

**UG0642**

**User Guide**

**Image Sharpening Filter**

February 2018



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## 1 Revision History

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The revision history describes the changes that were implemented in the document. The changes are listed by revision, starting with the most current publication.

### 1.1 Revision 4.0

In revision 4.0 of this document, the Resource Utilization section and the Resource Utilization Report were updated. For more information, see [Resource Utilization \(see page 16\)](#).

### 1.2 Revision 3.0

The following changes were made in revision 3.0 of this document.

- Information about median filter was removed, and information about unsharp masking kernel was added. For more information, see [Image Sharpening Filter Hardware Implementation \(see page 3\)](#)
- Details about the Image Sharpening Filter test bench were added. For more information, see [Test Bench \(see page 7\)](#).

### 1.3 Revision 2.0

In revision 2.0 of this document, the document was updated to address SAR 76068.

### 1.4 Revision 1.0

Revision 1.0 was the first publication of this document

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## Introduction

Human perception is sensitive to the edges and fine details of an image. As images are composed of high-frequency components, the visual quality of an image degrades if the frequency components are attenuated or removed. Image sharpening encompasses any enhancement technique that highlights the edges and fine details of an image.

Image sharpening is done by adding to the original image a signal proportional to a high-pass filtered version of the image. This process, referred to as unsharp masking on a one-dimensional signal, involves two steps. The original image is first filtered by a high-pass filter that extracts the high-frequency components. A scaled version of the high-pass filter output is then added to the original image, thereby producing a sharpened image.

Unsharp masking produces an edge image from an input image using the following equation:

$$g(x, y) = f(x, y) - f_{\text{smooth}}(x, y)$$

where,

$g(x, y)$  = edge image

$f(x, y)$  = input image

$f_{\text{smooth}}$  = smoothed image

The smoothed image is generated by applying mean filter on the input image.

The combined sharpening equation is:

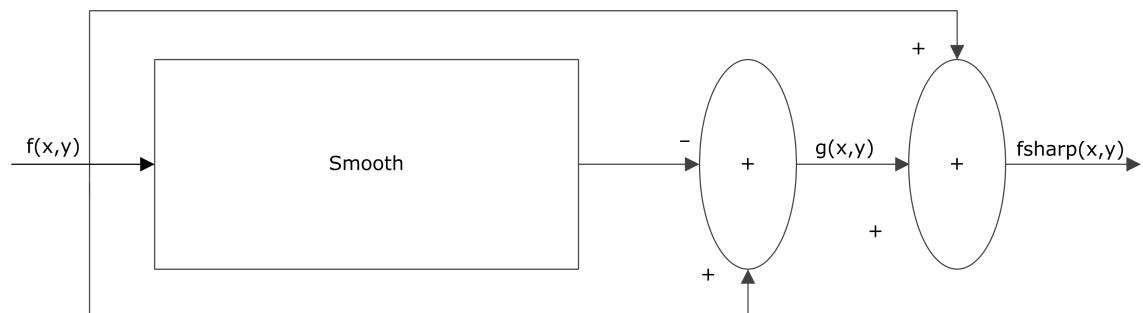
$$f_{\text{sharp}}(x, y) = f(x, y) + k \times g(x, y)$$

where,

$k$  = sharpness factor whose value varies between 0.2 and 0.7, with the larger values providing increased sharpening. The value is multiplied by 64 to generate an integer value for ease of calculation.

The following illustration shows the block diagram of the image sharpening process.

**Figure 1 • Image Sharpening Process Block Diagram**



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## Hardware Implementation

Microsemi Image Sharpening Filter IP core—a part of Microsemi’s imaging and video solutions IP suite—contains an unsharp masking algorithm with programmable gain for edge directions.

The Image Sharpening Filter hardware contains four one-line buffers storing one horizontal video line each. The incoming data stream fills these four buffers, one by one. In the design illustrated in this document, the median filter is implemented on a  $3 \times 3$  matrix, so three lines of the video form the  $3 \times 3$  window for the median. When the third buffer contains three pixel values, the read process is initiated.

Median filtering is only applied on channel Y. The Cb and Cr components are passed through the delay registers in order to be synchronized with channel Y. For channel Y, three pixels from each of the three video lines are read into three shift registers that form the  $3 \times 3$  2D array for median calculation. The shift registers are applied as input to the  $3 \times 3$  unsharp masking kernel, and the input is multiplied according to the unsharp kernel matrix shown in the following figure.

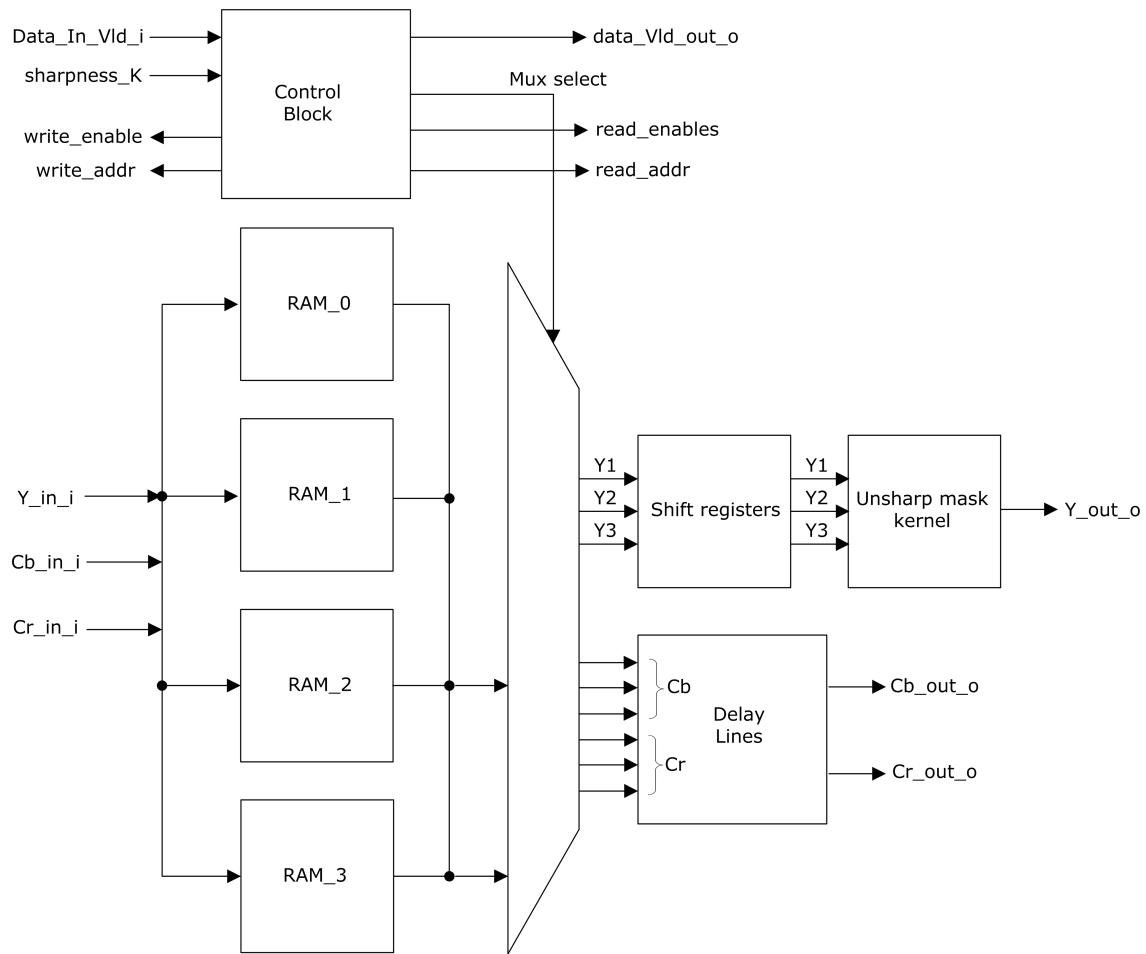
**Figure 2 • Unsharp Masking Kernel Matrix**

-1	-1	-1
-1	8	-1
-1	-1	-1

The new pixel column is shifted into the shift register, with the oldest data in the register being shifted out. The processed YCbCr value is sent to the sharpening equation to get the pixel sharpened. The sharpened pixels are sent out with a data valid signal. The  $3 \times 3$  window moves from the left to right and from top to bottom for each frame.

The following illustration shows the block diagram of the Image Sharpening Filter hardware.

**Figure 3 • Image Sharpening Filter Hardware**



### 3.1 Inputs and Outputs

The following table lists the input and output ports of the Image Sharpening Filter.

**Table 1 • Image Sharpening Filter Ports**

Signal Name	Description	Width	Description
RESET_n_1	Input		Active-low asynchronous reset signal to design.
SYS_CLK_I	Input		System clock.
Y_in_i	Input	$[(g\_DATAWIDTH / 3) - 1 : 0]$	Y pixel data input.
Cb_in_i	Input	$[(g\_DATAWIDTH / 3) - 1 : 0]$	Cb pixel data input.
Cr_in_i	Input	$[(g\_DATAWIDTH / 3) - 1 : 0]$	Cr pixel data input.
Data_In_Vld_i	Input		Input data valid signal.

Signal Name	Description	Width	Description
sharpness_K	Input	8 bits	Sharpness factor. Valid range is from 0.2 to 0.7. The value is multiplied by 64 to generate an integer value for ease of calculation.
Y_Out_o	Output	$[(g_{\_DATAWIDTH} / 3) - 1 : 0]$	Y pixel data output.
Cb_Out_o	Output	$[(g_{\_DATAWIDTH} / 3) - 1 : 0]$	Cb pixel data output.
Cr_Out_o	Output	$[(g_{\_DATAWIDTH} / 3) - 1 : 0]$	Cr pixel data output.
data_Vld_out_o	Output		Output data valid signal.

## 3.2 Configuration Parameters

The following table lists the configuration parameters for the Image Sharpening Filter design.

**Table 2 • Configuration Parameters**

Name	Description
g_DATAWIDTH	Defines Y data bit width
g_X_RES_WIDTH	Defines resolution bit width
g_DISPLAY_RESOLUTION	Defines the horizontal display resolution
g_VERT_DISPLAY_RESOLUTION	Defines the Vertical resolution data width



These are generic parameters that vary based on the application requirements.

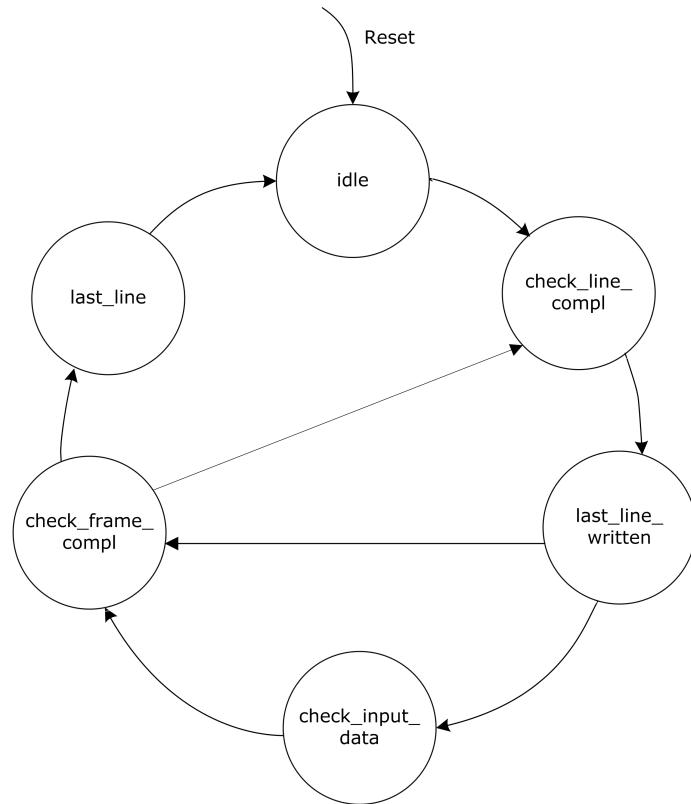
## 3.3 FSM Implementation

During the Image Sharpening Filter finite state machine (FSM) implementation, the FSM goes through the following states:

- **idle:** After the module is reset, the FSM goes into idle state and waits for the third pixel of the third line to be read. It then proceeds to `check_line_compl`.
- **check\_line\_compl:** The FSM waits for the output pixel count to be equal to the display resolution. It then proceeds to `last_line_written`.
- **last\_line\_written:** The FSM waits for the last input line. If the last line is written, it proceeds to `check_frame_compl`, else it proceeds to `check_input_data`.
- **check\_input\_data:** The FSM waits for the fourth pixel of the last line to be written into the line buffer. It then proceeds to `check_frame_compl`.
- **check\_frame\_compl:** The FSM waits for the output line count to be equal to the vertical resolution width. If the output is the last line, it proceeds to `last_line`, else it goes to `check_line_compl`.
- **last\_line:** The FSM waits for the last output pixel of the last line and then moves back to idle state.

The following illustration shows the FSM implementation for the Image Sharpening Filter.

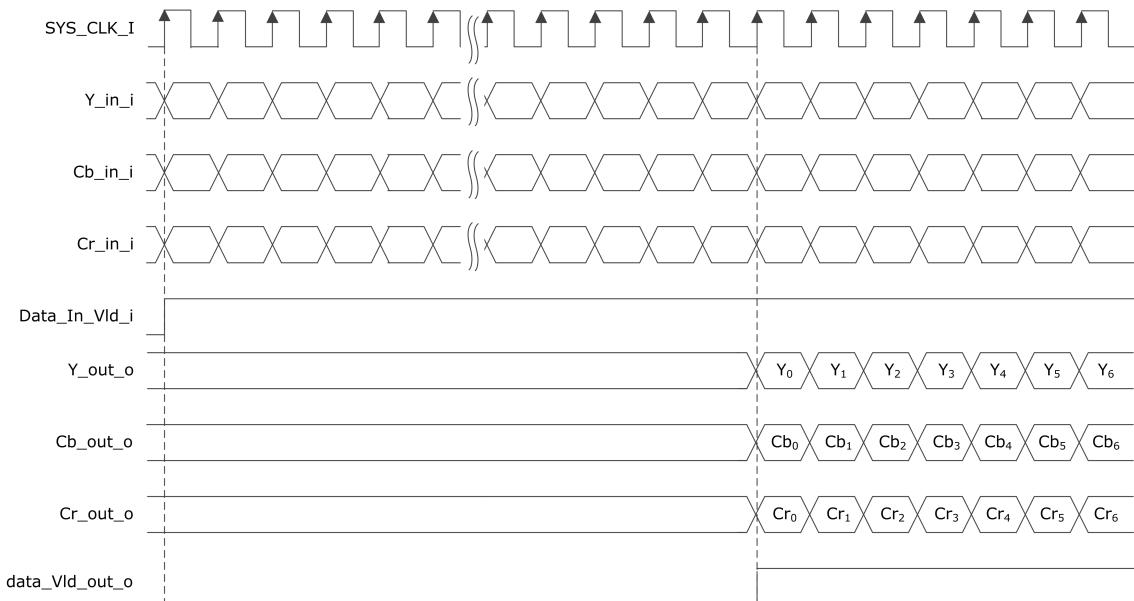
**Figure 4 • Image Sharpening Filter FSM**



### 3.4 Timing Diagram

The following illustration shows the timing diagram of the Image Sharpening Filter.

**Figure 5 • Image Sharpening Filter Timing Diagram**



### 3.5 Testbench

To demonstrate the functionality of the Image Sharpen core, a sample test bench file (`Image_Sharpen_Filter_tb.v`) is available in the Stimulus Hierarchy (View > Windows > Stimulus Hierarchy), and a sample test bench input image file (`rgb_in.txt`) is available in the stimulus directory within the Libero<sup>®</sup> SoC Files window (View > Windows > Files).

The following table lists the test bench parameters that can be configured according to the application, if necessary.

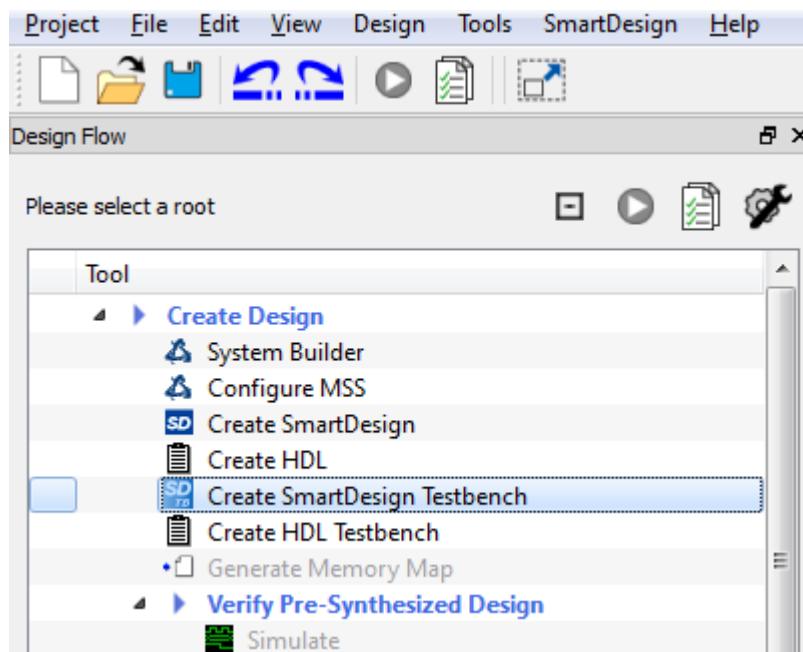
**Table 3 • Test Bench Configuration Parameters**

Name	Description
CLKPERIOD	Clock period
HEIGHT	Height of the image
WIDTH	Width of the image
WAIT	Number of clock cycles of delay between the transmission of one line of the input image and the next
IMAGE_FILE_NAME	Input image name

The following steps describe how to simulate the core using the testbench.

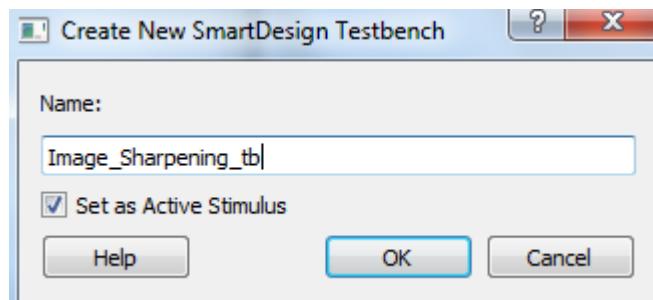
1. In the Libero SoC Design Flow window, expand **Create Design**, and double-click **Create SmartDesign Testbench**, as shown in the following figure.

**Figure 6 • Create SmartDesign Testbench**



2. Enter a name for the SmartDesign test bench, and click **OK**.

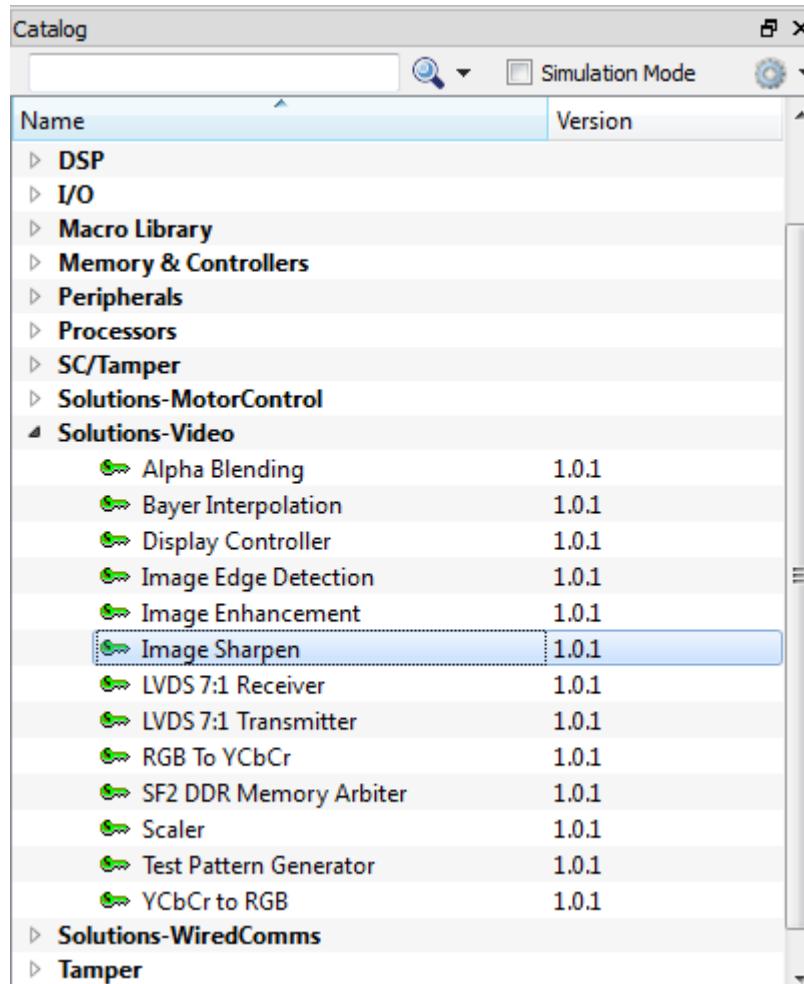
**Figure 7 • Create New SmartDesign Testbench Dialog Box**



A SmartDesign test bench is created, and a canvas appears to the right of the Design Flow pane.

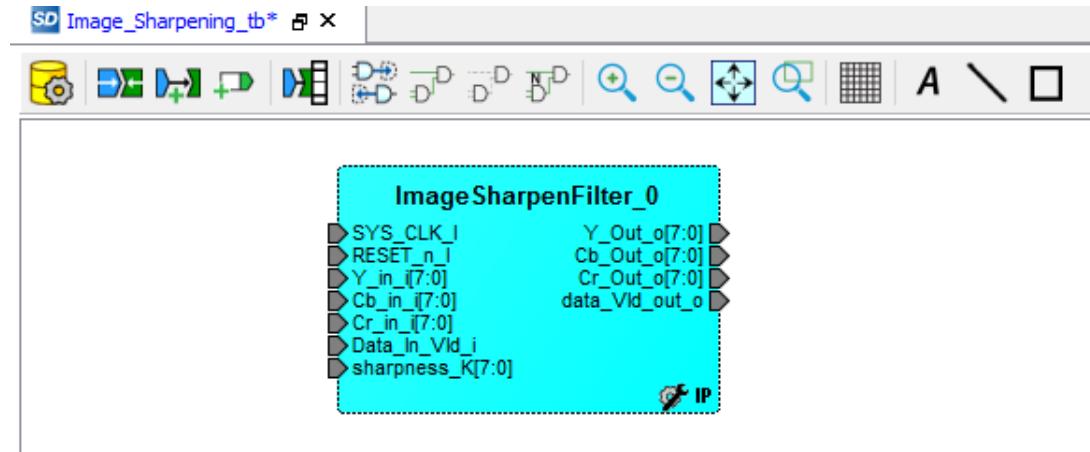
3. In the Libero SoC Catalog (View > Windows > Catalog), expand **Solutions-Video**, and drag the Image Sharpen IP core onto the SmartDesign test bench canvas.

**Figure 8 • Image Sharpen Core in Libero SoC Catalog**



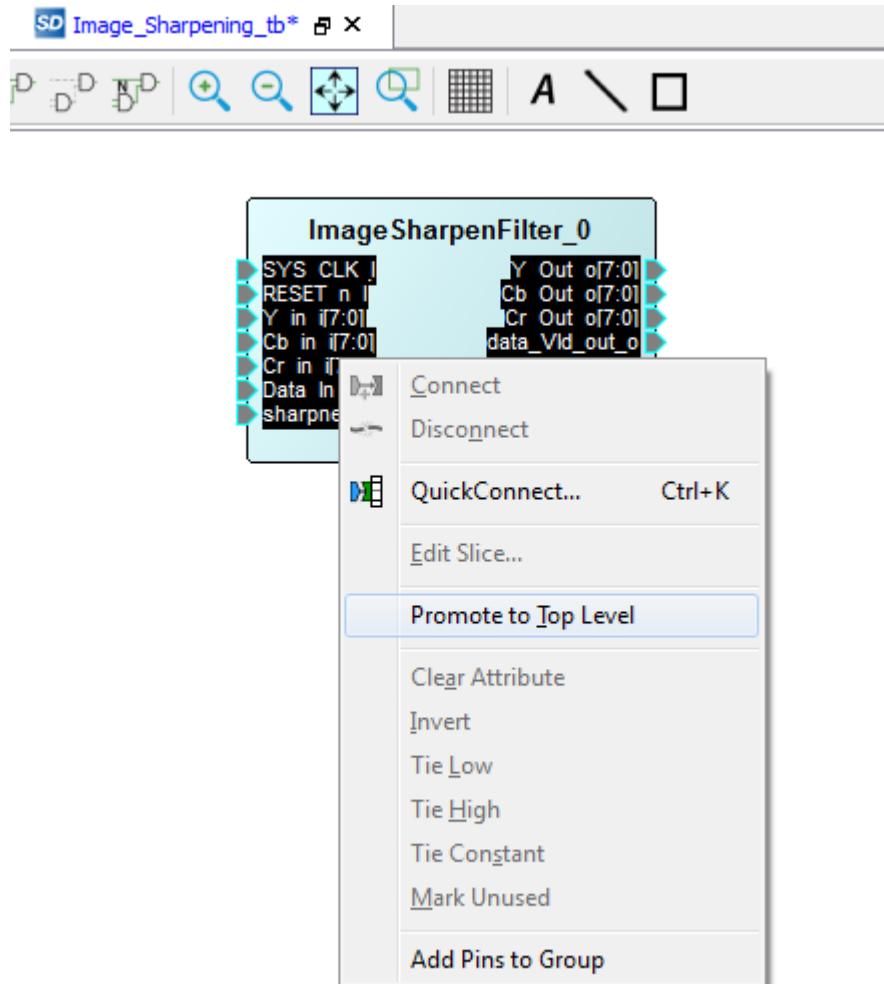
The core appears on the canvas, as shown in the following figure.

**Figure 9 • Image Sharpen Core on SmartDesign Test Bench Canvas**



4. Select all the ports of the core, right-click, and click **Promote to Top Level**, as shown in the following figure.

**Figure 10 • Promote to Top Level Option**



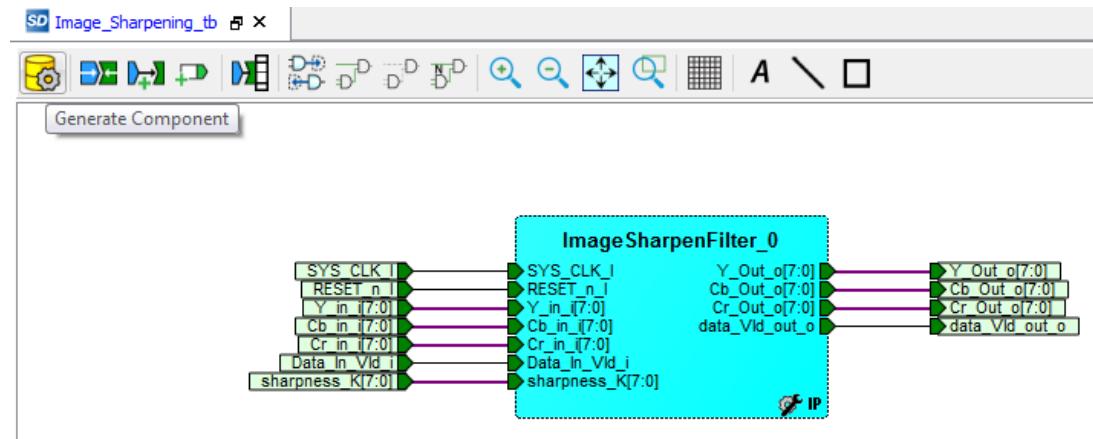
The ports are promoted to the top level, as shown in the following figure.

**Figure 11 • Image Sharpening Filter Ports Promoted to Top Level**



5. To generate the Image Sharpening Filter SmartDesign component, click the Generate Component icon on the SmartDesign Toolbar, as shown in the following figure.

**Figure 12 • Generate Component Icon**

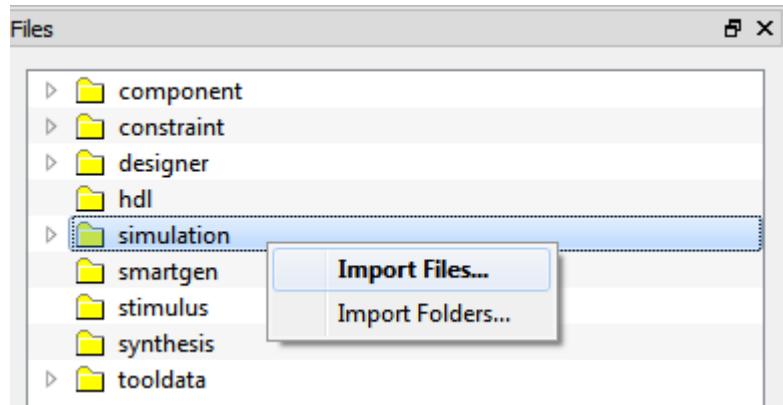


A sample test bench input image file is created at:

...\\Project\_name\\component\\Microsemi\\SolutionCore\\ImageSharpenFilter\\1.0.1\\Stimulus

6. In the Libero SoC Files window, right-click the simulation directory, and click **Import files...**, as shown in the following figure.

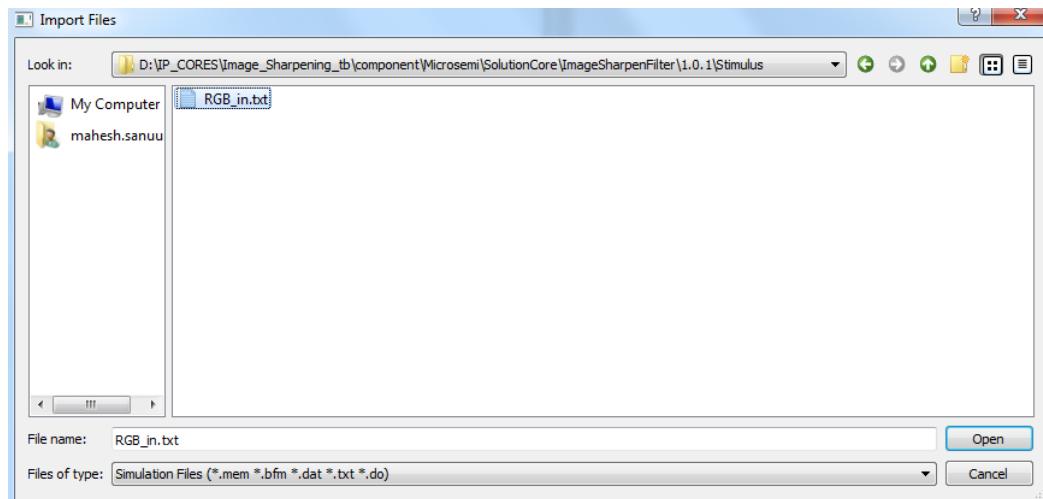
**Figure 13 • Import Files Option**



7. Do one of the following:

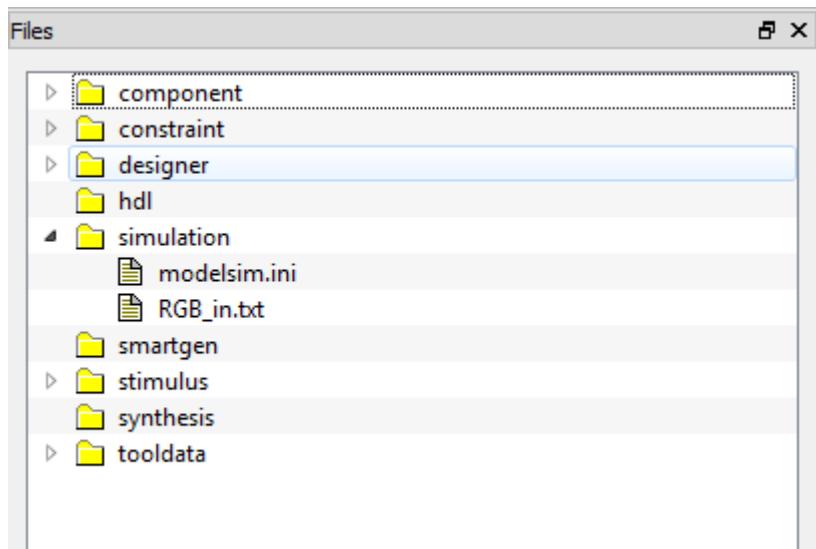
- To import the sample test bench input image, browse to the sample test bench input image file, and click **Open**, as shown in the following figure.

**Figure 14 • Input Image File Selection**



- To import a different image, browse to the folder containing the image file, and click **Open**. The input image file appears in the simulation directory, as shown in the following figure.

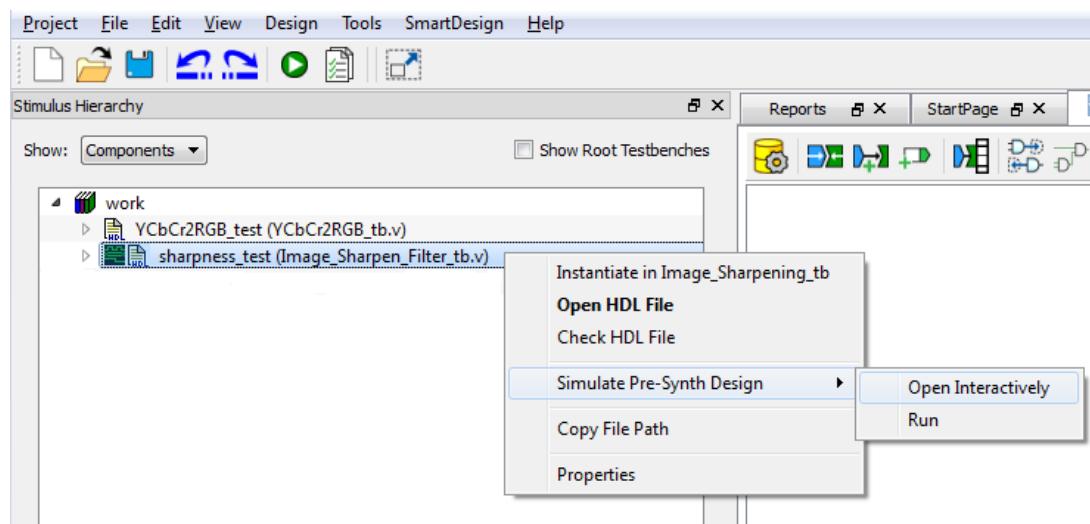
**Figure 15 • Input Image File in Simulation Directory**



8. In the Stimulus Hierarchy, expand **Work**, and right-click the Image Sharpening Filter test bench file (`Image_Sharpener_Filter_tb.v`).

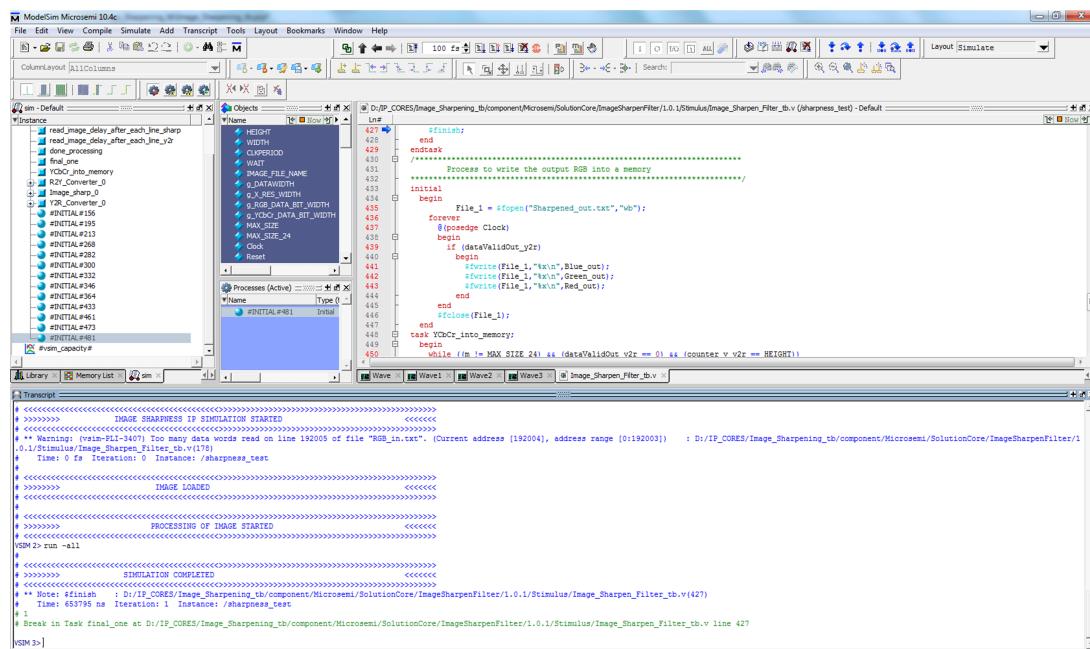
9. Click **Simulate Pre Synth Design**, then click **Open Interactively**.

**Figure 16 • Open Interactively Option**



The ModelSim tool appears with the test bench file loaded onto it, as shown in the following figure.

**Figure 17 • ModelSim Tool with Image Sharpening Filter Test Bench File**



10. If the simulation is interrupted because of the runtime limit in the DO file, use the `run -all` command to complete the simulation.

After the simulation is completed, the test bench output image file (.txt) appears in the simulation folder.

### 3.6 Simulation Results

This section shows an image before and after being processed using the Image Sharpening Filter.

The following figure shows the input image.

**Figure 18 • Input Image**



The following figure shows the output image.

**Figure 19 • Output Image**



### 3.7 Resource Utilization

The image sharpening filter block is implemented on an M2S150T SmartFusion®2 System-on-Chip (SoC) FPGA in the FC1152 package) and PolarFire FPGA (MPF300TS\_ES - 1FCG1152E package).

**Table 4 • Resource Utilization**

Resource	Utilization
DFFs	1272
4-Input LUTs	1270
MACC	1
RAM1Kx18	15
RAM64x18	0

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