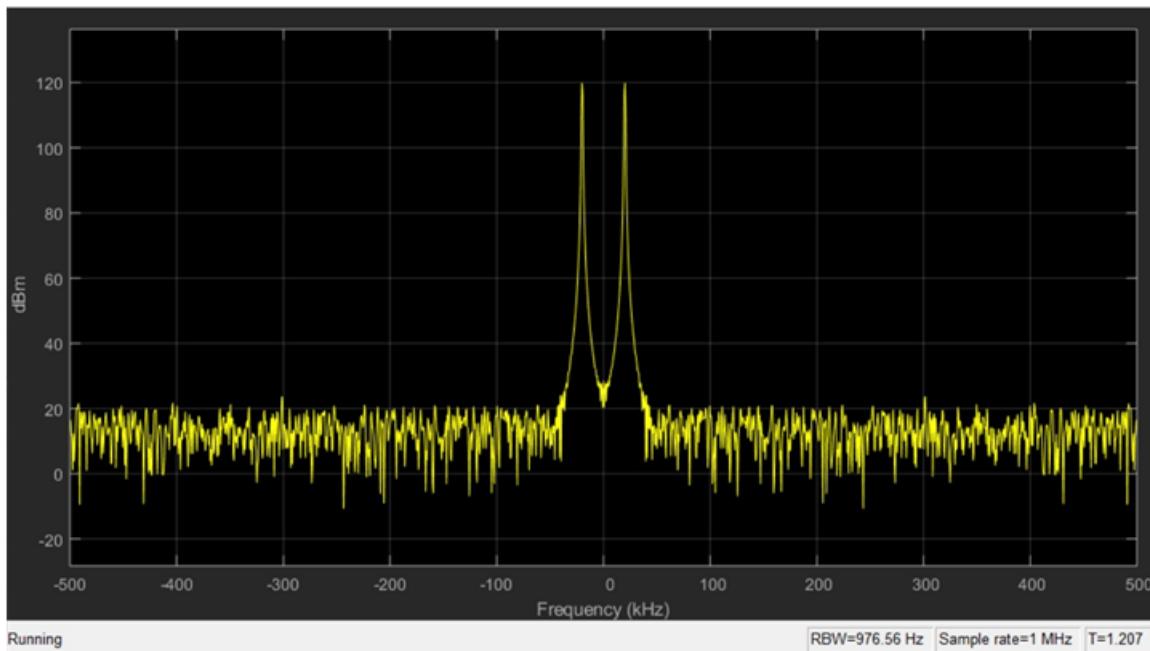
Figure 315: Generated Sine Wave



Wavelength of sine wave = *Simulink Sample Period / Frequency is selected, specifies the sample time for the block.* =>  $1\text{MHz}/20\text{KHz} = 0.5 * 10^{-4}$

The spectrum view of the sine wave is:

Figure 316: Sine Wave Output



Also:

$$\text{Number of Samples per period} = (2\pi / (1/1e6 * 20e3))$$

$$= 50 \text{ (Total number of samples in a single cycle)}$$

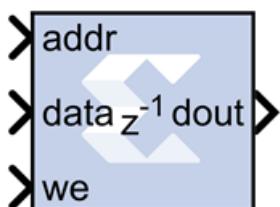
$$\text{Number of offset samples} = (\pi/2) * (50/2\pi) = 50/4$$

### LogiCORE Documentation

[LogiCORE IP DDS Compiler v6.0 Product Guide](#)

## Single Port RAM

The Xilinx Single Port RAM block implements a random access memory (RAM) with one data input and one data output port.



## Block Interface

The block has one output port and three input ports for address, input data, and write enable (WE). Values in a Single Port RAM are stored by word, and all words have the same arithmetic type, width, and binary point position.

A single-port RAM can be implemented using either block memory, distributed memory, or UltraRAM resources in the FPGA. Each data word is associated with exactly one address that must be an unsigned integer in the range 0 to  $d-1$ , where  $d$  denotes the RAM depth (number of words in the RAM). An attempt to read past the end of the memory is caught as an error in the simulation, though if a block memory implementation is chosen, it can be possible to read beyond the specified address range in hardware (with unpredictable results). When the single-port RAM is implemented in distributed memory or block RAM, the initial RAM contents can be specified through the block parameters.

The write enable signal must be Bool, and when its value is 1, the data input is written to the memory location indicated by the address input. The output during a write operation depends on the choice of memory implementation.

The behavior of the output port depends on the write mode selected (see below). When the WE is 0, the output port has the value at the location specified by the address line.

## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic Tab:**

Parameters specific to the Basic tab are as follows.

- **Depth:** The number of words in the memory; must be a positive integer.
- **Initial value vector:**

The Initial value vector stores the initial contents of the memory. When the vector length exceeds the memory depth, values with index higher than depth are ignored. When the depth exceeds the vector length, memory locations with addresses higher than the vector length are initialized to zero. Initialization values are saturated and rounded (if necessary) according to the precision specified on the data port.

UltraRAM memory is initialized to all 0's during power up or device reset. If implemented in UltraRAM, the Single Port RAM block cannot be initialized to user defined values.

- **Memory Type:** Option to select whether the single-port RAM will be implemented using **Distributed memory**, **Block RAM**, or **UltraRAM**.

Depending on your selection for **Memory Type**, the single-port RAM will be inferred or implemented as follows when the design is compiled:

- If the block will be implemented in **Distributed memory**, the Distributed Memory Generator v8.0 LogiCORE IP will be inferred or implemented when the design is compiled. This LogiCORE IP is described in *Distributed Memory Generator LogiCORE IP Product Guide* ([PG063](#)).
- If the block will be implemented in block RAM or UltraRAM, the XPM\_MEMORY\_SPRAM (Single Port RAM) macro will be inferred or implemented when the design is compiled. For information on the XPM\_MEMORY\_SPRAM Xilinx Parameterized Macro (XPM), refer to *UltraScale Architecture Libraries Guide* ([UG974](#)).
- **Write Mode:** Specifies memory behavior when WE is asserted. Supported modes are: **Read after write**, **Read before write**, and **No read On write**. **Read after write** indicates the output value reflects the state of the memory after the write operation. **Read before write** indicates the output value reflects the state of the memory before the write operation. **No read on write** indicates that the output value remains unchanged irrespective of change of address or state of the memory. There are device specific restrictions on the applicability of these modes. Also refer to the Write Modes and Hardware Notes topics below for more information.
- **Provide reset port for output register:** For block RAM or UltraRAM, exposes a reset port controlling the output register of the RAM. This port does not reset the memory contents to the initialization value.

**Note:** For Block RAM or UltraRAM, the reset port is available only when the latency of the Block RAM is greater than or equal to 1.

- **Initial value for output register:**

For Block RAM, the initial value for the output register. The initial value is saturated and rounded as necessary according to the precision specified on the data port of the Block RAM.

For UltraRAM, the output register is initialized to all 0's. The UltraRAM output register cannot be initialized to user defined values.

Other parameters used by this block are explained in the [Common Options in Block Parameter Dialog Boxes](#) topic at the beginning of this chapter.

## Write Modes

During a write operation (WE asserted), the data presented to the data input is stored in memory at the location selected by the address input. You can configure the behavior of the data out port A upon a write operation to one of the following modes:

- **Read after write**
- **Read before write**

- **No read on write**

These modes can be described with the help of the figure shown below. In the figure the memory has been set to an initial value of 5 and the address bit is specified as 4. When using **No read on write** mode, the output is unaffected by the address line and the output is the same as the last output when the WE was 0. For the other two modes, the output is obtained from the location specified by the address line, and hence is the value of the location being written to. This means that the output can be either the old value (**Read before write mode**), or the new value (**Read after write mode**).

Figure 317: Configuration for Read After Write

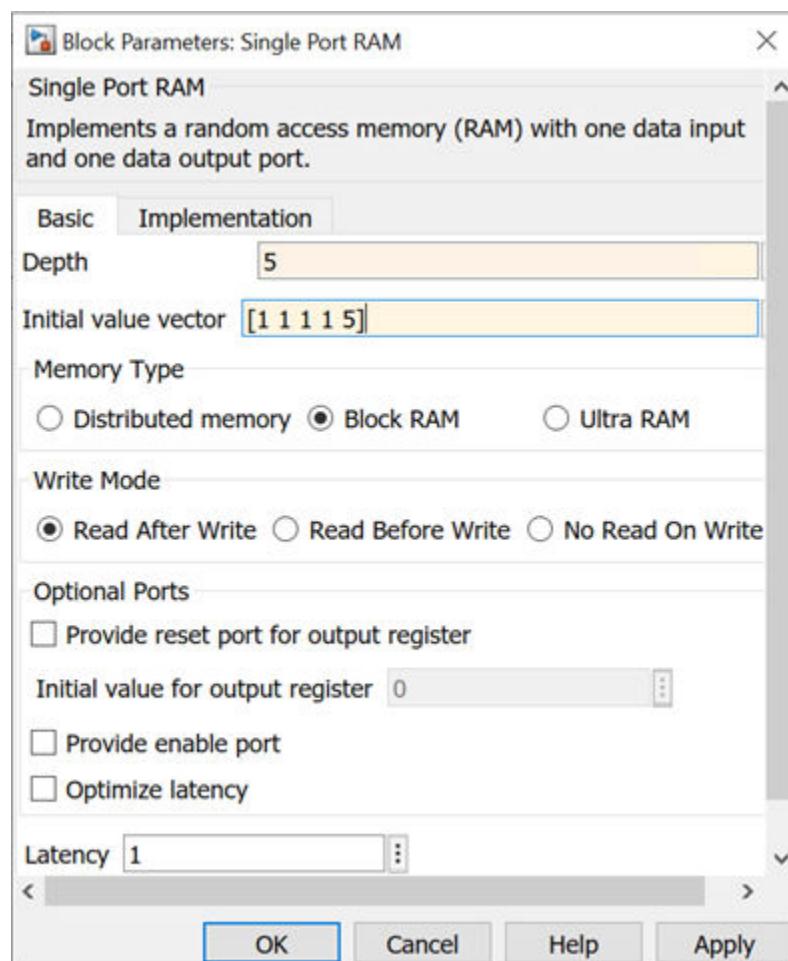
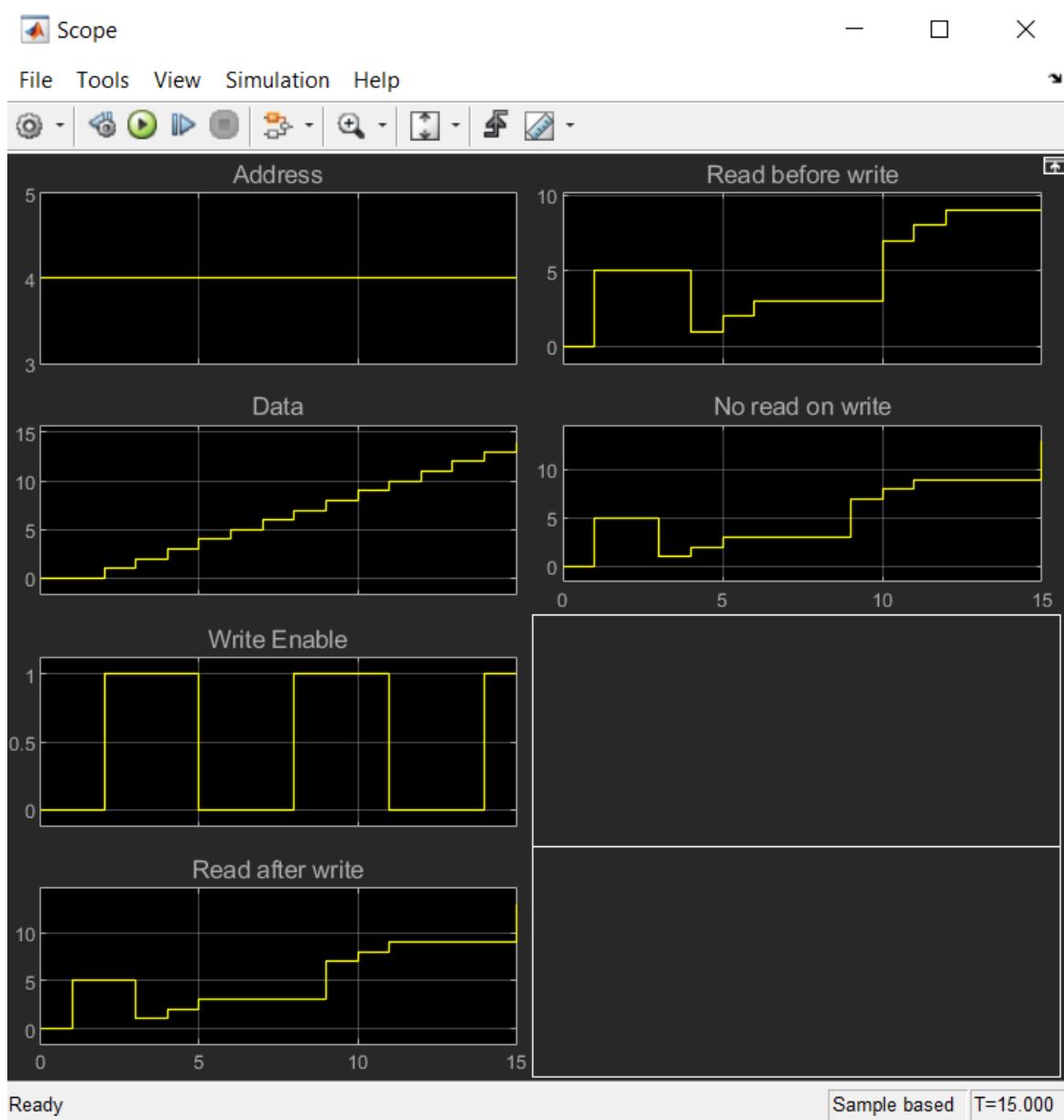


Figure 318: Write Output



### Hardware Notes

The distributed memory LogiCORE™ supports only the **Read before write** mode. The Xilinx Single Port RAM block also allows distributed memory with **Write Mode** option set to **Read after write** when specified latency is greater than 0. The **Read after write** mode for the distributed memory is achieved by using extra hardware resources (a MUX at the distributed memory output to latch data during a write operation).

## LogiCORE and XPM Documentation

Distributed Memory Generator LogiCORE IP Product Guide ([PG063](#)) (Distributed Memory)

UltraScale Architecture Memory Resources User Guide ([UG573](#)) - XPM\_MEMORY\_SPRAM Macro (UltraRAM)

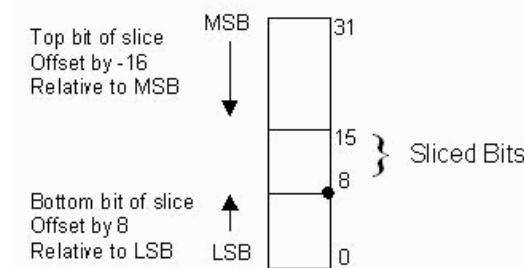
## Slice

The Xilinx Slice block allows you to slice off a sequence of bits from your input data and create a new data value. This value is presented as the output from the block. The output data type is unsigned with its binary point at zero.



The block provides several mechanisms by which the sequence of bits can be specified. If the input type is known at the time of parameterization, the various mechanisms do not offer any gain in functionality. If, however, a Slice block is used in a design where the input data width or binary point position are subject to change, the variety of mechanisms becomes useful. The block can be configured, for example, always to extract only the top bit of the input, only the integral bits, or only the first three fractional bits. The following diagram illustrates how to extract all but the top 16 and bottom 8 bits of the input.

*Figure 319: Extracting Top 16 and Bottom 8 Bits*



## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Parameters specific to the block are as follows.

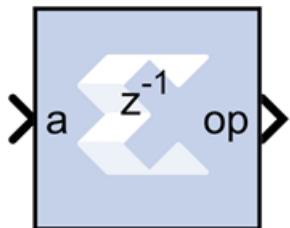
- **Width of slice (Number of bits):** Specifies the number of bits to extract.
- **Boolean output:** Tells whether single bit slices should be type Boolean.

- **Specify range as:** (Two bit locations | Upper bit location + width |Lower bit location + width). Allows you to specify either the bit locations of both end-points of the slice or one end-point along with number of bits to be taken in the slice.
- **Offset of top bit:** Specifies the offset for the ending bit position from the LSB, MSB or binary point.
- **Offset of bottom bit:** Specifies the offset for the ending bit position from the LSB, MSB or binary point.
- **Relative to:** Specifies the bit slice position relative to the Most Significant Bit (MSB), Least Significant Bit (LSB), or Binary point of the top or the bottom of the slice.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## SquareRoot

The Xilinx SquareRoot block performs the square root on the input. Currently, only the floating-point data type is supported.



### Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows.

- **Flow Control:**

- **Blocking:** Selects “Blocking” mode. In this mode, the lack of data on one input channel does block the execution of an operation if data is received on another input channel.
    - **NonBlocking:** Selects “Non-Blocking” mode. In this mode, the lack of data on one input channel does not block the execution of an operation if data is received on another input channel.

- **Optional ports:**

- **Input Channel Ports:**
  - **Has TLAST:** Adds a TLAST port to the Input channel.
  - **Has TUSER:** Adds a TUSER port to the Input channel.
  - **Provide enable port:** Adds an enable port to the block interface.
  - **Has Result TREADY:** Adds a TREADY port to the Result channel.
- **Exception Signals:**
  - **INVALID\_OP:** Adds an output port that serves as an invalid operation flag.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

# System Generator



**IMPORTANT!** The System Generator token will be removed in a future release of Vitis Model Composer. Please consider updating your model to use the [Vitis Model Composer Hub](#) block.

The System Generator token serves as a control panel for controlling system and simulation parameters, and it is also used to invoke the code generator for netlisting. Every Simulink® model containing any element from the HDL Blockset must contain at least one System Generator token. Once a System Generator token is added to a model, it is possible to specify how code generation and simulation should be handled.



## Token Parameters

The parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

- **Compilation tab:**

Parameters specific to the Compilation tab are as follows.
- **Board:**

Specifies a Xilinx, Partner, or Custom board you will use to test your design. You can specify a **Board** for any of the compilation targets you select with the **Compilation** setting described below (**IP Catalog**, **Hardware Co-Simulation**, **Synthesized Checkpoint**, or **HDL Netlist**).

When you select a **Board**, the **Part** field displays the name of the Xilinx device on the selected **Board**, and this part name cannot be changed.

For a Partner board or a custom board to appear in the **Board** list, you must configure Model Composer to access the board files that describe the board.

- **Part:** Defines the Xilinx FPGA or SoC part to be used. If you have selected a **Board**, the **Part** field will display the name of the Xilinx device on the selected **Board**, and this part name cannot be changed.
- **Compilation:**

Specifies the type of compilation result that should be produced when the code generator is invoked. The default compilation type is **IP Catalog**.

The **Settings** button is activated when one of these compilation types is selected:

- **IP Catalog compilation:** The **Settings** button brings up a dialog box that allows you to add a description of the IP that will be placed in the IP catalog.
- **Hardware Co-Simulation (JTAG) compilation:** The **Settings** button brings up a dialog box that allows you to use burst data transfers to speed up JTAG hardware co-simulation.
- **Hardware Description Language:** Specifies the HDL language to be used for compilation of the design. The possibilities are VHDL and Verilog.
- **VHDL library:** Specifies the name of VHDL work library for code generation. The default name is `xil_defaultlib`.
- **Use STD\_LOGIC type for Boolean or 1 bit wide gateways:** If your design's Hardware Description Language (HDL) is VHDL, selecting this option will declare a Boolean or 1-bit port (Gateway In or Gateway Out) as a STD-LOGIC type. If this option is not selected, Model Composer will interpret Boolean or 1-bit ports as vectors.

**Note:** When you enable this option and try to run Generate code and Run behavioral simulation in Vivado, you may see a failure during the elaboration phase.

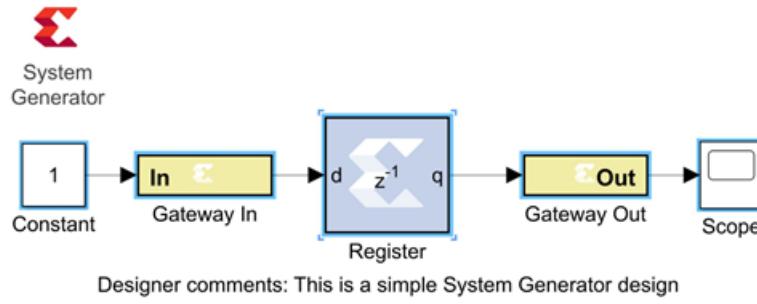
- **Target directory:** Defines where Model Composer should write compilation results. Because Model Composer and the FPGA physical design tools typically create many files, it is best to create a separate target directory, for example, a directory other than the directory containing your Simulink® model files.
- **Synthesis strategy:** Choose a Synthesis strategy from the pre-defined strategies in the drop-down list.

- **Implementation strategy:** Choose an Implementation strategy from the pre-defined strategies in the drop-down list.
- **Create interface document:** When this box is checked and the Generate button is activated for netlisting, Model Composer creates an HTM document that describes the design being netlisted. This document is placed in a “documentation” subfolder under the netlist folder.

Adding Designer Comments to the Generated Document: If you want to add personalized comments to the auto-generated document, follow this procedure.

1. As shown below, double click the Simulink canvas at the top level and add a comment that starts with **Designer Comments**:

Figure 320: Designer Comments



2. Double click on the System Generator token, click the **Create interface document** box at the bottom of the Compilation tab, then click **Generate**.
3. When netlisting is complete, navigate to the `documentation` subfolder underneath the `netlist` folder and double-click on the HTM document.

Designer Comments section is created in the document and your personalized comments are included.

Figure 321: Designer Comments Section



- **Create testbench:** This instructs Model Composer to create an HDL test bench. Simulating the test bench in an HDL simulator compares Simulink simulation results with ones obtained from the compiled version of the design. To construct test vectors, Model Composer simulates the design in Simulink, and saves the values seen at gateways. The top HDL file for the test bench is named <name>\_testbench.vhd/.v, where <name> is a name derived from the portion of the design being tested.

**Note:** Testbench generation is not supported for designs that have gateways (Gateway In or Gateway Out) configured as an AXI4-Lite Interface

- **Model Upgrade:** Generates a Status Report that helps you identify and upgrade blocks that are not the latest available.
- **Clocking tab:**

Parameters specific to the Clocking tab are as follows.

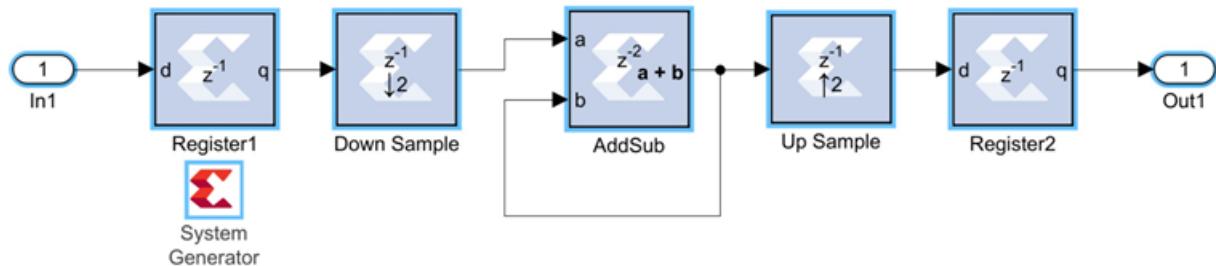
- **Enable multiple clocks:** Must be enabled in the top-level System Generator token of a multiple clock design. This indicates to the Code Generation engine that the clock information for the various Subsystems must be obtained from the System Generator tokens contained in those Subsystems. If not enabled, then the design will be treated as a single clock design where all the clock information is inherited from the top-level System Generator token.
- **FPGA clock period(ns):** Defines the period in nanoseconds of the system clock. The value need not be an integer. The period is passed to the Xilinx implementation tools through a constraints file, where it is used as the global PERIOD constraint. Multicycle paths are constrained to integer multiples of this value.

- **Clock pin location:** Defines the pin location for the hardware clock. This information is passed to the Xilinx implementation tools through a constraints file. This option should not be specified if the Model Composer design is to be included as part of a larger HDL design.
- **Provide clock enable clear pin:** This instructs Model Composer to provide a `ce_clr` port on the top-level clock wrapper. The `ce_clr` signal is used to reset the clock enable generation logic. Capability to reset clock enable generation logic allows designs to have dynamic control for specifying the beginning of data path sampling.
- **Simulink system period (sec):** Defines the Simulink System Period, in units of seconds. The Simulink system period is the greatest common divisor of the sample periods that appear in the model. These sample periods are set explicitly in the block dialog boxes, inherited according to Simulink propagation rules, or implied by a hardware oversampling rate in blocks with this option. In the latter case, the implied sample time is in fact faster than the observable simulation sample time for the block in Simulink. In hardware, a block having an oversampling rate greater than one processes its inputs at a faster rate than the data. For example, a sequential multiplier block with an over-sampling rate of eight implies a (Simulink) sample period that is one eighth of the multiplier block's actual sample time in Simulink. This parameter can be modified only in a master block.
- **Perform analysis:** Specifies whether an analysis (timing or resource) will or will not be performed on the Model Composer design when it is compiled. If **None** is selected, no timing analysis or resource analysis will be performed. If **Post Synthesis** is selected, the analysis will be performed after the design has been synthesized in the Vivado® toolset. If **Post Implementation** is selected, the analysis will be performed after the design is implemented in the Vivado toolset.
- **Analyzer type:** Two selections are provided: **Timing or Resource**. After generation is completed, a Timing Analyzer table or Resource Analyzer table is launched.
- **Launch analyzer:** Launches the Timing Analyzer or Resource Analyzer table, depending on the selection of **Analyzer type**. This will only work if you already ran analysis on the Simulink model and haven't changed the Simulink model since the last run.
- **General tab:**

Parameters specific to the General tab are as follows.

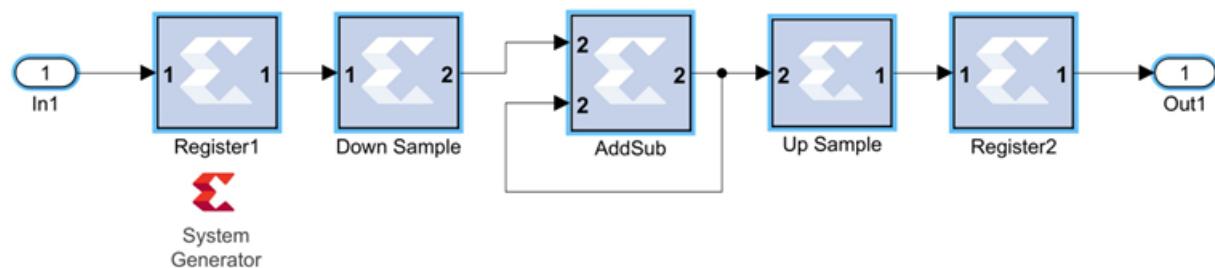
- **Block icon display:** Specifies the type of information to be displayed on each block icon in the model after compilation is complete. The various display options are described below.
  - **Default:** Displays the default block icon information on each block in the model. A block's default icon is derived from the `xbsIndex` library.

**Figure 322: Default Block Icon**



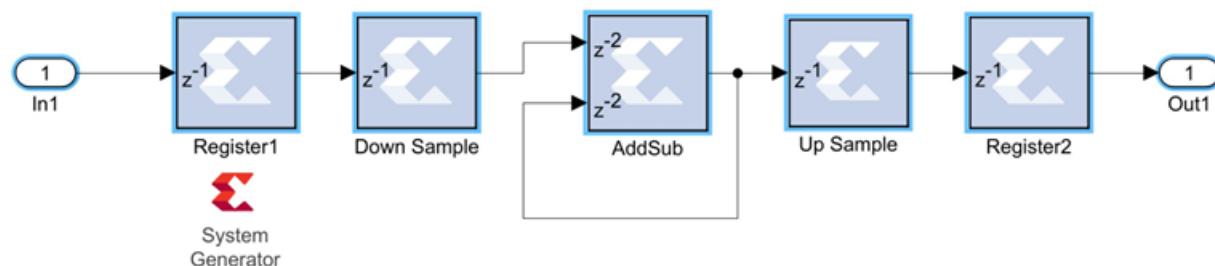
- **Normalized Sample Periods:** Displays the normalized sample periods for all the input and output ports on each block. For example, if the Simulink System Period is set to 4 and the sample period propagated to a block port is 4 then the normalized period that is displayed for the block port is 1 and if the period propagated to the block port is 8 then the sample period displayed would be 2 for example, a larger number indicates a slower rate.

**Figure 323: Normalized Sample Periods Icon**



- **Sample frequencies (MHz):** Displays sample frequencies for each block.
- **Pipeline stages:** Displays the latency information from the input ports of each block. The displayed pipeline stage might not be accurate for certain high-level blocks such as the FFT, RS Encoder/Decoder, Viterbi Decoder, etc. In this case the displayed pipeline information can be used to determine whether a block has a combinational path from the input to the output. For example, the Up Sample block in the figure below shows that it has a combinational path from the input to the output port.

**Figure 324: Sample Frequencies**



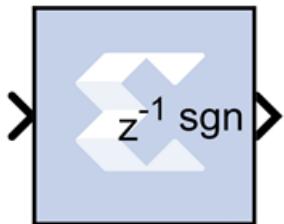
- **HDL port names:** Displays the HDL port name of each port on each block in the model.
- **Input data types:** Displays the data type of each input port on each block in the model.
- **Output data types:** Displays the data type of each output port on each block in the model.
- **Remote IP cache:** If selected, your design will access an IP cache whenever a Model Composer compilation performs Vivado synthesis as part of the compilation. If the compilation generates an IP instance for synthesis, and the Vivado synthesis tool generates synthesis output products, the tools create an entry in the cache area. If a new customization of the IP is created which has the exact same properties, the tools will copy the synthesis outputs from the cache to the design's output directory instead of synthesizing the IP instance again. Accessing the disk cache speeds up the iterative design process.

IP caching is described in HDL Library.

- **Clear cache:** Clicking this button clears the remote IP cache. Clearing the cache saves disk space, because the IP Cache can grow large, especially if your design uses many IP modules.

## Threshold

The Xilinx Threshold block tests the sign of the input number. If the input number is negative, the output of the block is -1; otherwise, the output is 1. The output is a signed fixed-point integer that is 2 bits long. The block has one input and one output.



### Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

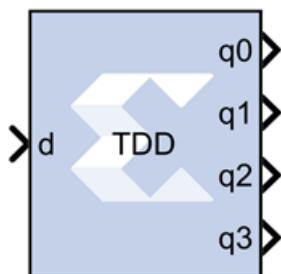
The block parameters do not control the output data type because the output is always a signed fixed-point integer that is 2 bits long.

### Xilinx LogiCORE

The Threshold block does not use a Xilinx LogiCORE™.

## Time Division Demultiplexer

The Xilinx Time Division Demultiplexer block accepts input serially and presents it to multiple outputs at a slower rate.

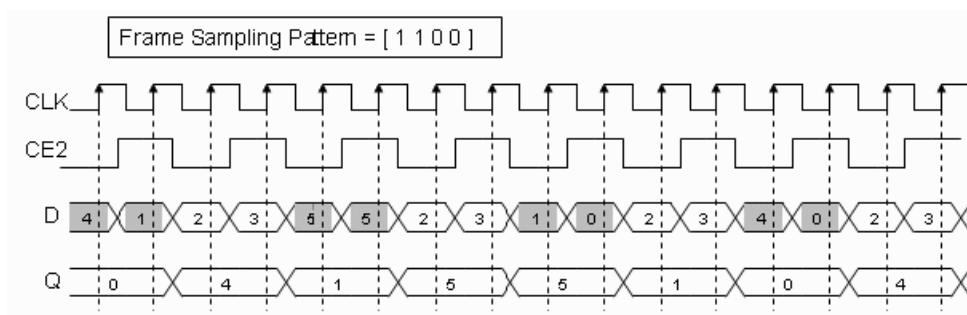


### Block Interface

The block has one data input port and a user-configurable number of data outputs, ranging from 1 to 32. The data output ports have the same arithmetic type and precision as the input data port. The time division demultiplexer block also has optional input-valid port (*vin*) and output-valid port (*vout*). Both the valid ports are of type Bool.

For single channel implementation, the time division demultiplexer block has one data input and output port. Optional data valid input and output ports are also allowed. The length of the frame sampling pattern establishes the length of the input data frame. The position of 1 indicates the input value to be downsampled and the number of 1's correspond to the downsampling factor. The behavior of the demultiplexer block in single channel mode can best be illustrated with the help of the figure below. Based on the frame sampling pattern entered, the first and second input values of every input data frame are sampled and presented to the output at the rate of 2.

Figure 325: Single Channel Implementation



For single channel implementation, the number of values to be sampled from a data frame should evenly divide the size of the input frame. Every input data frame value can also be qualified by using the optional valid port.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

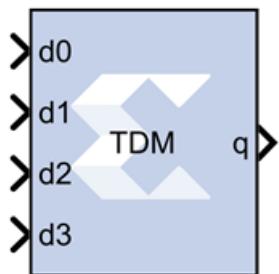
Parameters specific to this block are as follows.

- **Frame sampling pattern:** Specifies the size of the serial input data frame. The frame sampling pattern must be a MATLAB® vector containing only 1's and 0's.
- **Implementation:** Specifies the demultiplexer behavior to be either in single or multiple channel mode. The behaviors of these modes are explained above.
- **Provide Valid Port:** When selected, the demultiplexer has optional input and output valid ports (vin / vout). The vin port allows to qualify every input data value as part of the serial input data frame. The vout port marks the state of the output ports as valid or not.

Parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Time Division Multiplexer

The Xilinx Time Division Multiplexer block multiplexes values presented at input ports into a single faster rate output stream.



## Block Interface

The block has two to 32 input ports and one output port. All input ports must have the same arithmetic type, precision, and rate. The output port has the same arithmetic type and precision as the inputs. The block has optional ports vin and vout that specify when input and output respectively are valid. Both valid ports are of type Bool.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

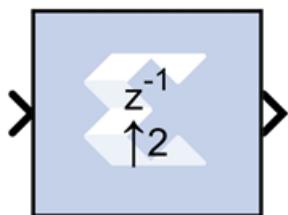
Parameters specific to the block are as follows.

- **Number of inputs:** Specifies the number of inputs (2 to 32).
- **Provide valid port:** When selected, the multiplexer is augmented with input and output valid ports named vin and vout respectively. When the vin port indicates that input values are invalid, the vout port indicates the corresponding output frame is invalid.
- **Optimization Parameter:** The Time Division Multiplexer block logic can be implemented in fabric (optimizing for resource usage) or in DSP48E1/DSP48E2 primitives (optimizing for speed). The default is **Resource**.
- **Resource:** Use combinatorial fabric (general interconnect) to implement the Time Division Multiplexer in the Xilinx device.
- **Speed:** Use DSP48 primitives to implement the Time Division Multiplexer in the Xilinx device.

Parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Up Sample

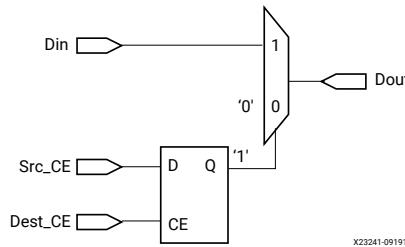
The Xilinx Up Sample block increases the sample rate at the point where the block is placed in your design. The output sample period is  $l/n$ , where  $l$  is the input sample period, and  $n$  is the sampling rate.



The input signal is up sampled so that within an input sample frame, an input sample is either presented at the output n times if samples are copied, or presented once with (n-1) zeroes interspersed if zero padding is used.

In hardware, the Up Sample block has two possible implementations. If the Copy Samples option is selected on the block parameters dialog box, the Din port is connected directly to Dout and no hardware is expended. Alternatively, if zero padding is selected, a mux is used to switch between the input sample and inserted zeros. The corresponding circuit for the zero padding Up Sample block is shown below.

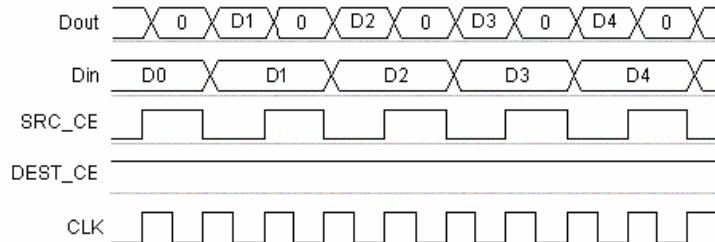
Figure 326: Zero Padding Up Sample Circuit



## Block Interface

The Up Sample block receives two clock enable signals, Src\_CE and Dest\_CE. Src\_CE is the clock enable signal corresponding to the input data stream rate. Dest\_CE is the faster clock enable, corresponding to the output data stream rate. Notice that the circuit uses a single flip-flop in addition to the mux. The flip-flop is used to adjust the timing of Src\_CE, so that the mux switches to the data input sample at the start of the input sample period, and switches to the constant zero after the first input sample. It is important to notice that the circuit has a combinational path from Din to Dout. As a result, an Up Sample block configured to zero pad should be followed by a register whenever possible.

Figure 327: Up Sample Output



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows.

- **Sampling rate (number of output samples per input sample):** Must be an integer with a value of 2 or greater. This is the ratio of the output sample period to the input, and is essentially a sample rate multiplier. For example, a ratio of 2 indicates a doubling of the input sample rate. If a non-integer ratio is desired, the Up Sample block can be used in combination with the Down Sample block.

- **Copy samples (otherwise zeros are inserted):** Allows you to choose what to do with the additional samples produced by the increased clock rate. By selecting Copy Samples, the same sample is duplicated (copied) during the extra sample times. If this checkbox is not selected, the additional samples are zero.
- **Provide enable port:** When checked, this option adds an en (enable) input port, if the Latency is specified as a positive integer greater than zero.
- **Latency:** This defines the number of sample periods by which the block's output is delayed. One sample period can correspond to multiple clock cycles in the corresponding FPGA implementation (for example, when the hardware is over-clocked with respect to the Simulink® model). The user defined sample latency is handled in the Up Sample block by placing shift registers that are clock enabled at the input sample rate, on the input of the block. The behavior of an Upsample block with non-zero latency is similar to putting a delay block, with equivalent latency, at the input of an Upsample block with zero latency.

Parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Vector Absolute

The Vector Absolute block outputs the absolute value of the input of vector type.

### Description

This block enables 1-D vector support for the primary block operation.



### Block Parameters

Double-click the icon in your Simulink® model to open the Block Parameters dialog box.

- **Basic tab:**

- **Precision:**

This parameter allows you to specify the output precision for fixed-point arithmetic. Floating-point arithmetic output will always be **Full** precision.

- **Full:** The block uses sufficient precision to represent the result without error.
    - **User Defined:** If you do not need full precision, this option allows you to specify a reduced number of total bits and/or fractional bits.

- **Fixed-point Output Type:**

Arithmetic type:

- **Signed (2's comp):** The output is a Signed (2's complement) number.
- **Unsigned:** The output is an Unsigned number.

- **Fixed-point Precision:**

- **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
- **Binary point:** Position of the binary point. in the fixed-point output.

- **Quantization:**

Refer to the section [Overflow and Quantization](#).

- **Overflow:**

Refer to the section [Overflow and Quantization](#).

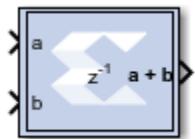
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

[LogiCORE IP Floating-Point Operator v7.1](#)

## Vector AddSub Fabric

The Vector Adder/Subtracter Fabric block supports the Addition/Subtraction operation for inputs of vector type.



## Block Parameters

Double-click the icon in your Simulink® model to open the Block Parameters dialog box.

- **Basic tab:**

Parameters specific to the Basic tab are as follows:

- **Operation:** Specifies the block operation to be Addition, Subtraction, or Addition/Subtraction. When Addition/Subtraction is selected, the block operation is determined by the sub input port, which must be driven by a Boolean signal. When the sub input is 1, the block performs subtraction. Otherwise, it performs addition.
- **Optional Ports:**
  - **Provide carry-in port:** When selected, allows access to the carry-in port, `cin`. The carry-in port is available only when **User defined** precision is selected and the binary point of the inputs is set to zero.
  - **Provide carry-out port:** When selected, allows access to the carry-out port, `cout`. The carry-out port is available only when **User defined** precision is selected, the inputs and output are unsigned, and the number of output integer bits equals  $x$ , where  $x = \max(\text{integer bits } a, \text{integer bits } b)$ .
- **Latency:** The **Latency** value defines the number of sample periods by which the block's output is delayed. One sample period might correspond to multiple clock cycles in the corresponding FPGA implementation (for example, when the hardware is over-clocked with respect to the Simulink model). Model Composer does not perform extensive pipelining unless you select the **Pipeline for maximum performance** option (on the Implementation tab, described below); additional latency is usually implemented as a shift register on the output of the block.
- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on each sample period. This blocks enable 1-D vector support for the primary block operation.
- **Output tab:**
  - **Precision:**

This parameter allows you to specify the output precision for fixed-point arithmetic. Floating point arithmetic output will always be **Full** precision.

    - **Full:** The block uses sufficient precision to represent the result without error.
    - **User Defined:** If you do not need full precision, this option allows you to specify a reduced number of total bits and/or fractional bits.
  - **User-Defined Precision:**
    - **Fixed-point Precision:**
      - **Signed (2's comp):** The output is a Signed (2's complement) number.
      - **Unsigned:** The output is an Unsigned number.
      - **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
      - **Binary point:** Position of the binary point. in the fixed-point output.

- **Quantization:** Refer to the section [Overflow and Quantization](#).
- **Overflow:** Refer to the section [Overflow and Quantization](#).
- **Implementation tab:**

Parameters specific to the Implementation tab are as follows:

- **Use behavioral HDL (otherwise use core):** The block is implemented using behavioral HDL. This gives the downstream logic synthesis tool maximum freedom to optimize for performance or area.

**Note:** For Floating-point operations, the block always uses the Floating-point Operator core.

- **Core Parameters:**

- **Implement using:** Core logic can be implemented in **Fabric** or in a **DSP48**, if a DSP48 is available in the target device. The default is **Fabric**.
- **Pipeline for maximum performance:**

The XILINX LogiCORE™ can be internally pipelined to optimize for speed instead of area. Selecting this option puts all user defined latency into the core until the maximum allowable latency is reached. If the **Pipeline for maximum performance** option is not selected and latency is greater than zero, a single output register is put in the core and additional latency is added on the output of the core.

The **Pipeline for maximum performance** option adds the pipeline registers throughout the block, so that the latency is distributed, instead of adding it only at the end. This helps to meet tight timing constraints in the design.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

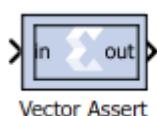
## LogiCORE Documentation

*Adder/Subtractor LogiCORE IP Product Guide (PG120)*

*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

## Vector Assert

The Vector Assert block asserts a user-defined sample rate and/or type on Vector inputs.



Hardware notes: In hardware this blocks costs nothing.

## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

Parameters specific to this block are as follows:

- **Type:**
  - **Assert type:** Specifies whether or not the block will assert that the type at its input is the same as the type specified. If the types are not the same, an error message is reported.
  - **Specify type:** Specifies whether or not the type to assert is provided from a signal connected to an input port named `type` or whether it is specified **Explicitly** from parameters in the Assert block dialog box.
  - **Output Type:** Specifies the data type of the output. Can be **Boolean**, **Fixed-point**, or **Floating-point**.
  - **Arithmetic Type:** If the Output Type is specified as Fixed-point, you can select **Signed (2's comp)** or **Unsigned** as the Arithmetic Type.
    - **Fixed-point Precision:**
      - **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
      - **Binary point:** Position of the binary point in the fixed-point output.
    - **Floating-point Precision:**
      - **Single:** Specifies single precision (32 bits).
      - **Double:** Specifies double precision (64 bits).
    - **Custom:** This block is listed in the following: Activates the field below so you can specify the Exponent width and the Fraction width.
      - **Exponent width:** Specify the exponent width.
      - **Fraction width:** Specify the fraction width.
- **Rate:**
  - **Assert rate:** specifies whether or not the block will assert that the rate at its input is the same as the rate specified. If the rates are not the same, an error message is reported.
  - **Specify rate:** Specifies whether or not the initial rate to assert is provided from a signal connected to an input port named `rate`, or whether it is specified explicitly from the **Sample rate** parameter in the Assert block dialog box.

- **Provide output port:** Specifies whether or not the block will feature an output port. The type and/or rate of the signal presented on the output port is the type and/or rate specified for assertion.
- **Super Sample Rate (SSR):** Use this configurable GUI parameter to control processing of multiple data samples on every sample period. This block enables 1-D vector data support for the primary block operation.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

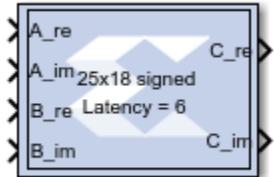
The **Output type** parameter in this block uses the same description as the Arithmetic Type described in the topic [Common Options in Block Parameter Dialog Boxes](#).

The Vector Assert block does not use a Xilinx LogiCORE™ and does not use resources when implemented in hardware.

## Vector Complex Mult

### Description

The Vector Complex Multiplier block supports multiplication of two complex input vectors.



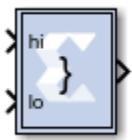
**Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This blocks enable 1-D vector support for the primary block operation.

### Data Type Support

- Supports fixed and floating-point data type inputs on both port A and B.
- The number of bits on Input port A should be greater than or equal to 26.
- The number of bits on Input port B should be greater than or equal to 17.

## Vector Concat

The Vector Concat block concatenates two or more inputs of type vector. The output is cast to an unsigned value with the binary point at zero.



The [Vector Reinterpret](#) block provides capabilities that can extend the functionality of the Vector Concat block.

### Block Interface

The block has  $n$  input ports, where  $n$  is a value between 2 and 1024, inclusively, and one output port. The first and last input ports are labeled `hi` and `low`, respectively. Input ports between these two ports are not labeled. The input to the `hi` port occupies the most significant bits of the output, and the input to the `lo` port occupies the least significant bits of the output.

### Block Parameters

Double-click the icon in your Simulink® model to open the Block Parameter dialog box.

Parameters specific to this block are as follows:

- **Number of Inputs:** Specifies number of inputs, between 2 and 1024, inclusively, to concatenate together.
- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This block enables 1-D vector data support for the primary block operation.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

The Vector Concat block does not use a Xilinx LogiCORE™.

## Vector Constant

The Vector Constant Block generates vector constant values.

### Description

The Vector Constant block generates a constant that can be a fixed-point value, a Boolean value, or a DSP48 instruction. This block is similar to the Simulink® Vector Constant block, but can be used to directly drive the inputs on HDL blocks.



## Block Parameters

Open the Block Parameters dialog box by double-clicking the icon in your Simulink model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows:

- **Constant Value:**

Specifies the value of the constant. When changed, the new value appears on the block icon. If the constant data type is specified as fixed-point and cannot be expressed exactly in the specified fixed-point type, its value is rounded and saturated as needed. A positive value is implemented as an unsigned number, a negative value as signed.

- **Output Type:** Specifies the data type of the output.

- Boolean
- Fixed-point
- Floating-point

- **Arithmetic Type:** Specifies the arithmetic type to use for a fixed-point output.

- Signed (2's comp)
- Unsigned
- DSP48 instruction

- **Fixed-point Precision:**

- **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
- **Binary point:** Position of the binary point. in the fixed-point output.

- **Floating-point Precision:**

- **Single:** Specifies single precision (32 bits).
- **Double:** Specifies double precision (64 bits).
- **Custom:** Activates the field below so you can specify the Exponent width and the Fraction width.
- **Exponent width:** Specifies the exponent width.

- **Fraction width:** Specifies the fraction width.
- **Sample Period:**
  - **Sampled Constant:** Allows a sample period to be associated with the constant output and inherited by blocks that the Constant block drives. This is useful mainly because the blocks eventually target hardware and the Simulink sample periods are used to establish hardware clock periods.
  - **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This block enables 1-D vector data support for the primary block operation.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Vector Convert

The Vector Convert block supports Data Type Conversion feature for vector type inputs.

Hardware notes: Rounding and saturating require hardware resources; truncating and wrapping do not.

### Description

The Vector Convert block converts each input sample to a number of a desired arithmetic type. For example, a number can be converted to a signed (two's complement) or unsigned value.



### Block Parameters

Open the Block Parameters dialog box by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows:

- **Output Type:**

- Specify the output data type.
  - Boolean
  - Fixed-point
  - Floating-point

- **Arithmetic Type:** If the Output Type is specified as fixed-point, you can select Signed (two's comp) or Unsigned.
- **Fixed-point Precision:**
  - **Number of bits:** Specifies the bit location of the binary point, where bit zero is the least significant bit
  - **Binary point:** Specifies the bit location of the binary point, where bit zero is the least significant bit.
- **Floating-point Precision:**
  - **Single:** Specifies single precision (32 bits).
  - **Double:** Specifies double precision (64 bits).
  - **Custom:** Activates the field below so you can specify the Exponent width and the Fraction width.
  - **Exponent width:** Specify the exponent width.
  - **Fraction width:** Specify the fraction width.
- **Quantization:**

Quantization errors occur when the number of fractional bits is insufficient to represent the fractional portion of a value. The options are to **Truncate** (for example, to discard bits to the right of the least significant representable bit), or to **Round(unbiased: +/- inf)** or **Round (unbiased: even values)**.

**Round (unbiased: +/- inf)** also known as "Symmetric Round (towards +/- inf)" or "Symmetric Round (away from zero)". This is similar to the MATLAB `round()` function. This method rounds the value to the nearest desired bit away from zero and when there is a value at the midpoint between two possible rounded values, the one with the larger magnitude is selected. For example, to round 01.0110 to a Fix\_4\_2, this yields 01.10, since 01.0110 is exactly between 01.01 and 01.10 and the latter is further from zero.

**Round (unbiased: even values)** also known as "Convergent Round (toward even)" or "Unbiased Rounding". Symmetric rounding is biased because it rounds all ambiguous midpoints away from zero which means the average magnitude of the rounded results is larger than the average magnitude of the raw results. Convergent rounding removes this by alternating between a symmetric round toward zero and symmetric round away from zero. That is, midpoints are rounded toward the nearest even number. For example, to round 01.0110 to a Fix\_4\_2, this yields 01.10, since 01.0110 is exactly between 01.01 and 01.10 and the latter is even. To round 01.1010 to a Fix\_4\_2, this yields 01.10, since 01.1010 is exactly between 01.10 and 01.11 and the former is even.
- **Overflow:**

Overflow errors occur when a value lies outside the representable range. For overflow the options are to **Saturate** to the largest positive/smallest negative value, to **Wrap** (for example, to discard bits to the left of the most significant representable bit), or to **Flag as error** (an overflow as a Simulink error) during simulation. **Flag as error** is a simulation only feature. The hardware generated is the same as when **Wrap** is selected.

- **Optional Ports:**

**Provide enable port:** Activates an optional enable (en) pin on the block. When the enable signal is not asserted the block holds its current state until the enable signal is asserted again or the reset signal is asserted.

- **Latency:**

The **Latency** value defines the number of sample periods by which the block's output is delayed. One sample period might correspond to multiple clock cycles in the corresponding FPGA implementation (for example, when the hardware is over-clocked with respect to the Simulink model). Model Composer will not perform extensive pipelining unless you select the **Pipeline for maximum performance** option (described below); additional latency is usually implemented as a shift register on the output of the block.

- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This blocks enable 1-D vector data support for the primary block operation.

- **Implementation tab:**

Parameters specific to the Implementation tab are as follows:

- **Performance Parameters:**

- **Pipeline for maximum performance:**

The Xilinx LogiCORE™ can be internally pipelined to optimize for speed instead of area. Selecting this option puts all user defined latency into the core until the maximum allowable latency is reached. If the **Pipeline for maximum performance** option is not selected and latency is greater than zero, a single output register is put in the core and additional latency is added on the output of the core.

The **Pipeline for maximum performance** option adds the pipeline registers throughout the block, so that the latency is distributed, instead of adding it only at the end. This helps to meet tight timing constraints in the design.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

[Floating-Point Operator LogiCORE IP Product Guide \(PG060\)](#)

## Vector DDFS

The Vector DDFS block generates Real and Imaginary vector output signals of desired frequency.

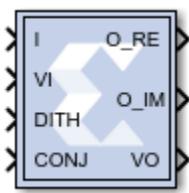
### Description

The input port I is used for providing the desired output frequency value as a vector type.

The input port I value should be equal to:

$$(\text{desired output Frequency} * \text{Sampling time} * 2^{(\text{Frequency Resolution})})$$

The VI input port and VO output are used for synchronization purposes with the other blocks in the design. The VO is just a delayed version of VI based on the block latency. The DITH input port is used to turn on/off the phase noise dithering feature. The CONJ input port is set to '1' to conjugate the complex exponential output. The output ports, O\_RE and O\_IM, generate Real and Imaginary components of the desired vector output frequency signal.



### Data Type Support

- The input port I should be a signed fixed-point data type.
- The input port VI, DITH, and CONJ should be Boolean data types.

### Block Parameters

- **Super Sample Rate (SSR):**

This configurable GUI parameter is primarily used to control the processing of multiple data samples on every sample period. This block enables 1-D vector support for the primary block operation.

- **Frequency Resolution (bits):**

Defines the smallest incremental step in frequency that the block can output. This should be an integer value.

- **Sin/Cos Table Depth:**

Defines the depth of the Sin/Cos Table and should be an integer value.

- **Sin/Cos Table Width:**

Defines the width of the Sin/Cos Table and should be an integer value.

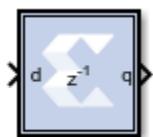
## Vector Delay

The Vector Delay block supports delay operation on vector type inputs.

Hardware notes: A delay line is a chain, each link of which is an SRL16 followed by a flip-flop.

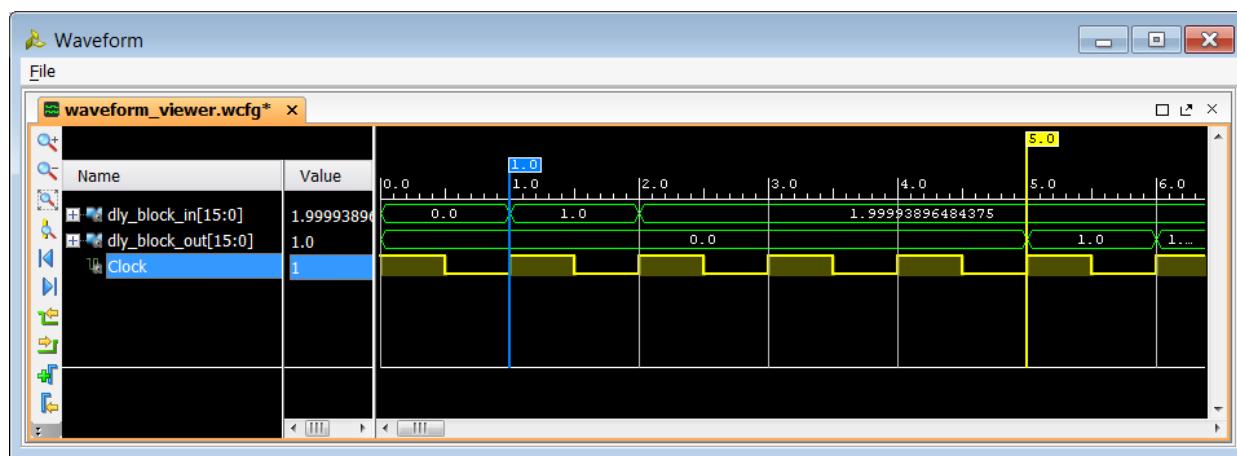
### Description

The Vector Delay block implements a fixed delay of L cycles.



The delay value is displayed on the block in the form  $z^{-L}$ , which is the *Z-transform* of the block's transfer function. Any data provided to the input of the block will appear at the output after L cycles. The rate and type of the data of the output is inherited from the input. This block is used mainly for matching pipeline delays in other portions of the circuit. The delay block differs from the register block in that the register allows a latency of only 1 cycle and contains an initial value parameter. The Vector Delay block supports a specified latency, but no initial value other than zeros. The figure below shows the Vector Delay block behavior when L=4 and Period=1s.

Figure 328: Vector Delay block behavior when L=4 and Period=1s



For delays that need to be adjusted during run-time, you should use the Addressable Shift Register block. Delays that are not an integer number of clock cycles are not supported and such delays should not be used in synchronous design (with a few rare exceptions).

## Block Parameters

Open the Block Parameters dialog box by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows:

- **Optional Ports:**

- **Provide synchronous reset port:** Activates an optional reset (rst) pin on the block. When the reset signal is asserted the block goes back to its initial state. Reset signal has precedence over the optional enable signal available on the block. The reset signal has to run at a multiple of the block's sample rate. The signal driving the reset port must be Boolean.
- **Provide enable port:** Activates an optional enable (en) pin on the block. When the enable signal is not asserted the block holds its current state until the enable signal is asserted again or the reset signal is asserted. Reset signal has precedence over the enable signal. The enable signal has to run at a multiple of the block's sample rate. The signal driving the enable port must be Boolean.

- **Latency:** Latency is the number of cycles of delay. The latency can be zero, provided that the **Provide enable port** check box is not checked. The latency must be a non-negative integer. If the latency is zero, the Vector Delay block collapses to a wire during logic synthesis. If the latency is set to L=1, the block will generally be synthesized as a flip-flop (or multiple flip-flops if the data width is greater than 1).
- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This block enables 1-D vector support for the primary block operation.

- **Implementation tab:**

Parameters specific to the Implementation tab are as follows:

- **Implement using behavioral HDL:** Uses behavioral HDL as the implementation. This allows the downstream logic synthesis tool to choose the best implementation.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

### Logic Synthesis using Behavioral HDL

This setting is recommended if you are using Synplify Pro as the downstream logic synthesis tool. The logic synthesis tool will implement the delay as it desires, performing optimizations such as moving parts of the delay line back or forward into blockRAMs, DSP48s, or embedded IOB flip-flops; employing the dedicated SRL cascade outputs for long delay lines based on the architecture selected; and using flip-flops to terminate either or both ends of the delay line based on path delays. Using this setting also allows the logic synthesis tool, if sophisticated enough, to perform retiming by moving portions of the delay line back into combinational logic clouds.

### Logic Synthesis using Structural HDL

If you do not check the **Implement using behavioral HDL** box, then structural HDL is used. This is the default setting and results in a known, but less-flexible, implementation which is often better for use with Vivado® synthesis. In general, this setting produces structural HDL comprising an SRL (Shift-Register LUT) delay of (L-1) cycles followed by a flip-flop, with the SRL and the flip-flop getting packed into the same slice. For a latency greater than L=33, multiple SRL/flip-flop sets are cascaded, albeit without using the dedicated cascade routes. For example, the following is the synthesis result for a 1-bit wide Vector Delay block with a latency of L=64.

## Vector Delay Delta

The Vector Delay Delta Block delays each vector element differently based on the given latency and delay latency values.

Hardware notes: A delay line is a chain, each link of which is an SRL16 followed by a flip-flop.

### Description

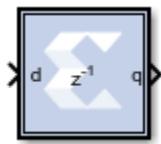
The delta latency parameter is used to generate each parallel path with different latency (for example, [Latency + Delta Latency \* (i-1)], where i represents the channel number in a range from 1 to the SSR value).

The delta latency should be an integer and greater than or equal to -Latency/(SSR-1).

For example when SSR is set to '4', Latency is set to '1', and Delta Latency is set to '3' then the four channels from 1 to 4 are delayed by 1,4,7, and 10 sample times respectively.

**Note:** In the Vector Delay Delta block, all the parallel channels are delayed by an equal number of sample times provided by Latency parameter.

The Vector Delay Delta block implements a fixed delay of L cycles.



### Block Parameters

- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This blocks enable 1-D vector and/or complex data support for the primary block operation.

See the Xilinx® [Vector Delay](#) block for further information on using this block.

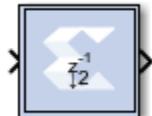
## Vector Down Sample

The Vector Down Sample block down samples input vector data.

Hardware notes: Sample and Latency controls determine the hardware implementation. The cost in hardware of different implementations varies considerably.

### Description

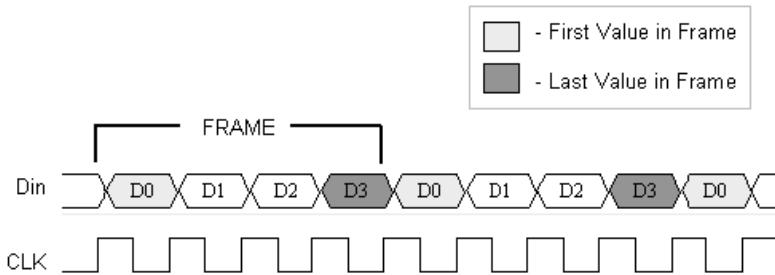
The Vector Down Sample block reduces the sample rate at the point where the block is placed in your design.



The input signal is sampled at even intervals, at either the beginning (first value), or end (last value) of a frame. The sampled value is presented on the output port and held until the next sample is taken.

A Vector Down Sample frame consists of  $I$  input samples, where  $I$  is sampling rate. An example frame for a Vector Down Sample block configured with a sampling rate of 4 is shown below.

**Figure 329: Vector Down Sample with Sampling Rate of 4**

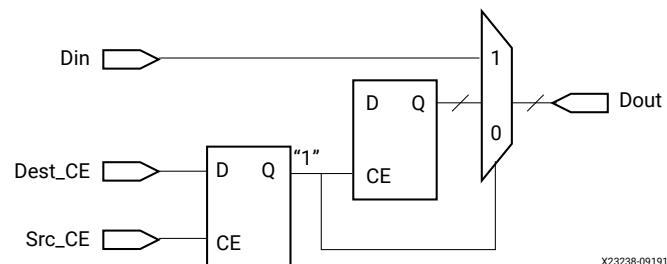


The Vector Down Sample block is realized in hardware using one of three possible implementations that vary in terms of implementation efficiency. The block receives two clock enable signals in hardware, `Src_CE`, and `Dest_CE`. `Src_CE` is the faster clock enable signal and corresponds to the input data stream rate. `Dest_CE` is the slower clock enable, corresponding to the output stream rate, for example, down sampled data. These enable signals control the register sampling in hardware.

### Zero Latency Vector Down Sample

The zero latency Vector Down Sample block must be configured to sample the first value of the frame. The first sample in the input frame passes through the mux to the output port. A register samples this value during the first sample duration and the mux switches to the register output at the start of the second sample of the frame. The result is that the first sample in a frame is present on the output port for the entire frame duration. This is the least efficient hardware implementation as the mux introduces a combinational path from `Din` to `Dout`. A single bit register adjusts the timing of the destination clock enable, so that it is asserted at the start of the sample period, instead of the end. The hardware implementation is shown below.

**Figure 330: Zero Latency Vector Down Sample**

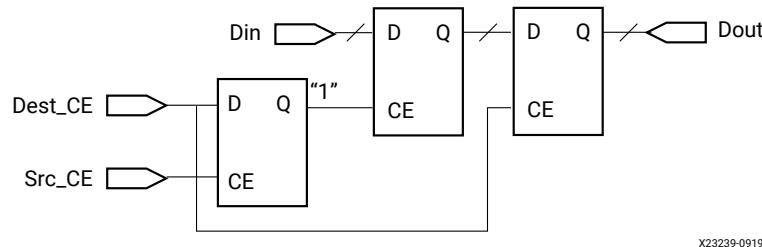


### Vector Down Sample with Latency

If the Vector Down Sample block is configured with latency greater than zero, a more efficient implementation is used. One of two implementations is selected depending on whether the Vector Down Sample block is set to sample the first or last value in a frame.

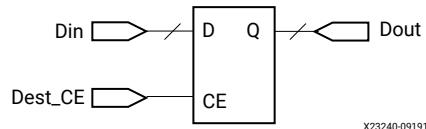
If the block samples the first value in a frame, two registers are required to correctly sample the input stream. The first register is enabled by the adjusted clock enable signal so that it samples the input at the start of the input frame. The second register samples the contents of the first register at the end of the sample period to ensure output data is aligned correctly.

Figure 331: Two Register Example



If the block samples the last value in a frame, a register samples the data input data at the end of the frame. The sampled value is presented for the duration of the next frame. The most efficient implementation is used when the Vector Down Sample block is configured to sample the last value of the frame.

Figure 332: One Register Example



## Block Parameters

The Block Parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Basic tab parameters are as follows.

- **Sampling Rate (number of input samples per output sample):** Must be an integer greater or equal to 2. This is the ratio of the output sample period to the input, and is essentially a sample rate divider. For example, a ratio of 2 indicates a 2:1 division of the input sample rate. If a non-integer ratio is desired, the Vector Up Sample block can be used in combination with the Vector Down Sample block.
- **Sample:** The Vector Down Sample block can sample either the first or last value of a frame. This parameter will determine which of these two values is sampled.
- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This blocks enable 1-D vector support for the primary block operation.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

### Xilinx LogiCORE

The Vector Down Sample block does not use a Xilinx® LogiCORE™.

## Vector FFT

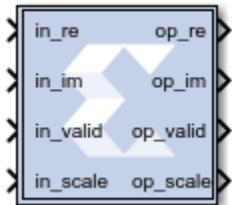
The Vector FFT block supports the FFT operation for vector type inputs.

### Description

The real part of the input data should be given to the `in_re` port, and the imaginary part should be given to the `in_im` port.

When the `in_valid` is high it indicates that the input data is valid. When `out_valid` is high, it indicates that the output data is valid. The valid indicator accompanies every set of input and output samples (for example, R number of samples). There is no back pressure flow control and once an FFT transform starts, 'R' data samples must be input into the core every clock for N/R consecutive clocks. Where N is the FFT length. However, for back-to-back transforms, the valid control input can stay high with no gaps.

The `in_scale` input port is used if scaling is required. And `out_scale` is used in if there is an internal overflow.



### Data Type Support

- The number of `in_scale` bits must be equal to  $\log_2(\text{FFT length})$ .
- `in_valid` and `out_valid` are of Boolean data type.

### Block Parameters

FFT length (N) is the size of the transformation, and should be powers of 2 in the range of  $2^{13}$  to  $2^{16}$ . SSR is the super sample rate, the number of samples processed in parallel every clock. Using a typical example with N=1024 and SSR=4, the core would compute one 1K FFT every 256 clock cycles, processing 4 input samples/clock.

The fixed-point output data size must be 27 bits or less, this is limited by the DSP48 multiplier A port size.

BRAM\_THRESHOLD is an implementation parameter with no functional implications, it controls the use of distributed RAM vs BRAM when implementing delay lines. It can be used to trade utilization numbers between these two types of resources. The higher the value, the more distributed RAM will be used instead of BRAM. Typical values to try are 258, 514, and 1026.

- **Scaling Ports:**

The scaling ports are called SI and SO. Their width matches the FFT size N, it is always  $\log_2(N)$ . There is one SI bit for every add/subtract stage, where internal overflows can occur. If that bit is set to zero then no scaling happens and bit growth is addressed by increasing the internal data sizes bit, one bit every stage. If the bit is set to 1 then the stage divides by 2, and no internal data growth is required to prevent overflows.

Generally, if the output data size is  $\log_2(N)$  bits larger than the input size, no scaling is required, and SI is set to all zeros. If the input and output data sizes are equal, then scaling on every stage is needed and SI should be set to all ones. In reality, scaling is data dependent and some combination of output size growth and non-zero SI bits are used. If partial scaling is used, the non-zero bits of SI should be the MSB ones. SI should be static, it should not change while data is being processed by the core (when VI is high).

Another important requirement to avoid internal overflows is to have one MSB margin bit at the data inputs, that is the two MSBs of I.RE and I.IM should be the same. This prevents overflows in complex multipliers. If the two rules outlined above are followed, then internal overflows are impossible by design.

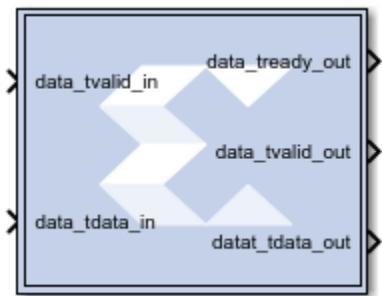
The SO port is an indicator of internal overflows, it is not normally used, only attach an unsigned signals of size  $\log_2(N)$  to it.

## Vector FIR

The Vector FIR block supports FIR filtering for vector type inputs.

### Description

This Vector FIR Compiler block provides a way to generate highly parameterizable, area-efficient, high-performance FIR filters with an AXI4-Stream-compliant interface.



### AXI Ports that are Unique to this Block

This block exposes the AXI CONFIG channel as a group of separate ports based on sub-field names. The sub-field ports are described as follows:

Configuration Channel Input Signals:

config_tdata_fsel	A sub-field port that represents the <b>fsel</b> field in the Configuration Channel vector. <b>fsel</b> is used to select the active filter set. This port is exposed when the number of coefficient sets is greater than one. Refer to the <a href="#">FIR Compiler V7.2 Product Guide</a> starting on page 5 for an explanation of the bits in this field.
-------------------	--

### Block Parameters

Open the block parameters dialog box by double-clicking the icon in your Simulink® model.

- **Filter Specification tab:**

Parameters specific to the Filter Specification tab are as follows:

- **Filter Coefficients:**

- **Coefficient Vector:** Specifies the coefficient vector as a single MATLAB row vector. The number of taps is inferred from the length of the MATLAB row vector. If multiple coefficient sets are specified, then each set is appended to the previous set in the vector. It is possible to enter these coefficients using the [FDATool](#) block as well.

- **Number of Coefficients Sets:** The number of sets of filter coefficients to be implemented. The value specified must divide without remainder into the number of coefficients.

- **Use Reloadable Coefficients:** Check to add the coefficient reload ports to the block. The set of data loaded into the reload channel will not take action until triggered by a re-configuration synchronization event. Refer to the [FIR Compiler V7.2 Product Guide](#) for a more detailed explanation of the RELOAD Channel interface timing. This block supports the `xlGetReloadOrder` function. See the Model Composer Utility function `xlGetReloadOrder` for details.

- **Filter Specification:**

- **Filter Type:**

- **Single\_Rate:** The data rate of the input and the output are the same.
- **Interpolation:** The data rate of the output is faster than the input by a factor specified by the Interpolation Rate value.
- **Decimation:** The data rate of the output is slower than the input by a factor specified in the Decimation Rate Value.
- **Rate Change Type:** This field is applicable to Interpolation and Decimation filter types. Used to specify an **Integer** or **Fixed\_Fractional** rate change.
- **Interpolation Rate Value:** This field is applicable to all Interpolation filter types and Decimation filter types for Fractional Rate Change implementations. The value provided in this field defines the up-sampling factor, or P for Fixed Fractional Rate (P/Q) resampling filter implementations.
- **Decimation Rate Value:** This field is applicable to the all Decimation and Interpolation filter types for Fractional Rate Change implementations. The value provided in this field defines the down-sampling factor, or Q for Fixed Fractional Rate (P/Q) resampling filter implementations.
- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This blocks enable 1-D vector support for the primary block operation.
  - If the filter type is Interpolation, the output vector size (SSR value on the output side) is equal to the SSR value on the input side multiplied by Interpolation Rate Value.
  - If the filter type is Decimation, the output vector size is equal to the SSR value on the input side divided by Decimation Rate Value.

- **Implementation tab:**

Parameters specific to the Implementation tab are as follows:

- **Coefficient Options:**

- **Coefficient Type:** Specify Signed or Unsigned.
  - **Quantization:** Specifies the quantization method to be used for quantizing the coefficients. This can be set to one of the following:
    - Integer\_Coefficients
    - Quantize\_Only
    - Maximize\_Dynamic\_Range
    - Normalize\_to\_Centre\_Coefficient
  - **Coefficient Width:** Specifies the number of bits used to represent the coefficients.

- **Best Precision Fractional Bits:** When selected, the coefficient fractional width is automatically set to maximize the precision of the specified filter coefficients.
- **Coefficient Fractional Bits:** Specifies the binary point location in the coefficients datapath options
- **Coefficients Structure:**
  - Specifies the coefficient structure. Depending on the coefficient structure, optimizations are made in the core to reduce the amount of hardware required to implement a particular filter configuration. The selected structure can be any of the following:
    - Inferred
    - Non-Symmetric
    - Symmetric

The vector of coefficients specified must match the structure specified unless Inferred from coefficients is selected in which case the structure is determined automatically from these coefficients.

- **Datapath Options:**

- **Output Rounding Mode:**

- Choose one of the following:
      - Full\_Precision
      - Truncate\_LSBs
      - Non\_Symmetric\_Rounding\_Down
      - Non\_Symmetric\_Rounding\_Up
      - Symmetric\_Rounding\_to\_Zero
      - Symmetric\_Rounding\_to\_Infinity
      - Convergent\_Rounding\_to\_Even
      - Convergent\_Rounding\_to\_Odd

- **Output Width:** Specify the output width. Edit box activated only if the Rounding mode is set to a value other than Full\_Precision.

- **Detailed Implementation tab:**

Parameters specific to the Detailed Implementation tab are as follows:

- **Filter Architecture:**

The following two filter architectures are supported.

- Systolic\_Multiply\_Accumulate
- Transpose\_Multiply\_Accumulate

**Note:** When selecting the Transpose Multiply-Accumulate architecture, these limitations apply:

- Symmetry is not exploited. If the **Coefficient Vector** specified on the Filter Specification tab is detected as symmetric, the FIR Compiler 7.2 block parameters dialog box will not allow you to select Transpose Multiply Accumulate.
- Multiple interleaved channels are not supported.

- **Optimization Options:** Specifies if the core is required to operate at maximum possible speed (“Speed” option) or minimum area (“Area” option). The “Area” option is the recommended default and will normally achieve the best speed and area for the design, however in certain configurations, the “Speed” setting might be required to improve performance at the expense of overall resource usage (this setting normally adds pipeline registers in critical paths).

- **Goal:**

- Area
- Speed
- Custom

- **List:**

A comma delimited list that specifies which optimizations are implemented by the block. The optimizations are as follows.

- **Data\_Path\_Fanout:** Adds additional pipeline registers on the data memory outputs to minimize fan-out. Useful when implementing large data width filters requiring multiple DSP slices per multiply-add unit.
- **Pre-Adder\_Pipeline:** Pipelines the pre-adder when implemented using fabric resources. This may occur when a large coefficient width is specified.
- **Coefficient\_Fanout:** Adds additional pipeline registers on the coefficient memory outputs to minimize fan-out. Useful for Parallel channels or large coefficient width filters requiring multiple DSP slices per multiply-add unit.
- **Control\_Path\_Fanout:** Adds additional pipeline registers to control logic when Parallel channels have been specified.
- **Control\_Column\_Fanout:** Adds additional pipeline registers to control logic when multiple DSP columns are required to implement the filter.

- **Control\_Broadcast\_Fanout:** Adds additional pipeline registers to control logic for fully parallel (one clock cycle per channel per input sample) symmetric filter implementations.
- **Control\_LUT\_Pipeline:** Pipelines the Look-up tables required to implement the control logic for Advanced Channel sequences.
- **No\_BRAM\_Read\_First\_Mode:** Specifies that Block RAM READ-FIRST mode should not be used.
- **Increased speed:** Multiple DSP slice columns are required for non-symmetric filter implementations.
- **Other:** Miscellaneous optimizations.

**Note:** All optimizations may be specified but are only implemented when relevant to the core configuration.

- **Memory Options:**

The memory type for MAC implementations can either be user-selected or chosen automatically to suit the best implementation options. Note that a choice of “Distributed” might result in a shift register implementation where appropriate to the filter structure. Forcing the RAM selection to be either Block or Distributed should be used with caution, as inappropriate use can lead to inefficient resource usage - the default Automatic mode is recommended for most applications.

- **Data Buffer Type:** Specifies the type of memory used to store data samples.
- **Coefficient Buffer Type:** Specifies the type of memory used to store the coefficients.
- **Input Buffer Type:** Specifies the type of memory to be used to implement the data input buffer, where present.
- **Output Buffer type:** Specifies the type of memory to be used to implement the data output buffer, where present.
- **Preference for other storage:** Specifies the type of memory to be used to implement general storage in the datapath.

- **DSP Slice Column Options:**

- **Multi-Column Support:** For device families with DSP slices, implementations of large high speed filters might require chaining of DSP slice elements across multiple columns. Where applicable (the feature is only enabled for multi-column devices), you can select the method of folding the filter structure across the multiple-columns, which can be Automatic (based on the selected device for the project) or Custom (you select the length of the first and subsequent columns).

- **Inter-Column Pipe Length:** Pipeline stages are required to connect between the columns, with the level of pipelining required being depending on the required system clock rate, the chosen device and other system-level parameters. The choice of this parameter is always left for you to specify.
- **Interface tab:**
  - **Data Channel Options:**
    - **Output TREADY:** This field enables the data\_tready port. With this port enabled, the block will support back-pressure. Without the port, back-pressure is not supported, but resources are saved and performance is likely to be higher.
  - **Control Options:**
    - **ACLKEN:** Active-High clock enable. Available for MAC-based FIR implementations.
    - **ARESETn (active low):** Active-low synchronous clear input that always takes priority over ACLKEN. A minimum ARESETn active pulse of two cycles is required, since the signal is internally registered for performance. A pulse of one cycle resets the control and datapath of the core, but the response to the pulse is not in the cycle immediately following.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

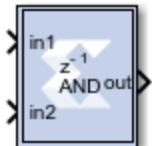
*FIR Compiler LogiCORE IP Product Guide ([PG149](#))*

## Vector Logical

The Vector Logical block supports logical operation for vector type inputs.

### Description

The Vector Logical Block performs bitwise logical operations on fixed-point numbers. Operands are zero padded and sign extended as necessary to make binary point positions coincide. The logical operation is performed and the result is delivered at the output port.



In hardware this block is implemented as synthesizable VHDL. If you build a tree of logical gates, this synthesizable implementation is best as it facilitates logic collapsing in synthesis and mapping.

## Block Parameters

Double-click the icon in your Simulink® model to open the Block Parameters dialog box.

- **Basic tab:** Parameters specific to the Basic tab are as follows:

- **Logical function:** Specifies one of the following bitwise logical operators: AND, NAND, OR, NOR, XOR, XNOR.
- **Number of inputs:** Specifies the number of inputs (1 - 1024).
- **Logical Reduction Operation:**

When the number of inputs is specified as 1, a unary logical reduction operation performs a bit-wise operation on the single operand to produce a single bit result. The first step of the operation applies the logical operator between the least significant bit of the operand and the next most significant bit. The second and subsequent steps apply the operator between the one-bit result of the prior step and the next bit of the operand using the same logical operator. The logical reduction operator implements the same functionality as that of the logical reduction operation in HDLs. The output of the logical reduction operation is always Boolean.

- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control the processing of multiple data samples on every sample period. This blocks enable 1-D vector data support for the primary block operation.
- **Output Type tab:**

Parameters specific to the Output Type tab are as follows:

- **Align binary point:** Specifies that the block must align binary points automatically. If not selected, all inputs must have the same binary point position.

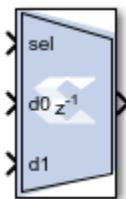
Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Vector Mux

The Vector Multiplexer block supports the Multiplexing feature for input of vector types.

### Description

The Vector Mux block implements a multiplexer. The block has one select input (type unsigned) and a user-configurable number of data bus inputs, ranging from 2 to 1024.



## Block Parameters

Open the Block Parameters dialog box by double-clicking the icon in your Simulink® model.

- **Basic tab:**

- **Number of inputs:** Specify a number between 2 and 32.
- **Optional Ports:**

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

- **Output tab:**

- **Precision:**

This parameter allows you to specify the output precision for fixed-point arithmetic. Floating-point arithmetic output will always be **Full** precision.

- **Full:** The block uses sufficient precision to represent the result without error.
  - **User Defined:** If you do not need full precision, this option allows you to specify a reduced number of total bits and/or fractional bits.

- **Fixed-point Output Type:**

- **Arithmetic type:**

- **Signed (2's comp):** The output is a Signed (2's complement) number.
    - **Unsigned:** The output is an Unsigned number.

- **Fixed-Point Precision:**

- **Number of bits:** Specifies the bit location of the binary point of the output number where bit zero is the least significant bit.
    - **Binary point:** Position of the binary point. in the fixed-point output.

- **Quantization:**

Refer to the section Overflow and Quantization in the topic [Common Options in Block Parameter Dialog Boxes](#).

- **Overflow:**

Refer to the section Overflow and Quantization in the topic [Common Options in Block Parameter Dialog Boxes](#).

- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This block enables 1-D vector support for the primary block operation.

Parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

### LogiCORE Documentation

*Floating-Point Operator LogiCORE IP Product Guide (PG060)*

## Vector Real Gateway In

The Vector Real Gateway In block converts vector inputs of type Simulink® integer, single, double, and fixed-point to Xilinx® fixed-point or floating-point data type.

Hardware notes: In hardware, these blocks become top level input ports.

### Description

The Vector Real Gateway In blocks are the inputs into the HDL portion of your Simulink design. These blocks convert Simulink integer, double and fixed-point data types into the Model Composer fixed-point type. Each block defines a top-level input port or interface in the HDL design generated by Model Composer.



### Conversion of Simulink Data to Model Composer Data

A number of different Simulink data types are supported on the input of Vector Real Gateway In. The data types supported include int8, uint8, int16, uint16, int32, uint32, single, double, and Simulink fixed-point data type(if Simulink fixed-point data type license is available). In all cases the input data is converted to a double internal to gateway, and then converted to target data type as specified on the Vector Real Gateway In block (Fixed-point, Floating-point or Boolean). When converting to Fixed-point from the internal double representation, the Quantization, and Overflow is further handled as specified in the Block GUI. For overflow, the options are to saturate to the largest positive/smallest negative value, to wrap (for example, to discard bits to

the left of the most significant representable bit), or to flag an overflow as a Simulink error during simulation. For quantization, the options are to round to the nearest representable value (or to the value furthest from zero if there are two equidistant nearest representable values), or to truncate (for example, to discard bits to the right of the least significant representable bit). It is important to realize that conversion, overflow and quantization do not take place in hardware. They take place only in the simulation model of the block.

## Gateway Blocks

As listed below, the Xilinx Vector Real Gateway In block is used to provide a number of functions:

- Converting data from Simulink integer, double, and fixed-point type to the Model Composer fixed-point type during simulation in Simulink.
- Defining top-level input ports or interface in the HDL design generated by Model Composer.
- Defining test bench stimuli when the **Create Testbench** box is checked in the Model Composer Hub block. In this case, during HDL code generation, the inputs to the block that occur during Simulink simulation are logged as a logic vector in a data file. During HDL simulation, an entity that is inserted in the top level test bench checks this vector, and the corresponding vectors produced by Vector Real Gateway Out blocks against expected results.
- Naming the corresponding port in the top level HDL entity.

## Block Parameters

Open the Block Parameters dialog box double-clicking the icon in your Simulink model.

- **Basic Tab:**

Parameters specific to the Basic tab are as follows:

- **Output Type:** Specifies the output data type. Can be **Boolean**, **Fixed-point**, or **Floating-point**.
- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This block enables 1-D vector support for the primary block operation.

- **Arithmetic Type:**

If the Output Type is specified as Fixed-point, you can select **Signed (2's comp)** or **Unsigned** as the Arithmetic Type.

- **Fixed-point Precision:**

- **Number of bits:** Specifies the bit location of the binary point, where bit zero is the least significant bit.
- **Binary point:** Specifies the bit location of the binary point, where bit zero is the least significant bit.

- **Floating-point Precision:**

- **Single:** Specifies single precision (32 bits).
- **Double:** Specifies double precision (64 bits).
- **Custom:** Activates the field below so you can specify the Exponent width and the Fraction width.
- **Exponent width:** Specify the exponent width.
- **Fraction width:** Specify the fraction width.

- **Quantization:**

Quantization errors occur when the number of fractional bits is insufficient to represent the fractional portion of a value. The options are to **Truncate** (for example, to discard bits to the right of the least significant representable bit), or to **Round(unbiased: +/- inf)** or **Round (unbiased: even values)**.

**Round(unbiased: +/- inf)** also known as "Symmetric Round (towards +/- inf)" or "Symmetric Round (away from zero)". This is similar to the MATLAB `round()` function. This method rounds the value to the nearest desired bit away from zero and when there is a value at the midpoint between two possible rounded values, the one with the larger magnitude is selected. For example, to round 01.0110 to a Fix\_4\_2, this yields 01.10, since 01.0110 is exactly between 01.01 and 01.10 and the latter is further from zero.

- **Overflow:**

Overflow errors occur when a value lies outside the representable range. For overflow the options are to **Saturate** to the largest positive/smallest negative value, to **Wrap** (for example, to discard bits to the left of the most significant representable bit), or to **Flag as error** (an overflow as a Simulink error) during simulation. **Flag as error** is a simulation only feature. The hardware generated is the same as when **Wrap** is selected.

- **Implementation Tab:**

Parameters specific to the Implementation tab are as follows:

- **Interface Options:**

- **Interface:**

- **None:** Implies that during HDL Netlist generation, this Vector Real Gateway In is translated as an Input Port at the top level.
    - **AXI4-Lite:** Implies that during HDL Netlist generation, an AXI4-Lite interface will be created, and this Vector Real Gateway In is mapped to one of the registers within the AXI4-Lite interface.

- **Auto assign address offset:**

If the Vector Real Gateway In is configured to be an AXI4-Lite interface, this option allows an address offset to be automatically assigned to the register within the AXI4-Lite interface that the Vector Real Gateway In is mapped to.

- **Address offset:**

If Auto assign address offset is not checked, then this entry box allows you to explicitly specify an address offset to use. Must be a multiple of 4.

- **Interface Name:**

If the Vector Real Gateway In is configured to be an AXI4-Lite interface, assigns a unique name to this interface. This name can be used to differentiate between multiple AXI4-Lite interfaces in the design. When using the IP catalog flow, you can expect to see an interface in the IP that Model Composer creates with the name

<design\_name>\_<interface\_name>\_ s\_axi.



**IMPORTANT!** The **Interface Name** must be composed of alphanumeric characters (lowercase alphabetic) or an underscore (\_) only, and must begin with a lowercase alphabetic character. `axi4_lite1` is acceptable, `1AXI4-Lite` is not.

- **Description:**

Additional designer comments about this Vector Real Gateway In that is captured in the interface documentation.

- **Default value:**

- **Constraints:**

- **IOB Timing Constraint:**

In hardware, a Vector Real Gateway In is realized as a set of input/output buffers (IOBs). There are three ways to constrain the timing on IOBs. They are: **None**, **Data Rate**, and **Data Rate, Set 'FAST' Attribute**.

- If **None** is selected, no timing constraints for the IOBs are put in the user constraint file produced by Model Composer. This means the paths from the IOBs to synchronous elements are not constrained.
- If **Data Rate** is selected, the IOBs are constrained at the data rate at which the IOBs operate. The rate is determined by System Clock Period provided on the Model Composer Hub block and the sample rate of the Gateway relative to the other sample periods in the design.
- If **Data Rate, Set 'FAST' Attribute** is selected, the constraints described above are produced. In addition, a FAST slew rate attribute is generated for each IOB. This reduces delay but increases noise and power consumption.

- **Specify IOB location constraints:** Checking this option allows IOB location constraints and I/O standards to be specified.
- **IOB pad locations, e.g. {'MSB', ..., 'LSB'}:** IOB pin locations can be specified as a cell array of strings in this edit box. The locations are package-specific.
- **IO Standards, e.g. {'MSB', ..., 'LSB'}:** I/O standards can be specified as a cell array of strings in this edit box. The locations are package-specific.

## Vector Real Gateway Out

The Vector Real Gateway Out block converts Xilinx® fixed-point or floating-point type vector inputs into vector outputs of type Simulink® integer, single, double, or fixed-point.

Hardware notes: In hardware these blocks become top level output ports or are discarded depending on how they are configured.

### Description

Vector Real Gateway Out blocks are the outputs from the HDL portion of your Simulink design. This block converts the Model Composer fixed-point or floating-point data type into a Simulink integer, single, double, or fixed-point data type.



According to its configuration, the Vector Real Gateway Out block can either define an output port for the top level of the HDL design generated by Model Composer, or be used simply as a test point that is trimmed from the hardware representation

### Gateway Blocks

As listed below, the Vector Real Gateway Out block is used to provide the following functions:

- Convert data from a Model Composer fixed-point or floating-point data type into a Simulink integer, single, double, or fixed-point data type.
- Define I/O ports for the top level of the HDL design generated by Model Composer. A Vector Real Gateway Out block defines a top-level output port.
- Define test bench result vectors when the Model Composer **Create Testbench** box is checked. In this case, during HDL code generation, the outputs from the block that occur during Simulink simulation are logged as logic vectors in a data file. For each top level port, an HDL component is inserted in the top-level test bench that checks this vector against expected results during HDL simulation.
- Name the corresponding output port on the top-level HDL entity.

## Block Parameters

- **Basic Tab:**

Parameters specific to the Basic tab are as follows.

- **Propagate data type to output:** This option is useful when you instantiate a Model Composer design as a sub-system into a Simulink design. Instead of using a Simulink double as the output data type by default, the Model Composer data type is propagated to an appropriate Simulink data type according to the following table:

**Table 78: Model Composer Data Type Propagation**

Model Composer Data Type	Simulink Data Type
XFloat_8_24	single
XFloat_11_53	double
Custom floating-point precision data type exponent width and fraction width less than those for single precision	single
Custom floating-point precision data type with exponent width or fraction width greater than that for single precision	double
XFix_<width>_<binpt>	sfix<width>_EN<binpt>
UFix_<width>_<binpt>	ufix<width>_EN<binpt>
XFix_<width>_0 where width is 8, 16 or 32	int<width> where width is 8, 16 or 32
UFix_<width>_0 where width is 8, 16 or 32	uint<width> where width is 8, 16 or 32
XFix_<width>_0 where width is other than 8, 16 or 32	sfix<width>
UFix_<width>_0 where width is other than 8, 16 or 32	ufix<width>

- **Translate into Output Port:** Having this box unchecked prevents the gateway from becoming an actual output port when translated into hardware. This checkbox is on by default, enabling the output port. When this option is not selected, the Vector Real Gateway Out block is used only during debugging, where its purpose is to communicate with Simulink Sink blocks for probing portions of the design. In this case, the Vector Real Gateway Out block turns gray in color, indicating that the gateway will not be translated into an output port.
- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This blocks enable 1-D vector support for the primary block operation.
- **Implementation Tab:** Parameters specific to the Implementation tab are as follows.
  - **Interface Options:**
    - **None:** During HDL Netlist generation, this Vector Real Gateway Out will be translated as an Output Port at the top level.

- **AXI4-Lite:** During HDL Netlist Generation, an AXI4-Lite interface will be created, and the Vector Real Gateway Out will be mapped to one of the registers within the AXI4-Lite interface.
- **Interrupt:** During an IP catalog Generation, this Vector Real Gateway Out is tagged as an Interrupt output port when the Model Composer design is packaged into an IP module that can be included in the Vivado® IP catalog.
- **Auto assign address offset:**

If a Vector Real Gateway Out is configured to be an AXI4-Lite interface, this option allows an address offset to be automatically assigned to the register within the AXI4-Lite interface that the Vector Real Gateway Out is mapped to.

- **Address offset:**

If Auto assign address offset is not checked, then this entry box allows you to explicitly specify a address offset to use. Must be a multiple of 4.

- **Interface Name:**

If the Vector Real Gateway Out is configured to be an AXI4-Lite interface, assigns a unique name to this interface. This name can be used to differentiate between multiple AXI4-Lite interfaces in the design. When using the IP catalog flow, you can expect to see an interface in the IP that Model Composer creates with the name

`<design_name>_<interface_name>_ s_axi.`



**IMPORTANT!** The **Interface Name** must be composed of alphanumeric characters (lowercase alphabetic) or an underscore (\_) only, and must begin with a lowercase alphabetic character. `axi4_lite1` is acceptable, `1AXI4-Lite` is not.

- **Description:**

Additional designer comments about this Vector Real Gateway Out that is captured in the interface documentation.

- **Constraints:**

- **IOB Timing Constraint:**

In hardware, a Vector Real Gateway Out is realized as a set of input/output buffers (IOBs). There are three ways to constrain the timing on IOBs. They are None, Data Rate, and Data Rate, Set 'FAST' Attribute.

- **None:** No timing constraints for the IOBs are put in the user constraint file produced by Model Composer. This means the paths from the IOBs to synchronous elements are not constrained.

- **Data Rate:**

The IOBs are constrained at the data rate that the IOBs operate. The rate is determined by System Clock Period provided on the Model Composer Hub block and the sample rate of the Gateway relative to the other sample periods in the design. For example, the following OFFSET = OUT constraints are generated for a Vector Real Gateway Out named 'Dout' that is running at the system period of 10 ns:

```
# Offset out constraints
NET "Dout(0)" OFFSET = OUT : 10.0 : AFTER "clk";
NET "Dout(1)" OFFSET = OUT : 10.0 : AFTER "clk";
NET "Dout(2)" OFFSET = OUT : 10.0 : AFTER "clk";
```

- **Specify IOB Location Constraints:** Checking this option allows IOB location constraints to be specified.
- **IOB Pad Locations, e.g. {'MSB', ..., 'LSB'}:** IOB pin locations can be specified as a cell array of strings in this edit box. The locations are package-specific.
- **Data Rate, Set 'FAST' Attribute:**

The OFFSET = OUT constraints described above are produced. In addition, a FAST slew rate attribute is generated for each IOB. This reduces delay but increases noise and power consumption. For the previous example, the following additional attributes are added to the constraints file.

```
NET "Dout(0)" FAST;
NET "Dout(1)" FAST;
NET "Dout(2)" FAST;
```

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Vector Real Mult

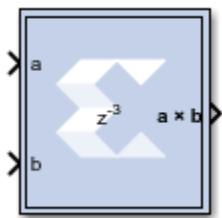
The Vector Real Multiplier block supports the multiplication feature for vector type inputs.

Hardware notes: To check for the optimum internal pipeline stages of the dedicated multiplier select **Test for optimum pipelining**.

Optimization Goal: For implementation into device fabric (LUTs), the Speed or Area optimization takes effect only if it is supported by IP for the particular device family. Otherwise, the results will be identical regardless of the selection.

### Description

The Vector Real Mult block implements a multiplier. It computes the product of the data on its two input ports, producing the result on its output port.



## Block Parameters

Open the Block Parameters dialog box by double-clicking the icon in your Simulink® model.

- **Basic tab:**

Parameters specific to the Basic tab are as follows.

- **Precision:**

This parameter allows you to specify the output precision for fixed-point arithmetic. Floating-point output always has **Full** precision.

- **Full:** The block uses sufficient precision to represent the result without error.
- **User Defined:** If you do not need full precision, this option allows you to specify a reduced number of total bits and/or fractional bits.

- **User-Defined Precision:**

- **Fixed-point Precision:**

- **Signed (2's comp):** The output is a Signed (2's complement) number.
- **Unsigned:** The output is an Unsigned number.
- **Number of bits:** Specifies the bit location of the binary point of the output number, where bit zero is the least significant bit.
- **Binary point:** Position of the binary point in the fixed-point output.

- **Quantization:** Refer to the Overflow and Quantization section in the [Common Options in Block Parameter Dialog Boxes](#) topic.
- **Overflow:** Refer to the Overflow and Quantization section in the [Common Options in Block Parameter Dialog Boxes](#) topic.
- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This block enables 1-D vector support for the primary block operation.
- **Optional Port:** Provide enable port.

- **Latency:** This defines the number of sample periods by which the block's output is delayed.
- **Saturation and Rounding of User Data Types in a Multiplier:** When saturation or rounding is selected on the user data type of a multiplier, latency is also distributed so as to pipeline the saturation/rounding logic first, and then additional registers are added to the core. For example, if a latency of three is selected, and rounding/saturation is selected, then the first register is placed after the rounding or saturation logic, and two registers are placed to pipeline the core. Registers are added to the core until optimum pipelining is reached and then further registers are placed after the rounding/saturation logic. However, if the data type you select does not require additional saturation/rounding logic, then all the registers are used to pipeline the core.
- **Implementation tab:**

Parameters specific to the Implementation tab are as follows:

- **Use behavioral HDL (otherwise use core):**

The block is implemented using behavioral HDL. This gives the downstream logic synthesis tool maximum freedom to optimize for performance or area.

**Note:** For Floating-point operations, the block always uses the Floating-point Operator core.

- **Core Parameters:**

- **Optimize for Speed|Area:** Directs the block to be optimized for either Speed or Area.
  - **Use embedded multipliers:** This field specifies that if possible, use the XtremeDSP slice (DSP48 type embedded multiplier) in the target device.
  - **Test for optimum pipelining:** Checks if the Latency provided is at least equal to the optimum pipeline length. Latency values that pass this test imply that the core produced is optimized for speed.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

### LogiCORE™ Documentation

*Multiplier LogiCORE IP Product Guide* ([PG108](#))

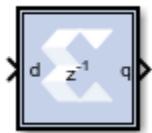
*Floating-Point Operator LogiCORE IP Product Guide* ([PG060](#))

## Vector Register

The Vector Register block supports vector type inputs.

## Description

The Vector Register block models a D flip-flop-based register, having latency of one sample period.



## Block Interface

The block has one input port for the data and an optional input reset port. The initial output value is specified by you in the block parameters dialog box (below). Data presented at the input will appear at the output after one sample period. Upon reset, the register assumes the initial value specified in the parameters dialog box.

The Vector Register block differs from the Xilinx Delay block by providing an optional reset port and a user specifiable initial value.

## Block Parameters

Open the Block Parameters dialog box by double-clicking the icon in your Simulink® model.

- **Basic Tab:**

Parameters specific to the Basic tab are as follows.

- **Initial value:** Specifies the initial value in the register.
- **Optional Ports:**
  - Provide synchronous reset port.
  - Provide enable port.
- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This block enables 1-D vector support for the primary block operation.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Xilinx LogiCORE

The Vector Register block is implemented as a synthesizable VHDL module. It does not use a Xilinx LogiCORE™.

## Vector Reinterpret

The Vector Reinterpret block changes the vector input signal type without altering the binary representation. You can change the signal between signed and unsigned, and relocate the binary point.

Hardware notes: In hardware this block costs nothing.

### Description

The Vector Reinterpret block forces its output to a new type without any regard for retaining the numerical value represented by the input.



The binary representation is passed through unchanged, so in hardware this block consumes no resources. The number of bits in the output will always be the same as the number of bits in the input.

The block allows for unsigned data to be reinterpreted as signed data, or, conversely, for signed data to be reinterpreted as unsigned. It also allows for the reinterpretation of the data's scaling, through the repositioning of the binary point within the data. The Xilinx Scale block provides an analogous capability.

An example of this block's use is as follows: if the input type is 6 bits wide and signed, with 2 fractional bits, and the output type is forced to be unsigned with 0 fractional bits, then an input of -2.0 (1110.00 in binary, two's complement) would be translated into an output of 56 (111000 in binary).

This block can be particularly useful in applications that combine it with the Xilinx Slice block or the Xilinx Concat block. To illustrate the block's use, consider the following scenario:

Given two signals, one carrying signed data, and the other carrying two unsigned bits (a `UFix_2_0`), you should design a system that concatenates the two bits from the second signal onto the tail (least significant bits) of the signed signal.

You can do so using two Vector Reinterpret blocks and one Vector Concat block. The first Vector Reinterpret block is used to force the signed input signal to be treated as an unsigned value with its binary point at zero. The result is then fed through the Vector Concat block along with the other signal's `UFix_2_0`. The Concat operation is then followed by a second Vector Reinterpret that forces the output of the Vector Concat block back into a signed interpretation with the binary point appropriately repositioned.

Though three blocks are required in this construction, the hardware implementation is realized as simply a bus concatenation, which has no cost in hardware.

## Block Parameters

Parameters specific to the block are as follows.

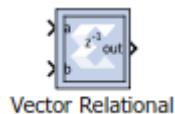
- **Force Arithmetic Type:** When checked, the Output Arithmetic Type parameter can be set and the output type is forced to the arithmetic type chosen according to the setting of the Output Arithmetic Type parameter. When unchecked, the arithmetic type of the output is unchanged from the arithmetic type of the input.
- **Output Arithmetic Type:** The arithmetic type (unsigned or signed, 2's complement, Floating-point) to which the output is to be forced.
- **Force Binary Point:** When checked, the Output Binary Point parameter can be set and the binary point position of the output is forced to the position supplied in the Output Binary Point parameter. When unchecked, the binary point position of the output is unchanged from the binary point position of the input.
- **Output Binary Point:** The position to which the output's binary point is to be forced. The supplied value must be an integer between zero and the number of bits in the input (inclusive).
- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This block enables 1-D vector data support for the primary block operation.

## LogiCORE Documentation

[LogiCORE IP Floating-Point Operator v7.1](#)

# Vector Relational

The Vector Relational block implements comparator for vector inputs.



## Block Parameters

The block parameters dialog box can be invoked by double-clicking the icon in your Simulink® model.

The only parameter specific to the Vector Relational block is:

- **Comparison:** specifies the comparison operation computed by the block.

**Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This block enables 1-D vector data support for the primary block operation.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## LogiCORE Documentation

[LogiCORE IP Floating-Point Operator v7.1](#)

# Vector Slice

The Vector Slice block supports vector type inputs.

Extracts a given range of bits from each sample of input vector and presents it at the output. The output type is ordinarily unsigned with binary point at zero, but can be Boolean when the slice is one bit wide.

Hardware notes: In hardware this block costs nothing.

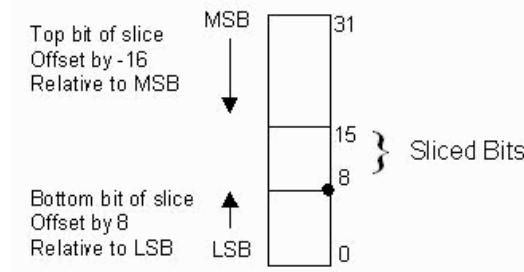
## Description

The Vector Slice block allows you to slice off a sequence of bits from your input data and create a new data value. This value is presented as the output from the block. The output data type is unsigned with its binary point at zero.



The block provides several mechanisms by which the sequence of bits can be specified. If the input type is known at the time of parameterization, the various mechanisms do not offer any gain in functionality. If, however, a Vector Slice block is used in a design where the input data width, or binary point position are subject to change, the variety of mechanisms becomes useful. The block can be configured, for example, always to extract only the top bit of the input, or only the integral bits, or only the first three fractional bits. The following diagram illustrates how to extract all but the top 16 and bottom 8 bits of the input.

Figure 333: Extracting all but the Top 16 and Bottom 8 Bits



## Block Parameters

Open the Block Parameters dialog box by double-clicking the icon in your Simulink® model.

Parameters specific to the block are as follows.

- **Width of slice (Number of bits):** Specifies the number of bits to extract.
- **Boolean output:** Tells whether single bit slices should be type Boolean.
- **Specify range as:** (Two bit locations | Upper bit location + width |Lower bit location + width). Allows you to specify either the bit locations of both end-points of the slice, or one end-point along with number of bits to be taken in the slice.
- **Offset of top bit:** Specifies the offset for the starting bit position from the LSB, MSBm. or binary point.
- **Offset of bottom bit:** Specifies the offset for the ending bit position from the LSB, MSBm, or binary point.
- **Relative to:** Specifies the bit slice position relative to the MSB, LSB, or binary point of the top or the bottom of the slice.
- **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This block enables 1-D vector support for the primary block operation.

Other parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Vector Up Sample

The Vector Up Sample block up samples input vector data. Inserted values can be zeros or copies of the most recent input sample.

Hardware notes: No hardware is needed if inserted values are copies of the input sample. Otherwise, a mux, and single bit flip-flop are used.

## Description

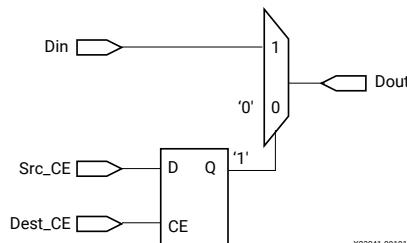
The Vector Up Sample block increases the sample rate at the point where the block is placed in your design. The output sample period is  $l/n$ , where  $l$  is the input sample period, and  $n$  is the sampling rate.



The input signal is up sampled so that within an input sample frame, an input sample is either presented at the output  $n$  times if samples are copied, or presented once with  $(n-1)$  zeroes interspersed if zero padding is used.

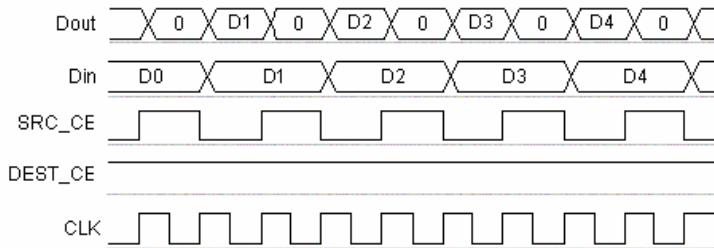
In hardware, the Vector Up Sample block has two possible implementations. If the Copy Samples option is selected on the block parameters dialog box, the Din port is connected directly to Dout and no hardware is expended. Alternatively, if zero padding is selected, a mux is used to switch between the input sample, and inserted zeros. The corresponding circuit for the zero padding Vector Up Sample block is shown below.

*Figure 334: Zero Padding Up Sample Circuit*



## Block Interface

The Vector Up Sample block receives two clock enable signals, Src\_CE, and Dest\_CE. Src\_CE is the clock enable signal corresponding to the input data stream rate. Dest\_CE is the faster clock enable, corresponding to the output data stream rate. Notice that the circuit uses a single flip-flop in addition to the mux. The flip-flop is used to adjust the timing of Src\_CE, so that the mux switches to the data input sample at the start of the input sample period, and switches to the constant zero after the first input sample. It is important to notice that the circuit has a combinational path from Din to Dout. As a result, a Vector Up Sample block configured to zero pad should be followed by a register whenever possible.

**Figure 335: Up Sample Output**

## Block Parameters

Open the Block Parameters dialog box by double-clicking the icon in your Simulink® model.

- **Basic tab:** Parameters specific to the Basic tab are as follows.
  - **Sampling rate (number of output samples per input sample):** Must be an integer with a value of 2 or greater. This is the ratio of the output sample period to the input, and is essentially a sample rate multiplier. For example, a ratio of 2 indicates a doubling of the input sample rate. If a non-integer ratio is desired, the Vector Up Sample block can be used in combination with the Vector Down Sample block.
  - **Copy samples (otherwise zeros are inserted):** Allows you to choose what to do with the additional samples produced by the increased clock rate. By selecting Copy Samples, the same sample is duplicated (copied) during the extra sample times. If this checkbox is not selected, the additional samples are zero.
  - **Provide enable port:** When checked, this option adds an en (enable) input port, if the Latency is specified as a positive integer greater than zero.
  - **Latency:** This defines the number of sample periods by which the block's output is delayed. One sample period can correspond to multiple clock cycles in the corresponding FPGA implementation (for example, when the hardware is over-clocked with respect to the Simulink model). The user defined sample latency is handled in the Vector Up Sample block by placing shift registers that are clock enabled at the input sample rate, on the input of the block. The behavior of a Vector Up Sample block with non-zero latency is similar to putting a delay block, with equivalent latency, at the input of an Vector Up Sample block with zero latency.
  - **Super Sample Rate (SSR):** This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This blocks enable 1-D vector support for the primary block operation.

Parameters used by this block are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

## Vector2Scalar

The Vector2Scalar block converts vector type input to scalar type output.

### Description

The Vector2Scalar block does the bit level concatenation of all the elements of the input vector to produce a scalar output.



For example, if the input vector is [0 1 2 7] of type `Ufix_3_0`, and the SSR parameter is 4, it produces Scalar output 3720 of type `Ufix_12_0`, whose binary value is 111 010 001 000. This value represents input vector when you split it into four groups each of 3 bits.

### Data Type Support

- The inputs must be Boolean or unsigned fixed-point signal.
- All inputs must have binary set to 0.

### Parameters

Super Sample Rate (SSR): This configurable GUI parameter is primarily used to control processing of multiple data samples on every sample period. This block enables 1-D vector support for the primary block operation.

## Vitis HLS

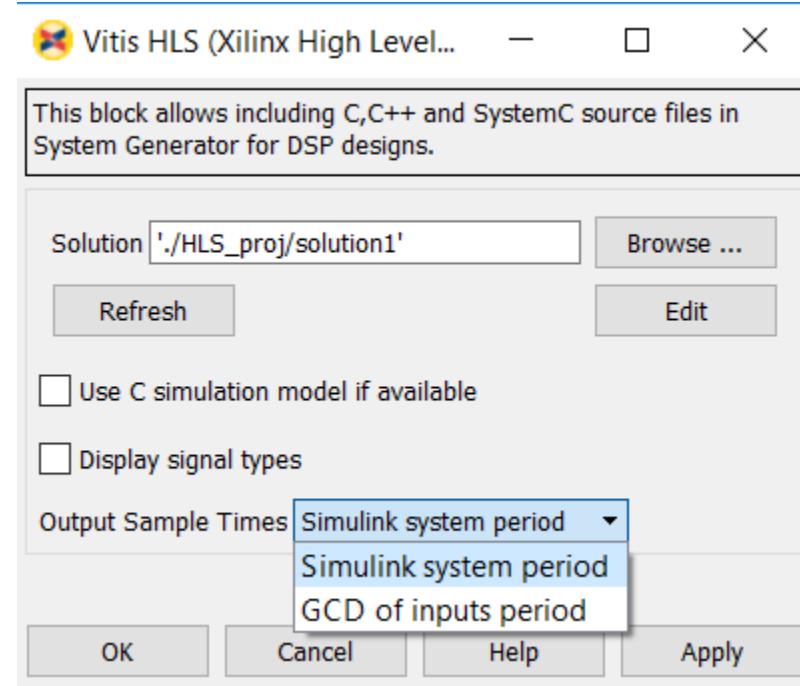
The Xilinx Vitis™ HLS block allows the functionality of a Vitis HLS design to be included in a Model Composer design. The Vitis HLS design can include C, C++ and System C design sources.



There are two steps to the method of including a Vitis HLS design into Model Composer. The first step is to use the Vitis HLS RTL Packaging feature to package the design files into a Solution directory. (Refer to Vitis HLS documentation for more information regarding RTL Packaging.) The second step is to place the Vitis HLS block in your Model Composer design and specify the Vitis HDL Solution directory as the target.

## Block Parameters Dialog Box

Figure 336: Block Parameters Dialog Box



- **Solution:** The path to the Solution space directory containing RTL packaged for Model Composer. This path is usually the path to a directory contained in a Vivado® HLS project. The path must be included in single quotes and must evaluate to a string.
- **Browse:** A standard directory browse button.
- **Refresh:** Updates the block ports to the latest package contained in the solution space.
- **Edit:** Opens the Vitis HLS project associated with solution space.
- **Use C simulation model if available:** Use the C simulation model if it is available in the Vitis HLS package. As shown below, the simulation model being used is shown on the Vitis HLS block. In this case, an RTL-model is used because a C simulation model is not available.
- **Display signal types:** Signal types to be used to drive input ports and emanating from output ports are displayed on the block icon when checked.
- **Output Sample Times:** Select either the **Simulink system period** or the **GCD of the inputs period**.

## Data Type Translation

Data Type Translation	
C/C++ Data Type	Model Composer Data Type
float	XFloat_32_23
double	XFloat_64_52
bool	UFix_1_0
(unsigned) char	(U)Fix_8_0
(unsigned) short	(U)Fix_16_0
(unsigned) int	(U)Fix_32_0
(unsigned) long	(U)FIX_<PlatformDependent>_0
(unsigned) long long	(U)Fix_64_0
ap_(u)fix<N,M>	(U)Fix_<N>_<N-M>
ap_(u)int<N>	(U)Fix_N_0

## Known Issues

- It is not possible to include a purely combinational design from Vitis HLS. The design must synthesize into an RTL design that contains a Clock and a Clock Enable input.
- The top-level module cannot contain C/C++ templates.
- Composite ports will be represented as UFix\_<N>\_0 only where N is the width of the port.
- The current C simulation model only supports fixed latency and interval designs. The latency and interval numbers are obtained from the synthesis engine.
- The current C simulation model supports the default block-level communication protocol (ap\_hs).
- The current C simulation model does not support the 'ap\_memory' and 'ap\_bus' interfaces.
- Vitis HLS block does not support combinational designs due to performance considerations. In the current implementation, Model Composer updates each HLS input port multiple times every clock cycle. So it is very costly to evaluate the DUT whenever inputs changes.
- The output values match RTL simulation results only when corresponding control signals indicate data are valid. So test bench and downstream blocks should read/observe data based on the communication protocol and control signals.
- Because the Vitis HLS block has to use the GCC shipped in the Vivado Design Suite to compile dll on Win-64 platform, users cannot use arbitrary bitwidth integers in C designs on win-64 systems.

## Vitis Model Composer Hub

Control implementation of the model.

## Description

The Vitis Model Composer Hub block controls the behavior of the Vitis Model Composer tool.

You can specify the targeted design flow for the generated output, the directory path for the output, and the desired device and design clock frequency using the following tabs.

- The **Hardware Selection** pane helps with device or board selection.
- The **Code Generation** pane provides options to select the output flow by selecting subsystems and specifying Code directory. Different options will be displayed depending on if the subsystem is targeting HDL, HLS, or AIE.

## Library

AI Engine/Tools; HLS/Tools; Utilities/Code Generation.



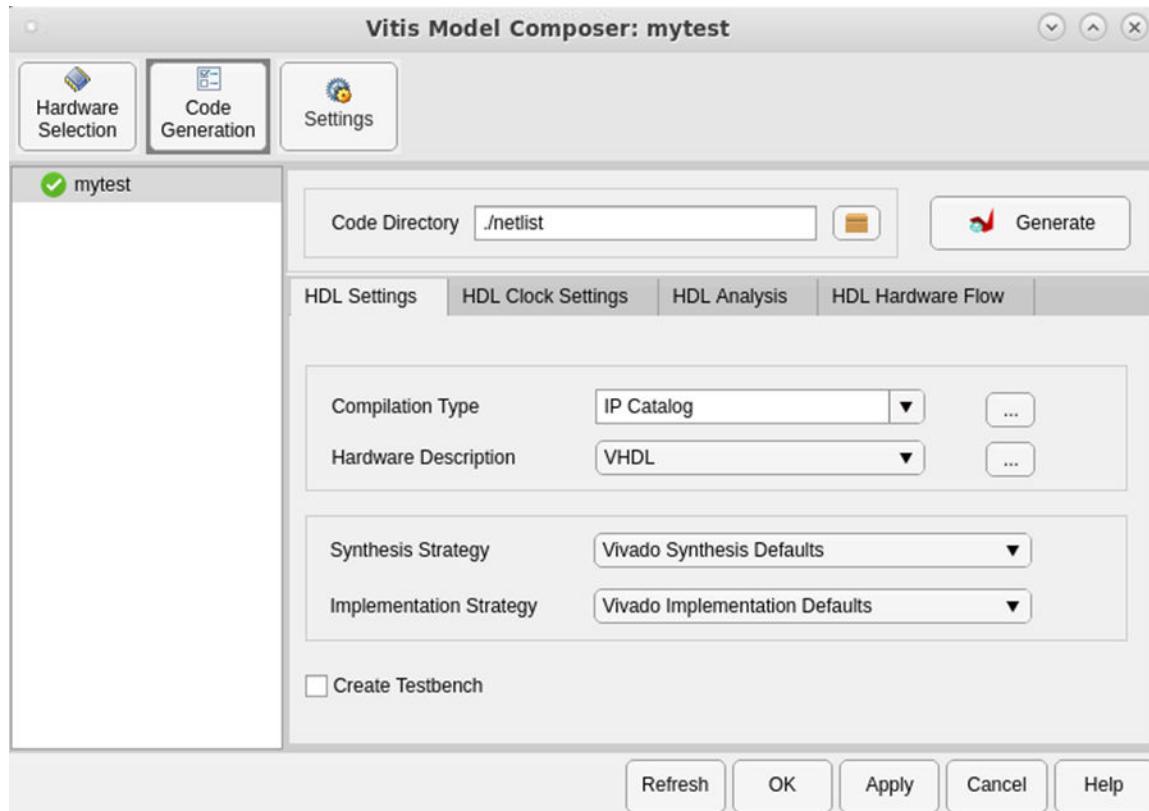
## Vitis Model Composer Hub

### Data Type Support

Data type support is not applicable to the Vitis Model Composer Hub block.

## Parameters

Figure 337: Vitis Model Composer Hub Block Parameters



The following section describes the configurable options available in each pane of the Vitis Model Composer Hub block.

- **Hardware Selection:** Clicking the browse button (...) displays the Device Chooser dialog box. This allows you to select a part, board, or platform to which your design is targeted. Vitis Model Composer obtains board and device data from the Vivado database.
- **Code Generation:** Select the subsystem name for which to generate code from the list on the left. Different settings will display depending on the type of code generation (HDL, HLS, or AI Engine) to be performed.
- **AIE Settings:**
  - **AIE Compiler Options:** When enabled, this option provides control over compiler debug options, execution target options etc.
  - **Create Testbench:** When enabled, Vitis Model Composer generates the test vectors while generating the code.

- **Run cycle-approximate AIE Simulation (SystemC) after code generation:** This option is only available if **Create testbench** is selected. When enabled, it runs the AIE simulation after code generation.
- **Simulation timeout (cycles):** When enabled, it specifies the number of cycles for which AIE simulation is run. The default value is 50000.
- **Plot AIE Simulation Output and Estimate Throughput:** When enabled, this option logs simulation data and allows visualization of the output of an AI Engine subsystem.
- **Collect profiling statistics and enable 'printf' for debugging:** When enabled, this option allows profiling data to be collected for analysis.
- **Collect data for Vitis Analyzer:** When enabled, this option provides a summary of the simulation results which can be viewed in the Vitis Analyzer.
- **Open Vitis Analyzer:** Click to invoke the Vitis Analyzer tool. This option is only enabled after AI Engine Simulation has been ran at least once after enabling.
- **AIE Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the Create Testbench option in the AIE Settings panel.
  - **Generate Hardware Validation Code:** When enabled, Vitis Model Composer generates code to be used for hardware validation.
  - **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
  - **Target:** Specify the target for hardware validation flow.
  - **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
  - **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
  - **Run hardware emulation after code generation:** When enabled, hardware emulation will run immediately after code generation.
- **HDL Settings:**
  - **Compilation Type:** Specifies the type of compilation result that should be produced when the code generator is invoked. The default compilation type is IP Catalog. When IP Catalog is selected, the Settings (...) button brings up a dialog box that allows you to add a description of the IP that will be placed in the IP catalog.
  - **Hardware Description:** Specifies the HDL language to be used for compilation of the design. The possibilities are VHDL and Verilog.
    - **VHDL library:** Specifies the name of VHDL work library for code generation. The default name is `xil_defaultlib`.

- **Use STD\_LOGIC type for Boolean or 1 bit wide gateways:** If your design's Hardware Description Language (HDL) is VHDL, selecting this option will declare a Boolean or 1-bit port (Gateway In or Gateway Out) as a STD-LOGIC type. If this option is not selected, Vitis Model Composer will interpret Boolean or 1-bit ports as vectors.

**Note:** When you enable this option and try to run Generate code and Run behavioral simulation in Vivado, you may see a failure during the elaboration phase.

- **Synthesis strategy:** Choose a Synthesis strategy from the pre-defined strategies in the drop-down menu.
- **Implementation strategy:** Choose an Implementation strategy from the pre-defined strategies in the drop-down menu.
- **Create testbench:** This instructs Vitis Model Composer to create an HDL test bench. Simulating the test bench in an HDL simulator compares Simulink simulation results with ones obtained from the compiled version of the design. To construct test vectors, Vitis Model Composer simulates the design in Simulink, and saves the values seen at gateways. The top HDL file for the test bench is named <name>\_testbench.vhd / .v, where <name> is a name derived from the portion of the design being tested.

**Note:** Testbench generation is not supported for designs that have gateways (Gateway In or Gateway Out) configured as an AXI4-Lite interface.

- **HDL Clock Settings:**

- **Enable multiple clocks:** Must be enabled when the design has multiple clocks. This indicates to the code generation engine that the clock information for the various subsystems must be obtained from the respective clock tabs. If not enabled, then the design will be treated as a single clock design.
- **Number of clocks:** Defines the number of clocks in the design. The number of clock tabs that appear will be equivalent to the number of clocks. In each clock tab, you must select the subsystem and configure the clock settings of that subsystem.
- **FPGA clock period (ns):**

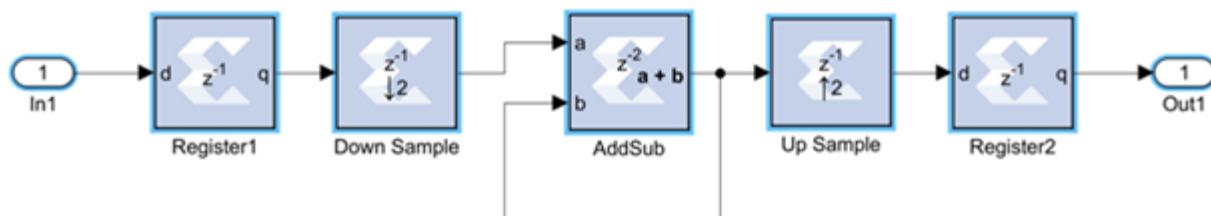
Defines the period in nanoseconds of the system clock. The value need not be an integer. The period is passed to the Xilinx implementation tools through a constraints file, where it is used as the global PERIOD constraint. Multicycle paths are constrained to integer multiples of this value.

- **Simulink system period (sec):** Defines the Simulink System Period, in units of seconds. The Simulink system period is the greatest common divisor of the sample periods that appear in the model. These sample periods are set explicitly in the block dialog boxes, inherited according to Simulink's propagation rules, or implied by a hardware oversampling rate in blocks with this option. In the final case, the implied sample time is in fact faster than the

observable simulation sample time for the block in Simulink. In hardware, a block having an oversampling rate greater than one processes its inputs at a faster rate than the data. For example, a sequential multiplier block with an over-sampling rate of eight implies a (Simulink) sample period that is one eighth of the multiplier block's actual sample time in Simulink. This parameter can be modified only in a master block.

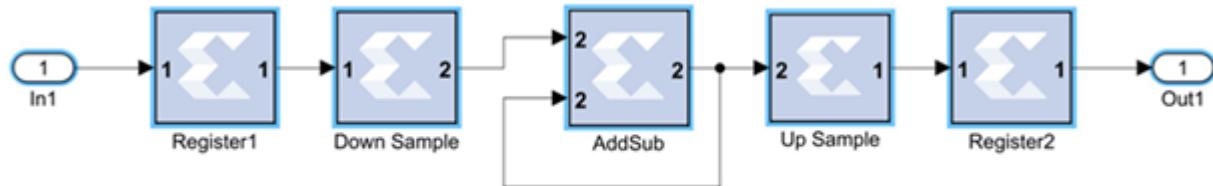
- **Clock pin location:** Defines the pin location for the hardware clock. This information is passed to the Xilinx implementation tools through a constraints file. This option should not be specified if the Vitis Model Composer design is to be included as part of a larger HDL design.
- **Provide clock enable clear pin:** This instructs Vitis Model Composer to provide a `ce_clr` port on the top-level clock wrapper. The `ce_clr` signal is used to reset the clock enable generation logic. The ability to reset clock enable generation logic allows designs to have dynamic control for specifying the beginning of data path sampling.
- **HDL Analysis:**
  - **Block icon display:** Specifies the type of information to be displayed on each block icon in the model after compilation is complete. The various display options are described below.
    - **Default:** Displays the default block icon information on each block in the model. A block's default icon is derived from the `xbsIndex` library.

Figure 338: Default Block Icon



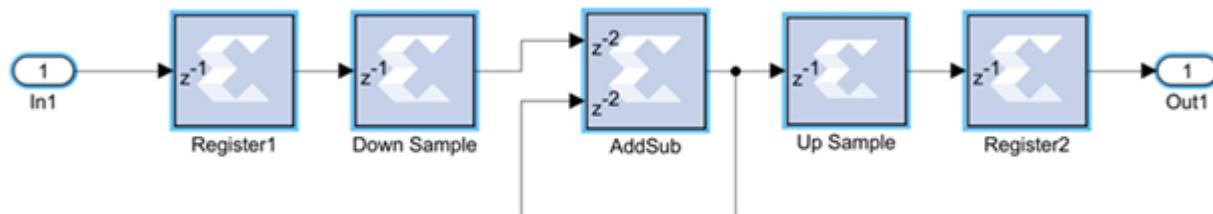
- **Normalized Sample Periods:** Displays the normalized sample periods for all the input and output ports on each block. For example, if the Simulink System Period is set to 4 and the sample period propagated to a block port is 4, then the normalized period that is displayed for the block port is 1; and if the period propagated to the block port is 8 then the sample period displayed would be 2 (a larger number indicates a slower rate).

Figure 339: Normalized Sample Periods Icon



- **Sample frequencies (MHz):** Displays sample frequencies for each block.
- **Pipeline stages:** Displays the latency information from the input ports of each block. The displayed pipeline stage might not be accurate for certain high-level blocks such as the FFT, RS Encoder/Decoder, Viterbi Decoder, etc. In this case the displayed pipeline information can be used to determine whether a block has a combinational path from the input to the output. For example, the Up Sample block in the following figure shows that it has a combinational path from the input to the output port.

Figure 340: Pipeline Stages



- **HDL port names:** Displays the HDL port name of each port on each block in the model.
- **Input data types:** Displays the data type of each input port on each block in the model.
- **Output data types:** Displays the data type of each output port on each block in the model.
- **Update the model:** Update the model to display the selected Block Icon type.
- **Perform Analysis:** Specifies whether an analysis (timing or resource) will or will not be performed on the Vitis Model Composer design when it is compiled. If **None** is selected, no timing analysis or resource analysis will be performed. If **Post Synthesis** is selected, the analysis will be performed after the design has been synthesized in the Vivado toolset. If **Post Implementation** is selected, the analysis will be performed after the design is implemented in the Vivado toolset.
- **Analysis Type:** Two selections are provided: Timing or Resource. After generation is completed, a Timing Analyzer table or Resource Analyzer table is launched.

- **Launch:** Launches the Timing Analyzer or Resource Analyzer table, depending on the selection of Analyzer type. This will only work if you already ran analysis on the Simulink model and haven't changed the Simulink model since the last run.
- **Remote IP cache:** If selected, your design will access an IP cache whenever a Vitis Model Composer compilation performs Vivado synthesis as part of the compilation. If the compilation generates an IP instance for synthesis, and the Vivado synthesis tool generates synthesis output products, the tools create an entry in the cache area. If a new customization of the IP is created which has identical properties, the tools will copy the synthesis outputs from the cache to the design's output directory instead of synthesizing the IP instance again. Accessing the disk cache speeds up the iterative design process. IP caching is described in HDL Library.
- **Create interface document:** When this check box is selected and the **Generate** button is activated for netlisting, Vitis Model Composer creates an HTM document that describes the design being netlisted. This document is placed in a `documentation` subfolder under the `netlist` folder.
- **Clear cache:** Clicking this button clears the remote IP cache. Clearing the cache saves disk space (the IP Cache can grow large, especially if your design uses many IP modules).
- **HDL Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the **Create Testbench** option in the HDL Settings panel. The HDL hardware flow is only supported for Versal® devices.
  - **Generate Hardware Validation Code:** When enabled, Vitis Model Composer generates code to be used for hardware validation.
  - **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
  - **Target:** Specify the target for hardware validation flow.
  - **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
  - **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
  - **Generate (BOOT.BIN/SD card image) after code generation:** When enabled, a BOOT.BIN (for baremetal HW system) or SD card image (for Linux HW system) will be generated after code generation.
- **HLS Settings:**
  - **Target:** Select IP Catalog to export the design to the Vivado IP Catalog. After C/C++ code generation, Vitis High-Level Synthesis (HLS) is invoked to synthesize the C code and create a project that can be exported as an IP to the Vivado IP Catalog. Select HLS C++ code to compile the design model into C++ code.
  - **FPGA clock frequency:** Specifies the clock frequency in MHz for the targeted device. This frequency is passed to the downstream tool flow.

- **Throughput factor:** Specifies the number of samples processed per clock to increase the throughput. A larger factor increases hardware resource usage. The throughput factor must be between 1 and 16.
- **Create testbench and run (C simulation/RTL cosimulation):** If selected, Vitis Model Composer runs simulation and generates test vectors while generating code.
- **Testbench stack size (MBytes):** This parameter prompts you to enter a larger stack size. When **Create and run testbench** is enabled, the **Testbench stack size** option specifies the size of the testbench stack frame during C simulation (CSIM). Occasionally, the default stack frame size of 10 MB allocate for execution of the testbench may be insufficient to run the test, due to large arrays allocated on the stack and/or deep nesting of subsystems. Typically when this happens, the test would fail with a segmentation fault and an associated error message. In such a case you can increase the size of the stack frame and rerun the test.
- **HLS Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the Create Testbench option in the HLS Settings panel. Generate Hardware Validation Code.

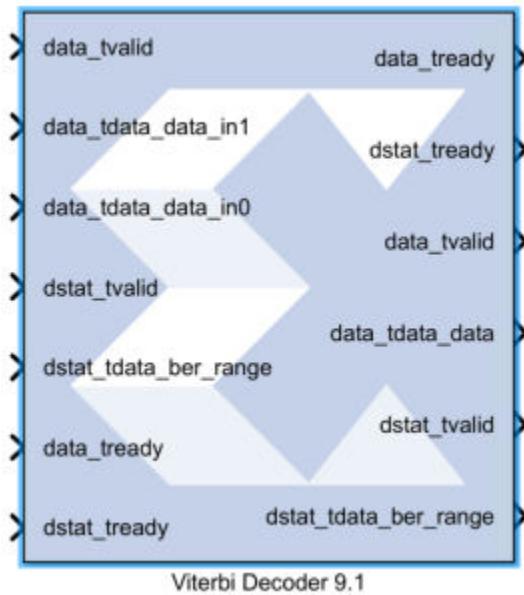
When enabled, Vitis Model Composer generates code to be used for hardware validation.

- **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
- **Target:** Specify the target for hardware validation flow.
- **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
- **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
- **Generate (BOOT.BIN/SD card image) after code generation:** When enabled, a BOOT.BIN (for baremetal HW system) or SD card image (for Linux HW system) will be generated after code generation.
- **Code Generation:** Select a subsystem containing blocks from the AI Engine, HDL, or HLS blocksets and specify the corresponding Code Directory. The Code Directory can be specified by entering the complete directory path or using the Browse button to provide a path.
- **Settings:** Specify whether the Model Composer Hub block should treat your model as a legacy System Generator design.

## Viterbi Decoder 9.1

**Note:** This block goes into the FPGA fabric and is a Licensed Core. Please visit the Xilinx web site to purchase the appropriate core license.

Data encoded with a convolution encoder can be decoded using the Xilinx Viterbi decoder block. This block adheres to the AXI4-Stream standard.



Viterbi Decoder 9.1

There are two steps to the decode process. The first weighs the cost of incoming data against all possible data input combinations; either a Hamming or Euclidean metric can be used to determine the cost. The second step traces back through the trellis and determines the optimal path. The length of the trace through the trellis can be controlled by the traceback length parameter.

The decoder achieves minimal error rates when using optimal convolution codes; the table below shows various optimal codes. For correct operation, convolution codes used for encoding must match with that for decoding.

**Table 79: Convolution Codes**

Constraint Length	Optimal Convolution Codes for 1/2 rate (octal)	Optimal Convolution Codes for 1/3 Rate (octal)
3	[7 5]	[7 7 5]
4	[17 13]	[17 13 15]
5	[37 33]	[37 33 25]
6	[57 65]	[57 65 71]
7	[117 127]	[117 127 155]
8	[357 233]	[357 233 251]
9	[755 633]	[755 633 447]

## Block Interface

The Xilinx Viterbi Decoder 9.1 block is AXI4 compliant. The following describes the standard AXI channels and pins on the interface.

- **S\_AXIS\_DATA Channel:**

- **s\_axis\_data\_tvalid:** TVALID for S\_AXIS\_DATA channel. Input pin, always available. This port indicates the values presents on the input data ports are valid.
- **s\_axis\_data\_tready:** TREADY for S\_AXIS\_DATA. Output pin, always available. This port indicates that the core is ready to accept data.
- **s\_axis\_data\_tdata:** Input TDATA. Different input data ports are available depending on the Viterbi Type selected on Page1 tab of the Block Parameters dialog box.

When Trellis Mode is selected, 5 input data pins become available – these are

`s_axis_data_tdata_tcm00, s_axis_data_tdata_tcm01,  
s_axis_data_tdata_tcm10, s_axis_data_tdata_tcm11 and  
s_axis_data_tdata_sector.`

The width of the Trellis mode inputs (`s_axis_data_tdata_tcm**`) can range from 4 to 6 corresponding to a data width (Soft\_Width value on Page2 tab) of 3 to 5.

`s_axis_data_tdata_sector` is always 4-bit wide. The decoder always functions as a rate 1/2 decoder when Trellis mode is selected.

For any other Viterbi Type (Standard/Multi-Channel/Dual Decoder), the Decoder supports rates from 1/2 to 1/7. Therefore, the block can have 2 to 7 input data ports labeled `s_axis_data_tdata_data_in0 - s_axis_data_tdata_data_in6`. Hard Coding requires each `tdata_data_in<n>` port to be 1 bit wide. Soft Coding allows these widths to be between 3 to 5 bits (inclusive).

- **s\_axis\_data\_tuser:** TUSER for S\_AXIS\_DATA. These ports are only present if External Puncturing is selected or it is a Dual Decoder or Block Valid signal is used with the core.
  - **s\_axis\_data\_tuser\_erase:** Port becomes available, when External Puncturing is selected (on Page2 tab). This input bus is used to indicate the presence of a null-symbol on the corresponding `data_in` buses. For e.g. `tuser_erase(0)` corresponds to `data_in0`, `tuser_erase(1)` corresponds to `data_in1` etc. If an erase bit is high, the data on the corresponding `data_in` bus is treated as a null-symbol internally to the decoder. The width of the erase bus is equal to the output rate of the decoder with a maximum value of 7.
  - **s\_axis\_data\_tuser\_sel:** Port becomes available when Dual Decoder is selected. This is used to select the correct set of convolution codes for the decoding of the input data symbols in the dual decoder case. When SEL is low, the input data is decoded using the first set of convolution codes. When it is high, the second set of convolution codes is applied.

- `s_axis_data_tuser_block_in`: Port becomes available when Block Valid option is selected on Page 5 tab.
- **M\_AXIS\_DATA Channel:**
  - `m_axis_data_tvalid`: TVALID for M\_AXIS\_DATA channel. Output pin, always available. It indicates whether the output data is valid or not.
  - `m_axis_data_tready`: TREADY for M\_AXIS\_DATA channel. Do not enable or tie high if downstream slave is always able to accept data. It becomes available when TREADY option is selected on Page 5 tab.
  - `m_axis_data_tdata`: Decoded TDATA for output data channel.
    - `m_axis_data_tdata_data`: Port represents the decoded output data and it is always 1 bit wide.
    - `m_axis_data_tdata_sector`: Port becomes available for Trellis Mode decoder. This port is always 4-bit wide. The output SECTOR is a delayed version of the input SECTOR bus. Both buses have a fixed width of 4 bits. The delay equals the delay through the Trellis Mode decoder.
  - `m_axis_data_tuser`: TUSER for M\_AXIS\_DATA channel. These ports are only present if the block is a Dual Decoder or it has normalization signal present or it has Block Valid option checked.
    - `m_axis_data_tuser_sel`: Port becomes available when the block is configured as a Dual Decoder. This signal is a delayed version of the input `s_axis_data_tuser_sel` signal. The delay equals to the delay through the Dual Decoder.
    - `m_axis_data_tuser_norm`: Port becomes available when NORM option is checked on Page 5 tab. This port indicates when normalization has occurred within the core. It gives an immediate indication of the rate of errors in the channel.
    - `m_axis_data_tuser_block_out`: Port becomes available when Block Valid option is checked on Page 5 tab. This signal is a delayed version of the input `s_axis_data_tuser_block_in` signal. The BLOCK\_OUT signal shows the decoded data corresponding to the original BLOCK\_IN set of data points. The delay equals the delay through the decoder.
- **S\_AXIS\_DSTAT Channel:**

**Note:** These ports become available when Use BER Symbol Count is selected on Page 5 tab.

- `s_axis_dstat_tvalid`: TVALID for S\_AXIS\_DSTAT channel.
- `s_axis_dstat_tready`: TREADY for S\_AXIS\_DSTAT channel. Indicates that the core is ready to accept data. Always high, except after a reset if there is not a TREADY on the output.

- **s\_axis\_dstat\_tdata\_ber\_range:** TDATA for S\_AXIS\_DSTAT channel. This is the number of symbols over which errors are counted in the BER block.
- **M\_AXIS\_DSTAT Channel:**

**Note:** These ports become available when Use BER Symbol Count is selected on Page 5 tab.

  - **m\_axis\_dstat\_tvalid:** TVALID for M\_AXIS\_DSTAT channel.
  - **m\_axis\_dstat\_tready:** TREADY for M\_AXIS\_DSTAT channel. Do not enable or tie high if downstream slave is always able to accept data. It becomes available when TREADY option is selected on Page 5 tab.
  - **m\_axis\_dstat\_tdata\_ber:** TDATA for M\_AXIS\_DSTAT channel. The Bit Error Rate (BER) bus output (fixed width 16) gives a measurement of the channel bit error rate by counting the difference between the re-encoded DATA\_OUT and the delayed DATA\_IN to the decoder.
- **Other Optional Pins:**
  - **aresetn:** The synchronous reset (`aresetn`) input can be used to re-initialize the core at any time, regardless of the state of `aclken` signal. `aresetn` needs to be asserted low for at least two clock cycles to initialize the circuit. This pin becomes available if ARESETN option is selected on the Page 5 tab. It must be of type Bool. If this pin is not selected, Model Composer ties this pin to inactive (high) on the core.
  - **aclken:** Carries the clock enable signal for the decoder. The signal driving `aclken` must be Bool. This pin becomes available if ACLKEN option is selected on Page 5 tab.

## Block Parameters

- **Page1 tab:**

Parameters specific to the Page1 tab are as follows.

- **Viterbi Type:**
  - **Number of Channels:** Used with the Multi-Channel selection, the number of channels to be decoded can be any value between 2 and 32.
  - **Standard:** This type is the basic Viterbi Decoder.
  - **Multi-Channel:** This type allows many interlaced channels of data to be decoded using a single Viterbi Decoder.
  - **Trellis Mode:** This type is a trellis mode decoder using the TCM and SECTOR\_IN inputs.
  - **Dual Decoder:** When selected, the block behaves as a dual decoder with two sets of convolutional codes. This makes the sel input port available.
- **Decoder Options:**

- **Use Reduced Latency:** The latency of the block depends on the traceback length and the constraint length. If this reduced latency option is selected, then the latency of the block is approximately halved and the latency is only 2 times the traceback length.
  - **Constraint length:** Equals  $n+1$ , where  $n$  is the length of the constraint register in the encoder.
  - **Traceback length:** Length of the traceback through the Viterbi trellis. Optimal length is 5 to 7 times the constraint length.
- Page2 tab:
- **Architecture:**
    - **Parallel:** Large but fast Viterbi Decoder.
    - **Serial:** Small but processes the input data in a serial fashion. The number of clock cycles needed to process each set of input symbols depends on the output rate and the soft width of the data.
  - **Best State:**
    - **Use Best State:** Gives improved BER performance for highly punctured data.
    - **Best State Width:** Indicates how many of the least significant bits to ignore when saving the cost used to determine the best state.
  - **Puncturing:**
    - **None:** Input data has not been punctured.
    - **External (Erased Symbols):** When selected an erase port is added to the block. The presence of null-symbols (that is, symbols which have been deleted prior to transmission across the channel) is indicated using the erasure input erase.
  - **Coding:**
    - **Soft Width:** The input width of soft-coded data can be anything in the range 3 to 5. Larger widths require more logic. If the block is implemented in serial mode, larger soft widths also increase the serial processing time.
    - **Soft Coding:** Uses the Euclidean metric to cost the incoming data against the branches of the Viterbi trellis.
    - **Hard Coding:** Uses the Hamming difference between the input data bits and the branches of the Viterbi trellis. Hard coding is only available for the standard parallel block.
  - **Data Format:**
    - **Signed Magnitude:**
    - **Offset Binary (available for soft coding only):**

See Table 1 in the associated LogiCORE™ Product Specification for the Signed Magnitude and Offset-Binary data format for Soft Width 3.

- **Page3 tab:**

- **Convolution 0:**

- **Output Rate 0:** Output Rate 0 can be any value from 2 to 7.
    - **Convolution Code 0 Radix:** The convolutional codes can be input and viewed in binary, octal, or decimal.
    - **Convolution Code Array (0-6):** First array of convolution codes. Output rate is derived from the array length. Between 2 and 7 (inclusive) codes can be entered. When dual decoding is used, a value of 0 (low) on the sel port corresponds to this array.

- **Page4 tab:**

The options on this tab are activated when you select **Dual Decoder** as the Viterbi Type on the Page1 tab.

- **Convolution 1:**

- **Output Rate 1:** Output Rate 1 can be any value from 2 to 7. This is the second output rate used if the decoder is dual. The incoming data is decoded at this rate when the SEL input is high. Output Rate 1 is not used for the non-dual decoder.
    - **Convolution Code 1 Radix:** The convolutional codes can be input and viewed in binary, octal, or decimal.

- **Page5 tab:**

- **BER Options:**

- **Use BER Symbol Count:** This bit-error-rate (BER) option monitors the error rate on the transmission channel.

- **Optional Pins:**

- **NORM:** Indicates when normalization has taken place internal to the Add Compare Select module.
    - **Block Valid:** Check this box if BLOCK\_IN and BLOCK\_OUT signals are required. These signals track the movement of a block of data through the decoder. BLOCK\_OUT corresponds to BLOCK\_IN delayed by the decoder latency.
    - **TREADY:** Selecting this option makes m\_axis\_data\_tready and m\_axis\_dstat\_tready pins available on the block.
    - **ACLKEN:** Carries the clock enable signal for the block. The signal driving aclken must be Bool.

- **ARESETN:** Adds a aresetn pin to the block. This signal resets the block and must be of type Bool. aresetn must be asserted low for at least 2 clock periods and at least 1 sample period before the decoder can start decoding code symbols.

Common Parameters used by this block, such as **Display shortened port names**, are explained in the topic [Common Options in Block Parameter Dialog Boxes](#).

### LogiCORE Documentation

*Viterbi Decoder LogiCORE IP Product Guide (PG027)*

---

## HLS Blockset

The Vitis Model Composer HLS block library includes the following blocks. The content shown here can also be accessed from the **Help** command for the block within the HLS block library in Simulink.

### Abs

Compute element-wise absolute value of input signal

#### Library

Math Functions/Math Operations



#### Description

The Abs block computes element-wise absolute value on the input data.

#### Data Type Support

Data type support is:

- Dimension: Input can be scalar, vector, or matrix.
- Data Types: Input supports signals of integer type, floating point data type (double, single, and half), and signed and unsigned fixed point type.
- Complex Numbers Support: Yes.

Output has the same dimension and data type as the input. Output of the Abs block is always real.

## Parameters

The Abs block has no parameters to set.

## atan

Compute element-wise arctangent function of an argument.

### Library

Math Functions / Math Operations



### Description

The atan block returns the output of the atan ( $x$ ) function for each element in array  $x$ .

### Data Type Support

Data types accepted at the inputs of the block are:

- Dimension: Input can be scalar, vector, or matrix.
- Data Types: Input supports signals of integer type, floating point type (double, single and half) and fixed point type.
- Complex Number Support: No

Output has the same dimension and type as the input. However, If the data type of the input is a fixed point type, the data type of the output is fixed point type with integer width fixed as 2. The reason for this is that the output of the atan function is between  $-\pi/2$  and  $\pi/2$ . Use the atan2 function if you need the output of the function to be between  $-\pi$  and  $\pi$ .

## Parameters

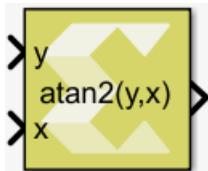
The Atan block has no parameters to set.

## atan2

Compute element-wise four-quadrant inverse tangent of input signal.

## Library

Math Functions / Math Operations



## Description

The atan2 block returns the output of the function  $\text{atan2}(y,x)$ .

## Data Type Support

Data types accepted at the inputs of the block are:

- Dimension: Inputs can be scalar, vector, or matrix. If one of the inputs is scalar and the other is a vector or matrix then the scalar input is expanded to match the other input dimension, and operation will be performed element wise. If both inputs are non-scalar, then they must match in dimension.
- Data Types: Input supports signals of integer type, floating point type (double, single, and half) and signed and unsigned fixed point type. Both inputs must be of the same data type.
- Complex Number Support: No

Except for fixed-point input data type, output has the same data type as the input. For fixed point input, the output data type will be signed fixed-point with a 3-bit integer width, to be able to represent numbers between  $-\pi$  and  $\pi$ .

## Parameters

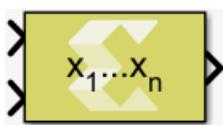
The atan2 block has no parameters to set.

## Bit Concat

Perform bitwise concatenation of input values into a single output value

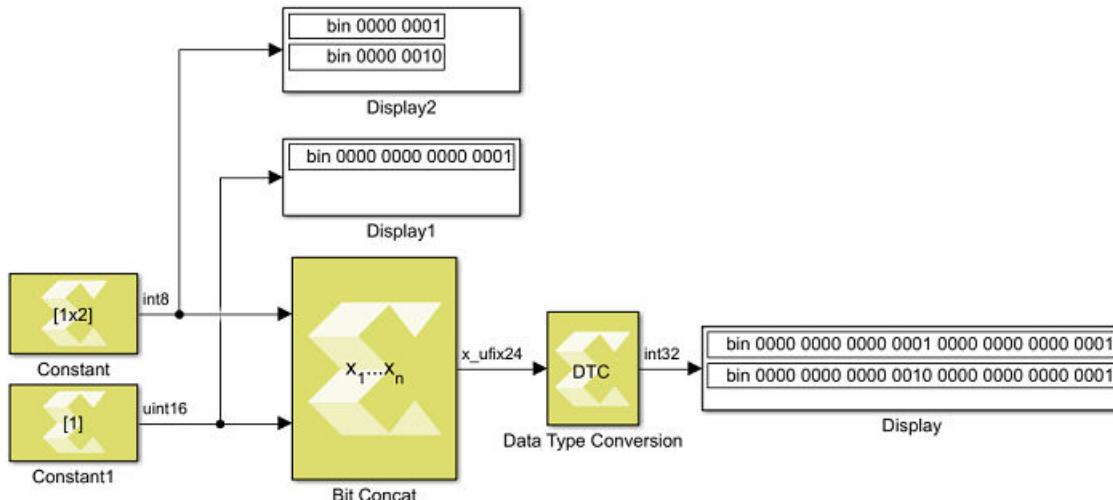
## Library

Logic and Bit Operations



## Description

Starting from the input with the highest order (the first input at the top in normal block orientation) the bit values of all input ports are concatenated into a single output bit vector. For multidimensional inputs the dimensions of all inputs must match and concatenation proceeds element-wise as it would in the scalar case. A scalar value on one input is automatically expanded to match the dimensions of the other input.



## Data Type Support

Data type support for the Bit Concat block is:

- All integer types (including Boolean) and fixed-point types are supported. Floating point types are not supported.
- All inputs must be of real numeric type. Complex types are not supported.
- Scalars, Vectors and 2-D Matrices are supported. Unless an input is a scalar, the dimensions of all inputs must agree.
- The output type is always an unsigned fixed-point type without fractional bits.

## Parameters

### Number of inputs

Sets the number of inputs to be concatenated. The minimum number of inputs is 2, the maximum is 128. The sum of all input bit widths shall not exceed 1024 bits.

## Bit Slice

Extract a range of bits from a value

## Library

Logic and Bit Operations



## Description

The Bit Slice block allows the element-wise extraction of a contiguous set of bits from the input values. The extracted bits are returned as unsigned fixed point values of an all-integer range, and you specify the width of the specified extraction range. The block dialog box allows you to specify the range of bits using one of these methods:

- **Bottom bit + width** - You specify the bottom bit and the number of bits to be extracted (**Slice width**).
- **Top bit + width** - You specify the top bit and the number of bits to be extracted (**Slice width**).
- **Top and bottom bit** - You specify the top and bottom bits and the number of bits to be extracted is implied.

The top and bottom bit specifications have multiple ways of specifying the position in relation to either the Least Significant Bit (LSB), the Binary Point of a fixed-point value, or the Most Significant Bit (MSB). In case of integer inputs the Binary Point and Least Significant Bit options are equivalent. Offsets to specify the position relative to these anchors can be positive or negative. However, an error will occur during simulation and/or code generation if the extraction range lies outside of the input type bit range.

## Data Type Support

The Bit Slice block accepts any real-valued integer or fixed-point type of any dimension  $N \leq 2$ . Floating point values and complex numeric types are not supported.

The output data type is always a real-valued unsigned fixed-point type with integer-only range. The output data has the same width as the extraction range you specify.

The output dimensions are the same as the input dimensions.

## Parameters

### Specify range as

The **Specify range as** parameter specifies the extraction range.

- If you select **Bottom bit + width**, parameters in the **Bottom of bit range** section are enabled and parameters in the **Top of bit range** section are disabled.

- If you select **Top bit + width**, parameters in the **Top of bit range** section are enabled and parameters in the **Bottom of bit range** section are disabled.
- If you select **Top and Bottom bit**, parameters in both the **Top of bit range** section and the **Bottom of bit range** section are enabled, and the **Slice width** parameter is disabled.

Following are the settings for the **Specify range as parameter**.

**Table 80: Specify Range As Parameter**

Setting	Description
<b>Bottom bit + width</b>	The <b>width</b> specifies the number of bits to extract. The <b>Bottom bit</b> of the range specifies the offset at which the range begins (offset of the least significant bit to be extracted).
<b>Top bit + width</b>	The <b>width</b> specifies the number of bits to extract. The <b>Top bit</b> of the range specifies the offset at which the range begins (offset of the most significant bit to be extracted).
<b>Top and bottom bit</b>	The <b>Top</b> bit of the range specifies the offset of the most significant bit to be extracted. The <b>bottom</b> bit of the range gives the offset of the least significant bit to be extracted. The width of the extracted range is given implicitly.

### Slice width

Specifies the width of the bit range to be extracted. **Slice width** is only enabled if the **Specify range as parameter** is set to **Top bit + width** or **Bottom bit + width**.

Enter a scalar positive integer value for **Slice width**.

### Bit position relative to

Defines the basis for offset specifications in both **Top of bit range** and **Bottom of bit range** sections of the block dialog box.

Following are the settings for the **Bit position relative to** parameter.

**Table 81: Bit Position Relative To Parameter**

Setting	Description
<b>Least Significant Bit</b>	Defines the offset parameter as counting from the LSB of the input value, with offset 0 denoting the LSB, offset 1 denoting the bit to the left of the LSB, etc. If the <b>Least Significant Bit</b> setting is selected, the <b>With offset</b> parameter cannot specify a negative offset.
<b>Binary point</b>	Defines the offset parameter as counting from the binary point of a fixed point value, with offset 0 denoting the least significant integer bit. A negative offset denotes a range starting in the fractional bits with offset -1 being the most significant fractional bit. A positive offset denotes a range starting in the integer portion of the value.
<b>Most Significant Bit</b>	Defines the offset parameter as counting from the MSB of the input value, with offset 0 denoting the MSB, offset -1 denoting the bit to the right of the MSB, etc. If the <b>Most Significant Bit</b> setting is selected, the <b>With offset</b> parameter cannot specify a positive offset.

### With offset

Specifies the offset to be applied to the basis specified by the corresponding **Bit position relative to** parameter. The **With offset** parameter is available in both **Top of bit range** and **Bottom of bit range** sections of the block dialog box.

Negative offsets specify bit positions to the right of the anchor (zero offset basis). Positive offsets specify bit positions to the left of the anchor.

## Bitwise AND

Perform element and bitwise Boolean AND operation on the inputs

### Library

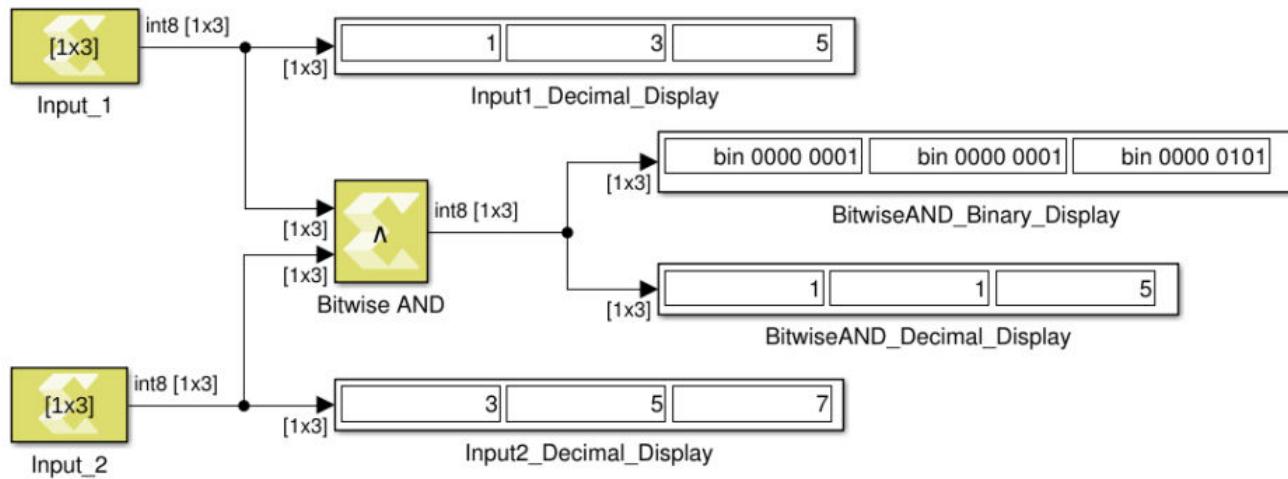
Logic and Bit Operations



### Description

The Bitwise AND block has two input signals and one output signal. The block performs element and bit-wise Boolean AND operation on the inputs. The first input corresponds to the top input port and the second input to the bottom input port. Both input ports must have the same data type. The dimension of the output signal matches the dimensions of the input signals. Unless an input is a scalar, the dimensions of all inputs must agree. A scalar value on one input is automatically expanded to match the dimension of the other input.

Figure 341: Bitwise AND



### Data Type Support

The block accepts integer, fixed-point, and Boolean types of real numeric type. It does not support floating point input types. Complex signals are not supported for this operation.

### Parameters

The Bitwise AND block has no parameters to set.

## Bitwise NOT

Perform element and bit-wise Boolean NOT operation on the input

### Library

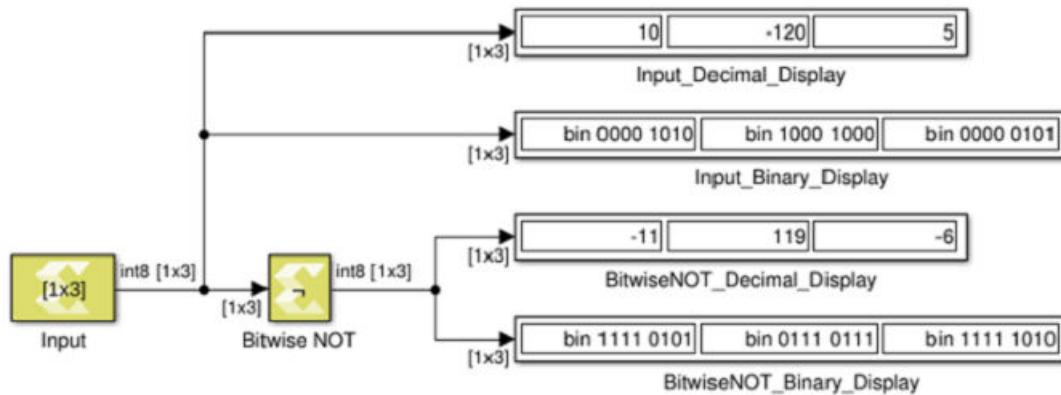
Logic and Bit Operations



### Description

The Bitwise NOT block has one input signal and one output signal. It performs element and bit-wise Boolean NOT operation on the input. The dimension of the output signals matches the dimension of the input signals.

Figure 342: Bitwise NOT



## Data Type Support

The Bitwise NOT block accepts integer, fixed-point, and Boolean types of real numeric type. The block does not support floating point input types. Complex signals are not supported.

## Parameters

The Bitwise NOT block has no parameters to set.

## Bitwise OR

Perform element and bitwise Boolean OR operation on the inputs

### Library

Logic and Bit Operations



### Description

The Bitwise OR block has two input signals and one output signal. The block performs element and bit-wise boolean OR operation on the inputs. The first input corresponds to the top input port and the second input to the bottom input port. The dimension of the output signal matches the dimensions of the input signals.

## Data Type Support

The Bitwise OR block supports native and fixed-point types except the floating point types (double, single, and half). If one of the inputs is scalar, the output dimension is non-scalar. If both inputs are non-scalar, they must have the same dimension. The dimension can be scalar, vector, or matrix.

## Parameters

The Bitwise OR block has no parameters to set.

# Bitwise XOR

Perform element and bit-wise Boolean XOR operation on the inputs

## Library

Logic and Bit Operations



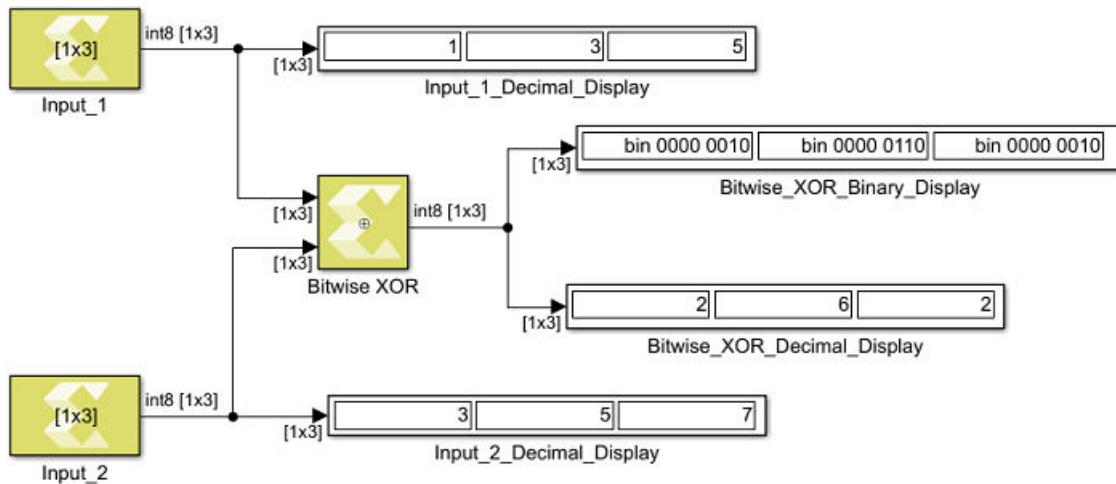
## Description

The Bitwise XOR block has two input signals and one output signal. The block performs element and bit-wise Boolean XOR operation on the inputs. The first input corresponds to the upper input port and the second input to the lower input port. The dimension of the output signal matches the dimensions of the input signals.

## Data Type Support

If one of the inputs is scalar, the output dimension is non-scalar. If both inputs are non-scalar, they must have the same dimension. The dimension can be scalar, vector, or matrix.

Figure 343: Bitwise XOR



## Parameters

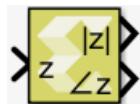
The Bitwise XOR block has no parameters to set.

## Complex to Polar

Perform an element-wise conversion of complex input signals into magnitude and radiant phase angle

### Library

Math Functions / Math Operations



### Description

The Complex to Polar block accepts a complex-valued signal of floating point data types such as double, single and half. It outputs the magnitude and phase angle of the input signal. The outputs are real values of the same data type as the block input. The input can be a scalar, vector or matrix of complex signals, in which case the output signals are also scalar, vector or matrix. The magnitude signal array contains the magnitudes of the corresponding complex input elements. The angle output similarly contains the angles of the input elements in radian.

### Data Type Support

Data type support for the input port is:

- Dimension: The input can be scalar, vector or matrix. If the input is not scalar then the outputs have the same dimension as the input.
- Data Types: Input supports complex signal of floating point data type such as double, single, and half.

The outputs are always real-valued signals of floating point data type such as double, single, and half.

## Parameters

The Complex to Polar block has no parameters to set.

# Complex to Real-Imag

Computes the real and imaginary components of the input

## Library

Math Functions / Math Operations



## Description

The Complex to Real-Imag block accepts a complex or real signal of any valid data type and outputs the real and/or imaginary components of the input signal. The outputs are real-valued signals of the same data type as the block input. The input can be a scalar, vector, or matrix. The outputs have the same dimensions as that of the input.

## Data Type Support

Data type support for the input port is:

- Supports real or complex input of any valid data type. The outputs are real-valued signals of the same data type as the block input.
- The input can be a scalar, vector, or matrix. The outputs have the same dimensions as that of the input.

## Parameters

- Output:

This parameter specifies the kind of output the block produces.

Settings for the **Output** parameter are:

**Table 82: Output Parameters**

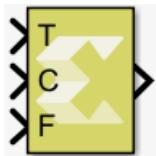
Setting	Description
<b>Real and imag</b>	Outputs real and imaginary parts of the input signal as Re and Im outputs of the block, respectively.
<b>Real</b>	Outputs the real part of the input signal as Re output of the block.
<b>Imag</b>	Outputs imaginary part of the input signal as Im output of the block. If the input is real, the Im output is zero valued.

## Conditional

Pass through input T when control input C satisfies a selected criteria; otherwise, pass through input F. The first and third input ports are data ports, and the second input port is the control port.

### Library

Signal Routing



### Description

The Conditional block passes through input T when control input C satisfies the selected criteria; otherwise, it passes through input F. The first and third input ports are data ports, and the second (or middle) input port is the control port.

### Data Type Support

Data type support for the Conditional block is:

- Inputs T and F should either be both complex or real, and can be scalar, vector, or matrix. For non fixed-point data types, inputs T and F do not necessarily have the same data type. But, for fixed point data types, both these inputs should be of fixed-point type. In that case the output data type will be fixed-point, and the number of integer and fractional bits will be set to accommodate both inputs without loss of precision. For example, if one of the inputs is `x_sfix16_En10` (1 signed bit, 5 integer bits and 10 fractional bits), and the other is `x_sfix16_En5` (1 signed bit, 10 integer bits, and 5 fractional bits), the output will be `x_sfix21_En10` (1 signed bit, 10 integer bits, and 10 fractional bits).

- Input C can be a scalar, vector, or matrix if inputs T and F are scalars and Threshold parameter is scalar. In this case, the output dimension matches with the input C dimension. Input C must match the dimension of input T and F if they are non scalars. Input C should be real and can be of any data type.

## Parameters

- Criteria for passing first input:**

This parameter is used to select the condition under which the block passes the first input (T). If the control input C meets the condition set in the **Criteria for passing first input** parameter, the block passes the first input (T). Otherwise, the block passes the third input (F).

Settings for the **Criteria for passing first input** parameter are:

**Table 83: Criteria for Passing First Input Settings**

Setting	Description
<b>C &gt;= Threshold</b>	Select input T if control input C is greater than or equal to the <b>Threshold</b> parameter.
<b>C &gt; Threshold</b>	Select input T if control input C is greater than the <b>Threshold</b> parameter.
<b>C ~= 0</b>	Select input T if control input C is not equal to 0. Selecting <b>C ~= 0</b> disables the <b>Threshold</b> parameter.

- Threshold:**

This parameter assigns the switch threshold that determines which input the block passes to the output. Threshold parameter is rounded to the same data type as that of the C input.

- Settings:**

**Table 84: Supported Threshold Settings**

Settings	Description
0	default value
real number, vector, or matrix	any real scalar, vector or matrix



**TIP:**

To specify a non-scalar threshold, use brackets. For example, the following entries are valid: [1 3 5].

For a non-scalar threshold, the inputs must be scalars. In that case, the output dimension is the same as the threshold dimension, and input 2 is compared to each element of the threshold, and depending on the criteria, either T or F is selected to populate the output signal.

- Dependencies:** Setting Criteria for passing first input to C ~= 0 disables this parameter.

## Conjugate

Apply element-wise complex conjugate operation to the input signal

### Library

Math Functions / Math Operations



### Description

The Conjugate block applies element-wise complex conjugate operation to the input signal.

The conjugate of a complex number is the number with equal real part, where the imaginary part is equal in magnitude but opposite in sign. The complex conjugate of  $a+bi$  is  $a-bi$ .

### Data Type Support

Data type support for the input is:

- The input signals can be signed integer, fixed-point, or floating-point data type.
- Boolean and unsigned data types are not supported.
- The input signals can be a scalars, vectors, or matrices.
- The input signal supports complex type.

The data type and dimension of the output signal are the same as those of input signal. For complex type input, only the magnitude of the imaginary part changes.

### Parameters

The Conjugate block has no parameters to set.

## Constant

Provides constant value as a source.

### Library

Source



## Description

The Constant block generates a constant output of the value specified by the **Constant value** parameter. If you select **Interpret vector parameters as 1-D** parameter and specify the constant value as a scalar, row matrix, or column matrix, then the output is a 1-D array. Otherwise, the output is always two-dimensional. The Constant block supports real or complex constant values.

## Data Type Support

By default, the Constant block outputs a signal with **double** data type and the same complexity as the **Constant value** parameter. However, you can specify the output to be any data type that Model Composer supports, including fixed-point and half data types by selecting the **Output data type** parameter.

## Parameters

- **Constant value:**

The Constant value parameter specifies the constant value output of the block.

You can enter any expression that MATLAB® evaluates as a scalar or matrix.

*Table 85: Settings*

Choices	Description
1.0	Constant Value

- **Interpret vector parameters as 1-D:**

Specifies whether the constant value should be interpreted as a 1-D array.

*Table 86: Settings*

Choices	Description
On	If the specified constant value is a scalar, row matrix, or column matrix, then the output is a 1-D array. Otherwise, the output is a 2-D matrix.
Off	The output is a 2-D scalar or matrix.

- **Sample time:**

Specifies block sample time as a numerical value. The sample time of a block indicates when, during simulation, the block generates outputs or updates its internal state.

The block allows you to specify a block sample time directly as a numerical value. For example, to generate output at every two seconds, you can directly set the discrete sample time by specifying the numerical value of 2 as the **Sample time** parameter.

Settings for **Sample time** are:

*Table 87: Sample Time Parameter*

Sample Time Type	Sample Time Supported	Description	Supported?
Discrete	$T_s$	Generates output at discrete samples $T_s$ . Discrete sample time is supported with the initial time offset value fixed to 0. The initial offset value is not configurable.	Yes
Continuous	0	Generate output continuously by dividing the sample hits into major time steps and minor time steps. The Simulink ODE solver you choose integrates all continuous states from the simulation start time to a given major or minor time step.	No
Inherited	-1	The sample time value is inherited from other sources. It is determined by applying a set of heuristics and based on the context of the block within the model by Simulink. Allowing a design to inherit sample time maximizes its reuse potential. For example, a design might fix the data types and dimensions of all its input and output signals. But you could reuse the design with different sample times (for example, discrete at 0.1 or discrete at 0.2, triggered, and so on).	Yes
Constant	inf	Constant sample time. Same as inherited sample time for HLS blocks.	Yes
Variable	-2	Variable Sample time.	No
Triggered	-1 (implicit)	Execute the block upon some implicit condition when it is inside a subsystem like triggered, function call, or iterator subsystem.	Yes

For additional details for simulating sample time, see [Types of Sample time in the Simulink documentation](#).

- **Output data type:**

This parameter specifies the data type of the output signal.

If the output data type is one of the integer types, then the Constant value is rounded off as explained below.

A value with the fractional part less than 0.5 is rounded towards zero, the fractional part more than 0.5 is rounded away from zero.

In case of a tie (fractional part is 0.5), the Constant value is rounded up, i.e. the negative Constant value, is rounded towards zero and the positive Constant value is rounded away from zero.

- **Settings:**

The following data types are supported:

**Table 88: Output Data Type Parameter**

Setting	Description
double, single, and half	Floating point data types.
int8, uint8, int16, uint16, int32, uint32	Signed and unsigned integer data types.
Logical	Boolean data type.
Fixed point data type	<ul style="list-style-type: none"><li>Fixed-point arithmetic data type with configurable output data type attributes like signedness, word length, fractional length.</li><li>Constant value conversion attributes rounding and overflow for reading constant value parameter.</li></ul>
Data type Expression	A string that specifies the output data type. See "Working with Data Type Expression" in the <i>Vitis Model Composer User Guide</i> ( <a href="#">UG1483</a> ).

## cosh

Element-wise computation of the hyperbolic cosine for a given argument

### Library

Math Functions / Math Operations



## Description

The cosh block returns the output of the function  $\cosh(x)$ , which is the hyperbolic cosine, for each element in array  $x$ .

The hyperbolic cosine of  $x$  is:

$$\cosh(x) = \frac{e^x + e^{-x}}{2}$$

## Data Type Support

Data type support is:

- Dimension: Input can be scalar, vector, or matrix.
- Data Types: Input supports signals of integer type, floating point data types (double, single, and half) and fixed point type.
- Complex Numbers: Complex numbers are not supported.

Output has the same dimension and data type as the input.

## Parameters

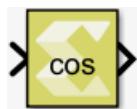
The cosh block has no parameters to set.

# Cosine

Computes cosine value for the input.

## Library

Math Functions / Math Operations



## Description

The Cosine block returns the output of the function  $\cos(x)$  for each element in array  $x$ .

## Data Type Support

Data type support is:

- Dimension: Input can be scalar, vector, or matrix.

- Data Types: Input supports signal of floating-point data types (double, single, and half), and signed fixed point type. It does not support integer, Boolean, and unsigned fixed point data types.
- Complex Numbers: Complex numbers are not supported.

Output has the same dimension and data type as the input. However, if the data type of the input is a fixed point type, the data type of the output is fixed point type with integer width fixed as 2.

## Parameters

The Cosine block has no parameters to set.

## Cumulative Sum

Compute the cumulative sum along the specified dimension of the input

### Library

Math Functions / Math Operations



### Description

The Cumulative Sum block computes the cumulative sum of the input signal along the specified dimension or across time (running sum). The output signal has the same dimensions, data type and complexity as the input signal.

Summing is performed in this way:

- Summing along Rows: If the block is configured for cumulative sum along rows, each element in the output signal is the sum of the corresponding element in the input and all of the elements in the same row and to the left of that element. If the input is 1-dimensional, each element in the output signal is the sum of the corresponding element in the input and all of the preceding elements.
- Summing along Columns: If the block is configured for cumulative sum along columns, each element in the output signal is the sum of the corresponding element in the input and all of the elements in the same column and above of that element. If the input is 1-dimensional, each element in the output signal is the sum of the corresponding element in the input and all of the preceding elements.

- Running sum: If the block is configured for running sum, each element in the output signal is the sum of the corresponding element in the input signal over time. In this case you can specify an optional reset port and restart the running sum when the reset signal is asserted.

## **Data Type Support**

Data type support is:

- Data input: The data In input is the data signal to be summed. It supports integer, fixed point and floating-point data types but not boolean. The signal can be complex or real. The signal can be a scalar, vector or matrix.
- Reset: The Reset input is applicable only for running sum with non-default reset type. The reset signal must be scalar and real, and its data type must be integer or floating-point. Fixed point data type is not supported.
- Output: The data type, dimension and complexity of the output signal are the same as those of input signal.

## **Parameters**

### **Sum input along**

This parameter specifies the dimension along which sum elements are computed.

Settings for the **Sum input along** parameter are:

*Table 89: Sum Input Along Parameter*

Setting	Description
<b>Columns</b>	The block computes the cumulative sum of each column of the input.
<b>Rows</b>	The block computes the cumulative sum of each row of the input.
<b>Channels (running sum)</b>	The block computes a running sum for each element of the input across time. When you select the <b>Channels (running sum)</b> option, you will also have to specify a <b>Reset port</b> parameter.

### **Reset port**

This parameter applies only to running sum. The **Reset port** parameter appears if you select **Channels (running sum)** for the **Sum input along** parameter.

Settings for the **Reset port** parameter are:

*Table 90: Reset Port Parameter*

Setting	Description
<b>None</b>	Omits the Reset port.

**Table 90: Reset Port Parameter (cont'd)**

Setting	Description
Non-zero sample	Triggers a reset operation at each sample time that the Reset input is not zero.

## Data Type Conversion

Convert the input to the data type of the output.

The block warns or errors out when an integer or fixed-point output overflows during simulation. To configure, select **Configuration Parameters** → **Diagnostics** → **Data Validity**. In the Data Validity pane, set **Wrap** or **Saturate** to **Overflow**.

### Library

Signal Attributes



### Description

The Data Type Conversion block has one input and one output. It converts the value of the input signal to the data type of the output. This conversion tries to preserve the mathematical value of the input signal. The data type of the output is specified via the mask dialog. The conversion is governed by the following rules:

- Conversions where the output data type is fixed-point, first select the nearest number that can be represented, taking into account the overflow mode. In case of a tie, the rounding mode breaks the tie.
- Conversions where the output data type is integer are performed as in the C language. Overflow is handled via truncation.
  - As per IEEE Standard for Floating-point Arithmetic (IEEE Standard 754, Section-7.2), conversion from floating-point to integral is an invalid operation, when the floating-point value is outside the range of the destination integer data type. In this case, the output integer value depends upon the implementation of a C compiler. Hence, the results from the HLS Data Type Conversion block may differ from the results from Simulink® Data Type Conversion block.
  - When the floating-point input value is outside the range of the integer data type, the simulation results between Model Composer and RTL co-simulation in Vitis HLS may also differ.

- During simulation, to check whether the input floating-point value goes outside the range of the destination integer type, in Simulink select **Model Configuration Parameters** → **Diagnostics** → **Data Validity**. Then set **Saturate on overflow** to either **warning** or **error**.
- Conversions where the output data type is floating point follow the rules implemented in the C language.

## Data Type Support

The input signal can be double, single, an integer, boolean, Xilinx supported half or Xilinx supported fixed-point data type.

The data type of the output is specified the mask parameters.

The input can be real or complex, and scalar, vector, or matrix. The output signal has the same complexity and dimensions as the input signal.

## Parameters

- Output data type:**

This parameter specifies the data type of the output signal. If `fixed` is specified, more parameters are available.

Settings for the **Output data type** parameter are as follows.

*Table 91: Output Data Type Parameter*

Setting	Description
double	double precision floating point
single	single precision floating point
int8	8-bit signed integer
uint8	8-bit unsigned integer
int16	16-bit signed integer
uint16	16-bit unsigned integer
int32	32-bit signed integer
uint32	32-bit unsigned integer
logical	boolean
fixed	Xilinx supported fixed-point
half	Xilinx supported half precision floating point
data type expression	A string that specifies the output data type. See "Working with Data Type Expression" in the <i>Vitis Model Composer User Guide</i> ( <a href="#">UG1483</a> ).

- Signedness:**

If the **Output data type** is set to **fixed**, the **Signedness** parameter specifies whether the output is a signed fixed-point or unsigned fixed-point data type.

Settings for the **Signedness** parameter are as follows.

*Table 92: Signedness Parameter*

Setting	Description
Signed	The output type contains both positive and negative numbers.
Unsigned	The output type contains only non-negative numbers.

This parameter is available only if **fixed** is selected as the setting for parameter **Output data type**.

- **Word length:**

If the **Output data type** is set to **fixed**, the **Word length** parameter specifies the number of bits used to represent it.

*Table 93: Word Length Parameter*

Choices	Description
16	
N	A positive integer

This parameter is available only if **fixed** is selected as the setting for parameter **Output data type**.

- **Fractional length:**

If the **Output data type** is set to **fixed**, the **Fractional length** parameter specifies the number of bits to the right of the binary point.

*Table 94: Fractional Length Parameter*

Choices	Description
10	
N	An integer

This parameter is available only if **fixed** is selected as the setting for parameter **Output data type**.

- **Round:**

If the **Output data type** is set to **fixed**, the **Round** parameter allows you to select among five rounding and two truncation options.

If one of the five rounding options is selected, the block always rounds to the nearest *supported precision*. The five rounding choices are relevant only in case of a tie. For example, assume the output type is signed fixed-point, with a word length of 6 and a fractional length of 2, and the input to the block is 2.74. In this case, the output is rounded to the nearest supported precision, 2.75, regardless of which one of the five rounding modes is selected. However, if the input value is 2.625 (halfway between 2.5 and 2.75), then the output value depends on the chosen rounding mode. If **Round to plus infinity** is selected, the value will be 2.75, and if **Round to zero** is selected, the value will be 2.5. For more information on this, refer to the *Vitis High-Level Synthesis User Guide* ([UG1399](#)).

If one of the two truncation options is selected, the output will be truncated to the supported precision specified by the truncation selection.

**Truncation to minus infinity** is the default setting for **Round** and requires the smallest hardware resources among all the options.

The **Round** parameter is available only if **fixed** is selected as the setting for the **Output data type** parameter.

Settings for the **Round** parameter are:

**Table 95: Round Parameter**

Setting	Description
Round to plus infinity	Rounding to plus infinity
Round to zero	Rounding to zero
Round to minus infinity	Rounding to minus infinity
Round to infinity	Rounding to infinity
Convergent rounding	Convergent rounding
Truncation to minus infinity	Truncation to minus infinity
Truncation to zero	Truncation to zero

- **Overflow:**

If the **Output data type** is set to **fixed**, the **Overflow** parameter specifies the overflow mode applied during conversion.

This parameter is available only if **fixed** is selected as the setting for parameter **Output data type**.

Settings for the **Overflow** parameter are:

**Table 96: Overflow Parameter**

Setting	Description
Saturation	Saturation

**Table 96: Overflow Parameter (cont'd)**

Setting	Description
Saturation to Zero	Saturation to zero
Symmetrical Saturation	Symmetrical saturation
Wrap around	Wrap around
Sign-Magnitude Wrap Around	Sign magnitude wrap around

- **Type Expression:**

If the **Output data type** is set to **data type expression**, the **Type Expression** parameter specifies the output data type as a string.

This parameter is available only if **data type expression** is selected as the setting for parameter **Output data type**.

- **Saturate on integer overflow:**

This parameter specifies whether integer overflow is handled by wrapping (default) or by saturating. This parameter is relevant only if the output is integral (int8, int16, int32, uint8, uint16, uint32).

When overflow is detected, the Diagnostic Viewer displays messages depending on the diagnostic action selected in the Configuration Parameters dialog box. To configure, in the **Configuration Parameters** → **Diagnostics** → **Data Validity** pane, set the Wrap or Saturate on overflow.

Settings for the **Saturate on integer overflow** parameter are:

**Table 97: Saturate On Integer Overflow Parameter**

Setting	Description
Not selected	Integer overflow is handled by wrapping.
Selected	Integer overflow is handled by saturation.

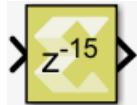
If the **Output data type** is set to **fixed** and overflow is detected, the Diagnostic Viewer displays messages that depend on the diagnostic action you specify in the Simulink Editor. To configure, select **Simulation** → **Model Configuration Parameters** → **Diagnostics** → **Data Validity** for your model in the Simulink Editor, then set the **Wrap on overflow** or **Saturate on overflow** parameter.

## Delay

Delay input signal by specified number of samples

## Library

Signal Operations



## Description

The delay block produces an output signal by delaying the input signal by the number of samples specified in the block dialog box. If the latency of the block is N, then the N-1 first output samples are always 0, and the N-th output sample is the first input sample.

## Data Type Support

All data types are supported.

Input can be a vector or a matrix. If input is a vector or a matrix and the latency value is a scalar, the scalar value will apply to all the elements of the input.

Output is complex if the input is complex.

## Parameters

### Latency

The **Latency** parameter specifies the number of samples by which the input signal is delayed.

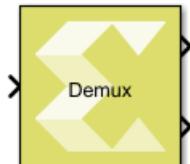
Latency should be a real, non-negative, scalar integer with minimum value as 1 and maximum value as  $2^{25}$ .

## Demux

Separates a vector input into a number of scalar and vector outputs.

## Library

Signal Routing



## Description

The Demux block input signal can be a scalar, a vector, a row matrix ( $1 \times N$ ), or a column matrix ( $N \times 1$ ). The block splits elements in the input signal into scalar and vector type output signals according to the width of each output port starting from the first port at the top right.

The number of output ports and the port widths are configurable using the Number of outputs block parameter,

You can specify the width of each port or it can be dynamically computed by the block based on how the parameter value is provided. Refer to the Parameters section below for more details.

When the value of the Number of outputs parameter is changed, the output ports are either added or removed starting from the last port at the bottom right.

Figure 344: Demux Parameter Dialog

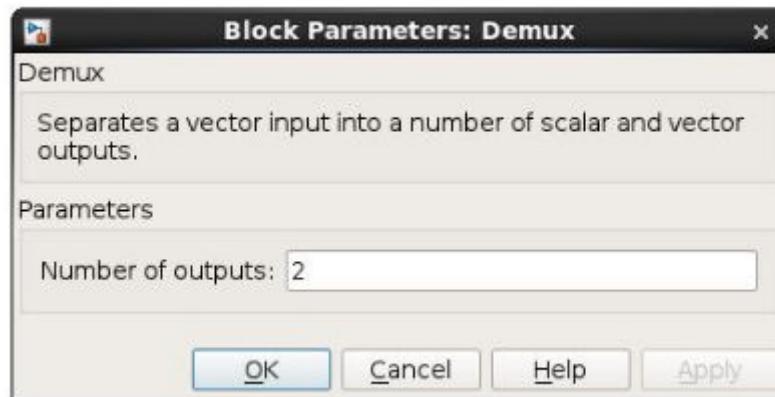
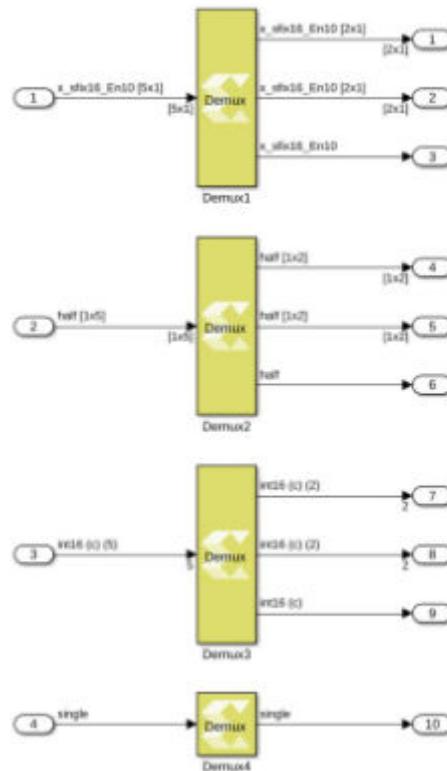


Figure 345: Demux Diagram



The output ports are added/removed starting from the last port at the bottom right.

## Data Type Support

- Inputs:**

- The block has one input port.
- The input signal can be a scalar, a vector ( $N$ ), a row matrix ( $1 \times N$ ), or column matrix ( $N \times 1$ ), where  $N$  is the width of input signal.
- The Demux block supports all native data types (double, single, uint8, int8, uint16, int16, uint32, int32, and boolean), and Model Composer supported half and fixed-point data types.
- The block supports input data in real or complex numeric type.

- Outputs:**

- The number of outputs for the block is specified using the Number of outputs block parameter.
- The value of the block parameter can be a finite positive integer,  $P$ , or an array of integers. The numbers in the array are used to decide the number of outputs as well as the width of each output signal.

- An output signal can be configured as a scalar, a vector (M), a row matrix (1xM), or a column matrix (Mx1) where M is less than or equal to the width of the input signal.
- The sum of widths of all output signals is ensured to be the same as the input signal width.
- The data type and the numeric type (real or complex) of output signals are the same as those of the input signal.

## Parameters

- **Number of outputs:**

This parameter takes number of outputs in several ways. Depending upon the parameter value, the output ports are added/removed starting from the last port at the bottom right.

**Table 98: Number of Outputs**

Option	Choices	Description
1	2	<p>The block icon is initially created with two output ports.</p> <p>The input signal width is equally divided between the two outputs. If the input signal width is an odd number, then any remainder of the width is assigned to the first port at the top right.</p>
2	P	<p>A finite integer value representing the number of output ports.</p> <p>P must be greater than 0.</p> <p>The block icon is redrawn with the specified number of output ports. The widths of the output ports are dynamically computed by the block as follows:</p> <p>The width of the input is equally divided among the outputs. Any remainder of the width is assigned, one each, to the outputs starting from the first port at the top right.</p> <p>For example, if N is 3, and the width of the input is 14, then the first output is assigned with the first 5 input elements, the second output is assigned with the next 5 input elements, and the third output is assigned with the last 4 input elements.</p>
3	[P]	<p>A finite positive integer in square brackets is treated just like option 2 above. Here, the number of outputs will be P.</p>
4	[-1 -1 -1]	<p>The block icon is redrawn with 3 output ports. Here -1 means that the width of the particular output port needs to be computed in the same way as it is explained in the option 2 above.</p>
5	[3 -1 -1]	<p>The block icon is redrawn with 3 output ports.</p> <p>You specify the width of the first output, and Model Composer computes the widths of the second and the third outputs.</p> <p>For example, if width of the input is 8, and the first output width is 3, then the remaining width of 5 is divided between the second and the third outputs. This results in the widths of the second and the third outputs to be set to 3 and 2 respectively.</p>
6	3 3 1	<p>The block icon is redrawn with 3 output ports.</p> <p>The width of each output port is already specified by the user. The sum of the width of the outputs is 7. The width of the input must be 7, otherwise, an error message appears.</p>

## Divide

Element-wise division

## Library

Math Functions / Math Operations



## Description

The Divide block has two input ports and one output port. The output signal (quotient) is the result of element-wise division of the first input (dividend) by the second input (divisor).

## Data Type Support

The data types of the dividend and divisor can be any integer, fixed point or floating point data type. Boolean dividends or divisors are not supported. The input signals can be real or complex. The input signals can be scalars, vectors or matrices. If neither input signal is scalar, they must either be vectors of the same length or matrices with the same number of rows and columns. When the output is integer or fixed point data type, the result is truncated to zero.

The output data type is chosen for maximal alignment with Vitis HLS. If the dividend and divisor are fixed point types and the fixed point parameters of the dividend are W1 (word length), FW1 (fractional length), and S1 (signedness), and the fixed point parameters of the divisor are W2, FW2, and S2, then the fixed point parameters of the quotient are as follows:

- $S = S1 \parallel S2$
- $FW2 \geq 0$ 
  - $W = W1 + FW2 + S2$
  - $FW = FW1$
- $FW2 < 0$ 
  - $W = W1 + S2$
  - $FW = FW1 + FW2$

## Parameters

The Divide block has no parameters.

## Equals

Perform element-wise equal to relational operation on the inputs. The top input corresponds to the first operand.

## Library

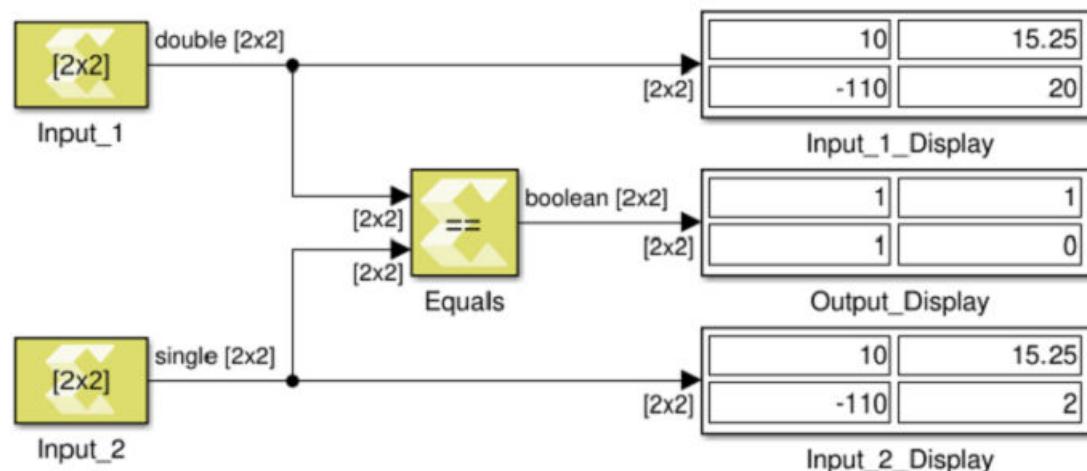
### Relational Operations



## Description

The Equals block performs element-wise comparison of inputs for equality. The block has two input ports and one output port. The output is true if the first input is equal to the second input.

Figure 346: Equals Block



## Data Type Support

Data types accepted at the inputs of the block are:

- The block supports all data types supported by Vitis Model Composer.
- The block supports inputs having different data types. The output data type is always Boolean.
- The block supports mixed dimensions for inputs, where one input is a scalar, and the other input is a vector/matrix. The scalar value is compared with each element of the multi-dimensional input value for equality. The output has the same dimension as the multi-dimension input.
- If both inputs are non-scalar then their dimensions must match.

The output data type is always Boolean.

## Parameters

The Equals block has no parameters to set.

## Exp

Perform an element-wise exponential value of the input

### Library

Math Functions / Math Operations



### Description

The Exp block returns the exponential  $e^x$  for each element in array  $x$ . The block supports all data types except Boolean. The input can be scalar, vector or matrix.

### Data Type Support

Data types accepted at the inputs of the block are:

- Dimension: Input can be scalar, vector, or matrix.
- Data Types: Input supports signal of integer, fixed point, and floating point data type. It does not support Boolean inputs.
- Complex numbers are not supported.

The output has the same dimension and type as the input.

## Parameters

The Exponential block has no parameters to set.

## Gain

Element-wise multiplication of the input by a constant gain factor

### Library

Math Functions / Math Operations



## Description

The Gain block multiplies the input signal by a constant gain factor.

You can specify the data type of the gain constant and built-in type promotion rules apply to determine the output data type. Alternatively, the output data type can be made the same as the input type. In case of integer overflow the block supports the option to saturate output values at the output type limits.

The block warns or errors out when an integer output overflows during simulation. To configure, select **Simulation** → **Model Configuration Parameters** → **Diagnostics** → **Data Validity** for your model in the Simulink Editor, then set the **Wrap on overflow** or **Saturate on overflow** parameter.

## Data Type Support

The block supports all data types except Boolean.

Data type support for the block is:

- The input can be a scalar, vector or matrix.
- If the input is a vector or matrix and the **Gain** is a scalar, the scalar value will apply to all the elements of the input.
- If neither the input nor the gain constant are scalar the dimensions of the input and the gain constant must match.

The output is complex if either the **Gain** constant or the input is complex.

## Parameters

### Gain

Specifies the constant gain factor. The **Gain** can be any valid MATLAB expression that evaluates to a real or complex scalar, vector, or matrix.

### Gain data type

This parameter specifies the type of conversion to be applied to the **Gain** factor constant before multiplication. If **fixed** is specified more parameters are available.

Settings for the **Gain data type** parameter are:

**Table 99: Gain Data Type Parameter**

Setting	Description
<b>double</b>	double precision floating-point
<b>single</b>	single precision floating-point
<b>int8</b>	8-bit signed integer
<b>uint8</b>	8-bit unsigned integer
<b>int16</b>	16-bit signed integer
<b>uint16</b>	16-bit unsigned integer
<b>int32</b>	32-bit signed integer
<b>uint32</b>	32-bit unsigned integer
<b>fixed</b>	fixed-point
<b>half</b>	half precision floating-point
<b>data type expression</b>	A string that specifies the output data type. See "Working with Data Type Expression" in the <i>Vitis Model Composer User Guide</i> ( <a href="#">UG1483</a> ).

Unless the **Output data type same as input** parameter is enabled, the output data type will be a function of the input type and the specified **Gain data type**.

- If either input or gain types are floating-point (double, single, or half), the output type will be floating-point. If both are floating-point, the output type will be the larger of both. The smaller type will be promoted to the larger before the operation.
- Otherwise, if either of input or **Gain data type** are fixed-point, the output type will be fixed-point with a bit width sufficient to hold the full output result. The other type (input or **Gain data type**) will be promoted to its equivalent fixed-point type.
- Otherwise, the input and **Gain data type** are integers. The output type will be the larger of either input or Gain data type, and will be a signed integer if either one is signed.

#### **Output data type same as input**

This parameter specifies the way the output data type is determined.

If disabled (unchecked) the output type is computed via built-in type promotion rules. If enabled (checked), the output data type is the same as the input type.

#### **Saturate on integer overflow**

This parameter specifies the behavior in case of integer overflow. By default the option is disabled and overflow would result in value wrap. With the option enabled, integer overflow gets mitigated by saturation at the limits of the output data type.

Settings for the **Saturate on integer overflow** parameter are:

**Table 100: Saturate On Integer Overflow Parameter**

Setting	Description
Unchecked	Wrap around
Checked	Saturation

When overflow is detected, the Diagnostic Viewer displays messages that depend on the diagnostic action you specify in the Simulink Editor. To configure, select **Simulation → Model Configuration Parameters → Diagnostics → Data Validity** for your model in the Simulink Editor, then set the **Wrap on overflow** or **Saturate on overflow** parameter.

## Greater

Performs element-wise greater than relational operation on the inputs. The top input corresponds to the first operand.

### Library

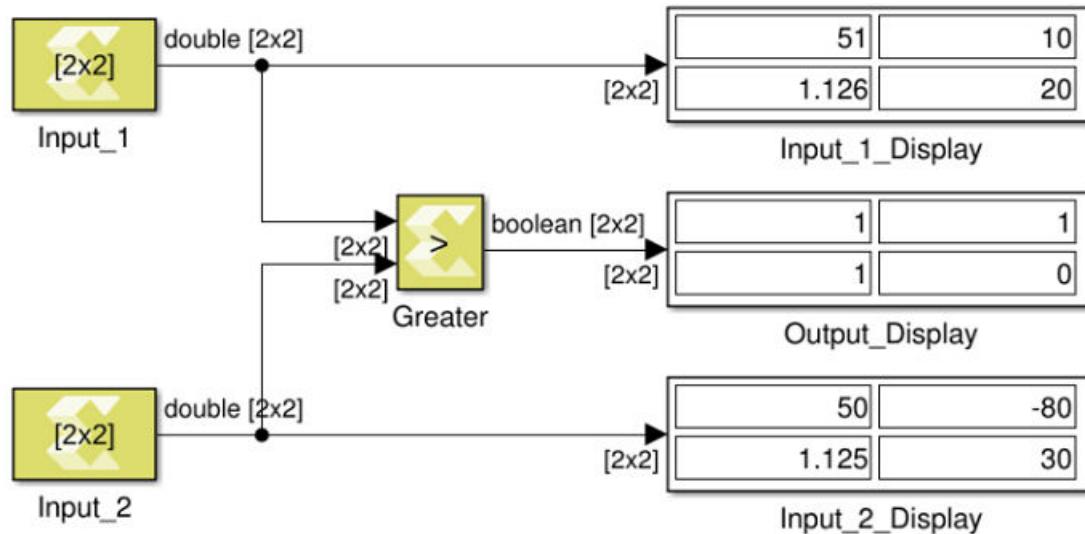
Relational Operations



### Description

The Greater block has two input signals and one output signal. The block compares the two inputs using element-wise greater than relational operation. The first input corresponds to the top input port and the second input to the bottom input port. The dimension of the output signal matches the dimensions of the input signals. An element of the output signal is true if the corresponding element of the first input signal is greater than the corresponding element of the second signal. Otherwise the element is false.

Figure 347: Greater Block



## Data Type Support

Data type support for the Greater block is:

- The data types of the input signals can be integer, fixed-point, Boolean, or floating-point data type.
- The input signals can be a scalars, vectors, or matrices. If both inputs are not scalar, their dimensions must match.
- The input signals must be real.
- The output signal is Boolean.
- The dimension of the output signal is scalar if both inputs are scalar. Otherwise it matches the dimensions of the non-scalar input.

## Parameters

The Greater block has no parameters to set.

## Greater Equals

Perform element-wise greater than or equal relational operation on the inputs. The top input corresponds to the first operand.

## Library

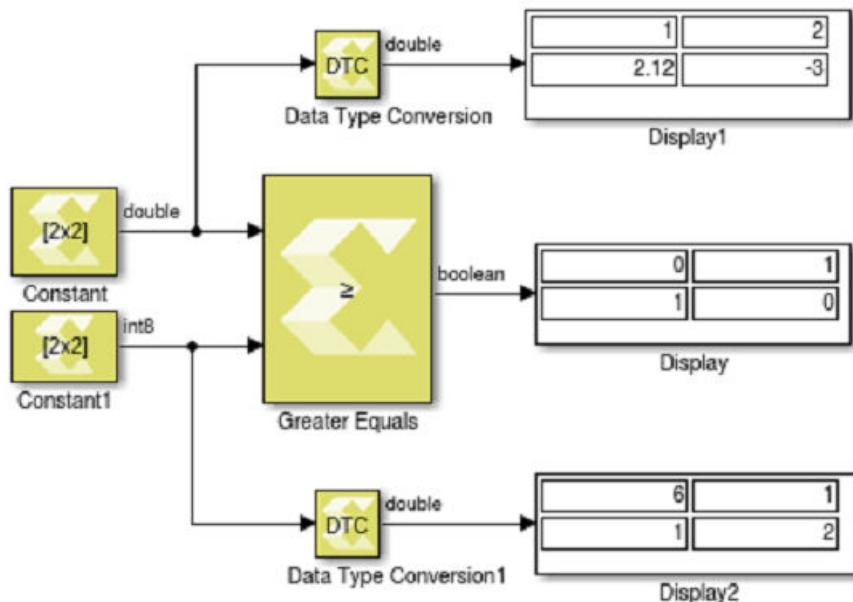
Relational Operations



## Description

The Greater Equals block performs element-wise greater than or equal relational operation on the inputs. The upper input is the first input and the lower input is the second input. The block returns true if the first input is greater than or equal to the second input. The output equals 1 for true and 0 for false.

Figure 348: Greater Equals Block



## Data Type Support

Data types accepted at the inputs of the block are:

- Data Types: Greater Equal block supports all data types supported by Model Composer (integer, floating-point, fixed-point, and Boolean).
- Dimension: The inputs can be scalar, vector, or matrix, or a combination of scalar, and matrix, or vector. If both the inputs are matrix or vector, they should have same dimension.
- Complex Number Support: No

The output is always Boolean.

Outputs for the different input types are:

Table 101: Input/Output

Inputs	Output
Both are scalar	Scalar
Both are vector	Vector of same dimension
Both are matrix	Matrix of same dimension
One is scalar and the other is vector or matrix	Dimension is that of the vector or matrix

## Parameters

The Greater Equals block has no parameters to set.

## Hermitian

Perform element-wise conjugate transpose operation on the input signal.

### Library

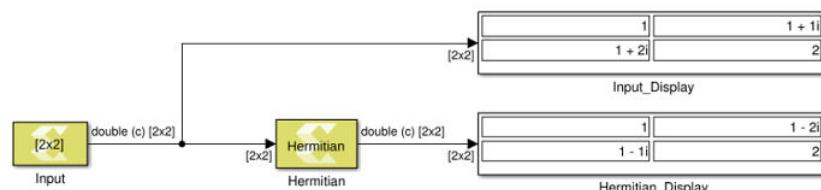
Math Functions / Matrices and Linear Algebra



### Description

The Hermitian block performs a conjugate transpose operation on the input signal.

Figure 349: Hermitian Block



### Data Type Support

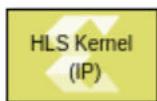
This block supports all data types supported by Xilinx® Model Composer. The input signal can be real or a complex number of scalar, vector, or matrix type.

## Parameters

The Hermitian block has no parameters to set.

## HLS Kernel

This block lets you import an HLS kernel code with a streaming interface.



## Library

HLS/User-Defined Functions

## Description

The HLS Kernel block allows you to import an HLS kernel, which is a proper HLS IP (an IP with interface specification using HLS pragmas). The primary use of this block is to co-simulate AI Engine domain with HLS.

**Note:** This block does not participate in HLS code generation and should not be part of the HLS subsystem in a design.

**Note:** Use this block to connect with AI Engine blocks using the AIE to HLS Kernel or HLS to AIE blocks and co-simulate a design with both AI Engines and PL components.

The block also accepts templated HLS functions.

Function arguments can be either of `hls::stream` type or of `scalar` or `vector` types. For example the following is a valid HLS function signature:

```
void func(hls::stream<unsigned int> &in, const ap_uint<8> (&param_in)[32],  
          hls::stream<unsigned int> &out, ap_uint<8> param_out);
```

For stream inputs and outputs, this block accepts variable size signals and produces variable size outputs. For stream inputs and outputs, the data width can only be 32, 64, or 128 bit wide.

## Parameters

Parameter Name	Parameter Type	Criticality	Description
Kernel header file	String	Mandatory	The name of the HLS kernel header file that contains the function declaration. The string could be just the file name, a relative path to the file or an absolute path of the file. Use the browse button to select the file.
Kernel function	String	Mandatory	The name of the kernel function in C/C++ for which HLS Kernel block is to be created.

Parameter Name	Parameter Type	Criticality	Description
Kernel source file	String	Optional	<p>The name of the source file that contains the kernel function implementation (definition). The string could be just the file name, a relative path to the file or the absolute path of the file.</p> <p>You can specify both the declaration and the definition of the function in the header file and leave this field empty.</p>
Kernel search paths	Vector of Strings	Optional	<p>If the kernel header file or the kernel source file is not found using the value provided through the 'Kernel header file' or 'Kernel source file' fields respectively, then the paths provided through 'Kernel search paths' are used to locate the files.</p> <p>This parameter allows use of environment variables while specifying paths for the kernel header file and the kernel source file. The environment variable can be used in either \${ENV} or \$ENV format.</p>
Preprocessor Options		Optional	<p>Optional preprocessor arguments for downstream compilation with specific preprocessor options.</p> <p>The following two preprocessor option formats will be accepted and multiple can be selected. -Dname and -Dname=definition. That is, the optional argument must begin with the -D string and if the option definition value is not provided, it is assumed to be 1.</p>

## Interface Spec

Specify the RTL interfaces for a subsystem

### Library

Tools



### Description

The Interface Spec block allows you to control what RTL interfaces should be synthesized for the ports of the subsystem in which the Interface Spec block is instantiated. This affects only code generation and synthesis, when an RTL model (an IP) is synthesized by Vitis HLS from the C++ model produced by Model Composer. The block has no effect on Simulink® simulation of your design. If your design does not have an Interface Spec block, Model Composer selects default interfaces for you. Interface synthesis is supported only to the subsystem for which you are generating C++ code. Therefore any Interface Spec blocks instantiated in subsystems nested within the subsystem for which you are generating C++ code are ignored.

The Interface Spec block is used as follows:

1. Instantiate the Interface Spec block in the subsystem for which you want to generate C++ code. The **Input ports** tab will be populated with one row for each input port of the parent subsystem. Similarly, the **Output ports** tab has one row for each output port of the parent subsystem.
2. Fill out the **Function Protocol**, **Input ports**, and **Output ports** tabs.

The information gathered by the Interface Specification block consists of three parts:

- The block-level Interface Protocol. This protocol is used to tell the IP when to start processing data. It is also used by the IP to indicate whether it accepts new data, or whether it has completed an operation, or whether it is idle.
- The port-level Interface Protocol for each input port of the parent subsystem.
- The port-level interface protocol for each output port of the parent subsystem.

The choice of port-level interface protocol should take into account the following considerations:

- Large array or matrix ports should use a streaming protocol such as AXI4-Stream, FIFO, or AXI4-Stream (video).
- Scalar ports can be implemented using any of the following protocols: Default, AXI4-Lite Slave, Constant, Valid Port, No protocol
- Video signals can be transported over an AXI4-Stream (video) interface. In this case you also need to specify the video format YUV 4:2:2, YUV 4:4:4, RGB or Mono. For video formats that have more than 1 color component, you also need to specify which port carries which color component and you need to assign the same name for the 'bundle' attribute for these (3) ports. All of the ports (either 3 or 1) that make up the video signal are implemented by a single AXI4-Stream interface that include start-of frame and end-of-line sideband signals. This follows the specifications described in the *AXI4-Stream Video IP and System Design Guide* ([UG934](#)).
- An AXI4-Lite Slave interface allows you to implement one or more ports.
- For further details refer to Interface Synthesis in the *Vitis High-Level Synthesis User Guide* ([UG1399](#)).

The interface specification block currently supports subsystems with at most 8 input ports and 8 output ports.

## Data Type Support

Data type support is not applicable to the Interface Spec block.

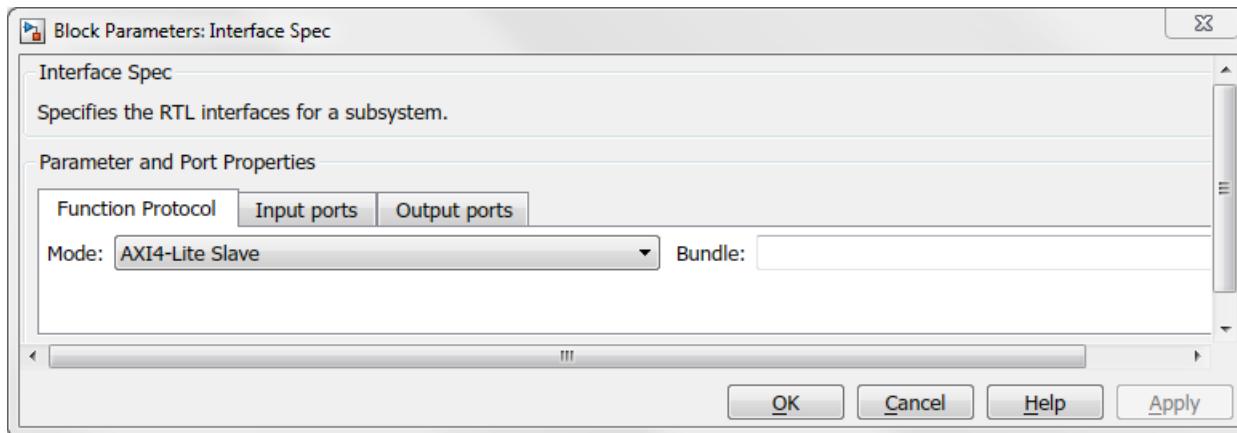
## Parameters

The parameters for the Interface Specification block fall into the following groups.

- The parameters that apply to the function protocol. These are Mode, and Bundle. In the GUI dialog, these parameters appear in the 'Functional Protocol' tab.

- The parameters that apply to the Input ports. For each input port, there is 1 set of parameters Mode, Bundle, Offset, Video Format, and Video Component. In the Block Parameter dialog, these parameters appear in the 'Input ports' tab.
- The parameters that apply to the Output ports. For each output port, there is 1 set of parameters Mode, Bundle, Offset, Video Format, and Video Component. In the GUI dialog, these parameters appear in the 'Output ports' tab.

Figure 350: Function Protocol Parameters



Parameters on the **Function Protocol** tab are as follows:

- **Mode:**

The **Mode** parameter specifies the block-level I/O protocol.

Following are the settings for the **Mode** parameter.

Table 102: Mode Parameter

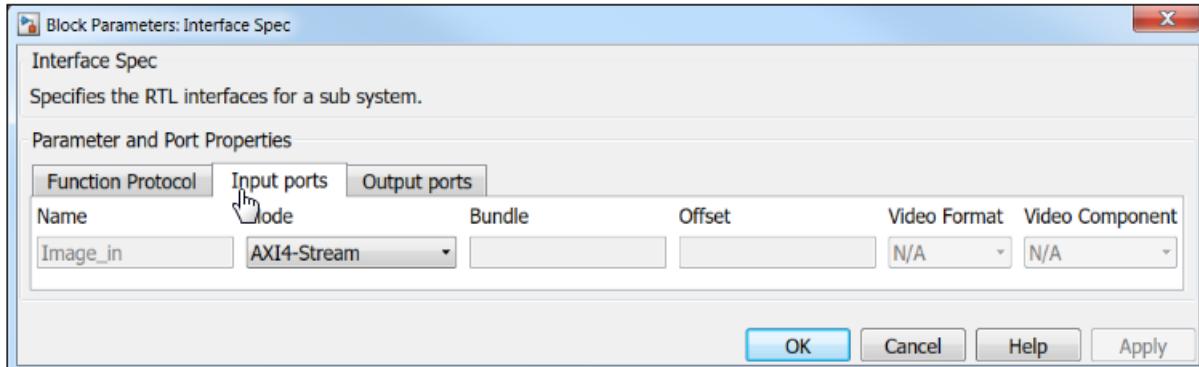
Setting	Description
AXI4-Lite Slave	Specifies AXI4-Lite Slave as the block-level I/O protocol.
Handshake	Specifies a handshake protocol as the block-level I/O protocol.
No block-level I/O Protocol	Specifies that there is no block-level I/O protocol.

The default choice for the function protocol is 'AXI4-Lite Slave'. However, if the DUT does not have any scalar ports then Handshake is selected as default function protocol.

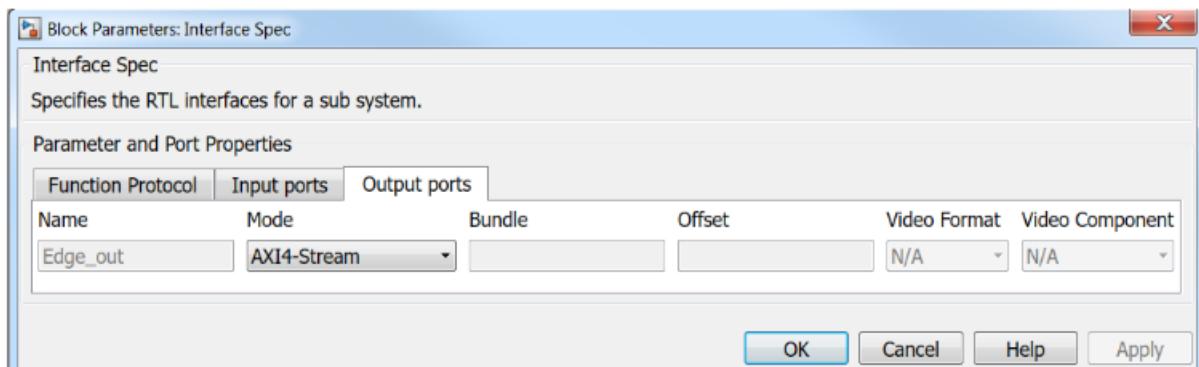
- **Bundle:**

The **Bundle** parameter is used in conjunction with the AXI4-Lite Slave interface to indicate that multiple ports should be grouped into the same interface. Enter a legal identifier in the C language (cannot contain spaces or special characters) for **Bundle**.

**Figure 351: Input Ports Tab**



**Figure 352: Output Ports Tab**



Parameters on the **Input ports** and **Output ports** tabs are as follows.

- **Mode:**

The **Mode** parameter specifies the I/O protocol for the input port or the output port.

Settings for the **Mode** parameter are:

**Table 103: Mode Parameter**

Setting	Description
<b>Default</b>	Specifies to use <b>AXI4-Lite Slave</b> if port is scalar, and use <b>AXI4-Stream</b> if the port is non-scalar.
<b>AXI4-Stream</b>	Specifies <b>AXI4-Stream</b> protocol.
<b>AXI4-Stream (video)</b>	Specifies <b>AXI4-Stream (video)</b> protocol. Allows you to specify <b>Bundle</b> , <b>Video Format</b> , and <b>Video Component</b> parameters.
<b>AXI4-Lite Slave</b>	Specifies <b>AXI4-Lite Slave</b> protocol. Allows you to specify <b>Bundle</b> and <b>Offset</b> parameters.
<b>FIFO</b>	Specifies a protocol for arrays whose elements are accessed in a sequential manner.

Table 103: Mode Parameter (cont'd)

Setting	Description
<b>Valid port</b>	Specifies a handshake protocol that only has a valid port.
<b>Constant</b>	Specifies a mode in which no I/O protocol is added to the port. The mode is intended for configuration inputs which only change when the device is in reset mode. This mode only applies to <b>Input ports</b> .
<b>No protocol</b>	Specifies that no I/O protocol is added to the port.
<b>Block RAM</b>	Specifies <b>Block RAM</b> interface protocol.

- **Bundle:**

The **Bundle** parameter applies to the input ports or output ports and it is used in conjunction with the **AXI4-Stream (video)** interfaces that have more than one color component. In this case there should be one port for each color component and these ports should specify the same name for the **Bundle** attribute so that they will be grouped into the same **AXI4-Stream (video)** interface.

The parameter is also used in conjunction with **AXI4-Lite Slave** interfaces to specify that ports with the same name for the **Bundle** attribute will be grouped into the same AXI4-Lite Slave interface.

Enter a legal identifier in the C language (cannot contain spaces or special characters) for **Bundle**.

- **Offset:**

The **Offset** parameter applies to the input ports or output ports and it is used in conjunction with the **AXI4-Lite Slave** interface. The parameter allows you to specify the address offset for a port within the **AXI4-Lite Slave** address map.

- **Video Format:**

The **Video Format** parameter applies to the input ports or output ports and it specifies the color format for a video signal. It applies only to **AXI4-Stream (video)** interfaces. Options are **Mono**, **YUV 4:2:2**, **YUV 4:4:4**, and **RGB**.

- **Video Component:**

The **VideoComponent** parameter applies to the input ports or output ports and it specifies the color component for a video signal. It applies only to **AXI4-Stream (video)** interfaces that use a **Video Format** with more than one color component. Options are **Mono**, **YUV 4:2:2**, **YUV 4:4:4**, and **RGB**.

The **Video Component** selections for the different **Video Format** options are as follows.

**Table 104: Video Component Option**

Video Format	Video Component Options
Mono	N/A
YUV 4:2:2	Y, U, V
YUV 4:4:4	Y, U, V
RGB	R, G, B

## Lesser

Performs element-wise less than relational operation on the inputs. The top input corresponds to the first operand.

### Library

Relational Operations



### Description

The Lesser block has two input signals and one output signal. The block compares two inputs using element-wise lesser relational operation. The first input corresponds to the top input port and the second input to the bottom input port. The dimension of the output signal matches the dimensions of the input signals. An element of the output signal is true if the corresponding element of the first input signal is less than the corresponding element of the second signal; otherwise the element is false.

### Data Type Support

Data types support for the Lesser block is:

- The data types of the input signals can be integer, fixed-point, boolean, or floating point data type.
- The input signals can be scalars, vectors, or matrices. If both inputs are not scalar, their dimensions must match.
- The input signals must be real.
- The output signal is boolean.
- The dimension of the output signal is scalar if both inputs are scalar. Otherwise it matches the dimensions of the non-scalar input.

## Parameters

The Lesser block has no parameters to set.

# Lesser Equals

Perform element-wise less than or equal relational operation on the inputs. The top input corresponds to the first operand.

## Library

Relational Operations



## Description

Performs element-wise less than or equal relational operation on the inputs. The block returns true (1) if the first input is less than or equal to the second input; returns false (0) otherwise.

## Data Type Support

The Lesser Equals block supports inputs of native data types of MATLAB® and Ap\_Fixed data type supported by Vitis HLS. The output type is always Boolean. It does not support complex data types. The block supports inputs of scalar, vector, and matrix dimensions. When both inputs have non-scalar dimensions then the dimensions of the inputs must match each other.

## Parameters

The Lesser Equals block has no parameters to set.

# Library Function

Import user created C function as a block

## Library

Library can be specified after you create the Library Function block.



## Description

The Library Function block allows you to bring C or C++ models into Model Composer for block simulation and code generation. The block I/O interface is determined by the function declaration, which is auto-discovered by the tool. The Library function block is created when you run the `xmc ImportFunction` script to specify the library function sources files and header search paths.

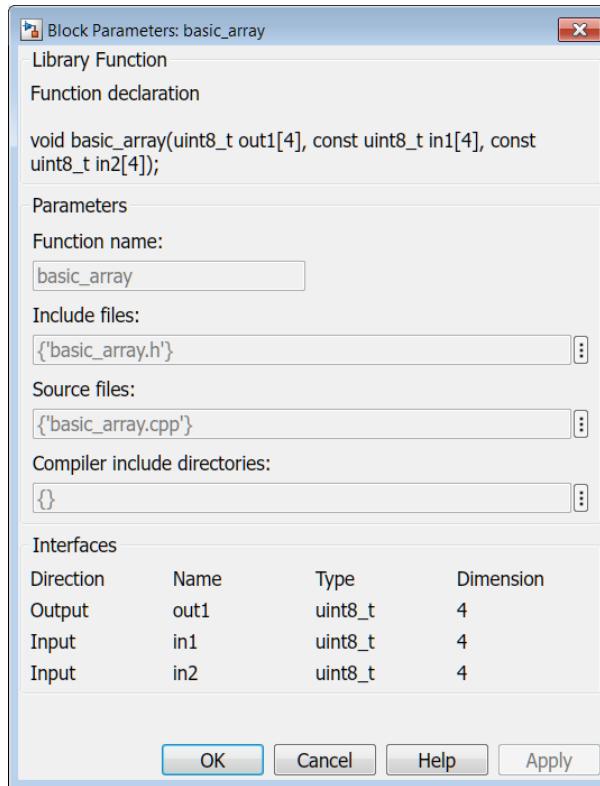
## Data Type Support

You can import functions that have scalar, vectors, or matrices as function parameters. All data types, including fixed-point are supported. Complex values, real, and imaginary components, and phase angles are not supported.

## Parameters

The block parameters dialog box for the Library Function block is shown below:

Figure 353: Block Parameters



The dialog box indicates the settings for these parameters which were specified when the block was created:

- **Function name**

- **Include files**
- **Source files**
- **Compiler include directories**

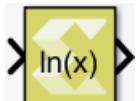
You cannot change these settings from the dialog box. To change these settings, you will have to recreate the block using the `xmcImportFunction` command.

## Log

Compute element-wise natural logarithm of input

### Library

Math Functions / Math Operations



### Description

The Log block returns the logarithm value for the provided input. The block supports input of all data types except Boolean. The input can be scalar, vector, or matrix.

### Data Type Support

Data types accepted at the inputs of the block are:

- Data Types: Input supports signals of integer, fixed-point, and floating-point data type. The block does not support Boolean inputs.
- Complex Number Support: No

The output has the same dimension and type as the input.

### Parameters

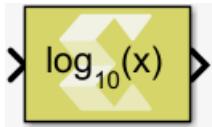
The Log block has no parameters to set.

## Log10

Compute element-wise base 10 logarithm of input

### Library

Math Functions / Math Operations



## Description

The Log10 block returns the base 10 logarithm value for the input. The block supports input of all data types except Boolean. The input can be scalar, vector, or matrix.

## Data Type Support

Data types accepted at the inputs of the block are:

- Data Types: Input supports signals of integer, fixed-point, and floating-point data type. The block does not support Boolean inputs.
- Complex Number Support: No

The output has the same dimension and type as the input.

## Parameters

The Log10 block has no parameters to set.

## Logical AND

Performs element-wise logical AND operation on inputs

## Library

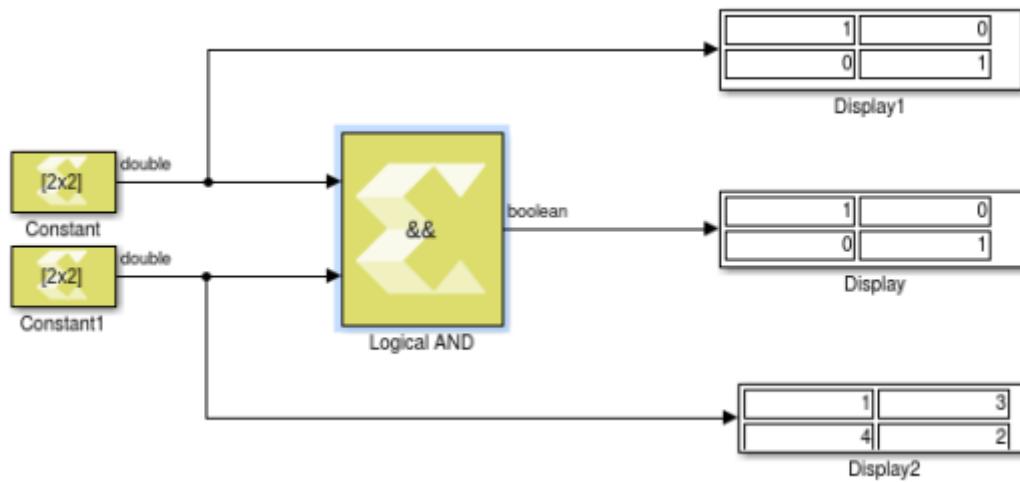
Logic and Bit Operations



## Description

The Logical AND block has two input ports and one output port. The block performs an element-wise logical AND operation on the inputs and produces a Boolean result on the output.

Figure 354: Logical AND Block



## Data Type Support

- The block supports inputs of different data types. The output data type is always Boolean.
- The block only supports real inputs.
- If one input is non-scalar type then the other input can be scalar type.
- If both inputs are non-scalar type then their dimensions must match. In case of non-scalar inputs, the output has the same dimension as the inputs.

## Parameters

The Logical AND block has no parameters to set.

## Logical NOT

Performs element-wise logical NOT operation on the input

### Library

Logic and Bit Operations



## Description

The Logical NOT block has one input port and one output port. The output is false if the input is a non-zero (true) value.

## Data Type Support

- The Logical NOT block supports all data types supported by Model Composer.
- The block only supports real inputs.

## Parameters

The Logical NOT block has no parameters to set.

# Logical OR

Performs element-wise logical OR operation on inputs

## Library

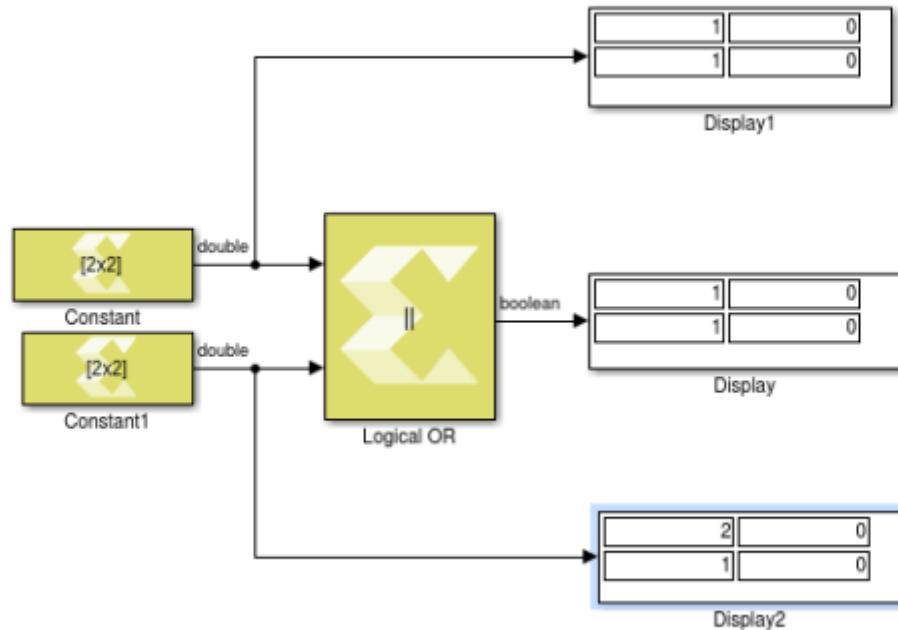
Logic and Bit Operations



## Description

The Logical OR block has two input ports and one output port. The block performs an element-wise logical OR operation on the inputs and produces a Boolean result on the output.

Figure 355: Logical OR Block



## Data Type Support

- The Logical OR block supports all data types supported by Model Composer.
- The block supports inputs of different data types. The output data type is always Boolean.
- The block only supports real inputs.
- The block supports scalar and non-scalar type inputs. If one input is non-scalar type then the other input can be scalar type. When both inputs are non-scalar type then their dimensions must match. In that case, the output has the same dimension as the inputs.

## Parameters

The Logical OR block has no parameters to set.

## Lookup Table

Perform one-dimensional lookup operation with an input index.

## Library

Lookup Tables



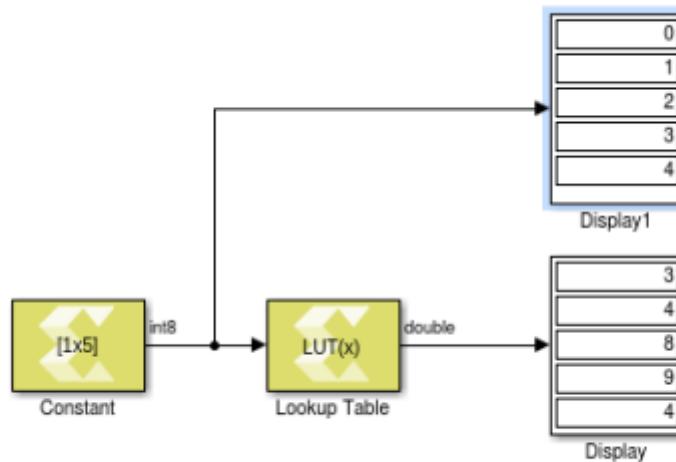
## Description

The Lookup Table block implements a simple read-only memory block with an input index. The block maps input to an output value by looking up a table of values you define with a **Table data** parameter.

The input value is used as a zero-based index into the table data. The **Input bias** parameter is an offset to the index value (to support negative indexing). A **When input is out of range** parameter lets you specify the behavior of the block if the index value exceeds the valid table size range.

**Note:** If the table size is not an exact power of 2, the block incurs additional hardware cost when it is implemented in a Xilinx device, due to a remainder calculation on the index.

Figure 356: Lookup Table Block



In the example above, the **Table data** setting for the Lookup Table block is [7 3 4 8 9 4 1 5] with an input bias of 1.

## Data Type Support

The Lookup Table block accepts the following data types to represent scalar index value: int8, uint8, int16, uint16, int32, uint32, and fixed-point type. Fixed-point inputs are shifted appropriately to generate an integer index.

The output data type is same as the **Table data** parameter type. Inputs for indexing must be real, but table data can be complex.

## Parameters

### Table Data

This parameter accepts a 1-D vector of table values. The size of the vector determines the valid index range for the input index. The data will be explicitly converted into the type specified in the **Output data type** parameter. If the input index exceeds table size and **Saturate at table ends** is specified for the **When input is out of range** parameter, then index value is saturated to either top or bottom of table size range. If **Wrap around** is specified for the **When input is out of range** parameter, the index is wrapped into the valid table size range.

**Note:** Large tables should be defined via a Simulink workspace variable due to space limitations in the block dialog box.

### Input bias

This parameter is an offset into the table data that will be added to the index input. This makes it possible to use negative indices and perform look up operation.

### When input is out of range

This parameter will guard the index value if it exceeds the valid table size range.

Following are the settings for the **When input is out of range** parameter.

**Table 105: When Input Is Out of Range Parameter**

Setting	Description
<b>Saturate at table ends</b>	If index value exceeds the valid table size range, then index value is saturated to either top or bottom of table size range, depending on the overflow direction.
<b>Wrap around</b>	If index value exceeds the valid table size range, then index value is wrapped into the valid table size range.

### Output data type

Specifies the output data type.

Following are settings for the **Output data type** parameter.

**Table 106: Output Data Type Parameter**

Setting	Description
<b>double</b>	double precision floating-point
<b>single</b>	single precision floating-point
<b>int8</b>	8-bit signed integer
<b>uint8</b>	8-bit unsigned integer
<b>int16</b>	16-bit signed integer
<b>uint16</b>	16-bit unsigned integer

Table 106: Output Data Type Parameter (cont'd)

Setting	Description
int32	32-bit signed integer
uint32	32-bit unsigned integer
boolean	boolean
fixed	fixed-point
half	half precision floating-point
data type expression	A string that specifies the output data type. See "Working with Data Type Expression" in the <i>Vitis Model Composer User Guide</i> ( <a href="#">UG1483</a> ).

## Matrix Multiply

Compute matrix product of two input signals. The first operand is the top input on the block.

### Library

Math Functions / Matrices and Linear Algebra



### Description

The Matrix Multiply block has two input ports and one output port. The output signal is the matrix product of the input signals where the first operand corresponds to the top input.

### Data Type Support

The data type of the input signals can be any floating-point, fixed-point, integer, or Boolean. The input signals can be real or complex. The input signals can be scalar, vector, or matrix, but they do need to be such that mathematically, the matrix product is defined. The table below shows valid combinations. Combinations that do not match any row in the table result in an error.

Table 107: Data Type Combinations

Dimensions of First Operand	Dimensions of Second Operand	Dimensions of Matrix Product	Conditions
K x L	L x M	K x M	K >= 1, L >= 1, M >= 1
K x L	L	K	K >= 1, L > 1
K x 1	1	K x 1	K >= 1
K	1	K	K >= 1
K	1 x M	K x M	K >= 1, M >= 1

The output data type is determined according to the following rules, in the order listed. T1 is a variable representing the type of the first operand; T2 is a variable representing the type of the second operand. These rules were chosen for maximum alignment with Vitis HLS, which may not correspond to the output data type computed via the internal rule of the Simulink® Matrix Product block.

*Table 108: Output Data Type*

Data Type of First Operand	Data Type of Second Operand	Data Type of Matrix Product
T1: floating-point	T2	The widest floating-point type between T1 and T2 if T2 is a floating-point type; otherwise T1
T1 fixed-point	T2: floating-point fixed-point	The widest floating-point type between T1 and T2 if T1 is a floating-point type; otherwise T2
fixed-point	integer	The smallest fixed-point type capable of representing the product without loss of precision
integer	fixed-point	The smallest fixed-point type capable of representing the product without loss of precision
T1: integer	T2: integer	Let W1 be the bit width of T1 and W2 be the bit width of T2. The product is the integer type with bit width $\max(W1, W2)$ and it is signed if either T1 or T2 are signed.
boolean	T2	T2
T1	boolean	T1

## Parameters

The Matrix Multiply block has no parameters to set.

## Max

Outputs the maximum value of an input or element-wise maximum value of multiple inputs.

### Library

Math Functions/Math Operations



### Description

The Max block with a single scalar or vector input, outputs the maximum value of the input.

If the block has more than one input, the non-scalar inputs must have the same dimensions. Any scalar input is expanded to the dimensions of the non-scalar inputs, and the block outputs element-wise maximum value of the inputs.

## Data Type Support

- The block supports floating-point, integer, and fixed-point data types.
- The block supports real valued inputs.
- For Number of Inputs = 1.
  - The block supports a scalar or vector (1-D or 2-D) input when it has only one input port. The output is a scalar.
- For Number of Inputs > 1.
  - The block supports scalar, vector, or matrix inputs when it has more than one input port.
  - The output has the same dimensions as those of the inputs when all the inputs have the same dimensions.
  - The block supports mixed dimensions for inputs when it has more than one input port, provided all the non-scalar inputs have the same dimensions. Any scalar input is expanded to the dimensions of non-scalar inputs, and the block outputs element-wise maximum value of the inputs. The output has the same dimensions as those of the non-scalar inputs.
- The block supports inputs having different data types. The output data type in this case is defined by the following set of rules.
  - If the data type of one of the inputs is a floating-point type, the data type of the output is the floating-point type among the data types of the inputs with the most precision.
  - If the data type of one of the inputs is a fixed-point type, the data type of the output is the smallest fixed-point type capable of representing the result without any loss of precision.
  - If the inputs are integral, the output is integral. If any input is signed, the output is signed. The bit width of the output is the largest among the bit widths of the inputs.

## Parameters

- **Number of inputs:**

This parameter determines the number of inputs.

*Table 109: Number of Inputs*

Choices	Description
1	Initially, the block icon has a single input.
N	A positive integer value. The block icon is redrawn with the specified number of input ports.

## Min

Outputs the minimum value of an input or element-wise minimum value of multiple inputs.

### Library

Math Functions/Math Operation



### Description

The Min block with a single scalar or vector input outputs the minimum value of the input.

If the block has more than one input, the non-scalar inputs must have the same dimensions. Any scalar input is expanded to the dimensions of non-scalar inputs and the block outputs element-wise minimum value of the inputs.

### Data Type Support

- The block supports floating-point, integer, and fixed-point data types.
- The block supports real valued inputs.
- Number of inputs = 1.
  - The block supports a scalar or vector (1-D or 2-D) input when it has only one input port. The output is a scalar.
- Number of inputs > 1.
  - The block supports scalar, vector, or matrix inputs when it has more than one input port.
  - The output has the same dimensions as those of the inputs when all the inputs have the same dimensions.
  - The block supports mixed dimensions for inputs when it has more than one input port, provided all the non-scalar inputs have the same dimensions. Any scalar input is expanded to the dimensions of non-scalar inputs and the block outputs element-wise minimum value of the inputs. The output has the same dimensions as those of the non-scalar inputs.
- The block supports inputs that have different data types. The output data type in this case is defined by the following set of rules.
  - If the data type of one of the inputs is a floating point type, the data type of the output is the floating point type among the data types of the inputs with the most precision.

- Otherwise, if the data type of one of the inputs is a fixed-point type, the data type of the output is the smallest fixed-point type capable of representing the result without any loss of precision.
- Otherwise, if the inputs are integral, the output is integral. If any input is signed, the output is signed. The bit width of the output is the largest among the bit widths of the inputs.

## Parameters

- Number of inputs:**

This parameter determines the number of inputs.

*Table 110: Number of Inputs*

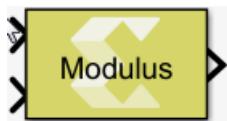
Choices	Description
1	Initially, the block icon is created with a single input.
N	A positive integer value. The block icon is redrawn with the specified number of input ports.

## Modulus

Performs element-wise modulus operation on the input signals

### Library

Math Functions / Math Operations



### Description

The Modulus block takes two inputs. The first input is taken as dividend and the second input is considered as divisor. The output is the remainder after division. For each element of the dividend A, compute the modulus operation (remainder after division) with regard to the corresponding element of the divisor B, as follows:

$$M = \text{mod}(A, B) = A - B \cdot \text{floor}(A / B)$$

The block can handle division by 0 by returning the NaN output for floating-point data types and 0 for the rest of the data types.

**Note:** For signed data types the remainder will have the same sign as the divisor B. If instead it should have the same sign as the dividend, use the Remainder block instead of the Modulus block.

## Data Type Support

Data types accepted at the inputs of the block are:

- The block supports all native Simulink® data types, as well as half precision floating-point, and fixed-point data types.
- For inputs of bool data type, the output value is always false.
- The block supports scalars, vectors, and 2D matrices.
- The input dimensions must match unless one input is a scalar, in which case, it gets broadcast to be used with each of the other input's elements. The output dimension is the larger of the two input dimensions.
- The block supports mismatched input data types. The output data type is decided by Vitis Model Composer data type propagation rules.
- The block operates on inputs of real numeric type only. For input of complex numeric type it issues an error.

## Parameters

The Modulus block has no parameters to set.

# Mux

Combines scalar and vector inputs into a larger vector output.

## Library

Signal Routing

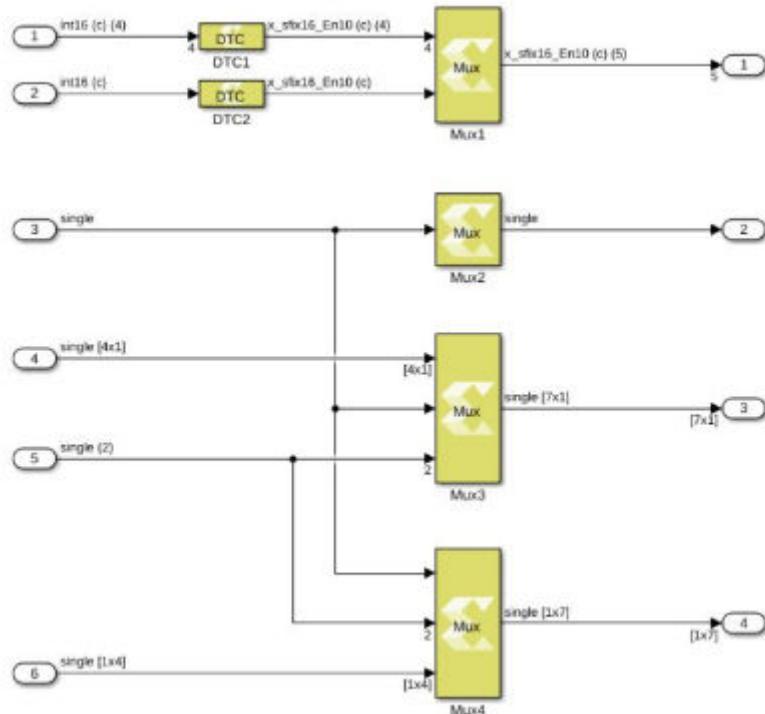


## Description

The Mux block combines scalar and vector inputs into a larger vector. The elements of the inputs are concatenated starting from the first input at the top left. The block takes an input signal that is a scalar, a vector, a row matrix, or a column matrix with the limitation that it cannot support a row matrix signal, and a column matrix signal at the same time. If an input is a row vector or a column vector, then the output also takes that form. The output is a non-virtual vector meaning that its elements are stored in contiguous memory.

The number of inputs to the block is configurable using the Number of inputs block parameter. When the value of the block parameter is changed, the input ports are added or removed starting from the last port at the bottom left.

*Figure 357: Mux Diagram*



**Note:** This figure shows how the Mux block computes output port dimensions.

## Data Type Support

- **Inputs:**

- The number of inputs is decided by value of the Number of inputs parameter.
- The input signal can be a scalar, a vector ( $M$ ), a row matrix ( $1 \times M$ ), or column matrix ( $M \times 1$ ).
- The block cannot have a row matrix and a column matrix as inputs at the same time.
- All inputs must have the same data type, and the same numeric type either real or complex.
- The Mux block supports all native data types (double, single, uint8, int8, uint16, int16, uint32, int32, and boolean), and Model Composer supported half and fixed-point data types.

- **Outputs:**

- The block has one output port.

- The output data type and numeric type are the same as the inputs.
- The output signal dimension depends upon the dimensions of the input signals.

## Parameters

- **Number of inputs:**

The value for the parameter must be a finite positive integer. When the value of the parameter changes, the input ports are either added or removed starting from the last port at the bottom left.

*Table 111: Number of Inputs Settings*

Choices	Description
2	The block icon is initially created with two input ports.
N	A finite positive integer value. The block icon is redrawn with the specified number of input ports.

## Negate

Perform element-wise unary minus operation on the input data

### Library

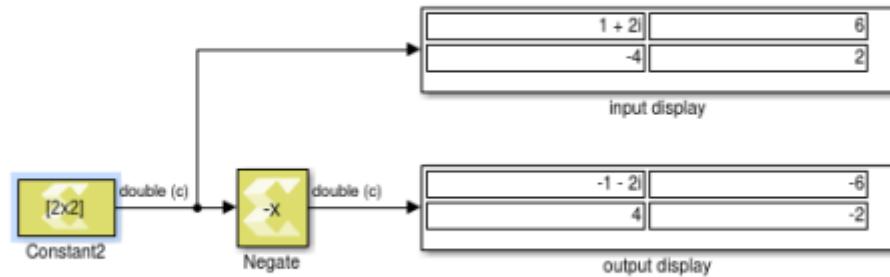
Math Functions / Math Operations



### Description

The Negate block computes element-wise minus operation on the input data. The block handles signedness of real and imaginary parts separately in case of complex data input.

Figure 358: Negate Block



## Data Type Support

Data type support is:

- Input Data Type: All data types are supported except unsigned integer and Boolean values.
- Output: The data type, dimension, and complexity of the output are the same as those of the input signal.

The block supports scalar, vector, and two-dimensional matrix data.

## Parameters

The Negate block has no parameters to set.

## Not Equals

Perform element-wise not equal to relational operation on the inputs. The top input corresponds to the first operand.

## Library

Relational Operations



## Description

The Not Equals block has two input signals and one output signal. The block compares two inputs using element-wise not equals relational operation. The first input corresponds to the top input port and the second input to the bottom input port. The dimension of the output signal matches the dimensions of the input signals. An element of the output signal is true if the corresponding element of the first input signal is not equal to the corresponding element of the second signal; otherwise the element is false.

## Data Type Support

Data type support for the block is:

- The data types of the input signals can be of any integer, fixed-point, boolean, or floating-point data type.
- The input signals can be a scalars, vectors, or matrices. If both inputs are not scalar, their dimension must match.
- The input signals can be complex.
- The output signal is boolean.
- The dimension of the output signal is scalar if both inputs are scalar. Otherwise, it matches the dimensions of the non-scalar input.

## Parameters

The Not Equals block has no parameters to set.

## Polar to Complex

Element-wise conversion of real magnitude and angle representation signals into a complex signal

## Library

Math Functions / Math Operations



## Description

The Polar to Complex block accepts a real signal of floating point data type such as double, single, or half. The first and second inputs represent magnitude and angle respectively. The angle is in radians. The outputs are complex values of the same data type as the block input for a given real magnitude and angle. The input can be scalar, vector or matrix of real signals, in which case the output signals are also scalar, vector, or matrix. The elements of a certain magnitude input map to the magnitudes of the corresponding complex output elements. Similarly, the elements of a certain angle input map to the angles of the corresponding complex output elements.

## Data Type Support

Data types accepted at the inputs of the block are:

- Dimension : The inputs can be scalar, array, or combination of scalar and an array. If both the inputs are arrays, they must have the same dimensions.
- Data Types: Supports signal of floating point data type such as double, single, and half. Both inputs must have the same data type.
- Complex Number Support: No

Outputs for the different input types are:

Table 112: Input/Output

Inputs	Output
Both are scalar	Scalar
Both are vector	Vector of same dimension
Both are matrix	Matrix of same dimension
One is scalar and the other is vector or matrix	Dimension is that of the vector or matrix

## Parameters

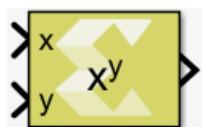
The Polar to Complex block has no parameters to set.

## Pow

Compute the element-wise power function

## Library

Math Functions / Math Operations



## Description

The Pow block computes the value of a base raised to the power exponent.  $Z = X^Y$  raises each element of  $X$  to the corresponding power in  $y$ . If one of inputs is a matrix and the other is a scalar, the scalar input is expanded to match the dimension of the non-scalar input to perform the operation. If both inputs are non-scalar, they must agree in dimension.

## Data Type Support

Data type support for the block is:

- Dimension: Inputs can be scalar, vector, or matrix. If one of the inputs is scalar and the other is a vector or matrix then the scalar input is expanded to match the other input dimension and the operation will be performed element-wise. If both inputs are non-scalar, then they must match in dimension.
- Data Types: Input supports signals of integer type, floating point data type (double, single, and half), and signed and unsigned fixed-point type. Both inputs must be of the same data type.
- Complex Numbers: Complex numbers are not supported.

A negative base value raised to a fractional power will result in a Not A Number (NAN) value.

## Parameters

The Pow block has no parameters to set.

# Product

Compute element-wise product of the input signals

## Library

Math Functions / Math Operations



## Description

The Product block computes the element-wise product of its input signals.

The block warns or errors out when an integer output overflows during simulation. To configure, select **Simulation** → **Model Configuration Parameters** → **Diagnostics** → **Data Validity** for your model in the Simulink® Editor, then set the **Wrap on overflow**, or **Saturate on overflow** parameter.

## Data Type Support

The Product block outputs the result of multiplying two inputs. Inputs can be two scalars, a scalar and a non-scalar, and two non-scalars of the same dimension. If one of the inputs is scalar and other input is vector/matrix then the scalar input is expanded to match the dimension of the other input to perform the operation. If input signals are both integer data types, such as int16, the datatype of the output is also an integer datatype int16. Hence an overflow of wrap around (no saturation) is likely if the output exceeds the range that is represented with int16. If the operation is to be applied without loss of precision or range, use fixed-point data types. If you want to narrow the bit width of the output signal, you can run it through a Data Type Conversion block and select a fixed-point data type that saturates.

The output dimension is the same as that of the inputs if both inputs are either scalar or non scalar. If one input is scalar and the other is a vector/matrix then the output dimension matches the dimension of the vector/matrix input. The output type is same as that of the inputs if both inputs are of the same type. Otherwise, the output type is defined as follows.

*Table 113: Input/Output*

Input Type	Output Type
(double, single)	double
(double, int)	double
(double, half)	double
(double, fixed)	double
(double, Boolean)	double
(single, int)	single
(single, half)	single
(single, fixed)	single
(single, Boolean)	single
(half, int)	half
(half, fixed)	half
(half, Boolean)	half
(fixed, int)	fixed
(fixed, Boolean)	fixed
(int, Boolean)	int

## Parameters

### Saturate on integer overflow

This parameter specifies whether integer overflow is handled by wrapping (default) or by saturating. This parameter is relevant only if the output is integral (int8, int16, int32, uint8, uint16, uint32).

Settings for the **Saturate on integer overflow** parameter are:

**Table 114: Saturate on Integer Overflow Parameter**

Setting	Description
Not selected	Integer overflow is handled by wrapping.
Selected	Integer overflow is handled by saturation.

When overflow is detected, the Diagnostic Viewer displays messages that depend on the diagnostic action you specify in the Simulink Editor. To configure, select **Simulation** → **Model Configuration Parameters** → **Diagnostics** → **Data Validity** for your model in the Simulink Editor, then set the **Wrap on overflow** or **Saturate on overflow** parameter.

## Product of Elements

Multiply the elements of the input signal

### Library

Math Functions / Math Operations



### Description

The Product of Elements block computes the product of the elements of the input signal. The block can be configured in the following ways.

- By default, the output is scalar and equal to the product of all (matrix) elements of the input signal.
- If the dimension to multiply over is specified to be **1**, the output is a row matrix ( $1 \times N$ ), where  $N$  is the number of columns of the input, and element  $(1,k)$  is the product of the elements of column  $k$  of the input.
- If the dimension to multiply over is specified to be **2**, the output is a column matrix ( $M \times 1$ ), where  $M$  is the number of rows of the input, and element  $(k,1)$  is the product of the elements of row  $k$  of the input.

### Data Type Support

The input signal can be real or complex. The input data type can be any Boolean, integer, floating-point, or fixed-point data type. The block can perform element-wise multiplication on real or complex number data.

## Parameter

### Multiply over

The **Multiply over** parameter value is used to decide whether elements will be multiplied in all dimensions or in one of the dimensions.

Following are the settings for the **Multiply over** parameter.

*Table 115: Multiply Over Parameter*

Setting	Description
All dimensions	Multiply all elements of the input signal (output is scalar)
Specified dimension	This option shows an edit box, <b>Dimension</b> , where the specific dimension value can be entered.

### Dimension

The **Dimension** parameter is displayed only if the **Multiply over** parameter value is set to **Specified dimension**.

Following are the settings for the **Dimension** parameter.

*Table 116: Dimension Parameter*

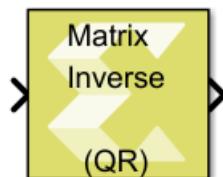
Setting	Description
1	Multiply input over row dimension. Output is a row matrix.
2	Multiply input over column dimension. Output is a column matrix.

## QR Inverse

Compute the inverse of a matrix using QR factorization

### Library

Math Functions / Matrices and Linear Algebra



### Description

The QR Inverse block provides the inverse of the input matrix A by performing QR factorization.

$$A^{-1} = Q^T R^{-1}$$

Q is an orthogonal matrix and R is an upper triangular square matrix. For singular matrix input the output would contain NaN or +inf/-inf.

## Data Type Support

Data type support is:

- Dimension: Input has to be a square matrix. Scalar and vector inputs are not supported.
- Data Types: Input supports signals of floating point data types (double, single, and half). It does not support integer, boolean, and fixed-point data types.
- Complex Numbers: Complex numbers are not supported.

The output has the same dimension and data type as the input.

## Parameters

The QR Inverse block has no parameters to set.

# Real-Imag to Complex

Computes the complex output from real and imaginary input.

## Library

Math Functions / Math Operations



## Description

The Real-Imag to Complex block converts the real and imaginary inputs to a complex-valued output signal. The input signal can be of any data type except boolean. The complex output has the same data type as that of the block input. The input can be a scalar, 1-D vector, or matrix of real signals. It is possible to specify the constant real or imaginary part from the block dialog.

## Data Type Support

Data type support for the input port is as follows.

- The block supports all data types except boolean. If the 'Input' is 'Real and Imag', both the inputs must have the same data type. Otherwise, 'Real part' or 'Imag part' parameter is converted to the same data type as that of the block input.

- Real and imaginary parts specified using inputs or block dialog must be real.
- The input can be a scalar, 1-D vector, or matrix.
- The output is always complex, and has the same data type as that of the input.
- Dimensions:
  - The output has the same dimensions as that of the input when both real and imaginary parts have the same dimensions.
  - The block supports mixed dimensions for real and imaginary inputs (specified as inputs or using block dialog). Any scalar input is expanded to the dimensions of non-scalar input, and the block has the same dimensions as those of the non-scalar input. If both the inputs are non-scalar, they must agree on dimensions.

## Parameters

- **Input:**

**Input** is a drop down menu parameter which specifies whether real, imaginary, or both of the parts of the output signal are specified as inputs.

- **Settings:**

Following are settings for the **Input** parameter.

**Table 117: Input Parameter**

Setting	Description
<b>Real and imag</b>	Real and imaginary parts of the output signal are specified using Re and Im inputs of the block, respectively.
<b>Real</b>	The block has only Re input in this case. Real part of the output signal is specified using the Re input of the block, while its imaginary part is specified using the Imag part parameter.
<b>Imag</b>	The block has only Im input in this case. Imaginary part of the output signal is specified using the Im input of the block, while its real part is specified using the Real part parameter.

- **Real part:** Specify the constant real part of the output signal when Input is set to Imag. This parameter is visible only when you set Input to Imag.

**Table 118: Real Part Parameter**

Choices	Description
0	The value of the Real part parameter must be a numeric, real-valued scalar, vector, or matrix.

- **Imag part:** Specify the constant imaginary part of the output signal when Input is set to Real. This parameter is visible only when you set Input to Real.

**Table 119: Imag Part Parameter**

Choices	Description
0	The value of the Imag part parameter must be a numeric, real-valued scalar, vector, or matrix.

## Reciprocal

Element-wise computation of the reciprocal for a given argument

### Library

Math Functions / Math Operations



### Description

The Reciprocal block returns the output of the function  $\text{inv}(x)$  for each element in array  $x$ . The block supports input of all data types except Boolean. The input can be scalar, vector or matrix.

### Data Type Support

Data types accepted at the inputs of the block:

- Dimension: Input can be scalar, vector, or matrix.
- Data Types: Input supports signals of integer, fixed-point, and floating-point data type. The block does not support Boolean inputs.
- Complex Number Support: No

The output has the same dimension and type as the input.

### Parameters

The Reciprocal block has no parameters to set.

## Reciprocal Sqrt

Element-wise computation of the reciprocal square root for a given argument

### Library

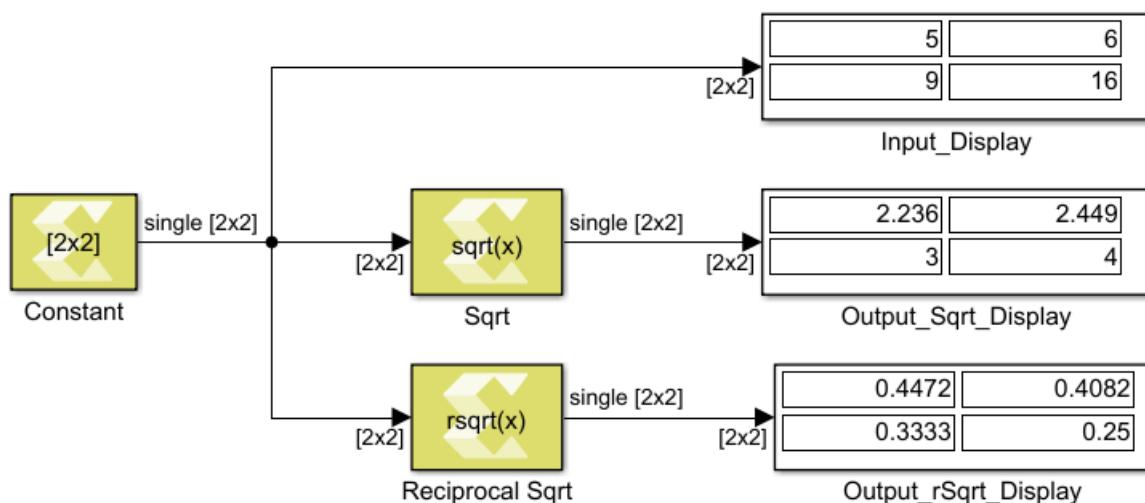
Math Functions / Math Operations



## Description

The Reciprocal Sqrt block returns the reciprocal square root for each element in an array. The block supports input of all data types except Boolean. The input can be a scalar, vector or a matrix.

Figure 359: Reciprocal Sqrt Block



## Data Type Support

Data type support is:

- Dimension: Input can be scalar, vector or matrix.
- Data Types: Input supports signals of integer, fixed-point, and floating point data type. It does not support Boolean inputs.
- Complex Numbers: Complex numbers are not supported.

The output has the same dimension and data type as the input.

## Parameters

The Reciprocal Square root block has no parameters to set.

## Reduction AND

Compute bitwise AND of the elements of the input over all dimensions or over a specified dimension

### Library

Logic and Bit Operations



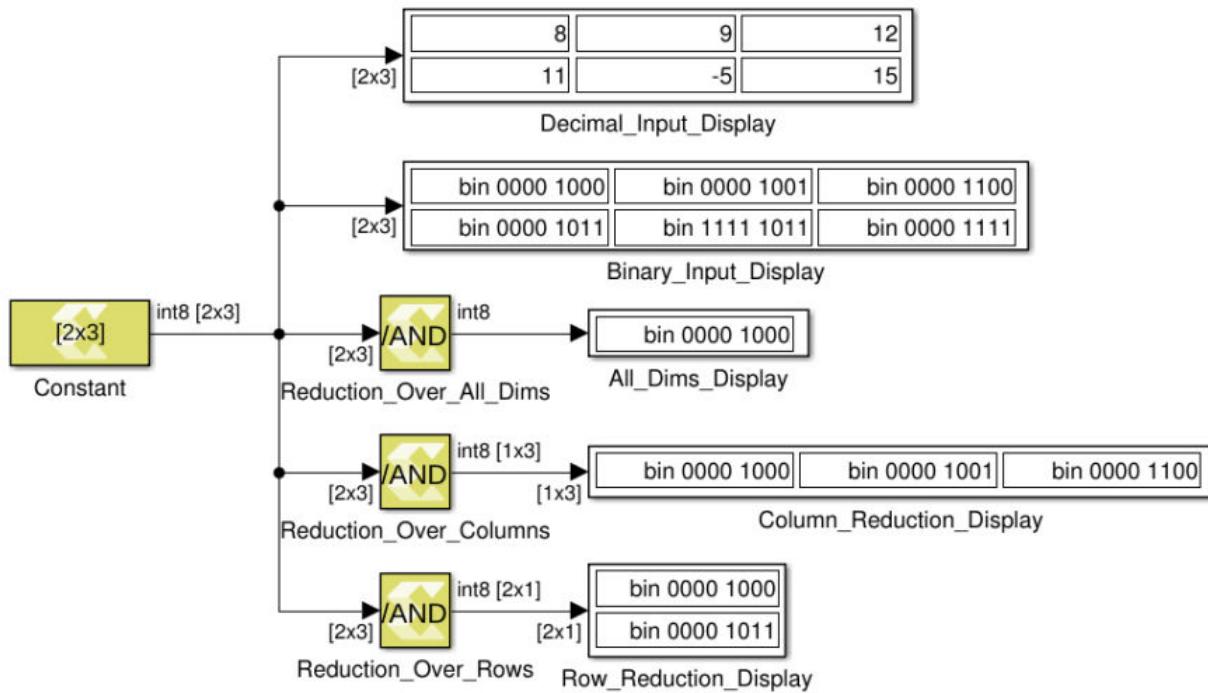
### Description

The Reduction AND block has one input signal and one output signal. It computes the bitwise AND of the elements of the input signal over all of the dimensions or over a specified dimension. The data type of the output signal is the same as that of the input signal. The dimension of the output signals depends on whether the reduction takes place over all dimensions or over a specified dimension.

- **Reduce over all dimensions:** The output is a scalar and it is the bitwise AND of the elements of the input signal.
- **Reduce over dimension 1:** The output is a row vector (2-D) with as many elements as the number of columns of the input. Each element in the output is the bitwise AND reduction of the elements of the corresponding column of the input.
- **Reduce over dimension 2:** The output is a column vector (2-D) containing as many elements as the number of rows of the input. Each element in the output is the bitwise AND reduction of the elements of the corresponding row of the input.

In the example below a 2x3 input signal of type int8 feeds into three different configurations of the Reduction AND block.

Figure 360: Reduction AND Block



## Data Type Support

- The input signal can be of any data type except for floating point types.
- The input signal must be real.
- The input signal must be a matrix if reduction is along dimension 2.
- The input signal can be a matrix, vector or scalar if reduction is along all dimensions or along dimension 1.

## Parameters

### Reduce over

This parameter specifies whether reduction takes place over all dimensions or over a specified dimension. If reduction is specified over all dimensions, the output signal is a scalar.

Following are the settings for the **Reduce over** parameter.

Setting	Description
All dimensions	The Reduce AND operator will be applied to all elements, producing a scalar output.

Setting	Description
<b>Specified dimension</b>	The Reduce AND operator will be applied along the specified dimension, producing a vector output along the opposite dimension. When <b>Dimension 1</b> is specified, the Reduction AND is applied along columns, producing a row vector as output. When <b>Dimension 2</b> is specified, the Reduction AND is applied along rows, producing a column vector as output.

**Note:** The dimension specified will be the one that gets reduced to size 1. For example, a 2-D M x N input matrix specifying **Dimension 1** (number of rows M) will result in a 1 x N row vector.

### Dimension

If the **Reduce over** parameter is set to **Specified dimension**, the **Dimension** parameter specifies over which dimension reduction takes place.

- If the input signal has dimensions M x N and the reduction **Dimension** is 1, the output has dimensions 1 x N.
- If the input signal has dimensions M x N and the reduction **Dimension** is 2, the output has dimensions M x 1.
- If the input signal is scalar or 1 x 1, the output dimension is 1 x 1.

Following are the settings for the **Dimension** parameter.

*Table 120: Dimension Parameter*

Setting	Description
1	Reduce over row dimension.
2	Reduce over column dimension.

**Note:** If the reduce **Dimension** is specified to be 2 the input signal must be two-dimensional.

## Reduction OR

Compute bitwise OR of the elements of the input over all dimensions or over a specified dimension

### Library

Logic and Bit Operations



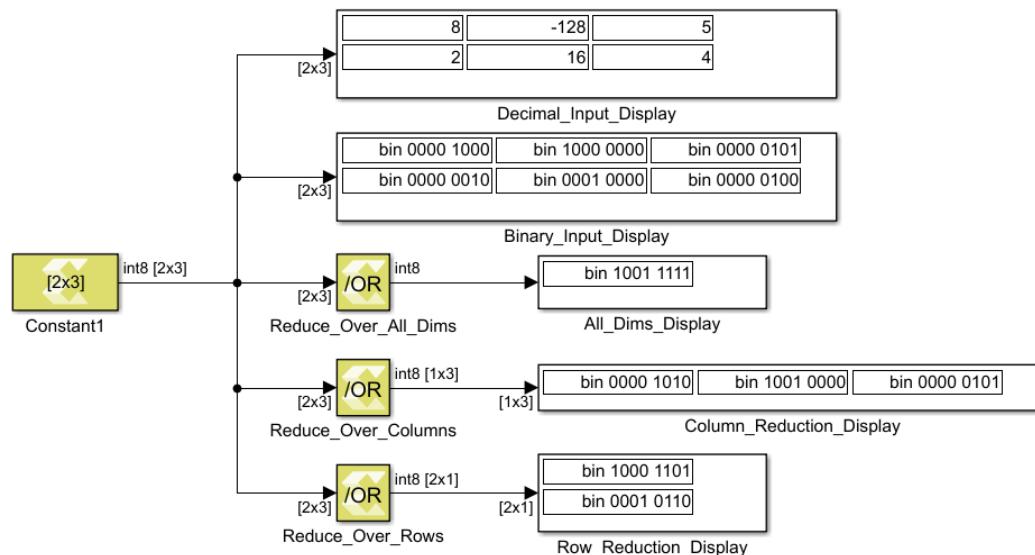
## Description

The Reduction OR block has one input signal and one output signal. It computes the bitwise OR of the elements of the input signal over all of the dimensions or over a specified dimension. The data type of the output signal is the same as that of the input signal. The dimension of the output signals depends on whether the reduction takes place over all dimensions or over a specified dimension.

- **Reduce over all dimensions:** The output is a scalar and it is the bitwise OR of all of the elements of the input signal.
- **Reduce over dimension 1:** The output is a row vector (2-D) with as many elements as the number of columns of the input. Each element in the output is the bitwise OR reduction of the elements of the corresponding column of the input.
- **Reduce over dimension 2:** The output is a column vector (2-D) containing as many elements as the number of rows of the input. Each element in the output is the bitwise OR reduction of the elements of the corresponding row of the input.

In the example below a 2x3 input signal of type int8 feeds into three different configurations of the Reduction OR block.

**Figure 361: Reduction OR Block**



## Data Type Support

- The input signal can be of any data type except for floating point types.
- The input signal must be real.
- The input signal must be a matrix if reduction is along dimension 2.

- The input signal can be a matrix, vector, or scalar if reduction is along all dimensions or along dimension 1.

## Parameters

### Reduce over

This parameter specifies whether reduction takes place over all dimensions or over a specified dimension. If reduction is specified over all dimensions, the output signal is a scalar.

Following are settings for the **Reduce over** parameter.

*Table 121: Reduce Over Parameter*

Setting	Description
All dimensions	Reduction takes place over all dimensions.
Specified dimension	Reduction takes place over the dimension specified by the <b>Dimension</b> parameter.

### Dimension

If the **Reduce over** parameter is set to **Specified dimension**, the **Dimension** parameter specifies over which dimension reduction takes place.

- If the input signal has dimensions M x N and the reduction **Dimension** is 1, the output has dimensions 1 x N.
- If the input signal has dimensions M x N and the reduction **Dimension** is 2, the output has dimensions M x 1.
- If the input signal is scalar or 1 x 1, the output dimension is 1 x 1.

Following are settings for the **Dimension** parameter.

*Table 122: Dimension Parameter*

Setting	Description
1	Reduce over row dimension.
2	Reduce over column dimension.

**Note:** If the reduce **Dimension** is specified to be 2 the input signal must be two-dimensional.

## Reduction XOR

Compute bitwise XOR of the elements of the input over all dimensions or over a specified dimension

## Library

Logic and Bit Operations



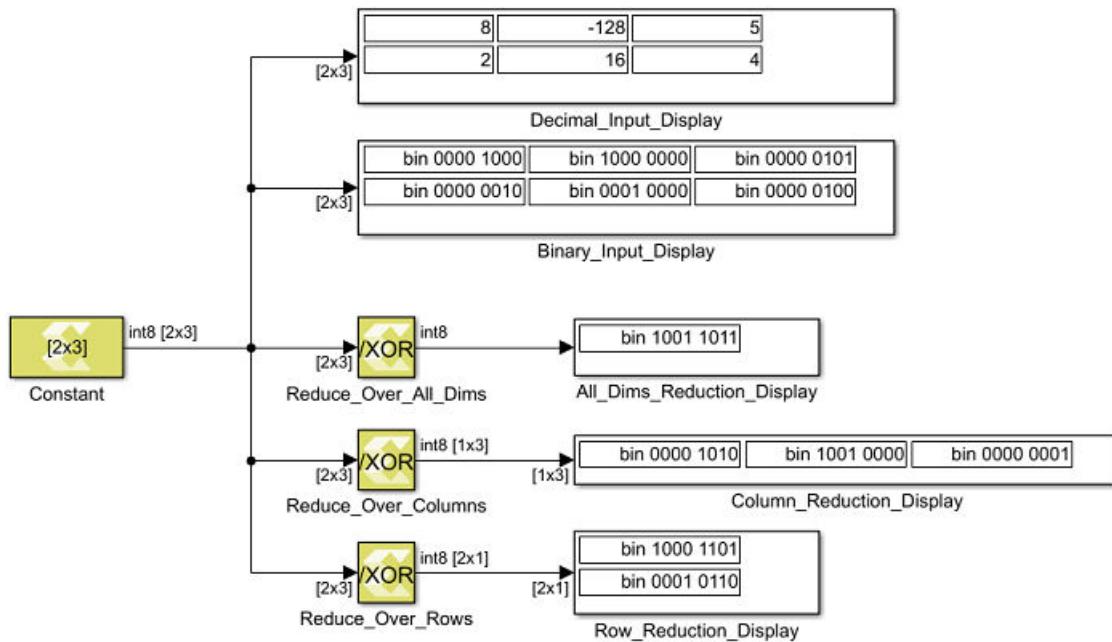
## Description

The Reduction XOR block has one input signal and one output signal. It computes the bitwise exclusive OR (XOR) of the elements of the input signal over all of the dimensions or over a specified dimension. The data type of the output signal is the same as that of the input signal. The dimension of the output signals depends on whether the reduction takes place over all dimensions or over a specified dimension.

- **Reduce over all dimensions:** The output is a scalar and it is the bitwise XOR of all of the elements of the input signal.
- **Reduce over dimension 1:** The output is a row vector (2-D) with as many elements as the number of columns of the input. Each element in the output is the bitwise XOR reduction of the elements of the corresponding column of the input.
- **Reduce over dimension 2:** The output is a column vector (2-D) containing as many elements as the number of rows of the input. Each element in the output is the bitwise XOR reduction of the elements of the corresponding row of the input.

In the example below a 2x3 input signal of type int8 feeds into three different configurations of the Reduction XOR block.

Figure 362: Reduction XOR Block



## Data Type Support

- The input signal can be of any data type except for floating point types.
- The input signal must be real.
- The input signal must be a matrix if reduction is along dimension 2.
- The input signal can be a matrix, vector or scalar if reduction is along all dimensions or along dimension 1.

## Parameters

### Reduce over

This parameter specifies whether reduction takes place over all dimensions or over a specified dimension. If reduction is specified over all dimensions, the output signal is a scalar.

Settings for the **Reduce over** parameter are:

Table 123: Reduce Over Parameter

Setting	Description
All dimensions	Reduction takes place over all dimensions.
Specified dimension	Reduction takes place over the dimension specified by the <b>Dimension</b> parameter.

### Dimension

If the **Reduce over** parameter is set to **Specified dimension**, the **Dimension** parameter specifies over which dimension reduction takes place.

- If the input signal has dimensions M x N and the reduction **Dimension** is 1, the output has dimensions 1 x N.
- If the input signal has dimensions M x N and the reduction **Dimension** is 2, the output has dimensions M x 1.
- If the input signal is scalar or 1 x 1, the output dimension is 1 x 1.

Settings for the **Dimension** parameter are:

*Table 124: Dimension Parameter*

Setting	Description
1	Reduce over row dimension.
2	Reduce over column dimension.

**Note:** If the reduce **Dimension** is specified to be 2 the input signal must be two-dimensional.

## Reinterpret

Element-wise reinterpretation of the input type into a compatible output type with the same bit width.

### Library

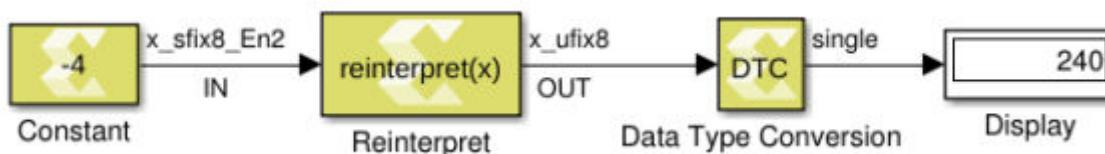
Signal Attributes



### Description

The Reinterpret block provides a mechanism for interpreting a value from a different data type. You can specify the output data type with the restriction that the bit widths of input and output data types must match.

*Figure 363: Reinterpret Block*



In the above example, the input is of fixed-point signed number (`x_sf8_En2`) represented with 8 bits, in which 2 bits are used for the fractional part (i.e., -4 = 1111 00.00). The Reinterpret block interprets the input type to unsigned fixed-point number (`x_uf8`), represented with 8 bits as that of input, and no bits are used for the fractional part. The output becomes 240 (1111 0000).

## Data Type Support

The data types of the input can be any integer, Boolean, fixed-point, or floating-point data type. The input can be any real or complex valued signal. If the input is real, the output is real. If the input is complex, the output is complex. The block supports scalar, vector, or matrix data.

Following are the supported output data types.

*Table 125: Input/Output*

Input Data Type	Supported Output Data Type
<code>double</code>	<code>double</code> , 64 bit fixed-point data
<code>single</code>	<code>single</code> , <code>int32</code> , <code>uint32</code> , 32 bit fixed-point data
<code>int8</code>	<code>int8</code> , <code>uint8</code> , 8 bit fixed-point data
<code>uint8</code>	<code>uint8</code> , <code>int8</code> , 8 bit fixed-point data
<code>int16</code>	<code>int16</code> , <code>uint16</code> , <code>half</code> , 16 bit fixed-point data
<code>int16</code>	<code>uint16</code> , <code>int16</code> , <code>half</code> , 16 bit fixed-point data
<code>uint16</code>	<code>int32</code> , <code>uint32</code> , <code>single</code> , 32 bit fixed-point data
<code>int32</code>	<code>int32</code> , <code>uint32</code> , <code>single</code> , 32 bit fixed-point data
<code>uint32</code>	<code>uint32</code> , <code>int32</code> , <code>single</code> , 32 bit fixed-point data
<code>bool</code>	<code>bool</code> , 1 bit fixed-point data
<code>fixed</code>	Same bit width fixed-point data with different fractional widths, all native data types if the bit width matches
<code>half</code>	<code>half</code> , <code>int16</code> , <code>uint16</code> , 16 bit fixed-point data type

## Parameters

### Output data type

This parameter specifies the output data type for reinterpreting the input data. If **fixed** is specified more parameters are available.

Following are the settings for the **Output data type** parameter.

*Table 126: Output Data Type Parameter*

Setting	Description
<code>double</code>	Double precision floating point
<code>single</code>	Single precision floating point
<code>int8</code>	8-bit signed integer

**Table 126: Output Data Type Parameter (cont'd)**

Setting	Description
<code>uint8</code>	8-bit unsigned integer
<code>int16</code>	16-bit signed integer
<code>uint16</code>	16-bit unsigned integer
<code>int32</code>	32-bit signed integer
<code>uint32</code>	32-bit unsigned integer
<code>boolean</code>	Boolean
<code>fixed</code>	Fixed-point
<code>half</code>	Half precision floating-point
<code>data type expression</code>	A string that specifies the output data type. See Working with Data Type Expression in the <i>Vitis Model Composer User Guide</i> ( <a href="#">UG1483</a> ).

## Remainder

Perform element-wise division on the input signal. The output is the remainder after the division.

### Library

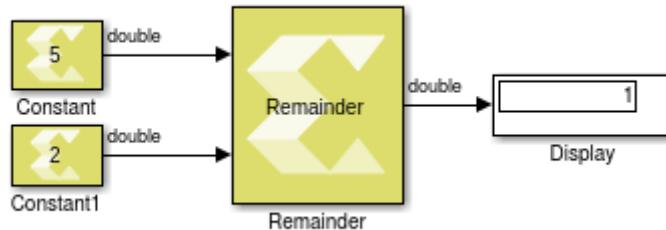
Math Functions / Math Operations



### Description

The remainder block takes two inputs. The dividend is the top input and the divisor is the bottom input. The block supports scalar, vector and matrix dimensions. The dimensions of the inputs must match unless one input is a scalar. The output has the larger dimension of the two inputs. The block can handle division by 0 and produces NaN as the output only for floating-point data types double and single.

Figure 364: Remainder Block



### Data Type Support

The Remainder block supports all MATLAB native data types, half precision floating-point data type, and fixed-point. The block operates on real type inputs where it requires both inputs to have the same type of data.

### Parameters

The Remainder block has no parameters to set.

## Reshape Row-Major

Changes the input dimensions in row-major order.

### Library

Math Functions/Math Operations



### Description

The Reshape Row-Major block changes the input dimensions based on the specified Output dimensionality parameter. The output contains elements of the input in row-major order, that is the first row of the input matrix followed by the second row, and so on.

### Data Type Support

- The block supports floating point, integer, boolean, and fixed-point data types.
- The block supports real and complex valued inputs.

- The input can be a scalar, 1-D vector, or matrix.
- The output has the same data type as the input.

## Parameters

- **Output dimensionality:**

This parameter specifies how the input should be reshaped. The settings for **Output dimensionality** are as follows:

*Table 127: Output Dimensionality Parameter Settings*

Choices	Description
<b>1-D array</b>	Converts the input to a 1-D vector. For a matrix input, the output consists of input matrix elements in row-major order.
<b>Column vector</b>	Converts the input to a M x 1 matrix, where M is the number of elements in the input signal. For a matrix input, the output consists of input matrix elements in row-major order.
<b>Row vector</b>	Converts the input to a 1 x N matrix, where N is the number of elements in the input signal. For a matrix input, the output consists of input matrix elements in row-major order.
<b>Custom</b>	Converts the input to an output which has dimensions specified by the user using the <b>Output dimensions</b> parameter. The conversion is done in row-major order. The value of the <b>Output dimensions</b> parameter must be a two-element vector. For example, a value of [M N] outputs an M x N matrix. The number of elements of the input must match the number of elements specified by the <b>Output dimensions</b> parameter.
<b>Derive from reference input port</b>	Creates a second input port on the block and derives the dimensions of the output from the dimensions of the second input port. Selecting this option disables the <b>Output dimensions</b> parameter. Both the inputs to the block must have the same number of elements.

- **Output dimensions:**

Specify Output dimensions when **Output dimensionality** is set to **Custom**. The settings for **Output dimensions** are as follows:

*Table 128: Output Dimensions Parameter Settings*

Choices	Description
[1, 1]	The value of the <b>Output dimensions</b> parameter must be a two-element vector.

## Shift Left

Perform logical shift left of input over a constant number of bit positions specified by a non-negative integer parameter

### Library

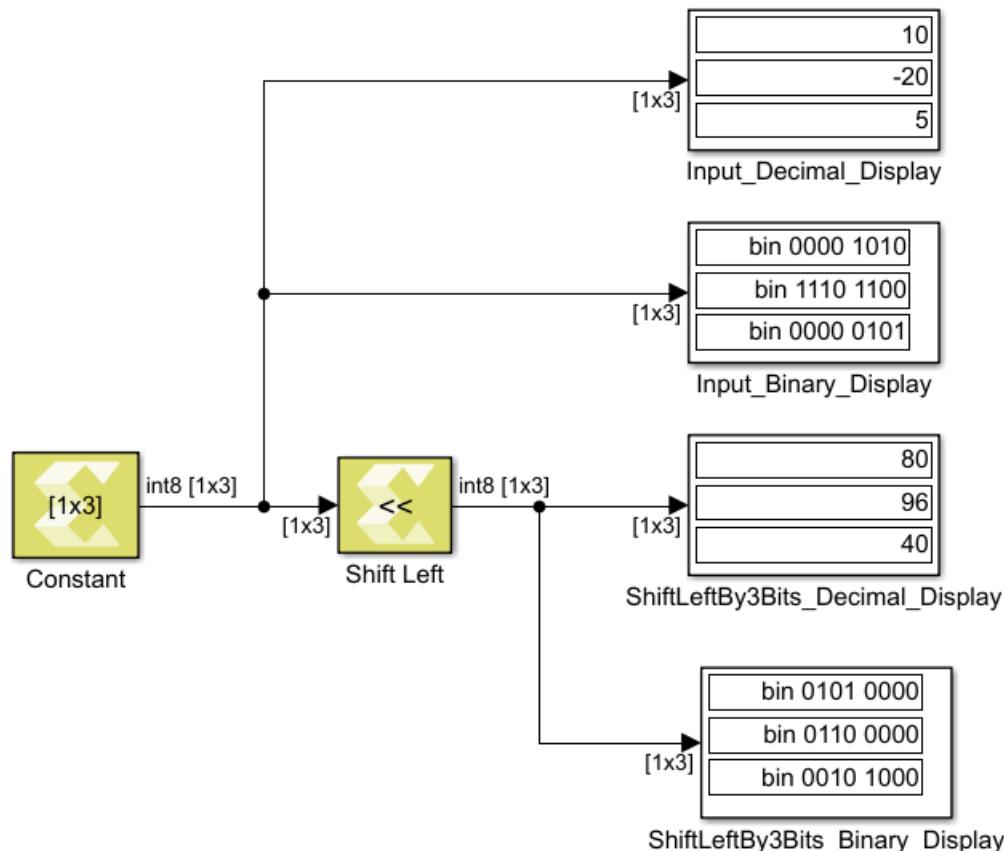
Logic and Bit Operations



## Description

The shift left block computes element-wise left shift of the input by a constant amount specified via a parameter. This is also known as a logical shift left. The shift amount specifies over how many bit positions bits are shifted. This shift amount must be a non-negative integer. The default value is 0. The output is of the same type, dimension, and numeric type (real or complex) as the input. The input type must be integral or fixed-point.

*Figure 365: Shift Left Block*



## Data Type Support

- Input: integer, fixed-point, but not logical or floating point.
- Output: output data type is the same as input data type.

## Parameters

### Shift by

This parameter specifies the number of bit positions over which the shift takes place.

Enter a scalar real non-negative integer for the **Shift by** parameter.

## Shift Right

Performs arithmetic shift right of input over a constant number of bit positions specified by a non-negative integer parameter

### Library

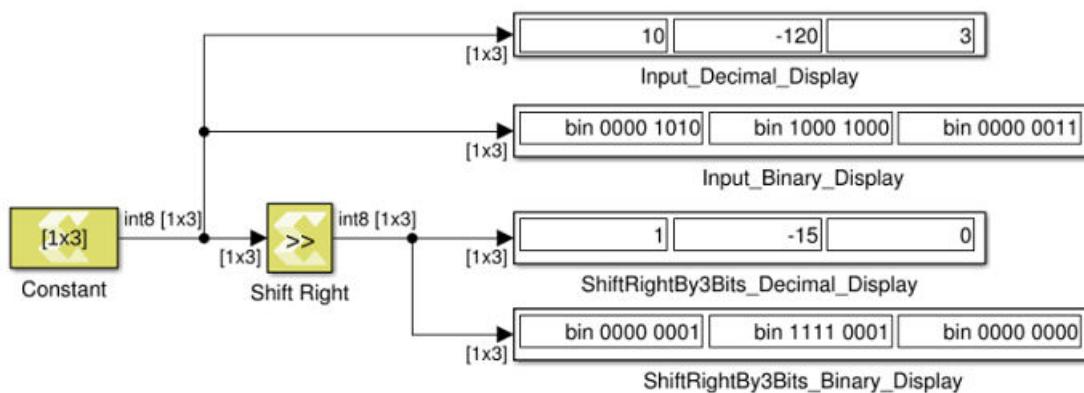
Logic and Bit Operations



### Description

The shift right block computes an element-wise right shift of the input by a constant amount specified via a **Shift by** parameter. This is also known as arithmetic shift right. The shift amount specifies over how many bit positions bits are shifted. This shift amount must be a non-negative integer. The default value is 0. The output is of the same type, dimension, and numeric type (real or complex) as the input. The input data must be integer or fixed-point type.

Figure 366: Shift Right Block



### Data Type Support

The Shift Right block supports integer and fixed-point input data, but not Boolean or floating type. Input data can be real or complex. Output data type and dimension are the same as that of input data.

## Parameters

### Shift by

This parameter specifies the number of bit positions over which the shift takes place.

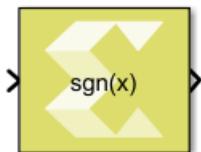
Enter a scalar real non-negative integer for the **Shift by** parameter.

## Signum

Performs signum function (sign extraction) on the input.

### Library

Math Functions/Math Operations



### Description

The Signum block returns the sign for each element of the real input. The block returns 1, 0, or -1 if the number is positive, equal to 0, or negative, respectively.

When the input  $s$  is complex, the block output is calculated as:

```
sign(s) = s ./ abs(s)
```

Where `sign` is the MATLAB® signum function, and `.` indicates element-wise division.

### Data Type Support

The Signum block supports signals of integer type, floating-point type (double, single and half), and fixed-point type for real inputs. The complex inputs are supported only for floating point data types.

The output data type, and dimension are the same as those of the input.

## Parameters

The Signum block has no parameters to set.

## Sine

Element-wise computation of the sine function for the given input

### Library

Math Functions / Math Operations



### Description

The Sine block returns the output of the function  $\sin(x)$  for each element in array  $x$ .

### Data Type Support

Data type support is:

- Dimension: Input can be scalar, vector or matrix.
- Data Types: Input supports signals of floating point data types (double, single, and half) and signed fixed-point type. It does not support integer, Boolean, and unsigned fixed-point data types.
- Complex Numbers: Complex numbers are not supported.

The output has the same dimension and data type as the input. However, If the data type of the input is a fixed-point type, the data type of the output is fixed-point type with integer width fixed as 2.

### Parameters

The Sine block has no parameters to set.

## sinh

Element-wise computation of the hyperbolic sine for a given argument

### Library

Math Functions / Math Operations



## Description

The sinh block returns the output of the function  $\sinh(x)$ , which is the hyperbolic sine, for each element in array  $x$ .

The hyperbolic sine of  $x$  is:

$$\sinh(x) = \frac{e^x - e^{-x}}{2}$$

## Data Type Support

Data type support is:

- Dimension: Input can be scalar, vector or matrix.
- Data Types: Input supports signals of integer type, floating-point data types (double, single, and half) and fixed-point type.
- Complex Numbers: Complex numbers are not supported.

The output has the same dimension and data type as the input.

## Parameters

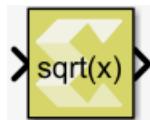
The sinh block has no parameters to set.

## Sqrt

Element-wise computation of the square root for a given argument

### Library

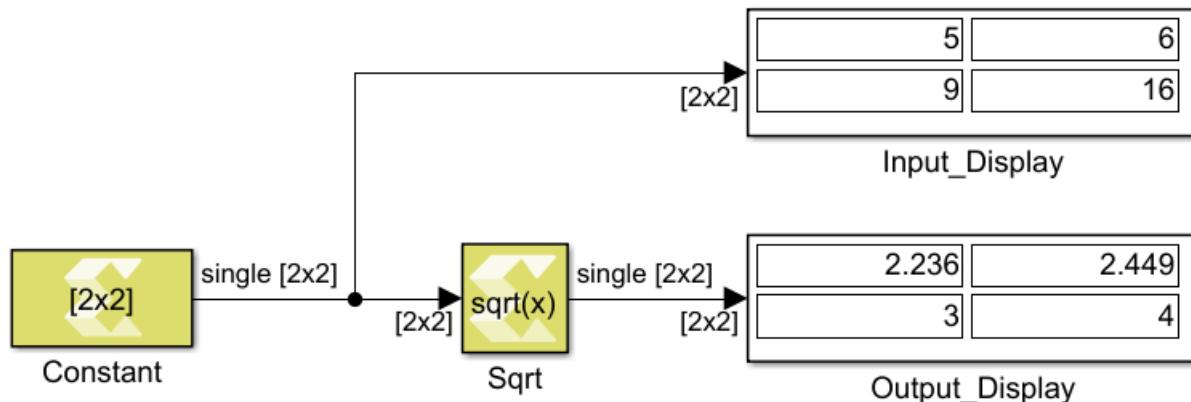
Math Functions / Math Operations



## Description

The Sqrt block returns the square root for each element in array  $x$ . The block supports input of all data types except boolean. The input can be a scalar, vector or a matrix.

Figure 367: Sqrt Block



## Data Type Support

Data type support is:

- Dimension: Input can be scalar, vector or matrix.
- Data Types: Input supports signals of integer, fixed-point and floating-point data type. It does not support Boolean inputs.
- Complex Numbers: Complex numbers are not supported.

The output has the same dimension and data type as the input.

## Parameters

The Sqrt block has no parameters to set.

## Submatrix

Select a subset of elements (submatrix) from matrix input

### Library

Math Functions / Matrices and Linear Algebra



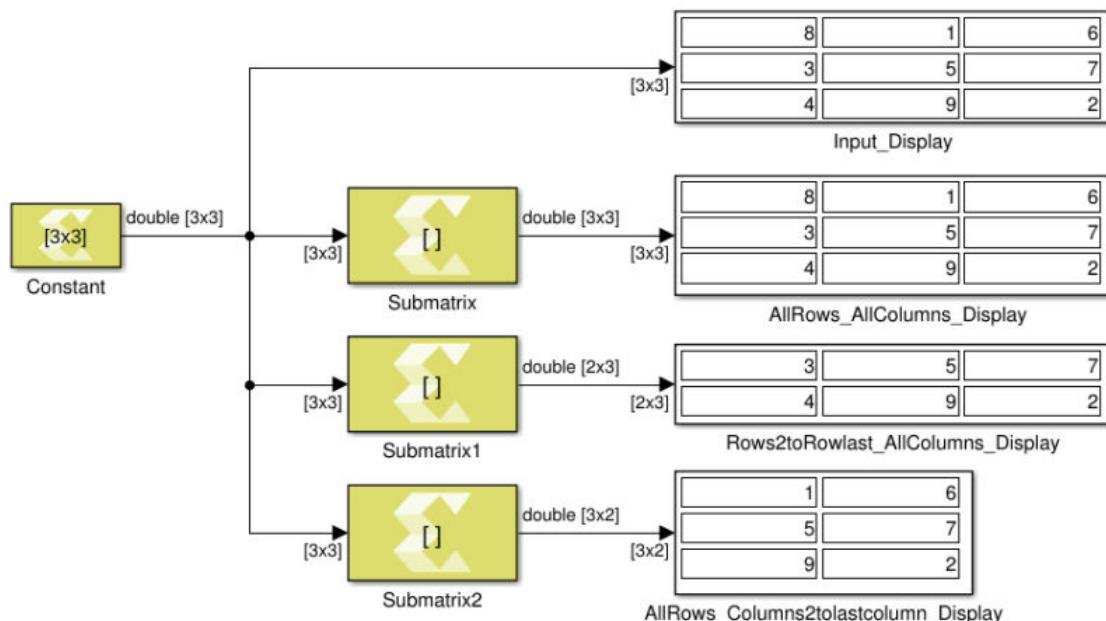
### Description

The Submatrix block extracts a contiguous submatrix from the M-by-N input matrix  $u$ . The **Row span** parameter provides three options for specifying the range of rows in  $u$  to be retained in submatrix output  $y$ :

- **All rows:** Specifies that  $y$  contains all  $M$  rows of  $u$ .
- **One row:** Specifies that  $y$  contains only one row from  $u$ . The **Row** parameter (described below) is enabled to allow selection of the desired row.
- **Range of rows:** Specifies that  $y$  contains one or more rows from  $u$ . The **Starting row** and **Ending row parameters** are enabled to allow selection of the desired range of rows.

The Column span parameter contains a corresponding set of three options for specifying the range of columns in  $u$  to be retained in the submatrix  $y$ : **All columns**, **One column**, or **Range of columns**. The **One column** option enables the **Column** parameter, and Range of columns options enable the **Starting column** and **Ending column** parameters.

*Figure 368: Submatrix Block*



## Data Type Support

All data types are supported. The output type is the same as the input type.

## Parameters

- **Row span:** The range of input rows to be retained in the output. Options are **All rows**, **One row**, or **Range of rows**.
- **Row:** The input row to be used as the row of the output. **Row** is enabled when you select **One row** for **Row span**.
- **Row index:** The index of the input row to be used as the first row of the output. **Row index** is enabled when you select **Index** for **Row**.

- **Row offset:** The offset of the input row to be used as the first row of the output. **Row offset** is enabled when you select **Offset from middle** or **Offset from last** for **Row**.
- **Starting row:** The input row to be used as the first row of the output. **Starting row** is enabled when you select **Range of rows** for **Row span**.
- **Starting row index:** The index of the input row to be used as the first row of the output. **Starting row index** is enabled when you select **Index** for **Starting row**.
- **Starting row offset:** The offset of the input row to be used as the first row of the output. **Starting row offset** is enabled when you select **Offset from middle** or **Offset from last** for **Starting row**.
- **Ending row:** The input row to be used as the last row of the output. **Ending row** is enabled when you select **Range of rows** for **Row span** and you select any option but **Last** for **Starting row**.
- **Ending row index:** The index of the input row to be used as the last row of the output. **Ending row index** is enabled when you select **Index** for **Ending row**.
- **Ending row offset:** The offset of the input row to be used as the last row of the output. **Ending row offset** is enabled when you select **Offset from middle** or **Offset from last** for **Ending row**.
- **Column span:** The range of input columns to be retained in the output. Options are **All columns**, **One column**, or **Range of columns**.
- **Column:** The input column to be used as the column of the output. **Column** is enabled when you select **One column** for **Column span**.
- **Column index:** The index of the input column to be used as the first column of the output. **Column index** is enabled when you select **Index** for **Column**.
- **Column offset:** The offset of the input column to be used as the first column of the output. **Column offset** is enabled when you select **Offset from middle** or **Offset from last** for **Column**.
- **Starting column:** The input column to be used as the first column of the output. **Starting column** is enabled when you select **Range of columns** for **Column span**.
- **Starting column index:** The index of the input column to be used as the first column of the output. **Starting column index** is enabled when you select **Index** for **Starting column**.
- **Starting column offset:** The offset of the input column to be used as the first column of the output. **Starting column offset** is enabled when you select **Offset from middle** or **Offset from last** for **Starting column**.
- **Ending column:** The input column to be used as the last column of the output. **Ending column** is enabled when you select **Range of columns** for **Column span** and you select any option but **Last** for **Starting column**.
- **Ending column index:** The index of the input column to be used as the last column of the output. **Ending column index** is enabled when you select **Index** for **Ending column**.

- **Ending column offset:** The offset of the input column to be used as the last column of the output. **Ending column offset** is enabled when you select **Offset from middle** or **Offset from last** for **Ending column**.

## Subtract

Perform element-wise subtraction

### Library

Math Functions / Math Operations



### Description

The Subtract block performs element-wise subtraction of two input signals.

The block warns or errors out when an integer output overflows during simulation. To configure, select **Simulation** → **Model Configuration Parameters** → **Diagnostics** → **Data Validity** for your model in the Simulink Editor, then set the **Wrap on overflow** or **Saturate on overflow** parameter.

### Data Type Support

The Subtract block supports any floating point, fixed-point, integer or Boolean data type. The block can perform element-wise subtraction on real and complex inputs. The input signals can be scalars, vectors or matrices. When both inputs have non-scalar dimensions, the dimensions must match each other.

### Parameters

#### Saturate on integer overflow

This parameter specifies whether integer overflow is handled by wrapping (default) or by saturating. This parameter is relevant only if the output is integral (int8, int16, int32, uint8, uint16, uint32).

Settings for the **Saturate on integer overflow** parameter are:

Table 129: Saturate On Integer Overflow Parameter

Setting	Description
Not selected	Integer overflow is handled by wrapping.
Selected	Integer overflow is handled by saturation.

When overflow is detected, the Diagnostic Viewer displays messages that depend on the diagnostic action you specify in the Simulink Editor. To configure, select **Simulation → Model Configuration Parameters → Diagnostics → Data Validity** for your model in the Simulink Editor, then set the **Wrap on overflow** or **Saturate on overflow** parameter.

## Sum

Perform element-wise addition of two input signals

### Library

Math Functions / Math Operations



### Description

The Sum block performs element-wise addition of two input signals.

The block warns or errors out when an integer output overflows during simulation. To configure, select **Simulation → Model Configuration Parameters → Diagnostics → Data Validity** for your model in the Simulink Editor, then set the **Wrap on overflow** or **Saturate on overflow** parameter.

### Data Type Support

Data types accepted at the inputs of the block are as follows.

- This block supports all data types supported by Vitis Model Composer. The block supports real and complex numbers.
- The input signals can be real or complex numbers of scalar, vector or matrix type. When both inputs are non-scalar then their dimensions must match.

Output data types are as follows.

- If the data type of one input is a floating point type, the data type of the output is the floating point type among the data types of the inputs with the most precision.
- Otherwise, if the data type of one input is a fixed-point type, the data type of the output is the smallest fixed-point type capable of representing the result without any loss of precision.
- Otherwise, if the data type of both inputs is Boolean the output is Boolean as well.
- Finally, if one input is integral and the other is also integral or Boolean, the output is integral. If both inputs are unsigned the output is unsigned, otherwise it is signed. The bit width of the output is largest among the bit widths of the inputs.

## Parameters

### Saturate on integer overflow

This parameter specifies whether integer overflow is handled by wrapping (default) or by saturating. This parameter is relevant only if the output is integral (int8, int16, int32, uint8, uint16, uint32).

Settings for the **Saturate on integer overflow** parameter are:

**Table 130: Saturate On Integer Overflow Parameter**

Setting	Description
Not selected	Integer overflow is handled by wrapping.
Selected	Integer overflow is handled by saturation.

When overflow is detected, the Diagnostic Viewer displays messages that depend on the diagnostic action you specify in the Simulink Editor. To configure, select **Simulation → Model Configuration Parameters → Diagnostics → Data Validity** for your model in the Simulink Editor, then set the **Wrap on overflow** or **Saturate on overflow** parameter.

## Sum of Elements

Perform element-wise addition on the input, column-wise, row-wise, or in all dimensions

### Library

Math Functions / Math Operations



### Description

This block performs element-wise addition on a vector or matrix type input. If input is a scalar then this block operates as a pass-through. The output is a scalar type if input is a vector or a matrix and the **Sum over** parameter is set as **All dimensions**.

### Data Type Support

Data type support for the block is:

- The Sum of Elements block supports any floating-point, fixed-point, integer or Boolean data type.

- The output type is a scalar or a vector depending on the dimensions of the input and the selection of the **Sum over** parameter.
- The block can perform element-wise addition on real or complex number data.

## Parameters

### Sum over

The **Sum over** parameter value is used to decide whether elements will be added in all dimensions or in one of the dimensions.

Following are settings for the **Sum over** parameter.

*Table 131: Sum Over Parameter*

Setting	Description
All dimensions	Add all elements of the input signal (output is scalar)
Specified dimension	This option shows an edit box, <b>Dimension</b> , where the specific dimension value can be entered.

### Dimension

The **Dimension** parameter is displayed only if the **Sum over** parameter value is set to **Specified dimension**.

Settings for the **Dimension** parameter are:

Setting	Description
1	Add input over row dimension. Output is a row matrix.
2	Add input over column dimension. Output is a column matrix.

## Tangent

Perform an element-wise computation of the tangent function for the given argument

### Library

Math Functions / Math Operations



### Description

The block returns the output of the function  $\tan(x)$  for each element in array  $x$ .

## Data Type Support

Data types accepted at the input of the block are:

- Dimension : Input can be scalar, vector or matrix.
- Data Types: Input supports signals of integer type, floating point type (double, single and half) and fixed-point type.
- Complex Number Support: No

Output has the same dimension and type as the input.

## Parameters

The Tangent block has no parameters to set.

## Transpose

Perform an element-wise transpose operation on the input signal

### Library

Math Functions / Matrices and Linear Algebra



### Description

The Transpose block performs a transpose operation on the input signal.

## Data Type Support

This block supports all data types supported by Vitis Model Composer. The input signal can be real or a complex number of scalar, vector, or matrix type. The output type is always the same as that of the input.

## Parameters

The Transpose block has no parameters to set.

## Unit Delay

Provides a delay of one sample period

## Library

Signal Operations



## Description

The Unit Delay block provides a delay of one sample period. The output has the same sample time as the input. The output dimension is the same as the initial condition dimension if the input is scalar. Otherwise, the output dimension is the same as the input dimension and should match the dimension of the initial condition.

## Data Type Support

Data type support is:

- All data types are supported.
- Input can be a vector or a matrix. If input is a vector or a matrix and the initial value is a scalar, the scalar value will apply to all the elements of the input during the first cycle.
- Output is complex if the input is complex.
- If the initial value is complex but the input signal is type real, the block gives an error indicating that the input type must be complex.

## Parameters

### Initial Condition

Specifies the initial value.

The **Initial Condition** can be scalar, vector, or matrix, of real or complex type.

## Vitis Model Composer Hub

Control implementation of the model.

## Description

The Vitis Model Composer Hub block controls the behavior of the Vitis Model Composer tool.

You can specify the targeted design flow for the generated output, the directory path for the output, and the desired device and design clock frequency using the following tabs.

- The **Hardware Selection** pane helps with device or board selection.

- The **Code Generation** pane provides options to select the output flow by selecting subsystems and specifying Code directory. Different options will be displayed depending on if the subsystem is targeting HDL, HLS, or AIE.

## Library

AI Engine/Tools; HLS/Tools; Utilities/Code Generation.



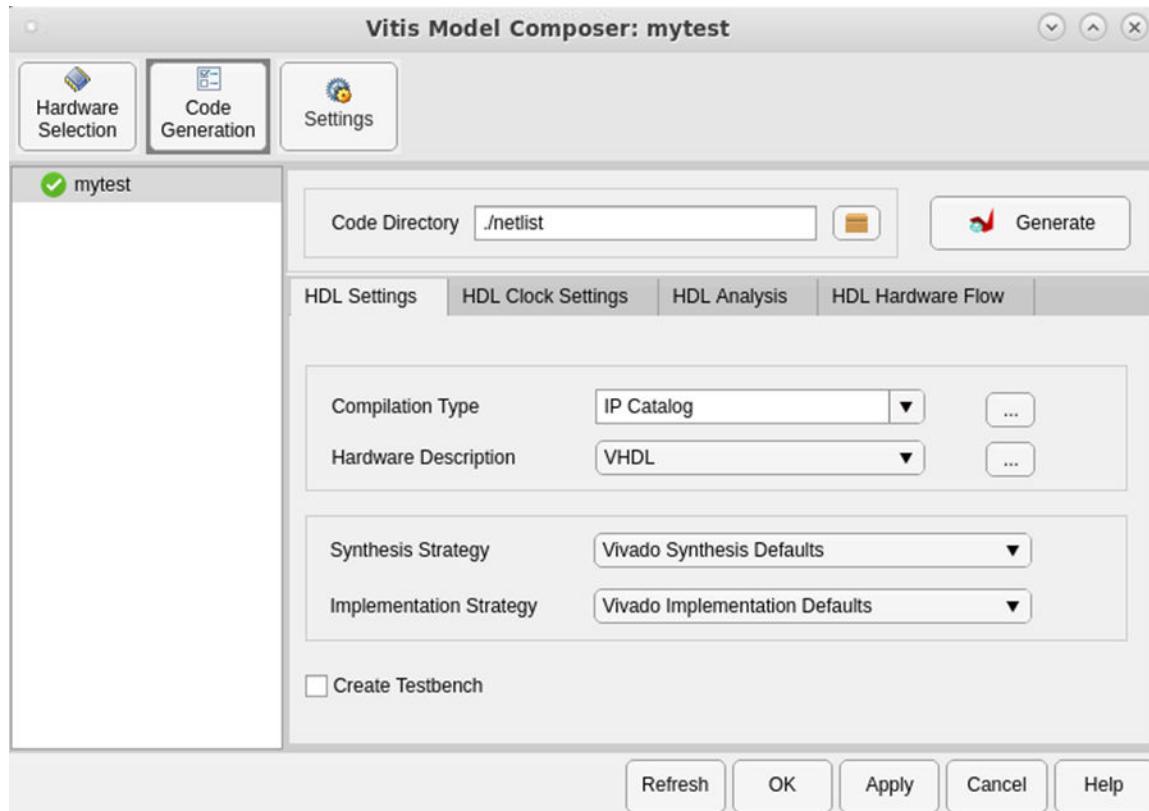
## Vitis Model Composer Hub

### Data Type Support

Data type support is not applicable to the Vitis Model Composer Hub block.

## Parameters

Figure 369: Vitis Model Composer Hub Block Parameters



The following section describes the configurable options available in each pane of the Vitis Model Composer Hub block.

- **Hardware Selection:** Clicking the browse button (...) displays the Device Chooser dialog box. This allows you to select a part, board, or platform to which your design is targeted. Vitis Model Composer obtains board and device data from the Vivado database.
- **Code Generation:** Select the subsystem name for which to generate code from the list on the left. Different settings will display depending on the type of code generation (HDL, HLS, or AI Engine) to be performed.
- **AIE Settings:**
  - **AIE Compiler Options:** When enabled, this option provides control over compiler debug options, execution target options etc.
  - **Create Testbench:** When enabled, Vitis Model Composer generates the test vectors while generating the code.

- **Run cycle-approximate AIE Simulation (SystemC) after code generation:** This option is only available if **Create testbench** is selected. When enabled, it runs the AIE simulation after code generation.
- **Simulation timeout (cycles):** When enabled, it specifies the number of cycles for which AIE simulation is run. The default value is 50000.
- **Plot AIE Simulation Output and Estimate Throughput:** When enabled, this option logs simulation data and allows visualization of the output of an AI Engine subsystem.
- **Collect profiling statistics and enable 'printf' for debugging:** When enabled, this option allows profiling data to be collected for analysis.
- **Collect data for Vitis Analyzer:** When enabled, this option provides a summary of the simulation results which can be viewed in the Vitis Analyzer.
- **Open Vitis Analyzer:** Click to invoke the Vitis Analyzer tool. This option is only enabled after AI Engine Simulation has been ran at least once after enabling.
- **AIE Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the Create Testbench option in the AIE Settings panel.
  - **Generate Hardware Validation Code:** When enabled, Vitis Model Composer generates code to be used for hardware validation.
  - **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
  - **Target:** Specify the target for hardware validation flow.
  - **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
  - **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
  - **Run hardware emulation after code generation:** When enabled, hardware emulation will run immediately after code generation.
- **HDL Settings:**
  - **Compilation Type:** Specifies the type of compilation result that should be produced when the code generator is invoked. The default compilation type is IP Catalog. When IP Catalog is selected, the Settings (...) button brings up a dialog box that allows you to add a description of the IP that will be placed in the IP catalog.
  - **Hardware Description:** Specifies the HDL language to be used for compilation of the design. The possibilities are VHDL and Verilog.
    - **VHDL library:** Specifies the name of VHDL work library for code generation. The default name is `xil_defaultlib`.

- **Use STD\_LOGIC type for Boolean or 1 bit wide gateways:** If your design's Hardware Description Language (HDL) is VHDL, selecting this option will declare a Boolean or 1-bit port (Gateway In or Gateway Out) as a STD-LOGIC type. If this option is not selected, Vitis Model Composer will interpret Boolean or 1-bit ports as vectors.

**Note:** When you enable this option and try to run Generate code and Run behavioral simulation in Vivado, you may see a failure during the elaboration phase.

- **Synthesis strategy:** Choose a Synthesis strategy from the pre-defined strategies in the drop-down menu.
- **Implementation strategy:** Choose an Implementation strategy from the pre-defined strategies in the drop-down menu.
- **Create testbench:** This instructs Vitis Model Composer to create an HDL test bench. Simulating the test bench in an HDL simulator compares Simulink simulation results with ones obtained from the compiled version of the design. To construct test vectors, Vitis Model Composer simulates the design in Simulink, and saves the values seen at gateways. The top HDL file for the test bench is named <name>\_testbench.vhd / .v, where <name> is a name derived from the portion of the design being tested.

**Note:** Testbench generation is not supported for designs that have gateways (Gateway In or Gateway Out) configured as an AXI4-Lite interface.

- **HDL Clock Settings:**

- **Enable multiple clocks:** Must be enabled when the design has multiple clocks. This indicates to the code generation engine that the clock information for the various subsystems must be obtained from the respective clock tabs. If not enabled, then the design will be treated as a single clock design.
- **Number of clocks:** Defines the number of clocks in the design. The number of clock tabs that appear will be equivalent to the number of clocks. In each clock tab, you must select the subsystem and configure the clock settings of that subsystem.
- **FPGA clock period (ns):**

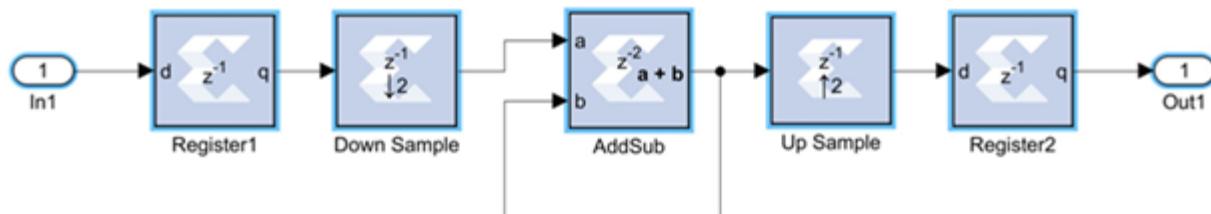
Defines the period in nanoseconds of the system clock. The value need not be an integer. The period is passed to the Xilinx implementation tools through a constraints file, where it is used as the global PERIOD constraint. Multicycle paths are constrained to integer multiples of this value.

- **Simulink system period (sec):** Defines the Simulink System Period, in units of seconds. The Simulink system period is the greatest common divisor of the sample periods that appear in the model. These sample periods are set explicitly in the block dialog boxes, inherited according to Simulink's propagation rules, or implied by a hardware oversampling rate in blocks with this option. In the final case, the implied sample time is in fact faster than the

observable simulation sample time for the block in Simulink. In hardware, a block having an oversampling rate greater than one processes its inputs at a faster rate than the data. For example, a sequential multiplier block with an over-sampling rate of eight implies a (Simulink) sample period that is one eighth of the multiplier block's actual sample time in Simulink. This parameter can be modified only in a master block.

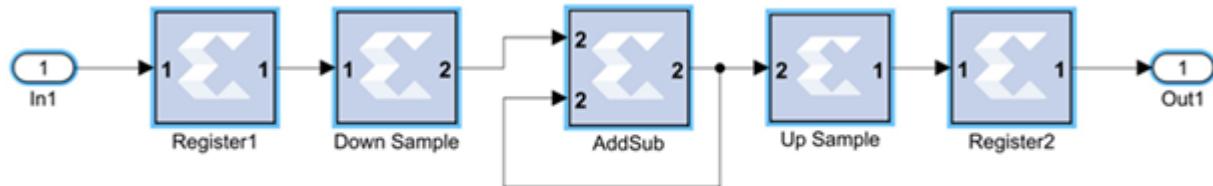
- **Clock pin location:** Defines the pin location for the hardware clock. This information is passed to the Xilinx implementation tools through a constraints file. This option should not be specified if the Vitis Model Composer design is to be included as part of a larger HDL design.
- **Provide clock enable clear pin:** This instructs Vitis Model Composer to provide a `ce_clr` port on the top-level clock wrapper. The `ce_clr` signal is used to reset the clock enable generation logic. The ability to reset clock enable generation logic allows designs to have dynamic control for specifying the beginning of data path sampling.
- **HDL Analysis:**
  - **Block icon display:** Specifies the type of information to be displayed on each block icon in the model after compilation is complete. The various display options are described below.
    - **Default:** Displays the default block icon information on each block in the model. A block's default icon is derived from the `xbsIndex` library.

**Figure 370: Default Block Icon**



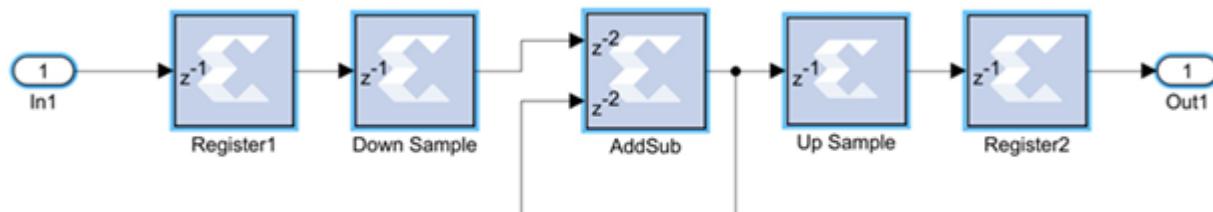
- **Normalized Sample Periods:** Displays the normalized sample periods for all the input and output ports on each block. For example, if the Simulink System Period is set to 4 and the sample period propagated to a block port is 4, then the normalized period that is displayed for the block port is 1; and if the period propagated to the block port is 8 then the sample period displayed would be 2 (a larger number indicates a slower rate).

Figure 371: Normalized Sample Periods Icon



- **Sample frequencies (MHz):** Displays sample frequencies for each block.
- **Pipeline stages:** Displays the latency information from the input ports of each block. The displayed pipeline stage might not be accurate for certain high-level blocks such as the FFT, RS Encoder/Decoder, Viterbi Decoder, etc. In this case the displayed pipeline information can be used to determine whether a block has a combinational path from the input to the output. For example, the Up Sample block in the following figure shows that it has a combinational path from the input to the output port.

Figure 372: Pipeline Stages



- **HDL port names:** Displays the HDL port name of each port on each block in the model.
- **Input data types:** Displays the data type of each input port on each block in the model.
- **Output data types:** Displays the data type of each output port on each block in the model.
- **Update the model:** Update the model to display the selected Block Icon type.
- **Perform Analysis:** Specifies whether an analysis (timing or resource) will or will not be performed on the Vitis Model Composer design when it is compiled. If **None** is selected, no timing analysis or resource analysis will be performed. If **Post Synthesis** is selected, the analysis will be performed after the design has been synthesized in the Vivado toolset. If **Post Implementation** is selected, the analysis will be performed after the design is implemented in the Vivado toolset.
- **Analysis Type:** Two selections are provided: Timing or Resource. After generation is completed, a Timing Analyzer table or Resource Analyzer table is launched.

- **Launch:** Launches the Timing Analyzer or Resource Analyzer table, depending on the selection of Analyzer type. This will only work if you already ran analysis on the Simulink model and haven't changed the Simulink model since the last run.
- **Remote IP cache:** If selected, your design will access an IP cache whenever a Vitis Model Composer compilation performs Vivado synthesis as part of the compilation. If the compilation generates an IP instance for synthesis, and the Vivado synthesis tool generates synthesis output products, the tools create an entry in the cache area. If a new customization of the IP is created which has identical properties, the tools will copy the synthesis outputs from the cache to the design's output directory instead of synthesizing the IP instance again. Accessing the disk cache speeds up the iterative design process. IP caching is described in HDL Library.
- **Create interface document:** When this check box is selected and the **Generate** button is activated for netlisting, Vitis Model Composer creates an HTM document that describes the design being netlisted. This document is placed in a `documentation` subfolder under the `netlist` folder.
- **Clear cache:** Clicking this button clears the remote IP cache. Clearing the cache saves disk space (the IP Cache can grow large, especially if your design uses many IP modules).
- **HDL Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the **Create Testbench** option in the HDL Settings panel. The HDL hardware flow is only supported for Versal® devices.
  - **Generate Hardware Validation Code:** When enabled, Vitis Model Composer generates code to be used for hardware validation.
  - **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
  - **Target:** Specify the target for hardware validation flow.
  - **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
  - **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
  - **Generate (BOOT.BIN/SD card image) after code generation:** When enabled, a BOOT.BIN (for baremetal HW system) or SD card image (for Linux HW system) will be generated after code generation.
- **HLS Settings:**
  - **Target:** Select IP Catalog to export the design to the Vivado IP Catalog. After C/C++ code generation, Vitis High-Level Synthesis (HLS) is invoked to synthesize the C code and create a project that can be exported as an IP to the Vivado IP Catalog. Select HLS C++ code to compile the design model into C++ code.
  - **FPGA clock frequency:** Specifies the clock frequency in MHz for the targeted device. This frequency is passed to the downstream tool flow.

- **Throughput factor:** Specifies the number of samples processed per clock to increase the throughput. A larger factor increases hardware resource usage. The throughput factor must be between 1 and 16.
- **Create testbench and run (C simulation/RTL cosimulation):** If selected, Vitis Model Composer runs simulation and generates test vectors while generating code.
- **Testbench stack size (MBytes):** This parameter prompts you to enter a larger stack size. When **Create and run testbench** is enabled, the **Testbench stack size** option specifies the size of the testbench stack frame during C simulation (CSIM). Occasionally, the default stack frame size of 10 MB allocate for execution of the testbench may be insufficient to run the test, due to large arrays allocated on the stack and/or deep nesting of subsystems. Typically when this happens, the test would fail with a segmentation fault and an associated error message. In such a case you can increase the size of the stack frame and rerun the test.
- **HLS Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the Create Testbench option in the HLS Settings panel. Generate Hardware Validation Code.

When enabled, Vitis Model Composer generates code to be used for hardware validation.

- **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
- **Target:** Specify the target for hardware validation flow.
- **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
- **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
- **Generate (BOOT.BIN/SD card image) after code generation:** When enabled, a BOOT.BIN (for baremetal HW system) or SD card image (for Linux HW system) will be generated after code generation.
- **Code Generation:** Select a subsystem containing blocks from the AI Engine, HDL, or HLS blocksets and specify the corresponding Code Directory. The Code Directory can be specified by entering the complete directory path or using the Browse button to provide a path.
- **Settings:** Specify whether the Model Composer Hub block should treat your model as a legacy System Generator design.

## Window Processing

Assemble an output matrix by applying the kernel subsystem to submatrices (windows) of the input matrix in row-major order

## Library

### Ports and Subsystems



## Description

The Window Processing block is a masked subsystem for assembling an output matrix by applying a kernel subsystem to sub matrices of the input matrix in row-major order. You customize the Window Processing block by specifying its parameters and by adding blocks to the Kernel subsystem for computing a scalar element of the output in terms of the corresponding input window. The computation can be thought of to proceed in the following steps:

1. Compute the padded input matrix depending on the setting of the **Output size** parameter.

Let the dimensions of the input be  $M_{in}, N_{in}$ ; let the dimensions of the window be  $M_{win}, N_{win}$ .

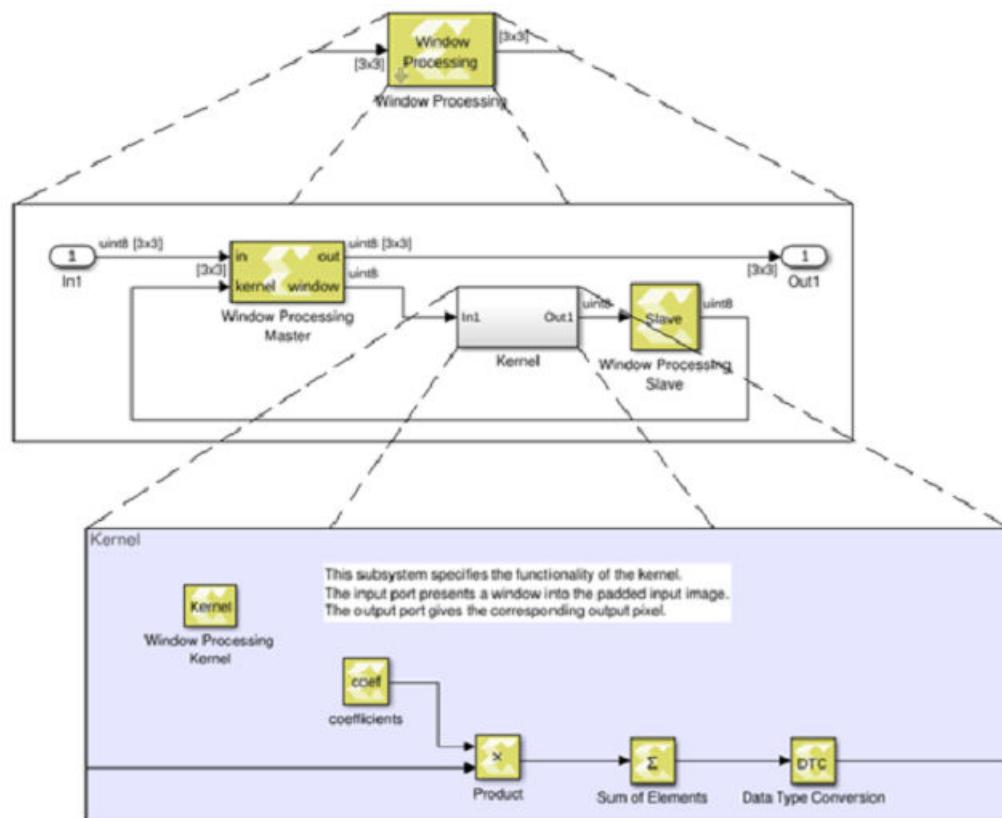
- If the **Output size** is set to **Valid**, no padding is performed, and the dimensions of the output are  $M_{in}-M_{win}+1, N_{in}-N_{win}+1$ .
- If the **Output size** is set to **Same as input**, the input is padded with  $M_{win}-1$  rows and  $N_{win}-1$  columns of 0s. Half of rows added is put at the top and the remainder goes at the bottom. If  $N_{win}$  is even then the bottom gets one more row of padding than the top. The same is done for adding the columns. The size of the output is the same as the size of the input.
- If the **Output size** is set to **Full**, the input is padded with  $2*(M_{win}-1)$  rows and  $2*(N_{win}-1)$  columns of 0s. Half of the padding rows (columns) are added at the top (left) and the other half at the bottom (right).

2. For each element  $(i,j)$  of the output (iterate over output in row-major order):

- Select the  $M \times N$  sub matrix from the padded input matrix starting with element  $(i,j)$
- Apply the kernel subsystem to this sub matrix
- Assign the scalar output of the kernel to element  $(i,j)$  of the output.

The hierarchy of the Window Processing block is shown below.

Figure 373: Hierarchy of Window Processing Block



Restrictions on the use of the Window Processing block are:

- The topology of the window processing subsystem shall not be modified. It must match the topology show in the figure above.
- The input signal must be a matrix.
- The kernel must have precisely one input port and one output port.
- The output of the kernel must be scalar.
- The input of the kernel must have the dimensions specified by the window size parameter.
- The dimensions of the input must be at least as large as the window size.
- The kernel must not contain any of the following blocks:
  - Blocks that have internal state, such as the Unit Delay block.
  - The following Digital Signal Processing blocks: FFT and IFFT.
  - Blocks created with the `xmcImportFunction` command.
- The kernel must not contain an if-action subsystem.

## Data Type Support

There are no restrictions on the data types of the input or output signals.

## Parameters

### Window size

This parameter specifies the size of the window. Enter a 2-element vector of real positive integers, for example [5,3], for the **Window size**. Please note that **Window size** cannot specify more than a total of 255 elements.

### Output size

This parameter specifies how the edges of the input image are treated.

Let  $M_{in}$ ,  $N_{in}$  be the dimensions of the input, and let  $M_{win}$ ,  $N_{win}$  be the **Window size**. The dimensions of the output are as follows:

- $M_{in}+M_{win}-1$ ,  $N_{in}+N_{win}-1$  if **Full** is selected for **Output size**.
- $M_{in}$ ,  $N_{in}$  if **Same as Input** is selected for **Output size**.
- $M_{in}-M_{win}+1$ ,  $N_{in}-N_{win}+1$  if **Valid** is selected for **Output size**.

## Supported Simulink Blocks

You can mix blocks from the HLS block library and blocks from Simulink®, and other add-on toolboxes, during simulation in Simulink. However, you can only generate output from Model Composer from the top-level subsystem that uses only a limited set of Simulink blocks that are supported for code generation.

The following Simulink blocks are fully supported by Model Composer for code generation, and can be found in the Vitis Model Composer HLS block library as well.

*Table 132: Supported Simulink Blocks*

Simulink Block	Description
Action Port	Place this block in a subsystem to link to a signal from an <b>If</b> block or a <b>Switch-Case</b> block.
Bus Creator	This block creates a bus signal from multiple inputs.
Bus Selector	Pulls signals from an input bus to pass to output.
Display	Provides numeric display of input values.
DocBlock	Create and edit text associated with a model, and save that text with the model.
From	Receive signals from the Goto block with the specified tag.
Goto	Send signals to From blocks that have the specified tag.
If	Provides an <b>IF/ELSEIF/ELSE</b> condition for branching inputs to alternate outputs.

**Table 132: Supported Simulink Blocks (cont'd)**

Simulink Block	Description
Import	Provide an input port for a subsystem or model.
Merge	Merge multiple input signals into a single output signal whose initial value is specified by the 'Initial output' parameter.
Outport	Provide an output port for a subsystem or model.
Scope	Displays time domain signals with respect to simulation time.
Stop Simulation	Stop simulation when input is non-zero.
Terminator	Used to "terminate" output signals to prevent warnings about unconnected output ports.
To File	Incrementally write data into a variable in the specified MAT-file.
To Workspace	Write input to specified timeseries, array, or structure in a workspace.

Refer to the Simulink documentation for a complete description of the block.

---

## AI Engine Blockset

**Note:** The AIE FIR Filter block which was part of AI Engine/DSP library will be deprecated in a future release. Please replace all instances of this block in the model with equivalent blocks from the Xilinx Toolbox/AI Engine/DSP library.

### AIE Class Kernel

This block allows you to import class-based kernels.



#### Library

AI Engine/User-Defined Functions

#### Description

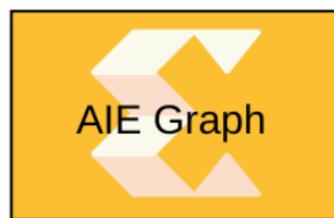
The AIE Class Kernel block is used to import class-based kernels. This block also supports importing class templates to define a family of kernels.

## Parameters

Parameter Name	Parameter Type	Criticality	Description
Kernel header file	String	Mandatory	Name of the header file that contains the kernel class and registerKernelClass method declarations. The string could be just the file name, a relative path to the file or an absolute path of the file. Use the browse button to choose the file.
Kernel class	String	Mandatory	Name of the kernel class which contains member variables and kernel member functions.
Kernel function	String	Mandatory	Name of the kernel member function for which the block is to be created. This function should be registered using the registerKernelClass method in the kernel header file.
Kernel source file	String	Mandatory	Name of the source file that contains where the kernel member function definition and non-default constructor parameter values are specified. The string could be the file name, a relative path to the file or an absolute path of the file.
Kernel search paths	Vector of strings	Optional	If the kernel header file or the kernel source file are not found using the value provided through the Kernel header file or Kernel source file fields respectively, then the paths provided through Kernel search paths are used to find the files. This parameter allows use of environment variables while specifying paths for the kernel header file and the kernel source file. The environment variable can be used in either \${ENV} or \$ENV format.
Preprocessor options		Optional	Optional preprocessor arguments for downstream compilation with specific preprocessor options. The following two preprocessor option formats are accepted and multiple can be selected: -D<name> and -D<name>=<definition> separated by a comma. That is, the optional argument must begin with -D and if the option <definition> value is not provided, it is assumed to be 1.

## AIE Graph

This block allows you to import an AI Engine graph.



## Library

AI Engine/User-Defined Functions

## Description

The AIE Graph block allows you to import an AI Engine program that consists of a dataflow graph specification written in C++.

## Parameters

- **Graph file:** Specifies whether the graph import should be done using the header file (\*.h) or using source file (\*.cpp). By default the header file is selected.
- **Graph Header file(\*.h):** This is the mandatory string that specify the file (.h), where the application graph class is defined and the Adaptive Data Flow (ADF) header (adf.h), kernel function prototypes are included. This parameter is only visible when you choose the **Header file (\*.h)** option in the Graph file.
- **Graph Source file (\*.cpp):** This is the mandatory string that specify the file (.cpp), where the adf dataflow graph is instantiated. This file should contain the main() function, from where the dataflow graph initializes and runs. This option is available only when the Source file (\*.cpp) is selected in Graph file.
- **Graph class:** This is a mandatory string that specifies the name of the graph class. This parameter is only visible when you choose the **Header file (\*.h)** option in the Graph file.
- **Graph search paths:** This is a vector of strings that specifies the search paths where header files, kernels, and other include files can be found and included for simulation. The search path \$XILINX\_VITIS/adf/include (where adf.h is defined) is included by default and does not need to be specified.
- **Preprocessor options:** This is an optional parameter and should be specified with a preprocessor argument for downstream compilation with specific preprocessor options. The following preprocessor option formats are accepted and multiple can be selected: '-D<name>' and '-D<name>=<definition>'. That is, the optional argument must begin with the '-D' string and if the option <definition> value is not provided, it is assumed to be 1.

## AIE Kernel

This block allows you to import an AI Engine kernel.



## Library

AI Engine/User-Defined Functions

## Description

The AIE Kernel block allows you to import an AI Engine kernel which is a C/C++ program. This block supports importing Window, Stream, Cascade, and Run time parameter as arguments to kernel function. This block also allows you to import a function template with typename template parameter T, and a non-type (integral) template parameter N.

## Parameters

Parameter Name	Parameter Type	Criticality	Description
Kernel header file	String	Mandatory	Name of the header file that contains the kernel function declaration. The string could be just the file name, a relative path to the file or an absolute path of the file. Use the browse button to choose the file.
Kernel function	String	Mandatory	Name of the kernel function for which the block is to be created. This function should be declared in the kernel header file.
Kernel init function	String	Optional	Name of the initialization function used by the kernel function.
Kernel source file	String	Mandatory	Name of the source file that contains the kernel function definition. The string could be the file name, a relative path to the file or an absolute path of the file.
Kernel search paths	Vector of Strings	Optional	If the kernel header file or the kernel source file are not found using the value provided through the 'Kernel header file' or 'Kernel source file' fields respectively, then the paths provided through 'Kernel search paths' are used to find the files. This parameter allows use of environment variables while specifying paths for the kernel header file and the kernel source file. The environment variable can be used in either \${ENV} or \$ENV format.
Preprocessor options		Optional	Optional preprocessor arguments for downstream compilation with specific preprocessor options. The following two preprocessor option formats are accepted and multiple can be selected: -Dname and -Dname=definition separated by a comma. That is, the optional argument must begin with -D and if the option definition value is not provided, it is assumed to be 1.

## AIE Signal Spec

This block is used to specify various properties on signals within, as well as at the boundary of an AI Engine subsystem.



## Library

AI Engine/Tools

## Description

The AIE Signal Spec block allows you to specify the Platform IO (PLIO) width and FIFO depth value within the AI Engine subsystem.

- Specifying the PLIO width at the boundary of the AI Engine subsystem will affect the throughput of data from the AI Engine domain to the programmable logic (PL) domain.
- Specifying the FIFO depth value can help avoid deadlock or stalling by creating more buffering in the paths.

## Parameters

- **Connection Tab:**
  - **FIFO Depth (32-bit words):** Should be a positive integer value and the default value is '0'.
- **Platform I/O Tab:**
  - **PLIO Width:** Only auto, 32, 64, and 128 are possible values. 'auto' is the default value.
  - **Specify PLIO frequency:** When set to ON, you can specify the Programmable logic frequency in MHz. The default value is 250 MHz. In general, choose a reasonable target frequency depending on the complexity of the algorithm implemented.

## DDS



DDS

## Library

AI Engine/DSP/Window IO

## Description

This block implements the Direct Digital Synthesizer (DDS) targeted for AI Engines.

## Parameters

- Main:

- **Output data type:** Describes the types of individual data samples output of the DDS function. The supported data types are `cint16` and `cfloat`.
- **Output window size (Number of samples):** Specifies the number of samples in output window. The value must be in the range 8 to 1024 and the default value is 32.
- **Phase increment:** Specifies the phase increment between samples. The value must be in the range 0 to  $2^{31}$  and the default value is 0. Input value  $2^{31}$  corresponds to Pi (i.e., 180).

Phase increment is calculated using the formula  $(F_o^*(2^N)) / F_s$

Where:

- $F_o$  = Output frequency
  - $N = 32$ , which represents the accumulator width, and it is fixed
  - $F_s$  = Sampling frequency
  - **Sample time:** Specifies the sample time for the block output port. The default value is -1.
- Advanced:
- **Target output throughput (MSPS):** Specifies the output sampling rate of the DDS function in Mega Samples per Second (MSPS). The value must be in the range 1 to 1000 and the default value is 200.

## DDS Stream



DDS Stream

## Library

AI Engine/DSP/Stream IO

## Description

This block implements the stream-based Direct Digital Synthesizer (DDS) targeted for AI Engines.

## Parameters

- **Main:** Output Data Type:

- Describes the type of individual data samples output of the DDS function. It should be `cint16` or `cfloat`.

Output Frame Size (Number of Samples):

- Specifies the number of samples in the output frame. The value must be in the range 8 to 1024 and the default value is 32.

Number of Parallel Outputs (SSR):

- This parameter specifies the number of output ports and must be of the form  $2^N$ , where N is a non-negative integer.

Phase Increment:

- Specifies the phase increment between samples. The value must be in the range 0 to  $2^{31}$  and the default value is 0. Input value  $2^{31}$  corresponds to Pi (i.e., 180). Phase increment is calculated using the formula  $(F_o * (2^N)) / F_s$  where:

- $F_o$  = Output frequency.
- $N = 32$ , which represents the accumulator width, and it is fixed.
- $F_s$  = Sampling frequency.

Initial Phase Offset:

- Specifies the initial phase offset. The default value is 0.

Sample Time:

- Specifies the sample time for the block output port. The default value is -1.

- **Advanced:** Target Output Throughput (MSPS):

- Specifies the output sampling rate of the DDS function in Mega Samples per Second (MSPS). The value must be in the range 1 to 1000 and the default value is 200.

## FFT



### Library

AI Engine/DSP/Window IO

### Description

This block implements the FFT targeted for AI Engines which use rounding method and saturates the output samples on overflow.

### Parameters

- **Main:**
  - **Input/Output data type:** Describes the type of individual data samples input to and output from the filter function. Supported types are cint16, cint32, and cfloat.
  - **FFT size:** This is an unsigned integer which describes the point size of the transformation. This must be  $2^N$ , where N is in the range 4 to 11 inclusive. However, for `cint16` datatype, the FFT size can be  $2^{12}$ , provided the FFT receives and outputs data to/from kernels on the same processor.
- **Note:** To understand more on achieving the 4096 point size FFT, refer to the AI Engine examples in [GitHub](#).
- **Input Window Size(Number of Samples):** Describes the number of samples used as an input to the FFT.
- **Scale output down by  $2^k$ :** Describes the power of 2 to scale the result by prior to output.
- **Advanced:**
  - **Target input throughput:** Specifies the rate at which data samples should be processed. The default value is 200.

- **Specify the number of cascade stages:** When this option is not enabled, the tool will determine the filter configuration that best achieves the specified input sampling rate. When this option is enabled and the 'Number of cascade stages' is specified, the tool will guarantee the same. In such cases, however, the specified sample rate constraint may not be achieved.
- **Number of cascade stages:** This determines the number of kernels the FFT will be divided over in series to improve throughput.

## FFT Dynamic Point



FFT Dynamic Point

### Library

AI Engine/DSP/Window IO

### Description

FFT Dynamic Point implementation targeted for AI Engines. This block supports performing different lengths of FFT on different input data windows. Each window must be preceded by a 256-bit header which describes run-time parameters of that window. The format of the header is described below.

#### Note:

- Every input frame must be appended by a header.
- If the FFT size (N) is smaller than the frame size, the block takes the N point FFT of the first N samples in the input frame, and discards the rest of the samples in the frame.
- If the frame size is an integer multiple (M) of max FFT size, M FFT iterations will be performed on a given input frame, resulting in multiple iterations of output samples, reducing the number of times the kernel needs to be triggered to process a given number of input data samples. As a result, the overheads incurred during kernel triggering are reduced and overall performance is increased

Figure 374: Header Format

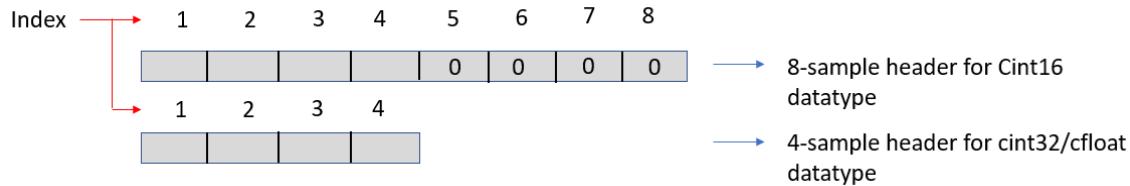


Table 133: Header Format

Index	Field Name	Description
1	Direction	<ul style="list-style-type: none"> <li>0 = Inverse FFT</li> <li>1 = Forward FFT</li> </ul>
2	Point size (radix 2 stages)	Point size described as power of 2. For example, value '5' describes a point size of '32'
3	Reserved	Reserved
4	Status (output only)	<ul style="list-style-type: none"> <li>0 = Legal point size</li> <li>1 = Illegal point size</li> </ul>

### Example Header Format

To implement the 32-point size FFT of 'cint16' datatype, the format of the header that should be preceded to the input data window should be as shown.



### Example (Input to Dynamic Point FFT)

To implement the FFT of different sizes, say, 64, 32 and 128, of type `cint32`, the format of the input should be as follows.

```
complex([1 6 0 0 ones(1,64) 1 5 0 0 ones(1,32) 1 7 0 0 ones(1,128)])
```

### Parameters

- **Main: Input Data Type/Output Data Type:**

- Describes the type of individual data samples input/output of the dynamic point FFT. It can be `cint16`, `cint32`, `cfloat` types.

FFT Maximum Size:

- Specifies the maximum FFT size that is supported by Dynamic point FFT. You can perform different lengths of FFT on different input data windows. It must be a power of 2 with a minimum value of 16. The maximum value supported by the library element is 65536.

Input Window Size:

- Specifies the number of samples in the input window excluding the header. The value must be in the range 8 to 1024 and the default value is 64.

Scale Output down by 2^:

- Describes the power of 2 shift down applied to the accumulation of FIR terms before output. It must be in the range 0 to 61.
- **Advanced: Target Output Throughput (MSPS):**

- Specifies the output sampling rate of the DDS function in Mega Samples per Second (MSPS). The value must be in the range 1 to 1000 and the default value is 200.

Specify the Number of Cascade Stages:

- When this option is not enabled, the tool will determine the FFT configuration that best achieves the specified input sampling rate. When the option is enabled, the Number of cascade stages can be specified (which describes the number of AI Engine processors to split the operation over). This allows resources to be traded for higher performance, but the specified input sampling rate constraint may not be achieved. The value must be in the range of 1 to 9.

## FFT Dynamic Point Stream



### Library

AI Engine/DSP/Stream IO

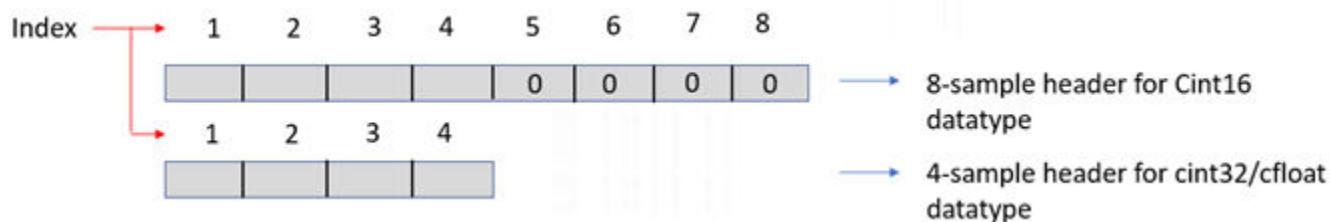
## Description

FFT Dynamic Point Stream implementation targeted for AI Engines. This block supports performing different lengths of FFT on input data streams. Each frame must be preceded by a 256-bit header which describes run-time parameters of that frame. The format of the header is described below. The block has two stream ports per subframe processor to maximize performance. The specified value for SSR parameter should be of the form  $2^N$ , where N is a positive integer.

### Note:

- Every input frame must be appended by a header.
- If the FFT size (N) is smaller than the frame size, the block takes the N point FFT of the first N samples in the input frame, and discards the rest of the samples in the frame.
- If the frame size is an integer multiple (M) of max FFT size, M FFT iterations will be performed on a given input frame, resulting in multiple iterations of output samples, reducing the number of times the kernel needs to be triggered to process a given number of input data samples. As a result, the overheads incurred during kernel triggering are reduced and overall performance is increased.

*Figure 375: Header Format*



*Table 134: Header Description*

Index	Field Name	Description
1	Direction	<ul style="list-style-type: none"> <li>• 0 = Inverse FFT</li> <li>• 1= Forward FFT</li> </ul>
2	Point size (radix 2 stages)	Point size described as power of 2. For example, value '5' describes a point size of '32'
3	Reserved	Reserved
4	Status (output only)	<ul style="list-style-type: none"> <li>• 0 = Legal point size</li> <li>• 1 = Illegal point size</li> </ul>

## Example Header Format

To implement the 32-point size FFT of `cint16` datatype, the format of the header that should be preceded to the input data window should be as shown in the following figure.

Figure 376: Example Header Format

1	2	3	4	5	6	7	8
1	5	0	0	0	0	0	0

### Example (Input to Dynamic Point FFT)

To implement the FFT of different sizes, say, 64, 32 and 128, of type `cint32`, the format of the input should be as follows:

```
complex([1 6 0 0 ones(1,64) 1 5 0 0 ones(1,32) 1 7 0 0 ones(1,128)])
```

### Parameters

- **Main:** Input/Output Data Type:
  - Describes the type of individual data samples input/output of the dynamic point FFT. It can be `cint16`, `cint32`, `cfloat` types.

FFT Maximum Size:

- Specifies the maximum FFT size that is supported by Dynamic Point FFT. You can perform different lengths of FFT on different input data frames. It must be a power of 2 with a minimum value of 16. The maximum value supported by the library element is 65536.

Input Window Size:

- Specifies the number of samples in the input frame excluding the header. The value must be in the range 16 to 65536 and the default value is 60.

Scale Output down by 2^:

- Describes the power of 2 shift down applied before output.

SSR:

- This parameter is intended to improve performance and support FFT sizes beyond the limitations of a single tile. For an SSR value of 'n' (which must be of the form  $2^N$ , where N is a positive integer), the FFT operation is performed in parallel and the actual FFT size is divided by 'n'. For example, a 16384 point FFT with an SSR value of 8 creates 8 stream inputs and there will be 8 subframe FFTs each of point size 2048. The specified FFT size and SSR values should be such that FFT size / SSR should not exceed 2048.

- **Advanced:** Target Output Throughput (MSPS):

- Specifies the output sampling rate of the FFT function in Mega Samples per Second (MSPS). The value must be in the range 1 to 1000 and the default value is 200.

Specify the Number of Cascade Stages:

- When this option is disabled, the tool will determine the FFT configuration that best achieves the specified input sampling rate. When the option is enabled, the Number of cascade stages can be specified (which describes the number of AI Engine processors to split the operation over). This allows resources to be traded for higher performance, but the specified input sampling rate constraint may not be achieved. The value must be in the range of 1 to 9.

## FFT Stream



FFT Stream

### Library

AI Engine/DSP/Stream IO

### Description

Stream-based FFT implementation targeted for AI Engines. The FFT block has two stream ports per subframe processor to maximize performance. The specified value for SSR parameter should be of the form  $2^N$ , where N is a positive integer.

### Parameters

- Main:** Input Data Type/Output Data Type:

- Describes the type of individual data samples input/output of the stream FFT. It can be `cint16`, `cint32`, `cfloat` types.

FFT Size:

- This is an unsigned integer which describes the point size of the transformation. This must be  $2^N$ , where N is in the range 4 to 11 inclusive.

Input Frame Size (Number of Samples):

- Specifies the number of samples for a particular frame. The value must be in the range 8 to 1024 and the default value is 64. The FFT operation will not begin until this number of samples has been input.

Scale Output Down by  $2^A$ :

- Describes the power of 2 shift down applied before output. The following table shows the range of valid values of this parameter for different data types.

**Table 135: Valid Parameters**

Data Type	Scale output down by $2^A$
cint16	[0, $\log_2(\text{FFT Size}) + 15$ ]
cint32	[0, $\log_2(\text{FFT Size}) + 31$ ]
cfloat	0

SSR:

- This parameter is intended to improve performance and support FFT sizes beyond the limitations of a single tile. For an SSR value of 'n' (which must be of the form  $2^N$ , where N is a positive integer), the FFT operation is performed in parallel and the actual FFT size is divided by 'n'. For example, a 16384 point FFT with SSR value of 8 creates 8 stream inputs and there will be 8 subframe FFTs each of point size 2048. The specified FFT size and SSR values should be such that  $(2 * \text{FFT size} / \text{SSR})$  is in the range of 16 and 4096.
- **Advanced:** Target Output Throughput (MSPS):
  - Specifies the output sampling rate of the FFT function in Mega Samples per Second (MSPS). The value must be in the range 1 to 1000 and the default value is 200.

Specify the Number of Cascade Stages:

- When this option is not enabled, the tool will determine the FFT configuration that best achieves the specified input sampling rate. When the option is enabled, the Number of cascade stages can be specified (which describes the number of AI Engine processors to split the operation over). This allows resources to be traded for higher performance, but the specified input sampling rate constraint may not be achieved. The value must be in the range of 1 to 9.

## FIFO



### Library

AI Engine/Interfaces

### Description

This block allows specification of the FIFO depth on a particular path. Specifying the FIFO depth value can help avoid deadlock or stalling by creating more buffering in the paths. This block does not affect functional simulation and will only impact the generated graph code. You can also set location constraints for the FIFO block using the Constraint manager. FIFOs can be either stream FIFOs, DMA FIFOs, or a combination of the two.

### Parameters

- **FIFO Depth (32-bit words)** : Should be a positive integer value and the default value is '0'.

## FIR Asymmetric



### Library

AI Engine/DSP/Window IO

## Description

This block implements the Single Rate Asymmetric FIR Filter targeted for AI Engines.

## Parameters

- **Main:**
  - **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
  - **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, or cfloat and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
    - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
    - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
  - **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via the input port.
  - **Filter coefficients:** This field should be specified with the asymmetric filter coefficients and must be in the range 4 to 240 inclusive.
  - **Input window size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be equal to input window size also by virtue of the single rate nature of this function.
  - **Scale output down by  $2^{\wedge}$ :** Describes the power of 2 shift down applied to the accumulation of FIR terms before output. It must be in the range 0 to 61.
  - **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
    1. Floor (truncate)
    2. Ceiling
    3. Round to positive infinity
    4. Round to negative Infinity
    5. Round symmetrical to Infinity
    6. Round symmetrical to zero
    7. Round convergent to even

## 8. Round convergent to odd

Modes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Advanced:**

- **Target input throughput (MSPS):** Specifies the rate at which data samples should be processed. The default value is 200.
- **Specify the number of cascade stages:** When this option is not enabled, the tool will determine the filter configuration that best achieves the specified input sampling rate. When the option is enabled, the 'Number of cascade stages' can be specified (which describes the number of AI Engine processors to split the operation over). However, this allows resource to be traded for higher performance and the specified input sampling rate constraint may not be achieved. The value must be in the range 1 to 9.

## FIR Asymmetric Decimation



### Library

AI Engine/DSP/Window IO

### Description

This block implements the FIR Asymmetric Decimation filter targeted for AI Engines.

### Parameters

- **Main:**

- **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
- **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
  - Complex types are only supported when the Input/Output data type is also complex.

- 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
- Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
- Filter coefficients data type must be a float type if the Input/Output data type is a float type.
- **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify filter coefficients via the input port.
- **Filter coefficients:** Specifies the asymmetric filter coefficients. The filter length must be in the range 4 to 240 and must be an integer multiple of the decimation factor.
- **Decimation factor:** An unsigned integer which describes the decimation factor of the filter. It must be in the range 2 to 7.
- **Input window size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be (Input window size/decimation factor). The input window size must be an integer multiple of the decimation factor and the resulting output window size must be a multiple of 256 bits.
- **Scale output down by 2<sup>n</sup>:** Describes the power of 2 shift down applied to the accumulation of FIR terms before output. It must be in the range 0 to 61.
- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
  1. Floor (truncate)
  2. Ceiling
  3. Round to positive infinity
  4. Round to negative Infinity
  5. Round symmetrical to Infinity
  6. Round symmetrical to zero
  7. Round convergent to even
  8. Round convergent to oddModes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.
- **Advanced:**
  - **Target input throughput (MSPS):** Specifies the rate at which data samples should be processed. The default value is 200.

- **Specify the number of cascade stages:** When this option is not enabled, the tool will determine the filter configuration that best achieves the specified input sampling rate. When the option is enabled, the 'Number of cascade stages' can be specified (which describes the number of AI Engine processors to split the operation over). However, this allows resources to be traded for higher performance and the specified input sampling rate constraint may not be achieved. The value must be in the range 1 to 9.

## FIR Asymmetric Decimation Stream



FIR Asymmetric Decimation Stream

### Library

AI Engine/DSP/Stream IO

### Description

This block implements the stream-based FIR Asymmetric Decimation filter targeted for AI Engines.

### Parameters

- **Main:**
  - **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
  - **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
    - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
    - Filter coefficients data type must be a float type if the Input/Output data type is a float type.

- **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify filter coefficients via the input port.
- **Filter coefficients:** Specifies the asymmetric filter coefficients. The filter length must be in the range 4 to 240 and must be an integer multiple of the decimation factor.
- **Decimation factor:** An unsigned integer which describes the decimation factor of the filter. It must be in the range 2 to 7.
- **Input frame size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be (Input window size/decimation factor). The input window size must be an integer multiple of the decimation factor and the resulting output window size must be a multiple of 256 bits.
- **Scale output down by  $2^N$ :** Describes the power of 2 shift down applied to the accumulation of FIR terms before output. It must be in the range 0 to 61.
- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
  1. Floor (truncate)
  2. Ceiling
  3. Round to positive infinity
  4. Round to negative Infinity
  5. Round symmetrical to Infinity
  6. Round symmetrical to zero
  7. Round convergent to even
  8. Round convergent to oddModes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Number of parallel input/output (SSR):** This parameter specifies the number of input (or output) ports and must be of the form  $2^N$ , where N is a non-negative integer.
- **Advanced:** Number of cascade stages:
  - Specifies the number of cascade stages. The tool will guarantee the same.

## FIR Asymmetric Stream



### Library

AI Engine/DSP/Stream IO

### Description

This block implements the stream-based FIR Asymmetric filter targeted for AI Engines.

### Parameters

- **Main:**
  - **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
  - **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, or cfloat and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
    - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
    - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
  - **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via the input port.
  - **Filter coefficients:** This field should be specified with the asymmetric filter coefficients and must be in the range 4 to 240 inclusive.
  - **Input frame size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be equal to input window size also by virtue of the single rate nature of this function.

- **Scale output down by  $2^N$ :** Describes the power of 2 shift down applied to the accumulation of FIR terms before output. It must be in the range 0 to 61.
- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
  1. Floor (truncate)
  2. Ceiling
  3. Round to positive infinity
  4. Round to negative Infinity
  5. Round symmetrical to Infinity
  6. Round symmetrical to zero
  7. Round convergent to even
  8. Round convergent to odd

Modes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Number of parallel input/output (SSR):** This parameter specifies the number of input (or output) ports and must be of the form  $2^N$ , where N is a non-negative integer.
- **Advanced:** Number of cascade stages:
  - Specifies the number of cascade stages. The tool will guarantee the same.

## FIR Resampler Filter



FIR Resampler Filter

### Library

AI Engine/DSP/Window IO

## Description

This block implements the FIR Fractional Asymmetric Interpolation and Decimation filter targeted for AI Engines.

**Note:** The FIR Fractional Interpolation block has been deprecated. Please use the FIR Resampler Filter block instead.

## Parameters

- **Main:**
  - **Input/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
  - **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
    - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
    - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
  - **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via input port.
  - **Filter coefficients:** This field should be specified with the asymmetric filter coefficients and must be in the range 4 to 240 inclusive.
  - **Interpolation factor:** An unsigned integer which describes the Interpolation factor of the filter. It must be in the range 3 to 16.
  - **Decimation factor:** An unsigned integer which describes the decimation factor of the filter. It must be in the range 2 to 16. The decimation factor should be less than the interpolation factor and should not be divisible by the interpolation factor.
  - **Input window size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be the input window size multiplied by the Interpolation factor and divided by the decimation factor. In this instance it would result in a fraction number of output samples which would be rounded down.
  - **Scale output down by 2<sup>n</sup>:** Describes the power of 2 shift down applied to the accumulation of FIR terms before output. It must be in the range 0 to 61.

- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:

1. Floor (truncate)
2. Ceiling
3. Round to positive infinity
4. Round to negative infinity
5. Round symmetrical to infinity
6. Round symmetrical to zero
7. Round convergent to even
8. Round convergent to odd

Modes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Advanced:**

- **Number of cascade stages:** This determines the number of kernels over which the function will be split. A higher number of cascade stages will result in higher throughput at the expense of resources. The value must be in the range 1 to 9.

## FIR Halfband Decimator



FIR Halfband Decimator

### Library

AI Engine/DSP/Window IO

### Description

This block implements the FIR Halfband Decimator targeted for AI Engines.

## Parameters

- **Main:**
  - **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
  - **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
    - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
    - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
  - **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via input port.
  - **Filter coefficients:** Specifies the filter coefficients as a vector of  $(N+1)/4+1$  elements, where 'N' is a positive integer that represents the filter length and must be in the range 4 to 240 inclusive.
  - **Input window size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be the Input window size divided by two by virtue of the halfband decimation factor.
  - **Scale output down by  $2^A$ :** Describes the power of 2 shift down applied to the accumulation of FIR terms before output. It must be in the range 0 to 61.
  - **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
    1. Floor (truncate)
    2. Ceiling
    3. Round to positive infinity
    4. Round to negative infinity
    5. Round symmetrical to infinity
    6. Round symmetrical to zero
    7. Round convergent to even
    8. Round convergent to odd

Modes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Advanced:**

- **Target input throughput (MSPS):** Specifies the rate at which data samples should be processed. The default value is 200.
- **Specify the number of cascade stages:** When this option is not enabled, the tool will determine the filter configuration that best achieves the specified input sampling rate. When the option is enabled, the 'Number of cascade stages' can be specified (which describes the number of AI Engine processors to split the operation over). However, this allows resource to be traded for higher performance and the specified input sampling rate constraint may not be achieved. The value must be in the range 1 to 9.

## FIR Halfband Decimator Stream



FIR Halfband Decimator Stream

### Library

AI Engine/DSP/Stream IO

### Description

This block implements the stream-based FIR Halfband Decimator filter targeted for AI Engines.

### Parameters

- **Main:**

- **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
- **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
  - Complex types are only supported when the Input/Output data type is also complex.

- 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
  - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
  - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
- **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via input port.
  - **Filter coefficients:** Specifies the filter coefficients as a vector of  $(N+1)/4+1$  elements, where 'N' is a positive integer that represents the filter length and must be in the range 4 to 240 inclusive.
  - **Input frame size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be the Input window size divided by two by virtue of the halfband decimation factor.
  - **Scale output down by  $2^A$ :** Describes the power of 2 shift down applied to the accumulation of FIR terms before output. It must be in the range 0 to 61.
  - **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
    1. Floor (truncate)
    2. Ceiling
    3. Round to positive infinity
    4. Round to negative infinity
    5. Round symmetrical to infinity
    6. Round symmetrical to zero
    7. Round convergent to even
    8. Round convergent to oddModes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.
- **Number of parallel input/output (SSR):** This parameter specifies the number of input (or output) ports and must be of the form  $2^N$ , where N is a non-negative integer.
  - **Number of parallel polyphases (interp\_poly):** Number of decimation polyphases into which data is split into for parallel computation. It must be integer divisible by interpolation factor.
  - **Advanced:** Number of cascade stages:
    - Specifies the number of cascade stages. The tool will guarantee the same.

## FIR Halfband Interpolator



FIR Halfband Interpolator

### Library

AI Engine/DSP/Window IO

### Description

This block implements the FIR Halfband Interpolator targeted for AI Engines.

### Parameters

- **Main:**
  - **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
  - **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
    - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
    - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
  - **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via the input port.
  - **Filter coefficients:** Specifies the filter coefficients as a vector of  $(N+1)/4+1$  elements, where 'N' is a positive integer that represents the filter length and must be in the range 4 to 240 inclusive.

- **Input window size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be the Input window size multiplied by two by virtue of the halfband interpolation factor.
- **Scale output down by  $2^{\wedge}$ :** Describes the power of 2 shift down applied to the accumulation of FIR terms before output. It must be in the range 0 to 61.
- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
  1. Floor (truncate)
  2. Ceiling
  3. Round to positive infinity
  4. Round to negative infinity
  5. Round symmetrical to infinity
  6. Round symmetrical to zero
  7. Round convergent to even
  8. Round convergent to odd

Modes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Use center tap to upshift data:** To upshift the data sample by the center tap coefficient (or its real part) position.
  - When it is set to 0, the center tap coefficient will be treated as any other coefficient.
  - When it is set to 1, the provided center tap's value will be used to upshift the input data sample.
    - $\text{taps}[] = \{c0, c2, c4, \dots, cN, cCT\}$  where  $N = (\text{TP\_FIR\_LEN}+1)/4$  and  $cCT$  is the center tap.

**Note:** When complex coefficients are used, the center tap's real part will be used for the upshift.

**Note:** Upshift is only supported with 16-bit coefficient types (i.e., int16 and cint16).

**Note:** When Upshift is enabled, the center tap value must be in the range 0 to 47.

**Example 1:**

A 7-tap FIR halfband interpolator has coefficients (1, 0, 2, 5, 2, 0, 1). This would be input as  $\text{taps}[] = \{1, 2, 5\}$  because the context of halfband interpolation allows the remaining coefficients to be inferred.

**Example 2:**

A 7-tap FIR halfband interpolator has coefficients (1, 2, 2, 1, 2, 1, 3). Here '3' is the center tap value.

Now, if the input has a data stream of all ones (i.e., 1, 1, 1, etc.):

- If the parameter is unset, the expected output will be: [1, 3, 2, 3..]
  - If the parameter is set, the expected output will be: [1,  $2^3$ , 2,  $2^3$ ...]=[1, 8, 2, 8..]
- **Advanced:**
    - **Target input throughput (MSPS):** Specifies the rate at which data samples should be processed. The default value is 200.
    - **Specify the number of cascade stages:** When this option is not enabled, the tool will determine the filter configuration that best achieves the specified input sampling rate. When the option is enabled, the 'Number of cascade stages' can be specified (which describes the number of AI Engine processors to split the operation over). However, this allows resource to be traded for higher performance and the specified input sampling rate constraint may not be achieved. The value must be in the range 1 to 9.

## FIR Halfband Interpolator Stream



FIR Halfband Interpolator Stream

### Library

AI Engine/DSP/Stream IO

### Description

This block implements the stream-based FIR Halfband Interpolator filter targeted for AI Engines.

### Parameters

- **Main:**
  - **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.

- **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
  - Complex types are only supported when the Input/Output data type is also complex.
  - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
  - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
  - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
- **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via the input port.
- **Filter coefficients:** Specifies the filter coefficients as a vector of  $(N+1)/4+1$  elements, where 'N' is a positive integer that represents the filter length and must be in the range 4 to 240 inclusive.
- **Input frame size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be the Input window size multiplied by two by virtue of the halfband interpolation factor.
- **Scale output down by  $2^k$ :** Describes the power of 2 shift down applied to the accumulation of FIR terms before output. It must be in the range 0 to 61.
- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
  1. Floor (truncate)
  2. Ceiling
  3. Round to positive infinity
  4. Round to negative infinity
  5. Round symmetrical to infinity
  6. Round symmetrical to zero
  7. Round convergent to even
  8. Round convergent to oddModes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Number of parallel input/output (SSR):** This parameter specifies the number of input (or output) ports and must be of the form  $2^k N$ , where N is a non-negative integer.
- **Number of parallel polyphases (interp\_poly):** Number of decimation polyphases into which data is split into for parallel computation. It must be integer divisible by interpolation factor.

- **Advanced:** Number of cascade stages:
  - Specifies the number of cascade stages. The tool will guarantee the same.

## FIR Interpolation



FIR Interpolation

### Library

AI Engine/DSP/Window IO

### Description

This block implements the FIR Asymmetric Interpolation filter targeted for AI Engines.

### Parameters

- **Main:**
  - **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
  - **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
    - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
    - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
  - **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via the input port.

- **Filter coefficients:** Specifies the filter coefficients as a vector of  $(N+1)/4+1$  elements, where 'N' is a positive integer that represents the filter length and must be in the range 4 to 240 inclusive.
- **Interpolation factor:** An unsigned integer which describes the interpolation factor of the filter. It must be in the range 1 to 16.
- **Input window size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be Input window size multiplied by interpolation factor.
- **Scale output down by  $2^A$ :** Describes power of 2 shift down applied to the accumulation of FIR terms before output. It must be in range 0 to 61.
- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
  1. Floor (truncate)
  2. Ceiling
  3. Round to positive infinity
  4. Round to negative infinity
  5. Round symmetrical to infinity
  6. Round symmetrical to zero
  7. Round convergent to even
  8. Round convergent to odd

Modes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Advanced:**
  - **Target input throughput (MSPS):** Specifies the rate at which data samples should be processed. The default value is 200.
  - **Specify the number of cascade stages:** When this option is not enabled, tool will determine the filter configuration that best achieves the specified input sampling rate. When the option is enabled and the 'Number of cascade stages' is specified, the tool will guarantee the same. In such cases, however, the specified input sampling rate constraint may not be achieved.

## FIR Interpolation Stream



FIR Interpolation Stream

### Library

AI Engine/DSP/Stream IO

### Description

This block implements the stream-based FIR Asymmetric Interpolation filter targeted for AI Engines.

### Parameters

- **Main:**
  - **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
  - **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
    - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
    - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
  - **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via the input port.

- **Filter coefficients:** Specifies the filter coefficients as a vector of  $(N+1)/4+1$  elements, where 'N' is a positive integer that represents the filter length and must be in the range 4 to 240 inclusive.
- **Interpolation factor:** An unsigned integer which describes the interpolation factor of the filter. It must be in the range 1 to 16.
- **Input frame size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be Input window size multiplied by interpolation factor.
- **Scale output down by  $2^A$ :** Describes power of 2 shift down applied to the accumulation of FIR terms before output. It must be in range 0 to 61.
- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
  1. Floor (truncate)
  2. Ceiling
  3. Round to positive infinity
  4. Round to negative infinity
  5. Round symmetrical to infinity
  6. Round symmetrical to zero
  7. Round convergent to even
  8. Round convergent to odd

Modes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Number of parallel input/output (SSR):** This parameter specifies the number of input (or output) ports and must be of the form  $2^N$ , where N is a non-negative integer.
- **Advanced:** Number of cascade stages:
  - Specifies the number of cascade stages. The tool will guarantee the same.

## FIR Symmetric



**FIR Symmetric**

### Library

AI Engine/DSP/Window IO

### Description

This block implements the Single Rate Symmetric FIR Filter targeted for AI Engines.

### Parameters

- **Main:**

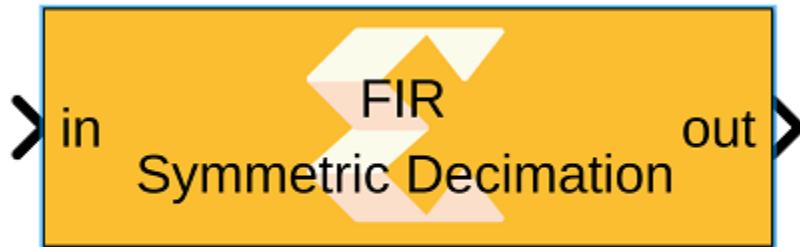
- **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
- **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
  - Complex types are only supported when the Input/Output data type is also complex.
  - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
  - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
  - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
- **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via the input port.

- **Filter coefficients:** This field should only be supplied for the first half of the filter length plus the center tap for odd lengths i.e., `taps[] = {c0, c1, c2, ..., cN [, cCT]}` where  $N = (\text{FILTER\_LENGTH})/2$  and `cCT` is the center tap where `FILTER_LENGTH` is odd. For example, a 7-tap filter might use coeffs (1, 3, 2, 5, 2, 3, 1). This could be input as `taps[] = {1,3,2,5}` because the context of symmetry allows the remaining coefficients to be inferred.
- **Filter length:** This is an unsigned integer which describes the number of taps in the filter.
- **Input window size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be the input window size by virtue the single rate nature of this filter.
- **Scale output down by  $2^{\wedge}$ :** Describes power of 2 shift down applied to the accumulation of FIR terms before output. It must be in range 0 to 61.
- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
  1. Floor (truncate)
  2. Ceiling
  3. Round to positive infinity
  4. Round to negative infinity
  5. Round symmetrical to infinity
  6. Round symmetrical to zero
  7. Round convergent to even
  8. Round convergent to oddModes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Advanced:**

- **Target input throughput (MSPS):** Specifies the rate at which data samples should be processed. The default value is 200.
- **Specify the number of cascade stages:** When this option is not enabled, the tool will determine the filter configuration that best achieves the specified input sampling rate. When the option is enabled and the 'Number of cascade stages' is specified, the tool will guarantee the same. In such cases, however, the specified input sampling rate constraint may not be achieved.

## FIR Symmetric Decimation



FIR Symmetric Decimation

### Library

AIE Engine/DSP/Window IO

### Description

This block implements the FIR Symmetric Decimation Filter targeted for AI Engines.

### Parameters

- **Main:**
  - **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
  - **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
    - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
    - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
  - **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via the input port.
  - **Filter coefficients:** This field should only be supplied for the first half of the filter length plus the center tap for odd lengths i.e.,  $taps[] = \{c_0, c_1, c_2, \dots, c_{N/2}, c_{CT}\}$  where  $N = (\text{FILTER\_LENGTH})/2$  and  $c_{CT}$  is the center tap where FILTER\_LENGTH is odd. For example, a 7-tap filter might use coeffs (1, 3, 2, 5, 2, 3, 1). This could be input as  $taps[] = \{1, 3, 2, 5\}$  because the context of symmetry allows the remaining coefficients to be inferred.

- **Filter length:** This is an unsigned integer which describes the number of taps in the filter. The filter length must be in the range 4 to 240 and must be an integer multiple of the decimation factor.
- **Decimation factor:** An unsigned integer which describes the decimation factor of the filter. It must be in the range 2 to 3. For larger factors, use the FIR Asymmetric decimation filter.
- **Input window size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be the input window size divided by decimation factor by virtue of the decimation factor.
- **Scale output down by 2<sup>n</sup>:** Describes power of 2 shift down applied to the accumulation of FIR terms before output. It must be in range 0 to 61.
- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
  1. Floor (truncate)
  2. Ceiling
  3. Round to positive infinity
  4. Round to negative infinity
  5. Round symmetrical to infinity
  6. Round symmetrical to zero
  7. Round convergent to even
  8. Round convergent to oddModes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Advanced:**

- **Target input throughput (MSPS):** Specifies the rate at which data samples should be processed. The default value is 200.
- **Specify the number of cascade stages:** When this option is not enabled, the tool will determine the filter configuration that best achieves the specified input sampling rate. When the option is enabled and the 'Number of cascade stages' is specified, the tool will guarantee the same. In such cases, however, the specified input sampling rate constraint may not be achieved.

## FIR Symmetric Decimation Stream



## FIR Symmetric Decimation Stream

### Library

AI Engine/DSP/Stream IO

### Description

This block implements the stream-based FIR Symmetric Decimation filter targeted for AI Engines.

### Parameters

- **Main:**
  - **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
  - **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
    - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
    - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
  - **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via the input port.
  - **Filter coefficients:** This field should only be supplied for the first half of the filter length plus the center tap for odd lengths i.e.,  $taps[] = \{c_0, c_1, c_2, \dots, c_{N/2}, c_{CT}\}$  where  $N = (\text{FILTER\_LENGTH})/2$  and  $c_{CT}$  is the center tap where FILTER\_LENGTH is odd. For example, a 7-tap filter might use coeffs (1, 3, 2, 5, 2, 3, 1). This could be input as  $taps[] = \{1, 3, 2, 5\}$  because the context of symmetry allows the remaining coefficients to be inferred.

- **Filter length:** This is an unsigned integer which describes the number of taps in the filter. The filter length must be in the range 4 to 240 and must be an integer multiple of the decimation factor.
- **Decimation factor:** An unsigned integer which describes the decimation factor of the filter. It must be in the range 2 to 3. For larger factors, use the FIR Asymmetric decimation filter.
- **Input frame size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be the input window size divided by decimation factor by virtue of the decimation factor.
- **Scale output down by  $2^{\wedge}$ :** Describes power of 2 shift down applied to the accumulation of FIR terms before output. It must be in range 0 to 61.
- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
  1. Floor (truncate)
  2. Ceiling
  3. Round to positive infinity
  4. Round to negative infinity
  5. Round symmetrical to infinity
  6. Round symmetrical to zero
  7. Round convergent to even
  8. Round convergent to odd

Modes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Number of parallel input/output (SSR):** This parameter specifies the number of input (or output) ports and must be of the form  $2^{\wedge}N$ , where N is a non-negative integer.
- **Advanced:** Number of cascade stages:
  - Specifies the number of cascade stages. The tool will guarantee the same.

## FIR Symmetric Stream



**FIR Symmetric Stream**

### Library

AI Engine/DSP/Stream IO

### Description

This block implements the stream-based FIR Symmetric filter targeted for AI Engines.

### Parameters

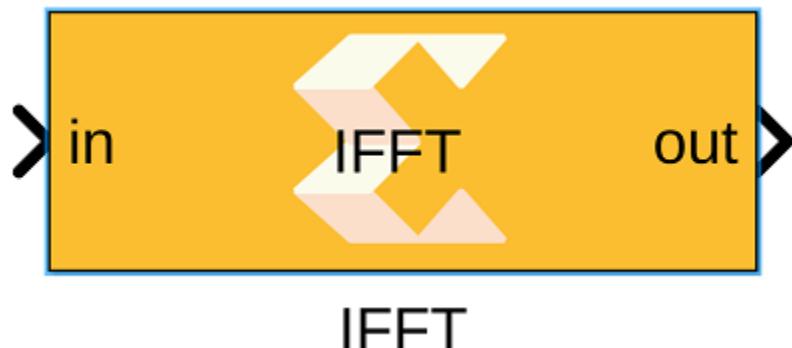
- **Main:**
  - **Input data type/Output data type:** Describes the type of individual data samples input to and output from the filter function. int16, cint16, int32, cint32, float, cfloat.
  - **Filter coefficients data type:** Describes the type of individual coefficients of the filter taps. It should be one of int16, cint16, int32, cint32, float, cfloat and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
    - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
    - Filter coefficients data type must be a float type if the Input/Output data type is a float type.
  - **Specify filter coefficients via input port:** When this option is enabled, the tool allows you to specify reloadable filter coefficients via the input port.

- **Filter coefficients:** This field should only be supplied for the first half of the filter length plus the center tap for odd lengths i.e., `taps[] = {c0, c1, c2, ..., cN [, cCT]}` where  $N = (\text{FILTER\_LENGTH})/2$  and `cCT` is the center tap where `FILTER_LENGTH` is odd. For example, a 7-tap filter might use coeffs (1, 3, 2, 5, 2, 3, 1). This could be input as `taps[] = {1,3,2,5}` because the context of symmetry allows the remaining coefficients to be inferred.
- **Filter length:** This is an unsigned integer which describes the number of taps in the filter.
- **Input frame size (Number of samples):** Describes the number of samples used as an input to the filter function. The number of values in the output window will be the input window size by virtue the single rate nature of this filter.
- **Scale output down by  $2^{\wedge}$ :** Describes power of 2 shift down applied to the accumulation of FIR terms before output. It must be in range 0 to 61.
- **Rounding mode:** Describes the selection of rounding to be applied during the shift down stage of processing. The rounding options are as follows:
  1. Floor (truncate)
  2. Ceiling
  3. Round to positive infinity
  4. Round to negative infinity
  5. Round symmetrical to infinity
  6. Round symmetrical to zero
  7. Round convergent to even
  8. Round convergent to odd

Modes 2 to 7 round to the nearest integer. They differ only in how they round for the value of 0.5.

- **Number of parallel input/output (SSR):** This parameter specifies the number of input (or output) ports and must be of the form  $2^{\wedge}N$ , where  $N$  is a non-negative integer.
- **Advanced:** Number of cascade stages:
  - Specifies the number of cascade stages. The tool will guarantee the same.

## IFFT



### Library

AI Engine/DSP/Window IO

### Description

This block implements the Inverse FFT targeted for AI Engines which use the rounding method and saturates the output samples on overflow.

### Parameters

- **Main:**
  - **Input/Output data type:** Describes the type of individual data samples input to and output from the filter function. Supported types are `cint16`, `cint32` and `cfloat`.
  - **IFFT size:** This is an unsigned integer which describes the point size of the transformation. This must be  $2^N$ , where  $N$  is in the range 4 to 11 inclusive. However, for `cint16` datatype, the IFFT size can be  $2^{12}$ , provided the IFFT receives and outputs data to/from kernels on the same processor.
- **Note:** To understand more on achieving the 4096 point size FFT, refer to the AI Engine examples in [GitHub](#).
- **Input Window Size (Number of Samples):** Describes the number of samples used as an input to the IFFT.
- **Scale output down by  $2^k$ :** Describes the power of 2 to scale the result by prior to output.
- **Advanced:**
  - **Target input throughput:** Specifies the rate at which data samples should be processed. The default value is 200.

- **Specify the number of cascade stages:** When this option is not enabled, the tool will determine the filter configuration that best achieves the specified input sampling rate. When this option is enabled and the 'Number of cascade stages' is specified, the tool will guarantee the same. In such cases, however, the specified sample rate constraint may not be achieved.
- **Number of cascade stages:** This determines the number of kernels the FFT will be divided over in series to improve throughput.

## IFFT Stream



IFFT Stream

### Library

AI Engine/DSP/Stream IO

### Description

Stream-based IFFT implementation targeted for AI Engines. The IFFT block has two stream ports per subframe processor to maximize performance. The specified value for SSR parameter should be of the form  $2^N$ , where N is a positive integer.

### Parameters

- **Main:** Input/Output Data Type:

- Describes the type of individual data samples input/output of the stream IFFT. It can be `cint16`, `cint32`, `cfloat` types.

IFFT Size:

- This is an unsigned integer which describes the point size of the transformation. This must be  $2^N$ , where N is in the range 4 to 11 inclusive.

Input Frame Size (Number of Samples):

- Specifies the number of samples for a particular frame. The value must be in the range 8 to 1024 and the default value is 64. The IFFT operation will not begin until this number of samples has been input.

Scale Output Down by  $2^A$ :

- Describes the power of 2 shift down applied before output. The following table shows the range of valid values of this parameter for different data types.

**Table 136: Valid Parameters**

Data Type	Scale output down by $2^A$
cint16	[0, log2(IFFT Size) + 15]
cint32	[0, log2(IFFT Size) + 31]
cfloat	0

SSR:

- This parameter is intended to improve performance and support IFFT sizes beyond the limitations of a single tile. For an SSR value of 'n' (which must be of the form  $2^N$ , where N is a positive integer), the IFFT operation is performed in parallel and the actual IFFT size is divided by 'n'. For example, a 16384 point IFFT with SSR value of 8 creates 8 stream inputs and there will be 8 subframe IFFTs each of point size 2048. The specified IFFT size and SSR values should be such that  $(2 * \text{IFFT size} / \text{SSR})$  is in the range of 16 and 4096.
- **Advanced:** Target Output Throughput (MSPS):
  - Specifies the output sampling rate of the IFFT function in Mega Samples per Second (MSPS). The value must be in the range 1 to 1000 and the default value is 200.

Specify the Number of Cascade Stages:

- When this option is not enabled, the tool will determine the IFFT configuration that best achieves the specified input sampling rate. When the option is enabled, the Number of cascade stages can be specified (which describes the number of AI Engine processors to split the operation over). This allows resources to be traded for higher performance, but the specified input sampling rate constraint may not be achieved. The value must be in the range of 1 to 9.

## Mixer



### Library

AI Engine/DSP/Window IO

### Description

This block implements the Mixer targeted for AI Engines.

### Parameters

- **Input/Output data type:** Describes the types of individual data samples input to and output from the Mixer function. The supported data types are `cint16`, `cint32`, and `cfloat`.
- **Input window size (Number of samples):** Specifies the number of samples in the input window. The value must be in the range 16 to 4096. Default value is 32.
- **Mixer mode:** This specifies the mixer operation modes. Two modes are supported by Mixer function:
  - **Single Input Mode:** This is a DDS plus Mixer for a single data input port. Each data input sample is complex multiplied with the corresponding DDS sample to create a modulated signal that is written to the output window. This is the default Mixer mode.
  - **Dual Input Mode:** This is a special configuration for symmetrical carriers and two data input ports. Each data sample of the first input is complex multiplied with the corresponding DDS sample to create a modulated signal. Each data sample of the second data input is complex multiplied with the conjugate (which is equivalent to a signal rotating in the opposite direction) of the DDS sample to create a second modulated signal. These two modulated signals are added together and written to the output window.
- **Phase increment :** This specifies the phase increment between the samples. The value should be in the range 0 to  $2^{31}$ .

Phase increment is calculated using the formula  $(F_o * (2^N)) / F_s$

Where:

- $F_o$  = Output frequency
- $N = 32$ , which represents the accumulator width, and it is fixed
- $F_s$  = Sampling frequency
- **Target input throughput (MSPS):** Specifies the input sampling rate of the function in Mega Samples per Second (MSPS). The value must be in the range 1 to 1000 and the default value is 200.

## Mixer Stream



Mixer Stream

### Library

AI Engine/DSP/Stream IO

### Description

This block implements the stream-based Mixer targeted for AI Engines.

### Parameters

- **Main:** Input/Output Data Type:
  - Describes the type of individual data samples output of the DDS function. It should be `cint16`, `cint32`, or `cfloat`.

Input Frame Size (Number of Samples):

- Specifies the number of samples in the input frame. The value must be in the range 8 to 1024 and the default value is 32.

Mixer Mode:

- This specifies the mixer operation modes. Two modes are supported by Mixer function:
  - **Single Input Mode:** This is a DDS plus Mixer for a single data input port. Each data input sample is complex multiplied with the corresponding DDS sample to create a modulated signal that is written to the output window. This is the default Mixer mode.
  - **Dual Input Mode:** This is a special configuration for symmetrical carriers and two data input ports. Each data sample of the first input is complex multiplied with the corresponding DDS sample to create a modulated signal. Each data sample of the second data input is complex multiplied with the conjugate (which is equivalent to a signal rotating in the opposite direction) of the DDS sample to create a second modulated signal. These two modulated signals are added together and written to the output window.

Number of parallel input/output (SSR):

- This parameter specifies the number of input (or output) ports and must be of the form  $2^N$ , where N is a non-negative integer.

Phase Increment:

- Specifies the phase increment between samples. The value must be in the range 0 to  $2^{31}$  and the default value is 0. Input value  $2^{31}$  corresponds to Pi (i.e., 180). Phase increment is calculated using the formula  $(F_o * (2^N)) / F_s$  where:
  - $F_o$  = Output frequency.
  - $N = 32$ , which represents the accumulator width, and it is fixed.
  - $F_s$  = Sampling frequency.

Initial Phase Offset:

- Specifies the initial phase offset. The default value is 0.
- **Advanced: Target Output Throughput (MSPS):**
  - Specifies the output sampling rate of the Mixer function in Mega Samples per Second (MSPS). The value must be in the range 1 to 1000 and the default value is 200.

## RTP Source



## RTP Source

### Library

AI Engine/Tools

### Description

This block can be used as a source for the RTP input of an AI Engine block. When the RTP input is a scalar, the 'RTP Value' parameter should be a row vector. At each time step, the output is set to one of the elements of the vector starting with the first element. If an element of the vector is NaN, at the corresponding sampling time, the output will be an empty variable size signal.

If the RTP input is a vector, the 'RTP value' parameter should be a matrix. Each column represents an RTP input vector. A NaN column will produce an empty variable size signal output.

### Parameters

- **RTP Value:** This represents the value which can be given as an input to an AI Engine block. This can be a scalar, vector, or a matrix and it accepts real or complex data.
- **Sample Time:** Specifies the interval between the times that the RTP source block output can change during simulation.
- **Form output after final data:** Represents a method to determine block output after the final data point.
  - **Empty:** This option sets the RTP block output to empty after final data.
  - **Holding Final value:** When this option is selected, block holds the final value.
  - **Cyclic repetition:** This option repeats the RTP block data from first value.

## To Fixed Size

This block takes a variable size vector as an input and produces a fixed size vector as output. The block copies samples from the input to the output.



### Library

AI Engine/Tools

### Description

The To Fixed Size block takes a variable size vector as an input and produces a fixed size vector as output. The block copies samples from the input to the output.

The input to the block will be buffered until the number of samples reaches the Output Size. The buffered samples will then be transferred to the out port, and the valid signal is set to true. When there are not enough samples buffered, the output port will be a vector of zeros, and the valid port is set to false.

Use this block when you need to connect a variable size signal to a block that does not accept a variable size signal. If the input variable size signal is not full, the output will not always be valid.

**Note:** It is recommended that you monitor the Valid output to make sure you are not processing invalid outputs. You can also connect the Valid output to a triggered subsystem.

### Parameters

- **Output Size:** This specifies the size of the output port:
  - **Inherit: Same as Input:** If this option is enabled, the block output size will be the same as input.
  - **Specify Output Size:** When this option is selected, you can specify the value of the required output size.

## To Variable Size



### Library

AI Engine/Tools

### Description

This block takes a fixed sized vector input and produces a variable sized vector output. The maximum size of the output vector is specified by the Output Size parameter. If there is not enough samples to pack the output, the output will be an empty variable size signal.

### Parameters

- **Show Valid Input:** If this option is enabled, the block will only accept the input data when the valid port is true.
- **Output Size:** This specifies the size of the output port.
  - **Inherit : Same as Input:** If this option is enabled, the block will only accept the input data when the valid port is true.
  - **Specify Output Size:** When this option is selected, you can specify the value of the required output size.

## Vitis Model Composer Hub

Control implementation of the model.

### Description

The Vitis Model Composer Hub block controls the behavior of the Vitis Model Composer tool.

You can specify the targeted design flow for the generated output, the directory path for the output, and the desired device and design clock frequency using the following tabs.

- The **Hardware Selection** pane helps with device or board selection.

- The **Code Generation** pane provides options to select the output flow by selecting subsystems and specifying Code directory. Different options will be displayed depending on if the subsystem is targeting HDL, HLS, or AIE.

## Library

AI Engine/Tools; HLS/Tools; Utilities/Code Generation.



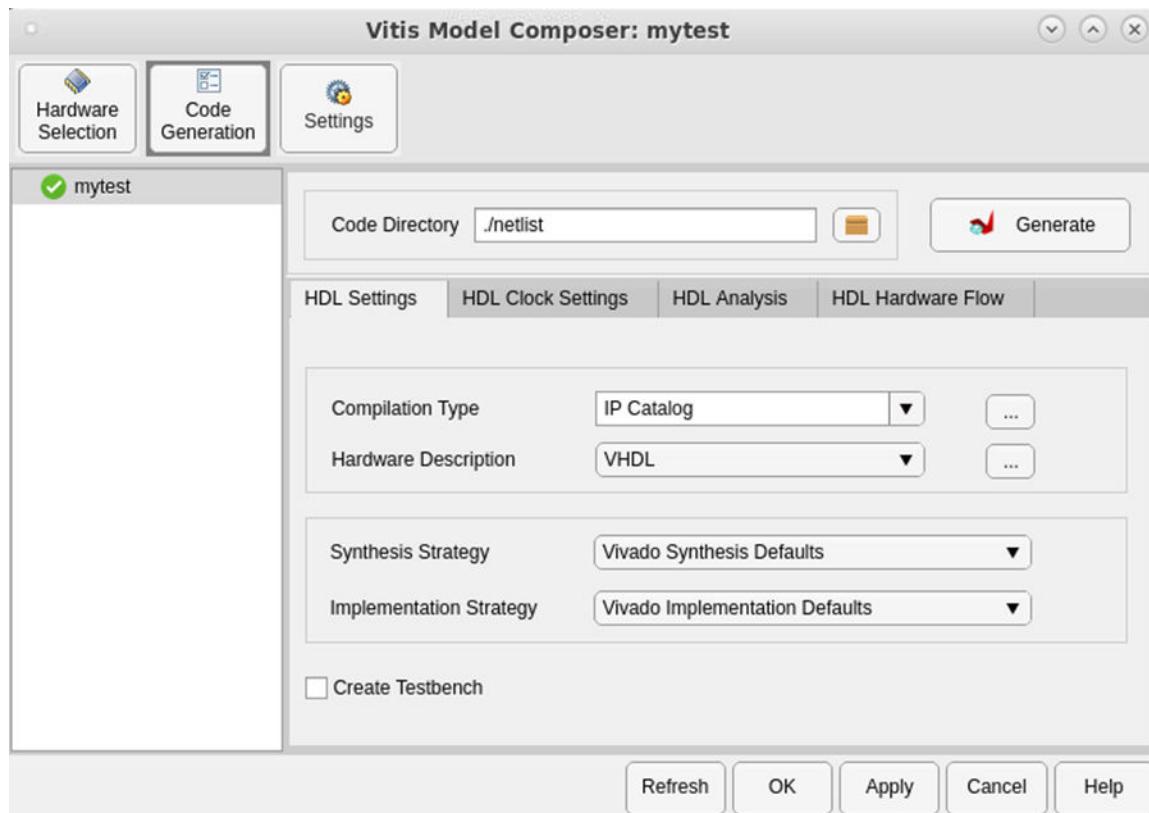
## Vitis Model Composer Hub

### Data Type Support

Data type support is not applicable to the Vitis Model Composer Hub block.

## Parameters

Figure 377: Vitis Model Composer Hub Block Parameters



The following section describes the configurable options available in each pane of the Vitis Model Composer Hub block.

- **Hardware Selection:** Clicking the browse button (...) displays the Device Chooser dialog box. This allows you to select a part, board, or platform to which your design is targeted. Vitis Model Composer obtains board and device data from the Vivado database.
- **Code Generation:** Select the subsystem name for which to generate code from the list on the left. Different settings will display depending on the type of code generation (HDL, HLS, or AI Engine) to be performed.
- **AIE Settings:**
  - **AIE Compiler Options:** When enabled, this option provides control over compiler debug options, execution target options etc.
  - **Create Testbench:** When enabled, Vitis Model Composer generates the test vectors while generating the code.

- **Run cycle-approximate AIE Simulation (SystemC) after code generation:** This option is only available if **Create testbench** is selected. When enabled, it runs the AIE simulation after code generation.
- **Simulation timeout (cycles):** When enabled, it specifies the number of cycles for which AIE simulation is run. The default value is 50000.
- **Plot AIE Simulation Output and Estimate Throughput:** When enabled, this option logs simulation data and allows visualization of the output of an AI Engine subsystem.
- **Collect profiling statistics and enable 'printf' for debugging:** When enabled, this option allows profiling data to be collected for analysis.
- **Collect data for Vitis Analyzer:** When enabled, this option provides a summary of the simulation results which can be viewed in the Vitis Analyzer.
- **Open Vitis Analyzer:** Click to invoke the Vitis Analyzer tool. This option is only enabled after AI Engine Simulation has been ran at least once after enabling.
- **AIE Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the Create Testbench option in the AIE Settings panel.
  - **Generate Hardware Validation Code:** When enabled, Vitis Model Composer generates code to be used for hardware validation.
  - **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
  - **Target:** Specify the target for hardware validation flow.
  - **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
  - **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
  - **Run hardware emulation after code generation:** When enabled, hardware emulation will run immediately after code generation.
- **HDL Settings:**
  - **Compilation Type:** Specifies the type of compilation result that should be produced when the code generator is invoked. The default compilation type is IP Catalog. When IP Catalog is selected, the Settings (...) button brings up a dialog box that allows you to add a description of the IP that will be placed in the IP catalog.
  - **Hardware Description:** Specifies the HDL language to be used for compilation of the design. The possibilities are VHDL and Verilog.
    - **VHDL library:** Specifies the name of VHDL work library for code generation. The default name is `xil_defaultlib`.

- **Use STD\_LOGIC type for Boolean or 1 bit wide gateways:** If your design's Hardware Description Language (HDL) is VHDL, selecting this option will declare a Boolean or 1-bit port (Gateway In or Gateway Out) as a STD-LOGIC type. If this option is not selected, Vitis Model Composer will interpret Boolean or 1-bit ports as vectors.

**Note:** When you enable this option and try to run Generate code and Run behavioral simulation in Vivado, you may see a failure during the elaboration phase.

- **Synthesis strategy:** Choose a Synthesis strategy from the pre-defined strategies in the drop-down menu.
- **Implementation strategy:** Choose an Implementation strategy from the pre-defined strategies in the drop-down menu.
- **Create testbench:** This instructs Vitis Model Composer to create an HDL test bench. Simulating the test bench in an HDL simulator compares Simulink simulation results with ones obtained from the compiled version of the design. To construct test vectors, Vitis Model Composer simulates the design in Simulink, and saves the values seen at gateways. The top HDL file for the test bench is named <name>\_testbench.vhd / .v, where <name> is a name derived from the portion of the design being tested.

**Note:** Testbench generation is not supported for designs that have gateways (Gateway In or Gateway Out) configured as an AXI4-Lite interface.

- **HDL Clock Settings:**

- **Enable multiple clocks:** Must be enabled when the design has multiple clocks. This indicates to the code generation engine that the clock information for the various subsystems must be obtained from the respective clock tabs. If not enabled, then the design will be treated as a single clock design.
- **Number of clocks:** Defines the number of clocks in the design. The number of clock tabs that appear will be equivalent to the number of clocks. In each clock tab, you must select the subsystem and configure the clock settings of that subsystem.
- **FPGA clock period (ns):**

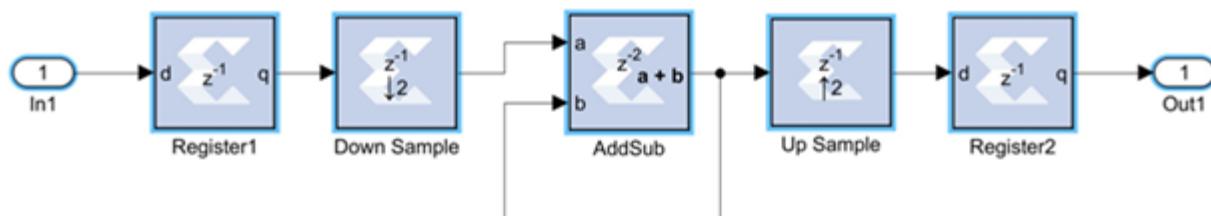
Defines the period in nanoseconds of the system clock. The value need not be an integer. The period is passed to the Xilinx implementation tools through a constraints file, where it is used as the global PERIOD constraint. Multicycle paths are constrained to integer multiples of this value.

- **Simulink system period (sec):** Defines the Simulink System Period, in units of seconds. The Simulink system period is the greatest common divisor of the sample periods that appear in the model. These sample periods are set explicitly in the block dialog boxes, inherited according to Simulink's propagation rules, or implied by a hardware oversampling rate in blocks with this option. In the final case, the implied sample time is in fact faster than the

observable simulation sample time for the block in Simulink. In hardware, a block having an oversampling rate greater than one processes its inputs at a faster rate than the data. For example, a sequential multiplier block with an over-sampling rate of eight implies a (Simulink) sample period that is one eighth of the multiplier block's actual sample time in Simulink. This parameter can be modified only in a master block.

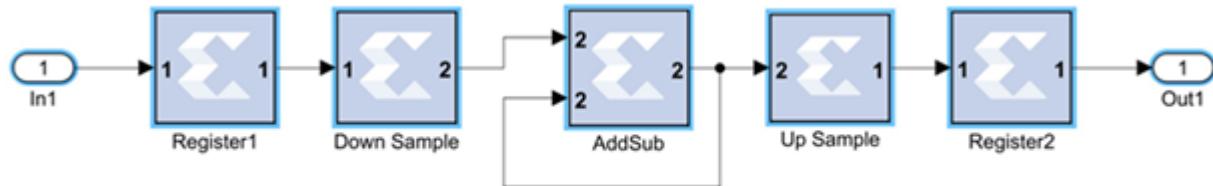
- **Clock pin location:** Defines the pin location for the hardware clock. This information is passed to the Xilinx implementation tools through a constraints file. This option should not be specified if the Vitis Model Composer design is to be included as part of a larger HDL design.
- **Provide clock enable clear pin:** This instructs Vitis Model Composer to provide a `ce_clr` port on the top-level clock wrapper. The `ce_clr` signal is used to reset the clock enable generation logic. The ability to reset clock enable generation logic allows designs to have dynamic control for specifying the beginning of data path sampling.
- **HDL Analysis:**
  - **Block icon display:** Specifies the type of information to be displayed on each block icon in the model after compilation is complete. The various display options are described below.
  - **Default:** Displays the default block icon information on each block in the model. A block's default icon is derived from the `xbsIndex` library.

**Figure 378: Default Block Icon**



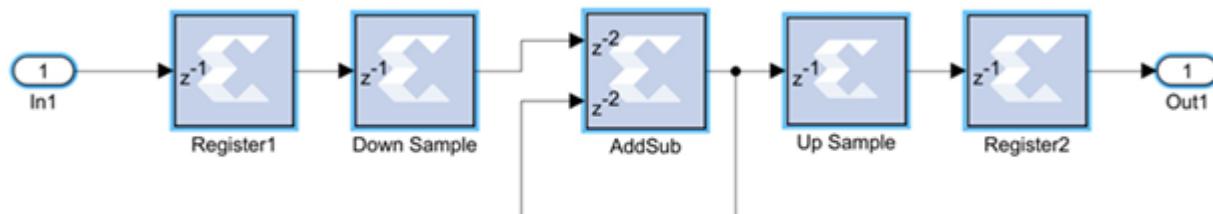
- **Normalized Sample Periods:** Displays the normalized sample periods for all the input and output ports on each block. For example, if the Simulink System Period is set to 4 and the sample period propagated to a block port is 4, then the normalized period that is displayed for the block port is 1; and if the period propagated to the block port is 8 then the sample period displayed would be 2 (a larger number indicates a slower rate).

Figure 379: Normalized Sample Periods Icon



- **Sample frequencies (MHz):** Displays sample frequencies for each block.
- **Pipeline stages:** Displays the latency information from the input ports of each block. The displayed pipeline stage might not be accurate for certain high-level blocks such as the FFT, RS Encoder/Decoder, Viterbi Decoder, etc. In this case the displayed pipeline information can be used to determine whether a block has a combinational path from the input to the output. For example, the Up Sample block in the following figure shows that it has a combinational path from the input to the output port.

Figure 380: Pipeline Stages



- **HDL port names:** Displays the HDL port name of each port on each block in the model.
- **Input data types:** Displays the data type of each input port on each block in the model.
- **Output data types:** Displays the data type of each output port on each block in the model.
- **Update the model:** Update the model to display the selected Block Icon type.
- **Perform Analysis:** Specifies whether an analysis (timing or resource) will or will not be performed on the Vitis Model Composer design when it is compiled. If **None** is selected, no timing analysis or resource analysis will be performed. If **Post Synthesis** is selected, the analysis will be performed after the design has been synthesized in the Vivado toolset. If **Post Implementation** is selected, the analysis will be performed after the design is implemented in the Vivado toolset.
- **Analysis Type:** Two selections are provided: Timing or Resource. After generation is completed, a Timing Analyzer table or Resource Analyzer table is launched.

- **Launch:** Launches the Timing Analyzer or Resource Analyzer table, depending on the selection of Analyzer type. This will only work if you already ran analysis on the Simulink model and haven't changed the Simulink model since the last run.
- **Remote IP cache:** If selected, your design will access an IP cache whenever a Vitis Model Composer compilation performs Vivado synthesis as part of the compilation. If the compilation generates an IP instance for synthesis, and the Vivado synthesis tool generates synthesis output products, the tools create an entry in the cache area. If a new customization of the IP is created which has identical properties, the tools will copy the synthesis outputs from the cache to the design's output directory instead of synthesizing the IP instance again. Accessing the disk cache speeds up the iterative design process. IP caching is described in HDL Library.
- **Create interface document:** When this check box is selected and the **Generate** button is activated for netlisting, Vitis Model Composer creates an HTM document that describes the design being netlisted. This document is placed in a `documentation` subfolder under the `netlist` folder.
- **Clear cache:** Clicking this button clears the remote IP cache. Clearing the cache saves disk space (the IP Cache can grow large, especially if your design uses many IP modules).
- **HDL Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the **Create Testbench** option in the HDL Settings panel. The HDL hardware flow is only supported for Versal® devices.
  - **Generate Hardware Validation Code:** When enabled, Vitis Model Composer generates code to be used for hardware validation.
  - **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
  - **Target:** Specify the target for hardware validation flow.
  - **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
  - **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
  - **Generate (BOOT.BIN/SD card image) after code generation:** When enabled, a BOOT.BIN (for baremetal HW system) or SD card image (for Linux HW system) will be generated after code generation.
- **HLS Settings:**
  - **Target:** Select IP Catalog to export the design to the Vivado IP Catalog. After C/C++ code generation, Vitis High-Level Synthesis (HLS) is invoked to synthesize the C code and create a project that can be exported as an IP to the Vivado IP Catalog. Select HLS C++ code to compile the design model into C++ code.
  - **FPGA clock frequency:** Specifies the clock frequency in MHz for the targeted device. This frequency is passed to the downstream tool flow.

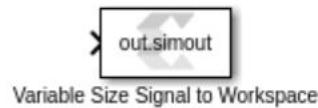
- **Throughput factor:** Specifies the number of samples processed per clock to increase the throughput. A larger factor increases hardware resource usage. The throughput factor must be between 1 and 16.
- **Create testbench and run (C simulation/RTL cosimulation):** If selected, Vitis Model Composer runs simulation and generates test vectors while generating code.
- **Testbench stack size (MBytes):** This parameter prompts you to enter a larger stack size. When **Create and run testbench** is enabled, the **Testbench stack size** option specifies the size of the testbench stack frame during C simulation (CSIM). Occasionally, the default stack frame size of 10 MB allocate for execution of the testbench may be insufficient to run the test, due to large arrays allocated on the stack and/or deep nesting of subsystems. Typically when this happens, the test would fail with a segmentation fault and an associated error message. In such a case you can increase the size of the stack frame and rerun the test.
- **HLS Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the Create Testbench option in the HLS Settings panel. Generate Hardware Validation Code.

When enabled, Vitis Model Composer generates code to be used for hardware validation.

- **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
- **Target:** Specify the target for hardware validation flow.
- **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
- **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
- **Generate (BOOT.BIN/SD card image) after code generation:** When enabled, a BOOT.BIN (for baremetal HW system) or SD card image (for Linux HW system) will be generated after code generation.
- **Code Generation:** Select a subsystem containing blocks from the AI Engine, HDL, or HLS blocksets and specify the corresponding Code Directory. The Code Directory can be specified by entering the complete directory path or using the Browse button to provide a path.
- **Settings:** Specify whether the Model Composer Hub block should treat your model as a legacy System Generator design.

## Variable Size Signal to Workspace

This block is used to save variable size signal data from your Simulink® simulation to the MATLAB® workspace.



## Library

AI Engine/Tools

## Description

AI Engine blocks produce variable signal outputs. The Variable Size Signal to Workspace block allows you to write data into the MATLAB workspace in a structured format.

**Note:** This block behaves similarly to the Simulink To Workspace block but will make it easier to analyze the output data by discarding empty sample in the input variable size signal and concatenating valid samples into a MATLAB vector. This block can only be connected to a variable size signal. The settings of the block can be accessed from Simulink Model settings (**Ctrl+E**) under the **Data Import/Export** tab. In particular, here you can set all simulation outputs as a single Simulink Simulation Output object or as individual variables.

## Parameters

- **Variable Name:** Using this parameter, you can specify the name for workspace variable.

## PLIO



## Library

AI Engine/Interfaces

## Description

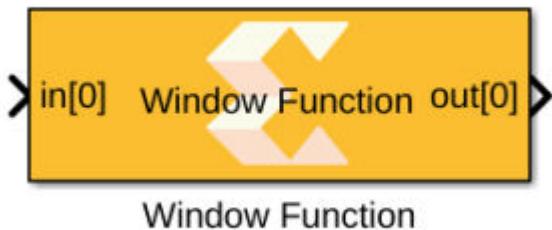
This block allows you to specify the Platform IO (PLIO) width. Specifying the PLIO width at the boundary of the AI Engine subsystem can affect the throughput of data between the AI Engine domain and the programmable logic (PL) domain. For example, assume your PL domain is running at 500 MHz and your AI Engine is running at 1GHz and datatype of the input signal to the AI Engine kernel that is directly connecting to PL is of type `int32`. For maximum throughput, you should set the PLIO width to 64 and the PL design should create a 64-bit wide data. This way for every 64-bit sample generated in the PL domain at 500 MHz, the AI Engine kernel will receive two 32-bit wide samples at 1 GHz.

## Parameters

- **FIFO Depth (32-bit words):**

Should be a non-negative integer value and the default value is '0'.

## Window Function



## Library

AI Engine/DSP/Window IO

## Description

Window function implementation targeted for AI Engines. This block is the utility to apply a windowing (scaling) function such as Hamming to a frame of input window data samples.

## Parameters

- **Main: Input/Output Data Type:**
  - Describes the type of individual data samples input/output of the dynamic point FFT. It can be `cint16`, `cint32`, or `cfloat` types.

**Filter coefficients data type:**

- Describes the type of individual coefficients of the filter taps. It should be one of int16, int32, or float and must also satisfy the following rules:
  - Complex types are only supported when the Input/Output data type is also complex.
  - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.
  - Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
  - Filter coefficients data type must be a float type if the Input/Output data type is a float type.

**Filter coefficients:**

- Specifies the filter coefficients as a vector of  $(N+1)/4+1$  elements, where 'N' is a positive integer that represents the filter length and must be in the range 4 to 240 inclusive.

**FFT Maximum Size:**

- Specifies the maximum FFT size that is supported by Dynamic point FFT. You can perform different lengths of FFT on different input data frames. It must be a power of 2 with a minimum value of 16. The maximum value supported by the library element is 65536.

**Use dynamic point size:**

- Describes whether to support run time selectable point size for the frames of data within the AIE window to be processed.
- For dynamic FFT, point size specifies the maximum point size and data can have smaller point sizes based on the header information. It is not trivial to derive the corresponding window function for each point size from the max point size. Hence, for example, if you specify the point size as 64, then you should specify 128 length coefficients where first 64 coefficients specify window function for point size of 64, the next 32 for the point size of 32, and so on.
- When the flag is enabled, the coefficient list array must specify the weights for the maximum point size and all smaller point sizes, so it must be in the range `FFT_POINT_SIZE + FFT_POINT_SIZE/2` to `2*FFT_POINT_SIZE`.

**Input Window Size:**

- Specifies the number of samples in the input frame excluding the header. The value must be in the range 16 to 65536 and the default value is 64.

**Scale Output down by  $2^A$ :**

- Describes the power of 2 shift down applied before output.

**SSR:**

- This parameter is intended to improve performance and support FFT sizes beyond the limitations of a single tile. For an SSR value of 'n' (which must be of the form  $2^N$ , where N is a positive integer), the FFT operation is performed in parallel and the actual FFT size is divided by 'n'. For example, a 16384 point FFT with SSR value of 8 creates 8 stream inputs and there will be 8 subframe FFTs each of point size 2048. The specified FFT size and SSR values should be such that FFT size / SSR should not exceed 2048.

## Window Function Stream



### Library

AI Engine/DSP/Stream IO

### Description

Window function implementation targeted for AI Engines. This block is the utility to apply a windowing (scaling) function such as Hamming to a frame of input Stream data samples.

The Windowing utility block is only expected to work with FFTs, which only allow  $2^n$  inputs/outputs ports.

### Parameters

- **Main:** Input/Output Data Type:
  - Describes the type of individual data samples input/output of the dynamic point FFT. It can be cint16, cint32, and cfloat types.
- Filter coefficients data type:
  - Describes the type of individual coefficients of the filter taps. It should be one of int16, int32, or float and must also satisfy the following rules:
    - Complex types are only supported when the Input/Output data type is also complex.
    - 32-bit types are only supported when the Input/Output data type is also a 32-bit type.

- Filter coefficients data type must be an integer type if the Input/Output data type is an integer type.
- Filter coefficients data type must be a float type if the Input/Output data type is a float type.

Filter coefficients:

- Specifies the filter coefficients as a vector of  $(N+1)/4+1$  elements, where 'N' is a positive integer that represents the filter length and must be in the range 4 to 240 inclusive.

FFT Maximum Size:

- Specifies the maximum FFT size that is supported by Dynamic point FFT. You can perform different lengths of FFT on different input data frames. It must be a power of 2 with a minimum value of 16. The maximum value supported by the library element is 65536.

Use dynamic point size:

- Describes whether to support run time selectable point size for the frames of data within the AIE window to be processed.
- For dynamic FFT, point size specifies the maximum point size and data can have smaller point sizes based on the header information. It is not trivial to derive the corresponding window function for each point size from the max point size. Hence, for example, if we specify point size as 64, then we should specify 128 length coefficients where first 64 coefficients specify window function for point size of 64, the next 32 for the point size of 32, and so on.
- When the flag is enabled, The coefficient list array must specify the weights for the maximum point size and all smaller point sizes, so must be in the range  $\text{FFT\_POINT\_SIZE} + \text{FFT\_POINT\_SIZE}/2$  to  $2*\text{FFT\_POINT\_SIZE}$ .

Input Window Size:

- Specifies the number of samples in the input frame excluding the header. The value must be in the range 16 to 65536 and the default value is 64.

Scale Output down by  $2^{\wedge}$ :

- Describes the power of 2 shift down applied before output.

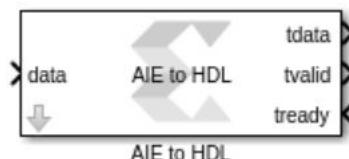
SSR:

- This parameter is intended to improve performance and support FFT sizes beyond the limitations of a single tile. For an SSR value of 'n' (which must be of the form  $2^{\wedge}N$ , where N is a positive integer), the FFT operation is performed in parallel and the actual FFT size is divided by 'n'. For example, a 16384 point FFT with SSR value of 8 creates 8 stream inputs and there will be 8 subframe FFTs each of point size 2048. The specified FFT size and SSR values should be such that FFT size / SSR should not exceed 2048
- The Windowing utility accepts only powers of 2 as the number of inputs/outputs.

# Utility Blocks

## AIE to HDL

This block is used to connect AI Engine domain to HDL domain using an AXI4-Stream interface.



### Library

Utilities/Connectors

### Description

This block provides an interface between the AI Engine and HDL blocks.

- Input to the AIE to HDL block is a variable size signal (`data`) from AIE blocks along with the `tready` signal which indicates that the consumer (HDL) can accept a transfer.
- Output from the AIE to HDL block is `tdata` and `tvalid` that indicates the producer has valid data available. A transfer takes place when both `tvalid` and `tready` boolean signals are set to TRUE(1).

If the `tready` signal is FALSE (0), the block buffers the input data until the `tready` signal is TRUE(1). If during simulation, the `tready` signal remains FALSE(0) for an extended amount of time, eventually the internal buffer of the block will overflow and the simulation will stop.

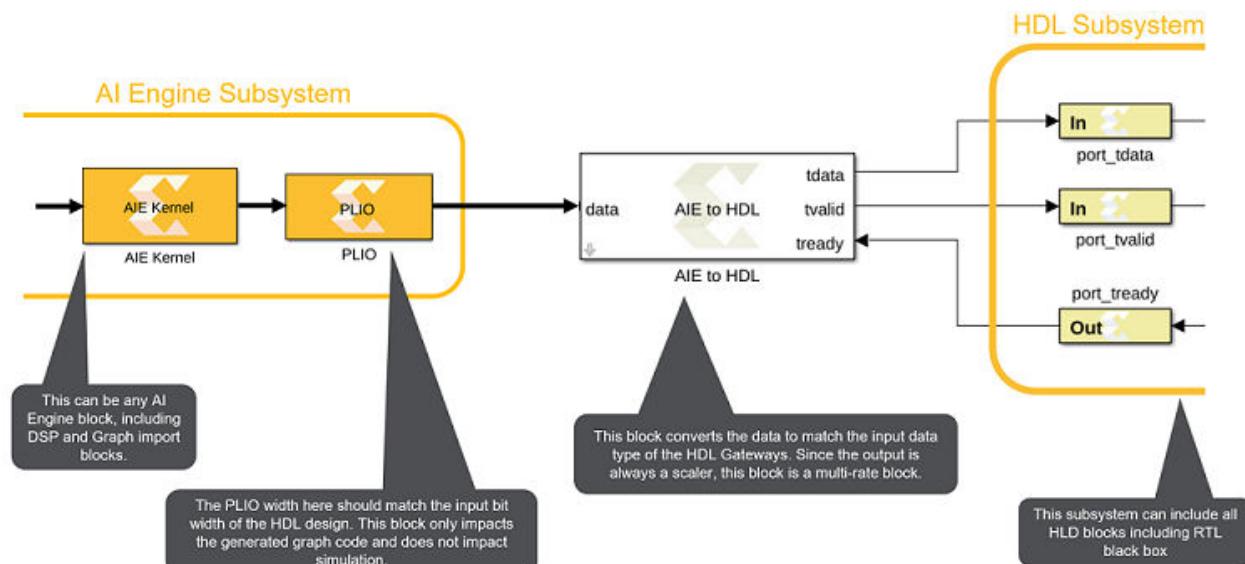
The `tdata` output is scalar but the `data` input is a variable size signal, making this block a multirate block.

If the HDL domain takes N clock cycles to process one input sample, `tready` will be TRUE(1) for one cycle out of the N clock cycles. In this case, the input sample time into the AIE to HDL block must be at least N times larger than the HDL domain sample period (specified in the HDL input gateway blocks) to avoid overflow of the internal buffers of the block.

### Topology

The image below depicts the topology of the connection between the AI Engine to HDL domain.

**Note:** The PLIO width should match the bitwidth of the output data type of the AIE to HDL block and also the output type of the `tdata` Gateway In block.



## Parameters

- Output Data Type:** The following table shows different Output data types that are supported by AIE to HDL blocks and the corresponding input data type to the block.

Output Data Type	Input to AIE to HDL Block
int32	int32
uint32	int8, uint8, int16, uint16, uint32, single, cint16
int64	int64
uint64	int8, uint8, int16, uint16, cint16, int32, uint32, cint32, uint64, single, single(c)
ufix128	int8, uint8, int16, uint16, cint16, int32, uint32, cint32, int64, uint64, single, single(c)

- Output Sample Time:** By default this parameter inherits the sample time from the `tready` input.

**Note:** For more information on setting this block and examples, refer to [GitHub](#).

## AIE to HLS

This block is used to connect the AI Engine domain to the HLS kernel block in cases where the data type or complexity of the ports do not match.



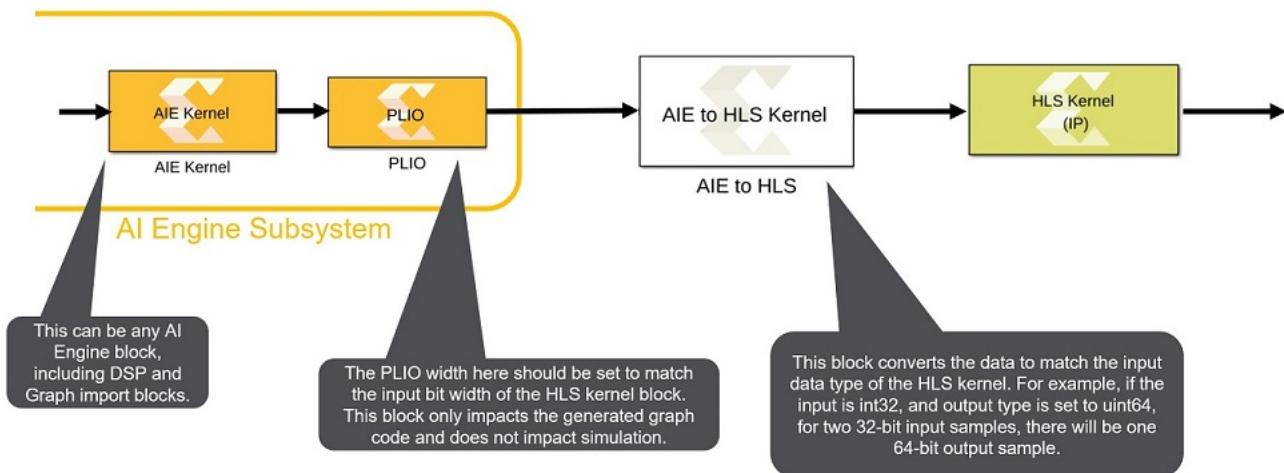
## Library

Utilities/Connectors

## Description

The AIE to HLS kernel block reformats a signal driven by an AI Engine block so that the resulting signal matches the data type and complexity required by the input of an HLS Kernel block.

## Topology



## Parameters

- Output Data Type:** Possible values are: cint16, int32, uint32, cint32, int64, uint64, sfix128, ufix128, float, and cfloat
- Output Size:** The size of the output port. The output port is a variable sized signal whose maximum size is specified by the Output Size parameter. Default Output Size is '1'. For example if the input signal to the block is a vector of size 24 and of uint16 data type and the output data type is set to uint64, each output sample will include four input samples. As such the output size must be equal to or larger than 8.

### Note:

1. The input data type must be one of the following: int8, int16, int32, int64, x\_sfix128, uint8, uint16, uint32, uint64, x\_ufix128.
2. The input can be real or complex, but complex inputs are supported only for int16 and int32.

## HDL to AIE

This block is used to connect the HDL domain to the AI Engine domain using the AXI4-Stream protocol.



## Library

Utilities/Connectors

## Description

This block provides an interface between the HDL and AI Engine blocks.

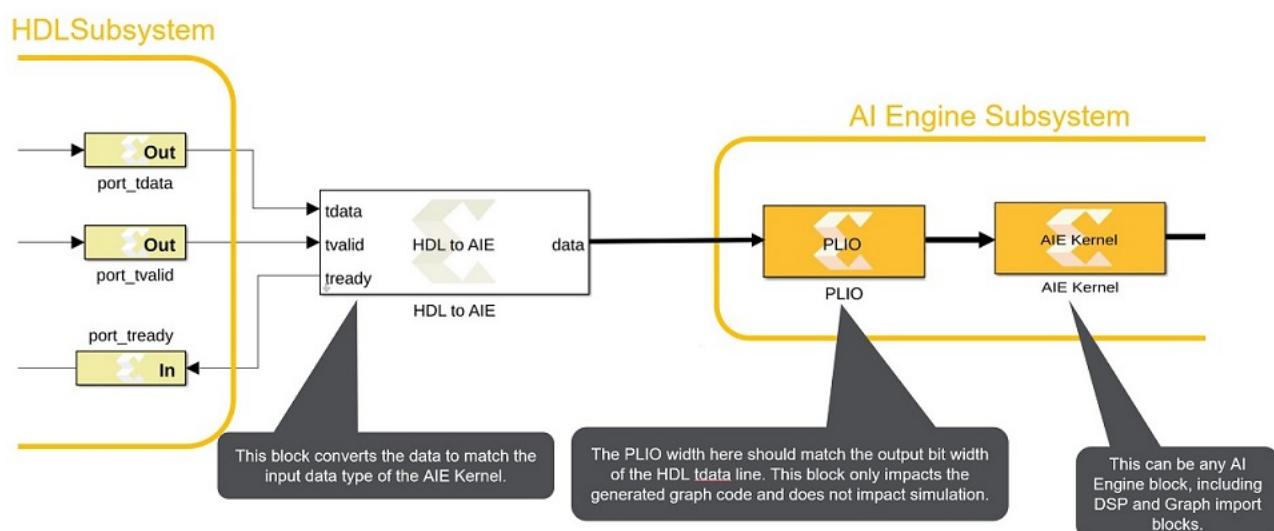
- Input to the HDL to AIE block is `tdata` which is the primary input for the data. The `tvalid` signal indicates that the producer has valid data.
- Output from the HDL to AIE block is a variable size signal (`data`) to AI Engine blocks along with the `tready` signal which indicates that the HDL to AIE block can accept a transfer. A transfer takes place when both `tvalid` and `tready` are set to TRUE(1).

## Topology

The following figure depicts the connection between the HDL and AI Engine domains using the HDL to AIE block.

**Note:** The bitwidth of the `tdata` input signal to the HDL to AIE block must match the PLIO bitwidth.

**Figure 381: HDL to AI Engine domains using the HDL to AIE block**



## Parameters

- **Output Data Type:** The following table shows the Output data types that are supported by the HDL to AIE blocks and the corresponding input data type to the block.

Output Data Type	Input to HDL to AIE block
int8	uint32, ufix64, ufix128
uint8	uint32, ufix64, ufix128
int16	uint32, ufix64, ufix128
uint16	uint32, ufix64, ufix128
cint16	uint32, ufix64, ufix128
int32	int32, ufix64, ufix128
uint32	uint32, ufix64, ufix128
cint32	ufix64, ufix128
int64	sfix64
uint64	ufix64, ufix128
float	uint32, ufix64, ufix128
float(c)	ufix64, ufix128

- **Output Sample Time:** Set the Output Sample Time to:

$$\text{output sample time} = \text{input sample time} * \frac{\text{output bit width}}{\text{input bit width}}$$

**Note:** For more information on setting this block and examples, refer to [GitHub](#).

- **Samples per output frame:** This determines the number of samples to be queued in the buffer before the block updates the frame. The size of the output frame should generally match the input size of the consuming AI Engine block.

## HLS to AIE

This block is used to connect an HLS kernel block to AI Engine domain when the datatype or complexities of the ports involved do not match.



## Library

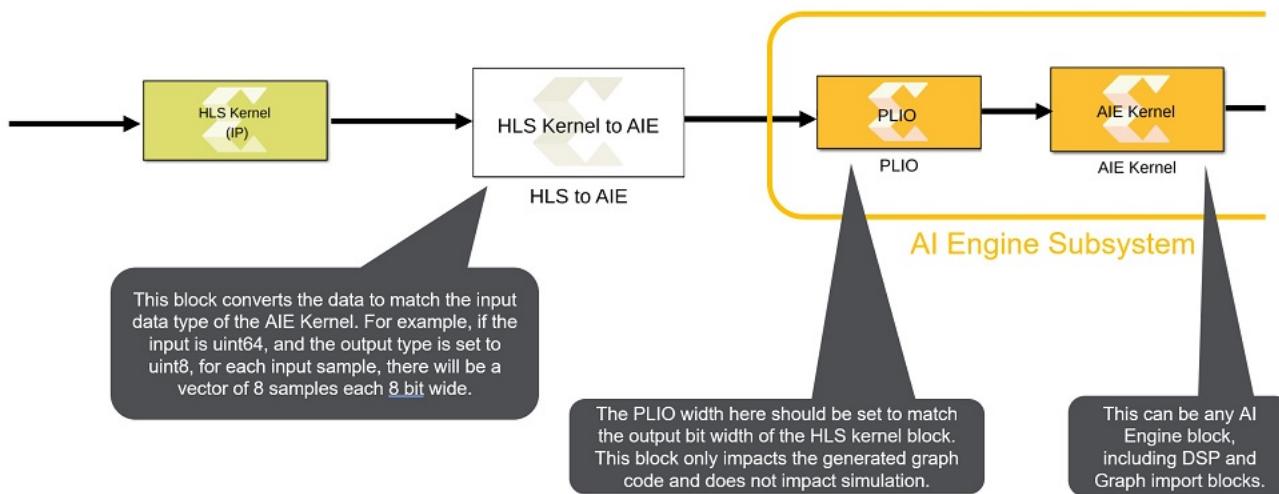
Utilities/Connectors

## Description

The HLS Kernel to AIE block reformats a signal driven by a port of an HLS Kernel block so that the resulting signal matches the data type and complexity required by an AI Engine block.

**Note:** The inputs to the block must be real and the supported input data types are: int32, int64, x\_sfix128, uint32, uint64, x\_ufix128.

## Topology



## Parameters

- AIE Input Type:** Possible values are: int8, int16, int32, int64, uint8, uint16, uint32, uint64, cint16, cint32, float, cfloat
- Output Size:** The size of the output port. The output port is a variable sized signal whose maximum size is specified by the Output Size parameter. Default size is '1'. For example if the input is a vector of size 24, its datatype is uint64, and the output datatype is set to uint8, for each input sample, there will be 8 output samples. As such the **Output Size** should be set to  $8 \times 24 = 192$  or larger.

## System Generator



**IMPORTANT!** The System Generator token will be removed in a future release of Vitis Model Composer. Please consider updating your model to use the [Vitis Model Composer Hub](#) block.

The System Generator token serves as a control panel for controlling system and simulation parameters, and it is also used to invoke the code generator for netlisting. Every Simulink® model containing any element from the HDL Blockset must contain at least one System Generator token. Once a System Generator token is added to a model, it is possible to specify how code generation and simulation should be handled.



## Token Parameters

The parameters dialog box can be invoked by double-clicking the icon in your Simulink model.

- **Compilation tab:**

Parameters specific to the Compilation tab are as follows.

- **Board:**

Specifies a Xilinx, Partner, or Custom board you will use to test your design. You can specify a **Board** for any of the compilation targets you select with the **Compilation** setting described below (**IP Catalog**, **Hardware Co-Simulation**, **Synthesized Checkpoint**, or **HDL Netlist**).

When you select a **Board**, the **Part** field displays the name of the Xilinx device on the selected **Board**, and this part name cannot be changed.

For a Partner board or a custom board to appear in the **Board** list, you must configure Model Composer to access the board files that describe the board.

- **Part:** Defines the Xilinx FPGA or SoC part to be used. If you have selected a **Board**, the **Part** field will display the name of the Xilinx device on the selected **Board**, and this part name cannot be changed.

- **Compilation:**

Specifies the type of compilation result that should be produced when the code generator is invoked. The default compilation type is **IP Catalog**.

The **Settings** button is activated when one of these compilation types is selected:

- **IP Catalog compilation:** The **Settings** button brings up a dialog box that allows you to add a description of the IP that will be placed in the IP catalog.

- **Hardware Co-Simulation (JTAG) compilation:** The **Settings** button brings up a dialog box that allows you to use burst data transfers to speed up JTAG hardware co-simulation.
- **Hardware Description Language:** Specifies the HDL language to be used for compilation of the design. The possibilities are VHDL and Verilog.
- **VHDL library:** Specifies the name of VHDL work library for code generation. The default name is `xil_defaultlib`.
- **Use STD\_LOGIC type for Boolean or 1 bit wide gateways:** If your design's Hardware Description Language (HDL) is VHDL, selecting this option will declare a Boolean or 1-bit port (Gateway In or Gateway Out) as a STD-LOGIC type. If this option is not selected, Model Composer will interpret Boolean or 1-bit ports as vectors.

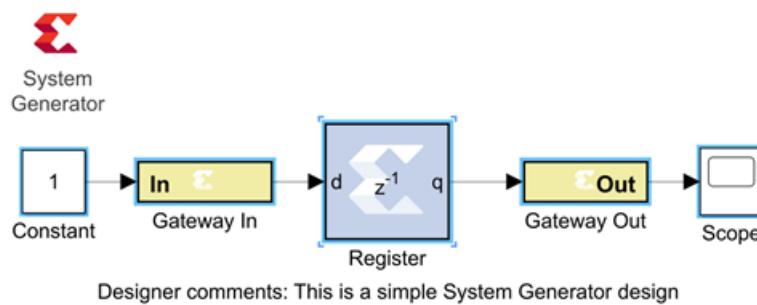
**Note:** When you enable this option and try to run Generate code and Run behavioral simulation in Vivado, you may see a failure during the elaboration phase.

- **Target directory:** Defines where Model Composer should write compilation results. Because Model Composer and the FPGA physical design tools typically create many files, it is best to create a separate target directory, for example, a directory other than the directory containing your Simulink® model files.
- **Synthesis strategy:** Choose a Synthesis strategy from the pre-defined strategies in the drop-down list.
- **Implementation strategy:** Choose an Implementation strategy from the pre-defined strategies in the drop-down list.
- **Create interface document:** When this box is checked and the Generate button is activated for netlisting, Model Composer creates an HTM document that describes the design being netlisted. This document is placed in a “documentation” subfolder under the netlist folder.

**Adding Designer Comments to the Generated Document:** If you want to add personalized comments to the auto-generated document, follow this procedure.

1. As shown below, double click the Simulink canvas at the top level and add a comment that starts with **Designer Comments**:

Figure 382: Designer Comments



2. Double click on the System Generator token, click the **Create interface document** box at the bottom of the Compilation tab, then click **Generate**.
3. When netlisting is complete, navigate to the documentation subfolder underneath the netlist folder and double-click on the HTM document.

Designer Comments section is created in the document and your personalized comments are included.

Figure 383: Designer Comments Section



- **Create testbench:** This instructs Model Composer to create an HDL test bench. Simulating the test bench in an HDL simulator compares Simulink simulation results with ones obtained from the compiled version of the design. To construct test vectors, Model Composer simulates the design in Simulink, and saves the values seen at gateways. The top HDL file for the test bench is named <name>\_testbench.vhd/.v, where <name> is a name derived from the portion of the design being tested.

**Note:** Testbench generation is not supported for designs that have gateways (Gateway In or Gateway Out) configured as an AXI4-Lite Interface

- **Model Upgrade:** Generates a Status Report that helps you identify and upgrade blocks that are not the latest available.
- **Clocking tab:**

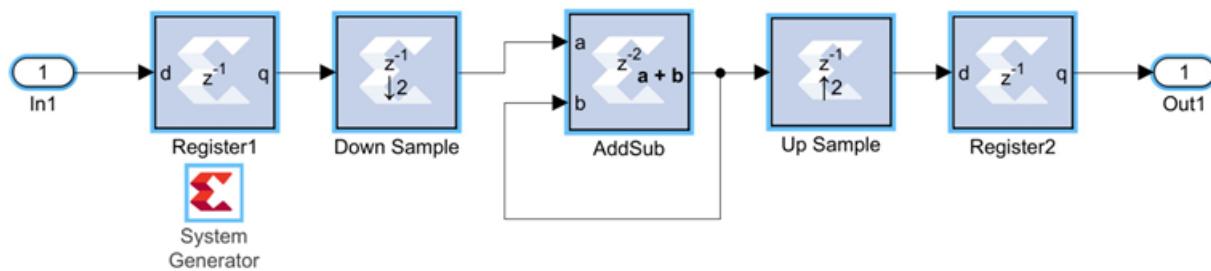
Parameters specific to the Clocking tab are as follows.

- **Enable multiple clocks:** Must be enabled in the top-level System Generator token of a multiple clock design. This indicates to the Code Generation engine that the clock information for the various Subsystems must be obtained from the System Generator tokens contained in those Subsystems. If not enabled, then the design will be treated as a single clock design where all the clock information is inherited from the top-level System Generator token.
  - **FPGA clock period(ns):** Defines the period in nanoseconds of the system clock. The value need not be an integer. The period is passed to the Xilinx implementation tools through a constraints file, where it is used as the global PERIOD constraint. Multicycle paths are constrained to integer multiples of this value.
  - **Clock pin location:** Defines the pin location for the hardware clock. This information is passed to the Xilinx implementation tools through a constraints file. This option should not be specified if the Model Composer design is to be included as part of a larger HDL design.
  - **Provide clock enable clear pin:** This instructs Model Composer to provide a `ce_clr` port on the top-level clock wrapper. The `ce_clr` signal is used to reset the clock enable generation logic. Capability to reset clock enable generation logic allows designs to have dynamic control for specifying the beginning of data path sampling.
  - **Simulink system period (sec):** Defines the Simulink System Period, in units of seconds. The Simulink system period is the greatest common divisor of the sample periods that appear in the model. These sample periods are set explicitly in the block dialog boxes, inherited according to Simulink propagation rules, or implied by a hardware oversampling rate in blocks with this option. In the latter case, the implied sample time is in fact faster than the observable simulation sample time for the block in Simulink. In hardware, a block having an oversampling rate greater than one processes its inputs at a faster rate than the data. For example, a sequential multiplier block with an over-sampling rate of eight implies a (Simulink) sample period that is one eighth of the multiplier block's actual sample time in Simulink. This parameter can be modified only in a master block.
  - **Perform analysis:** Specifies whether an analysis (timing or resource) will or will not be performed on the Model Composer design when it is compiled. If **None** is selected, no timing analysis or resource analysis will be performed. If **Post Synthesis** is selected, the analysis will be performed after the design has been synthesized in the Vivado® toolset. If **Post Implementation** is selected, the analysis will be performed after the design is implemented in the Vivado toolset.
  - **Analyzer type:** Two selections are provided: **Timing or Resource**. After generation is completed, a Timing Analyzer table or Resource Analyzer table is launched.
  - **Launch analyzer:** Launches the Timing Analyzer or Resource Analyzer table, depending on the selection of **Analyzer type**. This will only work if you already ran analysis on the Simulink model and haven't changed the Simulink model since the last run.
- **General tab:**

Parameters specific to the General tab are as follows.

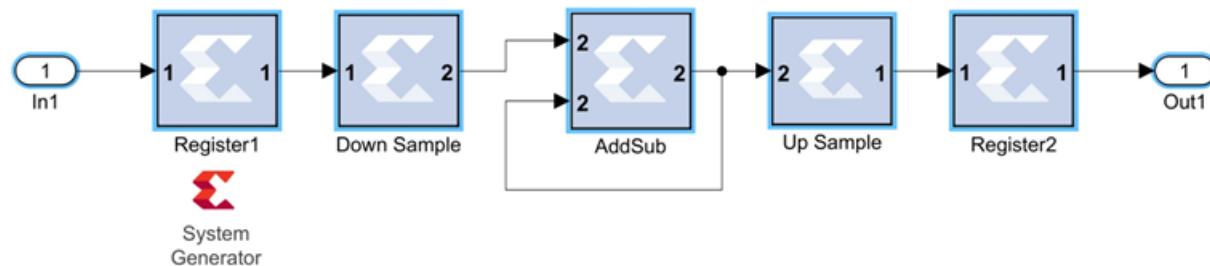
- **Block icon display:** Specifies the type of information to be displayed on each block icon in the model after compilation is complete. The various display options are described below.
  - **Default:** Displays the default block icon information on each block in the model. A block's default icon is derived from the xbsIndex library.

**Figure 384: Default Block Icon**



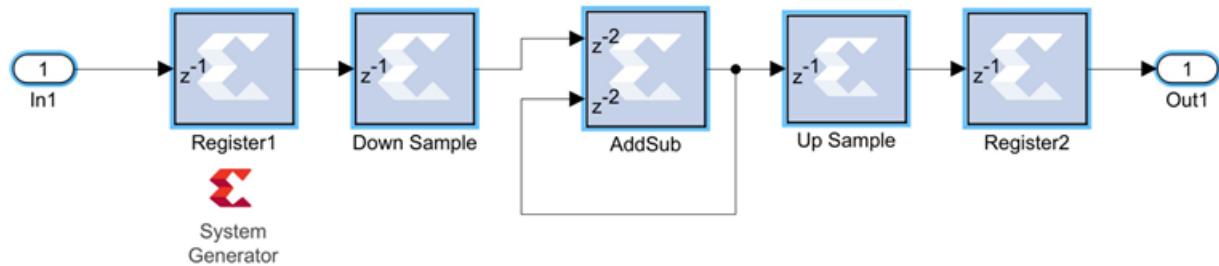
- **Normalized Sample Periods:** Displays the normalized sample periods for all the input and output ports on each block. For example, if the Simulink System Period is set to 4 and the sample period propagated to a block port is 4 then the normalized period that is displayed for the block port is 1 and if the period propagated to the block port is 8 then the sample period displayed would be 2 for example, a larger number indicates a slower rate.

**Figure 385: Normalized Sample Periods Icon**



- **Sample frequencies (MHz):** Displays sample frequencies for each block.
- **Pipeline stages:** Displays the latency information from the input ports of each block. The displayed pipeline stage might not be accurate for certain high-level blocks such as the FFT, RS Encoder/Decoder, Viterbi Decoder, etc. In this case the displayed pipeline information can be used to determine whether a block has a combinational path from the input to the output. For example, the Up Sample block in the figure below shows that it has a combinational path from the input to the output port.

Figure 386: Sample Frequencies



- HDL port names:** Displays the HDL port name of each port on each block in the model.
- Input data types:** Displays the data type of each input port on each block in the model.
- Output data types:** Displays the data type of each output port on each block in the model.
- Remote IP cache:** If selected, your design will access an IP cache whenever a Model Composer compilation performs Vivado synthesis as part of the compilation. If the compilation generates an IP instance for synthesis, and the Vivado synthesis tool generates synthesis output products, the tools create an entry in the cache area. If a new customization of the IP is created which has the exact same properties, the tools will copy the synthesis outputs from the cache to the design's output directory instead of synthesizing the IP instance again. Accessing the disk cache speeds up the iterative design process.

IP caching is described in [HDL Library](#).

- Clear cache:** Clicking this button clears the remote IP cache. Clearing the cache saves disk space, because the IP Cache can grow large, especially if your design uses many IP modules.

## To Fixed Size

This block takes a variable size vector as an input and produces a fixed size vector as output. The block copies samples from the input to the output.



### Library

AI Engine/Tools

## Description

The To Fixed Size block takes a variable size vector as an input and produces a fixed size vector as output. The block copies samples from the input to the output.

The input to the block will be buffered until the number of samples reaches the Output Size. The buffered samples will then be transferred to the out port, and the valid signal is set to true. When there are not enough samples buffered, the output port will be a vector of zeros, and the valid port is set to false.

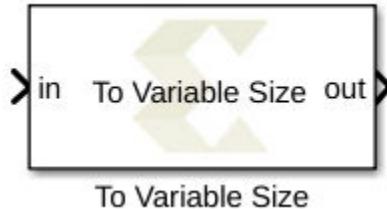
Use this block when you need to connect a variable size signal to a block that does not accept a variable size signal. If the input variable size signal is not full, the output will not always be valid.

**Note:** It is recommended that you monitor the Valid output to make sure you are not processing invalid outputs. You can also connect the Valid output to a triggered subsystem.

## Parameters

- **Output Size:** This specifies the size of the output port:
  - **Inherit: Same as Input:** If this option is enabled, the block output size will be the same as input.
  - **Specify Output Size:** When this option is selected, you can specify the value of the required output size.

## To Variable Size



## Library

AI Engine/Tools

## Description

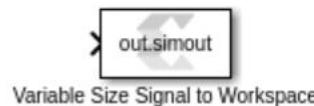
This block takes a fixed sized vector input and produces a variable sized vector output. The maximum size of the output vector is specified by the Output Size parameter. If there is not enough samples to pack the output, the output will be an empty variable size signal.

## Parameters

- **Show Valid Input:** If this option is enabled, the block will only accept the input data when the valid port is true.
- **Output Size:** This specifies the size of the output port.
  - **Inherit : Same as Input:** If this option is enabled, the block will only accept the input data when the valid port is true.
  - **Specify Output Size:** When this option is selected, you can specify the value of the required output size.

## Variable Size Signal to Workspace

This block is used to save variable size signal data from your Simulink® simulation to the MATLAB® workspace.



## Library

AI Engine/Tools

## Description

AI Engine blocks produce variable signal outputs. The Variable Size Signal to Workspace block allows you to write data into the MATLAB workspace in a structured format.

**Note:** This block behaves similarly to the Simulink To Workspace block but will make it easier to analyze the output data by discarding empty sample in the input variable size signal and concatenating valid samples into a MATLAB vector. This block can only be connected to a variable size signal. The settings of the block can be accessed from Simulink Model settings (Ctrl+E) under the **Data Import/Export** tab. In particular, here you can set all simulation outputs as a single Simulink Simulation Output object or as individual variables.

## Parameters

- **Variable Name:** Using this parameter, you can specify the name for workspace variable.

## Vitis Model Composer Hub

Control implementation of the model.

## Description

The Vitis Model Composer Hub block controls the behavior of the Vitis Model Composer tool.

You can specify the targeted design flow for the generated output, the directory path for the output, and the desired device and design clock frequency using the following tabs.

- The **Hardware Selection** pane helps with device or board selection.
- The **Code Generation** pane provides options to select the output flow by selecting subsystems and specifying Code directory. Different options will be displayed depending on if the subsystem is targeting HDL, HLS, or AIE.

## Library

AI Engine/Tools; HLS/Tools; Utilities/Code Generation.



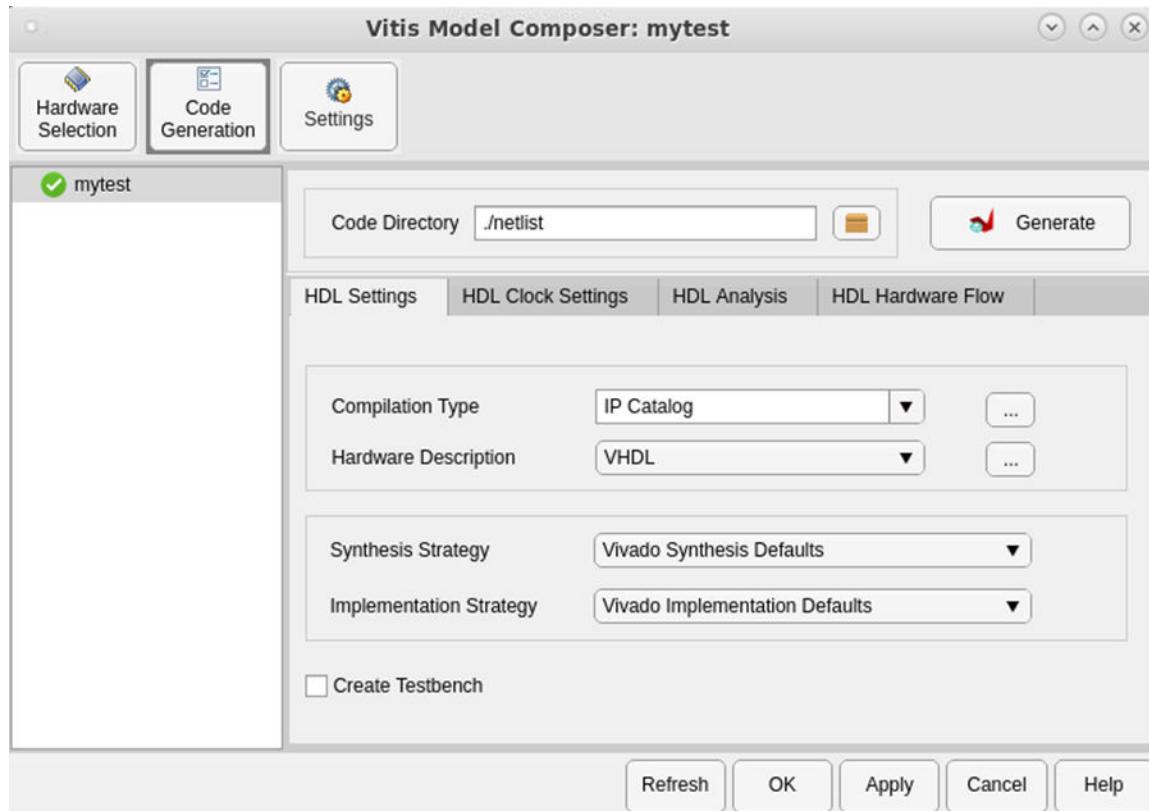
## Vitis Model Composer Hub

### Data Type Support

Data type support is not applicable to the Vitis Model Composer Hub block.

## Parameters

Figure 387: Vitis Model Composer Hub Block Parameters



The following section describes the configurable options available in each pane of the Vitis Model Composer Hub block.

- **Hardware Selection:** Clicking the browse button (...) displays the Device Chooser dialog box. This allows you to select a part, board, or platform to which your design is targeted. Vitis Model Composer obtains board and device data from the Vivado database.
- **Code Generation:** Select the subsystem name for which to generate code from the list on the left. Different settings will display depending on the type of code generation (HDL, HLS, or AI Engine) to be performed.
- **AIE Settings:**
  - **AIE Compiler Options:** When enabled, this option provides control over compiler debug options, execution target options etc.
  - **Create Testbench:** When enabled, Vitis Model Composer generates the test vectors while generating the code.

- **Run cycle-approximate AIE Simulation (SystemC) after code generation:** This option is only available if **Create testbench** is selected. When enabled, it runs the AIE simulation after code generation.
- **Simulation timeout (cycles):** When enabled, it specifies the number of cycles for which AIE simulation is run. The default value is 50000.
- **Plot AIE Simulation Output and Estimate Throughput:** When enabled, this option logs simulation data and allows visualization of the output of an AI Engine subsystem.
- **Collect profiling statistics and enable 'printf' for debugging:** When enabled, this option allows profiling data to be collected for analysis.
- **Collect data for Vitis Analyzer:** When enabled, this option provides a summary of the simulation results which can be viewed in the Vitis Analyzer.
- **Open Vitis Analyzer:** Click to invoke the Vitis Analyzer tool. This option is only enabled after AI Engine Simulation has been ran at least once after enabling.
- **AIE Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the Create Testbench option in the AIE Settings panel.
  - **Generate Hardware Validation Code:** When enabled, Vitis Model Composer generates code to be used for hardware validation.
  - **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
  - **Target:** Specify the target for hardware validation flow.
  - **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
  - **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
  - **Run hardware emulation after code generation:** When enabled, hardware emulation will run immediately after code generation.
- **HDL Settings:**
  - **Compilation Type:** Specifies the type of compilation result that should be produced when the code generator is invoked. The default compilation type is IP Catalog. When IP Catalog is selected, the Settings (...) button brings up a dialog box that allows you to add a description of the IP that will be placed in the IP catalog.
  - **Hardware Description:** Specifies the HDL language to be used for compilation of the design. The possibilities are VHDL and Verilog.
    - **VHDL library:** Specifies the name of VHDL work library for code generation. The default name is `xil_defaultlib`.

- **Use STD\_LOGIC type for Boolean or 1 bit wide gateways:** If your design's Hardware Description Language (HDL) is VHDL, selecting this option will declare a Boolean or 1-bit port (Gateway In or Gateway Out) as a STD-LOGIC type. If this option is not selected, Vitis Model Composer will interpret Boolean or 1-bit ports as vectors.

**Note:** When you enable this option and try to run Generate code and Run behavioral simulation in Vivado, you may see a failure during the elaboration phase.

- **Synthesis strategy:** Choose a Synthesis strategy from the pre-defined strategies in the drop-down menu.
- **Implementation strategy:** Choose an Implementation strategy from the pre-defined strategies in the drop-down menu.
- **Create testbench:** This instructs Vitis Model Composer to create an HDL test bench. Simulating the test bench in an HDL simulator compares Simulink simulation results with ones obtained from the compiled version of the design. To construct test vectors, Vitis Model Composer simulates the design in Simulink, and saves the values seen at gateways. The top HDL file for the test bench is named <name>\_testbench.vhd / .v, where <name> is a name derived from the portion of the design being tested.

**Note:** Testbench generation is not supported for designs that have gateways (Gateway In or Gateway Out) configured as an AXI4-Lite interface.

- **HDL Clock Settings:**

- **Enable multiple clocks:** Must be enabled when the design has multiple clocks. This indicates to the code generation engine that the clock information for the various subsystems must be obtained from the respective clock tabs. If not enabled, then the design will be treated as a single clock design.
- **Number of clocks:** Defines the number of clocks in the design. The number of clock tabs that appear will be equivalent to the number of clocks. In each clock tab, you must select the subsystem and configure the clock settings of that subsystem.
- **FPGA clock period (ns):**

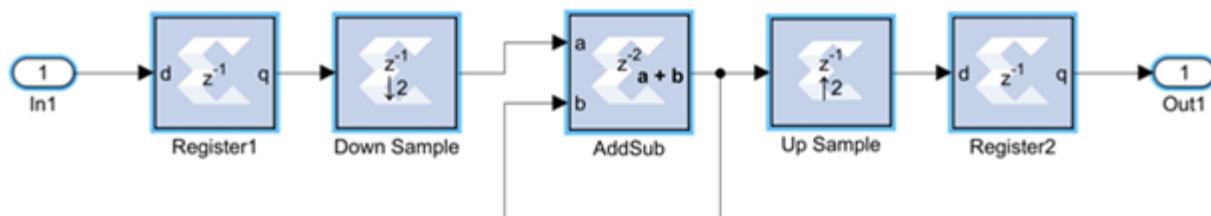
Defines the period in nanoseconds of the system clock. The value need not be an integer. The period is passed to the Xilinx implementation tools through a constraints file, where it is used as the global PERIOD constraint. Multicycle paths are constrained to integer multiples of this value.

- **Simulink system period (sec):** Defines the Simulink System Period, in units of seconds. The Simulink system period is the greatest common divisor of the sample periods that appear in the model. These sample periods are set explicitly in the block dialog boxes, inherited according to Simulink's propagation rules, or implied by a hardware oversampling rate in blocks with this option. In the final case, the implied sample time is in fact faster than the

observable simulation sample time for the block in Simulink. In hardware, a block having an oversampling rate greater than one processes its inputs at a faster rate than the data. For example, a sequential multiplier block with an over-sampling rate of eight implies a (Simulink) sample period that is one eighth of the multiplier block's actual sample time in Simulink. This parameter can be modified only in a master block.

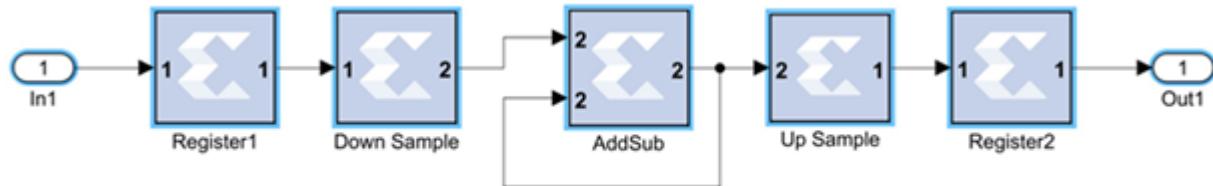
- **Clock pin location:** Defines the pin location for the hardware clock. This information is passed to the Xilinx implementation tools through a constraints file. This option should not be specified if the Vitis Model Composer design is to be included as part of a larger HDL design.
- **Provide clock enable clear pin:** This instructs Vitis Model Composer to provide a `ce_clr` port on the top-level clock wrapper. The `ce_clr` signal is used to reset the clock enable generation logic. The ability to reset clock enable generation logic allows designs to have dynamic control for specifying the beginning of data path sampling.
- **HDL Analysis:**
  - **Block icon display:** Specifies the type of information to be displayed on each block icon in the model after compilation is complete. The various display options are described below.
    - **Default:** Displays the default block icon information on each block in the model. A block's default icon is derived from the `xbsIndex` library.

Figure 388: Default Block Icon



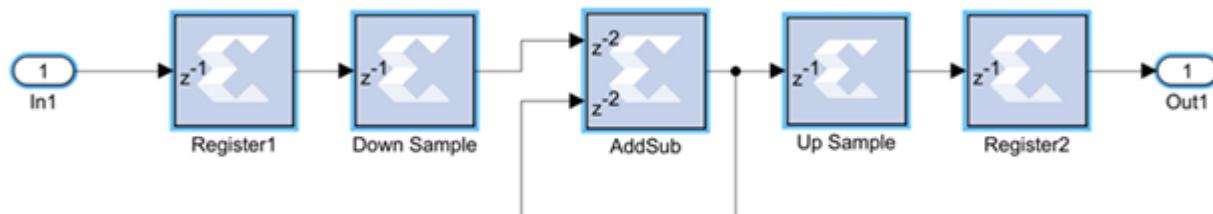
- **Normalized Sample Periods:** Displays the normalized sample periods for all the input and output ports on each block. For example, if the Simulink System Period is set to 4 and the sample period propagated to a block port is 4, then the normalized period that is displayed for the block port is 1; and if the period propagated to the block port is 8 then the sample period displayed would be 2 (a larger number indicates a slower rate).

Figure 389: Normalized Sample Periods Icon



- **Sample frequencies (MHz):** Displays sample frequencies for each block.
- **Pipeline stages:** Displays the latency information from the input ports of each block. The displayed pipeline stage might not be accurate for certain high-level blocks such as the FFT, RS Encoder/Decoder, Viterbi Decoder, etc. In this case the displayed pipeline information can be used to determine whether a block has a combinational path from the input to the output. For example, the Up Sample block in the following figure shows that it has a combinational path from the input to the output port.

Figure 390: Pipeline Stages



- **HDL port names:** Displays the HDL port name of each port on each block in the model.
- **Input data types:** Displays the data type of each input port on each block in the model.
- **Output data types:** Displays the data type of each output port on each block in the model.
- **Update the model:** Update the model to display the selected Block Icon type.
- **Perform Analysis:** Specifies whether an analysis (timing or resource) will or will not be performed on the Vitis Model Composer design when it is compiled. If **None** is selected, no timing analysis or resource analysis will be performed. If **Post Synthesis** is selected, the analysis will be performed after the design has been synthesized in the Vivado toolset. If **Post Implementation** is selected, the analysis will be performed after the design is implemented in the Vivado toolset.
- **Analysis Type:** Two selections are provided: Timing or Resource. After generation is completed, a Timing Analyzer table or Resource Analyzer table is launched.

- **Launch:** Launches the Timing Analyzer or Resource Analyzer table, depending on the selection of Analyzer type. This will only work if you already ran analysis on the Simulink model and haven't changed the Simulink model since the last run.
- **Remote IP cache:** If selected, your design will access an IP cache whenever a Vitis Model Composer compilation performs Vivado synthesis as part of the compilation. If the compilation generates an IP instance for synthesis, and the Vivado synthesis tool generates synthesis output products, the tools create an entry in the cache area. If a new customization of the IP is created which has identical properties, the tools will copy the synthesis outputs from the cache to the design's output directory instead of synthesizing the IP instance again. Accessing the disk cache speeds up the iterative design process. IP caching is described in HDL Library.
- **Create interface document:** When this check box is selected and the **Generate** button is activated for netlisting, Vitis Model Composer creates an HTM document that describes the design being netlisted. This document is placed in a `documentation` subfolder under the `netlist` folder.
- **Clear cache:** Clicking this button clears the remote IP cache. Clearing the cache saves disk space (the IP Cache can grow large, especially if your design uses many IP modules).
- **HDL Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the **Create Testbench** option in the HDL Settings panel. The HDL hardware flow is only supported for Versal® devices.
  - **Generate Hardware Validation Code:** When enabled, Vitis Model Composer generates code to be used for hardware validation.
  - **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
  - **Target:** Specify the target for hardware validation flow.
  - **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
  - **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
  - **Generate (BOOT.BIN/SD card image) after code generation:** When enabled, a BOOT.BIN (for baremetal HW system) or SD card image (for Linux HW system) will be generated after code generation.
- **HLS Settings:**
  - **Target:** Select IP Catalog to export the design to the Vivado IP Catalog. After C/C++ code generation, Vitis High-Level Synthesis (HLS) is invoked to synthesize the C code and create a project that can be exported as an IP to the Vivado IP Catalog. Select HLS C++ code to compile the design model into C++ code.
  - **FPGA clock frequency:** Specifies the clock frequency in MHz for the targeted device. This frequency is passed to the downstream tool flow.

- **Throughput factor:** Specifies the number of samples processed per clock to increase the throughput. A larger factor increases hardware resource usage. The throughput factor must be between 1 and 16.
- **Create testbench and run (C simulation/RTL cosimulation):** If selected, Vitis Model Composer runs simulation and generates test vectors while generating code.
- **Testbench stack size (MBytes):** This parameter prompts you to enter a larger stack size. When **Create and run testbench** is enabled, the **Testbench stack size** option specifies the size of the testbench stack frame during C simulation (CSIM). Occasionally, the default stack frame size of 10 MB allocate for execution of the testbench may be insufficient to run the test, due to large arrays allocated on the stack and/or deep nesting of subsystems. Typically when this happens, the test would fail with a segmentation fault and an associated error message. In such a case you can increase the size of the stack frame and rerun the test.
- **HLS Hardware Flow:** To generate the hardware image, specify the platform in the Target pane and select the Create Testbench option in the HLS Settings panel. Generate Hardware Validation Code.

When enabled, Vitis Model Composer generates code to be used for hardware validation.

- **HW System Type:** Choose between Baremetal or Linux hardware validation flow.
- **Target:** Specify the target for hardware validation flow.
- **Common SW Dir:** Provide the path to the folder containing the Petalinux common images. This option is only enabled when a Linux HW System Type is selected.
- **Target SDK Dir:** Provide the path to the folder containing the target SDK. This option is only enabled when a Linux HW System Type is selected.
- **Generate (BOOT.BIN/SD card image) after code generation:** When enabled, a BOOT.BIN (for baremetal HW system) or SD card image (for Linux HW system) will be generated after code generation.
- **Code Generation:** Select a subsystem containing blocks from the AI Engine, HDL, or HLS blocksets and specify the corresponding Code Directory. The Code Directory can be specified by entering the complete directory path or using the Browse button to provide a path.
- **Settings:** Specify whether the Model Composer Hub block should treat your model as a legacy System Generator design.

# Model Composer Utilities and Programmatic Access

## AI Engine Utilities

xmcLibraryPath	To set the root of the DSPLib from a MATLAB command window to a custom location in your local directory.
xmcVitisRead	Reads Vitis data files and outputs them into MATLAB.
xmcVitisWrite	Takes an existing array and creates a file that can be read by AIEmulator and x86simulator.

### xmcLibraryPath

`xmcLibraryPath` is a MATLAB utility that sets the root of the DSPLib from a MATLAB command window to a custom location in your local directory, using the MATLAB utility `xmcLibraryPath`.

#### Syntax

```
xmcLibraryPath('<Arg1>', 'dsplib', <Arg2>);
```

'<Arg1>' should be one of the options specified in the following list.

Arg1	Description
'set'	Set the DSPLib root to the custom location.
'reset'	Reset the DSPLib root to the default location.
'get'	To get the current DSPLib root location.
'getDefault'	To get the default DSPLib root location.

#### Example 1

```
xmcLibraryPath('set', 'dsplib', '/workspace/Github_Repo/Vitis_Libraries/dsp');
```

This option sets the DSPLib to point to the code from GitHub repository.

## Example 2

```
xmcLibraryPath('reset', 'dsplib');
```

This option sets the DSPLib to the Model Composer installed directory, which is the default location.

## xmcVitisRead

xmcVitisRead is a MATLAB utility that reads data files and outputs them into MATLAB. The function supports real and complex, signed and unsigned numbers. If the file contains timestamps, they will be added to a separate, parallel array.

### Syntax

```
A = xmcVitisRead(fileIn,dataType)
[A, TS] = xmcVitisRead(fileIn,dataType)
```

Where, the option `fileIn` is the file path and the `dataType` represents the datatype of the imported data.

The following table shows the list of datatypes and maximum possible columns allowed in the input file.

*Table 137: Data Types*

Data Types	Data Size (bits)	Maximum Possible Columns
int8	8	16
int16	16	8
int32	32	4
int64	64	2
uint8	8	16
uint16	16	8
uint32	32	4
uint64	64	2
cint16	32	4
cint32	64	2
float	32	4
cfloat	64	2

## Example

Let `Input.txt` be a file of the following format containing real numbers:

```
"T 470 ns
    1651 -17 6646 -5720
    T 472 ns
    8850 -2469 2711 7752
    T 474 ns
    -4938 -6103 -4659 -2352
    T 476 ns
    -2144 -6453 1410 5685
    T 478 ns
    -1591 1962 1190 8775"
```

The following function call imports the array as MATLAB `int16` values.

```
→ A = xmcVitisRead("Input.txt",'int16')
```

This is the resulting column vector:

```
A = [
    1651,
    -17,
    6646,
    -5720,
    8850,
    -2469,
    2711,
    7752,
    -4938,
    -6103,
    -4659,
    -2352,
    -2144,
    -6453,
    1410,
    5685,
    -1591,
    1962,
    1190,
    8775]
```

The following function call produces two arrays, signal and timestamp. The result is as follows.

```
→ [A, timestamp] = xmcVitisRead("Input.txt",'int16')

TS = [
    470,          A = [
    470,          1651,
    470,          -17,
    470,          6646,
    470,          -5270,
    472,          8850,
    472,          -2469,
    472,          2711,
    472,          7752,
    474,          -4938,
    474,          -6103,
    474,          -4659,
```

```
474,      -2352,
476,      -2144,
476,      -6453,
476,      1410,
476,      5685,
478,      -1591,
478,      1963,
478,      1190,
478]      8775]
```

 **IMPORTANT!** The function checks for the number of columns and returns an error if the number of columns exceeds the theoretical maximum for that data type.

 **IMPORTANT!** If the file contains timestamps but they are not required, the `timestamp` output can be left blank. Conversely, if the file does not have timestamps but two outputs are specified, the `timestamp` output will be an empty numeric array.

## xmcVitisWrite

This function takes an existing array and creates a file that can be read by AIEmulator and x86simulator. The input array can be of any real or complex data type.

- Complex data types are automatically detected, therefore only the data type (for example, `int16`) needs to be specified.
- The function also accepts the PLIO width and uses the data type to calculate the number of columns in the file. If the PLIO width is less than the size of the data type, the function will return an error.

### Syntax

```
xmcVitisWrite(fileName, arrayIn, dataType, widthPLIO)
```

Where:

- `fileName` is the output file name.
- `arrayIn` is the Input array.
- `dataType` is the datatype of the data.
- `widthPLIO` is the PLIO width (must be 32, 64, or 128)

The following table shows the list of datatypes and maximum possible columns in the output file, based on the PLIO width.

Table 138: Data Types

Data Types	Data Size (bits)	Maximum Possible Columns
int8	8	16
int16	16	8

Table 138: Data Types (cont'd)

Data Types	Data Size (bits)	Maximum Possible Columns
int32	32	4
int64	64	2
uint8	8	16
uint16	16	8
uint32	32	4
uint64	64	2
cint16	32	4
cint32	64	2
float	32	4
cfloat	64	2

### Example

Let A be an array of complex numbers of type `cfloat` and the PLIO width is set to 128.

```
A = [  
      3.142 + 1.463i,  
      6.288 + 3.079i,  
      3.333 + 1.493i,  
      3.781 + 8.781i,  
      3.142 + 1.463i]
```

**Note:** The data can be either a row or column vector.

The function call is as follows.

```
→ xmcvitisWrite("Output.txt", A, 'cfloat', 128);
```

The file will be saved as `Output.txt` in the working directory, as specified in the function call. The file content is as follows.

```
"3.142 1.463  
 6.288 3.079  
 3.333 1.493  
 3.781 8.781  
 3.142 1.463"
```

The columns are calculated automatically from the size of the data type and the PLIO width. A complex number is divided into two columns in the file, corresponding to real and imaginary parts in that order. A file with complex values will have at least two columns, while one with real values will have at least one.

# HDL Utilities

xilinx.analyzer	Provides the interface between the Model Composer model and Vivado® timing paths.
xilinx.environment.getcachePath and xilinx.environment.setcachePath	Used to get and set the path Model Composer uses to store the simulation cache.
xilinx.resource_analyzer	Enables cross-probing between the Model Composer model and Vivado resource utilization data.
xilinx.utilities.importBD	Imports a BD file created in the Vivado IP integrator and creates a stub for the Model Composer model that is part of the design.
xlAddTerms	Automatically adds sinks and sources to Model Composer models.
xlConfigureSolver	Configures the Simulink® solver settings of a model to provide optimal performance during Model Composer simulation.
xlFDA_denominator	Returns the denominator of the filter object in an FDATool block.
xlFDA_numerator	Returns the numerator of the filter object in an FDATool block.
xlGenerateButton	Provides a programmatic way to invoke the Model Composer code generator.
vmc_hub_set_param	Used to set parameter values in a HDL block.
xlGetReOrderedCoeff	The xlGetReOrderedCoeff function provides the re-ordered coefficient set of a FIR Compiler block.
xlOpenWaveformData	Allow you to populate saved simulation waveform data into running Waveform Viewer instance.
xlSetUseHDL	Sets the 'Use behavioral HDL' option of blocks in a model of a Subsystem.
xtBUtils	Provides programmatic access to several useful procedures such as layout, re-drawlines and getselected.

## xilinx.analyzer

xilinx.analyzer is a MATLAB® class that provides an interface between the Model Composer model and Vivado® timing paths.

The Model Composer timing analysis is supported for all compilation targets. The **Perform analysis** drop down menu under the **Clocking** tab of the Model Composer Hub block provides two options for the trade-off between total runtime vs. accuracy of the Vivado timing data. If you select either the **Post Synthesis** or the **Post Implementation** option of **Perform analysis** and click the **Generate** button, then Vivado timing paths information is collected during the netlist generation. The xilinx.analyzer class is used to access Vivado timing paths information. The xilinx.analyzer class object processes Vivado timing paths to find 50 unique paths with the worst slack value. The unique timing paths are sorted in increasing value of slack and saved in the analyzer object.

The cross-probing between Vivado timing paths and the Model Composer model is made possible using the following API functions in the xilinx.analyzer class.

**Table 139: xilinx.analyzer Class Functions**

Function Name	Description	Function Argument
xilinx.analyzer	This is a constructor of the class. A call to the xilinx.analyzer constructor returns object of the class.	First argument is Model Composer model name. Second argument is path to already generated netlist directory.
isValid	Indicates if timing analysis data is valid or not. Use this API to make sure that the xilinx.analyzer class construction was successful.	No argument
getErrorMessage	Returns an error message string if the call to the class constructor or other API function had an error.	No argument
getStatus	Returns 'FAILED' if any of the timing paths in the model have a violation, i.e., negative slack.	No argument
getVivadoStage	Returns either Post Synthesis or Post Implementation. This is the Vivado design stage after which timing analysis was performed.	No argument
paths	Returns an array of MATLAB structures. Each structure contains data for a timing path.	A string that is equal to either 'setup' or 'hold'
violations	Returns an array of MATLAB structures. Each member of the array is a path structure with a timing violation.	A string that is equal to either 'setup' or 'hold'
print	Prints timing path information such as Slack, Path Delay, Levels of Logic, Name of Source and Destination blocks, and Source and Destination clocks.	An array of MATLAB structures for timing path data. The array can have one or more structures.
highlight	In the Model Composer model, highlights blocks for the timing path passed in the argument. Blocks that are already highlighted in the model will remain highlighted.	MATLAB structure for one timing path
highlightOnePath	In the Model Composer model, highlights blocks for the timing path passed in the argument. Before highlighting blocks for this path, the blocks that are already highlighted in the model will be unhighlighted.	MATLAB® structure for one timing path
unhighlight	In the Simulink® model, unhighlights all blocks currently highlighted.	No argument
disp	Displays a summary of timing analysis results on the MATLAB console, including the worst slack value among all timing paths.	No argument
delete	This is a destructor of the xilinx.analyzer class	No argument

**Table 140: Timing Path Data in a MATLAB Structure**

Field Name	Description
Slack	The double value containing timing slack for the path
Delay	Total Data Path delay for the path
Levels_of_Logic	Number of elements in Vivado design for the timing path. The number of HDL blocks in the timing path may be different from Levels_of_Logic.
Source	First HDL block in the timing path
Destination	Last HDL block in the timing path

**Table 140: Timing Path Data in a MATLAB Structure (cont'd)**

Field Name	Description
Source_Clock	Name of the clock domain for the source block
Destination_Clock	Name of the clock domain for the destination block
Path_Constraints	Timing constraint used for the path. For a multi-clock design, the path constraint can be a multi-clock timing constraint.
Block_Masks	Cell array where each element contains mask information for a HDL block.
Simulink_Names	Cell array where each element contains hierarchical name of a block in Model Composer model
Vivado_Names	Cell array where each element contains name of HDL block in Vivado database
Type	A timing violation type. The value is either 'setup' or 'hold'.

## xilinx.analyzer - Construct xilinx.analyzer class object

### Syntax

```
analyzer_object = xilinx.analyzer(<name_of_the_model>,
'<path_to_netlist_directory>')
```

- **Description:**

A call to xilinx.analyzer constructor returns object of the class.

The first argument is the name of the Model Composer model. The model must be open before the class constructor is called.

The second argument is an absolute or relative path to the netlist directory. You must have read permission to the netlist directory.

To access API functions of the xilinx.analyzer class use the object of the class as described below. To get more details for a specific API function type the following at the MATLAB command prompt:

```
help xilinx.analyzer.<API_function>
```

- **Example:**

```
//Construct class. Must give the model name and absolute or relative path
//to the
//target directory

>> timing_object = xilinx.analyzer('fixed_point_IIR', './
netlist_for_timing_analysis')

timing_object =
Number of setup paths = 9
Worst case setup slack = -1.6430
```

## isValid - Check validity of Vivado timing paths

- **Syntax:**

```
result = analyzer_object.isValid();
```

- **Description:**

If timing analysis data is valid then the result equals '1', otherwise it is '0'. Use this API to make sure that the xilinx.analyzer class construction was successful and the timing data was valid.

- **Example:**

```
//Determine if timing analysis data is valid
>> valid_status = timing_object.isValid()
valid_status =
1
```

## getErrorMessage - Get an error message

- **Syntax:**

```
result = analyzer_object.getErrorMessage();
```

- **Description:**

Returns an error message string if the call to the class constructor or other API function had an error.

- **Example:**

```
//Determine if there was an error in the xilinx.analyzer constructor
//or in any of the API functions
>> err_msg = timing_object.getErrorMessage()
err_msg =
''
```

## getStatus - Timing analysis status

- **Syntax:**

```
string = analyzer_object.getStatus();
```

- **Description:**

The returned string is either 'PASSED' or 'FAILED'. If any of the timing paths have a violation, i.e. negative slack, then the timing analysis status is considered failed.

- **Example:**

```
//Determine if there were timing path violations in Simulink model
>> analysis_status = timing_object.getStatus()
analysis_status =
FAILED
```

### getVivadoStage - Get Vivado design stage for timing analysis

- **Syntax:**

```
string = analyzer_object.getVivadoStage();
```

- **Description:**

The returned string is the Vivado design stage after which timing analysis was performed and data collected in Vivado. The value is either 'Post Synthesis' or 'Post Implementation'.

- **Example:**

```
//Determine Vivado stage when timing data was collected
>> design_stage = timing_object.getVivadoStage()
design_stage =
Post Synthesis
```

### paths - Access all timing paths

- **Syntax:**

```
<array_of_timing_paths_structure> =
analyzer_object.paths('<violation_type>');
```

- **Description:**

The returned value is an array of MATLAB structures. Each structure contains data for a timing path, sorted in decreasing order of timing violation, i.e., in increasing order of slack value.

The argument `violation_type` is either 'setup' or 'hold' string.

- **Example:**

```
//Return an array of the timing path structures
>> all_timing_paths = timing_object.paths('setup')
all_timing_paths =
```

```
1x9 struct array with fields:
```

```
Slack
Delay
Levels_of_Logic
Source
Destination
Source_Clock
Destination_Clock
Path_Constraints
Block_Masks
Simulink_Names
Vivado_Names
Type
```

**Note:**

There are a total of nine timing paths in this timing analysis.

You can find the data fields in each timing path as shown in Example 1 in [Additional Information](#).

### violations - Access paths with timing violations

- **Syntax:**

```
<array_of_timing_paths_structure> =
analyzer_object.violations('<violation_type>');
```

- **Description:**

The returned value is an array of MATLAB structures. Each member of the array is data for a path with a timing violation. The array elements are sorted in decreasing order of timing violation. If there are no timing violations in the design then the API function returns an empty array.

The argument `violation_type` is either 'setup' or 'hold'.

- **Example:**

```
//Return an array of timing paths with setup violations
>> violating_paths = timing_object.violations('setup')
violating_paths =
1x2 struct array with fields:
    Slack
    Delay
    Levels_of_Logic
    Source
    Destination
    Source_Clock
    Destination_Clock
```

```
Path_Constraints
Block_Masks
Simulink_Names
Vivado_Names
Type
```

There are a total of two paths with violations in this timing analysis.

You can find the data fields in each timing path as shown in Example 3 in [Additional Information](#).

### print - Print timing path information

- **Syntax:**

```
analyzer_object.print(<timing_path_structures>);
```

- **Description:**

Prints timing data such as Slack, Path Delay, Levels of Logic, Name of Source and Destination blocks, Source and Destination clocks, Path Constraints, etc. for the input timing path structure.

The argument is an array of MATLAB structures with one or more elements.

- **Examples:**

```
//Print timing path information for path #1
>> timing_object.print(all_timing_paths(1))
Path Num          Slack (ns)          Delay (ns)          Levels
of Logic
Source/Destination Blocks          Source Clock          Destination
Clock             Path
Constraints
    1          -1.6430
11.5690          6
fixed_point_IIR/Delay1
clk                  clk
create_clock -name clk -period 2 [get_ports clk]

fixed_point_IIR/IIR Filter Subsystem/Delay4
ans =
    1

//Print timing path information for path #3
>> timing_object.print(all_timing_paths(3))
Path Num          Slack (ns)          Delay (ns)          Levels
of Logic
Source/Destination Blocks          Source Clock          Destination
Clock             Path
Constraints
    1          1.1320
```

```

0.5270          0
fixed_point_IIR/Delay1
clk           clk
create_clock -name clk -period 2 [get_ports clk]

fixed_point_IIR/Delay1
ans =
1

//Print timing path information for path #2 from violating_paths array
>> timing_obj.print(violating_paths(2))
Path Num      Slack (ns)      Delay (ns)      Levels
of Logic
Source/Destination Blocks      Source Clock      Destination
Clock      Path
Constraints
1           -1.3260
11.2520      6
fixed_point_IIR/Delay1
clk           clk
create_clock -name clk -period 2 [get_ports clk]

fixed_point_IIR/Delay2
ans =
1

```

## highlight - Highlight design blocks for a timing path

- Syntax:

```
analyzer_object.highlight(<timing_path_structure>);
```

- Description:

This API highlights HDL blocks for the timing path passed in the argument. It doesn't change the highlighting of a block from other paths, so more than one timing path can be highlighted if you use this function repeatedly.

The argument is the MATLAB structure for one timing path.

- Example:

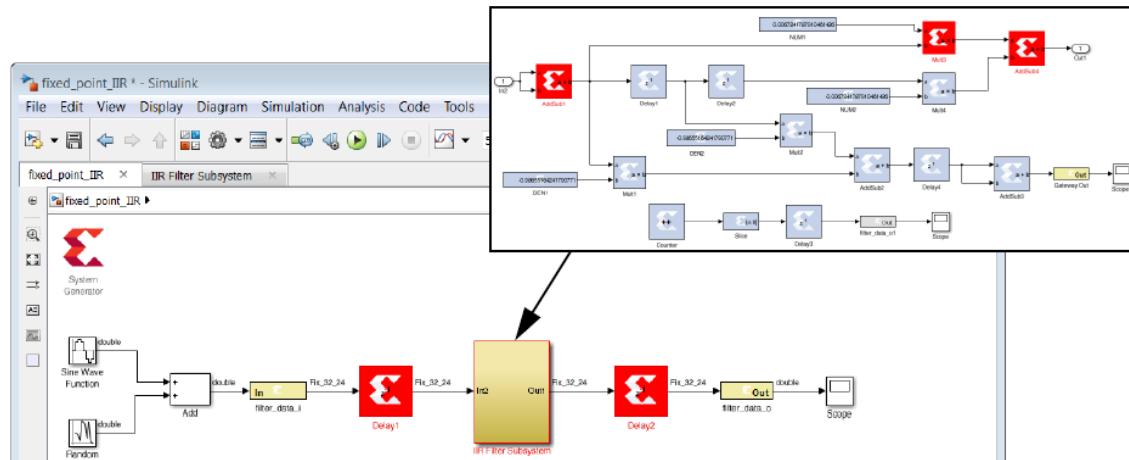
```

//Highlight Simulink model blocks in the selected path
//Don't change highlighting of currently highlighted blocks in the model
>> [result, err_msg] = timing_object.highlight(all_timing_paths(1));

```

Highlighted Model Composer model blocks appear as shown below.

Figure 392: HDL Model Blocks



## highlightOnePath - Highlight design blocks for one timing path

- Syntax:

```
analyzer_object.highlightOnePath(<timing_path_structure>);
```

- Description:

This API highlights HDL blocks for the timing path passed in the argument. If a block from other paths is already highlighted then it will be unhighlighted first, so only one path is highlighted at a time.

The argument is the MATLAB structure for one timing path.

- Example:

```
//Highlight a single path in Model Composer model, and unhighlight currently
//highlighted paths

>> [result, err_msg] = timing_object.highlightOnePath(violating_paths(2));
```

## unhighlight - Unhighlight design blocks

- Syntax:

```
analyzer_object.unhighlight();
```

- Description:

This API unhighlights blocks that are already highlighted. The blocks in Model Composer model are displayed in their original colors.

- **Example:**

```
//Unhighlight any Simulink block that is currently highlighted  
>> [result, err_msg] = timing_object.unhighlight();
```

## disp - Display summary of timing analysis

- **Syntax:**

```
analyzer_object.disp();
```

- **Description:**

This API displays the summary of timing paths on the MATLAB console, including the worst slack value.

- **Example:**

```
//Display a summary of timing analysis  
>> timing_object.disp()  
Number of setup paths = 9  
Worst case setup slack = -1.6430
```

## delete - Delete xilinx.analyzer class object

- **Syntax:**

```
analyzer_object.delete();
```

- **Description:**

This is a destructor for the xilinx.analyzer class.

- **Example:**

```
//Delete xilinx.analyzer object, i.e., timing_object  
>> timing_object.delete();
```

## Additional Information

Accessing data fields of timing path structures:

- **Example 1: Data for timing path #1:**

```
//Return the data fields for the timing path with the worst slack  
>> all_timing_paths(1)  
ans =
```

```

        Slack: -1.6430
        Delay: 11.5690
    Levels_of_Logic: 6
        Source: 'fixed_point_IIR/Delay1'
        Destination: 'fixed_point_IIR/IIR Filter Subsystem/Delay4'
        Source_Clock: 'clk'
    Destination_Clock: 'clk'
    Path_Constraints: 'create_clock -name clk -period 2 [get_ports ...]'
        Block_Masks: {1x5 cell}
    Simulink_Names: {1x5 cell}
    Vivado_Names: {1x5 cell}
        Type: 'setup'
    
```

- **Example 2: Data for timing path #3:**

```

//Return the data fields for a timing path
>> all_timing_paths(3)

ans =

        Slack: 1.1320
        Delay: 0.5270
    Levels_of_Logic: 0
        Source: 'fixed_point_IIR/Delay1'
        Destination: 'fixed_point_IIR/Delay1'
        Source_Clock: 'clk'
    Destination_Clock: 'clk'
    Path_Constraints: 'create_clock -name clk -period 2 [get_ports ...]'
        Block_Masks: {'fprintf(''','COMMENT: begin icon graphics'')...'}
    Simulink_Names: {'fixed_point_IIR/Delay1'}
    Vivado_Names: {'fixed_point_iir.fixed_point_iir_struct.delay1'}
    
```

Type: 'setup'

- **Example 3: Data for path #1 in violating\_paths array:**

```

//Return the data fields in a timing path with timing violations
>> violating_paths(1)

ans =

        Slack: -1.6430
        Delay: 11.5690
    Levels_of_Logic: 6
        Source: 'fixed_point_IIR/Delay1'
        Destination: 'fixed_point_IIR/IIR Filter Subsystem/Delay4'
        Source_Clock: 'clk'
    Destination_Clock: 'clk'
    Path_Constraints: 'create_clock -name clk -period 2 [get_ports ...]'
        Block_Masks: {1x5 cell}
    Simulink_Names: {1x5 cell}
    Vivado_Names: {1x5 cell}
        Type: 'setup'
    
```

## xilinx.environment.getcachepath and xilinx.environment.setcachepath

`xilinx.environment.getcachepath` is used to get the path Model Composer currently uses to store the simulation cache.

`xilinx.environment.setcachepath` is used to change the path Model Composer uses to store the simulation cache.

### Syntax

```
xilinx.environment.getcachepath  
xilinx.environment.setcachepath(path)
```

### Description

When you simulate a Simulink model containing Xilinx IP in Model Composer, the Vivado simulator simulation data for that particular IP configuration is cached to speed up the simulation.

Model Composer establishes the simulation cache at a default location at startup, and you can determine the current path to the simulation cache with the `xilinx.environment.getcachepath` command. If you need to change the location of the simulation cache, use the `xilinx.environment.setcachepath` command. You will need to have write permission on the destination path directory. The new path will apply for the remainder of your Model Composer session.

One reason you would use `xilinx.environment.setcachepath` is to set the path if you do not have write permission on the default directory Model Composer uses for caching simulation data.

### Examples

- **Example 1: Getting the current simulation cache path:**

```
>> xilinx.environment.getcachepath  
ans =  
C:\Users\my_login\AppData\Local\Xilinx\Sysgen\SysgenVivado\win64.o
```

- Example 2: Setting a new simulation cache path:

```
>> xilinx.environment.setcachepath('C:\sim_cache')

ans =
C:\sim_cache

>> xilinx.environment.getcachepath

ans =
C:\sim_cache
```

## xilinx.resource\_analyzer

`xilinx.resource_analyzer` is a MATLAB class that enables cross-probing between the Model Composer model and Vivado resource utilization data.

The Model Composer resource analysis is supported for all compilation targets. The **Perform analysis** drop down menu under the **Clocking** tab of the Model Composer Hub block provides two options for the trade-off between Vivado tools runtime vs. accuracy of the resource utilization data. If you select either the **Post Synthesis** or the **Post Implementation** option of **Perform analysis** and click the **Generate** button, then Vivado resource utilization information is collected during the netlist generation. Once the netlist generation has completed, the `xilinx.resource_analyzer` class is used to access this Vivado resource utilization results. The `xilinx.resource_analyzer` class object processes Vivado resource utilization data to display the number of resources (BRAMs, DSPs, Registers, and LUTs) used in the Simulink model, as well as by the subsystems and low-level blocks in the model.

The cross-probing between Vivado resource utilization results and the Model Composer model is made possible through the following API functions in the `xilinx.resource_analyzer` class.

**Table 141: Functions in `xilinx.resource_analyzer` Class**

Function Name	Description	Function Argument
<code>xilinx.resource_analyzer</code>	This is a constructor of the class. A call to the <code>xilinx.resource_analyzer</code> constructor returns object of the class.	First argument is design model name. Second argument is path to already generated netlist directory.
<code>getVivadoStage</code>	Returns either Post Synthesis or Post Implementation. This is the Vivado design stage after which resource analysis was performed.	No argument
<code>getDevicePart</code>	Returns a string for device part, package and speed grade for the device in which the design will be implemented.	No argument
<code>getDeviceResource</code>	Returns a string for the total count of the specified type of resource in the target Xilinx device.	(Optional) Resource type. Resource types are: BRAMs, DSPs, Registers, or LUTs.

Table 141: Functions in `xilinx.resource_analyzer` Class (cont'd)

Function Name	Description	Function Argument
<code>printDeviceResources</code>	Prints the total number of BRAMs, DSPs, Registers, and LUTs available on the target Xilinx device. The counts are printed in the MATLAB console.	No argument.
<code>getCount</code>	Returns a count for the particular resource type used by a block or subsystem.	(Optional) First argument is a Simulink handle or pathname for the block. (Optional) Second argument is Resource type. Resource types are: BRAMs, DSPs, Registers, or LUTs.
<code>print</code>	Returns a count for the particular resource type used by a block or subsystem.	(Optional) First argument is a Simulink handle or pathname for the block or subsystem. (Optional) Second argument is resource type. Resource types are: BRAMs, DSPs, Registers, or LUTs.
<code>getDistribution</code>	Returns three values: An array of MATLAB structures. Each element in the array is a structure containing the name of a block or subsystem directly under the subsystem in the argument, with a key-value pair of the resource type and number of resources used by that sub block or subsystem. A count of the resources used by the self (the block or subsystem specified in the argument). A count of the resources used by both blocks and subsystems combined.	First argument is a Simulink handle or pathname for the block or subsystem. Second argument is resource type. Resource types are: BRAMs, DSPs, Registers, or LUTs.
<code>getErrorMessage</code>	Returns an error message string if the call to the class constructor or other API function had an error.	No argument
<code>highlight</code>	In the Simulink model, highlights the specified block or subsystem with yellow color and red border.	A Simulink handle or pathname for the block to highlight.
<code>unhighlight</code>	In the Simulink model, unhighlights a block which is currently highlighted.	(Optional) A Simulink handle or pathname for the block to unhighlight.
<code>delete</code>	This is a destructor of the <code>xilinx.resource_analyzer</code> class.	No argument

**Table 142: Resource Data in a MATLAB Structure**

Field Name	Description
BRAMs	<p>Count of block RAM resources for a block or subsystem. BRAMs are counted in this way:</p> <ul style="list-style-type: none"> <li>• RAMB36E: 1 BRAM</li> <li>• RAMB36E: 1 BRAM</li> <li>• RAMB18E: 0.5 BRAM</li> <li>• FIFO18E: 0.5 BRAM</li> </ul> <p>Variations of Primitives (for example, RAM36E1 and RAM36E2) are all counted in the same way.</p> <p>Total BRAMs = (Number of RAMB36E) + (Number of FIFO36E) + 0.5 (Number of RAMB18E + Number of FIFO18E)</p>
DSPs	Count of DSP48 resources utilized by a block or subsystem.
Registers	Count of Flip-Flops and Latches used by the design is reported as the number of Registers utilized by the design model, a particular block, or a subsystem.
LUTs	Count of all LUT type resources utilized by a block or subsystem.

### xilinx.resource\_analyzer – Construct xilinx.resource\_analyzer class object

- **Syntax:**

```
resource_analyzer_obj =
xilinx.resource_analyzer('<name_of_the_model>', '<path_to_netlist_directory>');
```

- **Description:**

A call to `xilinx.resource_analyzer` constructor returns object of the class.

The first argument is the name of the Model Composer model. The model must be open before the class constructor is called.

The second argument is an absolute or relative path to the netlist directory. You must have read permission to the netlist directory.

To access API functions of the `xilinx.resource_analyzer` class use the object of the class as described below. To get more details for a specific API function type the following at the MATLAB command prompt:

```
help xilinx.resource_analyzer.<API_function>
```

- **Example:**

```
//Construct class. Must give the model name and absolute or relative path
//to the
//target directory

>> res_obj = xilinx.resource_analyzer('test_decimator', './')
```

```
netlist_for_resource_analysis')

res_obj =
Resources used by: test_decimator
BRAMs => 0.5
DSPs => 1
Registers => 273
LUTs => 153
```

## getVivadoStage – Get Vivado design stage for resource analysis

- **Syntax:**

```
string = resource_analyzer_obj.getVivadoStage();
```

- **Description:**

The returned string is the Vivado design stage after which resource analysis was performed and data collected in Vivado. The value is either Post Synthesis or Post Implementation.

- **Example:**

```
//Determine Vivado stage when resource data was collected
>> design_stage = res_obj.getVivadoStage()
design_stage =
Post Synthesis
```

## getDevicePart – Get target Xilinx device part name

- **Syntax:**

```
string = resource_analyzer_obj.getDevicePart();
```

- **Description:**

Gets the name of the Xilinx device to which your design is targeted.

- **Example:**

```
//Get the Xilinx part in which you will implement your design
>> part_name = res_obj.getDevicePart()
part_name =
xc7k325tfg676-3
```

**getDeviceResource – Get number of resources in target device**

- **Syntax:**

```
total_resource_count =  
resource_analyzer_obj.getDeviceResource(<resource_type>);
```

- **Description:**

The returned value is the total number of a particular type of resource contained in the Xilinx device for which you are targeting your design.

The `resource_type` may be:

- BRAMs - Block RAM and FIFO primitives
- DSPs - DSP48 primitives
- Registers - Registers and Flip-Flops
- LUTs - All LUT types combined

If no `resource_type` is provided, the command returns a MATLAB structure containing all device resources.

- **Example:**

```
//Determine the total number of Block RAMs in the Xilinx device  
>> total_brams = res_obj.getDeviceResource('BRAMs')  
  
total_brams =  
  
445  
  
//Determine the total number of Block RAMs, DSP blocks, Registers, and  
//LUTs in the  
//Xilinx device  
  
>> total_resource_count = res_obj.getDeviceResource  
  
total_resource_count =  
  
    BRAMs: '445'  
    DSPs: '840'  
Registers: '407600'  
    LUTs: '203800'
```

**printDeviceResources – Print number of resources in target device**

- **Syntax:**

```
resource_analyzer_obj.printDeviceResources();
```

- **Description:**

Prints the number of all types of resources in the used Xilinx device. The output is printed in the MATLAB console.

- **Example:**

```
//Print the number of all types of resources contained in the target
Xilinx device

>> res_obj.printDeviceResources()

BRAMs => 445
DSPs => 840
Registers => 407600
LUTs => 203800
```

### **getCount – Get resource utilization for subsystem or block**

- **Syntax:**

```
<block_resource_count> =
resource_analyzer_obj.getCount(<blockID>,<resource_type>);
```

- **Description:**

The returned value is the total number of a particular type of resource used in the specified subsystem or block.

The `blockID` can be either a Simulink handle or a pathname (a hierarchical name) for the subsystem or block.

The `resource_type` may be:

- BRAMs - Block RAM and FIFO primitives
- DSPs - DSP48 primitives
- Registers - Registers and Flip-Flops
- LUTs - All LUT types combined

If no `resource_type` is provided, the command returns a MATLAB structure containing all device resources.

- **Example:**

```
// Return register resource utilization for Simulink block with pathname
// test_decimator/addr_gen

>> regs_in_block = res_obj.getCount('test_decimator/addr_gen',
'Registers')

ans =

    105

//Return resource utilization for the entire Simulink model
```

```
>> total_resource_count = res_obj.getCount()

Resources used by: test_decimator
BRAMs => 0.5
DSPs => 1
Registers => 273
LUTs => 153
```

### print - Prints all resources used by a subsystem or block

- **Syntax:**

```
resource_analyzer_obj.print(<blockID>);
```

- **Description:**

Prints all resources (for all resource types: BRAMs, Registers, DSPs, and LUTs) used by a subsystem or block, in key-value pair. Resources are printed in the MATLAB console.

If you enter a `blockID` (which can be either a Simulink handle or a pathname), all resources used by the specified block or subsystem will be printed in the MATLAB console.

If no `blockID` argument is provided, all resources used by the top-level design will be printed in the MATLAB console.

- **Example:**

```
// Print resource utilization for Simulink subsystem with pathname
// test_decimator/addr_gen

>> res_obj.print('test_decimator/subsystem1')
Resources used by: test_decimator/subsystem1
BRAMs => 0.5
DSPs => 1
Registers => 49
LUTs => 97

//Print resource utilization for the entire Simulink model

>> res_obj.print()
Resources used by: test_decimator
BRAMs => 0.5
DSPs => 1
Registers => 273
LUTs => 153
```

### getDistribution - Get count of each resource type used by each block and subsystem under a specified subsystem

- **Syntax:**

```
[<distribution_array>, <self_count>, <total_count>] =
resource_analyzer_obj.getDistribution(<blockId>, <resource_type>)
```

- **Description:**

Returns count for the specified type of resource used by each block and subsystem directly under the subsystem passed as the argument.

The three returned values are:

- An array of MATLAB structures. Each element in the array is a structure containing the name of a block or subsystem directly under the subsystem in the argument, with a key-value pair of the resource type and number of resources used by that sub block or subsystem.
- A count of the resources used by the self (the block or subsystem specified in the argument).
- A count of the resources used by both blocks and subsystems combined.

The `blockID` can be either a Simulink handle or a pathname (a hierarchical name) for the subsystem or block. If no `blockID` is provided, then the command assumes the top-level module.

The `resource_type` may be:

- BRAMs - Block RAM and FIFO primitives
- DSPs - DSP48 primitives
- Registers - Registers and Flip-Flops
- LUTs - All LUT types combined

- **Example:**

```
// Return Register resource distribution for Simulink block with pathname
// test_decimator. This is top level of the design

>> [res_dist, self, total] = res_obj.getDistribution
('test_decimator','Registers')

res_dist =
1x8 struct array with fields:

    Name
    Hier_Name
    Count

self =
119

total =
273
//Return resource utilization for the entire Simulink model
```

```
>> total_resource_count = res_obj.getCount()

Resources used by: test_decimator
BRAMs => 0.5
DSPs => 1
Registers => 273
LUTs => 153
```

## getErrorMessage – Get an error message

- **Syntax:**

```
result = resource_analyzer_obj.getErrorMessage();
```

- **Description:**

Returns an error message string if the call to the class constructor or other API function had an error.

- **Example:**

```
//Determine if there was an error in the xilinx.resource_analyzer
constructor
//or in any of the API functions

>> err_msg = res_obj.getErrorMessage()

err_msg =
    ''
```

## highlight – Highlight design subsystems and blocks

- **Syntax:**

```
resource_analyzer_obj.highlight(<blockId>)
```

- **Description:**

This API highlights blocks in the Simulink model. Highlighted blocks in the Model Composer model are displayed in yellow and outlined in red. Highlighting blocks using this command does not change the highlighting of other blocks currently highlighted, so more than one block can be highlighted if you use this function repeatedly.

When you enter a `blockID` (which can be either a Simulink handle or a pathname) for a block or subsystem, the specified block or subsystem will be highlighted in the Simulink model. When the block/subsystem is highlighted then all parent subsystems up to the top level are also highlighted. When the top level module handle is provided as the `highlight` function argument no block is highlighted, but the Simulink model display changes to the top level, showing all blocks and subsystems at the top level.

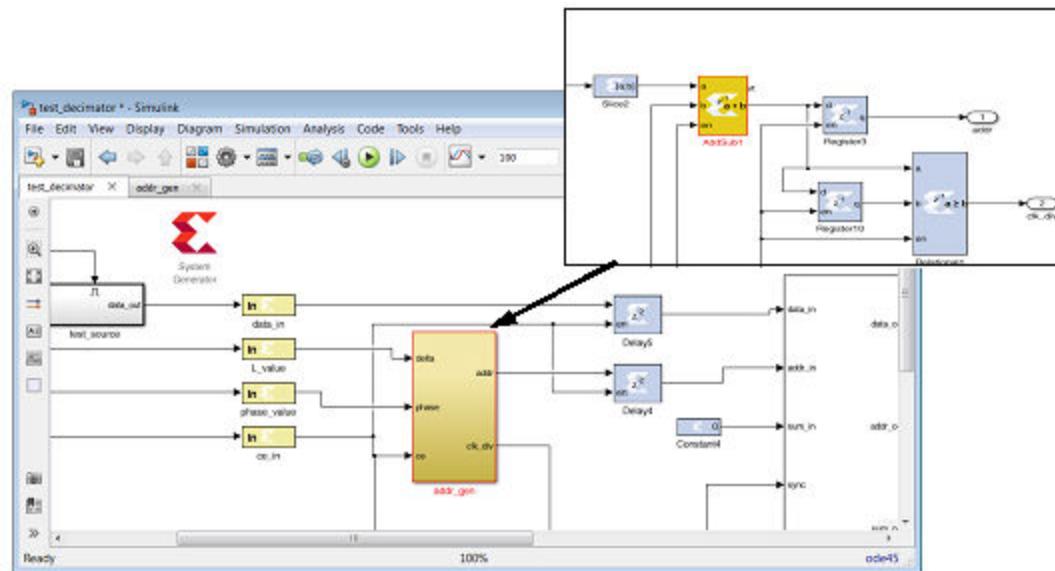
- Example:

```
//Highlight Simulink block with pathname fixed_point_IIR/IIR Filter
Subsystem/Mult1

>> res_obj.highlight('test_decimator/addr_gen/AddSub1')
```

Highlighted Model Composer model blocks appear as shown below.

**Figure 393: HDL Model Blocks**



### unhighlight – Unhighlight design subsystems and blocks

- Syntax:

```
resource_analyzer_obj.unhighlight(<blockId>)
```

- Description:

This API unhighlights blocks that are currently highlighted in the Simulink model. When they are unhighlighted, the blocks in the Model Composer model are displayed in their original colors.

If you enter a `blockID` (which can be either a Simulink handle or a pathname) for a block or subsystem, the specified block or subsystem will be unhighlighted in the Simulink model. When the block/subsystem is unhighlighted, all parent subsystems up to the top level are also unhighlighted.

If no `blockID` argument is provided, all currently highlighted blocks and subsystems will be unhighlighted.

- **Example:**

```
//Unhighlight Simulink block with pathname test_decimator/addr_gen/
Register4

>> res_obj.unhighlight('test_decimator/addr_gen/Register4')

//Unhighlight all Simulink blocks that are currently highlighted

>> res_obj.unhighlight();
```

### **delete – Delete xilinx.resource\_analyzer class object**

- **Syntax:**

```
resource_analyzer_obj.delete();
```

- **Description:**

This is a destructor for the `xilinx.resource_analyzer` class.

- **Example:**

```
//Delete xilinx.resource_analyzer object, i.e., res_obj

>> delete(res_obj);
```

OR

```
>> res_obj.delete();
```

## **xilinx.utilities.importBD**

`xilinx.utilities.importBD` imports a platform framework created in the Vivado IP integrator into a Model Composer model. The command provides an accelerated way to enter the Model Composer circuitry into the design. `xilinx.utilities.importBD` parses the platform framework for potential Model Composer ports and interfaces and creates a sample stub in the Simulink model.

Inputs to the `xilinx.utilities.importBD` command are the Vivado project to be imported and the name of the model to be created in Model Composer.

### **Syntax**

```
xilinx.utilities.importBD(vivado_project,matlab_file)
```

## Description

`xilinx.utilities.importBD` parses the platform framework Vivado project for potential Model Composer ports and interfaces and creates a sample stub to speed the development of the Model Composer model.

```
xilinx.utilities.importBD('<path_to_vivado_project_directory>/<project_name>.xpr',  
'mynewmodel')  
  
xilinx.utilities.importBD('C:\test_impportBD\platform.xpr', 'mynewmodel')
```

## xlAddTerms

`xlAddTerms` is similar to the `addterms` command in Simulink, in that it adds blocks to terminate or drive unconnected ports in a model. With `xlAddTerms`, output ports are terminated with a Simulink terminator block, and input ports are correctly driven with either a Simulink or HDL constant block. Additionally HDL gateway blocks can also be conditionally added.

The `optionStruct` argument can be configured to instruct `xlAddTerms` to set a block's property (e.g. set a constant block's value to 5) or to use different source or terminator blocks.

## Syntax

```
xlAddTerms(arg1,optionStruct)
```

## Description

In the following description, 'source block' refers to the block that is used to drive an unconnected port. And 'term block' refers to the block that is used to terminate an unconnected port.

```
xlAddTerms(arg1,optionStruct)
```

`xlAddTerms` takes either 1 or 2 arguments. The second argument, `optionStruct` argument is optional. The first argument can be the name of a system, or a block list.

*Table 143: xlAddTerms Arguments*

arg1	Description
<code>gcs</code>	A string-handle of the current system
<code>'top/test1'</code>	A string-handle of a system called test1. In this case, <code>xlAddTerms</code> is passed a handle to a system. This will run <code>xlAddTerms</code> on all the blocks under test1, including all children blocks of Subsystems.

Table 143: xlAddTerms Arguments (cont'd)

arg1	Description
{'top/test1'}	A block list of string handles. In this case, <code>xlAddTerms</code> is passed a handle to a block. This will run <code>xlAddTerms</code> only on the block called test1, and will not process child blocks.
{'t/b1';'t/b2';'t/b3'}	A block list of string handles.
[1;2;3]	A block list of numeric handles.

The `optionStruct` argument is optional, but when included, should be a MATLAB structure. The following table describes the possible values in the structure. The structure field names (as is true with all MATLAB structure field names) are case sensitive.

Table 144: optionStruct Arguments

optionStruct	Description
Source	<p><code>xlAddTerms</code> can terminate in-ports using any source block (refer to <code>SourceWith</code> field). The parameters of the source block can be specified using the <code>Source</code> field of the <code>optionStruct</code> by passing the parameters as sub-fields of the <code>Source</code> field. The <code>Source</code> field prompts <code>xlAddTerms</code> to do a series of <code>set_params</code> on the source block. Since it is possible to change the type of the source block, it is left to the user to ensure that the parameters here are relevant to the source block in use.</p> <p>E.g. when a Simulink constant block is used as a Source Block, setting the block's value to 10 can be done with:</p> <pre>Source.value = '10'</pre> <p>And when a HDL Constant block is used as a Source Block, setting the constant block to have a value of 10 and of type <code>UFIX_32_0</code> can be done with:</p> <pre>Source.const = '10'; Source.arith_type='Unsigned'; Source.bin_pt=0; Source.n_bits=32;</pre>
SourceWith	<p>The <code>SourceWith</code> field allows the source block to be specified. Default is to use a constant block. <code>SourceWith</code> has two sub-fields which must be specified.</p> <p><code>SourceWithBlock</code>: A string specifying the full path and name of the block to be used. e.g. 'built-in/Constant' or 'xbsIndex_r3/AddSub'.</p> <p><code>SourceWithPort</code>: A string specifying the port number used to connect. E.g. '1' or '3'. Specifying '1' instructs <code>xlAddTerms</code> to connect using port 1, etc.</p>
TermWith	<p>The <code>TermWith</code> field allows the term block to be specified. Default is to use a Simulink terminator block. <code>TermWith</code> has two sub-fields which must be specified.</p> <p><code>TermWithBlock</code>: A string specifying the full path and name of the block to be used. e.g. 'built-in/Terminator' or 'xbsIndex_r3/AddSub'.</p> <p><code>TermWithPort</code>:</p> <p>A string specifying the port number used to connect. E.g. '1' or '3'. Specifying '1' instructs <code>xlAddTerms</code> to connect using port 1, etc.</p>
UseGatewayIns	Instructs <code>xlAddTerms</code> to insert HDL gateway ins when required. The existence of the field is used to denote insertion of gateway ins. This field must not be present if gateway ins are not to be used.

Table 144: optionStruct Arguments (cont'd)

optionStruct	Description
GatewayIn	If gateway ins are inserted, their parameters can be set using this field, in a similar way as for Source and Term. For example: <pre>GatewayIn.arith_type='Unsigned'; GatewayIn.n_bits='32'; GatewayIn.bin_pt='0'</pre> will set the gateway in to output a ufix_32_0.
UseGatewayOuts	Instructs <code>x1AddTerms</code> to insert HDL gateway outs when required. The existence of the field is used to denote insertion of gateway outs. This field must not be present if gateway outs are not to be used.
GatewayOut	If gateway outs are inserted, their parameters can be set using this field, in a similar way as for Source and Term. For example: <pre>GatewayOut.arith_type='Unsigned'; GatewayOut.n_bits='32'; GatewayOut.bin_pt='0'</pre> This sets the gateway out to take an input of ufix_32_0.
RecurseSubsystems	Instructs <code>x1AddTerm</code> to recursively run <code>x1AddTerm</code> under all child Subsystems. Expects a scalar number, 1 or 0.

## Examples

Example 1: Runs `x1AddTerms` on the current system, with the default parameters: constant source blocks are used, and gateways are not added. Subsystems are recursively terminated.

```
x1AddTerms(gcs);
```

Example 2: Runs `x1AddTerms` on all the blocks in the Subsystem `tt./mySubsystem`.

```
x1AddTerms(find_system('tt/mySubsystem','SearchDepth',1));
```

Example 3: Runs `x1AddTerms` on the current system, setting the source block's constant value to 1, using gateway outs and changing the term block to use a Simulink display block.

```
s.Source.const = '10';
s.UseGatewayOuts = 1;
s.TermWith.Block = 'built-in/Display';
s.TermWith.Port = '1';
s.RecurseSubsystem = 1;
x1AddTerms(gcs,s);
```

## Remarks

Note that field names are case sensitive. When using the fields '`Source`', '`GatewayIn`' and '`GatewayOut`', users have to ensure that the parameter names to be set are valid.

## See Also

[xLTBUtils](#)

# xlConfigureSolver

The `xlConfigureSolver` function configures the Simulink solver settings of a model to provide optimal performance during Vitis Model Composer simulation.

## Syntax

```
xlConfigureSolver(<model_handle>);
```

## Description

The `xlConfigureSolver` function configures the model referred to by `<model_handle>`. `<model_handle>` can be a string or numeric handle to a Simulink model. Library models are not supported by this function since they have no simulation solver parameters to configure.

For optimal performance during Vitis Model Composer simulation, the following Simulink simulation configuration parameters are set:

```
'SolverType' = 'Variable-step'  
'Solver' = 'VariableStepDiscrete'  
'SolverMode' = 'SingleTasking'
```

# xlfda\_denominator

The `xlfda_denominator` function returns the denominator of the filter object stored in the Xilinx FDATool block.

## Syntax

```
[den] = xlfda_denominator(FDATool_name);
```

## Description

Returns the denominator of the filter object stored in the Xilinx FDATool block named `FDATool_name`, or throws an error if the named block does not exist. The block name can be local (e.g. 'FDATool'), relative (e.g. '../..//FDATool'), or absolute (e.g. 'untitled/foo/bar/FDATool').

## See Also

[xlfda\\_numerator](#), [FDATool](#)

## xlfda\_numerator

The xlfda\_numerator function returns the numerator of the filter object stored in the Xilinx FDATool block.

### Syntax

```
[ num ] = xlfda_numerator(FDATool_name);
```

### Description

Returns the numerator of the filter object stored in the Xilinx FDATool block named FDATool\_name, or throws an error if the named block does not exist. The block name can be local (e.g. 'FDATool'), relative (e.g. '../..//FDATool'), or absolute (e.g. 'untitled/foo/bar/FDATool').

### See Also

[xlfda\\_denominator](#), [FDATool](#)

## xlGenerateButton

The xlGenerateButton function provides a programmatic way to invoke the Vitis Model Composer code generator.

### Syntax

```
status = xlGenerateButton(sysgenblock)
```

### Description

xlGenerateButton invokes the Vitis Model Composer code generator and returns a status code. Invoking xlGenerateButton with a HDL block as an argument is functionally equivalent to opening the Model Composer Hub block, and clicking on the **Generate** button. The following is list of possible status codes returned by xlGenerateButton.

*Table 145: xlGenerateButton Status Codes*

Status	Description
1	Canceled
2	Simulation running
3	Check param error
4	Compile/generate netlist error
5	Netlister error
6	Post netlister script error

**Table 145: xlGenerateButton Status Codes (cont'd)**

Status	Description
7	Post netlist error
8	Post generation error
9	External view mismatch when importing as a configurable Subsystem

## See Also

[vmc\\_hub\\_get\\_param](#), [vmc\\_hub\\_set\\_param](#), Vitis Model Composer Hub block

## vmc\_hub\_get\_param

Get the value of a parameter in the Vitis Model Composer Hub block.

### Syntax

```
paramValue = vmchub_get_param(hubBlock, design_or_subsystem, parameter)
```

### Description

`vmchub_get_param` returns the name or value of the specified parameter for the specified design or subsystem in the Vitis Model Composer Hub block.

`vmchub_get_param` throws an error if:

- any of the inputs are not valid, or
- if the specified design or subsystem is not selected in the Vitis Model Composer Hub block, or
- if the Vitis Model Composer Hub block configuration has not been saved at least once.

### Example

```
>> vmchub_get_param('one_krnl_one_in_one_out_32bit_21a/Vitis Model Composer Hub', 'one_krnl_one_in_one_out_32bit_21a/Subsystem1/aie_ss', 'CreateTestbench')
ans =
logical
1
```

### Input Arguments

- **hubBlock:**  
Hub block path in the model
- **design\_or\_subsystem:** Path of subsystem or design that has been selected in the hub block
- **parameter:**  
Parameter of hub block

## Output Arguments

- **paramValue:** The value of the specified parameter for the specified design or subsystem specified in the hub block.

## vmc\_hub\_set\_param

Set the value of a parameter in the Vitis Model Composer Hub block.

### Syntax

```
vmchub_set_param(hubBlock, design_or_subsystem, parameter, paramValue)
```

### Description

`vmchub_set_param` sets the `paramValue` of the specified parameter for the specified design or subsystem in the Vitis Model Composer Hub block.

`vmchub_set_param` throws an error if:

- any of the inputs are not valid, or
- if the specified design or subsystem is not selected in the Vitis Model Composer Hub block, or
- if the Vitis Model Composer Hub block configuration has not been saved at least once.

### Example

```
>>> vmchub_set_param('one_krnl_one_in_one_out_32bit_21a/Vitis Model Composer Hub', 'one_krnl_one_in_one_out_32bit_21a/Subsystem1/aie_ss', 'CreateTestbench', 1)
```

### Input Arguments

- **hubBlock:** Hub block path in the model
- **design\_or\_subsystem:** Path of subsystem or design that has been selected in the hub block
- **parameter:** Parameter of hub block
- **paramValue:** The value to be set to the specified parameter for the specified design or subsystem specified in the hub block.

## Vitis Model Composer Hub Block Parameters

### Vitis Model Composer Hub Block Parameters

Tab	Field in the Model Composer Hub Block	Parameter Name	Allowed Values
Hardware Selection	Select Hardware	SelectHardware	Part or board name or platform file

Tab	Field in the Model Composer Hub Block	Parameter Name	Allowed Values
Code Generation	To select the subsystem in the left side panel	SelectSubsystem	0 or 1
Code Generation (DUT)	Code Directory	CodeDirectory	Directory
Code Generation (Hardware Flow)	Generate Hardware Image	GenerateHwImage	0 or 1
	HW System Type	HwSystemType	BareMetal or Linux
	Target	HwTarget	hw or hw_emu
	Common SW Dir	HWCommonSWDir	Directory
	Target SDK Dir	TargetSDKDir	Directory
Code Generation (HDL Subsystem)	Compilation Type	CompilationType	
	Hardware Description	HardwareDescription	
	Synthesis Strategy	SynthesisStrategy	
	Implementation Strategy	ImplementationStrategy	
	Create Testbench	CreateTestbench	
	Enable Multiple clocks	EnableMultipleClocks	
	FPGA Clock Period	FPGAClockPeriod	
	Simulink System Period	SimulinkSystemPeriod	
	Clock pin location	ClockPinLocation	
	Provide Clock enable clear pin	ProvideClockEnableClearPin	
	Block Icon Display	BlockIconDisplay	
	Perform Analysis	PerformAnalysis	
	Analysis Type	AnalyzerType	
	Remote IP Cache	RemoteIPCache	
	Create Interface document	CreateInterfaceDocument	
Code Generation (HLS Subsystem)	Target	Target	
	FPGA Clock Frequency	FPGAClockFrequency	
	Throughput factor	ThroughputFactor	
	Create Testbench and run C simulation	CreateTestbench	
	Testbench stack size	TestbenchStackSize	
Code Generation (AIE Subsystem)	AIE Compiler Options	AIECompilerOptions	
	Create Testbench	CreateTestbench	
	Run cycle-approximate AIE simulation	RunAIESimulation	
	Simulation Timeout	SimulationTimeout	
	Plot AIE simulation output and Estimate throughput	PlotAIESimulation	
	Collect Profiling Statistics	CollectProfilingStats	
	Collect Data for Vitis Analyzer	CollectDataForVitisAnalyzer	

## xlGetReOrderedCoeff

The xlGetReOrderedCoeff function provides the re-ordered coefficient set of a FIR Compiler block.

### Syntax

```
A = xlGetReOrderedCoeff(new_coeff_set, returnType, block_handle)
```

### Description

Note: All three parameters of this function are required.

- **new\_coeff\_set:** The new coefficient set that needs to be loaded into an existing FIR Compiler. Must be supplied to the function in the original order.
- **block\_handle:** This is the FIR Compiler block handle in the design. If a FIR Compiler block is selected, then this block\_handle can be specified as gcbh.
- **returnType:** This parameter specifies the re-ordered coefficient or just the reload order information format. This value can be specified as either 'coeff' or 'index'. A 'coeff' return type will modify the required coefficient set and provide the re-arranged coefficient set that can be directly supplied to the FIR compiler block. The 'index' return type provides only the coefficient address vector using the new\_coeff\_set that needs to be processed manually.

### Examples

Example 1:

If A is a row vector of coefficients, then the coefficients sorted in the reload order can be obtained as follows:

```
reload_order_coefficients = xlGetReOrderedCoeff(A, 'coeff', gcbh)
```

In this example, reload\_order\_coefficients specifies the order in which coefficients contained in A should be passed to the FIR Compiler through the reload channel.

Example 2:

This example shows how to use an input text file is generated.

```
reload_order_coefficients =
xlGetReOrderedCoeff(A, 'coeff', reload_<version>.txt)
```

Alternatively, the reload address vector can be obtained,

```
reload_order_coefficients = A(xlGetReOrderedCoeff(A, 'index', gcbh))
```

## See Also

[FIR Compiler 7.2 block](#)

# xlOpenWaveFormData

Allows you to populate saved simulation waveform data into a running Waveform Viewer instance.

## Syntax

```
xlOpenWaveFormData('C:/wavedata/model_name.wdb')
```

## How to Use

1. Make sure an instance of Waveform Viewer is opened in the current Model Composer session.
2. Locate the waveform data file (`model_name.wdb`) you would like to open.  
**Note:** Waveform data are saved under the `wavedata` directory.
3. Type `xlOpenWaveFormData ('C:/wavedata/model_name.wdb')` in the MATLAB console. Make sure you enter the absolute path of the waveform data file.
4. Observe the waveform data in Waveform Viewer.

## See Also

For information on using the Waveform Viewer to develop and troubleshoot your design, see [Vivado Design Suite User Guide: Logic Simulation \(UG900\)](#).

# xlSetUseHDL

This function sets the 'Use behavioral HDL' option of blocks in a model or Subsystem.

## Syntax

```
xlSetUseHDL(system, mode)
```

## Description

The model or system specified in the parameter system is set to either use cores or behavioral HDL, depending on the mode. Mode is a number, where 0 refers to using cores, and 1 refers to using behavioral HDL.

## Examples

Example 1:

```
xlSetUseHDL(gcs,0)
```

This call sets the currently selected system to use cores.

## xLTBUtils

The xLTBUtils command provides access to several features that include access to the layout, rerouting functions and to functions that return selected blocks and lines.

## Syntax

```
xLTBUtils(function, args)
e.g.
xLTBUtils('Layout',struct('verbose',1,'autoroute',0))
xLTBUtils('Layout',optionStruct)
xLTBUtils('Redrawlines',struct('autoroute',0))
xLTBUtils('RedrawLines',optionStruct)
[lines,blks]=xLTBUtils('GetSelected',handle,'all')
```

## Description

**xLTBUtils(function [,args])**

The function argument specifies the name of the function to execute. Further arguments (if required) can be tagged on as supplementary arguments to the function call. Note that the function argument string is not case sensitive. Possible values are enumerated below and explained further in the relevant subtopics.

**Table 146: Function Argument**

Function	Description
'Layout'	Runs the layout algorithm on a model to place and reroute lines on the model. Layout can be customized using the option structure that is detailed below.
'RedrawLines'	Runs the routing algorithm on a model to reroute lines on the model. RedrawLines can be customized using the option structure detailed below.
'GetSelected'	Returns MATLAB Simulink handles to blocks and lines that are selected on the system in focus.

### **'xITBUtils('Layout',optionStruct)**

Automatically places and routes a Simulink model. optionStruct is a MATLAB struct data-type, that contains the parameters for Layout. The optionStruct argument is optional.

Layout expects circuits to be placed left to right. After placement, Layout uses Simulink to autoroute the wire connections. Simulink will route avoiding anything visible on screen, including block labels. Setting "ignore\_labels" will 'allow' Simulink to route over labels – after which it is possible to manually move the labels to a more reasonable location. Note that field names are case sensitive.

*Table 147: optionStruct Argument*

Field Names	Description [Default values]
x_pitch, y_pitch	The gaps (pitch) between block (pixels). x_pitch specifies the amount of spacing to leave between blocks horizontally, and y_pitch specifies vertical spacing. [30].
x_start, y_start	Left (x_start) and top(y_start) margin spacing (pixels). The amount of spacing to leave on the left and top of a model. [10].
autoroute	Turns on Simulink auto-routing of lines. (1   0) [1]
ignore_labels	When auto-routing lines, Simulink will attempt to auto-route around text labels. Setting ignore_labels to 1 will minimize text label size during the routing process.
sys	Name of the system to layout. [gcs]
verbose	When set to 1, a wait bar is shown during the layout process.

### **xITBUtils('RedrawLines',optionStruct)**

The RedrawLines command will redraw all lines in a Simulink model. If there are lines selected, only selected lines are redrawn otherwise all lines are redrawn. If a branch is selected, the entire line is redrawn; main trunk and all other sub-branches.

*Table 148: RedrawLines Command*

Field Names	Description [Default values]
autoroute	Turns on Simulink auto-routing of lines. (1   0) [1]
sys	Name of the system to layout. [gcs]

### **xITBUtils('GetSelected',handle,arg)**

The GetSelected command returns handles to selected blocks and lines of the system in focus. The argument handle returns the Simulink model, in which the blocks and lines are selected. You can also provide the model name in place of the argument handle. The argument arg should be one of the string values described in the following table.

*Table 149: GetSelected Command*

GetSelected	Description [Default values]
'all'	Gets both selected lines and blocks.

**Table 149: GetSelected Command (cont'd)**

GetSelected	Description [Default values]
'lines'	Gets only selected lines.
'blocks'	Gets only selected blocks.

The `GetSelected` command will return an array with two items, an array of a structure containing line information (`lines`) and an array of block handles (`blks`). If the '`lines`' argument is used, `blks` is an empty array; similarly when the '`blocks`' argument is used, `lines` is an empty array.

## Examples

- **Example 1a: Performing Layouts:**

```
a.verbose = 1;  
a.autoroute= 0;  
xLTBUtils('Layout',a);
```

This will invoke the layout tool with verbose on and autoroute off.

- **Example 1b: Performing Layouts:**

```
xLTBUtils('Layout',struct('verbose',1,'autoroute',0));
```

This will also invoke the layout tool with verbose on and autoroute off.

- **Example 2: Redrawing lines:**

```
xLTBUtils('Redrawlines',struct('autoroute',0));
```

This will redraw the lines of the current system, with auto-routing off.

- **Example 3: Getting selected lines and blocks:**

```
xLTBUtils('GetSelected',handle,'all')  
lines =  
  
1x3 struct array with fields:  
Handle  
Name  
Parent  
SrcBlock  
SrcPort  
DstBlock  
DstPort  
Points  
Branch  
  
blks =
```

```
1.0e+003 *
3.0320
3.0480
```

This will return all selected lines and blocks in the current system. In this case, 3 lines and 2 blocks were selected. The first line handle can be accessed using the command:

```
lines(1).Handle
ans =
3.0740e+003
```

The handle to the first block can be accessed using the command:

```
blks(1)
ans =
3.0320e+003
```

## Remarks

The actions performed by Layout and RedrawLines will not be in the undo stack. Save a copy of the model before performing the actions, in order to revert to the original model.

This product contains certain software code or other information ("AT&T Software") proprietary to AT&T Corp. ("AT&T"). The AT&T Software is provided to you "AS IS". YOU ASSUME TOTAL RESPONSIBILITY AND RISK FOR USE OF THE AT&T SOFTWARE. AT&T DOES NOT MAKE, AND EXPRESSLY DISCLAIMS, ANY EXPRESS OR IMPLIED WARRANTIES OF ANY KIND WHATSOEVER, INCLUDING, WITHOUT LIMITATION, THE IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, WARRANTIES OF TITLE OR NON-INFRINGEMENT OF ANY INTELLECTUAL PROPERTY RIGHTS, ANY WARRANTIES ARISING BY USAGE OF TRADE, COURSE OF DEALING OR COURSE OF PERFORMANCE, OR ANY WARRANTY THAT THE AT&T SOFTWARE IS "ERROR FREE" OR WILL MEET YOUR REQUIREMENTS.

Unless you accept a license to use the AT&T Software, you shall not reverse compile, disassemble or otherwise reverse engineer this product to ascertain the source code for any AT&T Software.

© AT&T Corp. All rights reserved. AT&T is a registered trademark of AT&T Corp.

## See Also

[xlAddTerms](#)

# Programmatic Access

## Model Composer API for Programmatic Generation

### Introduction

A script of Model Composer for programmatic generation (PG API script) is a MATLAB M-function file that builds a Model Composer Subsystem by instantiating and interconnecting `xBlock`, `xSignal`, `xInport`, and `xOutport` objects. It is a programmatic way of constructing Model Composer diagrams (for example, Subsystems). As is demonstrated below with examples, the top-level function of a Model Composer programmatic script is its entry point and must be invoked through an `xBlock` constructor. Upon constructor exit, MATLAB adds the corresponding Model Composer Subsystem to the corresponding model. If no model is opened, a new untitled model is created and the Model Composer Subsystem is inserted into it.

The `xBlock` constructor creates an `xBlock` object. The object can be created from a library block or it can be a Subsystem. An `xSignal` object corresponds to a wire that connects a source block to a target. An `xInport` object instantiates a Simulink Inport and an `xOutport` object instantiates a Simulink Outport.

The API also has one helper function, `x1sub2script` which converts a Simulink diagram to a programmatic generation script.

The API works in three modes: *learning mode*, *production mode*, and *debugging mode*. The learning mode allows you to type in the commands without having a physical script file. It is very useful when you learn the API. In this mode, all blocks, ports and Subsystems are added into a Simulink model named `untitled`. Please remember to run `xBlock` without any argument or to close the untitled model before starting a new learning session. The production mode has an M-function file and is invoked through the `xBlock` constructor. You will have a Subsystem generated. The Subsystem can be either in the existing model or can be inserted in a new model. The debugging mode works the same as the production mode except that every time a new object is created or a new connection is established, the Simulink diagram is rerouted. It is very useful when you debug the script that you set some break points in the script or single step the script.

### **xBlock**

The `xBlock` constructor creates an `xBlock` object. The object can be created from a library block or it can be a Subsystem. The `xBlock` constructor can be used in three ways:

- to add a leaf block to the current Subsystem,
- to add a Subsystem to the current Subsystem,
- to attach a top-level Subsystem to a model.

The `xBlock` takes four arguments and is invoked as follows.

```
block = xBlock(source, params, inports, outports);
```

If the source argument is a string, it is expected to be a library block name. If the source block is in the `xbsIndex_r4` library or in the Simulink built-in library, you can use the block name without the library name. For example, calling `xBlock('AddSub', ...)` is equivalent to `xBlock('xbsIndex_r4/AddSub', ...)`. For a source block that is not in the `xbsIndex_r4` library or built-in library, you need to use the full path, for example, `xBlock('xbsTest_r4/Assert Relation', ...)`. If the source argument is a function handle, it is interpreted as a PG API function. If it is a MATLAB struct, it is treated as a configuration struct to specify how to attach the top-level to a model.

The `params` argument sets up the parameters. It can be a cell array for position-based binding or a MATLAB struct for name-based binding. If the source parameter is a block in a library, this argument must be a cell array. If the source parameter is a function pointer, this argument must be a cell array.

The `inports` and `outports` arguments specify how Subsystem input and output ports are bound. The binding can be a cell array for position-based binding or a MATLAB struct for name-based binding. When specifying an inport/outport binding, an element of a cell array can be an `xSignal`, an `xInport`, or an `xOutport` object. If the port binding argument is a MATLAB struct, a field of the struct is a port name of the block, a value of the struct is the object that the port is bound to.

The two port binding arguments are optional. If the arguments are missing when constructing the `xBlock` object, the port binding can be specified through the `bindPort` method of an `xBlock` object. The `bindPort` method is invoked as follows:

```
block.bindPort(inports, outports)
```

where `inports` and `outports` arguments specify the input and output port binding. In this case, the object block is created by `xBlock` with only two arguments, the source and the parameter binding.

Other `xBlock` methods include the following.

- `names = block.getOutportNames` returns a cell array of outport names.
- `names = block.getInportNames` returns a cell array of inport names.
- `nin = block.getNumInports` returns the number of inports.
- `nout = block.getNumoutports` returns the number of outports.
- `insigs = block.getInSignals` returns a cell array of incoming signals.
- `outsigs = block.getOutSignals` returns a cell array of outgoing signals.

## xImport

An `xImport` object represents a Subsystem input port.

The constructor

```
port = xImport(port_name)
```

creates an `xImport` object with name `port_name`,

```
[port1, port2, port3, ...] = xImport(name1, name2, name2, ...)
```

creates a list of input port with names, and

```
port = xImport
```

creates an input port with an automatically generated name.

An `xImport` object can be passed for port binding.

## METHODS

```
outsigs = port.getOutSignals
```

returns a cell array of out going signals.

## xOutport

An `xOutport` object represents a Subsystem output port.

The constructor

```
port = xOutport(port_name)
```

creates an `xOutport` object with name `port_name`,

```
[port1, port2, port3, ...] = xOutport(name1, name2, name2, ...)
```

creates a list of output port with names, and

```
port = xOutport
```

creates an output port with an automatically generated name.

An `xOutport` object can be passed for port binding.

## METHODS

```
port.bind(obj)
```

connects the object to port, where port is an `xOutport` object and obj is an `xSignal` or `xImport` object.

```
insigs = port.getInSignals  
returns a cell array of incoming signals.
```

## xSignal

An `xSignal` represents a signal object that connects a source to targets.

The constructor

```
sig = xSignal(sig_name)
```

creates an `xSignal` object with name `sig_name`,

```
[sig1, sig2, sig3, ...] = xSignal(name1, name2, name2, ...)
```

creates a list of signals with names, and

```
sig = xSignal
```

creates an `xSignal` for which a name is automatically generated.

An `xSignal` object can be passed for port binding.

## METHODS

```
sig.bind(obj)
```

connects the `obj` to `sig`, where `sig` is an `xSignal` object and `obj` is an `xSignal` or an `xInport` object.

```
src = sig.getSrc
```

returns a cell array of the source objects that are driving the `xSignal` object. The cell array can have at most one element. If the source is an input port, the source object is an `xInport` object. If the source is an output port of a block, the source object is a struct, having two fields `block` and `port`. The `block` field is an `xBlock` object and the `port` field is the port index.

```
dst = sig.getDst
```

returns a cell array of the destination objects that the `xSignal` object is driving. Each element can be either a struct or an `xOutport` object. It is defined same as the return value of the `getSrc` method.

## xlsub2script

`xlsub2script` is a helper function that converts a Subsystem into the top level of a Sysgen script.

`xlsub2script(Subsystem)` converts the Subsystem into the top-level script. The argument can also be a model.

By default, the generated M-function file is named after the name of the Subsystem with white spaces replaced with underscores. Once the `xlsub2script` finishes, a help message will guide you how to use the generated script. The main purpose of this `xlsub2script` function is to make learning Sysgen Script easier. This is also a nice utility that allows you to construct a Subsystem using graphic means and then convert the Subsystem to a PG API M-function.

`xlsub2script(block)`, where block is a leaf block, prints out the `xBlock` call that creates the block.

The following are the limitations of `xlsub2script`.

- If the Subsystem has mask initialization code that contains function calls such as `gcb`, `set_param`, `get_param`, `add_block`, and so on, the function will error out and you must modify the mask initialization code to remove those Simulink calls.
- If there is an access to global variables inside the Subsystem, you need add corresponding mask parameters to the top Subsystem that you run the `xlsub2script`.
- If a block's link is broken, that block is skipped.

`xlsub2script` can also be invoked as the following:

```
xlsub2script(subsyste, options)
```

where `options` is a MATLAB struct. The `options` struct can have two fields: `forcewrite`, and `basevars`.

If `xlsub2script` is invoked for the same Subsystem the second time, `xlsub2script` will try to overwrite the existing M-function file. By default, `xlsub2script` will pop up a question dialog asking whether to overwrite the file or not. If the `forcewrite` field of the `options` argument is set to be true or 1, `xlsub2script` will overwrite the M-function file without asking.

Sometimes a Subsystem is depended on some variables in the MATLAB base workspace. In that case, when you run `xlsub2script`, you want `xlsub2script` to pick these base workspace variables and generate the proper code to handle base workspace variables. The `basevars` field of the `options` argument is for that purpose. If you want `xlsub2script` to pick up every variable in the base workspace, you need to set the `basevars` field to be '`'all'`'. If you want `xlsub2script` to selectively pick up some variables, you can set the `basevars` field to be a cell array of strings, where each string is a variable name.

The following are examples of calling `xlsub2script` with the options argument:

```
xlsub2script(Subsystem, struct('forcefwrite', true));
xlsub2script(Subsystem, struct('forcefwrite', true, 'basevars',
    'all'));
options.basevars = {'var1', 'var2', 'var3'};
xlsub2script(Subsystem, options);
xlsub2script(Subsystem, struct('basevars', {{'var1', 'var2',
    'var3'}}));
```

In MATLAB, if the field of a struct is a cell array, when you call the `struct()` function call, you need the extra {}.

## xBlockHelp

`xBlockHelp(<block_name>)` prints out the parameter names and the acceptable values for the corresponding parameters. When you execute `xBlockHelp` without a parameter, the available blocks in the `xbsIndex_r4` library are listed.

For example, when you execute the following in the MATLAB command line:

```
xBlockHelp('AddSub')
```

You'll get the following table in the transcript:

'xbsIndex_r4/AddSub' Parameter Table		
Parameter	Acceptable value	Type
mode	'Addition' 'Subtraction' 'Addition or Subtraction'	String
use_carryin	'off' 'on'	String
use_carryout	'off' 'on'	String
en	'off' 'on'	String
latency	An Int value	Int
precision	'Full' 'User Defined'	String
arith_type	'Signed (2's comp)' 'Unsigned'	String
n_bits	An Int value	Int
bin_pt	An Int value	Int
quantization	'Truncate' 'Round (unbiased: +/- Inf)'	String

overflow	'Wrap' 'Saturate' 'Flag as error'	String
use_behavioral_HDL	'off' 'on'	String
pipelined	'off' 'on'	String
use_rpm	'off' 'on'	String

## PG API Examples

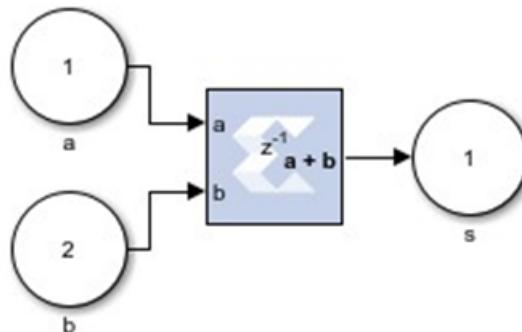
### Hello World

In this example, you will run the PG API in the *learning* mode where you can type the commands in the MATLAB® command shell.

1. To start a new learning session, in MATLAB command console, run: `xBlock`.
2. Type the following three commands in MATLAB command console to create a new Subsystem named 'Subsystem' inside a new model named 'untitled'.

```
[a, b] = xImport('a', 'b');
s = xOutport('s');
adder = xBlock('AddSub', struct('latency', 1), {a, b}, {s});
```

Figure 401: Subsystem Example



The above commands create the Subsystem with two Simulink Imports `a` and `b`, an adder block having a latency of one, and a Simulink Outport `s`. The two Imports source the adder which in turn sources the Subsystem outport. The `AddSub` parameter refers to the `AddSub` block inside the `xbsIndex_r4` library. By default, if the full block path is not specified, `xBlock` will search `xbsIndex_r4` and built-in libraries in turn. The library must be loaded before using `xBlock`. So please use `load_system` to load the library before invoking `xBlock`.

---

**TIP:** If you type `adder` in the MATLAB console, Model Composer will print a brief description of the adder block to the MATLAB console and the block is highlighted in the Simulink diagram. Similarly, you can type `a`, `b`, and `s` to highlight Subsystem Inports and Outports.

---

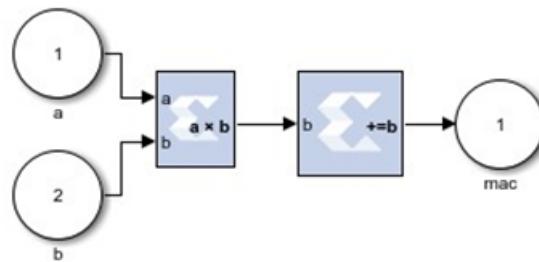
## MACC

1. Run this example in the learning mode. To start a new learning session, run: `xBlock`.
2. Type the following commands in the MATLAB console window to create a multiply-accumulate function in a new Subsystem.

```
[a, b] = xInport('a', 'b');
mac = xOutport('mac');
m = xSignal;
mult = xBlock('Mult', struct('latency', 0, 'use_behavioral_HDL', 'on'),
{a, b},
{m});
acc = xBlock('Accumulator', struct('rst', 'off', 'use_behavioral_HDL',
'on'), {m},
{mac});
```

By directing Model Composer to generate behavioral HDL, the two blocks should be packed into a single DSP48 block. As of this writing, Vivado synthesis only does so if you force the multiplier block to be combinational.

*Figure 402: Forcing a Mult Block*



**Note:** If you do not close the model that is created in example 1, example 2 is created in a model named `untitleded1`. Otherwise, a new model, `untitled`, is created for this example.

---

**TIP:** The PG API provides functions to get information about blocks and signals in the generated Subsystem. After each of the following commands, observe the output in the MATLAB console and the effect on the Simulink diagram.

---

```
mult_ins = mult.getInSignals
mult_ins{1}
mult_ins{2}
src_a = mult_ins{1}.getSrc
src_a{1}
m_dst = m.getDst
m_dst{1}
m_dst{1}.block
```

## MACC in a Masked Subsystem

If you want a particular Subsystem to be generated by the PG API and pass parameters from the mask parameters of that Subsystem to PG API, you need to run the PG API in *production* mode, where you need to have a physical M-function file and pass that function to the `xBlock` constructor.

1. Create the top-level PG API M-function file `MACC_sub.m` with the following lines.

```
function MACC_sub(latency, nbBits)
[a, b] = xImport('a', 'b');
mac = xOutputport('mac');
if latency <= 0
    error('latency must be positive');
elseif latency == 1
    a_in = a; b_in = b;
else
    [a_in, b_in] = xSignal;
    dblock1 = xBlock('Delay', struct('latency', latency - 1,
'reg_retimining', 'on'), {a}, {a_in});
    block2 = xBlock('Delay', struct('latency', latency - 1,
'reg_retimining', 'on'), {b}, {b_in});
end
m = xSignal;
mult = xBlock('Mult', struct('latency', 0, 'use_behavioral_HDL', 'on'),
{a_in}, {b_in}, {m});
acc = xBlock('Accumulator', struct('rst', 'off', 'n_bits', nbBits,
'use_behavioral_HDL', 'on'), {m}, {mac});
```

Figure 403: Top-Level PG API M-Function File

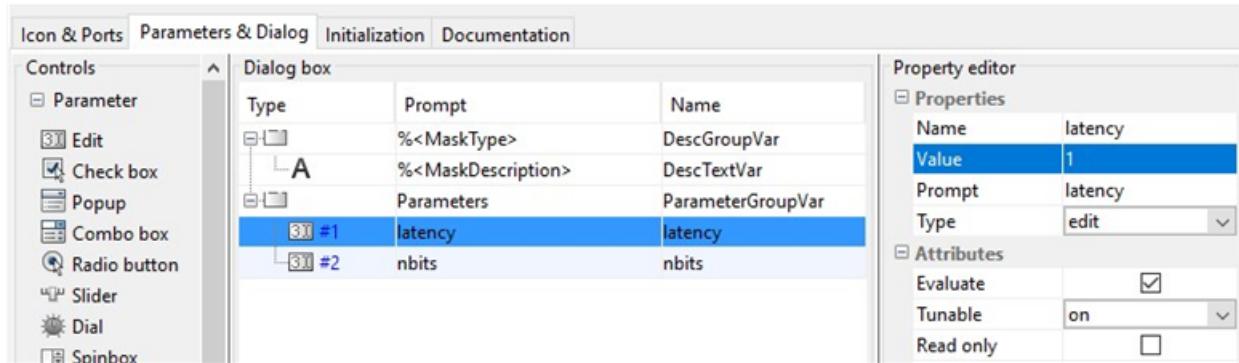
```
function MACC_sub(latency, nbBits)
[a, b] = xImport('a', 'b');
mac = xOutputport('mac');

if latency <= 0
    error('latency must be positive');
elseif latency == 1
    a_in = a; b_in = b;
else
    [a_in, b_in] = xSignal;
    dblock1 = xBlock('Delay', struct('latency', latency - 1, 'reg_retimining', 'on'), {a}, {a_in});
    block2 = xBlock('Delay', struct('latency', latency - 1, 'reg_retimining', 'on'), {b}, {b_in});
end

m = xSignal;
mult = xBlock('Mult', struct('latency', 0, 'use_behavioral_HDL', 'on'), {a_in}, {b_in}, {m});
acc = xBlock('Accumulator', struct('rst', 'off', 'n_bits', nbBits, 'use_behavioral_HDL', 'on'), {m}, {mac});
```

2. To mask the Subsystem defined by the script, add two mask parameters `latency` and `nbBits`.

Figure 404: Adding Latency Parameter



- Then put the following lines to the mask initialization of the Subsystem.

```
config.source = str2func('MACC_sub');
config.toplevel = gcb;
xBlock(config, {latency, nbits});
```

In the *production* mode, the first argument of the `xBlock` constructor is a MATLAB struct for configuration, which must have a `source` field and a `toplevel` field. The `source` field is a function pointer pointing to the M-function and the `toplevel` is a string specifying the Simulink Subsystem. If the top-level field is 1, an untitled model is created and a Subsystem inside that model is created.

Figure 405: Adding nbits Parameter

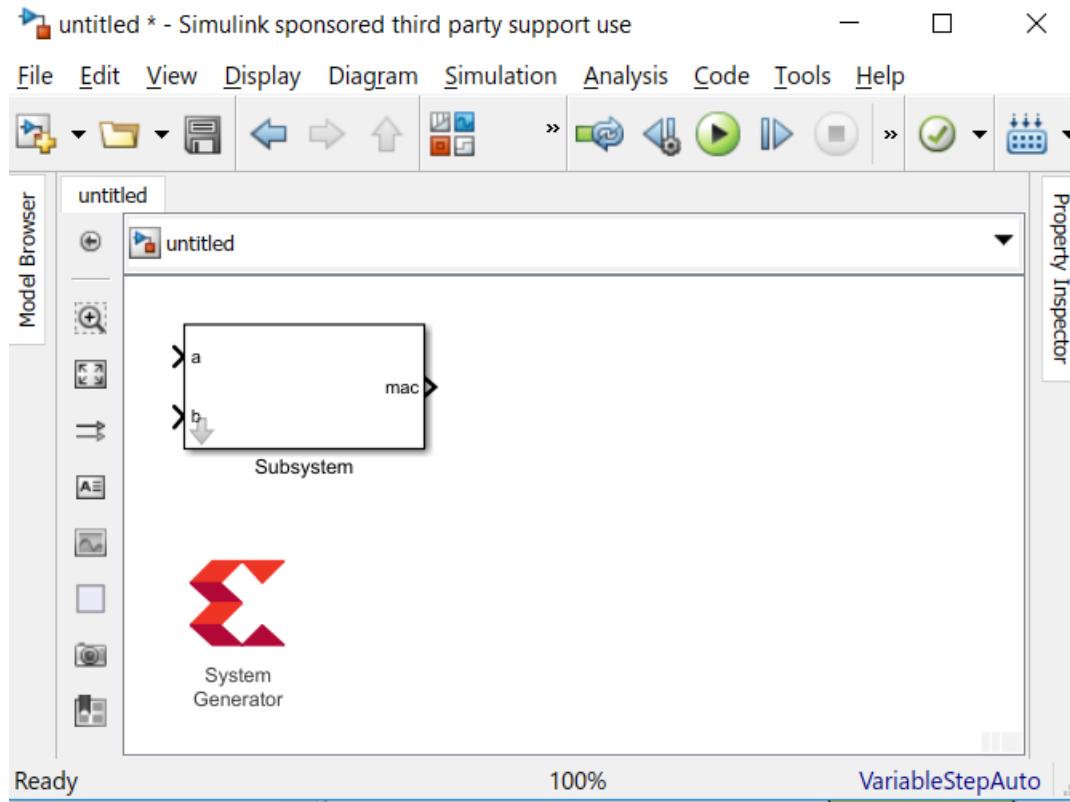


Alternatively you can use the MATLAB struct call to create the toplevel configuration:

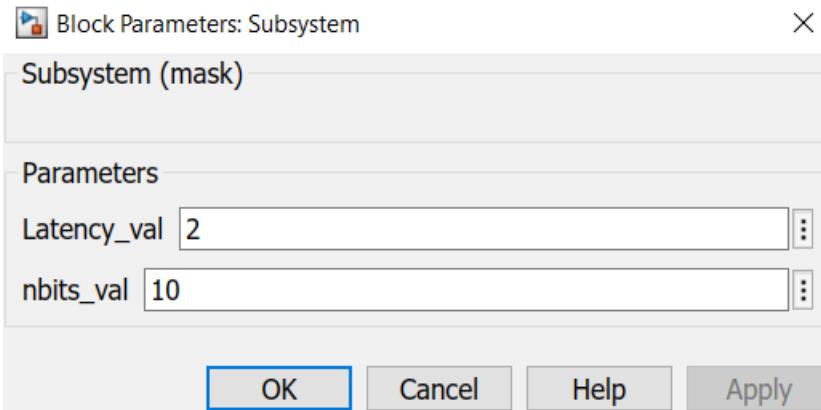
```
xBlock(struct('source', str2func(MACC_sub), 'toplevel', gcb), {latency,
nbits});
```

Then click **OK**.

You'll get the following Subsystem.

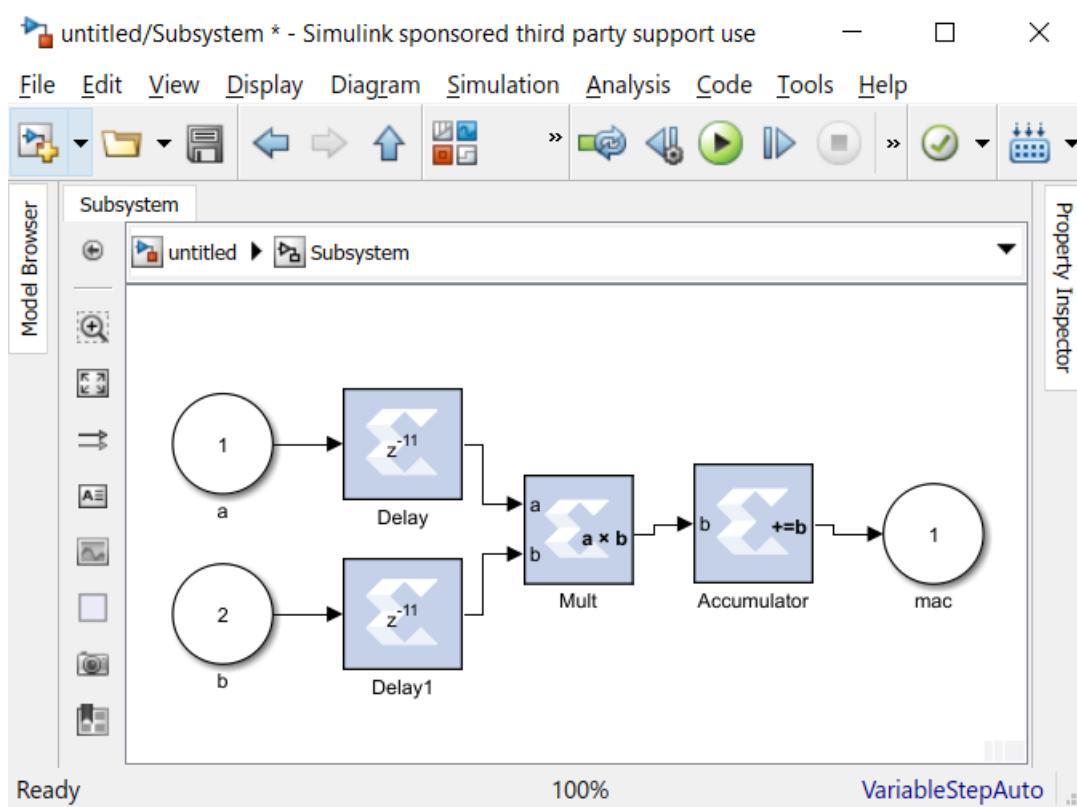
**Figure 406: Creating Toplevel Configuration**

4. Set the mask parameters as shown in the following figure, then click **OK**.

**Figure 407: Adding Mask Parameters**

The following diagram is generated:

Figure 408: Generated Diagram



**TIP:** Open `MACC_sub.m` in the MATLAB editor to debug the function. By default the `xBlock` constructor will do an auto layout in the end. If you want to see the auto layout every time a block is added, invoke the toplevel `xBlock` as the following:

```
config.source = str2func('MACC_sub');
config.toplevel = gcb;
config.debug = 1;
xBlock(config, {latency, nbits});
```

By setting the debug field of the configuration struct to be 1, you run the PG API in debug mode where every action will trigger an auto layout.



**TIP:** Most often you only want to re-generate the Subsystem if needed. The `xBlock` constructor has a caching mechanism. You can specify the list of dependent files in a cell array, and set the `depend` field of the toplevel configuration with this list. If any file in the 'depend' list is changed, or the argument list that passed to the toplevel function is changed, the Subsystem is re-generated. If you want to have the caching capability for the `MACC_sub`, invoke the toplevel `xBlock` as the following:

```
config.source = str2func('MACC_sub');
config.toplevel = gcb;
config.depend = {'MACC_sub.m'};
xBlock(config, {latency, nbits});
```

The depend field of the configuration struct is a cell array. Each element of the array is a file name. You can put a p-file name or an M-file name. You can also put a name without a suffix. The `xBlock` will use the first in the path.

## PG API Error/Warning Handling and Messages

### xBlock Error Messages

Condition	Error Message(s)
When calling <code>xBlock(NoSubSourceBlock, )</code> and the source block does not exist	Source block NoSubSourceBlock cannot be found.
When calling <code>xBlock(sourceblock, parameterBinding)</code> , and the parameters are illegal, <code>xBlock</code> will report the <code>Illegal parameterization</code> error. For example, <code>xBlock('AddSub', struct('latency', -1))</code> ;	Illegal parameterization: Latency Latency is set to a value of -1, but the value must be greater than or equal to 0
When the input port binding list contains objects other than <code>xSignal</code> or <code>xImport</code> :	Only objects of <code>xImport</code> or <code>xSignal</code> can appear in import binding list.
When the output port binding list contains objects other than <code>xSignal</code> or <code>xOutport</code> :	Only objects of <code>xOutport</code> or <code>xSignal</code> can appear in outport binding list.
If the first argument of <code>xBlock</code> is a function pointer, the 2nd argument of <code>xBlock</code> is expected to be a cell array, otherwise, an error is thrown:	Cell array is expected for the second argument of the <code>xBlock</code> call
If the source configuration struct has toplevel defined, it must point to a Simulink® Subsystem and it must be a char array, otherwise, an error is thrown:	Top level must be a char array
If an object in the outport binding list has already been driven by something, for example, if you try to have two driving sources, an error is thrown.	Source of <code>xSignal</code> object already exists

### xImport Error Messages

Condition	Error Message(s)
If you try to create an <code>xImport</code> object with the same name the second time, an error is thrown. For example, if you call <code>p = xImport('a', 'a')</code> .	A new block named 'untitled/Subsystem/a' cannot be added.

### xOutport Error Messages

Condition	Error Message(s)
If you try to create an <code>xOutport</code> object with the same name the second time, an error is thrown. For example, if you call <code>p = xOutport('a', 'a')</code> .	A new block named 'untitled/Subsystem/a' cannot be added.
If you try to bind an <code>xOutport</code> object twice, an error is thrown. For example, the following sequence of calls will cause an error: <code>[a, b] = xImport('a', 'b'); c = xOutport('c'); c.bind(a); c.bind(b);</code>	The destination port already has a line connection.

## xSignal Error Messages

Condition	Error Message(s)
If you try to bind an xSignal object with two sources, an error is thrown. For example, the following sequence of calls will cause an error: [a, b] = xlImport('a', 'b'); sig = xSignal; sig.bind(a); sig.bind(b);	Source of xSignal object already exists.

## xsub2script Error Messages

Condition	Error Message(s)
xlsub2script is invoked without any argument.	An argument is expected for xlsub2script
The first argument is not a Subsystem or the model is not opened.	The first argument must be a model, Subsystem, or a block. Please make sure the model is opened or the argument is a valid string for a model or a block.
A Subsystem has Simulink function calls in its mask initialization code.	Subsystem has Simulink function calls, such as gcb, get_param, set_param, add_block. Please remove these calls and run xlsub2script again or you can pick a different Subsystem to run xlsub2script.
The Subsystem has Goto blocks.	You have the following Goto blocks, please modify the model to remove them and run xlsub2script again.

## M-Code Access to Hardware Co-Simulation

HDL Hardware co-simulation in Model Composer brings on-chip acceleration and verification capabilities into the Simulink simulation environment. In the typical Model Composer flow, a Model Composer model is first compiled for a hardware co-simulation platform, during which a hardware implementation (bitstream) of the design is generated and associated to a hardware co-simulation block. The block is inserted into a Simulink model and its ports are connected with appropriate source and sink blocks. The whole model is simulated while the compiled Model Composer design is executed on an FPGA.

Alternatively, it is possible to programmatically control the hardware created through the Model Composer HDL hardware co-simulation flow using MATLAB M-code (M-Hwcosim). The M-Hwcosim interfaces allow for MATLAB objects that correspond to the hardware to be created in pure M-code, independent of the Simulink framework. These objects can then be used to read and write data into hardware.

This capability is useful for providing a scripting interface to hardware co-simulation, allowing for the hardware to be used in a scripted test bench or deployed as hardware acceleration in M-code. Apart from supporting the scheduling semantics of a Model Composer simulation, M-Hwcosim also gives the flexibility for any arbitrary schedule to be used. This flexibility can be exploited to improve the performance of a simulation, if the user has apriori knowledge of how the design works. Additionally, the M-Hwcosim objects provide accessibility to the hardware from the MATLAB console, allowing for the hardware internal state to be introspected interactively.

## ***Compiling Hardware for Use with M-Hwcosim***

Compiling hardware for use in M-Hwcosim follows the same flow as the typical Model Composer HDL hardware co-simulation flow. You start off with a Model Composer model in Simulink, select a hardware co-simulation target in the Compiling Hardware for Use with M-Hwcosim and click Generate. At the end of the generation, a hardware co-simulation library is created.

Among other files in the netlist directory, you can find a bit file and an hwc file. The bit file corresponds to the FPGA implementation, and the hwc file contains information required for M-Hwcosim. Both bit file and hwc file are paired by name, e.g. mydesign\_cw.bit and mydesign\_cw.hwc.

The hwc file specifies additional meta information for describing the design and the chosen hardware co-simulation interface. With the meta information, a hardware co-simulation instance can be instantiated using M-Hwcosim, through which you can interact with the co-simulation engine.

M-Hwcosim inherits the same concepts of ports and fixed point notations as found in the existing co-simulation block. Every design exposes its top-level ports for external access.

## ***M-Hwcosim Simulation Semantics***

The simulation semantics for M-Hwcosim differs from that used during hardware co-simulation in a Model Composer block diagram; the M-Hwcosim simulation semantics is more flexible and is capable of emulating the simulation semantics used in the block-based hardware co-simulation.

In the block-based hardware co-simulation, a rigid simulation semantic is imposed; before advancing a clock cycle, all the input ports of the hardware co-simulation are written to. Next all the output ports are read and the clock is advanced. In M-Hwcosim the scheduling of when ports are read or written to, is left to the user. For instance it would be possible to create a program that would only write data to certain ports on every other cycle, or to only read the outputs after a certain number of clock cycles. This flexibility allows users to optimize the transfer of data for better performance.

## ***Data Representation***

M-Hwcosim uses fixed point data types internally, while it consumes and produces double precision floating point values to external entities. All data samples passing through a port are fixed point numbers. Each sample has a preset data width and an implicit binary point position that are fixed at the compilation time. Data conversions (from double precision to fixed point) happen on the boundary of M-Hwcosim. In the current implementation, quantization of the input data is handled by rounding, and overflow is handled by saturation.

## Interfacing to Hardware from M-Code

When a model has been compiled for hardware co-simulation, the generated bitstream can be used in both a model-based Simulink flow, or in M-code executed in MATLAB. The general sequence of operations to access a bitstream in hardware typically follows the sequence described below.

1. Configure the hardware co-simulation interface. Note that the hardware co-simulation configuration is persistent and is saved in the `hwc` file. If the co-simulation interface is not changed, there is no need to re-run this step.
2. Create a M-Hwcosim instance for a particular design.
3. Open the M-Hwcosim interface.
4. Repeatedly run the following sub-steps until the simulation ends.
5. Write simulation data to input ports.
6. Read simulation data from output ports.
7. Advance the design clock by one cycle.
8. Close the M-Hwcosim interface.
9. Release the M-Hwcosim instance.

## Automatic Generation of M-Hwcosim Testbench

M-Hwcosim enables the test bench generation for hardware co-simulation. When the **Create testbench** option is checked in the Model Composer Hub block, the hardware co-simulation compilation flow generates an M-code script (`<design>_hwcosim_test.m`) and golden test data files (`<design>_<port>_hwcosim_test.dat`) for each gateway based on the Simulink simulation. The M-code script uses the M-Hwcosim API to implement a test bench that simulates the design in hardware and verifies the results against the golden test data. Any simulation mismatch is reported in a result file (`<design>_hwcosim_test.results`).

As shown below in the Example, the test bench code generated is easily readable and can be used as a basis for your own simulation code.

```
function multi_rates_cw_hwcosim_test
try
% Define the number of hardware cycles for the simulation.
ncycles = 10;

% Load input and output test reference data.
testdata_in2 = load('multi_rates_cw_in2_hwcosim_test.dat');
testdata_in3 = load('multi_rates_cw_in3_hwcosim_test.dat');
testdata_in7 = load('multi_rates_cw_in7_hwcosim_test.dat');
testdata_pb00 =
load('multi_rates_cw_pb00_hwcosim_test.dat');
testdata_pb01 =
```

```

load('multi_rates_cw_pb01_hwcosim_test.dat');
    testdata_pb02 =
load('multi_rates_cw_pb02_hwcosim_test.dat');
    testdata_pb03 =
load('multi_rates_cw_pb03_hwcosim_test.dat');
    testdata_pb04 =
load('multi_rates_cw_pb04_hwcosim_test.dat');

    % Pre-allocate memory for test results.
    result_pb00 = zeros(size(testdata_pb00));
    result_pb01 = zeros(size(testdata_pb01));
    result_pb02 = zeros(size(testdata_pb02));
    result_pb03 = zeros(size(testdata_pb03));
    result_pb04 = zeros(size(testdata_pb04));

    % Initialize sample index counter for each sample period to
be
    % scheduled.
    insp_2 = 1;
    insp_3 = 1;
    insp_7 = 1;
    outsp_1 = 1;
    outsp_2 = 1;
    outsp_3 = 1;
    outsp_7 = 1;

    % Define hardware co-simulation project file.
    project = 'multi_rates_cw.hwc';

    % Create a hardware co-simulation instance.
    h = Hwcosim(project);

    % Open the co-simulation interface and configure the
hardware.
    try
        open(h);
    catch
        % If an error occurs, launch the configuration GUI for the
user
        % to change interface settings, and then retry the process
again.
        release(h);
        drawnow;
        h = Hwcosim(project);
        open(h);
    end

    % Simulate for the specified number of cycles.
    for i = 0:(ncycles-1)

        % Write data to input ports based their sample period.
        if mod(i, 2) == 0
            h('in2') = testdata_in2(insp_2);
            insp_2 = insp_2 + 1;
        end
        if mod(i, 3) == 0
            h('in3') = testdata_in3(insp_3);
            insp_3 = insp_3 + 1;
        end
        if mod(i, 7) == 0
            h('in7') = testdata_in7(insp_7);
            insp_7 = insp_7 + 1;
        end
    end

```

```
% Read data from output ports based their sample period.
result_pb00(outsp_1) = h('pb00');
result_pb04(outsp_1) = h('pb04');
outsp_1 = outsp_1 + 1;
if mod(i, 2) == 0
    result_pb01(outsp_2) = h('pb01');
    outsp_2 = outsp_2 + 1;
end
if mod(i, 3) == 0
    result_pb02(outsp_3) = h('pb02');
    outsp_3 = outsp_3 + 1;
end
if mod(i, 7) == 0
    result_pb03(outsp_7) = h('pb03');
    outsp_7 = outsp_7 + 1;
end

% Advance the hardware clock for one cycle.
run(h);

end

% Release the hardware co-simulation instance.
release(h);

% Check simulation result for each output port.
logfile = 'multi_rates_cw_hwcosim_test.results';
logfd = fopen(logfile, 'w');
sim_ok = true;
sim_ok = sim_ok & check_result(logfd, 'pb00',
testdata_pb00, result_pb00);
sim_ok = sim_ok & check_result(logfd, 'pb01',
testdata_pb01, result_pb01);
sim_ok = sim_ok & check_result(logfd, 'pb02',
testdata_pb02, result_pb02);
sim_ok = sim_ok & check_result(logfd, 'pb03',
testdata_pb03, result_pb03);
sim_ok = sim_ok & check_result(logfd, 'pb04',
testdata_pb04, result_pb04);
fclose(logfd);
if ~sim_ok
    error('Found errors in simulation results. Please refer to
''%s'' for details.', logfile);
end

catch
err = lasterr;
try release(h); end
error('Error running hardware co-simulation testbench. %s',
err);
end

%-----
function ok = check_result(fd, portname, expected, actual)
ok = false;

fprintf(fd, ['\n' repmat('=', 1, 95), '\n']);
fprintf(fd, 'Output: %s\n\n', portname);
```

```
% Check the number of data values.
nvals_expected = numel(expected);
nvals_actual = numel(actual);
if nvals_expected ~= nvals_actual
    fprintf(fd, ['The number of simulation output values (%d)
differs ' ...
              'from the number of reference values (%d).\n'], ...
              nvals_actual, nvals_expected);
    return;
end

% Check for simulation mismatches.
mismatches = find(expected ~= actual);
num_mismatches = numel(mismatches);
if num_mismatches > 0
    fprintf(fd, 'Number of simulation mismatches = %d\n',
            num_mismatches);
    fprintf(fd, '\n');
    fprintf(fd, 'Simulation mismatches:\n');
    fprintf(fd, '-----\n');
    fprintf(fd, '%10s %40s %40s\n', 'Cycle', 'Expected values',
            'Actual values');
    fprintf(fd, '%10d %40.16f %40.16f\n', ...
            [mismatches-1; expected(mismatches); actual(mismatches)]);
    return;
end

ok = true;
fprintf(fd, 'Simulation OK\n');
```

## Resource Management

M-Hwcosim manages resources that it holds for a hardware co-simulation instance. It releases the held resources upon the invocation of the release instruction or when MATLAB exits. However, it is recommended to perform an explicit cleanup of resources when the simulation finishes or throws an error. To allow proper cleanup in case of errors, it is suggested to enclose M-Hwcosim instructions in a MATLAB try-catch block as illustrated below.

```
try
    % M-Hwcosim instructions here
catch
    err = lasterror;
    % Release any Hwcosim instances
    try release(hwcosim_instance); end
    rethrow(err);
end
```

The following command can be used to release all hardware co-simulation instances.

```
xlHwcosim('release'); % Release all Hwcosim instances
```

## M-Hwcosim MATLAB Class

The `Hwcosim` MATLAB class provides a higher level abstraction of the hardware co-simulation engine. Each instantiated `Hwcosim` object represents a hardware co-simulation instance. It encapsulates the properties, such as the unique identifier, associated with the instance. Most of the instruction invocations take the `Hwcosim` object as an input argument. For further convenience, alternative shorthand is provided for certain operations.

Actions	Syntax
Constructor	<code>h = Hwcosim(project)</code>
Destructor	<code>release(h)</code>
Open hardware	<code>open(h)</code>
Close hardware	<code>close(h)</code>
Write data	<code>write(h, 'portName', inData);</code>
Read data	<code>outData = read(h, 'portName');</code>
Run	<code>run(h);</code>
Port information	<code>portinfo(h);</code>
Set property	<code>set(h, 'propertyName', PropertyValue);</code>
Get property	<code>PropertyValue = get(h, 'propertyName');</code>

### Constructor

#### Syntax

```
h = Hwcosim(project);
```

#### Description

Creates an `Hwcosim` instance. Note that an instance is a reference to the hardware co-simulation project and does not signify an explicit link to hardware; creating a `Hwcosim` object informs the `Hwcosim` engine where to locate the FPGA bitstream, it does not download the bitstream into the FPGA. The bitstream is only downloaded to the hardware after an open command is issued.

The project argument should point to the `hwc` file that describes the hardware co-simulation.

Creating the `Hwcosim` object will list all input and output ports. The example below shows the output of a call to the `Hwcosim` constructor, displaying the ID of the object and a list of all the input and output gateways/ports.

```
>> h = Hwcosim(p)
Model Composer HDL Hardware Co-simulation Object
  id: 30247
  imports:
    gateway_in
    gateway_in2
  outputs:
    gateway_out
```

**Destructor****Syntax**

```
release(h);
```

**Description**

Releases the resources used by the Hwcosim object h. If a link to hardware is still open, release will first close the hardware.

**Open Hardware****Syntax**

```
open(h);
```

**Description**

Opens the connection between the host PC and the FPGA. Before this function can be called, the hardware co-simulation interface must be configured. The argument, h, is a handle to an Hwcosim object.

**Close hardware****Syntax**

```
close(h);
```

**Description**

Closes the connection between the host PC and the FPGA. The argument, h, is a handle to an Hwcosim object.

**Write data****Syntax**

```
h('portName') = inData; %If inData is array, results in burst write.  
h('portName') = [1 2 3 4];  
write(h, 'portName', inData);  
write(h, 'portName', [1 2 3 4]); %burst mode
```

## Description

Ports are referenced by their legalized names. Name legalization is a requirement for VHDL and Verilog synthesis, and converts names into all lower-case, replaces white space with underscores, and adds unique suffixes to avoid namespace collisions. To find out what the legalized input and output port names are, run the helper command `portinfo(h)`, or see the output of Hwcosim at the time of instance creation.

`inData` is the data to be written to the port. Normal single writes are performed if `inData` is a scalar value. If burst mode is enabled and `inData` is a  $1 \times n$  array, it will be interpreted as a timeseries and written to the port via burst data transfer.

## Read data

### Syntax

```
outData = h('portName');
outData = h('portName', 25); %burst mode
outData = read(h, 'portName');
outData = read(h, 'portName', 25); %burst
```

## Description

Ports are referenced by their legalized names (see previous class above).

If burst mode is enabled, and depending on whether the read command has 3 or 4 parameters (2 or 3 parameters in the case of a subscript reference `h('portName', ...)`), `outData` will be assigned a scalar or a  $1 \times n$  array. If an array, the data is the result of a burst data transfer.

## Run

### Syntax

```
run(h);
run(h, n);
run(h, inf); %start free-running clock
run(h, 0); %stop free-running clock
```

## Description

When the hardware co-simulation object is configured to run in single-step mode, the `run` command is used to advance the clock. `run(h)` will advance the clock by one cycle. `run(h,n)` will advance the clock by `n` cycles.

The `run` command is also used to turn on (and off) free-running clock mode: `run(h, inf)` will start the free-running clock and `run(h, 0)` will stop it.

A read of an output port will need to be preceded either by a 'dummy' `run` command or by a `write`, in order to force a synchronization of the read cache with the hardware.

## Port Information

### Syntax

```
portinfo(h);
```

### Description

This method will return a MATLAB struct array with fields `imports` and `outports`, which themselves are struct arrays holding all input and output ports, respectively, again represented as struct arrays. The fieldnames of the individual port structs are the legalized portnames themselves, so you may obtain a cell array of input port names suitable for `Hwcosim write` commands by issuing these commands:

```
a = portinfo(h);
imports = fieldnames(a.imports);
```

You can issue a similar series of commands for output ports (`outports`).

Additional information contained in the port structs are `simulink_name`, which provides the fully hierarchical Simulink name including spaces and line breaks, `rate`, which contains the signal's rate period with respect to the DUT clock, `type`, which holds the Model Composer data type information, and, if burst mode is enabled, `fifo_depth`, indicating the maximum size of data bursts that can be sent to Hardware in a batch.

## Set property

### Syntax

```
set(h, 'propertyName', PropertyValue);
```

### Description

The `set` method sets or changes any of the contents of the internal properties table of the `Hwcosim` instance `h`. It is required that `h` already exists before calling this method.

## Examples

```
set(h, 'booleanProperty', logical(0));
set(h, 'integerProperty', int32(12345));
set(h, 'doubleProperty', pi);
set(h, 'stringProperty', 'Rosebud!');
```

## Get property

### Syntax

The get property method returns the value of any of the contents of the internal properties table in the Hwcosim instance `h`, referenced by the `propertyName` key. It is required that `h` already exists before calling this method. If the `propertyName` key does not exist in `h`, the method throws an exception and prints an error message.

### Examples

```
bool_val = get(h, 'booleanProperty');

int_val = get(h, 'integerProperty');

double = get(h, 'doubleProperty');

str_val = get(h, 'stringProperty');
```

## M-Hwcosim Utility Functions

### xlHwcosim

#### Syntax

```
xlHwcosim('release');
```

#### Description

When M-Hwcosim objects are created global system resources are used to register each of these objects. These objects are typically freed when a release command is called on the object. xlHwcosim provides an easy way to release all resources used by M-Hwcosim in the event of an unexpected error. The release functions for each of the objects should be used if possible because the xlHwcosim call release the resources for all instances of a particular type of object.

#### Example

```
xlHwcosim('release') %release all instances of Hwcosim objects.
```

# Additional Resources and Legal Notices

---

## Xilinx Resources

For support resources such as Answers, Documentation, Downloads, and Forums, see [Xilinx Support](#).

---

## Documentation Navigator and Design Hubs

Xilinx® Documentation Navigator (DocNav) provides access to Xilinx documents, videos, and support resources, which you can filter and search to find information. To open DocNav:

- From the Vivado® IDE, select **Help**→**Documentation and Tutorials**.
- On Windows, select **Start**→**All Programs**→**Xilinx Design Tools**→**DocNav**.
- At the Linux command prompt, enter `docnav`.

Xilinx Design Hubs provide links to documentation organized by design tasks and other topics, which you can use to learn key concepts and address frequently asked questions. To access the Design Hubs:

- In DocNav, click the **Design Hubs View** tab.
- On the Xilinx website, see the [Design Hubs](#) page.

**Note:** For more information on DocNav, see the [Documentation Navigator](#) page on the Xilinx website.

---

## References

These documents provide supplemental material useful with this guide:

1. *Introduction to FPGA Design with Vivado High-Level Synthesis* ([UG998](#))
2. *Vivado Design Suite User Guide: High-Level Synthesis* ([UG902](#))
3. *UltraFast Vivado HLS Methodology Guide* ([UG1197](#))
4. *Vivado Design Suite User Guide: Designing with IP* ([UG896](#))
5. *Vivado Design Suite User Guide: Creating and Packaging Custom IP* ([UG1118](#))
6. *AI Engine Tools and Flows User Guide* ([UG1076](#))
7. *Vitis Model Composer Tutorial* ([UG1498](#))
8. *Vivado Design Suite User Guide: Using the Vivado IDE* ([UG893](#))
9. *Vivado Design Suite User Guide: Design Flows Overview* ([UG892](#))
10. *ISE to Vivado Design Suite Migration Guide* ([UG911](#))
11. *Vivado Design Suite User Guide: Using Constraints* ([UG903](#))
12. *Vivado Design Suite User Guide: Using Tcl Scripting* ([UG894](#))
13. *Vivado Design Suite Tutorial: Design Flows Overview* ([UG888](#))
14. *Vivado Design Suite User Guide: System-Level Design Entry* ([UG895](#))
15. *Vivado Design Suite User Guide: Release Notes, Installation, and Licensing* ([UG973](#))
16. *UltraFast Design Methodology Guide for FPGAs and SOCs* ([UG949](#))
17. [Vivado® Design Suite Documentation](#)
18. [Mathworks® Simulink® Documentation](#)

---

## Revision History

The following table shows the revision history for this document.

Section	Revision Summary
10/19/2022 Version 2022.2	
General Updates	Updated for 2022.2 release.
Automatic Code Generation	Updated to use Vitis Model Composer Hub block
Variant Subsystems and Model Composer	Replaces Configurable Subsystems and Model Composer
<a href="#">Chapter 5: Hardware Validation Flow for AI Engines and PL</a>	New chapter
<a href="#">AI Engine Blockset</a>	Added Window Function and Window Function Stream blocks
05/26/2022 Version 2022.1	
<a href="#">AI Engine Blockset</a>	Added new DSPLib Functions.
<a href="#">HDL Blockset</a>	Added new Gateway In/Out AXI Stream Functions.
General Updates	Updated for release 2022.1.

# Please Read: Important Legal Notices

The information disclosed to you hereunder (the "Materials") is provided solely for the selection and use of Xilinx products. To the maximum extent permitted by applicable law: (1) Materials are made available "AS IS" and with all faults, Xilinx hereby DISCLAIMS ALL WARRANTIES AND CONDITIONS, EXPRESS, IMPLIED, OR STATUTORY, INCLUDING BUT NOT LIMITED TO WARRANTIES OF MERCHANTABILITY, NON-INFRINGEMENT, OR FITNESS FOR ANY PARTICULAR PURPOSE; and (2) Xilinx shall not be liable (whether in contract or tort, including negligence, or under any other theory of liability) for any loss or damage of any kind or nature related to, arising under, or in connection with, the Materials (including your use of the Materials), including for any direct, indirect, special, incidental, or consequential loss or damage (including loss of data, profits, goodwill, or any type of loss or damage suffered as a result of any action brought by a third party) even if such damage or loss was reasonably foreseeable or Xilinx had been advised of the possibility of the same. Xilinx assumes no obligation to correct any errors contained in the Materials or to notify you of updates to the Materials or to product specifications. You may not reproduce, modify, distribute, or publicly display the Materials without prior written consent. Certain products are subject to the terms and conditions of Xilinx's limited warranty, please refer to Xilinx's Terms of Sale which can be viewed at <https://www.xilinx.com/legal.htm#tos>; IP cores may be subject to warranty and support terms contained in a license issued to you by Xilinx. Xilinx products are not designed or intended to be fail-safe or for use in any application requiring fail-safe performance; you assume sole risk and liability for use of Xilinx products in such critical applications, please refer to Xilinx's Terms of Sale which can be viewed at <https://www.xilinx.com/legal.htm#tos>.

## AUTOMOTIVE APPLICATIONS DISCLAIMER

AUTOMOTIVE PRODUCTS (IDENTIFIED AS "XA" IN THE PART NUMBER) ARE NOT WARRANTED FOR USE IN THE DEPLOYMENT OF AIRBAGS OR FOR USE IN APPLICATIONS THAT AFFECT CONTROL OF A VEHICLE ("SAFETY APPLICATION") UNLESS THERE IS A SAFETY CONCEPT OR REDUNDANCY FEATURE CONSISTENT WITH THE ISO 26262 AUTOMOTIVE SAFETY STANDARD ("SAFETY DESIGN"). CUSTOMER SHALL, PRIOR TO USING OR DISTRIBUTING ANY SYSTEMS THAT INCORPORATE PRODUCTS, THOROUGHLY TEST SUCH SYSTEMS FOR SAFETY PURPOSES. USE OF PRODUCTS IN A SAFETY APPLICATION WITHOUT A SAFETY DESIGN IS FULLY AT THE RISK OF CUSTOMER, SUBJECT ONLY TO APPLICABLE LAWS AND REGULATIONS GOVERNING LIMITATIONS ON PRODUCT LIABILITY.

## Copyright

© Copyright 2017-2022 Advanced Micro Devices, Inc. Xilinx, the Xilinx logo, Alveo, Artix, Kintex, Kria, Spartan, Versal, Vitis, Virtex, Vivado, Zynq, and other designated brands included herein are trademarks of Xilinx in the United States and other countries. AMBA, AMBA Designer, Arm, ARM1176JZ-S, CoreSight, Cortex, PrimeCell, Mali, and MPCore are trademarks of Arm Limited in the EU and other countries. All other trademarks are the property of their respective owners.