# Fixed-Point Blockset

**For Use with Simulink®**

**Modeling**

**Simulation**

**Implementation**

User's Guide

*Version 4*

The MathWorks

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*Fixed-Point Blockset User's Guide*

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# Preface

## What Is the Fixed-Point Blockset?

The Fixed-Point Blockset includes a collection of blocks that extend the standard Simulink® block library. With these blocks, you can create discrete-time dynamic systems that use fixed-point arithmetic. As a result, Simulink can simulate effects commonly encountered in fixed-point systems for applications such as control systems and time-domain filtering. The Fixed-Point Blockset includes these major features:

- Integer, fractional, and generalized fixed-point data types
  - Unsigned and two's complement formats
  - Word sizes in simulation from 1 to 128 bits
- Floating-point data types
  - IEEE-style singles and doubles
  - A nonstandard IEEE-style data type, where the fraction can range from 1 to 52 bits and the exponent can range from 1 to 11 bits
- Methods for overflow handling, scaling, and rounding of fixed-point data types
- Tools that facilitate
  - The collection of minimum and maximum simulation values
  - The optimization of scaling parameters
  - The display of input and output signals

In addition, you can generate C code for execution on a fixed-point embedded processor with Real-Time Workshop®. The generated code uses only integer types and automatically includes all operations, such as shifts, needed to account for differences in fixed-point locations.

### Exploring the Blockset

To open the main Fixed-Point Blockset library, type

```
fixpt
```

at the MATLAB® command line, or right-click on the Fixed-Point Blockset listing in the Simulink Library Browser. The main library contains 12 sublibraries. Refer to "Blocks—By Category" on page 10-13.

You can double-click on any block icon in a library to see its parameter dialog box. Click the **Help** button to view the HTML-based help for that block.

## How to Get Online Help

The Fixed-Point Blockset provides several ways to get online help:

- **Block, System, and Filter Help**

  Click the **Help** button in any block, system, or filter dialog box to view its HTML-based documentation.
- **Help Desk**

  Type `helpdesk` or `doc` at the MATLAB command line to load the main MATLAB help page into the Help browser.
- **Release Information**

Type `whatsnew fixpoint` at the MATLAB command line to view information related to the version of the Fixed-Point Blockset that you're using.

## System Requirements

The Fixed-Point Blockset is a multiplatform product that you install on a host computer running any of the operating systems supported by The MathWorks. The Fixed-Point Blockset requires

- MATLAB 6.5 (Release 13) or later
- Simulink 5.0 (Release 13) or later

If you want to generate code from your fixed-point models, you must have Real-Time Workshop®. If you want to create an executable from the generated code, you must have the appropriate C compiler and linker.

For the most up-to-date information about system requirements, see the system requirements section available in the support area of the MathWorks Web site (`http://www.mathworks.com/support`).

### Licensing Information

Beginning with Release 13, the Fixed-Point Blockset is shipped and installed with every copy of Simulink. You can edit a model containing fixed-point blocks without a fixed-point license. However, you must have a fixed-point license to

- Update a Simulink diagram (**Ctrl+D**) containing fixed-point data types
- Run a model containing fixed-point data types
- Generate code from a model containing fixed-point data types
- Log the minimum and maximum values produced by a simulation
- Handle overflows by saturating to the minimum or maximum possible value
- Automatically scale the output of a model using the autoscaling tool

The following products also depend on a fixed-point license to take full advantage of fixed-point features in Release 13:

- DSP Blockset
- Embedded Target for the TI TMS320C600™ DSP Platform
- Real-Time Workshop
- Real-Time Workshop Embedded Coder
- Stateflow®
- Stateflow Coder

- xPC Target

To work with a model containing blocks from the Fixed-Point Blockset without a fixed-point license,

1. Access the **Fixed-Point Settings** interface from the model by selecting **Tools** -> **Fixed-Point settings**.
2. Set the **Logging mode** parameter to `Force off` model wide.
3. Set the **Data type override** parameter to `True doubles` or `True singles` model wide.

## Related Products

The MathWorks provides several products that are especially relevant to the kinds of tasks you can perform with the Fixed-Point Blockset.

For more information about any of these products, see either

- The online documentation for that product if it is installed or if you are reading the documentation from the CD
- The products area of the MathWorks Web site (`http://www.mathworks.com/products`)

**Note** The toolboxes listed below all include functions that extend the capabilities of MATLAB. The blocksets all include blocks that extend the capabilities of Simulink.

| Product | Description |
|---|---|
| DSP Blockset | Design and simulate DSP systems |
| Filter Design Toolbox | Design and analyze advanced floating-point and fixed-point filters |
| Real-Time Workshop | Generate C code from Simulink models |
| Simulink | Design and simulate continuous- and discrete-time systems |
| Simulink Performance Tools | Manage and optimize the performance of large Simulink models |
| Simulink Report Generator | Automatically generate documentation for Simulink and Stateflow models |
| Stateflow | Design and simulate event-driven systems |

| Product | Description |
|---|---|
| Stateflow Coder | Generate C code from Stateflow charts |
| xPC Target | Perform real-time rapid prototyping using PC hardware |

## Using This Guide

This guide describes how to use the Fixed-Point Blockset to emulate fixed-point arithmetic when modeling discrete-time dynamic systems in Simulink. It contains tutorial information that describes how to use the blockset features, as well as a reference entry for each block and function in the blockset.

### Expected Background

This guide assumes you are familiar with both MATLAB and Simulink. If you are new to MATLAB, you should read the Getting Started with MATLAB documentation. If you are new to Simulink, you should read the Using Simulink documentation.

You should also have a basic understanding of Boolean algebra and binary word representations.

### If You Are a New User

Start with Chapter 1, “Introduction,” which describes how the Fixed-Point Blockset can help you bridge the gap between designing a dynamic system and implementing it on fixed-point digital hardware. Then read Chapter 2, “Getting Started with the Blockset,” which describes many Fixed-Point Blockset features and provides a simple example. After reading this chapter, you should be able to create simple fixed-point models. If you want detailed information about a specific block, refer to Chapter 10, “Block Reference.” If you want detailed information about a specific function, refer to Chapter 9, “Function Reference.”

### If You Are an Experienced User

Start with Chapter 6, “Tutorial: Feedback Controller Simulation,” which describes how to simulate a fixed-point digital controller design. You should then read those parts of the guide that address the functionality that concerns you. If you want detailed information about a specific block, refer to Chapter 10, “Block Reference.” If you want detailed information about a specific function, refer to Chapter 9, “Function Reference.”

## How This Book Is Organized

The organization of this guide is described below.

| Chapter Name | Description |
|---|---|
| Introduction | Describes how the Fixed-Point Blockset can help you bridge the gap between designing a dynamic system and implementing it on fixed-point digital hardware. |
| Getting Started with the Blockset | Shows you how to use many Fixed-Point Blockset features. After reading this chapter, you should be able to create simple fixed-point models. |
| Data Types and Scaling | Describes fixed-point data types, floating-point data types, and data type scaling. |
| Arithmetic Operations | Describes fixed-point arithmetic and its limitations. |
| Realization Structures | Describes how to create fixed-point realization structures. |
| Tutorial: Feedback Controller Simulation | Describes how to simulate a fixed-point digital controller design. |
| Tutorial: Producing Lookup Table Data | Describes how to create lookup table data using the lookup table approximation functions. |
| Code Generation | Describes the simulation features that are available for code generation. Recommendations for producing efficient code are provided. |
| Function Reference | Describes MATLAB M-file scripts and functions provided with the blockset. |
| Block Reference | Describes each fixed-point block in detail. |
| Glossary of Fixed-Point Terms | Presents a glossary of fixed-point terms used in The MathWorks documentation. |
| Selected Bibliography | Provides a selected list of references. |

## Installation

To determine if the Fixed-Point Blockset is installed on your system, type

```
ver
```

at the MATLAB command line. When you enter this command, MATLAB displays information about the version of MATLAB you are running, including a list of installed add-on products and their version numbers. Check the list to see if the Fixed-Point Blockset appears.

For information about installing the blockset, see your platform-specific MATLAB Installation guide.

If you experience installation difficulties and have Web access, look for the installation and license information at the MathWorks Web site (`http://www.mathworks.com/support`).

## Typographical Conventions

This manual uses some or all of these conventions.

| **Item** | **Convention** | **Example** |
|---|---|---|
| Example code | `Monospace` font | To assign the value 5 to `A`, enter<br>`A = 5` |
| Function names, syntax, filenames, directory/folder names, and user input | `Monospace` font | The `cos` function finds the cosine of each array element.<br>Syntax line example is<br>`MLGetVar ML_var_name` |
| Buttons and keys | **Boldface** with book title caps | Press the **Enter** key. |
| Literal strings (in syntax descriptions in reference chapters) | **`Monospace bold`** for literals | `f = freqspace(n,'`**`whole`**`')` |
| Mathematical expressions | *Italics* for variables<br>Standard text font for functions, operators, and constants | This vector represents the polynomial $p = x^2 + 2x + 3$. |
| MATLAB output | `Monospace` font | MATLAB responds with<br>`A =`<br>`    5` |
| Menu and dialog box titles | **Boldface** with book title caps | Choose the **File Options** menu. |
| New terms and for emphasis | *Italics* | An *array* is an ordered collection of information. |
| Omitted input arguments | (...) ellipsis denotes all of the input/output arguments from preceding syntaxes. | `[c,ia,ib] = union(...)` |
| String variables (from a finite list) | *`Monospace italics`* | `sysc = d2c(sysd,'`*`method`*`')` |

# Introduction

## Overview

This chapter provides a rationale for using fixed-point hardware in general, and the Fixed-Point Blockset in particular. The decision to use fixed-point hardware is simply a choice to represent numbers in a particular form. This representation often offers advantages in terms of the power consumption, size, memory usage, speed, and cost of the final product.

### Physical Quantities and Measurement Scales

A measurement of a physical quantity can take many numerical forms. For example, the boiling point of water is 100 degrees Celsius, 212 degrees Fahrenheit, 373 degrees Kelvin, or 671.4 degrees Rankine. No matter what number is given, the physical quantity is exactly the same. The numbers are different because four different scales are used.

Well known standard scales like Celsius are very convenient for the exchange of information. However, there are situations where it makes sense to create and use unique nonstandard scales. These situations usually involve making the most of a limited resource.

For example, nonstandard scales allow map makers to get the maximum detail on a fixed size sheet of paper. A typical road atlas of the USA will show each state on a two-page display. The scale of inches to miles will be unique for most states. By using a large ratio of miles to inches, all of Texas can fit on two pages. Using the same scale for Rhode Island would make poor use of the page. Using a much smaller ratio of miles to inches would allow Rhode Island to be shown with the maximum possible detail.

Fitting measurements of a variable inside an embedded processor is similar to fitting a state map on a piece of paper. The map scale should allow all the boundaries of the state to fit on the page. Similarly, the binary scale for a measurement should allow the maximum and minimum possible values to “fit.” The map scale should also make the most of the paper in order to get maximum detail. Similarly, the binary scale for a measurement should make the most of the processor in order to get maximum precision.

Use of standard scales for measurements has definite compatibility advantages. However, there are times when it is worthwhile to break convention and use a unique nonstandard scale. There are also occasions when a mix of uniqueness and compatibility makes sense.

## Selecting a Measurement Scale

Suppose that you want to make measurements of the temperature of liquid water, and that you want to represent these measurements using 8-bit unsigned integers. Fortunately, the temperature range of liquid water is limited. No matter what scale you use, liquid water can only go from the freezing point to the boiling point. Therefore, this is range of temperatures the you must capture using just the 256 possible 8-bit values: 0,1,2,...,255.

One approach to representing the temperatures is to use a standard scale. For example, the units for the integers could be Celsius. Hence, the integers 0 and 100 represent water at the freezing point and at the boiling point, respectively. On the upside, this scale gives a trivial conversion from the integers to degrees Celsius. On the downside, the numbers 101 to 255 are unused. By using this standard scale, more than 60% of the number range has been wasted.

A second approach is to use a nonstandard scale. In this scale, the integers 0 and 255 represent water at the freezing point and at the boiling point, respectively. On the upside, this scale gives maximum precision since there are 254 values between freezing and boiling instead of just 99. On the downside, the units are roughly 0.3921568 degree Celsius per bit so the conversion to Celsius requires division by 2.55, which is a relatively expensive operation on most fixed-point processors.

A third approach is to use a “semi-standard” scale. For example, the integers 0 and 200 could represent water at the freezing point and at the boiling point, respectively. The units for this scale are 0.5 degrees Celsius per bit. On the downside, this scale doesn’t use the numbers from 201 to 255, which represents a waste of more than 21%. On the upside, this scale permits relatively easy conversion to a standard scale. The conversion to Celsius involves division by 2, which is a very easy shift operation on most processors.

### Measurement Scales: Beyond Multiplication

One of the key operations in converting from one scale to another is multiplication. The preceding case study gave three examples of conversions from a quantized integer value $Q$ to a real-world Celsius value $V$ that involved only multiplication:

$$V = \begin{cases} \dfrac{100°C}{100\text{ bits}} \cdot Q_1 & \text{Conversion 1} \\ \dfrac{100°C}{255\text{ bits}} \cdot Q_2 & \text{Conversion 2} \\ \dfrac{100°C}{200\text{ bits}} \cdot Q_3 & \text{Conversion 3} \end{cases}$$

Graphically, the conversion is a line with slope $S$, which must pass through the origin. A line through the origin is called a purely linear conversion. Restricting yourself to a purely linear conversion can be very wasteful and it is often better to use the general equation of a line:

$$V = SQ + B$$

By adding a bias term $B$, you can obtain greater precision when quantizing to a limited number of bits.

The general equation of a line gives a very useful conversion to a quantized scale. However, like all quantization methods, the precision is limited and errors can be introduced by the conversion. The general equation of a line with quantization error is given by

$$V = SQ + B \pm Error$$

If the quantized value $Q$ is rounded to the nearest representable number, then

$$-\frac{S}{2} \le Error \le \frac{S}{2}$$

That is, the amount of quantization error is determined by both the number of bits and by the scale. This scenario represents the best case error. For other rounding schemes, the error can be twice as large.

## Example: Selecting a Measurement Scale

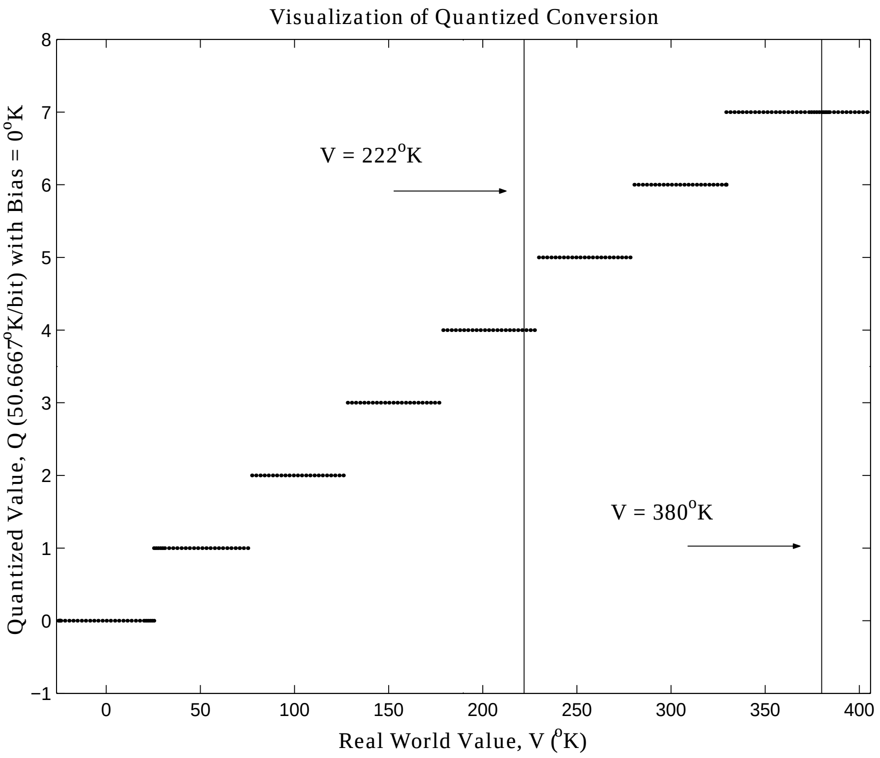
On typical electronically controlled internal combustion engines, the flow of fuel is regulated to obtain the desired ratio of air to fuel in the cylinders just prior to combustion. Therefore, knowledge of the current air flow rate is required. Some manufacturers use sensors that directly measure air flow while other manufacturers calculate air flow from measurements of related signals. The relationship of these variables is derived from the ideal gas equation. The ideal gas equation involves division by air temperature. For proper results, an absolute temperature scale such as Kelvin or Rankine must be used in the equation. However, quantization directly to an absolute temperature scale would cause needlessly large quantization errors.

The temperature of the air flowing into the engine has a limited range. On a typical engine, the radiator is designed to keep the block below the boiling point of the cooling fluid. Let's assume a maximum of 225$^o$ F (380$^o$ K). As the air flows through the intake manifold, it can be heated up to this maximum temperature. For a cold start in an extreme climate, the temperature can be as low as -60$^o$ F (222$^o$ K). Therefore, using the absolute Kelvin scale, the range of interest is 222$^o$ K to 380$^o$ K.

The air temperature needs to be quantized for processing by the embedded control system. Assuming an unrealistic quantization to 3-bit unsigned numbers: 0,1,2,...,7, the purely linear conversion with maximum precision is

$$V = \frac{380°K}{7.5\ \text{bit}} \cdot Q$$

The quantized conversion and range of interest are shown below.

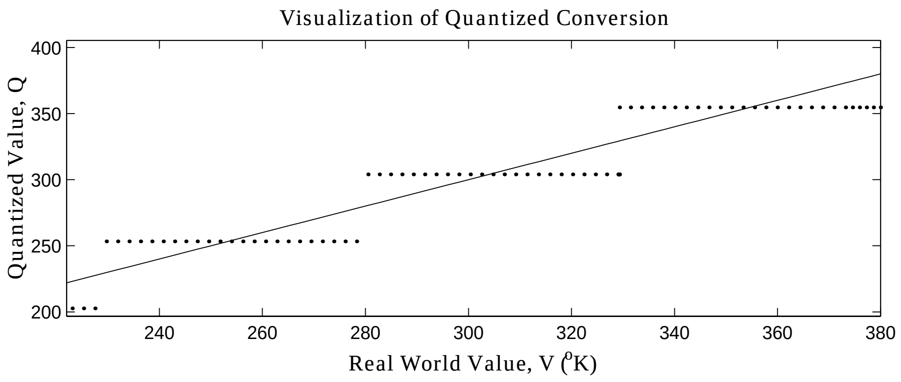


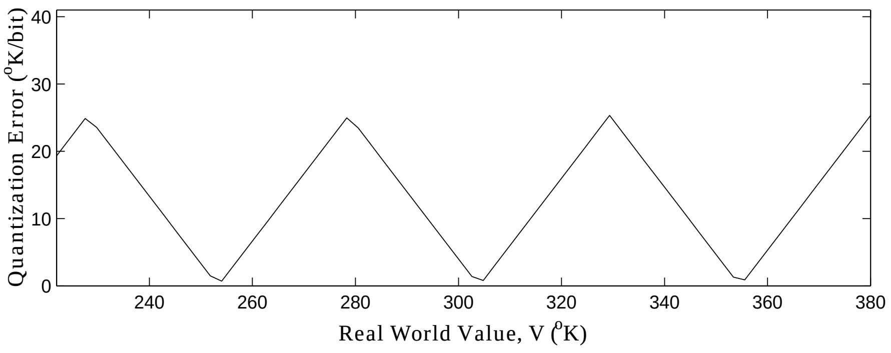
Notice that there are 7.5 possible quantization values. This is because only half of the first bit corresponds to temperatures (real-world values) greater than zero.

The quantization error is

$$-25.33°K/\text{bit} \le Error \le 25.33°K/\text{bit}$$

The range of interest of the quantized conversion and the absolute value of the quantized error are shown below.

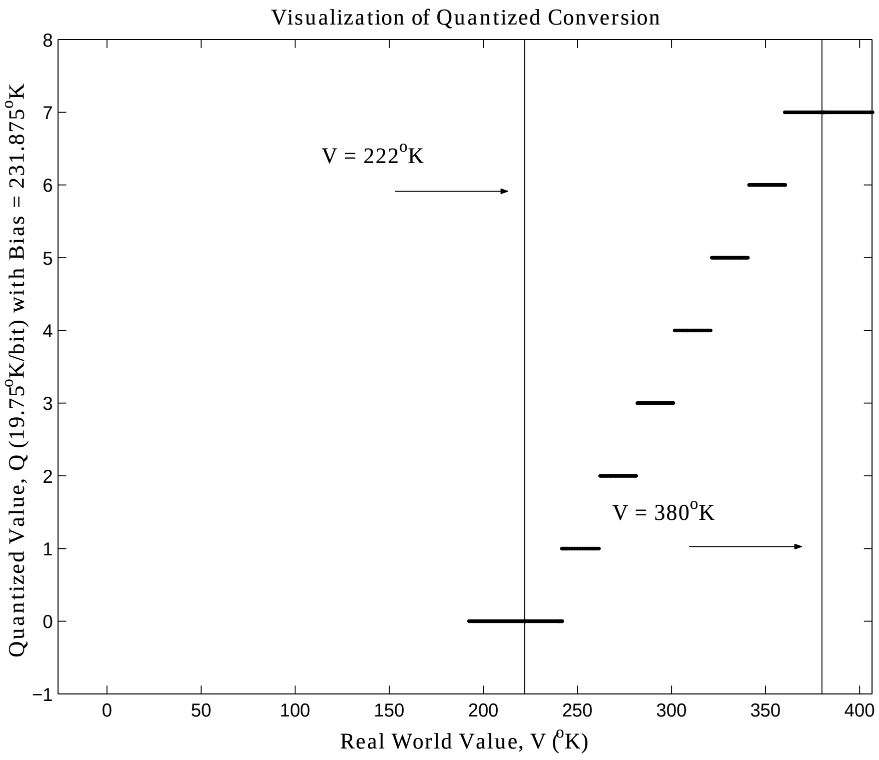




As an alternative to the purely linear conversion, consider the general linear conversion with maximum precision:

$$V = \left(\frac{380°K - 222°K}{8}\right) \cdot Q + 222°K + 0.5 \cdot \left(\frac{380°K - 222°K}{8}\right)$$

The quantized conversion and range of interest are shown below.

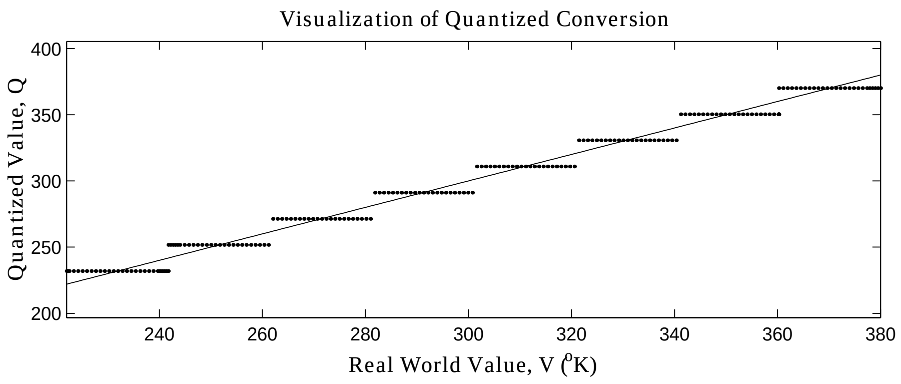


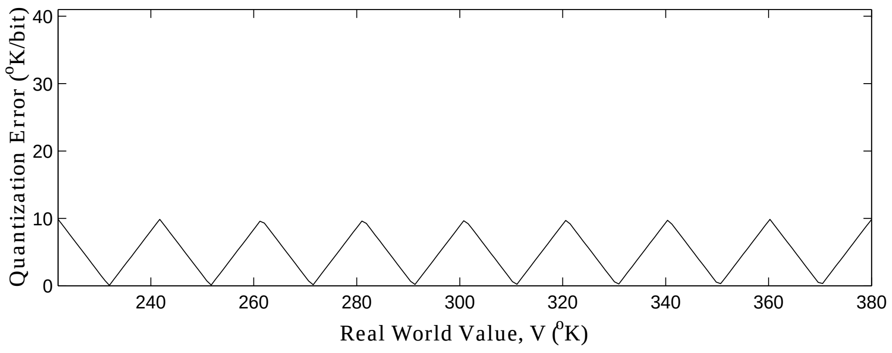
The quantization error is

$$-9.875°K/\text{bit} \le Error \le 9.875°K/\text{bit}$$

which is approximately 2.5 times smaller than the error associated with the purely linear conversion.

The range of interest of the quantized conversion and the absolute value of the quantized error are shown below.





Clearly, the general linear scale gives much better precision than the purely linear scale over the range of interest.

## Why Use Fixed-Point Hardware?

Digital hardware is becoming the primary means by which control systems and signal processing filters are implemented. Digital hardware can be classified as either off-the-shelf hardware (for example, microcontrollers, microprocessors, general purpose processors, and digital signal processors) or custom hardware. Within these two types of hardware, there are many architecture designs. These designs range from systems with a single instruction, single data stream processing unit to systems with multiple instruction, multiple data stream processing units.

Within digital hardware, numbers are represented as either fixed-point or floating-point data types. For both these data types, word sizes are fixed at a set number of bits. However, the dynamic range of fixed-point values is much less than floating-point values with equivalent word sizes. Therefore, in order to avoid overflow or unreasonable quantization errors, fixed-point values must be scaled. Since floating-point processors can greatly simplify the real-time implementation of a control law or digital filter, and floating-point numbers can effectively approximate real-world numbers, then why use a microcontroller or processor with fixed-point hardware support?

- **Size and Power Consumption** — The logic circuits of fixed-point hardware are much less complicated than those of floating-point hardware. This means that the fixed-point chip size is smaller with less power consumption when compared with floating-point hardware. For example, consider a portable telephone where one of the product design goals is to make it as portable (small and light) as possible. If one of today's high-end floating-point, general-purpose processors is used, a large heat sink and battery would also be needed resulting in a costly, large, and heavy portable phone.
- **Memory Usage and Speed** — In general fixed-point calculations require less memory and less processor time to perform.
- **Cost** — Fixed-point hardware is more cost effective where price/cost is an important consideration. When using digital hardware in a product, especially mass-produced products, fixed-point hardware costs much less than floating-point hardware and can result in significant savings.

After making the decision to use fixed-point hardware, the next step is to choose a method for implementing the dynamic system (for example, control system or digital filter). Floating-point software emulation libraries are generally ruled out because of timing or memory size constraints. Therefore, you are left with fixed-point math where binary integer values are scaled.

## Why Use the Fixed-Point Blockset?

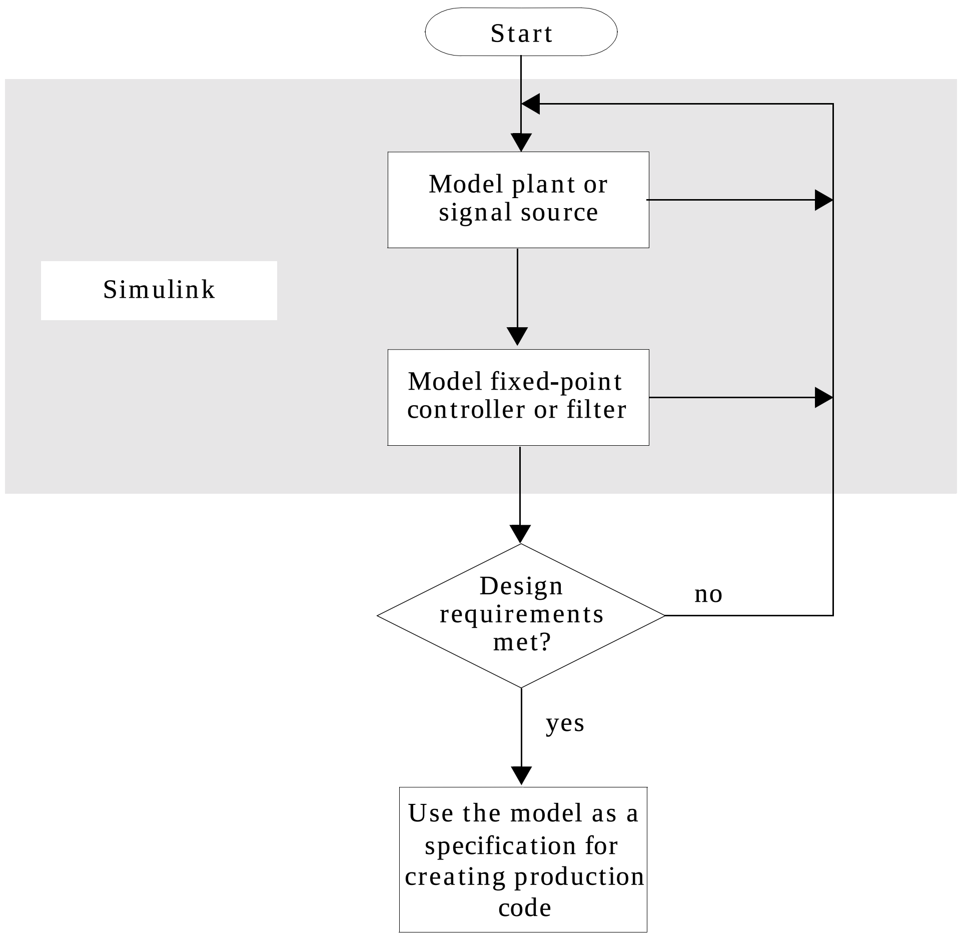
The Fixed-Point Blockset allows you to efficiently design control systems and digital filters that you will implement using fixed-point arithmetic. With the Fixed-Point Blockset, you can construct Simulink models that contain detailed fixed-point information about your systems. You can then perform bit-true simulations with the models to observe the effects of limited range and precision on your designs.

You can configure the **Fixed-Point Settings** interface to automatically log the overflows, saturations, and signal extremes of your simulations. You can also use it to automate scaling decisions and to compare your fixed-point implementations against idealized, floating-point benchmarks.

You can use the Fixed-Point Blockset with Real-Time Workshop to automatically generate efficient, integer-only C code representations of your designs. You can use this C code in a production target or for rapid prototyping. You can also use the Fixed-Point Blockset with Real-Time Workshop Embedded Coder to generate real-time C code for use on an integer production, embedded target.

## The Development Cycle

The Fixed-Point Blockset provides tools that aid in the development and testing of fixed-point dynamic systems. You directly design dynamic system models in Simulink, which are ready for implementation on fixed-point hardware. The development cycle is illustrated below.


Start
Simulink
Model plant or signal source
Model fixed-point controller or filter
Design requirements met?
no
yes
Use the model as a specification for creating production code

Using MATLAB, Simulink, and the Fixed-Point Blockset, you follow these steps of the development cycle:

1. Model the system (plant or signal source) within Simulink using the built-in blocks and double precision numbers. Typically, the model will contain nonlinear elements.
2. Design and simulate a fixed-point dynamic system (for example, a control system or digital filter) with the Fixed-Point Blockset that meets the design, performance, and other constraints.
3. Analyze the results and go back to **1** if needed.

When you have met the design requirements, you can use the model as a specification for creating production code using Real-Time Workshop.

The above steps interact strongly. In steps 1 and 2, there is a significant amount of freedom to select different solutions. Generally, you fine-tune the model based upon feedback from the results of the current implementation (step 3). There is no specific modeling approach. For example, you may obtain models from first principles such as equations of motion, or from a frequency response such as a sine sweep. There are many controllers that meet the same frequency-domain or time-domain specifications. Additionally, for each controller there are an infinite number of realizations.

The Fixed-Point Blockset helps expedite the design cycle by allowing you to simulate the effects of various fixed-point controller and digital filter structures.

## Compatibility with Simulink Blocks

You can connect built-in Simulink blocks directly to Fixed-Point Blockset blocks provided the signals use built-in Simulink data types. The built-in data types include `uint8`, `uint16`, `uint32`, `int8`, `int16`, `int32`, `single`, `double`, and `boolean`. The Fixed-Point Blockset supports all built-in data types. However, a fixed-point signal consisting of 8-, 16-, or 32-bit integers is compatible with built-in Simulink blocks only when its scaling is given by a slope of `1` and a bias of `0`.

Some Simulink blocks impose restrictions on the data type of the signals they can handle. For example, some Simulink blocks only accept doubles. To incorporate these blocks into your fixed-point model, you must configure the driving block(s) to use doubles.

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**Note** If you want to connect Simulink blocks that only handle built-in data types to Fixed-Point Blockset blocks that output blockset-specific data types, then you must use the Gateway Out or Conversion block to convert to a built-in data type.

---

Some Simulink blocks can accept signals of any data type. For these blocks, you can input any of the built-in data types or any of the blockset-specific data types. Examples of blockset-specific data types include 32-bit signed integers with a scaling of $2^{-8}$, and 18-bit unsigned integers with a scaling of $2^{0}$.

In some cases, fixed-point signals that are not built-in data types are converted to a real-world value as it enters the block. For example, the To Workspace block will output a 32-bit signed integer with a scaling of $2^{-8}$ as a double.

Refer to the Simulink documentation for detailed information about the data types handled by each Simulink block.

### Unified Simulink and Fixed-Point Blockset Blocks

Many core Simulink and Fixed-Point Blockset blocks with similar functions have been unified in Version 4.0 of the Fixed-Point Blockset. For example, the Sum block in the Simulink Math Operations library and the Sum block in the Fixed-Point Blockset Math library are now the same block. All the functionality from each original block has been maintained in unifying these blocks. Compatibility with fixed-point data types and/or specific fixed-point features are now available with all of these blocks, whether they are used from the Simulink Blockset or from the Fixed-Point Blockset. You do not need to make any changes to your previously-existing models as a result of this improvement. You can now use any of the unified blocks with either built-in data types or fixed-point data types, which eliminates the need for you to replace blocks in your models when you want to use different data types. This change does not require all Simulink users to have a Fixed-Point Blockset license. Refer to “Licensing Information” on page -xiii for more information.

Fixed-Point Blockset blocks that have been unified no longer have an “F” on their block icon. However, not all Fixed-Point Blockset blocks that have counterparts in Simulink libraries have been unified. You can still use the `fixpt_convert` function to replace nonunified Simulink blocks with their Fixed-Point Blockset counterparts in your models.

Non-unified Fixed-Point Blockset blocks have an advantage over their Simulink counterparts in that they can handle more data types. However, you may still want to use the Simulink counterparts of non-unified Fixed-Point Blockset blocks in some cases, since they support faster simulation times for the data types they handle.

The following table lists the unified blocks in this release, and the Simulink and Fixed-Point Blockset libraries in which they are found.

| Block | Simulink Library | Fixed-Point Blockset Library |
|---|---|---|
| Abs | Math Operations | Math |
| Constant | Sources | Sources |
| Data Store Memory | Signal Routing | N/A |
| Data Store Read | Signal Routing | N/A |
| Data Store Write | Signal Routing | N/A |
| Gain | Math Operations | Math |
| Inport | Ports & Subsystems, Sources | N/A |
| Logical Operator | Math Operations | Logic & Comparison |

| Block | Simulink Library | Fixed-Point Blockset Library |
|---|---|---|
| Look-Up Table | Look-Up Tables | Look-Up Tables |
| Look-Up Table (2-D) | Look-Up Tables | Look-Up Tables |
| Manual Switch | Signal Routing | N/A |
| Memory | Discrete | N/A |
| Merge | Signal Routing | N/A |
| Multiport Switch | Signal Routing | Select |
| Outport | Ports & Subsystems, Sinks | N/A |
| Product | Math Operations | Math |
| Rate Transition | Signal Attributes | N/A |
| Relational Operator | Math Operations | Logic & Comparison |
| Relay | Discontinuities | Nonlinear |
| Saturation | Discontinuities | Nonlinear |
| Sign | Math Operations | Nonlinear |
| Signal Specification | Signal Attributes | N/A |
| Slider Gain | Math Operations | N/A |
| Sum | Math Operations | Math |
| Switch | Signal Routing | Select |
| Unit Delay | Discrete | Delays & Holds |
| Zero-Order Hold | Discrete | Delays & Holds |

## Frame-Based Signals

Most real-time systems optimize throughput rates by processing data in “batch” or “frame-based” mode, where each batch or frame is a collection of consecutive signal samples that have been buffered into a single unit. You can process signals in Simulink as frame-based signals.

All built-in Fixed-Point Blockset blocks accept frame-based signals for simulation and code generation, except for the Dot Product and FIR blocks.

The DSP Blockset also supports frame-based processing, and can use blocks from the Fixed-Point Blockset in models that process frame-based signals.

For further understanding of frame-based processing, refer to “Working with Signals” in the DSP Blockset documentation.

## Matrix Signals

The Simulink documentation refers to two-dimensional (2-D) signals as *matrices*. Simulink blocks can output 2-D signals, which consist of streams of two-dimensional arrays emitted at a frequency of one 2-D array per sample time.

Fixed-Point Blockset blocks support matrix-based signals for simulation and code generation, except for the Dot Product and FIR blocks.

For further understanding of matrix-based processing, refer to “Working with Signals” in the Simulink documentation.

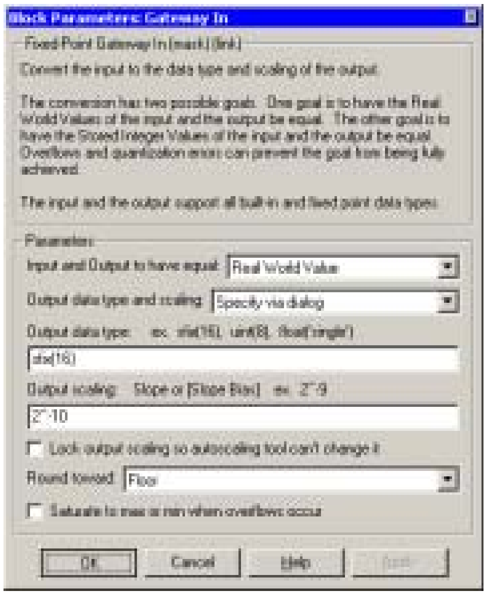
# Getting Started with the Blockset

## Overview of Blockset Features

This section provides a brief overview of important Fixed-Point Blockset features. After reading this section and the example that follows, you should be able to configure simple fixed-point models that suit your own application needs.

### Configuring Fixed-Point Blocks

You configure fixed-point blocks with a parameter dialog box. To configure blocks, you supply values for parameters via editable text fields, check boxes, and parameter lists. The dialog box for the Gateway In block is shown below.



Block Parameters: Gateway In

Fixed-Point Gateway In (mask) (link)

Convert the input to the data type and scaling of the output.

The conversion has two possible goals. One goal is to have the Real World Values of the input and the output be equal. The other goal is to have the Stored Integer Values of the input and the output be equal. Overflows and quantization errors can prevent the goal from being fully achieved.

The input and the output support all built-in and fixed point data types.

Parameters

Input and Output to have equal: Real World Value

Output data type and scaling: Specify via dialog

Output data type: ex. sfix(16), uint(8), float('single')

sfix(16)

Output scaling: Slope or [Slope Bias] ex. 2^-9

2^-10

☐ Lock output scaling so autoscaling tool can't change it

Round toward: Floor

☐ Saturate to max or min when overflows occur

The following sections discuss parameters associated with this block.

- "Real-World Values Versus Integer Values" on page 2-3
- "Selecting the Output Data Type" on page 2-3
- "Selecting the Output Scaling" on page 2-5
- "Rounding" on page 2-7

- “Overflow Handling” on page 2-7
- “Locking the Output Scaling” on page 2-8

For detailed information about each fixed-point block, refer to Chapter 10, “Block Reference.”

### Real-World Values Versus Integer Values

You can configure the fixed-point gateway blocks to treat signals as real-world values or as stored integers with the **Input and Output to have equal** parameter. The possible values are `Real World Value` and `Stored Integer`.

In terms of the variables defined in “The General [Slope Bias] Encoding Scheme” on page 2-6, the real-world value is given by $V$ and the stored integer value is given by $Q$. You may want to treat numbers as stored integer values if you are modeling hardware that produces integers as output.

### Selecting the Output Data Type

For many fixed-point blocks, you have the option of specifying the output data type via the block dialog box, or inheriting the output data type from another block. You control how the output data type is selected with the **Output data type and scaling** or **Output data type** parameter list. Some possible values are `Specify via dialog`, `Inherit via internal rule`, `Inherit via back propagation` and `Same as input`.

The Fixed-Point Blockset supports several fixed-point and floating-point data types. Fixed-point data types are characterized by their word size in bits and by their binary point. The binary point is the means by which fixed-point values are scaled. Additionally

- Unsigned and two’s complement formats are supported.
- The fixed-point word size can range from 1 to 128 bits in simulation.
- The binary point is not required to be contiguous with the fixed-point word.

Floating-point data types are characterized by their sign bit, fraction (mantissa) field, and exponent field. The Fixed-Point Blockset supports IEEE singles, IEEE doubles, and a nonstandard IEEE-style floating-point data type.

---

**Note** You can create Fixed-Point Blockset data types directly in the MATLAB workspace and then pass the resulting structure to a fixed-point block, or you can specify the data type directly with the block dialog box.

---

**Integers.** You specify unsigned and signed integers with the `uint` and `sint` functions, respectively.

For example, to specify a 16-bit unsigned integer via the block dialog box, you configure the **Output data type** parameter as `uint(16)`. To specify a 16-bit signed integer, you configure the **Output data type** parameter as `sint(16)`.

For integer data types, the default binary point is assumed to lie to the right of all bits.

**Fractional Numbers.** You specify unsigned and signed fractional numbers with the `ufrac` and `sfrac` functions, respectively.

For example, to configure the output as a 16-bit unsigned fractional number via the block dialog box, you specify the **Output data type** parameter to be `ufrac(16)`. To configure a 16-bit signed fractional number, you specify **Output data type** to be `sfrac(16)`.

Fractional numbers are distinguished from integers by their default scaling. Whereas signed and unsigned integer data types have a default binary point to the right of all bits, unsigned fractional data types have a default binary point to the left of all bits, while signed fractional data types have a default binary point to the right of the sign bit.

Both unsigned and signed fractional data types support *guard bits*, which act to “guard” against overflow. For example, `sfrac(16,4)` specifies a 16-bit signed fractional number with 4 guard bits. The guard bits lie to the left of the default binary point.

**Generalized Fixed-Point Numbers.** You specify unsigned and signed generalized fixed-point numbers with the `ufix` and `sfix` functions. respectively.

For example, to configure the output as a 16-bit unsigned generalized fixed-point number via the block dialog box, you specify the **Output data type** parameter to be `ufix(16)`. To configure a 16-bit signed generalized fixed-point number, you specify **Output data type** to be `sfix(16)`.

Generalized fixed-point numbers are distinguished from integers and fractionals by the absence of a default scaling. For these data types, you must explicitly specify the scaling with the **Output scaling** parameter, or inherit the scaling from another block. Refer to “Selecting the Output Scaling” on page 2-5 for more information.

**Floating-Point Numbers.** The Fixed-Point Blockset supports single-precision and double-precision floating-point numbers as defined by the IEEE Standard 754-1985 for Binary Floating-Point Arithmetic. You specify floating-point numbers with the `float` function.

For example, to configure the output as a single-precision floating-point number via the block dialog box, you specify the **Output data type** parameter to be `float('single')`. To configure a double-precision floating-point number, you specify **Output data type** to be `float('double')`.

You can also specify a nonstandard floating-point number that mimics the IEEE style. For this data type, the fraction (mantissa) can range from 1 to 52 bits and the exponent can range from 1 to 11 bits. For example, to configure a nonstandard floating-point number having 32 total bits and 9 exponents bits, you specify **Output data type** to be `float(32,9)`.

---

**Note** These numbers are normalized with a hidden leading 1 for all exponents except the smallest possible exponent. However, the largest possible exponent might not be treated as a flag for Infs or NaNs.

---

## Selecting the Output Scaling

Most data types supported by the Fixed-Point Blockset have a default scaling that you cannot change. However, for generalized fixed-point data types, you have the option of specifying the output scaling via the block dialog box, or inheriting the output scaling from another block. You control how the output scaling is selected with the **Output data type and scaling** or **Output data type** parameter.

The Fixed-Point Blockset supports two general scaling modes: binary point-only scaling and [Slope Bias] scaling. In addition to these general scaling modes, the blockset provides you with additional block-specific scaling choices for constant vectors and constant matrices. These scaling choices are based on binary point-only scaling and are designed to maximize precision. Refer to

"Example: Constant Scaling for Best Precision" on page 3-11 for more information.

To help you understand the supported scaling modes, the general [Slope Bias] encoding scheme is presented in the next section.

**The General [Slope Bias] Encoding Scheme.** When representing an arbitrarily precise real-world value with a fixed-point number, it is often useful to define a general [Slope Bias] encoding scheme

$$V \approx \tilde{V} = SQ + B$$

where

- $V$ is the real-world value.
- $\tilde{V}$ is the approximate real-world value.
- $Q$ is an integer that encodes $V$.
- $B$ is the bias.
- $S = F2^E$ is the slope.

The slope is partitioned into two components:

- $2^E$ specifies the binary point. $E$ is the fixed power-of-two exponent.
- $F$ is the fractional slope. It is normalized such that $1 \le F < 2$.

**Binary Point-Only Scaling.** This is "powers-of-two" scaling since it involves moving only the binary point. Binary point-only scaling does not require the binary point to be contiguous with the data word. The advantage of this scaling mode is the number of processor arithmetic operations is minimized.

You specify binary point-only scaling with the syntax `2^ E` where `E` is unrestricted. This creates a MATLAB structure with a bias $B$ = 0 and a fractional slope $F$ = 1.0.

For example, if you specify the value `2^-10` for the **Output scaling** parameter, then the generalized fixed-point number has a power-of-two exponent $E$ = -10. This value defines the binary point location to be 10 places to the left of the least significant bit.

**[Slope Bias] Scaling.** With this scaling mode, you can provide a slope and a bias. The advantage of [Slope Bias] scaling is that it typically provides more efficient use of a finite number of bits.

You specify [Slope Bias] scaling with the syntax `[slope bias]`, which creates a MATLAB structure with the given slope and bias.

For example, if you specify the value `[5/9 10]` for the **Output scaling** parameter, then the generalized fixed-point number has a slope of 5/9 and a bias of 10. The blockset would automatically store $F$ as 1.1111 and $E$ as -1 due to the normalization condition $1 \le F < 2$ .

## Rounding

You specify how fixed-point numbers are rounded with the **Round toward** or **Round integer calculations toward** parameter. These rounding modes are supported:

- `Zero`—This mode rounds toward zero and is equivalent to the MATLAB `fix` function.
- `Nearest`—This mode rounds toward the nearest representable number, with the exact midpoint rounded toward positive infinity. Rounding toward nearest is equivalent to the MATLAB `round` function.
- `Ceiling`—This mode rounds toward positive infinity and is equivalent to the MATLAB `ceil` function.
- `Floor`—This mode rounds toward negative infinity and is equivalent to the MATLAB `floor` function.

## Overflow Handling

You control how overflow conditions are handled for fixed-point operations with the **Saturate to max or min when overflows occur** check box.

If this box is selected, then overflows saturate to either the maximum or minimum value represented by the data type. For example, an overflow associated with a signed 8-bit integer can saturate to -128 or 127.

If this box is not selected, then overflows wrap to the appropriate value that is representable by the data type. For example, the number 130 does not fit in a signed 8-bit integer, and would wrap to -126.

### Locking the Output Scaling

If the output data type is a generalized fixed-point number, then you have the option of locking its scaling by selecting the **Lock output scaling so autoscaling tool can't change it** check box.

When locked, the automatic scaling script `autofixexp` will not change the output scaling. Otherwise, the `autofixexp` is free to adjust the scaling.

## Additional Features and Capabilities

In addition to the features described in "Configuring Fixed-Point Blocks" on page 2-2, the Fixed-Point Blockset provides you with these features and capabilities:

- An automatic scaling tool
- Code generation capabilities

### Automatic Scaling

You can use the `autofixexp` script to automatically change the scaling for each block that has generalized fixed-point output and does not have its scaling locked. The script uses the maximum and minimum values logged during the last simulation run. The scaling is changed such that the simulation range is covered and the precision is maximized.

As an alternative to (and extension of) the automatic scaling script, you can use the **Fixed-Point Settings** interface. This tool allows you to easily control the parameters associated with automatic scaling and display the simulation results for a given model. To learn how to use the **Fixed-Point Settings** interface, refer to Chapter 6, "Tutorial: Feedback Controller Simulation."

### Code Generation

With Real-Time Workshop, the Fixed-Point Blockset can generate C code. The code generated from fixed-point blocks uses only integer types and automatically includes all operations, such as shifts, needed to account for differences in fixed-point locations.

You can use the generated code on embedded fixed-point processors or rapid prototyping systems even if they contain a floating-point processor. The code is structured so that key operations can be readily replaced by optimized target-specific libraries that you supply. You can also use Target Language

Compiler to customize the generated code. Refer to Chapter 8, “Code Generation” for more information about code generation using fixed-point blocks.

## Example: Converting from Doubles to Fixed-Point

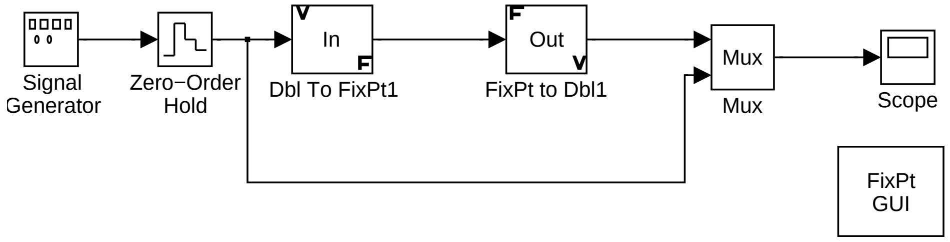
The purpose of this example is to show you how to simulate a continuous real-world doubles signal using a generalized fixed-point data type. The model used is the simplest possible model and employs only two fixed-point blocks. Although simple in design, the model gives you the opportunity to explore many of the important features of the Fixed-Point Blockset including

- Data types
- Scaling
- Rounding
- Logging minimum and maximum simulation values to the workspace
- Overflow handling

The model used in this example is given by the `fxpdemo_dbl2fix` demo. You can launch this demo by typing its name at the MATLAB command line:

```
fxpdemo_dbl2fix
```

The model is shown below.



### Block Descriptions

The Signal Generator block is configured to output a sine wave with an amplitude defined on the interval `[-5 5]`. It always outputs double-precision numbers.

The Gateway In block (Dbl To FixPt1) is used as the interface between Simulink and the Fixed-Point Blockset. Its function is to convert the double-precision numbers from the Signal Generator block into one of the

Fixed-Point Blockset data types. For simplicity, its output signal is limited to 5 bits in this example.

The Gateway Out (FixPt to Dbl1) block is used as the interface between the Fixed-Point Blockset and Simulink. Its function is to convert one of the Fixed-Point Blockset data types into a Simulink data type. In this example, it outputs double-precision numbers.

The FixPt GUI block opens the **Fixed-Point Settings** interface, `fxptdlg`. This tool provides convenient access to the global override and logging parameters, the logged minimum and maximum simulation data, the automatic scaling script, and the plot interface tool. It is not used in this example. If you have many fixed-point blocks whose scaling must be optimized, however, you should use this tool. Refer to Chapter 6, “Tutorial: Feedback Controller Simulation” for more information.

---

**Note** As described in “Compatibility with Simulink Blocks” on page 1-15, you can eliminate the gateway blocks from your fixed-point model if all signals use built-in data types.

---

## Simulation Results

The results of two simulation trials are given below. The first trial uses binary point-only scaling while the second trial uses [Slope Bias] scaling.

### Trial 1: Binary Point-Only Scaling

When using binary point-only scaling, your goal is to find the optimal power-of-two exponent $E$, as defined in “Selecting the Output Scaling” on page 2-5. For this scaling mode, the fractional slope $F$ is set to 1 and no bias is required.

The Gateway In block is configured in this way:

- **Output data type**

  The output data type is given by `sfix(5)`. This creates a MATLAB structure that is a 5-bit, signed generalized fixed-point number.

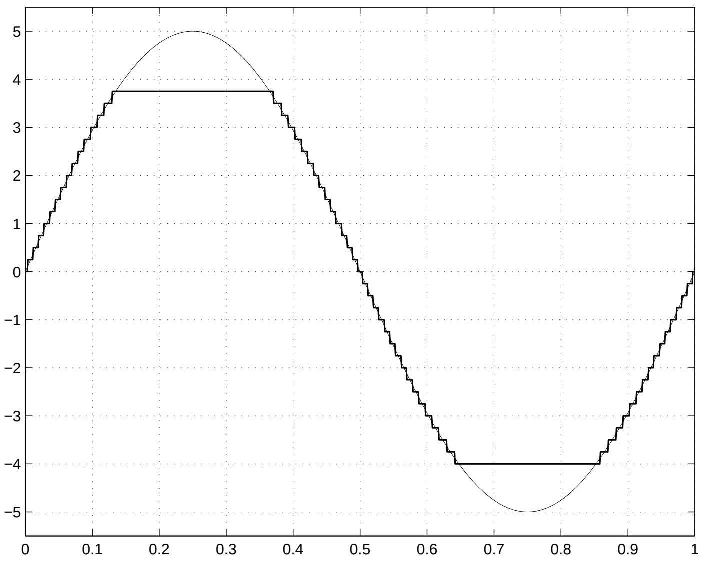
- **Output scaling**

  The output scaling is given by `2^ 2`, which puts the binary point two places to the left of the rightmost bit. This gives a maximum value of 011.11 = 3.75, a minimum value of 100.00 = -4.00, and a precision of $(1/2)^2 = 0.25$.
- **Rounding**

  The rounding mode is given by `Nearest`. This rounds the fixed-point result to the nearest representable number, with the exact midpoint rounded towards positive infinity.
- **Overflows**

  Fixed-point values that overflow will saturate to the maximum or minimum value represented by the word.

The resulting real-world and fixed-point simulation results are shown below.



The simulation clearly demonstrates the quantization effects of fixed-point arithmetic. The combination of using a 5-bit word with a precision of $(1/2)^2 = 0.25$ produces a discretized output that does not span the full range of the input signal.

If you want to span the complete range of the input signal with 5 bits using binary point-only scaling, then your only option is to sacrifice precision. Hence, the output scaling would be given by `2^ 1`, which puts the binary point one place to the left of the rightmost bit. This scaling gives a maximum value of 0111.1 = 7.5, a minimum value of 1000.0 = -8.0, and a precision of $(1/2)^1 = 0.5$.

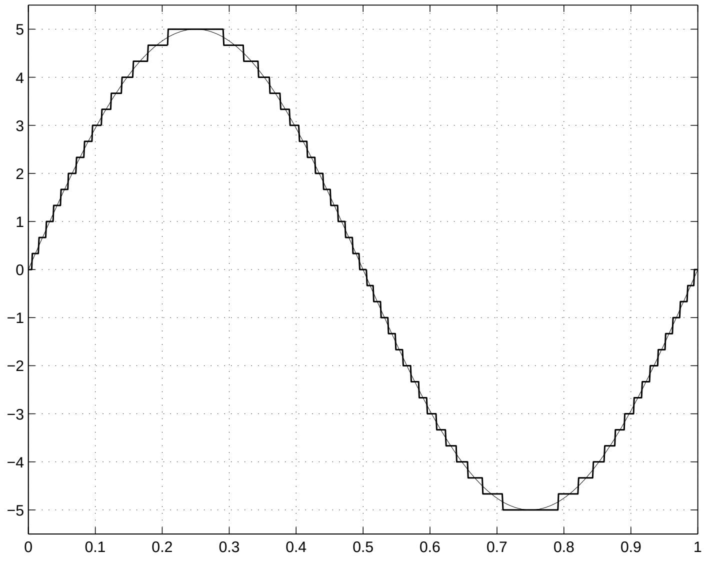
### Trial 2: [Slope Bias] Scaling

When using [Slope Bias] scaling, your goal is to find the optimal fractional slope *F* and fixed power-of-two exponent *E*, as defined in "Selecting the Output Scaling" on page 2-5. No bias is required for this example since the sine wave is defined on the interval `[-5 5]`. The Gateway In block configuration is the same as that of the previous trial except for the scaling.

To arrive at a value for the slope, you can begin by assuming a fixed power-of-two exponent of -2. In the previous trial, this value defined the binary point-only scaling and resulted in a precision of 0.25. To find the fractional slope, you divide the maximum value of the sine wave by the maximum value of the scaled 5-bit number. The result is 5.00/3.75 = 1.3333. The slope (and precision) is 1.3333·(0.25) = 0.3333. You specify this value as `[0.3333]` for the **Output scaling** parameter.

Of course, you could have specified a fixed power-of-two exponent of -1 and a corresponding fractional slope of 0.6667. Naturally, the resulting slope is the same since *E* was reduced by one bit but *F* was increased by one bit. In this case, the blockset would automatically store *F* as 1.3332 and *E* as -2 due to the normalization condition of $1 \le F < 2$.

The resulting real-world and fixed-point simulation results are shown below.



This somewhat cumbersome process used to find the slope is not really necessary. All that is required is the range of the data you are simulating and the size of the fixed-point word used in the simulation. In general, you can achieve reasonable simulation results by selecting your scaling based on the formula

$$\frac{(max - min)}{2^{ws} - 1}$$

where

- *max* is the maximum value to be simulated.
- *min* is the minimum value to be simulated.
- *ws* is the word size in bits.
- $2^{ws} - 1$ is the largest value of a word with whose size is given by *ws*.

For this example, the formula produces a slope of 0.32258.

## Demos

To help you learn the Fixed-Point Blockset, a collection of demos is provided. You can explore specific blockset features by changing block parameters and observing the effects of those changes.

The demos are divided into two groups: basic demos that illustrate the basic functionality of the Fixed-Point Blockset, and advanced demos that illustrate the functionality of systems built with fixed-point blocks. All demos are located in the `fxpdemos` directory.

You can access the demos through the MATLAB Demo browser. You start the Demo browser by clicking the Demos block in the Fixed-Point Blockset library, or by typing

```
demo blockset 'Fixed Point'
```

at the command line. To open a demo, double-click the name of the demo in lower pane of the Demo browser.

### Basic Fixed-Point Blockset Demos

The basic demos are listed below.

| Demo Name | Description |
|---|---|
| Double to Fixed-Point Conversion | Convert a double precision value to a fixed-point value. |
| Fixed-Point to Fixed-Point Conversion | Convert a fixed-point value to another fixed-point value. |
| Fixed-Point to Fixed-Point Inherited Conversion | Convert a fixed-point value to an inherited fixed-point value. |
| Fixed-Point Sine | Add and multiply two fixed-point sine wave signals. |
| Fixed-Point Filters | Simulate implementations of a fixed-point filter. |

| Demo Name | Description |
|---|---|
| Scaling a Fixed-Point Control Design | Simulate a fixed-point feedback design. |
| Generating Only Fixed-Point Code | Generate pure integer code for a fixed-point digital controller. |

"Example: Converting from Doubles to Fixed-Point" on page 2-10 discusses the Double to Fixed-Point Conversion demo, while Chapter 6, "Tutorial: Feedback Controller Simulation" discusses the Scaling a Fixed-Point Control Design demo.

## Advanced Fixed-Point Blockset Demos

The advanced demos are intended to show you how to build and test systems suited to your particular needs. The output of these demos is compared to the output of analogous built-in Simulink blocks with identical input.

The advanced demos are listed below.

| Demo Name | Description |
|---|---|
| Fixed-Point Integrators | Compare output from the Integrator Trapezoidal, Integrator Backward, and Integrator Forward blocks to output from the Simulink Discrete Integrator block. |
| Fixed-Point Derivatives | Compare output from the Derivative and Derivative: Filtered realizations to output from the Simulink derivatives built using the Discrete Filter and Transfer Fcn blocks. |
| Fixed-Point Lead and Lag Filters | Compare output from the Lead and Lag Filter block to output from analogous Simulink filters built using the Discrete Filter block. |
| Fixed-Point State Space | Compare output from the State-Space Realization realization to output from the analogous built-in Simulink State-Space and Discrete State-Space blocks. |

| Demo Name | Description |
|---|---|
| Fixed-Point Data Type Propagation | Illustrate data type propagation using the Data Type Propagation block, and the “`Inherit via back propagation`” setting. |
| Fixed-Point Function Approximation | Compare the fixed-point lookup approximation of a function with the ideal function. |

Additional fixed-point demos for direct form II, series cascade form, and parallel form realizations are discussed in Chapter 5, “Realization Structures.”

# Data Types and Scaling

## Overview

In digital hardware, numbers are stored in binary words. A binary word is a fixed-length sequence of binary digits (1's and 0's). The way in which hardware components or software functions interpret this sequence of 1's and 0's is described by a data type.

Binary numbers are represented as either fixed-point or floating-point data types. A fixed-point data type is characterized by the word size in bits, the binary point, and whether it is signed or unsigned. The binary point is the means by which fixed-point values are scaled. Within the Fixed-Point Blockset, fixed-point data types can be integers, fractionals, or generalized fixed-point numbers. The main difference between these data types is their default binary point. Floating-point data types are characterized by a sign bit, a fraction (or mantissa) field, and an exponent field. The blockset adheres to the IEEE Standard 754-1985 for Binary Floating-Point Arithmetic (referred to simply as the IEEE Standard 754 throughout this guide) and supports singles, doubles, and a nonstandard IEEE-style floating-point data type.

When choosing a data type, you must consider these factors:

- The numerical range of the result
- The precision required of the result
- The associated quantization error (i.e., the rounding mode)
- The method for dealing with exceptional arithmetic conditions

These choices depend on your specific application, the computer architecture used, and the cost of development, among others.

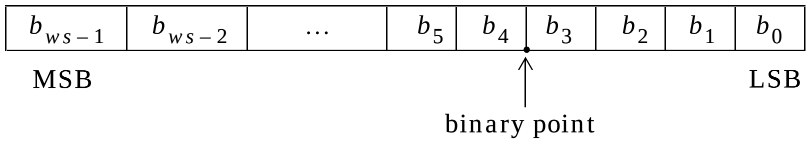
With the Fixed-Point Blockset, you can explore the relationship between data types, range, precision, and quantization error in the modeling of dynamic digital systems. With Real-Time Workshop, you can generate production code based on that model.

# Fixed-Point Numbers

Fixed-point numbers are stored in data types that are characterized by their word size in bits, binary point, and whether they are signed or unsigned. The Fixed-Point Blockset supports integers, fractionals, and generalized fixed-point numbers. The main difference between these data types is their default binary point.

**Note** Fixed-point word sizes up to 128 bits are supported.

A common representation of a binary fixed-point number (either signed or unsigned) is shown below.



where

- $b_i$ are the binary digits (bits).
- The size of the word in bits is given by *ws*.
- The most significant bit (MSB) is the leftmost bit, and is represented by location $b_{ws-1}$.
- The least significant bit (LSB) is the rightmost bit, and is represented by location $b_0$.
- The binary point is shown four places to the left of the LSB.

## Signed Fixed-Point Numbers

Computer hardware typically represents the negation of a binary fixed-point number in three different ways: sign/magnitude, one's complement, and two's complement. Two's complement is the preferred representation of signed fixed-point numbers and is supported by the Fixed-Point Blockset.

Negation using two's complement consists of a bit inversion (translation into one's complement) followed by the addition of a one. For example, the two's complement of 000101 is 111011.

Whether a fixed-point value is signed or unsigned is usually not encoded explicitly within the binary word (i.e., there is no sign bit). Instead, the sign information is implicitly defined within the computer architecture.

## Binary Point Interpretation

The binary point is the means by which fixed-point numbers are scaled. It is usually the software that determines the binary point. When performing basic math functions such as addition or subtraction, the hardware uses the same logic circuits regardless of the value of the scale factor. In essence, the logic circuits have no knowledge of a scale factor. They are performing signed or unsigned fixed-point binary algebra as if the binary point is to the right of $b_0$.

Within the Fixed-Point Blockset, the main difference between fixed-point data types is the default binary point. For integers and fractionals, the binary point is fixed at the default value. For generalized fixed-point data types, you must either explicitly specify the scaling by configuring dialog box parameters, or inherit the scaling from another block. The supported fixed-point data types are described below.

### Integers

The default binary point for signed and unsigned integer data types is assumed to be just to the right of the LSB. You specify unsigned and signed integers with the `uint` and `sint` functions, respectively.

### Fractionals

The default binary point for unsigned fractional data types is just to the left of the MSB, while for signed fractionals the binary point is just to the right of the MSB. If you specify guard bits, then they lie to the left of the binary point. You specify unsigned and signed fractional numbers with the `ufrac` and `sfrac` functions, respectively.

### Generalized Fixed-Point Numbers

For signed and unsigned generalized fixed-point numbers, there is no default binary point. You specify unsigned and signed generalized fixed-point numbers with the `ufix` and `sfix` functions, respectively.

## Scaling

The dynamic range of fixed-point numbers is much less than that of floating-point numbers with equivalent word sizes. To avoid overflow conditions and minimize quantization errors, fixed-point numbers must be scaled.

With the Fixed-Point Blockset, you can select a fixed-point data type whose scaling is defined by its default binary point, or you can select a generalized fixed-point data type and choose an arbitrary linear scaling that suits your needs. This section presents the scaling choices available for generalized fixed-point data types.

A fixed-point number can be represented by a general [Slope Bias] encoding scheme

$$V \approx \tilde{V} = SQ + B$$

where

- $V$ is an arbitrarily precise real-world value.
- $\tilde{V}$ is the approximate real-world value.
- $Q$ is an integer that encodes $V$.
- $S = F \cdot 2^E$ is the slope.
- $B$ is the bias.

The slope is partitioned into two components:

- $2^E$ specifies the binary point. $E$ is the fixed power-of-two exponent.
- $F$ is the fractional slope. It is normalized such that $1 \le F < 2$ .

---

**Note** $S$ and $B$ are constants and do not show up in the computer hardware directly – only the quantization value $Q$ is stored in computer memory.

---

The scaling modes available to you within this encoding scheme are described below. For detailed information about how the supported scaling modes effect fixed-point operations, refer to “Recommendations for Arithmetic and Scaling” on page 4-16.

### Binary Point-Only Scaling

As the name implies, binary point-only (or “powers-of-two”) scaling involves moving only the binary point within the generalized fixed-point word. The advantage of this scaling mode is the number of processor arithmetic operations is minimized.

With binary point-only scaling, the components of the general [Slope Bias] formula have these values:

- $F = 1$
- $S = 2^E$
- $B = 0$

That is, the scaling of the quantized real-world number is defined only by the slope $S$, which is restricted to a power of two.

In the Fixed-Point Blockset, you specify binary point-only scaling with the syntax `2^-E` where `E` is unrestricted. This creates a MATLAB structure with a bias $B = 0$ and a fractional slope $F = 1.0$. For example, the syntax `2^-10` defines a scaling such that the binary point is at a location 10 places to the left of the least significant bit.

### [Slope Bias] Scaling

When you scale by slope and bias, the slope $S$ and bias $B$ of the quantized real-world number can take on any value. You specify scaling by slope and bias with the syntax `[slope bias]`, which creates a MATLAB structure with the given slope and bias. For example, a [Slope Bias] scaling specified by `[5/9 10]` defines a slope of 5/9 and a bias of 10. The slope must be a positive number.

See “” on page 3-10 and “Example: Constant Scaling for Best Precision” on page 3-11 for more information.

## Quantization

The quantization $Q$ of a real-world value $V$ is represented by a weighted sum of bits. Within the context of the general [Slope Bias] encoding scheme, the value of an unsigned fixed-point quantity is given by

$$\tilde{V} = S \cdot \left[ \sum_{i=0}^{ws-1} b_i 2^i \right] + B$$

while the value of a signed fixed-point quantity is given by

$$\tilde{V} = S \cdot \left[ -b_{ws-1} 2^{ws-1} + \sum_{i=0}^{ws-2} b_i 2^i \right] + B$$

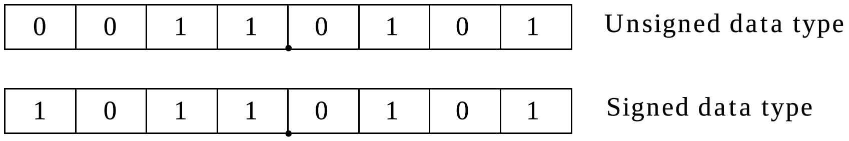
where

- $b_i$ are binary digits, with $b_i = 1, 0$.
- The word size in bits is given by $ws$, with $ws = 1,2,3,...,128$.
- $S$ is given by $F2^E$, where the scaling is unrestricted since the binary point does not have to be contiguous with the word.

$b_i$ are called *bit multipliers* and $2^i$ are called the *weights*.

## Example: Fixed-Point Format

The formats for 8-bit signed and unsigned fixed-point values are given below.



Note that you cannot discern whether these numbers are signed or unsigned data types merely by inspection since this information is not explicitly encoded within the word.

The binary number 0011.0101 yields the same value for the unsigned and two's complement representation since the MSB = 0. Setting $B = 0$ and using the appropriate weights, bit multipliers, and scaling, the value is

$$\tilde{V} = (F2^E) \cdot Q = 2^E \cdot \left[\sum_{i=0}^{ws-1} b_i 2^i\right]$$

$$= 2^{-4} \cdot (0 \cdot 2^7 + 0 \cdot 2^6 + 1 \cdot 2^5 + 1 \cdot 2^4 + 0 \cdot 2^3 + 1 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0)$$

$$= 3.3125$$

Conversely, the binary number 1011.0101 yields different values for the unsigned and two's complement representation since the MSB = 1.

Setting $B = 0$ and using the appropriate weights, bit multipliers, and scaling, the unsigned value is

$$\tilde{V} = (F2^E) \cdot Q = 2^E \cdot \left[\sum_{i=0}^{ws-1} b_i 2^i\right]$$

$$= 2^{-4} \cdot (1 \cdot 2^7 + 0 \cdot 2^6 + 1 \cdot 2^5 + 1 \cdot 2^4 + 0 \cdot 2^3 + 1 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0)$$

$$= 11.3125$$

while the two's complement value is

$$\tilde{V} = (F2^E) \cdot Q = 2^E \cdot \left[-b_{ws-1} 2^{ws-1} + \sum_{i=0}^{ws-2} b_i 2^i\right]$$

$$= 2^{-4} \cdot (-1 \cdot 2^7 + 0 \cdot 2^6 + 1 \cdot 2^5 + 1 \cdot 2^4 + 0 \cdot 2^3 + 1 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0)$$

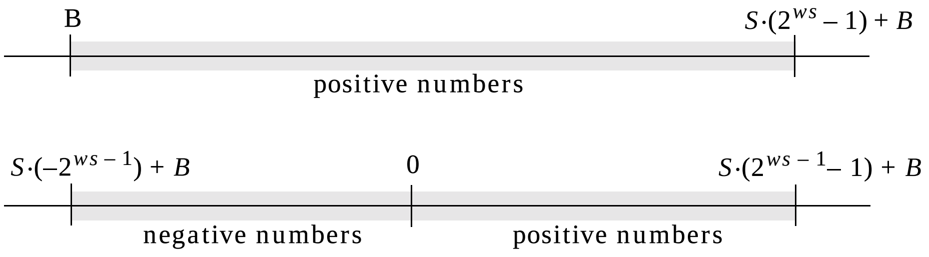
$$= -4.6875$$

## Range and Precision

The *range* of a number gives the limits of the representation while the *precision* gives the distance between successive numbers in the representation. The range and precision of a fixed-point number depends on the length of the word and the scaling.

## Range

The range of representable numbers for an unsigned and two's complement fixed-point number of size *ws*, scaling *S*, and bias *B* is illustrated below.


B
$S \cdot (2^{ws} - 1) + B$
positive numbers
$S \cdot (-2^{ws-1}) + B$
0
$S \cdot (2^{ws-1} - 1) + B$
negative numbers
positive numbers

For both the signed and unsigned fixed-point numbers of any data type, the number of different bit patterns is $2^{ws}$.

For example, if the fixed-point data type is an integer with scaling defined as $S = 1$ and $B = 0$, then the maximum unsigned value is $2^{ws} - 1$ since zero must be represented. In two's complement, negative numbers must be represented as well as zero so the maximum value is $2^{ws-1} - 1$. Additionally, since there is only one representation for zero, there must be an unequal number of positive and negative numbers. This means there is a representation for $-2^{ws-1}$ but not for $2^{ws-1}$.

## Precision

The precision (scaling) of integer and fractional data types is specified by the default binary point. For generalized fixed-point data types, the scaling must be explicitly defined as either [Slope Bias] or binary point-only. In either case, the precision is given by the slope.

## Fixed-Point Data Type Parameters

The low limit, high limit, and default binary point-only scaling for the supported fixed-point data types discussed in "Binary Point Interpretation" on page 3-4 are given below. See "Limitations on Precision" and "Limitations on Range" in Chapter 4 for more information.

**Fixed-Point Data Type Range and Default Scaling**

| Name | Data Type | Low Limit | High Limit | Default Scaling (~Precision) |
|---|---|---|---|---|
| Integer | `uint` | 0 | $2^{ws} - 1$ | 1 |
| | `sint` | $-2^{ws-1}$ | $2^{ws-1} - 1$ | 1 |
| Fractional | `ufrac` | 0 | $1 - 2^{-ws}$ | $2^{-ws}$ |
| | `sfrac` | –1 | $1 - 2^{-(ws-1)}$ | $2^{-(ws-1)}$ |
| Generalized Fixed-Point | `ufix` | N/A | N/A | N/A |
| | `sfix` | N/A | N/A | N/A |

### Range of an 8-Bit Fixed-Point Data Type — Binary Point-Only Scaling

The precision, range of signed values, and range of unsigned values for an 8-bit generalized fixed-point data type with binary point-only scaling follow. Note that the first scaling value ($2^1$) represents a binary point that is not contiguous with the word.

| Scaling | Precision | Range of Signed Values (low, high) | Range of Unsigned Values (low, high) |
|---|---|---|---|
| $2^{1}$ | 2.0 | -256, 254 | 0, 510 |
| $2^{0}$ | 1.0 | -128, 127 | 0, 255 |
| $2^{-1}$ | 0.5 | -64, 63.5 | 0, 127.5 |
| $2^{-2}$ | 0.25 | -32, 31.75 | 0, 63.75 |
| $2^{-3}$ | 0.125 | -16, 15.875 | 0, 31.875 |
| $2^{-4}$ | 0.0625 | -8, 7.9375 | 0, 15.9375 |
| $2^{-5}$ | 0.03125 | -4, 3.96875 | 0, 7.96875 |
| $2^{-6}$ | 0.015625 | -2, 1.984375 | 0, 3.984375 |

| Scaling | Precision | Range of Signed Values (low, high) | Range of Unsigned Values (low, high) |
|---|---|---|---|
| $2^{-7}$ | 0.0078125 | -1, 0.9921875 | 0, 1.9921875 |
| $2^{-8}$ | 0.00390625 | -0.5, 0.49609375 | 0, 0.99609375 |

**Range of an 8-Bit Fixed-Point Data Type — [Slope Bias] Scaling**

The precision and range of signed and unsigned values for an 8-bit fixed-point data type using [Slope Bias] scaling follow. The slope starts at a value of 1.25 and the bias is 1.0 for all slopes. Note that the slope is the same as the precision.

| Bias | Slope/Precision | Range of Signed Values (low, high) | Range of Unsigned Values (low, high) |
|---|---|---|---|
| 1 | 1.25 | -159, 159.75 | 1, 319.75 |
| 1 | 0.625 | -79, 80.375 | 1, 160.375 |
| 1 | 0.3125 | -39, 40.6875 | 1, 80.6875 |
| 1 | 0.15625 | -19, 20.84375 | 1, 40.84375 |
| 1 | 0.078125 | -9, 10.921875 | 1, 20.921875 |
| 1 | 0.0390625 | -4, 5.9609375 | 1, 10.9609375 |
| 1 | 0.01953125 | -1.5, 3.48046875 | 1, 5.98046875 |
| 1 | 0.009765625 | -0.25, 2.240234375 | 1, 3.490234375 |
| 1 | 0.0048828125 | 0.375, 1.6201171875 | 1, 2.2451171875 |

## Example: Constant Scaling for Best Precision

The Fixed-Point Blockset provides you with block-specific modes for scaling constant vectors and constant matrices. These scaling modes are based on binary point-only scaling and are described below:

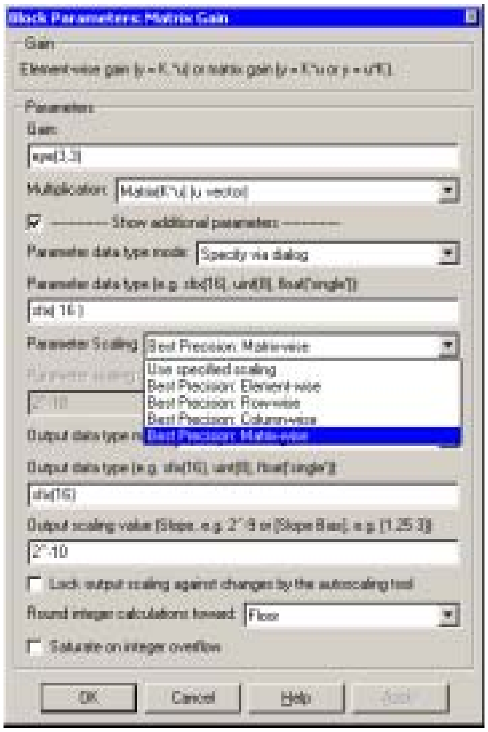
- **Constant Vector Scaling**

  Using this mode, you can scale a constant vector such that its precision is maximized element-by-element, or a common binary point is found based on the best precision for the largest value of the vector.

- **Constant Matrix Scaling**

  Using this mode, you can scale a constant matrix such that its precision is maximized element-by-element, or a common binary point is found based on the best precision for the largest value of each row, each column, or the whole matrix.

Constant matrix and constant vector scaling are available only for generalized fixed-point data types. All other fixed-point data types use their default scaling. The available constant matrix scaling modes are shown below for the Matrix Gain block.



Block Parameters: Matrix Gain

Gain

Element-wise gain (y = K.*u) or matrix gain (y = K*u or y = u*K).

Parameters

Gain:

eye(3,3)

Multiplication: Matrix(K*u) (u vector)

[✓] Show additional parameters

Parameter data type mode: Specify via dialog

Parameter data type (e.g. sfix(16), uint(8), float('single')):

sfix( 16 )

Parameter Scaling: Best Precision: Matrix-wise

Use specified scaling
Best Precision: Element-wise
Best Precision: Row-wise
Best Precision: Column-wise
Best Precision: Matrix-wise

Parameter scaling

2^-10

Output data type mode

Output data type (e.g. sfix(16), uint(8), float('single')):

sfix(16)

Output scaling value (Slope, e.g. 2^-9 or [Slope Bias], e.g. [1.25 3]):

2^-10

[ ] Lock output scaling against changes by the autoscaling tool

Round integer calculations toward: Floor

[ ] Saturate on integer overflow

OK Cancel Help Apply

To understand how you might use these scaling modes, consider a 5- by- 4 matrix of doubles, M, defined as

```
3.3333e-005  3.3333e-006  3.3333e-007  3.3333e-008
3.3333e-004  3.3333e-005  3.3333e-006  3.3333e-007
3.3333e-003  3.3333e-004  3.3333e-005  3.3333e-006
3.3333e-002  3.3333e-003  3.3333e-004  3.3333e-005
3.3333e-001  3.3333e-002  3.3333e-003  3.3333e-004
```

Now suppose M is input into the Matrix Gain block, and you want to scale it using one of the constant matrix scaling modes. The results of using these modes are described below:

- **Use Specified Scaling**

  Suppose the matrix elements are converted to a signed, 10-bit generalized fixed-point data type with binary point-only scaling of $2^{-7}$ (that is, the binary point is located seven places to the left of the rightmost bit). With this data format, M becomes

```
0            0            0            0
0            0            0            0
0            0            0            0
3.1250e-002  0            0            0
3.3594e-001  3.1250e-002  0            0
```

  Note that many of the matrix elements are zero, and for the nonzero entries, the scaled values differ from the original values. This is because a double is converted to a binary word of fixed size and limited precision for each element. The larger and more precise the conversion data type, the more closely the scaled values match the original values.

- **Best Precision: Element-wise**

  If M is scaled such that the precision is maximized for each matrix element, you obtain

```
3.3379e-005  3.3304e-006  3.3341e-007  3.3295e-008
3.3379e-004  3.3379e-005  3.3304e-006  3.3341e-007
3.3340e-003  3.3379e-004  3.3379e-005  3.3304e-006
3.3325e-002  3.3340e-003  3.3379e-004  3.3379e-005
3.3301e-001  3.3325e-002  3.3340e-003  3.3379e-004
```

- **Best Precision: Row-wise**

  If M is scaled based on the largest value for each row, you obtain

```
3.3379e-005  3.3379e-006  3.5763e-007 0
3.3379e-004  3.3379e-005  2.8610e-006 0
3.3340e-003  3.3569e-004  3.0518e-005 0
3.3325e-002  3.2959e-003  3.6621e-004 0
3.3301e-001  3.3203e-002  2.9297e-003 0
```

- **Best Precision: Column-wise**

  If M is scaled based on the largest value for each column, you obtain

```
0            0            0            0
0            0            0            0
2.9297e-003  3.6621e-004  3.0518e-005  2.8610e-006
3.3203e-002  3.2959e-003  3.3569e-004  3.3379e-005
3.3301e-001  3.3325e-002  3.3340e-003  3.3379e-004
```

- **Best Precision: Matrix-wise**

  If M is scaled based on its largest matrix value, you obtain

```
0            0            0            0
0            0            0            0
2.9297e-003  0            0            0
3.3203e-002  2.9297e-003  0            0
3.3301e-001  3.3203e-002  2.9297e-003  0
```

The disadvantage of scaling the matrix column-wise, row-wise, or matrix-wise is reduced precision resulting from the use of a common binary point. The advantage of using a common binary point is reduced code size and possibly increased processor speed.

## Floating-Point Numbers

Fixed-point numbers are limited in that they cannot simultaneously represent very large or very small numbers using a reasonable word size. This limitation can be overcome by using scientific notation. With scientific notation, you can dynamically place the binary point at a convenient location and use powers of the binary to keep track of that location. Thus, you can represent a range of very large and very small numbers with only a few digits.

You can represent any binary floating-point number in scientific notation form as $\pm f \times 2^{\pm e}$ where $f$ is the fraction (or mantissa); 2 is the radix or base (binary in this case); and $e$ is the exponent of the radix. The radix is always a positive number while $f$ and $e$ can be positive or negative.

When performing arithmetic operations, floating-point hardware must take into account that the sign, exponent, and fraction are all encoded within the same binary word. This results in complex logic circuits when compared with the circuits for binary fixed-point operations.

The Fixed-Point Blockset supports single-precision and double-precision floating-point numbers as defined by the IEEE Standard 754. Additionally, a nonstandard IEEE-style number is supported. To link the world of fixed-point numbers with the world of floating-point numbers, the concepts behind scientific notation are reviewed below.

### Scientific Notation

A direct analogy exists between scientific notation and radix point notation. For example, scientific notation using five decimal digits for the fraction would take the form

$$\pm d.dddd \times 10^{p} = \pm ddddd.0 \times 10^{p-4} = \pm 0.ddddd \times 10^{p+1}$$

where $p$ is an integer of unrestricted range. Radix point notation using five bits for the fraction is the same except for the number base

$$\pm b.bbbb \times 2^{q} = \pm bbbbb.0 \times 2^{q-4} = \pm 0.bbbbb \times 2^{q+1}$$

where $q$ is an integer of unrestricted range. The previous equation is valid for both fixed- and floating-point numbers. For both these data types, the fraction can be changed at any time by the processor. However, for fixed- point numbers the exponent never changes, while for floating-point numbers the exponent can be changed any time by the processor.

For fixed-point numbers, the exponent is fixed but there is no reason why the binary point must be contiguous with the fraction. For example, a word consisting of three unsigned bits is usually represented in scientific notation in one of these four ways.

$$bbb. = bbb. \times 2^{0}$$

$$bb.b = bbb. \times 2^{-1}$$

$$b.bb = bbb. \times 2^{-2}$$

$$.bbb = bbb. \times 2^{-3}$$

If the exponent were greater than 0 or less than -3, then the representation would involve lots of zeros.

$$bbb00000. = bbb. \times 2^{5}$$

$$bbb00. = bbb. \times 2^{2}$$

$$.00bbb = bbb. \times 2^{-5}$$

$$.00000bbb = bbb. \times 2^{-8}$$

These extra zeros never change to ones, however, so they don't show up in the hardware. Furthermore, unlike floating-point exponents, a fixed-point exponent never shows up in the hardware, so fixed-point exponents are not limited by a finite number of bits.

---

**Note** Restricting the binary point to being contiguous with the fraction is unnecessary; the Fixed-Point Blockset allows you to extend the binary point to any arbitrary location.

---

## The IEEE Format

The IEEE Standard 754 has been widely adopted, and is used with virtually all floating-point processors and arithmetic coprocessors — with the notable exception of many DSP floating-point processors.

Among other things, this standard specifies four floating-point number formats of which singles and doubles are the most widely used. Each format contains three components: a sign bit, a fraction field, and an exponent field. These components, as well as the specific formats for singles and doubles, are discussed below.

### The Sign Bit

While two's complement is the preferred representation for signed fixed-point numbers, IEEE floating-point numbers use a sign/magnitude representation, where the sign bit is explicitly included in the word. Using this representation, a sign bit of 0 represents a positive number and a sign bit of 1 represents a negative number.

### The Fraction Field

In general, floating-point numbers can be represented in many different ways by shifting the number to the left or right of the binary point and decreasing or increasing the exponent of the binary by a corresponding amount.

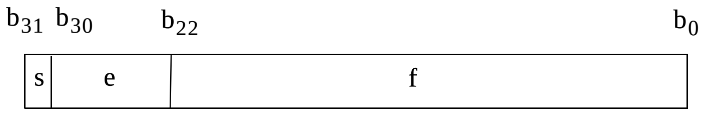
To simplify operations on these numbers, they are *normalized* in the IEEE format. A normalized binary number has a fraction of the form 1.*f* where *f* has a fixed size for a given data type. Since the leftmost fraction bit is always a 1, it is unnecessary to store this bit and is therefore implicit (or hidden). Thus, an n-bit fraction stores an $n$+1-bit number. The IEEE format also supports denormalized numbers, which have a fraction of the form 0.*f*. Normalized and denormalized formats are discussed in more detail in next section.

### The Exponent Field

In the IEEE format, exponent representations are biased. This means a fixed value (the bias) is subtracted from the field to get the true exponent value. For example, if the exponent field is 8 bits, then the numbers 0 through 255 are represented, and there is a bias of 127. Note that some values of the exponent are reserved for flagging `Inf` (infinity), `NaN` (not-a-number), and denormalized numbers, so the true exponent values range from -126 to 127. See the sections "Inf" and "NaN" on page 3-22.

### Single Precision Format

The IEEE single-precision floating-point format is a 32-bit word divided into a 1-bit sign indicator *s*, an 8-bit biased exponent *e*, and a 23-bit fraction *f*. A representation of this format is given below.



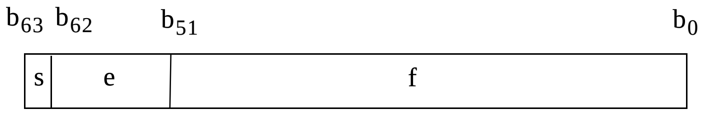
The relationship between this format and the representation of real numbers is given by

$$\text{value} = \begin{cases} (-1)^s \cdot (2^{e-127}) \cdot (1.f) & \text{normalized, } 0 < e < 255 \\ (-1)^s \cdot (2^{e-126}) \cdot (0.f) & \text{denormalized, } e = 0,\ f > 0 \\ \text{exceptional value} & \text{otherwise} \end{cases}$$

"Exceptional Arithmetic" on page 3-21 discusses denormalized values.

### Double Precision Format

The IEEE double-precision floating-point format is a 64-bit word divided into a 1-bit sign indicator *s*, an 11-bit biased exponent *e*, and a 52-bit fraction *f*. A representation of this format is given below.



The relationship between this format and the representation of real numbers is given by

$$\text{value} = \begin{cases} (-1)^s \cdot (2^{e-1023}) \cdot (1.f) & \text{normalized, } 0 < e < 2047 \\ (-1)^s \cdot (2^{e-1022}) \cdot (0.f) & \text{denormalized, } e = 0,\ f > 0 \\ \text{exceptional value} & \text{otherwise} \end{cases}$$

"Exceptional Arithmetic" on page 3-21 discusses denormalized values.

### Nonstandard IEEE Format

The Fixed-Point Blockset supports a nonstandard IEEE-style floating-point data type. This data type adheres to the definitions and formulas previously given for IEEE singles and doubles. You create nonstandard floating-point numbers with the `float` function:

```
float(TotalBits,ExpBits)
```

`TotalBits` is the total word size and `ExpBits` is the size of the exponent field. The size of the fraction field and the bias are calculated from these input arguments. You can specify any number of exponent bits up to 11, and any number of total bits such that the fraction field is no more than 53 bits.

When specifying a nonstandard format, you should remember that the number of exponent bits largely determines the range of the result and the number of fraction bits largely determines the precision of the result.

---

**Note** These numbers are normalized with a hidden leading one for all exponents except the smallest possible exponent. However, the largest possible exponent might not be treated as a flag for `Inf` or `NaN`.

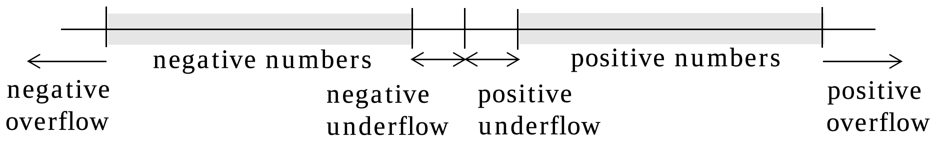
---

## Range and Precision

The range of a number gives the limits of the representation while the precision gives the distance between successive numbers in the representation. The range and precision of an IEEE floating-point number depend on the specific format.

### Range

The range of representable numbers for an IEEE floating-point number with *f* bits allocated for the fraction, *e* bits allocated for the exponent, and the bias of *e* given by $bias = 2^{e-1} - 1$ is given below.



where

- Normalized positive numbers are defined within the range $2^{1-bias}$ to $(2-2^{-f})\cdot 2^{bias}$.
- Normalized negative numbers are defined within the range $-2^{1-bias}$ to $-(2-2^{-f})\cdot 2^{bias}$.
- Positive numbers greater than $(2-2^{-f})\cdot 2^{bias}$, and negative numbers greater than $-(2-2^{-f})\cdot 2^{bias}$ are overflows.
- Positive numbers less than $2^{1-bias}$, and negative numbers less than $-2^{1-bias}$ are either underflows or denormalized numbers.
- Zero is given by a special bit pattern, where $e = 0$ and $f = 0$.

Overflows and underflows result from exceptional arithmetic conditions. Floating-point numbers outside the defined range are always mapped to ±Inf.

---

**Note** You can use the MATLAB commands `realmin` and `realmax` to determine the dynamic range of double-precision floating-point values for your computer.

---

### Precision

Due to a finite word size, a floating-point number is only an approximation of the “true” value. Therefore, it is important to have an understanding of the precision (or accuracy) of a floating-point result. In general, a value $v$ with an accuracy $q$ is specified by $v \pm q$. For IEEE floating-point numbers, $v = (-1)^s \cdot (2^{e-bias}) \cdot (1.f)$ and $q = 2^{-f} \cdot 2^{e-bias}$. Thus, the precision is associated with the number of bits in the fraction field.

---

**Note** In MATLAB, floating-point relative accuracy is given by the command `eps`, which returns the distance from 1.0 to the next largest floating-point number. For a computer that supports the IEEE Standard 754, `eps` = $2^{-52}$ or $2.2204 \times 10^{-16}$.

---

### Floating-Point Data Type Parameters

The high and low limits, exponent bias, and precision for the supported floating-point data types are given below.

| Data Type | Low Limit | High Limit | Exponent Bias | Precision |
|---|---|---|---|---|
| Single | $2^{-126} \approx 10^{-38}$ | $2^{128} \approx 3 \cdot 10^{38}$ | 127 | $2^{-23} \approx 10^{-7}$ |
| Double | $2^{-1022} \approx 2 \cdot 10^{-308}$ | $2^{1024} \approx 2 \cdot 10^{308}$ | 1023 | $2^{-52} \approx 10^{-16}$ |
| Nonstandard | $2^{(1-bias)}$ | $(2-2^{-f}) \cdot 2^{bias}$ | $2^{e-1}-1$ | $2^{-f}$ |

Due to the sign/magnitude representation of floating-point numbers, there are two representations of zero, one positive and one negative. For both representations $e = 0$ and $0.f = 0.0$.

## Exceptional Arithmetic

In addition to specifying a floating-point format, the IEEE Standard 754 specifies practices and procedures so that predictable results are produced independently of the hardware platform. Specifically, denormalized numbers, `Inf`, and `NaN` are defined to deal with exceptional arithmetic (underflow and overflow).

If an underflow or overflow is handled as `Inf` or `NaN`, then significant processor overhead is required to deal with this exception. Although the IEEE Standard 754 specifies practices and procedures to deal with exceptional arithmetic conditions in a consistent manner, microprocessor manufacturers may handle these conditions in ways that depart from the standard. Some of the alternative approaches, such as saturation and wrapping, are discussed in Chapter 4, “Arithmetic Operations.”

### Denormalized Numbers

Denormalized numbers are used to handle cases of exponent underflow. When the exponent of the result is too small (i.e., a negative exponent with too large a magnitude), the result is denormalized by right-shifting the fraction and leaving the exponent at its minimum value. The use of denormalized numbers is also referred to as gradual underflow. Without denormalized numbers, the gap between the smallest representable nonzero number and zero is much wider than the gap between the smallest representable nonzero number and the next larger number. Gradual underflow fills that gap and reduces the impact of exponent underflow to a level comparable with round off among the normalized numbers. Thus, denormalized numbers provide extended range for small numbers at the expense of precision.

### Inf

Arithmetic involving `Inf` (infinity) is treated as the limiting case of real arithmetic, with infinite values defined as those outside the range of representable numbers, or $-\infty \le (\text{representable numbers}) < \infty$. With the exception of the special cases discussed below (`NaN`), any arithmetic operation involving `Inf` yields `Inf`. `Inf` is represented by the largest biased exponent allowed by the format and a fraction of zero.

### NaN

A `NaN` (not-a-number) is a symbolic entity encoded in floating-point format. There are two types of `NaN`: signaling and quiet. A signaling `NaN` signals an invalid operation exception. A quiet `NaN` propagates through almost every arithmetic operation without signaling an exception. The following operations result in a `NaN`: $\infty - \infty$, $-\infty + \infty$, $0 \times \infty$, $0/0$, and $\infty/\infty$.

Both types of `NaN` are represented by the largest biased exponent allowed by the format and a fraction that is nonzero. The bit pattern for a quiet `NaN` is given by $0.f$ where the most significant number in $f$ must be a one, while the bit pattern for a signaling `NaN` is given by $0.f$ where the most significant number in $f$ must be zero and at least one of the remaining numbers must be nonzero.

# Arithmetic Operations

## Overview

When developing a dynamic system using floating-point arithmetic, you generally don’t have to worry about numerical limitations since floating-point data types have high precision and range. Conversely, when working with fixed-point arithmetic, you must consider these factors when developing dynamic systems:

- **Overflow**

  Adding two sufficiently large negative or positive values can produce a result that does not fit into the representation. This will have an adverse effect on the control system.
- **Quantization**

  Fixed-point values are rounded. Therefore, the output signal to the plant and the input signal to the control system do not have the same characteristics as the ideal discrete-time signal.
- **Computational noise**

  The accumulated errors that result from the rounding of individual terms within the realization introduces noise into the control signal.
- **Limit cycles**

  In the ideal system, the output of a stable transfer function (digital filter) approaches some constant for a constant input. With quantization, limit cycles occur where the output oscillates between two values in steady state.

This chapter describes the limitations involved when arithmetic operations are performed using encoded fixed-point variables. It also provides recommendations for encoding fixed-point variables such that simulations and generated code are reasonably efficient.

## Limitations on Precision

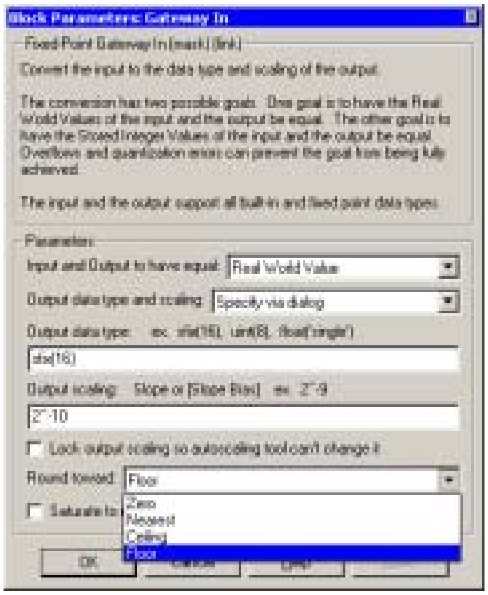
Computer words consist of a finite numbers of bits. This means that the binary encoding of variables is only an approximation of an arbitrarily precise real-world value. Therefore, the limitations of the binary representation automatically introduce limitations on the precision of the value. For a general discussion of range and precision in the Fixed-Point Blockset, refer to “Range and Precision” on page 3-8.

The precision of a fixed-point word depends on the word size and binary point location. Extending the precision of a word can always be accomplished with more bits, but you face practical limitations with this approach. Instead, you must carefully select the data type, word size, and scaling such that numbers are accurately represented. Rounding and padding with trailing zeros are typical methods implemented on processors to deal with the precision of binary words.

### Rounding

The result of any operation on a fixed-point number is typically stored in a register that is longer than the number’s original format. When the result is put back into the original format, the extra bits must be disposed of. That is, the result must be *rounded*. Rounding involves going from high precision to lower precision and produces quantization errors and computational noise.

The blockset provides four rounding modes, which are shown in the expanded drop-down menu in the dialog below.



Block Parameters: Gateway In

Fixed-Point Gateway In (mask) (link)

Convert the input to the data type and scaling of the output.

The conversion has two possible goals. One goal is to have the Real World Values of the input and the output be equal. The other goal is to have the Stored Integer Values of the input and the output be equal. Overflows and quantization errors can prevent the goal from being fully achieved.

The input and the output support all built-in and fixed point data types.

Parameters

Input and Output to have equal: Real World Value

Output data type and scaling: Specify via dialog

Output data type: ex. sfix(16), uint(8), float('single')

sfix(16)

Output scaling: Slope or [Slope Bias] ex. 2^-9

2^-10

☐ Lock output scaling so autoscaling tool can't change it

Round toward: Floor

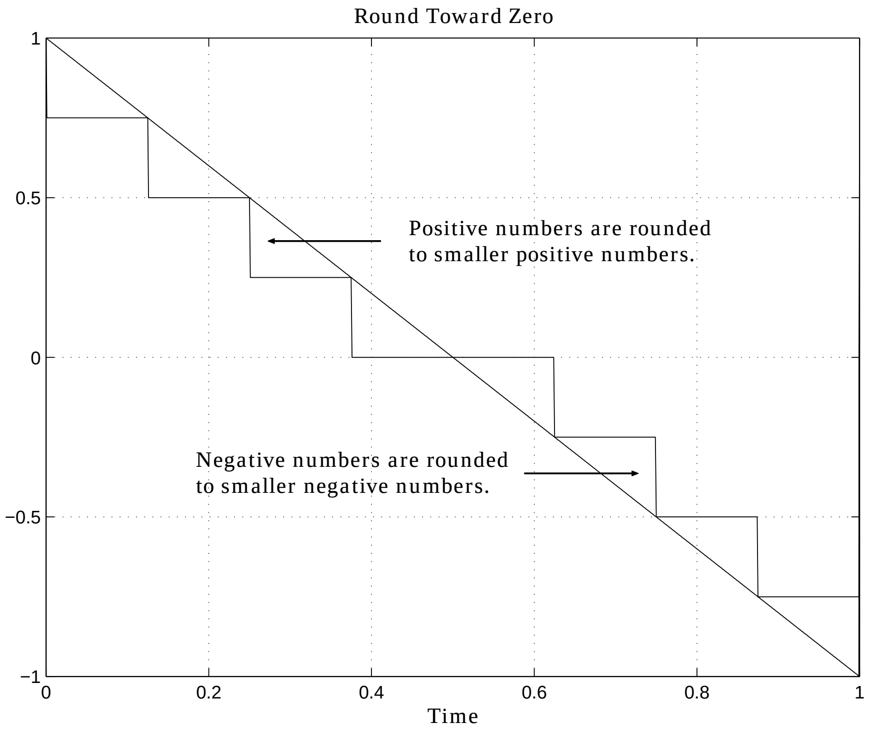
☐ Saturate to

The Fixed-Point Blockset rounding modes are discussed below. The data is generated using the Simulink Signal Generator block and doubles are converted to signed 8-bit numbers with binary point-only scaling of $2^{-2}$.

## Round Toward Zero

The simplest rounding mode computationally is when all digits beyond the number required are dropped. This mode is referred to as rounding toward zero, and it results in a number whose magnitude is always less than or equal to the more precise original value. In MATLAB, you can round to zero using the `fix` function.

Rounding toward zero introduces a cumulative downward bias in the result for positive numbers and a cumulative upward bias in the result for negative numbers. That is, all positive numbers are rounded to smaller positive numbers, while all negative numbers are rounded to smaller negative numbers. Rounding toward zero is shown below.

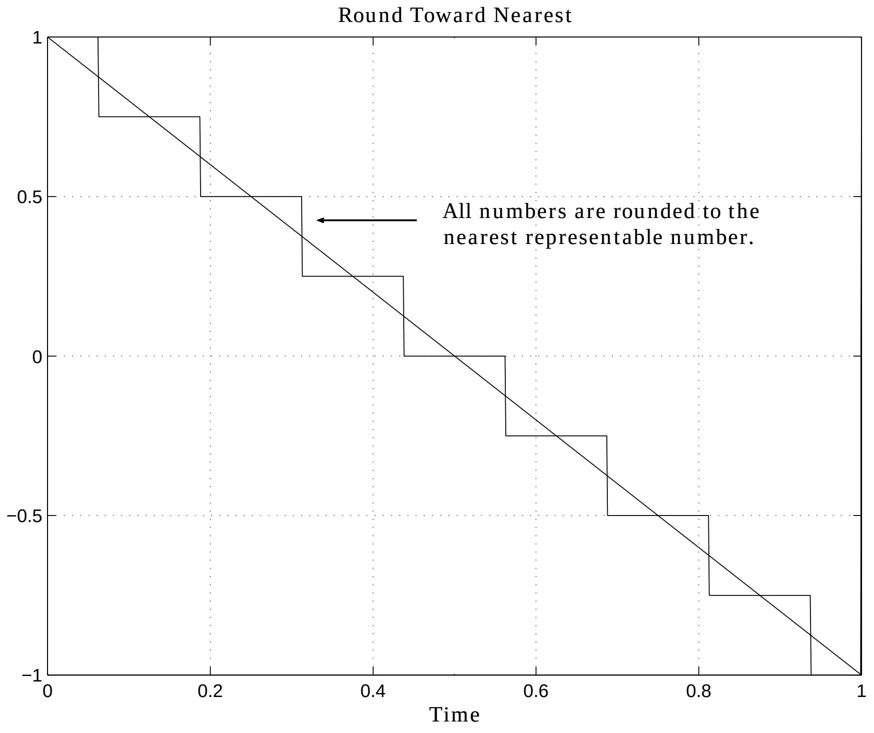


An example comparing rounding to zero and truncation for unsigned and two's complement numbers appears in "Example: Rounding to Zero Versus Truncation" on page 4-8.

### Round Toward Nearest

When you round toward nearest, the number is rounded to the nearest representable value. This mode has the smallest errors associated with it and these errors are symmetric. As a result, rounding toward nearest is the most useful approach for most applications.

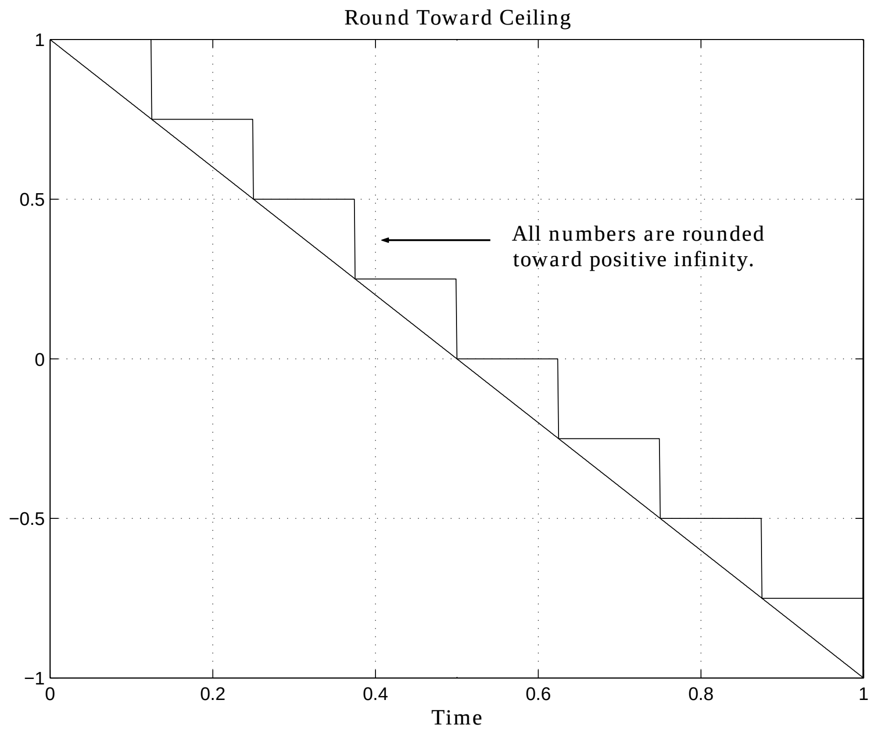
In MATLAB, you can round to nearest using the round function. Rounding toward nearest is shown below.



## Round Toward Ceiling

When you round toward ceiling, both positive and negative numbers are rounded toward positive infinity. As a result, a positive cumulative bias is introduced in the number.

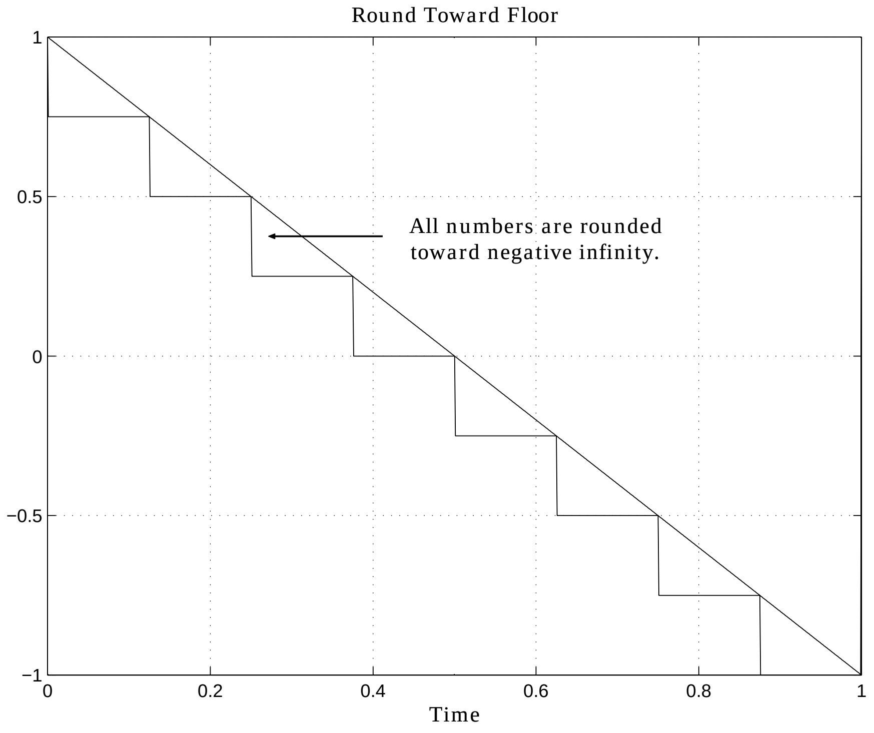
In MATLAB, you can round to ceiling using the `ceil` function. Rounding toward ceiling is shown below.



## Round Toward Floor

When you round toward floor, both positive and negative numbers are rounded to negative infinity. As a result, a negative cumulative bias is introduced in the number.

In MATLAB, you can round to floor using the `floor` function. Rounding toward floor is shown below.



Rounding toward ceiling and rounding toward floor are sometimes useful for diagnostic purposes. For example, after a series of arithmetic operations, you may not know the exact answer because of word-size limitations, which introduce rounding. If every operation in the series is performed twice, once rounding to positive infinity and once rounding to negative infinity, you obtain an upper limit and a lower limit on the correct answer. You can then decide if the result is sufficiently accurate or if additional analysis is required.

### Example: Rounding to Zero Versus Truncation

Rounding to zero and *truncation* or *chopping* are sometimes thought to mean the same thing. However, the results produced by rounding to zero and truncation are different for unsigned and two's complement numbers.

To illustrate this point, consider rounding a 5-bit unsigned number to zero by dropping (truncating) the two least significant bits. For example, the unsigned number 100.01 = 4.25 is truncated to 100 = 4. Therefore, truncating an unsigned number is equivalent to rounding to zero *or* rounding to floor.

Now consider rounding a 5-bit two's complement number by dropping the two least significant bits. At first glance, you may think truncating a two's complement number is the same as rounding to zero. For example, dropping the last two digits of -3.75 yields -3.00. However, digital hardware performing two's complement arithmetic yields a different result. Specifically, the number 100.01 = -3.75 truncates to 100 = -4, which is rounding to floor.

As you can see, rounding to zero for a two's complement number is not the same as truncation when the original value is negative. For this reason, the ambiguous term "truncation" is not used in this guide, and four explicit rounding modes are used instead.

## Padding with Trailing Zeros

Padding with trailing zeros involves extending the least significant bit (LSB) of a number with extra bits. This method involves going from low precision to higher precision.

For example, suppose two numbers are subtracted from each other. First, the exponents must be aligned, which typically involves a right shift of the number with the smaller value. In performing this shift, significant digits can "fall off" to the right. However, when the appropriate number of extra bits is appended, the precision of the result is maximized. Consider two 8-bit fixed-point numbers that are close in value and subtracted from each other

$$1.0000000 \cdot 2^{q} - 1.1111111 \cdot 2^{q-1}$$

where $q$ is an integer. To perform this operation, the exponents must be equal.

$$\begin{array}{r} 1.0000000 \cdot 2^{q} \\ \underline{-\ 0.1111111 \cdot 2^{q}} \\ 0.0000001 \cdot 2^{q} \end{array}$$

If the top number is padded by two zeros and the bottom number is padded with one zero, then the above equation becomes

$$\begin{array}{r} 1.000000000 \cdot 2^q \\ -\ 0.111111110 \cdot 2^q \\ \hline 0.000000010 \cdot 2^q \end{array}$$

which produces a more precise result. An example of padding with trailing zeros using the Fixed-Point Blockset is illustrated in “Digital Controller Realization” on page 6-7.

## Example: Limitations on Precision and Errors

Fixed-point variables have a limited precision because digital systems represent numbers with a finite number of bits. For example, suppose you must represent the real-world number 35.375 with a fixed-point number. Using the encoding scheme described in “Scaling” on page 3-5, the representation is

$$\tilde{V} = 2^{-2}Q + 32$$

The two closest approximations to the real-world value are $Q = 13$ and $Q = 14$.

$$\tilde{V} = 2^{-2}(13) + 32 = 35.25$$
$$\tilde{V} = 2^{-2}(14) + 32 = 35.50$$

In either case, the absolute error is the same:

$$|\tilde{V} - V| = 0.125 = \frac{F2^E}{2}$$

For fixed-point values within the limited range, this represents the worst-case error if round-to-nearest is used. If other rounding modes are used, the worst-case error can be twice as large:

$$|\tilde{V} - V| < F2^E$$

## Example: Maximizing Precision

Precision is limited by slope. To achieve maximum precision, you should make the slope as small as possible while keeping the range adequately large. The bias is adjusted in coordination with the slope.

Assume the maximum and minimum real-world value is given by $max(V)$ and $min(V)$, respectively. These limits may be known based on physical principles or engineering considerations. To maximize the precision, you must decide upon a rounding scheme and whether overflows saturate or wrap. To simplify matters, this example assumes the minimum real-world value corresponds to the minimum encoded value, and the maximum real-world value corresponds to the maximum encoded value. Using the encoding scheme described in "Scaling" on page 3-5, these values are given by

$$max(V) = F2^E(max(Q)) + B$$
$$min(V) = F2^E(min(Q)) + B$$

Solving for the slope, you get

$$F2^E = \frac{max(V) - min(V)}{max(Q) - min(Q)} = \frac{max(V) - min(V)}{2^{ws} - 1}$$

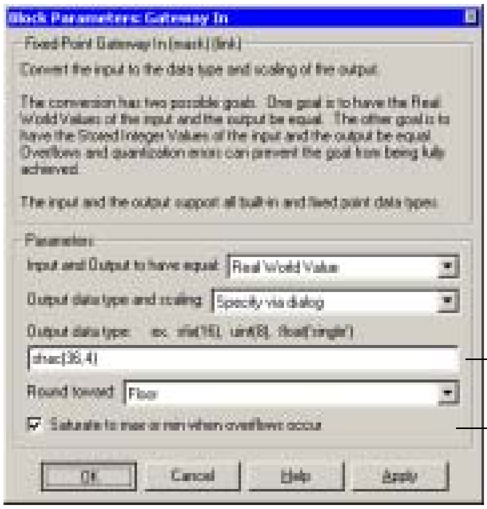
This formula is independent of rounding and overflow issues, and depends only on the word size, $ws$.

## Limitations on Range

Limitations on the range of a fixed-point word occur for the same reason as limitations on its precision. Namely, fixed-point words have limited size. For a general discussion of range and precision in the Fixed-Point Blockset, refer to "Range and Precision" in Chapter 3.

In binary arithmetic, a processor may need to take an n-bit fixed-point number and store it in m bits, where $m \neq n$. If m < n, the range of the number has been reduced and an operation can produce an overflow condition. Some processors identify this condition as `Inf` or `NaN`. For other processors, especially digital signal processors (DSPs), the value *saturates* or *wraps*. If m > n, the range of the number has been extended. Extending the range of a word requires the inclusion of *guard bits*, which act to "guard" against potential overflow. In both cases, the range depends on the word's size and scaling.

The Fixed-Point Blockset supports saturation and wrapping for all fixed-point data types, while guard bits are supported only for fractional data types. As shown below, you can select saturation or wrapping with the **Saturate to max or min when overflows occur** check box, and you can specify guard bits with the **Output data type** parameter.



Block Parameters: Gateway In

Fixed-Point Gateway In (mask) (link)

Convert the input to the data type and scaling of the output.

The conversion has two possible goals. One goal is to have the Real World Values of the input and the output be equal. The other goal is to have the Stored Integer Values of the input and the output be equal. Overflows and quantization errors can prevent the goal from being fully achieved.

The input and the output support all built-in and fixed point data types.

Parameters

Input and Output to have equal: Real World Value

Output data type and scaling: Specify via dialog

Output data type: ex. sfix(16), uint(8), float('single')

sfrac(36,4)

Round toward: Floor

[✓] Saturate to max or min when overflows occur

36-bit signed fractional data type with 4 guard bits. The total word size is 40 bits.

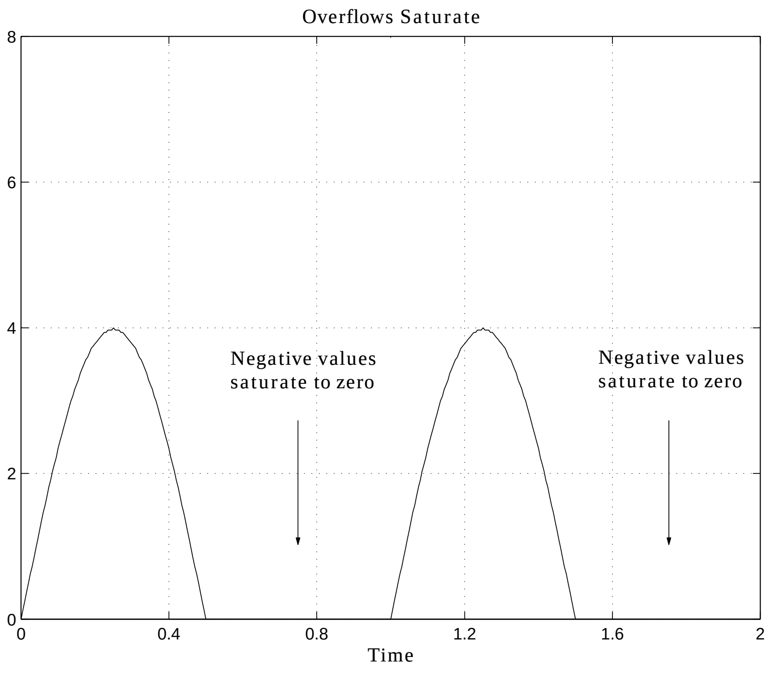
Saturate overflows.

## Saturation and Wrapping

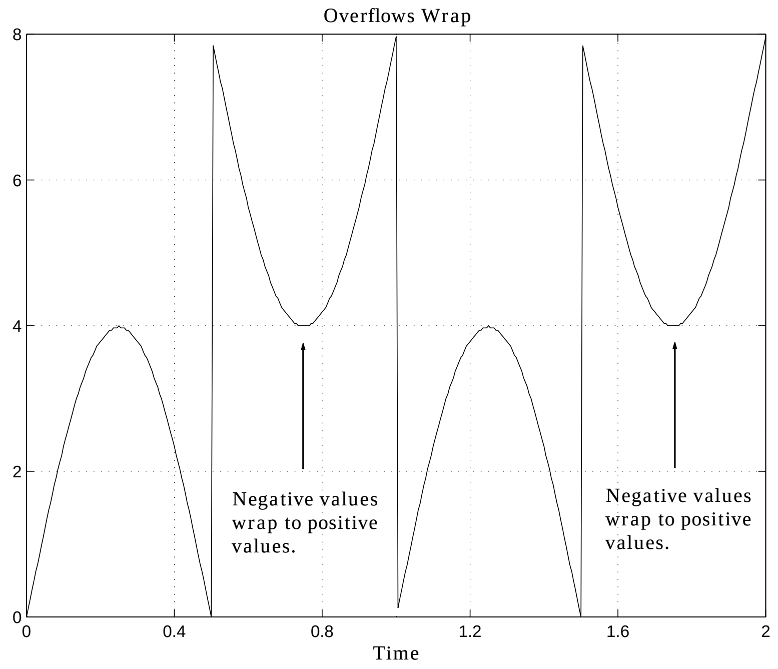
Saturation and wrapping describe a particular way that some processors deal with overflow conditions. For example, Analog Device's ADSP-2100 family of processors supports either of these modes. If a register has a saturation mode of operation, then an overflow condition is set to the maximum positive or negative value allowed. Conversely, if a register has a wrapping mode of operation, an overflow condition is set to the appropriate value within the range of the representation.

### Example: Saturation and Wrapping

Consider an 8-bit unsigned word with binary point-only scaling of $2^{-5}$. Suppose this data type must represent a sine wave that ranges from -4 to 4. For values between 0 and 4, the word can represent these numbers without regard to overflow. This is not the case with negative numbers. If overflows saturate, all negative values are set to zero, which is the smallest number representable by the data type. The saturation of overflows is shown below.



If overflows wrap, all negative values are set to the appropriate positive value. The wrapping of overflows is shown below.



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**Note** For most control applications, saturation is the safer way of dealing with fixed-point overflow. However, some processor architectures allow automatic saturation by hardware. If hardware saturation is not available, then extra software is required resulting in larger, slower programs. This cost is justified in some designs — perhaps for safety reasons. Other designs accept wrapping to obtain the smallest, fastest software.

---

## Guard Bits

You can eliminate the possibility of overflow by appending the appropriate number of guard bits to a binary word.

For a two's complement signed value, the guard bits are filled with either 0's or 1's depending on the value of the most significant bit (MSB). This is called *sign extension*. For example, consider a 4-bit two's complement number with value 1011. If this number is extended in range to 7 bits with sign extension, then the number becomes 1111101 and the value remains the same.

Guard bits are supported only for fractional data types. For both signed and unsigned fractionals, the guard bits lie to the left of the default binary point.

## Example: Limitations on Range

Fixed-point variables have a limited range for the same reason they have limited precision — because digital systems represent numbers with a finite number of bits. As a general example, consider the case where an integer is represented as a fixed-point word of size *ws*. The range for signed and unsigned words is given by $max(Q) - min(Q)$ where

$$min(Q) = \begin{cases} 0 & \text{unsigned} \\ -2^{ws-1} & \text{signed} \end{cases}$$

$$max(Q) = \begin{cases} 2^{ws} - 1 & \text{unsigned} \\ 2^{ws-1} - 1 & \text{signed} \end{cases}$$

Using the general [Slope Bias] encoding scheme described in "Scaling" on page 3-5, the approximate real-world value has the range $max(\tilde{V}) - min(\tilde{V})$ where

$$min(\tilde{V}) = \begin{cases} B & \text{unsigned} \\ -F2^E(2^{ws-1}) + B & \text{signed} \end{cases}$$

$$max(\tilde{V}) = \begin{cases} F2^E(2^{ws} - 1) + B & \text{unsigned} \\ F2^E(2^{ws-1} - 1) + B & \text{signed} \end{cases}$$

If the real-world value exceeds the limited range of the approximate value, then the accuracy of the representation can become significantly worse.

## Recommendations for Arithmetic and Scaling

This section describes the relationship between arithmetic operations and fixed-point scaling, and some basic recommendations that may be appropriate for your fixed-point design. For each arithmetic operation:

- The general [Slope Bias] encoding scheme described in “Scaling” on page 3-5 is used.
- The scaling of the result is automatically selected based on the scaling of the two inputs. In other words, the scaling is *inherited*.
- Scaling choices are based on
  - Minimizing the number of arithmetic operations of the result.
  - Maximizing the precision of the result.

  Additionally, binary point-only scaling is presented as a special case of the general encoding scheme.

In embedded systems, the scaling of variables at the hardware interface (the ADC or DAC) is fixed. However for most other variables, the scaling is something you can choose to give the best design. When scaling fixed-point variables, it is important to remember that:

- Your scaling choices depend on the particular design you are simulating.
- There is no best scaling approach. All choices have associated advantages and disadvantages. It is the goal of this section to expose these advantages and disadvantages to you.

### Addition

Consider the addition of two real-world values:

$$V_a = V_b + V_c$$

These values are represented by the general [Slope Bias] encoding scheme described in “Scaling” on page 3-5:

$$V_i = F_i 2^{E_i} Q_i + B_i$$

In a fixed-point system, the addition of values results in finding the variable $Q_a$:

$$Q_a = \frac{F_b}{F_a} \cdot 2^{E_b - E_a} Q_b + \frac{F_c}{F_a} \cdot 2^{E_c - E_a} Q_c + \frac{B_b + B_c - B_a}{F_a} \cdot 2^{-E_a}$$

This formula shows

- In general, $Q_a$ is not computed through a simple addition of $Q_b$ and $Q_c$.
- In general, there are two multiplies of a constant and a variable, two additions, and some additional bit shifting.

### Inherited Scaling for Speed

In the process of finding the scaling of the sum, one reasonable goal is to simplify the calculations. Simplifying the calculations should reduce the number of operations thereby increasing execution speed. The following choices can help to minimize the number of arithmetic operations:

- Set $B_a = B_b + B_c$. This eliminates one addition.
- Set $F_a = F_b$ *or* $F_a = F_c$. Either choice eliminates one of the two constant times variable multiplies.

The resulting formula is

$$Q_a = 2^{E_b - E_a} Q_b + \frac{F_c}{F_a} \cdot 2^{E_c - E_a} Q_c$$

or

$$Q_a = \frac{F_b}{F_a} \cdot 2^{E_b - E_a} Q_b + 2^{E_c - E_a} Q_c$$

These equations appear to be equivalent. However, your choice of rounding and precision may make one choice stand out over the other. To further simplify matters, you could choose $E_a = E_c$ or $E_a = E_b$. This will eliminate some bit shifting.

### Inherited Scaling for Maximum Precision

In the process of finding the scaling of the sum, one reasonable goal is maximum precision. You can determine the maximum precision scaling if the range of the variable is known. "Example: Maximizing Precision" on page 4-10 shows that you can determine the range of a fixed-point operation from $max(V_a)$ and $min(V_a)$. For a summation, you can determine the range from

$$min(\tilde{V}_a) = min(\tilde{V}_b) + min(\tilde{V}_c)$$
$$max(\tilde{V}_a) = max(\tilde{V}_b) + max(\tilde{V}_c)$$

You can now derive the maximum precision slope:

$$F_a 2^{E_a} = \frac{max(\tilde{V}_a) - min(\tilde{V}_a)}{2^{ws_a} - 1}$$
$$= \frac{F_b 2^{E_b}(2^{ws_b} - 1) + F_c 2^{E_c}(2^{ws_c} - 1)}{2^{ws_a} - 1}$$

In most cases the input and output word sizes are much greater than one, and the slope becomes

$$F_a 2^{E_a} \approx F_b 2^{E_b + ws_b - ws_a} + F_c 2^{E_c + ws_c - ws_a}$$

which depends only on the size of the input and output words. The corresponding bias is

$$B_a = min(\tilde{V}_a) - F_a 2^{E_a} \cdot min(Q_a)$$

The value of the bias depends on whether the inputs and output are signed or unsigned numbers.

If the inputs and output are all unsigned, then the minimum value for these variables are all zero and the bias reduces to a particularly simple form:

$$B_a = B_b + B_c$$

If the inputs and the output are all signed, then the bias becomes

$$B_a \approx B_b + B_c + F_b 2^{E_b}(-2^{ws_b - 1} + 2^{ws_b - 1}) + F_c 2^{E_c}(-2^{ws_c - 1} + 2^{ws_c - 1})$$
$$B_a \approx B_b + B_c$$

### Binary Point-Only Scaling

For binary point-only scaling, finding $Q_a$ results in this simple expression:

$$Q_a = 2^{E_b - E_a} Q_b + 2^{E_c - E_a} Q_c$$

This scaling choice results in only one addition and some bit shifting. The avoidance of any multiplications is a big advantage of binary point-only scaling.

---

**Note** The subtraction of values produces results that are analogous to those produced by the addition of values.

---

## Accumulation

The accumulation of values is closely associated with addition:

$$V_{a\_new} = V_{a\_old} + V_b$$

Finding $Q_{a\_new}$ involves one multiply of a constant and a variable, two additions, and some bit shifting:

$$Q_{a\_new} = Q_{a\_old} + \frac{F_b}{F_a} \cdot 2^{E_b - E_a} Q_b + \frac{B_b}{F_a} \cdot 2^{-E_a}$$

The important difference for fixed-point implementations is that the scaling of the output is identical to the scaling of the first input.

### Binary Point-Only Scaling

For binary point-only scaling, finding $Q_{a\_new}$ results in this simple expression:

$$Q_{a\_new} = Q_{a\_old} + 2^{E_b - E_a} Q_b$$

This scaling option only involves one addition and some bit shifting.

---

**Note** The negative accumulation of values produces results that are analogous to those produced by the accumulation of values.

---

## Multiplication

Consider the multiplication of two real-world values:

$$V_a = V_b \times V_c$$

These values are represented by the general [Slope Bias] encoding scheme described in “Scaling” on page 3-5:

$$V_i = F_i 2^{E_i} Q_i + B_i$$

In a fixed-point system, the multiplication of values results in finding the variable $Q_a$:

$$Q_a = \frac{F_b F_c}{F_a} \cdot 2^{E_b + E_c - E_a} Q_b Q_c + \frac{F_b B_c}{F_a} \cdot 2^{E_b - E_a} Q_b + \frac{F_c B_b}{F_a} \cdot 2^{E_c - E_a} Q_c$$
$$+ \frac{B_b B_c - B_a}{F_a} \cdot 2^{-E_a}$$

This formula shows

- In general, $Q_a$ is not computed through a simple multiplication of $Q_b$ and $Q_c$.
- In general, there is one multiply of a constant and two variables, two multiplies of a constant and a variable, three additions, and some additional bit shifting.

### Inherited Scaling for Speed

The number of arithmetic operations can be reduced with these choices:

- Set $B_a = B_b B_c$. This eliminates one addition operation.
- Set $F_a = F_b F_c$. This simplifies the triple multiplication – certainly the most difficult part of the equation to implement.
- Set $E_a = E_b + E_c$. This eliminates some of the bit-shifting.

The resulting formula is

$$Q_a = Q_b Q_c + \frac{B_c}{F_c} \cdot 2^{-E_c} Q_b + \frac{B_b}{F_b} \cdot 2^{-E_b} Q_c$$

### Inherited Scaling for Maximum Precision

You can determine the maximum precision scaling if the range of the variable is known. “Example: Maximizing Precision” on page 4-10 shows that you can determine the range of a fixed-point operation from $max(\tilde{V}_a)$ and $min(\tilde{V}_a)$.

For multiplication, you can determine the range from

$$min(\tilde{V}_a) = min(V_{LL}, V_{LH}, V_{HL}, V_{HH})$$
$$max(\tilde{V}_a) = max(V_{LL}, V_{LH}, V_{HL}, V_{HH})$$

where

$$V_{LL} = min(\tilde{V}_b) \cdot min(\tilde{V}_c)$$
$$V_{LH} = min(\tilde{V}_b) \cdot max(\tilde{V}_c)$$
$$V_{HL} = max(\tilde{V}_b) \cdot min(\tilde{V}_c)$$
$$V_{HH} = max(\tilde{V}_b) \cdot max(\tilde{V}_c)$$

### Binary Point-Only Scaling

For binary point-only scaling, finding $Q_a$ results in this simple expression:

$$Q_a = 2^{E_b + E_c - E_a} Q_b Q_c$$

## Gain

Consider the multiplication of a constant and a variable

$$V_a = K \cdot V_b$$

where $K$ is a constant called the gain. Since $V_a$ results from the multiplication of a constant and a variable, finding $Q_a$ is a simplified version of the general fixed-point multiply formula:

$$Q_a = \left(\frac{KF_b 2^{E_b}}{F_a 2^{E_a}}\right) \cdot Q_b + \left(\frac{KB_b - B_a}{F_a 2^{E_a}}\right)$$

Note that the terms in the parentheses can be calculated offline. Therefore, there is only one multiplication of a constant and a variable and one addition.

To implement the above equation without changing it to a more complicated form, the constants need to be encoded using a binary point-only format. For each of these constants, the range is the trivial case of only one value. Despite the trivial range, the binary point formulas for maximum precision are still valid. The maximum precision representations are the most useful choices unless there is an overriding need to avoid any shifting. The encoding of the constants is

$$\left(\frac{KF_b 2^{E_b}}{F_a 2^{E_a}}\right) = 2^{E_X} Q_X$$

$$\left(\frac{KB_b - B_a}{F_a 2^{E_a}}\right) = 2^{E_Y} Q_Y$$

resulting in the formula

$$Q_a = 2^{E_X} Q_X Q_B + 2^{E_Y} Q_Y$$

## Inherited Scaling for Speed

The number of arithmetic operations can be reduced with these choices:

- Set $B_a = KB_b$. This eliminates one constant term.
- Set $F_a = KF_b$ and $E_a = E_b$. This sets the other constant term to unity.

The resulting formula is simply

$$Q_a = Q_b$$

If the number of bits is different, then either handling potential overflows or performing sign extensions is the only possible operations involved.

## Inherited Scaling for Maximum Precision

The scaling for maximum precision does not need to be different than the scaling for speed unless the output has fewer bits than the input. If this is the case, then saturation should be avoided by dividing the slope by 2 for each lost bit. This will prevent saturation but will cause rounding to occur.

## Division

Division of values is an operation that should be avoided in fixed-point embedded systems, but it can occur in places. Therefore, consider the division of two real-world values:

$$V_a = V_b / V_c$$

These values are represented by the general [Slope Bias] encoding scheme described in “Scaling” on page 3-5:

$$V_i = F_i 2^{E_i} Q_i + B_i$$

In a fixed-point system, the division of values results in finding the variable $Q_a$:

$$Q_a = \frac{F_b 2^{E_b} Q_b + B_b}{F_c F_a 2^{E_c + E_a} Q_c + B_c F_a \cdot 2^{E_a}} - \frac{B_a}{F_a} \cdot 2^{-E_a}$$

This formula shows

- In general, $Q_a$ is not computed through a simple division of $Q_b$ by $Q_c$.
- In general, there are two multiplies of a constant and a variable, two additions, one division of a variable by a variable, one division of a constant by a variable, and some additional bit shifting.

### Inherited Scaling for Speed

The number of arithmetic operations can be reduced with these choices:

- Set $B_a = 0$. This eliminates one addition operation.
- If $B_c = 0$, then set the fractional slope $F_a = F_b / F_c$. This eliminates one constant times variable multiplication.

The resulting formula is

$$Q_a = \frac{Q_b}{Q_c} \cdot 2^{E_b - E_c - E_a} + \frac{(B_b / F_b)}{Q_c} \cdot 2^{-E_c - E_a}$$

If $B_c \neq 0$ , then no clear recommendation can be made.

### Inherited Scaling for Maximum Precision

You can determine the maximum precision scaling if the range of the variable is known. “Example: Maximizing Precision” on page 4-10 shows that you can determine the range of a fixed-point operation from $max(V_a)$ and $min(V_a)$. For division, you can determine the range from

$$min(\tilde{V}_a) = min(V_{LL}, V_{LH}, V_{HL}, V_{HH})$$
$$max(\tilde{V}_a) = max(V_{LL}, V_{LH}, V_{HL}, V_{HH})$$

where for nonzero denominators

$$V_{LL} = min(\tilde{V}_b)/min(\tilde{V}_c)$$
$$V_{LH} = min(\tilde{V}_b)/max(\tilde{V}_c)$$
$$V_{HL} = max(\tilde{V}_b)/min(\tilde{V}_c)$$
$$V_{HH} = max(\tilde{V}_b)/max(\tilde{V}_c)$$

### Binary Point-Only Scaling

For binary point-only scaling, finding $Q_a$ results in this simple expression:

$$Q_a = \frac{Q_b}{Q_c} \cdot 2^{E_b - E_c - E_a}$$

---

**Note** For the last two formulas involving $Q_a$, a divide by zero, and zero divided by zero are possible. In these cases, the hardware will give some default behavior but you must make sure that these default responses give meaningful results for the embedded system.

---

## Summary

From the previous analysis of fixed-point variables scaled within the general [Slope Bias] encoding scheme, you can conclude

- Addition, subtraction, multiplication, and division can be very involved unless certain choices are made for the biases and slopes.
- Binary point-only scaling guarantees simpler math, but generally sacrifices some precision.

Note that the previous formulas don't show the following:

- Constants and variables are represented with a finite number of bits.
- Variables are either signed or unsigned.
- Rounding and overflow handling schemes. You must make these decisions before an actual fixed-point realization is achieved.

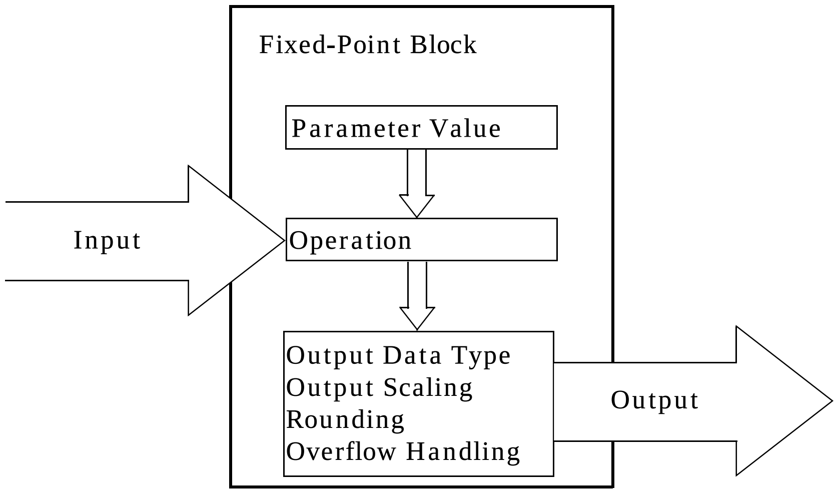
## Parameter and Signal Conversions

The previous sections of this chapter, together with Chapter 3, “Data Types and Scaling,” describe how data types, scaling, rounding, overflow handling, and arithmetic operations are incorporated into the Fixed-Point Blockset. With this knowledge, you can define the output of a fixed-point model by configuring fixed-point blocks to suit your particular application.

However, to completely understand the results generated by the Fixed-Point Blockset, you must be aware of these three issues:

- When numerical block parameters are converted from a double to a Fixed-Point Blockset data type
- When input signals are converted from one Fixed-Point Blockset data type to another (if at all)
- When arithmetic operations on input signals and parameters are performed

For example, suppose a fixed-point block performs an arithmetic operation on its input signal and a parameter, and then generates output having characteristics that are specified by the block. The following diagram illustrates how these issues are related.



The following sections discuss parameter conversions and signal conversions. "Rules for Arithmetic Operations" on page 4-30 discusses arithmetic operations.

## Parameter Conversions

Parameters of fixed-point blocks that accept numerical values are always converted from a double to a Fixed-Point Blockset data type. Parameters can be converted to the input data type, the output data type, or to a data type explicitly specified by the block. For example, the FIR block converts the **Initial condition** parameter to the input data type, and converts the **FIR coefficients** parameter to a data type you explicitly specify via the block dialog box.

Parameters are always converted before any arithmetic operations are performed. Additionally, parameters are always converted *offline* using round-to-nearest and saturation. Offline conversions are discussed below.

For information about parameter conversions for a specific block, refer to Chapter 10, "Block Reference."

### Offline Conversions

An offline conversion is a conversion performed by your development platform (for example, the processor on your PC), and not by the fixed-point processor you are targeting. For example, suppose you are using a PC to develop a program to run on a fixed-point processor, and you need the fixed-point processor to compute

$$y = \left(\frac{ab}{c}\right) \cdot u = C \cdot u$$

over and over again. If $a$, $b$, and $c$ are constant parameters, it is inefficient for the fixed-point processor to compute $ab/c$ every time. Instead, the PC's processor should compute $ab/c$ offline one time, and the fixed-point processor computes only $C \cdot u$. This eliminates two costly fixed-point arithmetic operations.

## Signal Conversions

Consider the conversion of a real-world value from one Fixed-Point Blockset data type to another. Ideally, the values before and after the conversion are equal.

$$V_a = V_b$$

where $V_b$ is the input value and $V_a$ is the output value. To see how the conversion is implemented, the two ideal values are replaced by the general [Slope Bias] encoding scheme described in “Scaling” on page 3-5:

$$V_i = F_i 2^{E_i} Q_i + B_i$$

Solving for the output data type’s stored integer value, $Q_a$ is obtained:

$$\begin{aligned} Q_a &= \frac{F_b}{F_a} 2^{E_b - E_a} Q_b + \frac{B_b - B_a}{F_a} 2^{-E_a} \\ &= F_s 2^{E_b - E_a} Q_b + B_{net} \end{aligned}$$

where $F_s$ is the adjusted fractional slope and $B_{net}$ is the net bias. The offline conversions and online conversions and operations are discussed below.

### Offline Conversions

Both $F_s$ and $B_{net}$ are computed offline using round-to-nearest and saturation. $B_{net}$ is then stored using the output data type and $F_s$ is stored using an automatically selected data type.

### Online Conversions and Operations

The remaining conversions and operations are performed *online* by the fixed-point processor, and depend on the slopes and biases for the input and output data types. The conversions and operations are given by these steps:

1. The initial value for $Q_a$ is given by the net bias, $B_{net}$:

   $$Q_a = B_{net}$$

2. The input integer value, $Q_b$, is multiplied by the adjusted slope, $F_s$:

   $$Q_{RawProduct} = F_s Q_b$$

3. The result of step **2** is converted to the modified output data type where the slope is one and bias is zero:

$$Q_{Temp} = convert(Q_{RawProduct})$$

This conversion includes any necessary bit shifting, rounding, or overflow handling.

**4** The summation operation is performed:

$$Q_a = Q_{Temp} + Q_a$$

This summation includes any necessary overflow handling.

### Streamlining Simulations and Generated Code

Note that the maximum number of conversions and operations is performed when the slopes and biases of the input signal and output signal differ (are mismatched). If the scaling of these signals is identical (matched), the number of operations is reduced from the worst (most inefficient) case. For example, when an input has the same fractional slope and bias as the output, only step **3** is required:

$$Q_a = convert(Q_b)$$

Exclusive use of binary point-only scaling for both input signals and output signals is a common way to eliminate the occurrence of mismatched slopes and biases, and results in the most efficient simulations and generated code.

## Rules for Arithmetic Operations

Fixed-point arithmetic refers to how signed or unsigned binary words are operated on. The simplicity of fixed-point arithmetic functions such as addition and subtraction allows for cost-effective hardware implementations.

This section describes the blockset-specific rules that are followed when arithmetic operations are performed on inputs and parameters. These rules are organized into four groups based on the operations involved: addition and subtraction, multiplication, division, and shifts. For each of these four groups, the rules for performing the specified operation are presented with an example using the rules.

### Computational Units

The core architecture of many processors contains several computational units including arithmetic logic units (ALUs), multiply and accumulate units (MACs), and shifters. These computational units process the binary data directly and provide support for arithmetic computations of varying precision. The ALU performs a standard set of arithmetic and logic operations as well as division. The MAC performs multiply, multiply/add, and multiply/subtract operations. The shifter performs logical and arithmetic shifts, normalization, denormalization, and other operations.

### Addition and Subtraction

Addition is the most common arithmetic operation a processor performs. When two n-bit numbers are added together, it is always possible to produce a result with n + 1 nonzero digits due to a carry from the leftmost digit. For two's complement addition of two numbers, there are three cases to consider:

- If both numbers are positive and the result of their addition has a sign bit of 1, then overflow has occurred; otherwise the result is correct.
- If both numbers are negative and the sign of the result is 0, then overflow has occurred; otherwise the result is correct.
- If the numbers are of unlike sign, overflow cannot occur and the result is always correct.

### Fixed-Point Blockset Summation Process

Consider the summation of two numbers. Ideally, the real-world values obey the equation

$$V_a = \pm V_b \pm V_c$$

where $V_b$ and $V_c$ are the input values and $V_a$ is the output value. To see how the summation is actually implemented, the three ideal values should be replaced by the general [Slope Bias] encoding scheme described in "Scaling" on page 3-5:

$$V_i = F_i 2^{E_i} Q_i + B_i$$

The equation in "Addition" on page 4-16 gives the solution of the resulting equation for the stored integer, $Q_a$. Using shorthand notation, that equation becomes

$$Q_a = \pm F_{sb} 2^{E_b - E_a} Q_b \pm F_{sc} 2^{E_c - E_a} Q_c + B_{net}$$

where $F_{sb}$ and $F_{sc}$ are the adjusted fractional slopes and $B_{net}$ is the net bias. The offline conversions, and online conversions and operations are discussed below.

**Offline Conversions.** $F_{sb}$, $F_{sc}$, and $B_{net}$ are computed offline using round-to-nearest and saturation. Furthermore, $B_{net}$ is stored using the output data type.

**Online Conversions and Operations.** The remaining operations are performed online by the fixed-point processor, and depend on the slopes and biases for the input and output data types. The worst (most inefficient) case occurs when the slopes and biases are mismatched. The worst-case conversions and operations are given by these steps:

**1** The initial value for $Q_a$ is given by the net bias, $B_{net}$:

$$Q_a = B_{net}$$

**2** The first input integer value, $Q_b$, is multiplied by the adjusted slope, $F_{sb}$:

$$Q_{RawProduct} = F_{sb}Q_b$$

3 The previous product is converted to the modified output data type where the slope is one and the bias is zero:

$$Q_{Temp} = convert(Q_{RawProduct})$$

This conversion includes any necessary bit shifting, rounding, or overflow handling.

4 The summation operation is performed:

$$Q_a = \pm Q_a + Q_{Temp}$$

This summation includes any necessary overflow handling.

5 Steps **2** to **4** are repeated for every number to be summed.

It is important to note that bit shifting, rounding, and overflow handling are applied to the intermediate steps (**3** and **4**) and not to the overall sum.

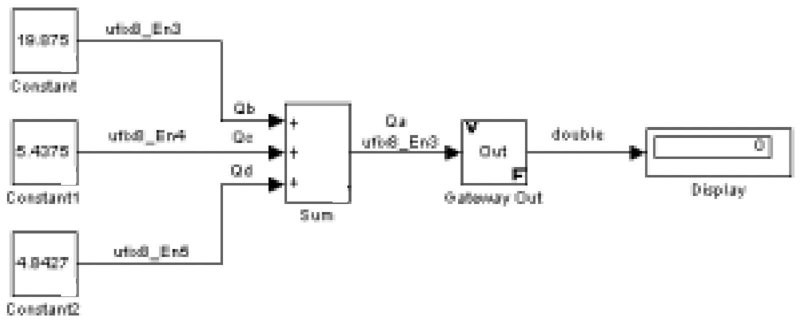
## Streamlining Simulations and Generated Code

If the scaling of the input and output signals is matched, the number of summation operations is reduced from the worst (most inefficient) case. For example, when an input has the same fractional slope as the output, step **2** reduces to multiplication by one and can be eliminated. Trivial steps in the summation process are eliminated for both simulation and code generation. Exclusive use of binary point-only scaling for both input signals and output signals is a common way to eliminate the occurrence of mismatched slopes and biases, and results in the most efficient simulations and generated code.

## Example: The Summation Process

Suppose you want to sum three numbers. Each of these numbers is represented by an 8-bit word, and each has a different binary point-only scaling. Additionally, the output is restricted to an 8-bit word with binary point-only scaling of $2^{-3}$.

The summation is shown below for the input values 19.875, 5.4375, and 4.84375.



Applying the rules from the previous section, the sum follows these steps:

**1** Since the biases are matched, the initial value of $Q_a$ is trivial:

$$Q_a = 00000.000$$

**2** The first number to be summed (19.875) has a fractional slope that matches the output fractional slope. Furthermore, the binary points and storage types are identical so the conversion is trivial:

$$Q_b = 10011.111$$

$$Q_{Temp} = Q_b$$

**3** The summation operation is performed:

$$Q_a = Q_a + Q_{Temp} = 10011.111$$

**4** The second number to be summed (5.4375) has a fractional slope that matches the output fractional slope, so a slope adjustment is not needed. The storage data types also match but the difference in binary points requires that both the bits and the binary point be shifted one place to the right:

$$Q_c = 0101.0111$$

$$Q_{Temp} = convert(Q_c)$$

$$Q_{Temp} = 00101.011$$

Note that a loss in precision of one bit occurs, with the resulting value of $Q_{Temp}$ determined by the rounding mode. For this example, round-to-floor is used. Overflow cannot occur in this case since the bits and binary point are both shifted to the right.

**5** The summation operation is performed:

$$Q_a = Q_a + Q_{Temp}$$

$$= \begin{array}{r} 10011.111 \\ +\,00101.011 \\ \hline 11001.010 \end{array} = 25.250$$

Note that overflow did not occur, but it is possible for this operation.

**6** The third number to be summed (4.84375) has a fractional slope that matches the output fractional slope, so a slope adjustment is not needed. The storage data types also match but the difference in binary points requires that both the bits and the binary point be shifted two places to the right:

$$Q_d = 100.11011$$

$$Q_{Temp} = convert(Q_d)$$

$$Q_{Temp} = 00100.110$$

Note that a loss in precision of two bit occurs, with the resulting value of $Q_{Temp}$ determined by the rounding mode. For this example, round-to-floor is used. Overflow cannot occur in this case since the bits and binary point are both shifted to the right.

**7** The summation operation is performed:

$$Q_a = Q_a + Q_{Temp}$$

$$= \begin{array}{r} 11001.010 \\ +\ 00100.110 \\ \hline 11110.000 \end{array} = 30.000$$

Note that overflow did not occur, but it is possible for this operation.

As shown below, the result of step **7** differs from the ideal sum:

$$\begin{array}{r} 10011.111\phantom{0} \\ 0101.0111 \\ +\quad 100.11011 \\ \hline 11110.001\phantom{0} \end{array} = 30.125$$

Blocks that perform addition and subtraction include the Sum, Matrix Gain, and FIR blocks.

## Multiplication

The multiplication of an n-bit binary number with an m-bit binary number results in a product that is up to m + n bits in length for both signed and unsigned words. Most processors perform n-bit by n-bit multiplication and produce a 2n-bit result (double bits) assuming there is no overflow condition.

For example, the Texas Instruments TMS320C2x family of processors performs two's complement 16-bit by 16-bit multiplication and produces a 32-bit (double bit) result.

### Fixed-Point Blockset Multiplication Process

Consider the multiplication of two numbers. Ideally, the real-world values obey the equation

$$V_a = V_b \times V_c$$

where $V_b$ and $V_c$ are the input values and $V_a$ is the output value. To see how the multiplication is actually implemented, the three ideal values should be replaced by the general [Slope Bias] encoding scheme described in "Scaling" on page 3-5:

$$V_i = F_i 2^{E_i} Q_i + B_i$$

The solution of the resulting equation for the output stored integer, $Q_a$, is given below:

$$Q_a = \frac{F_b F_c}{F_a} \cdot 2^{E_b + E_c - E_a} Q_b Q_c + \frac{F_b B_c}{F_a} \cdot 2^{E_b - E_a} Q_b + \frac{F_c B_b}{F_a} \cdot 2^{E_c - E_a} Q_c$$
$$+ \frac{B_b B_c - B_a}{F_a} \cdot 2^{-E_a}$$

The worst-case implementation of this equation occurs when the slopes and biases of the input and output signals are mismatched. This worst-case implementation is permitted in simulation but is not always permitted for code generation since it often requires more resources than is considered practical for an embedded system. For code generation and bit-true simulations, the biases must be zero and the fractional slopes must match for most blocks. When these requirements are met, the implementation reduces to

$$Q_a = 2^{E_b + E_c - E_a} Q_b Q_c$$

The bit-true implementation of this equation is discussed below.

**Offline Conversions.** As shown in the previous section, no offline conversions are performed.

**Online Conversions and Operations.** The online conversions and operations for matched slopes and biases of zero are given by these steps:

**1** The integer values, $Q_b$ and $Q_c$, are multiplied together:

$$Q_{RawProduct} = Q_b Q_c$$

To maintain the full precision of the product, the binary point of $Q_{RawProduct}$ is given by the sum of the binary points of $Q_b$ and $Q_c$.

**2** The previous product is converted to the output data type:

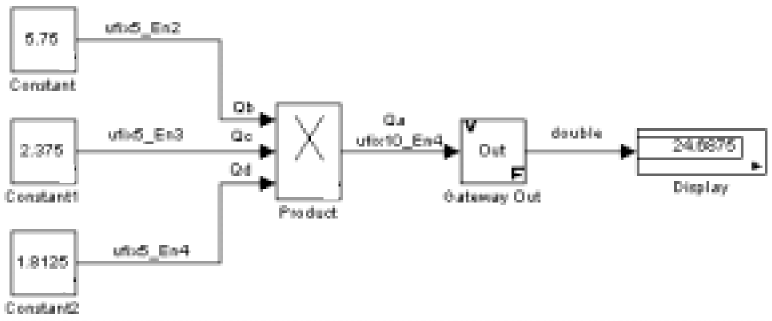
$$Q_a = convert(Q_{RawProduct})$$

This conversion includes any necessary bit shifting, rounding, or overflow handling. “Signal Conversions” on page 4-27 discusses conversions.

**3** Steps **1** and **2** are repeated for each additional number to be multiplied.

## Example: The Multiplication Process

Suppose you want to multiply three numbers. Each of these numbers is represented by a 5-bit word, and each has a different binary point-only scaling. Additionally, the output is restricted to a 10-bit word with binary point-only scaling of $2^{-4}$. The multiplication is shown below for the input values 5.75, 2.375, and 1.8125.



Applying the rules from the previous section, the multiplication follows these steps:

**1** The first two numbers (5.75 and 2.375) are multiplied:

$$
\begin{array}{lr}
Q_{RawProduct} = & 101.11 \\
 & \times\, 10.011 \\
\hline
 & 101.11 \cdot 2^{-3} \\
 & 101.11 \cdot 2^{-2} \\
 & +\, 101.11 \cdot 2^{1} \\
\hline
 & 01101.10101 = 13.65625
\end{array}
$$

Note that the binary point of the product is given by the sum of the binary points of the multiplied numbers.

**2** The result of step **1** is converted to the output data type:

$$
\begin{aligned}
Q_{Temp} &= convert(Q_{RawProduct}) \\
&= 001101.1010 = 13.6250
\end{aligned}
$$

"Signal Conversions" on page 4-27 discusses conversions. Note that a loss in precision of one bit occurs, with the resulting value of $Q_{Temp}$ determined by the rounding mode. For this example, round-to-floor is used. Furthermore, overflow did not occur but is possible for this operation.

**3** The result of step **2** and the third number (1.8125) are multiplied:

$$
\begin{array}{lr}
Q_{RawProduct} = & 01101.1010 \\
 & \times\, 1.1101 \\
\hline
 & 1101.1010 \cdot 2^{-4} \\
 & 1101.1010 \cdot 2^{-2} \\
 & 1101.1010 \cdot 2^{-1} \\
 & +\, 1101.1010 \cdot 2^{0} \\
\hline
 & 0011000.10110010 = 24.6953125
\end{array}
$$

Note that the binary point of the product is given by the sum of the binary points of the multiplied numbers.

**4** The product is converted to the output data type:

$$Q_a = convert(Q_{RawProduct})$$

$$= 011000.1011 = 24.6875$$

"Signal Conversions" on page 4-27 discusses conversions. Note that a loss in precision of 4 bits occurred, with the resulting value of $Q_{Temp}$ determined by the rounding mode. For this example, round-to-floor is used. Furthermore, overflow did not occur but is possible for this operation.

Blocks that perform multiplication include the Product, FIR, Gain, and Matrix Gain blocks.

## Division

As with multiplication, division with mismatched scaling is complicated. Mismatched division is permitted for simulation only. For code generation and bit-true simulation, the signals must all have zero biases and matched fractional slopes.

### Fixed-Point Blockset Division Process

Consider the division of two numbers. Ideally, the real-world values obey the equation

$$V_a = V_b / V_c$$

where $V_b$ and $V_c$ are the input values and $V_a$ is the output value. To see how the division is actually implemented, the three ideal values should be replaced by the general [Slope Bias] encoding scheme described in "Scaling" on page 3-5:

$$V_i = F_i 2^{E_i} Q_i + B_i$$

For the case where the slopes are one and the biases are zero for all signals, the solution of the resulting equation for the output stored integer, $Q_a$, is given below:

$$Q_a = 2^{E_b - E_c - E_a}(Q_b / Q_c)$$

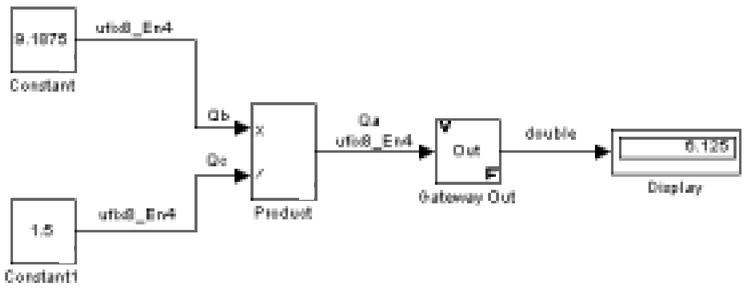
This equation involves an integer division and some bit shifts. If $E_a \geq E_b - E_c$, then any bit shifts are to the right and the implementation is simple. However, if $E_a < E_b - E_c$, then the bit shifts are to the left and the implementation can be more complicated. The essential issue is the output has more precision than the integer division provides. To get full precision, a *fractional* division is needed. The C programming language provides access to integer division only for fixed-point data types. Depending on the size of the numerator, some of the fractional bits may be obtained by performing a shift prior to the integer division. In the worst case, it may be necessary to resort to repeated subtractions in software.

In general, division of values is an operation that should be avoided in fixed-point embedded systems. Division where the output has more precision than the integer division (i.e., $E_a < E_b - E_c$) should be used with even greater reluctance. Division of signals with nonzero biases or mismatched slopes is not supported.

### Example: The Division Process

Suppose you want to divide two numbers. Each of these numbers is represented by an 8-bit word, and each has a binary point-only scaling of $2^{-4}$. Additionally, the output is restricted to an 8-bit word with binary point-only scaling of $2^{-4}$.

The division of 9.1875 by 1.5000 is shown below.



For this example,

$$Q_a = 2^{-4-(-4)-(-4)}(Q_b/Q_c)$$
$$= 2^{4}(Q_b/Q_c)$$

Assuming a large data type was available, this could be implemented as

$$Q_a = \frac{(2^4 Q_b)}{Q_c}$$

where the numerator uses the larger date type. If a larger data type was not available, integer division combined with four repeated subtractions would be used. Both approaches produce the same result, with the former being more efficient.

## Shifts

Nearly all microprocessors and digital signal processors support well-defined *bit-shift* (or simply *shift*) operations for integers. For example, consider the 8-bit unsigned integer 00110101. The results of a 2-bit shift to the left and a 2-bit shift to the right are shown below.

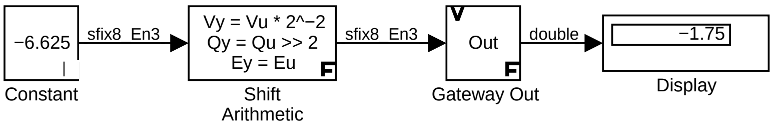
| Shift Operation | Binary Value | Decimal Value |
|---|---|---|
| No shift (original number) | 00110101 | 53 |
| Shift left by 2 bits | 11010100 | 212 |
| Shift right by 2 bits | 00001101 | 13 |

You can perform a shift with the Fixed-Point Blockset using the Shift Arithmetic block. Use this block to perform a bit shift, a binary point shift, or both. See Chapter 10, “Block Reference” for more information on performing bit and binary point shifts using the Shift Arithmetic block.

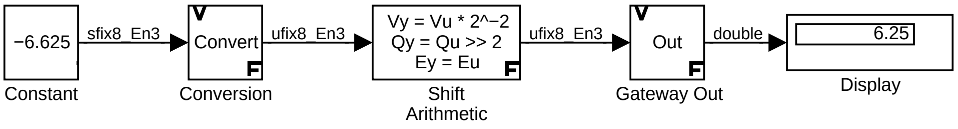
### Shifting Bits to the Right

The special case of shifting bits to the right requires consideration of the treatment of the left-most bit, which may contain sign information. A shift to the right can be classified either as a *logical* shift right or an *arithmetic* shift right. For a logical shift right, a 0 is incorporated into the most significant bit for each bit shift. For an arithmetic shift right, the most significant bit is recycled for each bit shift.

The Shift Arithmetic block performs an arithmetic shift right and, therefore, recycles the most significant bit for each bit shift right. For example, given the fixed-point number 11001.011 (-6.625), a bit shift two places to the right with the binary point unmoved yields the number 11110.010 (-1.75), as shown in the model below.



To perform a logical shift right on a signed number using the Shift Arithmetic block, use the Conversion block to cast the number as an unsigned number of equivalent length and scaling, as shown below. The model shows that the fixed-point signed number 11001.001 (-6.625) becomes 00110.010 (6.25).



## Example: Conversions and Arithmetic Operations

This example uses the FIR block to illustrate when parameters are converted from a double to a fixed-point number, when the input data type is converted to the output data type, and when the rules for addition, subtraction, and multiplication are applied. For details about conversions and operations, refer to "Parameter and Signal Conversions" on page 4-26 and "Rules for Arithmetic Operations" on page 4-30.

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**Note** If a block can perform all four arithmetic operations, such as the FIR block, then the rules for multiplication and division are applied first.

---

Suppose you configure the FIR block for two outputs (SIMO mode) where the first output is given by

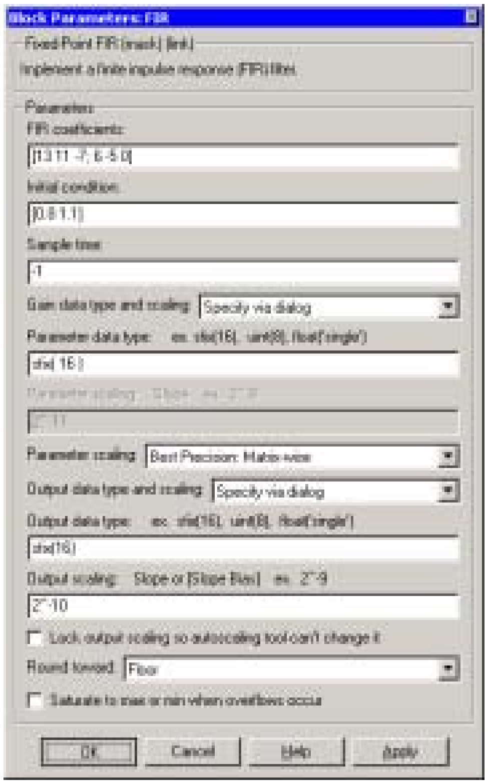
$$y_1(k) = 13 \cdot u(k) + 11 \cdot u(k-1) - 7 \cdot u(k-2)$$

and the second output is given by

$$y_2(k) = 6 \cdot u(k) - 5 \cdot u(k-1)$$

Additionally, the initial values of $u(k-1)$ and $u(k-2)$ are given by 0.8 and 1.1, respectively and all inputs, parameters, and outputs have binary point-only scaling.

To configure the FIR block for this situation, you must specify the **FIR coefficients** parameter as `[13 11 -7; 6 -5 0]` and the **Initial condition** parameter as `[0.8 1.1]` as shown below in the dialog box below.



Block Parameters: FIR

Fixed Point FIR (mask) (link)

Implement a finite impulse response (FIR) filter.

Parameters

FIR coefficients: [13 11 -7; 6 -5 0]

Initial condition: [0.8 1.1]

Sample time: -1

Gain data type and scaling: Specify via dialog

Parameter data type: ex. sfix(16), uint(8), float('single'): sfix( 16 )

Parameter scaling: Slope ex. 2^-9: 2^-11

Parameter scaling: Best Precision: Matrix-wise

Output data type and scaling: Specify via dialog

Output data type: ex. sfix(16), uint(8), float('single'): sfix(16)

Output scaling: Slope or [Slope Bias] ex. 2^-9: 2^-10

☐ Lock output scaling so autoscaling tool can't change it

Round toward: Floor

☐ Saturate to max or min when overflows occur

Parameter conversions and block operations are given below in the order in which they are carried out by the FIR block:

**1** The **FIR coefficients** parameter is converted from doubles to the **Parameter data type** value offline using round-to-nearest and saturation.

The **Initial condition** parameter is converted from doubles to the input data type offline using round-to-nearest and saturation.

**2** The coefficients and inputs are multiplied together for the initial time step for both outputs. For $y_1(0)$, the operations $13 \cdot u(0)$, $11 \cdot 0.8$, and $-7 \cdot 1.1$

are performed, while for $y_2(0)$, the operations $6 \cdot u(0)$ and $-5 \cdot 0.8$ are performed.

The results of these operations are then converted to the **Output data type** value using the specified rounding and overflow modes.

3 The sum is carried out for $y_1(0)$ and $y_2(0)$. Note that the rules for addition and subtraction are satisfied since the coefficients and inputs are already converted to the **Output data type** value.

4 Steps **2** and **3** are repeated for subsequent time steps.

# Realization Structures

## Overview

This chapter investigates how you can realize digital filters using the Fixed-Point Blockset.

The Fixed-Point Blockset addresses the needs of the control system and signal processing fields, and other fields where algorithms are implemented on fixed-point hardware. In signal processing, a digital filter is a computational algorithm that converts a sequence of input numbers to a sequence of output numbers. The algorithm is designed such that the output signal meets frequency-domain or time-domain constraints (desirable frequency components are passed, undesirable components are rejected).

In general terms, a discrete transfer function controller is a form of a digital filter. However, a digital controller may contain nonlinear functions such as look-up tables in addition to a discrete transfer function. This guide uses the term *digital filter* when referring to discrete transfer functions.

### Realizations and Data Types

In an ideal world where numbers, calculations, and storage of states have infinite precision and range, there are virtually an infinite number of realizations for the same system. In theory, these realizations are all identical to each other.

In the more realistic world of double-precision numbers, calculations, and storage of states, small nonlinearities are introduced due to the finite precision and range of floating-point data types. Therefore, each realization of a given system produces different results. In most cases however, these differences are small.

In the world of fixed-point numbers where precision and range are limited, the differences in the realization results can be very large. Therefore, you must carefully select the data type, word size, and scaling for each realization element such that results are accurately represented. To assist you with this selection, design rules for modeling dynamic systems with fixed-point math are provided in “Targeting an Embedded Processor” on page 5-3.

## Targeting an Embedded Processor

This section describes issues that often arise when targeting a fixed-point design for use on an embedded processor, such as some general assumptions about integer sizes and operations available on embedded processors. These assumptions lead to design issues and design rules that may be useful for your specific fixed-point design.

### Size Assumptions

Embedded processors are typically characterized by a particular bit size. For example, the terms “8-bit micro,” “32-bit micro,” or “16-bit DSP” are common. It is generally safe to assume that the processor is predominantly geared to processing integers of the specified bit size. Integers of the specified bit size are referred to as the *base data type*. Additionally, the processor typically provides some support for integers that are twice as wide as the base data type. Integers consisting of double bits are referred to as the *accumulator data type*. For example a 16-bit micro has a 16-bit base data type and a 32-bit accumulator data type.

Although other data types may be supported by the embedded processor, this section describes only the base and accumulator data types.

### Operation Assumptions

The embedded processor operations discussed in this section are limited to the needs of a basic simulation diagram. Basic simulations use multiplication, addition, subtraction, and delays. Fixed-point models also need shifts to do scaling conversions. For all these operations, the embedded processor should have native instructions that allow the base data type as inputs. For accumulator-type inputs, the processor typically supports addition, subtraction, and delay (storage/retrieval from memory), but not multiplication.

Multiplication is typically not supported for accumulator-type inputs due to complexity and size issues. A difficulty with multiplication is that the output needs to be twice as big as the inputs for full precision. For example, multiplying two 16-bit numbers requires a 32-bit output for full precision. The need to handle the outputs from a multiply operation is one of the reasons embedded processors include accumulator-type support. However, if multiplication of accumulator-type inputs is also supported, then there is a need to support a data type that is twice as big as the accumulator type. To restrict this additional complexity, multiplication is typically not supported for inputs of the accumulator type.

## Design Rules

The important design rules that you should be aware of when modeling dynamic systems with fixed-point math follow.

### Design Rule 1: Only Multiply Base Data Types

It is best to multiply only inputs of the base data type. Embedded processors typically provide an instruction for the multiplication of base-type inputs, but not for the multiplication of accumulator-type inputs. If necessary, you can combine several instructions to handle multiplication of accumulator-type inputs. However, this can lead to large, slow embedded code.

You can insert blocks to convert inputs from the accumulator-type to the base-type prior to multiply or gain blocks, if necessary.

### Design Rule 2: Delays Should Use the Base Data Type

There are two general reasons why a unit delay should use only base-type numbers:

- The unit delay essentially stores a variable's value to RAM, and one time step later, retrieves that value from RAM. Because the value must be in memory from one time step to the next, the RAM must be exclusively dedicated to the variable and can't be shared or used for another purpose. Using accumulator-type numbers instead of the base data type doubles the RAM requirements, which can significantly increase the cost of the embedded system.
- The unit delay typically feeds into a gain block. The multiplication design rule requires that the input (the unit delay signal) use the base data type.

### Design Rule 3: Temporary Variables Can Use the Accumulator Data Type

Except for unit delay signals, most signals are not needed from one time step to the next. This means that the signal values can be temporarily stored in shared and reused memory. This shared and reused memory can be RAM or it can simply be registers in the CPU. In either case, storing the value as an accumulator data type is not much more costly than storing it as a base data type.

### Design Rule 4: Summation Can Use the Accumulator Data Type

Addition and subtraction can use the accumulator data type if there is justification. The typical justification is reducing the buildup of errors due to round-off or overflow.

For example, a common filter operation is a weighted sum of several variables. Multiplying a variable by a weight naturally produces a product of the accumulator type. Before summing, each product can be converted back to the base data type. This approach introduces round-off error into each part of the sum.

Alternatively, the products can be summed using the accumulator data type, and the final sum can be converted to the base data type. Round-off error is introduced in just one point and the precision is generally better. The cost of doing an addition or subtraction using accumulator-type numbers is slightly more expensive, but if there is justification, it is usually worth the cost.

## Canonical Forms

The Fixed-Point Blockset does not attempt to standardize on one particular fixed-point digital filter design method. For example, you can produce a design in continuous time and then obtain an “equivalent” discrete-time digital filter using one of many transformation methods. Alternatively, you can design digital filters directly in discrete time. After you obtain a digital filter, it can be realized for fixed-point hardware using any number of canonical forms. Typical canonical forms are the direct form, series form, and parallel form, all of which are outlined in this chapter.

For a given digital filter, the canonical forms describe a set of fundamental operations for the processor. Since there are an infinite number of ways to realize a given digital filter, you must make the best realization on a per-system basis. The canonical forms presented in this chapter optimize the implementation with respect to some factor, such as minimum number of delay elements.

In general, when choosing a realization method, you must take these factors into consideration:

- **Cost**

  The cost of the realization might rely on minimal code and data size.
- **Timing constraints**

  Real-time systems must complete their compute cycle within a fixed amount of time. Some realizations might yield faster execution speed on different processors.
- **Output signal quality**

  The limited range and precision of the binary words used to represent real-world numbers will introduce errors. Some realizations are more sensitive to these errors than others.

The Fixed-Point Blockset allows you to evaluate various digital filter realization methods in a simulation environment. Following the development cycle outlined in “The Development Cycle” on page 1-13, you can fine-tune the realizations with the goal of reducing the cost (code and data size) or increasing signal quality. After you have achieved the desired performance, you can use the Real-Time Workshop to generate rapid prototyping C code and evaluate its performance with respect to your system’s real-time timing constraints. You can then modify the model based upon feedback from the rapid prototyping system.

The presentation of the various realization structures takes into account that a summing junction is a fundamental operator; thus you may find that the structures presented here look different from those in the fixed-point filter design literature. For each realization form, an example is provided using the transfer function shown below:

$$
\begin{aligned}
H_{ex}(z) &= \frac{1 + 2.2z^{-1} + 1.85z^{-2} + 0.5z^{-3}}{1 - 0.5z^{-1} + 0.84z^{-2} + 0.09z^{-3}} \\
&= \frac{(1 + 0.5z^{-1})(1 + 1.7z^{-1} + z^{-2})}{(1 + 0.1z^{-1})(1 - 0.6z^{-1} + 0.9z^{-2})} \\
&= 5.5556 - \frac{3.4639}{1 + 0.1z^{-1}} + \frac{-1.0916 + 3.0086z^{-1}}{1 - 0.6z^{-1} + 0.9z^{-2}}
\end{aligned}
$$

## Direct Form II

In general, a direct form realization refers to a structure where the coefficients of the transfer function appear directly as gain blocks. The direct form II realization method is presented as using the minimal number of delay elements, which is equal to *n*, the order of the transfer function denominator.

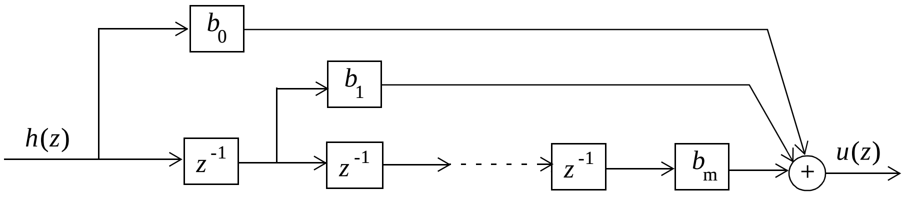
The canonical direct form II is presented as “Standard Programming” in *Discrete-Time Control Systems* by Ogata. It is known as the “Control Canonical Form” in *Digital Control of Dynamic Systems* by Franklin, Powell, and Workman.

You can derive the canonical direct form II realization by writing the discrete-time transfer function with input *e(z)* and output *u(z)* as

$$\frac{u(z)}{e(z)} = \frac{u(z)}{h(z)} \cdot \frac{h(z)}{e(z)}$$

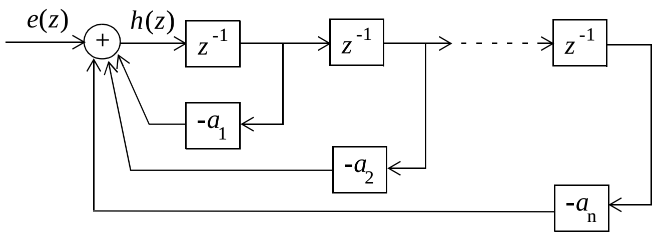
$$= \underbrace{(b_0 + b_1 z^{-1} + \ldots + b_m z^{-m})}_{\frac{u(z)}{h(z)}} \underbrace{\frac{1}{1 + a_1 z^{-1} + a_2 z^{-2} + \ldots + a_n z^{-n}}}_{\frac{h(z)}{e(z)}}$$

The block diagram for *u(z)/h(z)* follows.



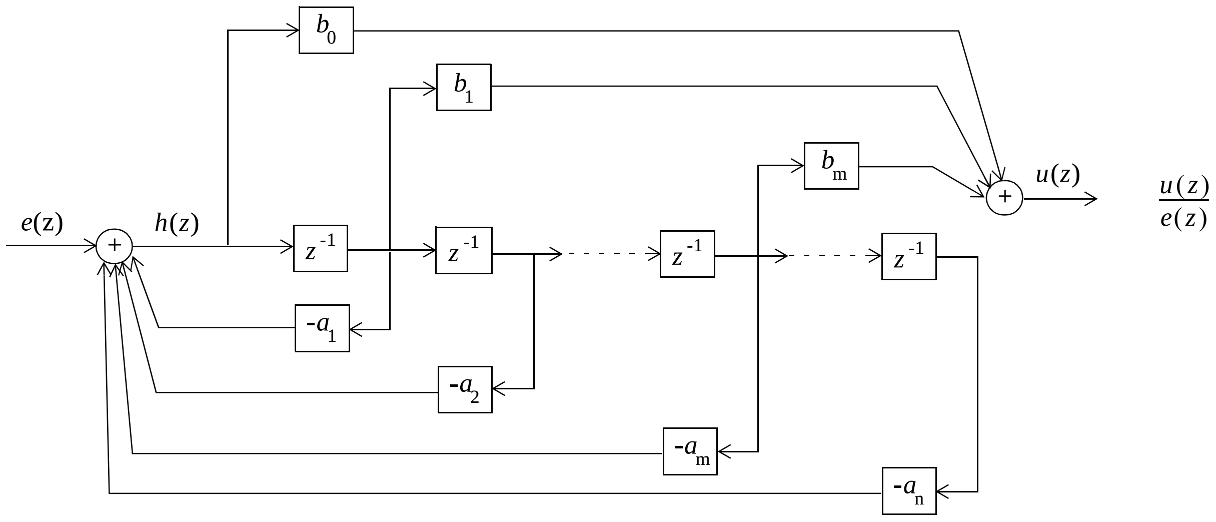
$$\frac{u(z)}{h(z)} = b_0 + b_1 z^{-1} + \ldots + b_m z^{-m}$$

The block diagrams for *h(z)/e(z)* follow.



$$\frac{h(z)}{e(z)} = \frac{1}{1 + a_1 z^{-1} + a_2 z^{-2} + \ldots + a_n z^{-n}}$$

Combining these two block diagrams yields the direct form II diagram shown below. Notice that the feedforward part (top of block diagram) contains the numerator coefficients and the feedback part (bottom of block diagram) contains the denominator coefficients.



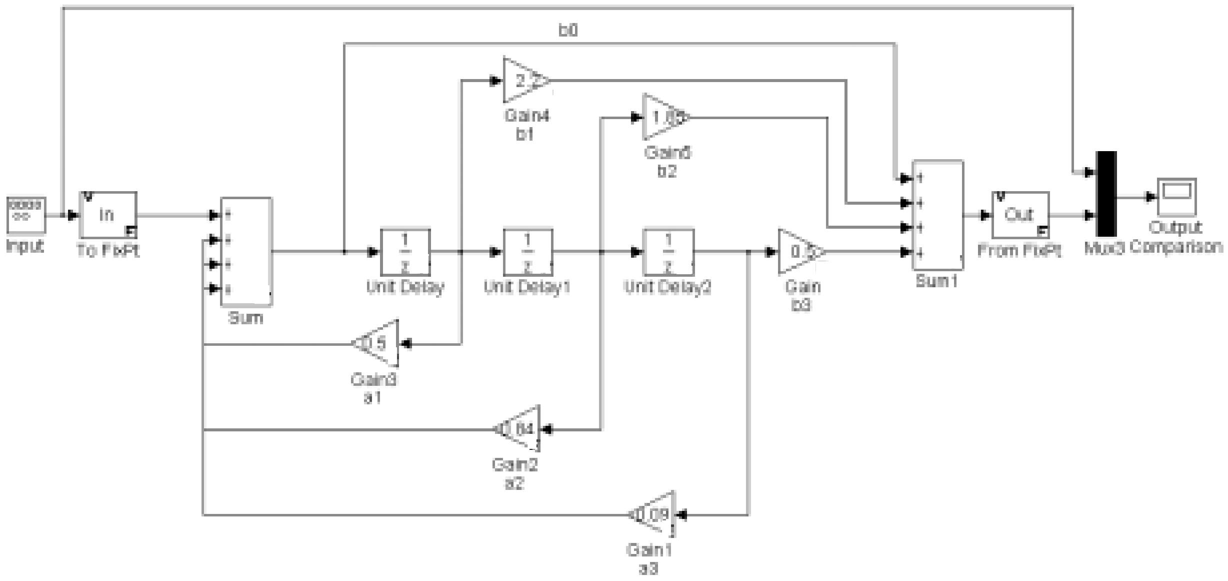
The direct form II example transfer function is given by

$$H_{ex}(z) = \frac{1 + 2.2z^{-1} + 1.85z^{-2} + 0.5z^{-3}}{1 - 0.5z^{-1} + 0.84z^{-2} + 0.09z^{-3}}$$

The realization of $H_{ex}(z)$ using the Fixed-Point Blockset is shown below. You can display this model by typing

```
fxpdemo_direct_form2
```

at the MATLAB command line.



## Series Cascade Form

In the canonical series cascade form, the transfer function *H(z)* is written as a product of first-order and second-order transfer functions.

$$H_i(z) = \frac{u(z)}{e(z)} = H_1(z) \cdot H_2(z) \cdot H_3(z) \ldots H_p(z)$$

This equation yields the canonical series cascade form.

$$\begin{tikzcd}
{} \arrow[r, "e(z)"] & \boxed{H_1(z)} \arrow[r] & \boxed{H_2(z)} \arrow[r] & \boxed{H_3(z)} \arrow[r, dashed] & \boxed{H_p(z)} \arrow[r, "u(z)"] & {}
\end{tikzcd}$$

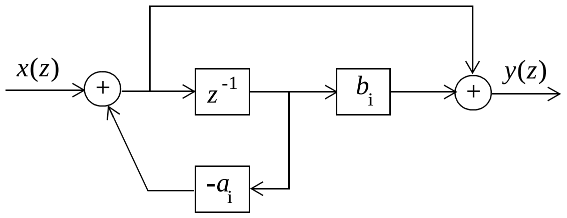
Factoring *H(z)* into $H_i(z)$ where $i = 1,2,3,\ldots,p$ can be done in a number of ways. Using the poles and zeros of *H(z)*, you can obtain $H_i(z)$ by grouping pairs of conjugate complex poles and pairs of conjugate complex zeros to produce second-order transfer functions, or by grouping real poles and real zeros to produce either first-order or second-order transfer functions. You could also group two real zeros with a pair of conjugate complex poles or vice versa. Since there are many ways to obtain $H_i(z)$, you should compare the various groupings to see which produces the best results for the transfer function under consideration.

For example, one factorization of *H(z)* might be

$$\begin{aligned} H(z) &= H_1(z)H_2(z)\ldots H_p(z) \\ &= \prod_{i=1}^{j} \frac{1 + b_i z^{-1}}{1 + a_i z^{-1}} \prod_{i=j+1}^{p} \frac{1 + e_i z^{-1} + f_i z^{-2}}{1 + c_i z^{-1} + d_i z^{-2}} \end{aligned}$$

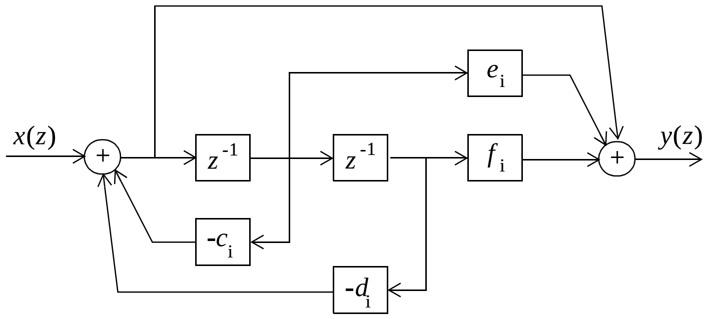
You must also take into consideration that the ordering of the individual $H_i(z)$'s will lead to systems with different numerical characteristics. You may want to try various orderings for a given set of $H_i(z)$'s to determine which gives the best numerical characteristics.

The first order diagram for *H(z)* follows.



$$\frac{y(z)}{x(z)} = \frac{1 + b_i z^{-1}}{1 + a_i z^{-1}}$$

The second order diagram for *H(z)* follows.



$$\frac{y(z)}{x(z)} = \frac{1 + e_i z^{-1} + f_i z^{-2}}{1 + c_i z^{-1} + d_i z^{-2}}$$

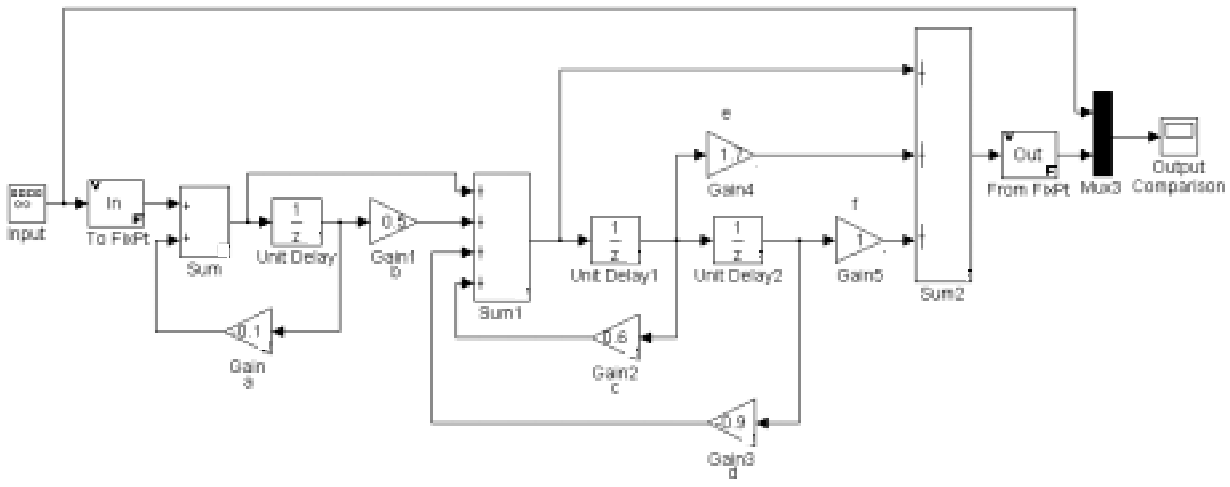
The series cascade form example transfer function is given by

$$H_{ex}(z) = \frac{(1 + 0.5z^{-1})(1 + 1.7z^{-1} + z^{-2})}{(1 + 0.1z^{-1})(1 - 0.6z^{-1} + 0.9z^{-2})}$$

The realization of *$H_{ex}(z)$* using the Fixed-Point Blockset is shown below. You can display this model by typing

```
fxpdemo_series_cascade_form
```

at the MATLAB command line.

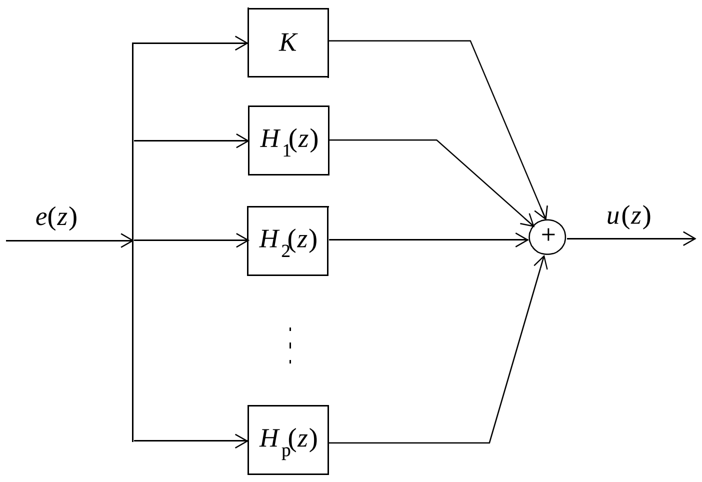


## Parallel Form

In the canonical parallel form, the transfer function *H(z)* is expanded into partial fractions. *H(z)* is then realized as a sum of a constant, first-order, and second-order transfer functions, as shown.

$$H_i(z) = \frac{u(z)}{e(z)} = K + H_1(z) + H_2(z) + \ldots + H_p(z)$$

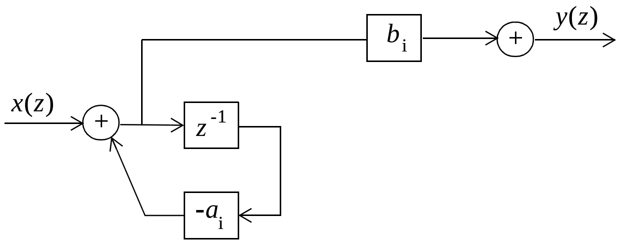
This expansion, where $K$ is a constant and the $H_i(z)$ are the first and second-order transfer functions, follows.



As in the series canonical form, there is no unique description for the first-order and second-order transfer function. Due to the nature of the Sum block, the ordering of the individual filters doesn't matter. However, because of the constant $K$, you can choose the first-order and second-order transfer functions such that their forms are simpler than those for the series cascade form described in the preceding section. This is done by expanding *H(z)* as

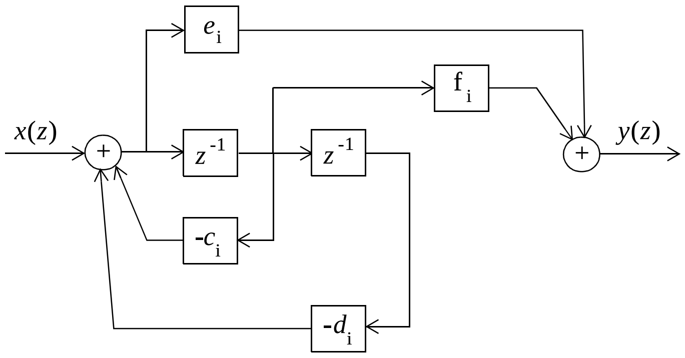
$$\begin{aligned} H(z) &= K + \sum_{i=1}^{j} H_i(z) + \sum_{i=j+1}^{p} H_i(z) \\ &= K + \sum_{i=1}^{j} \frac{b_i}{1 + a_i z^{-1}} + \sum_{i=j+1}^{p} \frac{e_i + f_i z^{-1}}{1 + c_i z^{-1} + d_i z^{-2}} \end{aligned}$$

The first order diagram for *H(z)* follows.



$$\frac{y(z)}{x(z)} = \frac{b_i}{1 + a_i z^{-1}}$$

The second order diagram for *H(z)* follows.



$$\frac{y(z)}{x(z)} = \frac{e_i + f_i z^{-1}}{1 + c_i z^{-1} + d_i z^{-2}}$$

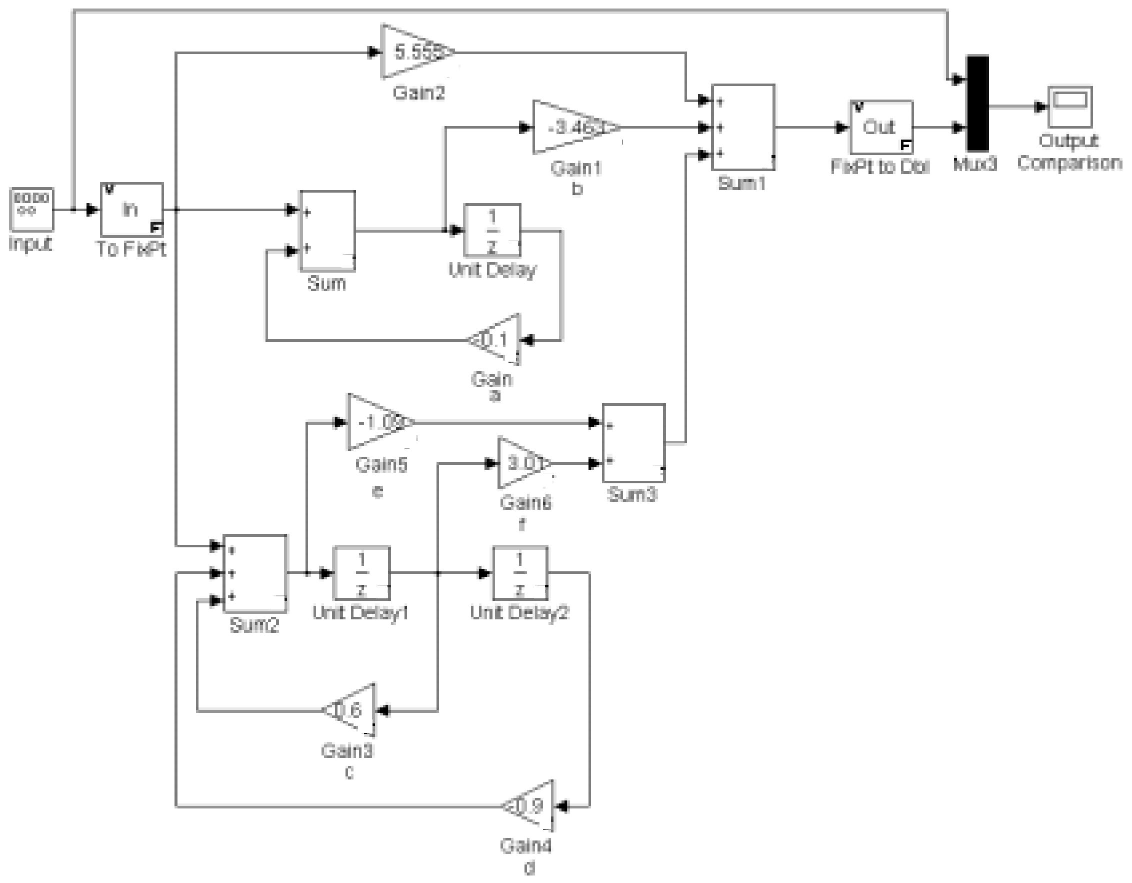
The parallel form example transfer function is given by

$$H_{ex}(z) = 5.5556 - \frac{3.4639}{1 + 0.1z^{-1}} + \frac{-1.0916 + 3.0086z^{-1}}{1 - 0.6z^{-1} + 0.9z^{-2}}$$

The realization of $H_{ex}(z)$ using the Fixed-Point Blockset is shown below. You can display this model by typing

```
fxpdemo_parallel_form
```

at the MATLAB command line.



# Tutorial: Feedback Controller Simulation

## Overview

The purpose of this tutorial is to show you how to simulate a fixed-point feedback design using the **Fixed-Point Settings** interface. In doing so, many of the essential features of the Fixed-Point Blockset are demonstrated. These include

- Selecting output data type
- Selecting output scaling
- Logging maximum and minimum simulation results
- Using the automatic scaling tool
- Overriding the output data type for a system or subsystem

## Simulink Model of a Feedback Design

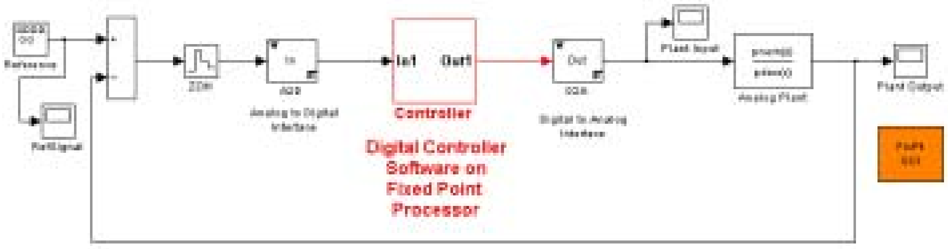
Run the Simulink model of the feedback design by launching the MATLAB Demo browser and selecting the Scaling a Fixed Point Control Design demo. Launch the Demo browser by typing

```
demo blockset 'Fixed Point'
```

at the command line, or by opening the Demos block found in the Fixed-Point Blockset library. Alternatively, you can access the model directly by typing its name at the command line:

```
fxpdemo_feedback
```

The demo's `.mdl` file automatically runs the M-file `preload_feedback`, which populates the workspace with the required parameter values. The feedback design model is shown below.


Reference
RefSignal
ZOH
A2D
Analog to Digital Interface
In1
Out1
Controller
Digital Controller Software on Fixed Point Processor
D2A
Digital to Analog Interface
Plant Input
Analog Plant
Plant Output

The model consists of the following blocks and subsystems:

- **Reference**

  This Simulink Signal Generator block generates a continuous-time reference signal. It is configured to output a square wave.

- **Sum**

  This Simulink or Fixed-Point Blockset Sum block subtracts the plant output from the reference signal.

- **ZOH**

  The Simulink or Fixed-Point Blockset Zero-Order Hold block samples and holds the continuous signal. This block is configured so that it quantizes the signal in time by an amount `tsamp` = 0.01 second.

- **Analog to Digital Interface**

  The analog to digital (A/D) interface consists of a Gateway In block that converts a Simulink double to a Fixed-Point Blockset data type. It represents any hardware that digitizes the amplitude of the analog input signal. In the real world, its characteristics are fixed.
- **Controller**

  The digital controller is a subsystem that represents the software running on the hardware target. Refer to “Digital Controller Realization” on page 6-7.
- **Digital to Analog Interface**

  The digital to analog (D/A) interface consists of a Gateway Out block that converts a Fixed-Point Blockset data type into a Simulink double. It represents any hardware that converts a digitized signal into an analog signal. In the real world, its characteristics are fixed.
- **Analog Plant**

  The analog plant is described by a transfer function, and is controlled by the digital controller. In the real world, its characteristics are fixed.
- **FixPt GUI**

  This block launches the **Fixed-Point Settings** interface.

The model also includes three scopes, which display the reference, plant input, and plant output signals.

## Simulation Setup

To set up this kind of fixed-point feedback controller simulation, you perform the following steps:

1 Identify all design components.

   In the real world, there are design components with fixed characteristics (the hardware) and design components with characteristics that you can change (the software). In this feedback design, the main hardware components are the A/D hardware, the D/A hardware, and the analog plant. The main software component is the digital controller.

2. Develop a theoretical model of the plant and controller.

   For the feedback design used in this tutorial, the plant is characterized by a transfer function. The characteristics of the plant are unimportant for this tutorial, and are not discussed.

   The digital controller model used in this tutorial is described by a *z*-domain transfer function and is implemented using a direct-form realization.

3. Evaluate the behavior of the plant and controller.

   You evaluate the behavior of the plant and the controller with a Bode plot. This evaluation is idealized since all numbers, operations, and states are double-precision.

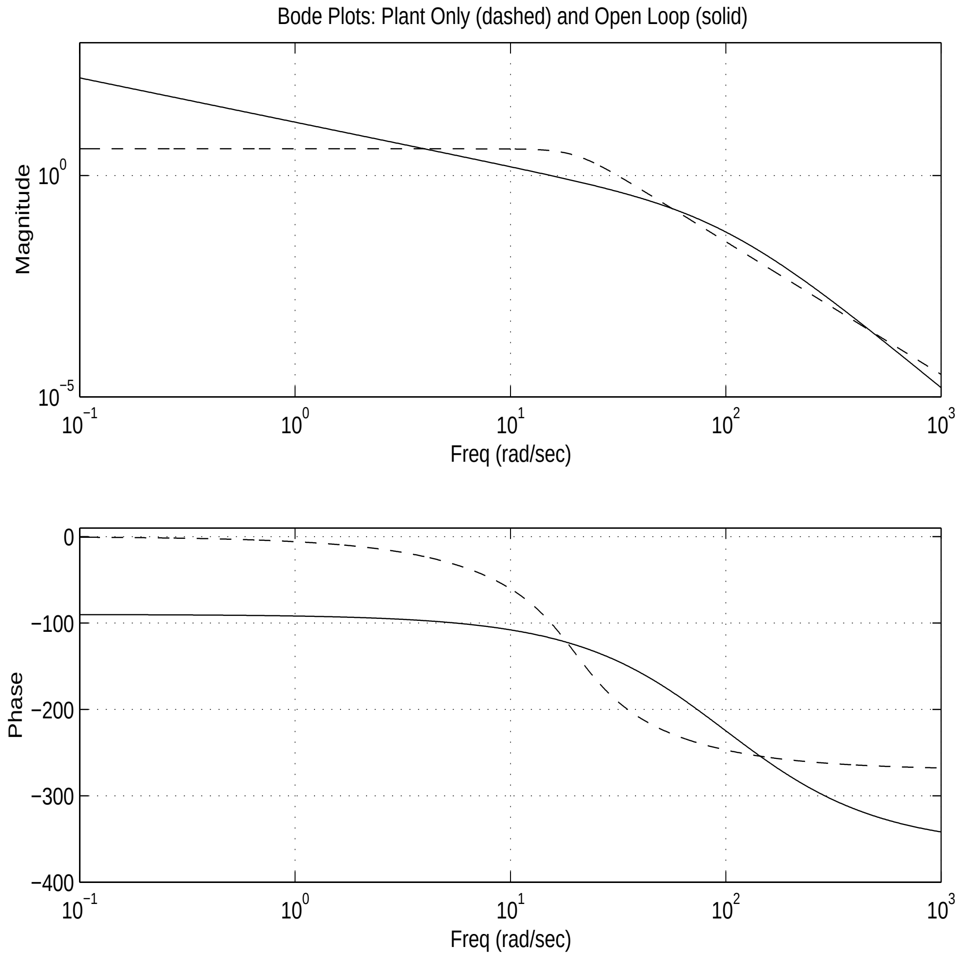
4. Simulate the system.

   You simulate the feedback controller design using Simulink and the Fixed-Point Blockset. Of course, in a simulation environment, you can treat all components (software *and* hardware) as though their characteristics are not fixed.

## Idealized Feedback Design

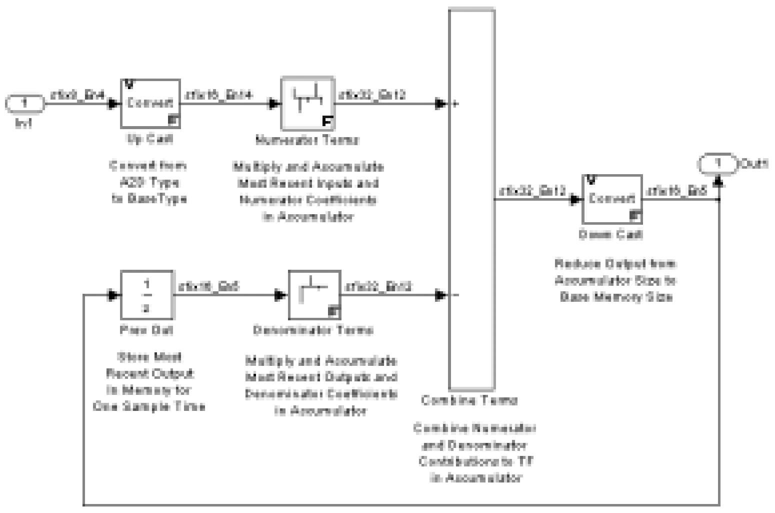
Open loop (controller and plant) and plant-only Bode plots for the Scaling a Fixed-Point Control Design demo are shown below. The open loop Bode plot results from a digital controller described in the idealized world of continuous time, double-precision coefficients, storage of states, and math operations.

The plant and controller design criteria are not important for the purposes of this tutorial. The Bode plots were created using the workspace variables produced by the `preload_feedback` M-file.



## Digital Controller Realization

In this simulation, the digital controller is implemented using the fixed-point direct-form realization shown below. The hardware target is a 16-bit processor. Variables and coefficients are generally represented using 16 bits, especially if these quantities are stored in ROM or global RAM. Use of 32-bit numbers is limited to temporary variables that exist briefly in CPU registers or in a stack.



The realization consists of these blocks:

- **Up Cast**

  Up Cast is a Fixed-Point Blockset Conversion block that connects the A/D hardware with the digital controller. It pads the output word of the A/D hardware with trailing zeros to a 16-bit number (the base data type).

- **Numerator Terms** and **Denominator Terms**

  Each of these Fixed-Point Blockset FIR blocks represents a weighted sum carried out in the CPU target. The word size and precision used in the calculations reflect those of the accumulator. Numerator Terms multiplies and accumulates the most recent inputs with the FIR numerator coefficients. Denominator Terms multiples and accumulates the most recent delayed outputs with the FIR denominator coefficients. The coefficients are stored in

ROM using the base data type. The most recent inputs are stored in global RAM using the base data type.

- **Combine Terms**

  Combine Terms is a Simulink or Fixed-Point Blockset Sum block that represents the accumulator in the CPU. Its word size and precision are twice that of the RAM (double bits).
- **Down Cast**

  Down Cast is a Fixed-Point Blockset Conversion block that represents taking the number from the CPU and storing it in RAM. The word size and precision are reduced to half that of the accumulator when converted back to the base data type.
- **Prev Out**

  Prev Out is a Simulink or Fixed-Point Blockset Unit Delay block that delays the feedback signal in memory by one sample period. The signals are stored in global RAM using the base data type.

## Direct Form Realization

The controller directly implements this equation

$$y(k) = \sum_{i=0}^{N} b_i u(k-1) - \sum_{i=1}^{N} a_i y(k-1)$$

where

- $u(k-1)$ represents the *input* from the previous time step.
- $y(k)$ represents the current output, and $y(k-1)$ represents the output from the previous time step.
- $b_i$ represents the FIR numerator coefficients.
- $a_i$ represents the FIR denominator coefficients.

The first summation in $y(k)$ represents multiplication and accumulation of the most recent inputs and numerator coefficients in the accumulator. The second summation in $y(k)$ represents multiplication and accumulation of the most recent outputs and denominator coefficients in the accumulator. Since the FIR coefficients, inputs, and outputs are all represented by 16-bit numbers (the base data type), any multiplication involving these numbers produces a 32-bit output (the accumulator data type).

## Simulation Results

Using Simulink and the Fixed-Point Blockset, you can easily transition from a digital controller described in the ideal world of double-precision numbers to one realized in the world of fixed-point numbers. The simulation approach used in this tutorial follows these steps:

- "1. Initial Guess at Scaling" on page 6-10. For this tutorial, you run an initial "proof of concept" simulation using a reasonable guess at the fixed-point word size and scaling. This step is included only to illustrate how difficult it is to guess the best scaling.
- "2. Data Type Override" on page 6-13. Perform a global override of the fixed-point data types and scaling using double-precision numbers. The maximum and minimum simulation values for each digital controller block are logged to the workspace.
- "3. Automatic Scaling" on page 6-15. Use the automatic scaling procedure. This procedure uses the doubles simulation values previously logged to the MATLAB workspace, and changes the scaling for each block that does not have its scaling fixed.

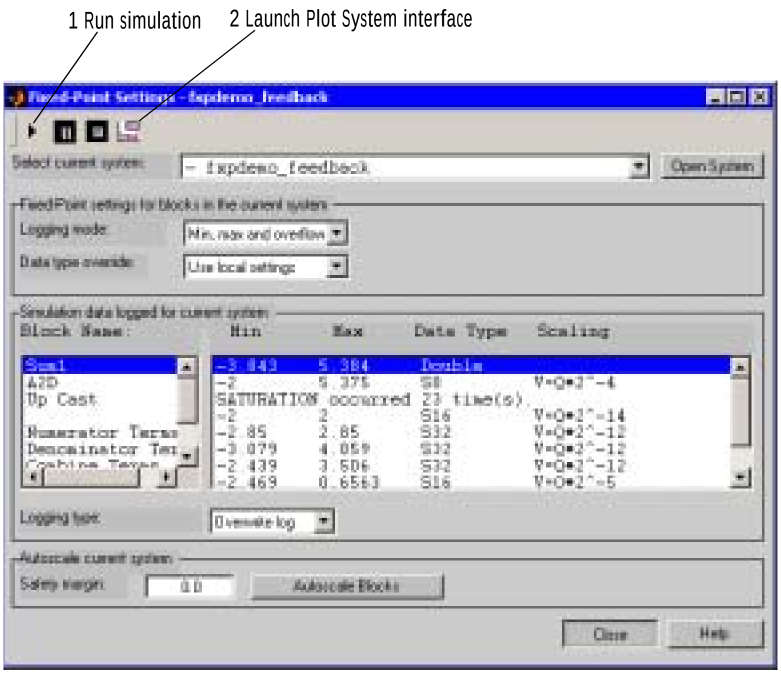
The feedback controller simulation is performed with the **Fixed-Point Settings** interface. You launch the interface by selecting the FixPt GUI block within the `fxpdemo_feedback` model, by selecting **Fixed-Point settings** from the **Tools** menu in the model window, by right-clicking in the model and selecting **Fixed-Point settings** from the menu that pops up, or by typing

```
fxptdlg('fxpdemo_feedback')
```

at the command line. The three steps of the simulation are described in the following sections. You determine the quality of the simulation results by examining the input and output of the analog plant.

### 1. Initial Guess at Scaling

In the first step, initial guesses for the scaling of each block are already specified in each block mask in the model. This step is included to illustrate the difficulty of guessing at the best scaling.



Fixed-Point Settings - fxpdemo_feedback

Select current system: - fxpdemo_feedback

Fixed-Point settings for blocks in the current system

Logging mode: Min, max and overflow

Data type override: Use local settings

Simulation data logged for current system

```
Block Name:           Min        Max       Data Type   Scaling
Sum1                  -3.843     5.384     Double
A2D                   -2         5.375     S8          V=Q*2^-4
Up Cast               SATURATION occurred 23 time(s).
                      -2         2         S16         V=Q*2^-14
Numerator Terms       -2.85      2.85      S32         V=Q*2^-12
Denominator Ter       -3.079     4.059     S32         V=Q*2^-12
Combine Terms         -2.439     3.506     S32         V=Q*2^-12
                      -2.469     0.6563    S16         V=Q*2^-5
```

Logging type: Overwrite log

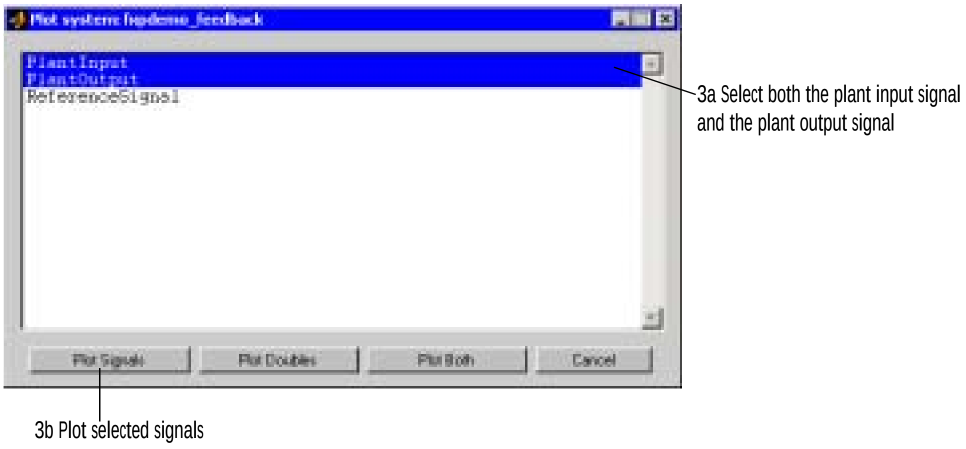
Autoscale current system

Safety margin: 0.0

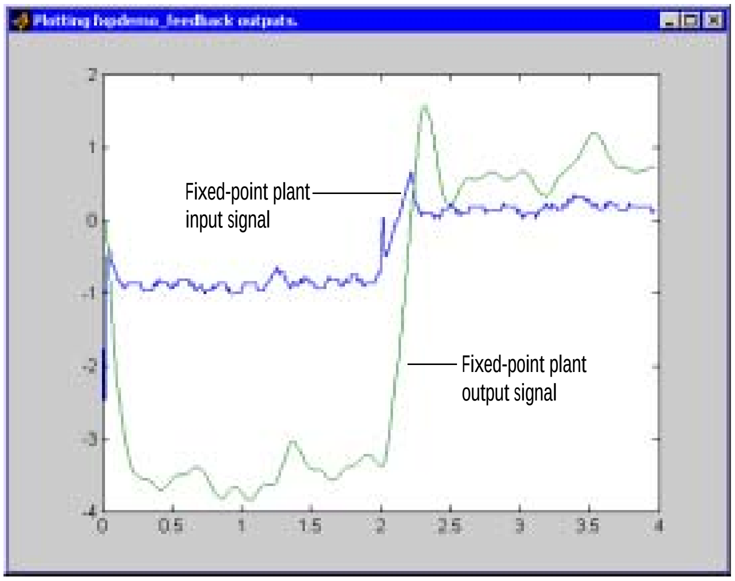
1 After you launch the **Fixed-Point Settings** interface, click the Run button in the dialog to run the simulation. When the simulation is finished, the **Simulation data logged for current system** pane of the interface displays the block name, the minimum and maximum simulation results, the data type, and the scaling for each block. The display shows that the Up Cast block saturated 23 times, indicating a poor guess for the scaling.

2 Click the Plot button. This launches the Plot System interface, which is shown below. This interface displays all MATLAB variable names that contain Scope block data for the current model.

3 To plot the simulation results, select one or more variable names in the Plot System interface, and then select the appropriate plot button. This simulation plots the fixed-point signals for the plant input and the plant output.



The plant input and output signals are shown below. These signals reflect the initial guess at scaling.



The Bode plot design sought to produce a well-behaved linear response for the closed-loop system. Clearly, the response is nonlinear. The nonlinear features are due to significant quantization effects. An important part of fixed-point design is finding scaling that reduce quantization effects to acceptable levels.

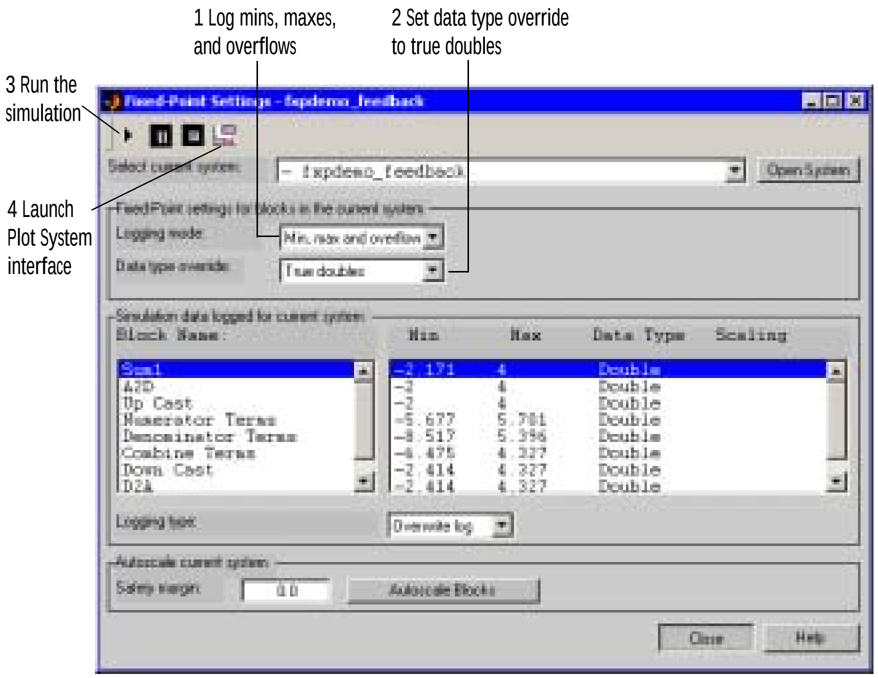
## 2. Data Type Override

You can obtain ideal simulation limits by using the automatic scaling tool. However, you must first perform a data type override with doubles of all blocks with fixed-point output, and you must log maximum and minimum simulation values for all blocks that are to be scaled.

---

**Note** When you use the automatic scaling tool, the maximum and minimum simulation values must cover the full intended operating range of your design in order for `autofixexp` to yield meaningful results. Refer to the `autofixexp` reference page for more information.

---


1 Log mins, maxes, and overflows
2 Set data type override to true doubles
3 Run the simulation
4 Launch Plot System interface
Open System
Autoscale Blocks
Close
Help

Fixed-Point Settings - fxpdemo_feedback

Select current system: - fxpdemo_feedback

Fixed-Point settings for blocks in the current system

Logging mode: Min, max and overflow

Data type override: True doubles

Simulation data logged for current system

| Block Name: | Min | Max | Data Type | Scaling |
|---|---|---|---|---|
| Sum1 | -2.171 | 4 | Double | |
| A2D | -2 | 4 | Double | |
| Up Cast | -2 | 4 | Double | |
| Numerator Terms | -5.677 | 5.781 | Double | |
| Denominator Terms | -8.517 | 5.396 | Double | |
| Combine Terms | -6.475 | 4.327 | Double | |
| Down Cast | -2.414 | 4.327 | Double | |
| D2A | -2.414 | 4.327 | Double | |

Logging type: Overwrite log

Autoscale current system

Safety margin: 0.0

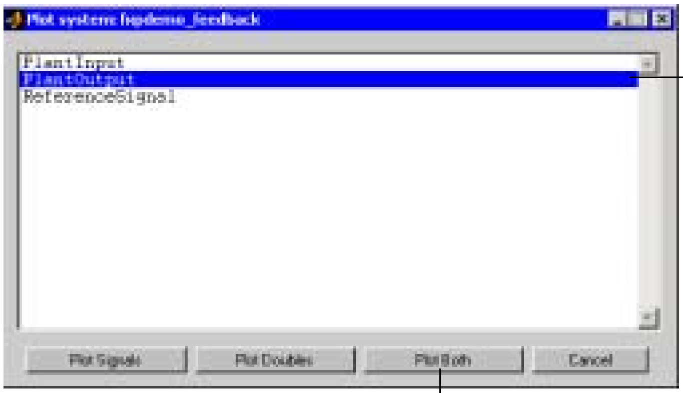
1 Make sure the **Logging mode** parameter is set to `Min, max and overflow` for the `fxpdemo_feedback` system. This overrides all local logging settings for the subsystems of the model.

2 Perform a data type override with doubles by setting the **Data type override** parameter in the interface to `True Doubles`. This overrides all local data type settings for the subsystems of the model.

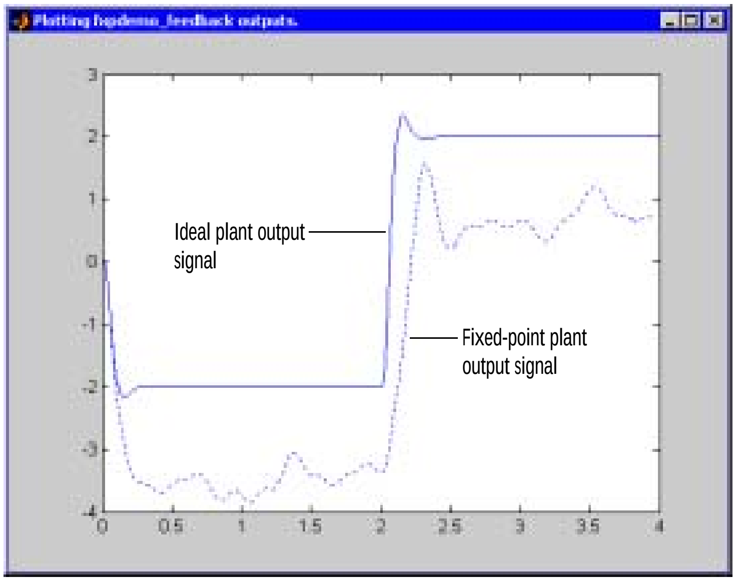
3 Run the simulation by clicking the Run button.

4 Click the Plot button to launch the Plot System interface.

5 Compare the ideal (doubles) and fixed-point plant output signals using the Plot System interface.


Plot system: fxpdemo_feedback
PlantInput
PlantOutput
ReferenceSignal
Plot Signals
Plot Doubles
Plot Both
Cancel
5a Select the plant output signal
5b Plot both ideal (doubles) and fixed-point signal

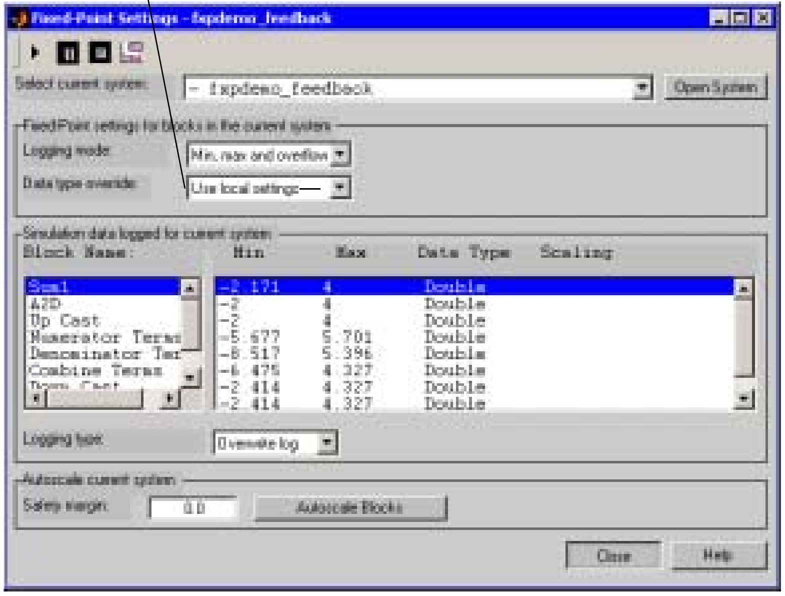
The ideal and fixed-point plant output signals are shown below. The ideal signal is produced by overriding the block output scaling with true doubles.



## 3. Automatic Scaling

Using the automatic scaling procedure, you can easily maximize the precision of the output data type while spanning the full simulation range. For a complex model, the absence of such a procedure can make achieving this goal tedious and time consuming.

Perform automatic scaling for the Controller block. This block is a subsystem representing software running on the target, and requires optimization.


1 Set data type override to Use local settings
Fixed-Point Settings - fxpdemo_feedback
Open System
Autoscale Blocks
Close
Help

Select current system: - fxpdemo_feedback

Fixed-Point settings for blocks in the current system

Logging mode: Min, max and overflow

Data type override: Use local settings

Simulation data logged for current system

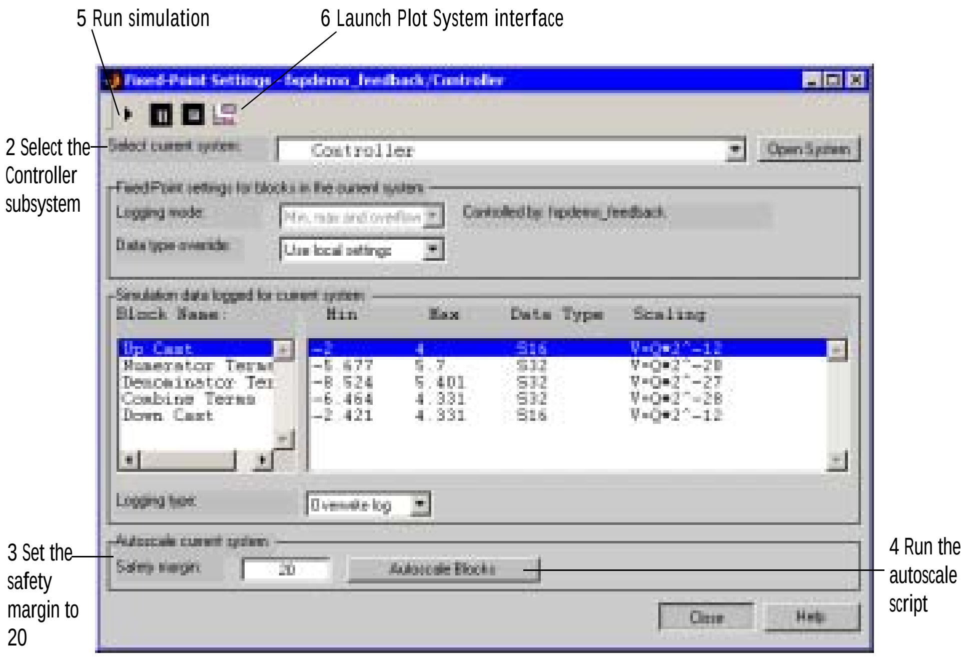
| Block Name: | Min | Max | Data Type | Scaling |
|---|---|---|---|---|
| Sum1 | -2.171 | 4 | Double | |
| A2D | -2 | 4 | Double | |
| Up Cast | -2 | 4 | Double | |
| Numerator Terms | -5.677 | 5.701 | Double | |
| Denominator Ter | -8.517 | 5.396 | Double | |
| Combine Terms | -6.475 | 4.327 | Double | |
| Down Cast | -2.414 | 4.327 | Double | |
| | -2.414 | 4.327 | Double | |

Logging type: Overwrite log

Autoscale current system

Safety margin: 0.0

**1** Turn off the data type override by setting **Data type override** in the **Fixed-Point Settings** interface to `Use local settings`. Each subsystem in the model now follows its own independent setting for this parameter.


5 Run simulation
6 Launch Plot System interface
2 Select the Controller subsystem
3 Set the safety margin to 20
4 Run the autoscale script
Open System
Autoscale Blocks
Close
Help

Fixed-Point Settings - fxpdemo_feedback/Controller

Select current system: Controller

Fixed-Point settings for blocks in the current system
Logging mode: Min, max and overflow    Controlled by: fxpdemo_feedback
Data type override: Use local settings

Simulation data logged for current system

| Block Name: | Min | Max | Data Type | Scaling |
|---|---|---|---|---|
| Up Cast | -2 | 4 | S16 | V=Q*2^-12 |
| Numerator Terms | -5.677 | 5.7 | S32 | V=Q*2^-28 |
| Denominator Ter | -8.524 | 5.401 | S32 | V=Q*2^-27 |
| Combine Terms | -6.464 | 4.331 | S32 | V=Q*2^-28 |
| Down Cast | -2.421 | 4.331 | S16 | V=Q*2^-12 |

Logging type: Overwrite log

Autoscale current system
Safety margin: 20

2 Select the Controller subsystem in the **Select current system** parameter of the interface.

3 Set the **Safety margin** parameter in the interface to 20. This sets the scaling so that the largest simulation value seen is at least 20% smaller than the maximum value allowed. The **Safety margin** parameter value multiplies the “raw” simulation values by a factor of 1.2. Setting this parameter to a value greater than 1 decreases the likelihood that an overflow will occur when fixed-point data types are being used.

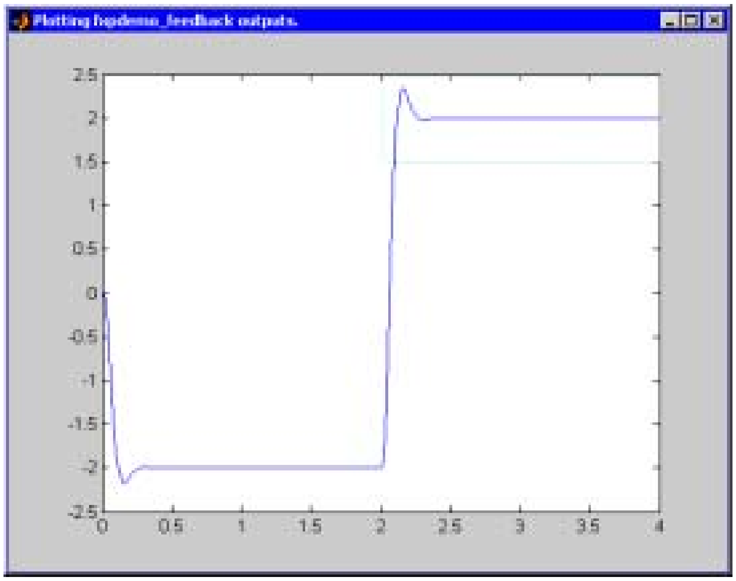
   Due to the nonlinear effects of quantization, a fixed-point simulation will produce results that are different from an idealized, doubles-based simulation. Signals in a fixed-point simulation may cover a larger or smaller range than in a doubles-based simulation. If the range increases enough, overflows or saturations could occur. A safety margin decreases the likelihood of this happening, but it may also decrease the precision of the simulation.

4 Run the `autofixexp` M-file script by clicking the **Autoscale Blocks** button. This script automatically changes the scaling on all fixed-point blocks that do not have their scaling locked, and that have their output data type specified as a generalized fixed-point number. This script uses the minimum and maximum data logged from the previous simulation to change each block's scaling such that the precision is maximized while the full range of simulation values is spanned for each block.

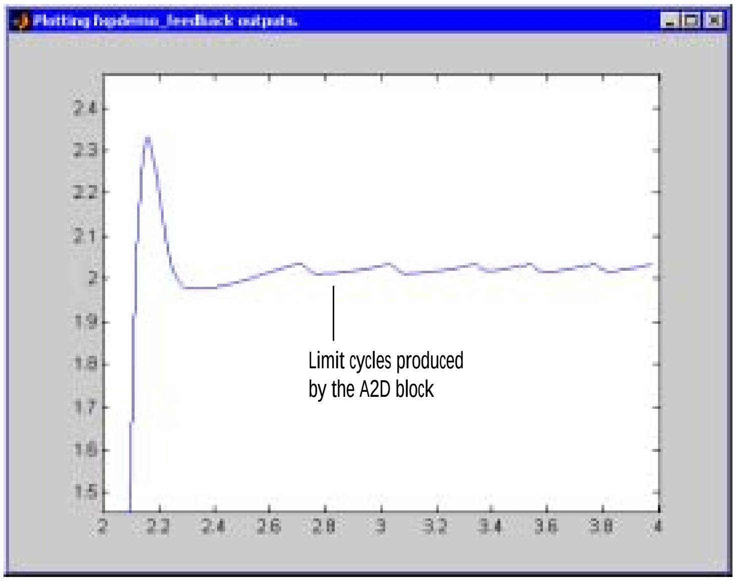
**Note** When you use the automatic scaling tool, the maximum and minimum simulation values must cover the full intended operating range of your design in order for `autofixexp` to yield meaningful results. Refer to the `autofixexp` reference page for more information.

5 Run the simulation by clicking the Run button. This simulation will use the new scaling set in Step 4.

6 Launch the Plot System interface and plot the plant output signal. The resulting plot is shown.



You can produce a close-up of a portion of the plot by clicking at the upper left of the region you want to expand, and dragging the pointer to the lower right while pressing the mouse button. When you then release the mouse button, you produce the following plot.



Note that a steady state has been achieved, but a small limit cycle is present in the steady state due to poor A/D design.

# Tutorial: Producing Lookup Table Data

## Overview

A function lookup table is a method by which you can approximate a function by a table with a finite number of points (X,Y). Function lookup tables are essential to many fixed-point applications. The function you want to approximate is called the *ideal function*. The X values of the lookup table are called the *breakpoints*. You approximate the value of the ideal function at a point by linearly interpolating between the two adjacent breakpoints closest to the point.

In creating the points for a function lookup table, you generally want to achieve one or both of the following goals:

- Minimize the worst case error for a specified maximum number of breakpoints
- Minimize the number of breakpoints for a specified maximum allowed error

This tutorial shows you how to create function lookup tables using the function `fixpt_look1_func_approx`. You can optimize the lookup table to minimize the number of data points, the error, or both. You can also restrict the spacing of the breakpoints to be even or even powers of two, in order to speed up computations using the table.

This tutorial also explains how to use the function `fixpt_look1_func_plot` to find the worst case error of a lookup table and plot the errors at all points.

## Worst Case Error for a Lookup Table

This section explains the worst case error of a lookup table, and how to find the worst case error using the function `fixpt_look1_func_plot`. It gives a simple example of the worst case error of a lookup table for the square root function.

The error at any point of a function lookup table is the absolute value of the difference between the ideal function at the point and the corresponding Y value found by linearly interpolating between the adjacent breakpoints. The *worst case error*, or *maximum absolute error*, of a lookup table is the maximum absolute value of all errors in the interval containing the breakpoints.

For example, if the ideal function is the square root, and the breakpoints of the lookup table are 0, .25 and 1, then in a perfect implementation of the lookup table, the worst case error is 1/8 = .125, which occurs at the point 1/16 = .0625. In practice, the error could be greater, depending on the fixed point quantization and other factors.

### Example: Square Root Function

This example shows how to use the function `fixpt_look1_func_plot` to find the maximum absolute error for the simple lookup table whose breakpoints are 0, .25, and 1. The corresponding Y data points of the lookup table, which you find by taking the square roots of the breakpoints, are 0, .5 and 1.

To use the function `fixpt_look1_func_plot`, you need to first define its parameters. To do so, type the following at the MATLAB prompt:

```
funcstr='sqrt(x)'; %Define the square root function
xdata=[0;.25;1]; %Set the breakpoints
ydata=sqrt(xdata); %Find the square root of the breakpoints
xmin = 0; %Set the minimum breakpoint
xmax = 1; %Set the maximum breakpoint
xdt = ufix(16); %Set the x data type
xscale = 2^-16; %Set the x data scaling
ydt = sfix(16); %Set the y data type
yscale = 2^-14; %Set the y data scaling
rndmeth = 'Floor'; %Set the rounding method
```

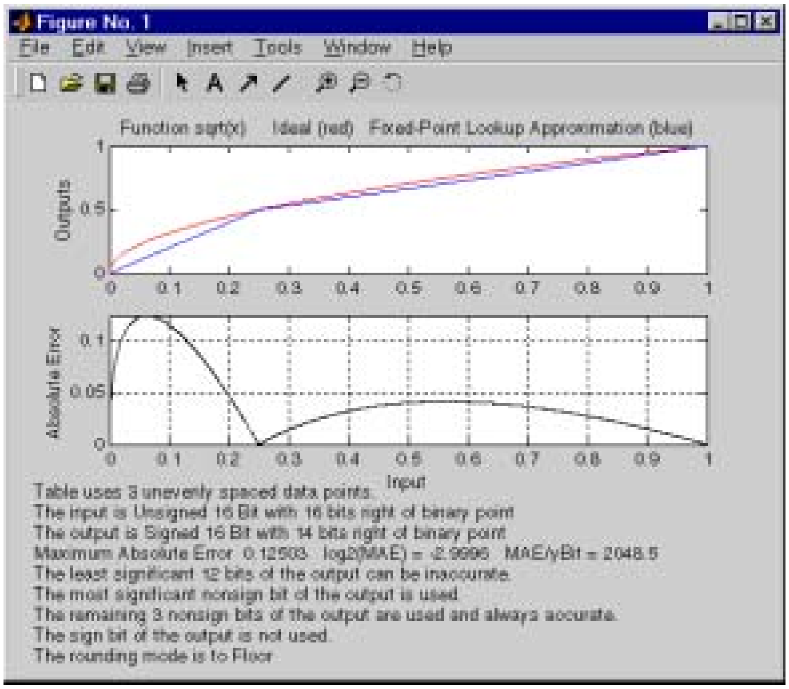
Next, type

```
errworst=fixpt_look1_func_plot(xdata,ydata,funcstr,...
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth)
```

This returns the worst case error of the lookup table as the variable `errworst`:

```
errworst =
    0.1250
```

It also generates the plots shown below. The upper box (Outputs) displays a plot of the square root function, and a plot of the fixed-point lookup approximation underneath. The approximation is found by linear interpolation between the breakpoints. The lower box (Absolute Error) displays the errors at all points in the interval from 0 to 1. Notice that the maximum absolute error occurs at .0625. The error at the breakpoints is 0.



```
Table uses 3 unevenly spaced data points.
The input is Unsigned 16 Bit with 16 bits right of binary point
The output is Signed 16 Bit with 14 bits right of binary point
Maximum Absolute Error 0.12503  log2(MAE) = -2.9996  MAE/yBit = 2048.5
The least significant 12 bits of the output can be inaccurate.
The most significant nonsign bit of the output is used.
The remaining 3 nonsign bits of the output are used and always accurate.
The sign bit of the output is not used.
The rounding mode is to Floor
```

## Creating Lookup Tables for a Sine Function

This section explains how to use the function `fixpt_look1_func_approx` to create lookup tables. It gives examples that show how to create lookup tables for the function sin(2$\pi x$) on the interval from 0 to .25. The section covers

### Parameters for fixpt_look1_func_approx

To use the function `fixpt_look1_func_approx`, you must first define its parameters. The required parameters for the function are

- `funcstr`—The ideal function
- `xmin`—The minimum input of interest
- `xmax`—The maximum input of interest
- `xdt`—The x data type
- `xscale`—The x data scaling
- `ydt`—The y data type
- `yscale`—The y data scaling
- `rndmeth`—The rounding method

In addition there are three optional parameters:

- `errmax`—The maximum allowed error of the lookup table
- `nptsmax`—The maximum number of points of the lookup table

- spacing—The allowed spacing between breakpoints

You must use at least one of the parameters errmax and nptsmax. The next section “Setting Function Parameters for the Lookup Table” on page 7-6 gives typical settings for these parameters.

### Using Only errmax

If you use only the errmax parameter, without nptsmax, the function creates a lookup table with the fewest points, for which the worst case error is at most errmax. See “Example 1: Using errmax with Unrestricted Spacing” on page 7-7.

### Using Only nptsmax

If you use only the nptsmax parameter without errmax, the function creates a lookup table with at most nptsmax points, which has the smallest worse case error. See “Example 2: Using nptsmax with Unrestricted Spacing” on page 7-10.

The section “Specifying Both errmax and nptsmax” on page 7-17 describes how the function behaves when you specify both errmax and nptsmax.

### Spacing

You can use the optional spacing parameter to restrict the spacing between breakpoints of the lookup table. The options are

- 'unrestricted'—The default.
- 'even'—The distance between any two adjacent breakpoints is the same.
- 'pow2'—The distance between any two adjacent breakpoints is the same and the distance is a power of two.

The section “Restricting the Spacing” on page 7-11 and the examples that follow it explain how to use the spacing parameter.

## Setting Function Parameters for the Lookup Table

To do the examples in this section, you must first set parameter values for the fixpt_look1_func_approx function. To do so, type the following at the MATLAB prompt:

```
funcstr = 'sin(2*pi*x)'; %Define the sine function
xmin = 0; %Set the minimum input of interest
```

```
xmax = 0.25; %Set the maximum input of interest
xdt = ufix(16); %Set the x data type
xscale = 2^-16; %Set the x data scaling
ydt = sfix(16); %Set the y data type
yscale = 2^-14; %Set the y data scaling
rndmeth = 'Floor'; %Set the rounding method
errmax = 2^-10; %Set the maximum allowed error
nptsmax = 21; %Specify the maximum number of points
```

If you exit MATLAB after typing these commands, you must retype them before trying any of the other examples in this section.

## Example 1: Using errmax with Unrestricted Spacing

The first example shows how to create a lookup table that has the fewest data points for a specified worst case error, with unrestricted spacing. Before trying the example, enter the same parameter values given in the section "Setting Function Parameters for the Lookup Table" on page 7-6, if you have not already done so in this MATLAB session.

You specify the maximum allowed error by typing

```
errmax = 2^-10;
```

### Creating the Lookup Table

To create the lookup table, type

```
[xdata,ydata,errworst]=fixpt_look1_func_approx(funcstr,...
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,errmax);
```

Note that the `nptsmax` and `spacing` parameters are not specified.

The function returns three variables:

- `xdata`, the vector of breakpoints of the lookup table
- `ydata`, the vector found by applying ideal function, $\sin(2\pi x)$, to `xdata`
- `errworst`, which specifies the maximum possible error in the lookup table

The value of `errworst` is less than or equal to the value of `errmax`.

You can find the number of X data points by typing

```
length(xdata)
```

```
ans =

    16
```

This means that 16 points are required to approximate sin($2\pi x$) to within the tolerance specified by `errmax`.

You can display the maximum error by typing `errworst`. This returns

```
errworst =
  9.7656e-004
```

## Plotting the Results

You can plot the output of the function `fixpt_look1_func_plot` by typing

```
fixpt_look1_func_plot(xdata,ydata,funcstr,xmin,xmax,xdt,...
xscale,ydt,yscale,rndmeth);
```

The resulting plots are shown.

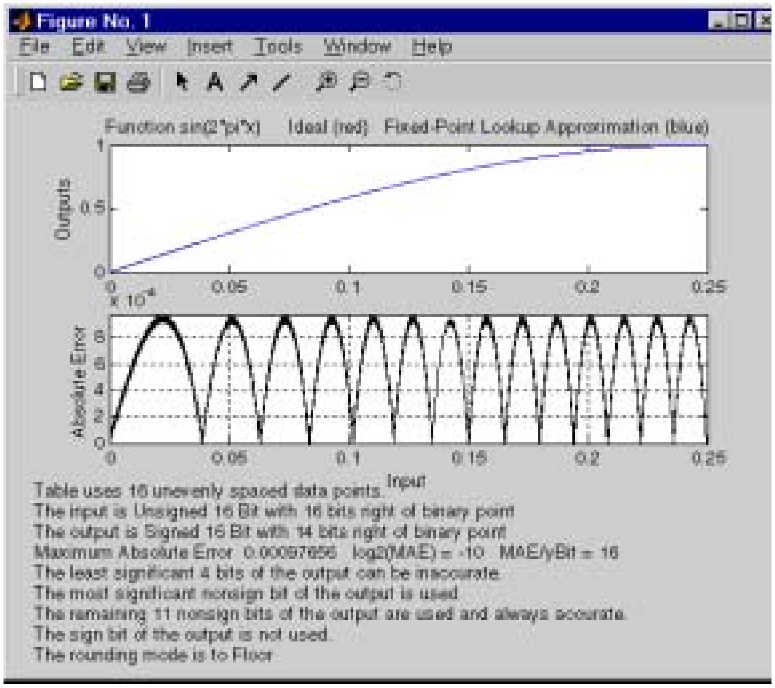


Figure No. 1
File Edit View Insert Tools Window Help
Function sin(2*pi*x)    Ideal (red)    Fixed-Point Lookup Approximation (blue)
Outputs
Absolute Error
x 10^-4
Input

```
Table uses 16 unevenly spaced data points.
The input is Unsigned 16 Bit with 16 bits right of binary point
The output is Signed 16 Bit with 14 bits right of binary point
Maximum Absolute Error  0.00097656   log2(MAE) = -10   MAE/yBit = 16
The least significant 4 bits of the output can be inaccurate.
The most significant nonsign bit of the output is used.
The remaining 11 nonsign bits of the output are used and always accurate.
The sign bit of the output is not used.
The rounding mode is to Floor
```

The upper plot shows the ideal function, sin(2πx) and the fixed-point lookup approximation between the breakpoints. In this example, the ideal function and the approximation are so close together that the two graphs appear to coincide. The lower plot displays the errors.

In this example, the Y data points, returned by the function `fixpt_look1_func_approx` as `ydata`, are equal to the ideal function applied to the points in `xdata`. However, you can define a different set of values for `ydata` after running `fixpt_look1_func_plot`. This can sometimes reduce the maximum error.

You can also change the values of `xmin` and `xmax` in order to evaluate the lookup table on a subset of the original interval.

To find the new maximum error after changing `ydata`, `xmin` or `xmax`, type

```
errworst=fixpt_look1_func_plot(xdata,ydata,funcstr,xmin,xmax,...
xdt,xscale,ydt,yscale,rndmeth)
```

## Example 2: Using nptsmax with Unrestricted Spacing

The next example shows how to create a lookup table that minimizes the worst case error for a specified maximum number of data points, with unrestricted spacing. Before starting the example, enter the same parameter values given in the section “Setting Function Parameters for the Lookup Table” on page 7-6, if you have not already done so in this MATLAB session.

### Setting the Number of Breakpoints

You specify the number of breakpoints in the lookup table by typing

```
nptsmax = 21;
```

### Creating the Look-Up Table

Next, type

```
[xdata,ydata,errworst]= fixpt_look1_func_approx(funcstr,
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,[],nptsmax);
```

The empty brackets, `[]`, tell the function to ignore the parameter `errmax`, which is not used in this example. Omitting `errmax` causes the function `fixpt_look1_func_approx` to return a look-up table of size specified by `nptsmax`, with the smallest worst case error.

The function returns a vector `xdata`, with 21 points. You can find the maximum error for this set of points is given by typing `errworst` at the MATLAB prompt. This returns

```
errworst =
  5.1139e-004
```

### Plotting the Results

To plot the lookup table along with the errors, type

```
fixpt_look1_func_plot(funcstr,xdata,xdt,xscale,ydata,ydt,...
yscale,rndmeth);
```

The resulting plots are shown.

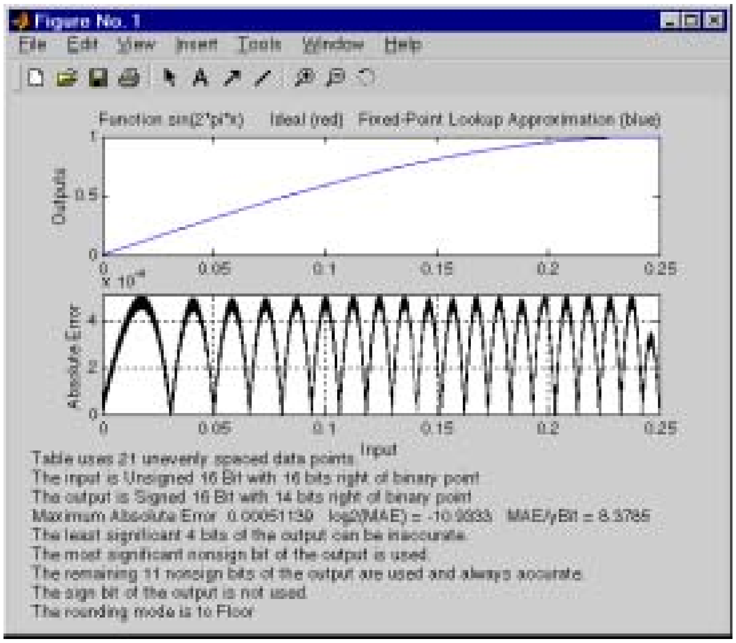


Figure No. 1
File Edit View Insert Tools Window Help
Function sin(2*pi*x)   Ideal (red)   Fixed-Point Lookup Approximation (blue)
Outputs
Absolute Error
x 10^-4
Input

```
Table uses 21 unevenly spaced data points
The input is Unsigned 16 Bit with 16 bits right of binary point
The output is Signed 16 Bit with 14 bits right of binary point
Maximum Absolute Error 0.00051139   log2(MAE) = -10.9333   MAE/yBit = 8.3785
The least significant 4 bits of the output can be inaccurate
The most significant nonsign bit of the output is used
The remaining 11 nonsign bits of the output are used and always accurate
The sign bit of the output is not used
The rounding mode is to Floor
```

## Restricting the Spacing

In the previous two examples, the function `fixpt_look1_func_approx` creates lookup tables with unrestricted spacing between the breakpoints. You can restrict the spacing to improve the computational efficiency of the look-up table, using the spacing parameter.

The options for spacing are

- `'unrestricted'`—The default.
- `'even'`—The distance between any two adjacent breakpoints is the same.
- `'pow2'`—The distance between any two adjacent breakpoints is the same and is a power of two.

Both power of two and even spacing increase the computational speed of the lookup table and use less command read-only memory (ROM). However, specifying either of the spacing restrictions along with `errmax` usually requires more data points in the lookup table than does unrestricted spacing, in order to achieve the same degree of accuracy. The section "Effect of Spacing on Speed, Error, and Memory Usage" on page 7-20 discusses the tradeoffs between different spacing options.

## Example 3: Using errmax with Even Spacing

The next example shows how to create a look-up table that has evenly spaced breakpoints and a specified worst case error. To try the example, you must first enter the parameter values given in the section "Setting Function Parameters for the Lookup Table" on page 7-6, if you have not already done so in this MATLAB session.

Next, at the MATLAB prompt type

```
spacing = 'even';
[xdata ydata errworst]=fixpt_look1_func_approx(funcstr,...
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,errmax,[],spacing);
```

You can find the number of points in the look-up table by typing `length(xdata)`.

```
ans =
    20
```

To plot the look-up table along with the errors, type

```
fixpt_look1_func_plot(xdata,ydata,funcstr,xmin,xmax,xdt,...
xscale,ydt,yscale,rndmeth);
```

This produces the following plots.

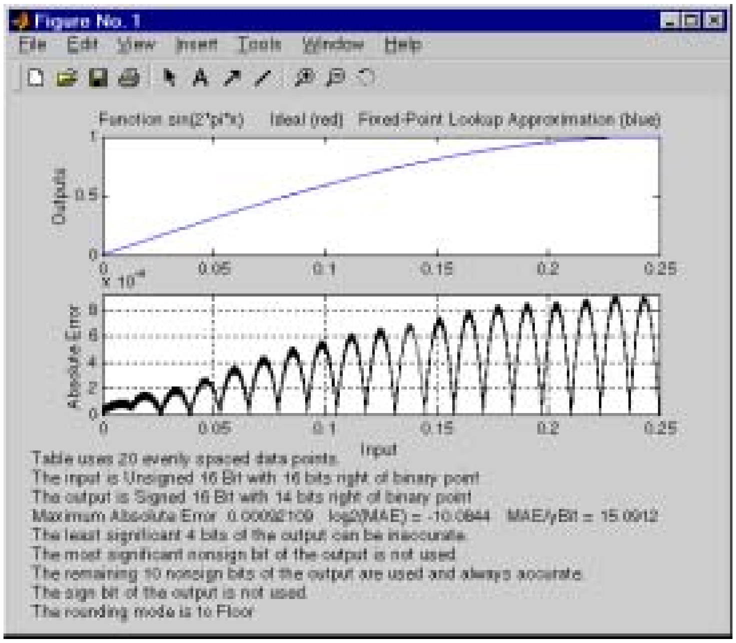


Figure No. 1
File Edit View Insert Tools Window Help
Function sin(2*pi*x)   Ideal (red)   Fixed-Point Lookup Approximation (blue)
Outputs
Absolute Error
x 10^-4
Input

```
Table uses 20 evenly spaced data points.
The input is Unsigned 16 Bit with 16 bits right of binary point
The output is Signed 16 Bit with 14 bits right of binary point
Maximum Absolute Error  0.00092109   log2(MAE) = -10.0844   MAE/yBit = 15.0912
The least significant 4 bits of the output can be inaccurate.
The most significant nonsign bit of the output is not used
The remaining 10 nonsign bits of the output are used and always accurate.
The sign bit of the output is not used.
The rounding mode is to Floor
```

## Example 4: Using nptsmax with Even Spacing

The next example shows how to create a look-up table that has evenly space breakpoints and minimizes the worst case error for a specified maximum number of points. To try the example, you must first enter the parameter values given in the section "Setting Function Parameters for the Lookup Table" on page 7-6, if you have not already done so in this MATLAB session.

Next, at the MATLAB prompt type

```
spacing='even';
[xdata ydata errworst]= fixpt_look1_func_approx(funcstr,...
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,[],nptsmax,spacing);
```

The result requires 21 evenly spaced points to achieve a maximum absolute error of `2^-10.2209`.

To plot the look-up table along with the errors, type

```
fixpt_look1_func_plot(xdata,ydata,funcstr,xmin,xmax,xdt,...
xscale,ydt,yscale,rndmeth);
```

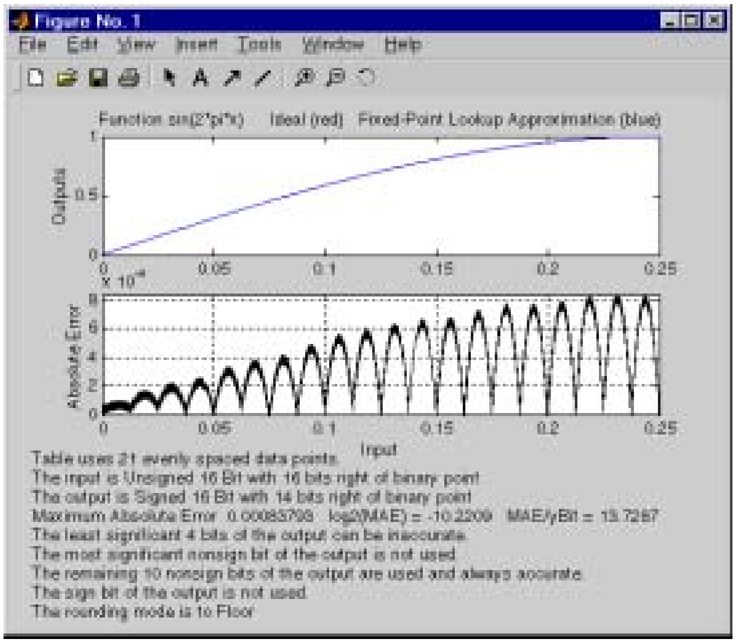


Figure No. 1
File Edit View Insert Tools Window Help
Function sin(2*pi*x) Ideal (red) Fixed-Point Lookup Approximation (blue)
Outputs
Absolute Error
x 10⁻⁴
Input

```
Table uses 21 evenly spaced data points.
The input is Unsigned 16 Bit with 16 bits right of binary point
The output is Signed 16 Bit with 14 bits right of binary point
Maximum Absolute Error  0.00083798   log2(MAE) = -10.2209   MAE/yBit = 13.7287
The least significant 4 bits of the output can be inaccurate.
The most significant nonsign bit of the output is not used
The remaining 10 nonsign bits of the output are used and always accurate.
The sign bit of the output is not used
The rounding mode is to Floor
```

## Example 5: Using errmax with Power of Two Spacing

The next example shows how to construct a look-up table that has power of two spacing and a specified worst case error. To try the example, you must first enter the parameter values given in the section “Setting Function Parameters for the Lookup Table” on page 7-6, if you have not already done so in this MATLAB session.

Next, at the MATLAB prompt type

```
spacing ='pow2';
[xdata ydata
errworst]=fixpt_look1_func_approx(funcstr,xmin,xmax,xdt,...
xscale,ydt,yscale,rndmeth,errmax,[],spacing);
```

To find out how many points are in the look-up table, type

```
length(xdata)
  ans =
      33
```

This means that 33 points are required to achieve the worst case error specified by `errmax`. To verify that these points are evenly spaced, type

```
widths=diff(xdata)
```

This generates a vector whose entries are the differences between consecutive points in `xdata`. Every entry of `widths` is $2^{-7}$.

To find the maximum error for the look-up table, type

```
errworst
  errworst =
    3.7209e-004
```

This is less than the value of `errmax`.

To plot the look-up table data along with the errors, type

```
fixpt_look1_func_plot(xdata,ydata,funcstr,xmin,xmax,xdt,...
xscale,ydt,yscale,rndmeth);
```

This displays the plots shown.

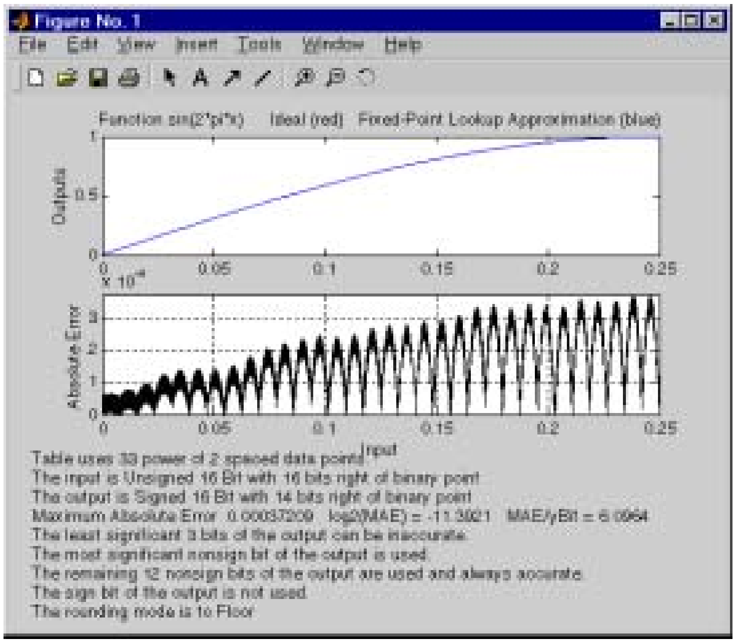


Figure No. 1
File Edit View Insert Tools Window Help
Function sin(2*pi*x)   Ideal (red)   Fixed-Point Lookup Approximation (blue)
Outputs
Absolute Error
x 10^-4
Input

Table uses 33 power of 2 spaced data points
The input is Unsigned 16 Bit with 16 bits right of binary point
The output is Signed 16 Bit with 14 bits right of binary point
Maximum Absolute Error 0.00037209 log2(MAE) = -11.3921 MAE/yBit = 6.0964
The least significant 3 bits of the output can be inaccurate
The most significant nonsign bit of the output is used
The remaining 12 nonsign bits of the output are used and always accurate
The sign bit of the output is not used
The rounding mode is to Floor

## Example 6: Using nptsmax with Power of Two Spacing

The next example shows how to create a look-up table that has power of two spacing and minimizes the worst case error for a specified maximum number of points. To try the example, you must first enter the parameter values given in the section “Setting Function Parameters for the Lookup Table” on page 7-6, if you have not already done so in this MATLAB session:

```
spacing ='pow2';
[xdata, errworst]= fixpt_look1_func_approx(funcstr,...
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,[],nptsmax,spacing);
```

The result requires 17 points to achieve a maximum absolute error of 2^-9.6267.

To plot the look-up table along with the errors, type

```
fixpt_look1_func_plot(funcstr,xdata,xdt,xscale,ydt,yscale,rndmet
h);
```

This produces the plots shown below.

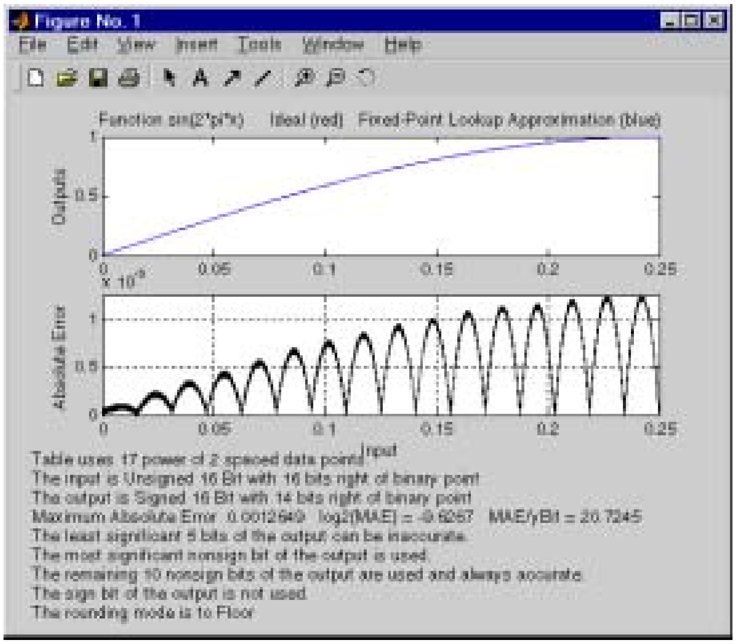


Figure No. 1
File Edit View Insert Tools Window Help
Function sin(2*pi*x)   Ideal (red)   Fixed-Point Lookup Approximation (blue)
Outputs
Absolute Error
x 10^-3
Input

```
Table uses 17 power of 2 spaced data points
The input is Unsigned 16 Bit with 16 bits right of binary point
The output is Signed 16 Bit with 14 bits right of binary point
Maximum Absolute Error  0.0012649   log2(MAE) = -9.6267   MAE/yBit = 20.7245
The least significant 5 bits of the output can be inaccurate.
The most significant nonsign bit of the output is used.
The remaining 10 nonsign bits of the output are used and always accurate.
The sign bit of the output is not used.
The rounding mode is to Floor
```

## Specifying Both errmax and nptsmax

If you include both the `errmax` and the `nptsmax` parameters, the function `fixpt_look1_func_approx` tries to find a look-up table with at most `nptsmax` data points, whose worst case error is at most `errmax`. If it can find a look-up table meeting both conditions, it uses the following order of priority for spacing:

1. Power of two
2. Even
3. Unrestricted

If the function cannot find any look-up table satisfying both conditions, it ignores nptsmax and returns a look-up table with unrestricted spacing, whose worst case error is at most errmax. In this case, the function behaves the same as if the nptsmax parameter were omitted.

Using the parameters described the section “Setting Function Parameters for the Lookup Table” on page 7-6, the following examples illustrate the results of using different values for nptsmax when you enter

```
[xdata ydata errworst]=fixpt_look1_func_approx(funcstr,
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,errmax,numptsmax);
```

The results for three different settings for nptsmax are as follows:

- numptsmax=33 — The function creates the look-up table with 33 points having power of two spacing as in Example 3.
- numptsmax=21 — Since the errmax and numptsmax conditions cannot be met with power of two spacing, the function creates the look-up table with 20 points having even spacing, as in Example 5.
- numptsmax=16 — Since the errmax and numptsmax conditions cannot be met with either power of two or even spacing, the function creates the lookup table with 16 points having unrestricted spacing, as in Example 1.

## Comparing the Examples

The following table summarizes the results for the examples. Note that when you specify errmax, even spacing requires more data points than unrestricted, and power of two spacing requires more points than even spacing.

| Example | Options | Spacing | Worst Case Error | Number of Points in Table |
|---|---|---|---|---|
| 1 | errmax=2^-10 | 'unrestricted' | 2^-10 | 16 |
| 2 | nptsmax=21 | 'unrestricted' | 2^-10.933 | 21 |
| 3 | errmax=2^-10 | 'even' | 2^-10.0844 | 20 |
| 4 | nptsmax=21 | 'even' | 2^-10.2209 | 21 |
| 5 | errmax=2^-10 | 'pow2' | 2^-11.3921 | 33 |
| 6 | nptsmax=21 | 'pow2' | 2^-9.627 | 17 |

## Summary: Using the Lookup Table Functions

The following summarizes how to use the lookup table approximation functions:

1. Define
   a. The ideal function to be approximated
   b. The range, `xmin` to `xmax`, over which to find X and Y data
   c. The fixed-point implementation: data type, scaling, and rounding method
   d. The maximum acceptable error, the maximum number of points, and the spacing
2. Run the `fixpt_look1_func_approx` function to generate X and Y data.
3. Use the `fixpt_look1_func_plot` function to plot the function and error between the ideal and approximated function using the selected X and Y data, and to calculate the error and the number of points used.
4. Vary input criteria, such as `errmax`, `nptsmax` and `spacing`, to produce sets of X and Y data that generate functions with varying worst-case error, number of points required, and spacing.
5. Compare results of the number of points required and maximum absolute error from various runs to choose the best set of X and Y data.

## Effect of Spacing on Speed, Error, and Memory Usage

This section compares the implementations of lookup tables that use breakpoints whose spacing is uneven, even, and power of two. This comparison is only valid when the breakpoints are not tunable. If the breakpoints can be tuned in the generated code, then all three cases generate the same code. The comparison will focus on the amount of read-only memory (ROM) used for data, the amount of ROM used for commands, and the speed with which the commands are executed.

As a specific example, this comparison uses the demo `fxpdemo_approx_sin`. There are three fixed-point lookup tables in this model. All three lookup tables approximate the function `sin(2*pi*u)` over the first quadrant. All three achieve a worst case error of less than `2^-8`. However, they have different restrictions on their breakpoint spacing.

You can use the model `fxpdemo_approx`, which this demo opens, to generate code with Real-Time Workshop. This section presents several segments of the generated code. These segments of code were edited and arranged for clarity and to emphasize key differences.

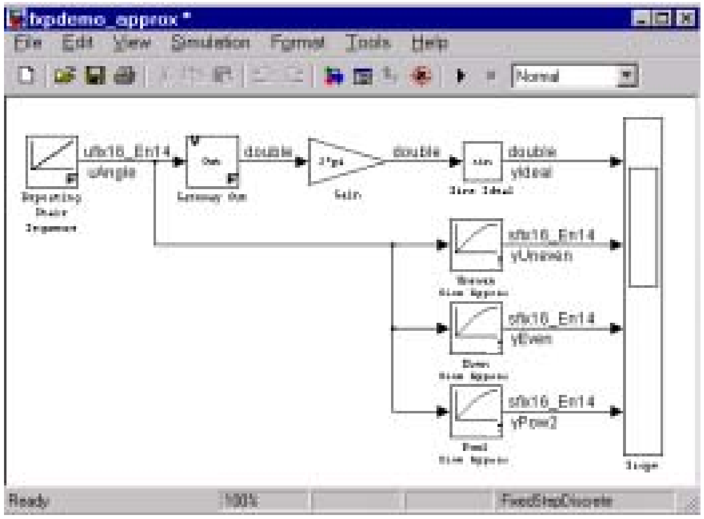
This section covers the following topics:

- “Data ROM Required” on page 7-21
- “Determining Out-of-Range Inputs” on page 7-22
- “Determining Input Location” on page 7-22
- “Interpolation” on page 7-24
- “Conclusion” on page 7-26

To open the demo, type at the MATLAB prompt

```
fxpdemo_approx_sin
```

This opens the model shown.



## Data ROM Required

This section looks at the data ROM required by each of the three spacing options.

### Uneven Case

Uneven spacing requires both Y data points and breakpoints:

```
int16_T  yuneven[8];
uint16_T xuneven[8];
```

The total bytes used is 32.

### Even Case

Even spacing requires only Y data points:

```
int16_T yeven[10];
```

The total bytes used is 20. The breakpoints are not explicitly required. The code will use the spacing between the breakpoints, and may use the smallest and largest breakpoint. At most three values related to the breakpoints are needed.

### Power of Two Case

Power of two spacing requires only Y data points:

```
int16_T ypow2[17];
```

The total bytes used is 34. The breakpoints are not explicitly required. The code will use the spacing between the breakpoints, and may use the smallest and largest breakpoint. At most three values related to the breakpoints are needed.

## Determining Out-of-Range Inputs

In all three cases you have to guard against the possibility that the input is less than the smallest breakpoint or greater than the biggest breakpoint. There may be differences in how occurrences of these possibilities are handled. However, the differences are generally minor and are normally not a key factor in deciding to use one spacing method over another. The subsequent sections assume that out-of-range inputs are impossible or have already been handled.

## Determining Input Location

This section describes how the three fixed point lookup tables determine where the current input is relative to the breakpoints.

### Uneven Case

Unevenly spaced breakpoints require a general-purpose algorithm such as a binary search to determine where the input lies in relation to the breakpoints. The following code provides an example:

```
iLeft = 0;
iRght = 7; /* number of breakpoints minus 1 */

while ( ( iRght - iLeft ) > 1 )
{
  i = ( iLeft + iRght ) >> 1;

if ( uAngle < xuneven[i] )
  {
    iRght = i;
  }
  else
  {
      iLeft = i;
    }
  }
```

The while loop executes up to log2(N) times where N is number of breakpoints.

### Even Case

Evenly spaced breakpoints require only one step to determine where the input lies in relation to the breakpoints:

```
  iLeft = uAngle / 455U;
```

The divisor `455U` represents the spacing between breakpoints. In general, the dividend would be `(uAngle - SmallestBreakPoint)`. In this example, the smallest breakpoint was zero, so the subtraction was optimized out.

### Power of Two Case

Power of two spaced breakpoints require only one step to determine where the input lies in relation to the breakpoints:

```
  iLeft = uAngle >> 8;
```

The number of shifts is 8 because the breakpoints have spacing `2^8`. The smallest breakpoint was zero, so `uAngle` replaced the general case of `(uAngle - SmallestBreakPoint)`.

### Comparison

To determine where the input is located with respect to the breakpoints, the unevenly spaced case clearly requires much more code than the other two cases. This code requires additional command ROM. This ROM penalty can be reduced if many lookup tables share the binary search algorithm as a function. Even if the code is shared, the number of clock cycles required to determine the location of the input is much higher for the unevenly spaced cases than the other two cases. If the code is shared, then function call overhead decreases the speed of execution a little more.

In the evenly spaced case and the power of two spaced case, you can determine the location of the input with a single line of code. The evenly spaced cased uses a general integer division. The power of two case uses a shift instead of general division because the divisor is an exact power of two. Without knowing the specific processor to be used, you cannot be certain that a shift is better than division.

Many processors can implement division with a single assembly language instruction, so the code will be small. However, this instruction often takes many clock cycles to complete. Quite a few processors do not provide a division instruction. Division on these processors is implemented via repeated subtractions. This is slow and requires a fair amount of machine code, but this code can be shared.

Most processors provide a way to do logical and arithmetic shifts left and right. A distinguishing difference is whether the processor can do N shifts in one instruction (barrel shift) or requires N instructions that shift one bit at a time. The barrel shift will require less code. Whether or not the barrel shift also increases speed depends on the hardware that supports the operation.

The compiler can also complicate the comparison. In the previous example, the command `uAngle >> 8` essentially takes the upper 8 bits in a 16 bit word. The compiler may detect this and replace the bit shifts with an instruction that takes the bits directly. If the number of shifts is some other value, such as 7, this optimization would not occur.

## Interpolation

In theory, you can calculate the interpolation with the following code:

```
y = ( yData[iRght] - yData[iLeft] ) * ( u - xData[iLeft] )
/ ( xData[iRght] - xData[iLeft] ) + yData[iLeft]
```

The term `(xData[iRght] - xData[iLeft])` is the spacing between neighboring breakpoints. If this value is constant, i.e., even spacing, some simplification is possible. If spacing is not just even but also a power of two, then very significant simplifications are possible for fixed-point implementations.

### Uneven Case

For the uneven case, one possible implementation of the ideal interpolation in fixed point is as follows:

```
xNum  = uAngle         - xuneven[iLeft];
xDen  = xuneven[iRght] - xuneven[iLeft];
yDiff = yuneven[iRght] - yuneven[iLeft];
```

```
MUL_S32_S16_U16( bigProd, yDiff, xNum );

  DIV_NZP_S16_S32_U16_FLOOR( yDiff, bigProd, xDen );

  yUneven = yuneven[iLeft] + yDiff;
```

The multiplication and division routines are not shown here. These can be somewhat involved and depend on the target processor. For example, these routines look quite different for a 16-bit processor than for a 32-bit processor.

### Even Case

Evenly spaced breakpoints implement interpolation using just slightly different calculations than the uneven case. The key difference is that the calculations do not directly use the breakpoints. This means the breakpoints are not required in ROM, which can be a very significant savings:

```
xNum  = uAngle - ( iLeft * 455U );

  yDiff = yeven[iLeft+1] - yeven[iLeft];

  MUL_S32_S16_U16( bigProd, yDiff, xNum );

  DIV_NZP_S16_S32_U16_FLOOR( yDiff, bigProd, 455U );

  yEven = yeven[iLeft] + yDiff;
```

### Power of Two Case

Power of two spaced breakpoints implement interpolation using very different calculations than the other two cases. Like the uneven case, breakpoints are not used in the generated code and therefore not required in ROM:

```
lambda = uAngle & 0x00FFU;

  yPow2 = ypow2[iLeft)+1] - ypow2[iLeft];

  MUL_S16_U16_S16_SR8(yPow2,lambda,yPow2);

  yPow2 += ypow2[iLeft];
```

This implementation has very significant advantages over the uneven and even implementations. The key difference is that a subtraction and a division are replaced by a bitwise-AND combined with a shift right at the end of the multiply. Another advantage is that the term `(u - xData[iLeft] ) / ( xData[iRght] - xData[iLeft])` is computed with no loss of precision, because the spacing is a power of two. In contrast, the uneven and even cases usually introduce rounding error in this calculation.

## Conclusion

The number of Y data points follows the expected pattern. For the same worst case error, unrestricted spacing (uneven) requires the fewest data points, and power of two spaced breakpoints requires the most. However, the implementation for the evenly spaced and the power of two cases does not need the breakpoints in the generated code. This reduces their data ROM requirements by a half. As a result, the evenly spaced case actually uses less data ROM than the unevenly spaced case. Also, the power of two case requires only slightly more ROM than the uneven case. Changing the worst case error can change these rankings. Nonetheless, when you compare data ROM usage, you should always take into account the fact that the evenly spaced and power of two spaced cases do not require their breakpoints in ROM.

The effort of determining where the current input is relative to the breakpoints strongly favors the evenly spaced and power of two spaced cases. With uneven spacing, you use a binary search method that loops up to log2(N) times. With even and power of two spacing, you can determine the location with the execution of one line of C code. But you cannot decide the relative advantages of power of two versus evenly spaced without detailed knowledge of the hardware and the C compiler.

The effort of calculating the interpolation favors the power of two case, which uses a bitwise AND operation and a shift to replace a subtraction and a division. The amount of advantage provided by this depends on the specific hardware, but you would expect an advantage in code size, speed, and also in accuracy. The evenly space case calculates the interpolation with a minor improvement in efficiency over the unevenly spaced case.

# Code Generation

## Overview

You can generate C code with the Fixed-Point Blockset using Real-Time Workshop. The code generated from fixed-point blocks uses only integer types and automatically includes all operations, such as shifts, needed to account for differences in fixed-point locations. You can use the generated code on embedded fixed-point processors or rapid prototyping systems even if they contain a floating-point processor. The code is structured so that key operations can be readily replaced by optimized target-specific libraries that you supply. You can also use Target Language Compiler to customize the generated code. For more information about code generation, refer to the Real-Time Workshop and the Target Language Compiler documentation.

You can also generate code for testing on a rapid prototyping system such as xPC, the Real-Time Windows Target, or dSPACE. The target compiler and processor may support floating-point operations in software or in hardware. In any case, the fixed-point blocks generate pure integer code and do not use floating-point operations. This allows valid bit-true testing even on a floating-point processor.

You can also generate code for nonreal-time testing. For example, you can generate code to run in nonreal-time on computers running any supported operating system. Even though the processors have floating-point hardware, the code generated by fixed-point blocks is pure integer code. The Generic Real-Time Target (GRT) and the Simulink Accelerator are examples of where nonreal-time code is generated and run.

## Code Generation Support

All fixed-point blocks support code generation, but not every simulation feature is supported. The code generation support is described below.

### Languages

- C support only

### Storage Class of Variables

- Fixed-Point Blockset code generation handles variables that do not match the target compiler sizes for `char`, `short`, `int`, or `long` data types. Code generation supports any variable having a width less than or equal to a `long`, either signed or unsigned. For example, the C40 compiler defines a `long` to be 32 bits. Therefore, the allowable sizes for variables range between 1 and 32 bits. This capability is particularly useful if you want to
  - Prototype on one target chip, but use a different target chip for production.
  - Provide bit-true simulation in a rapid prototyping environment for odd data type sizes used by FPGAs, ASICs, 24-bit DSPs, and so on.
- The Fixed-Point Blockset supports floating-point types, except for custom floating-point types.

### Storage Class of Parameters

- The Real-Time Workshop external mode support requires that parameters be 1 to 32 bits, either signed or unsigned. The parameter size must also be compatible with the target C compiler.
- No floating-point support

### Rounding Modes

- All four rounding modes are supported.
- Rounding to `floor` generates the most efficient code for most cases.

## Overflow Handling

- Saturation mode is supported.
- Wrapping mode is supported and generates the most efficient code.
- Automatic exclusion of saturation code when hardware saturation is available is currently not supported. Wrapping must be selected for Real-Time Workshop to exclude saturation code.

## Blocks

All blocks generate code for all operations with a few exceptions:

- The Look-Up Table, Look-Up Table (2D), and Dynamic Look-Up Table blocks generate code for all look-up methods except extrapolation.
- A few combinations of scaling and operations lead to highly inefficient code. These few cases are described in the next section.

## Scaling

- Binary point-only scaling is supported.
- [Slope Bias] scaling is supported for all blocks except when it leads to highly inefficient code. All blocks except four support all cases of [Slope Bias] scaling. The Gain, Matrix Gain, and FIR blocks support matched [Slope Bias] scaling where the block input signals and output signals have the same slopes and biases, but not mismatched [Slope Bias] scaling. The Product block supports mismatched slope, but not mismatched bias. For more information about matched and mismatched [Slope Bias] scaling, refer to "Signal Conversions" on page 4-27.

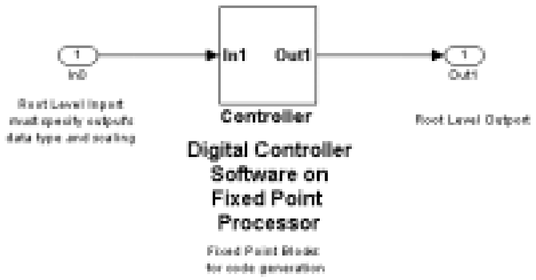
  We generally recommend that signals with [Slope Bias] scaling (such as a sensor input) are immediately converted to binary point-only scaling. This typically produces more efficient code.

## Generating Pure Integer Code

All blocks generate pure integer code except for the Gateway In, Gateway In Inherited, and Gateway Out blocks. These blocks must generate floating-point code when handling floating-point input or output. However, if the input or output is an integer and the block is configured to treat the input or output as a stored integer, then these blocks will also generate pure integer code.

### Example: Generating Pure Integer Code

This example outlines the steps you should take when generating pure integer code for your Fixed-Point Blockset model. The steps follow the description in the `fxpdemo_code_only` demo, which includes the model shown below.


1
In0
Root Level Input must specify outputs data type and scaling
In1
Out1
Controller
Digital Controller Software on Fixed Point Processor
Fixed Point Blocks for code generation
1
Out1
Root Level Output

---

**Note** This example generates code using the Embedded C Real-Time Target (ERT), which is available with Real-Time Workshop Production Coder. If your version of Real-Time Workshop does not support ERT code generation, then you may want to select the Generic Real-Time Target (GRT). Using GRT, all Fixed-Point Blockset blocks (except the gateway blocks) will generate pure integer code. However, the code related to the GRT infrastructure is not generated to exclude floating-point operations. For example, GRT may decide when to execute blocks based on a floating-point counter.

---

**1** Copy the fixed-point portion of your model to a new model.

If your original model includes blocks that represent hardware, analog systems, and other blocks not related to embedded software, then you must create a new model. This new model contains only the fixed-point portion, which represents the software that will be running on the fixed-point processor. For example, the digital controller subsystem shown above contains the fixed-point blocks from the `fxpdemo_feedback` model used for code generation.

**2** Add root-level Inport and Outport blocks.

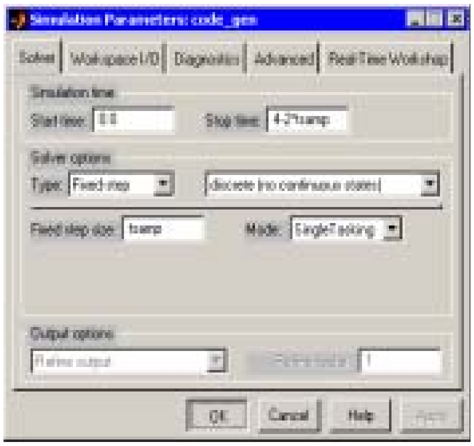
**e** Precede the blocks in your new model with root-level Inport blocks, and configure the Inport blocks to use the appropriate data type and scaling. For example, the Inport block shown above is configured to use the `sfix(8)` data type and to have an output scaling of `2^-4`.

**f** Follow the blocks in your new model with root-level Outport blocks.

**3** Configure the simulation parameters.

**a** Open the Simulink **Simulation Parameters** dialog box by selecting **Simulation parameters** under the **Simulation** menu.

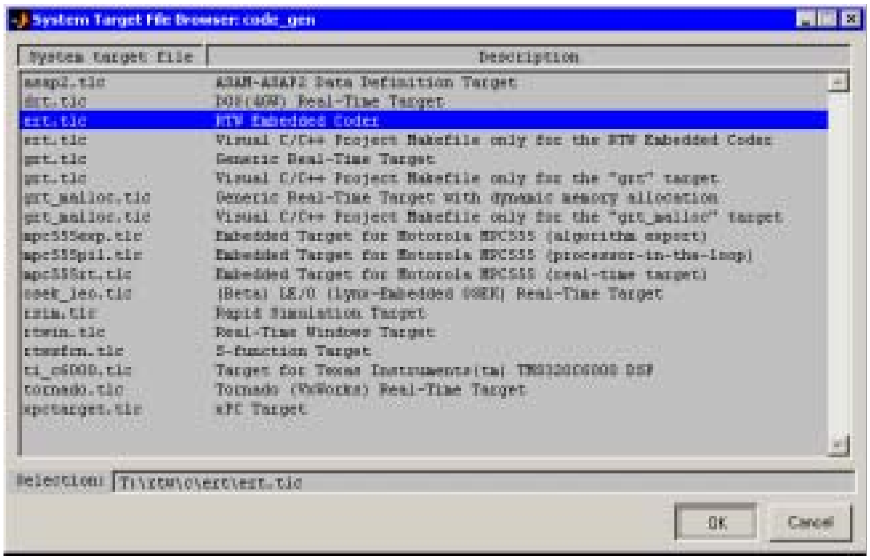
**b** In the **Solver** pane, configure **Solver options** to `Fixed-step` and `discrete (no continuous states)`, and configure **Fixed step size** to the required value. The **Solver** pane for this configuration is shown below.



Simulation time
Start time: 0.0 Stop time: 4-2*tsamp
Solver options
Type: Fixed-step discrete (no continuous states)
Fixed step size: tsamp Mode: SingleTasking
Output options
Refine output Refine factor: 1

**c** Select the **Real-Time Workshop** tab in the **Simulation Parameters** dialog box. Select the **Browse** button in the **Configuration** panel to open the **System Target File Browser** window. If it is available, select `RTW Embedded Coder` as the system target file as shown below, and click **OK**.

Note that you may not have ERT code generation capability. If this is the case, you should select the `Generic Real-Time Target`.

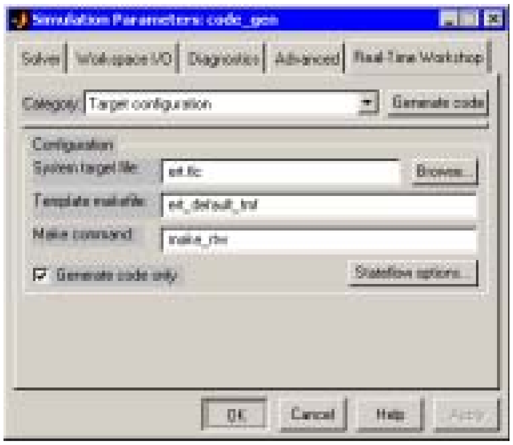


System Target File Browser: code_gen

| System target file | Description |
|---|---|
| asap2.tlc | ASAM-ASAP2 Data Definition Target |
| drt.tlc | DOS(4GW) Real-Time Target |
| ert.tlc | RTW Embedded Coder |
| ert.tlc | Visual C/C++ Project Makefile only for the RTW Embedded Coder |
| grt.tlc | Generic Real-Time Target |
| grt.tlc | Visual C/C++ Project Makefile only for the "grt" target |
| grt_malloc.tlc | Generic Real-Time Target with dynamic memory allocation |
| grt_malloc.tlc | Visual C/C++ Project Makefile only for the "grt_malloc" target |
| mpc555exp.tlc | Embedded Target for Motorola MPC555 (algorithm export) |
| mpc555pil.tlc | Embedded Target for Motorola MPC555 (processor-in-the-loop) |
| mpc555rt.tlc | Embedded Target for Motorola MPC555 (real-time target) |
| osek_leo.tlc | (Beta) LE/O (Lynx-Embedded OSEK) Real-Time Target |
| rsim.tlc | Rapid Simulation Target |
| rtwin.tlc | Real-Time Windows Target |
| rtwsfcn.tlc | S-function Target |
| ti_c6000.tlc | Target for Texas Instruments(tm) TMS320C6000 DSP |
| tornado.tlc | Tornado (VxWorks) Real-Time Target |
| xpctarget.tlc | xPC Target |

Selection: T:\rtw\c\ert\ert.tlc

The **Real-Time Workshop** pane now appears as shown below.



Simulation Parameters: code_gen

Category: Target configuration

Configuration

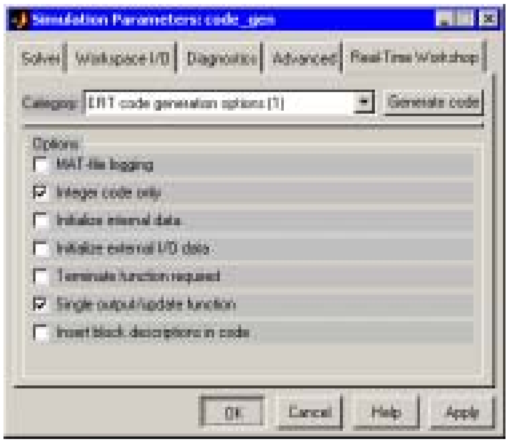
System target file: ert.tlc

Template makefile: ert_default_tmf

Make command: make_rtw

☑ Generate code only

**d** To configure the code generation parameters, select `ERT code generation options (1)` from the **Category** menu. Select the **Integer code only** check box and any other options that you require. The ERT code generation options for this configuration are shown below. If you are using GRT) the dialog box choices are slightly different.

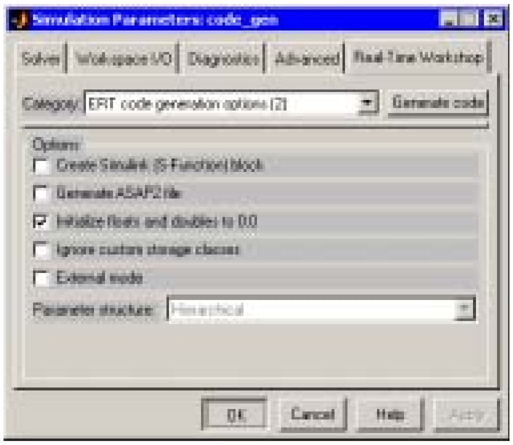


Category: ERT code generation options (1)

Options:

☐ MAT-file logging
☑ Integer code only
☐ Initialize internal data
☐ Initialize external I/O data
☐ Terminate function required
☑ Single output/update function
☐ Insert block descriptions in code

**e** Select `ERT code generation options (2)` from the **Category** menu. Select the **Initialize floats and doubles to 0.0** check box and any other options that you require, as shown below.



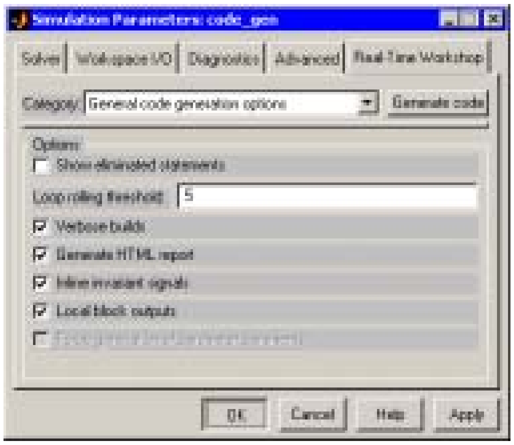
Category: ERT code generation options (2)

Options:

☐ Create Simulink (S-Function) block
☐ Generate ASAP2 file
☑ Initialize floats and doubles to 0.0
☐ Ignore custom storage classes
☐ External mode

Parameter structure: Hierarchical

**f** Select `General code generation` options from the **Category** menu. Select the **Generate HTML report** check box and any other options that you require, as shown below.



Category: General code generation options

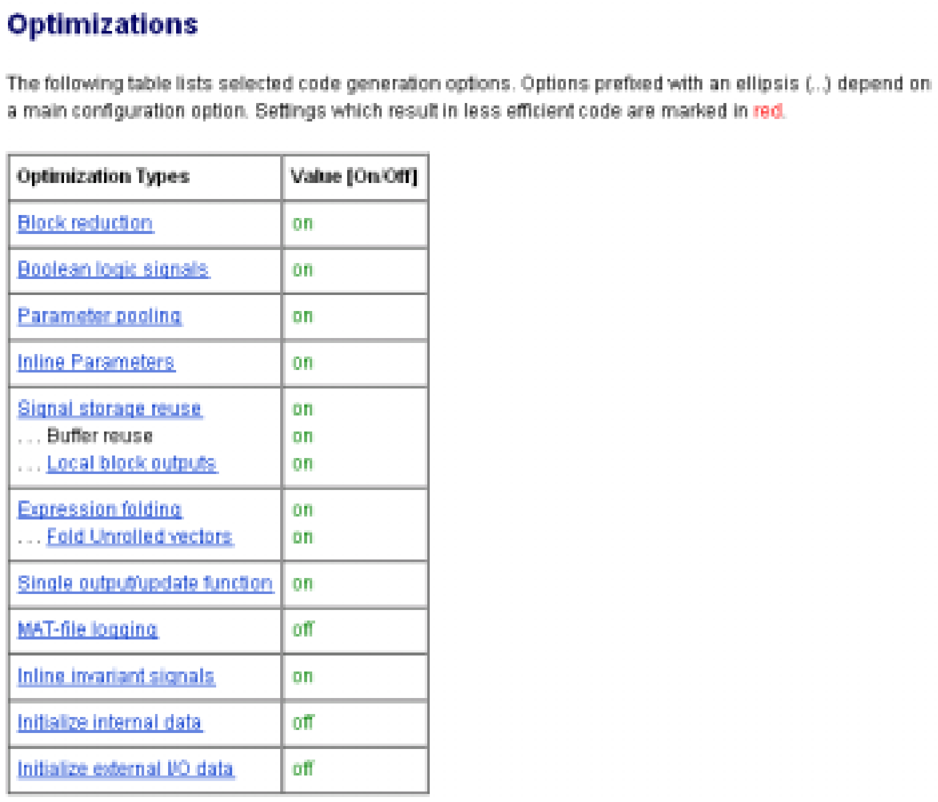
Options:

- [ ] Show eliminated statements
- Loop rolling threshold: 5
- [x] Verbose builds
- [x] Generate HTML report
- [x] Inline invariant signals
- [x] Local block outputs
- [ ] [illegible]

**g** Build the code by selecting the **Generate code** button.

## HTML Report

When you select the **Generate HTML report** check box, Real-Time Workshop creates a report containing information about the generated code. The report, which is displayed in the Help browser, includes a table of the current code generation options. The color of the values in the right column indicates how the values affect code optimization. Values displayed in green are optimal for code generation, while values displayed in red are less than optimal. If you see a red value, change the corresponding setting in the **Simulation Parameters** dialog box. Then select the **Real-Time Workshop** tab and click **Generate Code** to generate new code. A screenshot of a report follows:



## Optimizations

The following table lists selected code generation options. Options prefixed with an ellipsis (...) depend on a main configuration option. Settings which result in less efficient code are marked in red.

| Optimization Types | Value [On/Off] |
|---|---|
| Block reduction | on |
| Boolean logic signals | on |
| Parameter pooling | on |
| Inline Parameters | on |
| Signal storage reuse<br>. . . Buffer reuse<br>. . . Local block outputs | on<br>on<br>on |
| Expression folding<br>. . . Fold Unrolled vectors | on<br>on |
| Single output/update function | on |
| MAT-file logging | off |
| Inline invariant signals | on |
| Initialize internal data | off |
| Initialize external I/O data | off |

The HTML report is contained in a subdirectory called `HTML` in your current working directory.

## Using the Simulink Accelerator

You can use the Simulink Accelerator with your Fixed-Point Blockset model if the model meets the code generation restrictions.

The Simulink Accelerator can drastically increase the speed of some fixed-point models. This is especially true for models that execute at a very large number of time steps. The time overhead to generate code for a fixed-point model will generally be larger than the time overhead to set up a model for simulation. As the number of time steps increases, the relative importance of this overhead decreases.

Refer to the Simulink documentation for more information about the Simulink Accelerator.

## Using External Mode or rsim Target

If you are using the Real-Time Workshop external mode or rapid simulation (rsim) target, there are situations where you may get unexpected errors when tuning block parameters.

These errors can arise when you use blocks that support constant scaling for best precision and you use the `Best precision` scaling option. To avoid these errors, you should use the `Use specified scaling` parameter value. Refer to "Example: Constant Scaling for Best Precision" on page 3-11 for a description of the constant scaling feature. Refer to Chapter 10, "Block Reference" for a description of blocks that support this feature.

For more information about external mode or rapid simulation target, refer to the Real-Time Workshop documentation.

### External Mode

If you change a fixed-point block parameter by a sufficient amount (approximately a factor of two), the binary point changes. If you change a parameter such that the binary point moves during an external mode simulation (or during graphical editing) and you reconnect to the target, a checksum error occurs and you must rebuild the code.

For example, suppose a block has a parameter value of `-2`. You then build the code and connect in external mode. While connected, you change the parameter to `-4`. If the simulation is stopped and then restarted, this parameter change causes a binary point change. In external mode, the binary point is kept fixed. If you keep the parameter value of `-4` and disconnect from the target, then when you reconnect, a checksum error occurs and you must rebuild the code.

### Rapid Simulation Target

If a parameter change is great enough, and you are using the best precision mode for constant scaling, then you cannot use the rapid simulation target.

If you change a block parameter by a sufficient amount (approximately a factor of two), the best precision mode changes the binary point. Any change in the binary point requires the code to be rebuilt since the model checksum is changed. This means that if best precision parameters are changed over a great enough range, you cannot use the rapid simulation target and a checksum error message occurs when you initialize the rsim executable.

## Customizing Generated Code

You can customize generated code by directly modifying the Target Language Compiler file `fixpttarget.tlc`, which is located in the `fixpoint` directory. The two most important customizations are described below.

### Macros Versus Functions

You can modify the TLC file to generate macros or C functions calls. With macros, you can avoid the overhead of a function call. With function calls, you can significantly reduce the overall code size for large routines. Additionally, many debuggers will not allow you to single-step through macros. This is not the case with function calls. The factory default setting is to generate macros.

### Bit Sizes for Target C Compiler

You can modify the TLC file to accommodate custom target sizes by explicitly specifying the number of bits defined for `char`, `short`, `int`, or `long` data types.

If you do not manually override these sizes, then the sizes for the MATLAB host computer are automatically selected. For example, if you are running MATLAB under the Windows operating system, then `char`, `short`, `int`, and `long` default to 8, 16, 32, and 32 bits, respectively. Most other supported operating systems use the same data type sizes. However DEC Alpha, for example, defines a `long` as 64 bits.

# Function Reference

## Functions—By Category

This chapter contains reference pages for the Fixed-Point Blockset M-file functions. In some cases, you will not call these functions from the MATLAB command line. Instead, they are automatically called when you specify certain parameter values via block dialog boxes or via the **Fixed-Point Settings** interface.

| | |
|---|---|
| "Conversions" on page 9-3 | Functions for converting legacy models to fixed-point data types, converting floating-point to fixed-point numbers, and updating fixed-point models |
| "Fixed-Point Settings Interface" on page 9-3 | A function for calling the **Fixed-Point Settings** interface |
| "Global Changes" on page 9-3 | Functions for making global changes throughout a system or subsystem |
| "Lookup Tables" on page 9-3 | Functions for implementing and using lookup tables |
| "Data Type Structures" on page 9-4 | Functions to create MATLAB structures |
| "Tools" on page 9-4 | Functions that yield more information about a simulation or value |

## Conversions

| | |
|---|---|
| `fixpt_convert` | Convert Simulink models and subsystems to fixed-point equivalents |
| `fixpt_convert_prep` | Prepare a Simulink model for more complete conversion to fixed point |
| `fpupdate` | Update obsolete fixed-point blocks from previous Fixed-Point Blockset releases to current fixed-point blocks |
| `num2fixpt` | Quantize a value using a Fixed-Point Blockset representation |

## Fixed-Point Settings Interface

| | |
|---|---|
| `fxptdlg` | Invoke the **Fixed-Point Settings** interface |

## Global Changes

| | |
|---|---|
| `autofixexp` | Automatically change the scaling for each fixed-point block that does not have its scaling locked |
| `fixpt_restore_links` | Restore links for fixed-point blocks |
| `fixpt_set_all` | Set a property for every fixed-point block in a subsystem |

## Lookup Tables

| | |
|---|---|
| `fixpt_interp1` | Implement a 1-D lookup table |
| `fixpt_look1_func_approx` | Optimize, for a fixed-point function, the x values that are generated for a lookup table |
| `fixpt_look1_func_plot` | Plot a function with x values generated by the `fixpt_look1_func_approx` function |

## Data Type Structures

| | |
|---|---|
| `float` | Create a MATLAB structure describing a floating-point data type |
| `sfix` | Create a MATLAB structure describing a signed generalized fixed-point data type |
| `sfrac` | Create a MATLAB structure describing a signed fractional data type |
| `sint` | Create a MATLAB structure describing a signed integer data type |
| `ufix` | Create a MATLAB structure describing an unsigned generalized fixed-point data type |
| `ufrac` | Create a MATLAB structure describing an unsigned fractional data type |
| `uint` | Create a MATLAB structure describing an unsigned integer data type |

## Tools

| | |
|---|---|
| `fixptbestexp` | Determine the exponent that gives the best precision fixed-point representation of a value |
| `fixptbestprec` | Determine the maximum precision available for the fixed-point representation of a value |
| `showfixptsimerrors` | Display overflows from the last simulation |
| `showfixptsimranges` | Display the logged maximum and minimum values from the last simulation |

## Functions—Alphabetical List

The following pages contain the reference pages for the Fixed-Point Blockset functions in alphabetical order.

# autofixexp

**Purpose**

Automatically change the scaling for each fixed-point block that does not have its scaling locked

**Syntax**

```
autofixexp
```

**Description**

The `autofixexp` script automatically changes the scaling for each block that does not have its scaling locked. This script uses the maximum and minimum data obtained from the last simulation run to log data to the workspace. If the maximum and minimum data cover the intended range of your design, `autofixexp` changes the scaling such that the simulation range is covered and the precision is maximized.

---

**Note** The maximum and minimum simulation data must cover the full intended operating range of your design in order for `autofixexp` to yield meaningful results.

---

In order for you to obtain meaningful results from `autofixexp`, the maximum and minimum simulation data used by the script must exercise the full range of values over which your design is meant to run. Therefore, the simulation you run prior to using `autofixexp` should simulate your design over its full intended operating range.

It is especially important that you select inputs with appropriate speed and amplitude profiles for dynamic systems. The response of a linear dynamic system is frequency dependent. For example, a bandpass filter will show almost no response to very slow and very fast sinusoid inputs, whereas the signal of a sinusoid input with a frequency in the passband will be passed or even significantly amplified. The response of nonlinear dynamic systems can have complicated dependence on both the signal speed and amplitude.

For such reasons, practical knowledge of the intended use of your design is the best basis for selecting inputs to exercise your system. Even with well-selected inputs, however, it is often good engineering practice to add a safety margin. If you use the `RangeFactor` variable as described below, `autofixexp` can set the binary points so that an even larger simulation range is covered. A larger range reduces the chance of an overflow occurring. However, increased range results in reduced precision, so the safety margin you choose must be limited.

The script follows these steps:

1 The global variable `FixPtTempGlobal` is created to “steal” parameters (such as data type) from variables not known in the base workspace. For example, assume the Sum block has its output data type specified as `DerivedVar`. `DerivedVar` is derived in the mask initialization based on mask parameters and the block is under a mask.

   The value of the parameter `DerivedVar` is retrieved by temporarily replacing `DerivedVar` with `stealparameter(DerivedVar)` in the block dialog. A model update is then forced. When `stealparameter(DerivedVar)` is evaluated, it returns the value of `DerivedVar` without modification and stores the value in `FixPtTempGlobal`. The stolen value is immediately used by this procedure and is not needed again. Therefore, the procedure can move from one block to the next using the same global variable.

2 The `RangeFactor` variable allows you to specify a range differing from that defined by the maximum and minimum values logged in `FixPtSimRanges`. For example, a `RangeFactor` value of 1.55 specifies that a range *at least* 55 percent larger is desired. A value of 0.85 specifies that a range *up to* 15 percent smaller is acceptable.

   You should be aware that the scaling is not exact for the binary point-only case since the range is given (approximately) by a power of two. The lower limit is exact, but the upper limit is always one bit below a power of two.

   For example, if the maximum logged value is 5 and the minimum logged value is -0.5, then any `RangeFactor` from 4/5 to slightly under 8/5 would produce the same binary point since these limits are less than a factor of two from each other. The binary point selected will produce a range from -8 to +8 (minus a bit).

3 The global variable `FixPtSimRanges` is retrieved from the workspace. This is the variable that holds the maximum and minimum simulation values.

4 The workspace is searched for the variables `SlopeBits` and `BiasBits`, which specify the number of bits to use in representing slopes and biases. If these variables are not found, then they are automatically created with default values of 7 and 8, respectively.

5 All blocks that logged maximum and minimum simulation data are processed.

6 All blocks that do not have their scaling locked are automatically scaled. If the data type class is `FIX`, then binary point-only scaling is performed. If the

data type class is `INT`, then [Slope Bias] scaling is performed. To find out a data type's class, refer to its reference page.

**See Also** `fxptdlg`, `showfixptsimranges`

## Purpose

Determine the exponent that gives the best precision fixed-point representation of a value

## Syntax

```
out = fixptbestexp(RealWorldValue,TotalBits,IsSigned)
out = fixptbestexp(RealWorldValue,FixPtDataType)
```

## Description

`out = fixptbestexp(RealWorldValue,TotalBits,IsSigned)` determines the exponent that gives the best precision for the fixed-point representation of the real-world value specified by `RealWorldValue`. You specify the number of bits for the fixed-point number with `TotalBits`, and you specify whether the fixed-point number is signed with `IsSigned`. If `IsSigned` is `1`, the number is signed. If `IsSigned` is `0`, the number is not signed. The exponent is returned to `out`.

`out = fixptbestexp(RealWorldValue,FixPtDataType)` determines the exponent that gives the best precision based on the data type specified by `FixPtDataType`.

## Examples

The following command returns the exponent that gives the best precision for the real-world value 4/3 using a signed, 16-bit number:

```
out = fixptbestexp(4/3,16,1)
out =
   -14
```

Alternatively, you can specify the fixed-point data type:

```
out = fixptbestexp(4/3,sfix(16))
out =
   -14
```

This value means that the maximum precision representation of 4/3 is obtained by placing 14 bits to the right of the binary point:

01.01010101010101

You would specify the precision of this representation in fixed-point blocks by setting the scaling to `2^-14` or `2^fixptbestexp(4/3,16,1)`.

## See Also

`fixptbestprec`, `sfix`, `ufix`

# fixptbestprec

## Purpose

Determine the maximum precision available for the fixed-point representation of a value

## Syntax

```
out = fixptbestprec(RealWorldValue,TotalBits,IsSigned)
out = fixptbestprec(RealWorldValue,FixPtDataType)
```

## Description

`out = fixptbestprec(RealWorldValue,TotalBits,IsSigned)` determines the maximum precision for the fixed-point representation of the real-world value specified by `RealWorldValue`. You specify the number of bits for the fixed-point number with `TotalBits`, and you specify whether the fixed-point number is signed with `IsSigned`. If `IsSigned` is `1`, the number is signed. If `IsSigned` is `0`, the number is not signed. The maximum precision is returned to `out`.

`out = fixptbestprec(RealWorldValue,FixPtDataType)` determines the maximum precision based on the data type specified by `FixPtDataType`.

## Examples

The following command returns the maximum precision available for the real-world value 4/3 using a signed, 8-bit number:

```
out = fixptbestprec(4/3,8,1)
out =
   0.015625
```

Alternatively, you can specify the fixed-point data type:

```
out = fixptbestprec(4/3,sfix(8))
out =
   0.015625
```

This value means that the maximum precision available for 4/3 is obtained by placing six bits to the right of the binary point since $2^{-6}$ equals 0.015625:

01.010101

You can use the maximum precision as the scaling parameter in fixed-point blocks.

## See Also

`fixptbestexp`, `sfix`, `ufix`

## Purpose

Convert Simulink models and subsystems to fixed-point equivalents

## Syntax

```
res = fixpt_convert
res = fixpt_convert('SystemName')
res = fixpt_convert('SystemName','Display')
res = fixpt_convert('SystemName','Display','AutoSave')
```

## Description

`res` is a structure that contains lists of blocks handled during conversion. `res = fixpt_convert` converts the Simulink model or subsystem specified by `bdroot`. The fields of this structure are given below.

| Output Field | Description |
|---|---|
| `encapsulated` | Structure containing lists of blocks grouped by type that are encapsulated between fixed-point gateway blocks. The encapsulated versions are not truly fixed-point, but they will function within a fixed-point model. |
| `replaced` | Blocks that are replaced with fixed-point equivalents or with other blocks from a user-specified replacement list. |
| `skipped` | Blocks that are skipped because they are fixed-point compatible. Some of these blocks can cause errors if used in certain ways. For example, the Mux block can create lines that give different data types at downstream input ports. |

`res = fixpt_convert('SystemName')` converts the Simulink model or subsystem specified by `SystemName`.

`res = fixpt_convert('SystemName','`*`Display`*`')` returns information associated with the conversion according to the method specified by *`Display`*. The *`Display`* methods are given below.

| Display Method | Description |
|---|---|
| `filename` | Write detailed block information to the specified file. |
| `off` | Do not display block information. |

| Display Method | Description |
|---|---|
| `on` | Display detailed block information. |
| `on+filename` | Display detailed block information, and write detailed block information to the specified file. |
| `outline` | Display the conversion process outline. |
| `outline+filename` | Display the conversion process outline, and write detailed block information to the specified file. |

`res = fixpt_convert('SystemName','`*`Display`*`','`*`AutoSave`*`')` determines the state of the converted model or subsystem. If *`AutoSave`* is `on`, then the converted model or subsystem is saved and closed. If *`AutoSave`* is `off`, then the converted model or subsystem is unsaved and left open.

## Remarks

If your Simulink model references blocks from a custom Simulink library, then these blocks are encapsulated upon conversion. A block is encapsulated when it cannot be converted to an equivalent fixed-point block. Encapsulation involves associating a Gateway In or a Gateway Out block with the Simulink block. To reduce the number of blocks that are encapsulated, you should convert the entire library by passing the library name to `fixpt_convert`, and then converting the model.

To create a custom list of blocks to convert, you should use the `fixpt_convert_userpairs` script. To learn how to use this script, read the comments included in the M-file.

The data types for fixed-point outputs taking Boolean values are specified by the variable `LogicType`. The data types of all other fixed-point outputs and parameters are specified by the variable `BaseType`. You can change these variables to any data type. For example, in the MATLAB workspace you can type

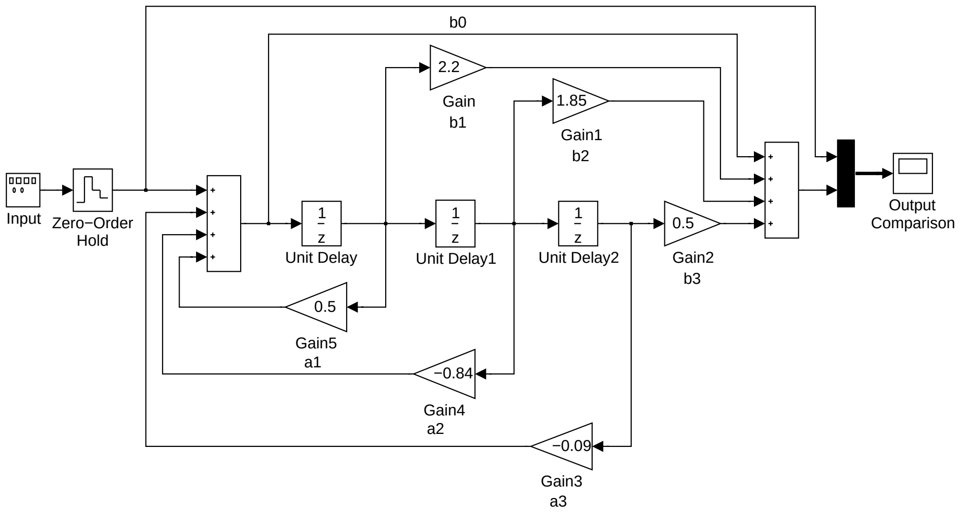
```
BaseType = sfix(16)
LogicType = uint(8)
```

The converted model will not work if these variables are not defined.

Best precision mode is used when available. Otherwise, the precision is set to $2^0$, which means that the binary point is to the right of all bits. To automatically set the scaling, run a simulation with doubles override on and then invoke the automatic scaling script, `autofixexp`. You can run `autofixexp` directly, or in conjunction with the **Fixed-Point Settings** interface, `fxptdlg`.

## Examples

This example uses `fixpoint_convert` to convert a Simulink model of a direct form II realization to its fixed-point equivalent. "Direct Form II" on page 5-7 discusses this realization. The Simulink model shown below, `fxpdemo_preconvet`, is included as a demo with the blockset.



The following command converts this model to its fixed-point equivalent, suppresses the display of detailed block information, and does not save the model after conversion:

```
res = fixpt_convert('fxpdemo_preconvert','off','off')
```

The built-in blocks that are replaced by fixed-point equivalent blocks are given by the `replaced` field:

```
res.replaced
ans =
        UnitDelay: {3x1 cell}
    ZeroOrderHold: {[1x40 char]}
             Gain: {6x1 cell}
              Sum: {2x1 cell}
```

The built-in blocks that are skipped since they are compatible with the Fixed-Point Blockset are given by the `skipped` field:

```
res.skipped
ans =
Mux: {'fxpdemo_preconvert_fixpt/Mux'}
```

The built-in blocks that are encapsulated by fixed-point gateway blocks so that they are made compatible with the Fixed-Point Blockset are given by the `encapsulated` field:

```
res.encapsulated
ans =
              Scope: {[1x42 char]}
    SignalGenerator: {'fxpdemo_preconvert_fixpt/Input'}
```

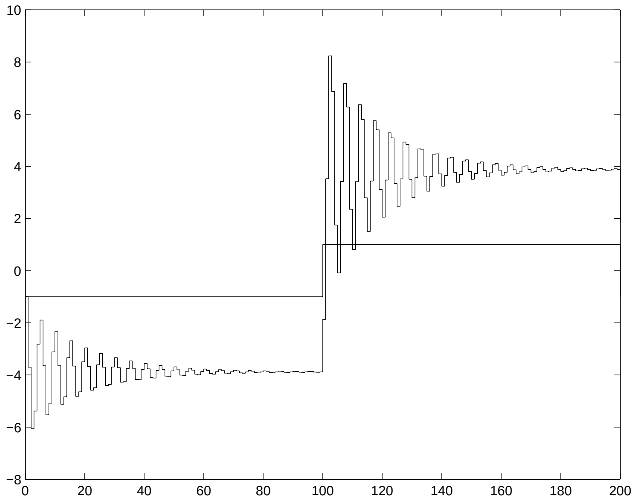
Note that the initial class of the base data type is `double`:

```
BaseType =
    Class: 'DOUBLE'
```

You can now run the simulation for the converted model:

```
sim fxpdemo_preconvert_fixpt
```

The output from the simulation is shown below. You should compare this output to the output produced by the fixed-point direct from II model, `fxpdemo_direct_form2`.



Next, define a fixed-point base data type:

```
BaseType = sfix(16)
```

Follow the automatic scaling procedure described in the `autofixexp` reference pages with 20% safety margin, and then run the simulation:

```
sim fxpdemo_preconvert_fixpt
```

The simulation now produces an error. This is because the vector signal leading into the scope is not homogeneous with regard to data type and scaling.

In general, solving the problem of nonhomogeneous signals requires that you analyze how the signal is being used. If the distinct scaling and data type properties are important, then you must fully or partially unvectorize the relevant part of the model. Alternatively, you can force the signals to be homogenous using the Gateway Out block. Since this example plots real-world values in the Scope, inserting gateway blocks on the signals leading into the Scope is an adequate solution.

## See Also

`autofixexp`, `fixpt_convert_prep`, `fxptdlg`

# fixpt_convert_prep

## Purpose

Prepare a Simulink model for more complete conversion to fixed-point data types

## Syntax

```
fixpt_convert_prep('SystemName')
```

## Description

`fixpt_convert_prep('SystemName')` prepares the Simulink model or subsystem specified by `SystemName` for more complete conversion (less encapsulation) to fixed-point data types using the `fixpt_convert` function. It does so by replacing this select set of blocks:

- Old style Latch blocks

  Old style Latch blocks are replaced with a version contained in the `fixpt_convert_lib` library. The old style Latch block contains a Transport Delay block, which is a very inefficient implementation for both floating-point and fixed-point data types.
- Function blocks acting like selectors

  Function blocks acting like selectors are replaced with the Selector block. Function blocks acting like selectors require that you specify the width of the input. To get this information, the model must be put into compile mode, which is inefficient.
- A select set of additional function blocks

  You can replace function blocks that have replacements in the `fixpt_convert_lib` library. Alternatively, you can use `fixpt_convert_prep` as a prototype for creating a customized list of function blocks to be replaced. To do this, copy the function and the library to another directory, and then customize the library to include function blocks that you commonly encounter when converting models from floating point to fixed point.

---

**Note** This function is meant to be a starting point for customizing the Simulink to Fixed-Point Blockset conversion process.

---

## See Also

`fixpt_convert`

## Purpose

Implement a 1-D lookup table

## Syntax

```
y = fixpt_interp1(xdata,ydata,x,xdt,xscale,ydt,yscale,rndmeth)
```

## Description

`fixpt_interp1(xdata,ydata,x,xdt,xscale,ydt,yscale,rndmeth)` implements a lookup table to find output(s) `y` for input(s) `x`. If `x` falls between two `xdata` values, then `y` is found by interpolating between the corresponding `ydata` pair. If `x` falls above the range given by `xdata`, `y` is given as the maximum `ydata` value. If `x` falls below the range given by `xdata`, `y` is given as the minimum `ydata` value.

If either the input data type, `xdt`, or the output data type, `ydt`, is floating point, then floating-point calculation is used to perform the interpolation. Otherwise, integer-only calculation is used. This calculation handles the input scaling, `xscale`, and the output scaling, `yscale`, appropriately, and obeys the designated rounding method, `rndmeth`.

## Examples

Define `xdata` as a vector of 33 evenly spaced points between 0 and 8, and `ydata` as the sinc of `xdata`.

```
xdata = linspace(0,8,33).';
ydata = sinc(xdata);
```

Now define your input `x` as a vector of 201 evenly spaced points between -1 and 9.

```
x = linspace(-1,9,201).';
```

Notice that `x` includes some values that are both lower and higher than the range of `xdata`.

You can now use `fixpt_interp1` to interpolate outputs for `x`.

```
y = fixpt_interp1(xdata,ydata,x,sfix(8),2^-3,sfix(16),2^-14,...
'Floor')
```

## See Also

`fixpt_look1_func_approx`, `fixpt_look1_func_plot`, `sfix`

# fixpt_look1_func_approx

## Purpose

Optimize for a fixed-point function, the x values, or breakpoints, that are generated for a lookup table

## Syntax

```
[xdata,ydata,errworst]=fixpt_look1_func_approx('funcstr',...
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,errmax)
```

```
[xdata,ydata,errworst]=fixpt_look1_func_approx('funcstr',...
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,[],nptsmax)
```

```
[xdata,ydata,errworst]=fixpt_look1_func_approx('funcstr',...
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,errmax,nptsmax)
```

```
[xdata,ydata,errworst]=fixpt_look1_func_approx('funcstr',...
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,errmax,nptsmax,spacing)
```

## Description

`fixpt_look1_func_approx('funcstr',xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,errmax)` optimizes the breakpoints of a lookup table over a specified range. The lookup table satisfies the maximum acceptable error, maximum number of points, and spacing requirements given by the optional parameters. The breakpoints refer to the x values of the lookup table. The command

```
[xdata,ydata,errworst]=fixpt_look1_func_approx('funcstr',...
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,errmax)
```

returns the X and Y coordinates of the lookup table as vectors `xdata` and `ydata`, respectively. It also returns the maximum absolute error of the lookup table as a variable `errworst`.

The fixed-point approximation is found by interpolating between the lookup table data points. The required input parameters are as follows.

| Input | Value |
|---|---|
| `'funcstr'` | Function of `x` `funcstr` is the function for which breakpoints are approximated. |
| `xmin` | Minimum value of `x` |
| `xmax` | Maximum value of `x` |
| `xdt` | Data type of `x` |

| Input | Value |
|---|---|
| xscale | Scaling for the x values |
| ydt | Data type of y |
| yscale | Scaling for the y values |
| rndmeth | Rounding mode supported by the Fixed-Point Blockset: 'Toward Zero', 'Nearest', 'Floor' (default value), 'Ceiling' |

- xmin and xmax specify the range over which the breakpoints are approximated.
- xdt, xscale, ydt, yscale, and rndmeth follow conventions used by the Fixed-Point Blockset.
- rndmeth has a default value listed in the input table.

In addition to the required parameters, there are three optional inputs, as follows.

| Input | Value |
|---|---|
| errmax | Maximum acceptable error |
| nptsmax | Maximum number of points |
| errworst | Spacing: 'even', 'pow2' (even power of 2), 'unrestricted' (default value) |

Of these, you must use at least one of the parameters errmax and nptsmax. If you omit one of these, use brackets, [], in place of the omitted parameter. The function will then ignore that requirement for the lookup table.

The outputs of the function are as follows.

| Output | Value |
|---|---|
| `xdata` | The breakpoints for the lookup table |
| `ydata` | The ideal function applied to the breakpoints |
| `errworst` | The worst case error, which is the maximum absolute error between the ideal function and the approximation given by the lookup table |

### Criteria For Optimizing the Breakpoints: errmax, nptsmax, and spacing

The approximation produced from the lookup table must satisfy the requirements for the maximum acceptable error, `errmax`, the maximum number of points, `nptsmax`, and the spacing, `spacing`. The requirements are

- The maximum absolute error is less than `errmax`.
- The number of points required is less than `nptsmax`.
- The spacing is specified as unrestricted, even or even power of 2.

### Modes for errmax and nptsmax

- If both `errmax` and `nptsmax` are specified

  The returned breakpoints will meet both criteria if possible. The `errmax` parameter is given priority, and `nptsmax` is ignored, if both criteria cannot be met with the specified spacing.
- If only `errmax` is specified

  The breakpoints that meet the error criteria, and have the least number of points are returned
- If only `nptsmax` is specified

  The breakpoints that require `nptsmax` or fewer, and give the smallest worst case error are returned

### Modes for Spacing

If no spacing is specified, and more than one spacing method meets the requirements given by `errmax` and `nptsmax`, power of 2 spacing is chosen over even spacing, which in turn is chosen over uneven spacing. This case occurs when the `errmax` and `nptsmax` are both specified, but typically does not occur when only one is specified:

- If `unrestricted` is entered, the function chooses the spacing that provides the best optimization.
- If `even` is entered, the function chooses an evenly spaced set of points, including the `pow2` spacing.
- If `pow2` spacing is entered, the function chooses an even power of 2 spaced set of points.

---

**Note** The global optimum may not be found. The worst case error can depend on fixed-point calculations, which are highly nonlinear. Furthermore, the optimization approach is heuristic.

---

The spacing you choose depends on the parameters you want to optimize: execution speed, function approximation error, ROM usage, and RAM usage:

- The execution speed depends on the bisection search, and the interpolation method.
- The error depends on how accurately the method approximates the nonuniform curvature of the function.
- The ROM usage depends on the amount of data and command ROM used.
- The RAM usage depends on how much global and stack RAM is used.

When the lookup table has even power of two spacing, division is replaced by a bit shift. As a result, the execution speed is faster than for evenly spaced data.

### Using the Approximation Function

1. Choose a function and use the `eval('funcstr');` command to view the function before creating the lookup table.
2. Define the remaining inputs.
3. Run the `fixpt_look1_func_approx` function.

4 Use the `fixpt_look1_func_plot` function to plot the function from the selected breakpoints, and to calculate the error and the number of points used.

5 Vary the inputs to produce sets of breakpoints that generate functions with varying number of points required and worst case error.

6 Compare the number of points required and worst case error from various runs to choose the best set of breakpoints.

### Calculating the Output Function

To calculate the function, use the returned breakpoints with

- The `eval` function
- A function lookup table. The x values are the breakpoints from the `fixpt_look1_func_approx` function, and the y values can be supplied using the `eval` function.

See Chapter 7, "Tutorial: Producing Lookup Table Data" for a tutorial on using `fixpt_look1_func_approx`.

The following table summarizes the effect of spacing on the execution speed, error, and memory used.

| Parameter | Even Power of Two Spaced Data | Evenly Spaced Data | Unevenly Spaced Data |
|---|---|---|---|
| Execution Speed | The execution speed is the fastest. The position search and interpolation are the same as for evenly spaced data. However, to increase the speed more, the position search is replaced by a bit shift, and the interpolation is replaced with a bit mask. | The execution speed is faster then that for unevenly spaced data because the position search is faster and the interpolation requires a simple division. | The execution speed is the slowest of the different spacings because the position search is slower, and the interpolation requires more operations. |
| Error | The error can be larger than that for unevenly spaced data because approximating a function with nonuniform curvature requires more points to achieve the same accuracy. | The error can be larger than that for unevenly spaced data because approximating a function with nonuniform curvature requires more points to achieve the same accuracy. | The error can be smaller because approximating a function with nonuniform curvature requires fewer points to achieve the same accuracy. |
| ROM Usage | Uses less command ROM, but more data ROM. | Uses less command ROM, but more data ROM. | Uses more command ROM, and less data ROM. |
| RAM Usage | Not significant. | Not significant. | Not significant. |

## Examples

This example produces a lookup table for a sine function. The inputs for the example are as follows:

```
funcstr = 'sin(2*pi*x)';
xmin = 0;
xmax = 0.25;
xdt = ufix(16);
xscale = 2^-16;
ydt = sfix(16);
yscale = 2^-14;
rndmeth = 'Floor';
errmax = 2^-10;
spacing = 'pow2';
```

To create the lookup table, type

```
[xdata, ydata, errWorst]=fixpt_look1_func_approx(funcstr,
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth,errmax,[],spacing);
```

The brackets [ ] are a place holder for the `nptsmax` parameter, which is not used in this example.

You can then plot the ideal function, the approximation, and the errors by typing

```
fixpt_look1_func_plot(xdata,ydata,funcstr,xmin,xmax,xdt,...
xscale,ydt,yscale,rndmeth);
```

The `fixpt_look1_func_plot` function produces a plot of the fixed-point sine function, using these breakpoints, and a plot of the error between the ideal function and the fixed-point function. The maximum absolute error and the number of points required are listed with the plot. The error drops to zero at a breakpoint, and increases between breakpoints due to the difference in curvature of the ideal function and the line drawn between breakpoints.

The resulting plots are shown.

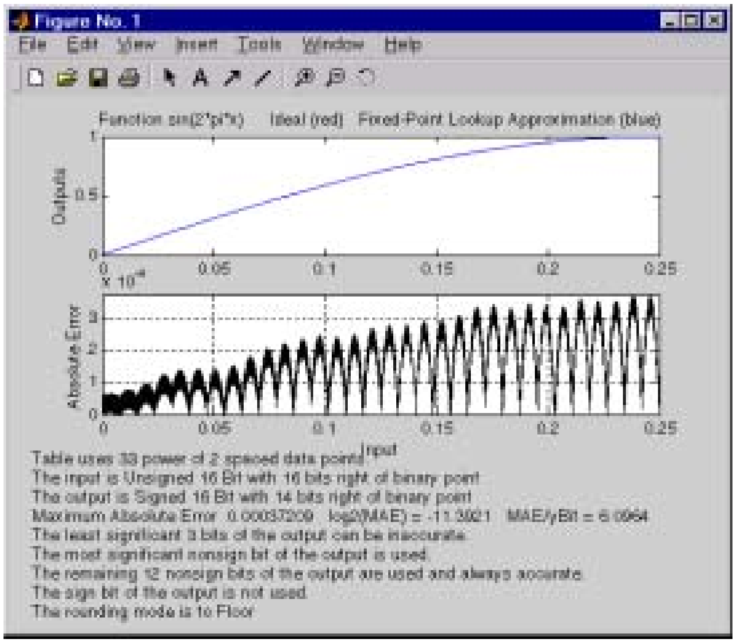


Figure No. 1
File Edit View Insert Tools Window Help
Function sin(2*pi*x) Ideal (red) Fixed-Point Lookup Approximation (blue)
Outputs
Absolute Error
x 10^-4
Input

```
Table uses 33 power of 2 spaced data points
The input is Unsigned 16 Bit with 16 bits right of binary point
The output is Signed 16 Bit with 14 bits right of binary point
Maximum Absolute Error 0.00037209  log2(MAE) = -11.3921  MAE/yBit = 6.0964
The least significant 3 bits of the output can be inaccurate
The most significant nonsign bit of the output is used
The remaining 12 nonsign bits of the output are used and always accurate
The sign bit of the output is not used
The rounding mode is to Floor
```

The lookup table requires 33 points to achieve a maximum absolute error of `2^-11.3922`.

**See Also** `fixpt_look1_func_plot`

# fixpt_look1_func_plot

## Purpose

Plot a function with x values generated by the `fixpt_look1_func_approx` function

## Syntax

```
errworst=fixpt_look1_func_plot(xdata,ydata,'funcstr',...
xmin,xmax,xdt,xscale,ydt,yscale,rndmeth)
```

## Description

`fixpt_look1_func_plot(xdata,ydata,'funcstr',xmin,xmax,xdt,xscale, ydt,yscale,rndmeth)` plots a lookup table approximation function and its error from the ideal function. You can use the `fixpt_look1_func_approx` function to generate `xdata` and `ydata`, the X and Y data points for the lookup table. The function returns the maximum absolute error as a variable `errworst`. The inputs are as follows.

| Input | Value |
|---|---|
| `xdata` | `x` values for the lookup table |
| `ydata` | `y` values for the lookup table |
| `'funcstr'` | Function of `x` |
| `xmin` | Minimum input of interest |
| `xmax` | Maximum input of interest |
| `xdt` | Data type of `x` |
| `xscale` | Scaling for the `x` values |
| `ydt` | Data type of `y` |
| `yscale` | Scaling for the `y` values |
| `rndmeth` | Rounding mode supported by the blockset: `'Toward Zero'`, `'Nearest'`, `'Floor'`, `'Ceiling'` |

The `fixpt_look1_func_approx` function applies the ideal function to the points in `xdata` to produce `ydata`. While this is the easiest way to generate `ydata`, you are not required to use these values for `ydata` as input for the `fixpt_look1_func_approx` function. Choosing different values for `ydata` can, in some cases, produce a lookup table with a smaller maximum absolute error.

See Chapter 7, “Tutorial: Producing Lookup Table Data” for a tutorial on using the function `fixpt_look1_func_plot`. For an example of the function, see the reference page for the `fixpt_look1_func_approx` function.

**See Also** `fixpt_look1_func_approx`

# fixpt_restore_links

## Purpose

Restore links for fixed-point blocks

## Syntax

```
res = fixpt_restore_links
res = fixpt_restore_links('SystemName')
res = fixpt_restore_links('SystemName','AutoSave')
```

## Description

`res = fixpt_restore_links` restores broken links for the fixed-point blocks contained in the model or subsystem specified by `bdroot`. By default, the models and libraries containing restored block links are left open and unsaved. `res` contains the names of the blocks that had broken links restored.

`res = fixpt_restore_links('SystemName')` restores links for the fixed-point blocks contained in the model or subsystem specified by `SystemName`.

`res = fixpt_restore_links('SystemName','`*`AutoSave`*`')` determines the state of the models or subsystems containing restored block links. If *`AutoSave`* is `on`, the models or subsystems are saved and closed. If *`AutoSave`* is `off`, the models or subsystems are unsaved and left open.

## Remarks

Breaking library links to fixed-point blocks will almost certainly produce an error when you attempt to run the model. If broken links exist, you will likely uncover them when upgrading to the latest release of the Fixed-Point Blockset.

**Purpose** Set a property for every fixed-point block in a subsystem

**Syntax**

```
fixpt_set_all(SystemName,fixptPropertyName,fixptPropertyValue)
```

**Description** `fixpt_set_all` sets the property `fixptPropertyName` of every applicable block in the model or subsystem `SystemName` to the value `fixptPropertyValue`.

**Examples** To set every fixed-point block in a model called `Filter_1` to round towards the floor and to saturate upon overflow, type

```
fixpt_set_all('Filter_1','RndMeth','Floor')
fixpt_set_all('Filter_1','DoSatur','on')
```

# float

## Purpose

Create a MATLAB structure describing a floating-point data type

## Syntax

```
a = float('single')
a = float('double')
a = float(TotalBits, ExpBits)
```

## Description

`float('single')` returns a MATLAB structure that describes the data type of an IEEE single (32 total bits, 8 exponent bits).

`float('double')` returns a MATLAB structure that describes the data type of an IEEE double (64 total bits, 11 exponent bits).

`float(TotalBits, ExpBits)` returns a MATLAB structure that describes a nonstandard floating-point data type that mimics the IEEE style. That is, the numbers are normalized with a hidden leading one for all exponents except the smallest possible exponent. However, the largest possible exponent might not be treated as a flag for Infs and NaNs.

`float` is automatically called when a floating-point number is specified in a block dialog box.

---

**Note** Unlike fixed-point numbers, floating-point numbers are not subject to any specified scaling.

---

## Examples

Define a nonstandard, IEEE-style, floating-point data type with 31 total bits (excluding the hidden leading one) and 9 exponent bits:

```
a = float(31,9)
a =
       Class: 'FLOAT'
    MantBits: 21
     ExpBits: 9
```

## See Also

`sfix`, `sfrac`, `sint`, `ufix`, `ufrac`, `uint`

## Purpose

Update obsolete fixed-point blocks from previous Fixed-Point Blockset releases to current fixed-point blocks

## Syntax

```
fpupdate('model')
fpupdate('model',blkprompt)
fpupdate('model',blkprompt,varprompt)
fpupdate('model',blkprompt,varprompt,muxprompt)
fpupdate('model',blkprompt,varprompt,muxprompt,message)
```

## Description

`fpupdate('model')` replaces all obsolete fixed-point blocks contained in `model` with current fixed-point blocks. The model must be opened prior to calling `fpupdate`.

`fpupdate('model',blkprompt)` prompts you for replacement of obsolete blocks. If `blkprompt` is 0 (the default), you will not be prompted. If `blkprompt` is 1, you will have these three options:

- `y` (default) replaces the block.
- `n` does not replace the block.
- `a` replaces all blocks without further prompting.

`fpupdate('model',blkprompt,varprompt)` gives you the option of updating variables that appear in each block's dialog box with their actual numerical values. Note that such an update is possible only if the variables can be evaluated in the MATLAB workspace. If `varprompt` is 1 (the default), you are prompted for each variable found in the block diagram. If `varprompt` is 0, all variables are automatically updated without prompting.

`fpupdate('model',blkprompt,varprompt, muxprompt)` allows you to update the input size parameters of the Mux and Demux blocks found in `model`. The input sizes of these blocks may need to be updated to account for the mismatch between the old and new fixed-point data representations. In the old representation, each number had a width of 2. In the new representation, each number has a width of 1. To update Mux and Demux blocks that have only fixed-point inputs, the vector that specifies the input size should be divided by 2. If `muxprompt` is 1 (the default), each Mux and Demux block found in `model` is updated. If `muxprompt` is 0, the Mux and Demux blocks are automatically updated without prompting.

`fpupdate('model',blkprompt,varprompt,muxprompt,message)` allows you to show or suppress any warning or update messages generated during the update process. If `message` is 1 (the default), all messages are displayed. If `message` is 0, all messages are suppressed.

`fpupdate` calls `addterms` to terminate any unconnected input or output ports by attaching Ground or Terminator blocks, respectively.

## Examples

To see how `fpupdate` works, convert the obsolete model `fixpoint/obsolete/fpex1.mdl`:

```
fpex1
fpupdate('fpex1')
```

## Purpose

Invokes the **Fixed-Point Settings** interface

## Syntax

```
fxptdlg('model')
```

## Description

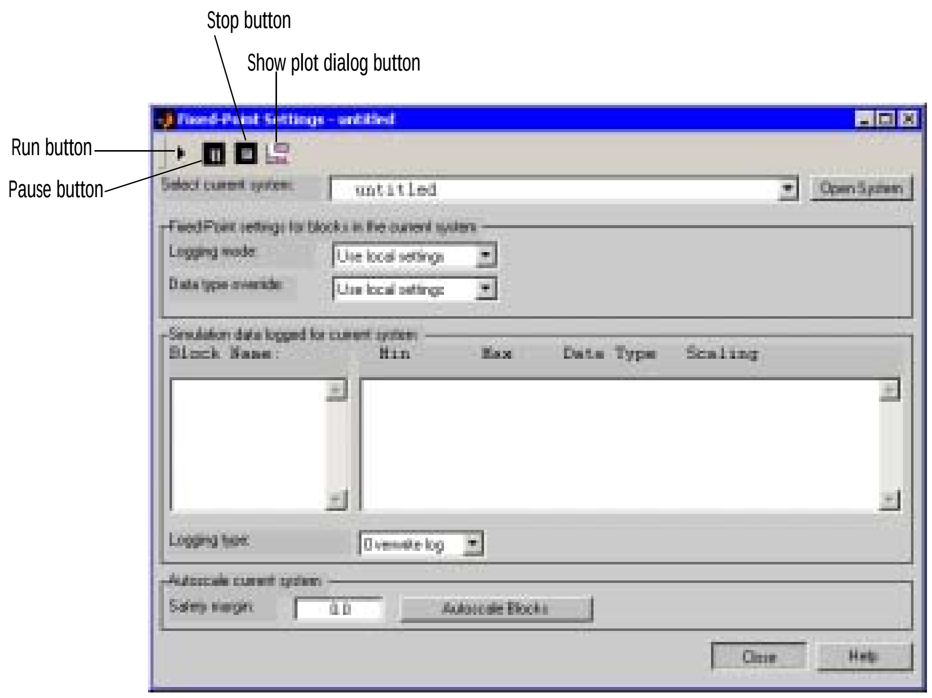
`fxptdlg('model')` brings up the **Fixed-Point Settings** interface for the MDL-file `model`. You can also invoke this interface by

- Selecting **Fixed-Point settings** in the **Tools** menu in the model window
- Right-clicking in any subsystem and selecting **Fixed-Point settings** from the menu that pops up
- Clicking on the FixPt GUI block, which is included with all blockset demos

The **Fixed-Point Settings** interface provides convenient access to global data type overrides and logging settings, the logged data, the automatic scaling script, and the Plot System interface. You can invoke the **Fixed-Point Settings** interface for any system or subsystem, and it controls the model specified by the **Select current system** parameter.

For each block in the model that logs data, the **Fixed-Point Settings** interface displays its name, minimum simulation value, maximum simulation value, data type, and scaling in the **Simulation data logged for current system** pane. Additionally, if a signal saturates or overflows, a message is displayed for the associated block indicating how many times saturation or overflow occurred. You can display a block's dialog box by double-clicking on the appropriate block entry in this pane.

## Parameters and Dialog Box



Fixed-Point Settings - untitled

Select current system: untitled

Fixed-Point settings for blocks in the current system

Logging mode: Use local settings

Data type override: Use local settings

Simulation data logged for current system

Block Name: Min Max Data Type Scaling

Logging type: Overwrite log

Autoscale current system

Safety margin: 0.0

**Select current system**

Displays the names of all systems and subsystems in currently opened models in a hierarchical format. The menu can be expanded and collapsed using the + and - signs. The information displayed in the rest of the **Fixed-Point Settings** interface applies to the subsystem designated by this parameter.

**Logging mode**

Controls which blocks log data. The value of this parameter for parent systems controls logging for all child subsystems, unless `Use local settings` is selected:

- `Use local settings`—Data is logged according to the value of this parameter set for each subsystem. Otherwise, settings for parent systems always override those of child systems.

- `Min, max and overflow`—Minimum value, maximum value, and overflow data is logged for all blocks in the current system or subsystem.
- `Overflow`—Only overflow data is logged for all blocks in the current system or subsystem.
- `Force off`—No data is logged for any block in the current system or subsystem. Use this selection to work with models containing fixed-point enabled blocks if you do not have a Fixed-Point Blockset license.

**Data type override**

Controls data type override. The value of this parameter for parent systems controls data type override for all child subsystems, unless `Use local settings` is selected:

- `Use local settings`—Data types are overridden according to the value of this parameter set for each subsystem. Otherwise, settings for parent systems override those of child systems.
- `Scaled doubles`—The output data type of all blocks in the current system or subsystem is overridden with doubles, however the scaling and bias specified in the mask of each block is maintained.
- `True doubles`—The output data type of all blocks in the current system or subsystem is overridden with true doubles. The overridden values have no scaling or bias.
- `True singles`—The output data type of all blocks in the current system or subsystem is overridden with true singles. The overridden values have no scaling or bias.
- `Force off`—No data type override is performed on any block in the current system or subsystem.

Set this parameter to `True doubles` or `True singles` to work with models containing fixed-point enabled blocks if you do not have a Fixed-Point Blockset license.

**Block Name**

Displays blocks that log data in the selected system or subsystem. The block path is described in terms of the blockset model name. The minimum value, maximum value, data type, and scaling are shown opposite each block name when the simulation is run.

**Logging type**

Controls the logging type:

- `Overwrite log`—Information in the **Simulation data logged for current system** pane is completely cleared before new logging data is entered.
- `Merge log`—New logging data is merged with any information previously appearing in the **Simulation data logged for current system** pane.

**Safety margin**

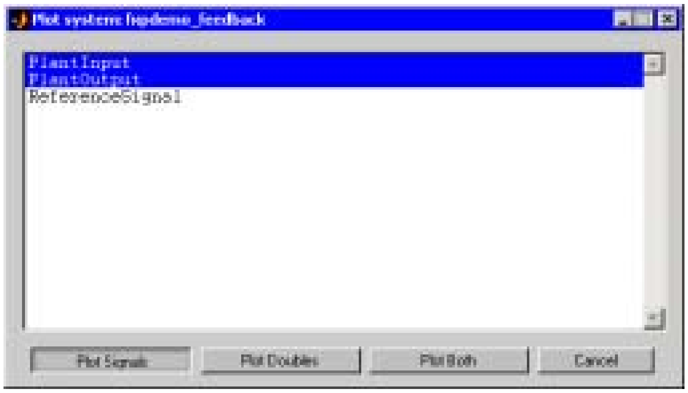
The **Safety margin** parameter is used as part of the automatic scaling procedure. Before automatic scaling is performed, you must run the simulation to collect min/max data. To learn how to do this, refer to Chapter 6, "Tutorial: Feedback Controller Simulation."

Simulation values are multiplied by the factor designated by this parameter, allowing you to specify a range different from that defined by the maximum and minimum values logged to the workspace. For example, a value of 55 specifies that a range *at least* 55 percent larger is desired. A value of -15 specifies that a range *up to* 15 percent smaller is acceptable.

The **Fixed-Point Settings** interface contains eight buttons:

- Run runs the model and updates the display with the latest simulation information.
- Pause pauses the simulation.
- Stop stops the simulation from running.
- Show plot dialog invokes the **Plot systems** interface, which displays any To Workspace, Outport, or Scope blocks found in the model.
- **Open System** invokes the **Fixed-Point Settings** interface for the system or subsystem displayed in the **Select current system** parameter.
- **Autoscale Blocks** invokes the automatic scaling script `autofixexp`.
- **Close** closes the interface.
- **Help** displays the HTML-based help for the `fxptdlg` function.

The **Plot systems** interface is shown below. In this example it is displaying variable names that correspond to Scope block outputs from the `fxpdemo_feedback` demo.



To plot the simulation results, select one or more variable names, and then select the appropriate plot button:

- **Plot Signals** plots the raw signal data for the selected variable(s).
- **Plot Doubles** plots doubles data for the selected variable(s). Doubles are generated when the **Data type override** parameter is set to `True doubles`.
- **Plot Both** plots both raw signal data and doubles data for the selected signal(s). Note that the doubles override does not overwrite the raw data.
- **Cancel** allows you to exit the interface without plotting.

## Examples

To learn how to use the **Fixed-Point Settings** interface, refer to Chapter 6, “Tutorial: Feedback Controller Simulation.”

## See Also

`autofixexp`, `showfixptsimerrors`, `showfixptsimranges`

# num2fixpt

## Purpose

Quantize a value using a Fixed-Point Blockset representation

## Syntax

```
outValue = num2fixpt(OrigValue,FixPtDataType,FixPtScaling,...
   RndMeth, DoSatur)
```

## Description

`num2fixpt(OrigValue,FixPtDataType,FixPtScaling, RndMeth, DoSatur)` casts a real-world value represented in floating-point doubles, `OrigValue`, as a fixed-point number, `outValue`.

| | |
|---|---|
| `OrigValue` | Identifies the real-world value to be cast to a fixed-point value. |
| `FixPtDataType` | Designates the desired fixed-point data type of `outValue`. |
| `FixPtScaling` | Indicates the scaling of the output in either Slope or [Slope Bias] format. |
| `RndMeth` | Specifies the rounding technique to be used on the output. If `FixPtDataType` is `FLOAT`, then `RndMeth` is ignored. |
| `DoSatur` | Indicates whether the output should be saturated to the minimum or maximum representable value upon underflow or overflow. If `FixPtDataType` is `FLOAT`, then `DoSatur` is ignored. |

## Examples

The command

```
   num2fixpt(Pi,sfix(8),2^-5,'Nearest',on)
```

returns `Pi` as a signed 8-bit fixed-point number with scaling of 2^-5. Rounding is towards the nearest representable value, and overflows saturate.

## See Also

`fixptbestexp`, `fixptbestprec`, `float`, `sfix`

## Purpose

Create a MATLAB structure describing a signed generalized fixed-point data type

## Syntax

```
a = sfix(TotalBits)
```

## Description

`sfix(TotalBits)` returns a MATLAB structure that describes the data type of a signed generalized fixed-point number with a word size given by `TotalBits`.

`sfix` is automatically called when a signed generalized fixed-point data type is specified in a block dialog box.

**Note** A default binary point is not included in this data type description. Instead, the scaling must be explicitly defined in the block dialog box.

## Examples

Define a 16-bit signed generalized fixed-point data type:

```
a = sfix(16)
a =
       Class: 'FIX'
    IsSigned: 1
    MantBits: 16
```

## See Also

`float`, `sfrac`, `sint`, `ufix`, `ufrac`, `uint`

## Purpose

Create a MATLAB structure describing a signed fractional data type

## Syntax

```
a = sfrac(TotalBits)
a = sfrac(TotalBits, GuardBits)
```

## Description

`sfrac(TotalBits)` returns a MATLAB structure that describes the data type of a signed fractional number with a word size given by `TotalBits`.

`sfrac(TotalBits, GuardBits)` returns a MATLAB structure that describes the data type of a signed fractional number. The total word size is given by `TotalBits` with `GuardBits` bits located to the left of the sign bit.

`sfrac` is automatically called when a signed fractional data type is specified in a block dialog box.

The default binary point for this data type is assumed to lie immediately to the right of the sign bit. If guard bits are specified, they lie to the left of the binary point in addition to the sign bit.

## Examples

Define an 8-bit signed fractional data type with 4 guard bits. Note that the range of this number is $-2^4 = -16$ to $(1 - 2^{(1 - 8)}) \cdot 2^4 = 15.875$:

```
a = sfrac(8,4)
a =
        Class: 'FRAC'
     IsSigned: 1
     MantBits: 8
    GuardBits: 4
```

## See Also

`float`, `sfix`, `sint`, `ufix`, `ufrac`, `uint`

**Purpose** Display overflows from the last simulation

**Syntax**

```
showfixptsimerrors
```

**Description** The `showfixptsimerrors` script displays any overflows from the last fixed-point simulation. This information is also visible in the **Fixed-Point Settings** interface.

**See Also** `fxptdlg`, `showfixptsimranges`

# showfixptsimranges

## Purpose

Display the logged maximum and minimum values from the last fixed-point simulation.

## Syntax

```
showfixptsimranges
```

## Description

The `showfixptsimranges` script displays the logged maximum and minimum values from the last fixed-point simulation.

The logged data is stored in the `FixPtSimRanges` cell array, which can be accessed by the `autofixexp` automatic scaling script.

## See Also

`autofixexp`, `fxptdlg`, `showfixptsimerrors`

## sint

**Purpose** Create a MATLAB structure describing a signed integer data type

**Syntax**

```
a = sint(TotalBits)
```

**Description** `sint(TotalBits)` returns a MATLAB structure that describes the data type of a signed integer with a word size given by `TotalBits`.

`sint` is automatically called when a signed integer is specified in a block dialog box.

The default binary point for this data type is assumed to lie to the right of all bits.

**Examples** Define a 16-bit signed integer data type:

```
a = sint(16)
a =
       Class: 'INT'
    IsSigned: 1
    MantBits: 16
```

**See Also** `float`, `sfix`, `sfrac`, `ufix`, `ufrac`, `uint`

## ufix

**Purpose** Create a MATLAB structure describing an unsigned generalized fixed-point data type

**Syntax**

```
a = ufix(TotalBits)
```

**Description** `ufix(TotalBits)` returns a MATLAB structure that describes the data type of an unsigned generalized fixed-point data type with a word size given by `TotalBits`.

`ufix` is automatically called when an unsigned generalized fixed-point data type is specified in a block dialog box.

---

**Note** The default binary point is not included in this data type description. Instead, the scaling must be explicitly defined in the block dialog box.

---

**Examples** Define a 16-bit unsigned generalized fixed-point data type:

```
a = ufix(16)
a =
        Class: 'FIX'
     IsSigned: 0
     MantBits: 16
```

**See Also** `float`, `sfix`, `sfrac`, `sint`, `ufrac`, `uint`

**Purpose** Create a MATLAB structure describing an unsigned fractional data type

**Syntax**

```
a = ufrac(TotalBits)
a = ufrac(TotalBits, GuardBits)
```

**Description** `ufrac(TotalBits)` returns a MATLAB structure that describes the data type of an unsigned fractional number with a word size given by `TotalBits`.

`ufrac(TotalBits, GuardBits)` returns a MATLAB structure that describes the data type of an unsigned fractional number. The total word size is given by `TotalBits` with `GuardBits` bits located to the left of the binary point.

`ufrac` is automatically called when an unsigned fractional data type is specified in a block dialog box.

The default binary point for this data type is assumed to lie immediately to the left of all bits. If guard bits are specified, then they lie to the left the default binary point.

**Examples** Define an 8-bit unsigned fractional data type with 4 guard bits. Note that the range of this number is from 0 to $(1 - 2^{-8}) \cdot 2^4 = 15.9375$:

```
a = ufrac(8,4)
a =
        Class: 'FRAC'
     IsSigned: 0
     MantBits: 8
    GuardBits: 4
```

**See Also** `float`, `sfix`, `sfrac`, `sint`, `ufix`, `uint`

# uint

**Purpose** Create a MATLAB structure describing an unsigned integer data type

**Syntax** `a = uint(TotalBits)`

**Description** `uint(TotalBits)` returns a MATLAB structure that describes the data type of an unsigned integer with a word size given by `TotalBits`.

`uint` is automatically called when an unsigned integer is specified in a block dialog box.

The default binary point for this data type is assumed to lie to the right of all bits.

**Examples** Define a 16-bit unsigned integer:

```
a = uint(16)
a =
       Class: 'INT'
    IsSigned: 0
    MantBits: 16
```

**See Also** `float`, `sfix`, `sfrac`, `sint`, `ufix`, `ufrac`

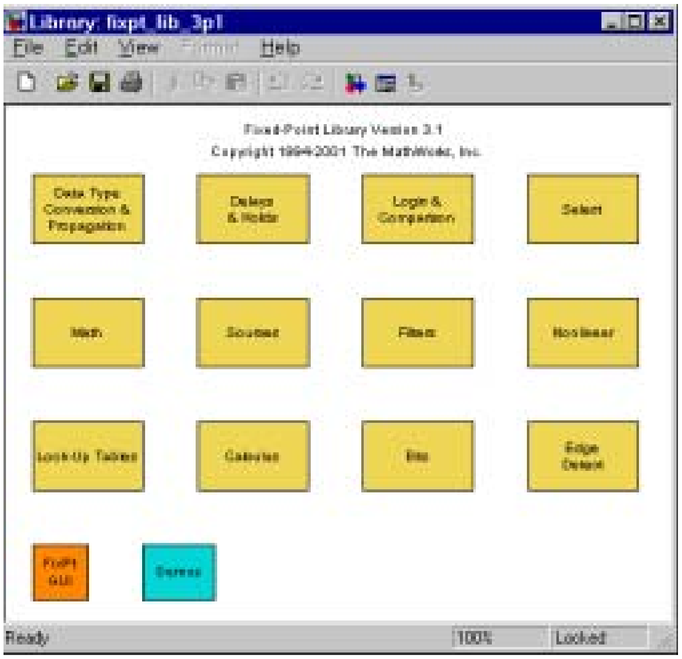
# Block Reference

## Overview of the Block Reference Pages

To open the main Fixed-Point library, type

```
fixpt
```

at the MATLAB prompt. This opens the main library window as shown below.



The main library contains twelve sublibraries. To open a sublibrary, double-click on its icon. These tables describe how the Fixed-Point Blockset blocks are grouped into the sublibraries:

- “Bits” on page 10-14
- “Calculus” on page 10-14
- “Data Type” on page 10-16
- “Delays & Holds” on page 10-16
- “Edge Detect” on page 10-18
- “Filters” on page 10-18

- “Logic & Comparison” on page 10-19
- “LookUp” on page 10-19
- “Math” on page 10-20
- “Nonlinear” on page 10-21
- “Select” on page 10-21
- “Sources” on page 10-22

Fixed-Point Blockset block reference pages appear in alphabetical order and contain some or all of this information:

- The block name and icon
- The purpose of the block
- A description of the block
- Additional remarks about block usage
- The data types and numeric type (complex or real) accepted and generated by the block
- The block parameter dialog box, including a brief description of each parameter
- The rules for some or all of these topics, as they apply to the block:
  - Converting block parameters from double precision numbers to Fixed-Point Blockset data types
  - Converting the input data type(s) to the output data type
  - Performing block operations between inputs and parameters
- An example using the block
- The block characteristics, including some or all of these, as they apply to the block:
  - Input Port(s)—the data type(s) accepted by the block and whether the inputs can be a scalar or vector
  - Output Port(s)—the data type(s) produced by the block and whether the outputs can be a scalar or vector
  - Dimensionalized—whether the block accepts and/or generates multidimensional signal arrays. For more information, see “Signal Basics” in the Using Simulink documentation.

- Direct Feedthrough—whether the block or any of its ports has direct feedthrough
- Sample Time—how the block's sample time is determined, whether by the block itself or inherited from the block that drives it or is driven by it
- Scalar Expansion—whether or not scalars are expanded to vectors
- States—the number of discrete states
- Vectorized—whether or not the block accepts and/or generates vector signals
- Zero Crossing—whether the block detects zero-crossing events. For more information, see "Zero Crossing Detection" in the Using Simulink documentation.

## The Block Dialog Box

You configure Fixed-Point Blockset blocks with a parameter dialog box. The parameter dialog box provides you with

- The name and block type at the top of the dialog box
- A brief description of the block's behavior below the title
- Zero or more editable parameter fields, check boxes, or parameter lists below the description. You specify the parameter values using valid MATLAB expressions.
- A row of four buttons labeled **OK**, **Cancel**, **Help,** and **Apply** at the bottom of the dialog box. The **OK** button sets the current parameter values and closes the dialog box. The **Cancel** button reverts all the parameter values back to their values at the time the dialog box was opened, losing any changes you made. The **Help** button displays the HTML-based reference information for the block. The **Apply** button sets the current parameter values, but does not close the dialog box.

Simulink stores the strings entered in these fields and passes them to MATLAB for evaluation when a simulation is started. If MATLAB variables are used, the simulation uses the values that exist in the workspace at the start of the simulation. These variables are not necessarily the same as when the variables are entered into the dialog box fields. If a simulation is running when a parameter is changed, MATLAB evaluates the parameter as soon as you click the **OK** or **Apply** button.

## Common Block Features

For convenience, the following sections describe common block features:

- “Block Parameters” on page 10-6
- “Block Icon Labels” on page 10-10
- “Port Data Type Display” on page 10-10

### Block Parameters

Many Fixed-Point Blockset blocks use the same parameters, which you configure through the block dialog box. Some common block parameters are associated with these blockset features:

- Parameter and output data type selection
- Parameter and output scaling selection
- Autoscaling
- Rounding
- Overflow handling

Block-specific parameters are described in the block reference pages.

#### Selecting the Data Type and Scaling

For many fixed-point blocks, you need to associate data type and scaling information with numerical parameters and output signals. Fixed-Point Blockset blocks often provide you with the option of inheriting information from an input signal, from the next block downstream, or by an internal rule. Alternatively, you can often specify the data type and scaling yourself in the dialog. You control this option with the **Output data type mode** and **Parameter data type mode** parameters. These drop-down lists often support one or more of the following four choices:

- `Specify via dialog`—You explicitly specify the output data type and scaling with the **Output data type** and **Output scaling value** parameters, or the parameter data type and scaling with the **Parameter data type** and **Parameter scaling value** parameters.
- `Inherit via back propagation`—Specified data type and scaling information is inherited by backpropagation from the next block downstream. In many cases, you will find that the Data Type Propagation

block provides you with the most flexibility when back propagating the data type.

- `Inherit via internal rule`—The specified data type information is inherited from the input(s). The goal of the inheritance rule is to select the "natural" data type and scaling for the output. The specific rule that is used depends on the block operation.

  For example, if you are multiplying two signed 16-bit signals, the Product block produces the natural output of a signed 32-bit data type. An "unnatural" output is produced if the inputs have different signs and different sizes. In this case, some trial and error may be required to achieve satisfactory results.

  If you are adding signals, two natural choices for the output data type and scaling are possible: to preserve the precision or to prevent overflow. However, blocks only support one rule. For example, the Sum block preserves precision. If your goal is to prevent overflow, then you should manually configure the data type and scaling.

- `Same as input`—The output data type and scaling are the same as the input signal.

In addition, the **Output data type mode** and **Parameter data type mode** parameters often include built-in data types in their drop-down lists for easy selection. Built-in data types can also be entered into the **Output data type** or **Parameter data type** parameter if `Specify via dialog` is selected for the **Output data type mode** or **Parameter data type mode** parameter.

The supported fixed-point data types that may be entered into the **Output data type** or **Parameter data type** parameter and their default scalings are shown below.

**Output Data Types and Default Scaling**

| Data Type | Description | Default Scaling |
|---|---|---|
| `float` | Floating-point number | None |
| `sfix` | Signed generalized fixed-point number | None |
| `sfrac` | Signed fractional number | Right of the sign bit |

**Output Data Types and Default Scaling (Continued)**

| Data Type | Description | Default Scaling |
|---|---|---|
| `sint` | Signed integer | Right of the least significant bit |
| `ufix` | Unsigned generalized fixed-point number | None |
| `uint` | Unsigned integer | Right of the least significant bit |
| `ufrac` | Unsigned fractional number | Left of the most significant bit |

In the Fixed-Point Blockset, the word size in bits of fixed-point data types is given as an argument to the data type. For example, `sfix(16)` specifies a 16-bit signed generalized fixed-point number. Word sizes from 1 to 128 bits are supported in simulation.

Floating-point data types are IEEE-style and are specified as `float('single')` for single-precision numbers and `float('double')` for double-precision numbers. Nonstandard IEEE-style numbers are specified as `float(TotalBits,ExpBits)` where `TotalBits` is the total number of physical bits and `ExpBits` is the number of exponent bits.

For more information about supported fixed-point data types and their default scaling, refer to Chapter 3, "Data Types and Scaling."

If you select `Specify via dialog` for the **Output data type mode** or **Parameter data type mode** parameter, you must also explicitly specify the output or parameter scaling with the **Output scaling value** or **Parameter scaling value** parameter. The supported scaling modes for generalized fixed-point data types are given below. Default scaling is used for all other fixed-point data types.

**Scaling Modes for Generalized Fixed-Point Data Types**

| Scaling Mode | Description |
|---|---|
| Binary point-only | Specify binary point-only (powers-of-two) scaling. For example, a scaling of `2^-10` (or `pow2(-10)`) places the binary point at a location 10 places to the left of the least significant bit. |
| [Slope Bias] | Specify [Slope Bias] scaling. For example, a scaling of `[5/9 10]` specifies a slope of 5/9 and a bias of 10. When using this mode, you must specify a positive slope. |

Note that some blocks provide a form of binary point-only scaling for constant vectors and constant matrices. Refer to “Example: Constant Scaling for Best Precision” on page 3-11 for more information.

## Locking the Output Scaling

If the **Lock output scaling against changes by the autoscaling tool** check box is selected, then the automatic scaling tool `autofixexp` will not change the **Output scaling value** parameter. Otherwise, the automatic scaling tool is free to adjust the scaling. You can run `autofixexp` directly from the command line, or through the **Fixed-Point Settings** interface, `fxptdlg`.

## Rounding

You can choose the rounding mode for the block operation with the **Round integer calculations toward** parameter list. The available rounding modes are shown below.

**Rounding Modes**

| Rounding Mode | Description |
|---|---|
| `Zero` | Round the output towards zero. |
| `Nearest` | Round the output towards the nearest representable number, with the exact midpoint rounded towards positive infinity. |

**Rounding Modes (Continued)**

| Rounding Mode | Description |
|---|---|
| `Ceiling` | Round the output towards positive infinity. |
| `Floor` | Round the output towards negative infinity. |

### Handling Overflows

Overflow handling for fixed-point numbers is specified with the **Saturate on integer overflow** check box. If selected, fixed-point overflow results saturate. Otherwise, overflow results wrap. Whenever a result saturates, a warning is displayed.

## Block Icon Labels

Many Fixed-Point Blockset icons look like those of built-in Simulink blocks. In fact, many Simulink blocks with fixed-point capabilities appear in the Fixed-Point Blockset libraries. For this reason, all blocks that belong only to the Fixed-Point Blockset have an “F” on their icons.

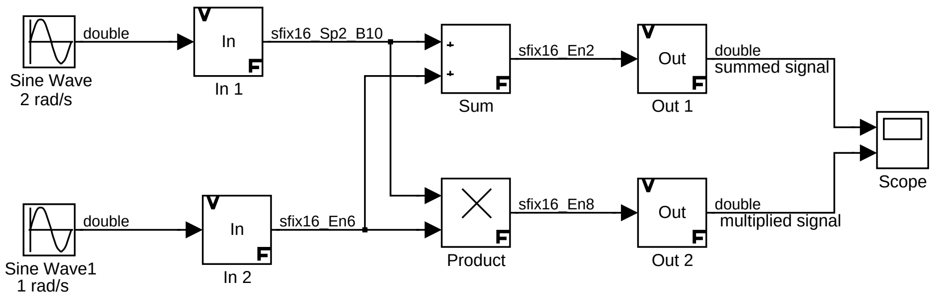
The Gateway In, Gateway In Inherited, and Gateway Out blocks have additional labels, which reflect how the input and output signals are treated. If the block input or output is treated as a real-world value, then a “V” appears next to the relevant port on the block icon. If the block input or output is treated as a stored integer, then an “I” appears next to the relevant port on the block icon.

## Port Data Type Display

To display the data types of ports in your model, select **Port data types** from the Simulink **Format** menu.

The port display for fixed-point signals consists of three parts: the data type, the number of bits, and the scaling. The data type and number of bits reflect the block’s **Output data type** parameter value or the data type that is inherited from the driving block or through backpropagation. The scaling reflects the block’s **Output scaling value** parameter value or the scaling that is inherited from the driving block or through backpropagation.

For example, the model below displays its port data types:



The data type display associated with the `In 1` block in the model indicates that the output data type is `sfix(16)` (a signed, 16-bit, generalized fixed-point number) with [Slope Bias] scaling of `[0.2 10]`. Note that this scaling is not the block's default scaling. The data type display associated with the `In 2` block indicates that the output data type is `sfix(16)` with binary point-only scaling of `2^-6`.

The following table provides a key for various symbols that may appear in the port data type display for Fixed-Point Blockset blocks.

**Port Data Type Display Symbols**

| Symbol | Description |
|---|---|
| `uint` | unsigned integer fixed-point data type |
| `sint` | signed integer fixed-point data type |
| `ufrac` | unsigned fraction fixed-point data type |
| `sfrac` | signed fraction fixed-point data type |
| `ufix` | unsigned generalized fixed-point data type |
| `sfix` | signed generalized fixed-point data type |
| `fltu` | doubles-override of an unsigned fixed-point data type |
| `flts` | doubles-override of a signed fixed-point data type |
| `B` | bias |

**Port Data Type Display Symbols (Continued)**

| Symbol | Description |
|---|---|
| E | 2^ |
| e | 10^ |
| F | fractional slope |
| n | negative |
| p | decimal point |
| S | slope |

For more information on Fixed-Point Blockset data types, refer to “Fixed-Point Data Type Parameters” on page 3-9.

For more information on [Slope Bias] and binary point-only scaling, refer to “Scaling” on page 3-5.

## Blocks—By Category

The Fixed-Point Blockset blocks are divided into the following sublibraries:

| | |
|---|---|
| "Bits" on page 10-14 | Blocks that manipulate the bits of a signal |
| "Calculus" on page 10-14 | Blocks that perform calculus functions |
| "Data Type" on page 10-16 | Blocks that manipulate or convert the data type of a signal |
| "Delays & Holds" on page 10-16 | Blocks that delay or hold a signal |
| "Edge Detect" on page 10-18 | Blocks that detect a change in a signal or a signal edge |
| "Filters" on page 10-18 | Blocks that filter a signal |
| "Logic & Comparison" on page 10-19 | Blocks that perform logic and comparison functions |
| "LookUp" on page 10-19 | Blocks that implement lookup tables |
| "Math" on page 10-20 | Blocks that perform math functions |
| "Nonlinear" on page 10-21 | Blocks that limit or truncate a signal |
| "Select" on page 10-21 | Blocks that select which input or which part of an input gets passed on |
| "Sources" on page 10-22 | Blocks that create a signal |

## Bits

| | |
|---|---|
| Bit Clear | Set the specified bit of the stored integer to zero |
| Bit Set | Set the specified bit of the stored integer to one |
| Bitwise Operator | Perform the specified bitwise operation on the inputs |
| Shift Arithmetic | Arithmetically shift the bits and/or the binary point of a signal |

## Calculus

| | |
|---|---|
| Accumulator | Compute a cumulative sum |
| Accumulator Resettable | Compute a cumulative sum with external Boolean reset |
| Accumulator Resettable Limited | Compute a limited cumulative sum with external Boolean reset |
| Derivative | Compute a discrete time derivative |
| Difference | Calculate the change in a signal over one time step |
| Integrator Backward | Perform discrete-time integration of a signal using the backward method |
| Integrator Backward Resettable | Perform discrete-time integration of a signal using the backward method, with external Boolean reset |
| Integrator Backward Resettable Limited | Perform discrete-time limited integration of a signal using the backward method, with external Boolean reset |
| Integrator Forward | Perform discrete-time integration of a signal using the forward method |
| Integrator Forward Resettable | Perform discrete-time integration of a signal using the forward method, with external Boolean reset |
| Integrator Forward Resettable Limited | Perform discrete-time limited integration of a signal using the forward method, with external Boolean reset |

| | |
|---|---|
| Integrator Trapezoidal | Perform discrete-time integration of a signal using the trapezoidal method |
| Integrator Trapezoidal Resettable | Perform discrete-time integration of a signal using the trapezoidal method, with external Boolean reset |
| Integrator Trapezoidal Resettable Limited | Perform discrete-time limited integration of a signal using the trapezoidal method, with external Boolean reset |
| Sample Rate Probe | Output weighted sample rate |
| Sample Time Add | Add the input signal to weighted sample time |
| Sample Time Divide | Divide the input signal by weighted sample time |
| Sample Time Multiply | Multiply the input signal by weighted sample time |
| Sample Time Probe | Output weighted sample time |
| Sample Time Subtract | Subtract weighted sample time from the input signal |

## Data Type

| | |
|---|---|
| Conversion | Convert from one Fixed-Point Blockset data type to another |
| Conversion Inherited | Convert from one Fixed-Point Blockset data type to another, and inherit the data type and scaling |
| Data Type Duplicate | Set all inputs to the same data type |
| Data Type Propagation | Configure the data type and scaling of the propagated signal based on information from the reference signals |
| Gateway In | Convert a Simulink data type to a Fixed-Point Blockset data type |
| Gateway In Inherited | Convert a Simulink data type to a Fixed-Point Blockset data type, and inherit the data type and scaling |
| Gateway Out | Convert a Fixed-Point Blockset data type to a Simulink data type |
| Scaling Strip | Remove scaling and map to a built in integer |

## Delays & Holds

| | |
|---|---|
| Integer Delay | Delay a signal N sample periods |
| Tapped Delay | Delay a scalar signal multiple sample periods and output all the delayed versions |
| Unit Delay | Delay a signal one sample period |
| Unit Delay Enabled | Delay a signal one sample period, if the external enable signal is on |
| Unit Delay Enabled External IC | Delay a signal one sample period, if the external enable signal is on, with an external initial condition |
| Unit Delay Enabled Resettable | Delay a signal one sample period, if the external enable signal is on, with an external Boolean reset |

| | |
|---|---|
| Unit Delay Enabled Resettable External IC | Delay a signal one sample period, if the external enable signal is on, with an external Boolean reset and initial condition |
| Unit Delay External IC | Delay a signal one sample period, with an external initial condition |
| Unit Delay Resettable | Delay a signal one sample period, with an external Boolean reset |
| Unit Delay Resettable External IC | Delay a signal one sample period, with an external Boolean reset and initial condition |
| Unit Delay With Preview Enabled | Output the signal and the signal delayed by one sample period, if the external enable signal is on |
| Unit Delay With Preview Enabled Resettable | Output the signal and the signal delayed by one sample period, if the external enable signal is on, with an external Boolean reset |
| Unit Delay With Preview Enabled Resettable External RV | Output the signal and the signal delayed by one sample period, if the external enable signal is on, with an external RV reset |
| Unit Delay With Preview Resettable | Output the signal and the signal delayed by one sample period, with an external Boolean reset |
| Unit Delay With Preview Resettable External RV | Output the signal and the signal delayed by one sample period, with an external RV reset |
| Zero-Order Hold | Implement a zero-order hold of one sample period |

## Edge Detect

| | |
|---|---|
| Detect Change | Detect a change in a signal's value |
| Detect Decrease | Detect a decrease in a signal's value |
| Detect Fall Negative | Detect a falling edge when the signal's value decreases to a strictly negative value, and its previous value was nonnegative |
| Detect Fall Nonpositive | Detect a falling edge when the signal's value decreases to a nonpositive value, and its previous value was strictly positive |
| Detect Increase | Detect an increase in a signal's value |
| Detect Rise Nonnegative | Detect a rising edge when a signal's value increases to a nonnegative value, and its previous value was strictly negative |
| Detect Rise Positive | Detect a rising edge when a signal's value increases to a strictly positive value, and its previous value was nonpositive |

## Filters

| | |
|---|---|
| Filter Direct Form I | Implement a Direct Form I realization of a filter |
| Filter Direct Form I Time Varying | Implement a time varying Direct Form I realization of a filter |
| Filter Direct Form II | Implement a Direct Form II realization of a filter |
| Filter Direct Form II Time Varying | Implement a time varying Direct Form II realization of a filter |
| Filter First Order | Implement a discrete-time first order filter |
| Filter Lead or Lag | Implement a discrete-time lead or lag filter |
| Filter Real Zero | Implement a discrete time filter that has a real zero and no pole |

| | |
|---|---|
| FIR | Implement a fixed-point finite impulse response (FIR) filter |
| State-Space | Implement discrete-time state space |

## Logic & Comparison

| | |
|---|---|
| Compare to Constant | Determine if a signal is equal to the specified constant |
| Compare To Zero | Determine if a signal is equal to zero |
| Interval Test | Determine if a signal is in a specified interval |
| Interval Test Dynamic | Determine if a signal is in a specified interval |
| Logical Operator | Perform the specified logical operation on the inputs |
| Relational Operator | Perform the specified relational operation on the inputs |

## LookUp

| | |
|---|---|
| Cosine | Implement a cosine function in fixed-point using a lookup table approach that exploits quarter wave symmetry |
| Look-Up Table | Approximate a one-dimensional function using a selected lookup method |
| Look-Up Table Dynamic | Provide a region of zero output |
| Look-Up Table (2-D) | Approximate a two-dimensional function using a selected lookup method |
| Sine | Implement a sine function in fixed-point using a lookup table approach that exploits quarter wave symmetry |

## Math

| | |
|---|---|
| Abs | Output the absolute value of the input |
| Add | Add two inputs |
| Decrement Real World | Decrease the real world value of the signal by one |
| Decrement Stored Integer | Decrease the stored value of a signal by one |
| Decrement Time To Zero | Decrease the real world value of the signal by the sample time, but only to zero |
| Decrement To Zero | Decrease the real world value of a signal by one, but only to zero |
| Divide | Divide the first input by the second input |
| Dot Product | Generate the dot product of two input vectors |
| Gain | Multiply the input by a constant |
| Increment Real World | Increase the real world value of the signal by one |
| Increment Stored Integer | Increase the stored integer value of a signal by one |
| Matrix Gain | Multiply the input by a constant matrix |
| MinMax | Determine the minimum or maximum input value |
| MinMax Running Resettable | Determine the minimum or maximum of a signal over time |
| Multiply | Multiply two inputs |
| Multiply Matrix | Multiply two input matrices |
| Product | Multiply or divide inputs |
| Product of Elements | Collapse the input vector by multiplying all elements |
| Product of Elements Inverted | Collapse the input vector by dividing all elements |
| Subtract | Subtract the second input from the first input |
| Sum | Add or subtract inputs |

| | |
|---|---|
| Sum of Elements | Collapse the input vector by adding all elements |
| Sum of Elements Negated | Collapse the input vector by subtracting all elements |
| Unary Minus | Negate the input |

## Nonlinear

| | |
|---|---|
| Dead Zone | Provide a region of zero output |
| Dead Zone Dynamic | Set the input within the bounds to zero |
| Rate Limiter | Limit the rising and falling rates of the signal |
| Rate Limiter Dynamic | Limit the rising and falling rates of the signal |
| Relay | Switch output between two constants |
| Saturation | Bound the range of the input |
| Saturation Dynamic | Bound the range of the input |
| Sign | Indicate the sign of the input |
| Wrap To Zero | Set output to zero if input is above threshold |

## Select

| | |
|---|---|
| Index Vector | Output the element of the input vector that corresponds to the value of the control input |
| Multi-Port Switch | Switch output between different inputs based on the value of the first input |
| Switch | Switch output between the first input and the third input based on the value of the second input |

## Sources

| | |
|---|---|
| Constant | Generate a constant value |
| Counter Free | Count up and overflow back to zero after the maximum value possible is reached for the specified number of bits |
| Counter Limited | Count up, and wrap back to zero after outputting the specified upper limit |
| Repeating Sequence Interpolated | Output a discrete-time sequence and repeat, interpolating between data points |
| Repeating Sequence Stair | Output a discrete time sequence and repeat |

## Blocks — Alphabetical List

The following pages contain the reference sheets for the Fixed-Point Blockset blocks in alphabetical order.

# Abs

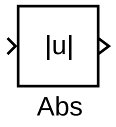
## Purpose

Output the absolute value of the input

## Library

Simulink Math Operations and Fixed-Point Blockset Math

## Description



The Abs block outputs the absolute value of the input.

For signed data types, the absolute value of the most negative value is problematic since it is not representable by the data type. In this case, the behavior of the block is controlled by the **Saturate on integer overflow** check box. If selected, the absolute value of the data type saturates to the most positive value. If not selected, the absolute value of the most negative value represented by the data type has no effect.

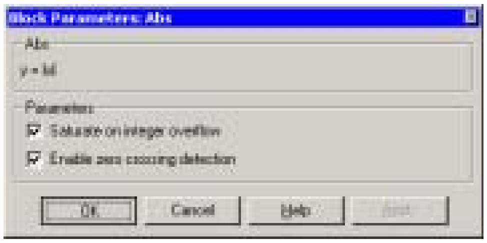
For example, suppose the block input is an 8-bit signed integer. The range of this data type is from -128 to 127, and the absolute value of -128 is not representable. If the **Saturate on integer overflow** check box is selected, then the absolute value of -128 is 127. If it is not selected, then the absolute value of -128 remains at -128.

## Data Type Support

An Abs block accepts real signals of any data type supported by Simulink except `boolean`, including fixed-point data types. The Abs block also accepts complex `single` and `double` inputs. The block outputs a real value of the same data type as the input.

For a discussion on the data types supported by Simulink, refer to "Data Types Supported by Simulink" in the Using Simulink documentation.

## Parameters and Dialog Box



Block Parameters: Abs

Abs

y = |u|

Parameters

[✓] Saturate on integer overflow

[✓] Enable zero crossing detection

**Saturate on integer overflow**

When selected, the block maps signed integer input elements corresponding to the most negative value of that data type to the most positive value of that data type:

- For 8-bit integers, -128 is mapped to 127.
- For 16-bit integers, -32768 maps to 32767.
- For 32-bit integers, -2147483648 maps to 2147483647.

When not selected, the block does not act on signed integer input elements corresponding to the most negative value of that data type:

- For 8-bit integers, -128 remains -128.
- For 16-bit integers, -32768 remains -32768.
- For 32-bit integers, -2147483648 remains -2147483648.

**Enable zero crossing detection**

Select to enable zero crossing detection. For more information, see “Zero Crossing Detection” in the Using Simulink documentation.

## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from driving block |
| Zero Crossing | No, unless **Enable zero crossing detection** is selected |

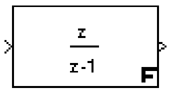
## Purpose

Compute a cumulative sum

## Library

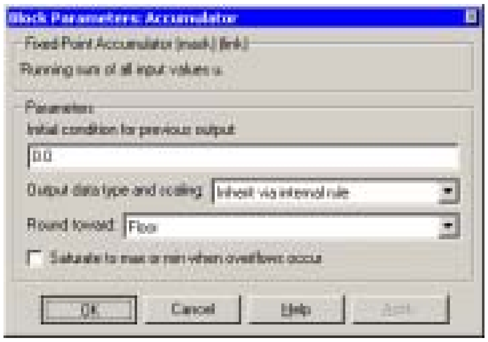
Calculus

## Description



At time step n, the Accumulator block computes a cumulative sum of all input values u up to time n and outputs the sum.

## Parameters and Dialog Box


Block Parameters: Accumulator

Fixed Point Accumulator (mask) (link)

Running sum of all input values u.

Parameters

Initial condition for previous output

0.0

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Initial condition for previous output**

Set the initial condition for the previous output.

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or inherit the data type and scaling from the driving block or by backpropagation.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same data type as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of inputs and gain |

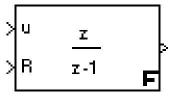
## Purpose

Compute a cumulative sum with external Boolean reset

## Library

Calculus

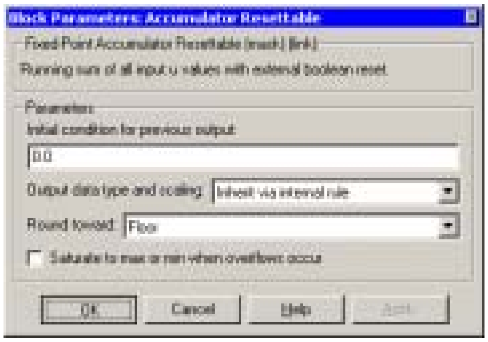
## Description



The Accumulator Resettable block computes a cumulative sum, based on the values of an external Boolean reset signal.

The block can reset its state based on an external reset signal R. The block has two input ports, one for the input signal u, and another for the reset signal R. When the reset is false at time n, the block adds the current value of the input signal u to the sum at time n-1. When the reset is true at time n, the block resets the sum to the value of the **Initial condition for previous output** parameter, and outputs the sum.

## Parameters and Dialog Box


Block Parameters: Accumulator Resettable

Fixed Point Accumulator Resettable (mask) (link)

Running sum of all input u values with external boolean reset.

Parameters

Initial condition for previous output

0.0

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Initial condition for previous output**

Set the initial condition for the previous output.

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or inherit the data type and scaling from the driving block or by backpropagation.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

**Characteristics**

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same data type as the input |
| Direct Feedthrough | Of the input and reset source ports |
| Scalar Expansion | Of inputs and gain |

**See Also**

Accumulator

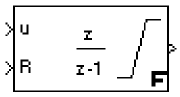
## Purpose

Compute a limited cumulative sum with external Boolean reset

## Library

Calculus

## Description



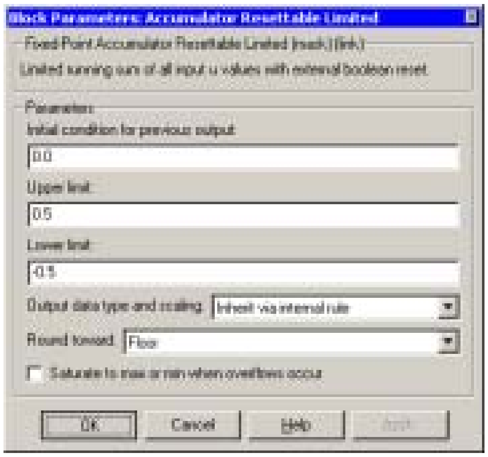
The Accumulator Resettable Limited block computes a cumulative sum, based on the values of an external Boolean reset signal.

The block can reset its state based on an external reset signal R. When the cumulative sum reaches one of the limits given by the **Upper limit** and **Lower limit** parameters, the sum saturates to that limit.

The block has two input ports, one for the input signal u, and another for the reset signal R. When the reset R is false at time n, the block adds the current value of the input signal u to the sum at time n-1. When the cumulative sum is outside the limits given by the **Upper limit** and **Lower limit** parameters, the sum saturates to one of the bounds.

When the reset R is true at time n, the block resets the sum to the value of the **Initial condition for previous output** parameter, and outputs the sum.

## Parameters and Dialog Box



Block Parameters: Accumulator Resettable Limited

Fixed Point Accumulator Resettable Limited (mask) (link)

Limited running sum of all input u values with external boolean reset

Parameters

Initial condition for previous output: 0.0

Upper limit: 0.5

Lower limit: -0.5

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Initial condition for previous output**

Set the initial condition for the previous output.

**Upper limit**

The upper limit for saturation of the cumulative sum.

**Lower limit**

The lower limit for saturation of the cumulative sum.

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or inherit the data type and scaling from the driving block or by backpropagation.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same data type as the input |
| Direct Feedthrough | Of the input and reset source ports |
| Scalar Expansion | Of inputs and gain |

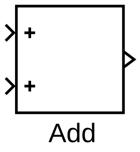
## See Also

Accumulator

**Purpose** Add or subtract inputs

**Library** Math

**Description** The Add block is an implementation of the Sum block. See "Sum" on page 10-217 for more information.



# Bit Clear

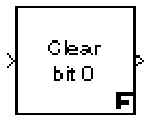
## Purpose

Set the specified bit of the stored integer to zero

## Library

Bits

## Description

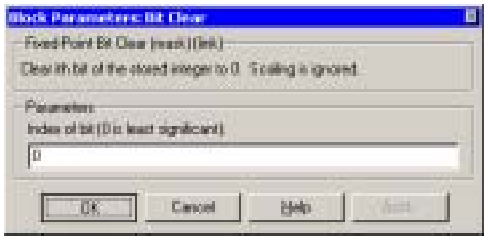


The Bit Clear block sets the specified bit, given by its index, of the stored integer to zero. Scaling is ignored.

You can specify the bit to be set to zero with the **Index of bit** parameter, where bit zero is the least significant bit.

True floating-point data types are not supported.

## Parameters and Dialog Box


Block Parameters: Bit Clear

Fixed-Point Bit Clear (mask) (link)

Clear ith bit of the stored integer to 0. Scaling is ignored.

Parameters

Index of bit (0 is least significant):

0

**Index of bit**

Index of bit where bit 0 is the least significant bit.

## Examples

If the Bit Clear block is turned on for bit 2, bit 2 is set to 0. A vector of constants 2.^[0 1 2 3 4] is represented in binary as [00001 00010 00100 01000 10000]. With bit 2 set to 0, the result is [00001 00010 00000 01000 10000], which is represented in decimal as [1 2 0 8 16].

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset, except a true floating-point data type |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

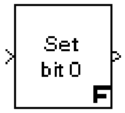
**Purpose**

Set the specified bit of the stored integer to one

**Library**

Bits

**Description**

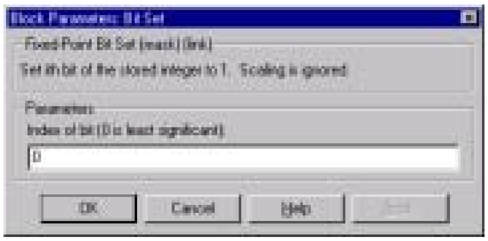


The Bit Set block sets the specified bit of the stored integer to one. Scaling is ignored.

You can specify the bit to be set to one with the **Index of bit** parameter, where bit zero is the least significant bit.

True floating-point data types are not supported.

**Parameters and Dialog Box**



Block Parameters: Bit Set

Fixed-Point Bit Set (mask) (link)

Set ith bit of the stored integer to 1. Scaling is ignored.

Parameters

Index of bit (0 is least significant)

0

**Index of bit**

Index of bit where bit 0 is the least significant bit.

**Examples**

If the Bit Set block is turned on for bit 2, bit 2 is set to 1. A vector of constants 2.^[0 1 2 3 4] is represented in binary as [00001 00010 00100 01000 10000]. With bit 2 set to 1, the result is [00101 00110 00100 01100 10100], which is represented in decimal as [5 6 4 12 20].

**Characteristics**

| | |
|---|---|
| Input Port | Any data type supported by the blockset, except a true floating-point data type |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

**See Also**

Bit Clear

# Bitwise Operator

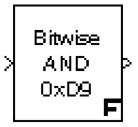
## Purpose

Perform the specified bitwise operation on the inputs

## Library

Bits

## Description



The Bitwise Operator block performs the specified bitwise operation on its operands.

Unlike the logic operations performed by the Logical Operator block, bitwise operations treat the operands as a vector of bits rather than a single number. You select the bitwise Boolean operation with the **Operator** parameter list. The supported operations are given below.

| Operation | Description |
|---|---|
| AND | TRUE if the corresponding bits are all TRUE |
| OR | TRUE if at least one of the corresponding bits is TRUE |
| NAND | TRUE if at least one of the corresponding bits is FALSE |
| NOR | TRUE if no corresponding bits are TRUE |
| XOR | TRUE if an odd number of corresponding bits are TRUE |
| NOT | TRUE if the input is FALSE (available only for single input) |

Unlike the Simulink Bitwise Logical Operator block, the Bitwise Operator block does not support shift operations. Refer to “Shifts” on page 4-41 to learn how to perform shift operations with the Fixed-Point Blockset.

The size of the output depends on the number of inputs, their vector size, and the selected operator:

- The NOT operator accepts only one input, which can be a scalar or a vector. If the input is a vector, the output is a vector of the same size containing the bitwise logical complements of the input vector elements.
- For a single vector input, the block applies the operation (except the NOT operator) to all elements of the vector. If a bit mask is not specified, then the output is a scalar. If a bit mask is specified, then the output is a vector.

- For two or more inputs, the block performs the operation between all of the inputs. If the inputs are vectors, the operation is performed between corresponding elements of the vectors to produce a vector output.

When configured as a multi-input XOR gate, this block performs an addition-modulo-two operation as mandated by the IEEE Standard for Logic Elements.

If the **Use bit mask** check box is not selected, then the block can accept multiple inputs. You select the number of input ports with the **Number of input ports** parameter. The input data types must be identical.

If the **Use bit mask** check box is selected, then a single input is associated with the bit mask you specify with the **Bit Mask** parameter. You specify the bit mask using any valid MATLAB expression. For example, you can specify the bit mask 00100101 as `2^5+2^2+2^0`. Alternatively, you can use strings to specify a hexadecimal bit mask such as `{'FE73','12AC'}`. If the bit mask is larger than the input signal data type, then it is ignored.

---

**Note** The output data type, which is inherited from the driving block, should represent zero exactly. Data types that satisfy this condition include signed and unsigned integers and any floating-point data type.

---

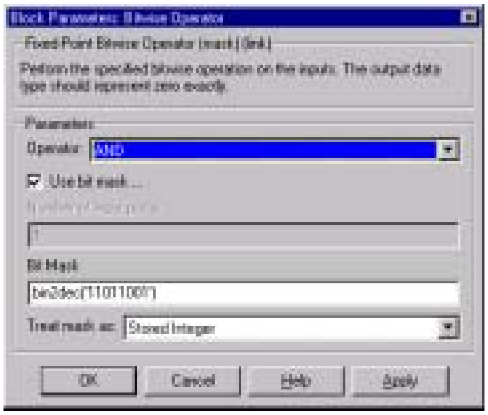
The **Treat mask as** parameter list controls how the mask is treated. The possible values are `Real World Value` and `Stored Integer`. In terms of the general encoding scheme described in “Scaling” on page 3-5, `Real World Value` treats the mask as $V = SQ + B$ where $S$ is the slope and $B$ is the bias. `Stored Integer` treats the mask as a stored integer, $Q$. For more information about this parameter list, refer to the Gateway In block.

## Remarks

You can use the bit mask to perform a bit set or a bit clear on the input. To perform a bit set, you configure the **Operator** parameter list to `OR` and create a bit mask with a 1 for each corresponding input bit that you want to set to 1. To perform a bit clear, you configure the **Operator** parameter list to `AND` and create a bit mask with a 0 for each corresponding input bit that you want to set to 0.

For example, suppose you want to perform a bit set on the fourth bit of an 8-bit input vector. The bit mask would be 00010000, which you can specify as `2^4` in the **Bit mask** parameter. To perform a bit clear, the bit mask would be 11101111, which you can specify as 2^7+2^6+2^5+2^3+2^2+2^1+2^0 in the **Bit mask** parameter.

## Parameters and Dialog Box


Block Parameters: Bitwise Operator

Fixed-Point Bitwise Operator (mask) (link)

Perform the specified bitwise operation on the inputs. The output data type should represent zero exactly.

Parameters

Operator: AND

[✓] Use bit mask ...

Number of input ports: 1

Bit Mask: bin2dec('11011001')

Treat mask as: Stored Integer

**Operator**

The bitwise logical operator associated with the specified operands.

**Use bit mask**

Specify if the bit mask is used (single input only).

**Number of input ports**

The number of inputs.

**Bit Mask**

The bit mask to associate with a single input.

**Treat mask as**

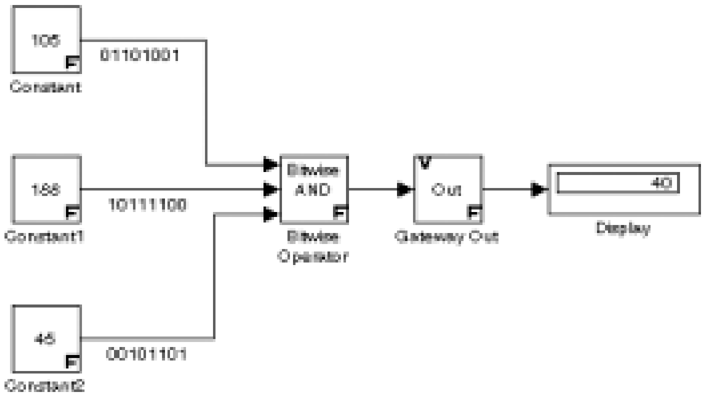
Treat the mask as a real-world value or as an integer.

## Conversions

The **Bit Mask** parameter is converted from a double to the input data type offline using round-to-nearest and saturation. Refer to “Parameter Conversions” on page 4-27 for more information about parameter conversions.

## Examples

To help you understand the Bitwise Operator block logic operations, consider the fixed-point model shown below.



The Constant blocks are configured to output an 8-bit unsigned integer (`uint(8)`). The results for all logic operations are shown below.

| Operation | Binary Value | Decimal Value |
|---|---|---|
| AND | 00101000 | 40 |
| OR | 11111101 | 253 |
| NAND | 11010111 | 215 |
| NOR | 00000010 | 2 |
| XOR | 11111000 | 248 |
| NOT | N/A | N/A |

## Characteristics

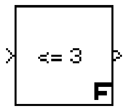
| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | No |
| Scalar Expansion | Of inputs |

# Compare To Constant

**Purpose** Determine if a signal is equal to the specified constant

**Library** Logic & Comparison

**Description**

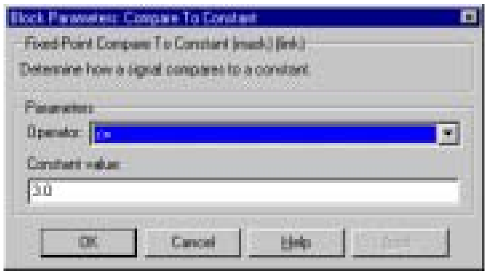


The Compare To Constant block determines if a signal is equal to the specified constant where:

- The output is true (not 0) when the input signal is equal to the specified constant.
- The output is false (equal to 0) when the input signal is not equal to the specified constant.

You enter the constant with the **Constant value** parameter.

**Parameters and Dialog Box**



Block Parameters: Compare To Constant

Fixed-Point Compare To Constant (mask) (link)

Determine how a signal compares to a constant

Parameters

Operator: [illegible]

Constant value:

3.0

**Operator**

Specify how the input is compared to the constant value.

**Constant value**

Specify the constant value that the input is compared with.

**Characteristics**

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | An 8-bit unsigned integer |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

**See Also** Compare to Zero

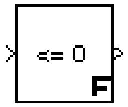
## Purpose

Determine if a signal is equal to zero

## Library

Logic & Comparison

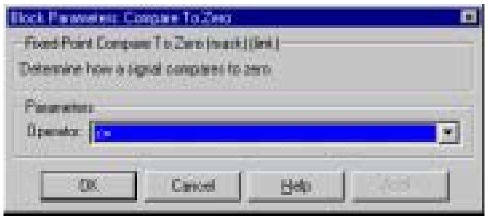
## Description



The Compare To Zero block determines if a signal is equal to zero where:

- The output is true (not 0) when the input signal is equal to zero.
- The output is false (equal to 0) when the input signal is not equal to zero.

## Parameters and Dialog Box


Block Parameters: Compare To Zero

Fixed-Point Compare To Zero (mask) (link)

Determine how a signal compares to zero.

Parameters

Operator: ==

**Operator**

Specify how the input is compared to zero.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | An 8-bit unsigned integer |
| Direct Feedthrough | Yes |

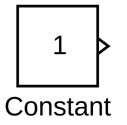
## See Also

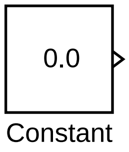
Compare To Constant

**Purpose** Generate a constant value

**Library** Simulink Sources and Fixed-Point Blockset Sources

**Description**





The Constant block generates a real or complex constant value. The block generates a scalar, vector, or matrix output, depending on the dimensionality of the **Constant value** parameter and the setting of the **Interpret vector parameters as 1-D** parameter.

The output of the block has the same dimensions and elements of the **Constant value** parameter. If you specify a vector for this parameter, and you want the block to interpret it as 1-D, select the **Interpret vector parameters as 1-D** parameter.

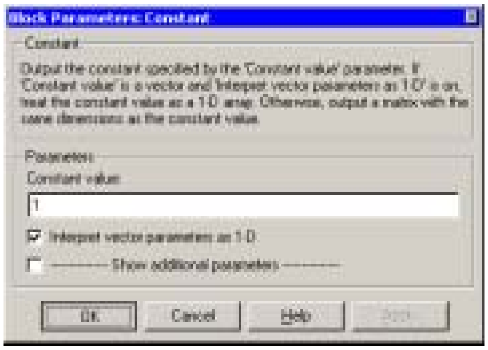
When the **Show additional parameters** check box is selected, some of the parameters that become visible are common to many blocks. For a detailed description of these parameters, refer to “Block Parameters” on page 10-6.

**Data Type Support**

By default, a Constant block outputs a signal whose data type and complexity is the same as that of the block’s **Constant value** parameter. However, you can specify the output to be any supported data type supported by Simulink, as well as fixed-point data types.

For a discussion on the data types supported by Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

**Parameters and Dialog Box**



Block Parameters: Constant

Constant

Output the constant specified by the 'Constant value' parameter. If 'Constant value' is a vector and 'Interpret vector parameters as 1-D' is on, treat the constant value as a 1-D array. Otherwise, output a matrix with the same dimensions as the constant value.

Parameters

Constant value:

1

[✓] Interpret vector parameters as 1-D

[ ] Show additional parameters

**Constant value**

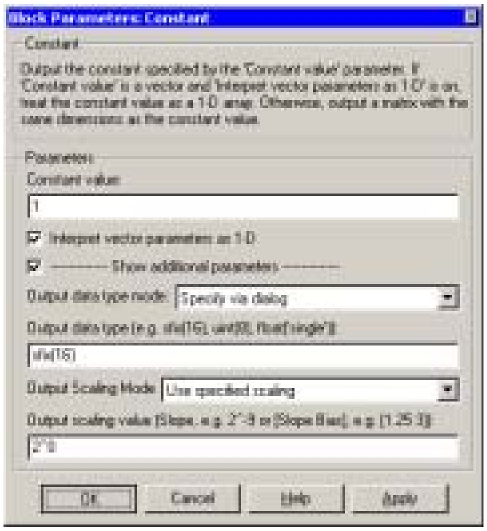
Constant value output by the block. It can be a scalar, vector, or matrix.

**Interpret vector parameters as 1-D**

If selected, a vector specified for the **Constant value** parameter results in a 1-D signal.

**Show additional parameters**

If selected, additional parameters specific to implementation of the block become visible as shown.



Block Parameters: Constant

Constant

Output the constant specified by the 'Constant value' parameter. If 'Constant value' is a vector and 'Interpret vector parameters as 1-D' is on, treat the constant value as a 1-D array. Otherwise, output a matrix with the same dimensions as the constant value.

Parameters

Constant value:

1

☑ Interpret vector parameters as 1-D

☑ ---------- Show additional parameters ----------

Output data type mode: Specify via dialog

Output data type (e.g. sfix(16), uint(8), float('single')):

sfix(16)

Output Scaling Mode: Use specified scaling

Output scaling value [Slope, e.g. 2^-9 or [Slope Bias], e.g. [1.25 3]]:

2^0

**Output data type mode**

Specify how the data type of the output is designated. The data type can be inherited through backpropagation, or can be designated in the **Constant value** parameter; for example `int8(29)`. You can also choose a built-in data type from the drop-down list. Lastly, if you choose `Specify via dialog`, the **Output data type**, **Output Scaling Mode**, and **Output scaling value** parameters become visible.

**Output data type**

Specify any data type, including fixed-point data types. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Output Scaling Mode**

Specify how the scaling of the output is designated. The output can be automatically scaled to maintain best vector-wise precision without overflow, or you can choose to specify the scaling in the dialog via the **Output scaling value** parameter. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Output scaling value**

Set the output scaling using binary point-only or [Slope Bias] scaling. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter, and if `Use specified scaling` is selected for the **Output Scaling Mode** parameter.

## Conversions and Operations

The **Constant value** parameter is converted from its data type to the specified output data type offline using round-to-nearest and saturation. Refer to "Parameter Conversions" on page 4-27 for more information about parameter conversions.

## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | No |
| Sample Time | Constant |
| Scalar Expansion | No |
| Zero Crossing | No |

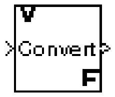
## Purpose

Convert from one Fixed-Point Blockset data type to another

## Library

Data Type

## Description

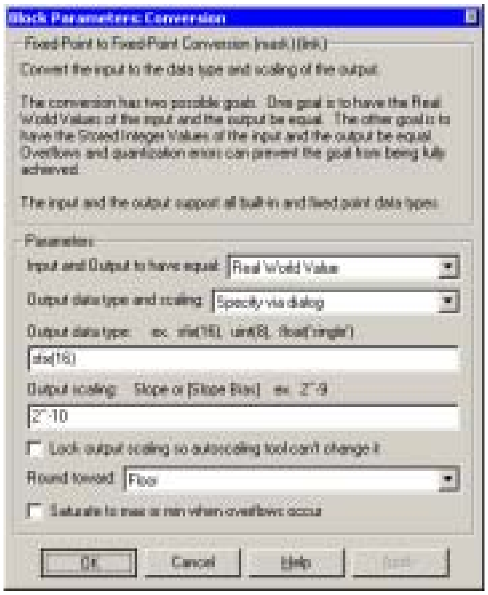


The Conversion block converts from one Fixed-Point Blockset data type to another.

This block requires that you specify the data type and scaling for the conversion. If you want to inherit this information from an input signal, you should use the Conversion Inherited block.

For a detailed description of all block parameters, refer to “Block Parameters” on page 10-6. For more information about converting from one Fixed-Point Blockset data type to another, refer to “Signal Conversions” on page 4-27.

## Parameters and Dialog Box



Fixed-Point to Fixed-Point Conversion (mask) (link)

Convert the input to the data type and scaling of the output.

The conversion has two possible goals. One goal is to have the Real World Values of the input and the output be equal. The other goal is to have the Stored Integer Values of the input and the output be equal. Overflows and quantization errors can prevent the goal from being fully achieved.

The input and the output support all built-in and fixed point data types.

Parameters

Input and Output to have equal: Real World Value

Output data type and scaling: Specify via dialog

Output data type: ex. sfix(16), uint(8), float('single')

sfix(16)

Output scaling: Slope or [Slope Bias] ex. 2^-9

2^-10

☐ Lock output scaling so autoscaling tool can't change it

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Input and Output to have equal**

Specify the type of value of the input and output that are to be equal.

**Output data type and scaling**
Specify the output data type and scaling via the dialog box, or inherit the data type and scaling via backpropagation.

**Output data type**
Any data type supported by the Fixed-Point Blockset.

**Output scaling**
Set the output scaling using binary point-only or [Slope Bias] scaling. These scaling modes are available only for generalized fixed-point data types.

**Lock output scaling so autoscaling tool can't change it**
If selected, **Output scaling** is locked. This feature is available only for generalized fixed-point output.

**Round toward**
Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**
If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |

## See Also

Conversion Inherited

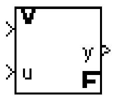
## Purpose

Convert from one Fixed-Point Blockset data type to another, and inherit the data type and scaling

## Library

Data Type

## Description



The Conversion Inherited block forces dissimilar data types to be the same. The first (top) input is used as the reference signal and the second (bottom) input is converted to the reference type by inheriting the data type and scaling information. Either input will be scalar expanded such that the output has the same width as the widest input.

If you want to specify the data type and scaling when converting from one Fixed-Point Blockset data type to another, you should use the Conversion block.

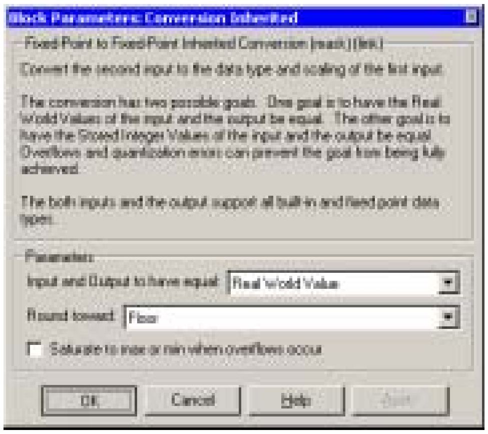
For a detailed description of all block parameters, refer to “Block Parameters” on page 10-6. For more information about converting from one Fixed-Point Blockset data type to another, refer to “Signal Conversions” on page 4-27.

## Remarks

Inheriting the data type and scaling provides these advantages:

- It makes reusing existing models easier.
- It allows you to create new fixed-point models with less effort since you can avoid the detail of specifying the associated parameters.

## Parameters and Dialog Box



Block Parameters: Conversion Inherited

Fixed-Point to Fixed-Point Inherited Conversion (mask) (link)

Convert the second input to the data type and scaling of the first input.

The conversion has two possible goals. One goal is to have the Real World Values of the input and the output be equal. The other goal is to have the Stored Integer Values of the input and the output be equal. Overflows and quantization errors can prevent the goal from being fully achieved.

The both inputs and the output support all built-in and fixed point data types.

Parameters

Input and Output to have equal: Real World Value

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Input and Output to have equal**
Specify the type of value of the input and output that are to be equal.

**Round toward**
Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**
If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |

## See Also

Conversion

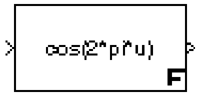
## Purpose

Implement a cosine function in fixed-point using a lookup table approach that exploits quarter wave symmetry

## Library

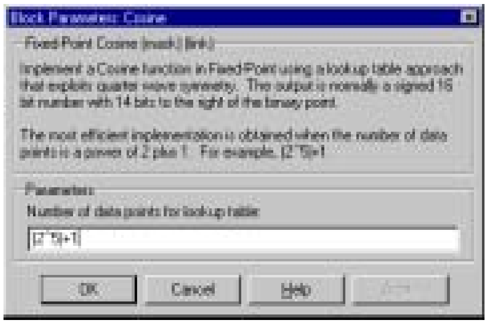
LookUp

## Description



The Cosine block implements a cosine function using a lookup table that exploits quarter wave symmetry. The output is normally a signed 16 bit number with 14 bits to the right of the binary point.

## Parameters and Dialog Box


Block Parameters: Cosine

Fixed-Point Cosine (mask) (link)

Implement a Cosine function in Fixed-Point using a lookup table approach that exploits quarter wave symmetry. The output is normally a signed 16 bit number with 14 bits to the right of the binary point.

The most efficient implementation is obtained when the number of data points is a power of 2 plus 1. For example, (2^5)+1

Parameters

Number of data points for lookup table:

(2^5)+1

**Number of data points for lookup table**

The number of data points in the lookup table

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |

# Counter Free

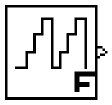
## Purpose

Count up and overflow back to zero after the maximum value possible is reached for the specified number of bits

## Library

Sources

## Description



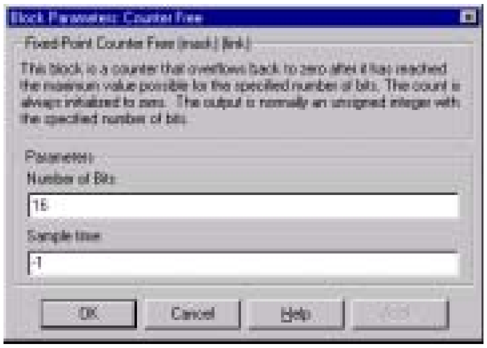
The Counter Free block counts up until the maximum possible value, $2^{Nbits} - 1$, is reached, where Nbits is the number of bits. Then the counter overflows to zero, and restarts counting up. The counter is always initialized to zero.

You can specify the number of bits with the **Number of Bits** parameter.

You can specify the sample time with the **Sample time** parameter.

The output is an unsigned integer. If the global doubles override is selected, the Counter Free does not wrap back to zero.

## Parameters and Dialog Box



Block Parameters: Counter Free

Fixed-Point Counter Free (mask) (link)

This block is a counter that overflows back to zero after it has reached the maximum value possible for the specified number of bits. The count is always initialized to zero. The output is normally an unsigned integer with the specified number of bits.

Parameters

Number of Bits: 16

Sample time: -1

**Number of Bits**

Specified number of bits.

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Output Port | Unscaled integer or a floating-point data type |
| Scalar Expansion | No |
| Vectorized | No |

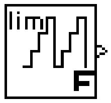
**Purpose**

Count up and wrap back to zero after outputting the specified upper limit

**Library**

Sources

**Description**



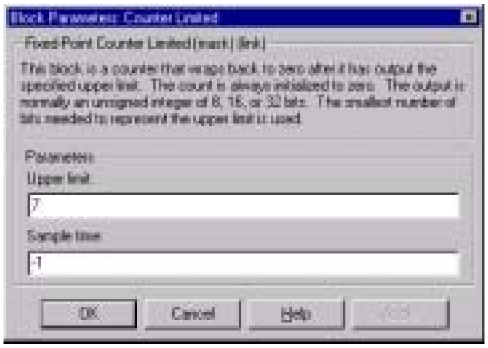
The Counter Limited block counts up until the specified upper limit is reached. Then the counter wraps back to zero, and restarts counting up. The counter is always initialized to zero.

You can specify the upper limit with the **Upper limit** parameter.

You can specify the sample time with the **Sample time** parameter. A **Sample time** of -1 means that the sample time is inherited.

The output is an unsigned integer of 8, 16, or 32 bits, with the smallest number of bits needed to represent the upper limit.

**Parameters and Dialog Box**



Block Parameters: Counter Limited

Fixed-Point Counter Limited (mask) (link)

This block is a counter that wraps back to zero after it has output the specified upper limit. The count is always initialized to zero. The output is normally an unsigned integer of 8, 16, or 32 bits. The smallest number of bits needed to represent the upper limit is used.

Parameters

Upper limit

7

Sample time

-1

**Upper limit**

Upper limit.

**Sample time**

Sample time.

**Characteristics**

| | |
|---|---|
| Output Port | Unscaled integer or a floating-point data type |
| Scalar Expansion | No |
| Vectorized | No |

**See Also**

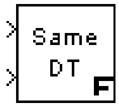
Counter Free

# Data Type Duplicate

**Purpose** Force all inputs to the same data type

**Library** Data Type

**Description**



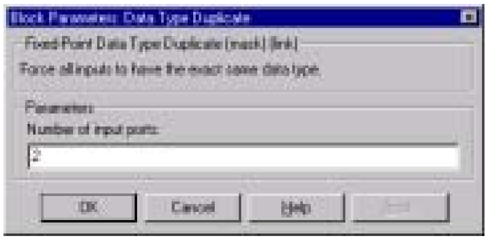
The Data Type Duplicate block forces all inputs to have exactly the same data type. Other attributes of input signals, such as dimension, complexity, and sample time, are completely independent.

You can use the Data Type Duplicate block to check for consistency of data types among blocks. If all signals do not have the same data type, the block returns an error message.

The Data Type Duplicate block is typically used such that one signal to the block controls the data type for all other blocks. The other blocks are set to inherit their data types via backpropagation.

The block is also used in a user created library. These library blocks can be placed in any model, and the data type for all library blocks are configured according to the usage in the model. To create a library block with more complex data type rules than duplication, use the Data Type Propagation block.

**Parameters and Dialog Box**


Block Parameters: Data Type Duplicate

Fixed-Point Data Type Duplicate (mask) (link)

Force all inputs to have the exact same data type.

Parameters

Number of input ports:

2

**Number of input ports**

Number of input ports.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Scalar Expansion | Yes |
| States | 0 |
| Vectorized | Yes |

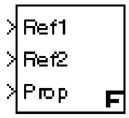
**Purpose**

Set the data type and scaling of the propagated signal based on information from the reference signals

**Library**

Data Type

**Description**



The Data Type Propagation block allows you to control the data type and scaling of signals in your model. You can use this block in conjunction with fixed-point blocks that have their **Specify data type and scaling** parameter configured to `Inherit via back propagation`.

The block has three inputs: Ref1 and Ref2 are the reference inputs, while the Prop input back propagates the data type and scaling information gathered from the reference inputs. This information is then passed on to other fixed-point blocks.

The block provides you with many choices for propagating data type and scaling information. For example, you can:

- Use the number of bits from the Ref1 reference signal, or use the number of bits from widest reference signal.
- Use the range from the Ref2 reference signal, or use the range of the reference signal with the greatest range.
- Use a bias of zero, regardless of the biases used by the reference signals.
- Use the precision of the reference signal with the least precision.

You specify how data type information is propagated with the **Propagated data type** parameter list. If the parameter list is configured as `Specify via dialog`, then you manually specify the data type via the **Propagated data type** edit field. Refer to “Selecting the Data Type and Scaling” on page 10-6 to learn how to specify the data type. If the parameter list is configured as `Inherit via propagation rule`, then you must use the parameters described in “Inheriting Data Type Information” on page 10-55.

You specify how scaling information is propagated with the **Propagated scaling** parameter list. If the parameter list is configured as `Specify via dialog`, then you manually specify the scaling via the **Propagated scaling** edit field. Refer to “Selecting the Data Type and Scaling” on page 10-6 to learn how to specify the scaling. If the parameter list is configured as `Inherit via propagation rule`, then you must use the parameters described in “Inheriting Scaling Information” on page 10-57.

## Remarks

After you use the information from the reference signals, you can apply a second level of adjustments to the data type and scaling by using individual multiplicative and additive adjustments. This flexibility has a variety of uses. For example, if you are targeting a DSP, then you can configure the block so that the number of bits associated with a MAC (multiply and accumulate) operation is twice as wide as the input signal, and has a certain number of guard bits added to it.

The Data Type Propagation block also provides a mechanism to force the computed number of bits to a useful value. For example, if you are targeting a 16-bit micro, then the target C compiler is likely to support sizes of only 8 bits, 16 bits, and 32 bits. The block will force these three choices to be used. For example, suppose the block computes a data type size of 24 bits. Since 24 bits is not directly usable by the target chip, the signal is forced up to 32 bits, which is natively supported.

There is also a method for dealing with floating-point reference signals. This makes it easier to create designs that are easily retargeted from fixed-point chips to floating-point chips or visa versa.

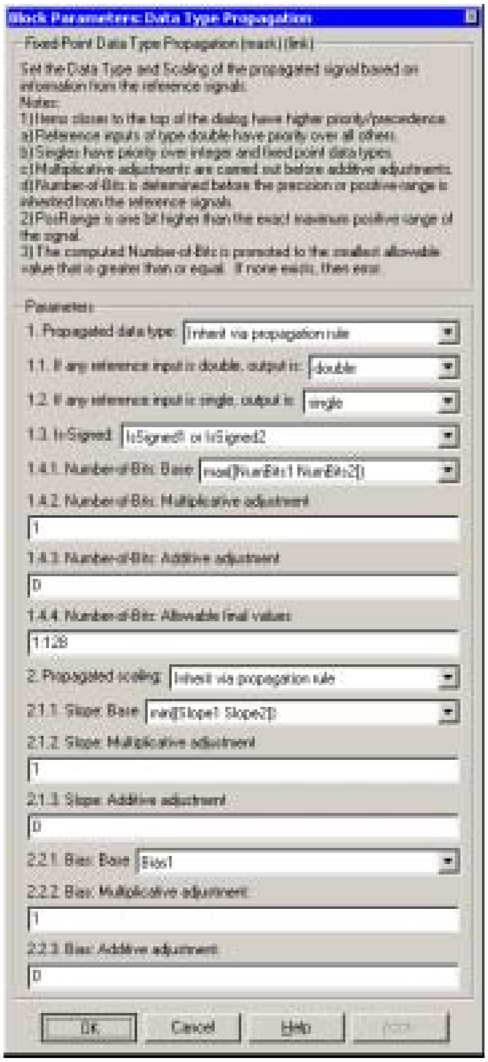
The Data Type Propagation block allows you to set up libraries of useful subsystems that will be properly configured based on the connected signals. Without this data type propagation process, a subsystem that you use from a library will almost certainly not work as desired with most integer or fixed-point signals, and manual intervention to configure the data type and scaling would be required. This block can eliminate the manual intervention in many situations.

### Precedence Rules

The precedence of the dialog box parameters decreases from top to bottom. Additionally:

- Double-precision reference inputs have precedence over all other data types.
- Single-precision reference inputs have precedence over integer and fixed-point data types.
- Multiplicative adjustments are carried out before additive adjustments.
- The number of bits is determined before the precision or positive range is inherited from the reference inputs.

## Parameters and Dialog Box



Block Parameters: Data Type Propagation

Fixed-Point Data Type Propagation (mask) (link)

Set the Data Type and Scaling of the propagated signal based on information from the reference signals.
Notes:
1) Items closer to the top of the dialog have higher priority/precedence
a) Reference inputs of type double have priority over all others
b) Singles have priority over integer and fixed point data types
c) Multiplicative adjustments are carried out before additive adjustments
d) Number-of-Bits is determined before the precision or positive-range is inherited from the reference signals
2) PosRange is one bit higher than the exact maximum positive range of the signal
3) The computed Number-of-Bits is promoted to the smallest allowable value that is greater than or equal. If none exists, then error.

Parameters

1. Propagated data type: Inherit via propagation rule

1.1. If any reference input is double, output is: double

1.2. If any reference input is single, output is: single

1.3. Is-Signed: IsSigned1 or IsSigned2

1.4.1. Number-of-Bits: Base: max([NumBits1 NumBits2])

1.4.2. Number-of-Bits: Multiplicative adjustment: 1

1.4.3. Number-of-Bits: Additive adjustment: 0

1.4.4. Number-of-Bits: Allowable final values: 1:128

2. Propagated scaling: Inherit via propagation rule

2.1.1. Slope: Base: min([Slope1 Slope2])

2.1.2. Slope: Multiplicative adjustment: 1

2.1.3. Slope: Additive adjustment: 0

2.2.1. Bias: Base: Bias1

2.2.2. Bias: Multiplicative adjustment: 1

2.2.3. Bias: Additive adjustment: 0

**Propagated data type**

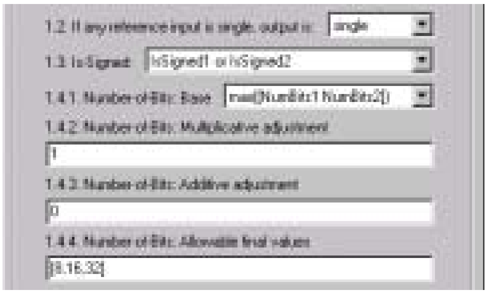
Use the parameter list to propagate the data type via the dialog box, or inherit the data type from the reference signals. Use the edit field to specify the data type via the dialog box.

**Propagated scaling**

Use the parameter list to propagate the scaling via the dialog box, or inherit the scaling from the reference signals. Use the edit field to specify the scaling via the dialog box.

### Inheriting Data Type Information

If the **Propagated data type** parameter is `Inherit via propagation rule`, then these dialog box parameters are available to you.



1.2 If any reference input is single, output is: single

1.3 IsSigned: IsSigned1 or IsSigned2

1.4.1 Number-of-Bits: Base: max([NumBits1 NumBits2])

1.4.2 Number-of-Bits: Multiplicative adjustment

1

1.4.3 Number-of-Bits: Additive adjustment

0

1.4.4 Number-of-Bits: Allowable final values

[8,16,32]

The **If any reference input is single, output is** parameter list can be `single` or `double`. This parameter makes it easier to create designs that are easily retargeted from fixed-point chips to floating-point chips or visa versa.

The **Is-Signed** parameter list specifies the sign of Prop. The parameter values are described below.

| Parameter Value | Description |
|---|---|
| `IsSigned1` | Prop is a signed data type if Ref1 is a signed data type. |
| `IsSigned2` | Prop is a signed data type if Ref2 is a signed data type. |
| `IsSigned1 or IsSigned2` | Prop is a signed data type if either Ref1 or Ref2 are signed data types. |
| `TRUE` | Ref1 and Ref2 are ignored, and Prop is always a signed data type. |
| `FALSE` | Ref1 and Ref2 are ignored, and Prop is always an unsigned data type. |

For example, if the Ref1 signal is `ufix(16)`, the Ref2 signal is `sfix(16)`, and the **Is-Signed** parameter is `IsSigned1 or IsSigned2`, then Prop is forced to be a signed data type.

The **Number-of-bits: base** parameter list specifies the number of bits used by Prop for the base data type. The parameter values are described below.

| Parameter Value | Description |
|---|---|
| `NumBits1` | The number of bits for Prop is given by the number of bits for Ref1. |
| `NumBits2` | The number of bits for Prop is given by the number of bits for Ref2. |
| `max([NumBits1 NumBits2])` | The number of bits for Prop is given by the reference signal with largest number of bits. |
| `min([NumBits1 NumBits2])` | The number of bits for Prop is given by the reference signal with smallest number of bits. |
| `NumBits1+NumBits2` | The number of bits for Prop is given by the sum of the reference signal bits. |

Refer to "Targeting an Embedded Processor" on page 5-3 for more information about the base data type.

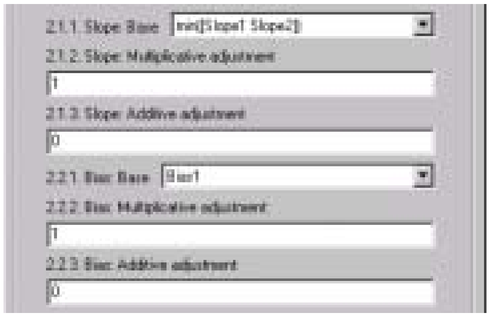
The **Number-of-bits: Multiplicative adjustment** parameter allows you to adjust the number of bits used by Prop by including a multiplicative adjustment. For example, suppose you want to guarantee that the number of bits associated with a multiply and accumulate (MAC) operation is twice as wide as the input signal. To do this, you configure this parameter to the value `2`.

The **Number-of-bits: Additive adjustment** parameter allows you to adjust the number of bits used by Prop by including an additive adjustment. For example, if you are performing multiple additions during a MAC operation, the result may overflow. To prevent overflow, you can associate guard bits with the propagated data type. To associate four guard bits, you specify the value `4`.

The **Number-of-bits: Allowable final values** parameter allows you to force the computed number of bits used by Prop to a useful value. For example, if you are targeting a processor that supports only 8, 16, and 32 bits, then you configure this parameter to `[8,16,32]`. The block always propagates the smallest specified value that fits. If you want to allow all fixed-point data types, you would specify the value `1:128`.

### Inheriting Scaling Information

If the **Propagated scaling** parameter is `Inherit via propagation rule`, then these dialog box parameters are available to you.



2.1.1. Slope: Base: min([Slope1 Slope2])
2.1.2. Slope: Multiplicative adjustment: 1
2.1.3. Slope: Additive adjustment: 0
2.2.1. Bias: Base: Bias1
2.2.2. Bias: Multiplicative adjustment: 1
2.2.3. Bias: Additive adjustment: 0

The **Slope: Base** parameter list specifies the slope used by Prop for the base data type. The parameter values are described below.

| Parameter Value | Description |
|---|---|
| `Slope1` | The slope of Prop is given by the slope of Ref1. |
| `Slope2` | The slope of Prop is given by the slope of Ref2. |
| `max([Slope1 Slope2])` | The slope of Prop is given by the maximum slope of the reference signals. |
| `min([Slope1 Slope2])` | The slope of Prop is given by the minimum slope of the reference signals. |
| `Slope1*Slope2` | The slope of Prop is given by the product of the reference signal slopes. |
| `Slope1/Slope2` | The slope of Prop is given by the ratio of the Ref1 slope to the Ref2 slope. |
| `PosRange1` | The range of Prop is given by the range of Ref1. |

| Parameter Value | Description |
|---|---|
| PosRange2 | The range of Prop is given by the range of Ref2. |
| max([PosRange1 PosRange2]) | The range of Prop is given by the maximum range of the reference signals. |
| min([PosRange1 PosRange2]) | The range of Prop is given by the minimum range of the reference signals. |
| PosRange1*PosRange2 | The range of Prop is given by the product of the reference signal ranges. |
| PosRange1/PosRange2 | The range of Prop is given by the ratio of the Ref1 range to the Ref2 range. |

You control the precision of Prop with Slope1 and Slope2, and you control the range of Prop with PosRange1 and PosRange2. Additionally, PosRange1 and PosRange2 are one bit higher than the maximum positive range of the associated reference signal.

The **Slope: Multiplicative adjustment** parameter allows you to adjust the slope used by Prop by including a multiplicative adjustment. For example, if you want 3 bits of additional precision (with a corresponding decrease in range), the multiplicative adjustment is 2^-3.

The **Slope: Additive adjustment** parameter allows you to adjust the slope used by Prop by including an additive adjustment. An additive slope adjustment is often not needed. The most likely use is to set the multiplicative adjustment to 0, and set the additive adjustment to force the final slope to a specified value.

The **Bias: Base** parameter list specifies the bias used by Prop for the base data type. The parameter values are described below.

| Parameter Value | Description |
|---|---|
| Bias1 | The bias of Prop is given by the bias of Ref1. |
| Bias2 | The bias of Prop is given by the bias of Ref2. |

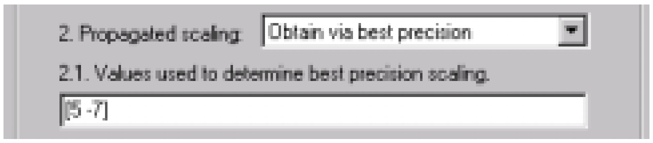
| Parameter Value | Description |
|---|---|
| `max([Bias1 Bias2])` | The bias of Prop is given by the maximum bias of the reference signals. |
| `min([Bias1 Bias2])` | The bias of Prop is given by the minimum bias of the reference signals. |
| `Bias1*Bias2` | The bias of Prop is given by the product of the reference signal biases. |
| `Bias1/Bias2` | The bias of Prop is given by the ratio of the Ref1 bias to the Ref2 bias. |
| `Bias1+Bias2` | The bias of Prop is given by the sum of the reference biases. |
| `Bias1-Bias2` | The bias of Prop is given by the difference of the reference biases. |

The **Bias: Multiplicative adjustment** parameter allows you to adjust the bias used by Prop by including a multiplicative adjustment.

The **Bias: Additive adjustment** parameter allows you to adjust the bias used by Prop by including an additive adjustment.

If you want to guarantee that the bias associated with Prop is zero, you should configure both the multiplicative adjustment and the additive adjustment to `0`.

If the **Propagated scaling** parameter is `Obtain via best precision`, then the following dialog box parameters are available to you.



2. Propagated scaling: Obtain via best precision

2.1. Values used to determine best precision scaling.

[5 -7]

You specify any values, such as the upper and lower limits on the propagated input, for the **Values used to determine best precision scaling**, which constrains the precision chosen to apply to those limits. Based on the data type, the scaling will automatically be selected such that these values can be represent with no overflow error and minimum quantization error.

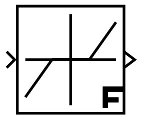
## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

**Purpose** Provide a region of zero output

**Library** Nonlinear

**Description**

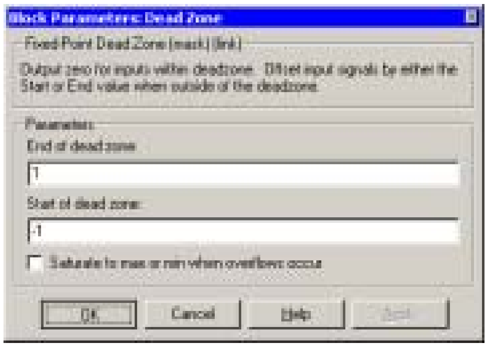


Dead Zone

The Dead Zone block generates zero output within a specified region, called its dead zone. The upper limit of the dead zone is specified with the **End of dead zone** parameter, while the lower limit of the dead zone is specified with the **Start of dead zone** parameter. The block output depends on the both on the input signal and on the dead zone:

- If the input is within the dead zone (greater than the lower limit and less than the upper limit), the output is zero.
- If the input is greater than or equal to the upper limit of the dead zone, the output is the input minus the upper limit.
- If the input is less than or equal to the lower limit of the dead zone, the output is the input minus the lower limit.

**Parameters and Dialog Box**



Block Parameters: Dead Zone

Fixed Point Dead Zone (mask) (link)

Output zero for inputs within deadzone. Offset input signals by either the Start or End value when outside of the deadzone.

Parameters

End of dead zone: 1

Start of dead zone: -1

[ ] Saturate to max or min when overflows occur

**End of dead zone**

Specify the upper limit of the dead zone.

**Start of dead zone**

Specify the lower limit of the dead zone.

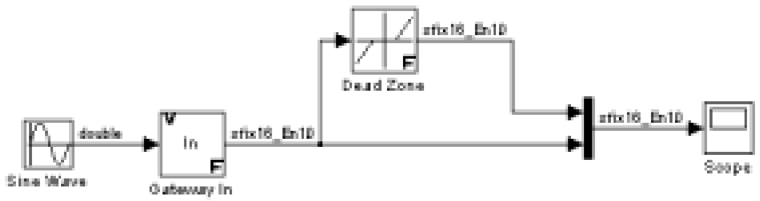
**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

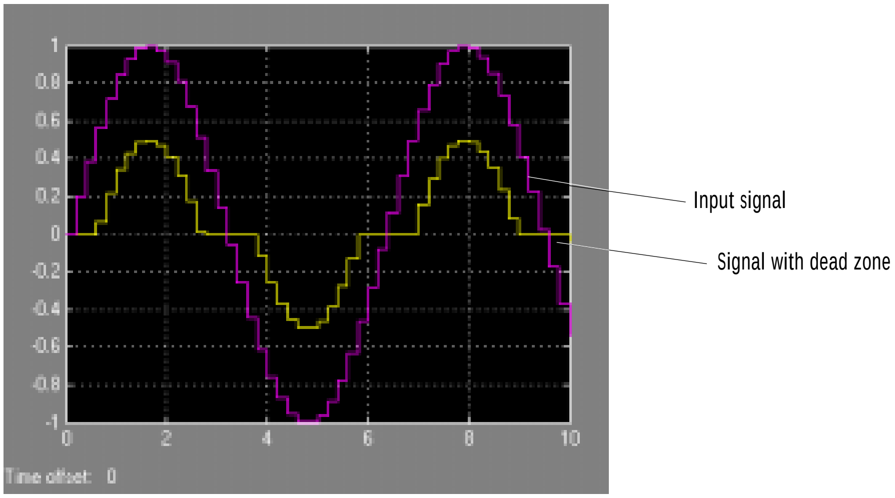
## Examples

Consider the model shown below, which compares a fixed-point signal and the output generated by the Dead Zone block. The signal source is a sine wave with unit amplitude.

The **Start of dead zone** parameter is configured to -0.5 and the **End of dead zone** parameter is configured to 0.5.



The resulting output is shown below.



## Characteristics

| | |
|---|---|
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes, of parameters |

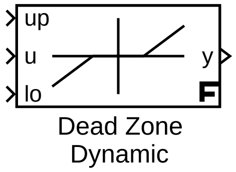
## Purpose

Set inputs within the bounds to zero

## Library

Nonlinear

## Description

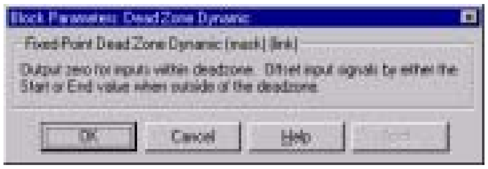


The Dead Zone Dynamic block dynamically bounds the range of the input signal, providing a region of zero output. The bounds change according to the upper and lower limit input signals where

- The input within the bounds is set to zero.
- The input below the lower limit is shifted down by the lower limit.
- The input above the upper limit is shifted down by the upper limit.

The input for the upper limit is the up port, and the input for the lower limit is the `lo` port.

## Parameters and Dialog Box


Block Parameters: Dead Zone Dynamic

Fixed Point Dead Zone Dynamic (mask) (link)

Output zero for inputs within deadzone. Offset input signals by either the Start or End value when outside of the deadzone.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

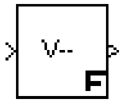
## See Also

Dead Zone

# Decrement Real World

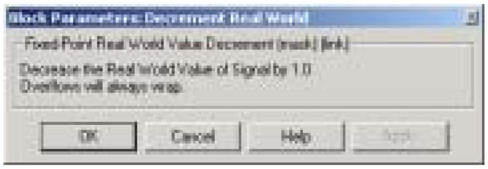
| | |
|---|---|
| **Purpose** | Decrease the real world value of the signal by one |
| **Library** | Math |

**Description**



The Decrement Real World block decreases the real world value of the signal by one. Overflows always wrap.

**Parameters and Dialog Box**



Block Parameters: Decrement Real World

Fixed-Point Real World Value Decrement (mask) (link)

Decrease the Real World Value of Signal by 1.0
Overflows will always wrap.

**Characteristics**

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | No |

**See Also**

Decrement Stored Integer, Decrement Time To Zero, Decrement To Zero

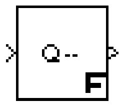
## Purpose

Decrease the stored integer value of a signal by one

## Library

Math

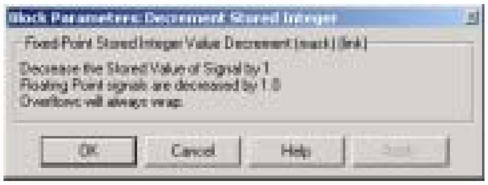
## Description



The Decrement Stored Integer block decreases the stored integer value of a signal by one.

Floating-point signals are also decreased by one, and overflows always wrap.

## Parameters and Dialog Box



Block Parameters: Decrement Stored Integer

Fixed-Point Stored Integer Value Decrement (mask) (link)

Decrease the Stored Value of Signal by 1
Floating Point signals are decreased by 1.0
Overflows will always wrap

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | No |

## See Also

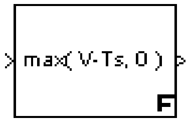
Decrement Real World, Decrement Time To Zero, Decrement To Zero

## Decrement Time To Zero

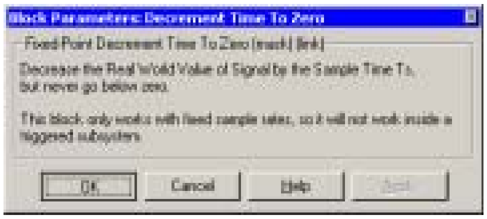
**Purpose** Decrease the real-world value of the signal by the sample time, but only to zero.

**Library** Math

**Description** The Decrement Time To Zero block decreases the real-world value of the signal by the sample time, Ts. The output will never go below zero. This block only works with fixed sample rates.



**Parameters and Dialog Box**



Block Parameters: Decrement Time To Zero

Fixed Point Decrement Time To Zero (mask) (link)

Decrease the Real World Value of Signal by the Sample Time Ts, but never go below zero.

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

**Characteristics**

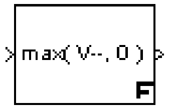
| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | No |

**See Also** Decrement Real World, Decrement Stored Integer, Decrement To Zero

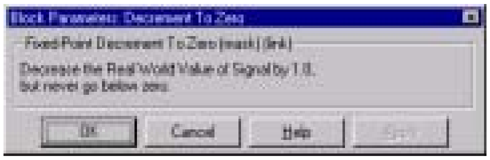
**Purpose** Decreases the real-world value of a signal by one, but only to zero.

**Library** Math

**Description** The Decrement To Zero block decreases the real-world value of the signal by one. The output will never go below zero.



**Parameters and Dialog Box**



Fixed-Point Decrement To Zero (mask) (link)

Decrease the Real World Value of Signal by 1.0,
but never go below zero.

**Characteristics**

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | No |

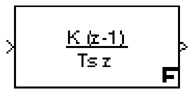
**See Also** Decrement Real World, Decrement Stored Integer, Decrement Time To Zero

# Derivative

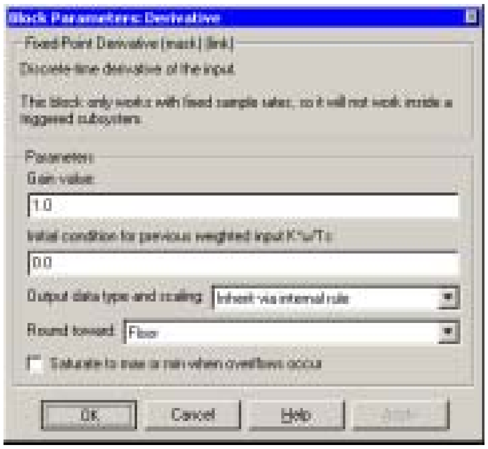
**Purpose** Compute a discrete time derivative

**Library** Calculus

**Description** The Derivative block computes a discrete time derivative, by subtracting the input value at the previous time step from the current value, and dividing by the sample time.



**Parameters and Dialog Box**



Block Parameters: Derivative

Fixed Point Derivative (mask) (link)

Discrete-time derivative of the input.

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

Parameters

Gain value:

1.0

Initial condition for previous weighted input K*u/Ts:

0.0

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Gain value**

Specify the weight by which the sample time is multiplied.

**Initial condition for previous weighted input K*u/Ts**

Set the initial condition for the previous scaled input.

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or inherit the data type and scaling from the driving block or by backpropagation.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of inputs and gain |

# Detect Change

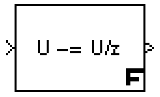
## Purpose

Detect a change in a signal's value

## Library

Edge Detect

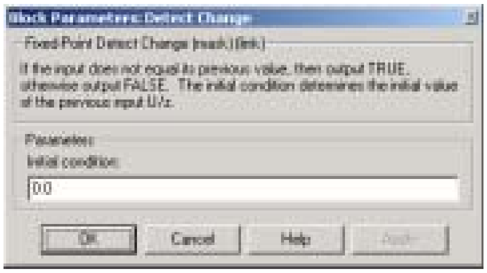
## Description



The Detect Change block determines if an input does not equal its previous value where

- The output is true (not 0), when the input signal does not equal its previous value.
- The output is false (equal to 0), when the input signal equals its previous value.

## Parameters and Dialog Box


Block Parameters: Detect Change

Fixed-Point Detect Change (mask) (link)

If the input does not equal its previous value, then output TRUE, otherwise output FALSE. The initial condition determines the initial value of the previous input U/z.

Parameters

Initial condition:

0.0

**Initial condition**

Set the initial condition for the previous input U/z.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | An 8-bit unsigned integer |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |
| Vectorized | Yes |

## See Also

Detect Decrease, Detect Fall Negative, Detect Fall Nonpositive, Detect Increase, Detect Rise Nonnegative, Detect Rise Positive

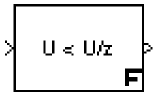
## Purpose

Detect a decrease in a signal's value

## Library

Edge Detect

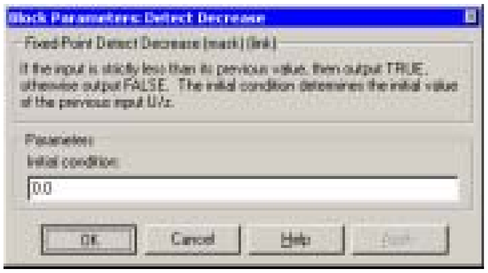
## Description



The Detect Decrease block determines if an input is strictly less than its previous value where

- The output is true (not 0), when the input signal is less than its previous value.
- The output is false (equal to 0), when the input signal is greater than or equal to its previous value.

## Parameters and Dialog Box



Fixed Point Detect Decrease (mask) (link)

If the input is strictly less than its previous value, then output TRUE, otherwise output FALSE. The initial condition determines the initial value of the previous input U/z.

Parameters

Initial condition:

0.0

**Initial condition**

Set the initial condition for the previous input U/z.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | An 8-bit unsigned integer |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |
| Vectorized | Yes |

## See Also

Detect Change, Detect Fall Negative, Detect Fall Nonpositive, Detect Increase, Detect Rise Nonnegative, Detect Rise Positive

# Detect Fall Negative

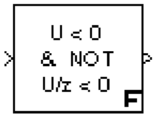
## Purpose

Detect a falling edge when the signal's value decreases to a strictly negative value, and its previous value was nonnegative

## Library

Edge Detect

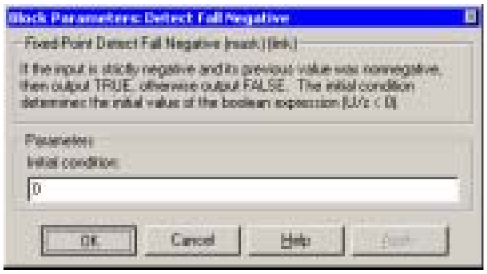
## Description



The Detect Fall Negative block determines if the input is less than zero, and its previous value was greater than or equal to zero where

- The output is true (not 0), when the input signal is less than zero, and its previous value was greater than or equal to zero.
- The output is false (equal to 0), when the input signal is greater than or equal to zero, or if the input signal is nonnegative, its previous value was positive or zero.

## Parameters and Dialog Box



Block Parameters: Detect Fall Negative

Fixed-Point Detect Fall Negative (mask) (link)

If the input is strictly negative and its previous value was nonnegative, then output TRUE, otherwise output FALSE. The initial condition determines the initial value of the boolean expression (U/z < 0).

Parameters

Initial condition:

0

**Initial condition**

Set the initial condition of the Boolean expression U/z < 0.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | An 8-bit unsigned integer |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |
| Vectorized | Yes |

## See Also

Detect Change, Detect Decrease, Detect Fall Nonpositive, Detect Increase, Detect Rise Nonnegative, Detect Rise Positive

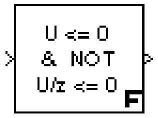
## Purpose

Detect a falling edge when the signal's value decreases to a nonpositive value, and its previous value was strictly positive

## Library

Edge Detect

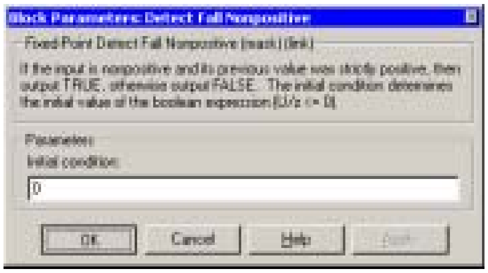
## Description



The Detect Fall Nonpositive block determines if the input is less than or equal to zero, and its previous value was positive where

- The output is true (not 0), when the input signal is less than or equal to zero, and its previous value was greater than zero.
- The output is false (equal to 0), when the input signal is greater than zero, or if it is nonpositive, its previous value was nonpositive.

## Parameters and Dialog Box


Block Parameters: Detect Fall Nonpositive

Fixed-Point Detect Fall Nonpositive (mask) (link)

If the input is nonpositive and its previous value was strictly positive, then output TRUE, otherwise output FALSE. The initial condition determines the initial value of the boolean expression (U/z <= 0).

Parameters

Initial condition:

0

**Initial condition**

Set the initial condition of the boolean expression U/z <= 0.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | An 8-bit unsigned integer |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |
| Vectorized | Yes |

## See Also

Detect Change, Detect Decrease, Detect Fall Negative, Detect Increase, Detect Rise Nonnegative, Detect Rise Positive

# Detect Increase

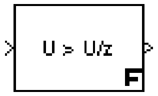
## Purpose

Detect an increase in a signal's value

## Library

Edge Detect

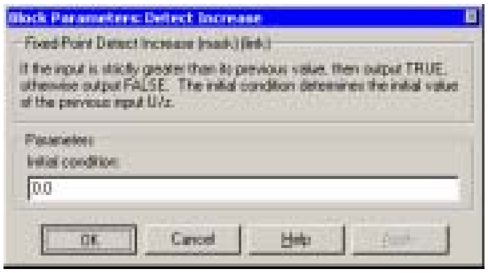
## Description



The Detect Increase block determines if an input is strictly greater than its previous value where

- The output is true (not 0), when the input signal is greater than its previous value.
- The output is false (equal to 0), when the input signal is less than or equal to its previous value.

## Parameters and Dialog Box



Block Parameters: Detect Increase

Fixed-Point Detect Increase (mask) (link)

If the input is strictly greater than its previous value, then output TRUE, otherwise output FALSE. The initial condition determines the initial value of the previous input U/z.

Parameters

Initial condition:

0.0

**Initial condition**

Set the initial condition for the previous input U/z.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | An 8-bit unsigned integer |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |
| Vectorized | Yes |

## See Also

Detect Change, Detect Decrease, Detect Fall Negative, Detect Fall Nonpositive, Detect Rise Nonnegative, Detect Rise Positive

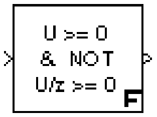
## Purpose

Detect a rising edge when a signal's value increases to a nonnegative value, and its previous value was strictly negative

## Library

Edge Detect

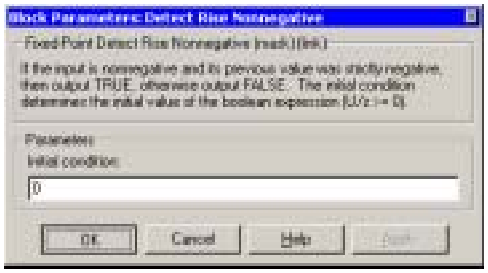
## Description



The Detect Rise Nonnegative block determines if the input is greater than or equal to zero, and its previous value was less than zero where

- The output is true (not 0), when the input signal is greater than or equal to zero, and its previous value was less than zero.
- The output is false (equal to 0), when the input signal is less than zero, or if nonnegative, its previous value was greater than or equal to zero.

## Parameters and Dialog Box



Block Parameters: Detect Rise Nonnegative

Fixed-Point Detect Rise Nonnegative (mask) (link)

If the input is nonnegative and its previous value was strictly negative, then output TRUE, otherwise output FALSE. The initial condition determines the initial value of the boolean expression (U/z >= 0).

Parameters

Initial condition:

0

**Initial condition**

Set the initial condition of the Boolean expression U/z >= 0.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | An 8-bit unsigned integer |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |
| Vectorized | Yes |

## See Also

Detect Change, Detect Decrease, Detect Fall Negative, Detect Fall Nonpositive, Detect Increase, Detect Rise Positive

## Detect Rise Positive

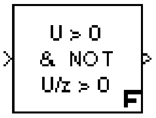
### Purpose

Detect a rising edge when a signal's value increases to a strictly positive value, and its previous value was nonpositive

### Library

Edge Detect

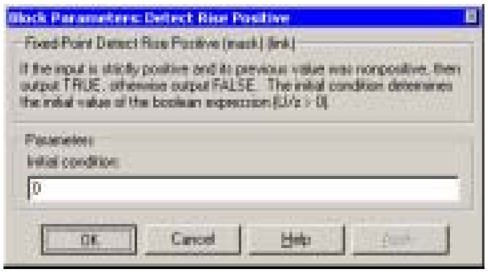
### Description



The Detect Rise Positive block determines if the input is strictly positive, and its previous value was nonpositive where

- The output is true (not 0), when the input signal is greater than zero, and its previous value was less than zero.
- The output is false (equal to 0), when the input is negative or zero, or if the input is positive, its previous value was also positive.

### Parameters and Dialog Box



Fixed Point Detect Rise Positive (mask) (link)

If the input is strictly positive and its previous value was nonpositive, then output TRUE, otherwise output FALSE. The initial condition determines the initial value of the boolean expression (U/z > 0).

Parameters

Initial condition:

0

**Initial condition**

Set the initial condition of the Boolean expression U/z > 0.

### Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | An 8-bit unsigned integer |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |
| Vectorized | Yes |

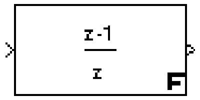
### See Also

Detect Change, Detect Decrease, Detect Fall Negative, Detect Fall Nonpositive, Detect Increase, Detect Rise Nonnegative

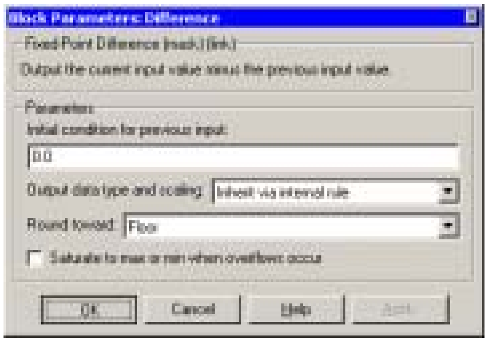
**Purpose** Calculate the change in a signal over one time step

**Library** Calculus

**Description** The Difference block outputs the current input value minus the previous input value.



**Parameters and Dialog Box**


Block Parameters: Difference

Fixed Point Difference (mask) (link)

Output the current input value minus the previous input value.

Parameters

Initial condition for previous input:

0.0

Output data type and scaling: Inherit via internal rule

Round toward: Floor

Saturate to max or min when overflows occur

**Initial condition for previous output**

Set the initial condition for the previous output.

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or inherit the data type and scaling from the driving block or by backpropagation.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

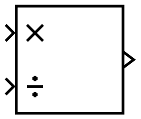
## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of inputs and gain |

**Purpose** Multiply or divide inputs

**Library** Math

**Description** The Divide block is an implementation of the Product block. See “Product” on page 10-175 for more information.



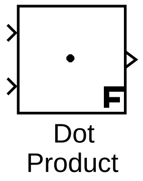
Divide

# Dot Product

**Purpose** Generate the dot product of two input signals

**Library** Math

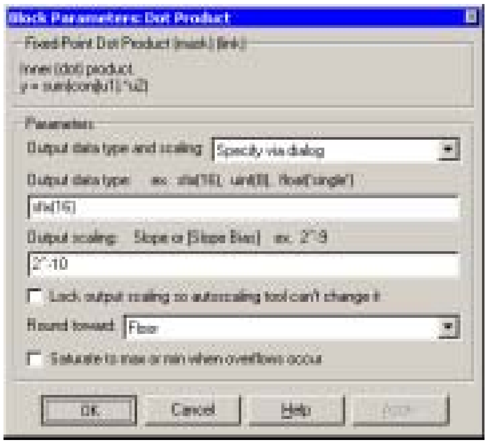
**Description** The Dot Product block generates the dot product of two input vectors. The scalar output, y, is equal to the MATLAB operation



```
y = sum(conj(u1).* u2)
```

where u1 and u2 represent the input vectors. If both inputs are vectors, they must be the same length.

## Parameters and Dialog Box



Block Parameters: Dot Product

Fixed-Point Dot Product (mask) (link)

Inner (dot) product
y = sum(conj(u1).*u2)

Parameters

Output data type and scaling: Specify via dialog

Output data type:    ex: sfix(16), uint(8), float('single')

sfix(16)

Output scaling:   Slope or [Slope Bias]   ex: 2^-9

2^-10

☐ Lock output scaling so autoscaling tool can't change it

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or inherit the data type and scaling from the driving block or by backpropagation.

**Output data type**

Specify any data type supported by the Fixed-Point Blockset.

**Output scaling**

Set the output scaling using binary point-only or [Slope Bias] scaling. These scaling modes are available only for generalized fixed-point data types.

**Lock output scaling so autoscaling tool can't change it**

If selected, **Output scaling** is locked. This feature is available only for generalized fixed-point output.

**Round toward**

Select the rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Direct Feedthrough | Yes |
| Scalar Expansion | No |

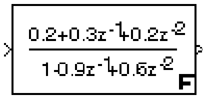
**Purpose**

Implement a Direct Form I realization of a filter

**Library**

Filters

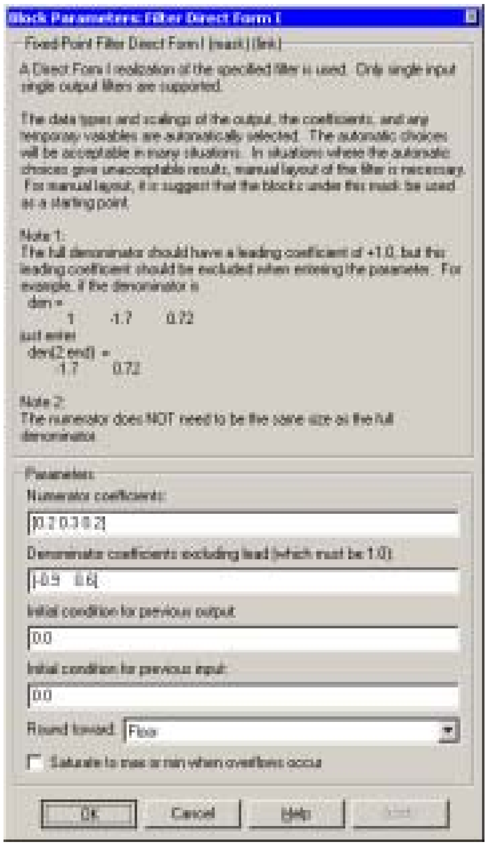
**Description**



The Filter Direct Form I block implements a Direct Form I realization of the filter specified by the **Numerator coefficients** and the **Denominator coefficients excluding lead** parameters. The block only supports single input-single output filters.

The block automatically selects the data types and scalings of the output, the coefficients, and any temporary variables.

**Parameters and Dialog Box**



Block Parameters: Filter Direct Form I

Fixed-Point Filter Direct Form I (mask) (link)

A Direct Form I realization of the specified filter is used. Only single input single output filters are supported.

The data types and scalings of the output, the coefficients, and any temporary variables are automatically selected. The automatic choices will be acceptable in many situations. In situations where the automatic choices give unacceptable results, manual layout of the filter is necessary. For manual layout, it is suggest that the blocks under this mask be used as a starting point.

Note 1:
The full denominator should have a leading coefficient of +1.0, but this leading coefficient should be excluded when entering the parameter. For example, if the denominator is
```
 den =
        1     -1.7     0.72
just enter
 den(2:end) =
      -1.7     0.72
```

Note 2:
The numerator does NOT need to be the same size as the full denominator.

Parameters

Numerator coefficients:

[0.2 0.3 0.2]

Denominator coefficients excluding lead (which must be 1.0):

[-0.9  0.6]

Initial condition for previous output:

0.0

Initial condition for previous input:

0.0

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Numerator coefficients**

Coefficients for the numerator of the filter.

**Denominator coefficients excluding lead**

Coefficients for the denominator of the filter, excluding the leading coefficient, which must be 1.0.

**Initial condition for previous output**

Set the initial condition for the previous output.

**Initial condition for previous input**

Set the initial condition for the previous input.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset—it must be a scalar |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of initial conditions |
| Vectorized | No |

## See Also

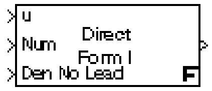
Filter Direct Form I Time Varying, FIR

# Filter Direct Form I Time Varying

**Purpose** Implement a time varying Direct Form I realization of a filter

**Library** Filters

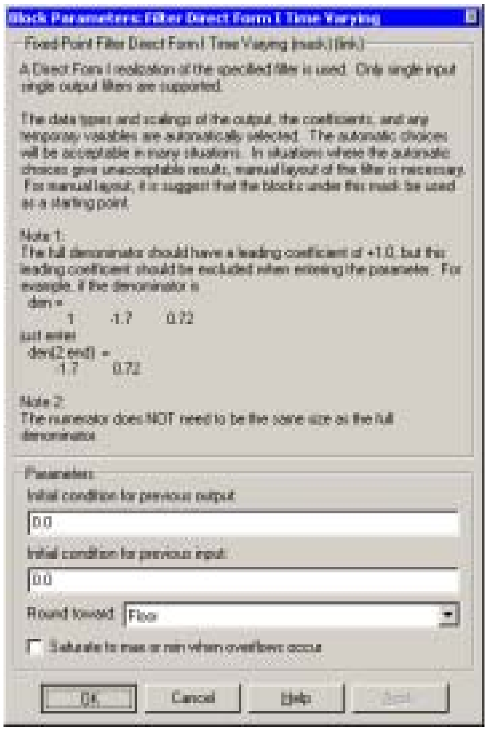
**Description**



The Filter Direct Form I Time Varying block implements a Direct Form I realization of the specified filter. The block only supports single input-single output filters.

The block automatically selects the data types and scalings of the output, the coefficients, and any temporary variables.

**Parameters and Dialog Box**



Block Parameters: Filter Direct Form I Time Varying

Fixed Point Filter Direct Form I Time Varying (mask) (link)

A Direct Form I realization of the specified filter is used. Only single input single output filters are supported.

The data types and scalings of the output, the coefficients, and any temporary variables are automatically selected. The automatic choices will be acceptable in many situations. In situations where the automatic choices give unacceptable results, manual layout of the filter is necessary. For manual layout, it is suggest that the blocks under this mask be used as a starting point.

Note 1:
The full denominator should have a leading coefficent of +1.0, but this leading coefficent should be excluded when entering the parameter. For example, if the denominator is

```
 den =
        1      -1.7      0.72
just enter
 den(2:end) =
       -1.7      0.72
```

Note 2:
The numerator does NOT need to be the same size as the full denominator.

Parameters

Initial condition for previous output: 0.0

Initial condition for previous input: 0.0

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Initial condition for previous output**

Set the initial condition for the previous output.

**Initial condition for previous input**

Set the initial condition for the previous input.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Port u | Any data type supported by the blockset—it must be a scalar |
| Input Port Num | Any data type supported by the blockset—it must be a scalar |
| Input Port Den No Lead | Any data type supported by the blockset—it must be a scalar |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of initial conditions |
| Vectorized | No |

## See Also

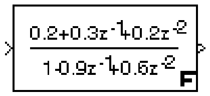
Filter Direct Form I, FIR

# Filter Direct Form II

**Purpose** Implement a Direct Form II realization of a filter

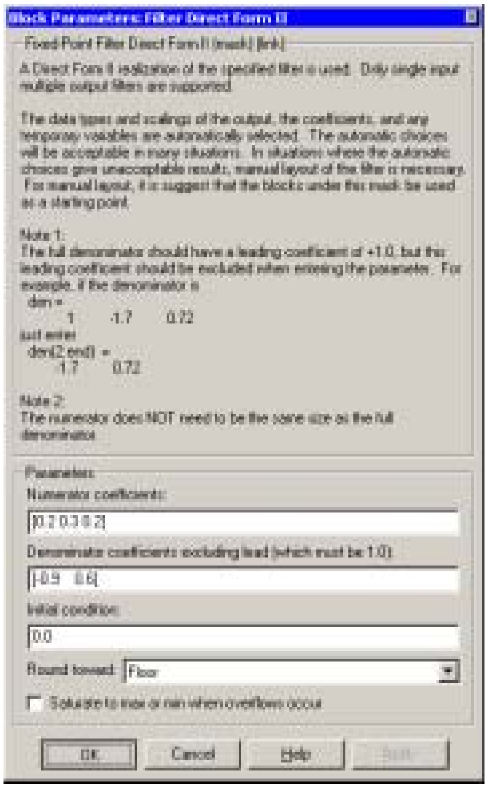
**Library** Filters

**Description** The Filter Direct Form II block implements a Direct Form II realization of the filter specified by the **Numerator coefficients** and the **Denominator coefficients excluding lead** parameters. The block only supports single input-single output filters.



The block automatically selects the data types and scalings of the output, the coefficients, and any temporary variables.

**Parameters and Dialog Box**



Fixed Point Filter Direct Form II (mask) (link)

A Direct Form II realization of the specified filter is used. Only single input multiple output filters are supported.

The data types and scalings of the output, the coefficients, and any temporary variables are automatically selected. The automatic choices will be acceptable in many situations. In situations where the automatic choices give unacceptable results, manual layout of the filter is necessary. For manual layout, it is suggest that the blocks under this mask be used as a starting point.

Note 1:
The full denominator should have a leading coefficient of +1.0, but this leading coefficient should be excluded when entering the parameter. For example, if the denominator is

```
 den =
       1       -1.7       0.72
just enter
 den(2:end) =
      -1.7      0.72
```

Note 2:
The numerator does NOT need to be the same size as the full denominator.

Parameters

Numerator coefficients: [0.2 0.3 0.2]

Denominator coefficients excluding lead (which must be 1.0): [-0.9 0.6]

Initial condition: 0.0

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Numerator coefficients**

Coefficients for the numerator of the filter.

**Denominator coefficients excluding lead**

Coefficients for the denominator of the filter, excluding the leading coefficient, which must be 1.0.

**Initial condition**

Set the initial condition.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset—it must be a scalar |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of initial conditions |
| Vectorized | No |

## See Also

Filter Direct Form II Time Varying, FIR

# Filter Direct Form II Time Varying

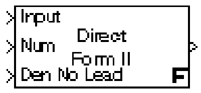
## Purpose

Implement a time varying Direct Form II realization of a filter

## Library

Filters

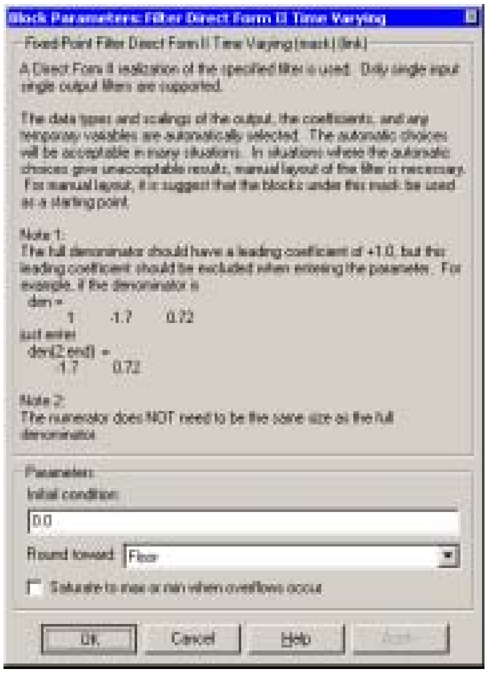
## Description



The Filter Direct Form II Time Varying block implements a Direct Form II realization of the specified filter. The block only supports single input-single output filters.

The block automatically selects the data types and scalings of the output, the coefficients, and any temporary variables.

## Parameters and Dialog Box



Fixed Point Filter Direct Form II Time Varying (mask) (link)

A Direct Form II realization of the specified filter is used. Only single input single output filters are supported.

The data types and scalings of the output, the coefficients, and any temporary variables are automatically selected. The automatic choices will be acceptable in many situations. In situations where the automatic choices give unacceptable results, manual layout of the filter is necessary. For manual layout, it is suggest that the blocks under this mask be used as a starting point.

Note 1:
The full denominator should have a leading coefficient of +1.0, but this leading coefficient should be excluded when entering the parameter. For example, if the denominator is

```
 den =
       1      -1.7      0.72
just enter
 den(2:end) =
      -1.7     0.72
```

Note 2:
The numerator does NOT need to be the same size as the full denominator.

Parameters

Initial condition:
0.0

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Initial condition**

Set the initial condition.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**
If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Port u | Any data type supported by the blockset—it must be a scalar |
| Input Port Num | Any data type supported by the blockset—it must be a scalar |
| Input Port Den No Lead | Any data type supported by the blockset—it must be a scalar |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of initial conditions |
| Vectorized | No |

## See Also

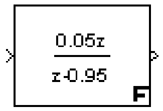
Filter Direct Form II, FIR

# Filter First Order

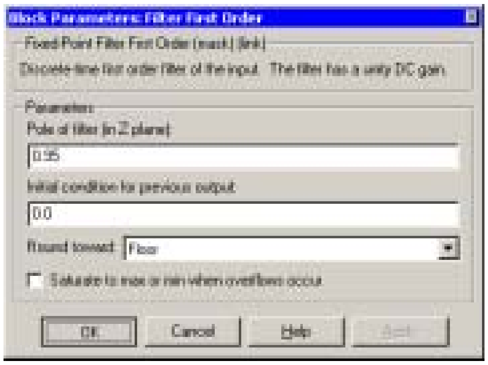
**Purpose** Implement a discrete-time first order filter

**Library** Filters

**Description** The Filter First Order block implements a discrete-time first order filter of the input. The filter has a unity DC gain.



**Parameters and Dialog Box**



Block Parameters: Filter First Order

Fixed-Point Filter First Order (mask) (link)

Discrete-time first order filter of the input. The filter has a unity DC gain.

Parameters

Pole of filter (in Z plane)

0.95

Initial condition for previous output

0.0

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Pole of filter (in Z plane)**
Set the pole of the filter.

**Initial condition for previous output**
Set the initial condition for the previous output.

**Round toward**
Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**
If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset—it must be a scalar |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of initial conditions |
| Vectorized | No |

## See Also

FIR

# Filter Lead or Lag

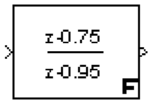
**Purpose**

Implement a discrete-time lead or lag filter

**Library**

Filters

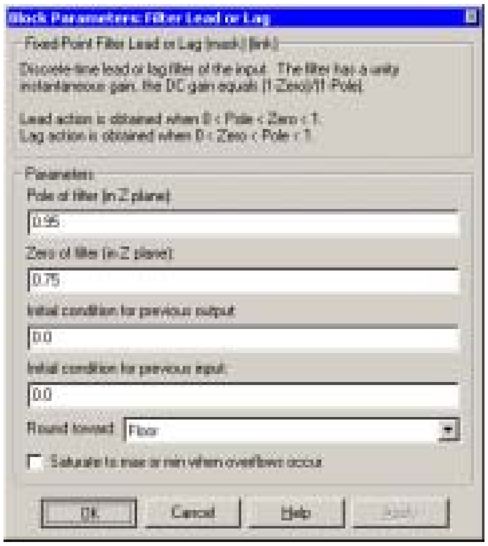
**Description**



The Filter Lead or Lag block implements a discrete-time lead or lag filter of the input. The instantaneous gain of the filter is one, and the DC gain is equal to (1-z)/(1-p), where z is the zero and p is the pole of the filter.

The block implements a lead filter when 0 < z < p < 1, and implements a lag filter when 0 < p < z < 1.

**Parameters and Dialog Box**



Block Parameters: Filter Lead or Lag

Fixed Point Filter Lead or Lag (mask) (link)

Discrete-time lead or lag filter of the input. The filter has a unity instantaneous gain, the DC gain equals (1-Zero)/(1-Pole).

Lead action is obtained when 0 < Pole < Zero < 1.
Lag action is obtained when 0 < Zero < Pole < 1.

Parameters

Pole of filter (in Z plane): 0.95

Zero of filter (in Z plane): 0.75

Initial condition for previous output: 0.0

Initial condition for previous input: 0.0

Round toward: Floor

[ ] Saturate to max or min when overflows occur

**Pole of filter (in Z plane)**

Set the pole of the filter.

**Zero of filter (in Z plane)**

Set the zero of the filter.

**Initial condition for previous output**

Set the initial condition for the previous output.

**Initial condition for previous input**

Set the initial condition for the previous input.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset—it must be a scalar |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of initial conditions |
| Vectorized | No |

## See Also

FIR

## Filter Real Zero

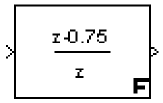
**Purpose**

Implement a discrete-time filter that has a real zero and no pole

**Library**

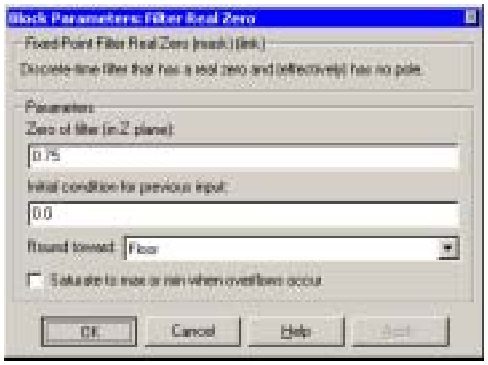
Filters

**Description**



The Filter Real Zero block implements a discrete-time filter that has a real zero and effectively has no pole.

**Parameters and Dialog Box**



Block Parameters: Filter Real Zero

Fixed-Point Filter Real Zero (mask) (link)

Discrete-time filter that has a real zero and (effectively) has no pole.

Parameters

Zero of filter (in Z plane):

0.75

Initial condition for previous input:

0.0

Round toward: Floor

Saturate to max or min when overflows occur

**Zero of filter (in Z plane)**

Set the zero of the filter.

**Initial condition for previous input**

Set the initial condition for the previous input.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset—it must be a scalar |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of initial conditions |
| Vectorized | No |

## See Also

FIR

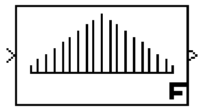
## Purpose

Implement a fixed-point finite impulse response (FIR) filter

## Library

Filters

## Description



The FIR block samples and holds the N most recent inputs, multiplies each input by a specified value (its FIR coefficient), and stacks them in a vector. This block supports both single-input/single-output (SISO) and single-input/multi-output (SIMO) modes.

For the SISO mode, the **FIR coefficients** parameter is specified as a row vector. For the SIMO mode, the **FIR coefficients** are specified as a matrix where each row corresponds to a separate output.

The **Initial condition** parameter provides the initial values for all times preceding the start time in the FIR realization. You specify the time interval between samples with the **Sample time** parameter.

You can choose whether or not to specify the data type and scaling of the FIR coefficients in the dialog with the **Gain data type and scaling** parameter. If you select `Specify via dialog` for this parameter, the **Parameter data type** and **Parameter scaling** parameters become visible.

You can specify the scaling for the FIR coefficients with the **Parameter scaling** parameter. Note that there are two dialog box parameters that control the FIR coefficient scaling: one associated with an edit field, and one associated with a parameter list. If **Parameter data type** is a generalized fixed-point number such as `sfix(16)`, the **Parameter scaling** list provides you with these scaling modes:

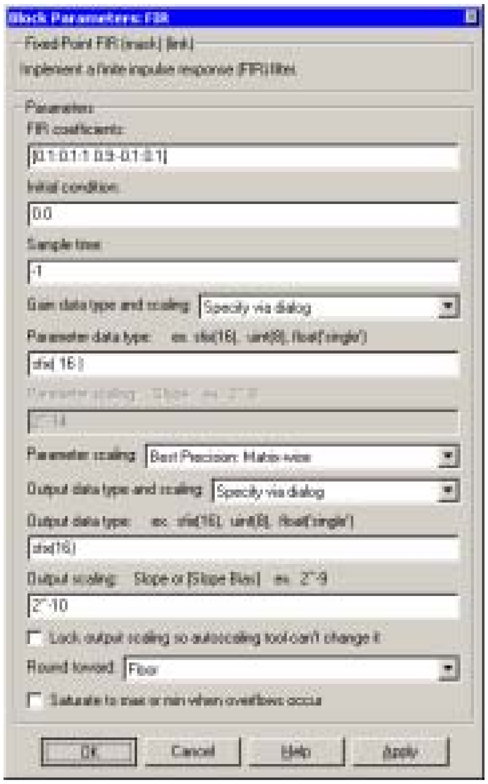
- `Use Specified Scaling`—This mode uses the [Slope Bias] or binary point-only scaling specified for the editable **Parameter scaling** parameter (for example, `2^-10`).
- `Best Precision: Element-wise`—This mode produces binary points such that the precision is maximized for each element of the **FIR coefficients** parameter.
- `Best Precision: Row-wise`—This mode produces a common binary point for each element of the **FIR coefficients** row based on the best precision for the largest value of that row.

- `Best Precision: Column-wise`—This mode produces a common binary point for each element of the **FIR coefficients** column based on the best precision for the largest value of that column.
- `Best Precision: Matrix-wise`—This mode produces a common binary point for each element of the **FIR coefficients** matrix based on the best precision for the largest value of the matrix.

If the FIR coefficients are specified as a row vector, then scaling element-wise and column-wise produce the same result, while scaling matrix-wise and row-wise produce the same result.

For a detailed description of all other block parameters, refer to "Block Parameters" on page 10-6.

## Parameters and Dialog Box



Fixed Point FIR (mask) (link)

Implement a finite impulse response (FIR) filter.

Parameters

FIR coefficients:
[0.1:0.1:1 0.9:-0.1:0.1]

Initial condition:
0.0

Sample time:
-1

Gain data type and scaling: Specify via dialog

Parameter data type: ex. sfix(16), uint(8), float('single')
sfix( 16 )

Parameter scaling: Slope ex. 2^-9
2^-14

Parameter scaling: Best Precision: Matrix-wise

Output data type and scaling: Specify via dialog

Output data type: ex. sfix(16), uint(8), float('single')
sfix(16)

Output scaling: Slope or [Slope Bias] ex. 2^-9
2^-10

☐ Lock output scaling so autoscaling tool can't change it

Round toward: Floor

☐ Saturate to max or min when overflows occur

**FIR coefficients**

FIR coefficients. One row per output.

**Initial condition**

Initial values for all times preceding the start time.

**Sample time**

Sample time.

**Gain data type and scaling**

Choose whether to specify the data type of the FIR coefficients via the dialog or via an internal rule. If `Specify via dialog` is selected, the **Parameter data type** and **Parameter scaling** parameters become visible.

**Parameter data type**

Any data type supported by the Fixed-Point Blockset. This parameter is only visible if `Specify via dialog` is selected for the **Gain data type and scaling** parameter.

**Parameter scaling**

Set the parameter scaling using binary point-only or [Slope Bias] scaling. Additionally, the **FIR coefficients** vector or matrix can be scaled using the constant vector or constant matrix scaling modes for maximizing precision. These scaling modes are available only for generalized fixed-point data types. This parameter is only visible if `Specify via dialog` is selected for the **Gain data type and scaling** parameter.

**Parameter scaling**

This drop-down list enables you to specify the parameter scaling in the dialog or by an inherited rule. This parameter is only visible if `Specify via dialog` is selected for the **Gain data type and scaling** parameter.

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or inherit the data type and scaling from the driving block or by backpropagation.

**Output data type**

Any data type supported by the Fixed-Point Blockset.

**Output scaling**

Set the output scaling using binary point-only or [Slope Bias] scaling. These scaling modes are available only for generalized fixed-point data types.

**Lock output scaling so autoscaling tool can't change it**

If selected, **Output scaling** is locked. This feature is available only for generalized fixed-point output.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Conversions and Operations

The **FIR coefficients** parameter is converted from doubles to the specified data type offline using round-to-nearest and saturation.The **Initial condition** parameter is converted from doubles to the input data type offline using round-to-nearest and saturation. Refer to "Parameter Conversions" on page 4-27 for more information about parameter conversions.

The FIR block first multiplies its inputs by the **FIR coefficients** parameter, converts those results to the output data type using the specified rounding and overflow modes, and then carries out the summation. Refer to "Rules for Arithmetic Operations" on page 4-30 for more information about the rules this block adheres to when performing operations.

## Examples

Suppose you want to configure this block for two outputs (SIMO mode) where the first output is given by

$$y_1(k) = a_1 \cdot u(k) + b_1 \cdot u(k-1) + c_1 \cdot u(k-2)$$

the second output is given by

$$y_2(k) = a_2 \cdot u(k) + b_2 \cdot u(k-1)$$

and the initial values of $u(k-1)$ and $u(k-2)$ are given by `ic1` and `ic2`, respectively. To configure the FIR block for this situation, you must specify the **FIR coefficient** parameter as `[a1 b1 c1; a2 b2 c2]` where `c2` = 0, and the **Initial condition** parameter as `[ic1 ic2]`.

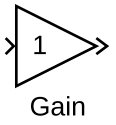
## Characteristics

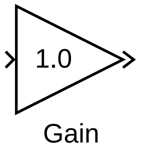
| | |
|---|---|
| Input Ports | Any data type supported by the blockset—it must be a scalar |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of initial conditions |
| Vectorized | No |

**Purpose** Multiply the input by a constant

**Library** Simulink Math Operations and Fixed-Point Blockset Math

**Description**





The Gain block multiplies the input by a constant value (gain). The input and the gain can each be a scalar, vector, or matrix.

You specify the value of the gain in the **Gain** parameter. The **Multiplication** parameter lets you specify element-wise or matrix multiplication. For matrix multiplication, this parameter also lets you indicate the order of the multiplicands.

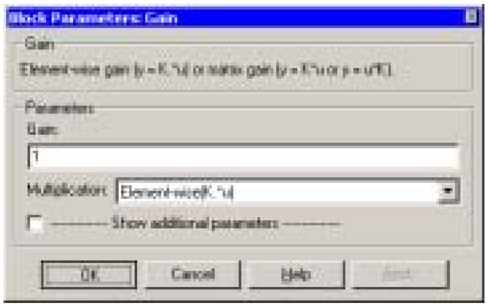
When the **Show additional parameters** check box is selected, some of the parameters that become visible are common to many blocks. For a detailed description of these parameters, refer to “Block Parameters” on page 10-6.

**Data Type Support**

The Gain block accepts a real or complex scalar, vector, or matrix of any data type supported by Simulink except `boolean`. The Gain block also accepts fixed-point data types. If the input of the Gain block is real and the gain is complex, the output is complex.

For a discussion on the data types supported by Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

**Parameters and Dialog Box**



Gain

Element-wise gain (y = K.*u) or matrix gain (y = K*u or y = u*K).

Parameters

Gain:

1

Multiplication: Element-wise(K.*u)

Show additional parameters

**Gain**

Specify the value by which to multiply the input. The gain may be a scalar, vector, or matrix.

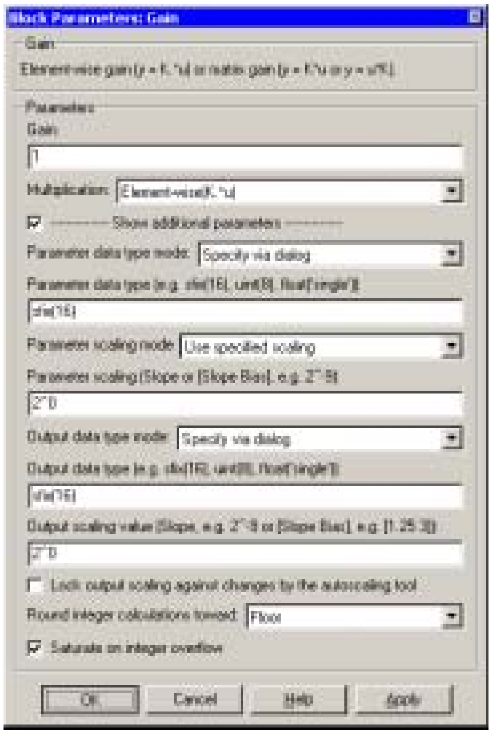
**Multiplication**

Specify the multiplication mode:

- `Element-wise(K*u)`—Each element of the input is multiplied by each element of the gain. The block performs expansions, if necessary, so that the input and gain have the same dimensions.
- `Matrix(K*u)`—The input and gain are matrix multiplied with the input as the second operand.
- `Matrix(u*K)`—The input and gain are matrix multiplied with the input as the first operand.
- `Matrix(K*u)(u vector)`—The input and gain are matrix multiplied with the input as the second operand, and the input is a vector. The input and the output are required to be vectors and their lengths are determined by the dimensions of the gain.

**Show additional parameters**

If selected, additional parameters specific to implementation of the block become visible as shown.


Block Parameters: Gain

Gain

Element-wise gain (y = K.*u) or matrix gain (y = K*u or y = u*K).

Parameters

Gain:

1

Multiplication: Element-wise(K.*u)

[✓] ---------- Show additional parameters ----------

Parameter data type mode: Specify via dialog

Parameter data type (e.g. sfix(16), uint(8), float('single')):

sfix(16)

Parameter scaling mode: Use specified scaling

Parameter scaling (Slope or [Slope Bias], e.g. 2^-9):

2^0

Output data type mode: Specify via dialog

Output data type (e.g. sfix(16), uint(8), float('single')):

sfix(16)

Output scaling value (Slope, e.g. 2^-9 or [Slope Bias], e.g. [1.25 3]):

2^0

[ ] Lock output scaling against changes by the autoscaling tool

Round integer calculations toward: Floor

[✓] Saturate on integer overflow

**Parameter data type mode**

Set the data type and scaling of the gain to be the same as that of the input, or to be inherited via an internal rule. Alternatively, choose to specify the data type and scaling of the gain through the **Parameter data type**, **Parameter scaling mode**, and **Parameter scaling** parameters in the dialog.

**Parameter data type**

Set the gain data type. This parameter is only visible if `Specify via dialog` is selected for the **Parameter data type mode** parameter.

**Parameter scaling mode**

Set the mode to determine the scaling of the gain.

- `Use specified scaling`—This mode allows you to set the scaling of the gain in the **Parameter scaling** parameter.

- `Best Precision: Element-wise`—This mode sets binary points for the elements of the gain such that the precision of each element is maximized.
- `Best Precision: Row-wise`—This mode sets a common binary point within each row of the gain such that the largest element of each row has the best possible precision.
- `Best Precision: Column-wise`—This mode sets a common binary point within each column of the gain such that the largest element of each column has the best possible precision.
- `Best Precision: Matrix-wise`—This mode sets a common binary point for all the elements of the gain such that the largest element has the best possible precision.

This parameter is only visible if `Specify via dialog` is selected for the **Parameter data type mode** parameter.

**Parameter scaling**

Set the gain scaling using either binary point-only or [Slope Bias] scaling. This parameter is only visible if `Specify via dialog` is selected for the **Parameter data type mode** parameter, and if `Use specified scaling` is selected for the **Parameter scaling mode** parameter.

**Output data type mode**

Set the data type and scaling of the output to be the same as that of the input, or to be inherited via an internal rule or by backpropagation. Alternatively, choose to specify the data type and scaling of the output through the **Output data type** and **Output scaling value** parameters in the dialog.

If you select `Inherit via internal rule` for this parameter, Simulink chooses a combination of output scaling and data type that requires the smallest amount of memory consistent with accommodating the output range and maintaining the output precision of the block. If the **Production hardware characteristics** parameter on the **Advanced** pane of the **Simulation Parameters** dialog is set to `Unconstrained integer sizes`, Simulink chooses the output data type without regard to hardware constraints. If the parameter is set to `Microprocessor`, Simulink chooses the smallest available hardware data type capable of meeting the range and precision constraints. For example, if the block multiplies an input of type `int8` by a gain of `int16` and `Unconstrained integer sizes` is specified, the output data type is `sfix24`. If `Microprocessor` is specified and the microprocessor supports 8-bit, 16-bit, and 32-bit words, the output data type is `int32`. If none of the word lengths provided by the target microprocessor can accommodate the output range, Simulink displays an error message in the Simulink Diagnostic Viewer.

**Output data type**

Set the output data type. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Output scaling value**

Set the output scaling using either binary point-only or [Slope Bias] scaling. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Lock output scaling against changes by the autoscaling tool**

If selected, scaling of outputs is locked. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Round integer calculations toward**

Select the rounding mode for fixed-point output.

**Saturate on integer overflow**

If selected, overflows saturate.

## Conversions and Operations

The gain is converted from doubles to the specified data type offline using round-to-nearest and saturation. Refer to “Parameter Conversions” on page 4-27 for more information about parameter conversions. The input and gain are then multiplied, and the result is converted to the output data type using the specified rounding and overflow modes. Refer to “Rules for Arithmetic Operations” on page 4-30 for more information about the rules this block adheres to when performing operations.

## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from driving block |

| | |
|---|---|
| Scalar Expansion | Of input and **Gain** parameter for `Element-wise` multiplication |
| Zero Crossing | No |

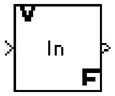
## Purpose

Convert a Simulink data type to a Fixed-Point Blockset data type

## Library

Data Type

## Description

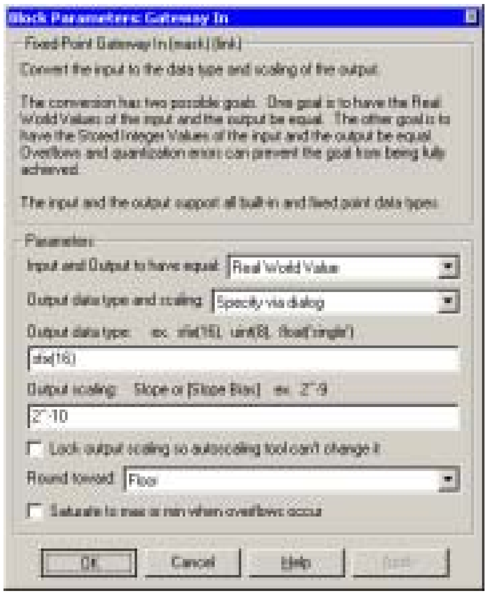


The Gateway In block converts a built-in Simulink data type to a Fixed-Point Blockset data type.

The **Input and Output to have equal** parameter list controls how the input is processed. The possible values are **Real World Value** and **Stored Integer**. In terms of the general encoding scheme described in “Scaling” on page 3-5, **Real World Value** treats the input as $V = SQ + B$ where $S$ is the slope and $B$ is the bias. $V$ is used to produce $Q = (V - B)/S$, which is stored in the output. **Stored Integer** treats the input as a stored integer, $Q$. The value of $Q$ is directly used to produce the output. In this mode, the input and output are identical except that the input is a raw integer lacking proper scaling information. In both modes, the output data type includes the scaling information needed to correctly interpret the signal as a real-world value.

For a detailed description of all other block parameters, refer to “Block Parameters” on page 10-6.

## Parameters and Dialog Box



Block Parameters: Gateway In

Fixed Point Gateway In (mask) (link)

Convert the input to the data type and scaling of the output.

The conversion has two possible goals. One goal is to have the Real World Values of the input and the output be equal. The other goal is to have the Stored Integer Values of the input and the output be equal. Overflows and quantization errors can prevent the goal from being fully achieved.

The input and the output support all built-in and fixed point data types.

Parameters

Input and Output to have equal: Real World Value

Output data type and scaling: Specify via dialog

Output data type: ex. sfix(16), uint(8), float('single')

sfix(16)

Output scaling: Slope or [Slope Bias] ex. 2^-9

2^-10

☐ Lock output scaling so autoscaling tool can't change it

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Input and Output to have equal**

Specify the type of value that the input and output are to have equal.

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or inherit the data type and scaling by backpropagation.

**Output data type**

Any data type supported by the Fixed-Point Blockset.

**Output scaling**

Set the output scaling using binary point-only or [Slope Bias] scaling. These scaling modes are available only for generalized fixed-point data types.

**Lock output scaling so autoscaling tool can't change it**

If selected, **Output scaling** is locked. This feature is available only for generalized fixed-point output.

**Round toward**

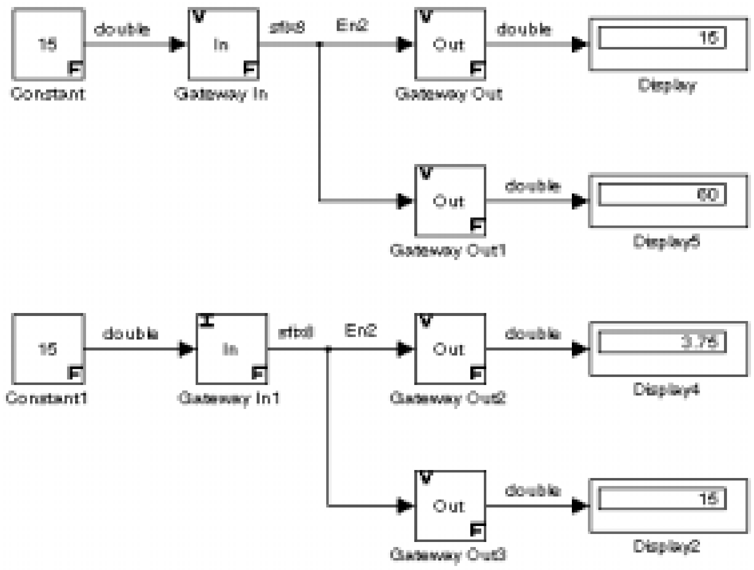
Rounding mode for fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Examples

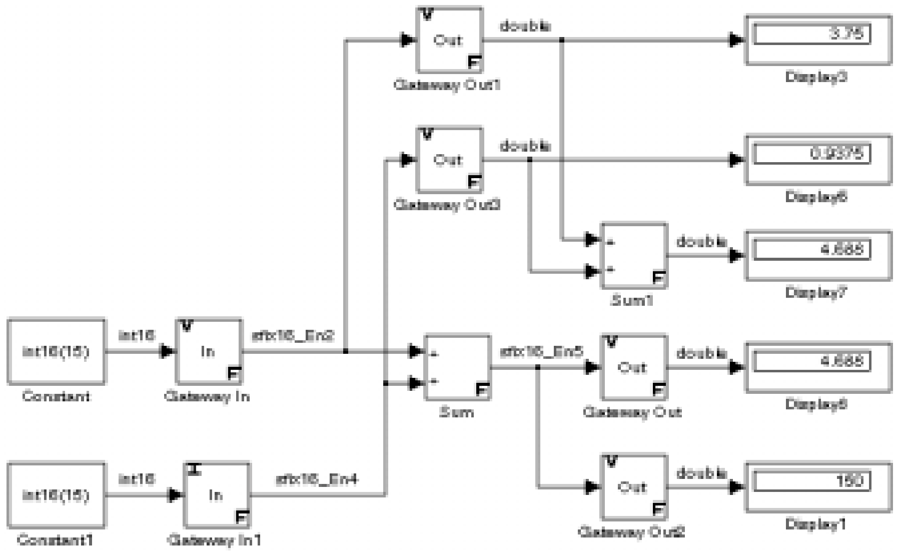
This example uses the Gateway In block to help you understand the difference between a real-world value and a stored integer. Consider the two fixed-point models shown below.



In the top model, the Gateway In block treats the input as a real-world value, and maps that value to an 8-bit signed generalized fixed-point data type with a scaling of $2^{-2}$. If the value is output from the Gateway Out block as a real-world value, then the scaling and data type information is retained and the output value is 001111.00, or 15. If the value is output from the Gateway Out block as a stored integer, then the scaling and data type information is not retained and the stored integer is interpreted as 00111100, or 60.

In the bottom model, the Gateway In block treats the input as a stored integer, and the data type and scaling information is not applied. If the value is output from the Gateway Out block as a real-world value, then the scaling and data type information is applied to the stored integer, and the output value is 000011.11, or 3.75. If the value is output from the Gateway Out block as a stored integer, then you get back the original input value of 15.

The model shown below illustrates how a summation operation applies to real-world values and stored integers, and how scaling information is dealt with in generated code.



Note that the summation operation produces the correct result when the Gateway Out block outputs a real-world value. This is because the specified scaling information is applied to the stored integer value. However, when the Gateway Out block outputs a stored integer value, then the summation operation produces an unexpected result due to the absence of scaling information.

If you generate code for the above model, then the code captures the appropriate scaling information. The code for the Sum block is shown below. The inputs to this block are tagged with the specified scaling information so that the necessary shifts are performed for the summation operation.

```
/* Sum Block: <Root>/Sum
   *
   *  y =  u0 + u1
   *
   * Input0  Data Type:  Fixed Point    S16  2^-2
   * Input1  Data Type:  Fixed Point    S16  2^-4
   * Output0 Data Type:  Fixed Point    S16  2^-5
   *
```

```
     * Round Mode: Floor
     * Saturation Mode: Wrap
     *
     */
    sum = ((in1) << 3);
    sum += ((in2) << 1);
```

## Characteristics

| | |
|---|---|
| Input Port | Any built-in Simulink data type |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | No |

## See Also

Gateway In Inherited

# Gateway In Inherited

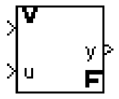
## Purpose

Convert a Simulink data type to a Fixed-Point Blockset data type, and inherit the data type and scaling

## Library

Data Type

## Description



The Gateway In Inherited block converts a built-in Simulink data type to a Fixed-Point Blockset data type.

The block requires two inputs. The first (top) input provides the data type and scaling information. The second (bottom) input passes through to the output, and inherits the data type and scaling of the first input. If you want to explicitly specify the output data type and scaling, use the Gateway In block.

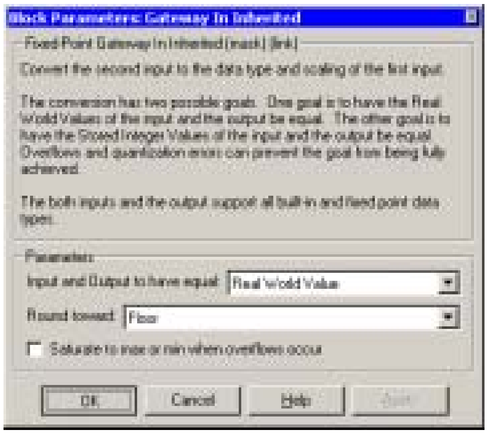
The **Input and Output to have equal** parameter controls how the input is processed. The possible values are `Real World Value` and `Stored Integer`. In terms of the general encoding scheme described in “Scaling” on page 3-5, `Real World Value` treats the input as $V = SQ + B$ where $S$ is the slope and $B$ is the bias. `Stored Integer` treats the input as a stored integer, $Q$. For more information about this parameter list, refer to the Gateway In block.

For a detailed description of all other block parameters, refer to “Block Parameters” on page 10-6.

Inheriting the data type and scaling provides these advantages:

- It makes reusing existing models easier.
- It allows you to create new fixed-point models with less effort since you can avoid the detail of specifying the associated parameters.

## Parameters and Dialog Box



Block Parameters: Gateway In Inherited

Fixed Point Gateway In Inherited (mask) (link)

Convert the second input to the data type and scaling of the first input.

The conversion has two possible goals. One goal is to have the Real World Values of the input and the output be equal. The other goal is to have the Stored Integer Values of the input and the output be equal. Overflows and quantization errors can prevent the goal from being fully achieved.

The both inputs and the output support all built-in and fixed point data types.

Parameters

Input and Output to have equal: Real World Value

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Input and Output to have equal**

Specify the type of value that the input and output are to have equal.

**Round toward**

Rounding mode for fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Port | Any built-in Simulink data type |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | No |

## See Also

Gateway In

# Gateway Out

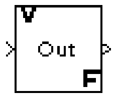
**Purpose**

Convert a Fixed-Point Blockset data type to a Simulink data type

**Library**

Data Type

**Description**



The Gateway Out block converts any data type supported by the Fixed-Point Blockset to a Simulink data type.

The **Output and Input to have equal** parameter controls how the output is treated. The possible values are `Real World Value` and `Stored Integer`. In terms of the general encoding scheme described in "Scaling" on page 3-5, `Real World Value` treats the output as $V = SQ + B$ where $S$ is the slope and $B$ is the bias. `Stored Integer` treats the output as a stored integer, $Q$. Selecting `Stored Integer` may be useful in these circumstances:

- If you are generating code for a fixed-point processor, the resulting code only uses integers and does not use floating-point operations.
- If you want to partition your model based on hardware characteristics. For example, part of your model may involve simulating hardware that produces integers as output.

---

**Note** If the fixed-point signal is a true integer such as `sint(8)` or `uint(16)`, then `Real World Value` and `Stored Integer` produce identical output values.

---

For more information about this parameter list, refer to the Gateway In block description.

The **Output data type** parameter list specifies the Simulink data type to use for the output. All built-in data types are supported as well as the `boolean` data type. `auto` indicates the Fixed-Point Blockset data type is converted to whatever data type Simulink back propagates.

**Remarks**

The MATLAB built-in integer data types are limited to 32 bits. If you want to output fixed-point numbers that range between 33 and 53 bits without loss of precision or range, you should use the Gateway Out block to store the value inside a double.

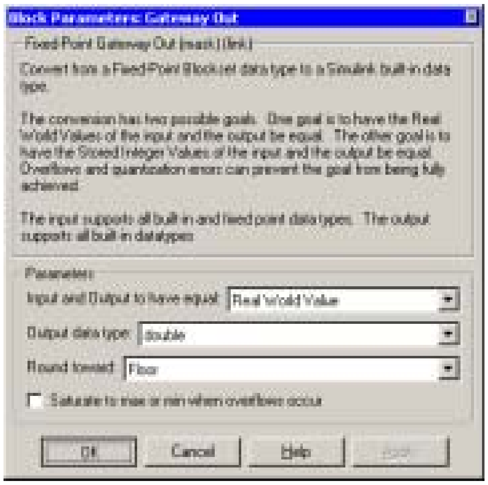
If you want to output fixed-point numbers with more than 53 bits without loss of precision or range, then you must break the number into pieces using the Gain block, and then output the pieces using the Gateway Out block.

For example, suppose the original signal is an unsigned 128-bit value with default scaling. You can break this signal into four pieces using four parallel Gain blocks configured with the gain and output settings shown below.

| Piece | Gain | Output Data Type |
|---|---|---|
| 1 | `2^0` | `uint(32)` – Least significant 32 bits |
| 2 | `2^-32` | `uint(32)` |
| 3 | `2^-64` | `uint(32)` |
| 4 | `2^-96` | `uint(32)` – Most significant 32 bits |

For each Gain block, you must also configure the **Round toward** parameter to `Floor`, and the **Saturate to max or min when overflows occur** check box must be cleared.

## Parameters and Dialog Box



Block Parameters: Gateway Out

Fixed-Point Gateway Out (mask) (link)

Convert from a Fixed-Point Blockset data type to a Simulink built-in data type.

The conversion has two possible goals. One goal is to have the Real World Values of the input and the output be equal. The other goal is to have the Stored Integer Values of the input and the output be equal. Overflows and quantization errors can prevent the goal from being fully achieved.

The input supports all built-in and fixed point data types. The output supports all built-in datatypes.

Parameters

Input and Output to have equal: Real World Value

Output data type: double

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Output and Input to have equal**

Specify the type of value the input and output are to have equal.

**Output data type**
Any built-in data type supported by Simulink.

**Round toward**
Rounding mode for fixed-point output.

**Saturate to max or min when overflows occur**
If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Any built-in Simulink data type |
| Direct Feedthrough | Yes |
| Scalar Expansion | N/A |

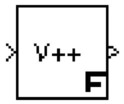
## See Also

Gateway In

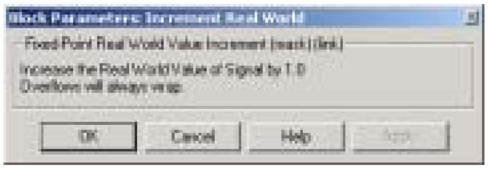
**Purpose** Increase the real world value of the signal by one

**Library** Math

**Description** The Increment Real World block increases the real world value of the signal by one. Overflows always wrap.



**Parameters and Dialog Box**



Block Parameters: Increment Real World

Fixed-Point Real World Value Increment (mask) (link)

Increase the Real World Value of Signal by 1.0
Overflows will always wrap.

**Characteristics**

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | No |

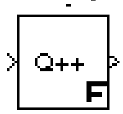
**See Also** Increment Stored Integer

# Increment Stored Integer

**Purpose** Increase the stored integer value of a signal by one

**Library** Math

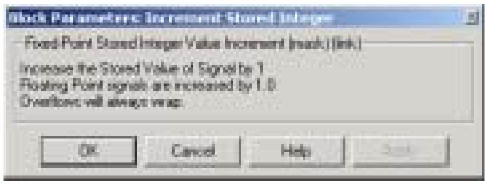
**Description**



The Increment Stored Integer block increases the stored integer value of a signal by one.

Floating-point signals are also increased by one, and overflows always wrap.

**Parameters and Dialog Box**



Fixed-Point Stored Integer Value Increment (mask) (link)

Increase the Stored Value of Signal by 1
Floating Point signals are increased by 1.0
Overflows will always wrap.

**Characteristics**

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | No |

**See Also** Increment Real World

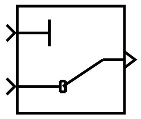
## Purpose

Switch output between different inputs based on the value of the first input

## Library

Select

## Description



The Index Vector block is an implementation of the Multi-Port Switch block. See "Multi-Port Switch" on page 10-172 for more information.

# Integer Delay

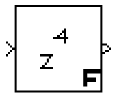
## Purpose

Delay a signal N sample periods

## Library

Delays & Holds

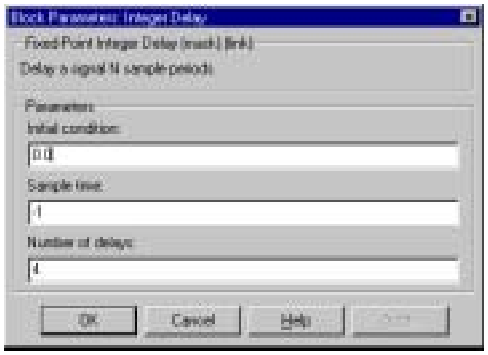
## Description



The Integer Delay block delays its input by N sample periods.

The block accepts one input and generates one output, both of which can be scalar or vector. If the input is a vector, all elements of the vector are delayed by the same sample period.

## Parameters and Dialog Box


Block Parameters: Integer Delay

Fixed-Point Integer Delay (mask) (link)

Delay a signal N sample periods

Parameters

Initial condition:

0.0

Sample time:

-1

Number of delays:

4

**Initial condition**

The initial output of the simulation.

**Sample time**

Sample time.

**Number of delays**

The number of periods to delay the input signal.

## Conversions

The **Initial condition** parameter is converted from a double to the input data type offline using round-to-nearest and saturation.

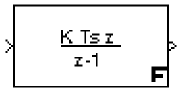
## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | No |
| Scalar Expansion | Of input or initial conditions |

**Purpose** Perform discrete-time integration of a signal using the backward method

**Library** Calculus

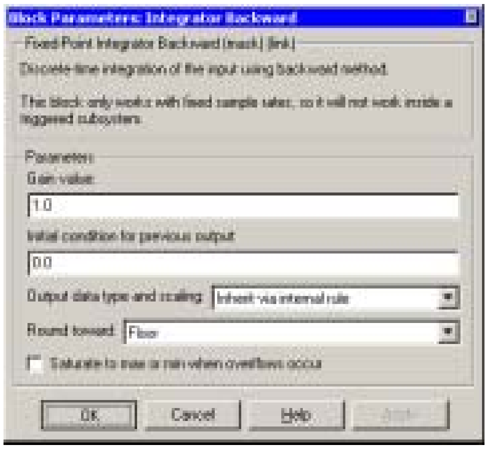
**Description**



The Integrator Backward block performs a discrete-time integration of a signal using the backward method. The block multiplies the input by the weighted sample time and adds the result to the cumulative sum since time zero. The block outputs the sum up to the nth time step at time n.

**Remarks** The output of the Integrator Backward block differs from the output of the Integrator Forward block only by the first and last terms in the cumulative sum.

**Parameters and Dialog Box**



Block Parameters: Integrator Backward

Fixed Point Integrator Backward (mask) (link)

Discrete-time integration of the input using backward method.

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

Parameters

Gain value: 1.0

Initial condition for previous output: 0.0

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Gain value**

Specify the weight by which the sample time is multiplied.

**Initial condition for previous output**

Set the initial condition for the previous output.

**Output data type and scaling**

The options are

- `Specify via dialog`
- `Inherit via internal rule`

- `Inherit via back propagation`

  When `Specify via dialog` is selected, you can specify the **Output data type** and **Output scaling** parameters.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of inputs and gain |

## See Also

Integrator Backward Resettable, Integrator Backward Resettable Limited, Integrator Forward, Integrator Forward Resettable, Integrator Forward Resettable Limited, Integrator Trapezoidal, Integrator Trapezoidal Resettable, Integrator Trapezoidal Resettable Limited

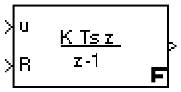
**Purpose**

Perform discrete-time integration of a signal using the backward method with external Boolean reset

**Library**

Calculus

**Description**



The Integrator Backward Resettable block performs a discrete-time integration of a signal using the backward method.

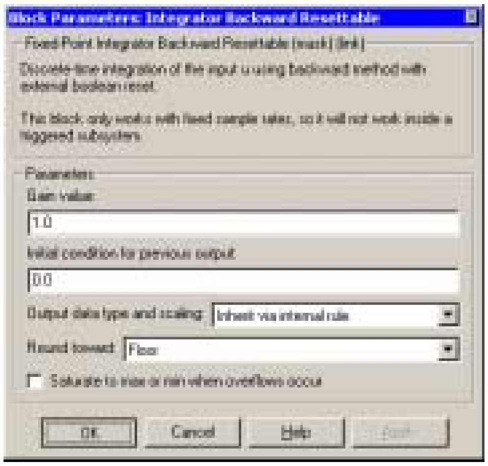
The block can reset its state based on an external reset signal R. When the reset signal R is false, the block multiplies the input by the weighted sample time and adds the result to the cumulative sum since time zero.

When the reset signal R is true, the block outputs the **Initial condition for previous output** parameter.

**Remarks**

The output of the Integrator Backward Resettable block differs from the output of the Integrator Forward Resettable block only by the first and last terms in the cumulative sum.

**Parameters and Dialog Box**



Block Parameters: Integrator Backward Resettable

Fixed Point Integrator Backward Resettable (mask) (link)

Discrete-time integration of the input u using backward method with external boolean reset.

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

Parameters

Gain value:

1.0

Initial condition for previous output:

0.0

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Gain value**

Specify the weight by which the sample time is multiplied.

**Initial condition for previous output**

Set the initial condition for the previous output.

**Output data type and scaling**

The options are

- `Specify via dialog`
- `Inherit via internal rule`
- `Inherit via back propagation`

When `Specify via dialog` is selected, you can specify the **Output data type** and **Output scaling** parameters.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes, of the input and reset source ports |
| Scalar Expansion | Of inputs and gain |

## See Also

Integrator Backward, Integrator Backward Resettable Limited, Integrator Forward, Integrator Forward Resettable, Integrator Forward Resettable Limited, Integrator Trapezoidal, Integrator Trapezoidal Resettable, Integrator Trapezoidal Resettable Limited

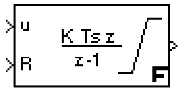
## Purpose

Perform discrete-time limited integration of a signal using the backward method, with external Boolean reset

## Library

Calculus

## Description



The Integrator Backward Resettable Limited block performs a discrete-time integration of a signal using the backward method.

The block can reset its state based on an external reset signal R. When the cumulative sum reaches one of the limits given by the **Upper limit** and **Lower limit** parameters, the sum saturates to that limit.

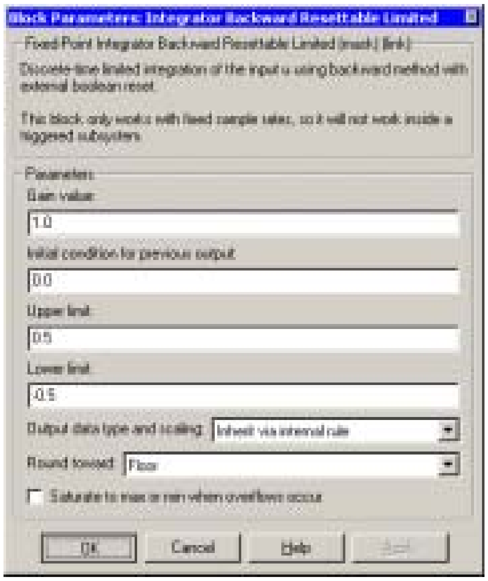
When the reset signal R is false, the block multiplies the input by the weighted sample time and adds the result to the cumulative sum since time zero.

When the reset signal R is true, the block outputs the **Initial condition for previous output** parameter.

## Remarks

The output of the Integrator Backward Resettable Limited block differs from the output of the Integrator Forward Resettable Limited block only by the first and last terms in the cumulative sum.

## Parameters and Dialog Box



Block Parameters: Integrator Backward Resettable Limited

Fixed-Point Integrator Backward Resettable Limited (mask) (link)

Discrete-time limited integration of the input u using backward method with external boolean reset.

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

Parameters

Gain value:

1.0

Initial condition for previous output:

0.0

Upper limit:

0.5

Lower limit:

-0.5

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Gain value**

Specify the weight by which the sample time is multiplied.

**Initial condition for previous output**

Set the initial condition for the previous output.

**Upper limit**

The upper limit for saturation of the cumulative sum.

**Lower limit**

The lower limit for saturation of the cumulative sum.

**Output data type and scaling**

The options are

- `Specify via dialog`
- `Inherit via internal rule`
- `Inherit via back propagation`

When `Specify via dialog` is selected, you can specify the **Output data type** and **Output scaling** parameters.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes, of the input and reset source ports |
| Scalar Expansion | Of inputs and gain |

## See Also

Integrator Backward, Integrator Backward Resettable, Integrator Forward, Integrator Forward Resettable, Integrator Forward Resettable Limited, Integrator Trapezoidal, Integrator Trapezoidal Resettable, Integrator Trapezoidal Resettable Limited

# Integrator Forward

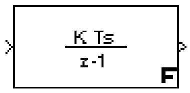
## Purpose

Perform discrete-time integration of a signal using the forward method

## Library

Calculus

## Description

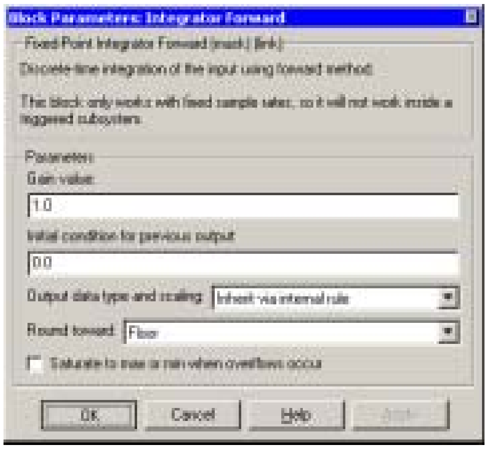


The Integrator Forward block performs a discrete-time integration of a signal using the forward method. The block multiplies the input by the weighted sample time and adds the result to the cumulative sum since time zero. The block outputs the sum up to the nth time step at time n+1. The first term of the sum is the **Initial condition for previous output** parameter.

## Remarks

The output of the Integrator Forward block differs from the output of the Integrator Backward block only by the first and last terms in the cumulative sum.

## Parameters and Dialog Box



Block Parameters: Integrator Forward

Fixed-Point Integrator Forward (mask) (link)

Discrete-time integration of the input using forward method.

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

Parameters

Gain value:

1.0

Initial condition for previous output:

0.0

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Gain value**

Specify the weight by which the sample time is multiplied.

**Initial condition for previous output**

Set the initial condition for the previous output.

**Output data type and scaling**

The options are

- `Specify via dialog`

- `Inherit via internal rule`
- `Inherit via back propagation`

  When `Specify via dialog` is selected, you can specify the **Output data type** and **Output scaling** parameters.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of inputs and gain |

## See Also

Integrator Backward, Integrator Backward Resettable, Integrator Backward Resettable Limited, Integrator Forward Resettable, Integrator Forward Resettable Limited, Integrator Trapezoidal, Integrator Trapezoidal Resettable, Integrator Trapezoidal Resettable Limited

# Integrator Forward Resettable

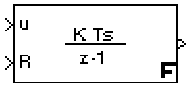
## Purpose

Perform discrete-time integration of a signal using the forward method, with external Boolean reset

## Library

Calculus

## Description



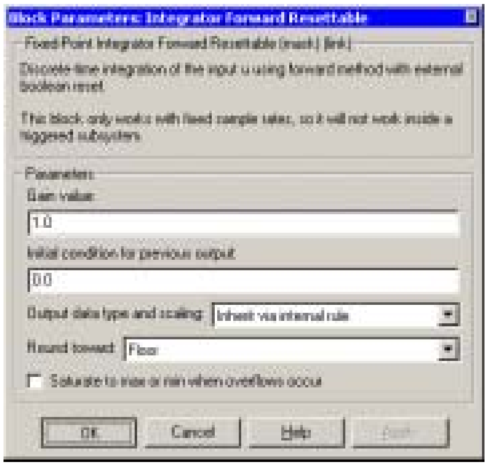
The Integrator Forward Resettable block performs a discrete-time integration of a signal using the forward method. When the external reset signal R is false, the block multiplies the input by the weighted sample time and adds the result to the cumulative sum since time zero.

When the external reset signal R is true, the block outputs the **Initial condition for previous output** parameter.

## Remarks

The output of the Integrator Forward Resettable block differs from the output of the Integrator Backward Resettable block only by the first and last terms in the cumulative sum.

## Parameters and Dialog Box



Block Parameters: Integrator Forward Resettable

Fixed-Point Integrator Forward Resettable (mask) (link)

Discrete-time integration of the input u using forward method with external Boolean reset.

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

Parameters

Gain value:

1.0

Initial condition for previous output:

0.0

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Gain value**

Specify the weight by which the sample time is multiplied.

**Initial condition for previous output**

Set the initial condition for the previous output.

**Output data type and scaling**

The options are

- `Specify via dialog`
- `Inherit via internal rule`
- `Inherit via back propagation`

When `Specify via dialog` is selected, you can specify the **Output data type** and **Output scaling** parameters.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of inputs and gain |

## See Also

Integrator Backward, Integrator Backward Resettable, Integrator Backward Resettable Limited, Integrator Forward, Integrator Forward Resettable Limited, Integrator Trapezoidal, Integrator Trapezoidal Resettable, Integrator Trapezoidal Resettable Limited

# Integrator Forward Resettable Limited

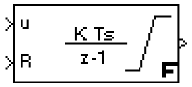
**Purpose**

Perform discrete-time limited integration of a signal using the forward method, with external Boolean reset

**Library**

Calculus

**Description**



The Integrator Forward Resettable Limited block performs a discrete-time integration of a signal using the forward method. When the cumulative sum reaches one of the limits given by the **Upper limit** and **Lower limit** parameters, the sum saturates to that limit.

When the external reset signal R is false, the block multiplies the input by the weighted sample time and adds the result to the cumulative sum since time zero.

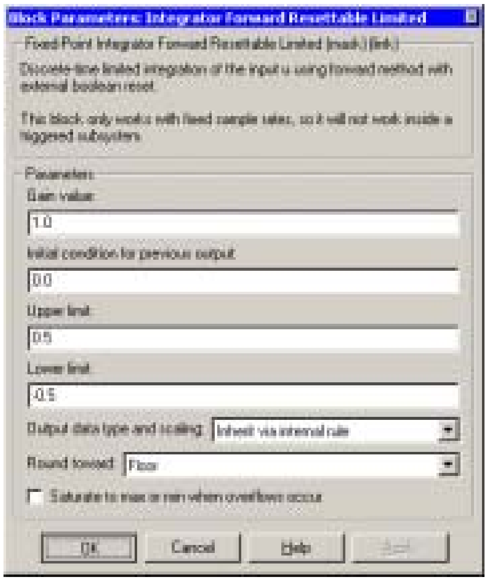
When the external reset signal R is true, the block outputs the **Initial condition for previous output** parameter.

The first term of the sum is the product of the weighted sample time and the value of the **Initial condition for previous input parameter**.

**Remarks**

The output of the Integrator Forward Resettable Limited block differs from the output of the Integrator Backward Resettable Limited block only by the first and last terms in the cumulative sum.

## Parameters and Dialog Box



Block Parameters: Integrator Forward Resettable Limited

Fixed Point Integrator Forward Resettable Limited (mask) (link)

Discrete-time limited integration of the input u using forward method with external boolean reset.

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

Parameters

Gain value: 1.0

Initial condition for previous output: 0.0

Upper limit: 0.5

Lower limit: -0.5

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Gain value**

Specify the weight by which the sample time is multiplied.

**Initial condition for previous output**

Set the initial condition for the previous output.

**Upper limit**

The upper limit for saturation of the cumulative sum.

**Lower limit**

The lower limit for saturation of the cumulative sum.

**Output data type and scaling**

The options ar:

- `Specify via dialog`
- `Inherit via internal rule`
- `Inherit via back propagation`

When `Specify via dialog` is selected, you can specify the **Output data type** and **Output scaling** parameters.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of inputs and gain |

## See Also

Integrator Backward, Integrator Backward Resettable, Integrator Backward Resettable Limited, Integrator Forward, Integrator Forward Resettable, Integrator Trapezoidal, Integrator Trapezoidal Resettable, Integrator Trapezoidal Resettable Limited

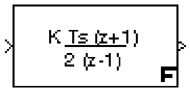
## Purpose

Perform discrete-time integration of a signal using the trapezoidal method

## Library

Calculus

## Description



The Integrator Trapezoidal block performs a discrete-time integration of a signal using the trapezoidal method. At time step k, the block computes the average of the inputs at times k-1 and k, multiplies the average by the weighted sample time, and adds the result to the cumulative sum since time zero. The block outputs the sum up to the kth time step at time.

The block calculates the output at time k by the rule

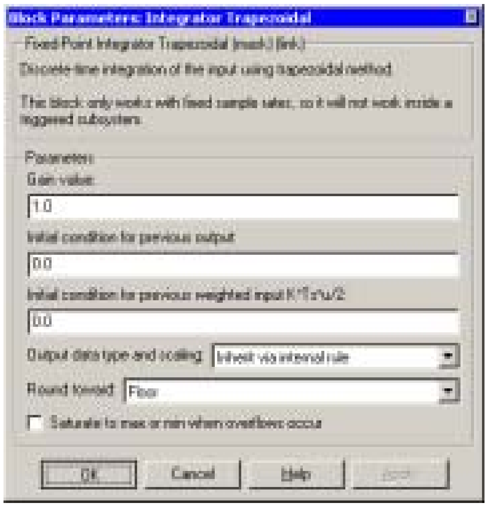
$$y(k) = y(k-1) + w(k) + w(k-1)$$

where $u(k)$ is the input at time k and

$$w(k) = \frac{K \cdot Ts}{2} \cdot u(k)$$

At the first time step, $y(0)$ is set to the value of **Initial condition for previous output**, and $w(0)$ is set to the value of **Initial condition for previous weighted input K*Ts*u/2**.

## Parameters and Dialog Box



Block Parameters: Integrator Trapezoidal

Fixed Point Integrator Trapezoidal (mask) (link)

Discrete-time integration of the input using trapezoidal method

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

Parameters

Gain value:
1.0

Initial condition for previous output
0.0

Initial condition for previous weighted input K*Ts*u/2
0.0

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Gain value**

Specify the weight by which the sample time is multiplied.

**Initial condition for previous output**

Set the initial condition for the previous output.

**Initial condition for previous weighted input K*Ts*u/2**

Set the initial condition for the previous weighted input.

**Output data type and scaling**

The options are

- `Specify via dialog`
- `Inherit via internal rule`
- `Inherit via back propagation`

When `Specify via dialog` is selected, you can specify the **Output data type** and **Output scaling** parameters.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of inputs and gain |

## See Also

Integrator Backward, Integrator Backward Resettable, Integrator Backward Resettable Limited, Integrator Forward, Integrator Forward Resettable, Integrator Forward Resettable Limited, Integrator Trapezoidal Resettable, Integrator Trapezoidal Resettable Limited

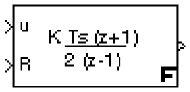
## Purpose

Perform discrete-time integration of a signal using the trapezoidal method, with external Boolean reset

## Library

Calculus

## Description



The Integrator Trapezoidal Resettable block performs a discrete-time integration of a signal using the trapezoidal method.

The block can reset its state based on an external reset signal R. When the reset signal R is false at time k, the block calculates the output at time k by the rule

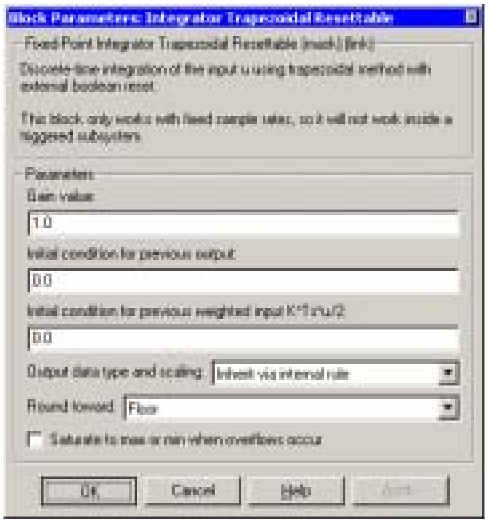
$$y(k) = y(k-1) + w(k) + w(k-1)$$

where $u(k)$ is the input at time k and

$$w(k) = \frac{K \cdot Ts}{2} \cdot u(k)$$

When the reset signal R is true at time k, the block resets the output *y(k)* to the value of the **Initial condition for previous output** parameter, and resets *w(k)* to the value of the **Initial condition for previous weighted input K*Ts*u/2** parameter.

## Parameters and Dialog Box


Block Parameters: Integrator Trapezoidal Resettable

Fixed-Point Integrator Trapezoidal Resettable (mask) (link)

Discrete-time integration of the input u using trapezoidal method with external boolean reset.

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

Parameters

Gain value:

1.0

Initial condition for previous output:

0.0

Initial condition for previous weighted input K*Ts*u/2:

0.0

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Gain value**

Specify the weight by which the sample time is multiplied.

**Initial condition for previous output**

Set the initial condition for the previous output.

**Initial condition for previous weighted input K*Ts*u/2**

Set the initial condition for the previous weighted input.

**Output data type and scaling**

The options are

- `Specify via dialog`
- `Inherit via internal rule`
- `Inherit via back propagation`

When `Specify via dialog` is selected, you can specify the **Output data type** and **Output scaling** parameters.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes, of the input and reset source ports |
| Scalar Expansion | Of inputs and gain |

## See Also

Integrator Backward, Integrator Backward Resettable, Integrator Backward Resettable Limited, Integrator Forward, Integrator Forward Resettable, Integrator Forward Resettable Limited, Integrator Trapezoidal, Integrator Trapezoidal Resettable Limited

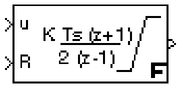
## Purpose

Perform discrete-time limited integration of a signal using the trapezoidal method, with external Boolean reset

## Library

Calculus

## Description



The Integrator Trapezoidal Resettable Limited block performs a discrete-time integration of a signal using the trapezoidal method.

The block can reset its state based on an external reset signal R. When the cumulative sum reaches one of the limits given by the **Upper limit** and **Lower limit** parameters, the sum saturates to that limit.

When the reset signal R is false at time step k, the block calculates the output at time k by the rule

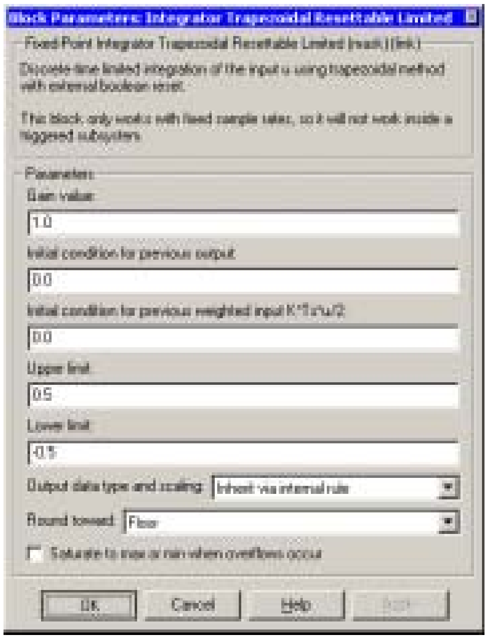
$$y(k) = y(k-1) + w(k) + w(k-1)$$

where $u(k)$ is the input at time k and

$$w(k) = \frac{K \cdot Ts}{2} \cdot u(k)$$

When the reset signal R is true at time k, the block resets the output *y(k)* to the value of the **Initial condition for previous output** parameter. The block also resets *w(k)* to the value of the **Initial condition for previous weighted input K*Ts*u/2** parameter.

## Parameters and Dialog Box



Block Parameters: Integrator Trapezoidal Resettable Limited

Fixed Point Integrator Trapezoidal Resettable Limited (mask) (link)

Discrete-time limited integration of the input u using trapezoidal method with external boolean reset.

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

Parameters

Gain value: 1.0

Initial condition for previous output: 0.0

Initial condition for previous weighted input K*Ts*u/2: 0.0

Upper limit: 0.5

Lower limit: -0.5

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Gain value**

Specify the weight by which the sample time is multiplied.

**Initial condition for previous output**

Set the initial condition for the previous output.

**Initial condition for previous weighted input K*Ts*u/2**

Set the initial condition for the previous weighted input.

**Upper limit**

The upper limit for saturation of the cumulative sum.

**Lower limit**

The lower limit for saturation of the cumulative sum.

**Output data type and scaling**

The options are

- `Specify via dialog`
- `Inherit via internal rule`

- `Inherit via back propagation`

  When `Specify via dialog` is selected, you can specify the **Output data type** and **Output scaling** parameters.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes, of the input and reset source ports |
| Scalar Expansion | Of inputs and gain |

## See Also

Integrator Backward, Integrator Backward Resettable, Integrator Backward Resettable Limited, Integrator Forward, Integrator Forward Resettable, Integrator Forward Resettable Limited, Integrator Trapezoidal, Integrator Trapezoidal Resettable

# Interval Test

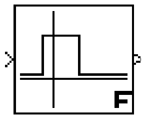
## Purpose

Determine if a signal is in a specified interval

## Library

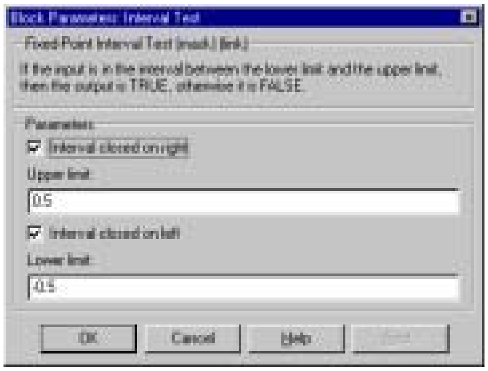
Logic & Comparison

## Description



The Interval Test block outputs TRUE if the input is between the values specified by the **Lower limit** and **Upper limit** parameters. The block outputs FALSE if the input is outside those values. The output of the block when the input is equal to the **Lower limit** or the **Upper limit** is determined by whether the boxes next to **Interval closed on left** and **Interval closed on right** are selected in the dialog box.

## Parameters and Dialog Box



Fixed-Point Interval Test (mask) (link)

If the input is in the interval between the lower limit and the upper limit, then the output is TRUE, otherwise it is FALSE.

Parameters

[✓] Interval closed on right

Upper limit: 0.5

[✓] Interval closed on left

Lower limit: -0.5

**Interval closed on right**

When the box is selected, the **Upper limit** is included in the interval for which the block outputs TRUE.

**Upper limit**

The upper limit of the interval for which the block outputs TRUE.

**Interval closed on left**

When the box is selected, the **Lower limit** is included in the interval for which the block outputs TRUE.

**Lower limit**

The lower limit of the interval for which the block outputs TRUE.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same data type as input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

## See Also

Interval Test Dynamic

# Interval Test Dynamic

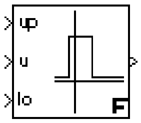
## Purpose

Determine if a signal is in a specified interval

## Library

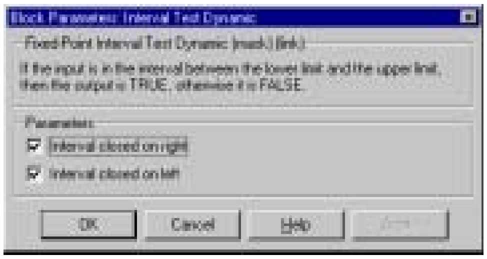
Logic & Comparison

## Description



The Interval Test Dynamic block outputs TRUE if the input is between the values of the external signals up and lo. The block outputs FALSE if the input is outside those values. The output of the block when the input is equal to the signal up or the signal lo is determined by whether the boxes next to **Interval closed on left** and **Interval closed on right** are selected in the dialog box.

## Parameters and Dialog Box



Block Parameters: Interval Test Dynamic

Fixed-Point Interval Test Dynamic (mask) (link)

If the input is in the interval between the lower limit and the upper limit, then the output is TRUE, otherwise it is FALSE.

Parameters

[✓] Interval closed on right

[✓] Interval closed on left

**Interval closed on right**

When the box is selected, the **Upper limit** is included in the interval for which the block outputs TRUE.

**Interval closed on left**

When the box is selected, the **Lower limit** is included in the interval for which the block outputs TRUE.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same data type as output |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

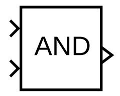
## See Also

Interval Test

**Purpose** Perform the specified logical operation on the inputs

**Library** Simulink Math Operations and Fixed-Point Blockset Logic & Comparison

**Description** The Logical Operator block performs the specified logical operation on its inputs. An input value is TRUE (1) if it is nonzero and FALSE (0) if it is zero.



Logical Operator

You select the Boolean operation connecting the inputs with the **Operator** parameter list. The block icon updates to display the selected operator. The supported operations are given below.

| Operation | Description |
|---|---|
| AND | TRUE if all inputs are TRUE |
| OR | TRUE if at least one input is TRUE |
| NAND | TRUE if at least one input is FALSE |
| NOR | TRUE when no inputs are TRUE |
| XOR | TRUE if an odd number of inputs are TRUE |
| NOT | TRUE if the input is FALSE |

The number of input ports is specified with the **Number of input ports** parameter. The output type is specified with the **Output data type mode** and/or the **Output data type** parameters. An output value is 1 if TRUE and 0 if FALSE.

**Note** The output data type should represent zero exactly. Data types that satisfy this condition include signed and unsigned integers, and any floating-point data type.

The size of the output depends on input vector size and the selected operator:

- If the block has more than one input, any nonscalar inputs must have the same dimensions. For example, if any input is a 2-by-2 array, all other nonscalar inputs must also be 2-by-2 arrays.

  Scalar inputs are expanded to have the same dimensions as the nonscalar inputs.

  If the block has more than one input, the output has the same dimensions as the inputs (after scalar expansion) and each output element is the result of applying the specified logical operation to the corresponding input elements. For example, if the specified operation is AND and the inputs are 2-by-2 arrays, the output is a 2-by-2 array whose top left element is the result of applying AND to the top left elements of the inputs, etc.

- For a single vector input, the block applies the operation (except the NOT operator) to all elements of the vector. The output is always a scalar.
- The NOT operator accepts only one input, which can be a scalar or a vector. If the input is a vector, the output is a vector of the same size containing the logical complements of the input vector elements.

When configured as a multi-input XOR gate, this block performs an addition-modulo-two operation as mandated by the IEEE Standard for Logic Elements.

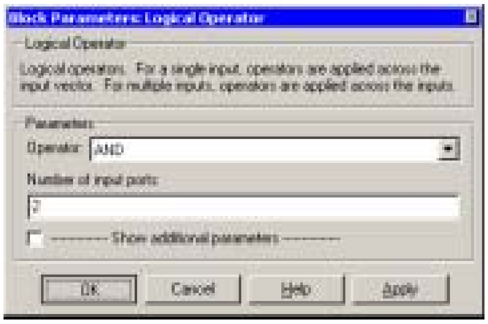
When the **Show additional parameters** check box is selected, some of the parameters that become visible are common to many blocks. For a detailed description of these parameters, refer to “Block Parameters” on page 10-6.

## Data Type Support

A Logical Operator block accepts real or complex signals of any data type supported by Simulink, as well as fixed-point data types. However, if the **Output data type mode** parameter is set to `Logical`, the input may only be `boolean` or `double`.

For a discussion on the data types supported by Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

## Parameters and Dialog Box



Logical Operator

Logical operators. For a single input, operators are applied across the input vector. For multiple inputs, operators are applied across the inputs.

Parameters

Operator: AND

Number of input ports: 2

☐ --------- Show additional parameters ---------

**Operator**

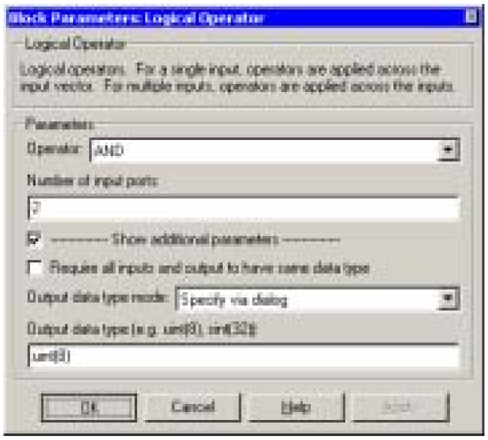
The logical operator to be applied to the block inputs. Valid choices are the operators listed previously.

**Number of input ports**

The number of block inputs. The value must be appropriate for the selected operator.

**Show additional parameters**

If selected, additional parameters specific to implementation of the block become visible as shown.



Logical Operator

Logical operators. For a single input, operators are applied across the input vector. For multiple inputs, operators are applied across the inputs.

Parameters

Operator: AND

Number of input ports: 2

☑ --------- Show additional parameters ---------

☐ Require all inputs and output to have same data type

Output data type mode: Specify via dialog

Output data type (e.g. uint(8), sint(32)):

uint(8)

**Require all inputs and output to have same data type**

Select to require all inputs and the output to have the same data type.

**Output data type mode**

Set the output data type to `Boolean`, or choose to specify the data type through the **Output data type** parameter.

Alternatively, you can select `Logical` to have the output data type determined by the **Boolean Logic Signals** parameter in the **Advanced** tab of the **Simulation Parameters** interface. If you select `Logical` and **Boolean Logic Signals** is `on`, then the output data type is always `Boolean`. If you select `Logical` and **Boolean Logic Signals** is `off`, then the output data type will match the input data type, which may be `Boolean` or `double`.

**Logical output data type**

Output data type. You should only use data types that represent zero exactly. Data types that satisfy this condition include signed and unsigned integers and any floating-point data type. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

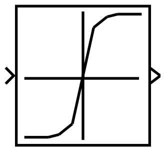
## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from the driving block |
| Scalar Expansion | Of inputs |
| Zero Crossing | No |

**Purpose** Approximate a one-dimensional function using the specified lookup method

**Library** Simulink Look-Up Tables and Fixed-Point Blockset LookUp

**Description** The Look-Up Table block computes an approximation to some function `y=f(x)` given data vectors `x` and `y`.



**Note** To map two inputs to an output, use the Look-Up Table (2-D) block.

The length of the `x` and `y` data vectors provided to this block must match. Also, the `x` data vector must be strictly monotonically increasing after conversion to the input's fixed-point data type, except in the following case. If the input `x` and the output signal are both either `single` or `double`, and if the lookup method is `Interpolation-Extrapolation`, then `x` may be monotonically increasing rather than strictly monotonically increasing. Note that due to quantization, the `x` data vector may be strictly monotonic in doubles format, but not so after conversion to a fixed-point data type.

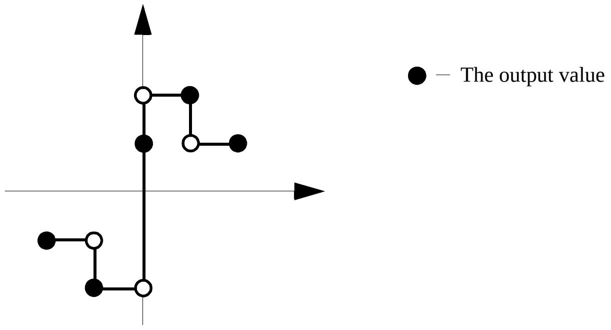
You define the table by specifying the **Vector of input values** parameter as a 1-by-n vector and the **Vector of output values** parameter as a 1-by-n vector. The block generates output based on the input values using one of these methods selected from the **Look-up method** parameter list:

- `Interpolation-Extrapolation`—This is the default method; it performs linear interpolation and extrapolation of the inputs.
  - If a value matches the block's input, the output is the corresponding element in the output vector.
  - If no value matches the block's input, then the block performs linear interpolation between the two appropriate elements of the table to determine an output value. If the block input is less than the first or greater than the last input vector element, then the block extrapolates using the first two or last two points.
- `Interpolation-Use End Values`—This method performs linear interpolation as described above but does not extrapolate outside the end points of the input vector. Instead, the end-point values are used.

- `Use Input Nearest`—This method does not interpolate or extrapolate. Instead, the element in `x` nearest the current input is found. The corresponding element in `y` is then used as the output.
- `Use Input Below`—This method does not interpolate or extrapolate. Instead, the element in `x` nearest and below the current input is found. The corresponding element in `y` is then used as the output. If there is no element in `x` below the current input, then the nearest element is found.
- `Use Input Above`—This method does not interpolate or extrapolate. Instead, the element in `x` nearest and above the current input is found. The corresponding element in `y` is then used as the output. If there is no element in `x` above the current input, then the nearest element is found.

To create a table with step transitions, repeat an input value with different output values. For example, these input and output parameter values create the input/output relationship described by the plot that follows:

```
Vector of input values:   [-2 -1 -1  0 0 0 1 1 2]
Vector of output values:  [-1 -1 -2 -2 1 2 2 1 1]
```



This example has three step discontinuities: at *u* = -1, 0, and +1.

When there are two points at a given input value, the block generates output according to these rules:

- When the input signal *u* is less than zero, the output is the value connected with the point first encountered when moving away from the origin in a negative direction. In this example, when *u* is -1, *y* is -2, marked with a solid circle.

- When *u* is greater than zero, the output is the value connected with the point first encountered when moving away from the origin in a positive direction. In this example, when *u* is 1, *y* is 2, marked with a solid circle.
- When *u* is at the origin and there are two output values specified for zero input, the actual output is their average. In this example, if there were no point at $u = 0$ and $y = 1$, the output would be 0, the average of the two points at $u = 0$. If there are three points at zero, the block generates the output associated with the middle point. In this example, the output at the origin is 1.

The Look-Up Table block icon displays a graph of the input vector versus the output vector. When a parameter is changed on the block's dialog box, the graph is automatically redrawn when you click the **Apply** or **Close** button.

When the **Show additional parameters** check box is selected, some of the parameters that become visible are common to many blocks. For a detailed description of these parameters, refer to “Block Parameters” on page 10-6.

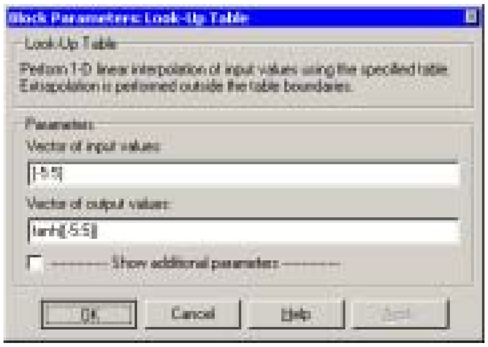
To avoid parameter saturation errors, the automatic scaling script `autofixexp` employs a special rule for the Look-Up Table block. `autofixexp` modifies the scaling by using the output look-up values in addition to the logged minimum and maximum simulation values. This prevents the data from being saturated to different values. The look-up values are given by the **Vector of output values** parameter (the `YDataPoints` variable).

## Data Type Support

The Look-Up Table block supports all data types supported by Simulink, as well as fixed-point data types.

For a discussion on the data types supported by Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

## Parameters and Dialog Box


Block Parameters: Look-Up Table

Look-Up Table

Perform 1-D linear interpolation of input values using the specified table. Extrapolation is performed outside the table boundaries.

Parameters

Vector of input values:

[-5:5]

Vector of output values:

tanh([-5:5])

☐ ---------- Show additional parameters ----------

**Vector of input values**

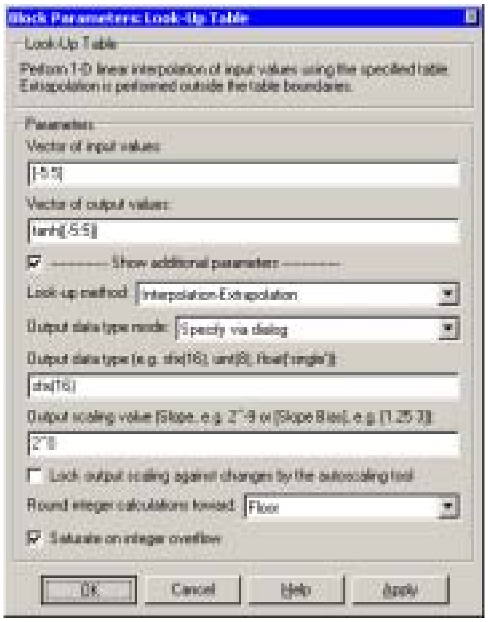
Specify the vector of input values. The input values vector must be the same size as the output values vector. Also, the input values vector must be strictly monotonically increasing after conversion to the input's fixed-point data type, except in the following case. If the input values vector and the output signal are both either `single` or `double`, and if the lookup method is `Interpolation-Extrapolation`, then the input values vector may be monotonically increasing rather than strictly monotonically increasing. Note that due to quantization, the input values vector may be strictly monotonic in doubles format, but not so after conversion to a fixed-point data type.

**Vector of output values**

Specify the vector of output values. The output values vector must be the same size as the input values vector.

**Show additional parameters**

If selected, additional parameters specific to implementation of the block become visible as shown.



Block Parameters: Look-Up Table

Look-Up Table

Perform 1-D linear interpolation of input values using the specified table. Extrapolation is performed outside the table boundaries.

Parameters

Vector of input values:

[-5:5]

Vector of output values:

tanh([-5:5])

[✓] ---------- Show additional parameters ----------

Look-up method: Interpolation-Extrapolation

Output data type mode: Specify via dialog

Output data type (e.g. sfix(16), uint(8), float('single')):

sfix(16)

Output scaling value (Slope, e.g. 2^-9 or [Slope Bias], e.g. [1.25 3]):

2^-9

[ ] Lock output scaling against changes by the autoscaling tool

Round integer calculations toward: Floor

[✓] Saturate on integer overflow

**Look-up method**

Specify the lookup method. See “Description” on page 10-149 for a discussion of the options for this parameter.

**Output data type mode**

You can set the output signal to a built-in data type from this drop-down list, or you can choose the output data type and scaling to be the same as the input. Alternatively, you can choose to inherit the output data type and scaling by backpropagation. Lastly, if you choose `Specify via dialog`, the **Output data type**, **Output scaling value**, and **Lock output scaling against changes by the autoscaling tool** parameters become visible.

**Output data type**

Specify any data type, including fixed-point data types. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Output scaling value**

Set the output scaling using binary point-only or [Slope Bias] scaling. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Lock output scaling against changes by the autoscaling tool**

If selected, scaling of outputs is locked. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Round integer calculations toward**

Select the rounding mode for the fixed-point output.

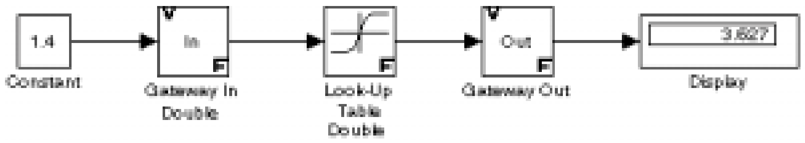
**Saturate on integer overflow**

If selected, overflows saturate.

## Conversions and Operations

The **Vector of input values** parameter is converted from doubles to the input data type. The **Vector of output values** parameter is converted from doubles to the output data type. Both conversion are performed offline using round-to-nearest and saturation. Refer to “Parameter Conversions” on page 4-27 for more information about parameter conversions.

## Examples



Suppose the Look-Up Table block in the above model is configured to use a vector of input values given by `[-5:5]`, and a vector of output values given by `sinh([-5:5])`. The following results are generated.

| Look-Up Method | Input | Output | Comment |
|---|---|---|---|
| `Interpolation-Extrapolation` | `1.4` | `2.153` | N/A |
|  | `5.2` | `83.59` | N/A |

| Look-Up Method | Input | Output | Comment |
|---|---|---|---|
| `Interpolation-Use End Values` | `1.4` | `2.153` | N/A |
| | `5.2` | `74.2` | The value for `sinh(5.0)` was used. |
| `Use Input Above` | `1.4` | `3.627` | The value for `sinh(2.0)` was used. |
| | `5.2` | `74.2` | The value for `sinh(5.0)` was used. |
| `Use Input Below` | `1.4` | `1.175` | The value for `sinh(1.0)` was used. |
| | `-5.2` | `-74.2` | The value for `sinh(-5.0)` was used. |
| `Use Input Nearest` | `1.4` | `1.175` | The value for `sinh(1.0)` was used. |

## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from driving block |
| Scalar Expansion | No |
| Zero Crossing | No |

## See Also

Look-Up Table Dynamic, Look-Up Table (2-D)

# Look-Up Table Dynamic

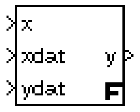
## Purpose

Approximate a one-dimensional function using a selected look-up method and a dynamically specified table

## Library

LookUp

## Description



The Look-Up Table Dynamic block computes an approximation to some function y=f(x) given x, y data vectors. The look-up method can use interpolation, extrapolation, or the original values of the input.

The x data vector must be strictly monotonically increasing after conversion to the input's fixed-point data type. Note that due to quantization, the x data vector may be strictly monotonic in doubles format, but not so after conversion to a fixed-point data type.

---

**Note** Unlike the Look-Up Table block, the Look-Up Table Dynamic block allows you to change the table data without stopping the simulation. For example, you may want to automatically incorporate new table data if the physical system you are simulating changes.

---

You define the look-up table by inputting the x and y table data to the block as 1-by-n vectors. To help reduce the ROM used by the code generated for this block, you can use different data types for the x table data and the y table data. However, these restrictions apply:

- The y table data and the output vector must have the same sign, the same bias, and the same fractional slope.
- The x table data and the x data vector must have the same sign, the same bias, and the same fractional slope. Additionally, the precision and range for the x data vector must greater than or equal to the precision and range for the x table data.

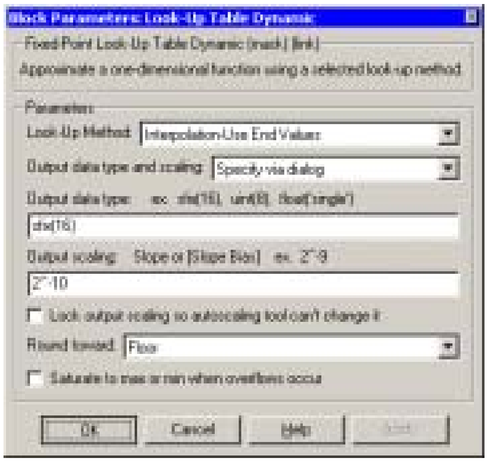
The block generates output based on the input values using one of these methods selected from the **Look-up method** parameter list:

- `Interpolation-Extrapolation`—This is the default method; it performs linear interpolation and extrapolation of the inputs.

  - If a value matches the block's input, the output is the corresponding element in the output vector.
  - If no value matches the block's input, then the block performs linear interpolation between the two appropriate elements of the table to determine an output value. If the block input is less than the first or greater than the last input vector element, then the block extrapolates using the first two or last two points.
- `Interpolation-Use End Values`—This method performs linear interpolation as described above but does not extrapolate outside the end points of the input vector. Instead, the end-point values are used.
- `Use Input Nearest`—This method does not interpolate or extrapolate. Instead, the element in `x` nearest the current input is found. The corresponding element in `y` is then used as the output.
- `Use Input Below`—This method does not interpolate or extrapolate. Instead, the element in `x` nearest and below the current input is found. The corresponding element in `y` is then used as the output. If there is no element in `x` below the current input, then the nearest element is found.
- `Use Input Above`—This method does not interpolate or extrapolate. Instead, the element in `x` nearest and above the current input is found. The corresponding element in `y` is then used as the output. If there is no element in `x` above the current input, then the nearest element is found.

For a detailed description of all other block parameters, refer to “Block Parameters” on page 10-6.

## Parameters and Dialog Box



Block Parameters: Look-Up Table Dynamic

Fixed-Point Look-Up Table Dynamic (mask) (link)

Approximate a one-dimensional function using a selected look-up method

Parameters

Look-Up Method: Interpolation-Use End Values

Output data type and scaling: Specify via dialog

Output data type: ex. sfix(16), uint(8), float('single')

sfix(16)

Output scaling: Slope or [Slope Bias] ex. 2^-9

2^-10

☐ Lock output scaling so autoscaling tool can't change it

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Look-Up Method**

Look-up method.

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or inherit the data type and scaling by backpropagation.

**Output data type**

Any data type supported by the Fixed-Point Blockset.

**Output scaling**

Set the output scaling using binary point-only or [Slope Bias] scaling. These scaling modes are available only for generalized fixed-point data types.

**Lock output scaling so autoscaling tool can't change it**

If selected, **Output scaling** is locked. This feature is available only for generalized fixed-point output.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Conversions

The table data is converted from doubles to the x data type. This conversion is performed offline using round-to-nearest and saturation. Refer to "Parameter Conversions" on page 4-27 for more information about parameter conversions.

## Examples

For an example that illustrates the look-up methods supported by this block, see the example included in the Look-Up Table block reference pages.

## Characteristics

| | |
|---|---|
| Input Port(s) | Any data type supported by the blockset |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | No |

## See Also

Look-Up Table, Look-Up Table (2-D)

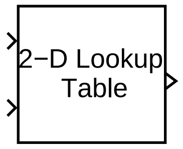
**Purpose**

Approximate a two-dimensional function using a selected look-up method

**Library**

Simulink Look-Up Tables and Fixed-Point Blockset LookUp

**Description**



Look−Up
Table (2−D)

The Look-Up Table (2-D) block computes an approximation to some function `z=f(x,y)` given `x`, `y`, `z` data points.

The **Row index input values** parameter is a 1-by-m vector of `x` data points, the **Column index input values** parameter is a 1-by-n vector of `y` data points, and the **Matrix of output values** parameter is an m-by-n matrix of `z` data points. Both the row and column vectors must be monotonically increasing. These vectors must be strictly monotonically increasing in the following cases:

- The input and output data types are both fixed-point.
- The input and output data types are different.
- The lookup method is not `Interpolation-Extrapolation`.
- The matrix of output values is complex.
- Minimum, maximum, and overflow logging is on.

The block generates output based on the input values using one of these methods selected from the **Look-up method** parameter list:

- `Interpolation-Extrapolation`—This is the default method; it performs linear interpolation and extrapolation of the inputs.
  - If the inputs match row and column parameter values, the output is the value at the intersection of the row and column.
  - If the inputs do not match row and column parameter values, then the block generates output by linearly interpolating between the appropriate row and column values. If either or both block inputs are less than the first or greater than the last row or column values, the block extrapolates using the first two or last two points.
- `Interpolation-Use End Values`—This method performs linear interpolation as described above but does not extrapolate outside the end points of `x` and `y`. Instead, the end-point values are used.
- `Use Input Nearest`—This method does not interpolate or extrapolate. Instead, the elements in `x` and `y` nearest the current inputs are found. The corresponding element in `z` is then used as the output.

- `Use Input Below`—This method does not interpolate or extrapolate. Instead, the elements in `x` and `y` nearest and below the current inputs are found. The corresponding element in `z` is then used as the output. If there are no elements in `x` or `y` below the current inputs, then the nearest elements are found.
- `Use Input Above`—This method does not interpolate or extrapolate. Instead, the elements in `x` and `y` nearest and above the current inputs are found. The corresponding element in `z` is then used as the output. If there are no elements in `x` or `y` above the current inputs, then the nearest elements are found.

To avoid parameter saturation errors, the automatic scaling script `autofixexp` employs a special rule for the Look-Up Table (2-D) block. `autofixexp` modifies the scaling by using the output look-up values in addition to the logged minimum and maximum simulation values. The output look-up values are converted to the specified output data type. This prevents the data from being saturated to different values.

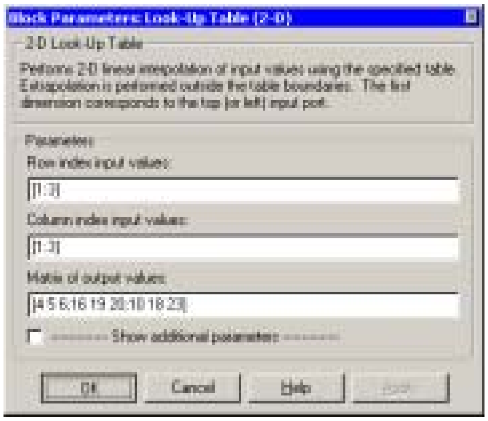
When the **Show additional parameters** check box is selected, some of the parameters that become visible are common to many blocks. For a detailed description of these parameters, refer to "Block Parameters" on page 10-6.

## Data Type Support

The Look-Up Table (2-D) block supports all data types supported by Simulink, as well as fixed-point data types.

For a discussion on the data types supported by Simulink, refer to "Data Types Supported by Simulink" in the Using Simulink documentation.

## Parameters and Dialog Box



Block Parameters: Look-Up Table (2-D)

2-D Look-Up Table

Performs 2-D linear interpolation of input values using the specified table. Extrapolation is performed outside the table boundaries. The first dimension corresponds to the top (or left) input port.

Parameters

Row index input values:
[1:3]

Column index input values:
[1:3]

Matrix of output values:
[4 5 6;16 19 20;10 18 23]

☐ Show additional parameters

**Row index input values**

The row values for the table, entered as a vector. The vector values must increase monotonically.

**Column index input values**

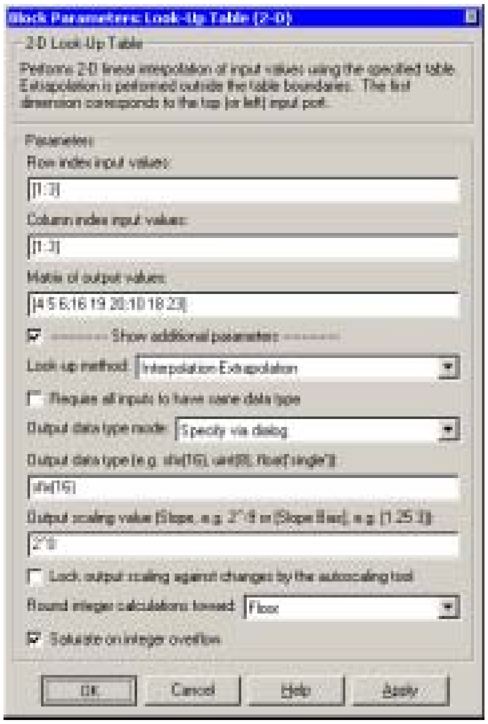
The column values for the table, entered as a vector. The vector values must increase monotonically.

**Matrix of output values**

The table of output values. The matrix size must match the dimensions defined by the **Row** and **Column** parameters.

**Show additional parameters**

If selected, additional parameters specific to implementation of the block become visible as shown.



Block Parameters: Look-Up Table (2-D)

2-D Look-Up Table

Performs 2-D linear interpolation of input values using the specified table. Extrapolation is performed outside the table boundaries. The first dimension corresponds to the top (or left) input port.

Parameters

Row index input values:
[1:3]

Column index input values:
[1:3]

Matrix of output values:
[4 5 6;16 19 20;10 18 23]

[✓] ---------- Show additional parameters ----------

Look-up method: Interpolation-Extrapolation

[ ] Require all inputs to have same data type

Output data type mode: Specify via dialog

Output data type (e.g. sfix(16), uint(8), float('single')):
sfix(16)

Output scaling value (Slope, e.g. 2^-9 or [Slope Bias], e.g. [1.25 3]):
2^0

[ ] Lock output scaling against changes by the autoscaling tool

Round integer calculations toward: Floor

[✓] Saturate on integer overflow

**Look-up method**

Specify the lookup method. See “Description” on page 10-160 for a discussion of the options for this parameter.

**Require all inputs to have same data type**

Select to require all inputs to have the same data type.

**Output data type mode**

You can set the output signal to a built-in data type from this drop-down list, or you can choose the output data type and scaling to be the same as the input. Alternatively, you can choose to inherit the output data type and scaling by backpropagation. Lastly, if you choose `Specify via dialog`, the **Output data type**, **Output scaling value**, and **Lock output scaling against changes by the autoscaling tool** parameters become visible.

**Output data type**

Specify any data type, including fixed-point data types. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Output scaling value**

Set the output scaling using binary point-only or [Slope Bias] scaling. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Lock output scaling against changes by the autoscaling tool**

If selected, scaling of outputs is locked. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Round integer calculations toward**

Select the rounding mode for the fixed-point output.

**Saturate on integer overflow**

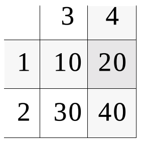
If selected, overflows saturate.

## Examples

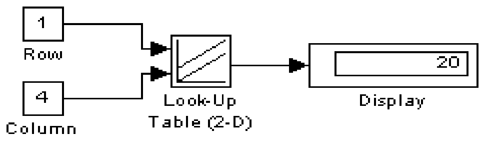
In this example, the block parameters are defined as

```
Row:       [1 2]
Column:    [3 4]
Table:     [10 20; 30 40]
```

The first figure shows the block outputting a value at the intersection of block inputs that match row and column values. The first input is 1 and the second input is 4. These values select the table value at the intersection of the first row (row parameter value 1) and second column (column parameter value 4).

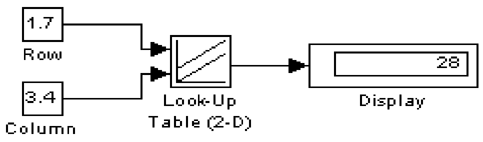


|   | 3 | 4 |
|---|---|---|
| 1 | 10 | 20 |
| 2 | 30 | 40 |



In the second figure, the first input is 1.7 and the second is 3.4. These values cause the block to interpolate between row and column values, as shown in the table at the left. The value at the intersection (28) is the output value.

|  | 3 | 3.4 | 4 |
|---|---|---|---|
| 1 | 10 | 14 | 20 |
| 1.7 | 24 | 28 | 34 |
| 2 | 30 | 34 | 40 |



## Characteristics

|  |  |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from driving blocks |
| Scalar Expansion | Of one input if the other is a vector |
| Zero Crossing | No |

## See Also

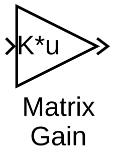
Look-Up Table, Look-Up Table Dynamic

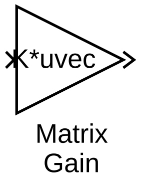
# Matrix Gain

**Purpose** Multiply input by a constant matrix

**Library** Simulink Math Operations and Fixed-Point Blockset Math

**Description** The Matrix Gain block is an implementation of the Gain block. See “Gain” on page 10-101 for more information.





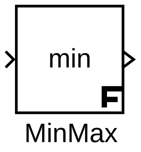
## Purpose

Output the minimum or maximum input value

## Library

Math

## Description

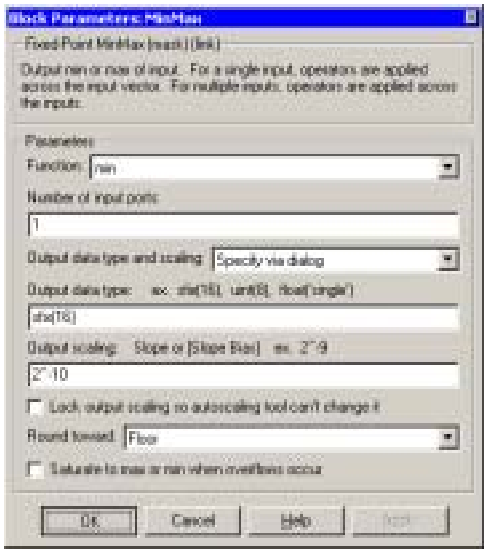


The MinMax block outputs either the minimum or the maximum element of the inputs. You can choose which function to apply with the **Function** parameter.

You specify the number of input ports with the **Number of input ports** parameter. If the block has one input port, the input must be a scalar or a vector. The block outputs a scalar equal to the minimum or maximum element of the input vector.

If the block has multiple input ports, the non-scalar inputs must all have the same dimensions. The block expands any scalar inputs to have the same dimensions as the non-scalar inputs. The block outputs a signal having the same dimensions as the input. Each output element equals the minimum or maximum of the corresponding input elements.

## Parameters and Dialog Box



Block Parameters: MinMax

Fixed-Point MinMax (mask) (link)

Output min or max of input. For a single input, operators are applied across the input vector. For multiple inputs, operators are applied across the inputs.

Parameters

Function: min

Number of input ports:

1

Output data type and scaling: Specify via dialog

Output data type: ex: sfix(16), uint(8), float('single')

sfix(16)

Output scaling: Slope or [Slope Bias] ex: 2^-9

2^-10

☐ Lock output scaling so autoscaling tool can't change it

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Function**

Specify the function to apply to the input; `min` or `max`.

**Number of input ports**

Specify the number of inputs to the block.

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or inherit the data type and scaling from the driving block or by back propagation.

**Output data type**

Specify any data type supported by the Fixed-Point Blockset.

**Output scaling**

Set the output scaling using binary point-only or [Slope Bias] scaling. These scaling modes are available only for generalized fixed-point data types.

**Lock output scaling so autoscaling tool can't change it**

If selected, **Output scaling** is locked. This feature is available only for generalized fixed-point output.

**Round toward**

Select the rounding mode for the fixed-point output.

**Saturate to min or max when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

| | |
|---|---|
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes, of inputs |

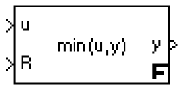
## See Also

MinMax Running Resettable

**Purpose** Determine the minimum or maximum of a signal over time

**Library** Math

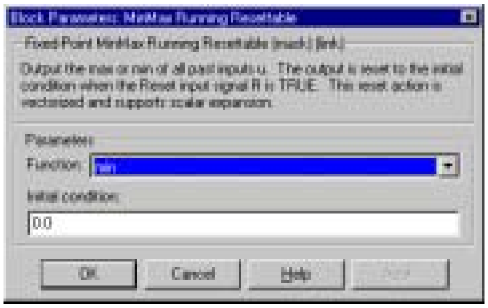
**Description**



The MinMax Running Resettable block outputs the minimum or maximum of all past inputs u. You specify whether the block outputs the minimum or the maximum with the **Function** parameter.

The block can reset its state based on an external reset signal R. When the reset signal R is TRUE, the block resets the output to the value of the **Initial condition** parameter.

**Parameters and Dialog Box**



Block Parameters: MinMax Running Resettable

Fixed Point MinMax Running Resettable (mask) (link)

Output the max or min of all past inputs u. The output is reset to the initial condition when the Reset input signal R is TRUE. This reset action is vectorized and supports scalar expansion.

Parameters

Function: min

Initial condition:

0.0

**Function**

Specify whether the block outputs the minimum or the maximum.

**Initial condition**

Initial condition.

**Characteristics**

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same data type as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

**See Also** MinMax

# Multiply

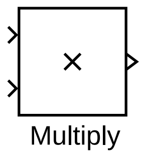
## Purpose

Multiply or divide inputs

## Library

Math

## Description

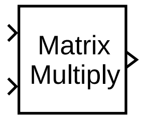


The Multiply block is an implementation of the Product block. See “Product” on page 10-175 for more information.

**Purpose** Multiply or divide inputs

**Library** Math

**Description** The Multiply Matrix block is an implementation of the Product block. See "Product" on page 10-175 for more information.

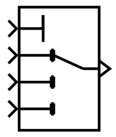


Multiply
Matrix

**Purpose** Choose between multiple block inputs

**Library** Simulink Signal Routing and Fixed-Point Blockset Select

**Description** The Multi-Port Switch block chooses between a number of inputs. The first (top) input is called the *control input*, while the rest of the inputs are called *data inputs*. The value of the control input determines which data input is passed through to the output port.



Multiport Switch

If the control input is an integer value, then the specified data input is passed through to the output. For example, suppose the **Use zero-based indexing** parameter is not selected. If the control input is 1, then the first data input is passed through to the output. If the control input is 2, then the second data input is passed through to the output, and so on. If the control input is not an integer value, the block first truncates the value to an integer by rounding to floor. If the truncated control input is less than 1 or greater than the number of input ports, an out-of-bounds error is returned.

You specify the number of data inputs with the **Number of input ports** parameter. The data inputs can be scalar or vector. The block output is determined by these rules:

- If you specify only one data input and that input is a vector, the block behaves as an “index selector,” and not as a multi-port switch. The block output is the vector element that corresponds to the value of the control input.
- If you specify more than one data input, the block behaves like a multi-port switch. The block output is the data input that corresponds to the value of the control input. If at least one of the data inputs is a vector, the block output is a vector. Any scalar inputs are expanded to vectors.
- If the inputs are scalar, the output is a scalar.

When the **Show additional parameters** check box is selected, some of the parameters that become visible are common to many blocks. For a detailed description of these parameters, refer to “Block Parameters” on page 10-6.

The Index Vector block, also in the Fixed-Point Blockset Select library, is another implementation of the Multi-Port Switch block that has different default parameter settings.

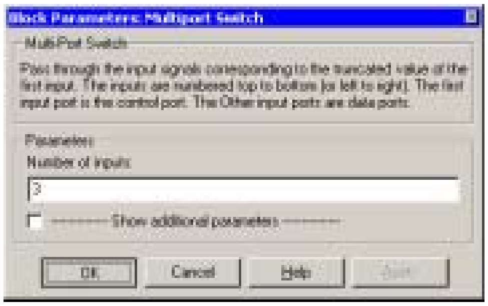
## Data type support

The control and data inputs of a Multi-Port Switch block can be signals of any data type supported by Simulink, except `boolean`. They can also be fixed-point data types.

The control inputs must be real. The data inputs can be real or complex.

For a discussion on the data types supported by Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

## Parameters and Dialog Box



Block Parameters: Multiport Switch

Multi-Port Switch

Pass through the input signals corresponding to the truncated value of the first input. The inputs are numbered top to bottom (or left to right). The first input port is the control port. The Other input ports are data ports.

Parameters

Number of inputs: 3

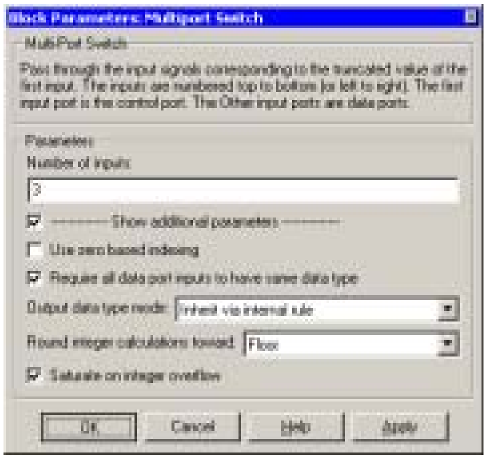
[ ] Show additional parameters

**Number of input ports**

Specify the number of data inputs to the block.

**Show additional parameters**

If selected, additional parameters specific to implementation of the block become visible as shown.



Block Parameters: Multiport Switch

Multi-Port Switch

Pass through the input signals corresponding to the truncated value of the first input. The inputs are numbered top to bottom (or left to right). The first input port is the control port. The Other input ports are data ports.

Parameters

Number of inputs: 3

[✓] Show additional parameters

[ ] Use zero based indexing

[✓] Require all data port inputs to have same data type

Output data type mode: Inherit via internal rule

Round integer calculations toward: Floor

[✓] Saturate on integer overflow

**Use zero based indexing**

If selected, the block uses zero-based indexing. Otherwise, the block uses one-based indexing.

**Require all data port inputs to have same data type**

Select to require all data port inputs to have the same data type.

**Output data type mode**

You can choose to inherit the output data type and scaling by backpropagation or by an internal rule. The internal rule causes the output of the block to have the same data type and scaling as the input with the larger positive range.

**Round integer calculations toward**

Select the rounding mode for the fixed-point output.

**Saturate on integer overflow**

If selected, overflows saturate.

## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from driving blocks |
| Scalar Expansion | Yes |
| Zero Crossing | No |

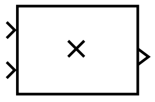
## Purpose

Multiply or divide inputs

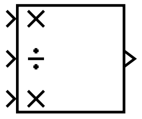
## Library

Simulink Math Operations and Fixed-Point Blockset Math

## Description



Product



Product

The Product block performs multiplication or division of its inputs.

This block produces outputs using either element-wise or matrix multiplication, depending on the value of the **Multiplication** parameter. You specify the operations with the **Number of inputs** parameter. Multiply(*) and divide(/) characters indicate the operations to be performed on the inputs:

- If there are two or more inputs, then the number of characters must equal the number of inputs. For example, "*/*" requires three inputs. For this example, if the **Multiplication** parameter is set to `Element-wise`, the block divides the elements of the first (top) input by the elements of the second (middle) input, and then multiplies by the elements of the third (bottom) input. In this case, all nonscalar inputs to this block must have the same dimensions.

  If, however, the **Multiplication** parameter is set to `Matrix`, the block output is the matrix product of the inputs marked "*" and the inverse of inputs marked "/", with the order of operations following the entry in the **Number of inputs** parameter. The dimensions of the inputs must be such that the matrix product is defined.

---

**Note** To perform a dot product on input vectors, use the Dot Product block.

---

- If only multiplication of inputs is required, then a numeric parameter value equal to the number of inputs can be supplied instead of "*" characters. This may be used in conjunction with either element-wise or matrix multiplication.
- If a single vector is input and the **Multiplication** parameter is set to `Element-wise`, then a single "*" will cause the block to output the scalar product of the vector elements. A single "/" will cause the block to output the inverse of the scalar product of the vector elements.
- If a single matrix is input and the **Multiplication** parameter is set to `Element-wise`, then a single "*" or "/" will cause the block to error out. If,

however, the **Multiplication** parameter is set to `Matrix`, then a single “*” will cause the block to output the matrix unchanged, and a single “/” will cause the block to output the inverse of the matrix.

When the **Show additional parameters** check box is selected, some of the parameters that become visible are common to many blocks. For a detailed description of these parameters, refer to “Block Parameters” on page 10-6.

For your convenience, the Fixed-Point Blockset Math library contains the following implementations of the Product block, each with different default parameter settings:

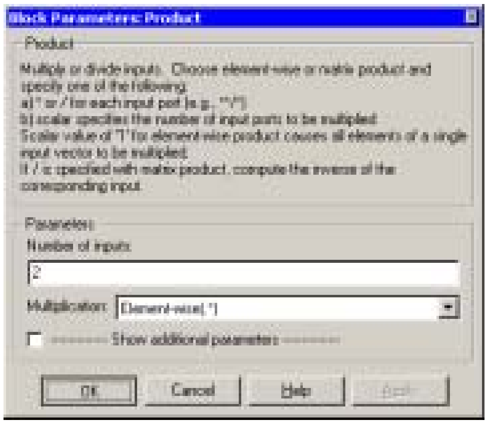
- Multiply
- Divide
- Product of Elements
- Product of Elements Inverted
- Multiply Matrix

## Data Type Support

The Product block accepts real or complex signals of any data type supported by Simulink, except `boolean`. The Product block also supports fixed-point data types. All input signals must be of the same data type.

For a discussion on the data types supported by Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

## Parameters and Dialog Box


Block Parameters: Product

Product

Multiply or divide inputs. Choose element-wise or matrix product and specify one of the following:
a) * or / for each input port (e.g., **/*)
b) scalar specifies the number of input ports to be multiplied
Scalar value of "1" for element-wise product causes all elements of a single input vector to be multiplied.
If / is specified with matrix product, compute the inverse of the corresponding input.

Parameters

Number of inputs:
2

Multiplication: Element-wise(.*)

Show additional parameters

**Number of inputs**

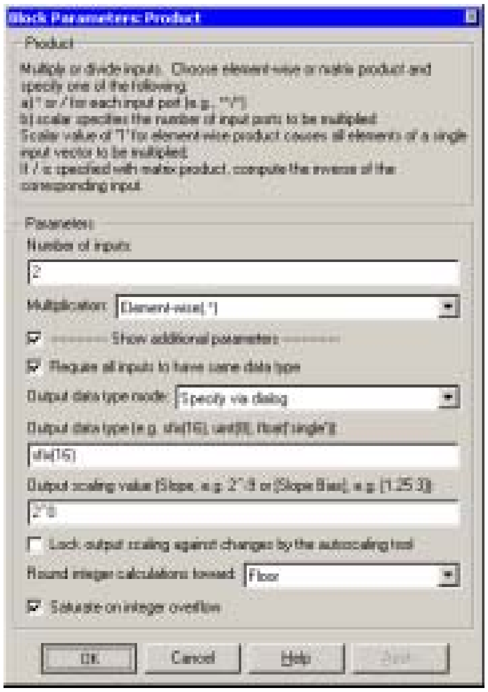
Enter the number of inputs or a combination of "*" and "/" symbols. See "Description" above for a complete discussion of this parameter.

**Multiplication**

Specify element-wise or matrix multiplication. See "Description" above for a complete discussion of this parameter.

**Show additional parameters**

If selected, additional parameters specific to implementation of the block become visible as shown.


Block Parameters: Product

Product

Multiply or divide inputs. Choose element-wise or matrix product and specify one of the following:
a) * or / for each input port (e.g., **/*)
b) scalar specifies the number of input ports to be multiplied
Scalar value of "1" for element-wise product causes all elements of a single input vector to be multiplied.
If / is specified with matrix product, compute the inverse of the corresponding input.

Parameters

Number of inputs: 2

Multiplication: Element-wise(.*)

[✓] Show additional parameters

[✓] Require all inputs to have same data type

Output data type mode: Specify via dialog

Output data type (e.g. sfix(16), uint(8), float('single')): sfix(16)

Output scaling value (Slope, e.g. 2^-9 or [Slope Bias], e.g. [1.25 3]): 2^0

[ ] Lock output scaling against changes by the autoscaling tool

Round integer calculations toward: Floor

[✓] Saturate on integer overflow

**Require all inputs to have same data type**

Select this parameter to require that all inputs must have the same data type.

**Output data type mode**

Specify the output data type and scaling to be the same as the first input, or inherit the data type and scaling by an internal rule or by backpropagation. You can also choose a built-in data type from the drop-down list. Lastly, if you choose `Specify via dialog`, the **Output data type**, **Output scaling value**, and **Lock output scaling against changes by the autoscaling tool** parameters become visible.

If you select `Inherit via internal rule` for this parameter, Simulink chooses a combination of output scaling and data type that requires the smallest amount of memory consistent with accommodating the output range and maintaining the output precision (and avoiding underflow in the case of division operations). If the **Production hardware characteristics** parameter on the **Advanced** pane of the **Simulation Parameters** dialog is set to `Unconstrained integer sizes`, Simulink chooses the data type without regard to hardware constraints. If the parameter is set to `Microprocessor`, Simulink chooses the smallest available hardware data type capable of meeting range, precision, and underflow constraints. For example, if the block multiplies inputs of type `int8` and `int16` and `Unconstrained integer sizes` is specified, the output data type is `sfix24`. If `Microprocessor` is specified and the microprocessor supports 8-bit, 16-bit, and 32-bit words, the output data type is `int32`. If none of the word lengths provided by the target microprocessor can accommodate the output range, Simulink displays an error message in the Simulink Diagnostic Viewer.

**Output data type**

Specify any data type, including fixed-point data types. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Output scaling value**

Set the output scaling using binary point-only or [Slope Bias] scaling. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Lock output scaling against changes by the autoscaling tool**

If selected, scaling of outputs is locked. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Round integer calculations toward**

Select the rounding mode for fixed-point output.

**Saturate on integer overflow**

If selected, overflows saturate.

## Conversions and Operations

The Product block first performs the specified multiply or divide operations on the inputs, and then converts the results to the output data type using the specified rounding and overflow modes. Refer to "Rules for Arithmetic Operations" on page 4-30 for more information about the rules that this block obeys when performing fixed-point operations.

## Characteristics

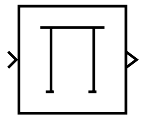
| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from driving block |
| Scalar Expansion | Yes |
| Zero Crossing | No |

# Product of Elements

**Purpose** Multiply or divide inputs

**Library** Math

**Description** The Product of Elements block is an implementation of the Product block. See “Product” on page 10-175 for more information.

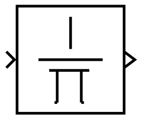


# Product of Elements Inverted

**Purpose** Multiply or divide inputs

**Library** Math

**Description** The Product of Elements Inverted block is an implementation of the Product block. See “Product” on page 10-175 for more information.

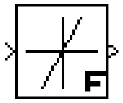

Product of Elements Inverted

# Rate Limiter

**Purpose** Limit the rising and falling rates of a signal

**Library** Nonlinear

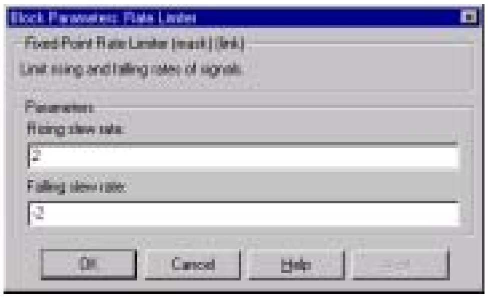
**Description** The Rate Limiter block limits the rising and falling rates of a signal.



Use the **Rising slew rate** parameter to set the limit on the rising rate of the signal.

Use the **Falling slew rate** parameter to set the limit on the falling rate of the signal.

**Parameters and Dialog Box**



Block Parameters: Rate Limiter

Fixed-Point Rate Limiter (mask) (link)

Limit rising and falling rates of signals.

Parameters

Rising slew rate:

2

Falling slew rate:

-2

**Rising slew rate**
Limit on the rising rate of the signal.

**Falling slew rate**
Limit on the falling rate of the signal.

**Characteristics**

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

**See Also** Rate Limiter Dynamic

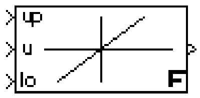
## Purpose

Limit the rising and falling rates of the signal

## Library

Nonlinear

## Description



The Rate Limiter Dynamic block limits the rising and falling rates of the signal.

The external signal up sets the upper limit on the rising rate of the signal.

The external signal lo sets the lower limit on the falling rate of the signal.

## Parameters and Dialog Box

Fixed Point Rate Limiter Dynamic (mask) (link)

Limit rising and falling rates of signals.

## Characteristics

| | |
|---|---|
| Input Ports | Any data type supported by the blockset |
| Output Port | Same data type as input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

## See Also

Rate Limiter

# Relational Operator

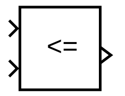
## Purpose

Perform the specified relational operation on the inputs

## Library

Simulink Math Operations and Fixed-Point Blockset Logic & Comparison

## Description



Relational Operator

The Relational Operator block performs the specified comparison of its two inputs.

The relational operator connecting the two inputs is selected with the **Relational Operator** parameter. The block icon updates to display the selected operator. The supported operations are given below.

| Operation | Description |
|---|---|
| == | TRUE if the first input is equal to the second input |
| ~= | TRUE if the first input is not equal to the second input |
| < | TRUE if the first input is less than the second input |
| <= | TRUE if the first input is less than or equal to the second input |
| >= | TRUE if the first input is greater than or equal to the second input |
| > | TRUE if the first input is greater than the second input |

You can specify inputs as scalars, arrays, or a combination of a scalar and an array:

- For scalar inputs, the output is a scalar.
- For array inputs, the output is an array of the same dimensions, where each element is the result of an element-by-element comparison of the input arrays.
- For mixed scalar/array inputs, the output is an array, where each element is the result of a comparison between the scalar and the corresponding array element.

The output data type is specified with the **Output data type mode** and **Output data type** parameters. The output equals 1 for TRUE and 0 for FALSE.

---

**Note** The output data type selected should represent zero exactly. Data types that satisfy this condition include signed and unsigned integers and any floating-point data type.

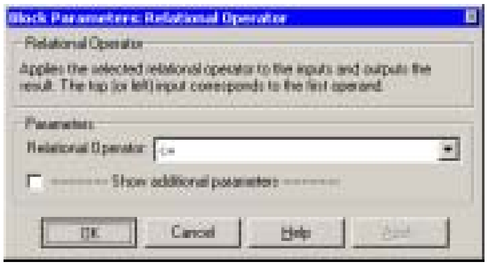
---

## Data Type Support

A Relational Operator block accepts real or complex signals of any data type supported by Simulink, as well as fixed-point data types. However, if the **Output data type mode** parameter is set to `Logical`, the input may only be `boolean` or `double`. One input can be real and the other complex if the operator is == or `!=`.

For a discussion on the data types supported by Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

## Parameters and Dialog Box



Block Parameters: Relational Operator

Relational Operator

Applies the selected relational operator to the inputs and outputs the result. The top (or left) input corresponds to the first operand.

Parameters

Relational Operator: <=

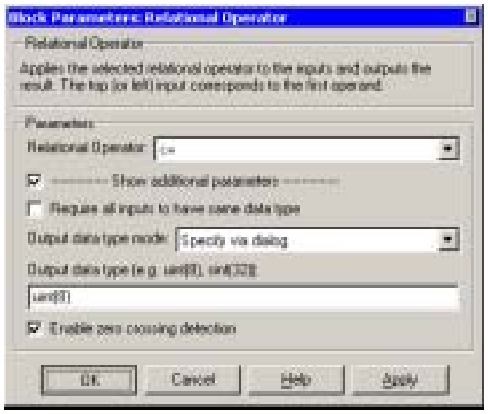
Show additional parameters

**Relational Operator**

Designate the relational operator used to compare the two inputs.

**Show additional parameters**

If selected, additional parameters specific to implementation of the block become visible as shown.



Block Parameters: Relational Operator

Relational Operator

Applies the selected relational operator to the inputs and outputs the result. The top (or left) input corresponds to the first operand.

Parameters

Relational Operator: <=

[✓] ------- Show additional parameters -------

[ ] Require all inputs to have same data type

Output data type mode: Specify via dialog

Output data type (e.g. uint(8), sint(32)):

uint(8)

[✓] Enable zero crossing detection

**Require all inputs to have same data type**

Select to require inputs to have the same data type.

**Output data type mode**

Set the output data type to `boolean`, or choose to specify the data type through the **Output data type** parameter.

Alternatively, you can select `Logical` to have the output data type determined by the **Boolean Logic Signals** parameter in the **Advanced** tab of the **Simulation Parameters** interface. If you select `Logical` and **Boolean Logic Signals** is `on`, then the output data type is always `boolean`. If you select `Logical` and **Boolean Logic Signals** is `off`, then the output data type will match the input data type, which is always `double`.

**Output data type**

Specify the output data type. You should only use data types that represent zero exactly. Data types that satisfy this condition include signed and unsigned integers and any floating-point data type. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Enable zero crossing detection**

Select to enable zero crossing detection. For more information, see “Zero Crossing Detection” in the Using Simulink documentation.

## Conversions and Operations

The input with the smaller positive range is converted to the data type of the other input offline using round-to-nearest and saturation. This conversion is performed prior to comparison. Refer to “Parameter Conversions” on page 4-27 for more information about parameter conversions.

## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from driving block |
| Scalar Expansion | Of inputs |
| Zero Crossing | No, unless **Enable zero crossing detection** is selected. |

## Relay

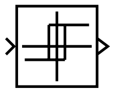
### Purpose

Switch output between two constants

### Library

Simulink Discontinuities and Fixed-Point Blockset Nonlinear

### Description



The Relay block allows its output to switch between two specified values. When the relay is on, it remains on until the input drops below the value of the **Switch off point** parameter. When the relay is off, it remains off until the input exceeds the value of the **Switch on point** parameter. The block accepts one input and generates one output.

The **Switch on point** value must be greater than or equal to the **Switch off point**. Specifying a **Switch on point** value greater than the **Switch off point** value models hysteresis, whereas specifying equal values models a switch with a threshold at that value.

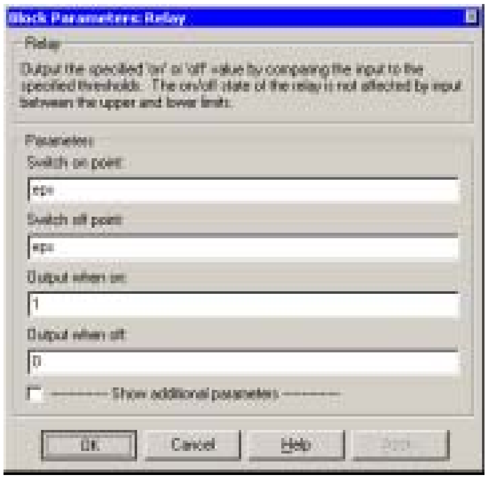
When the **Show additional parameters** check box is selected, some of the parameters that become visible are common to many blocks. For a detailed description of these parameters, refer to "Block Parameters" on page 10-6.

### Data Type Support

The Relay block accepts real or complex signals of any data type supported by Simulink, except `boolean`. It also accepts fixed-point data types.

For a discussion on the data types supported by Simulink, refer to "Data Types Supported by Simulink" in the Using Simulink documentation.

## Parameters and Dialog Box



Block Parameters: Relay

Relay

Output the specified 'on' or 'off' value by comparing the input to the specified thresholds. The on/off state of the relay is not affected by input between the upper and lower limits.

Parameters

Switch on point:

eps

Switch off point:

eps

Output when on:

1

Output when off:

0

☐ Show additional parameters

**Switch on point**

The “on” threshold for the relay.

**Switch off point**

The “off” threshold for the relay.

**Output when on**

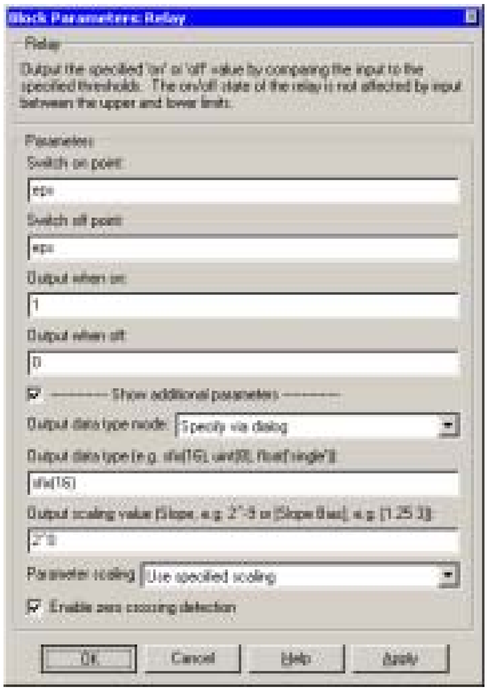
The output when the relay is on.

**Output when off**

The output when the relay is off.

**Show additional parameters**

If selected, additional parameters specific to implementation of the block become visible as shown.


Block Parameters: Relay

Relay

Output the specified 'on' or 'off' value by comparing the input to the specified thresholds. The on/off state of the relay is not affected by input between the upper and lower limits.

Parameters

Switch on point: eps

Switch off point: eps

Output when on: 1

Output when off: 0

[✓] Show additional parameters

Output data type mode: Specify via dialog

Output data type (e.g. sfix(16), uint(8), float('single')): sfix(16)

Output scaling value (Slope, e.g. 2^-9 or [Slope Bias], e.g. [1.25 3]): 2^0

Parameter scaling: Use specified scaling

[✓] Enable zero crossing detection

**Output data type mode**

Specify the output data type and scaling to be the same as the inputs, or inherit the data type and scaling by backpropagation. Lastly, if you choose `Specify via dialog`, the **Output data type**, **Output scaling value**, and **Parameter Scaling** parameters become visible.

**Output data type**

Specify any data type, including fixed-point data types. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Output scaling value**

Set the output scaling using binary point-only or [Slope Bias] scaling. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter, and is only enabled if `Use specified scaling` is selected for the **Parameter Scaling** parameter.

**Parameter Scaling**

- `Use Specified Scaling`—This mode allows you to specify the output scaling in the **Output scaling value** parameter
- `Best Precision: Vector-wise`—This mode produces a common binary point for each element of the output vector based on the best precision for the largest value of the vector.

  This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Enable zero crossing detection**

Select to enable zero crossing detection. For more information, see "Zero Crossing Detection" in the Using Simulink documentation.

## Conversions and Operations

The **Switch on point** and **Switch off point** parameters are converted to the input data type offline using round-to-nearest and saturation.

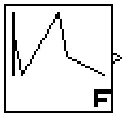
## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from driving block |
| Scalar Expansion | Yes |
| Zero Crossing | No, unless **Enable zero crossing detection** is selected |

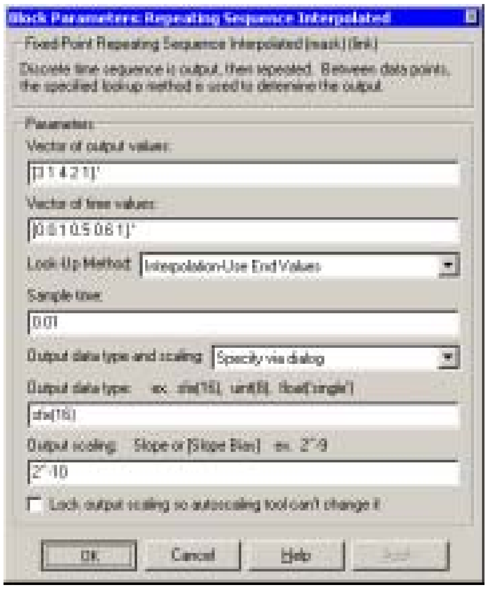
**Purpose** Output discrete-time sequence and repeat, interpolating between data points

**Library** Sources

**Description** The Repeating Sequence Interpolated block outputs a discrete-time sequence and then repeats it. Between data points, the block uses the method specified by the **Look-Up Method** parameter to determine the output.



**Parameters and Dialog Box**


Block Parameters: Repeating Sequence Interpolated

Fixed Point Repeating Sequence Interpolated (mask) (link)

Discrete time sequence is output, then repeated. Between data points, the specified lookup method is used to determine the output.

Parameters

Vector of output values: [3 1 4 2 1]'

Vector of time values: [0 0.1 0.5 0.6 1]'

Look-Up Method: Interpolation-Use End Values

Sample time: 0.01

Output data type and scaling: Specify via dialog

Output data type: ex. sfix(16), uint(8), float('single')

sfix(16)

Output scaling: Slope or [Slope Bias] ex. 2^-9

2^-10

☐ Lock output scaling so autoscaling tool can't change it

**Vector of output values**

Column vector containing output values of the discrete time sequence.

**Vector of time values**

Column vector containing time values. The time values must be a strictly increasing and the vector must have the same size as the vector of output values.

**Look-Up Method**

Specify the lookup method to determine the output between data points.

**Sample time**

Sample time.

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or by inheriting the data type and scaling by backpropagation.

**Output data type**

Any data type supported by the blockset.

**Output scaling**

Select the scaling method using the specified scaling or using the best precision.

**Lock output scaling so autoscaling tool can't change it**

If the box is selected, output scaling is locked.

## Characteristics

| | |
|---|---|
| Output Port | Any data type supported by the blockset |
| Scalar Expansion | Yes |

## See Also

Repeating Sequence Stair

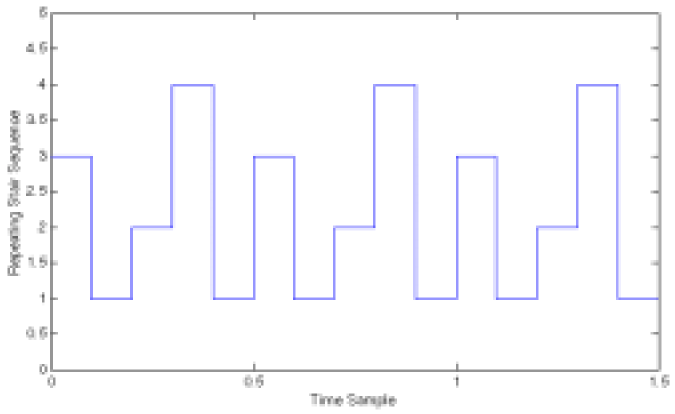
# Repeating Sequence Stair

**Purpose** Output and repeat the discrete time sequence

**Library** Sources

**Description** The Repeating Sequence Stair block outputs and repeats a discrete time sequence.

You can specify the stair sequence with the **Vector of output values** parameter. For example, the vector can be specified as `[3 1 2 4 1]'`, producing the stair sequence shown in the plot.



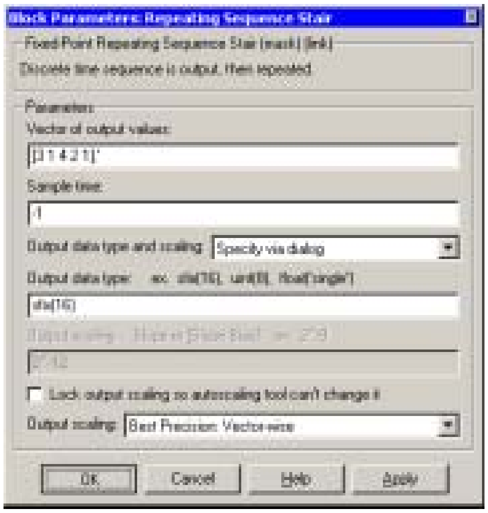
You can specify the sample time with the **Sample time** parameter.

You can select the output data type and scaling with the **Output data type and scaling** parameter, and set the output data type with the **Output data type** parameter.

For fixed-point data types, you can set the output scaling with the **Output scaling** parameter, and, below that parameter, select the method for scaling the output with the **Output scaling** parameter.

For a detailed description of all block parameters, refer to “Block Parameters” on page 9-4. For more information about converting from one Fixed-Point Blockset data type to another, refer to “Signal Conversions” on page 4-26.

## Parameters and Dialog Box



Block Parameters: Repeating Sequence Stair

Fixed-Point Repeating Sequence Stair (mask) (link)

Discrete time sequence is output, then repeated.

Parameters

Vector of output values:
[3 1 4 2 1]'

Sample time:
-1

Output data type and scaling: Specify via dialog

Output data type: ex. sfix(16), uint(8), float('single')
sfix(16)

Output scaling: Slope or [Slope Bias] ex. 2^-9
2^-12

☐ Lock output scaling so autoscaling tool can't change it

Output scaling: Best Precision: Vector-wise

**Vector of output values**

Vector containing values of the repeating stair sequence.

**Sample time**

Sample time.

**Output data type and scaling**

Specify the output data type and scaling via the dialog box, or by inheriting the data type and scaling by backpropagation.

**Output data type**

Any data type supported by the blockset.

**Output scaling**

Slope or [Slope Bias] scaling.

**Lock output scaling so autoscaling tool can't change it**

If the box is selected, output scaling is locked.

**Output scaling**

Select the scaling method using the specified scaling or using the best precision.

## Characteristics

| | |
|---|---|
| Output Port | Any data type supported by the blockset |
| Scalar Expansion | No |
| Vectorized | No |

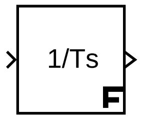
## See Also

Repeating Sequence Interpolated

**Purpose** Support calculations involving sample time

**Library** Calculus

**Description** The Sample Rate Probe block is an implementation of the Sample Time Multiply block. See “Sample Time Multiply” on page 10-200 for more information.



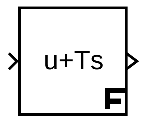
Sample Rate Probe

## Sample Time Add

**Purpose** Support calculations involving sample time

**Library** Calculus

**Description** The Sample Time Add block is an implementation of the Sample Time Multiply block. See “Sample Time Multiply” on page 10-200 for more information.

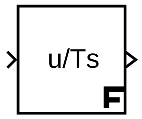


Sample Time Add

**Purpose** Support calculations involving sample time

**Library** Calculus

**Description** The Sample Time Divide block is an implementation of the Sample Time Multiply block. See “Sample Time Multiply” on page 10-200 for more information.



Sample Time Divide

# Sample Time Multiply

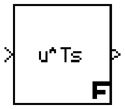
**Purpose**

Support calculations involving sample time

**Library**

Calculus

**Description**



The Sample Time Multiply block adds, subtracts, multiplies, or divides the input signal, u, by a weighted sample time Ts.

You specify the math operation with the **Operation** parameter. Additionally, you can specify to use only the weight with either the sample time or its inverse.

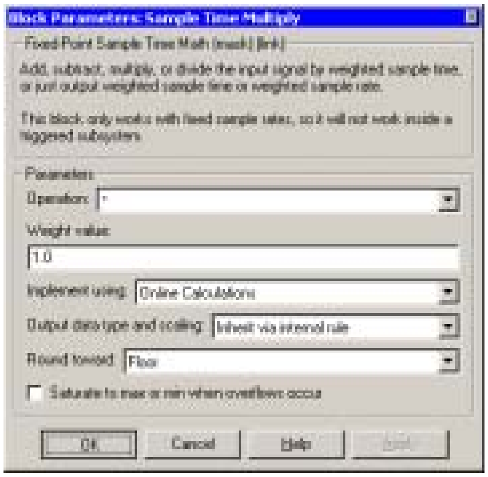
Enter the weighting factor in the **Weight value** parameter. If the weight is 1, w is removed from the equation.

For a detailed description of all block parameters, refer to “Block Parameters” on page 9-4. For more information about converting from one Fixed-Point Blockset data type to another, refer to “Signal Conversions” on page 4-26.

The Calculus library contains the following implementations, which are all linked to the Sample Time Multiply block but have different parameter settings:

- Sample Time Divide
- Sample Time Add
- Sample Time Subtract
- Sample Time Probe
- Sample Rate Probe

## Parameters and Dialog Box



Block Parameters: Sample Time Multiply

Fixed-Point Sample Time Math (mask) (link)

Add, subtract, multiply, or divide the input signal by weighted sample time, or just output weighted sample time or weighted sample rate.

This block only works with fixed sample rates, so it will not work inside a triggered subsystem.

Parameters

Operation: *

Weight value:

1.0

Implement using: Online Calculations

Output data type and scaling: Inherit via internal rule

Round toward: Floor

☐ Saturate to max or min when overflows occur

**Operation**

Specify operation to use: +, -, *, /, Ts only, 1/Ts only.

**Weight value**

Enter weight of sample time.

**Implement using**

Specify online calculations or offline scaling adjustment.

**Output data type and scaling**

Specify whether the output data type and scaling are inherited by an internal rule or by backpropagation.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

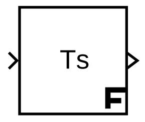
## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | For all math operations options except `Ts` and `1/Ts` |
| Scalar Expansion | No, the weight is always a scalar |

**Purpose** Support calculations involving sample time

**Library** Calculus

**Description** The Sample Time Probe block is an implementation of the Sample Time Multiply block. See “Sample Time Multiply” on page 10-200 for more information.



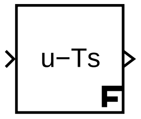
Sample Time Probe

## Sample Time Subtract

**Purpose** Support calculations involving sample time

**Library** Calculus

**Description** The Sample Time Subtract block is an implementation of the Sample Time Multiply block. See “Sample Time Multiply” on page 10-200 for more information.

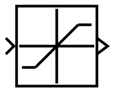


Sample Time Subtract

**Purpose** Limit the range of a signal

**Library** Simulink Discontinuities and Fixed-Point Blockset Nonlinear

**Description**



The Saturation block imposes upper and lower bounds on a signal. When the input signal is within the range specified by the **Lower limit** and **Upper limit** parameters, the input signal passes through unchanged. When the input signal is outside these bounds, the signal is clipped to the upper or lower bound.

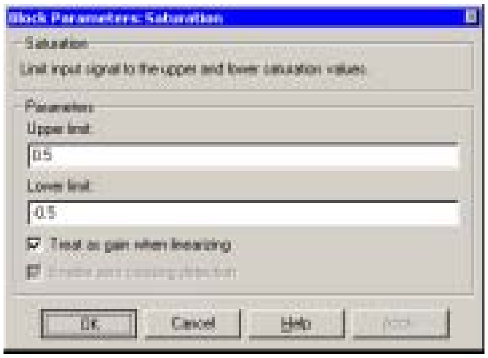
When the **Lower limit** and **Upper limit** parameters are set to the same value, the block outputs that value.

**Data Type Support**

A Saturation block accepts real signals of any data type supported by Simulink, except `boolean`. It also accepts fixed-point data types. The output data type is the same as the input data type.

For a discussion on the data types supported by Simulink, refer to "Data Types Supported by Simulink" in the Using Simulink documentation.

**Parameters and Dialog Box**



Block Parameters: Saturation

Saturation

Limit input signal to the upper and lower saturation values.

Parameters

Upper limit:

0.5

Lower limit:

-0.5

☑ Treat as gain when linearizing

☑ Enable zero crossing detection

**Upper limit**

Specify the upper bound on the input signal. When the input signal to the Saturation block is above this value, the output of the block is clipped to this value.

**Lower limit**

Specify the lower bound on the input signal. When the input signal to the Saturation block is below this value, the output of the block is clipped to this value.

**Treat as gain when linearizing**

Linearization commands in Simulink treat this block as a gain in state space. Select this parameter to cause linearization commands to treat the gain as 1; otherwise, the commands treat the gain as 0.

**Enable zero crossing detection**

Select to enable zero crossing detection. For more information, see “Zero Crossing Detection” in the Using Simulink documentation.

## Conversions and Operations

Both the **Upper limit** and **Lower limit** parameters are converted to the input data type offline using round-to-nearest and saturation.

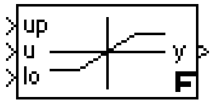
## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from driving block |
| Scalar Expansion | Of parameters and input |
| Zero Crossing | No, unless **Enable zero crossing detection** is selected |

**Purpose** Bound the range of the input

**Library** Nonlinear

**Description** The Saturation Dynamic block bounds the range of the input signal to upper and lower saturation values. The input signal outside of these limits saturates to one of the bounds where



- The input below the lower limit is set to the lower limit.
- The input above the upper limit is set to the upper limit.

The input for the upper limit is the up port, and the input for the lower limit is the `lo` port.

**Parameters and Dialog Box**

Fixed Point Saturation Dynamic (mask) (link)

Bound the range of the input

**Characteristics**

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

**See Also** Saturation

# Scaling Strip

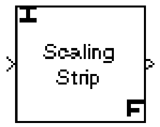
## Purpose

Remove scaling and map to a built in integer

## Library

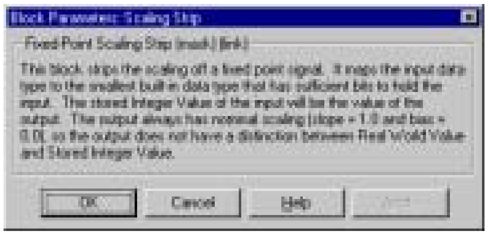
Data Type

## Description



The Scaling Strip block strips the scaling off a fixed point signal. It maps the input data type to the smallest built in data type that has enough data bits to hold the input. The stored integer value of the input is the value of the output. The output always has nominal scaling (slope = 1.0 and bias = 0.0), so the output does not make a distinction between real world value and stored integer value.

## Parameters and Dialog Box


Block Parameters: Scaling Strip

Fixed Point Scaling Strip (mask) (link)

This block strips the scaling off a fixed point signal. It maps the input data type to the smallest built in data type that has sufficient bits to hold the input. This stored Integer Value of the input will be the value of the output. The output always has nominal scaling (slope = 1.0 and bias = 0.0), so the output does not have a distinction between Real World Value and Stored Integer Value.

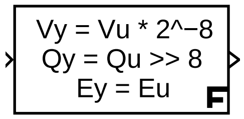
## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

**Purpose** Shift the bits and/or binary point of a signal

**Library** Bits

**Description**



Shift Arithmetic

The Shift Arithmetic block can be used to shift the bits or the binary point of a signal, or both.

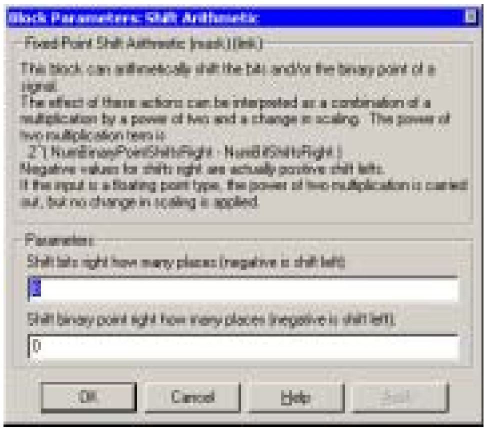
For example, the effects of binary point shifts two places to the right and two places to the left on an input of data type `sfix(8)` are shown below.

| Shift Operation | Binary Value | Decimal Value |
|---|---|---|
| No shift (original number) | 11001.011 | -6.625 |
| Binary point shift right by 2 places | 1100101.1 | -26.5 |
| Binary point shift left by 2 places | 110.01011 | -1.65625 |

This block performs arithmetic bit shifts on signed numbers. Therefore, the most significant bit is recycled for each bit shift. The effects of bit shifts two places to the right and two places to the left on an input of data type `sfix(8)` follow.

| Shift Operation | Binary Value | Decimal Value |
|---|---|---|
| No shift (original number) | 11001.011 | -6.625 |
| Bit shift right by 2 places | 11110.010 | -1.75 |
| Bit shift left by 2 places | 00101.100 | 5.5 |

## Parameters and Dialog Box



Block Parameters: Shift Arithmetic

Fixed-Point Shift Arithmetic (mask) (link)

This block can arithmetically shift the bits and/or the binary point of a signal.
The effect of these actions can be interpreted as a combination of a multiplication by a power of two and a change in scaling. The power of two multiplication term is
2^( NumBinaryPointShiftsRight - NumBitShiftsRight )
Negative values for shifts right are actually positive shift lefts.
If the input is a floating point type, the power of two multiplication is carried out, but no change in scaling is applied.

Parameters

Shift bits right how many places (negative is shift left)

3

Shift binary point right how many places (negative is shift left)

0

**Shift bits right how many places (negative is shift left)**

The number of places the bits of the input signal is shifted. A positive value indicates a shift right, while a negative value indicates a shift left.

**Shift binary point right how many places (negative is shift left)**

The number of places the binary point of the input signal is shifted. A positive value indicates a shift right, while a negative value indicates a shift left.

## Characteristics

| | |
|---|---|
| Input Port | Any data type supported by the blockset. Inputs may be scalar or vector. |
| Output Port | Any data type supported by the blockset. Output is scalar if the input is scalar, and vector if the input is vector. |
| Direct Feedthrough | Yes |
| Sample Time | Inherited |
| Scalar Expansion | No |
| Vectorized | Yes, accepts vector inputs |

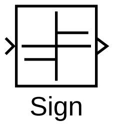
**Purpose**

Indicate the sign of the input

**Library**

Simulink Math Operations and Fixed-Point Blockset Nonlinear

**Description**



The Sign block indicates the sign of the input:

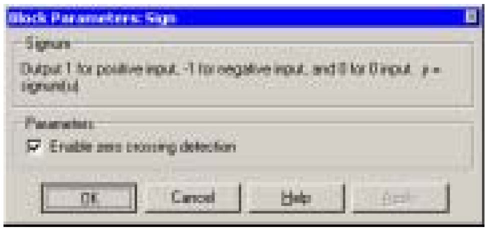
- The output is 1 when the input is greater than zero.
- The output is 0 when the input is equal to zero.
- The output is -1 when the input is less than zero.

**Data Type Support**

The Sign block accepts real or complex signals of any data type supported by Simulink, as well as fixed-point data types. The output is a signed data type with the same number of bits as the input, and with nominal scaling (a slope of one and a bias of zero).

For a discussion on the data types supported by Simulink, refer to "Data Types Supported by Simulink" in the Using Simulink documentation.

**Parameters and Dialog Box**


Block Parameters: Sign

Signum

Output 1 for positive input, -1 for negative input, and 0 for 0 input. y = sign(u)

Parameters

☑ Enable zero crossing detection

**Enable zero crossing detection**

Select to enable zero crossing detection. For more information, see "Zero Crossing Detection" in the Using Simulink documentation.

**Characteristics**

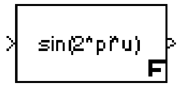
| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from the driving block |
| Scalar Expansion | N/A |
| Zero Crossing | No, unless **Enable zero crossing detection** is selected |

# Sine

**Purpose** Implement a sine wave in fixed-point using a lookup table approach that exploits quarter wave symmetry

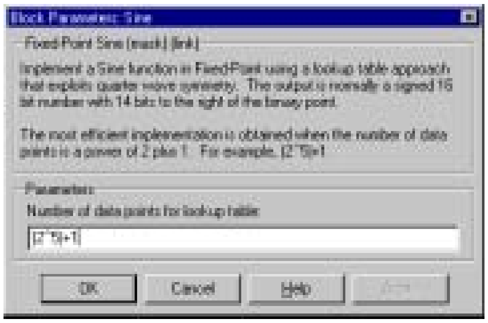
**Library** Lookup

**Description** The Sine block implements a sine wave in fixed-point using a lookup table method that exploits quarter wave symmetry.



You can set the number of data points to retrieve from the lookup table with the **Number of data points for lookup table** parameter.

**Parameters and Dialog Box**



Block Parameters: Sine

Fixed-Point Sine (mask) (link)

Implement a Sine function in Fixed-Point using a lookup table approach that exploits quarter wave symmetry. The output is normally a signed 16 bit number with 14 bits to the right of the binary point.

The most efficient implementation is obtained when the number of data points is a power of 2 plus 1. For example, (2^5)+1

Parameters

Number of data points for lookup table:

(2^5)+1

**Number of data points for lookup table**
Number of data points to retrieve from the lookup table.

**Characteristics**

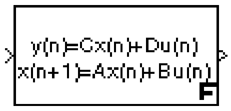
| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | N/A |

## State-Space

**Purpose** Implement discrete-time state space

**Library** Filters

**Description**



The State-Space block implements the system described by

$$y(n) = Cx(n) + Du(n)$$

$$x(n+1) = Ax(n) + Bu(n)$$

where *u* is the input, *x* is the state, and *y* is the output. Both equations have the same data type.

The matrices A, B, C and D have the following characteristics:

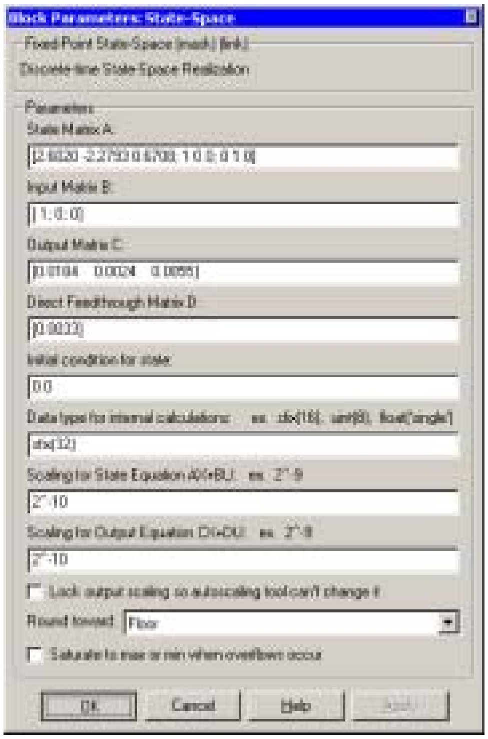
- A must be an n-by-n matrix, where n is the number of states.
- B must be an n-by-m matrix, where m is the number of inputs.
- C must be an r-by-n matrix, where r is the number of outputs.
- D must be an r-by-m matrix.

In addition:

- The state x must be a n-by-1 vector
- The input u must be a m-by-1 vector
- The output y must be a r-by-1 vector

The block accepts one input and generates one output. The input vector width is determined by the number of columns in the B and D matrices. The output vector width is determined by the number of rows in the C and D matrices.

## Parameters and Dialog Box



Fixed-Point State-Space (mask) (link)

Discrete-time State-Space Realization

Parameters

State Matrix A: [2.6020 -2.2793 0.6708; 1 0 0; 0 1 0]

Input Matrix B: [ 1; 0; 0]

Output Matrix C: [0.0184 0.0024 0.0055]

Direct Feedthrough Matrix D: [0.0033]

Initial condition for state: 0.0

Data type for internal calculations: ex. sfix(16), uint(8), float('single'): sfix(32)

Scaling for State Equation AX+BU: ex. 2^-9: 2^-10

Scaling for Output Equation CX+DU: ex. 2^-9: 2^-10

☐ Lock output scaling so autoscaling tool can't change it

Round toward: Floor

☐ Saturate to max or min when overflows occur

**State Matrix A**

Matrix of states.

**Input Matrix B**

Column vector of inputs.

**Output Matrix C**

Column vector of outputs.

**Direct Feedthrough Matrix D**

Matrix for direct feedthrough.

**Initial condition for state**

Initial condition for the state.

**Data type for internal calculations**

Data type for internal calculations. Some examples are `sfix(16)`, `unit(8)`, and `float('single')`.

**Scaling for State Equation AX+BU**

Scaling for state equations.

**Scaling for Output Equation CX+DU**

Scaling for output equations.

**Lock output scaling so autoscaling tool can’t change it**

If the box is selected, the output scaling is locked.

**Round toward**

Rounding mode for the fixed-point output.

**Saturate to max or min when overflows occur**

If selected, fixed-point overflows saturate.

## Characteristics

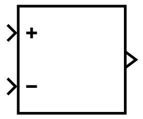
| | |
|---|---|
| Input Ports | Any data type supported by the blockset—it must be a scalar |
| Output Port | Any data type supported by the blockset |
| Direct Feedthrough | Yes |
| Scalar Expansion | Of initial conditions |
| Vectorized | No |

# Subtract

**Purpose** Add or subtract inputs

**Library** Math

**Description** The Subtract block is an implementation of the Sum block. See “Sum” on page 10-217 for more information.



Subtract

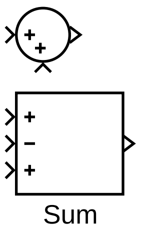
## Purpose

Add or subtract inputs

## Library

Simulink Math Operations and Fixed-Point Blockset Math

## Description



The Sum block performs addition or subtraction on its inputs. This block can add or subtract scalar, vector, or matrix inputs. It can also collapse the elements of a single input vector.

You specify the operations of the block with the **List of Signs** parameter. Plus (+), minus (-), and spacer (|) characters indicate the operations to be performed on the inputs:

- If there are two or more inputs, then the number of characters must equal the number of inputs. For example, "+-+" requires three inputs and configures the block to subtract the second (middle) input from the first (top) input, and then add the third (bottom) input.

  All nonscalar inputs must have the same dimensions. Scalar inputs will be expanded to have the same dimensions as the other inputs.

- A spacer character creates extra space between ports on the block's icon.
- If only addition of all inputs is required, then a numeric parameter value equal to the number of inputs can be supplied instead of "+" characters.
- If only one vector is input, then a single "+" or "-" will collapse the vector using the specified operation.

When the **Show additional parameters** check box is selected, some of the parameters that become visible are common to many blocks. For a detailed description of these parameters, refer to "Block Parameters" on page 10-6.

For your convenience, the Fixed-Point Blockset Math library contains the following implementations of the Sum block, each with different default parameter settings:

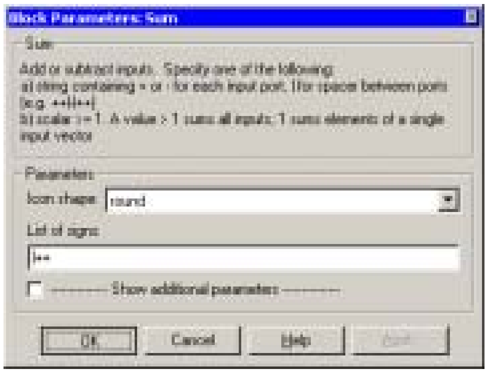
- Add
- Subtract
- Sum of Elements
- Sum of Elements Negated

## Data Type Support

The Sum block accepts real or complex signals of any data type supported by Simulink, as well as fixed-point data types. The inputs may be of different data types unless the **Require all inputs to have same data type** parameter is selected.

For a discussion on the data types supported by Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

## Parameters and Dialog Box


Block Parameters: Sum

Sum

Add or subtract inputs. Specify one of the following:
a) string containing + or - for each input port, | for spacer between ports (e.g. ++|-|++)
b) scalar >= 1. A value > 1 sums all inputs; 1 sums elements of a single input vector

Parameters

Icon shape: round

List of signs:

|++

☐ Show additional parameters

**Icon shape**

Designate the icon shape of the block.

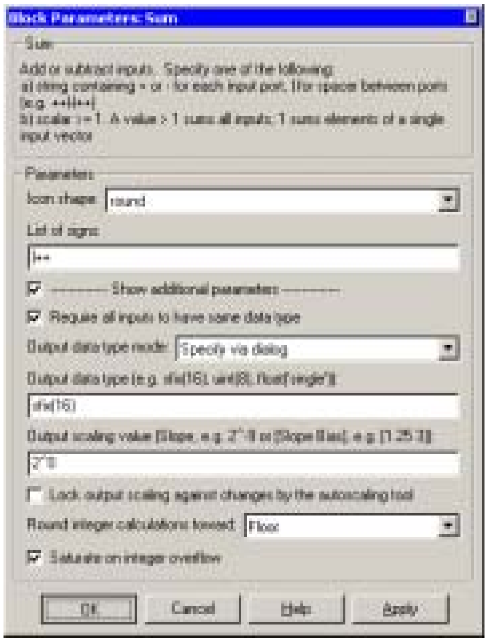
**List of signs**

Enter as many plus (+) and minus (-) characters as there are inputs. Addition is the default operation, so if you only want to add the inputs, enter the number of input ports. For a single vector input, “+” or “-” will collapse the vector using the specified operation.

You can manipulate the positions of the input ports on the block icon by inserting spacers (|) between the signs in the **List of signs** parameter. For example, “++|--” creates an extra space between the second and third input ports.

**Show additional parameters**

If selected, additional parameters specific to implementation of the block become visible as shown.


Block Parameters: Sum

Sum

Add or subtract inputs. Specify one of the following:
a) string containing + or - for each input port, | for spacer between ports (e.g. ++|-|++)
b) scalar >= 1. A value > 1 sums all inputs; 1 sums elements of a single input vector

Parameters

Icon shape: round

List of signs: |++

[✓] ---------- Show additional parameters ----------

[✓] Require all inputs to have same data type

Output data type mode: Specify via dialog

Output data type (e.g. sfix(16), uint(8), float('single')):

sfix(16)

Output scaling value (Slope, e.g. 2^-9 or [Slope Bias], e.g. [1.25 3]):

2^0

[ ] Lock output scaling against changes by the autoscaling tool

Round integer calculations toward: Floor

[✓] Saturate on integer overflow

**Require all inputs to have same data type**

Select this parameter to require that all inputs must have the same data type.

**Output data type mode**

Specify the output data type and scaling to be the same as the first input, or inherit the data type and scaling from an internal rule or by backpropagation. You can also choose a built-in data type from the drop-down list. Lastly, if you choose `Specify via dialog`, the **Output data type**, **Output scaling value**, and **Lock output scaling against changes by the autoscaling tool** parameters become visible.

**Output data type**

Specify any data type, including fixed-point data types. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Output scaling value**

Set the output scaling using binary point-only or [Slope Bias] scaling. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Lock output scaling against changes by the autoscaling tool**

If selected, scaling of outputs is locked. This parameter is only visible if `Specify via dialog` is selected for the **Output data type mode** parameter.

**Round integer calculations toward**

Select the rounding mode for fixed-point output.

**Saturate on integer overflow**

If selected, overflows saturate.

## Conversions and Operations

The Sum block first converts the input data type(s) to the output data type using the specified rounding and overflow modes, and then performs the specified operations. Refer to "Rules for Arithmetic Operations" on page 4-30 for more information about the rules that this block obeys when performing fixed-point operations.

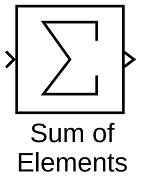
## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from driving blocks |
| Scalar Expansion | Yes |
| States | 0 |
| Zero Crossing | No |

**Purpose** Add or subtract inputs

**Library** Math

**Description** The Sum of Elements block is an implementation of the Sum block. See “Sum” on page 10-217 for more information.

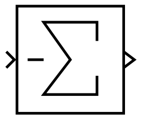


# Sum of Elements Negated

**Purpose** Add or subtract inputs

**Library** Math

**Description** The Sum of Elements Negated block is an implementation of the Sum block. See “Sum” on page 10-217 for more information.



Sum of Elements Negated

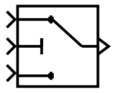
**Purpose**

Switch output between the first input and the third input based on the value of the second input

**Library**

Simulink Signal Routing and Fixed-Point Blockset Select

**Description**



The Switch block passes through the first (top) input or the third (bottom) input based on the value of the second (middle) input. The first and third inputs are called *data inputs*. The second input is called the *control input*.

You select the conditions under which the first input is passed with the **Criteria for passing first input** parameter. You can make the block check whether the control input is greater than or equal to the threshold value, purely greater than the threshold value, or nonzero. If the control input meets the condition set in the **Criteria for passing first input parameter**, then the first input is passed. Otherwise, the third input is passed.

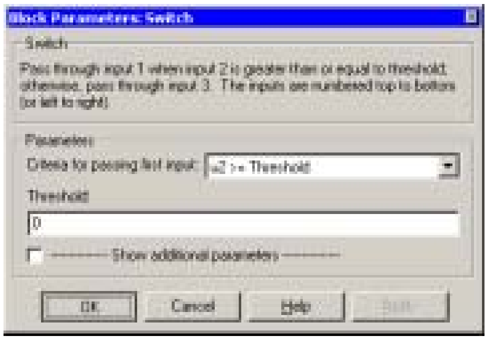
When the **Show additional parameters** check box is selected, some of the parameters that become visible are common to many blocks. For a detailed description of these parameters, refer to “Block Parameters” on page 10-6.

**Data Type Support**

The data and control inputs of a Switch block accept real or complex signals of any data type supported by Simulink, as well as fixed-point data types. The data type of the threshold is `double`.

For a discussion on the data types supported by Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

**Parameters and Dialog Box**



Pass through input 1 when input 2 is greater than or equal to threshold; otherwise, pass through input 3. The inputs are numbered top to bottom (or left to right).

Criteria for passing first input: u2 >= Threshold

Threshold: 0

☐ Show additional parameters

**Criteria for passing first input**

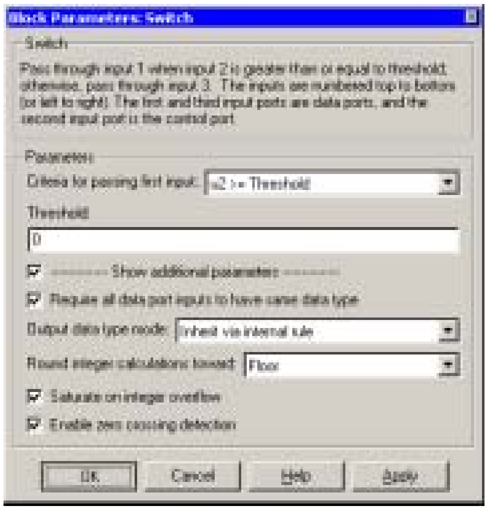
Select the conditions under which the first input is passed. You can make the block check whether the control input is greater than or equal to the threshold value, purely greater than the threshold value, or nonzero. If the control input meets the condition set in this parameter, then the first input is passed. Otherwise, the third input is passed.

**Threshold**

Assign the switch threshold that determines which input is passed to the output.

**Show additional parameters**

If selected, additional parameters specific to implementation of the block become visible as shown.


Block Parameters: Switch

Switch

Pass through input 1 when input 2 is greater than or equal to threshold; otherwise, pass through input 3. The inputs are numbered top to bottom (or left to right). The first and third input ports are data ports, and the second input port is the control port.

Parameters

Criteria for passing first input: u2 >= Threshold

Threshold

0

☑ Show additional parameters

☑ Require all data port inputs to have same data type

Output data type mode: Inherit via internal rule

Round integer calculations toward: Floor

☑ Saturate on integer overflow

☑ Enable zero crossing detection

**Require all data port inputs to have same data type**

Select to require all data inputs to have the same data type.

**Output data type mode**

Choose to inherit the output data type and scaling by backpropagation or by an internal rule. The internal rule causes the output of the block to have the same data type and scaling as the input with the larger positive range.

**Round integer calculations toward**

Select the rounding mode for fixed-point output.

**Saturate on integer overflow**

If selected, overflows saturate.

**Enable zero crossing detection**

Select to enable zero crossing detection. For more information, see “Zero Crossing Detection” in the Using Simulink documentation.

## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Inherited from driving block |
| Scalar Expansion | Yes |
| Zero Crossing | No, unless **Enable zero crossing detection** is selected |

## See Also

Multi-Port Switch

# Tapped Delay

## Purpose

Delay a scalar signal multiple sample periods and output all the delayed versions

## Library

Delays & Holds

## Description

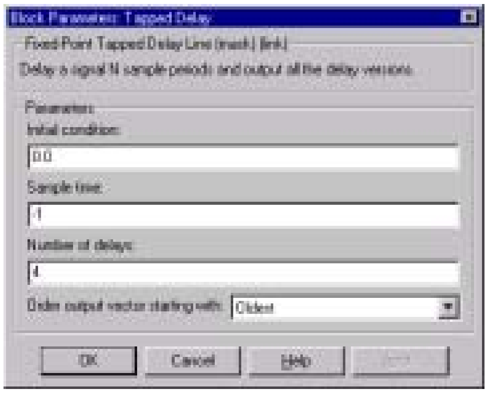
The Tapped Delay block delays its input by the specified number of sample periods, and outputs all the delayed versions.

This block provides a mechanism for discretizing a signal in time, or resampling the signal at a different rate. You specify the time between samples with the **Sample time** parameter. You specify the number of delays with the **Number of delays** parameter. A value of -1 instructs the block to inherit the number of delays by backpropagation. Each delay is equivalent to the $z^{-1}$ discrete-time operator, which is represented by the Unit Delay block.

The block accepts one scalar input and generates an output for each delay. The input must be a scalar. You specify the order of the output vector with the **Order output vector starting with** parameter list. **Oldest** orders the output vector starting with the oldest delay version and ending with the newest delay version. **Newest** orders the output vector starting with the newest delay version and ending with the oldest delay version.

The block output for the first sampling period is specified by the **Initial condition** parameter. Careful selection of this parameter can minimize unwanted output behavior.

## Parameters and Dialog Box


Block Parameters: Tapped Delay

Fixed Point Tapped Delay Line (mask) (link)

Delay a signal N sample periods and output all the delay versions.

Parameters

Initial condition:

0.0

Sample time:

-1

Number of delays:

4

Order output vector starting with: Oldest

**Initial condition**
The initial output of the simulation.

**Sample time**
Sample time.

**Number of delays**
The number of discrete-time operators.

**Order output vector starting with**
Specify whether the oldest delay version is output first, or the newest delay version is output first.

## Conversions

The **Initial condition** parameter is converted from a double to the input data type offline using round-to-nearest and saturation.

## Characteristics

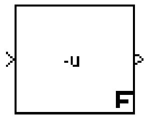
| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input |
| Direct Feedthrough | No |
| Scalar Expansion | Yes—of initial conditions |

# Unary Minus

**Purpose** Negate the input

**Library** Math

**Description**

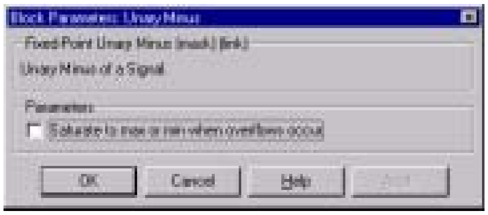


The Unary Minus block negates the input. The block accepts only signed data types.

For signed data types, you cannot accurately negate the most negative value since the result is not representable by the data type. In this case, the behavior of the block is controlled by the **Saturate to max or min when overflows occur** check box. If selected, the most negative value of the data type wraps to the most positive value. If not selected, the operation has no effect. If an overflow occurs, then a warning is returned to the MATLAB command line.

For example, suppose the block input is an 8-bit signed integer. The range of this data type is from -128 to 127, and the negation of -128 is not representable. If the **Saturate to max or min when overflows occur** check box is selected, then the negation of -128 is 127. If it is not selected, then the negation of -128 remains at -128.

**Parameters and Dialog Box**



Block Parameters: Unary Minus

Fixed-Point Unary Minus (mask) (link)

Unary Minus of a Signal

Parameters

☐ Saturate to max or min when overflows occur

**Saturate to max or min when overflows occur**
If selected, fixed-point overflows saturate.

**Characteristics**

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Port | Same as the input (a nonzero bias is negated offline) |
| Direct Feedthrough | No |
| Scalar Expansion | Yes—of input or initial conditions |

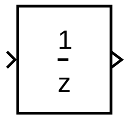
**Purpose**

Delay a signal one sample period

**Library**

Simulink Discrete and Fixed-Point Blockset Delays & Holds

**Description**



Unit Delay

The Unit Delay block delays its input by the specified sample period. This block is equivalent to the $z^{-1}$ discrete-time operator. The block accepts one input and generates one output, which can be either both scalar or both vector. If the input is a vector, all elements of the vector are delayed by the same sample period.

You specify the block output for the first sampling period with the **Initial conditions** parameter. Careful selection of this parameter can minimize unwanted output behavior. The time between samples is specified with the **Sample time** parameter. A setting of -1 means the sample time is inherited.

The Unit Delay block provides a mechanism for discretizing one or more signals in time, or for resampling the signal at a different rate. If your model contains multirate transitions, then you must add Unit Delay blocks between the slow-to-fast transitions. The sample rate of the Unit Delay block must be set to that of the slower block. For fast-to-slow transitions, use the Zero Order Hold block. For more information about multirate transitions, refer to the Simulink or the Real-Time Workshop documentation.

---

**Note** The Unit Delay block accepts continuous signals. When it has a continuous sample time, the block is equivalent to the Simulink Memory block.

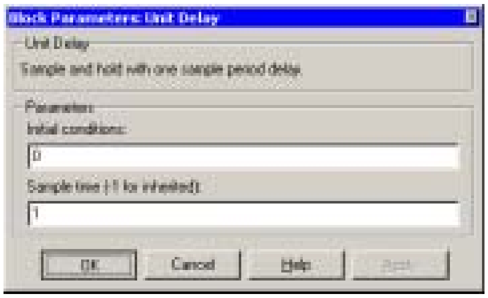
---

**Data Type Support**

The Unit Delay block accepts real or complex signals of any data type supported by Simulink, as well as fixed-point data types. If the data type of the input signal is user-defined, the initial condition must be zero.

For a discussion on the data types supported by Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

## Parameters and Dialog Box


Block Parameters: Unit Delay

Unit Delay

Sample and hold with one sample period delay.

Parameters

Initial conditions:

0

Sample time (-1 for inherited):

1

**Initial conditions**

The output of the simulation for the first sampling period, during which the output of the Unit Delay block is otherwise undefined.

**Sample time**

The time interval between samples. To inherit the sample time, set this parameter to -1.

## Conversions and Operations

The **Initial conditions** parameter is converted from a double to the input data type offline using round-to-nearest and saturation.

## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | No |
| Sample Time | Discrete or continuous. When inheriting a continuous signal, this block acts as a Simulink Memory block. |
| Scalar Expansion | Of input or initial conditions |
| States | Yes—inherited from driving block for nonfixed-point data types. |
| Zero Crossing | No |

## See Also

Unit Delay Enabled, Unit Delay Enabled External IC, Unit Delay Enabled Resettable, Unit Delay Enabled Resettable External IC, Unit Delay External IC, Unit Delay Resettable, Unit Delay Resettable External IC, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable, Unit Delay

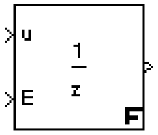
With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable, Unit Delay With Preview Resettable External RV

# Unit Delay Enabled

**Purpose** Delay a signal one sample period, if the external enable signal is on

**Library** Delays & Holds

**Description** The Unit Delay Enabled block delays a signal by one sample period when the external enable signal E is on. While the enable is off, the block is disabled. It holds the current state at the same value and outputs that value. The enable signal is on when E is not 0, and off when E is 0.

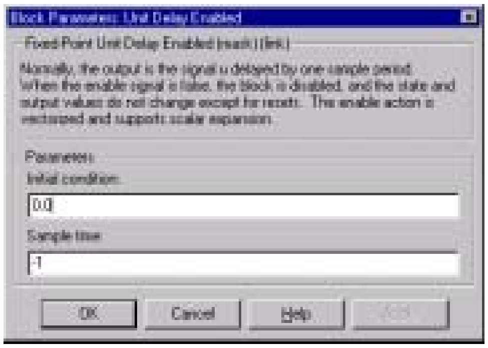


You specify the block output for the first sampling period with the value **Initial condition** parameter.

The output data type is the same as the input u data type. The data type of the input u and the enable E can be any data type.

You input the sample time with the **Sample time** parameter**.** A setting of -1 means the **Sample time** is inherited.

**Parameters and Dialog Box**



Block Parameters: Unit Delay Enabled

Fixed-Point Unit Delay Enabled (mask) (link)

Normally, the output is the signal u delayed by one sample period. When the enable signal is false, the block is disabled, and the state and output values do not change except for resets. This enable action is vectorized and supports scalar expansion.

Parameters

Initial condition:

0.0

Sample time:

-1

**Initial condition**

Initial condition.

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port u | Any data type supported by the blockset |
| Input Port E | Any data type supported by the blockset |
| Output Port | Same as the input u |
| Direct Feedthrough | No |
| Scalar Expansion | Yes |

## See Also

Unit Delay, Unit Delay Enabled External IC, Unit Delay Enabled Resettable, Unit Delay Enabled Resettable External IC, Unit Delay External IC, Unit Delay Resettable, Unit Delay Resettable External IC, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable, Unit Delay With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable, Unit Delay With Preview Resettable External RV

# Unit Delay Enabled External IC

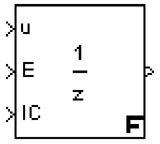
## Purpose

Delay a signal one sample period, if the external enable signal is on, with an external initial condition

## Library

Delays & Holds

## Description



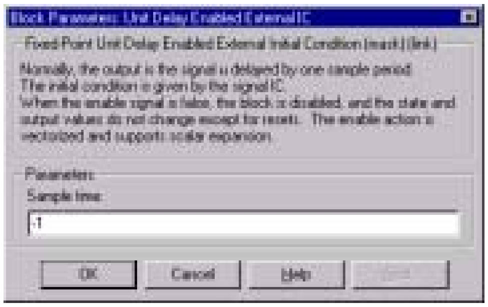
The Unit Delay Enabled External IC block delays a signal by one sample period when the enable signal `E` is on. While the enable is off, the block holds the current state at the same value and outputs that value. The enable `E` is on when `E` is not 0, and off when `E` is 0.

The initial condition of this block is given by the signal `IC`.

The input `u` and `IC` data types must be the same, and are any data type. The output data type is the same as `u` and `IC`. The enable `E` is any data type.

You specify the time between samples with the **Sample time** parameter**.** A setting of `-1` means the **Sample time** is inherited.

## Parameters and Dialog Box



Block Parameters: Unit Delay Enabled External IC

Fixed Point Unit Delay Enabled External Initial Condition (mask) (link)

Normally, the output is the signal u delayed by one sample period.
The initial condition is given by the signal IC.
When the enable signal is false, the block is disabled, and the state and output values do not change except for resets. The enable action is vectorized and supports scalar expansion.

Parameters

Sample time:

-1

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port `u` | Any data type supported by the blockset |
| Input Port `E` | Any data type supported by the blockset |
| Input Port `IC` | Same as the input `u` |
| Output Port | Same as the input `u` |
| Direct Feedthrough | Yes, of the reset input port<br>No, of the enable input port<br>Yes, of the external `IC` port |
| Scalar Expansion | Yes |

## See Also

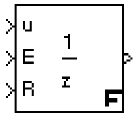
Unit Delay, Unit Delay Enabled, Unit Delay Enabled Resettable, Unit Delay Enabled Resettable External IC, Unit Delay External IC, Unit Delay Resettable, Unit Delay Resettable External IC, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable, Unit Delay With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable, Unit Delay With Preview Resettable External RV

# Unit Delay Enabled Resettable

**Purpose** Delay a signal one sample period, if the external enable signal is on, with an external Boolean reset

**Library** Delays & Holds

**Description** The Unit Delay Enabled Resettable block combines the features of the Unit Delay Enabled and Unit Delay Resettable blocks.



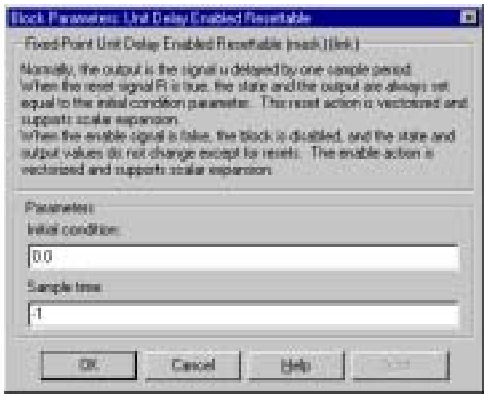
The block can reset its state based on an external reset signal R. When the enable signal E is on and the reset signal R is false, the block outputs the input signal delayed by one sample period.

When the enable signal E is on and the reset signal R is true, the block resets the current state to the initial condition, specified by the **Initial condition** parameter, and outputs that state delayed by one sample period.

When the enable signal is off, the block is disabled, and the state and output do not change except for resets. The enable signal is on when E is not 0, and off when E is 0.

You specify the time between samples with the **Sample time** parameter**.** A setting of -1 means the **Sample time** is inherited.

**Parameters and Dialog Box**



Fixed-Point Unit Delay Enabled Resettable (mask) (link)

Normally, the output is the signal u delayed by one sample period.
When the reset signal R is true, the state and the output are always set equal to the initial condition parameter. This reset action is vectorized and supports scalar expansion.
When the enable signal is false, the block is disabled, and the state and output values do not change except for resets. The enable action is vectorized and supports scalar expansion.

Parameters
Initial condition:
0.0
Sample time:
-1

**Initial condition**

The initial output of the simulation.

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port `u` | Any data type supported by the blockset |
| Input Port `E` | Any data type supported by the blockset |
| Input Port `R` | Any data type supported by the blockset |
| Output Port | Same as the input `u` |
| Direct Feedthrough | No, of the input port<br>No, of the enable port<br>Yes, of the reset port |
| Scalar Expansion | Yes |

## See Also

Unit Delay, Unit Delay Enabled, Unit Delay Enabled External IC, Unit Delay Enabled Resettable External IC, Unit Delay External IC, Unit Delay Resettable, Unit Delay Resettable External IC, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable, Unit Delay With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable, Unit Delay With Preview Resettable External RV

# Unit Delay Enabled Resettable External IC

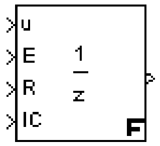
## Purpose

Delay a signal one sample period, if the external enable signal is on, with an external Boolean reset and initial condition

## Library

Delays & Holds

## Description



The Unit Delay Enabled Resettable External IC block combines the features of the Unit Delay Enabled, Unit Delay External IC, and Unit Delay Resettable blocks.

The block can reset its state based on an external reset signal `R`. When the enable signal `E` is on and the reset signal `R` is false, the block outputs the input signal delayed by one sample period.

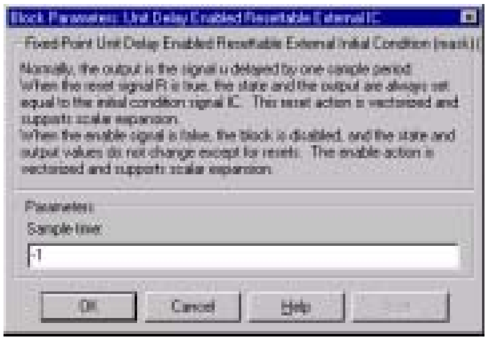
When the enable signal `E` is on and the reset signal `R` is true, the block resets the current state to the initial condition given by the signal `IC`, and outputs that state delayed by one sample period.

When the enable signal is off, the block is disabled, and the state and output do not change except for resets. The enable signal is on when `E` is not 0, and off when `E` is 0.

The output data type is the same as the input `u` and the initial condition `IC` data type, which can be any data type, but must be the same. The enable `E` and reset `R` can be any data type.

You specify the time between samples with the **Sample time** parameter**.** A setting of `-1` means the **Sample time** is inherited.

## Parameters and Dialog Box


Block Parameters: Unit Delay Enabled Resettable External IC

Fixed Point Unit Delay Enabled Resettable External Initial Condition (mask)

Normally, the output is the signal u delayed by one sample period.
When the reset signal R is true, the state and the output are always set equal to the initial condition signal IC. This reset action is vectorized and supports scalar expansion.
When the enable signal is false, the block is disabled, and the state and output values do not change except for resets. The enable action is vectorized and supports scalar expansion.

Parameters

Sample time:

-1

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port `u` | Any data type supported by the blockset |
| Input Port `E` | Any data type supported by the blockset |
| Input Port `R` | Any data type supported by the blockset |
| Input Port `IC` | Same as the input `u` |
| Output Port | Same as the input `u` |
| Direct Feedthrough | No, of the input port<br>No, of the enable port<br>Yes, of the enable port<br>Yes, of the external `IC` port |
| Scalar Expansion | Yes |

## See Also

Unit Delay, Unit Delay Enabled, Unit Delay Enabled External IC, Unit Delay Enabled Resettable, Unit Delay External IC, Unit Delay Resettable, Unit Delay Resettable External IC, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable, Unit Delay With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable, Unit Delay With Preview Resettable External RV

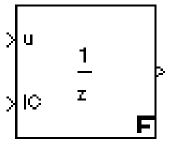
## Purpose

Delay a signal one sample period, with an external initial condition

## Library

Delays & Holds

## Description



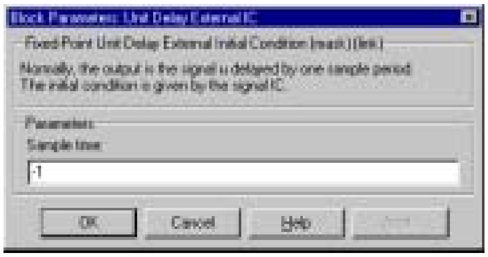
The Unit Delay External IC block delays its input by one sample period. This block is equivalent to the $z^{-1}$ discrete-time operator. The block accepts one input and generates one output, both of which can be scalar or vector. If the input is a vector, all elements of the vector are delayed by the same sample period.

The block's output for the first sample period is equal to the signal `IC`.

The input `u` and initial condition `IC` data types must be the same, and are any data type.

You specify the time between samples with the **Sample time** parameter**.** A setting of `-1` means the **Sample time** is inherited.

## Parameters and Dialog Box



Fixed Point Unit Delay External Initial Condition (mask) (link)

Normally, the output is the signal u delayed by one sample period.
The initial condition is given by the signal IC.

Parameters

Sample time

-1

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port `u` | Any data type supported by the blockset |
| Input Port `IC` | Same as the input `u` |
| Output Port | Same as the input `u` |
| Direct Feedthrough | No, of the input port<br>Yes, of the external `IC` port |
| Scalar Expansion | Yes |

## See Also

Unit Delay, Unit Delay Enabled, Unit Delay Enabled External IC, Unit Delay Enabled Resettable, Unit Delay Enabled Resettable External IC, Unit Delay Resettable, Unit Delay Resettable External IC, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable, Unit Delay With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable, Unit Delay With Preview Resettable External RV

# Unit Delay Resettable

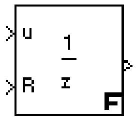
## Purpose

Delay a signal one sample period, with an external Boolean reset

## Library

Delays & Holds

## Description

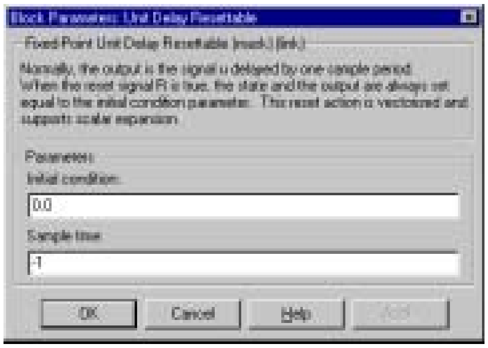


The Unit Delay Resettable block delays a signal one sample period.

The block can reset its state based on an external reset signal R. The block has two input ports, one for the input signal u and the other for the external reset signal R. When the reset signal is false, the block outputs the input signal delayed by one time step. When the reset signal is true, the block resets the current state to the initial condition, specified by the **Initial condition** parameter, and outputs that state delayed by one time step.

You specify the time between samples with the **Sample time** parameter**.** A setting of -1 means the **Sample time** is inherited.

## Parameters and Dialog Box



Block Parameters: Unit Delay Resettable
Fixed-Point Unit Delay Resettable (mask) (link)
Parameters
OK
Cancel
Help
Apply

Normally, the output is the signal u delayed by one sample period. When the reset signal R is true, the state and the output are always set equal to the initial condition parameter. This reset action is vectorized and supports scalar expansion.

Initial condition:
0.0

Sample time:
-1

**Initial condition**

The initial output of the simulation.

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port u | Any data type supported by the blockset |
| Input Port R | Any data type supported by the blockset |
| Output Port | Same as the input u |
| Direct Feedthrough | No, of the input port<br>Yes, of the reset port |
| Scalar Expansion | Yes |

## See Also

Unit Delay, Unit Delay Enabled, Unit Delay Enabled External IC, Unit Delay Enabled Resettable, Unit Delay Enabled Resettable External IC, Unit Delay External IC, Unit Delay Resettable External IC, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable, Unit Delay With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable, Unit Delay With Preview Resettable External RV

# Unit Delay Resettable External IC

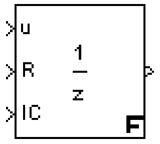
## Purpose

Delay a signal one sample period, with an external Boolean reset and initial condition

## Library

Delays & Holds

## Description



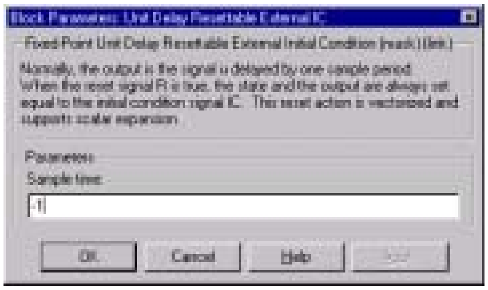
The Unit Delay Resettable External IC block delays a signal one sample period.

The block can reset its state based on an external reset signal `R`. The block has two input ports, one for the input signal `u` and the other for the reset signal `R`. When the reset signal is false, the block outputs the input signal delayed by one time step. When the reset signal is true, the block resets the current state to the initial condition given by the signal `IC` and outputs that state delayed by one time step.

The input `u` and initial condition `IC` must be the same data type, but can be any data type. The output is the same data type as the inputs `u` and `IC`. The reset `R` can be any data type.

You specify the time between samples with the **Sample time** parameter**.** A setting of `-1` means the **Sample time** is inherited.

## Parameters and Dialog Box



Block Parameters: Unit Delay Resettable External IC

Fixed-Point Unit Delay Resettable External Initial Condition (mask) (link)

Normally, the output is the signal u delayed by one sample period. When the reset signal R is true, the state and the output are always set equal to the initial condition signal IC. This reset action is vectorized and supports scalar expansion.

Parameters

Sample time:

-1

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port `u` | Any data type supported by the blockset |
| Input Port `R` | Any data type supported by the blockset |
| Input Port `IC` | Same as the input `u` |
| Output Port | Same as the input `u` |
| Direct Feedthrough | No, of the input port<br>Yes, of the reset port<br>Yes, of the external `IC` port |
| Sample Time | Inherited |
| Scalar Expansion | Yes |

## See Also

Unit Delay, Unit Delay Enabled, Unit Delay Enabled External IC, Unit Delay Enabled Resettable, Unit Delay Enabled Resettable External IC, Unit Delay External IC, Unit Delay Resettable, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable, Unit Delay With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable, Unit Delay With Preview Resettable External RV

# Unit Delay With Preview Enabled

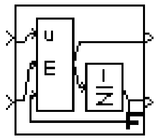
## Purpose

Output the signal and the signal delayed by one sample period, if the external enable signal is on

## Library

Delays & Holds

## Description



The Unit Delay With Preview Enabled block supports calculations that have feedback and depend on the current input.

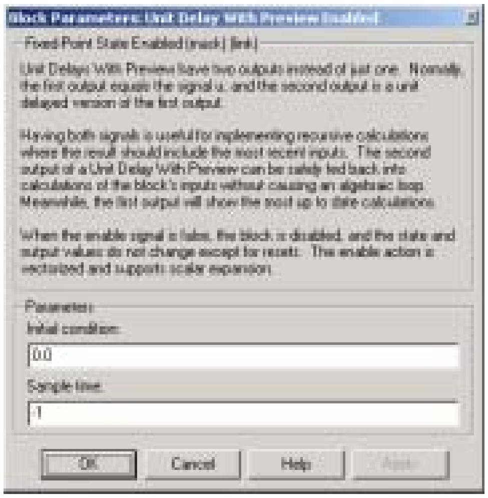
The block has two output ports. When the external enable signal E is on, the upper port outputs the signal and the lower port outputs the signal delayed by one sample period. The block has two input ports, one for the input signal u and the other for the enable signal E.

When the enable signal E is off, the block is disabled, and the state and output values do not change, except for resets. The enable signal is on when E is not 0, and off when E is 0.

The input u and initial condition IC must be the same data type, but can be any data type. The output is the same data type as the inputs u and IC. The reset R can be any data type.

You specify the time between samples with the **Sample time** parameter**.** A setting of -1 means the **Sample time** is inherited.

## Parameters and Dialog Box



Block Parameters: Unit Delay With Preview Enabled

Fixed-Point State Enabled (mask) (link)

Unit Delays With Preview have two outputs instead of just one. Normally, the first output equals the signal u, and the second output is a unit delayed version of the first output.

Having both signals is useful for implementing recursive calculations where the result should include the most recent inputs. The second output of a Unit Delay With Preview can be safely fed back into calculations of the block's inputs without causing an algebraic loop. Meanwhile, the first output will show the most up to date calculations.

When the enable signal is false, the block is disabled, and the state and output values do not change except for resets. The enable action is vectorized and supports scalar expansion.

Parameters

Initial condition:

0.0

Sample time:

-1

**Initial condition**

Initial condition.

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port `u` | Any data type supported by the blockset |
| Input Port `E` | Any data type supported by the blockset |
| Output Ports | Same as the input `u` |
| Direct Feedthrough | Yes, to upper output port<br>No, to lower output port |
| Scalar Expansion | Yes |

## See Also

Unit Delay, Unit Delay Enabled, Unit Delay Enabled External IC, Unit Delay Enabled Resettable, Unit Delay Enabled Resettable External IC, Unit Delay External IC, Unit Delay Resettable, Unit Delay Resettable External IC, Unit Delay With Preview Enabled Resettable, Unit Delay With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable, Unit Delay With Preview Resettable External RV

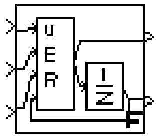
## Purpose

Output the signal and the signal delayed by one sample period, if the external enable signal is on, with an external Boolean reset

## Library

Delays & Holds

## Description



The Unit Delay With Preview Enabled Resettable block supports calculations that have feedback and depend on the current input.

The block can reset its state based on an external reset signal R. The block has two output ports. When the external enable signal E is on and the reset R is false, the upper port outputs the signal and the lower port outputs the signal delayed by one sample period. The block has two input ports, one for the input signal u and the other for the enable signal E.

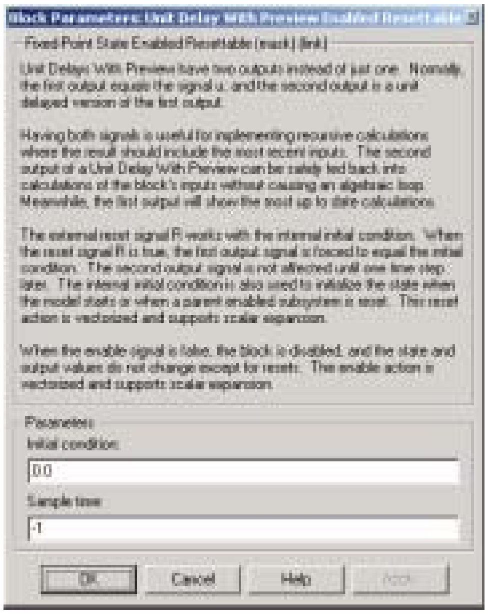
When the enable signal E is on and the reset R is true, the block resets the current state to the initial condition given by the **Initial condition** parameter. The block outputs that state delayed by one sample time through the lower output port, and outputs the state without a delay through the upper output port.

When the Enable signal is off, the block is disabled, and the state and output values do not change, except for resets. The enable signal is on when E is not 0, and off when E is 0.

The input u and initial condition IC must be the same data type, but can be any data type. The output is the same data type as the inputs u and IC. The reset R can be any data type.

You specify the time between samples with the **Sample time** parameter**.** A setting of -1 means the **Sample time** is inherited.

## Parameters and Dialog Box



Block Parameters: Unit Delay With Preview Enabled Resettable

Fixed-Point State Enabled Resettable (mask) (link)

Unit Delays With Preview have two outputs instead of just one. Normally the first output equals the signal u, and the second output is a unit delayed version of the first output.

Having both signals is useful for implementing recursive calculations where the result should include the most recent inputs. The second output of a Unit Delay With Preview can be safely fed back into calculations of the block's inputs without causing an algebraic loop. Meanwhile, the first output will show the most up to date calculations.

The external reset signal R works with the internal initial condition. When the reset signal R is true, the first output signal is forced to equal the initial condition. The second output signal is not affected until one time step later. The internal initial condition is also used to initialize the state when the model starts or when a parent enabled subsystem is reset. This reset action is vectorized and supports scalar expansion.

When the enable signal is false, the block is disabled, and the state and output values do not change except for resets. The enable action is vectorized and supports scalar expansion.

Parameters

Initial condition:

0.0

Sample time:

-1

**Initial condition**

Initial condition.

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port u | Any data type supported by the blockset |
| Input Port E | Any data type supported by the blockset |
| Input Port R | Any data type supported by the blockset |
| Output Ports | Same as the input u |
| Direct Feedthrough | Yes, to upper output port<br>No, to lower output port |
| Scalar Expansion | Yes |

## See Also

Unit Delay, Unit Delay Enabled, Unit Delay Enabled External IC, Unit Delay Enabled Resettable, Unit Delay Enabled Resettable External IC, Unit Delay

External IC, Unit Delay Resettable, Unit Delay Resettable External IC, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable, Unit Delay With Preview Resettable External RV

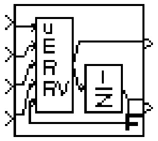
## Purpose

Output the signal and the signal delayed by one sample period, if the external enable signal is on, with an external RV reset

## Library

Delays & Holds

## Description



The Unit Delay With Preview Enabled Resettable External RV block supports calculations that have feedback and depend on the current input.

The block can reset its state based on an external reset signal R. The block has two output ports. When the external enable signal E is on and the reset R is false, the upper port outputs the signal and the lower port outputs the signal delayed by one sample period. The block has two input ports, one for the input signal u and the other for the enable signal E.

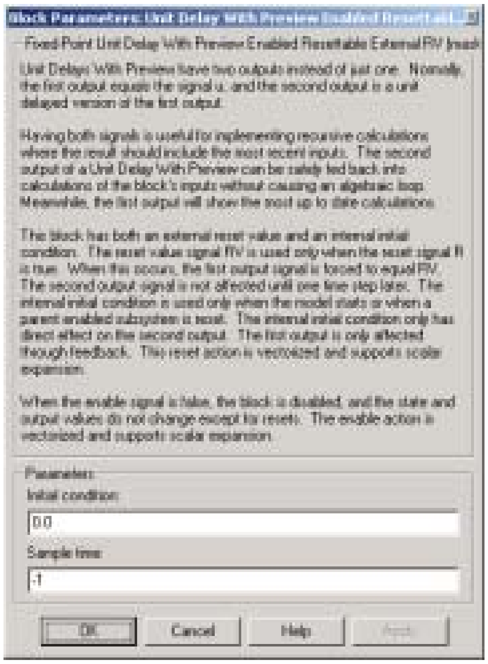
When the enable signal E is on and the reset R is true, the upper output signal is forced to equal the external reset signal RV. The lower output signal is not affected until one time step later, at which time it is equal to the external reset signal RV at the previous time step. The block uses the internal **Initial condition** only when the model starts or when a parent enabled subsystem is used. The internal **Initial condition** only affects the lower output signal. The first output is only affected through feedback.

When the Enable signal is off, the block is disabled, and the state and output values do not change, except for resets. The enable signal is on when E is not 0, and off when E is 0.

The input u and initial condition IC must be the same data type, but can be any data type. The output is the same data type as the inputs u and IC. The reset R can be any data type.

You specify the time between samples with the **Sample time** parameter**.** A setting of -1 means the **Sample time** is inherited.

## Parameters and Dialog Box


Block Parameters: Unit Delay With Preview Enabled Resettabl...

Fixed-Point Unit Delay With Preview Enabled Resettable External RV (mask

Unit Delays With Preview have two outputs instead of just one. Normally the first output equals the signal u, and the second output is a unit delayed version of the first output.

Having both signals is useful for implementing recursive calculations where the result should include the most recent inputs. The second output of a Unit Delay With Preview can be safely fed back into calculations of the block's inputs without causing an algebraic loop. Meanwhile, the first output will show the most up to date calculations.

This block has both an external reset value and an internal initial condition. The reset value signal RV is used only when the reset signal R is true. When this occurs, the first output signal is forced to equal RV. The second output signal is not affected until one time step later. The internal initial condition is used only when the model starts or when a parent enabled subsystem is reset. The internal initial condition only has direct effect on the second output. The first output is only affected through feedback. This reset action is vectorized and supports scalar expansion.

When the enable signal is false, the block is disabled, and the state and output values do not change except for resets. The enable action is vectorized and supports scalar expansion.

Parameters

Initial condition:

0.0

Sample time:

-1

**Initial condition**

Initial condition.

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port u | Any data type supported by the blockset |
| Input Port E | Any data type supported by the blockset |
| Input Port R | Any data type supported by the blockset |
| Input Port RV | Same as the input u |
| Output Ports | Same as the input u |
| Direct Feedthrough | Yes, to upper output port<br>No, to lower output port |
| Scalar Expansion | Yes |

**See Also**

Unit Delay, Unit Delay Enabled, Unit Delay Enabled External IC, Unit Delay Enabled Resettable, Unit Delay Enabled Resettable External IC, Unit Delay External IC, Unit Delay Resettable, Unit Delay Resettable External IC, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable, Unit Delay With Preview Resettable, Unit Delay With Preview Resettable External RV

# Unit Delay With Preview Resettable

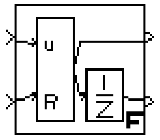
**Purpose**

Output the signal and the signal delayed by one sample period, with an external Boolean reset

**Library**

Delays & Holds

**Description**



The Unit Delay With Preview Resettable block supports calculations that have feedback and depend on the current input.

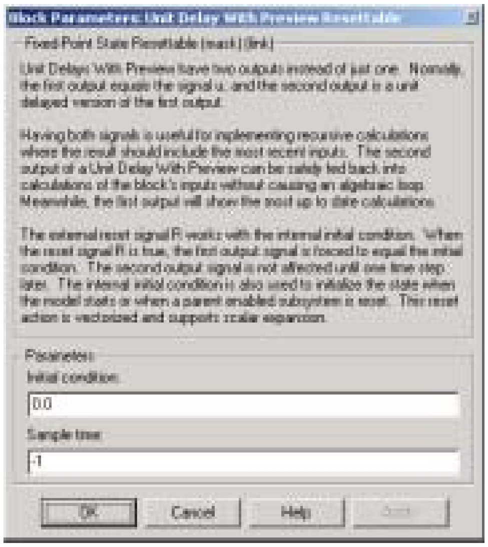
The block can reset its state based on an external reset signal R. The block has two output ports. When the reset R is false, the upper port outputs the signal and the lower port outputs the signal delayed by one sample period.

When the reset R is true, the block resets the current state to the initial condition given by the **Initial condition** parameter. The block outputs that state delayed by one sample time through the lower output port, and outputs the state without a delay through the upper output port.

The input u and initial condition IC must be the same data type, but can be any data type. The output is the same data type as the inputs u and IC. The reset R can be any data type.

You specify the time between samples with the **Sample time** parameter**.** A setting of -1 means the **Sample time** is inherited.

## Parameters and Dialog Box



Block Parameters: Unit Delay With Preview Resettable

Fixed-Point State Resettable (mask) (link)

Unit Delays With Preview have two outputs instead of just one. Normally the first output equals the signal u, and the second output is a unit delayed version of the first output.

Having both signals is useful for implementing recursive calculations where the result should include the most recent inputs. The second output of a Unit Delay With Preview can be safely fed back into calculations of the block's inputs without causing an algebraic loop. Meanwhile, the first output will show the most up to date calculations.

The external reset signal R works with the internal initial condition. When the reset signal R is true, the first output signal is forced to equal the initial condition. The second output signal is not affected until one time step later. The internal initial condition is also used to initialize the state when the model starts or when a parent enabled subsystem is reset. This reset action is vectorized and supports scalar expansion.

Parameters

Initial condition:

0.0

Sample time:

-1

**Initial condition**

Initial condition.

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port u | Any data type supported by the blockset |
| Input Port R | Any data type supported by the blockset |
| Output Ports | Same as the input u |
| Direct Feedthrough | Yes, to upper output port<br>No, to lower output port |
| Scalar Expansion | Yes |

## See Also

Unit Delay, Unit Delay Enabled, Unit Delay Enabled External IC, Unit Delay Enabled Resettable, Unit Delay Enabled Resettable External IC, Unit Delay External IC, Unit Delay Resettable, Unit Delay Resettable External IC, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable, Unit Delay With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable External RV

# Unit Delay With Preview Resettable External RV

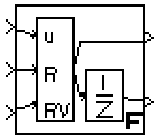
## Purpose

Output the signal and the signal delayed by one sample period, with an external RV reset

## Library

Delays & Holds

## Description



The Unit Delay With Preview Resettable External RV block supports calculations that have feedback and depend on the current input.

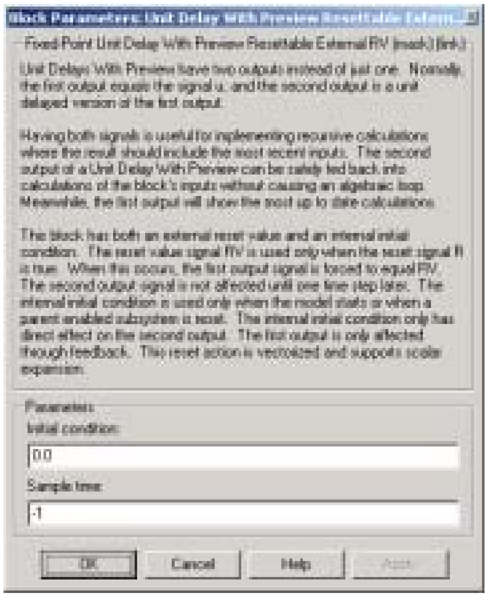
The block can reset its state based on an external reset signal R. The block has two output ports. When the external reset R is false, the upper port outputs the signal and the lower port outputs the signal delayed by one sample period.

When the external reset R is true, the upper output signal is forced to equal the external reset signal RV. The lower output signal is not affected until one time step later, at which time it is equal to the external reset signal RV at the previous time step. The block uses the internal **Initial condition** only when the model starts or when a parent enabled subsystem is used. The internal **Initial condition** only affects the lower output signal. The first output is only affected through feedback.

The input u and initial condition IC must be the same data type, but can be any data type. The output is the same data type as the inputs u and IC. The reset R can be any data type.

You specify the time between samples with the **Sample time** parameter**.** A setting of -1 means the **Sample time** is inherited.

## Parameters and Dialog Box



Block Parameters: Unit Delay With Preview Resettable Extern...

Fixed-Point Unit Delay With Preview Resettable External RV (mask) (link)

Unit Delays With Preview have two outputs instead of just one. Normally the first output equals the signal u, and the second output is a unit delayed version of the first output.

Having both signals is useful for implementing recursive calculations where the result should include the most recent inputs. The second output of a Unit Delay With Preview can be safely fed back into calculations of the block's inputs without causing an algebraic loop. Meanwhile, the first output will show the most up to date calculations.

This block has both an external reset value and an internal initial condition. The reset value signal RV is used only when the reset signal R is true. When this occurs, the first output signal is forced to equal RV. The second output signal is not affected until one time step later. The internal initial condition is used only when the model starts or when a parent enabled subsystem is reset. The internal initial condition only has direct effect on the second output. The first output is only affected through feedback. This reset action is vectorized and supports scalar expansion.

Parameters

Initial condition:

0.0

Sample time:

-1

**Initial condition**

Initial condition.

**Sample time**

Sample time.

## Characteristics

| | |
|---|---|
| Input Port u | Any data type supported by the blockset |
| Input Port R | Any data type supported by the blockset |
| Input Port RV | Same as the input u |
| Output Ports | Same as the input u |
| Direct Feedthrough | Yes, to upper output port<br>No, to lower output port |
| Scalar Expansion | Yes |

## See Also

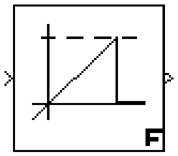
Unit Delay, Unit Delay Enabled, Unit Delay Enabled External IC, Unit Delay Enabled Resettable, Unit Delay Enabled Resettable External IC, Unit Delay External IC, Unit Delay Resettable, Unit Delay Resettable External IC, Unit Delay With Preview Enabled, Unit Delay With Preview Enabled Resettable, Unit Delay With Preview Enabled Resettable External RV, Unit Delay With Preview Resettable

## Wrap To Zero

**Purpose** Set output to zero if input is above threshold

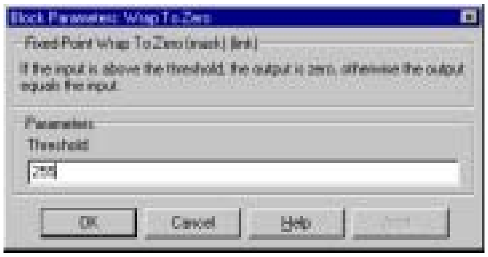
**Library** Nonlinear

**Description**



The Wrap To Zero block sets the output to zero if the input is above the value set by the **Threshold** parameter, and outputs the input if the input is less than or equal to the **Threshold**.

**Parameters and Dialog Box**



Block Parameters: Wrap To Zero

Fixed-Point Wrap To Zero (mask) (link)

If the input is above the threshold, the output is zero, otherwise the output equals the input.

Parameters

Threshold

255

**Threshold**

When the input exceeds the threshold, the output is set to zero.

**Characteristics**

| | |
|---|---|
| Input Port | Any data type supported by the blockset |
| Output Ports | Same as the input |
| Direct Feedthrough | Yes |
| Scalar Expansion | Yes |

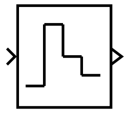
**Purpose**

Implement a zero-order hold of one sample period

**Library**

Simulink Discrete and Fixed-Point Blockset Delays & Holds

**Description**



The Zero-Order Hold block samples and holds its input for the specified sample period. The block accepts one input and generates one output, both of which can be scalar or vector. If the input is a vector, all elements of the vector are held for the same sample period.

You specify the time between samples with the **Sample time** parameter**.** A setting of -1 means the **Sample time** is inherited.

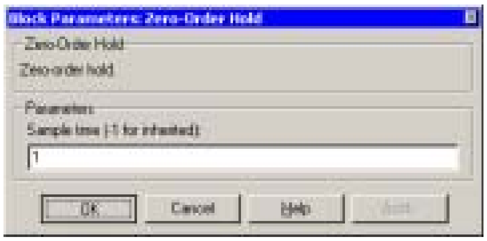
This block provides a mechanism for discretizing one or more signals in time, or resampling the signal at a different rate. If your model contains multirate transitions, you must add Zero-Order Hold blocks between the fast-to-slow transitions. The sample rate of the Zero-Order Hold must be set to that of the slower block. For slow-to-fast transitions, use the Unit Delay block. For more information about multirate transitions, refer to the Simulink or the Real-Time Workshop documentation.

**Data Type Support**

The Zero-Order Hold block accepts real or complex signals of any data type supported by Simulink, as well as fixed-point data types.

For a discussion on the data types supported by Simulink, refer to “Data Types Supported by Simulink” in the Using Simulink documentation.

**Parameters and Dialog Box**



Block Parameters: Zero-Order Hold

Zero-Order Hold

Zero-order hold

Parameters

Sample time (-1 for inherited):

1

**Sample time**

Specify the time between samples. A value of -1 means the sample time is inherited.

## Characteristics

| | |
|---|---|
| Dimensionalized | Yes |
| Direct Feedthrough | Yes |
| Sample Time | Discrete |
| Scalar Expansion | No |
| Zero Crossing | No |

# Glossary of Fixed-Point Terms

This glossary defines terms related to fixed-point data types and numbers. These terms may appear in some or all of the documents that describe products from The MathWorks that have fixed-point support.

**arithmetic shift** A shift of the bits of a binary word for which the sign bit is recycled for each bit shift to the right. A zero is incorporated into the least significant bit of the word for each bit shift to the left. In the absence of overflows or underflows, each arithmetic shift to the right is equivalent to a division by 2, and each arithmetic shift to the left is equivalent to a multiplication by 2.

*See Also* binary point, binary word, bit, logical shift, most significant bit

**bias** Part of the numerical representation used to interpret a fixed-point number. Along with the slope, the bias forms the scaling of the number. Fixed-point numbers can be represented as

$$value = (slope \times integer) + bias$$

where the slope can be expressed as

$$slope = fractional\,slope \times 2^{exponent}$$

*See Also* fixed-point representation, fractional slope, integer, scaling, slope, [Slope Bias]

**binary number** A value represented in a system of numbers that has two as its base and that uses 1's and 0's (bits) for its notation.

*See Also* bit

**binary point** A symbol in the shape of a period that separates the integer and fractional parts of a binary number. Bits to the left of the binary point are integer bits and/or sign bits, and bits to the right of the binary point are fractional bits.

*See Also* binary number, bit, fraction, integer, radix point

| | |
|---|---|
| **binary point-only scaling** | The scaling of a binary number that results from shifting the binary point of the number right or left, and which therefore can only occur by powers of two.<br><br>*See Also* binary number, binary point, scaling |
| **binary word** | A fixed-length sequence of bits (1's and 0's). In digital hardware, numbers are stored in binary words. The way in which hardware components or software functions interpret this sequence of 1's and 0's is described by a data type.<br><br>*See Also* bit, data type, word |
| **bit** | The smallest unit of information in computer software or hardware. A bit can have the value 0 or 1. |
| **ceiling (round toward)** | A rounding mode that rounds to the closest representable number in the direction of positive infinity.<br><br>*See Also* floor (round toward), nearest (round toward), rounding, truncation, zero (round toward) |
| **contiguous binary point** | A binary point that occurs within the word length of a data type. For example, if a data type has four bits, its contiguous binary point must be understood to occur at one of the following five positions:<br><br>.0000<br>0.000<br>00.00<br>000.0<br>0000.<br><br>*See Also* data type, noncontiguous binary point, word length |

**data type** A set of characteristics that define a group of values. A fixed-point data type is defined by its word length, its fraction length, and whether it is signed or unsigned. A floating-point data type is defined by its word length and whether it is signed or unsigned.

*See Also* fixed-point representation, floating-point representation, fraction length, [Slope Bias], word length

**data type override** A parameter in the **Fixed-Point Settings** interface that allows you to set the output data type and scaling of Fixed-Point Blockset blocks on a system or subsystem level.

*See Also* data type, scaling

**exponent** Part of the numerical representation used to express a floating-point or fixed-point number.

1. Floating-point numbers are typically represented as

$$value = mantissa \times 2^{exponent}$$

2. Fixed-point numbers can be represented as

$$value = (slope \times integer) + bias$$

where the slope can be expressed as

$$slope = fractional\,slope \times 2^{exponent}$$

The exponent of a fixed-point number is equal to the negative of the fraction length:

$$exponent = -1 \times fraction\ length$$

*See Also* bias, fixed-point representation, floating-point representation, fraction length, fractional slope, integer, mantissa, slope

**fixed-point representation**

A method for representing numerical values and data types that have a set range and precision.

1. Fixed-point numbers can be represented as

$$value = (slope \times integer) + bias$$

where the slope can be expressed as

$$slope = fractional\,slope \times 2^{exponent}$$

The slope and the bias together represent the scaling of the fixed-point number.

2. Fixed-point data types can be defined by their word length, their fraction length, and whether they are signed or unsigned.

*See Also* bias, data type, exponent, fraction length, fractional slope, integer, precision, range, scaling, slope, word length

**floating-point representation**

A method for representing numerical values and data types that can have changing range and precision.

1. Floating-point numbers can be represented as

$$value = mantissa \times 2^{exponent}$$

2. Floating-point data types are defined by their word length.

*See Also* data type, exponent, mantissa, precision, range, word length

**floor (round toward)**

A rounding mode that rounds to the closest representable number in the direction of negative infinity.

*See Also* ceiling (round toward), nearest (round toward), rounding, truncation, zero (round toward)

**fraction**

The part of a fixed-point number represented by the bits to the right of the binary point. The fraction represents numbers that are less than one.

*See Also* binary point, bit, fixed-point representation

| | |
|---|---|
| **fraction length** | The number of bits to the right of the binary point in a fixed-point representation of a number.<br><br>*See Also* binary point, bit, fixed-point representation, fraction, integer length |
| **fractional slope** | Part of the numerical representation used to express a fixed-point number. Fixed-point numbers can be represented as<br><br>$value = (slope \times integer) + bias$<br><br>where the slope can be expressed as<br><br>$slope = fractional\,slope \times 2^{exponent}$<br><br>*See Also* bias, exponent, fixed-point representation, integer, slope |
| **guard bits** | Extra bits in either a hardware register or software simulation that are added to the high end of a binary word to ensure that no information is lost in case of overflow.<br><br>*See Also* binary word, bit, overflow |
| **integer** | 1. The part of a fixed-point number represented by the bits to the left of the binary point. The integer represents numbers that are greater than or equal to one.<br><br>2. Part of the numerical representation used to express a fixed-point number, also called the stored integer. Fixed-point numbers can be represented as<br><br>$value = (slope \times integer) + bias$<br><br>where the slope can be expressed as<br><br>$slope = fractional\,slope \times 2^{exponent}$<br><br>*See Also* bias, fixed-point representation, fractional slope, integer, slope |

| | |
|---|---|
| **integer length** | The number of bits to the left of the binary point in a fixed-point representation of a number.<br>*See Also* binary point, bit, fixed-point representation, fraction length, integer |
| **least significant bit (LSB)** | The bit in a binary word that can represent the smallest value. The LSB is the rightmost bit in a big-endian-ordered binary word.<br>*See Also* big-endian, binary word, bit, most significant bit |
| **logging** | A tool provided by the **Fixed-Point Settings** interface that outputs the minimum values, maximum values, and any overflows for all Fixed-Point Blockset blocks in any model that you run with a fixed-point license.<br>*See Also* overflow |
| **logical shift** | A shift of the bits of a binary word, for which a zero is incorporated into the most significant bit for each bit shift to the right and into the least significant bit for each bit shift to the left.<br>*See Also* arithmetic shift, binary point, binary word, bit, most significant bit |
| **mantissa** | Part of the numerical representation used to express a floating-point number. Floating-point numbers are typically represented as<br>$value = mantissa \times 2^{exponent}$<br>*See Also* exponent, floating-point representation |
| **most significant bit (MSB)** | The bit in a binary word that can represent the largest value. The MSB is the leftmost bit in a big-endian-ordered binary word.<br>*See Also* big-endian, binary word, bit, least significant bit |

**nearest (round toward)** A rounding mode that rounds to the closest representable number, with the exact midpoint rounded to the closest representable number in the direction of positive infinity.

*See Also* ceiling (round toward), floor (round toward), rounding, truncation, zero (round toward)

**noncontiguous binary point** A binary point that is understood to fall outside of the word length of a data type. For example, the binary point for the following 4-bit word is understood to occur two bits to the right of the word length

0000_ _.

thereby giving the bits of the word the following potential values:

$2^5 2^4 2^3 2^2$_ _.

*See Also* binary point, data type, word length

**one's complement representation** A representation of signed fixed-point numbers. Negating a binary number in one's complement requires a bitwise complement. That is, all 0's are flipped to 1's and all 1's are flipped to 0's. In one's complement notation there are two ways to represent zero. A binary word of all 0's represents "positive" zero, while a binary word of all 1's represents "negative" zero.

*See Also* binary number, binary word, sign/magnitude representation, signed fixed-point, two's complement representation

**overflow** The situation that occurs when calculation results are outside the range of the data type being used. In many cases you can choose to either saturate or wrap overflows.

*See Also* saturation, underflow, wrapping

**padding** Extending the least significant bit of a binary word with one or more zeros.

*See Also* least significant bit

**precision**

1. A measure of the smallest numerical interval that a fixed-point data type and scaling can represent, determined by the value of the number's least significant bit. The precision is given by the slope, or the number of fractional bits. The term "resolution" is sometimes used as a synonym for this definition.

2. A measure of the difference between a real-world numerical value and the value of its quantized representation. This is sometimes called quantization error or quantization noise.

*See Also* data type, fraction, least significant bit, quantization, quantization error, range, slope, underflow

**Q format**

A representation used by Texas Instruments to encode signed two's complement fixed-point data types. This fixed-point notation takes the form

*Qm.n*

where

- *Q* indicates that the number is in Q format.
- *m* is the number of bits used to designate the two's complement integer part of the number.
- *n* is the number of bits used to designate the two's complement fractional part of the number, or the number of bits to the right of the binary point.

In Q format notation, the most significant bit is assumed to be the sign bit.

*See Also* binary point, bit, data type, fixed-point representation, fraction, integer, two's complement

**quantization**

The representation of a value by a data type that has too few bits to represent it exactly.

*See Also* bit, data type, quantization error, underflow

**quantization error**

The error introduced when a value is represented by a data type that has too few bits to represent it exactly, or when a value is converted from one data type to a shorter data type. Quantization error is also called quantization noise.

*See Also* bit, data type, quantization, underflow

**radix point**

A symbol in the shape of a period that separates the integer and fractional parts of a number in any base system. Bits to the left of the radix point are integer and/or sign bits, and bits to the right of the radix point are fraction bits.

*See Also* binary point, bit, fraction, integer, sign bit

**range**

The span of numbers that a certain data type can represent.

*See Also* data type, precision

**resolution**

*See* **precision**

**rounding**

Limiting the number of bits required to express a number. One or more least significant bit(s) are dropped, resulting in a loss of precision. Rounding is necessary when a value can not be expressed exactly by the number of bits designated to represent it.

*See Also* bit, ceiling (round toward), floor (round toward), least significant bit, nearest (round toward), precision, truncation, zero (round toward)

**saturation**

A method of handling numeric overflow or underflow that represents overflows as the biggest number in the range of the data type being used, and underflows as the smallest number in the range.

*See Also* overflow, underflow, wrapping

**scaling**

1. The format used for a fixed-point number of a given word length and signedness. The slope and bias together form the scaling of a fixed-point number.

2. Changing the slope and/or bias of a fixed-point number without changing the stored integer.

*See Also* bias, fixed-point representation, integer, slope

|  |  |
|---|---|
| **shift** | A movement of the bits of a binary word either towards the most significant bit ("to the left") or towards the least significant bit ("to the right"). Shifts to the right may either be logical, where the spaces emptied at the front of the word with each shift are filled in with zeros, or arithmetic, where the word is sign extended as it is shifted to the right.<br><br>*See Also* arithmetic shift, logical shift, sign extension |
| **sign bit** | The bit (or bits) in a signed binary number that indicates whether the number is positive or negative.<br><br>*See Also* binary number, bit |
| **sign extension** | Adding additional bits that have the value of the most significant bit to the high end of a two's complement number. Sign extension does not change the value of the binary number.<br><br>*See Also* binary number, guard bits, most significant bit, two's complement representation, word |
| **sign/magnitude representation** | A representation of signed fixed-point or floating-point numbers. In sign/magnitude representation, one bit of a binary word is always the dedicated sign bit, while the remaining bits of the word encode the magnitude of the number. Negation using sign/magnitude representation consists of flipping the sign bit from 0 (positive) to 1 (negative), or from 1 to 0.<br><br>*See Also* binary word, bit, fixed-point representation, floating-point representation, one's complement representation, sign bit, signed fixed-point, two's complement representation |
| **signed fixed-point** | A fixed-point number or data type that can represent both positive and negative numbers.<br><br>*See Also* data type, fixed-point representation, unsigned fixed-point |

| | |
|---|---|
| **slope** | Part of the numerical representation used to express a fixed-point number. Along with the bias, the slope forms the scaling of a fixed-point number. Fixed-point numbers can be represented as $value = (slope \times integer) + bias$ where the slope can be expressed as $slope = fractional\,slope \times 2^{exponent}$ *See Also* bias, fixed-point representation, fractional slope, integer, scaling, [Slope Bias] |
| **[Slope Bias]** | A representation used by the Fixed-Point Blockset to define the scaling of a fixed-point number. *See Also* bias, scaling, slope |
| **truncation** | A rounding mode that drops one or more least significant bits from a number. *See Also* ceiling (round toward), floor (round toward), nearest (round toward), rounding, zero (round toward) |
| **two's complement representation** | A common representation of signed fixed-point numbers. Negation using signed two's complement representation consists of a translation into one's complement followed by the binary addition of a one. *See Also* binary word, one's complement representation, sign/magnitude representation, signed fixed-point |
| **underflow** | The situation that occurs when calculation results are too small for the range of the data type being used. In many cases you can choose to either saturate or wrap underflows. *See Also* data type, overflow, precision, saturation, wrapping |

| | |
|---|---|
| **unsigned fixed-point** | A fixed-point number or data type that can only represent numbers greater than or equal to zero.<br>*See Also* data type, fixed-point representation, signed fixed-point |
| **word** | A fixed-length sequence of binary digits (1's and 0's). In digital hardware, numbers are stored in words. The way hardware components or software functions interpret this sequence of 1's and 0's is described by a data type.<br>*See Also* binary word, data type |
| **word length** | The number of bits in a binary word or data type.<br>*See Also* binary word, bit, data type |
| **wrapping** | A method of handling overflow or underflow. Wrapping uses modulo arithmetic to cast a number that falls outside of the representable range of the data type being used back into the representable range.<br>*See Also* data type, overflow, range, saturation, underflow |
| **zero (round toward)** | A rounding mode that rounds to the closest representable number in the direction of zero.<br>*See Also* ceiling (round toward), floor (round toward), nearest (round toward), rounding, truncation |

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