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Features

- Input data words from 4 to 32 bits
- Coefficient width from 4 to 24 bits
- Output data words from 2 to 31 bits
- Taps from 6 to 80 for symmetric filters
- Taps from 6 to 40 for non-symmetric filters
- Support for cascading multiple filters to create larger filters
- Support for symmetric, non-symmetric, and negative symmetry filters
- Full precision
- Scaleable output
- Input and output synchronization signals
- Registered output
- 2's complement or unsigned input data
- Uses SelectRAM™ for high density and performance
- Uses Fast Carry logic for high speed
- Drop-in modules for the XC4000E, EX, XL, and XV families
- High performance and density guaranteed through Relational Placed Macro (RPM) mapping and placement technology
- Available in Xilinx CORE Generator

General Description

FIR filters are one of the most basic building blocks used in digital signal processing, taxing the performance that DSP hardware can deliver. Multiply accumulates must be performed at an ever-increasing rate and demands in the billions of MACs per second range are not uncommon.

Field programmable gate arrays (FPGAs) using distributed arithmetic algorithms can implement large numbers of taps at MHz data sample rates, outperforming DSP processors by one or two orders of magnitude. A wide range of sample rates can be handled by applying the most efficient struc-

ture that just meets the required performance with the least number of FPGA configurable logic blocks (CLBs).

Serial distributed arithmetic operates at relatively low sample rates (3 to 15 million samples per second) but consumes few CLBs. Bits are processed serially, but all taps are processed in parallel. If higher sample rates are required, structures are available which process 2, 3, 4, or all of the bits in parallel. Multi-rate FIR filters can also be supported, resulting in higher sample rates with the same number of resources.

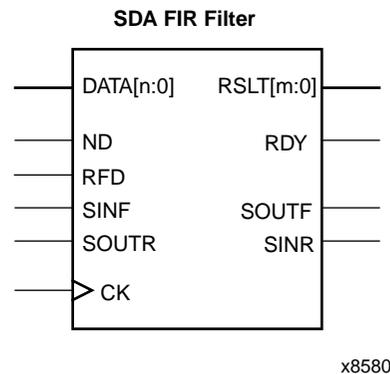


Figure 1: Core Schematic Symbol

Functional Description

The FIR filter coefficients are formatted and stored in distributed ROM look-up tables when the module is generated, and the filter architecture is such that full precision is maintained through all stages of arithmetic processing. For example, a 10 tap symmetrical filter processing 8-bit input data and coefficients would yield a 19-bit result (the product of a signed and balanced 8-bit data sample and similar coefficient yields a 15-bit result, and the sum of 10 such results yields a 19-bit full precision output).

The maximum output resolution is automatically calculated and displayed on the filter parameterization window after the balance of the other filter parameters have been entered. The user can choose a full precision output or select fewer output bits if desired. In the above example, the 19-bit output could be scaled to only 12-bits if desired, resulting in the 7 LSB bits being trimmed from the filter's full precision output. Note that truncation does not significantly reduce the amount of logic consumed by the filter since full-

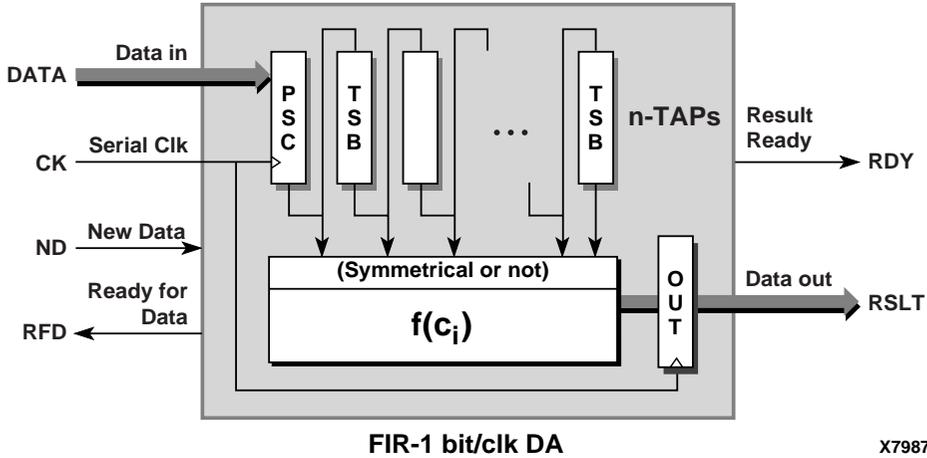


Figure 2: Serial Distributed Arithmetic FIR Filter Block Diagram

precision is always maintained internally regardless the output bus width. The important point is that no noise is introduced into the system as a result of arithmetic operations or truncation.

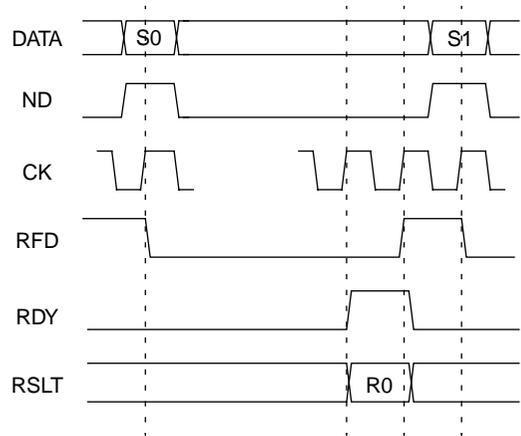
The SDA FIR filter processes data in a bit-serial fashion and therefore requires either N or N+1 clock cycles to process N-bit sample data. (Neither the number of taps nor the bit-width of the coefficients are factors in the number of clock cycles necessary to process input data of a given bit-width.) Filters with non-symmetric impulse responses require N clock cycles to process N-bit sample data, whereas symmetric filters require an additional cycle. The user must therefore provide a clock that is at least N, or N+1, times the data sample rate.

Hand-shake Control

The filter requires a continuous clock operating at a frequency that is at least N, or N+1, times the sample rate (assuming N-bit sample data.) The filter indicates that it has finished processing any previous data samples by asserting its ready-for-data (RFD) output. A new piece of sample data may be loaded into the filter by asserting the new-data (ND) port. It is critical that ND only be asserted when RFD is High or corruption will occur within the filter. On the cycle after ND is asserted, RFD goes Low indicating that the filter is now processing the new sample. After N, or N+1, clock cycles RFD will return High indicating that the filter is ready to receive the next piece of sample data.

The filter indicates that a valid result is present on the result (RSLT) output port by asserting the result-ready (RDY) output. Valid filter outputs are stable for one clock cycle only;

the cycle on which RDY is asserted. At all other times the filter's RSLT output is undefined.



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Figure 3: Timing Diagram

Pinout

Port names for the schematic symbol are shown in Figure 1 and described in Table 1.

Table 1: CORE Signal Pinout

Signal	Signal Direction	Description
DATA[n:0]	Input	PARALLEL DATA INPUT – N-bit wide sample data
ND	Input	NEW DATA - When asserted, the value on the DATA port is captured and internal processing begins. Must not be asserted when RFD is Low.
RFD	Output	READY FOR DATA – Active High. Indicates when the last bit of the previously loaded sample is about to be processed and new data may be loaded into the filter.
SINF	Input	SERIAL CASCADE DATA IN, FORWARD - Used when cascading multiple filters. Leave open-circuit when not cascading.
SOUTR	Output	SERIAL CASCADE DATA OUT, REVERSE - Used when cascading multiple filters. Leave open-circuit when not cascading.
CK	Input	BIT RATE CLOCK - With the exception of asynchronous control inputs (where applicable), control and data inputs are captured, and new output data formed on rising clock transitions.
RSLT[m:0]	Output	RESULT – Parallel filter output. The result of summing the products of the coefficients and the recorded sample data.
RDY	Output	RESULT READY – Active High. Indicates that valid output data is present on the RSLT port.
SOUTF	Output	SERIAL CASCADE DATA OUT, FORWARD - Used when cascading multiple filters. Leave open-circuit when not cascading.
SINR	Input	SERIAL CASCADE DATA IN, REVERSE - Used when cascading multiple filters. Leave open-circuit when not cascading.

Core Generator Parameters

The CORE Generator parameterization window for this macro is shown in Figure 6. The parameters are as follows:

- **Component Name:** Enter a name for the output files generated for this module.
- **Input Width:** Select an input bit width from the pull-down menu. The valid range is 4-32.
- **Output Width:** Full arithmetic precision is carried throughout the filter, however you may truncate the output bit-width to a smaller value. The valid range depends on other filter parameters.
- **Generate Cascadeable Section:** Allows this module to be combined with other filter modules to form larger filters. Check this box when constructing a filter for cascading purposes.
- **Impulse Response:** Select whether the filter should have a symmetric or non-symmetric impulse response.
- **Anti-Symmetry:** Select whether the filter should have an anti-symmetric (also known as negative-symmetry) impulse response. This control is only enabled if a symmetric impulse response is selected.
- **Number Of Taps:** Choose the number of taps required for the filter. For symmetric filters the valid range is 6 to 80 taps. For non-symmetrical filters the range is 6 to 40.
- **Shape:** For symmetric filters with between 27 and 40 taps two different shape floorplans are available. The rectangle of CLBs occupied by the filter can be tall-and-thin or short-and-wide.
- **Coefficient Width:** Specify the bit-width necessary for the filter's largest coefficient. The valid range is 4-24.
- **Trim Empty ROMs:** Since not all coefficients will require all 'coefficient width' bits to express them, this option allows the filter's internal look-up tables to be optimized to the smallest possible dimensions given the actual coefficient values.
- **Load Coefficients:** Get the filter coefficients from a specified file.
- **Show Coefficients:** Display the coefficients after they have been loaded.
- **.coe File:** Displays the name of the coefficient file. This field is read-only.

Specifying Filter Coefficients

Not all of the parameters necessary to completely specify a filter's characteristics can be entered on the parameterization window. Specifically the filter coefficients must be loaded from a text file (known as a COE file) described below. In addition, all the parameters visible on the parameterization window may be assigned in the COE file. COE files may take any root filename but must end with the extension ".COE".

To select and load a COE file, press the "Load Coefficients..." button on the filter parameterization window and choose the desired file from the dialog-box. To review the

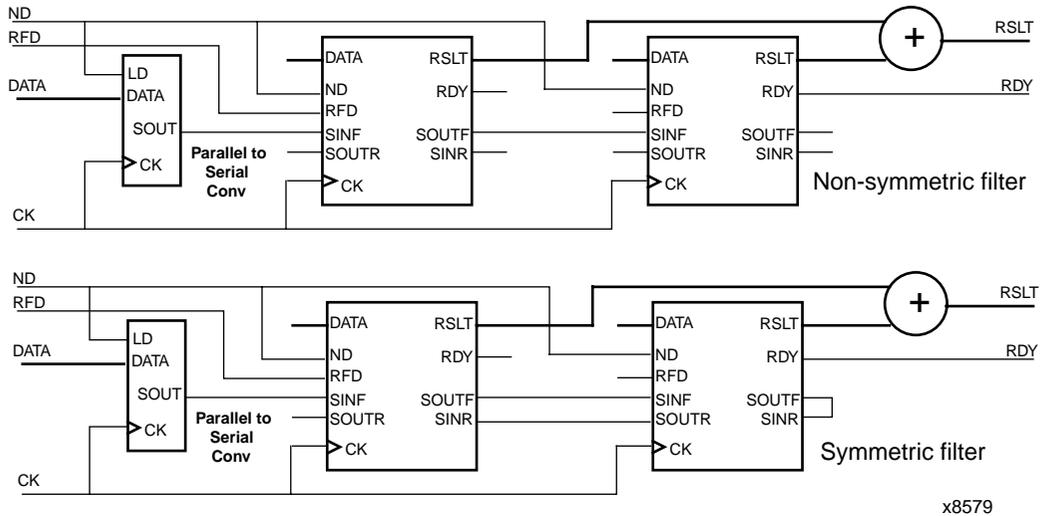


Figure 4: Cascading Several Filter Modules to Create Larger Filters

filter's coefficient-values at any time, press the "Show Coefficients..." button. Any field on the parameterization window that is assigned a value in the COE file will lose its previous value when the COE file is loaded. Changing a parameter value that was previously loaded from a COE file causes the COE file's name to be highlighted in red, indicating that the settings have been changed since the file was loaded.

For a detailed description of COE file syntax, please refer to the Xilinx CORE Generator User Guide. The list of COE file keywords supported by the Serial Distributed Arithmetic FIR Filter are shown in the parameter File Information table at the end of this datasheet. An example COE file is shown below.

```

component_name = section1;
antisymmetry = false;
trim_empty_roms = false;
short_wide_floorplan = true;
input_width = 8;
coef_width = 8;
number_of_taps = 10;
cascade = true;
symmetry = true;
signed_input_data = true;
output_width = 19;
coefdata = 1,2,3,4,5;

```

Figure 5: Example COE File For SDA FIR Filter

When specifying filter coefficients in a COE file, the radix is assumed to be 10. You may however specify COEFDATA values in hexadecimal by adding the command RADIX=16.

Filters with non-symmetric impulse responses require as many coefficients specified in their COE file as they have taps. I.e. a 10-tap non-symmetric filter requires 10 coefficients, $C_0 - C_9$.

Filters with symmetric impulse responses require half as many coefficients specified in their COE file as they have taps. I.e. a 10-tap symmetric filter requires only 5 coefficients, $C_0 - C_4$. Coefficients $C_5 - C_9$ are assigned the values of coefficients $C_4 - C_0$ when anti-symmetry is not selected, and the negated values of coefficients $C_4 - C_0$ when anti-symmetry is selected.

Cascading Multiple SDA FIR Filters

Filters requiring numbers of taps greater than the limit imposed by this module can be constructed by 'cascading' several filter modules and summing the results of each to form a final output. Cascading filter modules is performed using the SINF and SOUTF pins in the case of non-symmetric filters, and also the SINR and SOUTR pins in the case of symmetric filters. See Figure 4.

In cascade-mode, each filter module receives its sample data bit-serially from its neighbor. Setting a filter's cascade option suppresses the generation of the parallel-to-serial converter and the module's parallel DATA port becomes redundant. Therefore, the first filter in the chain should receive its sample data from an external parallel to serial converter. Serial data is passed along the chain of filter modules via the SINF-SOUTF links. If the composite filter is

required to have a non-symmetric impulse response then the SOUTF pin of the last module in the chain may be left open circuit.

If the composite filter is required to have a symmetric impulse response, then the SOUTF pin of the last filter in the chain should be attached to its own SINR pin. This has the effect of sending the emerging sample data back along the filter chain in the reverse direction. The data propagates back along the chain of filters via the SOUTR-SINR links. The SOUTR pin on the first filter module may be left open-circuit.

Since the SDA FIR filter module's latency is related to the number of taps it implements, to ensure that results appear on the outputs of each of the filter modules at the same instant, make all cascaded sections the same number of taps. Only the last filter in the chain may have an odd number of taps, i.e. when the total number of taps is desired to be odd, give each filter module an even number of taps,

except the last one which may be odd. (The same number of taps as the other sections minus 1.)

Core Resource Utilization

Table 2 shows the approximate number of CLBs required for various example bit widths. Table 3 shows the maximum speed for data sample rates using XC4000E-1 devices. The sample rate is calculated by dividing the system clock by the number of bits in the data word, N for non-symmetrical FIR filters, or N+1 for symmetric filters. Sample rates are independent of the number of taps, but a small increase in delay per clock is a function of the width of the coefficients due to the increase in the width for the adders.

Table 2: CLB Utilization for Example SDA FIR Filter Implementations

Taps	Symmetry	CLB Counts for Example Data Word Widths ¹							
		5-bit	8-bit	10-bit	12-bit	14-bit	16-bit	18-bit	20-bit
8	Symmetrical		33	36	39	42	45	52	55
	Non-symmetrical		46	54	59	64	69	77	85
16	Symmetrical	53	61	69	71	76	81	96	102
	Non-symmetrical		80	95	104	112	123	138	
24	Symmetrical	80	89	101	108	116	127	146	154
	Non-symmetrical		101	114	127	140	153	174	187
32	Symmetrical	93	107	118	126	137	148	175	182
40	Symmetrical	116	138	154	165	179	191	226	239
48	Symmetrical		158	173	187	202	217	246	261
64	Symmetrical		197	215	233	250	268	305	323
80	Symmetrical		236	257	278	299	320	364	385

Note:

1. Coefficient width is equal to the word width.

Table 3: SDA FIR Filter Data Sample Rates in MHz Using XC4000E-1

Symmetry	5-bit	8-bit	10-bit	12-bit	14-bit	16-bit	18-bit	20-bit
Symmetrical	13.3	8.9	7.3	6.2	5.3	4.7	4.2	3.8
Non-symmetrical	16.0	10.0	8.0	6.7	5.7	5.0	4.4	4.0

Ordering Information

This macro comes free with the Xilinx CORE Generator. For additional information contact your local Xilinx sales representative, or e-mail requests to dsp@xilinx.com.

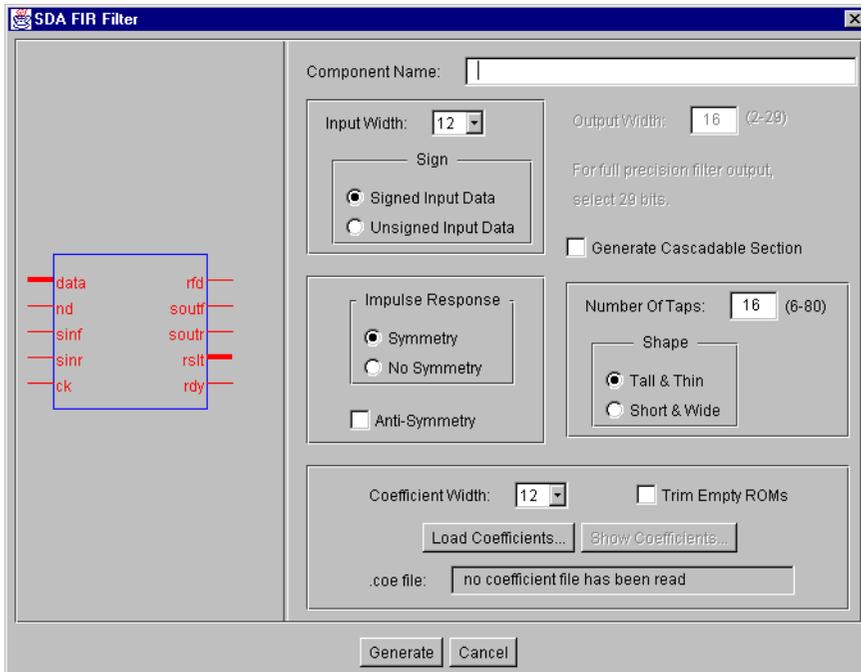


Figure 6: SDA FIR Filter Parameterization Window

Parameter File Information

Parameter Name	Type	Notes
Component_Name	String	
Input_Width	Integer	4 - 32
Output_Width	Integer	
Coef_Width	Integer	4 - 24
Number_Of_Taps	Integer	6 - 80
Symmetry	Boolean	True/False
Antisymmetry	Boolean	True/False
Trim_Empty_ROMs	Boolean	True/False
Cascade	Boolean	True/False
Signed_Input_Data	Boolean	True/False
Short_Wide_Floorplan	Boolean	True/False
CoefData{n}	Integer	
		0 ≤ n ≤ 39
Radix*	Integer	10 or 16

*COE file only.