Revision History

The following table shows the revision history for this document.

<table>
<thead>
<tr>
<th>Date</th>
<th>Version</th>
<th>Revision</th>
</tr>
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<tr>
<td>07/27/2018</td>
<td>2018.2</td>
<td>Updated for hardware and software tools for Vivado® Design Suite 2018.2. Updated Figure 1-3, Figure 3-2, Figure 3-3, Figure 3-7, Figure 3-8, Figure 5-1, and Figure 5-6.</td>
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</tr>
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Introduction

About this TRD

This document describes the features and functions of the Zynq® UltraScale+™ MPSoC Video Codec Unit (VCU) targeted reference design (TRD). The VCU TRD is an embedded video encoding/decoding application partitioned between the SoC processing system (PS), VCU, and programmable logic (PL) for optimal performance. The design demonstrates the capabilities and performance throughput of the VCU embedded macro block available in Zynq UltraScale+ MPSoC devices.

The TRD serves as a platform to tune the performance parameters of the VCU to arrive at optimal configurations for encoder and decoder blocks.

The TRD demonstrates the following hard block features in the PS and PL:

- VCU hard block capable of performing up to 4K (3840 x 2160) @ 60 Hz
- Simultaneous encoding and decoding of single and multiple streams
- PS DisplayPort controller for 4K (3840 x 2160) @ 30 Hz
- GPU used for rendering a graphical user interface (GUI)
- PS DDR memory for capture pipeline, encoder, decoder, and display pipeline while operating up to 4K (3840 x 2160) @ 60 Hz
- Extensible platform uses:
  - GStreamer v1.12 pipeline architecture to construct a multimedia pipeline [Ref 1]
  - Standard Linux software frameworks
  - OpenMAX™ v1.1.2 based client interface for the VCU
  - Modular and hierarchical architecture (enables partner modules)
  - Configurable IP subsystems
• System software configuration:
  ° Linux symmetric multi-processing (SMP) on the application processing unit (APU)

This user guide describes the architecture of the reference design and provides a functional
description of its components. It is organized as follows:

• Chapter 1, Introduction (this chapter) provides a high-level overview of the Zynq
  UltraScale+ MPSoC device architecture, the reference design architecture, and a
  summary of key features.

• Chapter 2, Targeted Reference Design Details gives an overview of the design modules
  and design components that make up this reference design.

• Chapter 3, APU Software Platform describes the APU software platform covering the
  middleware and operating system layers of the Linux software stack and the Linux
  GStreamer application running on the APU.

• Chapter 4, System Considerations describes system architecture considerations
  including boot flow, system address map, video buffer formats, and performance
  analysis.

• Chapter 5, Hardware Platform describes the hardware platform of the design including
  key PS and PL peripherals.

• Appendix A, Input Configuration File lists additional resources and references.
Zynq UltraScale+ MPSoC Overview

The Zynq device is a heterogeneous, multi-processing SoC built on the 16-nm FinFET technology. Figure 1-1 shows a high-level block diagram of the device architecture and key building blocks inside the processing system (PS) and the programmable logic (PL).

**Zynq UltraScale+ MPSoC Processing System**

**Zynq UltraScale+ MPSoC Programmable Logic**

The MPSoC key features include:

- Application processing unit (APU) with a 64-bit quad-core Arm® Cortex™-A53 processor
- Real-time processing unit (RPU) with a 32-bit dual-core Arm Cortex-R5 processor
- Multimedia blocks
  - Graphics processing unit (GPU) Arm Mali-400MP2
  - Video codec (encoder/decoder) unit up to 4K (3840 x 2160) 60 frames per second (FPS)
• DisplayPort controller interface up to 4K (3840 x 2160) 30 FPS

• High-speed peripherals
  ° PCIe root complex and Endpoint (Gen1 or Gen2 x1, x2, and x4 lanes)
  ° USB 3.0/2.0 with host, device and on-the-go (OTG) modes
  ° Serial advanced technology attachment (SATA) 3.1 host

• Low-speed peripherals
  ° Gigabit Ethernet, controller area network (CAN), universal asynchronous receiver-transmitter (UART), Serial Peripheral Interface (SPI), Quad SPI, NAND flash memory, Secure Digital embedded Multimedia Card (SD/eMMC), inter IC (I2C), and general purpose I/O (GPIO)

• Platform management unit (PMU)

• Configuration security unit (CSU)

• 6-port DDR controller with error correction code (ECC), supporting x32 and x64 DDR4/3/3L and LPDDR4/3

**Reference Design Overview**

The MPSoC device has a heterogeneous processor architecture. The TRD makes use of multiple processing units available inside the PS using this software configuration:

The APU consists of quad-core Arm Cortex-A53 cores configured to run in SMP Linux mode. The main task of the application is to configure and control the video pipelines using a Qt v5.9.4 based graphical user application. See Figure 1-2.
Chapter 1: Introduction

Figure 1-2 shows the software state after the boot process has completed and the individual applications have been started on the target processing units. The TRD does not make use of virtualization and therefore does not run a hypervisor on the APU.

The APU application controls the following video data paths implemented in a combination of PS and PL (see Figure 1-3):

- Capture pipeline capturing video frames into DDR memory from an HDMI source connected through the PL, an image sensor on an FMC daughter card connected via MIPI CSI-2 Rx subsystem through the PL, serial digital interface (SDI) source connected through the PL, and a test pattern generator (TPG) implemented inside the PL. Additionally, video can be sourced from a SATA drive, USB 3.0 device, or an SD card, which is also used as a boot device.

- Processing (memory-to-memory) pipeline includes VCU doing encode/decode. Video frames are read from DDR memory, processed by the VCU, and written back to memory.

- Display pipeline reading video frames from memory and sending them to a monitor via the DisplayPort Tx controller inside the PS, SDI transmitter subsystem through the PL or the HDMI transmitter subsystem through the PL. The DisplayPort Tx controller supports...
two layers—one for video, the other for graphics and the SDI transmit subsystem with mixer IP support up to four layers and HDMI transmitter subsystem with mixer IP supports up to eight such layers. The graphics layer is rendered by the GPU.

The TRD consists of four designs which are highlighted in four colors as shown in Figure 1-3.

The remaining blocks are common to all designs. Refer to Chapter 2, Targeted Reference Design Details for more details.

![VCU TRD Block Diagram](X0050-072218)

**Figure 1-3: VCU TRD Block Diagram**

The reference design targets the ZCU106 evaluation board. The board has an onboard HDMI transmitter and receiver connector, SDI transmitter and receiver connector, and a DisplayPort connector interface. The evaluation board provides the HDMI reference clock, data recovery unit (DRU) clock, and the reference clock for the design. The PS_REF_CLK is
sourced from another dedicated clock generator present on the evaluation board. Figure 1-4 shows the block diagram of the TRD along with the board components.

**Figure 1-4: High-Level Block Diagram of ZCU106 Device Architecture**

## Key Features

Target platforms and extensions:

- ZCU106 evaluation board (see *ZCU106 Evaluation Board User Guide* (UG1244)) [Ref 2]
- Optional: Leopard Imaging LI-IMX274MIPI-FMC image sensor daughter card [Ref 3]
- SDI Receiver - Black Magic Teranex Mini HDMI to 12G converter
- SDI Transmitter - Black Magic Teranex Mini 12G to HDMI converter

Xilinx tools:

- Vivado® Design Suite 2018.2
- Xilinx® Software Development Kit (XSDK) 2018.2 [Ref 4]
- PetaLinux tools 2018.2
Hardware interfaces and IP:

- **GPU**
- **Video inputs**
  - TPG (PL)—referred to as *TPG* from here on
  - HDMI Rx
  - MIPI CSI-2 Rx
  - File source (SATA, SD, and USB 3.0)
  - SDI Rx
- **Video outputs**
  - DisplayPort Tx controller
  - HDMI Tx
  - SDI Tx
- **Video compression/decompression**
  - VCU hard block
- **Auxiliary peripherals**
  - SD
  - I2C
  - GPIO
  - Ethernet
  - UART
  - USB 2.0
  - AXI Performance Monitor (APM)

Software components:

- **Operating systems**
  - APU: SMP Linux
- **Linux frameworks/libraries**
  - Video: Video4Linux (V4L2), Media controller
  - Display: Direct Rendering Manager/Kernel Mode Setting (DRM/KMS), X-Server (X.Org)
  - Graphics: Qt5, OpenGL ES2
• User application:
  ° APU: GStreamer-based command line application, QT GUI application

Supported video formats:

• Input resolution
  ° 4Kp60 (3840 x 2160)
  ° 4Kp30 (3840 x 2160)
  ° 1080p60 (1920 x 1080)

• Output resolution
  ° 4Kp60 (3840 x 2160) — HDMI only
  ° 4Kp30 (3840 x 2160) — HDMI and DisplayPort
  ° Native 1080p60 on both DisplayPort and HDMI

• Pixel formats
  ° NV12 (two-plane versions of the YUV 4:2:0 format) for the video layer
  ° HDMI source with the RBG/YUYV format
Chapter 2

Targeted Reference Design Details

Design Modules
The VCU TRD consists of four design modules (DMs). A short summary of each design follows.

DM1 - PL HDMI Video Capture
This module enables capture from the HDMI Rx subsystem implemented in the PL into a file or to streamout video. The video captured from the HDMI Rx subsystem is encoded and stored in USB/SATA/SD drives. The module can streamout encoded data through an Ethernet interface.

DM2 - PL SDI Video Capture
This module enables capture from the SDI Rx subsystem implemented in the PL into a file or to streamout video. The video captured from the SDI Rx subsystem is encoded and stored in USB/SATA/SD drives. The module can streamout encoded data through an Ethernet interface.

DM3 - PL SDI Video Capture and SDI Display
This module extends DM2 and enables capture of video from an SDI Rx subsystem implemented in the PL. The video can be displayed via SDI Tx through the PL, recorded into USB/SATA/SD drives, or can be a streamout.

DM4 – Full-fledged VCU TRD
This module extends DM1 and enables video capture from an HDMI source, an image sensor connected via CSI-2 Rx, or a test pattern generator (TPG) implemented in the PL. The video can be displayed via DP Tx through the PS, via HDMI Tx through the PL, can be recorded into USB/SATA/SD drives, or can be a streamout.

Table 2-1 shows for each design module (row) which other module (column) it builds upon or is a combination of.
Chapter 2: Targeted Reference Design Details

The Zynq UltraScale+ MPSoC VCU TRD wiki for 2018.2 provides additional content including:

- Prerequisites for building and running the reference design.
- Instructions for running the pre-built SD card image on the evaluation board.
- Detailed step-by-step design and tool flow tutorials for each design module.

A link to the `rdf0428-zcu106-vcu-trd-2018-2.zip` targeted reference design ZIP file is provided in the wiki page.

## Design Components

Download the targeted reference design ZIP file.

The file contains the following components grouped by processing unit or PL.

**APU**

- `vcu_apm_lib`: Library that provides the interface to query read and write throughput of the VCU encoder/decoder.
- `vcu_gst_lib`: Interface library that manages the video capture, processing, and display pipelines using the GStreamer, V4L2, and DRM frameworks.
- `petalinux_bsp`: PetaLinux board support package (BSP) to build a pre-configured SMP Linux image for the APU. The BSP includes the following components:
  - First stage boot loader (FSBL)
  - Arm trusted firmware (ATF)
  - U-Boot
  - Linux kernel
  - Device tree
  - PMU firmware
  - Root file system (rootfs).
• vcu_qt: Application that uses the vcu_gst_lib, vcu_apm_lib, and vcu_video_lib libraries and provides a GUI to control and visualize various parameters of this design.

• vcu_video_lib: Library that configures various video pipelines in the design.

• vcu_gst_app: Command line application that uses the vcu_gst_lib, vcu_apm_lib, and vcu_video_lib libraries. It allows you to configure and run the capture, display, record and streamout pipelines through the command line.

PL

• Vivado: Vivado IP integrator design that integrates the capture, processing (encode/decode), and display pipeline.
Chapter 3

APU Software Platform

Introduction

This chapter describes the application processing unit (APU) Linux software platform, which is further subdivided into a middleware layer, an operating system (OS) layer, and an application stack (see Figure 3-1). The two layers are examined in conjunction because they interact closely for most Linux subsystems. These layers are further grouped by vertical domains which reflect the organization of this chapter:

- Video
- Display
- Graphics
- Accelerator
Software Architecture

Figure 3-1 shows the APU Linux software platform.

The middleware layer is a horizontal layer implemented in the user-space. It provides the following functionality:

- Interfaces with the application layer
- Provides access to kernel frameworks
The OS layer is a horizontal layer implemented in the kernel-space. It provides the following functionality:

- Provides a stable, well-defined API to user-space
- Includes device drivers and kernel frameworks (subsystems)
- Accesses the hardware

**Video**

To model and control video capture pipelines such as the ones used in this TRD on Linux systems, multiple kernel frameworks and APIs must work in concert. For simplicity, the overall solution is referred to as Video4Linux (V4L2), although the framework only provides part of the required functionality. Individual components are discussed in the following sections.

**Driver Architecture**

*Figure 3-2* shows the VL42 driver stack.
Figure 3-2 shows a generic V4L2 driver model of a video pipeline. The video pipeline driver loads the necessary subdevice drivers and registers the device nodes it needs, based on the
video pipeline configuration specified in the device tree. The framework exposes the following device node types to user space to control certain aspects of the pipeline:

- **Media device node**: /dev/media*
- **Video device node**: /dev/video*
- **V4L subdevice node**: /dev/v4l-subdev*

*Note:* The * means [0...n], e.g., /dev/media1, /dev/media2, and so on.

These steps describe the data flow within software:

1. The V4L2 source driver allocates frame buffer for the capture device.
2. The V4L2 framework exports the DMA_BUF file descriptor (FD) to the encoder GStreamer element.
3. The encoder reads the source buffer from the capture device, encodes it, and writes the encoded bitstream to a bitstream buffer. The encoded bitstream does not use DMA_BUF framework for sharing the buffer.
4. The decoder allocates a decoded frame buffer, reads the bitstream buffer, and writes the decoded frame buffer into memory.
5. The decoder shares the decoded frame buffer using the DMA_BUF framework with the DRM display device.

**Media Framework**

The main goal of the media framework is to discover the device topology of a video pipeline and to configure it at run time. To achieve this, pipelines are modeled as an oriented graph of building blocks called *entities* connected through pads.

A pad is a connection endpoint through which an entity can interact with other entities. Data produced by an entity flows from the entity’s output to one or more entity inputs. A link is a point-to-point oriented connection between two pads, either on the same entity or on different entities. Data flows from a source pad to a sink pad.

An entity is a basic media hardware building block. It can correspond to a large variety of blocks such as physical hardware devices (e.g., image sensors), logical hardware devices (e.g., soft IP cores inside the PL), DMA channels, or physical connectors. Physical or logical devices are modeled as subdevice nodes and DMA channels as video nodes.
A media device node is created that allows the user space application to configure the video pipeline and its subdevices through the libmediactl and libv4l2subdev libraries. The media controller API provides this functionality:

- Enumerates entities, pads, and links
- Configures pads
  - Sets media bus format
  - Sets dimensions (width/height)
- Configures links
  - Enable/disable
  - Validates formats

Figure 3-3 shows the media graph for the TPG, HDMI Rx, and CSI Rx video capture pipelines as generated by the media-ctl utility. The TPG subdevice is shown in white with its corresponding control interface address and subdevice node in the center. The numbers on the edges are pads and the solid arrows represent active links. The grey boxes are video nodes that correspond to frame buffer write channels, in this case write channels (outputs).
Chapter 3: APU Software Platform

Graphics

Qt is a full development framework with tools designed to streamline the creation of applications and user interfaces for desktop, embedded, and mobile platforms. Qt uses standard C++ with extensions including signals and slots that simplify handling of events. This helps in the development of both the GUI and server applications which receive their own set of event information and should process them accordingly.

Display

Linux kernel and user-space frameworks for display and graphics are intertwined and the software stack can be quite complex with many layers and different standards and APIs. On the kernel side, the display and graphics portions are split with each having their own APIs. However, both are commonly referred to as a single framework, namely DRM/KMS. This split is advantageous, especially for SoCs that often have dedicated hardware blocks for display and graphics. The display pipeline driver responsible for interfacing with the display

Figure 3-3: Video Capture Media Pipelines: TPG Left, HDMI Rx Center, CSI Rx Right
uses the kernel mode setting (KMS) API and the GPU responsible for drawing objects into memory uses the direct rendering manager (DRM) API. Both APIs are accessed from user-space through a single device node.

**Accelerator**

The Video Codec Unit (VCU) core supports multi-standard video encoding and decoding of H.264 and H.265 standards. A software stack on the CPU controls various functions of Encoder and Decoder blocks.

The VCU software stack consists of a custom kernel module and a custom user space library known as Control Software (CtrlSW). The OpenMAX™ (OMX) integration layer (IL) is integrated on top of CtrlSW, and the GStreamer framework is used to integrate the OMX IL component and other multimedia elements (see the OpenMAX website [Ref 5]).

OpenMAX (Open Media Acceleration) is a cross-platform API that provides a comprehensive streaming media codec and application portability by enabling accelerated multimedia components.

GStreamer is the cross-platform/open source multimedia framework. Its core function is to provide a framework for plug-ins, data flow, and media type handling and negotiation. It also provides an API to write applications using the various plug-ins.

You can develop your application at all three levels: CtrlSW, OMX IL, and GStreamer (Figure 3-4).

![Acceleration Layers](image-url)

**Figure 3-4:** Acceleration Layers
Software Stack

The APU Linux multimedia software stack is divided into an application layer and a platform layer. The application layer is purely implemented in the Linux user-space whereas the platform layer contains middleware (user-space libraries) and operating system (OS) components (kernel-space drivers). Figure 3-5 shows a simplified version of the Linux software stack. This chapter focuses on the application layer implemented in the user-space.

A user application based on GStreamer demonstrates the features of the TRD. Figure 3-5 shows the software stack present in the TRD. Table 3-1 describes the software components.

Table 3-1: Software Stack Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kernel drivers</td>
<td>This layer contains the kernel drivers for HDMI, test pattern generator (TPG), IMX274 sensor driver, MIPI CSI-2 Rx subsystem, Xilinx Video Demosaic, Xilinx Video Gamma LUT, VPSS Color Space Converter (CSC), Xilinx Video Processing Subsystem (Scaler Only configuration, 2X configuration), HDMI Tx subsystem, HDMI Rx subsystem, Xilinx Video Pipeline (XVIPP), Mixer, VCU, DisplayPort controller, and the Mali GPU.</td>
</tr>
</tbody>
</table>
Chapter 3: APU Software Platform

The TRD application (vcu_qt) is a multi-threaded Linux application with the following main tasks:

- Displays unprocessed video from one or more sources.
- Applies a processing function (encode/decode).
- Provides a GUI for user input.
- Interfaces with lower level layers in the stack to control video pipeline parameters and video data flow.

The application consists of multiple components that have been specifically developed for the VCU TRD (see Figure 3-6). These interfaces are explained in more detail in subsequent sections:

- GUI application (vcu_qt)
- GStreamer interface library (vcu_gst_lib)
- Video library (vcu_video_lib)
- AXI Performance Monitor (APM) library (vcu_apm_lib)
- GStreamer command line application (vcu_gst_app)

### Table 3-1: Software Stack Components (Cont’d)

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>User space libraries</td>
<td>User space libraries include the media and v412 lib for the video pipeline, GStreamer libraries, lib_decode libraries for VCU, libdrm for the DRM device, and Mali user-space libraries for the GPU.</td>
</tr>
<tr>
<td>OpenMAX v1.1.2</td>
<td>The OpenMAX integration layer (IL) components for encoder and decoder provides an abstraction for VCU to a user space media framework like GStreamer (a complete, cross-platform solution to play, record, convert, and stream audio and video) [Ref 5]. It implements a standard application programming interface (API) for the user space media framework.</td>
</tr>
<tr>
<td>GStreamer framework</td>
<td>GStreamer is the cross-platform/open source multimedia framework, and provides the infrastructure to integrate multiple multimedia components and create pipelines. Various GStreamer plug-ins are used for input, filter, and display components.</td>
</tr>
</tbody>
</table>
GUI Application (vcu_qt)

The vcu_qt application is a multi-threaded Linux application that uses the Qt graphics toolkit to render a GUI. The GUI provides control knobs for user input and a display area to show the captured video stream. The GUI shown in Figure 3-7 contains the following control elements displayed on top of the video output area:

- Control bar (top)
- Video info panel (top-right)
- System performance panels (bottom)
Chapter 3: APU Software Platform

Number of Inputs

This determines the number of active video sources. In the current version of the TRD, a maximum of four sources are supported (the default value is one).

Input Options

The following 4K/1080p video sources (3840 x 2160) are available:

- HDMI: Implemented in the PL.
- File: MP4 streams reside in SD card/USB/SATA.
- Test Pattern Generator (TPG): Implemented in the PL.
- CSI: Implemented in the PL (option: MIPI: MIPI CSI, model LI-IMX274 MIPI-FMC v1.1).
- SDI: Implemented in the PL.

Codec

- **Enc**—This option selects encoder in the pipeline.
- **Enc-Dec**—This option selects encode and decode in the pipeline.

Figure 3-7: Control Elements Displayed on Top of the Video Output Area
• **Pass-through**—This option selects displaying the raw video source.

**Preset**

There are six predefined presets. If you edit any control options, preset the mode switches to **Custom**. See **Table 3-2**.

**Table 3-2: Predefined Preset Descriptions**

<table>
<thead>
<tr>
<th>Preset</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVC Low (1)</td>
<td>Encoder type = H264, bitrate = 10 Mb/s</td>
</tr>
<tr>
<td>AVC Medium (1)</td>
<td>Encoder type = H264, bitrate = 30 Mb/s</td>
</tr>
<tr>
<td>AVC High (1)</td>
<td>Encoder type = H264, bitrate = 60 Mb/s</td>
</tr>
<tr>
<td>HEVC Low (1)</td>
<td>Encoder type = H265, bitrate = 10 Mb/s</td>
</tr>
<tr>
<td>HEVC Medium (1)</td>
<td>Encoder type = H265, bitrate = 30 Mb/s</td>
</tr>
<tr>
<td>HEVC High (1)</td>
<td>Encoder type = H265, bitrate = 60 Mb/s</td>
</tr>
<tr>
<td>Custom</td>
<td>User-specific options</td>
</tr>
</tbody>
</table>

**Notes:**
1. The following settings are common for these options: Profile = **Main**, Rate control = **CBR**, Filler data = **true**, QP = **uniform**, L2 cache = **true**, Latency mode = **Normal**, Low bandwidth = **true**, GoP (Group of Pictures) mode = **Basic**, B-frame = **0**, Slice = **4**, and GoP length = **30** (see **Figure 3-8**).

**Output Options**

This option allows you to select the sink for the pipeline. Supported output sink types are:

- HDMI Tx
- DisplayPort
- Record
- Stream Out

For the **DisplayPort** output option, either the **enc-dec Codec** or **Pass-through** option can be selected.

For the **Record** and **Stream Out** output options, only **Encode** can be selected in Codec.
### Settings

You can control the Encoder, Record, and Stream Out configuration from the GUI (see Figure 3-8 and Table 3-3). Settings options are enabled when the pipeline is in the stop state.

#### Figure 3-8: Encoder Parameter Panel

#### Table 3-3: Encoder Parameter Panel Settings

<table>
<thead>
<tr>
<th>Encoder Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Encoder</strong></td>
<td>This can be either H264 or H265.</td>
</tr>
<tr>
<td><strong>Profile</strong></td>
<td>The standard defines a set of capabilities, which are referred to as profiles, targeting specific classes of applications. These are declared as a profile code (profile_idc) and a set of constraints applied in the encoder. This allows a decoder to recognize the requirements to decode that specific stream. H264 supports Baseline, Main, and High profile. In H265, only the Main profile is supported.</td>
</tr>
</tbody>
</table>
| **QP**            | Quantization in an encoder is controlled by a quantization parameter. It specifies how to generate the QP per coding unit (CU). Two modes are supported:  
• Uniform: All CUs of the slice use the same QP  
• Auto: The QP is chosen according to the CU content using a pre-programmed lookup table. |
| **Rate Control**  | Constant bit rate (CBR) is supported. CBR mode generates a constant bit rate that you can predefine. |
Chapter 3: APU Software Platform

Table 3-3: Encoder Parameter Panel Settings (Cont’d)

<table>
<thead>
<tr>
<th>Encoder Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitrate</td>
<td>Encoding bitrate. In digital multimedia, bitrate often refers to the number of bits used per unit of playback time to represent a continuous medium such as audio or video after source coding (data compression).</td>
</tr>
<tr>
<td>B-frame</td>
<td>Short for bidirectional frame or bidirectional predictive frame, a video compression method used by the MPEG standard. The setting ranges from 0 to 4.</td>
</tr>
</tbody>
</table>
| Slice             | Number of slices produced for each frame. Each slice contains one or more complete macroblock/CTU row(s). Slices are distributed over the frame as regularly as possible. If slice size is also defined, more slices can be produced to fit the slice size requirement. Range:  
  • 4-22 4Kp resolution with HEVC codec  
  • 4-32 4Kp resolution with AVC codec  
  • 4-32 1080p resolution with HEVC codec  
  • 4-32 1080p resolution with AVC codec |
| GoP Length        | In video coding, a group of pictures, or GoP structure, specifies the order in which intra- and inter-frames are arranged. And GoP Length is a length between two intra-frames. The GoP is a collection of successive pictures within a coded video stream. Each coded video stream consists of successive GoPs from which the visible frames are generated. Its range is from 1–1000. The GoP length must be a multiple of B-Frames+1. |
| Filler Data       | Filler data network abstraction layer (NAL) units for CBR rate control. It can be enabled or disabled. Applies to CBR mode only. |
| L2 Cache          | Enable or disable L2cache buffer in the encoding process. |
| Latency Mode      | Encoder latency mode. It can be normal or sub_frame mode. |
| Low Bandwidth     | If enabled, decreases the vertical search range used for P-frame motion estimation to reduce the bandwidth. |
| GoP Mode          | Group of Pictures mode. It can be Basic, low_delay_p, or low_delay_b. |
Record

The Record panel allows you to configure recording parameters. See Figure 3-9 and Table 3-4.

![Record Panel Image]

Table 3-4: Record Panel Settings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
</table>
| Storage       | This option specifies the storage device for the recorded file. The list is dynamically populated based on mounted storage devices. Supported storage devices are SD, USB, and SATA.  
**Note:** Due to speed and storage constraints, using a USB or SATA storage device is recommended for recording. |
| Output File Name | Name of the output file.  
A recorded file is saved as source_H26x_rec_<timestamp>.mp4 where source can be HDMI, TPG, or MIPI and codec can be H264/H265. |
| Duration      | This option specifies the recording time duration. It ranges from 1–3 minutes. |
Stream Out

The Stream Out panel allows you to configure streaming parameters. See Figure 3-10 and Table 3-5.

![Stream Out Panel](image)

**Figure 3-10:** Stream Out Panel

<table>
<thead>
<tr>
<th><strong>Parameter</strong></th>
<th><strong>Setting</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>SINK</td>
<td>Provides the sink option for the stream out case. It is set to <strong>PS Ethernet</strong>.</td>
</tr>
<tr>
<td>Host IP</td>
<td>Provides the option to enter the Host IP address.</td>
</tr>
<tr>
<td>IP</td>
<td>Shows the IP address of the board if the Ethernet link is up. If no Ethernet link is connected, it shows <strong>Not Connected</strong>.</td>
</tr>
<tr>
<td>Port</td>
<td>Port number of the Ethernet link. The default is <strong>5004</strong>.</td>
</tr>
</tbody>
</table>

**Note:** IDR is not user configurable. In the encoder code, the idr value = gop-length.
Monitor Options

The GUI monitors CPU utilization and bandwidth utilization for encoder and decoder AXI ports. See Figure 3-11 through Figure 3-13.

![CPU Utilization Plot](Image)

_Figure 3-11: CPU Utilization Plot_

![Encoder Bandwidth Utilization Plot](Image)

_Figure 3-12: Encoder Bandwidth Utilization Plot_

![Decoder Bandwidth Utilization Plot](Image)

_Figure 3-13: Decoder Bandwidth Utilization Plot_

GSTreamer Application (vcu_gst_app)

The vcu_gst_app is a command line multi-threaded Linux application that uses the vcu_gst_lib interface similar to vcu_qt. The difference is to manually feed the input configuration and run the pipeline each time, whereas with vcu_qt, the application has to launch only once.
The command line application requires an input configuration file (input.cfg) to be provided in plain text. Refer to Appendix A, Input Configuration File for the file format and description.

---

**GStreamer Interface Library (vcu_gst_lib)**

The VCU GStreamer interface configures various video pipelines in the design and controls the data flow through these pipelines. It implements these features:

- Display configuration
- VCU configuration
- Video pipeline control
- Video buffer management

The VCU GStreamer interface library exports interfaces:

- Set video pipeline parameters such as resolution, format, and source type (v4l2src, filesrc).
- Set encoder parameters.
- Start and stop the pipeline.
- Calculate FPS.
- Perform error handling.
- Calculate bit rate for file playback.
- Poll for an end of stream (EOS) event.

**Description**

GStreamer is a library for constructing graphs of media-handling components. The applications it supports range from simple playback and audio/video streaming to complex audio (mixing) and video processing.

GStreamer uses a plug-in architecture which makes the most of GStreamer functionality implemented as shared libraries. The GStreamer base functionality contains functions for registering and loading plug-ins and for providing the fundamentals of all classes in the form of base classes. Plug-in libraries get dynamically loaded to support a wide spectrum of codecs, container formats, and input/output drivers.
Table 3-6 describes the plug-ins used in the GStreamer interface library.

<table>
<thead>
<tr>
<th>Plug-in</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>v4l2src</td>
<td>v4l2src can be used to capture video from V4L2 devices like Xilinx HDMI-RX and TPG. Example pipeline: <code>gst-launch-1.0 v4l2src ! kmssink</code> This pipeline shows the video captured from a <code>/dev/video0</code> and rendered on a display unit.</td>
</tr>
<tr>
<td>kmssink</td>
<td>The kmssink is a simple video sink that renders raw video frames directly in a plane of a DRM device. Example pipeline: <code>gst-launch-1.0 v4l2src ! &quot;video/x-raw, format=NV12, width=3840, height=2160&quot; ! kmssink</code></td>
</tr>
<tr>
<td>omxh26xdec</td>
<td>Decoder omxh26xdec is a hardware-accelerated video decoder that decodes encoded video frames. Example pipeline: <code>gst-launch-1.0 filesrc location=/media/card/abc.mp4 ! qtdemux ! h26xparse ! omxh26xdec ! kmssink</code> This pipeline shows an <code>.mp4</code> multiplexed file where the encoded format is h26x encoded video. Note: Use omxh264dec for H264 decoding and omxh265dec for H265 decoding.</td>
</tr>
<tr>
<td>omxh26xenc</td>
<td>Encoder omxh26xenc is a hardware-accelerated video encoder that encodes raw video frames. Example pipeline: <code>gst-launch-1.0 v4l2src ! omxh26xenc ! filesink location=out.h26x</code> This pipeline shows the video captured from a V4L2 device that delivers raw data. The data is encoded to the h26x encoded video type and stored to a file. Note: Use omxh264enc for H264 encoding and omxh265enc for H265 encoding.</td>
</tr>
</tbody>
</table>
**Multi-Stream**

When the number of inputs is more than one in the command line application, it is a multi-stream use case.

The command line application supports multi-streaming, multi-recording, or multi-display. See Figure 3-14.

The input source type can be TPG, HDMI, or MIPI. For multi-streaming or multi-recording, the source type can be HDMI or MIPI.

*Figure 3-14: Multi-Stream—3 HDMI and 1 MIPI Input Sources @ 1080p60*
Video Buffer Management

The vcu_gst_lib library uses the DMABUF framework for sharing buffers between a display device (DRM), a video capture device (V4L2), and a video processing accelerator (the VCU) (see Figure 3-15).

The following steps are performed in DMA buffer sharing.

In the capture-encode side:
1. The V4L2 capture device (the client driver) allocates buffer.
2. The v4l2src plug-in exports the DMA buffer to the gst-omx plug-in.
3. The gst-omx plug-in passes the file descriptor to the encoder driver.
4. The encoder driver uses the DMA_BUF framework and reads the kernel buffer for encoding.

In the playback side:
1. The decoder driver allocates DMA buffer.
2. The gst-omx plug-in exports the file descriptor (FD) to the kmssink plug-in.
3. The kmssink plug-in passes the file descriptor to the DisplayPort controller driver.
4. The DisplayPort driver uses the kernel DMA_BUF framework to know the decoder buffer location.
5. The DisplayPort DMA reads the decoded buffer without copying the buffer in kernel memory.

---

**AXI Performance Monitor (APM) Library (vcu_apm_lib)**

This library provides an interface to the vcu_qt application for reading VCU encoder/decoder memory throughput performance numbers.

The programming model follows:

1. Call `perf_monitor_init()` on startup.
2. Periodically call `perf_monitor_get_rd_wr_cnt()` for each VCU APM. This API returns the number of read+write transactions happening on the AXI Performance Monitor port in bytes.
3. Call `perf_monitor_deinit()` on exit.

---

**Video Library (vcu_video_lib)**

The vcu_video_lib library configures various video pipelines in the design. It implements the following features:

- Query display configurations
- Media pipeline configuration for video capture

The vcu_video_lib library exports and imports the following interfaces:

- TPG video source controls (to vcu_gst_lib library)
- CSI video source controls (to vcu_gst_lib library)
- Interfaces from various middleware layers (V4L2, Media Controller, DRM)

**Query Display Configurations**

The libdrm library is used to validate if the resolution is supported by the monitor and to query the native resolution of the monitor. The graphics plane is configured by the Qt EGLFS backend outside of this library. The pixel format for each of the two planes is configured statically in the device tree.
Media Pipeline Configuration

The video capture pipeline present in this design is *TPG input*. It implements a media controller interface that allows you to configure the media pipeline and its sub-devices. The libmediactl and libv4l2subdev libraries provide the following functionality:

- Enumerate entities, pads, and links
- Configure sub-devices
  - Set media bus format
  - Set dimensions (width/height)

The video_lib library sets the media bus format and video resolution on each sub-device source and sink pad for the entire media pipeline. The formats between pads that are connected through links need to match.
System Considerations

This chapter describes the boot process and address mapping.

Boot Process

The reference design uses a non-secure boot flow and SD boot mode. The sequence diagram in Figure 4-1 shows the exact steps and order in which the individual boot components are loaded and executed.

The platform management unit (PMU) is responsible for handling primary pre-boot tasks and is the first unit to wake up after power-on reset (POR). After the initial boot process, the PMU continues to run and is responsible for handling various clocks and resets of the system as well as system power management. In the pre-configuration stage, the PMU executes the PMU ROM and releases the reset of the configuration security unit (CSU). It then enters the PMU server mode where it monitors power.

The CSU handles the configuration stages and executes the boot ROM as soon as it comes out of reset. The boot ROM determines the boot mode by reading the boot mode register, it initializes the on-chip memory (OCM), and reads the boot header. The CSU loads the PMU firmware into the PMU RAM and signals to the PMU to execute the firmware, which
provides advanced management features instead of the PMU ROM. It then loads the first stage boot loader (FSBL) into OCM and switches into tamper monitoring mode.

In this design, the FSBL is executed on APU-0. It initializes the PS and configures the PL and APU based on the boot image header information. The following steps are performed:

1. The PL is configured with a bitstream and the PL reset is deasserted.
2. The Arm trusted firmware (ATF) is loaded into OCM and executed on APU-0.
3. The second stage boot loader U-Boot is loaded into DDR to be executed by APU-0.

**Note:** At this point, RPU-1 is still held in reset because no executable has been loaded thus far.

For more information on the boot process, see chapters Programming View of Zynq UltraScale+ MPSoC Devices and System Boot and Configuration in Zynq UltraScale+ MPSoC Software Developer Guide (UG1137) [Ref 6], and chapter Boot and Configuration in Zynq UltraScale+ MPSoC Technical Reference Manual (UG1085) [Ref 7].

**Global Address Map**

For more information on system addresses, see chapter 8 in Zynq UltraScale+ MPSoC Technical Reference Manual (UG1085) [Ref 7].

**Memory**

The DMA instances in the PL use a 36-bit address space so they can access the DDR Low and DDR High address regions for receiving and transmitting video buffers to be shared with the APU application. Table 4-1 lists the APU software components used in this design and where they are stored or executed from in memory.

<table>
<thead>
<tr>
<th>Component</th>
<th>Processing Unit</th>
<th>Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSBL</td>
<td>APU-0</td>
<td>OCM</td>
</tr>
<tr>
<td>Arm trusted firmware (ATF)</td>
<td>APU-0</td>
<td>OCM</td>
</tr>
<tr>
<td>U-boot</td>
<td>APU-0</td>
<td>DDR</td>
</tr>
<tr>
<td>Linux kernel/device tree/rootfs</td>
<td>APU (SMP)</td>
<td>DDR</td>
</tr>
<tr>
<td>vcu_qt application (Linux)</td>
<td>APU (SMP)</td>
<td>DDR</td>
</tr>
</tbody>
</table>

**Video Buffer Format**

The TRD uses two layers (or planes) for DisplayPort Tx and up to eight layers for the HDMI Tx subsystem. These layers get alpha-blended inside the display subsystem, which sends a single video stream to the DisplayPort controller or HDMI Transmitter subsystem. The bottom layer is used for video frames and the top layer is used for graphics. The graphics layer consists of the GUI and is rendered by the GPU. It overlays certain areas of the video.
frame with GUI control elements while other parts of the frame are transparent. A mechanism called *pixel alpha* is used to control the opacity of each pixel in the graphics plane.

The pixel format used for the graphics plane is called ARGB8888 or AR24. It is a packed format that uses 32 bits to store the data value of one pixel (32 bits per pixel or BPP), 8 bits per component (BPC) —also called color depth or bit depth. The individual components are: alpha value (A), red color (R), green color (G), blue color (B). The alpha component describes the opacity of the pixel: An alpha value of 0% means the pixel is fully transparent (invisible); an alpha value of 100% means the pixel is fully opaque.

The pixel format used for the video plane is NV12. In NV12 format, all Y samples are found first in memory as an array of unsigned characters. This is followed immediately by an array of unsigned characters containing interleaved Cb and Cr samples.

Aside from the pixel format, a video buffer is further described by a number of other parameters (see Figure 4-2). For this design, the relevant parameters are width, height, and stride as the PS display pipeline does not allow for setting an x or y offset.

![Video Buffer Area](image)

**Figure 4-2: Video Buffer Area**

The active area is the part of the video buffer that is visible on the screen. The active area is defined by the height and width parameters, also called the video dimensions. Those are typically expressed in number of pixels because the bits per pixel depend on the pixel format as explained above.

The stride or pitch is the number of bytes from the first pixel of a line to the first pixel of the next line of video. In the simplest case, the stride equals the width multiplied by the bits per pixel, converted to bytes. For example, AR24 requires 32 BPP which is four bytes per pixel.
A video buffer with an active area of 1920 x 1080 pixels therefore has a stride of 
4 x 1920 = 7,680 bytes. Some DMA engines require the stride to be a power of two to 
optimize memory accesses. In this design, the stride always equals the width in bytes.
Hardware Platform

This chapter gives an overview of the TRD hardware.

Hardware Overview

Figure 5-1 shows the hardware block diagram. The HDMI Rx capture pipeline consists of the HDMI RX IP, video processing subsystem IP enabled for scaler and color space conversion functionality and the frame buffer write IP that converts the packed video data to a semi-planar format and writes the data into memory. The second live path consists of the TPG sourcing the live video input that goes to a frame buffer write IP. The third live path is the MIPI CSI-2 Rx capture pipeline, which consists of IMX274 Sensor, MIPI CSI-2 Receiver Subsystem (CSI Rx), the AXI subset converter, Demosaic IP, Gamma LUT IP, video processing subsystem IP enabled for scaler and color space conversion functionality, and the frame buffer write IP.

The processing pipeline consists of the VCU LogiCORE™ IP that contains the VCU primitive has four 128-bit AXI interfaces coming out, which are multiplexed for each of the encoder and decoder ports. The TRD supports two display pipelines: One is through PS DisplayPort controller. Another is through the PL HDMI Tx pipeline, consisting of the video mixer and HDMI Tx subsystems.

The display pipeline consists of the PS DisplayPort controller. The GPU renders the graphics in the graphics layer. DisplayPort direct memory access (DPDMA) fetches both graphics and the video layer from memory. The DisplayPort controller processes data and sends it out using the DisplayPort Standard to external display devices. The HDMI transmitter display pipeline is controlled by the Video Mixer, which fetches both graphics and the video layer from memory and sends to the HDMI Tx subsystem. The HDMI Tx subsystem processes data and sends it out to an external display device.
Chapter 5: Hardware Platform

The data flow is as follows:

1. Video frames captured by MIPI CSI, HDMI, or TPG are written to memory by the frame buffer write IP.
2. The encoder fetches the frame buffer, encodes it, and writes the encoded bitstream into memory.
3. The decoder fetches the encoded bitstream, decodes it, and writes the decoded frame back into memory.
4. The DisplayPort DMA fetches the decoded frames and sends them to the DisplayPort controller. Similarly, Mixer fetches the decoded frames and sends them to the HDMI Tx subsystem.

Clocking

This section describes the clocking mechanism used in the TRD. The primary clock is sourced from si570_user sources that provide a 300 MHz reference clock to the PL. A mixed-mode clock manager (MMCM) block in PL uses the si570 clock as a primary input clock and generates the reference clock for the VCU PLL, AXI4-Lite clock, and video pixel clock. The VCU PLL generates the core clock and MCU clock based on the input reference.
clock. The AXI4-Lite clock for VCU is generated from PL_CLK0 port. Figure 5-2 shows the clocking mechanism used for the TRD.

Figure 5-2: Clocking

Reset

A synchronous reset mechanism is used in the TRD. PL_RESET0 is used as a master reset signal. Interconnect and peripheral reset signals are generated using proc_sys_rst IP in PL.

Video Pipelines

A capture pipeline receives frames from an external source or produces video frames internally. The captured video frames are written into memory.

A memory-to-memory (M2M) pipeline reads video frames from memory, does certain processing, and then writes the processed frames back into memory.

An output pipeline reads video frames from memory and sends the frames to a sink. In this case, the sink is a display. Therefore this pipeline is also referred to as a display pipeline.
**TPG Capture Pipeline**

The TPG capture pipeline is shown in Figure 5-3.

This pipeline consists of three main components, each of them controlled by the APU via an AXI-Lite based register interface:

- The Video Timing Controller (VTC) generates video timing signals including horizontal and vertical sync and blanking signals. The timing signals are converted to AXI-Stream using the video-to-AXI-Stream bridge with the data bus tied off. The video timing over AXI-Stream bus is connected to the input interface of the TPG, thus making the TPG behave like a timing-accurate video source with a set frame rate as opposed to using the free-running mode.

- The Video Test Pattern Generator (TPG) can be configured to generate various test patterns including color bars, zone plates, moving ramps, moving box and more. The color space format is configurable and set to YUV 4:2:0 in this design. For more information, see the Video Test Pattern Generator LogiCORE IP Product Guide (PG103) [Ref 8].

- The Video Frame Buffer Write IP provides high-bandwidth direct memory access between memory and AXI4-Stream video type target peripherals, which support the AXI4-Stream Video protocol. In this pipeline, the IP takes AXI4-Stream input data from the TPG and converts it to AXI4-MM format. The output is connected to the HP1 high performance PS/PL interface via an AXI interconnect. For each video frame transfer, an interrupt is generated. A GPIO is used to reset the core between resolution changes. For more information refer to the Video Frame Buffer Read and Video Frame Buffer Write LogiCORE IP Product Guide (PG278) [Ref 9].
HDMI Rx Capture Pipeline

The HDMI receiver capture pipeline is shown in Figure 5-4.

This pipeline consists of four main components, each of them controlled by the APU via an AXI-Lite base register interface:

- The Video PHY controller (VPHY) enables plug-and-play connectivity with Video Transmit or Receive subsystems. The interface between the media access control (MAC) and physical (PHY) layers are standardized to enable ease of use in accessing shared gigabit-transceiver (GT) resources. The data recovery unit (DRU) is used to support lower line rates for the HDMI protocol. An AXI4-Lite register interface is provided to enable dynamic accesses of transceiver controls/status. For more information refer to the Video PHY Controller LogiCORE IP Product Guide (PG230) [Ref 10].

- The HDMI Receiver Subsystem (HDMI Rx) interfaces with PHY layers and provides HDMI decoding functionality. The subsystem is a hierarchical IP that bundles a collection of HDMI Rx-related IP subcores and outputs them as a single IP. The subsystem receives the captured TMDS data from the video PHY layer. It then extracts the video stream from the HDMI stream and in this design converts it to an AXI4-Stream output interface. For more information, see the HDMI 1.4/2.0 Receiver Subsystem Product Guide (PG236) [Ref 11].

- The Video Processing Subsystem (VPSS) is a collection of video processing IP subcores. In this design, the VPSS uses the Scaler only configuration which provides scaling, color space conversion, and chroma resampling functionality. The VPSS takes AXI4-Stream input data from the HDMI Rx Subsystem and depending on the input format and resolution, converts and scales it to the desired output format and resolution again using AXI4-Stream. A GPIO is used to reset the subsystem between resolution changes.
For more information, see the Video Processing Subsystem Product Guide (PG231) [Ref 12].

- The Video Frame Buffer Write IP uses the same configuration as the one in the TPG capture pipeline. It takes AXI4-Stream input data from the VPSS and converts it to AXI4-MM format. The output is connected to the HP1 high performance PS/PL interface via an AXI interconnect. For each video frame transfer, an interrupt is generated. A GPIO is used to reset the IP between resolution changes.

Similar to the TPG pipeline, the HDMI Rx, VPSS Scaler, and Frame Buffer Write IPs are configured to transport 2 pixels per clock (ppc), enabling up to 2160p60 performance. Although the color format and depth at the HDMI Rx are determined by the HDMI source, the VPSS always converts the format to YUV 4:2:0, 8 bits per component (bpc), which is then written to memory by the Frame Buffer Write IP as NV12 format.

**MIPI CSI-2 Rx Capture Pipeline**

The MIPI CSI-2 receiver capture pipeline is shown in Figure 5-5.

![Figure 5-5: CSI Video Capture Pipeline](image-url)

This pipeline consists of eight components, six of which are controlled by the APU via an AXI-Lite based register interface, one is controlled by the APU via an I2C register interface, and one is configured statically:

- The Sony IMX274 is a 1/2.5 inch CMOS digital image sensor with an active imaging pixel array of 3864H x2196V. The image sensor is controlled via an I2C interface using...
an AXI I2C controller in the PL. It is mounted on a FMC daughter card and has a MIPI output interface that is connected to the MIPI CSI-2 Rx subsystem inside the PL. For more information, see the LI-IMX274MIPI-FMC data sheet [Ref 3].

- The MIPI CSI-2 Receiver Subsystem (CSI Rx) includes a MIPI D-PHY core that connects four data lanes and one clock lane to the sensor on the FMC card. It implements a CSI-2 receive interface according to the MIPI CSI-2 standard v1.1. The subsystem captures images from the IMX274 sensor in RAW10 format and outputs AXI4-Stream video data. For more information, see the MIPI CSI-2 Receiver Subsystem Product Guide (PG232) [Ref 13].

- The AXI subset converter is a statically configured IP core that converts the raw 10-bit (RAW10) AXI4-Stream input data to raw 8-bit (RAW8) AXI4-Stream output data by truncating the two least significant bits (LSB) of each data word.

- The Demosaic IP core reconstructs sub-sampled color data for images captured by a Bayer color filter array image sensor. The color filter array overlaid on the silicon substrate enables CMOS image sensors to measure local light intensities that correspond to different wavelengths. However, the sensor measures the intensity of only one principal color at any location (pixel). The Demosaic IP receives the RAW8 AXI4-Stream input data and interpolates the missing color components for every pixel to generate a 24-bit, 8bpc RGB output image transported via AXI4-Stream. A GPIO is used to reset the IP between resolution changes.

- The Gamma LUT IP core is implemented using a look-up table (LUT) structure that is programmed to implement a gamma correction curve transform on the input image data. A programmable number of gamma tables enable having separate gamma tables for all color channels, in this case red, green, and blue. The Gamma IP takes AXI4-Stream input data and produces AXI4-Stream output data, both in 24-bit RGB format. A GPIO is used to reset the IP between resolution changes.

- The Video Processing Subsystem (VPSS) is a collection of video processing IP subcores. This instance uses the Color Space Converter (CSC) configuration to perform color correction tasks including contrast, brightness, and red/green/blue gain control. The CSC takes AXI4-Stream input data and produces AXI4-Stream output data, both in 24-bit RGB format. A GPIO is used to reset the subsystem between resolution changes. For more information, see the Video Processing Subsystem Product Guide (PG231) [Ref 12].

- The Video Processing Subsystem (VPSS) is a collection of video processing IP subcores. This instance uses the Scaler only configuration, which provides scaling, color space conversion, and chroma resampling functionality. The VPSS takes AXI4-Stream input data in 24-bit RGB format and converts it to a 16-bit, 8bpc YUV 4:2:0 output format using AXI4-Stream. A GPIO is used to reset the subsystem between resolution changes.

- The Video Frame Buffer Write IP uses the same configuration as the one in the TPG and HDMI Rx capture pipelines. It takes YUV 4:2:0 sub-sampled AXI4-Stream input data and converts it to AXI4-MM format which is written to memory as 16-bit packed YUYV. The AXI-MM interface is connected to the HP1 high performance PS/PL port via an AXI
interconnect. For each video frame transfer, an interrupt is generated. A GPIO is used to reset the IP between resolution changes.

Similar to the TPG and HDMI Rx capture pipelines, all the IPs in this pipeline are configured to transport 2ppc, enabling up to 2160p60 performance.

**SDI Rx Capture Pipeline**

The SDI Rx capture pipeline is shown in Figure 5-6.

![Figure 5-6: SDI Rx Capture Pipeline](image)

The serial digital interface (SDI) receiver subsystem implements an SDI receive interface in accordance with the SDI family of standards. The subsystem receives video from a native SDI interface and generates AXI4-Stream video. The SMPTE UHD-SDI receiver core receives multiplexed native SDI data streams and generates non-multiplexed 10-bit SDI data streams in YUV422 format. There is an AXI subset converter between the SDI Rx subsystem and the Video Frame Buffer Write, which converts video from 10-bit to 8-bit format for further processing by the pipeline.

The Video Frame Buffer Write IP is used as the Frame Grabber logic, which is designed to allow efficient and high bandwidth access between AXI4-Streaming Video In interfaces to the Zynq® UltraScale+ MPSoC PS DDR memory. The Video Frame Buffer IP can write a variety of video formats to the Zynq UltraScale+ MPSoC PS DDR memory.

**DP Tx Display Pipeline**

The DP Tx display pipeline (see Figure 5-7) is configured to read video frames from memory via two separate channels: one for video, the other for graphics. The video and graphics layers are alpha-blended to create a single output video stream that is sent to the monitor via the DisplayPort controller. This design does not use the audio feature of the DisplayPort controller, therefore it is not discussed in this user guide. The major components used in this design, as shown in the figure, are:

- DisplayPort DMA (DPDMA)
• Audio/Video (A/V) buffer manager
• Video blender
• DisplayPort controller (DP Tx)
• PS-GTR gigabit transceivers

The DPDMA is a 6-channel DMA engine that fetches data from memory and forwards it to the A/V buffer manager. The video layer can consist of up to three channels, depending on the chosen pixel format, whereas the graphics layer is always a single channel. The used pixel formats are described in Video Buffer Format. The remaining two channels are used for audio.

The A/V buffer manager can receive data either from the DPDMA (non-live mode) or from the PL (live mode) or a combination of the two. In this design, only non-live mode is used for both video and graphics. The three video channels feed into a video pixel unpacker and the graphics channel into a graphics pixel unpacker. Because the data is not timed in non-live mode, video timing is locally generated using the internal video timing controller. A stream selector forwards the selected video and graphics streams to the dual-stream video blender.

The video blender unit consists of input color space converters (CSC) and chroma re-samplers (CRS), one pair per stream, a dual-stream alpha blender, and one output color space converter and chroma re-sampler. The two streams must have the same dimensions and color format before entering the blender. The alpha blender can be configured for global alpha (single alpha value for the entire stream) or per pixel alpha. A single output stream is sent to the DisplayPort controller.

The DisplayPort controller supports the DisplayPort v1.2a protocol. It does not support multi-stream transport or other optional features. The DisplayPort controller is responsible for managing the link and physical layer functionality. The controller packs video data into
transfer units and sends them over the main link. In addition to the main link, the controller has an auxiliary channel, which is used for source/sink communication.

Four high-speed gigabit transceivers (PS-GTRs) are implemented in the serial input output unit (SIOU) and shared between the following controllers: PCIe, USB 3.0, DP, SATA, and SGMII Ethernet. The DP controller supports up to two lanes at a maximum line rate of 5.4 Gb/s. The link rate and lane count are configurable based on bandwidth requirements.

For more information on the DisplayPort controller and the PS-GTR interface, see Chapter 29 PS-GTR Transceivers and Chapter 33 DisplayPort Controller in Zynq UltraScale+ Device Technical Reference Manual (UG1085) [Ref 7].

**HDMI Tx Display Pipeline**

The HDMI transmitter display pipeline is shown in Figure 5-10.

![HDMI Tx Display Pipeline](image)

**Figure 5-8: HDMI Tx Display Pipeline**

This pipeline consists of three main components, each of them controlled by the APU via an AXI-Lite base register interface:

- The video mixer IP core is configured to support blending of up to two video layers and one graphics layer into one single output video stream. The three layers are configured to be memory-mapped AXI4 interfaces connected to the HP0 high performance PS/PL interface via an AXI interconnect; the main AXI4-Stream layer is unused. The two video layers are configured for 16-bit YUYV, the graphics layer is configured for 32-bit ARGB, (see Video Buffer Format for details). A built-in color space converter and chroma resampler convert the input formats to a 24-bit RGB output format. Pixel-alpha blending is used to blend the graphics layer with the underlying video layers. The AXI4-Stream output interface is a 48-bit bus that transports 2 ppc for up to 2160p60 performance. It is connected to the HDMI Tx subsystem input interface. A GPIO is used to reset the subsystem between resolution changes. For more information refer to the Video Mixer LogiCORE IP Product Guide (PG243) [Ref 14].
• The HDMI Transmitter Subsystem (HDMI Tx) interfaces with PHY layers and provides HDMI encoding functionality. The subsystem is a hierarchical IP that bundles a collection of HDMI TX-related IP sub-cores and outputs them as a single IP. The subsystem generates an HDMI stream from the incoming AXI4-Stream video data and sends the generated TMDS data to the video PHY layer. For more information refer to the *HDMI 1.4/2.0 Transmitter Subsystem Product Guide* (PG235) [Ref 13].

• The Video PHY Controller is shared between the HDMI Rx and HDMI Tx pipelines. Refer to *HDMI Rx Capture Pipeline* for more information on the VPHY and its configuration.

### SDI Tx Display Pipeline

The SDI Tx display pipeline is shown in Figure 5-9.

The SMPTE UHD-SDI transmitter subsystem accepts AXI4 Video streams and outputs native SDI streams by using Xilinx transceivers as the physical layer.

The Video Mixer enables you to mix video layers and allows mixing up to four streaming or memory layers. Each layer can be up to 4K resolution and can perform color space conversion. The TRD design uses memory layer 1 to fetch video data.

### Address Map

Table 5-1 shows the address map for various IP blocks used in PL.

<table>
<thead>
<tr>
<th>IP Core</th>
<th>Base Address</th>
<th>Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDMI 1.4/2.0 Receiver Subsystem v2.0</td>
<td>0xA0000000</td>
<td>64k</td>
</tr>
<tr>
<td>HDMI 1.4/2.0 Transmitter Subsystem v2.0</td>
<td>0xA0020000</td>
<td>128k</td>
</tr>
<tr>
<td>Video Processing Subsystem (VPSS)</td>
<td>0xA0080000</td>
<td>256k</td>
</tr>
<tr>
<td>Video PHY controller</td>
<td>0xA0060000</td>
<td>64k</td>
</tr>
</tbody>
</table>
Table 5-2 shows the address map of various IP blocks used in the PL of a SDI design.

Table 5-2: Address Map for IP Blocks in SDI Design

<table>
<thead>
<tr>
<th>IP Core</th>
<th>Base Address</th>
<th>Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDMI frame buffer write</td>
<td>0xA0100000</td>
<td>64k</td>
</tr>
<tr>
<td>TPG frame buffer write</td>
<td>0xA00C0000</td>
<td>64k</td>
</tr>
<tr>
<td>Video Test Pattern Generator (TPG)</td>
<td>0xA00E0000</td>
<td>64k</td>
</tr>
<tr>
<td>Video Mixer</td>
<td>0xA0070000</td>
<td>64k</td>
</tr>
<tr>
<td>H.264/H.265 Video Codec Unit (VCU)</td>
<td>0xA0100000</td>
<td>1M</td>
</tr>
<tr>
<td>Video Timing controller</td>
<td>0xA00D0000</td>
<td>64k</td>
</tr>
<tr>
<td>HDMI I2C controller</td>
<td>0xA0050000</td>
<td>4k</td>
</tr>
<tr>
<td>Sensor I2C controller</td>
<td>0xA0051000</td>
<td>4k</td>
</tr>
<tr>
<td>MIPI CSI-2 Receiver Subsystem</td>
<td>0xA00F0000</td>
<td>64k</td>
</tr>
<tr>
<td>Sensor Demosaic</td>
<td>0xA0250000</td>
<td>64k</td>
</tr>
<tr>
<td>Gamma LUT</td>
<td>0xA0270000</td>
<td>64k</td>
</tr>
<tr>
<td>Video Processing Subsystem (VPSS-CSC)</td>
<td>0xA0240000</td>
<td>64k</td>
</tr>
<tr>
<td>Video Processing Subsystem (VPSS-Scaler)</td>
<td>0xA0200000</td>
<td>256k</td>
</tr>
<tr>
<td>CSI frame buffer write</td>
<td>0xA0260000</td>
<td>64k</td>
</tr>
</tbody>
</table>

Interrupt Map

Table 5-3 shows interrupt ID mapping.

Table 5-3: Interrupt ID Map

<table>
<thead>
<tr>
<th>IP Core</th>
<th>Interrupt ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDMI 1.4/2.0 Receiver Subsystem v2.0</td>
<td>91</td>
</tr>
<tr>
<td>Video PHY controller</td>
<td>92</td>
</tr>
<tr>
<td>HDMI frame buffer write</td>
<td>90</td>
</tr>
<tr>
<td>H.264/H.265 Video Codec Unit (VCU)</td>
<td>96</td>
</tr>
<tr>
<td>TPG frame buffer write</td>
<td>104</td>
</tr>
</tbody>
</table>
Table 5-3: Interrupt ID Map (Cont’d)

<table>
<thead>
<tr>
<th>IP Core</th>
<th>Interrupt ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDMI I2C controller</td>
<td>94</td>
</tr>
<tr>
<td>HDMI 1.4/2.0 Transmitter Subsystem v2.0</td>
<td>93</td>
</tr>
<tr>
<td>Video Mixer</td>
<td>95</td>
</tr>
<tr>
<td>HDMI frame buffer read</td>
<td>89</td>
</tr>
<tr>
<td>Sensor I2C controller</td>
<td>107</td>
</tr>
<tr>
<td>MIPI CSI-2 Receiver Subsystem</td>
<td>105</td>
</tr>
<tr>
<td>CSI frame buffer write</td>
<td>106</td>
</tr>
</tbody>
</table>

Table 5-4 shows interrupt ID mapping in an SDI design.

Table 5-4: Table 5-3: Interrupt ID Map in SDI Design

<table>
<thead>
<tr>
<th>IP Core</th>
<th>Interrupt ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDI Receiver Subsystem</td>
<td>89</td>
</tr>
<tr>
<td>SDI Transmit Subsystem</td>
<td>90</td>
</tr>
<tr>
<td>SDI TX Frame Buffer Read</td>
<td>91</td>
</tr>
<tr>
<td>SDI RX Frame Buffer Write</td>
<td>92</td>
</tr>
<tr>
<td>Video Mixer</td>
<td>93</td>
</tr>
<tr>
<td>I2C Bus Topology</td>
<td></td>
</tr>
</tbody>
</table>

I2C is a two-wire bus for attaching low-speed peripherals. It uses two bidirectional open-drain lines, SDA (serial data) and SCL (serial clock), pulled up with resistors. In standard mode, a 7-bit address space and a 400 kHz bus speed are used. In this reference design, PS I2C and AXI I2C (PL) controllers are used to configure several I2C slaves. The I2C topology limited to the devices used in this design is shown in Figure 5-10.

Figure 5-10: I2C Bus Topology
The PS I2C1 controller is connected via MIO to two 8-channel I2C multiplexers (TCA9548) on the ZCU106 board, one at address 0x74, the other at address 0x75.

The I2C multiplexer at address 0x74 has a Si570 programmable clock synthesizer at address 0x5D connected to channel 3. The Si570 clock synthesizer is connected to the PL via a differential clock pair. It generates a fixed reference clock for the HDMI Rx data recovery unit (DRU). See see Clocking for more information.

The I2C multiplexer at address 0x75 has a 64 kb EEPROM at address 0x57 on the FMC daughter card connected to channel 0. The EEPROM is used to store field replaceable unit (FRU) information data as defined in the Intel Platform Management FRU Information Storage Definition [Ref 16].

The PL HDMI I2C controller is connected to two clock devices that are on a shared I2C bus. The SI5324 at address 0x68 is a programmable, low-bandwidth, jitter-attenuating, precision clock multiplier. Its output clock is used to drive the HDMI Tx GT reference clock. The DP159 at address 0x5E is a DisplayPort to TMDS retimer supporting HDMI output signals.

The PL sensor I2C controller is connected to a Sony IMX274 image sensor at address 0x1A on the FMC daughter card.
Appendix A

Input Configuration File

This list describes the file format of the input configuration file (input.cfg).

Descriptions

Common Configuration: Starting point of a common configuration

Num Of Input: Provides the number of inputs. Ranges from 1 to 4.

Output: Selects the video interface.
   Options: HDMI or DP

Out Type:
   Options: display, record and stream

Display Rate: Pipeline frame rate
   Options: 30 or 60

Exit: Tells the application that configuration is finished.

Input Configuration: Starting point of a common configuration

Input Num: Starting nth input configuration
   Options: 1–4

Input Type: Input source type
   Options: TPG, TPG_2, HDMI, HDMI_2, MIPI, File

Uri: File path. Applicable for file playback only. File path should be appended by “file:///”.
   Options: file:///media/usb/abc.mp4

Raw: Tells the pipeline to process or pass-through.
   Options: True, False
Appendix A: Input Configuration File

Width: Width of the live source
   Options: 3840, 1920

Height: Height of the live source
   Options: 2160, 1080

Exit: Tells the application when configuration is finished.

Encoder Configuration: Starting point of common configuration

Encoder Num: Starting nth encoder configuration
   Options: 1–4

Encoder Name: Name of encoder
   Options: AVC, HEVC

Profile: Name of profile
   Options: baseline, main or high for AVC. Main for HEVC.

Rate Control: Rate control options
   Options: CBR, VBR, and low latency

Filler Data: Filler data NAL units for CBR rate control
   Options: True, False

QP: The QP control mode is used by the VCU encoder.
   Options: Uniform or Auto

L2 Cache: Enable or disable the L2 Cache buffer in the encoding process.
   Options: True, False

Latency Mode: Encoder latency mode
   Options: normal, sub_frame

Low Bandwidth: If enabled, decreases the vertical search range used for P-frame motion estimation to reduce the bandwidth.
   Options: True, False
Appendix A: Input Configuration File

GoP Mode: Group of Pictures mode
- Options: Basic, low_delay_p, low_delay_b

Bitrate: Target bit rate in Kbps
- Options: 1–60000

B frames: Number of B frames between two consecutive P frames
- Options: 0–4

Slice: Number of slices produced for each frame. Each slice contains one or more complete macroblock/coding tree unit (CTU) row(s). Slices are distributed over the frame as regularly as possible. If slice size is defined as well, more slices can be produced to fit the slice size requirement.
- Options:
  - 4–22 4Kp resolution with HEVC
  - 4–32 4Kp resolution with AVC
  - 4–32 1080p resolution with HEVC
  - 4–32 1080p resolution with AVC

GoP Length: Distance between two consecutive I frames
- Options: 1-1000

Format: Format of input data
- Options: NV12

Preset:
- Options: HEVC_HIGH, HEVC_MEDIUM, HEVC_LOW, AVC_HIGH, AVC_MEDIUM, AVC_LOW, Custom

Exit: Tells the application encoder that configuration is finished.

Record Configuration: Starting point of a common configuration

Record Num: Starting nth record configuration
- Options: 1–4

Out File Name: Record file path
- Options: /media/usb/abc.mp4
Appendix A: Input Configuration File

Duration: Duration in minutes
  Options: 1–3

Exit: Tells the application record that configuration is finished.

Streaming Configuration: Starting point of a common configuration

Streaming Num: Starting nth streaming configuration
  Options: 1–4

Host IP: The host to send the packets to
  Options: 192.168.25.89

Port: The port to send the packets to
  Options: 1024–65534

Exit: Tells application streaming that configuration is finished.

Trace Configuration: Starting point of common configuration

FPS Info: Displays fps info on the console
  Options: True, False

APM Info: Displays the apm counter number on the console
  Options: True, False

Pipeline Info: Displays pipeline info on the console.
  Options: True, False

Exit: Tells the application streaming that configuration is finished.
Appendix B

Additional Resources and Legal Notices

Xilinx Resources

For support resources such as Answers, Documentation, Downloads, and Forums, see Xilinx Support.

Solution Centers

See the Xilinx Solution Centers for support on devices, software tools, and intellectual property at all stages of the design cycle. Topics include design assistance, advisories, and troubleshooting tips.

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.

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• 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.
Appendix B: Additional Resources and Legal Notices

References

The most up-to-date information for this design is available on these websites:

- Zynq UltraScale+ MPSoC ZCU106 Evaluation Kit
- Zynq UltraScale+ MPSoC ZCU106 Evaluation Kit Documentation
- Zynq UltraScale+ MPSoC ZCU106 Evaluation Kit Master Answer Record (AR 69344)
- H.264/H.265 Video Codec Unit IP Core website
- Zynq UltraScale+ MPSoC VCU TRD wiki for 2018.2

These documents and sites provide supplemental material:

1. GStreamer open source media framework (gstreamer.freedesktop.org/)
2. ZCU106 Evaluation Board User Guide (UG1244)
3. Leopard Imaging Inc. website
4. Xilinx Software Development Kit (XSDK)
5. OpenMAX website
6. Zynq UltraScale+ MPSoC Software Developer Guide (UG1137)
8. Video Test Pattern Generator Product Guide (PG103)
9. Video Frame Buffer Read and Video Frame Buffer Write LogiCORE IP Product Guide (PG278)
11. HDMI 1.4/2.0 Receiver Subsystem Product Guide (PG236)
13. MIPI CSI-2 Receiver Subsystem LogiCORE IP Product Guide (PG232)
15. HDMI 1.4/2.0 Transmitter Subsystem Product Guide (PG235)
16. Intel Platform Management Field Replaceable Unit (FRU) Information Storage Definition
17. FFmpeg (ffmpeg.org)
18. Open Asymmetric Multi Processing (OpenAMP) framework repository (github.com/OpenAMP/open-amp)
19. FreeRTOS (www.freertos.org)
20. Zynq UltraScale+ MPSoc Data Sheet: Overview (DS891)

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