Overview

This document describes the LCD-Pro IP architecture, including the next cores: UltiEVC display controller, UltiEBB 2D graphic accelerator, UltiEMC DDR memory controller, UltiVidin video input core, UltiDMA DMA controller, UltiSPI2AHB SPI slave core and UltiSPI_M SPI master core.
Full core interfaces and registers are described for user reference.

This document describes the LCD-Pro IP core for Full Version[1].

[1] Refer to LCD-Pro IP architecture datasheet (DS0031) for more information on other versions.

1 INTRODUCTION

LCD-Pro IP is designed as multipurpose Video controller, targeted for TFT displays, based on Lattice ECP2-50 FPGA.

The module's functionality is implemented using an FPGA-based system-on-chip (Lattice ECP2-50 FPGA). The system-on-chip is based on the SoC interconnect, enabling simplified FPGA design integration and IP-block oriented design for the FPGA.
One of the features of the LCD-Pro IP modules is the ability to operate as a standalone USB peripheral.
LCD-Pro IP supports the 8051-based high speed USB peripheral controller, Cypress EZ-USB FX2 (CY7C68013A), used for interfacing the LCD-Pro IP module to a device with USB host functionality, such as PCs and USB-OTG compliant devices.

1.1 FEATURES

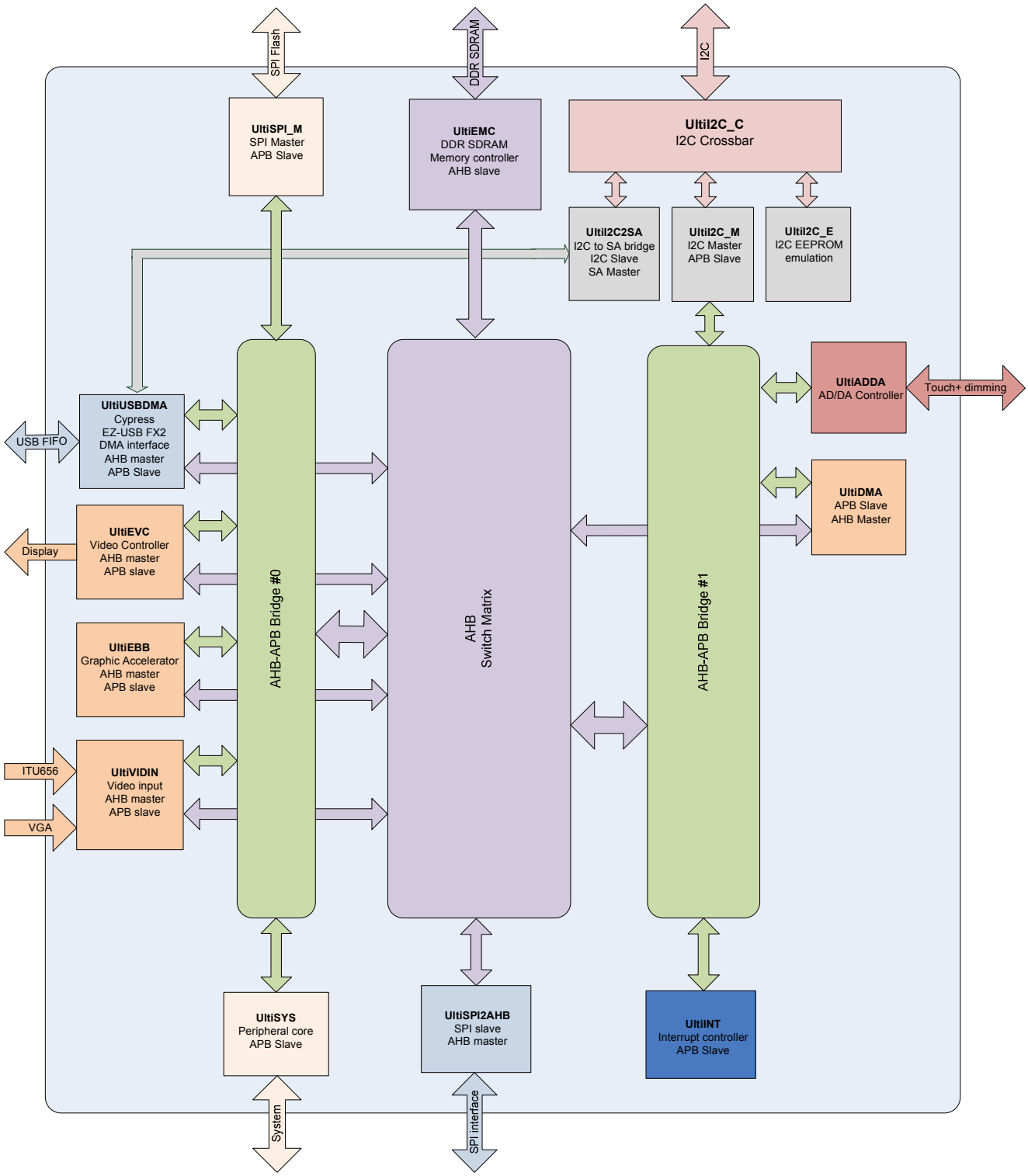
- Supports Lattice ECP2 family
- Supports video controller module
- Supports touch controller module
- Supports backlight dimming control
- Supports memory controller module
- Supports USB controller module
- Supports Video input module
- Supports SPI master module
- System-on-chip architecture based

2 CORE ARCHITECTURE

The LCD-Pro IP includes the next cores:

- UltiEVC
- UltiEBB
- UltiVidin
- USB_DMA
- UltiSPI_M
- UltiEMC
- UltiI2C_M
- UltiI2C_C
- UltiI2C_E
- UltiI2C2SA
- UltiADDA
- UltiDMA
- UltiINT
- UltiSPI2AHB
- UltiSYS
- SoC buses, switch matrix and bridges

2.1 BLOCK SCHEMATICS



LCD-Pro IP Block Diagram. Full version: Full version Video Controller + Video Input module

3 System Interconnect

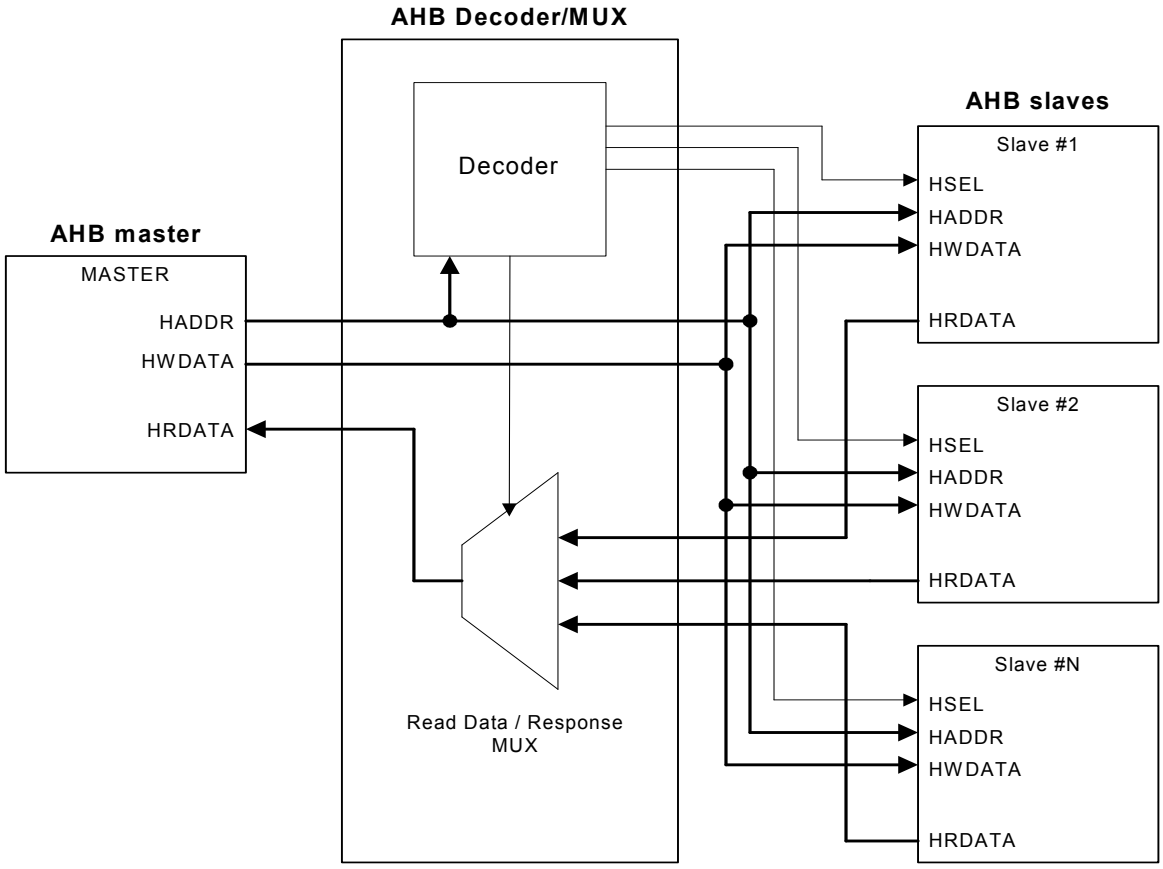
The LCD-Pro IP is based on SoC interconnection, bus structure is organized in 2 layers:

1. AHB bus: high speed, multiplexed, pipelined bus
2. APB bus: low speed multiplexed bus, not pipelined, used primarily for peripheral access

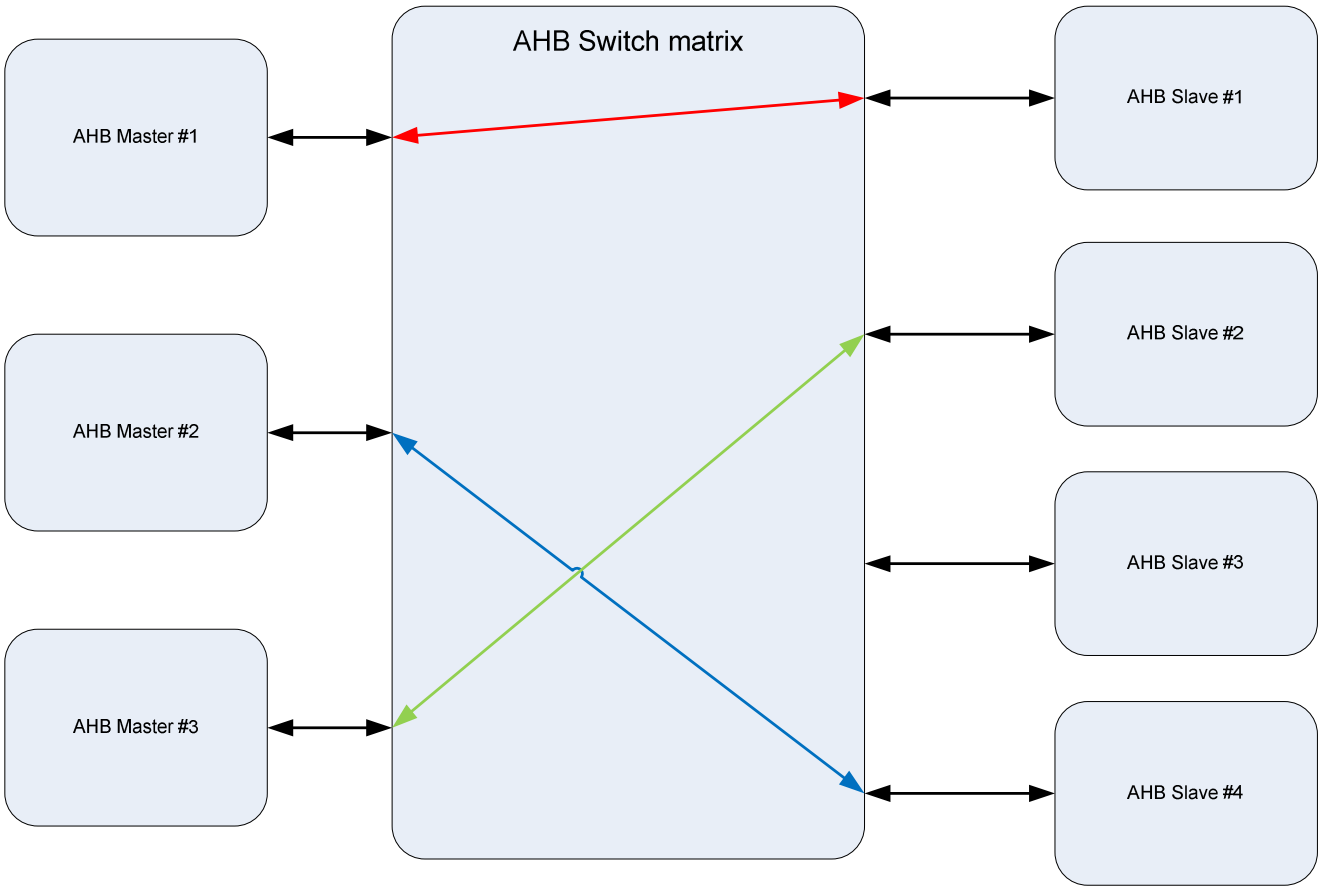
3.1 AHB bus

The AHB bus is the main system interconnect in LCD-Pro IP SoC, providing high-speed system interface for system bus masters. AHB is a multiplexed bus, where one AHB master can perform transaction to an only one AHB slave at the same time. AHB is also a pipelined bus, and the slave response to the master transaction is active at least one clock cycle after the master's request. The bus protocol is synchronous, and the pipelined operation enables high transfer speeds.

AHB slaves are connected to the master via a bus decoder/multiplexor which generates slave enable signals and muxes the slave response lines to the master. Additionally the decoder behaves as a default, idle slave.



AHB Bus decoding/multiplexing



Multilayer AHB switch matrix operation

The AHB switch matrix appears as a slave to the AHB master which attempts the transaction. The switch matrix accepts the transaction, delaying the transfer with the HREADY line until the slave access becomes available.

A master also has the capability to lock a bus for its use in consecutive transfers.

Simultaneous bus transactions through the AHB switch matrix raise effective bus bandwidth, and reduce access latencies. For example, a video controller could fetch image data at a constant rate from the video memory concurrently to a DMA I/O transfer from the system memory to the Ethernet controller.

In LCD-Pro IP, the AHB bus has a 32 bit data bus clocked at 96 MHz. The AHB address bus is 32 bits wide, which can be used to address 4.294.967.296 bytes (4 GB)

3.2 APB bus

APB bus is the peripheral bus, designed for simpler or slower devices, primarily peripherals. It is a non-pipelined multiplexed synchronous bus which allows a single master to drive multiple slaves. The protocol does not support burst transfers, and does not support transfer sizes less than the bus width. The minimum addressable chunk of address space on the APB bus is the bus width.

APB is envisioned as the hierarchical extension of the AHB bus. The APB bus master is, effectively, an AHB-to-APB bus bridge. The AHB-APB bus bridge behaves as an AHB slave, which converts the AHB transfers to the APB transfers. The address space of the APB bus is mapped in the address space of the AHB bus.

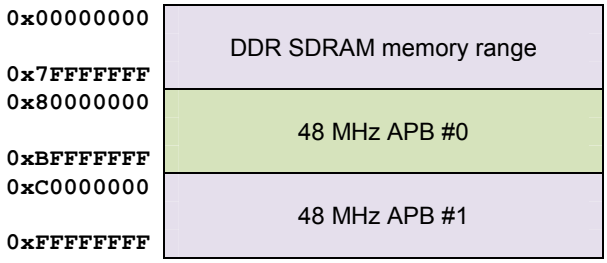
On LCD-Pro IP, the APB bus has a 32-bit address and data bus size. Only part of this address range is decoded for slave selection, so user has to take care not to access non-existing addresses, which will wrap to unknown APB slave. The APB bus is clocked on 48 MHz. The APB bridge resamples the transfer internally between the faster AHB clock domain and the slower APB clock domain. Running the APB logic on a slower clock enables better timing optimization in the logic design, as it decouples the slow peripheral access bus from the fast system bus.

The APB decoder is connected to a dedicated AHB layer on the AHB interconnection matrix, which prevents the AHB bus operation being interrupted by slow APB transfers from a high priority master.

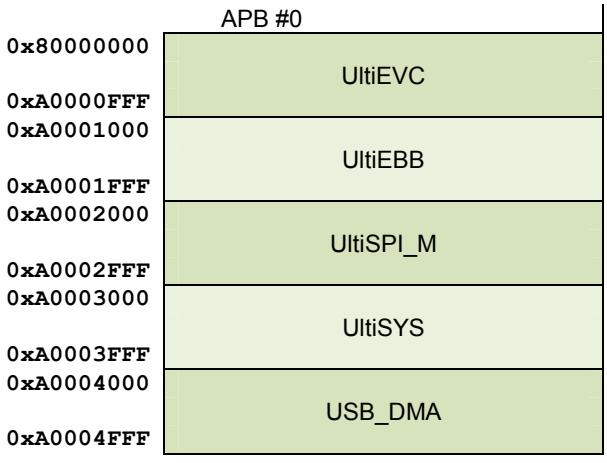
3.3 Address range mapping

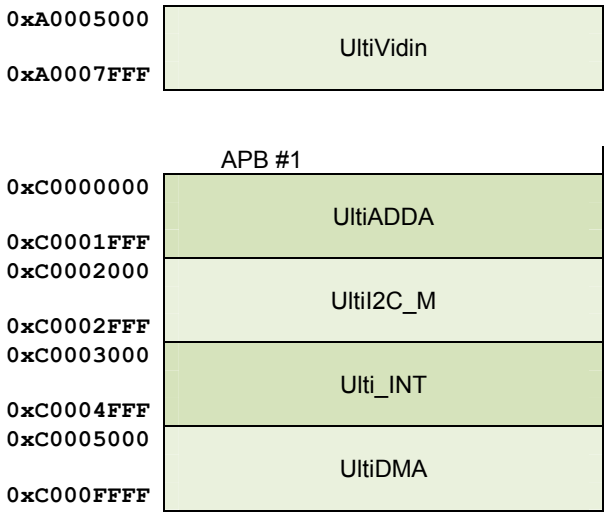
The only true AHB slave in the system is the UltiEMC DDR memory controller. As the source of the image refresh, it requires the burst capability and high bandwidth offered by the AHB.
Additionally, two distinct AHB-to-APB interface bridges are present, each of them mapped to a different address range.
The control interfaces of the IP in the system are mapped to the APB buses.

The LCD-Pro IP AHB interconnection matrix maps the AHB address space into ranges:



The APB address spaces are further divided. Several cores are mapped to the 48 MHz APB.





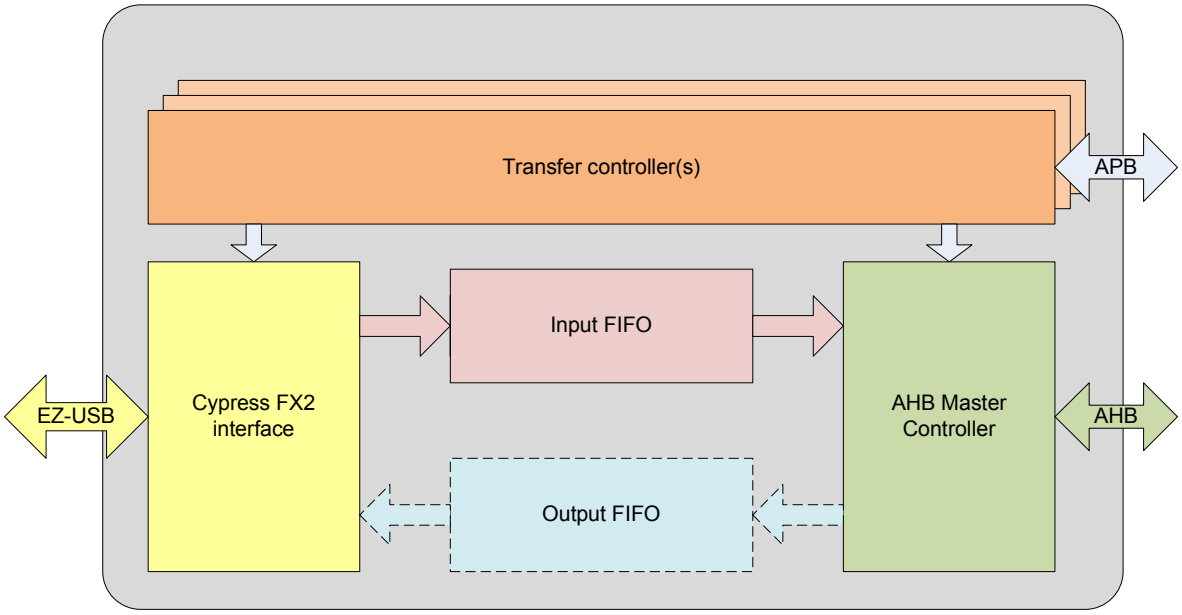
Note: The apparently large address range of the UltiEVC is due to the functionality of the AHB-APB bridge. For the APB slave with the highest base address, the bridge will map the entire remainder of the address space. Identical decoding principle is used also by the AHB switch matrix, hence the large address space assigned to the APB.

4 System Components

4.1 USB Interface

The Cypress USB DMA is a programmable data pump used to transfer data from the USB endpoints of the external Cypress EZ-USB FX2 chip to the LCD-Pro IP video memory. The primary function is to transfer image data. With its quantum fifo interface, the Cypress can support high speed USB data streaming to the device over bulk or isochronous USB endpoints. Additionally, it supports issue of single access operations on the AHB bus.

The USB DMA uses a modular internal architecture which enables the hardware to be easily configured for the target application, based on the number of the data endpoints and their direction. In LCD-Pro IP, the USB DMA is currently configured to work as a single endpoint, downstream data pipe, enabling transfer of data from the USB host to the LCD-Pro IP device.



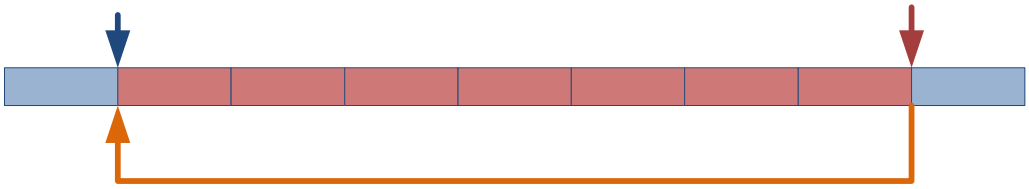
For configuration, the DMA interface also behaves as an APB slave, enabling the configuration of the USB DMA.

4.1.1 Bulk access

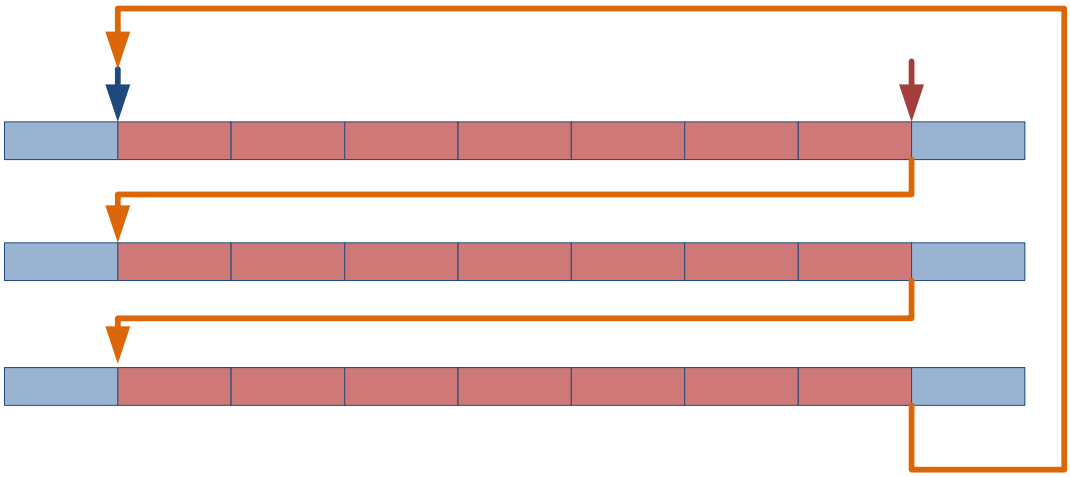
Bulk access operation enables the transfer of a data stream from the USB endpoint to the LCD-Pro IP device memory (the streaming from the memory to the USB endpoint is not currently implemented, but is possible).
The USB DMA supports several bulk access operating modes, enabling operation from simple data transfers to image transfers, which require image dimension information for correct alignment. The USB DMA supports several operating modes.

- Linear: the data is written to the AHB bus incrementally from a defined base address.

- Circular: the data is written to the AHB bus incrementally from a defined base address for a specific data count, after which it returns back to the starting address.



- Stride: used for image transfer. The data is written to the AHB bus incrementally from a starting address for a specified number of data elements. After that the new starting address is defined as old starting address incremented by the stride length. After a specific data count has been reached, the new starting address to the original base address.



The USB DMA bulk interface transfers data in 16-word bursts, which is the maximum specified burst size on the AHB bus. Data sizes less than a word (32 bits) are not supported. The destination addresses and counts need to be defined in quantums of the burst size. These limitations reflect the nature of the interface, which supports high speed operation of the interface while keeping the logic simple.

4.1.2 Single access

The single access mode enables random access to the bus address space. It supports single read and write accesses of all sizes. The single access mode utilizes two USB endpoints for a request-response protocol. The requests are sent over one endpoint, while over the second endpoint the responses are received by the USB host.

Over each endpoint a stream of messages is transferred.

4.1.2.1 Request message

A request message is 16 bytes in size.

	0	1	2	3
0x0	Tag	Command/Size	A0	A1
0x4	A2	A3	D0	D1
0x8	D2	D3	padding	
0xC	padding			

A request message consists of:

- Tag - the identifier of the operation in the stream, used to identify the corresponding response message in the response stream. The tag of the request will be copied to the response.
- Command/size – the identifier used to define the bus operation.
- A[3:0] – the bus address in little endian ordering (A0 = LSB byte, A3 = MSB byte)
- D[3:0] – the bus data (for write operations) in little endian ordering (D0 = LSB byte, D3 = MSB byte). Dummy data/padding for read operations.
- Padding – dummy data to align on 16 byte boundary (to pack messages into a single USB frame and for future use).

The command/size identifier:

7	6	5	4	3	2	1	0
HWRITE	RFU				HSIZE2	HSIZE1	HSIZE0

The HWRITE line is mapped to the HWRITE flag on the AHB bus.

- 1 – AMBA write
- 0 – AMBA read

The HSIZE[2:0] identifier is mapped to the HSIZE bus on the AHB bus.

- 000 = Byte
- 001 = Halfword (16 bits)
- 010 = Word (32 bits)

Bits 6:3 are RFU and should be set to 0.

4.1.2.2 Response message

A response message is 8 bytes in size.

	0	1	2	3
0x0	Tag	D0	D1	D2
0x4	D3	Padding		

A response message consists of:

- Tag - the identifier of the operation in the stream, used to match the response message in the response stream to its corresponding request message The tag of the request is copied to the response.
- D[3:0] – the bus data (for read operations) in little endian ordering (D0 = LSB byte, D3 = MSB byte). Dummy data/padding for write operations.

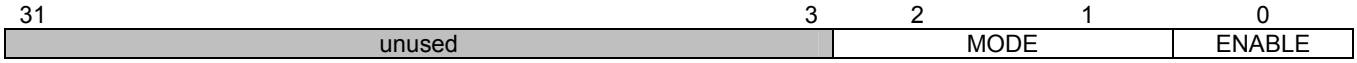
- Padding – dummy data to align on 8 byte boundary (to pack messages into a single USB frame and for future use).

4.1.3 Registers

The USB DMA has several APB-mapped registers used to control the DMA transfer.

Offset	Name	Description
0x0	MODE	Operating mode for bulk transfer
0x4	ADDR	Address for bulk transfer
0x8	CNT	Data count for bulk transfer
0xC	STRIDE	Stride for bulk transfer stride mode
0x10	LINE	Line for bulk transfer line mode
0x14	RESET	Reset for the entire USB DMA
0x18	PE_CNT	PKTEND timeout counter

The MODE register is used to control the USB DMA bulk operating mode.

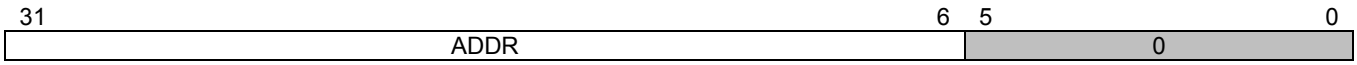


The MODE parameter denotes the operating mode.

- 00 – Linear mode
- 01 – Circular mode
- 10 – Stride mode

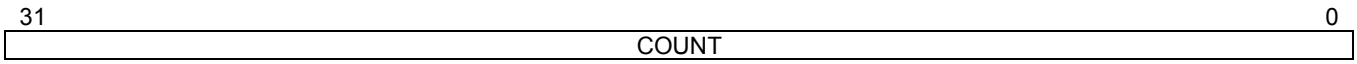
The ENABLE bit serves as the mode initiator/local reset. The USB DMA needs to be disabled (ENABLE = 0) before the parameters (mode, address, stride, line, count) can be modified. Once the ENABLE bit is set from 0 to 1, the parameters from the registers are initialized and transfer can begin.

The ADDR register contains the address of the bulk transfer. The address must be aligned to the bus burst boundary.



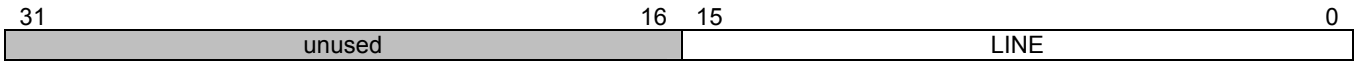
The bits 5:0 of the address counter MUST be always set to 0.

The CNT register holds the data count for the transfer. Which is the size of the circular buffer in the Circular transfer mode, and the size of the image for transfer in the Stride mode.



The STRIDE register holds the stride size for the Stride transfer mode. Not used otherwise.

The LINE register holds the size of the image line for the Stride transfer mode. Not used otherwise.



The RESET register contains the reset bit. This bit resets the entire USB DMA while set to 1.

unused	RESET

The initial state of the reset bit is set to '1' which keeps the DMA machine in total reset. This is to prevent the transient occurring during the system power-up and Cypress SDRAM, and to prevent contention on external lines until the Cypress FX2 boot up process is completed.

The PE_CNT register holds the timeout counter for the PKTEND commit line of the Cypress FX2.

31 … 13	12 … 0
unused	PE_CNT

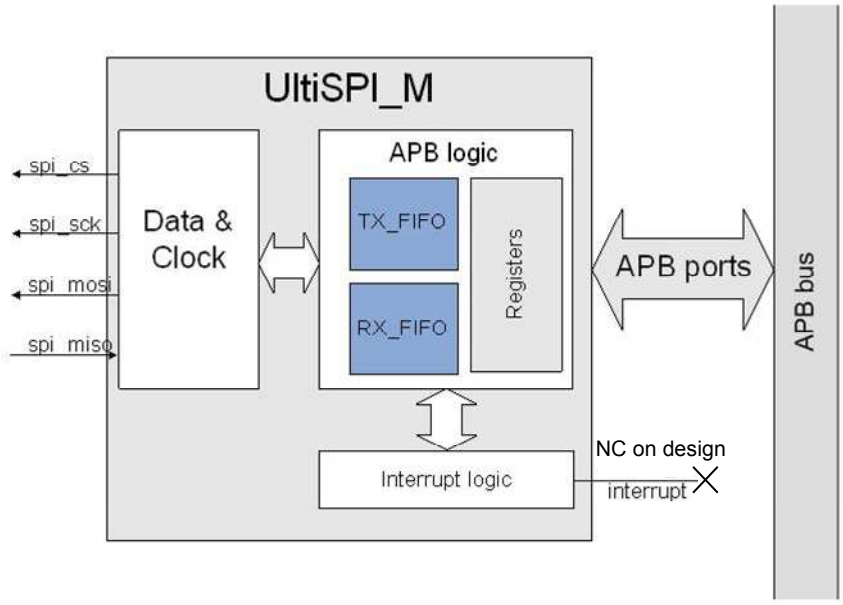
This is used with single access mode to enable the commit of the last packet in the Cypress FX2 FIFO to the USB domain even if the packet is not completely full (required for the FX2 to auto-commit the packet to the USB domain). The timeout counter is reset to PE_CNT on each byte transferred to FX2. When the timeout reaches 0 (no response has been issued for a given period of time indicating that the transfer queue is completed), the PKTEND is issued and the packet is committed.

This register is initialized by the FX2 firmware and should not be modified!

4.2 SPI master interface

SPI master interface is implemented using the UltiSPI_M core, based on FIFO interface for data and registers for configuration.

SPI interface consists of two FIFOs for data flow, registers for configuration and interrupt logic (the interrupt output line is not connected on LCD-Pro IP design). SPI interface consists of chip select output, clock output, serial data output and serial data input. Both transmit and receive FIFO are 2048 bytes deep.



Internal structure of SPI master interface

4.2.1 Registers

Register	Width (bits)	Read/Write	Address offset
FIFO	8	R/W	0x00
TX_STATUS	16	R	0x10
RX_STATUS	16	R	0x20
CLK_DIV	5	R/W	0x30
SPI_CONFIG	9	R/W	0x40
TRN_BYTE_NUM	12	R/W	0x50
FRAME_SIZE	12	R/W	0x60
TIMEOUT	16	R/W	0x70
DESEL_TIME	8	R/W	0x80
STATUS	3	R/W*	0x90
INT_MASK	4	R/W	0xA0
INTERRUPT	4	R/Clear on write '1'	0xB0

SPI_master registers

- - write access to the STATUS register is used for start (write "001") or reset (write "1XX").

The FIFO register is organized as follows

Register bit(s)	Description
FIFO	Write to TX_FIFO, read from RX_FIFO

The TX_STATUS is organized as follows

Register bit(s)	Description
TX_STATUS[11:0]	Number of bytes in TX_FIFO
TX_STATUS[14]	TX_FIFO empty flag
TX_STATUS[15]	TX_FIFO full flag

The RX_STATUS is organized as follows

Register bit(s)	Description
RX_STATUS[11:0]	Number of bytes in RX_FIFO
RX_STATUS[14]	RX_FIFO empty flag
RX_STATUS[15]	RX_FIFO full flag

The SPI_CONFIG register is organized as follows

Register bit(s)	Description
SPI_CONFIG[0]	CPOL mode
SPI_CONFIG[1]	CPHA mode
SPI_CONFIG[3:2]	RFU
SPI_CONFIG[7: 4]	Reserved: must be all 0s
SPI_CONFIG[8]	CS active polarity. If CS(0) is active low, write '0' to SPI_CONFIG[8].

The STATUS register is organized as follows

Register bit(s)	Description
STATUS[0]	Write – (‘1’) start operation Read - UltiSPI_M busy (‘1’) or idle (‘0’)
STATUS[1]	Read only. (‘1’) TX_FIFO underrun occurred during last operation. This bit is cleared on beginning of each new operation. (‘0’) no underrun occurred.
STATUS[2]	Write – (‘1’) reset UltiSPI_M Read – (‘1’) RX_FIFO overrun occurred during last operation. This bit is cleared on beginning of each new operation. (‘0’) no overrun occurred

The INT_MASK register is organized as follows

Register bit(s)	Description
INT_MASK[0]	Mask (‘1’) or unmask (‘0’) INTERRUPT[0]
INT_MASK[1]	Mask (‘1’) or unmask (‘0’) INTERRUPT[1]
INT_MASK[2]	Mask (‘1’) or unmask (‘0’) INTERRUPT[2]
INT_MASK[3]	Mask (‘1’) or unmask (‘0’) INTERRUPT[3]

The INTERRUPT register is organized as follows

Register bit(s)	Description
INTERRUPT[0]	Interrupt on UltiSPI_M idle. Reset by writing ‘1’.
INTERRUPT[1]	Interrupt on error, TX_FIFO underrun, or RX_FIFO overrun. Reset by writing ‘1’.
INTERRUPT[2]	Interrupt on TX_FIFO empty. Reset by writing ‘1’.
INTERRUPT[3]	Interrupt on RX_FIFO not empty. Reset by writing ‘1’.

4.2.2 General description and operation

All time periods are calculated in the number of the clock cycles, so the configuration parameters need to be calculated in relation to the 48Mhz AMBA APB interface clock frequency. All relevant registers need to be set prior to the starting of the operation and TX_FIFO needs to be filled with at least one byte.

All frequencies obtainable by dividing the 48Mhz frequency with an even number up to 16 are possible. Highest frequency is equal to the half of the system frequency, set when writing 0 or 2 to the divider register. Desired frequency is set by the register CLK_DIV. After reset, UltiSPI_M is set to the highest frequency.
The SPI mode of operation and the polarity of chip select are configured by the register SPI_CONFIG. This register sets CPOL, CPHA and active state of the chip select output. After reset all these bits are set to ‘0’, setting the idle clock low, data sampling on the rising edge and the chip select active low.
The number of bytes to be transmitted on the write operation is set by the register TRN_BYTE_NUM. Present maximum size is 4096 bytes. Data is written in format N-1, so to send 2 bytes this register should be set to 0x001.
The total length of the SPI frame is set by the register FRAME_SIZE. Present maximum size is 4096 bytes. The size of frame can be set to any value, which if larger than the value in TRN_BYTE_NUM means that, after sending bytes, frame will be extended to the size specified, with data being inputted to RX_FIFO.
If TX_FIFO does not contain enough data to complete the write operation, or RX_FIFO is full during read operation, UltiSPI_M will go to stall mode, stopping clock for a number of system clock cycles defined in the TIMEOUT register. If operation still cannot be completed after this period expires, system will report error in register STATUS and set chip select output to the inactive state. Maximum value for this interval is 0xFFFF. After reset, this register is set to 0x0000.

SPI devices set minimum intervals between two operations, which is the minimum time for chip select set to the inactive state. This interval can be set by the register DESEL_TIME; it will always be executed after operation is completed. During this interval, UltiSPI_M will report busy state and not allow new operations. Maximum value is 0xFF, after reset this register is set to 0x00.
An operation or core reset is started by a write access to the register *status*, with the following options:

- Write 0x1 starts the operation, if TX_FIFO is not empty. Otherwise, write access is ignored.
- Write 0x4 resets UltiSPI_M, emptying FIFOs and resetting all registers to the reset value.

Status of the device and the result of the previous operation (whether error occurred or not) can be read from the register STATUS. Bits have the following meaning:

- STATUS[0] = '1' (busy), '0' (idle)
- STATUS[1] = '1' (TX FIFO underrun, not enough data to transmit, TIMEOUT period expired), '0' (transmit OK)
- STATUS[2] = '1' (RX FIFO overrun, not enough space to receive, TIMEOUT period expired), '0' (receive OK)

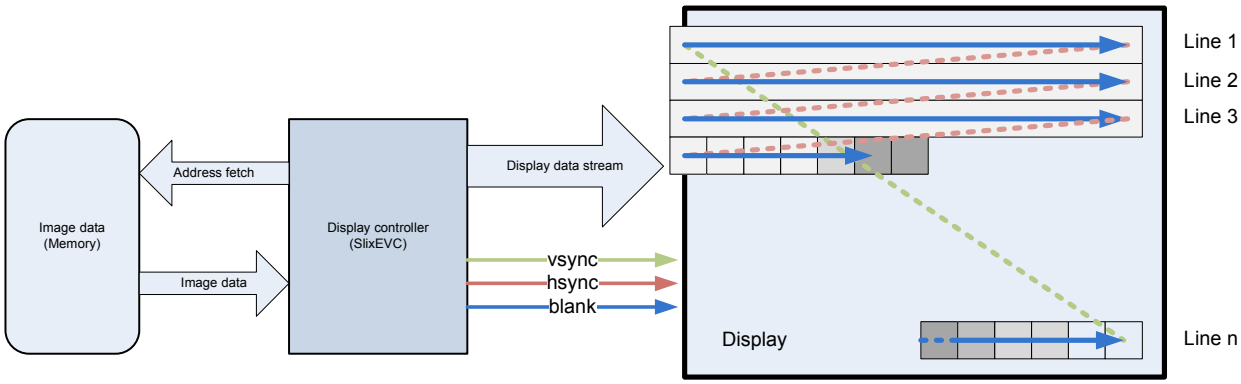
Status of the transmit FIFO can be read from the register TX_STATUS, with 12 LSB bits showing the number of bytes in the FIFO and TX_STATUS [14] being equal to the empty flag, and TX_STATUS[15] to the full flag.
Status of the receive FIFO can be read from the register RX_STATUS, with 12 LSB bits showing number of bytes in the FIFO and RX_STATUS [14] being equal to the empty flag, and RX_STATUS[15] to the full flag.
FIFO data access is done over the same address on APB, accessing TX_FIFO on writes and RX_FIFO on reads. When writing, it is not possible to overrun FIFO, starting the fill process again. When reading from an empty FIFO, FIFO will output last valid data and remain in the empty state. Both data write and read are mapped to the same APB address, but all writes are forwarded to the transmission FIFO, and reads are only from the receiver FIFO. To empty transmission FIFO, UltiSPI_M has to be reset. Data access is 8-bit, while registers are various sizes, with the biggest being 32 bits.

4.3 EVC video controller

The EVC video controller interface is implemented using the UltiEVC core.
UltiEVC is a high performance modular embedded graphic display controller, targeted for driving active matrix flat panel displays. UltiEVC supports multi-layer overlay between multiple frame buffers with color-key transparency and alpha blending.
AMBA AHB interface is used as video memory interface and AMBA APB interface is used as register interface.

4.3.1 General Description

A display controller's function is to continuously refresh the image present on a graphic display device. The sequence of displayed images can be described as a continuous video stream, which can be either sourced externally or generated by scanning the image data present in a memory device. The UltiEVC generates the image stream by reading a memory area in the display memory, the frame buffer. The UltiEVC is capable of reading multiple frame buffer areas into different layers, and blending them into a single image, enabling complex graphics effects within the display controller.



The refresh operation is accompanied by generating the display control signals for horizontal and vertical synchronization (hsync and vsync) and data enable (blank). These signals define the refresh cycle and refresh rate of the display and are usually specific for a display panel. Timings for control signals are software configurable.
The following characteristics are given for the LCD-Pro IP configuration:

- Active matrix display refresh
- Display resolution:
  - up to 1366x768 (2 16-bit layers, no video input) (1)
  - up to 800x480 (4 layers) (1)
- 16 bit data output
- Display power-up sequence control
- Internal pixel clock generator
- ARM AMBA 3 compliant system interconnection
  - AHB memory interface
  - APB register interface
- RGB8, RGB16,RGB32, ARGB32 frame buffer formats
- Multi-layer window and overlay image assembly (n° 4 layers available (2))
- Variable frame buffer geometry – stripe setting per layer
- Common overlay with color-key transparency
- Alpha blending with per-layer fading
- Alpha mask layer support

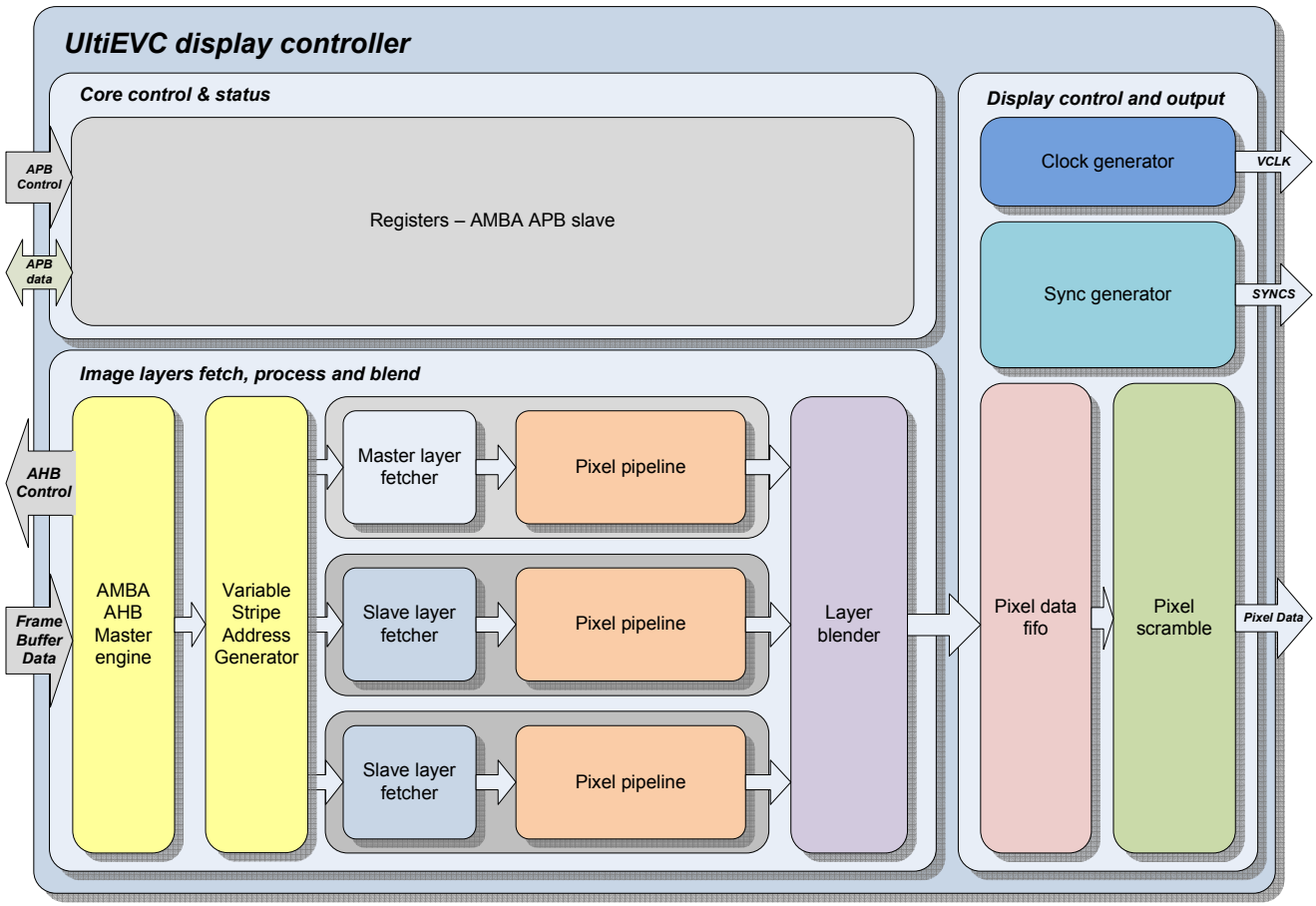
NOTE (1) : The max display resolution depends on many factors, such as the number of layers effectively used for blending, the display refresh rate and the contemporary use of video input features. It is suggested to contact Exor International for any request regarding the specific application.
NOTE (2) : The max number of layers which can be effectively used depends on many factors, such as the display resolution and refresh rate and the contemporary use of video input features. It is suggested to contact Exor International for any request regarding the specific application.

4.3.2 Core architecture

The UltiEVC core consists of:

- Register APB slave
- Address generator
- AHB master
- Master and slave (overlay) layer fetchers
- Pixel pipelines
- Layers blending module
- Clock generator module
- Syncs generator module
- Pixel data fifo
- Pixel scramble module

Diagram below shows UltiEVC core architecture (simplified diagram; the real core contains n° 4 layers)

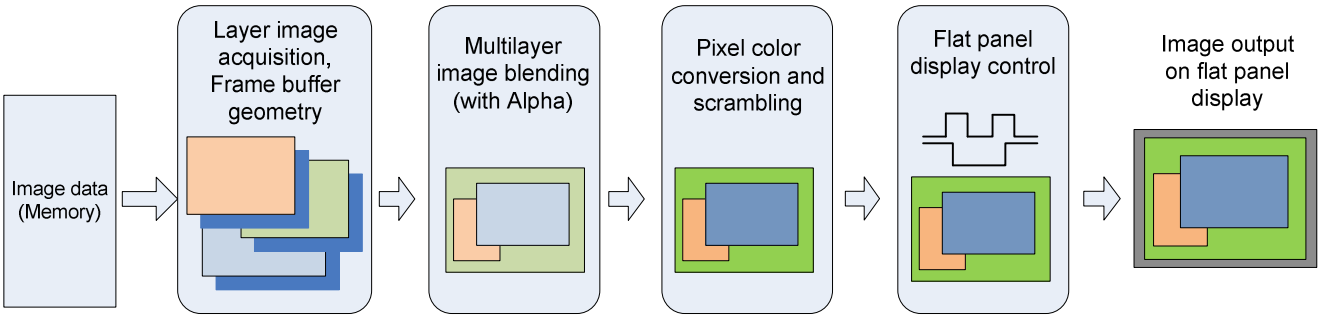


UltiEVC Block Diagram

4.3.3 Functional description

The operation of the UltiEVC can be divided into:

- Layer image acquisition with frame buffer geometry handling
- Multi-layer image blending (with Alpha channel)
- Pixel color conversion and scrambling
- Flat panel display control



EVC operation in phases

4.3.4 Layer image acquisition

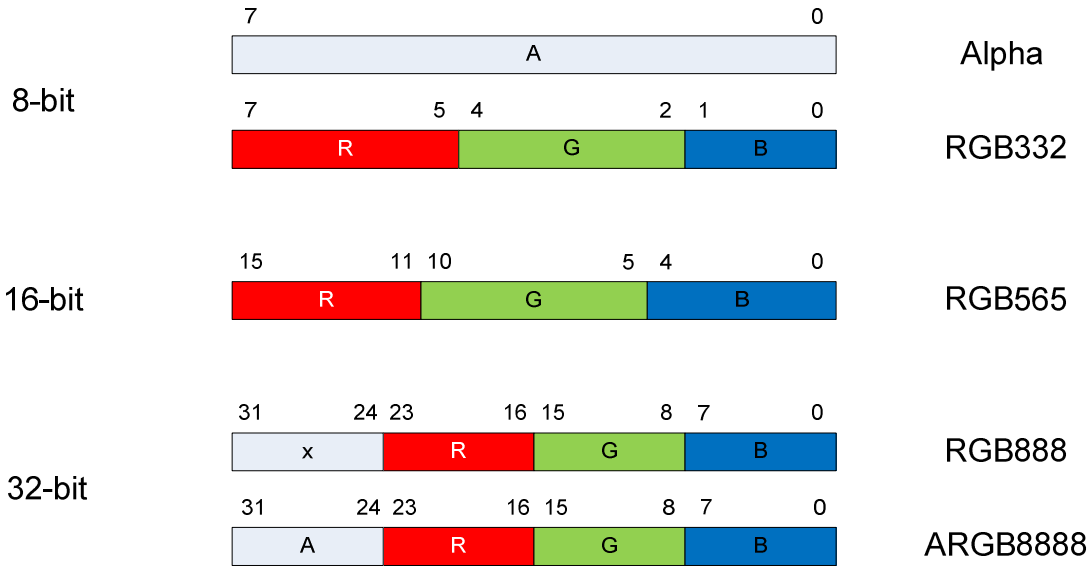
The source images for the UltiEVC are stored in the display video memory. UltiEVC behaves as an AHB master and accesses the video memory through the on-chip AMBA AHB bus. Each image is stored in its own respective memory area (a frame buffer).

The image in memory is stored as RGB pixel data in 8, 16 or 32-bit format with or without Alpha information.

All formats are RGB. 8-bit format can be used either as 8-bit alpha channel information (for alpha mask) or as 8-bit RGB with 3 bits for red channel, 3 bits for green channel and 2 bits for blue channel (RGB 332).

16-bit format allows for RGB565, with 5 bits for red, 6 for green and 5 for blue.

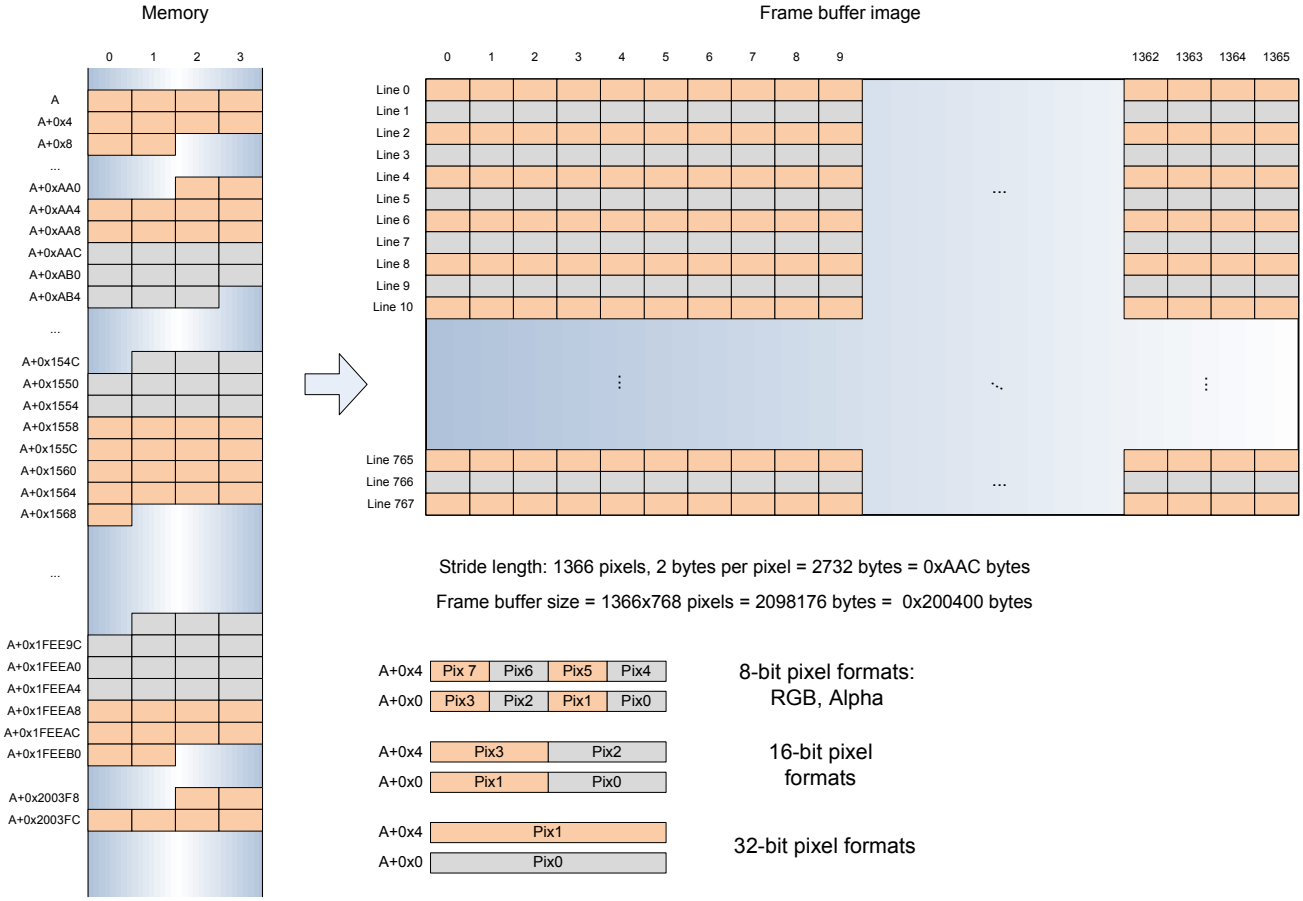
32-bit format allows for RGB888, with 8 bits for each channel, and the upper 8 bits of a 32 bit word stand unused, or for ARGB8888, with 3-byte packing of pixels and alpha channel in the MSB byte.



EVC pixel formats in memory

Each frame buffer is a rectangular memory area consisting of multiple lines. The size of a frame buffer is limited by the size of the system memory. The width of a frame buffer line in the memory is called the stripe, or stride. The stripe is also the distance in memory between two vertically adjacent pixels. EVC supports variable stripe length for each frame buffer, and is able to support any frame buffer geometry, which allows for more efficient memory usage.

The stripe used for a frame buffer is defined in bytes. Depending on the color depth used, the pixel geometry of the frame buffer , and the maximum achievable resolution is changed accordingly. For a defined frame buffer, the maximum horizontal resolution is equal to the stripe divided by the number of bytes occupied by a single pixel. The pixels of an individual line are ordered in ascending order in memory.



Frame buffer geometry and memory organization

For the memory organization in **Error! Reference source not found.**, the EVC allows the maximum image of 1366x768 pixels with 16-bit color. If the color depth is changed to 32 bits, the maximum image resolution is decreased to 683 pixels.

The maximum vertical resolution is constrained only by the size of the allocated memory space. EVC has no limitation in the number of lines for a given frame buffer (other than the address bus width) and will successively increment the image address with the stripe count during the image fetch.

The address of a pixel within the frame buffer can be defined by the equation:

```
Pix_address = y*STRIPE + x*BPP;
```

Where:

- STRIPE is the length of the frame buffer line (the stripe) in bytes
- x, and y are the horizontal and vertical coordinates, respectively
- BPP is the number of bytes occupied by each pixel

The frame buffer organization is rectangular. For a given stride, each line of the image will be put in the corresponding line of the frame buffer, regardless of the horizontal resolution of the actual image. The remaining part of the frame buffer line will not be used.

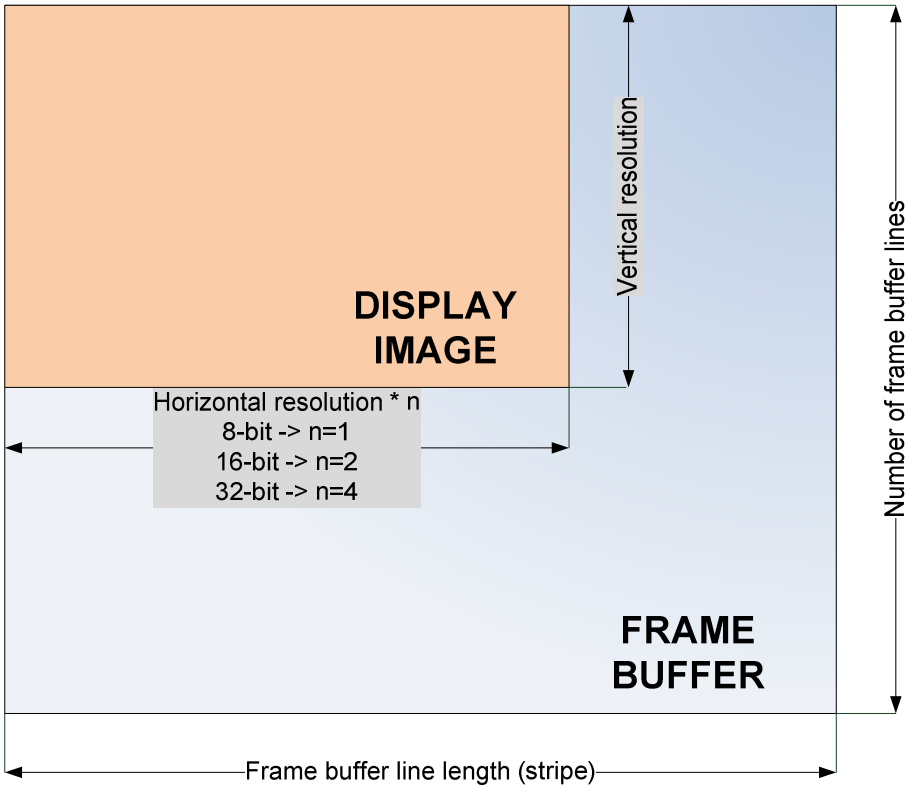


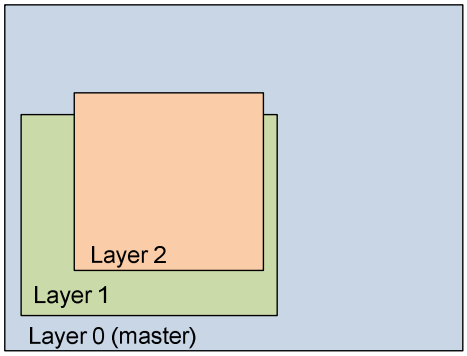
Image within a frame buffer

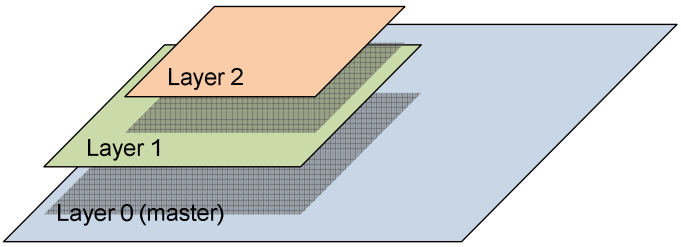
For more efficient memory usage, each image can be allocated a frame buffer exactly the size of the image.

4.3.5 Layer image definition

The image which is output to the display can be composed from multiple overlay image layers. Each overlay layer is fetched from its defined memory region (which acts as a separate frame buffer).

The overlay layers are divided into the master layer, which is always present, and a variable number of slave layers. Slave layers are overlayed over the master layer, with each subsequent slave layer being overlayed over the previous one. The master layer can be deactivated, but in that case the contents of the layer fetched from memory is replaced by a rectangle of a chosen color.



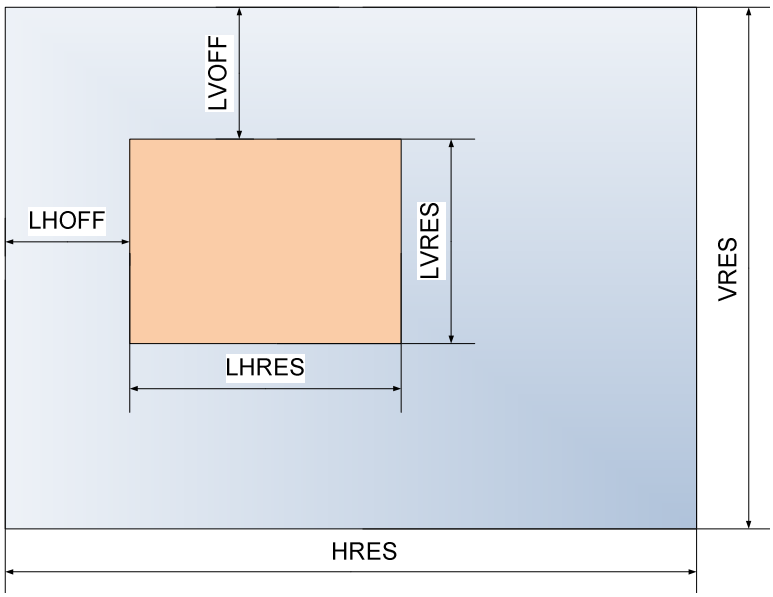


For each layer a visible overlay rectangle can be defined. The visible rectangle can be less or equal in size to the master layer (the screen resolution), and can be placed anywhere within the master layer visible rectangle as long as its boundaries are within the visible area of the master layer. Only the data in the bounding rectangle will be fetched from the frame buffer memory.

The layer rectangles can be simply overlayed, or blended together using alpha blending. When the layers are simply overlayed, each pixel within the visible rectangle of an overlay layer masks the pixels in the visible layers below. When the layers are alpha-blended, the layer image is used in alpha-compositing operation.

A visible rectangle is defined by 4 parameters:

- rectangle size: LHRES and LVRES
- rectangle offset: LHOFF and LVOFF



Overlay image geometry

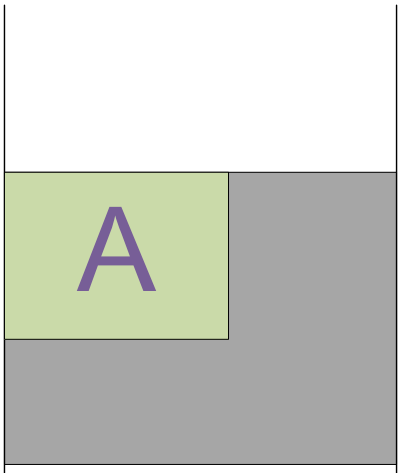
Note: the Master layer is bound to the flat panel display size, and the layer parameters are undefined for the master layer.

4.3.5.1 Layer smooth positioning

The image within the rectangle is always fetched from the base address in memory defined by the LBADDR register. Modifying the LHOFF and LVOFF will move the image across the visible screen.

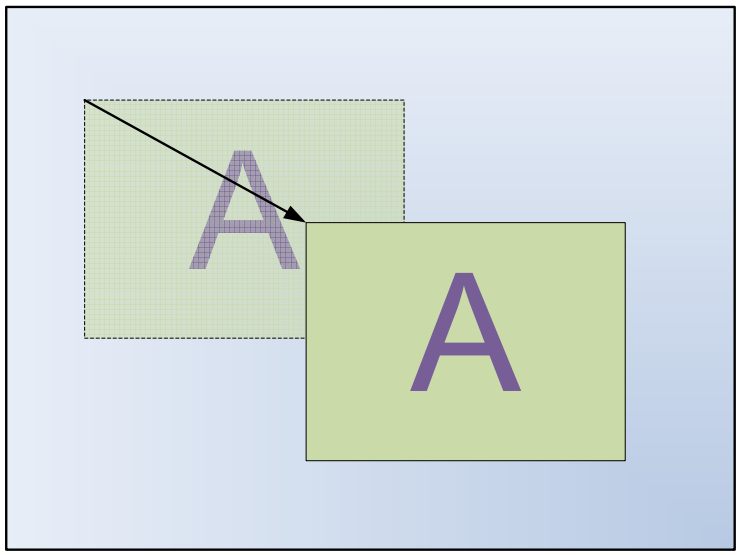
This functionality is fundamental for achieving hardware cursor operation. A layer can be set to display a cursor image, and be fluidly moven around by setting LHOFF and LVOFF.

Memory



The image resides within a frame buffer area in the memory. The layer base address (LBADDR) register of the overlay layer is set to point to the beginning pixel of the image.

Output image



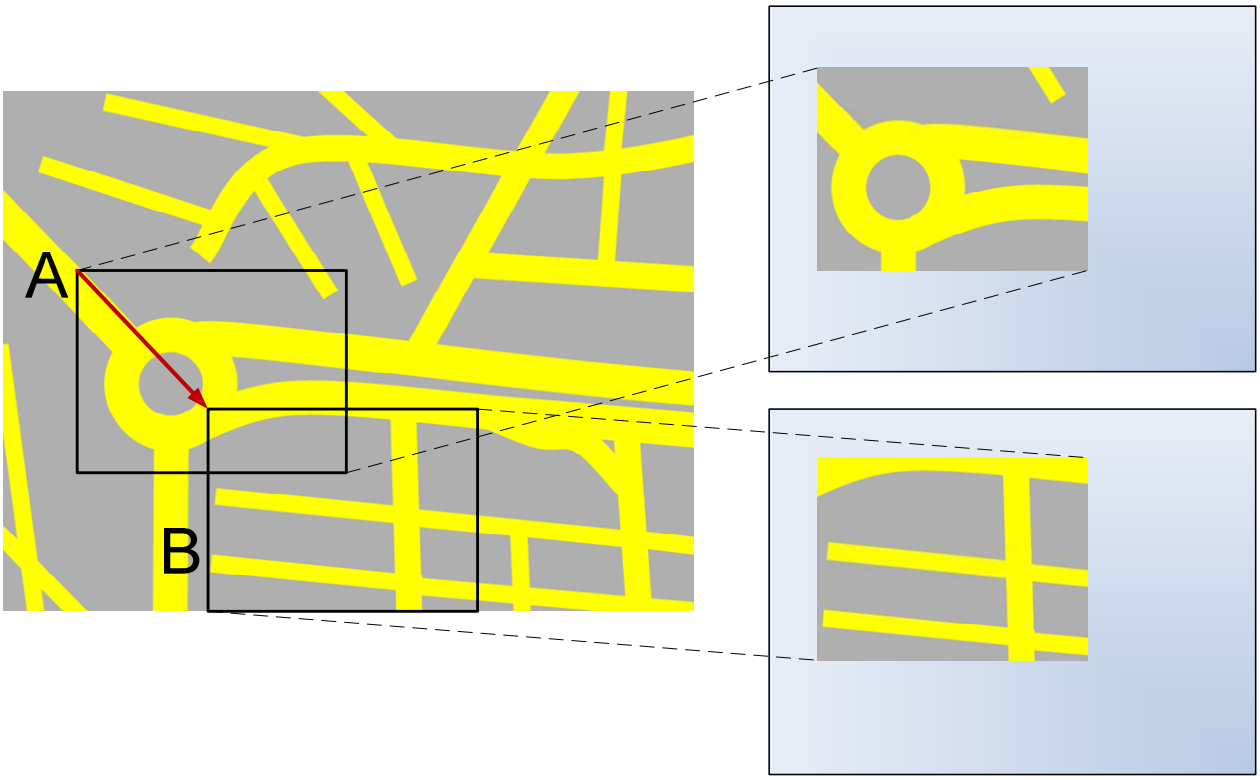
The layer rectangle can be moved around the screen by LHOFF and LVOFF, but it will constantly refresh from the same address in the memory.

LHOFF and LVOFF are defined in pixels or lines, and can be set to any value within the visible area of the screen.

4.3.5.2 Smooth Scrolling

The image fetched to fill the overlay rectangle is defined by a rectangular area within a frame buffer with equal size in pixels (geometry within the frame buffer is defined by the layer color depth). The base address of the layer is the address of the upper left pixel in the layer rectangle within the frame buffer.

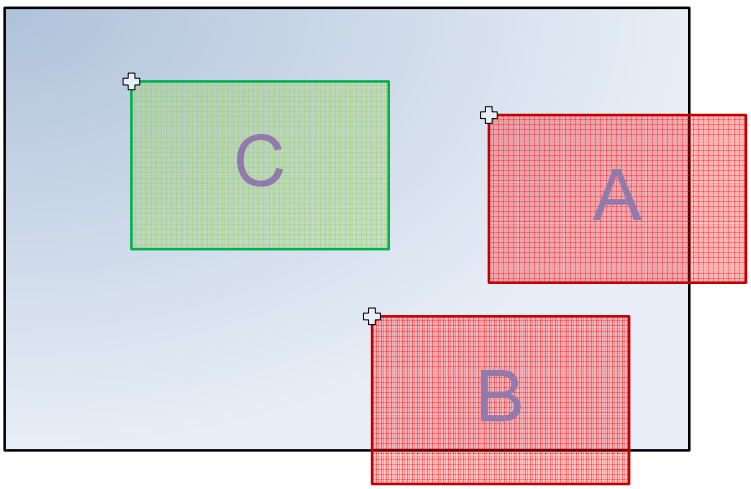
The starting point of the image can be changed by changing the base address of the layer. If the image contained in the overlay frame buffer is larger than the visible rectangle part, by changing the base address scrolling of the image in the frame buffer can be performed.



Scroll function

In **Error! Reference source not found.**, the overlay rectangle does not change the screen position, but the base address is changed from the base coordinates of rectangle A to the base coordinates of rectangle B, resulting in a “scroll” effect of the map image.

In case the position and the size of the rectangle within the frame buffer causes the rectangle to exceed the frame buffer boundaries, the image will be corrupted. The visible window within the frame buffer must not cross the frame buffer boundaries.



Proper positioning of a layer visible rectangle within a frame buffer

In **Error! Reference source not found.**, only the rectangle “C” is properly positioned. The rectangles “A” and “B” are not, due to crossing of the frame buffer border. In case of rectangle “A”, the line crosses the stripe boundary into the next line, and fetches incorrect data. In case of rectangle “B”, the rectangle includes a part of the memory outside the logical space allocated for the frame buffer.

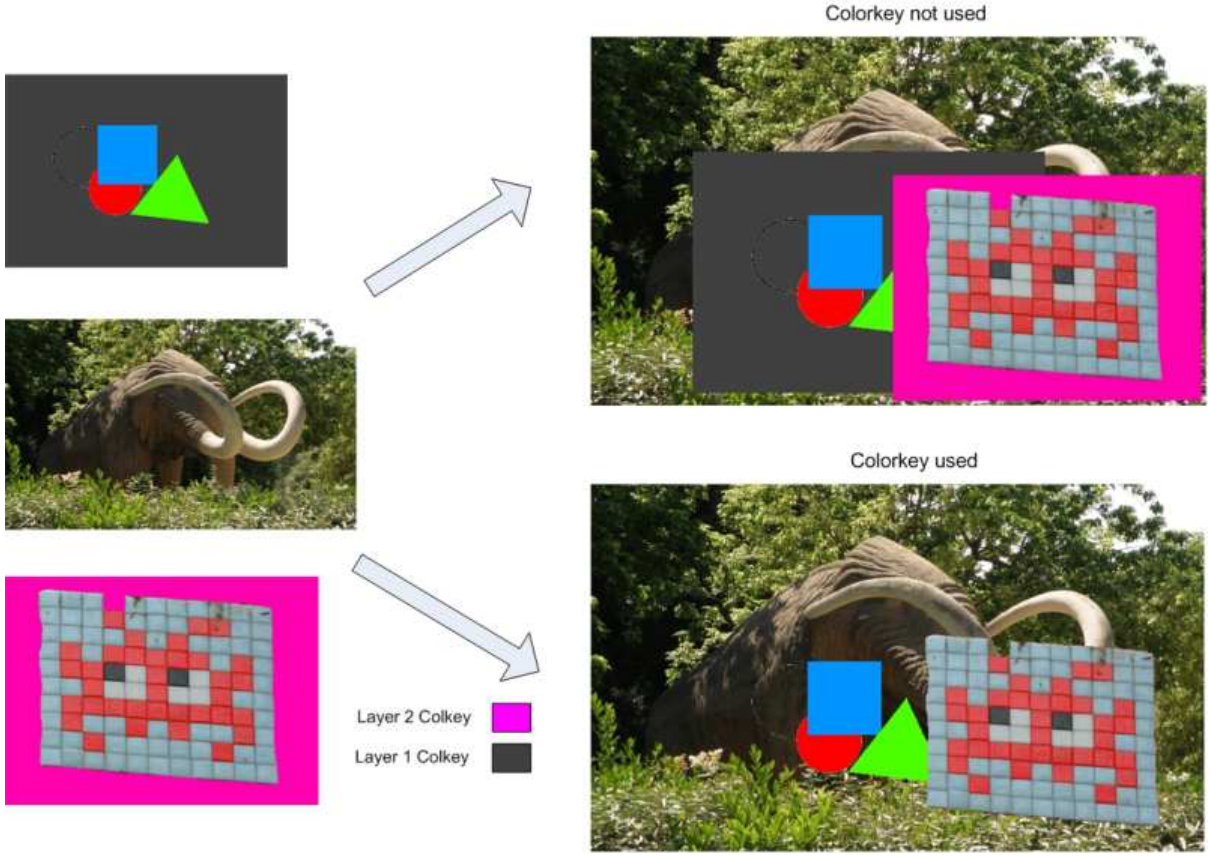
Rectangle positioning and scrolling in the UltiEVC is applicable only to the slave layers and overlay rectangles. The master layer, which defines the image resolution and contains the background image, can have its rectangle positioned only at the beginning of a frame buffer in memory.

4.3.6 Multi –layer blending

Multi-layer blending is a process of combining multiple image windows into a single resulting image. UltiEVC supports blending of multiple image layers.

4.3.6.1 Basic Overlay (Color-keyed overlay)

The layers are overlayed so that the image data of the higher layer replaces the image data of the lower layer. The lower layer image data is however fetched from memory. In case the color key is used, any pixel that is matched to the color key is removed from the image and set to be transparent.



Color-keyed overlay

The color key (transparent color) can be set independently for each layer through the COLKEY parameter, however it cannot be applied to the master layer. If a transparent pixel is overlayed by a higher layer nontransparent pixel, it will be replaced by the higher layer.

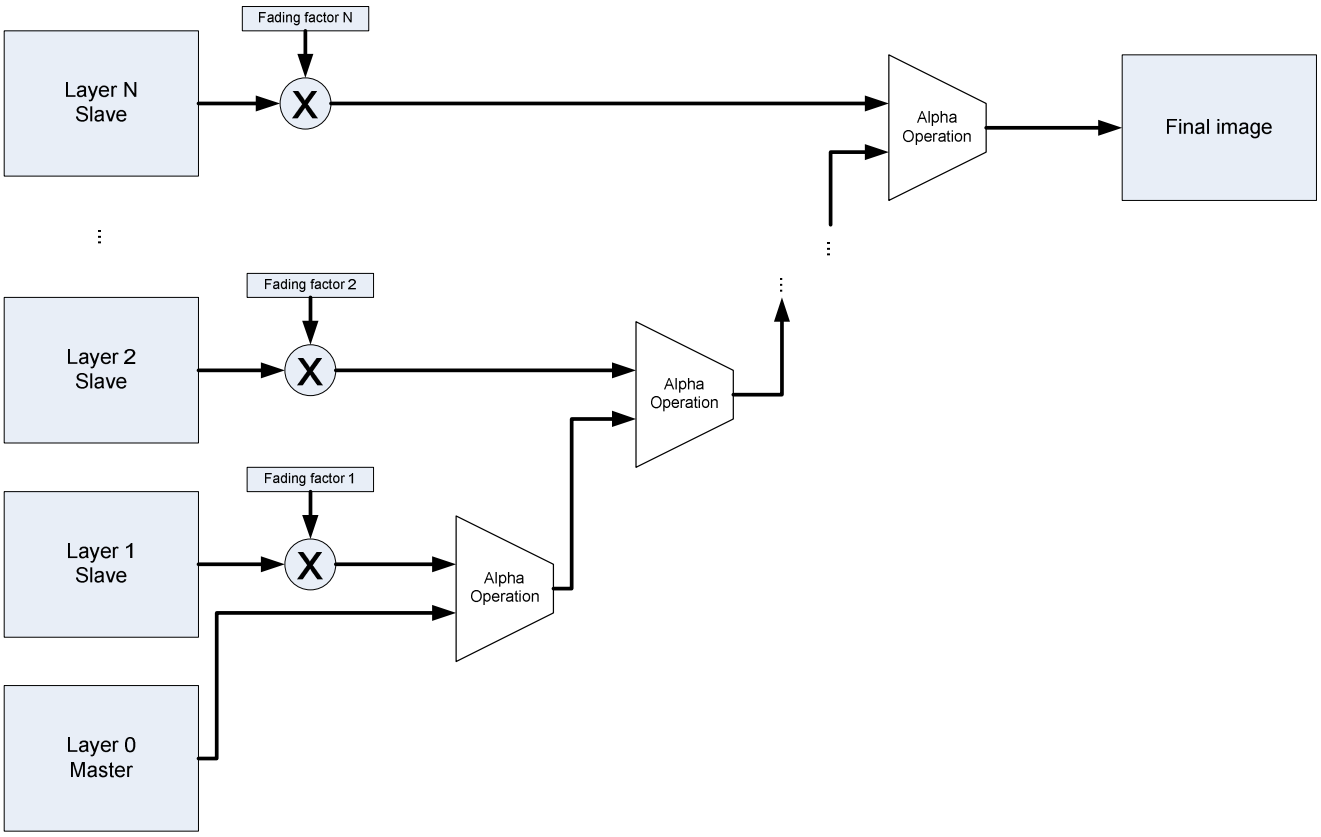
4.3.6.2 Alpha Blending

If Alpha blending is used, the two layers are combined using alpha compositing. Alpha compositing operation is defined on two pixels A and B, with the mixing factor alpha(α) attached to the pixel A. The basic alpha operation defines a pixel C as

$$C = A * \alpha + B * (1 - \alpha)$$

The alpha blending operation results in an effect of transparent overlay. The pixel A appears overlayed over the pixel B with a transparency factor α, where $0 \leq \alpha \leq 1$.
The alpha operation is performed on each color component (R,G,B) independently.

In UltiEVC, alpha blending can be performed between multiple layers, where overlay layers are consecutively blended into the result of the previous blending. The blending process starts with the master layer and the first overlay layer, and finishes with the last overlay layer.



Alpha blending between multiple layers

The equation used for blending of each color channel (red, green, or blue) in a particular overlay layer is:

$$\alpha_i = \frac{\alpha_{px}\alpha_{ch}}{256}$$

$$R_i = \frac{\alpha_i C_i + (1 - \alpha_i) R_{i-1}}{256}$$

$$R_0 = C_0$$

For $i > 0$, where R_i is the resulting pixel color for the current layer, α_{px} is individual pixel alpha, α_{ch} is the overall fading alpha (layer fading factor), α_i is the resultant per pixel alpha prescaled by the fading factor, C_i is the current layer pixel color, and R_{i-1} is the result of previous blending operation.

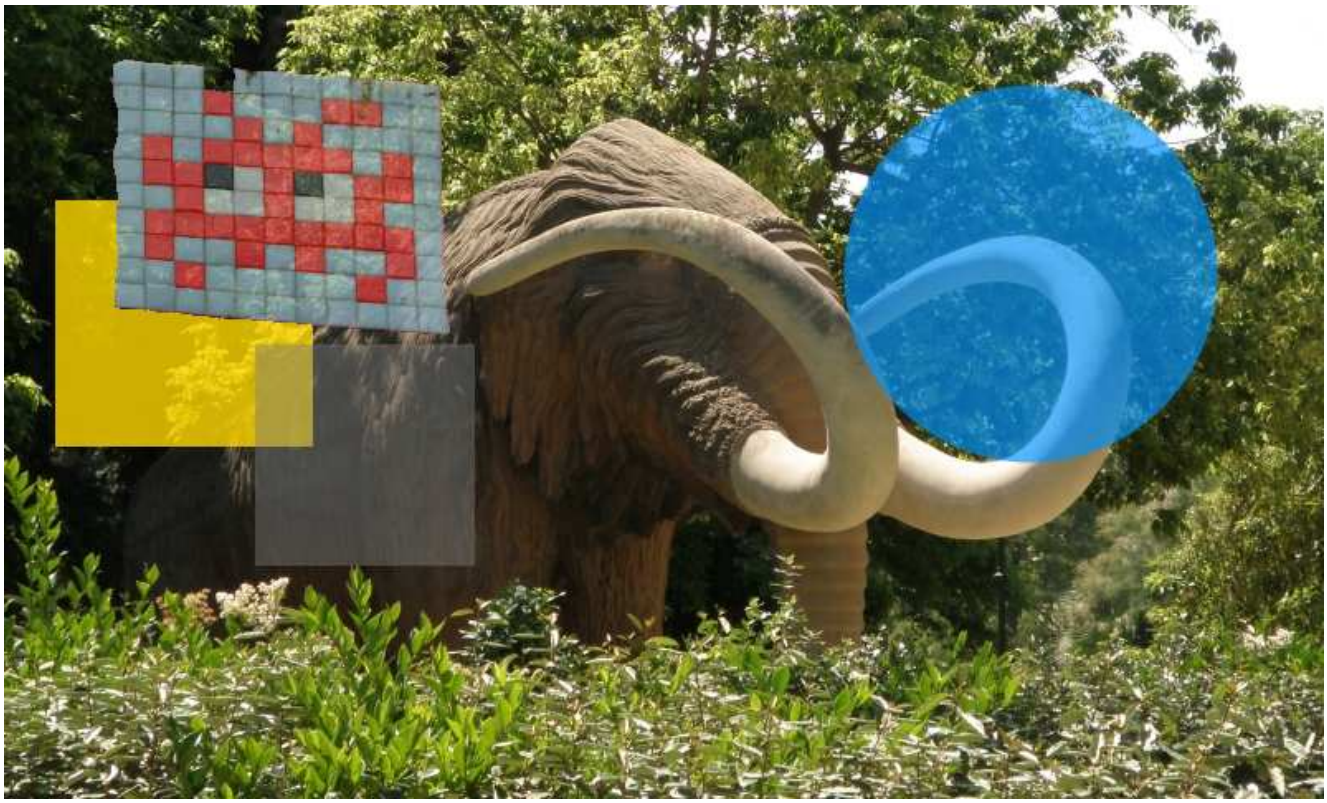
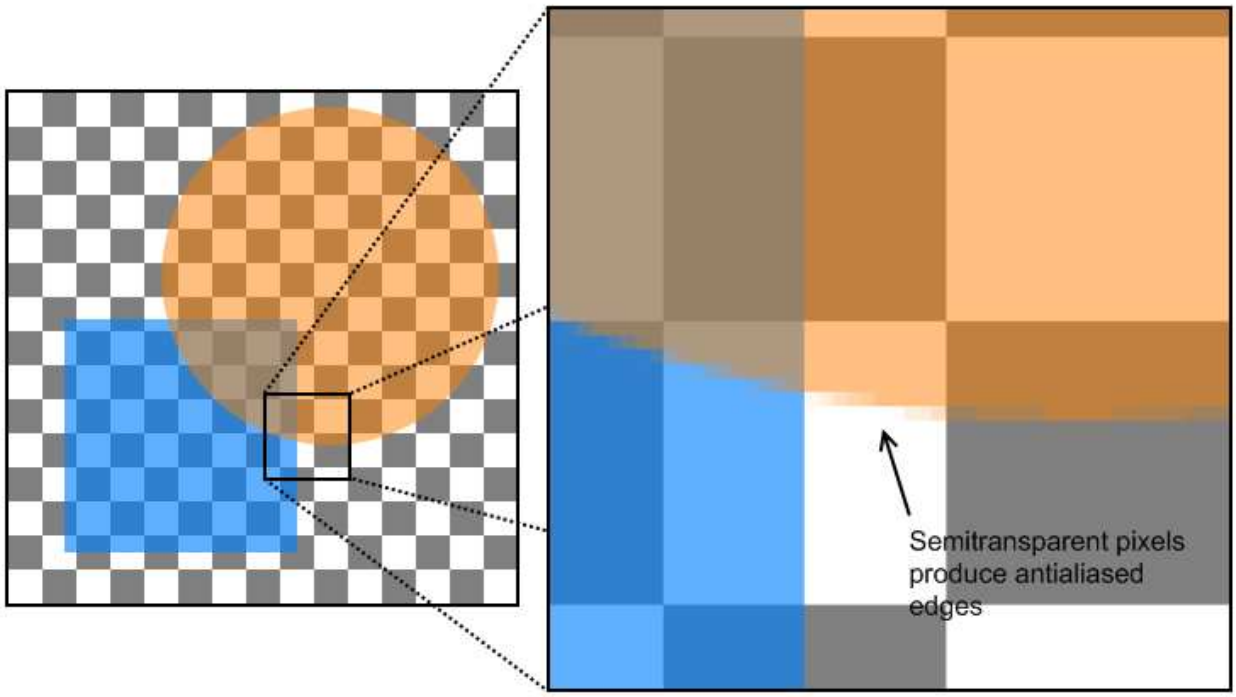


Image composited using alpha blending

Alpha information used in the blending process is an 8-bit number,from 0 to 255, allowing for 255 transparency levels, where 0xFF(255) generates a fully opaque pixel, and 0x0 stands for fully transparent pixel.

> *Note: The alpha value 0xFF is interpreted as a special case (255 is incremented to 256 in the calculation) to allow the calculation to produce a fully opaque pixel. That means that the step in alpha value from alpha = 0xFE to alpha = 0xFF is actually 2.*

32-bit ARGB images have the alpha channel embedded in the image itself, allowing for individual alpha values, α_{px}, for each pixel. This allows for advanced transparency effects, and is most prominently used for edge anti-aliasing, where the transparency of the boundary pixels is varied to create a smooth transition.



Antialising through alpha blending

Images of a lower colordepth, and 24 bit RGB images without alpha information have no room for alpha factors and are interpreted as fully opaque ($\alpha_{px} = 255$). However, an 8-bit alpha channel can be attached to them by using dedicated alpha layers.

Each layer has an additional alpha prescaling factor, or a fading factor. The fading factor premultiplies the alpha channel of the layer (whether implied to opaque or defined by the pixel). This allows fading and definition of overall transparency for a single layer. The overall layer alpha α_{ch} is defined in the layer LALPHA parameter.

The master layer is always treated as completely opaque, and has no transparency. α_{ch} and α_{px} are set to 0xFF regardless of the actual setting. LALPHA is not defined on the master layer, hence $R_0 = C_0$.

4.3.6.3 Alpha mask layers

For 16-bit layers there is no space sufficient to add full alpha transparency information to the image. Also it may be desired to change the alpha channel without disturbing the original RGB data, 16 or 24 bit. For those purposes, Alpha mask layers are used.

Each slave layer can be used as the alpha mask layer for the layer with the previous index. When functioning in alpha mask mode, the layer fetches an 8-bit monochrome image. Each pixel of the monochrome image is attached as the alpha factor to the corresponding pixel of the layer displayed beneath it.

In order to have the pixel-by-pixel alignment of the color and the mask layer, the two visible rectangles have to be of the same size and the same position within the visible image. The LHOFF, LVOFF, LHRES and LVRES parameters of the two layers must always be kept identical between the two layers.

Areas outside of the alpha mask layer will be considered as having the alpha layer equal to 0, or completely transparent. If needed, the alpha mask layer can be moved around independently of the color layer, which will shift the transparency information (mask) over the underlying image.

4.3.7 Pixel color conversion and scrambling

Various flat panel displays require different color formats for image refresh. However, not all color formats are convenient for memory storage and operations in the image datapath and blending process. Some displays show colors by using a smaller number of bits, and compensate the remaining number of bits by pulse width modulation of individual pixels (FRC). Additionally, it is hard to create a blending pipeline to work with multiple/various color formats.

Pixel scrambling is a conversion process which translates the internal color format, or blender color format, to the external display color format. The pixel scrambler unit takes the result of the blender (in 8, 16 or 24 bit color) and translates it to the external display color format, pixel by pixel.

Pixel scrambling allows decoupling of the internal and the external color format. The internal color format is therefore aligned with the pipeline processing and software requirements.

UltiEVC supports pixel scrambling for the following combinations of internal and external color formats.

External color formats	Internal color formats		
	RGB8	RGB16	RGB32
RGB16	Yes	Yes	Yes

Supported pixel scrambling combinations

4.3.8 Flat panel display control

For flat panel displays, the display control parameters define the timing of control signals, consisting of:

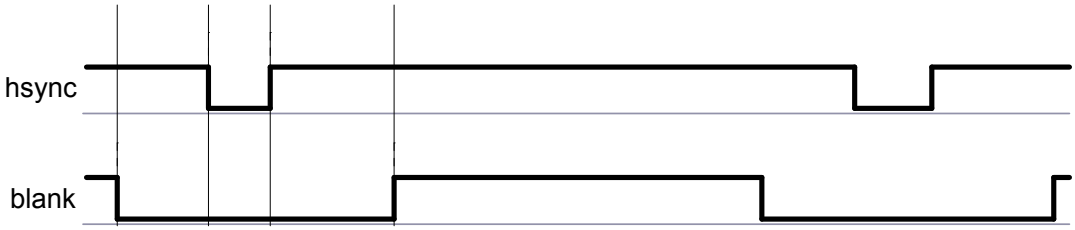
Signal	Function
disp_clk	Display clock
Vsync	Vertical sync signal (frame start)
Hsync	Horizontal sync signal (line start)
Blank	Blank/Pixel data valid signal
pix_data	Pixel data

The display clock is the driver for the synchronous logic of the flat panel display. It defines the time base of the display timing and the pixel data rate. The pixel data is output from the UltiEVC to the display synchronous to the display clock. Within the UltiEVC the output display clock can be inverted (new data can be output on rising or falling edge of the display clock) to ensure valid data sampling in the display.

Some displays do not use the blank (pixel valid) signal, but sample pixels on every active clock edge. For these displays, the clock must be active only when the valid pixel data is output. This functionality is supported through clock burst mode of the UltiEVC.

Flat panel displays are refreshed line by line. Therefore each frame consists of VRES line refresh cycles, where each line consists of HRES pixel data elements. HRES and VRES are the horizontal and vertical resolution, respectively.

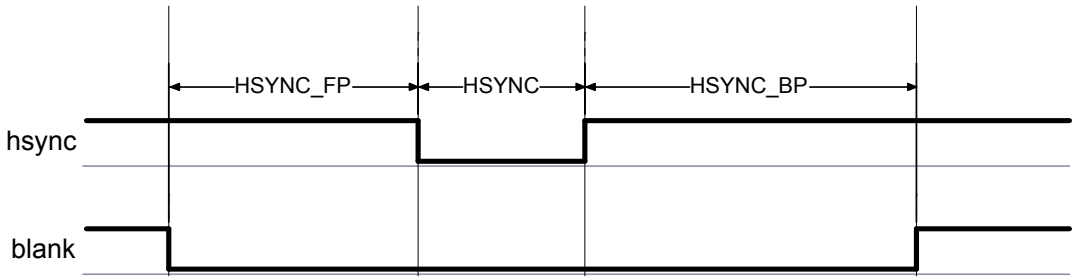
Each line refresh has the following structure. For each line, all of the timing is expressed in periods of the display clock.



Entire pixel line

The blank signal is asserted when valid pixel data is present on the pixel bus. The length of each blank impulse is equal to HRES periods of display clock, while the number of blank impulses in each frame is equal to VRES.
The blank signal can be turned off, in which case it remains in inactive state.

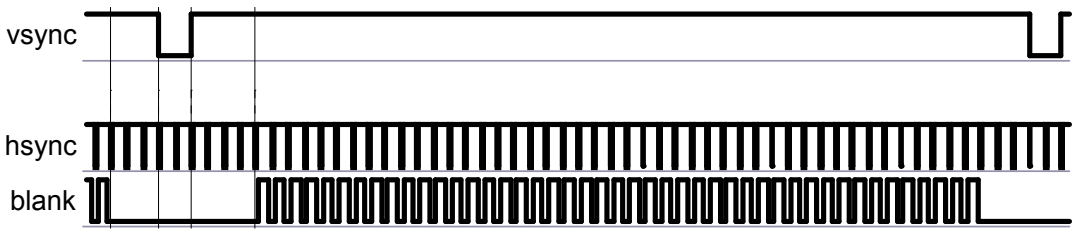
The hsync signal is used for line start detection. Length of hsync is always expressed in number of clock periods. Length of hsync is marked HSYNC on following picture. Each display can demand pauses between last pixel and assertion of hsync, or pause from deassertion of hsync to first pixel in new line. This intervals are also a expressed in clock periods and usually called hsync front porch (HSYNC_FP on picture) and hsync back porch (HSYNC_BP on picture).



Hsync front and back porches

The period of hsync signal can be calculated as HYNC_FP + HSYNC + HSYNC_BP + HRES.
The hsync signal can be turned off, in which case it stays in inactive state.

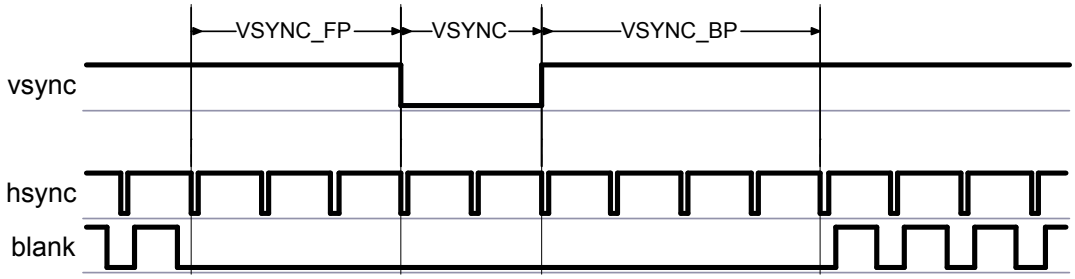
The complete image frame consists of VRES line refresh cycles as shown below.



Full image frame

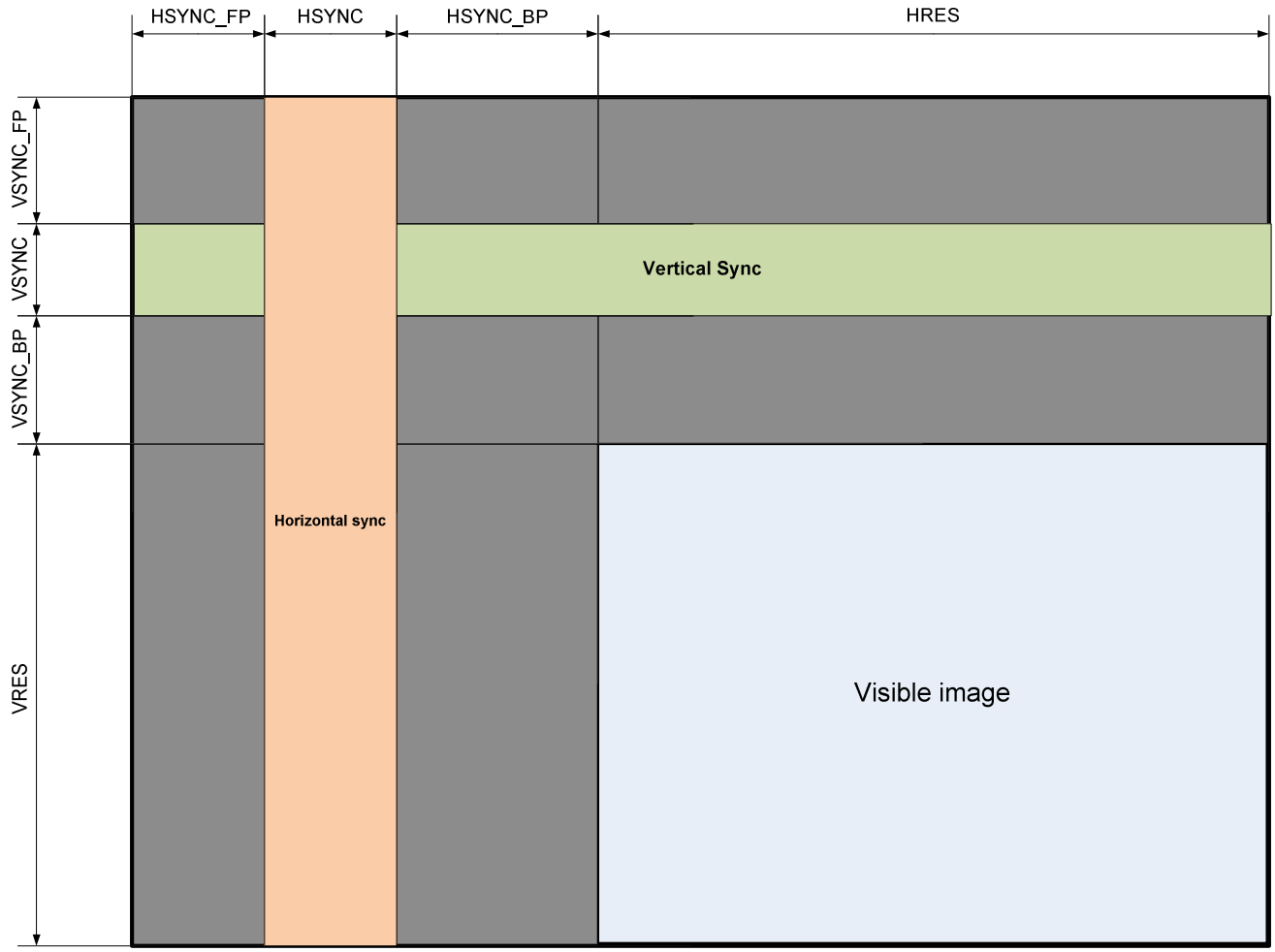
The vsync signal is used for frame start detection. Vsync timing parameters are expressed in number of hsync signal periods. In UltiEVC, the vsync signal always asserts and deasserts together with the asserting of the hsync signal. The length of vsync is marked VSYNC on the following picture.

Each display can demand pauses between the last pixel line and the assertion of vsync, or a pause from deassertion of vsync to the first pixel line in the new frame. These intervals are also a multiple of the hsync signal period and are usually called vsync front porch (VSYNC_FP on picture) and vsync back porch (VSYNC_BP on picture). The vsync signal can be turned off, in which case it will remain in inactive state.



Vsync front and back porches

The overall refresh sequence can be visualised as the image being larger than the actual visible image, with horizontal and vertical sync areas in the nonvisible space.



2D Visualization of flat panel display timing

4.3.9 Configuration and control

The registers are accessed through the AMBA APB interface. All registers are 32-bit and located on adjacent addresses.

The layer control registers accessed through the APB are shadowed in the EVC hardware. The update of the registers in the EVC hardware occurs automatically on each VSYNC. This prevents image artifacts which occur because of configuration changes during operation. Each frame is completely output using the same configuration, which prevents logic glitches.

The UltiEVC is controlled through an array of registers mapped within the AMBA APB address space of the core. All registers occupy 1 word (32 bits) of address space, even if their physical size is less, and are aligned to 1-word boundaries (The address is always a multiple of 4).

The register space is divided into a variable number of register banks. Each bank is 64 bytes in size.

Each register bank is assigned a specific function, and contains registers relevant to that function. The functions of register banks are summarized in the table below.

Bank	Function	Base address
Bank 0	Display control and timing parameters	0x00
Bank 1	Master layer control parameters	0x40
Bank 2	Overlay layer 1 control parameters	0x80
Bank 3	Overlay layer 2 control parameters	0xC0
Bank 4	Overlay layer 3 control parameters	0x100

Bank 0 defines a separate set of registers, while banks 1 … 4 define an identical set of registers, as each bank controls a generic image layer control structure.

For any register, the absolute AMBA address in the system is calculated as:

Register address = core base address + bank base address + register offset

4.3.9.1 Display parameter registers

The display control, signal and timing parameters are defined through 12 registers in bank 0. The register offset is calculated from the bank base address.

Register	Bits	Access	Function	Offset
HSY_FP	8	R/W	Horizontal sync front porch	0x00
HSY	8	R/W	Horizontal sync period	0x04
HSY_BP	8	R/W	Horizontal sync back porch	0x08
HRES	16	R/W	Horizontal resolution	0x0C
VSY_FP	8	R/W	Vertical sync front porch	0x10
VSY	8	R/W	Vertical sync	0x14
VSY_BP	8	R/W	Vertical sync back porch	0x18
VRES	16	R/W	Vertical resolution	0x1C
SCTRL	6	R/W	Signal enable & polarity control	0x20
CLKCTRL	8	R/W	Clock selection and division control	0x24
DCTRL	4	R/W	Display color depth and pixel merge control	0x28
PWRCTRL	4	R/W	Power control signals control	0x2C

HSY_FP

Bank 0, offset 0x00

31 … 8	7 … 0
unused	HSYNC_FP

The HSY_FP register contains the value of the horizontal front porch.
HSY_FP[7:0] contains the HSYNC_FP value, e.g. the number of display clock periods between the deassertion of blank signal and the assertion of hsync signal.

HSY

Bank 0, offset 0x04

31 … 8	7 … 0
unused	HSYNC

The HSY register contains the value of the horizontal sync. HSY[7:0] contain the HSYNC value, e.g. the number of display clock periods during which the hsync signal is asserted.

HSY_BP

Bank 0, offset 0x08

31 … 8	7 … 0
unused	HSYNC_BP

The HSY_BP register contains the value of the horizontal back porch. HSY_BP[7:0] contain the HSYNC_BP value, e.g. the number of display clock periods between the deassertion of hsync signal and the assertion of blank signal.

HRES

Bank 0, offset 0x0C

31 … 16	15 … 0
unused	HRES

The HRES register contains the value of the horizontal resolution. HRES[15:0] contain the HRES value, e.g. the number of pixels in a display line, and the number of display clock periods during which the blank signal is asserted.

VSY_FP

Bank 0, offset 0x10

31 … 8	7 … 0
unused	VSYNC_FP

The VSY_FP register contains the value of the vertical front porch.
VSY_FP[7:0] contains the VSYNC_FP value, e.g. the number of HSYNC periods between the last deassertion of blank signal in the previous frame and the assertion of vsync signal.

VSY

Bank 0, offset 0x14

31 … 8	7 … 0
unused	VSYNC

The VSY register contains the value of the vertical sync. VSY[7:0] contain the VSYNC value, e.g. the number of HSYNC periods during which the vsync signal is asserted.

VSY_BP

Bank 0, offset 0x18

31 … 8	7 … 0
unused	VSYNC_BP

The VSY_BP register contains the value of the vertical back porch. VSY_BP[7:0] contain the VSYNC_BP value, e.g. the number of display clock periods between the deassertion of the vsync signal and the first active line refresh cycle.

VRES

Bank 0, offset 0x1C

31 … 16	15 … 0
Unused	VRES

The VRES register contains the value of the vertical resolution. VRES[15:0] contain the VRES value, e.g. the number of lines in a display frame, and the number of blank signal pulses within a display frame.

SCTRL

Bank 0, offset 0x20

31 … 6	5	4	3	2	1	0
Unused	ENPOL	ENEN	HSPOL	HSEN	VSPOL	VSEN

The SCTRL register defines whether the control signals VSYNC, HSYNC and BLANK(enable) are used, and what is their active polarity (value when the signal is asserted).

The VSEN, HSEN and ENEN flags define whether the VSYNC,HSYNC and BLANK(EN) signals are driven by the state machine or kept inactive. The VSPOL,HSPOL and ENPOL flags define the active state (“1” for active high, or “0” for active low) for VSYNC, HSYNC and BLANK(EN) signals, respectively.

Flag	Value	Behavior
VSEN	0	VSYNC is disabled. Set to inactive state.
	1	VSYNC is enabled.
VSPOL	0	VSYNC is active low
	1	VSYNC is active high
HSEN	0	HSYNC is disabled. Set to inactive state.
	1	HSYNC is enabled.
HSPOL	0	HSYNC is active low
	1	HSYNC is active high
ENEN	0	BLANK/EN is disabled. Set to inactive state.
	1	BLANK is enabled.
ENPOL	0	BLANK is active low
	1	BLANK is active high

CLKCTRL

Bank 0, offset 0x24

31 … 8	7	6	5 … 3	2 … 0
unused	CKINV	CKBRST	CKDIV	CKSEL

The CLKCTRL register defines the pixel clock frequency and behavior. Specific clock frequencies are generated within the UltiEVC, which can be later subjected to division to get the final pixel clock.

The flags CKSEL[2:0] define the base clock frequency.

CKSEL[2:0]	Base clock frequency
000	24 MHz
001	32 MHz
010	38 MHz
011	48 MHz
100	64 MHz
101	76 MHz
110	96 MHz
111	Reserved

The flags CKDIV[2:0] define the division factor applied to the base clock frequency to obtain the final pixel clock frequency. (note here, that some division factors might generate already present base frequencies).

CKDIV[2:0]	Base clock divider
000	1 (no division)
001	2
010	4
011	8
100	Reserved
101	Reserved
110	Reserved
111	Reserved

The CKBRST flag controls the clock behavior. When CKBRST is active, the clock will be active (toggling) only during the BLANK active period (pixel valid data period, even if blank signal is not enabled).

The CKINV flag controls clock polarity. When CKINV is high, the clock is inverted, and the pixel data will be synchronous to the falling edge of the display clock. Otherwise the data will be synchronous to the rising edge of the display clock.

Flag	Value	Behavior
CKBURST	0	Display clock is free running.
	1	Display clock is bursting only during blank periods.
CKINV	0	Display clock is normal, data synchronous to rising edge.
	1	Display clock is inverted, data synchronous to falling edge.

DCTRL

Bank 0, offset 0x28

31 … 7	6 … 4	3	2 … 0
unused	BDEPTH	RGBBG	DCOLOR

The DCTRL register defines the color depth and pixel scrambling settings for the current display.
The display color depth and configuration is set through DCOLOR[2:0] parameter.

DCOLOR[2:0]	Bits per pixel	Available colors
001	16	65536
All other values	Reserved	

The RGBBG bit controls the color component order within the pixel. If set to “0”, the order is RGB. If set to “1”, the order is RBG.

Flag	Value	Behavior
RGBBG	0	Color order RGB is used
	1	Color order RBG is used

The internal pixel format used by the blender (or largest BPP in layers) is set by the BDEPTH[2:0] parameter. Separation of the internal BPP (set by this parameter) and the external BPP (set by the DCOLOR) enables adapting output to any BPP or pixel format without changing internal hardware configuration.

BDEPTH[2:0]	Bits per pixel	Available colors
000	Reserved	
001	8	256
010	16	65,536
011	Reserved	
100	32	16,777,216
101	Reserved	
110	Reserved	
111	Reserved	

*Note: when UltiEVC is used in Alpha blending configuration, the BDEPTH parameter **must** be set to “100” as the blending color depth is always 32-bit when using the alpha blender.*

PWRCTRL

Bank 0, offset 0x2C

31 … 4	3	2	1	0
unused	BLEN	VEEN	VDEN	VEN

The PWRCTRL register contains flags directly mapped to the external display control signals: enable backlight, enable VEE, enable VDD, and enable video signal.

The BLEN flag is mapped to BLIGHT_EN external signal which controls the backlight and/or CCFL inverter.

The VEEN flag controls the VEE power control signal.

The VDEN flag controls the VDD power control signal.

The VEN flag controls the UltiEVC output. When the VEN flag is asserted, the display control state machine starts and the output signal tristate control is deactivated, starting the display refresh.

Flag	Value	Behavior
VEN	0	Video control signals are disabled and tristated
	1	Video control signals are enabled and driven
VDEN	0	VDD enable signal is deasserted
	1	VDD enable signal is asserted
VEEN	0	VEE enable signal is deasserted
	1	VEE enable signal is asserted
BLEN	0	Backlight enable signal is deasserted
	1	Backlight enable signal is asserted

4.3.9.2 Layer control registers

LBADDRn

Banks 1..4, offset 0x0

31	0
BADDR	

The LBADDRn contains the base address for an image layer. It contains an address in the video memory at which the first pixel of the layer's image is located.

The base address of the layer must be aligned to the color depth boundary. If color depth is 8-bit, the base address must be byte-aligned. For 16-bit pixels the address must be halfword-aligned. For 32 bit pixels the address must be word-aligned.

LSTRIPEn

Banks 1..4, offset 0x04

31	0
LSTRIPE	

The LSTRIPEn contains the stripe for an image layer and defines the image geometry. The LSTRIPE parameter is the length of a frame buffer line in bytes, decremented by 1.

```
LSTRIPE = line_length_in_bytes  - 1;
```

The stripe is defined in bytes. The line length in pixels is derived by dividing the byte count with the BPP for the current layer. The stripe can be arbitrarily small and of any value, allowing linear memory organization for small images such as cursors.

LCTRLn

Banks 1..4, offset 0x08

31	9	8	7	6	4	3	0
unused		LYREN	CKEY	LBPP		LCOLF	

The LCTRLn is the control register for an individual layer. It contains flags that control the layer's color depth, color format, and whether the layer is enabled. Additionally it contains control bits for the layer's memory fetcher and pipeline modules.

The LCOLF[3:0] value contains the information on the layer's color format.

LCOLF[3:0]	Layer color format
0000	RGB
0001	RGBA
0010	Reserved
0011	RGBAE
0100	Reserved
0101	Reserved
0110	Reserved
0111	Reserved
1000	Reserved
1001	Reserved
1010	Reserved
1011	Reserved
1100	Reserved
1101	Reserved
1110	Reserved
1111	Reserved

When LCOLF[3:0] is set to RGB, alpha information is neglected in the blending process, and the pixels are treated as 24-bit color. If alpha blending is disabled in the hardware configuration, this is the only available setting.

When LCOLF[3:0] is set to RGBA, the alpha information is used in the blending process. The alpha values attached to pixels are used in the blending process. For 16-bit layers, the alpha value is implicitly 0xFF. RGBA setting is available only for slave overlay layers.

When LCOLF[3:0] is set to RGBAE, the alpha information is used, but it is drawn from the adjacent upper overlay layer. If Layer 1 is set to be RGBAE, Layer 2 will be used as the alpha mask layer.

Note: the layer used as the alpha mask layer must be set to 8 BPP/RGB color. For most applications, the LHOFF, LVOFF, LHRES and LVRES values must match the values of the color layer which is being masked.

The LBPP[2:0] value defines what is the number of bits per pixel defined for the current layer.

LBPP[2:0]	Layer color depth
000	Reserved
001	8 bits per pixel
010	16 bits per pixel
011	Reserved
100	32 bits per pixel (24 bpp)
101	Reserved
110	Reserved
111	Reserved

The LBPP defines the memory space occupied by a single pixel. The pixel formatting within the memory space is then further described by LCOLF.

The CKEY bit defines whether the color-key transparency is used on a layer, if the colorkey module is implemented within the layer's processing pipeline. In other case, this bit has no effect.

The LYREN bit defines whether the selected layer is active. If the layer is activated, then layer image data will be fetched from its memory area and shown on the screen. If not, the layer will be inactive, and the image data will not be fetched nor output to the screen.

Flag	Value	Behavior
CKEY	0	Colorkey is disabled. All colors are shown.
	1	Colorkey is enabled. Transparent color is omitted from overlay.
LYREN	0	Layer is disabled.
	1	Layer is enabled, fetched and displayed.

Note: when the master layer (Layer 0) is disabled, fetching from memory is disabled, but the Layer 0 outputs a rectangle filled with BASECOLOR, defined by the size of the display. Colorkey is undefined for Layer 0.

LBASECOLOR

Bank 1, offset 0x0C

31	0
BASECOLOR	

The BASECOLOR value defines the color being pumped into the master layer if the fetching of the image is disabled. The entire display image covered by the master layer will be set to pixels of the color written to the BASECOLOR register.

LCOLKEYn

Banks 2..4, offset 0x0C

31	0
COLKEY	

The COLKEY value defines the transparent color within an individual overlay layer. If the colorkey module is not present in the pipeline configuration this register will have no effect. The written colorkey value is dependant on the color depth of the layer, the appropriate subrange of the register will always be used based on the colorkey depth and color format.

LHRESn

Banks 1..4, offset 0x10

31	16	15	0
unused		LHRES	

The LHRES register contains the value of the horizontal size for the layer. LHRES[15:0] contains the horizontal size of the overlay bounding rectangle in pixels. For layer 1 (master layer), this register has no effect as the master layer resolution is defined by the screen resolution.

LVRESn

Banks 1..4, offset 0x14

31	16	15	0
unused		LVRES	

The LVRES register contains the value of the vertical size for the layer. LHRES[15:0] contains the vertical size of the overlay bounding rectangle in pixels. For layer 1 (master layer), this register has no effect as the master layer resolution is defined by the screen resolution.

LHOFFn

Banks 1..4, offset 0x18

31	16	15	0
unused		LHOFF	

The LHOFF register contains the value of the horizontal offset for the overlay bounding rectangle. LHOFF[15:0] contains the offset of the overlay bounding rectangle in pixels. For layer 1 (master layer), this register has no effect.

LVOFFn

Banks 1..4, offset 0x1C

31	16	15	0
unused		LVOFF	

The LVOFF register contains the value of the vertical offset for the overlay bounding rectangle. LVOFF[15:0] contains the vertical size of the overlay bounding rectangle. For layer 1 (master layer), this register has no effect.

LALPHAn

Banks 1..4, offset 0x20

31	8	7	0
unused		LALPHA	

The LALPHA register contains the value of the overall layer alpha, or the fading factor, which is used as a prescaler for the alpha values in the given layer. Setting LALPHA to 0 generates a completely transparent image, while setting LALPHA to 0xFF retains the original image transparency.

Note: if LALPHA is set to 0 it is probably wise to deactivate the layer to avoid unnecessary bandwidth consumption.

4.3.10 Configuration example

Example is written for the Hitachi TX18D16VM1CBA-3 display, 800x480 with 64k colors. EVC is configured for 4 layers, each supporting alpha blending. Layer #0 is set to 16-bit pixels, layer #1 to 16-bit pixels and transparent color 0xF81F, with alpha fading, and layers #2 and #3 to 32-bit pixels in ARGB format.

```
/* Define UINT32 example: typedef unsigned long UINT32; */
/* base_addr is address offset of the UltiEVC core on the APB bus */
/* wait function inserts a delay od time specified in the parameter */

/* initialize synch control registers */
*( (UINT32 *)(base_addr + 0x00) ) = 0x28; /* hor front porch = 40 */
*( (UINT32 *)(base_addr + 0x04) ) = 0x20; /* hsync = 32 */
*( (UINT32 *)(base_addr + 0x08) ) = 0x22; /* hor back porch = 34 */
*( (UINT32 *)(base_addr + 0x0C) ) = 0x320; /* hor res = 800 */
*( (UINT32 *)(base_addr + 0x10) ) = 0x0B; /* ver front porch = 11 */
*( (UINT32 *)(base_addr + 0x14) ) = 0x01; /* vsync = 1 */
*( (UINT32 *)(base_addr + 0x18) ) = 0x03; /* ver back porch = 3 */
*( (UINT32 *)(base_addr + 0x1C) ) = 0x1E0; /* ver res = 480 */
*( (UINT32 *)(base_addr + 0x20) ) = 0x35; /* synch control,  enable blank, hsync and vsync,
hsync and vsync active low, blank active high */
*( (UINT32 *)(base_addr + 0x24) ) = 0x81; /* 48 MHz clock, inverted */
*( (UINT32 *)(base_addr + 0x28) ) = 0x41; /* Internal pixel width 32-bit, output pixel
width 16-bit */

/* initialize layer#0 to address 0x0, stripe 4096, 16-bit */
*( (UINT32 *)(base_addr + 0x40) ) = 0x0; /* frame buffer address */
*( (UINT32 *)(base_addr + 0x44) ) = 0x0FFF; /* frame buffer stripe */
*( (UINT32 *)(base_addr + 0x48) ) = 0x121; /* enable layer, 16-bit pixels, alpha enabled */

/* initialize layer#1 to address 0x00C00000, stripe 4096, 16-bit, trans color 0xF81F, gen.
alpha factor 0xA0, size (300,300), offset (20, 20) */
*( (UINT32 *)(base_addr + 0x80) ) = 0xC00000; /* frame buffer address */
*( (UINT32 *)(base_addr + 0x84) ) = 0x0FFF; /* frame buffer stripe */
*( (UINT32 *)(base_addr + 0x88) ) = 0x1A1; /* enable layer, color-keyed transparency, 16-
bit pixels, alpha enabled */
*( (UINT32 *)(base_addr + 0x8C) ) = 0xF81F; /* transparent color */
*( (UINT32 *)(base_addr + 0x90) ) = 0x12C; /* layer width = 300 */
*( (UINT32 *)(base_addr + 0x94) ) = 0x12C; /* layer height = 300 */
*( (UINT32 *)(base_addr + 0x98) ) = 0x14; /* layer hor offset = 20 */
*( (UINT32 *)(base_addr + 0x9C) ) = 0x14; /* layer ver offset = 20 */
*( (UINT32 *)(base_addr + 0xA0) ) = 0xA0; /* layer alpha factor 0xA0 */

/* initialize layer#2 to address 0x01400000, stripe 4096, 32-bit, gen. alpha factor 0xFF,
size (300,300), offset (448, 160) */
*( (UINT32 *)(base_addr + 0xC0) ) = 0x1400000; /* frame buffer address */
*( (UINT32 *)(base_addr + 0xC4) ) = 0x0FFF; /* frame buffer stripe */
*( (UINT32 *)(base_addr + 0xC8) ) = 0x141; /* enable layer, 32-bit pixels, alpha enabled */
*( (UINT32 *)(base_addr + 0xD0) ) = 0x12C; /* layer width = 300 */
*( (UINT32 *)(base_addr + 0xD4) ) = 0x12C; /* layer height = 300 */
*( (UINT32 *)(base_addr + 0xD8) ) = 0x1C0; /* layer hor offset = 448 */
*( (UINT32 *)(base_addr + 0xDC) ) = 0xA0; /* layer ver offset = 160 */
*( (UINT32 *)(base_addr + 0xE0) ) = 0xFF; /* alpha fading factor = 0xFF (no fading) */

/* initialize layer#3 to address 0x01800000, stripe 4096, 32-bit, gen. alpha factor 0xFF,
size (300,300), offset (448, 160) */
*( (UINT32 *)(base_addr + 0x100) ) = 0x1800000; /* frame buffer address */
*( (UINT32 *)(base_addr + 0x104) ) = 0x0FFF; /* frame buffer stripe */
*( (UINT32 *)(base_addr + 0x108) ) = 0x141; /* enable layer, 32-bit pixels, alpha enabled
*/
```

```
*( (UINT32 *)(base_addr + 0x110) ) = 0x12C; /* layer width = 300 */
*( (UINT32 *)(base_addr + 0x114) ) = 0x12C; /* layer width = 300 */
*( (UINT32 *)(base_addr + 0x118) ) = 0x1C0; /* layer hor offset = 448 */
*( (UINT32 *)(base_addr + 0x11C) ) = 0xA0; /* layer ver offset = 160 */
*( (UINT32 *)(base_addr + 0x120) ) = 0xFF; /* alpha fading factor = 0xFF (no fading) */

/* power on display */
/* Displays usually require a pause between power-up phases. For that reason, wait(time)
function is called between power pin assertions.*/
*( (UINT32 *)(base_addr + 0x2C) ) = 0x02; /* Turn on VDD power */
Wait(100 ms);
*( (UINT32 *)(base_addr + 0x2C) ) = 0x0A; /* Turn on VEE power */
Wait(100 ms);
*( (UINT32 *)(base_addr + 0x2C) ) = 0x0B; /* Turn on back light */
```

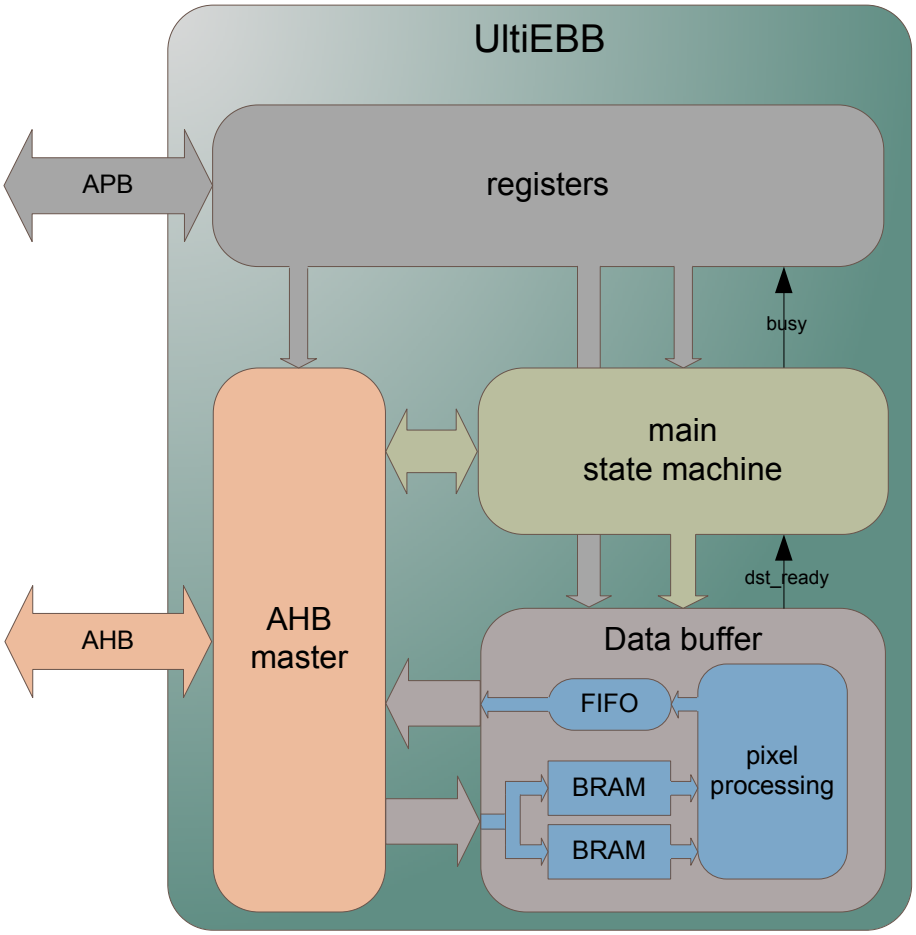
4.4 BitBlit core: UltiEBB

The BitBlit functionalities are implemented by the UltiEBB core.

UltiEBB core contains:

- Slave and registers module (AMBA 3 APB interconnect)
- Master interface module (AMBA 3 AHB interconnect)
- Data buffer and pixel processing module
- Main state machine and calculation module

The diagram below shows the UltiEBB block diagram and its connections inside the LCD-Pro IP design..



Block diagram of UltiEBB

4.4.1 Registers

All registers are aligned to the AMBA data bus width (4 bytes). The address is calculated by adding the offset to the AMBA base address of the EBB core.

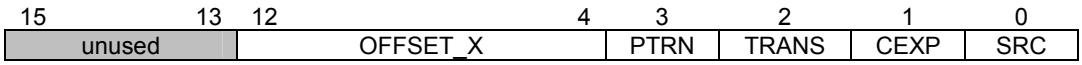
Register	Bits	Access	Function	Offset
OPR1	29	R/W	Configure SRC1 format (solid color, color expansion, pattern, transparency, and alpha bitmask) and pattern/color expansion offset.	0x00
SRC1_ADDR	32	R/W	SRC1 memory address (first pixel with positive direction, last pixel with negative)	0x04
SRC1_STRIPE	16	R/W	SRC1 pixel line stripe	0x08
FG_COL_1	32	R/W	SRC1 foreground color (color expansion, solid fill)	0x0C
BG_COL_1	32	R/W	SRC1 background color (color expansion)	0x10
OPR2	29	R/W	Configure SRC2 format (solid color, color expansion, alpha bitmask) and color expansion offset.	0x14
SRC2_ADDR	32	R/W	SRC2 memory address (first pixel with positive direction, last pixel with negative)	0x18
SRC2_STRIPE	16	R/W	SRC2 pixel line stripe	0x1C
FG_COL_2	32	R/W	SRC2 foreground color (color expansion, solid fill)	0x20
BG_COL_2	32	R/W	SRC2 background color (color expansion)	0x24
OPERATION	7	R/W	ROP operation	0x28
DST_ADDR	32	R/W	DST memory address (first pixel with positive direction, last pixel with negative)	0x2C
DST_STRIPE	16	R/W	DST pixel line stripe	0x30
TP_COL	32	R/W	Transparent color	0x34
PATT_XW	9	R/W	Pattern horizontal width	0x38
PATT_YW	9	R/W	Pattern vertical width	0x3C
XWIDTH	16	R/W	Blitted area horizontal width	0x40
YWIDTH	16	R/W	Blitted area vertical width	0x44
CTRL	10	R/W*	Main control register (picture BPP, picture format (TBD), positive/negative direction, module start, module reset).	0x48

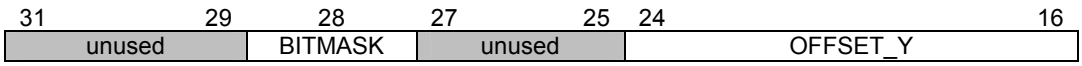
Registers in UltiEBB

* CTRL register's bit 8 is used for starting the BitBlt operation and reading the status of the core. Writing '1' to the bit 8 starts the new operation, if core is in the idle mode, while read of this bit always returns the status of core. Other bits in CTRL register have standard behavior.

OPR1

offset 0x00





OPR1 register defines the SRC1 bitmap format.

SRC flag configures the SRC1 load from the memory ('1') or use of the solid color ('0'). If the solid color mode is used, the value stored in the FG_COL_1 register will be used as the SRC1 operand.

CEXP flag enables the color expansion of the SRC1 bitmap (‘1’) or disables it (‘0’). The color expansion is supported only for the monochromatic bitmaps, transforming ‘1’ to the foreground color pixel (set by the register FG_COL_1) and ‘0’ to the background color pixel (set by the register BG_COL_1).

TRANS flag enables the color-keyed transparency function, detecting the transparent pixels (set in the register TP_COL) in the SRC1 bitmap and replacing them with the corresponding pixels in the SRC2 bitmap.

PTRN flag enables the pattern functionality on the SRC1, using a bitmap of variable size (up to 512x512 pix) as a repeating pattern which is then used as the SRC1 operand.

BITMASK flag enables the alpha bitmask functionality on the SRC1, using a monochromatic bitmap (BPP = 8) as a source of alpha parameters, combining them with 24 LSB bits stored in foreground color register to form a 32-bit pixel.

Flag	Value	Behavior
SRC	0	SRC1 operand is equal to the FG_COL_1 foreground color
	1	SRC2 operand is fetched from memory
CEXP	0	SRC1 operand is not color expanded
	1	SRC1 operand is color expanded
TRANS	0	Transparent pixels in SRC1 are ignored.
	1	All pixels resulting from operations with transparent pixels from SRC1 bitmap are replaced with corresponding SRC2 bitmap pixels.
PTRN	0	SRC1 bitmap is outputted normally
	1	SRC1 bitmap is outputted as a pattern with dimensions defined in PATT_XW and PATT_YW, replicated inside output bitmap with dimensions XWIDTH and YWIDTH.
BITMASK	0	SRC1 bitmap is outputted normally
	1	SRC1 bitmap is outputted as an 8-bit monochromatic bitmap, combined with RGB in foreground color register to form 32-bit pixels.

OPR1 register flags

OFFSET_X[8:0] parameter defines the horizontal offset in the pattern mode (starting position in the pattern), or the bit offset in the color expand mode (bits [2:0]). Setting the offset larger than the pattern size in the pattern mode, or larger than seven in the color expand mode will result in the core malfunction. Offset is expressed in the number of pixel (pattern mode) or bit (color expand mode) to be outputted first. First pixel in the pattern is tagged by 0, while first pixel in the monochromatic bitmap is tagged 7 (MSB bit in the byte).

OFFSET_Y[8:0] parameter defines the vertical offset in the pattern mode (starting position in the pattern). Setting the offset larger than the pattern size in the pattern mode, or larger than seven in the color expand mode will result in the core malfunction. Offset is expressed in the number of pixel (pattern mode) or bit (color expand mode) to be outputted first. First pixel in the pattern is tagged by 0, while first pixel in the monochromatic bitmap is tagged 7 (MSB bit in the byte).

SRC1_ADDR

offset 0x04

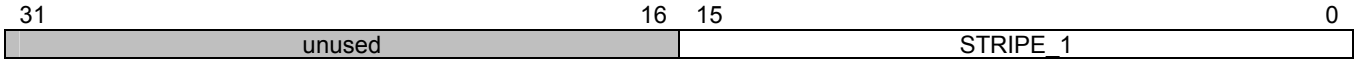
31	0
ADDR_1	

SRC1_ADDR register defines the address of the first pixel in SRC1 bitmap (positive direction) or the last pixel (negative direction).

ADDR_1[31:0] contains the SRC1 bitmap address in bytes. Depending on the direction of the operation, the first pixel to be processed will be located in the upper left corner of the bitmap (positive direction) or the lower right corner (negative direction). The bitmap address should always point to the first pixel to be processed.

SRC1_STRIPE

offset 0x08

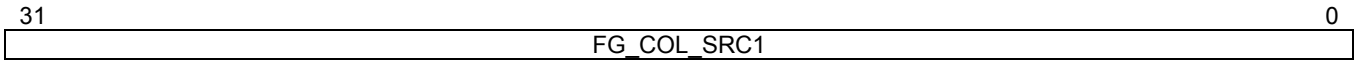


SRC1_STRIPE register defines the stripe size of the SRC1 bitmap.

STRIPE_1[15:0] contains the size of the memory block allocated for the each line in the SRC1 bitmap. The size of the memory block is expressed in bytes.

FG_COL_1

offset 0x0C

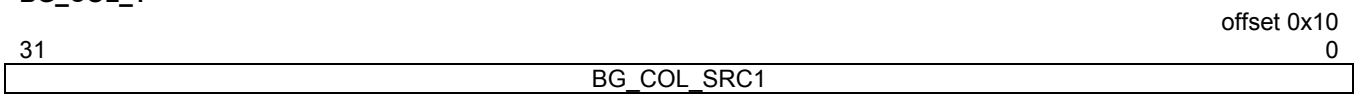


FG_COL_1 register defines the foreground color pixel for the SRC1 bitmap.

FG_COL_SRC1[31:0] contains the foreground color pixel for the SRC1 bitmap, used in the color expand mode and the solid color mode. Depending on the BPP (configured in the CTRL register), only bits [7:0] (BPP=1), bits [15:0] (BPP=2) or bits [23:0] (BPP=3) will be used. Bits [31:24] are RFU.

BG_COL_1

offset 0x10

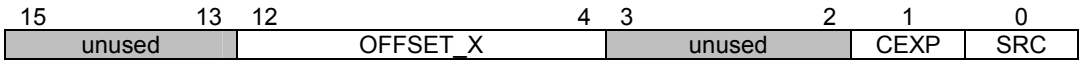


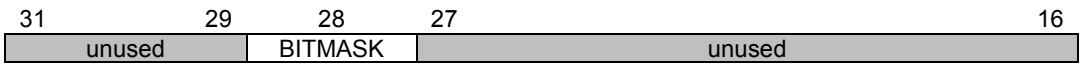
BG_COL_1 register defines the background color pixel for the SRC1 bitmap.

BG_COL_SRC1[31:0] contains the background color pixel for the SRC1 bitmap, used in the color expand mode. Depending on the BPP (configured in the CTRL register), only bits [7:0] (BPP=1), bits [15:0] (BPP=2) or bits [23:0] (BPP=3) will be used. Bits [31:24] are RFU.

OPR2

offset 0x14





OPR2 register defines the SRC2 bitmap format.

SRC flag configures the SRC2 load from the memory (‘1’) or use of the solid color (‘0’). If the solid color mode is used, the value stored in FG_COL_2 register will be used as the SRC2 operand.

CEXP flag enables (‘1’) or disables (‘0’) the color expansion of the SRC2 bitmap. The color expansion is supported only for the monochromatic bitmaps, transforming ‘1’ to the foreground color pixel (set by the register FG_COL_2) and ‘0’ to the background color pixel (set by the register BG_COL_2).

BITMASK flag enables the alpha bitmask functionality on the SRC1, using a monochromatic bitmap (BPP = 8) as a source of alpha parameters, combining them with 24 LSB bits stored in foreground color register to form a 32-bit pixel.

Flag	Value	Behavior
SRC	0	SRC2 operand is equal to the SRC2 foreground color
	1	SRC2 operand is fetched from memory
CEXP	0	SRC2 operand is not color expanded
	1	SRC2 operand is color expanded
BITMASK	0	SRC2 bitmap is outputted normally
	1	SRC2 bitmap is outputted as an 8-bit monochromatic bitmap, combined with RGB in foreground color register to form 32-bit pixels.

OPR2 register flags

OFFSET_X[8:0] parameter defines the bit offset in the color expand mode. Setting the offset larger than seven will result in the core malfunction. Offset is expressed in number of bit to be outputted first. First bit in the monochromatic bitmap is tagged 7 (MSB bit in the byte).

SRC2_ADDR

offset 0x18

31	0
ADDR_2	

SRC2_ADDR register defines the address of the first pixel in the SRC2 bitmap (positive direction) or the last pixel (negative direction).

ADDR_2[31:0] contains the SRC2 bitmap address in bytes. Depending on the direction of the operation, the first pixel to be processed will be located in the upper left corner of the bitmap (positive direction) or the lower right corner (negative direction). The bitmap address should always point to the first pixel to be processed.

SRC2_STRIPE

offset 0x1C

31	16	15	0
unused		STRIPE_2	

SRC2_STRIPE register defines the stripe size of the SRC2 bitmap.

STRIPE_2[15:0] contains the size of the memory block allocated for the each line in the SRC2 bitmap. The size of the memory block is expressed in bytes.

FG_COL_2

offset 0x20

31	0
FG_COL_SRC2	

FG_COL_2 register defines the foreground color pixel for the SRC2 bitmap.

FG_COL_SRC2[31:0] contains the foreground color pixel for the SRC2 bitmap, used in the color expand mode and the solid color mode. Depending on the BPP (configured in the CTRL register), only bits [7:0] (BPP=1), bits [15:0] (BPP=2) or bits [23:0] (BPP=3) will be used. Bits [31:24] are RFU.

BG_COL_2

offset 0x24

31	0
BG_COL_SRC2	

BG_COL_2 register defines the foreground color pixel for the SRC2 bitmap.

BG_COL_SRC2[31:0] contains the background color pixel for the SRC2 bitmap, used in the color expand mode. Depending on the BPP (configured in the CTRL register), only bits [7:0] (BPP=1), bits [15:0] (BPP=2) or bits [23:0] (BPP=3) will be used. Bits [31:24] are RFU.

OPERATION

offset 0x28

31	7	6	5	4	0
unused		NEG_OP1	NEG_OP2	OP_T	

OPERATION register defines ROP or ALPHA operations to be performed on SRC1 and SRC2.

OP_T[4:0] parameter configures the elementary ROP or ALPHA operation to be performed on SRC1 and SRC2.

OP_T[4:0]	**ROP**
00000	A **OVER** B
00001	A **AND** B
00010	A **OR** B
00011	A **XOR** B
001XX	RFU
OP_T[4:0]	**ALPHA**
01000	A **OVER** B
01001	A **IN** B
01010	A **OUT** B
01011	A **ATOP** B
01100	A **XOR** B
01101	A **PLUS** B
0111X	RFU
OP_T[4:0]	**CHANNEL**
1????	A **CH** B

OP_T predefined values

The **channel** operation is used for the combining of two source pictures into the one destination picture, on color component level. Writing '1' to OP_T[x] selects use of that color component from the SRC2, while writing '0' selects use of color component from the SRC1.

OP_T[3:0]	**CHANNEL OPERATION**
0000	A(SRC1) & R(SRC1) & G(SRC1) & B(SRC1)
0001	A(SRC1) & R(SRC1) & G(SRC1) & B(SRC2)
0010	A(SRC1) & R(SRC1) & G(SRC2) & B(SRC1)
0011	A(SRC1) & R(SRC1) & G(SRC2) & B(SRC2)
0100	A(SRC1) & R(SRC2) & G(SRC1) & B(SRC1)
0101	A(SRC1) & R(SRC2) & G(SRC1) & B(SRC2)
0110	A(SRC1) & R(SRC2) & G(SRC2) & B(SRC1)
0111	A(SRC1) & R(SRC2) & G(SRC2) & B(SRC2)
1000	A(SRC2) & R(SRC1) & G(SRC1) & B(SRC1)
1001	A(SRC2) & R(SRC1) & G(SRC1) & B(SRC2)
1010	A(SRC2) & R(SRC1) & G(SRC2) & B(SRC1)

1011	A(SRC2) & R(SRC1) & G(SRC2) & B(SRC2)
1100	A(SRC2) & R(SRC2) & G(SRC1) & B(SRC1)
1101	A(SRC2) & R(SRC2) & G(SRC1) & B(SRC2)
1110	A(SRC2) & R(SRC2) & G(SRC2) & B(SRC1)
1111	A(SRC2) & R(SRC2) & G(SRC2) & B(SRC2)

Channel operations

NEG_OP1 flag configures whether the SRC1 pixel is inverted or not before ROP operation.

NEG_OP2 flag configures whether the SRC2 pixel is inverted or not before ROP operation.

These flags are ignored in ALPHA operations.

Flag	Value	Behavior
NEG_OP1	0	A = SRC1
	1	A = **NOT**(SRC1)
NEG_OP2	0	B = SRC2
	1	B = **NOT**(SRC2)

OPERATION register flags

DST_ADDR

offset 0x2C

31	0
ADDR_D	

DST_ADDR register defines the address of the first pixel in the DST bitmap (positive direction) or the last pixel (negative direction).

ADDR_D[31:0] contains the DST bitmap address in bytes. Depending on the direction of the operation, the first pixel to be processed will be located in the upper left corner of the bitmap (positive direction) or the lower right corner (negative direction). Bitmap address should always point to the first pixel to be processed.

DST_STRIPE

offset 0x30

31	16	15	0
unused		STRIPE_D	

DST_STRIPE register defines the stripe size of the DST bitmap.

STRIPE_D[15:0] contains the size of the memory block allocated for the each line in the DST bitmap. The size of the memory block is expressed in bytes - 1.

TP_COL

offset 0x34

31	0
TRAN_COL	

TP_COL register defines the transparent color for the SRC1 bitmap.

TRAN_COL[31:0] contains the transparent color pixel for the SRC1 bitmap, used in the transparent mode. Depending on the BPP (configured in the CTRL register), only bits [7:0] (BPP=1), bits [15:0] (BPP=2) or bits [23:0] (BPP=3) will be used. Bits [31:24] are RFU.

PATT_XW

offset 0x38

31 … 9	8 … 0
unused	PATTERN_XWIDTH

PATT_XW register defines the horizontal resolution of the pattern.

PATTERN_XWIDTH [9:0] contains the horizontal resolution of the SRC1 bitmap, outputted in the pattern mode. The resolution is expressed in the number of pixels - 1.

PATT_YW

offset 0x3C

31 … 9	8 … 0
unused	PATTERN_YWIDTH

PATT_YW register defines the vertical resolution of the pattern.

PATTERN_YWIDTH [9:0] contains the vertical resolution of the SRC1 bitmap, outputted in the pattern mode. The resolution is expressed in the number of pixels - 1.

XWIDTH

offset 0x40

31 … 16	15 … 0
unused	OUTPUT_XWIDTH

XWIDTH register defines the horizontal resolution of the output bitmap.

OUTPUT_XWIDTH [15:0] contains the horizontal resolution of the DST bitmap, SRC2 bitmap and the horizontal resolution of the SRC1 bitmap when not in the pattern mode. The resolution is expressed in the number of pixels - 1.

YWIDTH

offset 0x44

31 … 16	15 … 0
unused	OUTPUT_YWIDTH

YWIDTH register defines the vertical resolution of the output bitmap.

OUTPUT_YWIDTH [15:0] contains the vertical resolution of the DST bitmap, the SRC2 bitmap, and the vertical resolution of the SRC1 bitmap when not in the pattern mode. The resolution is expressed in the number of pixels - 1.

CTRL

offset 0x48

31 … 10	9	8	7	6 … 4	3 … 0
unused	RESET	START_BUSY	DIR_NEG	COLOR_BPP	COLOR_FORMAT

CTRL register is the main control register.

COLOR_FORMAT[3:0] parameter is reserved for the future use.

COLOR_BPP[2:0] parameter configures the number of bytes per pixel in the DST bitmap and SRC1 and SRC2 bitmaps (when not using the color expand mode).

COLOR_BPP[2:0]	Bits per pixel	Available colors
000	Reserved	
001	8	256
010	16	65536
011	Reserved	
100	24	16,777,216
101	Reserved	
110	Reserved	
111	Reserved	

COLOR_BPP predefined values

DIR_NEG flag configures direction of moving over source and destination maps, starting from upper left pixel and moving to the right and down (positive direction), or starting from bottom right pixel, and moving left and up (negative direction).

START_BUSY flag is used for starting the EBB operation (write access) and reading status of the EBB core (read access). New operation will be started only if EBB is in the idle state.

RESET flag is used for resetting the EBB core, in case of need for the operation termination. Flag is self-clearing, so '0' will always be read from this location.

Flag	Value	Behavior
DIR_NEG	0	Positive direction, upper left corner will be blitted first.
	1	Negative direction, lower right corner will be blitted first.
START	0 (write)	Access is ignored
	1 (write)	EBB will start a new operation if it is in idle state.
BUSY	0 (read)	EBB is in idle state.
	1 (read)	EBB is busy.
RESET	0	Access is ignored.
	1	Last AHB operation will be finished, and then EBB will go to the idle state.

CTRL register flags

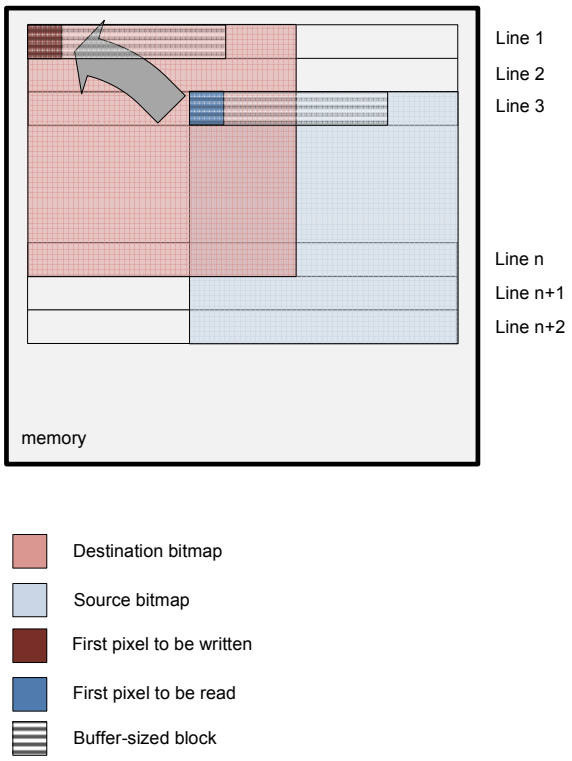
4.4.2 Operation

4.4.2.1 Moving bitmap

Most commonly used BitBlit operation is moving bitmaps. The bitmaps can be copied from the any memory location to the any memory location (full address range is supported). The bitmaps can be written in the linear memory mode (one line continuing after the other, with no unused memory locations), or in the rectangular memory mode, with a fixed size memory block allocated for the each line. Both modes and any sub variant are supported by EBB, due to the adaptable logic supporting any stripe size (memory block allocated for each line) and starting address. The addresses of the each subsequent line will be calculated by adding the stripe size, with the arbitrary number of pixels being processed in each line. In case of the rectangular memory, empty space between the two lines will be treated as a part of line not being processed. Both sources and the destination bitmap can be configured independently, allowing use of the any bitmap format and easy adaptation to the memory organization of the display controller.
User must take care when the memory areas of the old bitmap and the new bitmap overlap, because in that case data corruption could occur. The bitmap overlapping can be divided into the two discrete cases, associated with the two modes of operation: the positive direction and the negative direction.

- positive direction – to be used when moving the first line starting from the left side and moving to the right will not corrupt any unbuffered pixels

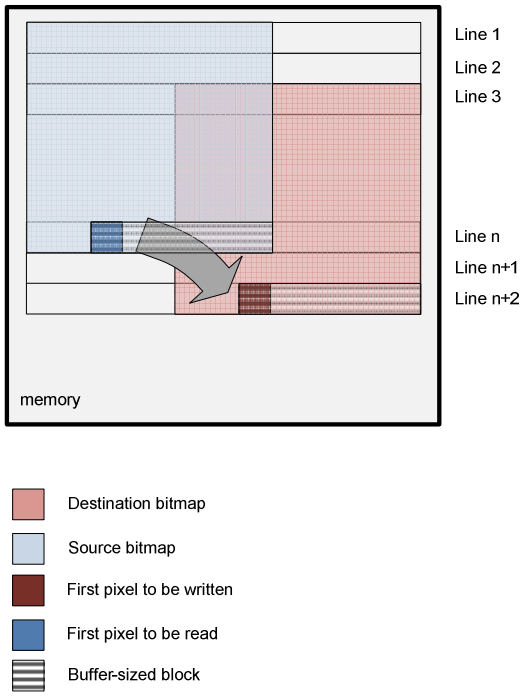
  The bitmap addresses should point to the first pixel in the bitmap (upper-left pixel), which is the first pixel to be processed.



Positive direction mode

- negative direction – to be used when moving last line from the right side and moving to the left will not corrupt any unbuffered pixels

The bitmap addresses should point to the last pixel in the bitmap (lower-right pixel), which will be processed in the first buffer (memory bursts always start with lower addresses, i.e. pixels on the left side, so lower-right pixel will not be processed first, but it will be transferred in the first block of pixels).



Negative direction mode

4.4.2.2 ROP

EBB can perform different ROPs (raster operations) on one or two source bitmaps, and output the result to the destination address. Full range of the bitwise Boolean operations is supported, suitable for the picture processing or the bitmap animation.

Inversion	**Description**
A = SRC1	Operand A is equal to SRC1 bitmap.
A = **NOT(**SRC1)	Operand A is equal to inverted SRC1 bitmap.
B = SRC2	Operand B is equal to SRC2 bitmap.
B = **NOT**(SRC2)	Operand B is equal to inverted SRC2 bitmap.
Boolean operation	**Description**
A **OVER** B	Copy operand A to DST bitmap.
A **AND** B	Write result of bitwise AND between A and B operands.
A **OR** B	Write result of bitwise OR between A and B operands.
A **XOR** B	Write result of bitwise XOR between A and B operands.

ROP operations

- DST = **NOT**(SRC1)

source 1

destination

- DST = SRC1 **AND** SRC2

source 1

source 2

destination

- DST = **NOT**(SRC1) **AND** SRC2

source 1

source 2

destination

- DST = SRC1 **AND NOT**(SRC2)

source 1

source 2

destination

- DST = **NOT**(SRC1) **AND NOT**(SRC2)

source 1 *source 2* *destination*



- DST = SRC1 **OR** SRC2

source 1 *source 2* *destination*



- DST = **NOT**(SRC1) **OR** SRC2

source 1 *source 2* *destination*



- DST = SRC1 **OR NOT**(SRC2)

source 1 *source 2* *destination*



- DST = **NOT**(SRC1) **OR NOT**(SRC2)

source 1 *source 2* *destination*

- DST = SRC1 **XOR** SRC2

source 1 *source 2* *destination*

- DST = **NOT**(SRC1) **XOR** SRC2

source 1 *source 2* *destination*

- DST = SRC1 **XOR NOT**(SRC2)

source 1 *source 2* *destination*

- DST = **NOT**(SRC1) **XOR NOT**(SRC2)

source 1 *source 2* *destination*



4.4.2.3 Pattern

EBB supports versatile pattern generation, in combination with the other functions. The bitmaps with the resolution up to 512x512 pixels can be used as a SRC1 input for the pattern generation, replicated to the DST bitmap size, and used as an input for ROP. The starting point for the pattern generation can be offset, both on the horizontal and on the vertical axis.
The pattern bitmap has to be aligned to the AMBA data bus width, due to the pattern hardware limitations. If using 32-bit AMBA data bus, the horizontal resolution will have to be a multiple of 4 (BPP = 1) or 2 (BPP = 2).

- DST = *PATT*(SRC1) (pattern starting at the middle of the picture)

source 1 *destination*


- DST = *PATT*(SRC1) **AND NOT**(SRC2) (pattern starting at the middle of the picture)

source 1 *source 2* *destination*

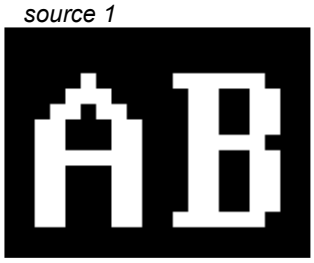


4.4.2.4 Color expand

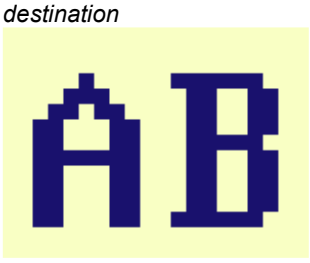
EBB supports monochromatic bitmap expansion, substituting all white pixels (set to '1') with the foreground color and all black pixels (set to '0') with the background color. The result of the color expansion can then be used in ROP (similar to the result of pattern generation). The color expand mode and the pattern mode are not supported at the same time. The input bitmap has to have the stripe size rounded to the byte size, and it can be offset by any number of bits (the offset larger than 1 byte and the vertical offset are not supported, because they can be achieved by changing the starting address). The maximum horizontal resolution of the monochromatic bitmaps is currently limited to 2048/BPP, when using mixed monochromatic and RGB bitmaps.

- DST = *CE*(SRC1)

source 1



destination



4.4.2.5 Solid color

One or both operands can be replaced by a solid color, enabling easy extraction of a single color, replacement of one color by another (see later in 4.4.2.6), or adding color component to the picture, besides standard solid color fill.

- DST = *SOLID*(0x0000FF)

destination

- DST = SRC1 **AND** *SOLID*(0x0000FF)

source 1

destination

- DST = SRC1 **OR** *SOLID*(0x800000)

source 1

destination

4.4.2.6 Transparency

EBB supports the color-keyed transparency function. The transparency logic detects pixels with the transparent color in the SRC1 bitmap, and replaces all output pixels resulting from this pixel (either equal to the transparent pixel, or the result of a ROP on the transparent pixel) with the corresponding pixels from the SRC2 bitmap. The resulting bitmap is equal to writing only non-transparent pixels in the SRC1 bitmap (with selected ROP) to the DST bitmap, if SRC2 is equal to DST. If SRC2 is not equal to DST, the resulting bitmap is equal to writing only non-transparent pixels (with selected ROP) from the SRC1 bitmap to the SRC2 bitmap, and then moving the result to the DST bitmap.
When using the color expand mode, the transparent color is detected after expansion, enabling transparency of either the foreground or the background color.

- DST = *TRAN*(SRC1) **OVER** SRC2

source 1

source 2

destination

- DST = NOT(*TRAN*(SRC1)) **OVER** SRC2

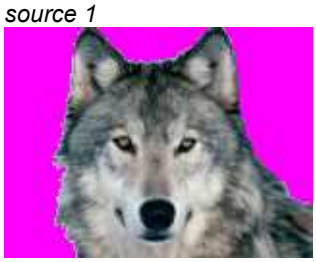
source 1

source 2

destination

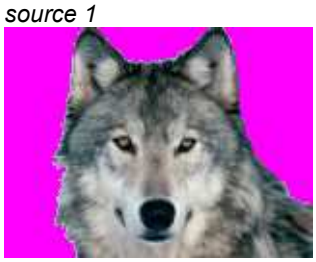
- DST = NOT(*TRAN*(SRC1)) **AND** SRC2

source 1 *source 2* *destination*



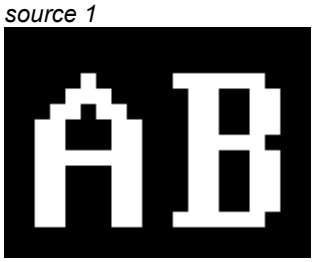
- DST = *TRAN*(PATT(SRC1)) **OVER** SRC2

source 1 *source 2* *destination*



- DST = *TRAN*(*CE*(SRC1)) **OVER** SRC2 (background color is transparent)

source 1 *source 2* *destination*



- DST = *TRAN*(SRC1) **OVER** *SOLID*(0x00FF00)

source 1 *destination*


4.4.2.7 Alpha blending

The EBB core supports the alpha blending of the 32-bit ARGB bitmaps and the 8-bit alpha bitmasks. Any combination of these two types of input can be used as an input for the alpha blending. Before blending, both bitmaps can be additionally faded, multiplying their alpha factors with the alpha stored in the respective foreground color register. To disable fading function, write 0xFF to the bits (31:24) of the respective FG_COL_? register.
The EBB core supports Porter-Duff alpha blending functions, using a LUT implemented in a single BRAM to perform the division. Due to the limitations of hardware, some error in calculation has to be expected, especially with very low alpha parameters.

- DST = SRC1 **OVER** SRC2
  - Alpha calculation

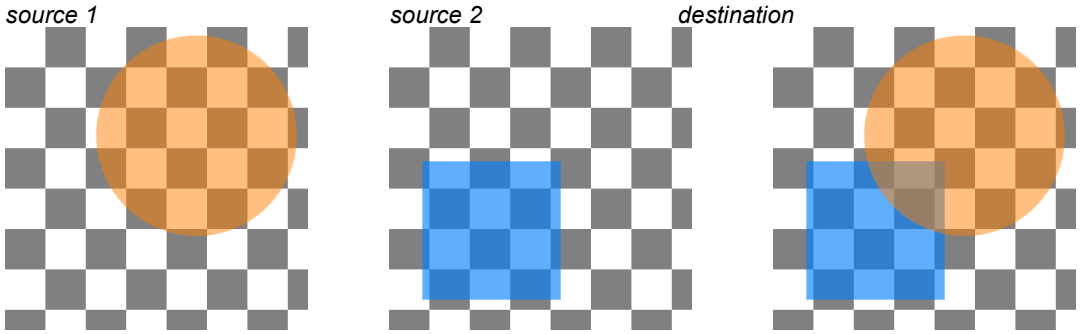
$$\alpha = \alpha_1 + (1 - \alpha_1)\alpha_2$$

  - Color component calculation

$$C = \frac{\alpha_1 C_1 + (1 - \alpha_1)\alpha_2 C_2}{\alpha_1 + (1 - \alpha_1)\alpha_2}$$

  - Usage

    Object drawn in the SRC1 bitmap is placed in front of the object drawn in the SRC2 bitmap.



- DST = SRC1 **IN** SRC2
  - Alpha calculation

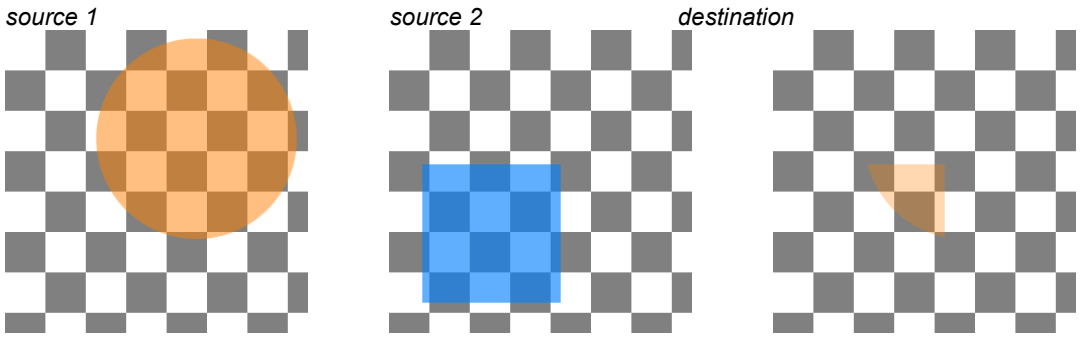
$$\alpha = \alpha_1 \alpha_2$$

  - Color component calculation

$$C = \frac{\alpha_1 \alpha_2 C_1}{\alpha_1 \alpha_2}$$

  - Usage

    Show only the part of the object drawn in the SRC1 bitmap contained in the object drawn in the SRC2 bitmap.



- DST = SRC1 **OUT** SRC2
  - Alpha calculation

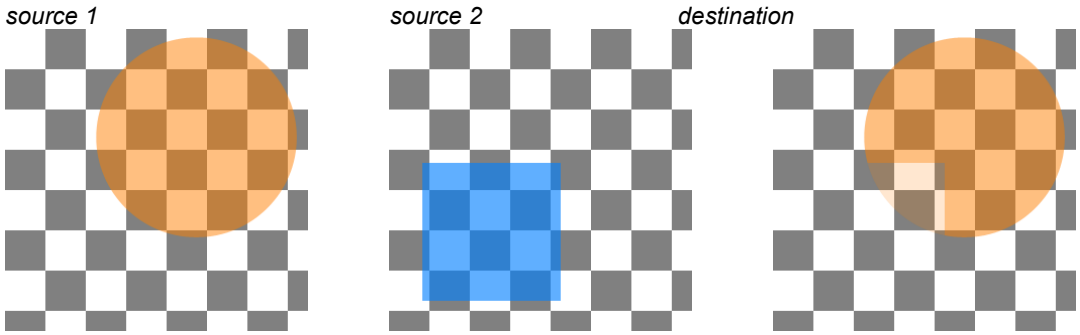
$$\alpha = \alpha_1(1-\alpha_2)$$

  - Color component calculation

$$C = \frac{\alpha_1(1-\alpha_2)C_1}{\alpha_1(1-\alpha_2)}$$

  - Usage

    Show only the part of the object drawn in the SRC1 bitmap contained outside of the object drawn in the SRC2 bitmap.



- DST = SRC1 **ATOP** SRC2
  - Alpha calculation

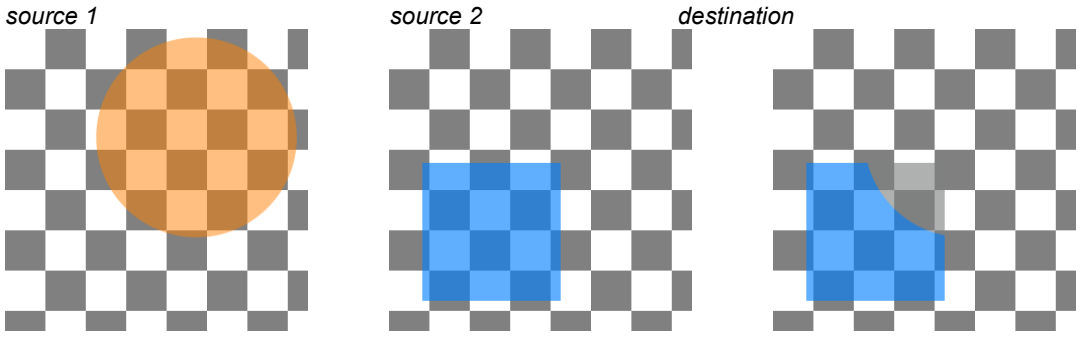
$$\alpha = \alpha_1\alpha_2 + (1-\alpha_1)\alpha_2$$

  - Color component calculation

$$C = \frac{\alpha_1\alpha_2C_1 + (1-\alpha_1)\alpha_2C_2}{\alpha_1\alpha_2 + (1-\alpha_1)\alpha_2}$$

  - Usage

Show only the part of the object drawn in the SRC1 bitmap contained in the object drawn in the SRC2 bitmap, and the part of the object drawn in the SRC2 bitmap contained outside of the object drawn in the SRC1 bitmap.



- DST = SRC1 **XOR** SRC2
  - Alpha calculation

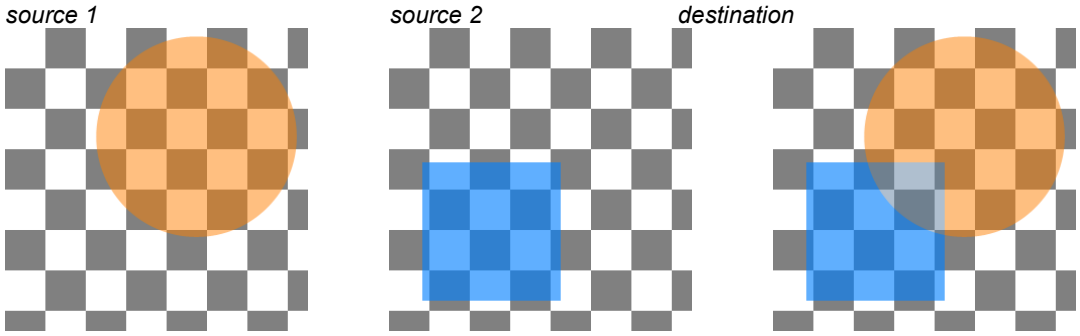
$$\alpha = \alpha_1(1-\alpha_2) + (1-\alpha_1)\alpha_2$$

  - Color component calculation

$$C = \frac{\alpha_1(1-\alpha_2)C_1 + (1-\alpha_1)\alpha_2 C_2}{\alpha_1(1-\alpha_2) + (1-\alpha_1)\alpha_2}$$

  - Usage

Show only the part of the object drawn in the SRC1 bitmap contained outside of the object drawn in the SRC2 bitmap, and the part of the object drawn in the SRC2 bitmap contained outside of the object drawn in the SRC1 bitmap.



- DST = SRC1 **PLUS** SRC2
  - Alpha calculation

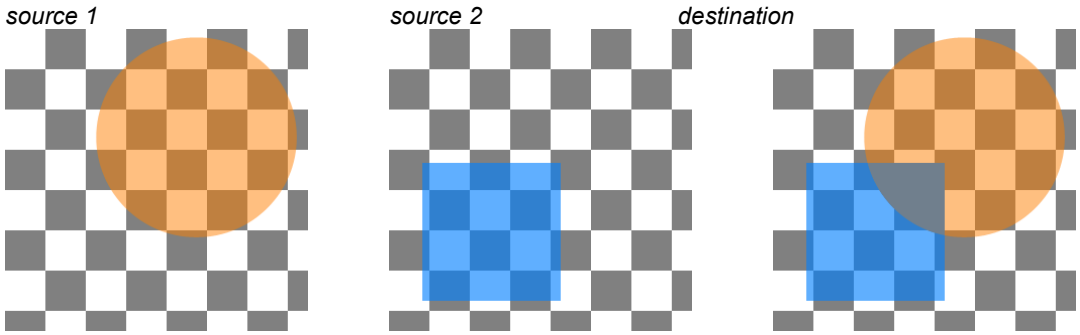
$$\alpha = \alpha_1 + \alpha_2$$

- Color component calculation

$$C = \frac{\alpha_1 C_1 + \alpha_2 C_2}{\alpha_1 + \alpha_2}$$

- Usage

  Show sum of both objects. Alpha and color components are both clipped to the maximum value in case of the overflow.



- DST = *FAD*(SRC1) **OVER** SRC2
  - Alpha calculation

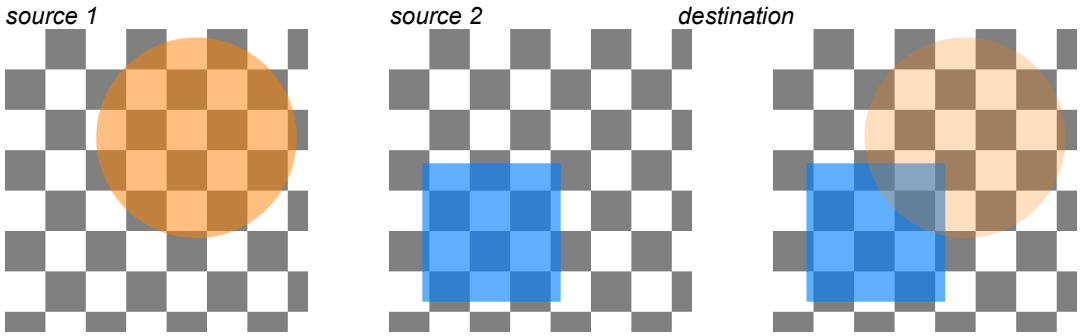
$$\alpha = \alpha_F \alpha_1 + (1 - \alpha_F \alpha_1)\alpha_2$$

  - Color component calculation

$$C = \frac{\alpha_F \alpha_1 C_1 + (1 - \alpha_F \alpha_1)\alpha_2 C_2}{\alpha_F \alpha_1 + (1 - \alpha_F \alpha_1)\alpha_2}$$

  - Usage

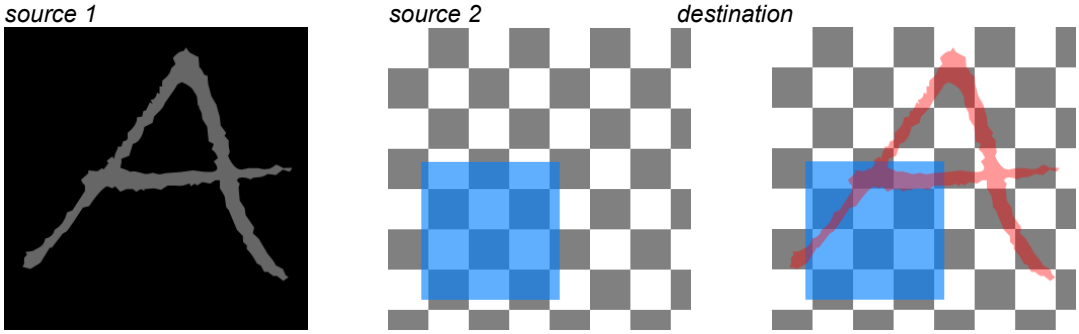
    Object drawn in the SRC1 bitmap is multiplied by a constant alpha factor (increasing transparency), then placed in front of the object drawn in the SRC2 bitmap.



Alpha mask
Besides standard 32-bit ARGB format, SRC1 and SRC2 bitmaps can be 8-bit alpha bitmasks. They are combined with the RGB components (bits [23:0]) stored in the foreground color register to form full 32-bit pixel bitmaps. This operation is especially useful in the generation of fonts with anti-aliased edges.

- DST = *BITMASK*(SRC1) **OVER** SRC2

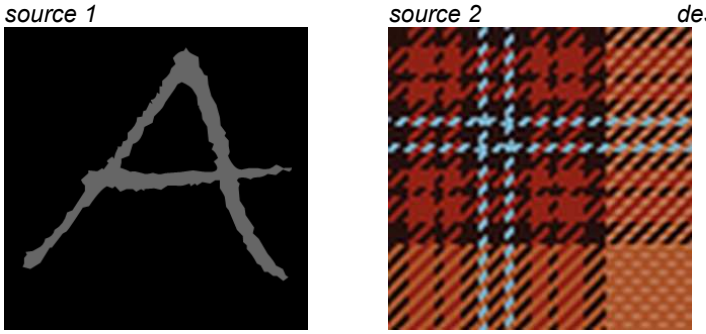
source 1 *source 2* *destination*



Alpha channel
In the channel mode, each color component (R, G, B or alpha) can be selected between SRC1 and SRC2 pixel components to form the DST pixel. Bits [3:0] of the OPERATION register do selection of components to be used. This operation is especially useful for merging 24-bit bitmaps with the 8-bit alpha bitmask to form a 32-bit ARGB bitmap.
Channel mode also supports the alpha fading, multiplying the alpha factor of each source with the value stored in the FG_COL_?(31:24), to achieve an increase in the transparency. To disable this function, write 0xFF to FG_COL_?(31:24).

- DST = *BITMASK*(SRC1) **CH** SRC2, (OPERATION[3:0] = “0111”)

source 1 *source 2* *destination*



4.4.3 Configuration examples

Examples are written for three use cases – simple ROP operation, alpha blending of two images and channel operation for alpha bitmask and pattern.

Example 1: simple ROP operation
Simple ROP operation, source_1 AND source_2, with source_1 image on address 0x0 and source_2 image on address 0x200000. The result will be stored on address 0x1000000. Images are in 24-bit format (RGB).

```
/* Define UINT32 example: typedef unsigned long UINT32; */
/* base_addr is address offset of the UltiEBB core on the APB bus */

UINT32 temp_reg;

*( (UINT32 *)(base_addr + 0x0) ) = 0x01; /* OPR1 enabled */
*( (UINT32 *)(base_addr + 0x4) ) = 0x0; /* set src1 address to 0x00000000 */
*( (UINT32 *)(base_addr + 0x8) ) = 0x0FFF; /* set src1 stripe to 4k */
*( (UINT32 *)(base_addr + 0x14) ) = 0x1; /* OPR2 enabled */
*( (UINT32 *)(base_addr + 0x18) ) = 0x200000; /* set src2 address to 0x00200000 */
*( (UINT32 *)(base_addr + 0x1C) ) = 0x0FFF; /* set src2 stripe to 4k */
*( (UINT32 *)(base_addr + 0x28) ) = 0x1; /* set operation to 1, AND */
*( (UINT32 *)(base_addr + 0x2C) ) = 0x1000000; /* set dst address to 0x01000000 */
*( (UINT32 *)(base_addr + 0x30) ) = 0x07FF; /* set dst stripe to 2k */
*( (UINT32 *)(base_addr + 0x40) ) = 0x9F; /* set x_width to 160 */
*( (UINT32 *)(base_addr + 0x44) ) = 0x77; /* set y_width to 120 */
*( (UINT32 *)(base_addr + 0x48) ) = 0x0140; /* set BPP to 4, positive direction (control
register). Start ROP */
/* poll busy flag until operation is done */
do {
       temp_reg = *( (UINT32 *)(base_addr + 0x48) ) & 0x0100;
} while (temp_reg != 0);
```

Example 2: alpha blending
Alpha blending of two pictures, source_1 OVER source_2, with source_1 image on address 0x800000 and source_2 image on address 0xA00000. The result will be stored on address 0x1000000. Images are in 32-bit format (ARGB).

```
/* Define UINT32 example: typedef unsigned long UINT32; */
/* base_addr is address offset of the UltiEBB core on the APB bus */

UINT32 temp_reg;

*( (UINT32 *)(base_addr + 0x0) ) = 0x01; /* OPR1 enabled */
*( (UINT32 *)(base_addr + 0x4) ) = 0x800000; /* set src1 address to 0x00800000 */
*( (UINT32 *)(base_addr + 0x8) ) = 0x0FFF; /* set src1 stripe to 4k */
*( (UINT32 *)(base_addr + 0xC) ) = 0xFF000000; /* set SRC1 foreground color to 0xFF000000,
for alpha fading */
*( (UINT32 *)(base_addr + 0x14) ) = 0x1; /* OPR2 enabled */
*( (UINT32 *)(base_addr + 0x18) ) = 0xA00000; /* set src2 address to 0x00A00000 */
*( (UINT32 *)(base_addr + 0x1C) ) = 0x0FFF; /* set src2 stripe to 4k */
*( (UINT32 *)(base_addr + 0x20) ) = 0xFF000000; /* set SRC2 foreground color to 0xFF000000,
for alpha fading */
*( (UINT32 *)(base_addr + 0x28) ) = 0x8; /* set operation to 8, SRC1 OVER SRC2 (ALPHA)*/
*( (UINT32 *)(base_addr + 0x2C) ) = 0x1000000; /* set dst address to 0x01000000 */
*( (UINT32 *)(base_addr + 0x30) ) = 0x0FFF; /* set dst stripe to 4k */
*( (UINT32 *)(base_addr + 0x40) ) = 0x12B; /* set x_width to 300 */
*( (UINT32 *)(base_addr + 0x44) ) = 0x12B; /* set y_width to 300 */
```

```
*( (UINT32 *)(base_addr + 0x48) ) = 0x0140; /* set BPP to 4, positive direction (control
register). Start alpha blending */
/* poll busy flag until operation is done */
do {
       temp_reg = *( (UINT32 *)(base_addr + 0x48) ) & 0x0100;
} while (temp_reg != 0);
```

Example 3

Alpha channel operation of two pictures, alpha(source_1) combined with the RGB(source_2), with source_1 image on address 0xC00000 and source_2 image on address 0xE00000. The result will be stored on address 0x1000000. Source_1 image is 24-bit RGB, source_2 image 8-bit alpha bitmask, and result 32-bit ARGB.

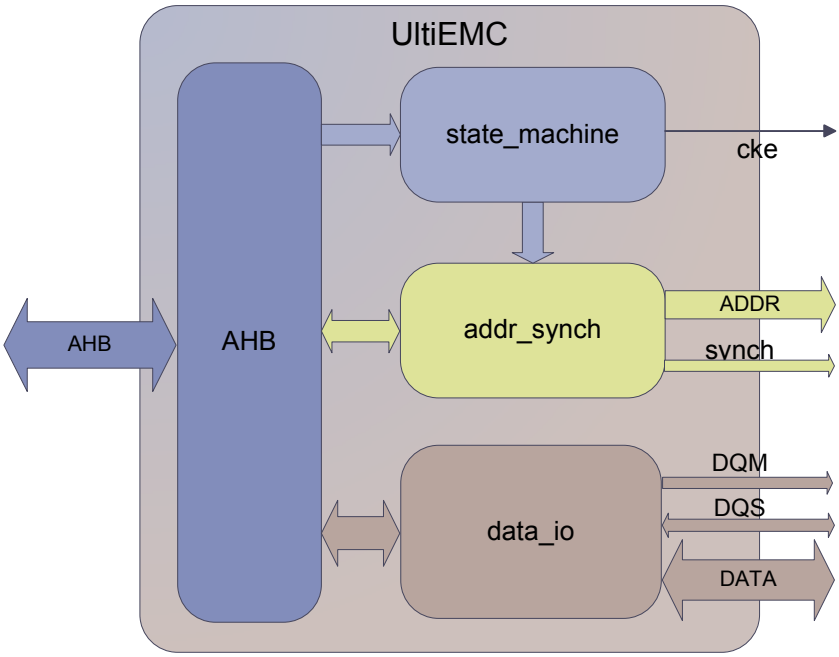
```
/* Define UINT32 example: typedef unsigned long UINT32; */
/* base_addr is address offset of the UltiEBB core on the APB bus */

UINT32 temp_reg;

*( (UINT32 *)(base_addr + 0x0) ) = 0x01; /* OPR1 enabled */
*( (UINT32 *)(base_addr + 0x4) ) = 0xC00000; /* set src1 address to 0x00C00000 */
*( (UINT32 *)(base_addr + 0x8) ) = 0x0FFF; /* set src1 stripe to 4k */
*( (UINT32 *)(base_addr + 0xC) ) = 0xFF000000; /* set SRC1 foreground color to 0xFF000000,
for alpha fading */
*( (UINT32 *)(base_addr + 0x14) ) = 0x1; /* OPR2 enabled */
*( (UINT32 *)(base_addr + 0x18) ) = 0xE00000; /* set src2 address to 0x00E00000 */
*( (UINT32 *)(base_addr + 0x1C) ) = 0x0FFF; /* set src2 stripe to 4k */
*( (UINT32 *)(base_addr + 0x20) ) = 0xFF000000; /* set SRC2 foreground color to 0xFF000000,
for alpha fading */
*( (UINT32 *)(base_addr + 0x28) ) = 0x17; /* set operation to 17, SRC1 CH SRC2 (alpha SRC1,
RGB SRC2)*/
*( (UINT32 *)(base_addr + 0x2C) ) = 0x1000000; /* set dst address to 0x01000000 */
*( (UINT32 *)(base_addr + 0x30) ) = 0x0FFF; /* set dst stripe to 4k */
*( (UINT32 *)(base_addr + 0x40) ) = 0x12B; /* set x_width to 300 */
*( (UINT32 *)(base_addr + 0x44) ) = 0x12B; /* set y_width to 300 */
*( (UINT32 *)(base_addr + 0x48) ) = 0x0140; /* set BPP to 4, positive direction (control
register). Start channel operation. */
/* poll busy flag until operation is done */
do {
       temp_reg = *( (UINT32 *)(base_addr + 0x48) ) & 0x0100;
} while (temp_reg != 0);
```

4.5 DDR memory controller: UltiEMC

The DDR memory controller is implemented by the UltiEMC core, providing a ready-to-use memory controller which is suitable for the 16-bit data bus width of the DDR devices used on the reference design.
The core behaves as an AMBA 3 AHB bus slave device, giving full access to the DDR memory address space (mapped inside the address space of UltiEMC).



UltiEMC Block Diagram

At power up the memory controller is still initialized accordingly with the DDR device used; no configuration registers are given.

4.6 Video Input core: UltiVIDIN

UltiVIDIN implements the video input core, used to receive the ITU656 pixel stream or the VGA digital input.

ITU656 is decoded and deinterlaced, while VGA input is simply forwarded to the video input mux.
Selected input is then scaled and outputted to the memory.
UltiVIDIN supports upscaling (up to the factor 2) in the horizontal direction and downscaling in the horizontal and the vertical direction up to the factor 7.96875.

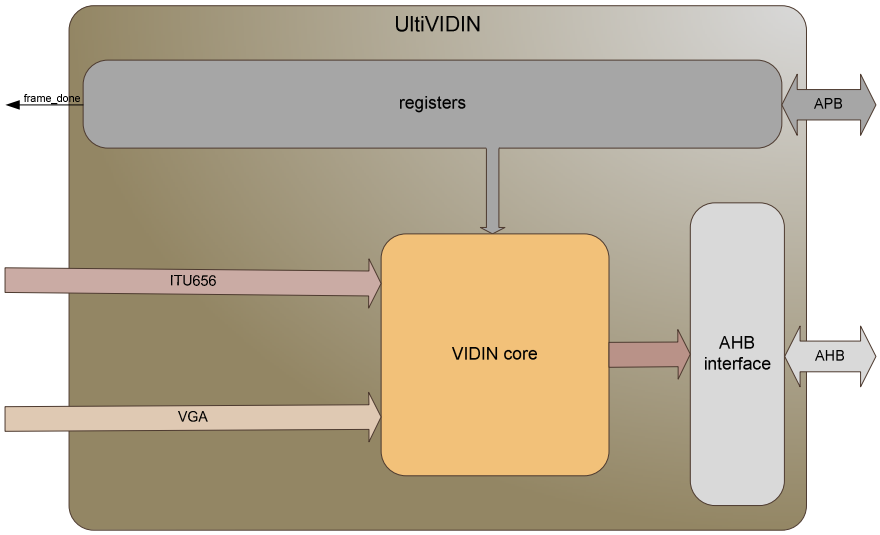
The output format is fully SW configurable, with any starting address and any stripe.
Output can be continuous or limited to just one frame, with the optional horizontal and/or vertical flip.

The image is always stored in the 16 bits per pixel format (BPP = 2).

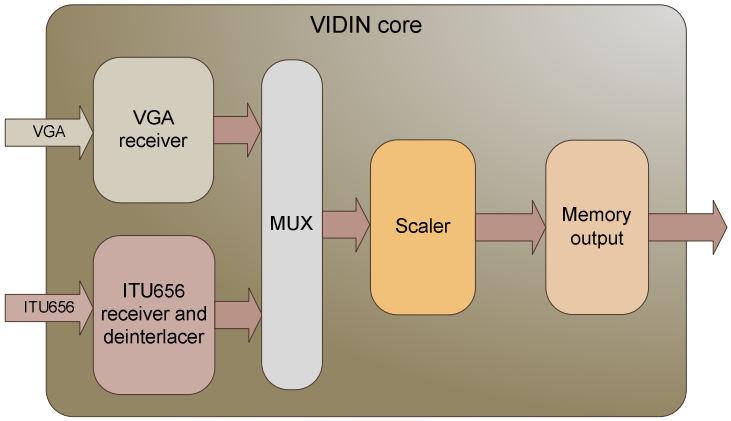
One ITU656 input stream and one VGA input core are present on design.

UltiVIDIN consists of the following modules:

- Registers with the APB interface
- VIDIN core containing ITU656 deinterlacer, VGA input, scaler and memory output
- AHB interface



Block diagram of UltiVIDIN



Simplified block diagram of VIDIN core

4.6.1 Registers

All registers are aligned to the AMBA APB data bus width (4 bytes).

Register	Bits	Access	Function	Offset
CONTROL	9	R/W	Configure VIDIN operation; output enable, one-shot mode, horizontal/vertical flip, double horizontal resolution	0x00
HSFC	8	R/W	Horizontal scaling factor.	0x04
HSFC_R	8	R/W	Reciprocal horizontal scaling factor.	0x08
VSFC	8	R/W	Vertical scaling factor.	0x0C
VSFC_R	8	R/W	Reciprocal vertical scaling factor.	0x10
MEM_ADDR	32	R/W	Memory address of first pixel in frame.	0x14
MEM_STRIPE	16	R/W	Stripe size of image in memory.	0x18
HCROPP	16	R/W	Horizontal crop size.	0x1C
HLENGTH	16	R/W	Output horizontal resolution.	0x20
VCROPP	10	R/W	Vertical crop size.	0x24
VHEIGHT	10	R/W	Output vertical resolution.	0x28
SOURCE	3	R/W	Image source selection.	0x2C
LINENUM	12	R	Total number of lines in VGA frame.	0x30
LINELEN	15	R	Total length of line in VGA frame.	0x34
HOROFF	13	R/W	Horizontal offset of VGA image.	0x38
VEROFF	13	R/W	Vertical offset of VGA image.	0x3C
HORRES	13	R/W	Horizontal resolution of VGA image.	0x40
VERRES	13	R/W	Vertical resolution of VGA image.	0x44

Registers in the UltiVIDIN core

CONTROL

offset 0x00

31 9	8	7 4	3	2	1	0
RFU	DBL_HRES	RFU	VFLIP_EN	HFLIP_EN	ONESHOT_EN	MEM_EN

CONTROL register configures the operation of UltiVIDIN.

MEM_EN flag enables (‘1’) or disables (‘0’) writing to the memory. This flag is self-clearing if one-shot mode is enabled.

ONESHOT_EN flag enables (‘1’) or disables (‘0’) the one-shot mode. When enabled, VIDIN will output one frame to the memory and disable writing to the memory (clear MEM_EN flag).

HFLIP_EN flag enables (‘1’) or disables (‘0’) the horizontal flip mode. When enabled, VIDIN will output the image to the decreasing addresses in the each stripe (the second pixel will go to the lower address than the first one).

VFLIP_EN flag enables (‘1’) or disables (‘0’) the vertical flip mode. When enabled, VIDIN will output image to the decreasing addresses for the each stripe (the second line will go to the lower address than the first line).

DBL_HRES flag enables (‘1’) or disables (‘0’) the doubling of the input pixels to the scaler module. This feature works only if the pixel clock frequency is at least 2x lower than the memory clock.

HSFC

offset 0x04

31 8	7 0
RFU	HSCALE

HSFC register defines the horizontal scaling factor (together with the DBL_HRES flag in the CONTROL register).

HSCALE[7:0] contains the horizontal scaling factor, multiplied by 32. 5 LSB digits are decimals. If the DBL_HRES flag is asserted, actual scaling factor is divided by 2. Maximum scaling factor is 7.96875, while the minimum scaling factor is 0.5 (HSCALE set to 0x20 and DBL_HRES flag set to ‘1’).

HSFC_R

offset 0x08

31 … 8	7 … 0
RFU	HSCALE_R

HSFC_R register defines the reciprocal horizontal scaling factor.

HSCALE_R[7:0] contains the reciprocal horizontal scaling factor, multiplied by 128. 7 LSB digits are decimals. To avoid the division in the HW, the reciprocal scaling factor (reciprocal = 1/x) has to be calculated by the user and written to this register.

WARNING!
To avoid an error in the calculation, the internal value of the HSFC_R register will change only on write to the HSFC register. User should write the reciprocal scaling factor to the HSFC_R first, and then the scaling factor to the HSFC.

VSFC

offset 0x0C

31 … 8	7 … 0
RFU	VSCALE

VSFC register defines the vertical scaling factor.

VSCALE[7:0] contains the vertical scaling factor, multiplied by 32. 5 LSB digits are decimals. The maximum scaling factor is 7.96875, while the minimum scaling factor is 1.0 (VSCALE set to 0x20).

VSFC_R

offset 0x10

31 … 8	7 … 0
RFU	VSCALE_R

VSFC_R register defines the reciprocal vertical scaling factor.

VSCALE_R[7:0] contains the reciprocal vertical scaling factor, multiplied by 128. 7 LSB digits are decimals. To avoid the division in the HW, the reciprocal scaling factor (reciprocal = 1/x) has to be calculated by the user and written to this register.

WARNING!
To avoid an error in the calculation, the internal value of the VSFC_R register will change only on write to the VSFC register. User should write the reciprocal scaling factor to the VSFC_R first, and then the scaling factor to the VSFC.

MEM_ADDR

offset 0x14

31 … 0
M_ADDRESS

MEM_ADDR register defines the memory address of the first pixel in the input frame.

M_ADDRESS [31:0] contains the memory address (in bytes) of the first pixel in the input frame. Depending on the horizontal/vertical flip, the first pixel from the input frame will be located in the upper left corner of the output image (no flip), the upper right corner of the output image (horizontal flip), the lower left corner of the output image (vertical flip), or the lower right corner of the output image (horizontal and vertical flip). User should calculate the memory address accordingly.

MEM_STRIPE

offset 0x18

31 … 16	15 … 0
unused	MEMORY_STRIPE

MEM_STRIPE register defines the stripe size of the output image, written in the format STRIPE-1.

MEMORY_STRIPE[15:0] contains the size of the memory block allocated for the each line in the output image. The size of the memory block is expressed in bytes (with 1 subtracted). The maximum supported memory stripe is 65536 bytes.

HCROPP

offset 0x1C

31 … 16	15 … 0
RFU	HOR_CROPP

HCROPP register defines the number of the pixels to be cropped.

HOR_CROPP[15:0] contains the number of the pixels which will be discarded at the beginning of the each line. If 0x0 is written to this register, no pixels will be cropped. The maximum number of cropped pixels is 65535.

HLENGTH

offset 0x20

31 … 16	15 … 0
RFU	HOR_RES

HLENGTH register defines the horizontal resolution of the output image.

HOR_RES[15:0] contains the maximum output resolution (written in format HRES-1). Maximum supported resolution is 65536.
The input image will be scaled, HOR_CROPP number of pixels will be discarded and the remaining pixels outputted to the memory. If the resulting resolution is smaller or equal to the HOR_RES, all pixels will be outputted, otherwise excess pixels on the end of the line will be discarded.

VCROPP

offset 0x24

31 … 10	9 … 0
RFU	VER_CROPP

VCROPP register defines the number of the lines to be cropped.

VER_CROPP[9:0] contains the number of the lines which will be discarded at the beginning of the each frame. If 0x0 is written to this register, no lines will be cropped. The maximum number of cropped lines is 1023.

VHEIGHT

offset 0x28

31 … 10	9 … 0
RFU	VER_RES

VHEIGHT register defines the vertical resolution of the output image.

VER_RES[9:0] contains the maximum output resolution (written in format VRES-1). The maximum supported resolution is 1024.
The input image will be scaled, VERR_CROPP number of lines will be subtracted and remaining lines outputted to the memory. If resulting resolution is smaller or equal to the VER_RES, all lines will be outputted, otherwise excess lines will be discarded at the end of the frame.

SOURCE

offset 0x2C

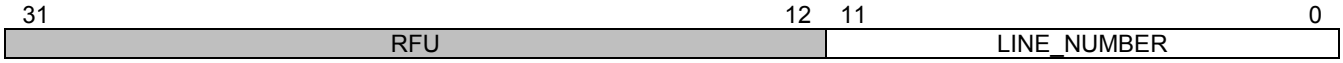
31 … 3	2 … 1	0
RFU	ITU656_SEL	INPUT_SEL

SOURCE register configures inputs to the ITU656 deinterlacer and to the scaler.

INPUT_SEL configures input to the scaler, VGA image ('1') or output from ITU656 mux ('0').
ITU656_SEL[1:0] contains ITU656 input stream selector. Only '00' is allowed on actual design.

LINENUM

offset 0x30



LINENUM register contains result of the line counting in each VGA frame.

LINE_NUMBER [11:0] contains result of the line counting in the VGA frame. Number is equal to the number of hsync pulses in each VGA frame.

LINELEN

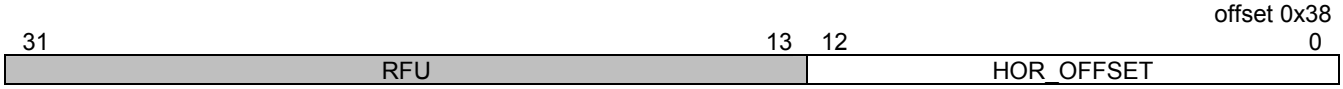
offset 0x34

LINELEN register contains result of the internal clock period counting in each VGA line.

LINE_LENGTH [14:0] contains result of the internal clock period counting in each VGA line. Number is equal to the number of clock periods contained in each VGA line. Length of the clock period depends on the clock connected to the VGA logic.

HOROFF

offset 0x38



HOROFF register contains the number of the VGA clocks between the hsync pulse and the first valid pixel.

HOR_OFFSET [12:0] contains the number of pixel clocks between the deassertion of the hsync signal and the first valid pixel. This number is equal to the horizontal back porch, and depends on the timing of the VGA input. It is set by the software depending on the values read from the registers LINENUM and LINELEN.

VEROFF

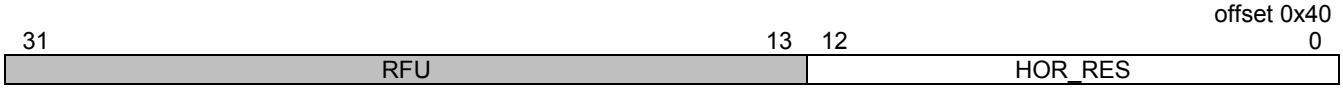
offset 0x3C

VEROFF register contains the number of the lines between the vsync pulse and the first line which contains valid pixels.

VER_OFFSET [12:0] contains the number of lines (i.e. hsync pulses) between the deassertion of the vsync signal and the first line which contains valid pixels. This number is equal to the vertical back porch, and depends on the timing of the VGA input. It is set by software depending on the values read from the registers LINENUM and LINELEN.

HORRES

offset 0x40



HORRES register contains the horizontal resolution of the VGA input.

HOR_RES [12:0] contains the horizontal resolution (i.e. number of visible pixels in each line) of the VGA input.

VERRES

offset 0x44

31	13	12	0
RFU		VER_RES	

VERRES register contains the vertical resolution of the VGA input.

VER_RES [12:0] contains the vertical resolution (i.e. number of visible lines in each frame) of the VGA input.

4.6.2 UltiVIDIN operation

The VIDIN core can be divided into the 4 main components:

- ITU656 receiver and deinterlacer
- VGA receiver
- scaler
- memory interface

The ITU656 receiver and deinterlacer receive the input pixel stream in the ITU656 format. It performs deinterlacing and then forwards the resulting frame in the full resolution to the scaler.

The VGA receiver simply samples VGA input and outputs only synch signals and valid pixels. It also serves as cross-clock bridge between VGA clock and scaler clock (i.e. pixel processing clock).

Muxing between these two sources was explained above, only one of the video inputs can be processed at one time by the scaler and memory output.

The scaler downscales the input image using the factors stored in the HSFC, HSFC_R, VSFC and VSFC_R registers. Each scaling factor has to be inputted in normal and reciprocal version, to avoid division in the VIDIN core. Additionally, pixels can be doubled, effectively multiplying the horizontal input resolution by 2 before applying the scaling algorithm. The upscaling in the horizontal direction can be achieved this way. User should take care that the horizontal resolution of the resulting image (after scaling) doesn't exceed 2048. Bigger resolutions are not supported by the scaler, and will result in the image corruption. The resulting image is forwarded to the memory interface.

The memory interface is used for buffering the input pixel stream and outputting it to the memory. The scaled image is outputted to the memory in the desired format. The memory interface also performs cropping (horizontal and/or vertical) and flipping (horizontal and vertical) of the image.
If flipping image, the location of the upper left pixel in the memory will not be equal to the address stored in the MEM_ADDR register. To avoid complicated calculations in the HW, the VIDIN core was designed in such a way that address stored in the MEM_ADDR register should point to the location of the first pixel to be written into the memory (i.e. upper left pixel of the image, before flipping). This pixel will be the one of the corner pixels in the output image, depending on the flip settings. For the address calculation, see **Error! Reference source not found.** below:

VFLIP	HFLIP	MEM_ADDR <-> upper left pixel address
0	0	$MEM\_ADDR = ADD_{ULP}$
0	1	$MEM\_ADDR = ADD_{ULP} + HOR\_RES * BPP$
1	0	$MEM\_ADDR = ADD_{ULP} + VER\_RES * (MEM\_STRIPE + 1)$
1	1	$MEM\_ADDR = ADD_{ULP} + HOR\_RES * BPP + VER\_RES * (MEM\_STRIPE + 1)$

Calculation of the MEM_ADDR

All numbers used in this calculation are in the same format as written in the registers – i.e. (number-1) for the resolutions and the stripe size.

Memory interface can also operate in the continuous or the one-shot mode. When one-shot mode is enabled (by setting ONESHOT_EN flag in the CONTROL register), VIDIN will (when output is enabled, MEM_EN = '1') always output exactly 1 frame (it will wait until the start of the next frame, and then start writing to memory. It will stop only after the final pixel in

frame was outputted). In case of an overflow, VIDIN will wait for the beginning of the next frame, and attempt outputting the frame again. After successfully writing one frame, VIDIN will clear MEM_EN flag. To output another frame, user should set MEM_EN flag again.

All changes in the scaler and memory interface parameters are applied only after the beginning of the next frame (i.e. after vsync is detected in the input stream). To enable detection of at least 1 frame outputted to the memory, VIDIN generates *frame_done* pulse. This signal should be connected to the interrupt controller, to enable detection of the outputted frames. It should be mentioned that, when operating in the one-shot mode, *frame_done* will be asserted only after successful output of a whole frame (in case of an overflow, VIDIN will attempt to output the frame again). When outputting continuously, *frame_done* will be asserted on each vsync detected on the output (if no overflow happened during this frame), except the first one after core was enabled (MEM_EN flag was asserted). Therefore, the core will always assert *frame*_done after successful output of one frame, not vsync detection on the memory interface.

When changing muxing parameters, user should first disable the core (clear MEM_EN flag) and wait for the *frame_done* strobe, then change the parameters and enable core operation again. After this, user should wait for the next *frame_done* strobe to be sure that at least one frame was outputted with the new settings.

4.6.3 Configuration example

The example features ITU656 pixel doubling which assumes that the internal ITU656 logic clock is at least 2x larger than input ITU656 clock.

```
/* Define UINT32 example: typedef unsigned long UINT32; */
/* base_addr is address offset of the UltiVIDIN core on the APB bus */

/*////////////////////////////////////////////////////////////////////
/ ITU656 input, upscaling 1.11 horizontally and no scaling vertically,
/ horizontal and vertical flip, output one frame only
////////////////////////////////////////////////////////////////////*/
/* horizontal scaling 1.8 (0x39, 0x47) */
*( (UINT32 *)(base_addr + 0x08) ) = 0x39;
*( (UINT32 *)(base_addr + 0x04) ) = 0x47;

/* vertical scaling 1 (0x20, 0x80) */
*( (UINT32 *)(base_addr + 0x10) ) = 0x80;
*( (UINT32 *)(base_addr + 0x0C) ) = 0x20;

/* memory address */
*( (UINT32 *)(base_addr + 0x14) ) = 0x001DF63E;

/* memory stripe */
*( (UINT32 *)(base_addr + 0x18) ) = 0x0FFF;

/* horizontal crop */
*( (UINT32 *)(base_addr + 0x1C) ) = 0x0;

/* horizontal resolution */
*( (UINT32 *)(base_addr + 0x20) ) = 0x31F;

/* vertical crop */
*( (UINT32 *)(base_addr + 0x24) ) = 0x0;

/* vertical resolution */
*( (UINT32 *)(base_addr + 0x28) ) = 0x1DF;

/* source ITU656, sel ch 0 */
*( (UINT32 *)(base_addr + 0x2C) ) = 0x0;

/* enable output, single shot, double hor res, hor and vert flip */
*( (UINT32 *)(base_addr + 0x00) ) = 0x010F;
```

4.7 AD/DA controller: UltiADDA

UltiADDA is an AD/DA converter, targeted for the brightness control and the resistive touch control.
Conversion values are 13-bit wide, with an effective 12-bit resolution.
N° 8 channels are handled on design.

Both A/D and D/A conversion use the same externally generated ramp voltage and conversion counter (AVAL). One period of ramp voltage is required for conversion of one A/D or D/A channel, which results in conversion time of 125 us per channel (1 ms per 8 channels).

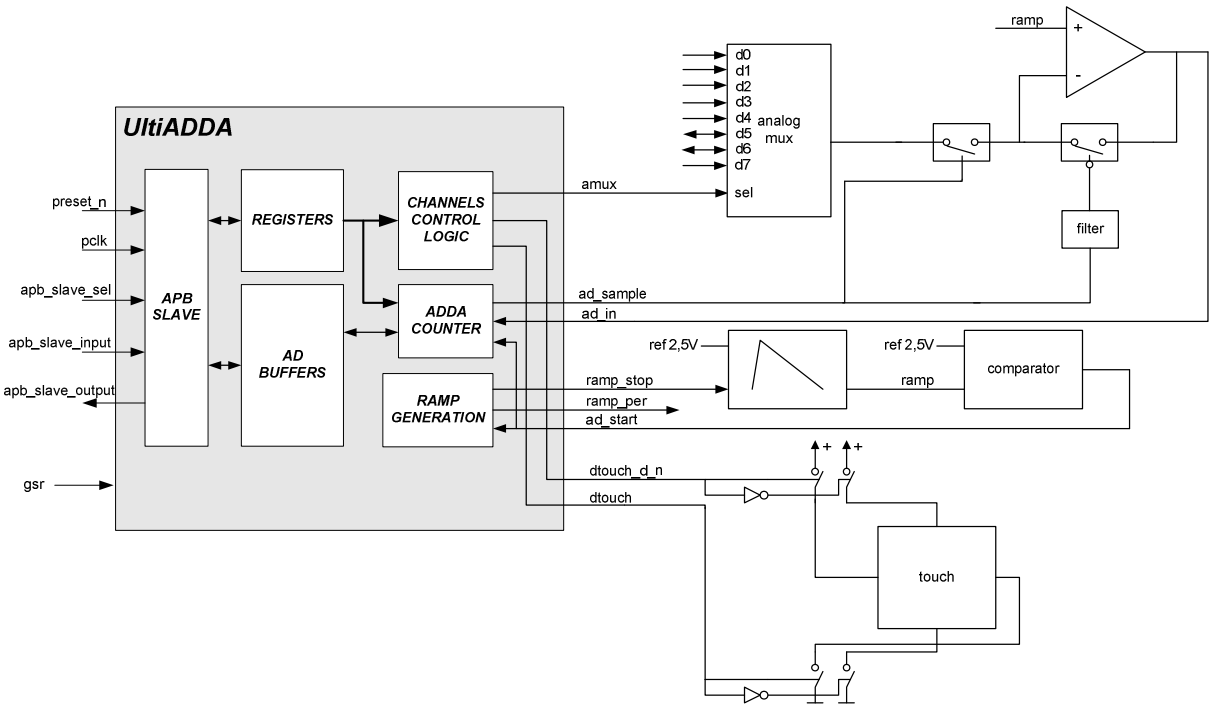
The initialization values for UltiADDA and the values related with AD and DA conversions are mapped into the internal FPGA memory.

The initialization value for UltiADDA is built of three MSBs that define the next ULTIADDA channel to be processed and 13 bits used as a DA value if particular channel is defined as a DA channel.
The results of AD conversion (captured values) are stored in two separated memory buffers. The first one stores the results of X-touch conversion, while the second one contains the results of Y-touch conversion.

Prior to the start of the UltiADDA conversion cycle it is necessary to write the type of each channel into the UltiADDA control register ADDA_CTRL: for every channel the MSBs [15:13] must define the next channel to be processed and for channels defined as D/A digital values must be written into corresponding LSBs [12:0]. For channels defined as A/D, LSBs [12:0] can be 0.

Besides these memory locations, mapped into distributed RAMs, there is an 8-bit register ADDA_CTRL. This register is used for the definition of the channel type (AD or DA), and enabling the conversion.

Diagram below shows UltiADDA core architecture and external related circuitry.



UltiADDA Block Diagram

4.7.1 Functional description

Conversion cycles

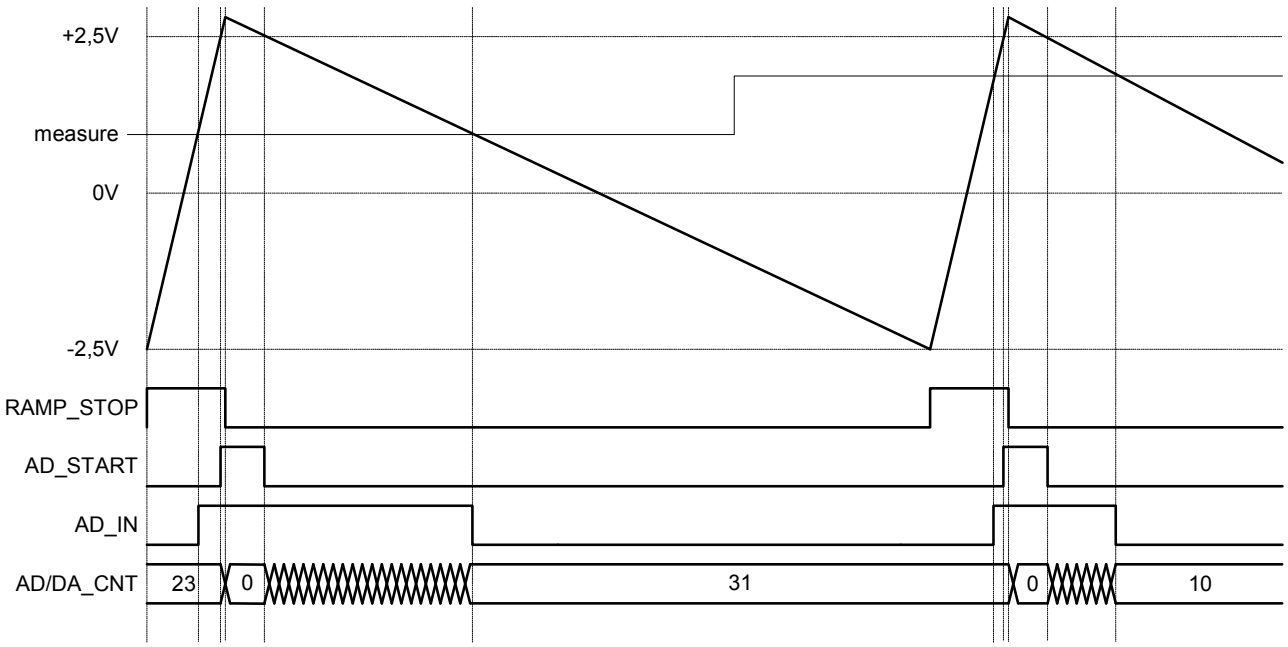
Once the conversion cycle is started, the first channel processed is channel 0. The next channel to be processed is determined by the 3 most significant bits (13, 14, 15) in memory location reserved for the D/A value of the channel currently being processed (pointer, linked list of channels). The last channel in the chain must be the channel 7 (GND). This method results in variable conversion cycle duration, for example:

channel conversion sequence	conversion cycle duration [periods of ramp voltage]
0 → 7	2
0 → 2 → 7	3
0 → 5 → 3 → 7	4
. . . .	. . .
0 → any combination of 1,2,3,4,5,6 → 7	8

A/D conversion

On the falling edge of AD_START, the counter AVAL starts counting from 0 up. RAMP_STOP is the signal for control of the ramp voltage. When high, ramp rises from negative to positive saturation voltage, and vice versa. AD_START is high when ramp is above reference voltage level, and is used for synchronizing the start of AVAL counter. When input analog voltage (from analog mux currently addressed input) equals the externally generated ramp voltage, AD_IN becomes active (low), the current AVAL value is written into internal FPGA memory (captured values memory space).

Since the start of AVAL is synchronized with ramp reaching reference voltage VREF (signal AD_START), *range scaling* software routines should use only the value of reference GND measured on channel 7.



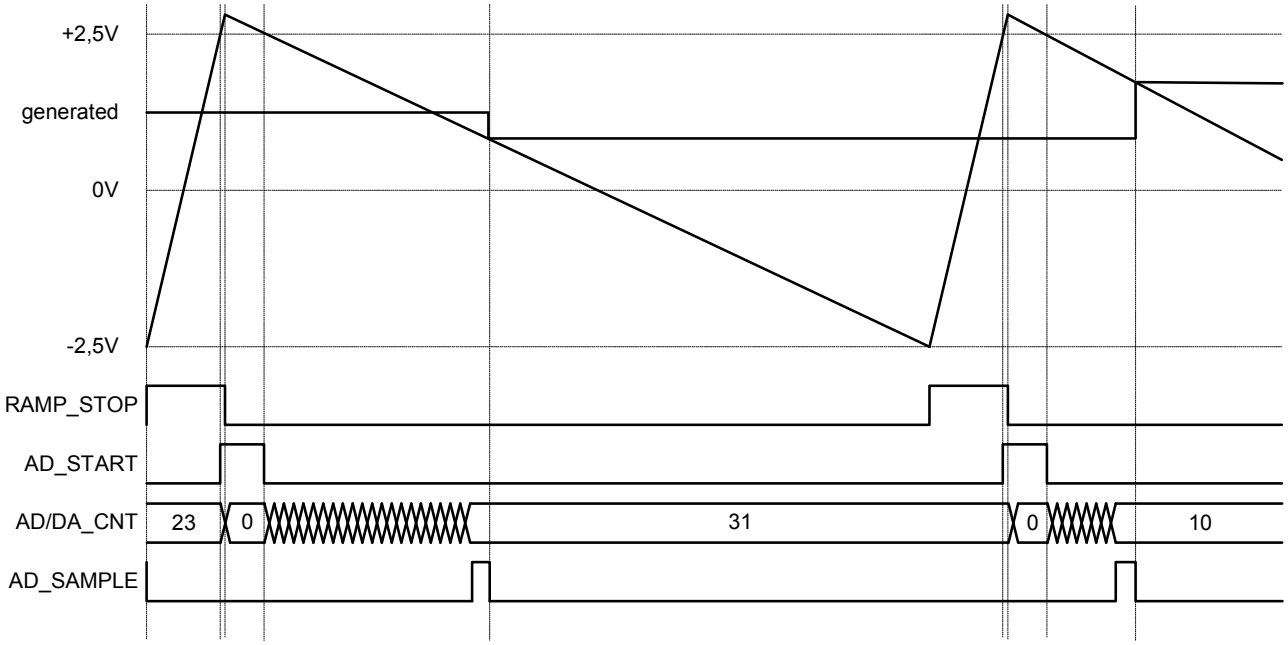
AD conversion

D/A conversion

If the next channel to be processed is defined as D/A (in ADDA_CTRL register), during ramp reset period digital value for the channel is transferred from internal FPGA memory to internal register (it holds the value unchanged during the comparison), where it is compared with AVAL, which again starts counting from zero up on the falling edge of AD_START.

When AVAL reaches the desired, from internal memory read digital value, and AMUX bits select the corresponding analog output, AD_SAMPLE is activated (high.

The activation of AD_SAMPLE always lasts for the same amount of time (counter controlled) as a result, the ramp voltage is being transferred to the wanted analog output. In order to hold this voltage level until the next charging, analog output must have sample and hold circuit (capacitor). The digital value 0x0000 of AVAL represents the most positive D/A voltage value, and 0x1FFF represents the most negative D/A voltage value.



DA conversion

4.7.2 Memory and registers

UltiADDA architecture requires eight 16-bit wide locations for next channel (3 bits per channel are used) definition and DA value initialization (13 bits per channel are used). It also requires 16 16-bit wide locations for storage of AD conversion's results (lower 13 bits per channel are used).

Memory mapping is the following:

Offset	Type	Purpose
0x00	W	B[15:13] next channel, B[12:0] = 0
0x04	W	B[15:13] next channel, B[12:0] = 0
0x08	W	B[15:13] next channel, B[12:0] = 0
0x0C	W	B[15:13] next channel, B[12:0] = 0
0x10	W	B[15:13] next channel, B[12:0] = 0
0x14	W	B[15:13] next channel, B[12:0] DA value if set as DA channel
0x18	W	B[15:13] next channel, B[12:0] DA value if set as DA channel
0x1C	W	B[15:13] next channel, B[12:0] = 0
0x40	R	B[15:13] don't care, B[12:0] result of AD conversion – X touch
0x44	R	B[15:13] don't care, B[12:0] result of AD conversion – X touch
0x48	R	B[15:13] don't care, B[12:0] result of AD conversion – X touch
0x4C	R	B[15:13] don't care, B[12:0] result of AD conversion – X touch
0x50	R	B[15:13] don't care, B[12:0] result of AD conversion – X touch
0x54	R	B[15:13] don't care, B[12:0] result of AD conversion if set as AD – X touch
0x58	R	B[15:13] don't care, B[12:0] result of AD conversion if set as AD – X touch
0x5C	R	B[15:13] don't care, B[12:0] result of AD conversion – X touch
0x80	R	B[15:13] don't care, B[12:0] result of AD conversion – Y touch
0x84	R	B[15:13] don't care, B[12:0] result of AD conversion – Y touch
0x88	R	B[15:13] don't care, B[12:0] result of AD conversion – Y touch
0x8C	R	B[15:13] don't care, B[12:0] result of AD conversion – Y touch
0x90	R	B[15:13] don't care, B[12:0] result of AD conversion – Y touch
0x94	R	B[15:13] don't care, B[12:0] result of AD conversion if set as AD – Y touch
0x98	R	B[15:13] don't care, B[12:0] result of AD conversion if set as AD – Y touch
0x9C	R	B[15:13] don't care, B[12:0] result of AD conversion – Y touch

Control register

Offset 0xC0

31 … 6	5	4 … 1	0
unused	ADDA6	ADDA5	unused	AD_DISABLE

ADDA_CTRL (WRITE operation) register is used for storing the channel type (A/D or D/A) for every UltiADDA channel that can be programmed.

Flag	Value	Behavior
AD_DISABLE	0	UltiADDA operation is enabled
	1	UltiADDA operation is enabled
ADDA5	0	Channel is defined as A/D
	1	Channel is defined as D/A
ADDA6	0	Channel is defined as A/D
	1	Channel is defined as D/A

In ADDA_CTRL register channel ADDA5 and ADDA6 can be programmed. ADDA5 and ADDA6 are automatically returned to DA mode after single A/D conversion is performed. Therefore, proper sequence for reading ADDA5 or ADDA6 is:

1. Set ADDA_CTRL bit 5 (or bit 6)
2. Wait at least 2ms
3. Read data

The AD/DA channels currently used are:

Channel	Type	Description
ADDA0	A/D	GND
ADDA1	A/D	GND
ADDA2	A/D	Analog touch panel X/Y input
ADDA3	A/D	Half Y – touch panel temperature compensation
ADDA4	A/D	Half X – touch panel temperature compensation
ADDA5	D/A	Display contrast regulation
ADDA6	D/A	Display backlight intensity

4.8 UltiDMA

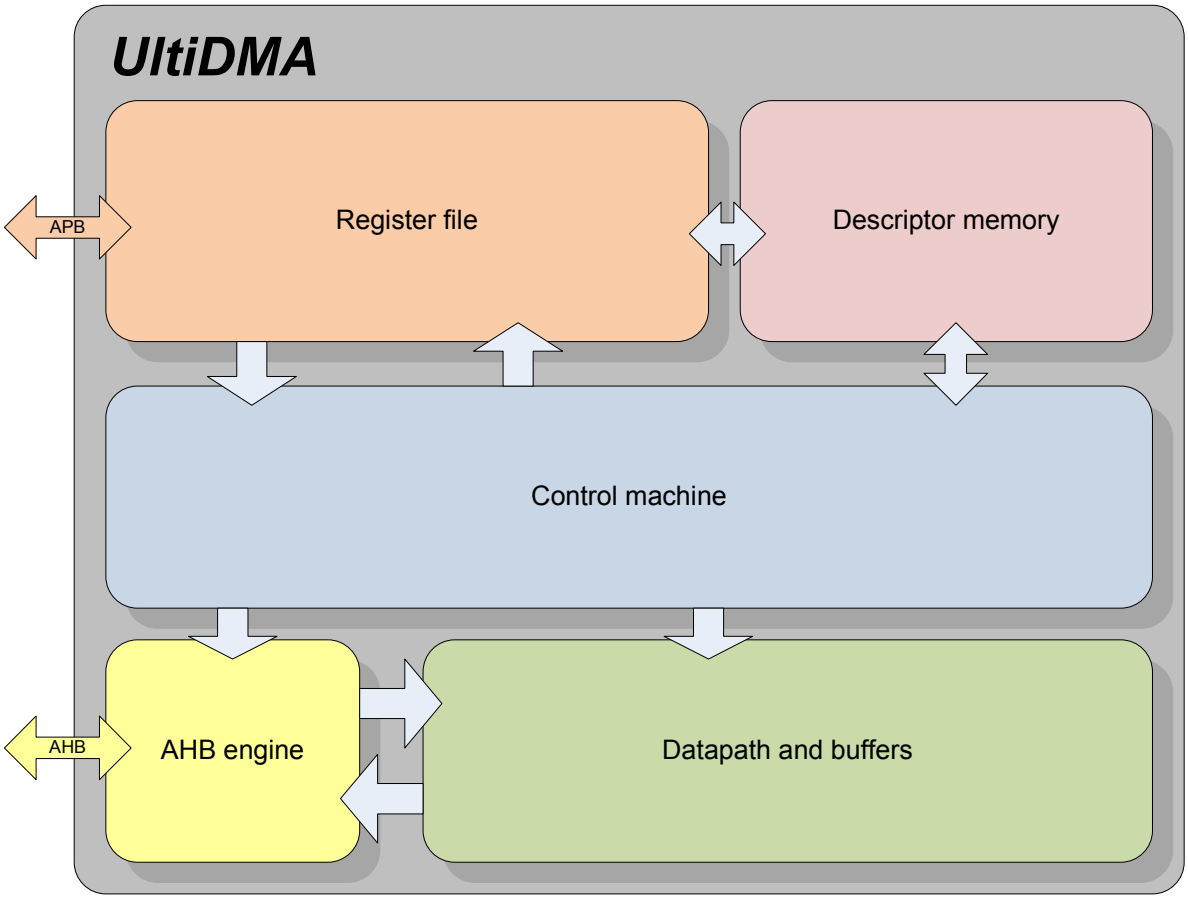
UltiDMA is a high performance multichannel DMA controller capable of executing data transactions on the AMBA 3 AHB interconnect. It is compliant with AMBA3 interconnect protocol and uses AHB as its DMA interface and APB as its register interface.

The role of UltiDMA is to provide DMA support for peripheral cores which do not have their own memory master. It is also used to accelerate the transfers between the memory and the peripheral devices (or between two distinct memory areas). DMA is the preferred method to move large blocks of data between the system memory and the peripherals.

In FPGA-based systems where a large number of relatively slow, slave only peripherals require frequent servicing, adding memory masters for the peripherals would result in a challenging implementation of the AMBA AHB interconnection matrix. Also, implementing dedicated memory masters on all cores would essentially multiply the master logic, raising the design consumption and complexity. For most peripherals, a single external DMA controller can service multiple peripherals on demand, raising performance, however increasing of the overall logic utilization only by the fixed cost of DMA and not with a variable additional cost per peripheral. Additionally, the DMA controller requires adding only one additional AHB master to enable DMA functionality for multiple other cores, thereby reducing the potential stress on the AMBA AHB interconnect.

Main Features

- Byte stream copy between arbitrary source and destination address per channel
- 4 channels
- Fixed priority between channels
- Various access modes: fixed address, single access, burst access, memory access
- Support for data pumping
- Support for transfer chaining
- Interrupt support (interrupt signal not connected on actual design)
- Support for contiguous or split, single or multiple operations per channel
- Support for external triggering and arbitrary trigger assignment per channel
- Support for CRC32 calculation on a selected channel



UltiDMA architecture

4.8.1 Operation

Basic operation
The basic operation of the DMA controller is a sequence of read-write cycles between two areas on the AMBA bus: a source pointer and a destination pointer.A read-write cycle consist of a read transfer, and a write transfer. Multiple read-write cycles comprise a DMA operation. A DMA operation transfers an exact, defined number of bytes from the source to the destination. This number of bytes is defined as operation length.

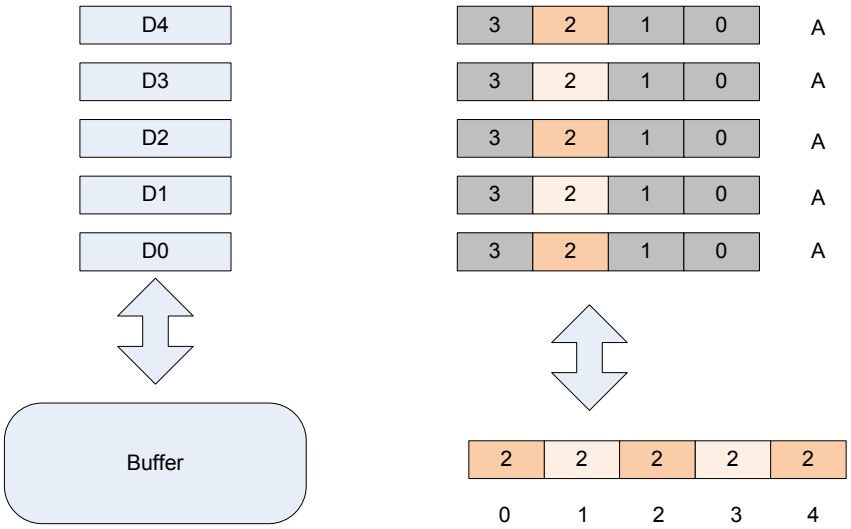
The source and the destination are two addresses on the AMBA bus, which can represent any specific device: memory, peripheral, FIFO, register etc. To enable transfer from various kinds of peripherals to memory, or from peripheral to peripheral, the DMA supports multiple transfer modes. Each area has its own specific set transfer size, which defines the size of the data request on the AMBA bus. The transfer size is used in conjunction with the transfer mode to define the transfer properties.

Transfer sizes
Each transfer area has a defined transfer size. The transfer size is the size of an individual data request on the bus.
UltiDMA supports byte, half word(2 bytes) and word(4 bytes) transfer sizes.

All transfer modes respect the defined transfer sizes, except the memory mode, which uses the largest available transfer size.
The size can be set arbitrarily for source and the destination area. The UltiDMA data path handles the conversion between data sizes.

Transfer modes
In a DMA operation, **both source and the destination pointer have defined transfer modes**. A read transfer from the source area or the write transfer to the destination area is always performed in a defined mode. The UltiDMA controller supports 4 transfer modes.

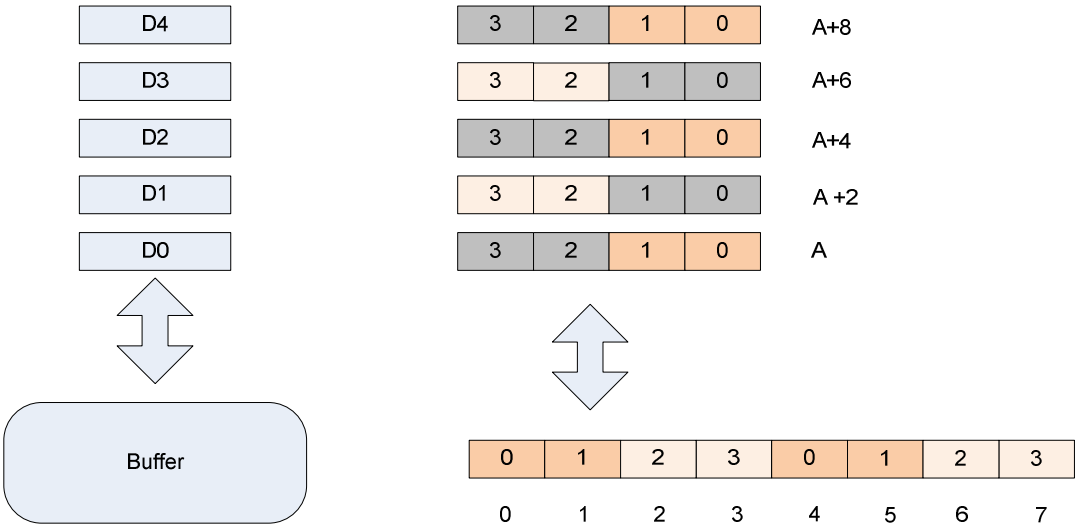
a) Fixed access mode
In the fixed access mode, the source or the destination address is not incremented between transfer beats. A read or write transfer in fixed mode is actually a series of consecutive single read or write accesses (AHB NONSEQ requests) of a defined, fixed size, to a single address. This mode is usually used for data pumping from or to a fifo or a register. The data stream will be read from or written to a single address. The address must be aligned to the data size.



Data transfer in fixed access mode

b) Single access mode
In the single access mode, the source or the destination address is incremented, however the transfer is single access. A read or write transfer in single access mode is actually a series of consecutive single read or write accesses (AHB NONSEQ requests)) of a defined, fixed size, to a series of consecutive addresses, with the address incremented by the size of the data on the bus. This mode is usually used for accessing multiple addresses on slaves which do not support burst operations, and require fixed data size (Usually for APB access). The address must be aligned to the data size.

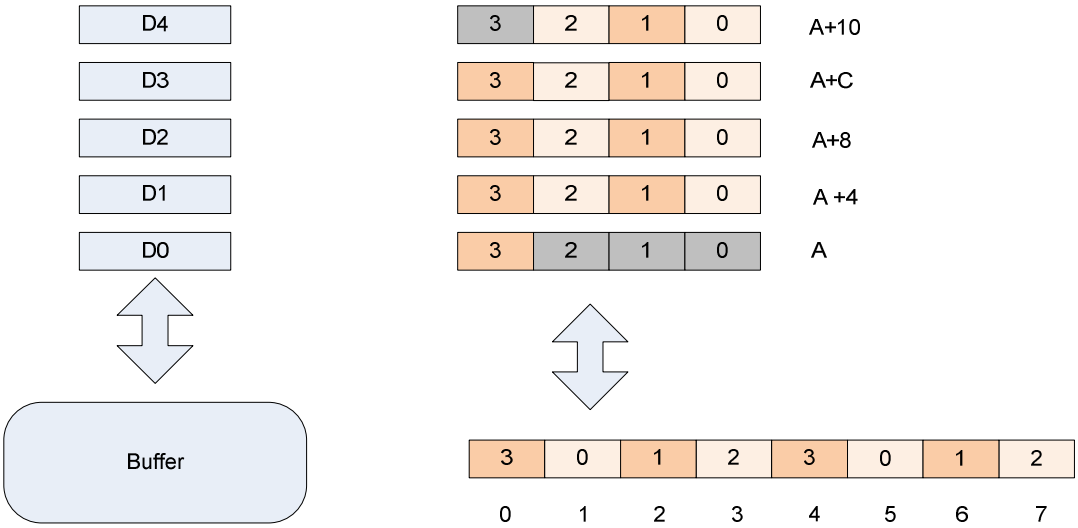
c) Burst access mode
In the burst access mode, the source or the destination address is incremented, and the transfer is a full AMBA AHB burst. A read or write transfer in burst access mode is an AHB burst access (AHB NONSEQ followed by AHB SEQ requests)) of a defined, fixed size, to a series of consecutive addresses, with the address incremented by the size of the data on the bus. This mode is usually used for accessing multiple addresses on slaves which support burst operations, and require fixed data size. The address must be aligned to the data size.



Data transfers in single and burst modes

d) Memory access mode

Memory access mode is similar to the burst access mode, but removes the necessity of having an address aligned to the data size. The memory access mode treats the incoming data as a stream of bytes, but accesses are performed in the largest possible data size on the bus(word). This mode is used for efficiently accessing memory. The byte stream which is read or written can start on any address.



Data transfers in memory mode

For source accesses in memory mode, the data is read in words, and the alignment is internally compensated. For destination accesses in memory mode, the DMA logic handles the alignment by writing a short lead-in burst of bytes to compensate word alignment, and then continues its access in words. The final transfer is also performed using a word, which allows for 0-3 bytes to be overwritten by dummy data after the end of the actual transferred data. The programmer must take this into account when allocating the memory buffer.

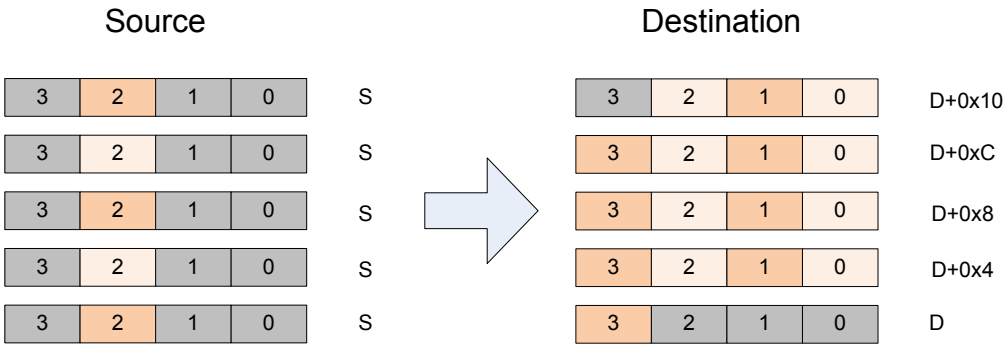
Using transfer modes

The source and the destination can be set to its own independent transfer mode, providing capabilities for various transfer setups:

> *Note: the diagrams represent the entire bus lane, divided in bytes, during the transfer sequence. Each box represents a byte. Active data is highlighted in orange. The alternating light/dark orange colors represent the sequence of input data. The alternating light/dark sequence of the source stream is kept in the destination stream to show how the DMA controller aligns the data. Gray boxes represent bytes unused on the bus lane.*
>
> *In some cases, destination will show more data than the source. The data exists in the source, however it is omitted to keep the illustrations compact.*

Source in fixed mode, byte size, destination in memory mode

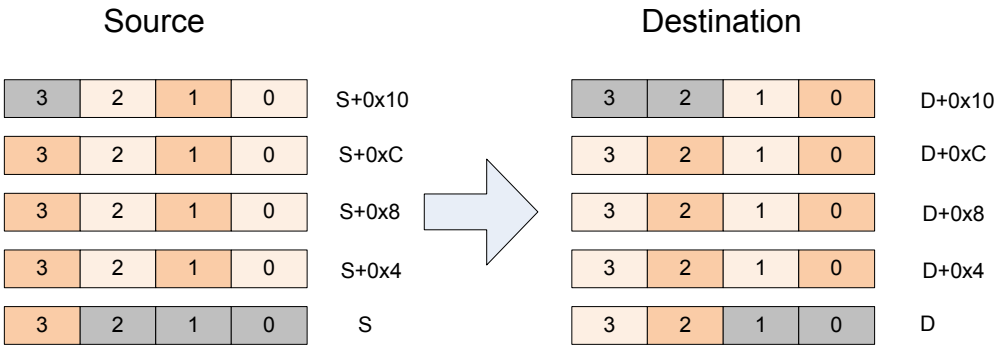
- Data pumping from a fifo to memory



Data pumping – single location (FIFO) replicated to a series of memory locations

Source in memory mode, destination in memory mode

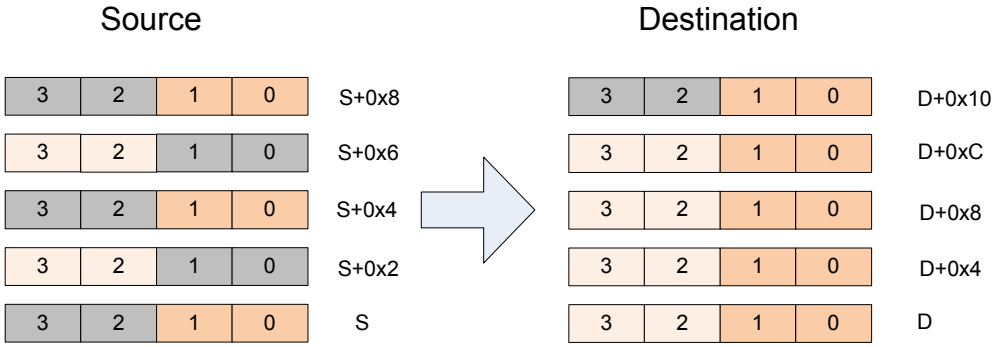
- Memcpy function acceleration



Memory-to-memory copy

Source in burst mode, half word size, destination in memory mode

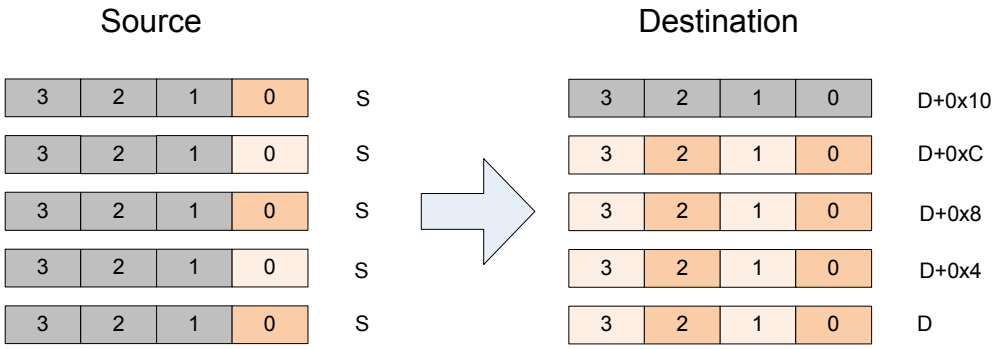
- Copying from a slave which supports bursts to the memory



Transferring a burst of half words to a contiguous block of memory. Example: register dump from a peripheral

Source in fixed mode, byte size, destination in single mode, word size

- Direct register initialization from data incoming from a fifo buffer (SPI flash, for instance). The byte stream from the fifo is converted to an array of words which are written to consecutive registers.



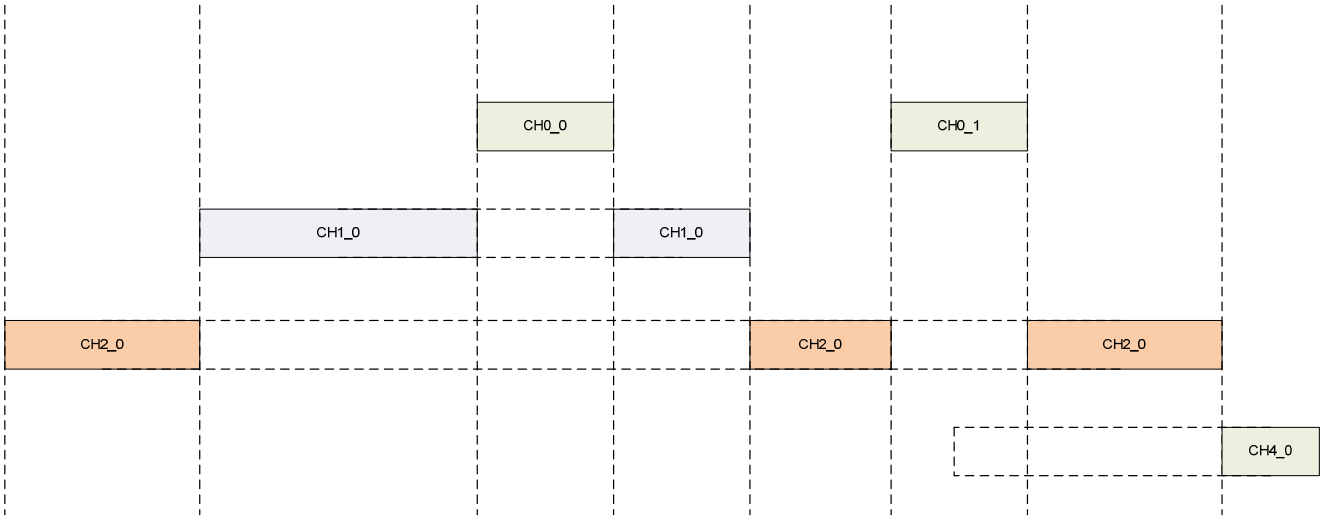
Transferring a sequence of bytes from a single address to a sequence of words in consecutive addresses. Example: register initialization from external byte-wide memory.

Various other useful combinations are possible.

Channels

UltiDMA has 4 channels implemented. A channel provides an independent, discrete setting for a DMA operation. Having 4 channels means that settings for 4 independent transfers can be kept in the DMA controller. In triggered operation, this allows for the external peripheral to trigger a predefined transfer, and accelerate reaction to the transfer request, thus also relieving the CPU of the need to initialize and start a DMA transfer on demand.

The DMA controller can service only a single channel at a time. The channels are set in priority order, Channel 0 being of the highest priority, and channel 4 being of the lowest priority. The channels behave like leveled interrupt subroutines. A DMA operation of a certain priority can be interrupted only by a channel of a higher priority. Once the DMA channel has started an operation, it will perform the operation until the operation is complete, or until the operation has been interrupted by a channel of a higher priority. Once the interrupting operation is complete, the DMA will return to the interrupted operation and finish it.



Timeline of multichannel operations on UltiDMA

Each channel has an assigned channel descriptor located in the descriptor memory internal to the DMA core. The channel descriptor contains the control word with parameters (src/dest mode/size, interrupt enable and src/dest address write back, used for operation chaining), operation length in bytes, source and destination address.

A channel is activated on its starting condition, defined by the channel's operating mode. Channels are activated either on enable, or on external trigger. After the operation completes, the transfer is reported as done. The behavior of the channel during transfer, after transfer and between transfers is determined by the selected operating mode.

Operation chaining

The DMA supports operation chaining. On the start of DMA operation, the settings of the operation are copied from the channel descriptor to a shadowed internal memory, which is used subsequently instead of the descriptor. The descriptor retains the original settings during the operation.

However, the source or the write pointer can be selected by the user to be updated after the operation is completed. The address which is written back to the source or the destination pointer is the first address following the last address of the previous operation (for fixed transfer mode, this is the same address, for memory mode, this is the byte-aligned address).

This allows for multiple operations being chained into one contiguous block.

4.8.2 Configuration and control

The register access to the UltiDMA used an address space of 512 bytes, divided into two areas: the descriptor memory and registers.

Channel 0 Descriptor	Control Word 0	0x0
	Length 0	0x4
	Source address 0	0x8
	Destination address 0	0xC
Channel 1 Descriptor	Control Word 1	0x10
	Length 1	0x14
	Source address 1	0x18
	Destination address 1	0x1C
Channel 2..	Control word 2	0x20
	…	…
	…	…
Channel 3..	Control word 3	0x30
	…	…
Registers	Control register	0x100
	Control register 2	0x104
	Trigger register 1	0x108
	Trigger register 2	0x10C
	Status register	0x110
	Interrupt register	0x114
	CRC data register	0x118
	CRC control register	0x11C
RFU	RFU	0x120
	...	
	RFU	0x1FC

The registers on address offsets greater than or equal to 0x120 are reserved for future use.

4.8.2.1 Channel descriptors

Control word

Channel index * 4 + offset 0x0

31 … 13	12	11	10	9 … 8	7 … 5	4 … 3	2 … 0
Unused	DWB	SWB	IEN	DMODE	DSIZE	SMODE	SSIZE

First word in each descriptor is a control word setting for the channel, defining the source and destination modes and sizes, interrupt generation and optional address write back for source or destination.

The SSIZE[2:0] and DSIZE [2:0] values contain the information on the set size for the source(S) and the destination (D) , respectively.

S/DSIZE[2:0]	AMBA data size
000	Byte
001	Half word(2 bytes)
010	Word (4 bytes)
011	Reserved
100	Reserved
101	Reserved
110	Reserved
111	Reserved

The SMODE[1:0] and DMODE[1:0] values define the transfer mode for the source(S) and the destination (D) , respectively.

S/DMODE[1:0]	DMA transfer mode
00	Fixed access mode
01	Single access mode
10	Burst access mode
11	Memory access mode

The IEN bit defines whether the completion of the transfer will cause an interrupt.

The SWB and DWB flags control the write back of the address to the descriptor at the end of the transfer, used for operation chaining.

Flag	Value	Behavior
IEN	0	Interrupt is not asserted.
	1	Interrupt is asserted at the end of the transfer.
SWB	0	Source address of the descriptor is preserved.
	1	Source address of the descriptor is updated from the channel.
DWB	0	Destination address of the descriptor is preserved.
	1	Destination address of the descriptor is updated from the channel.

Length

Channel index * 4 + offset 0x04

31 … 0
LEN

The LEN field contains the size of the operation in bytes.

Source address

Channel index * 4 + offset 0x08

31 … 0
SRC

The SRC field contains the source address for the operation.

Destination address

Channel index * 4 + offset 0x0C

31 … 0
DST

The SRC field contains the destination address for the operation.

4.8.2.2 Registers

Apart from channel descriptors, the core is controlled through 4 registers.

DMA_CTRL control register

Offset 0x100

15 12	11 8	7 4	3 0
CTRL3	CTRL2	CTRL1	CTRL0

31 28	27 24	23 20	19 16
NOT USED	NOT USED	NOT USED	NOT USED

The DMA_CTRL register contains the control settings for channels 0-3. Each channel is controlled by its associated control field, CTRL[3:0]. The control field for the desired channel is located at DMA_CTRL[channel_index*4+3:channel_index*4].

The control field contains 4 control flags.

3	2	1	0
ALT	SPLIT	TRIG	SINGLE

Not all combinations of the control bits are usable. The actually usable (and useful) configurations are summarized in table below.

ALT	SPLIT	TRIG	SINGLE	Description
0	0	0	0	Channel is inactive
0	0	0	1	Channel is active in “single run” mode. The operation will be executed. The channel will not be activated again until it is deactivated and activated again.

DMA_CTRL2 control register

Offset 0x104

31 0
NOT USED

The DMA_CTRL2 register is actually NOT USED.

TRIG_REG register

Offset 0x108

31 0
NOT USED

The TRIG_REG register is actually NOT USED.

TRIG_REG2 register

Offset 0x10C

31 0
NOT USED

The TRIG_REG2 register is actually NOT USED.

STATUS register
The status register is a read-write register through which the core's current operation status can be detected and monitored. The status register contains a status field for each channel, labeled ST0-ST3.

Offset 0x110

15 … 8	7 … 6	5 … 4	3 … 2	1 … 0
NOT USED	ST3	ST2	ST1	ST0

31 … 16
NOT USED

Fields STx[1:0] show the status of the channels 0-3.
Each status field contains 2 control flags.

1	0
DONE	BUSY

Flag	Value	Behavior
BUSY	0	Channel is idle, no operation is in progress
	1	Channel is active, operation is in progress.
DONE	0	Channel operation did not complete
	1	Channel operation is completed

The status register shows the status of all channel operations. The BUSY bit of STn shows if channel n is currently being serviced, e.g. if the transfer is in progress. The DONE bit of STn shows if channel n has completed its operation. The DONE bit will raise to '1' when the operation completes.

The DONE bit for a given channel is cleared by writing a "1" to its location.

INTERRUPT register
The interrupt register is a read-write register which contains the interrupt request status for all DMA channels.

Offset 0x114

31 … 4	3 … 0
RFU	INT

INT[3:0] are the interrupt request bits for the DMA channels. A channel will signalize an interrupt at the end of its operation if its IEN bit is set in the descriptor control word. The interrupt request will be set as '1'.

Flag	Value	Behavior
INT[x]	0	Interrupt is not asserted.
	1	Interrupt is asserted.

The interrupt for a given channel is cleared by writing a '1' to the location of the asserted interrupt.

CRC register

Offset 0x118

31 … 0
CRC value

The CRC register contains the 32-bit CRC value calculated on the data output during the transfer on a selected DMA channel, if the CRC calculation is enabled. The selected DMA channel, and the CRC enable, is configured in the CRCTRL register.

The CRC value is calculated and updated whenever the selected channel is transferring data and the CRC calculation is enabled. The CRC value is reset by writing any value to the CRC register.

The CRC is calculated using the standard IEEE 802.3 CRC32 polynomial and CRC calculation method.

CRCTRL register

0x11C

4	3	0
unused	CRCEN	CHIDX

The CRCTRL register controls the CRC calculation engine inside the DMA.

The CRCEN bit controls whether the CRC is actively calculated.

Flag	Value	Behavior
CRCEN	0	CRC disabled
	1	CRC enabled

The CHIDX[3:0] contains the value from 0 to 3, representing index of the channel for which the CRC is calculated during transfer.

To enable CRC, the user must select the channel for which the CRC is calculated by writing its index to CHIDX, and enable CRC calculation by setting CRCEN to '1'.

4.8.2.3 Programming

The programming of the UltiDMA follows a simple model.

1) Set transfer parameters for the channel in the appropriate descriptor
2) Enable the channel
3) Detect transfer end

The setting of the transfer parameters is done by initializing a channel's descriptor in the descriptor memory.

Example:
The user wants to initialize Channel 2 to copy an array of 128 bytes from a fixed address using byte-by-byte reads, to an arbitrary byte location in the memory. The DMA should update destination address in the descriptor after the transfer end, and interrupt should be asserted at the end of the transfer.

The descriptor settings are:

0x20	0b1|0|1|11|010|00|000 (0x1740)	DWB and IEN active, SWB inactive DST: Memory mode, Size Word SRC: Fixed mode, Size byte
0x24	0x80	Length: 128 bytes
0x28	0xA0005000	Source address: Fifo buffer
0x2C	0x00800000	Destination address: Memory

After the descriptor is set, the channel is ready to be enabled. The channel is enabled in single run mode by setting the SINGLE bit of CTRL2 in the DMA_CTRL register to '1'. Other bits are set to '0'.

Note: the programmer must watch that he does not overwrite or clear the control bits of other channels while setting EN or TR bits. The write to DMA_CTRL registers overwrites the entire register! To set individual bits, the registers should be read, masked, then written back.

The transfer end will be detected by interrupt. Otherwise, the transfer end can be detected by polling the STATUS register and waiting for the ST2 field to change into "10" meaning that the DMA channel is idle and the operation is done. The DONE bit must be cleared afterwards by writing a "1" to its location.

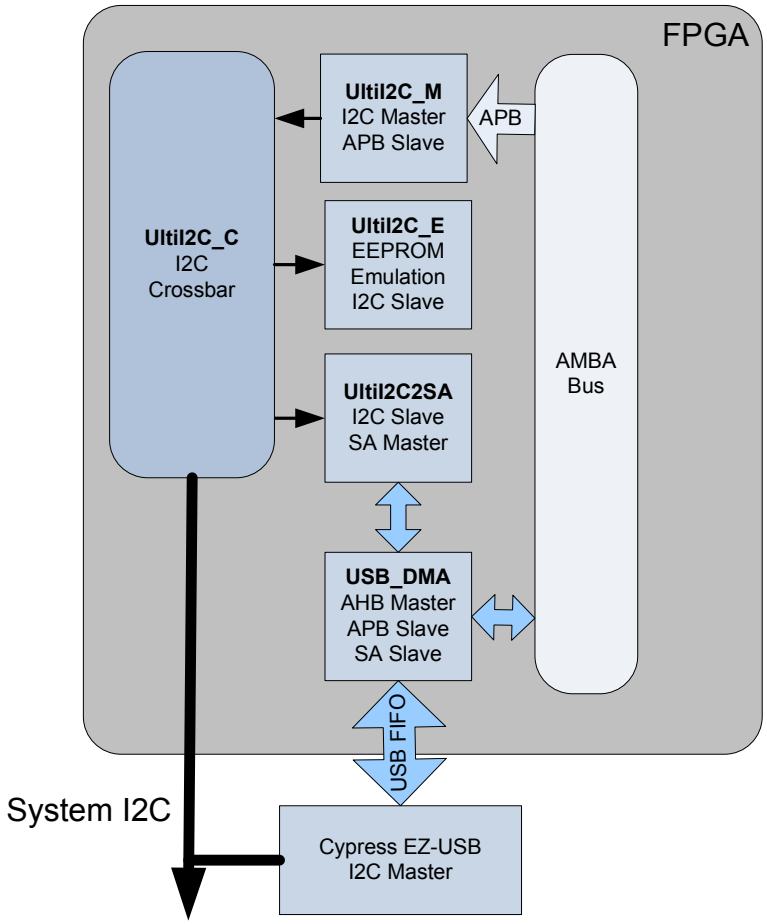
4.9 I2C architecture and interface

I2C is used in LCD-Pro IP as the local system control and supervision bus. A number of I2C peripherals are required in the system. For example, an I2C serial eeprom located on the display board enables plug&play capability for the display.

The Cypress uses the I2C to read the contents of a serial eeprom at boot-up to determine it's vendor and product ID. To avoid an additional serial eeprom in the system, and to avoid that an accidental change of data in the eeprom corrupts the devices vendor and product ID (used to load the driver on the USB host), the VID/PID data is hard-coded in the FPGA design, using an I2C eeprom emulation (**UltiI2C_E** core, slave address 0x50).

The **UltiI2C2SA** allows access to AMBA bus via I2C external master device.

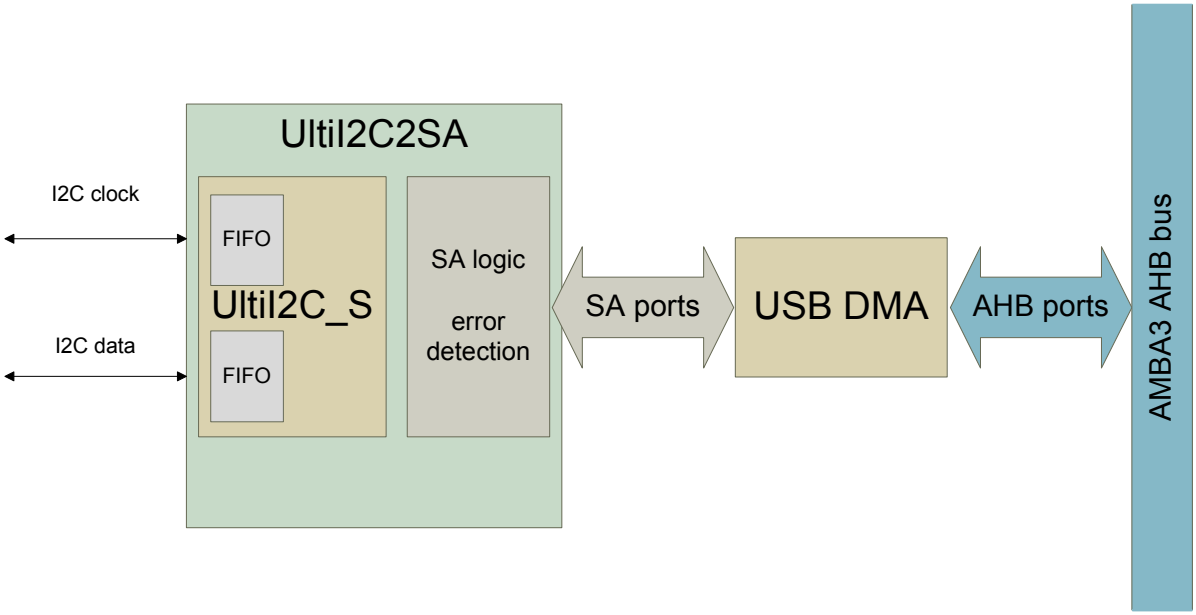
The **UltiI2C_M** core performs the functionalities of I2C master device (driven by AMBA 3 APB interface).



The **UltiI2C_C** Crossbar can connect multiple I2C buses together, and effectively acts as an I2C hub, redirecting data from any input to all outputs. The crossbar also performs resampling and filtering of the I2C data to avoid glitches and oscillatory behavior.

4.9.1 UltiI2C2SA core

UltiI2C2SA is a wrapper module, used for transforming the I2C transfers to the SA bus, used by the USB DMA to enable single access AHB operations to multiple devices. This enables access to the devices connected to the AMBA bus over the I2C bus, available to all I2C Masters. Data can either be written (first 5 bytes transferred over I2C being address and transfer size, followed by data to be written) or read (reading data over AHB and then outputting it over I2C, using address and transfer size from the previous write command). Invalid transfers are detected, and reported by not acknowledging the next operation over I2C. Wrapper has an I2C slave address **0x20**.
Diagram below shows internal structure of UltiI2C2SA module, and connection to the AMBA3 AHB interface.



Architecture of UltiI2C2SA

UltiI2C2SA wrapper consists of the SA wrapper and the I2C slave with FIFOs for reading and writing. Both the standard mode (100 kHz) and the fast mode (400 kHz) are supported.
UltiI2C_S, an I2C slave module, will store received data in the FIFO and request a write operation over the SA bus. In case of a faulty transfer, FIFOs are flushed, and the whole module reset.

Communication protocol
Since I2C is a byte-oriented bus, a protocol for the communication had to be defined. Protocol is as follows:

When writing, first 4 bytes after I2C slave address contain AHB address. Bytes are sent in the format MSB first (first byte is addr[31:24], second byte addr[23:16], and so on…). Next byte is the transfer size identifier, with the valid values 0x02 (word, 32 bits), 0x01 (half-word, 16 bits) and 0x00 (byte, 8 bits). After those 5 bytes, the core will receive data to be written. Depending on the transfer size, 1, 2 or 4 bytes will be expected. Data is received in order LSB first (first byte is word[7:0], second byte is word[15:8] and so on). Transfer can be interrupted after first 5 bytes, if only address and transfer size are being sent (in preparation for the read operation).

7 bits	1 bit	8 bits	8 bits	8 bits	8 bits	8 bits	? bits
I2C slave address	0	ADDR[31:24]	ADDR[23:16]	ADDR[15:8]	ADDR[7:0]	Transfer size	Data

Data format when writing

When reading, after slave address UltiI2C2SA will start outputting data, read from the address inputted in the last write operation, in format LSB first (see below). Number of bytes to be sent is determined by the transfer size identifier, also

saved from the last write transfer. Repeated read mode is not supported, and address will not be incremented after the operation.

7 bits	1 bit	8 bits	8 bits	..
I2C slave address	1	Data [7:0]	Data[15:8]	..

Data format when reading

If an invalid transfer is detected (too few or too many received bytes during write operation, read data not acknowledged by the I2C master, address not aligned for the transfer size) then error is signaled by not acknowledging the next operation over I2C. If possible, error is detected early enough to avoid access over SA (in case of too few bytes received when writing, or not aligned address), but sometimes SA access is not avoided, and data corruption is possible.
In case of the SA operation not completed in time for I2C transfer to continue (input FIFO full or read operation not finished), UltiI2C2SA will stall the I2C transfer by pulling down the clock line, until I2C operation can be completed.

UltiI2C2SA aligns data automatically on the SA data bus when writing, using the selected transfer size and the address. It also outputs over I2C only selected bytes when reading, preserving the I2C bandwidth.

4.9.2 UltiI2C_M

UltiI2C_M is an I2C master module, based on the FIFO interface for data flow, and the registers for the configuration. It enables the I2C communication to all AHB masters. It will automatically detect the bus collision or the data transfer error, and release bus to the other masters.

4.9.2.1 Registers

Register	Width (bits)	Read/Write	Address offset
FIFO	8	R/W	0x00
TX_STATUS	10	R	0x10
RX_STATUS	10	R	0x20
MODE_F_S	1	R/W	0x30
SLV_ADDR	7	R/W	0x40
TRN_BYTE_NUM	5	R/W	0x50
RCV_BYTE_NUM	5	R/W	0x60
START	3	R/W	0x70
STATUS	5	R	0x80
INT_MASK	4	R/W	0x90
INTERRUPT	4	R/Clear on write ‘1’	0xA0

FIFO

Register bit(s)	Description
FIFO[7:0]	Write – write byte to TX FIFO Read – read byte from RX FIFO

TX_STATUS

Register bit(s)	Description
TX_STATUS[7:0]	Number of bytes in TX_FIFO
TX_STATUS[8]	TX_FIFO empty flag
TX_STATUS[9]	TX_FIFO full flag

RX_STATUS

Register bit(s)	Description
RX_STATUS[7:0]	Number of bytes in RX_FIFO
RX_STATUS[8]	RX_FIFO empty flag
RX_STATUS[9]	RX_FIFO full flag

MODE_F_S

Register bit(s)	Description
MODE_F_S[0]	'0' – 100 kHz scl frequency, Standard mode '0' – 400 kHz scl frequency, Fast mode

SLV_ADDR

Register bit(s)	Description
SLV_ADDR [6:0]	I2C slave address (without write/read bit).

TRN_BYTE_NUM

Register bit(s)	Description
TRN_BYTE_NUM [5:0]	Number of bytes to be transmitted after I2C slave address.

RCV_BYTE_NUM

Register bit(s)	Description
RCV_BYTE_NUM [5:0]	Number of bytes to be received after I2C slave address.

START

Register bit(s)	Description
START[1:0]	Write "01" starts write operation Write "10" starts read operation Write "11" starts write followed by read.
START[2]	Write '1' to reset UltiI2C_M. This will also clear all registers except INT_MASK. This register is set to all '1' at reset.

STATUS

Register bit(s)	Description
STATUS[0]	UltiI2C_M busy (‘1’) or idle (‘0’)
STATUS[1]	Error occurred on I2C bus while doing last operation (set to ‘1’). This bit is cleared on beginning of each new operation.
STATUS[2]	Banned I2C address entered into SLV_ADDR register.
STATUS[3]	TX_FIFO underrun occurred during last operation. This bit is cleared on beginning of each new operation.
STATUS[4]	RX_FIFO overrun occurred during last operation. This bit is cleared on beginning of each new operation.

INT_MASK

Register bit(s)	Description
INT_MASK[0]	Mask (‘1’) or unmask (‘0’) INTERRUPT[0]
INT_MASK[1]	Mask (‘1’) or unmask (‘0’) INTERRUPT[1]
INT_MASK[2]	Mask (‘1’) or unmask (‘0’) INTERRUPT[2]
INT_MASK[3]	Mask (‘1’) or unmask (‘0’) INTERRUPT[3]

INTERRUPT

Register bit(s)	Description
INTERRUPT[0]	Interrupt on UltiI2C_M finished with operation. Reset by writing ‘1’.
INTERRUPT[1]	Interrupt on error on I2C, TX_FIFO underrun or RX_FIFO overrun. Reset by writing ‘1’.
INTERRUPT[2]	Interrupt on TX_FIFO empty. Reset by writing ‘1’.
INTERRUPT[3]	Interrupt on RX_FIFO not empty. Reset by writing ‘1’.

NOTE: Interrupt signal of UltiI2C_M is not connected on LCD-Pro IP design.

4.9.2.2 Operation

UltiI2C_M supports 100 kHz I2C clock frequency (the Standard mode) and 400 kHz I2C clock frequency (the Fast mode). Desired mode is set by the register MODE_F_S. After the reset, UltiI2C_M is set to the Standard mode.

I2C slave address is set by the register SLV_ADDR. This register is 7 bits wide, and stores the slave address without LSB bit, which sets either write or read access. This is not according to the I2C specification, where slave addresses are written in full length. Address 0x20 is a banned value (it corresponds to UltiI2C_E address, which should be accessed only by external devices).

The number of bytes to be transmitted on write operation is set by the register TRN_BYTE_NUM, and is limited by the size of the data counter. Present maximum size is 31 bytes.

The number of bytes to be received on read operation is set by the register RCV_BYTE_NUM, and is limited by the size of the data counter. Present maximum size is 31 bytes.

Operation is started by the write access to the register *start*, with the following options:

- Write 0x1 starts write operation
- Write 0x2 starts read operation

- Write 0x3 starts write operation followed by the read operation (used for writing address to slave, then reading data from that slave)
- Write 0x4 resets UltiI2C_M, emptying FIFOs, and resetting all registers (including this one) to the reset value.

Status of the device and the result of the previous operation (whether error occurred or not) can be read from the register STATUS. Bits have the following meaning:

- STATUS[0] = '1' (busy), '0' (idle)
- STATUS[1] = '1' (error in last transfer, either unexpected start or stop, no acknowledge from slave), '0' (operation finished successfully)
- STATUS[2] = '1' (banned I2C slave address), '0' (slave address ok)
- STATUS[3] = '1' (TX FIFO underrun, not enough data to transmit), '0' (transmit OK)
- STATUS[4] = '1' (RX FIFO overrun, not enough space to receive), '0' (receive OK)

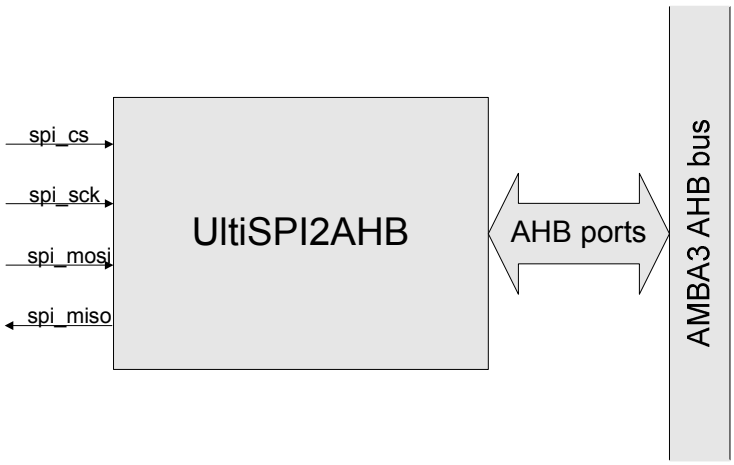
Status of the transmit FIFO can be read from the register TX_STATUS, with 8 LSB bits showing the number of bytes in FIFO and TX_STATUS [8] being equal to the empty flag, and TX_STATUS[9] to the full flag. Present size of the TX FIFO is 16 bytes.

Status of the receive FIFO can be read from the register RX_STATUS, with 8 LSB bits showing number of bytes in FIFO and RX_STATUS [8] being equal to the empty flag, and RX_STATUS[9] to the full flag. Present size of the RX FIFO is 16 bytes.

FIFO data access is done over the same address on APB, accessing TX_FIFO on writes and RX_FIFO on reads. When writing, it is possible to overrun FIFO, starting the fill process again. When reading from the empty FIFO, FIFO will output last valid data and remain in the empty state. Both data write and data read are mapped to the same APB address, but all writes are forwarded to the transmission FIFO, and reads are only from the receiver FIFO. To empty transmission FIFO, UltiI2C_M has to be reset. Data access is 8-bit, while registers are various sizes, with biggest being 10 bits wide.

UltiSPI2AHB core

UltiSPI2AHB is an AHB wrapper for SPI interface (AHB master, **SPI slave**) based on 8-bit frames. Small instruction set is included, enabling simple register and memory access operations.



UltiSPI2AHB block diagram

4.9.3 Instruction set

Instruction code	Name	Byte num (min)
Register access		
00000 (0x00)	Read B	3
00001 (0x01)	Write B	3
00010 (0x02)	Read HW	4
00011 (0x03)	Write HW	4
00100 (0x04)	Read W	6
00101 (0x05)	Write W	6
00110 (0x06)	RFU	
00111 (0x07)	RFU	
01000 (0x08)	Read block	2 + block size
01001 (0x09)	Write block	2 + block size
01010 (0x0A)	RFU	
01011 (0x0B)	RFU	
01100 (0x0C)	RFU	
01101 (0x0D)	RFU	
01110 (0x0E)	RFU	
01111 (0x0F)	RFU	
10000 (0x10)	Set pointer B0	2
10001 (0x11)	Set pointer B1	2
10010 (0x12)	Set pointer B2	2
10011 (0x13)	Set pointer B3	2
10100 (0x14)	RFU	
10101 (0x15)	RFU	
10110 (0x16)	RFU	
10111 (0x17)	RFU	
11000 (0x18)	Get pointer	5
11001 (0x19)	Set pointer	5
11010 (0x1A)	Set block	2
11011 (0x1B)	RFU	
11100 (0x1C)	NOP	1
11101 (0x1D)	POST_OP	1
11110 (0x1E)	RFU	1
11111 (0x1F)	Reset ERROR response	1

Instruction codes

Response code	Name
0xAA	READY
0xBB	WAIT
0xCC	OK
0xDD	ERROR

Response codes

4.9.4 Operation

UltiSPI2AHB is set to operate in SPI MODE 0, with SPI clock low in idle state and data sampled on rising clock edge and outputted on falling clock edge. Frame size is limited to 8 bits; all other frame sizes are forbidden. All operations are performed by issuing the instruction code. In case of write operations, the instruction code is followed by data. For both read or write operations, the instruction is finished with NOP or POST_OP frames. UltiSPI2AHB will issue READY response on first frame (if not busy and no error detected), followed by appropriate response depending on each instruction. If error is detected, UltiSPI2AHB will respond with ERROR response, until reset by instruction "Reset ERROR response" (0x0F). This way, SPI master can detect errors.
All operations use one of the 8 32-bit wide address pointers which cover the entire AMBA address space.

When in idle mode, UltiSPI2AHB will always respond on the first frame (instruction code) with READY. If total instruction length is 1 Byte, next frame will also be responded by READY, while other lengths have various responses. New instructions while busy with the previous instruction are strictly forbidden, and result with the ERROR response on all following frames, until the reset command is received. When performing operation on the AHB bus, slave will respond with WAIT if not finished and OK when finished. When reading, valid data will follow the OK response.
Instruction codes are all 5-bit, located in the upper 5 bits of instruction code frame. Lower 3 bits are used to select the address pointer associated with the operation.

Read Byte (0x00)
This instruction reads one byte from the address on the AMBA bus contained in PT[2:0]. After receiving the first frame, UltiSPI2AHB will start the read operation over AHB. Next frame(s) will be answered by WAIT if operation is not finished or OK if operation is finished. First frame after OK response will be responded by byte read over AHB. Master has to send NOP or POST_OP instructions after the first frame until slave responds with OK and sends data. Otherwise, error will be detected.

- First frame

SPI master output							
'0'	'0'	'0'	'0'	'0'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Next frame(s)

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

Or :

SPI master output							
'1'	'1'	'1'	'0'	'1'	INCDEC	AM1	AM0
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

- Last frame

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
Byte read over AHB							

Or:

SPI master output							
'1'	'1'	'1'	'0'	'1'	INCDEC	AM1	AM0
UltiSPI2AHB SPI slave output							
Byte read over AHB							

Write Byte (0x01)
This instruction writes byte contained in the second frame to the address contained in the pointer PT[2:0]. First frame is answered by READY, all other frames with WAIT until write operation is complete. SPI master has to send NOP instructions after the second (data) frame until receiving OK response, or error will be detected.

- First frame

SPI master output							
'0'	'0'	'0'	'0'	'1'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Data frames

SPI master output							
D[7]	D[6]	D[5]	D[4]	D[3]	D[2]	D[1]	D[0]
UltiSPI2AHB SPI slave output							
WAIT (0xBB)							

- Next frames

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

Or:

SPI master output							
'1'	'1'	'1'	'0'	'1'	INCDEC	AM1	AM0
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

Read Halfword (0x02)
This instruction reads one halfword from the address on the AMBA bus contained in PT[2:0]. After receiving the first frame, UltiSPI2AHB will start the read operation over AHB. Next frame(s) will be answered by WAIT if operation is not finished or OK if operation is finished. First two frames after OK response will be responded by the bytes read over AHB. Master has to send NOP or POST_OP instructions after the first frame until slave responds with OK and sends data. Otherwise, error will be detected.

- First frame

SPI master output							
'0'	'0'	'0'	'1'	'0'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Next frame(s)

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

Or :

SPI master output							
'1'	'1'	'1'	'0'	'1'	INCDEC	AM1	AM0
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

- Last frames

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
Byte read over AHB							

Or:

SPI master output							
'1'	'1'	'1'	'0'	'1'	INCDEC	AM1	AM0
UltiSPI2AHB SPI slave output							
Byte read over AHB							

Write Halfword (0x03)
This instruction writes a half word contained in the frames 2 and 3 to the address contained in the pointer PT[2:0]. First frame is answered by READY, all other frames with WAIT until write operation is complete. SPI master has to send NOP instructions after the second (data) frame until receiving OK response, or error will be detected.

- First frame

SPI master output							
'0'	'0'	'0'	'1'	'1'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Data frames

SPI master output							
D[7]	D[6]	D[5]	D[4]	D[3]	D[2]	D[1]	D[0]
UltiSPI2AHB SPI slave output							
WAIT (0xBB)							

- Next frames

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

Or:

SPI master output							
'1'	'1'	'1'	'0'	'1'	INCDEC	AM1	AM0
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

Read Word (0x04)
This instruction reads one word from the address on the AMBA bus contained in PT[2:0]. After receiving the first frame, UltiSPI2AHB will start the read operation over AHB. Next frame(s) will be answered by WAIT if operation is not finished or OK if operation is finished. First frame after OK response will be responded by byte read over AHB. Master has to send NOP or POST_OP instructions after the first frame until slave responds with OK and sends data. Otherwise, error will be detected.

- First frame

SPI master output							
'0'	'0'	'1'	'0'	'0'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Next frame(s)

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

Or :

SPI master output							
'1'	'1'	'1'	'0'	'1'	INCDEC	AM1	AM0
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

- Last frames

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
Byte read over AHB							

Or:

SPI master output							
'1'	'1'	'1'	'0'	'1'	INCDEC	AM1	AM0
UltiSPI2AHB SPI slave output							
Byte read over AHB							

Write Word (0x05)
This instruction writes a word contained in frames 2,3,4 and 5 to the address contained in the pointer PT[2:0]. First frame is answered by READY, all other frames with WAIT until write operation is complete. SPI master has to send NOP instructions after the second (data) frame until receiving OK response, or error will be detected.

- First frame

SPI master output							
'0'	'0'	'1'	'0'	'1'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Data frames

SPI master output							
D[7]	D[6]	D[5]	D[4]	D[3]	D[2]	D[1]	D[0]
UltiSPI2AHB SPI slave output							
WAIT (0xBB)							

- Next frames

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

Or:

SPI master output							
'1'	'1'	'1'	'0'	'1'	INCDEC	AM1	AM0
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

Read block from memory (0x08)
This instruction reads bytes from the memory location pointed by the pointer PT[2:0]. After each read, pointer is incremented by 1. Size of the block is determined by the value in the block size register + 1, giving maximum block size of 256 (0xFF in the block size register). If for some reason AHB operation was not completed before new byte should be transmitted, UltiSPI2AHB will report an error. After receiving the instruction code, UltiSPI2AHB will start the first AHB operation. If it is not finished by the next frame, UltiSPI2AHB will transmit WAIT. If finished, UltiSPI2AHB will transmit OK, and follow with bytes of data read over AHB. The pointer PT[2:0] is autoincremented with the block size after successful operation completion.

- First frame

SPI master output							
'0'	'1'	'0'	'0'	'0'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Next frame(s)

SPI master output							
'0'	'1'	'0'	'0'	'0'			
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

- Next N frames (N is number in block size register + 1)

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
Byte read over AHB							

Write block into memory (0x09)
This instruction writes bytes transmitted after the instruction code to the memory location addressed by the pointer PT[2:0]. After each write, pointer is incremented by 1. Size of the block is determined by the value in the block size register + 1, giving maximum block size of 256 (0xFF in the block size register). If for some reason AHB operation was not completed before new byte was received, UltiSPI2AHB will report an error. The pointer PT[2:0] is autoincremented with the block size after successful operation completion.

- First frame

SPI master output							
'0'	'1'	'0'	'0'	'1'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Next N frames (N is number in block size register + 1)

SPI master output							
D[7+8*i]	D[6+8*i]	D[5+8*i]	D[4+8*i]	D[3+8*i]	D[2+8*i]	D[1+8*i]	D[0+8*i]
UltiSPI2AHB SPI slave output							
WAIT (0xBB)							

- Next frames

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
WAIT (0xBB) / OK (0xCC)							

Set byte 0 in pointer (0x10)
This instruction writes byte contained in the second frame to the byte B0 of the pointer PT[2:0]. Both frames are responded by READY.

- First frame

SPI master output							
'1'	'0'	'0'	'0'	'0'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Second frame

SPI master output							
M_A [7]	M_A [6]	M_A [5]	M_A [4]	M_A [3]	M_A [2]	M_A [1]	M_A[0]
UltiSPI2AHB SPI slave output							
READY (0xAA)							

Set byte 1 in pointer (0x11)
This instruction writes byte contained in the second frame to the byte B1 of the pointer PT[2:0]. Both frames are responded by READY.

- First frame

SPI master output							
'1'	'0'	'0'	'0'	'1'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Second frame

SPI master output							
M_A [15]	M_A [14]	M_A [13]	M_A [12]	M_A [11]	M_A [10]	M_A [9]	M_A[8]
UltiSPI2AHB SPI slave output							
READY (0xAA)							

Set byte 2 in pointer (0x12)
This instruction writes byte contained in the second frame to the byte B2 of the pointer PT[2:0]. Both frames are responded by READY.

- First frame

SPI master output							
'1'	'0'	'0'	'1'	'0'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Second frame

SPI master output							
M_A [23]	M_A [22]	M_A [21]	M_A [20]	M_A [19]	M_A [18]	M_A [17]	M_A[16]
UltiSPI2AHB SPI slave output							
READY (0xAA)							

Set byte 3 in pointer (0x13)
This instruction writes byte contained in the second frame to the byte B3 of the pointer PT[2:0]. Both frames are responded by READY.

- First frame

SPI master output							
'1'	'0'	'0'	'1'	'1'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Second frame

SPI master output							
M_A [31]	M_A [30]	M_A [29]	M_A [28]	M_A [27]	M_A [26]	M_A [25]	M_A[24]
UltiSPI2AHB SPI slave output							
READY (0xAA)							

Get pointer (0x18)
This instruction reads the address on the AMBA bus contained in PT[2:0]. First frame is responded with READY.

- First frame

SPI master output							
'1'	'1'	'0'	'0'	'0'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Data frames

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							
Byte read over AHB							

Set pointer (0x19)
This instruction writes a word contained in frames 2,3,4 and 5 to the pointer PT[2:0]. All frames are answered with READY.

- First frame

SPI master output							
'1'	'1'	'0'	'0'	'1'	PT2	PT1	PT0
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Data frames

SPI master output							
D[7]	D[6]	D[5]	D[4]	D[3]	D[2]	D[1]	D[0]
UltiSPI2AHB SPI slave output							
READY (0xAA)							

Set block (0x1A)
This instruction writes byte contained in the second frame to the block size register. Both frames are responded by READY.

- First frame

SPI master output							
'1'	'1'	'0'	'1'	'0'			
UltiSPI2AHB SPI slave output							
READY (0xAA)							

- Second frame

SPI master output							
BS [7]	BS [6]	BS [5]	BS [4]	BS [3]	BS [2]	BS [1]	BS[0]
UltiSPI2AHB SPI slave output							
READY (0xAA)							

NOP (0x1C)

This instruction is used as the padding when waiting for the response from UltiSPI2AHB. The response depends on the previous action. If SPI slave is idle, it will return READY.

- First frame

SPI master output							
'1'	'1'	'1'	'0'	'0'			
UltiSPI2AHB SPI slave output							

POST_OP (0x1D)

This instruction is used as the padding when waiting for the response from UltiSPI2AHB. It is used to execute an additional operation on the pointer used in the active operation. The response depends on the previous action. If SPI slave is idle, it will return READY.

- First frame

SPI master output							
'1'	'1'	'1'	'0'	'1'	INCDEC	AM1	AM0
UltiSPI2AHB SPI slave output							

The INCDEC field defines the operation: Increment or decrement the pointer, 0 being for increment, 1 for decrement.

The AM[1:0] field defines the increment/decrement amount:
"00" – increment/decrement by 1
"01" – increment/decrement by 2
"10" – increment/decrement by 4
"11" – RFU

Reset error response (0x1F)

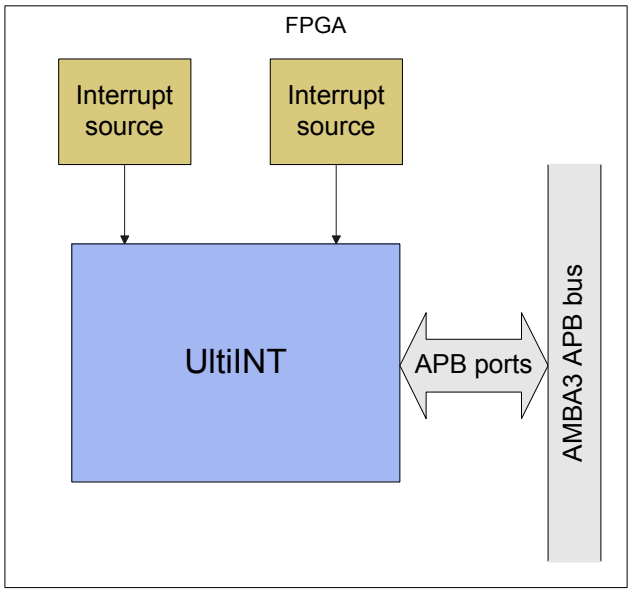
In case of error detected in the SPI protocol, UltiSPI2AHB will stop all operations and respond with ERROR until this instruction is received. SPI master will have to detect ERROR response, send this instruction to reset UltiSPI2AHB (preferably until receiving READY response) and repeat the last instruction.

- First frame

SPI master output							
'0'	'1'	'1'	'1'	'1'			
UltiSPI2AHB SPI slave output							
ERROR (0xDD) / READY (0xAA)							

4.10 UltiINT Interrupt controller

UltiINT is an interrupt controller with the APB slave interface to the configuration registers.



UltiINT block diagram

UltiINT consists of the interrupt logic, detecting interrupt requests and forwarding them to the selected interrupt output port[2] , and the APB interface logic used for the register access.

NOTE[2] : On actual design no external output port is used; UltiInt interrupt controller is only used to collect interrupt signals from other cores and allow them to be simultaneously accessed on the same status register.

The mode of operation of the UltiINT core is configured the registers.

Each input can be set to the level sensitivity (high/low) or the edge sensitivity (rising/falling). Bits in the INTERRUPT register have to be cleared by writing '1', they will not reset when interrupt conditions are removed.

4.10.1 Configuration and register map

The useful registers are shown and described below.

Register	Width (bits)	Read/Write	Address offset
INT_LEVEL	2	R/W	0x00
INT_EDGE	2	R/W	0x10
INTERRUPT	2	R/Clear on write '1'	0x30

UltiINT registers

Register bit	Description
INT_LEVEL [x]	**'1'** - internal_int[x] input active high (INT_EDGE[x] set to '0') or active on rising edge (INT_EDGE[x] set to '1') **'0'** - internal_int[x] input active low (INT_EDGE[x] set to '0') or active on falling edge (INT_EDGE[x] set to '1')
INT_EDGE [x]	**'1'** - internal_int[x] input edge sensitive **'0'** - internal_int[x] input level sensitive
INTERRUPT [x]	**'1'** - INTERRUPT [x] set **'0'** - INTERRUPT [x] not set Clear when write '1'

On actual design, the following interrupt inputs are connected:

- INTERNAL_INT[0] = Interrupt from EVC (vsync_pulse)
- INTERNAL_INT[1] = Interrupt from video input (frame_done)

4.11 UltiSYS

UltiSYS is a system support module, holding miscellaneous peripheral devices. Devices and signals connected to UltiSYS are:

- N° 2 system LEDs outputs
- PWM controller output (fixed 11.71 Khz frequency, programmable duty cycle)

4.11.1 Registers and use

Register	Width (bits)	Read/Write	Address offset
LED_REG	2	R/W	0x50
PWM_DUTY	13	R/W	0x60

LED_REG

Register bit(s)	Description
LED_REG[0]	'1' turns on led, '0' turns off (RED led typically, 'error' signal)
LED_REG[1]	'1' turns on led, '0' turns off (GREEN led typically, 'run' signal)

PWM_DUTY

Register bit(s)	Description
PWM_DUTY[31]	'1' turns on PWM, '0' turns off
PWM_DUTY[11:0]	PWM duty cycle – 12 bits