



## Parallel FIR Filter

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## User's Guide

## Introduction

This document serves as a guide containing technical information about the Lattice Parallel FIR Filter core.

## Overview

The Parallel FIR Filter core is one of two FIR cores supported by Lattice. This core is designed to perform filtering with zero latency and is well suited for real-time applications.

This Parallel FIR Filter core comes with the following documentation and files:

- Data sheet
- Protected netlist and database
- Protected RTL simulation models
- Source files for instantiating the core

## Core Specification

### Features

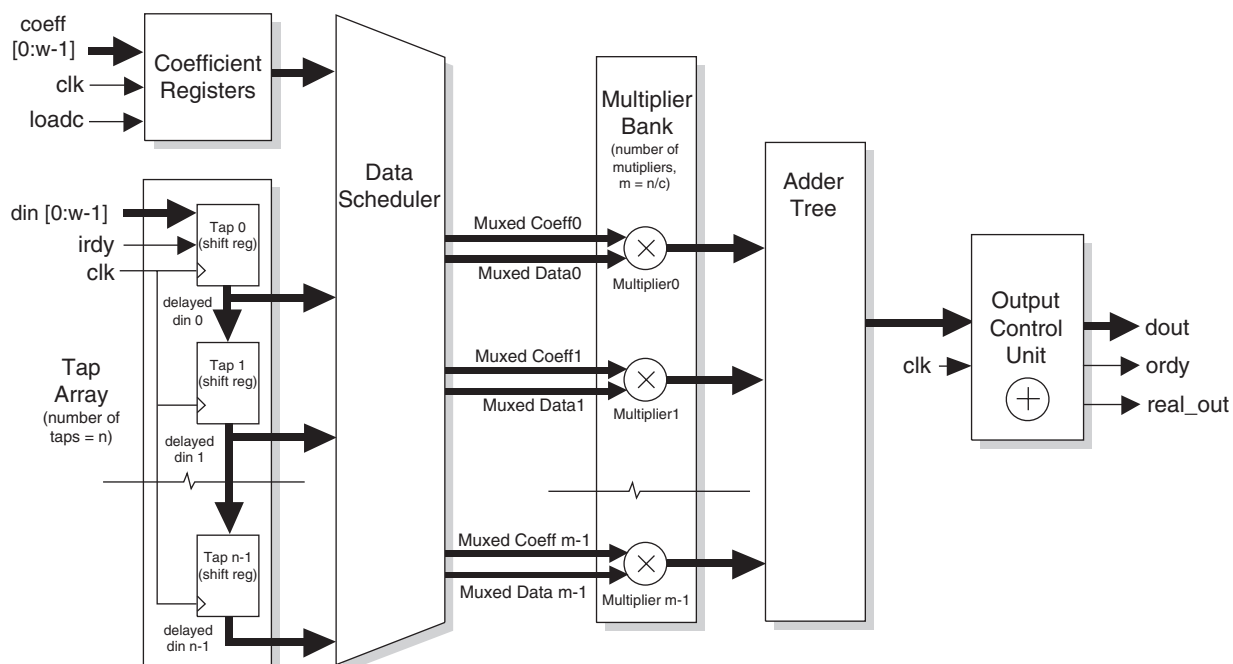
- Variable number of taps up to 64
- Data and coefficients up to 32 bits
- Output size consistent with data size
- Zero-latency operation
- Signed or unsigned data and coefficients
- Full arithmetic precision
- Fixed or loadable coefficients
- Decimation and interpolation
- Real or complex data
- Selectable rounding
- Scalable outputs
- Fully parallel implementation
- Multi-cycle modes for area/time tradeoffs
- Optimization based on symmetry of filter

## General Description

Many digital systems use filters to remove noise, provide spectral shaping, or perform signal detection. Two types of common filters that provide these functions are finite impulse response (FIR) and infinite impulse response (IIR) filters. IIR filters are used in systems that can tolerate phase distortion. FIR filters are used in systems that require linear phase and they have an inherently stable structure. For this reason, FIR filters are designed into a large number of systems.

The Parallel FIR Filter core can perform filtering with zero latency and is well suited for real-time applications. The core supports two modes of computation/filtering: single-cycle mode and multi-cycle mode. In single-cycle, the filtering is done in one clock cycle and in multi-cycle, filtering is done in multiple clock cycles.

Figure 1 shows the block diagram of the Parallel FIR Filter core.

**Figure 1. Parallel FIR Filter Core Functional Block Diagram**

## Signal Descriptions

Table 1 shows the definitions of the I/O interface ports available in this core.

**Table 1. Parallel FIR Filter Input and Output Signals**

Port Name	Type	Active State	Signal Description
clk	Input	Rising edge	Clock. Master clock input to the Parallel FIR Filter core.
din[31..3:0]	Input	N/A	Data Input. Data to be processed. In the complex parallel I/O mode, the din bus includes both the real and imaginary parts.
dout[131..3:0]	Output	N/A	Data Output. The data is the filter output. In the complex parallel I/O mode, the dout bus includes both the real and imaginary parts.
reset_n	Input	Low	Reset. This signal resets all the delayed data signals to 0.
coeff[31..3:0]	Input	N/A	Coefficient. Coefficients for the filter are loaded sequentially while asserting the loadc signal.
loadc	Input	High	Load Coefficient. This signal is asserted high to load the filter coefficients (data on the coeff bus).
irdy	Input	High	Input Ready. irdy is asserted high to indicate the availability of a valid input data in the complex-serial or multi-cycle modes.
ordy	Output	High	Output Ready. ordy is asserted high by the core to signify the availability of a valid dout in multi-cycle or decimation modes.
real_out	Output	High	Real Part Output. real_out is asserted high to indicate that the real part of the complex data is being output at dout. This signal is available only in complex-serial mode.

## Configuration Parameters Description

The user configuration parameters such as filter type, data width, number of taps and data types, which are configurable, are described in Table 2. These parameters are configured using IPexpress™, included with Lattice's ispLEVER® design tools.

**Table 2. Parallel FIR Filter Parameter Definitions**

Name	Default Value	Value	Description
Filter Type	Single-cycle	Single-cycle, multi-cycle, decimation or interpolation	Type of filter selected by the user. This determines the rest of the parameter options.
Data Width	8 bits	Real: 4 to 32 bits Complex: 4 to 16 bits	Width of input data ( $W$ ) in bits. The width of the coefficients is also equal to this parameter. For complex data types, the data width is equal to the width of the real part and the range is from 4 to 16 bits.
Number of Taps	16	4 to 64	Number of taps ( $N$ ) in the filter.
Computational Cycles	2	2 to 32	Number of cycles ( $C$ ) for multi-cycle filters. Number of cycles to perform the filtering process. The output is computed once in cycles.
Decimation Ratio	2	2 to 32	For decimation filters. Decimation is downsampling of the bit stream.
Interpolation Ratio	2	2 to 32	For interpolation filters. Interpolation is the reverse of decimation.
Rounding Method	Nearest	Truncation or nearest	Types of rounding available.
Arithmetic Type	Signed	Signed or unsigned	Specifies the type of arithmetic modules for the core. If the symmetry of the core is even or odd, then the arithmetic type is always signed.
Data Type	Real	Real or complex	Specifies the data type of the inputs ( $d_{in}$ and $coeff$ ) and the output ( $d_{out}$ ) of the Parallel FIR core. When complex I/O mode is selected, the arithmetic type is always signed.
Complex I/O Mode	Parallel	Parallel or serial	In the parallel I/O mode, real and imaginary parts are applied on the data bus in the same clock cycle. In the serial mode, real data is applied in the first clock cycle, followed by the imaginary data in the next cycle.
Output Width	Full precision	4 to 97	Width of output data ( $W$ ) in bits. If the width is less than the maximum output width determined by the core generator, the outputs are scaled.
Coeffs Loadable	Fixed	Fixed or run-time loadable	Determines if the coefficients are run-time loadable. If the coefficients are run-time loadable, the core has two additional input ports, $coeff$ and $loadc$ , for loading purposes. If the coefficients are fixed during core configuration, no additional input ports are used.
Coefficients Format	Hexadecimal	Hexadecimal or decimal	The coefficient values are either in hexadecimal or decimal format.
Symmetry	Even	None, even, or odd	Specifies the impulse response of the filter. Even symmetry applies to symmetric impulse response, while Odd symmetry applies to anti-symmetric impulse response. Decimation and Interpolation filters do not have symmetry (The value None should be selected). If the symmetry of the core is even or odd, then the arithmetic type is always signed.

## Functional Description

### Tap Array

The Tap Array module essentially stores delayed versions or taps of input data. The number of taps of the FIR filter and the data width are user parameters, and they are fixed at the time of core generation. The array consists of  $N$  taps each of width  $W$ , which are organized as shift registers. All the data registers are reset when the  $reset_n$  input is asserted. At every clock edge, the data values are shifted into the next sequential shift register inside the Tap Array, with the first register getting the value from the input data port  $d_{in}$ .

## Coefficient Registers

The Coefficient Registers module stores the FIR filter coefficients. The coefficients can either be loaded at run time or can be fixed during core generation. If the user chooses to fix the coefficients, then the `coeff` bus and `loadc` ports are not used in this module. For fixed coefficients, the values are hardcoded. If the coefficients are configured to be loaded, they are loaded into the `coeff` registers sequentially at every clock edge. The `coeff` loading starts at the first clock edge after `loadc` goes high and continues as long as `loadc` is active.

## Data Scheduler

Data scheduling is necessary to schedule the tap and coefficient data to the multiplier bank for multi-cycle computations. This module has the necessary multiplexers to supply the tap and coefficient data to the multiplier bank in batches. For a multi-cycle implementation with  $C$  cycles, the number of multipliers,  $M$  is equal to  $(N/C)$  rounded to the next higher integer. For a fully parallel implementation ( $C = 1$ ), the data scheduler reduces to a direct connection. The data scheduler is also used to multiplex data for optimizing decimation and interpolation filters.

## Multiplier Bank

The Multiplier Bank has  $M$  number of  $W$  bit wide multipliers, where  $M$  is determined as the number of taps  $N$  divided by the number of computational cycles  $C$  rounded to the next higher integer ( $M = \text{ceil}(N/C)$ ). The number of multipliers is equal to the number of taps for a fully parallel implementation. The input to the bank comes from the data scheduler and the output goes to the adder tree. The maximum delay through the multiplier bank is equal to the delay of a single multiplier.

## Adder Tree and Output Control Unit

The Adder Tree has parallel adders instantiated in a binary tree fashion. The Output Control Unit has the scaling and rounding logic to achieve output scalability and selectable rounding. There are also data registers to provide synchronous registered output from the filter core. For a multi-cycle or decimation filtering, an adder is present in the block, which when combined with the output registers, makes an accumulator.

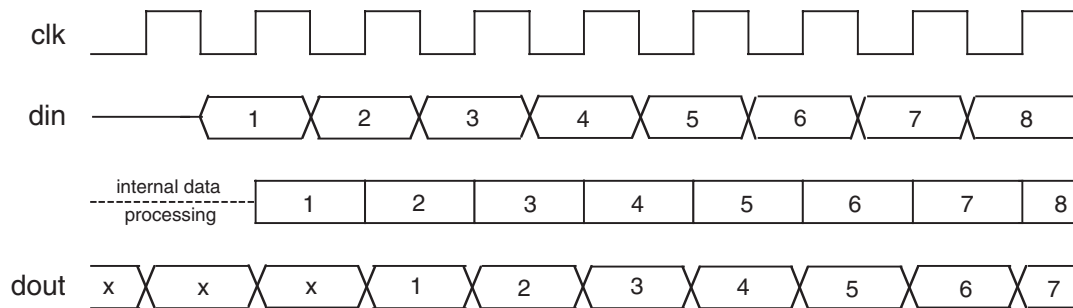
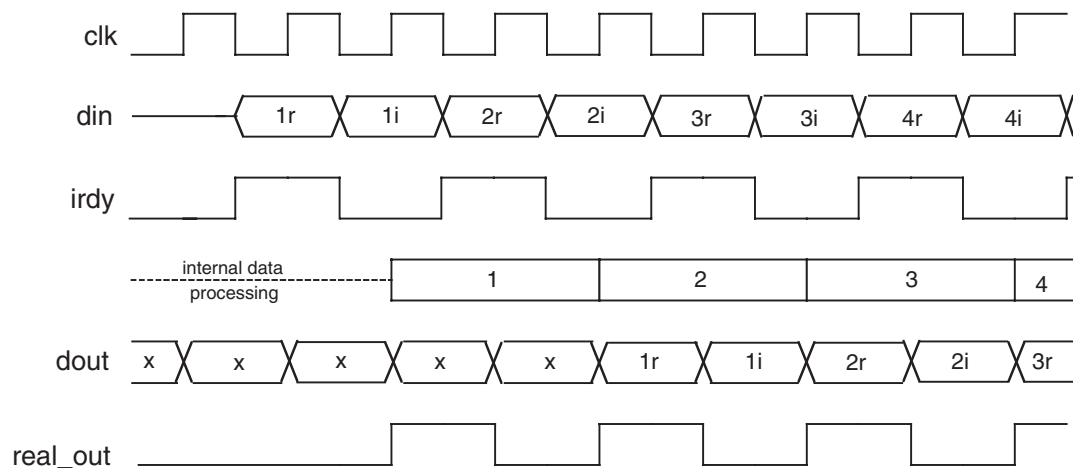
## Core Operation

There are four distinct implementations of parallel FIR filter: single-cycle, multi-cycle, decimation and interpolation. This section describes these implementation types in detail. A note on rounding and truncation is also given in this section. Complex data type is supported in all the filter implementations. For a complex data type, the complex input data can be either supplied all at once (complex-parallel) or in two stages, real data followed by imaginary data (complex-serial). The following notations are used:

N	Number of taps
W	Width of input data and coefficients
C	Number of cycles for a multi-cycle operation
D	Decimation ratio
U	Interpolation ratio
M	Number of multipliers, determined as $M = \text{Next higher integer to } (N/C)$
OW	Output width
OFW	Output full width

## Single Cycle

This is the simplest of all implementations, in that it assumes availability of sufficient resources for parallel implementation. For an  $N$ -tap filter, it uses  $N$  multipliers and  $N - 1$  adders. The output is available on every cycle. The timing diagrams for the single-cycle implementations are given in Figures 2 and 3. As seen in the timing diagram, real and imaginary parts of the input are supplied in successive clock cycles in complex serial mode. The data rate is equal to half the clock rate. The input `irdy` should be asserted high to coincide with every valid real data at the `din` port. Similarly, the core asserts the output `real_out` whenever the real part of the output data is placed on the output bus.

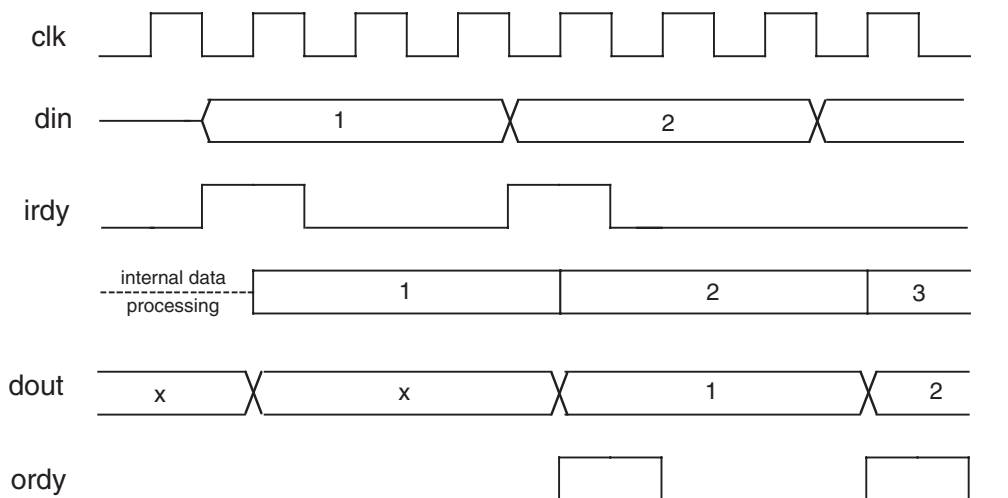
**Figure 2. Timing for Single-cycle, Real or Complex-parallel Mode****Figure 3. Timing for Single-cycle, Complex-serial Mode**

## Multi-cycle

In a multi-cycle implementation, each output is computed over a period of  $C$  cycles. The implementation is similar to the parallel implementation, except that fewer resources are used over multiple cycles. The number of multipliers and adders used is not more than  $1/M^{\text{th}}$  of those used in fully parallel implementation. There is an additional accumulator (an adder and a register combination) to accumulate the final sum through the  $C$  cycles. The timing diagrams for multi-cycle implementations are given in Figures 4 and 5.

## Real and Complex-parallel Modes

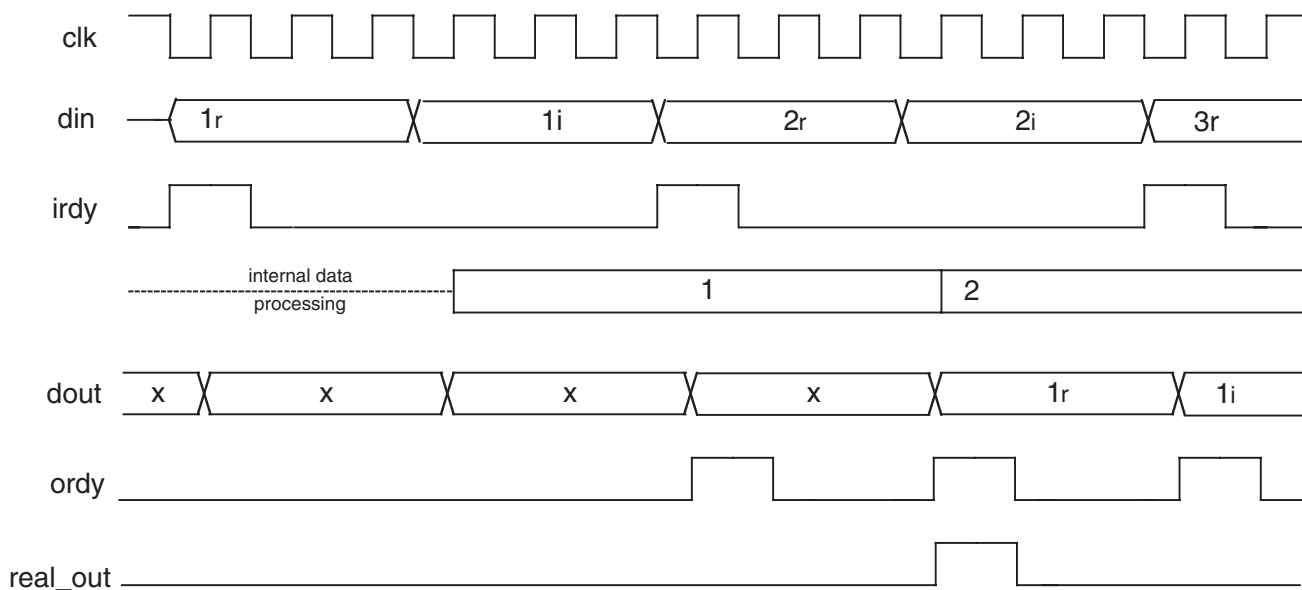
The signal **irdy** is asserted during the first cycle of a multi-cycle operation, in the real and complex-parallel modes. The data output of the core changes every  $C$  cycles and remains unchanged during the data cycle (each data cycle is  $C$  clock cycles wide). The output **ordy** goes high during the first clock cycle of each data cycle. This operation is shown in Figure 4.

**Figure 4. Timing for Multi-cycle (3 Cycles), Real or Complex-parallel Mode**

### Complex-serial Mode

The data and handshake signals for a typical complex-serial mode configuration ( $C = 3$ ) are shown in Figure 5. Every input data cycle has a real data cycle followed by an imaginary data cycle. Each of these real and imaginary data cycles is  $C$  clock cycles wide. The **irdy** input signal must be asserted high during the first cycle of every input data cycle.

The output data cycles also contain a real data cycle followed by an imaginary data cycle. The **ordy** output signal goes high during the first clock cycle of every output real or imaginary data cycle. The **real\_out** output signal goes high during the first clock cycle of every output real data cycle.

**Figure 5. Timing for Multi-cycle (3 Cycles), Complex-serial Mode**

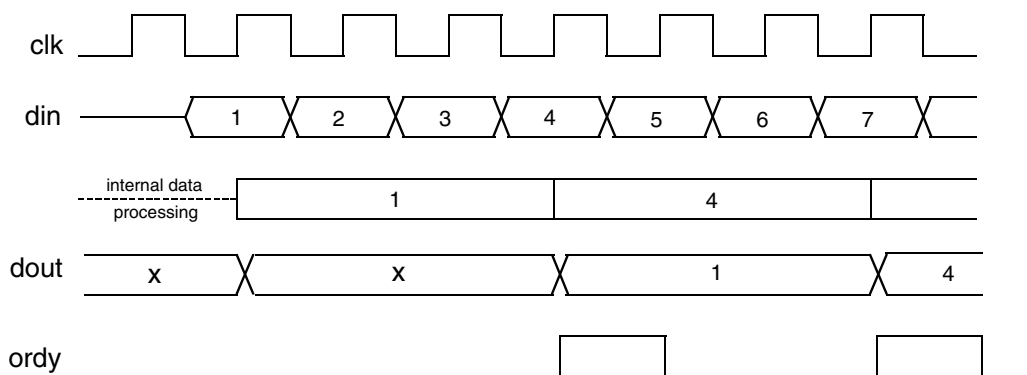
## Decimation

Decimation is downsampling of the data stream. In a simple decimation filter with decimation ratio 'D', every  $D^{\text{th}}$  sample of the input is sent to the output. The danger with downsampling is that aliasing can occur if the input signal is not band-limited to  $1/D$  of the original bandwidth. Therefore, to prevent aliasing, it is necessary to do a lowpass filtering before downsampling. The decimation filter implementation is, therefore, a cascade of a lowpass filter and a downsampler. The implementation of this is similar to a normal FIR, except that  $D - 1$  samples are skipped at the output, after every valid output. The output data rate is  $1/D^{\text{th}}$  of the input rate. The arithmetic resources are reused in this design, as it is not necessary to compute an output for every input sample.

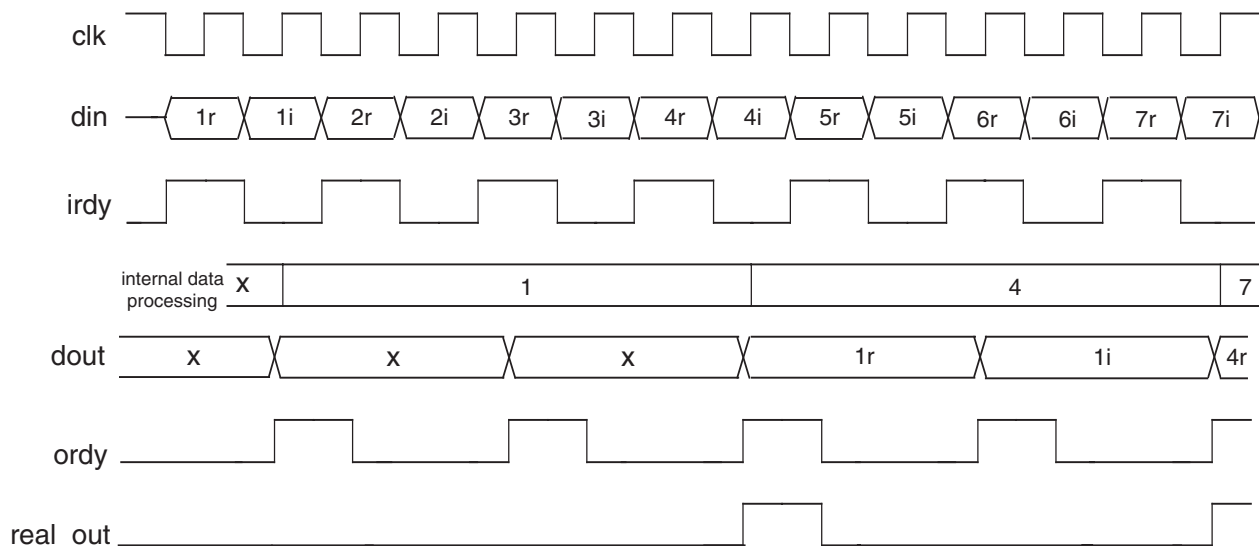
The output signal, `ordy`, goes high during the first cycle of each data output. For, complex-serial mode, there is an additional output, `real_out`, which goes high during the first cycle of every real part of the complex data.

The timing diagrams for two decimation filter implementations are shown in Figures 6 and 7.

**Figure 6. Timing for Real or Complex-parallel, Decimation Mode (Ratio = 3)**



**Figure 7. Timing for Complex-serial, Decimation Mode (Ratio = 3)**



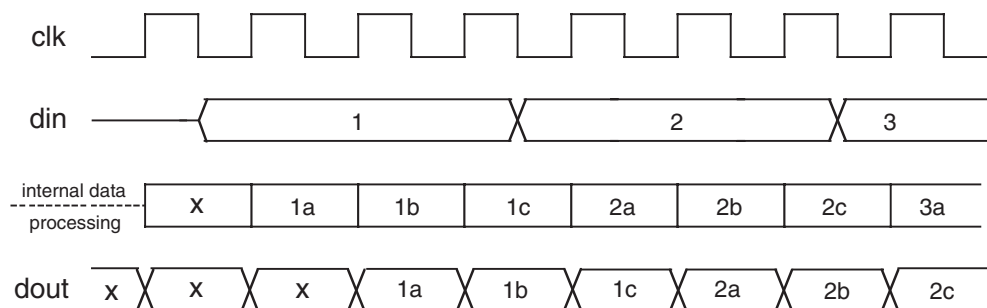
## Interpolation

Interpolation is the reverse process of decimation. In this mode, the data is upsampled. For an interpolation ratio  $U$ ,  $U - 1$  'zeros' are introduced between any two consecutive samples and the resulting expanded stream is passed through a lowpass filter. The operational environment of an interpolation filter is similar to a regular FIR filter, except

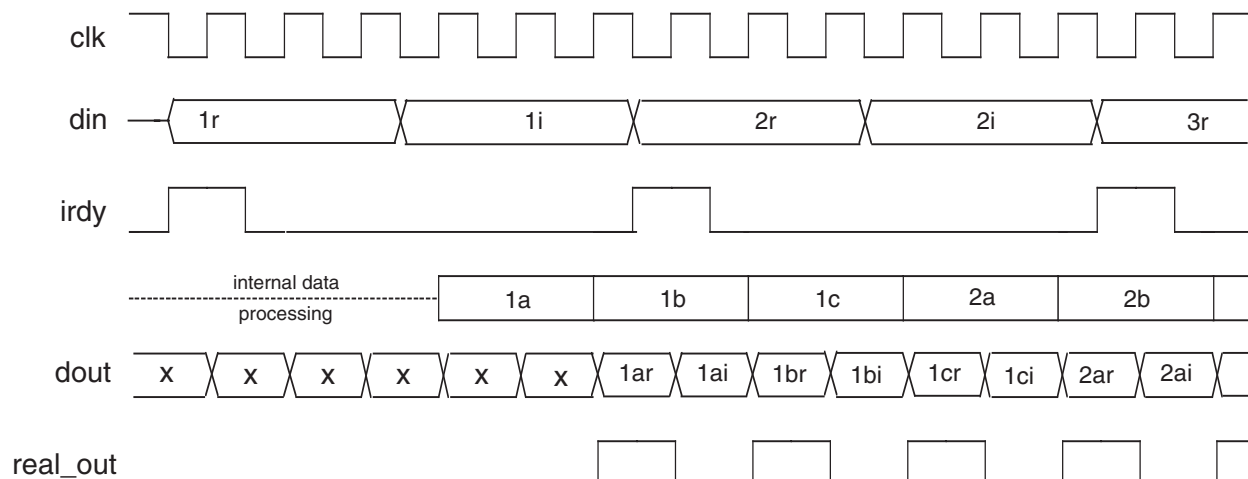


the input data rate is reduced by 'U' and 0's are introduced in the taps. The timing diagrams for two Interpolation Filter implementations are shown in Figures 8 and 9.

**Figure 8. Timing for Real or Complex-parallel, Interpolation Mode (Ratio = 3)**



**Figure 9. Timing for Complex-serial, Interpolation Mode (Ratio = 3)**



## Output Scaling and Rounding

When the user defined output width (OW) of the filter is less than the full output width of the filter (OFW), the outputs are scaled using a rounding scheme that is based on the parameter "rounding method". If the rounding method is defined as "truncation", the least significant OFW-OW bits are simply discarded and the most significant OW bits are retained in the output. If the rounding method is selected to be "nearest", the most significant OW bits are retained and they are rounded based on the value of the least significant bits that are discarded. Truncation takes the value to the next step towards minus infinity and rounding nearest takes the value to the nearest step in either direction.

Table 3 illustrates the output scaling and rounding for two numbers using integer, fixed point, signed and unsigned representations. In the example, the full output width (OFW) is 8 and the desired output width (OW) is 6. Output scaling in this case is equivalent to a division by 4.

**Table 3. Example Description of Output Scaling and Rounding**

Binary	Mode	Decimal	Full Precision Divide by 4	Truncation	Nearest
1010 1001	Unsigned, integer	169	42.25	42	42
	Signed, Integer	-87	-21.75	-22	-22
	Unsigned, FP between bit 3 and bit 4	10.5625	2.640625	2.625	2.625
	Signed, FP between bit 3 and bit 4	-5.4375	-1.359375	-1.375	-1.375
1010 1011	Unsigned, integer	171	42.75	42	43
	Signed, Integer	-85	-21.25	-22	-21
	Unsigned, FP between bit 3 and bit 4	10.6875	2.671875	2.625	2.6875
	Signed, FP between bit 3 and bit 4	-5.3125	-1.328125	-1.375	-1.3125

## IPexpress

The Lattice IP configuration tool, IPexpress, is incorporated in the ispLEVER software. IPexpress includes a GUI for entering the required parameters to configure the core. For more information on using IPexpress and the ispLEVER design software, refer to the software help and tutorials included with ispLEVER. For more information on ispLEVER, see the Lattice web site at: [www.latticesemi.com/software](http://www.latticesemi.com/software).

## Available Configuration(s) for Evaluation

Table 4 lists the available configuration with the corresponding parameters. To obtain the evaluation version of this core, visit the Lattice web site at [www.latticesemi.com](http://www.latticesemi.com).

**Table 4. Available Core Configuration**

Parameter File Name	Input Data Width	No. of Taps	FIR Type	Symmetry	Arithmetic Type	Data Type	Output Data Width (Full data width)	Fixed Coefficients
fir_para_xp_1_002.lpc	8 bits	16	Single cycle	Symmetric	Signed	Real	Full (21)	60, 44, D9, 37, 35, 16, F6, 39 (HEX)

Figure 10. Dialog Box for Configuring the Parallel FIR Filter Core

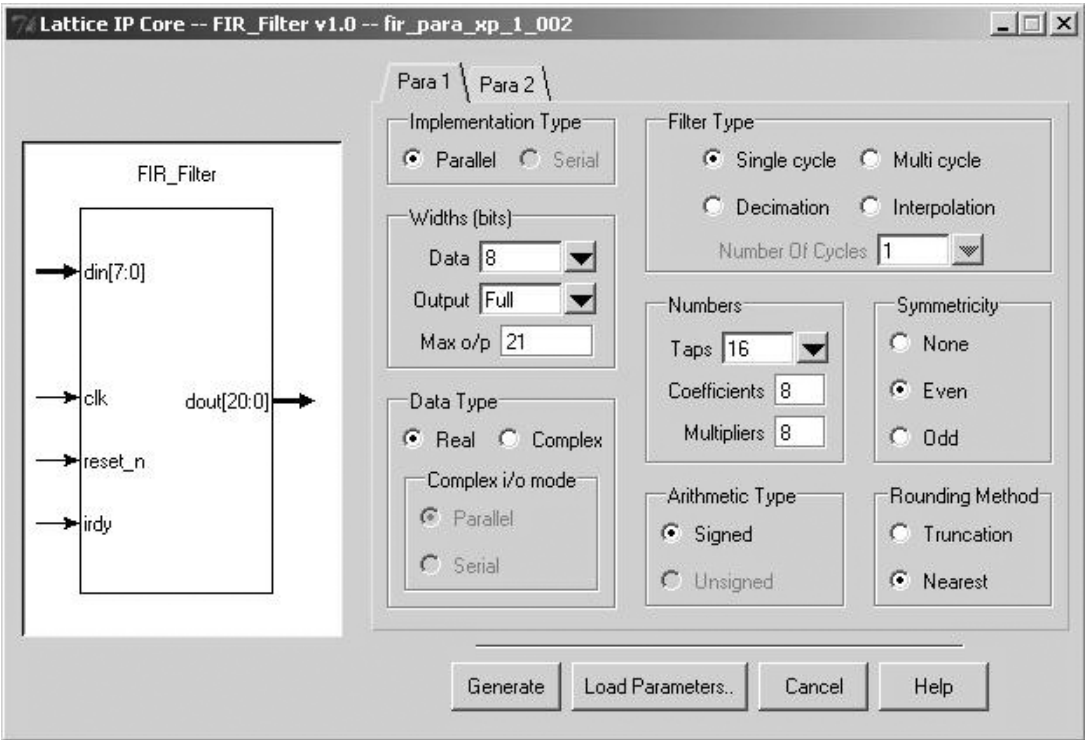
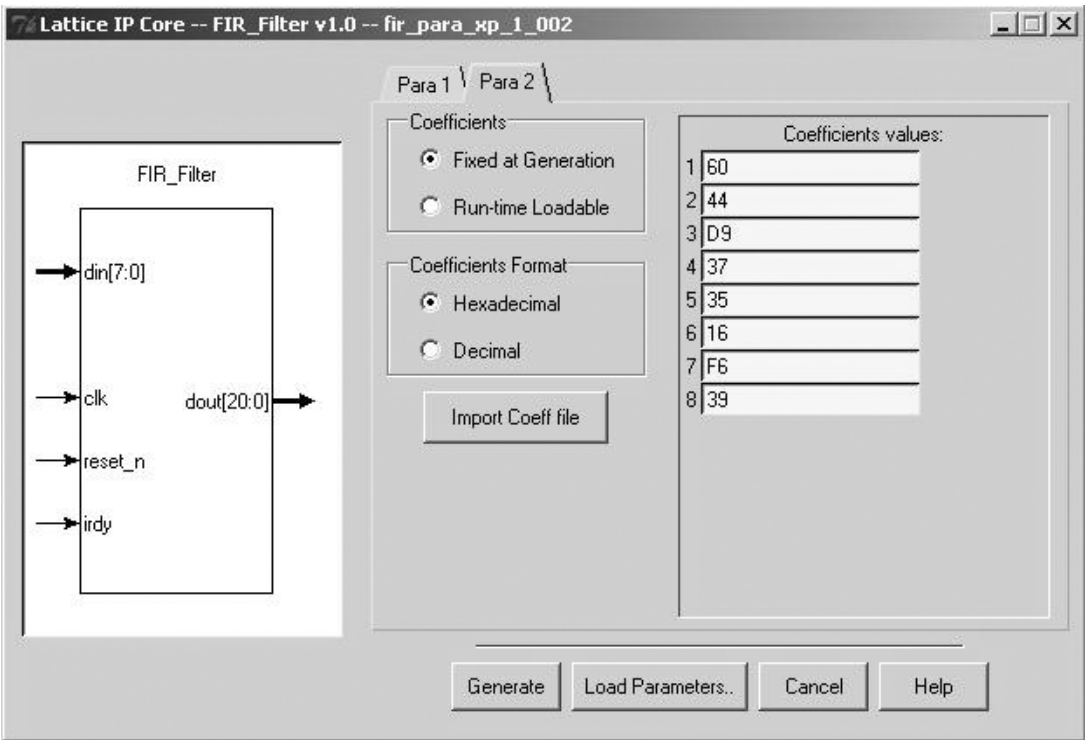


Figure 11. Dialog Box for Specifying the Coefficients



## References and Related Information

The following document will provide further information on implementing this core:

- ispLEVER Software User Manual

In addition to this Parallel FIR Filter core, Lattice also offers the Serial FIR Filter for similar applications. For more information, refer to the following document:

- Serial FIR Filter Core User's Guide

## Technical Support Assistance

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Internet: [www.latticesemi.com](http://www.latticesemi.com)

## Appendix for ispXPGA® FPGAs

**Table 5. Performance and Resource Utilization<sup>1</sup>**

Parameter File	Parameters	LUT4s <sup>2</sup>	ispXPGA PFUs <sup>3</sup>	Registers	External Pins	System EBRs	f <sub>MAX</sub> <sup>1</sup> (MHz)
fir_para_xp_1_002.lpc	See Table 6	858	297	149	31	None	51

1. Performance and utilization characteristics are generated using LFX1200B-04FE680C in Lattice's ispLEVER 3.x software. The evaluation version of this IP core only works on this specific device density, package, and speed grade.
2. Look-Up Table (LUT) is the standard logic block of the ispXPGA. LUT4 is a 4-input LUT.
3. Programmable Function Unit (PFU) contains LUTs and other resources.

## Supplied Netlist Configurations

The Ordering Part Number (OPN) is FIR-PARA-XP-N1. Table 6 lists the Lattice-specific netlist that are available in the Evaluation Package, which can be downloaded from the Lattice web site at [www.latticesemi.com](http://www.latticesemi.com).

**Table 6. Description of Netlist Configuration**

Parameter File Name	Input Data Width	No. of Taps	FIR Type	Symmetry	Arithmetic Type	Data Type	Output Data Width (Full data width)	Fixed Coefficients
fir_para_xp_1_002.lpc	8 bits	16	Single cycle	Symmetric	Signed	Real	Full (21)	60, 44, D9, 37, 35, 16, F6, 39 (HEX)

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