# Introduction

|  |  |
| --- | --- |
| IP quick facts | |
| Supported device families | Zynq®-7000, 7 series |
| Supported user interfaces | AXI Lite, AXI Stream |
| **Provided with core** | |
| Design files | VHDL |
| Simulation model | - |
| Constraints file | XDC |
| Software driver | N/A |
| **Tested design flows** | |
| Design entry | Vivado™ Design Suite 2019.1 |
| Synthesis | Vivado Synthesis 2019.1 |

This user guide describes the Digilent Zmod DAC 1411 AXI Adapter Intellectual Property. This IP provides the means to interface the Zmod DAC1411 Low Level Controller with an AXI based processing system. The Zmod DAC 1411 AXI Adapter provides a set of control registers that can be accessed by the processor over an AXI Lite interface, allows users to indirectly access the SPI configuration interface of the AD9717 featured by the Zmod DAC1411, implements a circular buffer used to store sample data and implements a bridge between the AXI Stream interface and the circular buffer. Sample data is meant to be loaded in the circular buffer through a DMA engine.

# Features

* Allows control of the Zmod DAC 1411 through a set of control and status registers that can be accessed on the AXI Lite interface.
* Implements a 4Ksample circular buffer for each of the two channels of the Zmod DAC 1411.
* Provides an AXI Stream interface facilitating data transfer through a DMA engine.

# Performance

The IP is designed to allow interfacing the ZmodDAC1411 Low Level Controller with an AXI based processing system. The sample data is defined by the processing system in system memory and moved by a DMA engine in the 4K sample circular buffer implemented in BRAM memory. The circular buffer’s output channels should be connected to the Low Level Controller’s input data channels and can be read at a programmable rate between 100MSPS and 61.035KSPS. The SPI indirect access port (IAP) is meant to be used for configuration purposes only.

# Overview



Figure 1. Zmod DAC 1411 Low Level Controller block diagram.

The structure of the IP is presented in Figure 1. The main functional blocks are the Register File, the Circular Buffer and the SPI Command Control block. The details of the hardware implementation are described in the sections below.

## Register Space

The Zmod DAC1411 AXI Adapter register space is described in Table 1.

|  |  |  |
| --- | --- | --- |
| **Address Space Offset** | **Register Name** | **Description** |
| 00h | CR | Control register |
| 04h | SR | Status register |
| 08h | IER | Interrupt enable register |
| 0Ch | CMD\_TX | Command Transmit register |
| 10h | CMD\_RX | Command Receive register |
| 18h | AXIS\_MM2S\_LENGTH | AXI-Stream MM2S Transfer Length (Bytes) |
| 1Ch | SCALE | Scale Control register |
| 24h | SC1LGMULTCOEF | Channel1 low gain multiplicative calibration coefficient |
| 28h | SC1LGADDCOEF | Channel1 low gain additive calibration coefficient |
| 2Ch | SC1HGMULTCOEF | Channel1 high gain multiplicative calibration coefficient |
| 30h | SC1HGADDCOEF | Channel1 high gain additive calibration coefficient |
| 34h | SC2LGMULTCOEF | Channel2 low gain multiplicative calibration coefficient |
| 38h | SC2LGADDCOEF | Channel2 low gain additive calibration coefficient |
| 3Ch | SC2HGMULTCOEF | Channel2 high gain multiplicative calibration coefficient |
| 40h | SC2HGADDCOEF | Channel2 high gain additive calibration coefficient |

Table : General overview and detailed description of register space.

A detailed description of each individual register can be found in the subsections below.

### Control Register (CR – offset 00h)

The main purpose of this register is to provide control over the IP in every aspect of its functionality.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 31 | 30 5 | 5 | 4 | 3 | 2 | 1 | 0 |
| **RST** | **-** | **TEST\_MODE** | **RUN\_STP** | **INTR\_EN** | **CMD\_READ\_EN** | **CMD\_R/S** | **-** |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 1 | CMD\_R/S | 0 | R/W | Setting this bit this will enable the SPI IAP interface to push out commands from the SPI transmit command FIFO. Cleared by the IP when the command sequence is transmitted successfully. |
| 2 | CMD\_READ\_EN | 0 | R/W | Setting this bit enables the SPI IAP to load received data in the SPI receive command FIFO. |
| 3 | INTR\_EN | 0 | R/W | Interrupt enable bit. |
| 4 | DAC\_EN | 0 | R/W | Setting this bit enables the Circular Buffer’s output address counter and also configures the Zmod DAC 1411 output relay. |
| 6 | OUT\_ADDR\_CNT\_RST | 0 | R/W | Setting this bit resets the Circular Buffer’s output address counter. |
| 29-16 | DIV\_RATE | 0 | R/W | The Circular Buffer’s output counter frequency is divided by DIV\_RATE. |
| 31 | RST | 0 | R/W | Resets all registers and state machines to their default values. |

### Status Register (SR – offset 04h)

The main purpose of this register is to provide status information over the IP in every aspect of its functionality.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 31 21 | 21 | 20 17 | 16 10 | 9 3 | 2 | 1 | 0 |
| **-** | BUF\_FULL | CMD\_TX\_RX\_ERROR | CMD\_RX\_COUNT | CMD\_TX\_COUNT | CMD\_RUNNING | - | CMD\_TX\_DONE |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0 | CMD\_TX\_DONE | 0 | W1C | SPI command interface command sequence complete status bit. |
| 2 | CMD\_RUNNING | 0 | R | Signals that the SPI command interface is not idle. |
| 3-9 | CMD\_TX\_COUNT | 0h | R | Reports the number of bytes in the SPI command transmit FIFO. |
| 10-16 | CMD\_RX\_COUNT | 0h | R | Reports the number of bytes in the SPI command receive FIFO. |
| 17-20 | CMD\_TX\_RX\_ERROR | 0 | R/W | Reserved for error reporting. |
| 21 | BUF\_FULL | 0 | W1C | The IP sets this bit once the circular buffer is full. The software can only clear this bit (the access type is write 1 to clear) |

### Interrupt enable register (IER – offset 08h)

Register to mask which status bits will be used as an interrupt

|  |  |  |  |
| --- | --- | --- | --- |
| 31 22 | 21 | 20 1 | 0 |
| **-** | BUF\_FULL | - | CMD\_TX\_DONE |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0 | CMD\_TX\_DONE | 0 | R/W | SPI command interface transaction complete interrupt enable mask bit |
| 21 | BUF\_FULL | 0 | R/W | Buffer Full interrupt enable mask bit |

### Command Transmit register (CMD\_TX – offset 0Ch)

Write accesses to this register will load SPI commands in the SPI command transmit FIFO.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 31 24 | 23 | 22 21 | 20 12 | 11 8 | 7 0 |
| - | Read/Write | Width | - | Address | Data |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 23 | Read/Write | 0 | R/W | Write this bit to 1 for a read command and to 0 for a write command |
| 22-21 | Width | 0h | R/W | Only 1 byte SPI transfers are supported. This field should be always 0h. |
| 11-8 | Address | 0h | R/W | AD9717 SPI register address |
| 7-0 | Data | 0h | R/W | Data byte to be sent to the AD9717. Ignored for read operations |

### Command Receive register (CMD\_RX – offset 10h)

|  |
| --- |
| 31 0 |
| CMD\_RX |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0-31 | CMD\_RX | 0 | R | SPI command receive data. Reading this register will trigger a read operation on the SPI command receive FIFO and will decrement the CMD\_RX\_COUNT field in the Status Register. |

### AXI-Stream MM2S Transfer Length (AXIS\_MM2S\_LENGTH – offset 18h)

Number of bytes to be transferred on the data path using the AXI-Stream protocol.

|  |  |
| --- | --- |
| 31 26 | 25 0 |
| - | AXIS\_MM2S\_LENGTH |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0-25 | LENGTH | 0 | R/W | Indicates the number of bytes to transfer for the MM2S channel. |

### SCALE register (SCALE– offset 18h)

DAC scale settings.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 21 | SC1\_HG\_LG | 0 | R/W | Scale select for channe1.  0 – Low gain  1 – High Gain |
| 22 | SC2\_HG\_LG | 0 | R/W | Scale select for channel2.  0 – Low gain  1 – High Gain |

**SC1LGMULTCOEF (Offset 24h)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0-17 | VAL | 0 | R/W | Channel1 low gain multiplicative coefficient |
| 18-31 | Reserved | 0 | R | Unused |

**SC1LGADDCOEF (Offset 28h)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0-17 | VAL | 0 | R/W | Channel1 low gain additive coefficient |
| 18-31 | Reserved | 0 | R | Unused |

**SC1HGMULTCOEF (Offset 2Ch)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0-17 | VAL | 0 | R/W | Channel1 high gain multiplicative coefficient |
| 18-31 | Reserved | 0 | R | Unused |

**SC1HGADDCOEF (Offset30h)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0-17 | VAL | 0 | R/W | Channel1 high gain additive coefficient |
| 18-31 | Reserved | 0 | R | Unused |

**SC2LGMULTCOEF (Offset 34h)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0-17 | VAL | 0 | R/W | Channel2 low gain multiplicative coefficient |
| 18-31 | Reserved | 0 | R | Unused |

**SC2LGADDCOEF (Offset 38h)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0-17 | VAL | 0 | R/W | Channel2 low gain additive coefficient |
| 18-31 | Reserved | 0 | R | Unused |

**SC2HGMULTCOEF (Offset 3Ch)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0-17 | VAL | 0 | R/W | Channel2 high gain multiplicative coefficient |
| 18-31 | Reserved | 0 | R | Unused |

**SC2HGADDCOEF (Offset 40h)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits** | **Field Name** | **Default Value** | **Access Type** | **Description** |
| 0-17 | VAL | 0 | R/W | Channel2 high gain additive coefficient |
| 18-31 | Reserved | 0 | R | Unused |

## Circular Buffer

The circular buffer’s write port is controlled by the AXI Stream to BRAM bridge. When the AXI Stream’s valid signal is in the logic high state, the circular buffer’s wr\_en signal will be asserted and the address counter will be incremented. The top value of the address counter is programmed through the MM2S\_Length register and is limited at 214-1. The buffer’s read port is enabled by the DAC\_EN bit in the xxx register which also controls the Zmod DAC 1411’s xxx signal. Thus, the Zmod’s output will be in hugh impedance unless the circular buffer’s read port is enabled. While the read port is enabled, the read address is incremented at a rate that can be programmed through the xxx register.

## SPI Adapter

The SPI Adapter block is a bridge between the Register File and the Zmod DAC 1411 Low Level Controller’s SPI indirect access port (IAP). Only 8 byte data transfers are currently supported on the SPI interface. The SPI commands are composed of a command word and a data byte which are passed through the CMD\_TX Register. The format of the CMD\_TX Register is illustrated in Figure 2.



Figure : CMD\_TX Format (Move to register description)

A write access to the CMD\_TX Register on the AXI Lite interface will trigger the SPI Adapter block to load the SPI command in a transmit FIFO and will increment the transmit FIFO command count (CMD\_TX\_COUNT field in the Status Register). More SPI read and write commands can be queued in the transmit FIFO by successive write accesses to the CMD\_TX register. Once all desired SPI commands are loaded in the transmit FIFO the CMD\_R/S bit in the Control Register should be set. In response, the IP will assert the sSPI\_EnTx port that will enable the Zmod DAC 1411 Low Level Controller to fetch commands from the transmit FIFO. The Zmod DAC 1411 Low Level Controller will decode the R/W bit in the command word and, in the case of a read command, it will load the data byte received on the SPI port in the SPI Adapter’s receive FIFO also increasing the receive FIFO data counter (CMD\_RX\_COUNT field in the Status Register). The CMD\_TX\_COUNT field will be decremented for each SPI transaction signaled as successful by the Zmod DAC 1411 Low Level Controller. The CMD\_DONE bit in the Status Register will be set on the successful completion of the last command in the transmit FIFO. Read command data can be accessed from software by reading the CMD\_RX register. Each read access of this register will assert the receive FIFO’s read enable signal also decrementing the CMD\_RX\_COUNT field in the Status Register. The CMD\_RX should only be accessed after the command sequence completion is signaled by the CMD\_DONE flag.

## Calibration

The Zmod DAC1411 calibration is not performed at the Zmod DAC 1411 AXI Adapter level. The multiplicative and additive calibration coefficients are computed in software based on parameters read from the Zmod’s EEPROM memory and written to the configuration registers (addresses 24h-40h). The content of the configuration registers is exported as eight 18bit output ports(the configuration interface) to the Zmod DAC 1411 Low Level controller.

## Clocking

The IP is divided in three clock domains:

The system clock domain (100MHz), which clocks the Circular Buffer read port, the command transmit FIFO read port and the command receive FIFO write port.

The AXI Stream clock that clocks the Circular Buffer write port and the Axi Stream to BRAM bridge.

The AXI Lite clock that clocks the Register File.

# Port description

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Signal Name | Interface | Signal Type | Init State | Description |
| SysClk | - | I | N/A | 100MHz input clock signal. |
| AxiStreamClk | S2MM | I | N/A | Input clock associated with the S2MM AXI Stream interface |
| lRst\_n | - | I | N/A | Synchronous reset of negative polarity. |
| sZmodControllerRst\_n | - | O | N/A | Active low reset output synchronized in the SysClk clock domain. Asserted when the external reset signal (lRst\_n) is asserted or when a software reset occurs. |
|  |  |  |  |  |
| sInitDone\_n | - | I | N/A | Active low flag indicating when the Zmod Low Level Controller initialization is complete. |
| sSync | - | O | N/A | Signal used to synchronize multiple AD9648 devices. For more details see [] (Zmod DAC 1411 Low Level Controller) |
| lIrqOut | - | O | N/A | Interrupt output (Level). |
| sCh1In[13:0] | - | I | N/A | 14 bit output data channel 1 (connect to Zmod DAC 1411 Low Level Controller channel 1 input). |
| sCh1In[13:0] | - | I | N/A | 14 bit output data channel 2 (connect to Zmod DAC 1411 Low Level Controller channel 2 input). |
| sCh1LgMultCoef | - | O | N/A | Channel1 low gain multiplicative coefficient output port. |
| sCh1LgAddCoef | - | O | N/A | Channel1 low gain additive coefficient output port. |
| sCh1HgMultCoef | - | O | N/A | Channel1 high gain multiplicative coefficient output port. |
| sCh1HgAddCoef | - | O | N/A | Channel1 high gain additive coefficient output port. |
| sCh2LgMultCoef | - | O | N/A | Channel2 low gain multiplicative coefficient output port. |
| sCh2LgAddCoef | - | O | N/A | Channel2 low gain additive coefficient output port. |
| sCh2HgMultCoef | - | O | N/A | Channel2 high gain multiplicative coefficient output port. |
| sCh2HgAddCoef | - | O | N/A | Channel2 high gain additive coefficient output port. |
| sCh1ScaleSelect | - | O | N/A | Channel1 scale select output port.  • 1 = High Gain.  • 0 = Low Gain. |
| sCh2ScaleSelect | - | O | N/A | Channel2 scale select output port.  • 1 = High Gain.  • 0 = Low Gain. |
| sExtSPI\_Idle | - | I | N/A | Flag indicating that the Low Level Controller configuration state machine is in the IDLE state. |
| sCmdDone | - | I | N/A | Pulse indicating that the SPI command has been successfully completed. |
| sSPI\_TxRdEn | - | I | N/A | Read enable signal used to load data from the transmit command FIFO. |
| sSPI\_TxDout[23:0] | - | O | N/A | Transmit command FIFO output data containing the transfer length, the register address and the register data that are passed to the SPI controller. |
| sSPI\_TxValid | - | O | N/A | Transmit command FIFO data valid signal. |
| sSPI\_RxWrEn | - | I | N/A | Receive command FIFO write enable signal. |
| sSPI\_RxDin[7:0] | - | I | N/A | Receive command FIFO input data. |

|  |  |  |  |
| --- | --- | --- | --- |
| AXI4 Lite Interface Signals | | | |
| AXI\_LITE\* | Input / Output | AXI4 Lite interface used to communicate with the control and status registers | |
| AXI4 Stream Interface Signals | | | |
| MM2S\* | Input | | AXI4 Stream interface – connect to a DMA engine to transfer data from system memory to the IP’s Circular Buffer |

# Designing with the core

## Constraints

The IP does not constrain the clocks it requires as inputs, therefore clocks need to be constrained in the top-level design either manually or by relying on the auto-derived constraints, if using clock modifying blocks. For more information see [4]. No other constraints are required.

# References

The following documents provide additional information on the subjects discussed:

1. Xilinx Inc., *UG471: 7 Series FPGAs SelectIO Resources*, v1.4, May 13, 2014.
2. Xilinx Inc., *UG472: 7 Series FPGAs Clocking Resources*, v1.6, October 2, 2012.
3. Analog Devices, AD9717 Datasheet, Rev B.
4. Xilinx Inc., UG903: Using Constraints, v2014.3, October 31, 2014