

Sensor Demosaic v1.0

LogiCORE IP Product Guide

PG286 November 15, 2019



Table of Contents

IP Facts

Chapter 1: Overview

Feature Summary	7
Applications	7
Licensing and Ordering	7

Chapter 2: Product Specification

Standards	8
Performance	8
Port Descriptions	9

Chapter 3: Designing with the Core

General Design Guidelines	18
Clocking	18
Resets	19
System Considerations	19

Chapter 4: Design Flow Steps

Customizing and Generating the Core	20
Constraining the Core	22
Simulation	23
Synthesis and Implementation	24

Chapter 5: Detailed Example Design

Simulation Example Design	26
Synthesizable Example Design	28

Appendix A: Verification, Compliance, and Interoperability

Simulation	31
Hardware Testing	31
Interoperability	32

Appendix B: Upgrading

Appendix C: Debugging

Finding Help on Xilinx.com	34
Debug Tools	35
Hardware Debug	36

Appendix D: Additional Resources

Xilinx Resources	37
Documentation Navigator and Design Hubs	37
References	38
Revision History	38
Please Read: Important Legal Notices	39

Introduction

The Xilinx LogiCORE™ IP Sensor Demosaic core provides an optimized hardware block that reconstructs sub-sampled color data for images captured by a Bayer image sensor. The color filter array overlaid on the silicon substrate enables CMOS or CCD image sensors to measure local light intensities that correspond to different wavelengths. However, the sensor measures the intensity of one principal color at any location. The Sensor Demosaic IP provides an efficient and low-footprint solution to interpolate the missing color components for every pixel.

Features

- RGB Bayer image sensor support
- One, two, four, or eight pixel-wide AXI4-Stream video interface
- Supports 8, 10, 12, and 16 bits per color component
- Supports spatial resolutions from 64 x 64 up to 8192 x 4320
- Supports 4K 60 fps in all supported device families ⁽¹⁾

1. Performance on low power devices might be lower.

LogiCORE IP Facts Table	
Core Specifics	
Supported Device Family ⁽¹⁾	UltraScale+™ Families, UltraScale™ Architecture, Zynq® -7000, 7 Series
Supported User Interfaces	AXI4-Lite, AXI4-Stream ⁽²⁾
Resources	Performance and Resource Utilization web page
Provided with Core	
Design Files	Not Provided
Example Design	Yes
Test Bench	Not Provided
Constraints File	XDC
Simulation Models	Encrypted RTL, VHDL or Verilog Structural
Supported Software Drivers ⁽³⁾	Standalone, V4L2
Tested Design Flows ⁽⁴⁾	
Design Entry	Vivado® Design Suite
Simulation	For supported simulators, see the Xilinx Design Tools: Release Notes Guide .
Synthesis	Vivado Synthesis
Support	
Release Notes and Known Issues	Master Answer Record: 68769
All Vivado IP Change Logs	Master Vivado IP Change Logs: 72775
Xilinx Support web page	

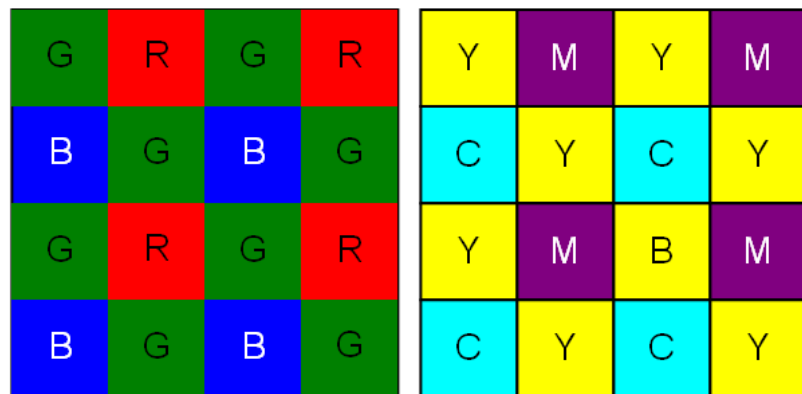
Notes:

1. For a complete listing of supported devices, see the Vivado IP Catalog.
2. Video protocol as defined in the *Video IP: AXI Feature Adoption* section of *AXI Reference Guide* [Ref 1].
3. Standalone driver details can be found in the Vitis directory (<install_directory>/Vitis/<release>/data/embeddedsw/doc/xilinx_drivers.htm). [Linux Demosaic Driver Page](#).
4. For the supported versions of the tools, see the [Xilinx Design Tools: Release Notes Guide](#).

Overview

Images captured by a CMOS/CCD image sensor are monochrome in nature. To generate a color image, three primary colors (typically red, green, and blue) are required for each pixel. Before the invention of color image sensors, the color image was created by superimposing three identical images with three different primary colors. These images were captured by placing different color filters in front of the sensor, allowing a certain bandwidth of the visible light to pass through.

Kodak scientist Dr. Bryce Bayer realized that an image sensor with a Color Filter Array (CFA) pattern would allow the reconstruction of all the colors of a scene from a single image capture. The color filter array is manufactured as part of the image sensor as a layer laid over the phototransistors. Example CFA patterns are shown in [Figure 1-1](#). These are called Bayer patterns and are used in most digital imaging systems.



X22003-112618

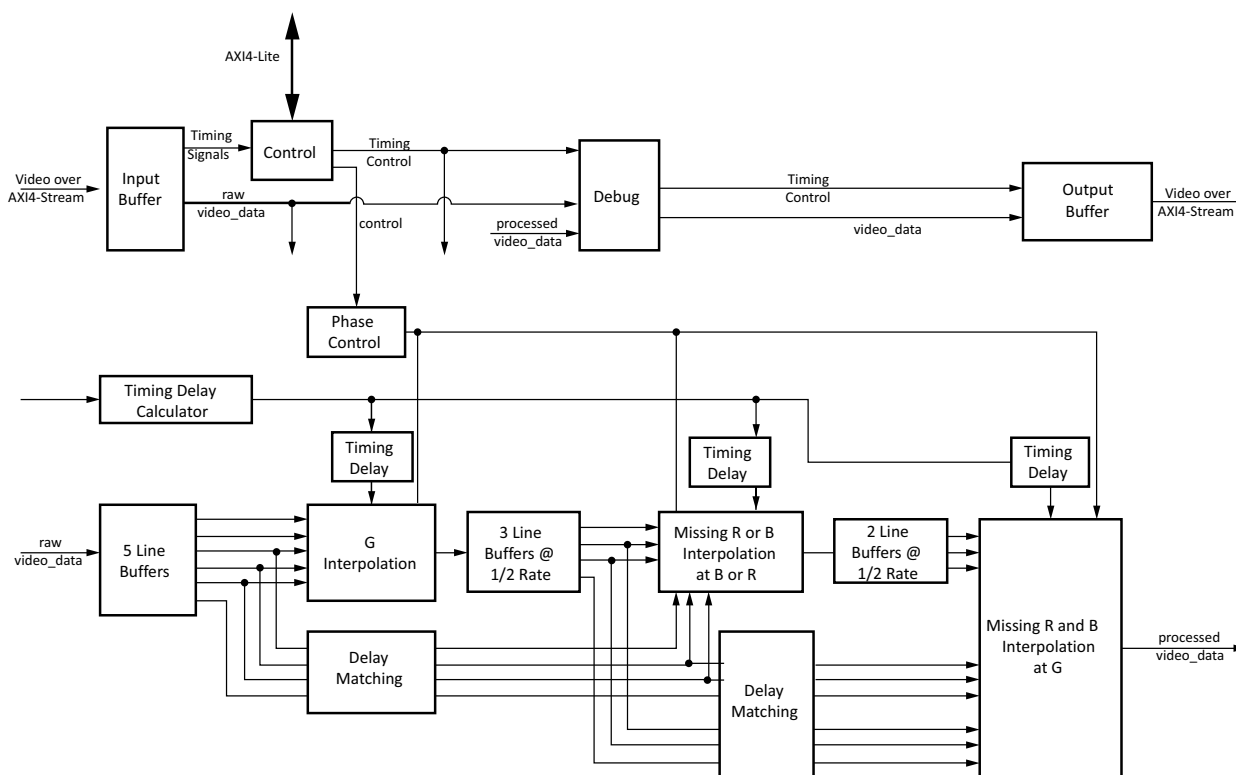
Figure 1-1: RGB and CMY Bayer Sensor Demosaic Patterns

The original data for each pixel contains information only about one color, based on which color filter is positioned over that pixel. However, information for all three primary colors is needed at each pixel to reconstruct a color image. Some missing information can be recreated from the information available in neighboring pixels. This process of recreating the missing color information is called color interpolation or demosaicing, and might require dedicated hardware to process the image data in real-time.

There is no exact method to fully recover the missing information, as color channels have been physically sub-sampled by the CFA before proper low-pass filtering takes place, which might lead to aliasing between color channels.

Perfect recovery of the original signal might not be possible; however, the aliasing can be suppressed significantly by capitalizing on the temporal and spatial redundancies and structured nature of natural images/video sequences.

A variety of simple interpolation methods, such as Pixel Replication, Nearest Neighbor Interpolation, Bilinear Interpolation, and Bicubic Interpolation have been widely used for CFA demosaicing. Simple methods usually compromise quality, and more elaborate methods require the use of an external frame buffer. The Sensor Demosaic core was designed to efficiently suppress interpolation artifacts, such as the zipper and color aliasing effects, by minimizing Chrominance Variances in a 5x5 neighborhood, as illustrated in Figure 1-2.



X21999-112618

Figure 1-2: Xilinx Sensor Demosaic Block Diagram

Image sensor data sheets specify whether the starting position, pixel(0,0) of the Bayer sampling grid is on a red-green or a blue-green line, and whether or not the first pixel is green. The Sensor Demosaic IP core supports all four possible Bayer phase combinations.

Feature Summary

The Sensor Demosaic core reconstructs a color image from an RGB Bayer filtered sensor using a 5x5 interpolation aperture.

Applications

- Pre-processing block for image sensors
 - Video surveillance
 - Industrial imaging
 - Video conferencing
 - Machine vision
 - Other imaging applications
-

Licensing and Ordering

This Xilinx® LogiCORE™ IP module is provided at no cost under the terms of the [Xilinx Core License Agreement](#). The module is shipped as part of the Vivado Design Suite. For full access to all core functionalities in simulation and in hardware, you must request a free license for the core. Contact your [local Xilinx sales representative](#) for information about pricing and availability.

For more information, visit the [Sensor Demosaic product web page](#).

Information about other Xilinx LogiCORE IP modules is available at the [Xilinx Intellectual Property](#) page. For information on pricing and availability of other Xilinx LogiCORE IP modules and tools, contact your [local Xilinx sales representative](#).

Product Specification

Standards

The Sensor Demosaic core is compliant with the AXI4-Stream Video Protocol and AXI4-Lite interconnect standards. Refer to the *Video IP: AXI Feature Adoption* section of the *Vivado AXI Reference Guide* (UG1037) [Ref 1] and *AXI4-Stream Video IP and System Design Guide* (UG934) [Ref 2] for additional information.

Performance

The following sections detail the performance characteristics of the Sensor Demosaic core.

Maximum Frequencies

The following are typical clock frequencies for the target devices:

- UltraScale+™ devices with -1 speed grade or higher: 300 MHz
- Virtex[®]-7 and Virtex UltraScale™ devices with -2 speed grade or higher: 300 MHz
- Kintex[®]-7 and Kintex UltraScale™ devices with -2 speed grade or higher: 300 MHz
- Artix[®]-7 devices with -2 speed grade or higher: 150 MHz

The maximum achievable clock frequency can vary. The maximum achievable clock frequency and all resource counts can be affected by other tool options, additional logic in the device, using a different version of Xilinx[®] tools, and other factors.

Throughput

The Sensor Demosaic supports bi-directional data throttling between its AXI4-Stream slave and master interfaces. If the slave side data source is not providing valid data samples (`s_axis_video_tvalid` is not asserted), the core cannot produce valid output samples after its internal buffers are depleted. Similarly, if the master side interface is not ready to accept valid data samples (`m_axis_video_tready` is not asserted) the core cannot accept valid input samples after its buffers become full.

If the master interface is able to provide valid samples (`s_axis_video_tvalid` is High) and the slave interface is ready to accept valid samples (`m_axis_video_tready` is High), typically the core can process and produce one, two, four, or eight pixels specified by **Samples Per Clock** in the Vivado Integrated Design Environment (IDE) per `ap_clk` cycle.

However, at the end of each scan line and frame the core flushes internal pipelines for several clock cycles, during which the `s_axis_video_tready` is deasserted signaling that the core is not ready to process samples.

When the Sensor Demosaic is processing timed streaming video (which is typical for most video sources), the flushing periods coincide with the blanking periods and therefore do not reduce the throughput of the system.

When operating on a streaming video source (that is, not frame buffered data), the Sensor Demosaic must operate minimally at the burst data rate. For example, 148.5 MHz for a 1080p60 video source for a one sample per clock configuration of the IP. For a 4K 60 fps video source, the core must operate at 297 MHz for a two sample per clock configuration, or 148.5 MHz for a four sample per clock configuration on slower devices such as Artix®-7.

Resource Utilization

For full details about performance and resource utilization, visit the [Sensor Demosaic Performance and Resource Utilization web page](#).

Port Descriptions

The Sensor Demosaic core uses industry standard control and data interfaces to connect to other system components. The following sections describe the various interfaces available with the core. [Figure 2-1](#) illustrates an I/O diagram of the Sensor Demosaic core.

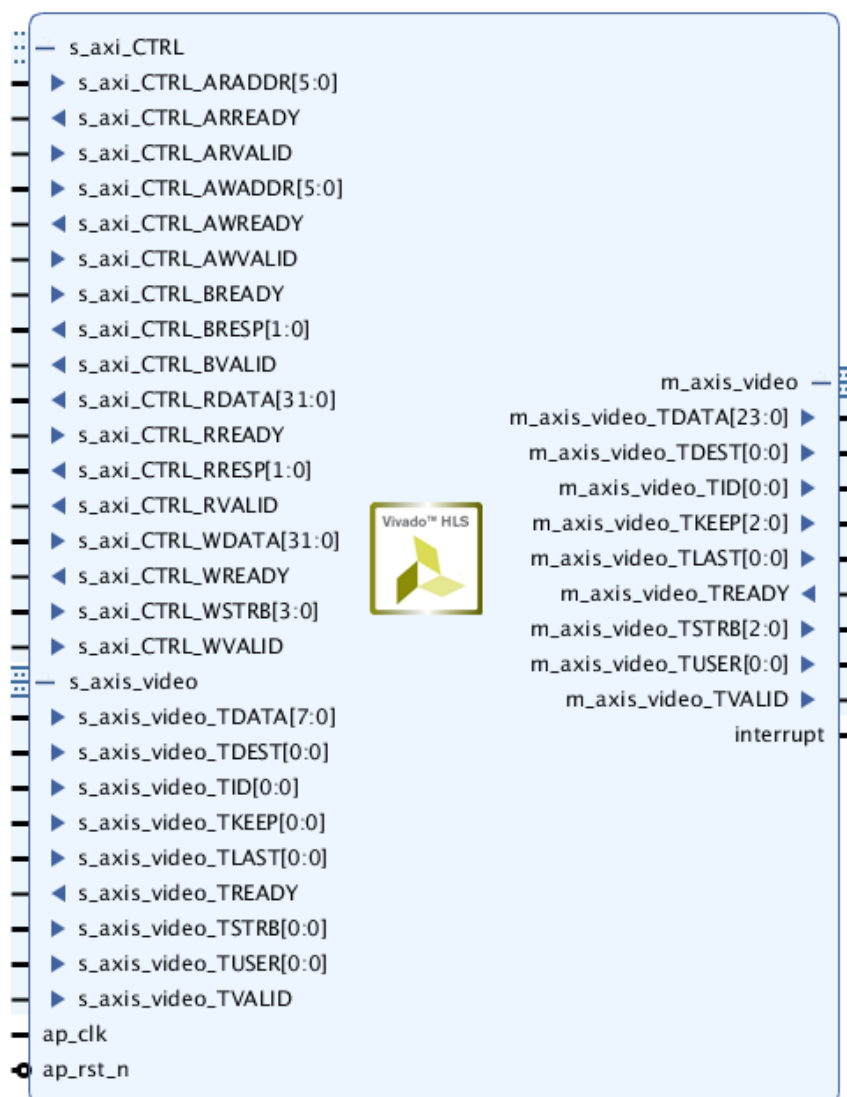


Figure 2-1: Sensor Demosaic Core Top-Level Signaling Interface

Common Interface Signals

Table 2-1 summarizes the signals which are either shared by, or not part of the dedicated AXI4-Stream data or AXI4-Lite control interfaces.

Table 2-1: Common Interface Signals

Signal Name	Direction	Width	Description
AP_CLK	I	1	Video Core Clock
AP_RST_N	I	1	Video Core Active Low Clock Enable
INTERRUPT	O	1	Interrupt Request Pin

The **AP_CLK** and **AP_RST_N** signals are shared between the core, the AXI4-Stream data interfaces, and the AXI4-Lite control interface. The **INTERRUPT** pin is not supported and is reserved for future use.

AP_CLK

The AXI4-Stream and AXI4-Lite interfaces must be synchronous to the core clock signal **AP_CLK**. All AXI4-Stream interface input signals and AXI4-Lite control interface input signals are sampled on the rising edge of **AP_CLK**. All AXI4-Stream output signal changes occur after the rising edge of **AP_CLK**.

AP_RST_N

The **AP_RST_N** pin is an active-Low synchronous reset input pertaining to both AXI4-Lite and AXI4-Stream interfaces. When **AP_RST_N** is set to 0, the core resets at the next rising edge of **AP_CLK**.

Data Interface

The Sensor Demosaic core receives and transmits data using AXI4-Stream interfaces that implement a video protocol as defined in the *Video IP: AXI Feature Adoption* section of the (UG761) *AXI Reference Guide* [Ref 1].

AXI4-Stream Signal Names and Descriptions

Table 2-2 describes the AXI4-Stream signal names and descriptions.



IMPORTANT: In Table 2-2, $TotalDataWidth = data_width * number_of_components * samples_per_clock$. The three values correspond to Maximum Data Width, Number of Video Components, and Samples Per Clock in the IDE respectively. Refer to Chapter 4, *Design Flow Steps* for more information.

Table 2-2: AXI4-Stream Data Interface Signal Descriptions

Signal Name	Direction	Width	Description
s_axis_video_tdata	I	$(data_width * samples_per_clock + 7) / 8 * 8$	Input Video Data
s_axis_video_tvalid	I	1	Input Video Valid Signal
s_axis_video_tready	O	1	Input Ready
s_axis_video_tuser	I	1	Input Video Start Of Frame
s_axis_video_tlast	I	1	Input Video End Of Line
s_axi_video_tstrb	I	s_axis_video tdata/8	Input video data strobe indicates whether the content of the associated byte of TDATA is processed as a data byte or a position byte

Table 2-2: AXI4-Stream Data Interface Signal Descriptions (Cont'd)

Signal Name	Direction	Width	Description
s_axi_video_tkeep	I	s_axis_video_tdata/8	Input video byte qualifier that indicates whether the content of the associated byte of TDATA is processed as part of the data stream
s_axi_video_tid	I	1	Input video data stream identifier
s_axi_video_tdest	I	1	Input video data routing information
m_axis_video_tdata	O	(TotalDataWidth+7)/8*8	Output Video Data
m_axis_video_tvalid	O	1	Output Valid
m_axis_video_tready	I	1	Output Ready
m_axis_video_tuser	O	1	Output Video Start Of Frame
m_axis_video_tlast	O	1	Output Video End Of Line
m_axi_video_tstrb	O	m_axis_video_tdata/8	Output video data strobe indicates whether the content of the associated byte of TDATA is processed as a data byte or a position byte
m_axi_video_tkeep	O	m_axis_video_tdata/8	Output video byte qualifier that indicates whether the content of the associated byte of TDATA is processed as part of the data stream
m_axi_video_tid	O	1	Output video data stream identifier
m_axi_video_tdest	O	1	Output video data routing information

Video Data

The AXI4-Stream interface specification restricts **TDATA** widths to integer multiples of 8 bits. Therefore, any bit data must be padded with zeros on the MSB to form a N*8 bit wide vector before connecting to **s_axis_video_tdata**. Padding does not affect the size of the core.

Similarly, data on the Sensor Demosaic output **m_axis_video_tdata** is packed and padded to multiples of 8 bits as necessary. Zero padding the most significant bits is only necessary for 10 and 12 bit wide data. [Table 2-3](#) and [Table 2-4](#) explain the pixel mapping of AXI4-Stream interface with two pixels per clock and 10 bits per component configuration.

Table 2-3: Dual Pixels per Clock, 10 Bits per Component Mapping for RGB

63:60	59:50	49:40	39:30	29:20	19:10	9:0
zero padding	R1	B1	G1	R0	B0	G0

Table 2-4: Dual Pixels per Clock, 10 bits per Component Mapping for Bayer Sensor

23:20	19:10	9:0
Zero Padding	Bayer Sample 1	Bayer Sample 0

READY/VALID Handshake

A valid transfer occurs whenever **READY**, **VALID**, and **AP_RST_N** are High at the rising edge of **AP_CLK**, as seen in Figure 2-2. During valid transfers, **DATA** only carries active video data. Blank periods and ancillary data packets are not transferred through the AXI4-Stream video protocol.

Guidelines on Driving s_axis_video_tvalid

When **s_axis_video_tvalid** is asserted, no interface signals (except the Sensor Demosaic core driving **s_axis_video_tready**) can change value until the transaction completes (**s_axis_video_tready**, **s_axis_video_tvalid**, and **AP_RST_N** are High on the rising edge of **AP_CLK**). When asserted, **s_axis_video_tvalid** can only be deasserted after a transaction has completed. Transactions cannot be retracted or aborted. In any cycle following a transaction, **s_axis_video_tvalid** can either be deasserted or remain asserted to initiate a new transfer.

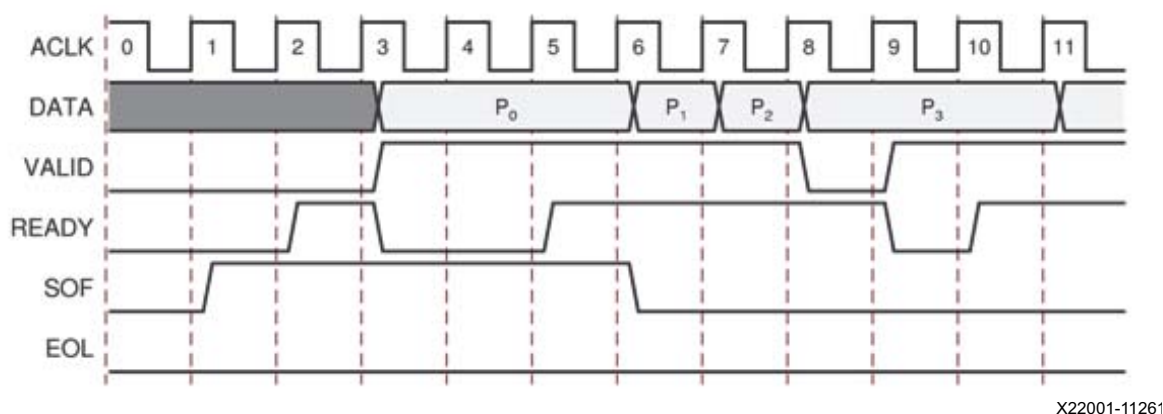


Figure 2-2: Example of READY/VALID Handshake, Start of a New Frame

Guidelines on Driving m_axis_video_tready

The **m_axis_video_tready** signal can be asserted before, during, or after the cycle in which the Sensor Demosaic core asserts **m_axis_video_tvalid**. The assertion of **m_axis_video_tready** can be dependent on the value of **m_axis_video_tvalid**. A slave

that can immediately accept data qualified by `m_axis_video_tvalid` should preassert its `m_axis_video_tready` signal until data is received. Alternatively, `m_axis_video_tready` can be registered and driven the cycle following `VALID` assertion.



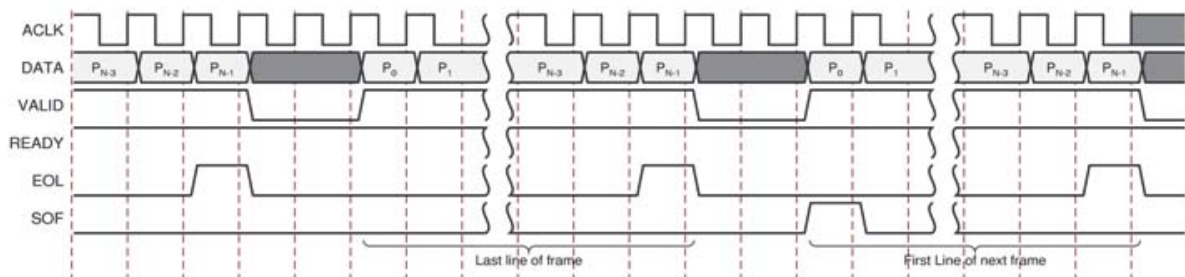
RECOMMENDED: To minimize latency, your custom core slave interface should drive `READY` independently, or preassert `READY`.

Start of Frame Signals - `m_axis_video_tuser0`, `s_axis_video_tuser0`

The Start-Of-Frame (**SOF**) signal, physically transmitted over the AXI4-Stream **TUSER0** signal, marks the first pixel of a video frame. The SOF pulse is one valid transaction wide, and must coincide with the first pixel of the frame, as seen in Figure 2-2. The **SOF** signal serves as a frame synchronization signal, which allows downstream cores to reinitialize, and detect the first pixel of a frame. The **SOF** signal can be asserted an arbitrary number of **AP_CLK** cycles before the first pixel value is presented on **DATA**, as long as a **VALID** is not asserted.

End of Line Signals - `m_axis_video_tlast`, `s_axis_video_tlast`

The End-Of-Line (**EOL**) signal, physically transmitted over the AXI4-Stream **TLAST** signal, marks the last pixel of a line. The **EOL** pulse is 1 valid transaction wide, and must coincide with the last pixel of a scanline, as seen in Figure 2-3.



X22000-112618

Figure 2-3: Use of EOL and SOF Signals

Control Interface

The AXI4-Lite register interface dynamically controls the behavior of the core. The AXI4-Lite slave interface facilitates integrating the core into a processor system, or along with other video or AXI4-Lite compliant IP, connected through AXI4-Lite interface to an AXI4-Lite master. The core cannot be instantiated without the AXI4-Lite control interface.

AXI4-Lite Interface

The AXI4-Lite interface allows you to dynamically control parameters within the core. Core configuration can be accomplished using an AXI4-Lite master state machine, or an embedded Arm®, or a soft system processor such as a MicroBlaze™ processor.

The Sensor Demosaic core can be controlled through the AXI4-Lite interface by using functions provided by the driver in the Vitis™ software platform. Another method is performing read and write transactions to the Sensor Demosaic register space, but this method should only be used when the first method is not available.

Table 2-5: AXI4-Lite Interface Signals

Signal Name	Direction	Width	Description
s_axi_CTRL_awvalid	I	1	AXI4-Lite Write Address Channel Write Address Valid.
s_axi_CTRL_awread	O	1	AXI4-Lite Write Address Channel Write Address Ready. Indicates DMA ready to accept the write address.
s_axi_CTRL_awaddr	I	32	AXI4-Lite Write Address Bus
s_axi_CTRL_wvalid	I	1	AXI4-Lite Write Data Channel Write Data Valid.
s_axi_CTRL_wready	O	1	AXI4-Lite Write Data Channel Write Data Ready. Indicates DMA is ready to accept the write data.
s_axi_CTRL_wdata	I	32	AXI4-Lite Write Data Bus
s_axi_CTRL_bresp	O	2	AXI4-Lite Write Response Channel. Indicates results of the write transfer.
s_axi_CTRL_bvalid	O	1	AXI4-Lite Write Response Channel Response Valid. Indicates response is valid.
s_axi_CTRL_bready	I	1	AXI4-Lite Write Response Channel Ready. Indicates target is ready to receive response.
s_axi_CTRL_arvalid	I	1	AXI4-Lite Read Address Channel Read Address Valid
s_axi_CTRL_arready	O	1	Ready. Indicates DMA is ready to accept the read address.
s_axi_CTRL_araddr	I	32	AXI4-Lite Read Address Bus
s_axi_CTRL_rvalid	O	1	AXI4-Lite Read Data Channel Read Data Valid
s_axi_CTRL_rready	I	1	AXI4-Lite Read Data Channel Read Data Ready. Indicates target is ready to accept the read data.
s_axi_CTRL_rdata	O	32	AXI4-Lite Read Data Bus
s_axi_CTRL_rresp	O	2	AXI4-Lite Read Response Channel Response. Indicates results of the read transfer.

Register Space

The core has seven core-specific registers which allow you to dynamically control the operation of the core. All registers have an initial value of 0. Table 2-6 describes the register names.

Table 2-6: Register Names and Descriptions

Address (hex) BASEADDR +	Register Name	Access Type	Register Description
0x0000	Control	R/W	Bit 0: ap_start (Read/Write/COH) ⁽¹⁾ Bit 1: ap_done (Read/COR) ⁽¹⁾ Bit 2: ap_idle (Read) Bit 3: ap_ready (Read) Bit 7: auto_restart (Read/Write) Others: reserved
0x0004	Global Interrupt Enable	R/W	Bit 0: Global Interrupt Enable Others: reserved This register is not used but reserved for future use.
0x0008	IP Interrupt Enable Register	R/W	Bit 0: ap_done Bit 1: ap_ready Others: reserved This register is not used but reserved for future use.
0x000C	IP Interrupt Status Register	R	Bit 0: ap_done Bit 1: ap_ready Others: reserved This register is not used but reserved for future use.
0x0010	Active Width	R/W	Number of Active Pixels per Scanline
0x0018	Active Height	R/W	Number of Active Lines per Frame
0x0028	Bayer Phase	R/W	Bits 1-0: Bayer sampling grid starting position

Notes:

1. COR = Clear on Read, COH - Clear on Handshake

CONTROL (0x0000) Register

This register controls running of Sensor Demosaic. Bit 0 of the `control` register, `ap_start`, kicks off the core from software. Writing 1 to this bit start the core to generate a video frame. To set the core in free running mode, bit 7 of this register, `auto_restart`, must be set to 1. Bit 1-3 are not used now but reserved for future use.

ACTIVE_WIDTH (0x0010) Register

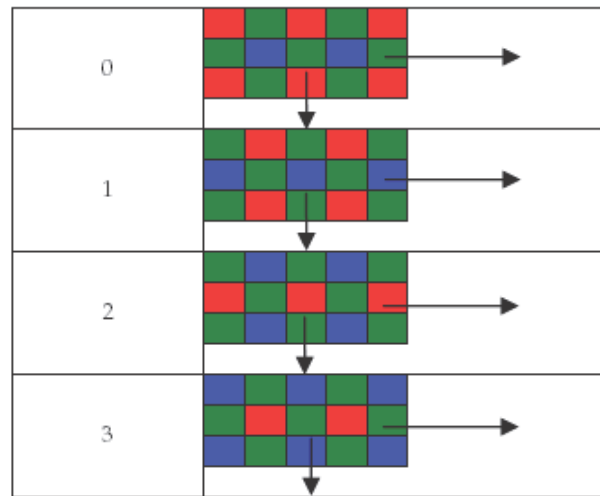
The `active_width` register encodes the number of active pixels per scan. Supported values are 64 and the value provided in the Maximum number of Columns field in the IDE. To avoid processing errors, you should restrict values written to `active_width` to the range supported by the core instance.

ACTIVE_HEIGHT (0x0018) Register

The `active_height` register encodes the number of active scan lines per frame. Supported values are between 64 and the value provided in the Maximum number of Rows field in the IDE. To avoid processing errors, you should restrict values written to `active_height` to the range supported by the core instance.

BAYER_PHASE (0x0028) Register

Image sensor data sheets specify whether the starting position, pixel(0,0), of the Bayer sampling grid is on a red-green, or blue-green line, and whether the first pixel is green or not. The Xilinx® Sensor Demosaic IP supports all four possible Bayer phase combinations. Bits 1:0 specify whether the top-left corner of the Bayer sampling grid starts with Green, Red, or Blue Pixel, according to Figure 2-4, which displays top-left corner of the image sample matrix along with the Bayer Phase Register value combinations.



X22002-112618

Figure 2-4: Bayer Phase Register Combination Definitions

Designing with the Core

General Design Guidelines

The Sensor Demosaic core interpolates Bayer sub-sampled image sensor data to downstream processing modules that process RGB data. The core processes samples provided using an AXI4-Stream slave interface, outputs pixels using an AXI4-Stream master interface, and is controlled using an AXI4-Lite interface. The Sensor Demosaic block cannot change the input/output image sizes, the input and output pixel clock rates, or the frame rate.



RECOMMENDED: *The Sensor Demosaic core is designed to be used in conjunction with the Video In to AXI4-Stream and Video Timing Controller cores.*

The Video Timing Controller core measures the timing parameters, such as number of active scan lines, number of active pixels per scan line of the image sensor. The Video In to AXI4-Stream core formats couples the sensor data interface to AXI4-Stream.

Clocking

The Sensor Demosaic has only one clock domain. All interfaces (master and slave AXI4-Stream video interfaces and AXI4-Lite interface) use the `ap_clk` pin as its clock source.

Pixel throughput of the Sensor Demosaic core is defined by the product of the clock frequency times the **Samples per Clock** setting in the Vivado® IDE. With a clock frequency of 300 MHz for `ap_clk`, and a two sample per clock configuration, the Sensor Demosaic is capable of a 600 mega pixel throughput rate, which is sufficient to handle 4K resolutions at 60Hz.

Resets

The Sensor Demosaic only has a hardware reset option, `ap_rst_n` pin. No software reset option is available. The external reset pulse needs to be held for 16 or more `ap_clk` cycles to reset the core. The `ap_rst_n` signal is synchronous to the `ap_clk` clock domain. The `ap_rst_n` signal resets the entire core including the AXI4-Lite and AXI4-Stream interfaces.

System Considerations

The Sensor Demosaic core must be configured for the actual input image frame-size to operate properly. To gather the frame size information from the image video stream, it can be connected to the Video In to AXI4-Stream input and the Video Timing Controller. The timing detector logic in the Video Timing Controller gathers the video timing signals. The AXI4-Lite control interface on the Video Timing Controller allows the system processor to read out the measured frame dimensions, and program all downstream cores, such as the Sensor Demosaic, with the appropriate image dimensions.

Programming Sequence

All Sensor Demosaic processing parameters other than image size can be changed dynamically on a frame-by-frame basis and the change is picked up immediately. If the image size needs to be changed on the fly or the entire system needs to be restarted, it is recommended that pipelined Xilinx® IP video cores are disabled/reset from system output towards the system input, and programmed/enabled from system output to system input.

Design Flow Steps

This chapter describes customizing and generating the core, constraining the core, and the simulation, synthesis and implementation steps that are specific to this IP core. More detailed information about the standard Vivado[®] design flows and the IP integrator can be found in the following Vivado Design Suite user guides:

- *Vivado Design Suite User Guide: Designing IP Subsystems using IP Integrator* (UG994) [\[Ref 8\]](#)
- *Vivado Design Suite User Guide: Designing with IP* (UG896) [\[Ref 4\]](#)
- *Vivado Design Suite User Guide: Getting Started* (UG910) [\[Ref 6\]](#)
- *Vivado Design Suite User Guide: Logic Simulation* (UG900) [\[Ref 7\]](#)

Customizing and Generating the Core

You can customize the IP for use in your design by specifying values for the various parameters associated with the IP core using the following steps:

1. Select the IP from the IP catalog.
2. Double-click on the selected IP or select the Customize IP command from the toolbar or popup menu.

For details, see the sections, “Working with IP” and “Customizing IP for the Design” in the *Vivado Design Suite User Guide: Designing with IP* (UG896) [\[Ref 4\]](#) and the “Working with the Vivado IDE” section in the *Vivado Design Suite User Guide: Getting Started* (UG910) [\[Ref 6\]](#).

If you are customizing and generating the core in the Vivado IP Integrator, see the *Vivado Design Suite User Guide: Designing IP Subsystems Using IP Integrator* (UG994) [\[Ref 8\]](#) for detailed information. IP Integrator might auto-compute certain configuration values when validating or generating the design. To check whether the values do change, see the description of the parameter in this chapter. To view the parameter value you can run the `validate_bd_design` command in the Tcl console.

Note: Figures in this chapter are illustrations of the Vivado IDE. This layout might vary from the current version.

Interface

The Xilinx® Sensor Demosaic core is easily configured to meet your specific requirements through the Vivado Design Suite. This section provides a quick reference to parameters that can be configured at generation time.

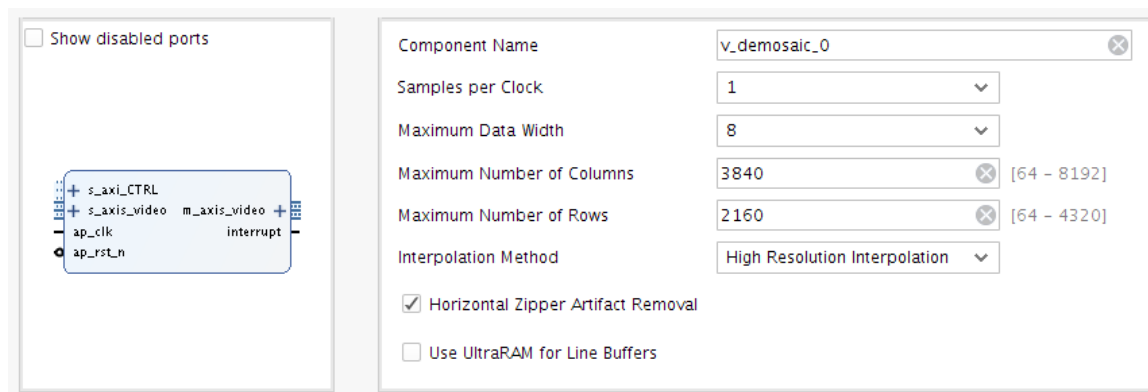


Figure 4-1: Customize IP Screen

The screen displays a representation of the IP symbol on the left side, and the parameter assignments on the right side, which are described as follows:

- **Component Name:** The component name is used as the base name of output files generated for the module. Names must begin with a letter and must be composed from characters: a to z, 0 to 9, and "_".
- **Samples Per Clock:** Specifies the number of pixel processed per clock cycle. Permitted values are 1, 2, 4, and 8 samples per clock. This parameter determines the throughput of the IP. The more samples per clock, the larger throughput it provides. The larger throughput always needs more hardware resources.
- **Maximum Data Width:** Specifies the bit width of input samples. Permitted values are 8, 10, 12, and 16 bits. This parameter should match the Video Component Width of the video IP core connected to the slave AXI4-Stream video interface.
- **Maximum Number of Columns:** Specifies maximum video columns/pixels the IP core could produce at run time. Any video width that is less than the Maximum Number of Columns can be programmed through AXI4-Lite control interface without regenerating the core.
- **Maximum Number of Rows:** Specifies maximum video rows/lines the IP core could produce at run time. Any video height that is less than the Maximum Number of Rows can be programmed through AXI4-Lite control interface without regenerating the core.
- **Interpolation Method:** There are two interpolation methods from which to choose:
 - **Fringe Tolerant Interpolation:** This method produces softer images with suppressed fringing artifacts. Use this option for low-cost optics that could possibly introduce color fringing artifacts.

- **High Resolution Interpolation:** This method is suggested for high quality optics and applications where high resolution is essential. Selecting this uses more block RAMs and slices and approximately doubles the number of DSP48s.
- **Horizontal Zipper Artifact Removal:** This option adds a post processing smoothing filter to remove horizontal zipper artifacts. The post processing filter softens the output image, and incurs some additional slice resources.
- **Use UltraRAM for Line Buffers:** In UltraScale+ devices, line buffers used for interpolating the pixels can be stored in UltraRAM instead of Block RAM.

User Parameters

Table 4-1 shows the relationship between the fields in the Vivado IDE and the User Parameters (which can be viewed in the Tcl Console).

Table 4-1: Vivado IDE Parameter to User Parameter Relationship

Vivado IDE Parameter/Value	User Parameter/Value	Default Value
Top-Level Parameters		
Samples per Clock	SAMPLES_PER_CLOCK	1
Maximum Number of Columns	MAX_COLS	3840
Maximum Number of Rows	MAX_ROWS	2160
Maximum Data Width	MAX_DATA_WIDTH	8
Interpolation Method	ALGORITHM	0
High Resolution Interpolation	0	
Fringe Tolerant Interpolation	1	
Horizontal Zipper Arifact Removal	ENABLE_ZIPPER_REMOVAL	true
Use UltraRAM for Line Buffers	USE_URAM	0

Output Generation

For details, see “Generating IP Output Products” in the *Vivado Design Suite User Guide: Designing with IP* (UG896) [Ref 4].

Constraining the Core

This section contains information about constraining the core in the Vivado Design Suite.

Required Constraints

The only constraints required are clock frequency constraints for the core clock, `ap_clk`. Paths from AXI4-Lite signals should be constrained with a `set_false_path`, causing setup and hold checks to be ignored for AXI4-Lite signals. These constraints are provided in the XDC constraints file included with the core.

Device, Package, and Speed Grade Selections

This section is not applicable for this IP core.

Clock Frequencies

This section is not applicable for this IP core.

Clock Management

This section is not applicable for this IP core.

Clock Placement

This section is not applicable for this IP core.

Banking

This section is not applicable for this IP core.

Transceiver Placement

This section is not applicable for this IP core.

I/O Standard and Placement

This section is not applicable for this IP core.

Simulation

For comprehensive information about Vivado simulation components, as well as information about using supported third party tools, see the *Vivado Design Suite User Guide: Logic Simulation* (UG900) [Ref 7].

Synthesis and Implementation

This section contains information about synthesis and implementation in the Vivado Design Suite. For details about synthesis and implementation, see the Synthesizing IP and Implementing IP sections in the *Vivado Design Suite User Guide: Designing with IP (UG896)* [\[Ref 4\]](#).

Detailed Example Design

This chapter provides two example systems that include the Sensor Demosaic core; a simulation example design and a synthesizable example design. The example designs highlight the following key system-level aspects of designing with the Sensor Demosaic core:

- Typical usage of sensor demosaic in conjunction with other cores and AXI master.
- Configuration of sensor demosaic registers on the fly.

The supported platforms are listed in [Table 5-1](#).

Table 5-1: Supported Platforms

Development Boards	Additional Hardware	Processor
KC705	N/A	MicroBlaze™ processor
ZCU102	N/A	R5
ZCU104	N/A	R5
ZCU106	N/A	R5

To open the example project, perform the following steps:

1. Select the **Sensor Demosaic IP** from IP Catalog.
2. Double-click on the selected IP or right-click the IP and select **Customize IP** from the menu.
3. Configure the build-time parameters in the **Customize IP** window and click **OK**. The Vivado® IDE generates an example design matching the build-time configuration.
4. In the **Generate Output Products** window, select **Generate** or **Skip**. If **Generate** is selected, the output products of the IP are generated after a brief moment.
5. Right-click **Sensor Demosaic** in **Sources** panel and select **Open IP Example Design** from the menu.
6. In the **Open IP Example Design** window, select example project directory and click **OK**. The Vivado software then runs automation to generate example design in selected directory.

The generated project contains two example designs. Figure 5-1 shows the Source panel of the example project. The synthesizable example block design, along with the top-level file, resides in the Design Sources catalog. Simulation example design files (including the block design file, SystemVerilog test bench, and another task file) are under Simulation Sources.

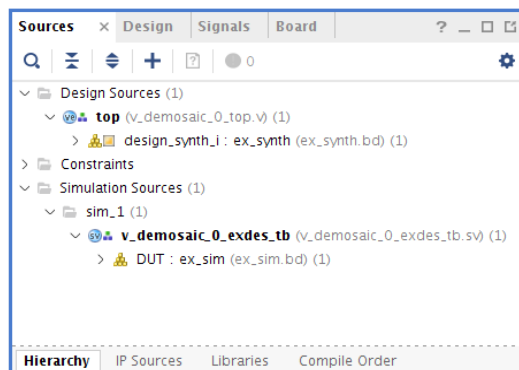


Figure 5-1: Example Project Source Panel

Simulation Example Design

The simulation example design contains the following video IP cores:

- Video Test Pattern Generator (TPG)
- Sensor Demosaic
- Video Timing Controller (VTC)
- AXI4-Stream to Video Output bridge

The design also contains a AXI Verification IP (VIP) core (to enable register programming) connected to an AXI interconnect.

After all configurations are performed, the AXI VIP core starts the TPG, Sensor Demosaic, and Video Timing Controller cores. Because this design runs an RTL simulation, running large video frames can take a long time. Xilinx recommends running a small video size for this example design. Width and height values, as well as other register settings, can be changed in the simulation test bench `v_demosaic_0_exdes_tb.sv` file.

The TPG core is in free-running mode after kickoff. It generates video stream pixels at the clock rate of `ap_clk`. The Sensor Demosaic core receives video frames from the AXI4-Stream slave interface and generates video output. The AXI4-Stream to Video Out core, working with Video Timing Controller, interfaces from the AXI4-Stream interface implementing a Video Protocol to a video source (parallel video data, video syncs, and blanks).

The example design checks the output port is locked from the AXI4-Stream to Video Out core. The locked port indicates that the output timing is locked to the output video. The example design indicates that the test has completed successfully if video lock is successfully detected.

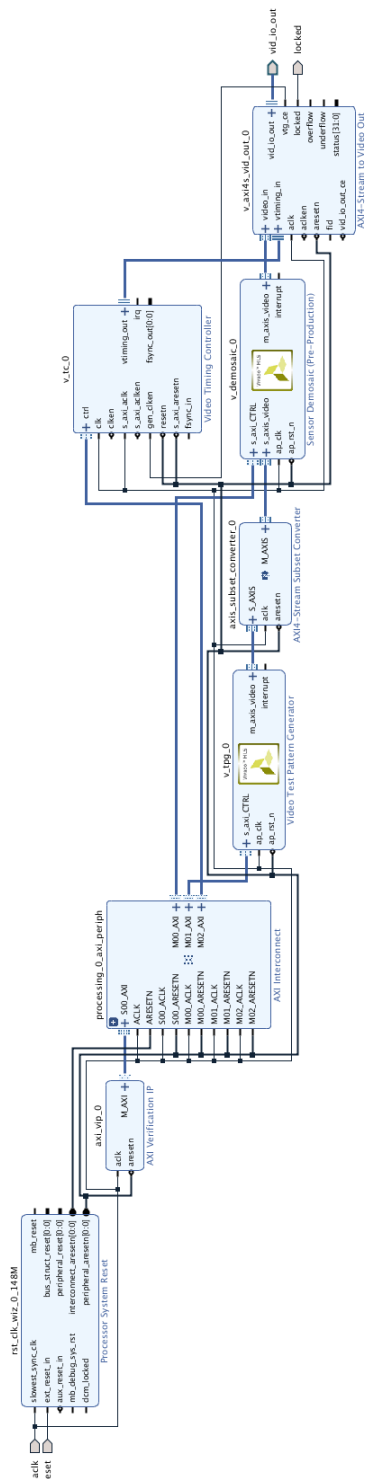


Figure 5-2: Simulation Example Block Design

Figure 5-3: Synthesizable Example Block Design

The difference between the synthesizable design and the simulation example design is the use of a processor instead of the AXI VIP core as AXI master. The locked port of AXI4-Stream to Video Out is connected to the axi_gpio_lock core and the processor polls the corresponding register for a sign that the test passed.

The synthesizable example design requires both Vivado and the Vitis software platform.

The first step is to run synthesis, implementation, and bitstream generation in Vivado. After all those steps are done, select **File > Export > Export Hardware**. In the window, select **Include bitstream**, select an export directory and click **OK**.

The remaining work is performed in the Vitis software platform. The Sensor Demosaic example design file can be found at Vitis software platform directory:

```
(<install_directory>/<release>/data/embeddedsw/XilinxProcessorIPLib/drivers/
v_demosaic_v1_0/examples/
```

Example application design source files (contained within the **examples** folder) are tightly coupled with the Sensor Demosaic example design available in Vivado Catalog.

The **vdemosaic_example.tcl** file automates the process of generating the downloadable bit and **.elf** files from the provided example **.hdf** file.

To run the provided Tcl script:

1. Copy the exported example design hdf file in the **examples** directory of the driver.
2. Launch the Xilinx Software Command-Line Tool (**xsct**) terminal.
3. Use **cd** to access the **examples** directory.
4. Source the **.tcl** file:

```
xsct%>source vdemosaic_example.tcl
```

5. Execute the script:

```
xsct%>vdemosaic_example <xsa_file_name.xsa>
```

The Tcl script performs the following actions:

- Creates the workspace
- Creates the HW project
- Creates BSP
- Creates application project
- Builds BSP and application project

After the process is complete, the required files are available in:

```
bit file -> vdemosaic_example_hw_platform/hw folder
elf file -> vdemosaic_example.sdk/vtpg_example_design/{Debug/Release} folder
```

Next, perform the following steps to run the software application:



IMPORTANT: *To do so, make sure that the hardware is powered on and a Digilent Cable or an USB Platform Cable is connected to the host PC. Also, ensure that a USB cable is connected to the UART port of the board.*

1. Launch the Vitis software platform.
2. Set the workspace to the `vdemosaic_example.sdk` folder in the prompted window. The Vitis software platform project opens automatically. If a welcome page shows up, close that page.
3. Download the bitstream into the FPGA by selecting **Xilinx Tools > Program FPGA**. The Program FPGA dialog box opens.
4. Ensure that the Bitstream field shows the bitstream file generated by the Tcl script, and then click **Program**.

Note: The DONE LED on the board turns green if the programming is successful.

5. A terminal program (HyperTerminal or PuTTY) is needed for UART communication. Open the program, choose the appropriate port, set the baud rate to 115200, and establish a serial port connection.
6. Select and right-click the `vdemosaic_example_design` application in the Project_Explorer panel.
7. Select **Run As > Launch on Hardware (System Debugger)**.
8. Select the **Binaries** and **Qualifier** in the window, and click **OK**. The example design test results are shown in the terminal program.

For more information, visit www.xilinx.com/tools/vitis.htm.

When executed on the board, the example application performs the following actions:

- Programs the Video Clock Generator to 1080p@60Hz
- Programs the TPG and Sensor Demosaic to 1080p@60Hz
- Checks for Video Lock and reports the status (PASS/FAIL) on UART
- Repeats steps 1-3 for 4KP@30Hz and 4KP@60Hz

Verification, Compliance, and Interoperability

Simulation

A highly parameterizable test bench was used to test the Sensor Demosaic core in Vivado® HLS. Testing included the following:

- Register accesses
 - Processing multiple frames of data
 - Varying IP throughput and pixel data width
 - Testing of various frame sizes
 - Varying parameter settings
-

Hardware Testing

The Sensor Demosaic core has been validated in hardware by Xilinx to represent a variety of parameterizations, including the following:

- A test design was developed for the core that incorporated a processor, AXI4-Lite interconnect and various other peripherals. The processor was responsible for the following:
 - Programming the video clock to match tested video resolution
 - Configuring the Sensor Demosaic core with different resolutions
 - Launching the test
 - Reporting the Pass/Fail status of the test and any errors that were found

Interoperability

The core slave (input) AXI4-Stream interface can work directly with Bayer pattern data, and the core produces RGB video data.

Upgrading

This appendix contains information about upgrading to a more recent version of the IP core. This appendix does not apply to this core.

Debugging

This appendix includes details about resources available on the Xilinx Support website and debugging tools.

Finding Help on Xilinx.com

To help in the design and debug process when using the Sensor Demosaic core, the [Xilinx Support web page](#) contains key resources such as product documentation, release notes, answer records, information about known issues, and links obtaining further product support.

Documentation

This product guide is the main document associated with the Sensor Demosaic. This guide, along with documentation related to all products that aid in the design process, can be found on the [Xilinx Support web page](#) or by using the Xilinx Documentation Navigator.

Download the Xilinx Documentation Navigator from the [Downloads page](#). For more information about this tool and the features available, open the online help after installation.

Answer Records

Answer Records include information about commonly encountered problems, helpful information on how to resolve these problems, and any known issues with a Xilinx product. Answer Records are created and maintained daily ensuring that users have access to the most accurate information available.

Answer Records for this core are listed below, and can also be located by using the Search Support box on the main [Xilinx support web page](#). To maximize your search results, use proper keywords such as

- Product name
- Tool message(s)
- Summary of the issue encountered

A filter search is available after results are returned to further target the results.

Master Answer Records for the Sensor Demosaic Core

AR: [68769](#)

Technical Support

Xilinx provides technical support at the [Xilinx Support web page](#) for this LogiCORE™ IP product when used as described in the product documentation. Xilinx cannot guarantee timing, functionality, or support if you do any of the following:

- Implement the solution in devices that are not defined in the documentation.
- Customize the solution beyond that allowed in the product documentation.
- Change any section of the design labeled DO NOT MODIFY.

To contact Xilinx Technical Support, navigate to the [Xilinx Support web page](#).

Debug Tools

There are many tools available to address Sensor Demosaic core design issues. It is important to know which tools are useful for debugging various situations.

Vivado Design Suite Debug Feature

The Vivado® Design Suite debug feature inserts logic analyzer and virtual I/O cores directly into your design. The debug feature also allows you to set trigger conditions to capture application and integrated block port signals in hardware. Captured signals can then be analyzed. This feature in the Vivado IDE is used for logic debugging and validation of a design running in Xilinx devices.

The Vivado logic analyzer is used with the logic debug IP cores, including:

- ILA 2.0 (and later versions)
- VIO 2.0 (and later versions)

See the *Vivado Design Suite User Guide: Programming and Debugging* (UG908) [\[Ref 5\]](#).

Hardware Debug

Hardware issues can range from link bring-up to problems seen after hours of testing. This section provides debug steps for common issues. The Vivado debug feature is a valuable resource to use in hardware debug. The signal names mentioned in the following individual sections can be probed using the Vivado debug feature for debugging the specific problems.

General Checks

Ensure that all the timing constraints for the core were properly incorporated from the example design and that all constraints were met during implementation.

- Does it work in post-place and route timing simulation? If problems are seen in hardware but not in timing simulation, this could indicate a PCB issue. Ensure that all clock sources are active and clean.
- If using MMCMs in the design, ensure that all MMCMs have obtained lock by monitoring the **LOCKED** port.

Additional Resources

Xilinx Resources

For support resources such as Answers, Documentation, Downloads, and Forums, see [Xilinx Support](#).

Documentation Navigator and Design Hubs

Xilinx[®] Documentation Navigator provides access to Xilinx documents, videos, and support resources, which you can filter and search to find information. To open the Xilinx Documentation Navigator (DocNav):

- From the Vivado[®] IDE, select **Help > Documentation and Tutorials**.
- On Windows, select **Start > All Programs > Xilinx Design Tools > DocNav**.
- At the Linux command prompt, enter `docnav`.

Xilinx Design Hubs provide links to documentation organized by design tasks and other topics, which you can use to learn key concepts and address frequently asked questions. To access the Design Hubs:

- In the Xilinx Documentation Navigator, click the **Design Hubs View** tab.
- On the Xilinx website, see the [Design Hubs](#) page.

Note: For more information on Documentation Navigator, see the [Documentation Navigator](#) page on the Xilinx website.

References

These documents provide supplemental material useful with this user guide:

1. *Vivado AXI Reference Guide* ([UG1037](#))
2. *AXI4-Stream Video IP and System Design Guide* ([UG934](#))
3. *ISE to Vivado Design Suite Migration Guide* ([UG911](#))
4. *Vivado Design Suite User Guide: Designing with IP* ([UG896](#))
5. *Vivado Design Suite User Guide: Programming and Debugging* ([UG908](#))
6. *Vivado Design Suite User Guide: Getting Started* ([UG910](#))
7. *Vivado Design Suite User Guide: Logic Simulation* ([UG900](#))
8. *Vivado Design Suite User Guide: Designing IP Subsystems Using IP Integrator* ([UG994](#))

Revision History

The following table shows the revision history for this document.

Section	Revision Summary
11/15/2019 Version 1.0	
Synthesizable Example Design	Updated with the Vitis software platform flow.
12/05/2018 Version 1.0	
Table 2-6	Updated Bayer Phase register address from 0x0020 to 0x0028.
04/04/2018 Version 1.0	
General updates	- Added option to use UltraRAM for line buffers on UltraScale+ devices. - Added support for ZCU102, ZCU104, and ZCU106 boards in the synthesizable example design.
10/04/2017 Version 1.0	
General updates	Initial Xilinx release.

Please Read: Important Legal Notices

The information disclosed to you hereunder (the "Materials") is provided solely for the selection and use of Xilinx products. To the maximum extent permitted by applicable law: (1) Materials are made available "AS IS" and with all faults, Xilinx hereby DISCLAIMS ALL WARRANTIES AND CONDITIONS, EXPRESS, IMPLIED, OR STATUTORY, INCLUDING BUT NOT LIMITED TO WARRANTIES OF MERCHANTABILITY, NON-INFRINGEMENT, OR FITNESS FOR ANY PARTICULAR PURPOSE; and (2) Xilinx shall not be liable (whether in contract or tort, including negligence, or under any other theory of liability) for any loss or damage of any kind or nature related to, arising under, or in connection with, the Materials (including your use of the Materials), including for any direct, indirect, special, incidental, or consequential loss or damage (including loss of data, profits, goodwill, or any type of loss or damage suffered as a result of any action brought by a third party) even if such damage or loss was reasonably foreseeable or Xilinx had been advised of the possibility of the same. Xilinx assumes no obligation to correct any errors contained in the Materials or to notify you of updates to the Materials or to product specifications. You may not reproduce, modify, distribute, or publicly display the Materials without prior written consent. Certain products are subject to the terms and conditions of Xilinx's limited warranty, please refer to Xilinx's Terms of Sale which can be viewed at <https://www.xilinx.com/legal.htm#tos>; IP cores may be subject to warranty and support terms contained in a license issued to you by Xilinx. Xilinx products are not designed or intended to be fail-safe or for use in any application requiring fail-safe performance; you assume sole risk and liability for use of Xilinx products in such critical applications, please refer to Xilinx's Terms of Sale which can be viewed at <https://www.xilinx.com/legal.htm#tos>.

AUTOMOTIVE APPLICATIONS DISCLAIMER

AUTOMOTIVE PRODUCTS (IDENTIFIED AS "XA" IN THE PART NUMBER) ARE NOT WARRANTED FOR USE IN THE DEPLOYMENT OF AIRBAGS OR FOR USE IN APPLICATIONS THAT AFFECT CONTROL OF A VEHICLE ("SAFETY APPLICATION") UNLESS THERE IS A SAFETY CONCEPT OR REDUNDANCY FEATURE CONSISTENT WITH THE ISO 26262 AUTOMOTIVE SAFETY STANDARD ("SAFETY DESIGN"). CUSTOMER SHALL, PRIOR TO USING OR DISTRIBUTING ANY SYSTEMS THAT INCORPORATE PRODUCTS, THOROUGHLY TEST SUCH SYSTEMS FOR SAFETY PURPOSES. USE OF PRODUCTS IN A SAFETY APPLICATION WITHOUT A SAFETY DESIGN IS FULLY AT THE RISK OF CUSTOMER, SUBJECT ONLY TO APPLICABLE LAWS AND REGULATIONS GOVERNING LIMITATIONS ON PRODUCT LIABILITY.

This document contains preliminary information and is subject to change without notice. Information provided herein relates to products and/or services not yet available for sale, and provided solely for information purposes and are not intended, or to be construed, as an offer for sale or an attempted commercialization of the products and/or services referred to herein.

© Copyright 2017-2019 Xilinx, Inc. Xilinx, the Xilinx logo, Alveo, Artix, Kintex, Spartan, Versal, Virtex, Vivado, Zynq, and other designated brands included herein are trademarks of Xilinx in the United States and other countries. AMBA, AMBA Designer, Arm, ARM1176JZ-S, CoreSight, Cortex, PrimeCell, Mali, and MPCore are trademarks of Arm Limited in the EU and other countries. All other trademarks are the property of their respective owners.