**FIRMWARE for FADC250 Ver2 ADC FPGA**

**Table of Content:**

1. Functional (Requirement) Description
	1. Revision
	2. Overview
	3. Pedestal Subtraction
	4. Programmable Pulse Generator.
	5. Channel Data Processing
		1. Option 1: Raw Mode
		2. Option 2: Pulse Mode
		3. Option 3: Integral
		4. Trigger Input Buffer
	6. Trigger Path Processing
	7. Acceptance Pulse (Hit Bits)
2. Conceptual Architecture Diagram.
	1. Overview
	2. Data Buffer
	3. Process Algorithm
	4. VME FPGA Interface
3. Data Format
	1. Internal
	2. To FIFO (to VME FPGA)
	3. To Hit Sum FPGA
4. Modified Fast Bus Address Mapping
5. VHDL Block Diagram
6. VHDL Test Bench and Test Vector.
7. Size, Power, and Performance

**ADC FPGA Functional Description**

**Revision:**

 Add Status 2 to read back ADC counts. The ADC channel is select with Config 1 bit 11 down to 8.

 Add Status 3 and 4 to read FPGA core temp and Vint.

**Overview:**

The ADC FPGA receives 12-bit data words streaming at 250 MHz from 16 ADC. It performs **Channel Data Processing** for each ADC, computes **Energy Sum** of all ADC, and generates **Acceptance Pulse** for each ADC. The data selected in Channel Data Processing and results of Energy Sum are passed to CTRL FPGA to be sent to VME host and CTP respectively. The code is modular such that processing algorithms can easily be added or deleted.

Figure 1. Block Diagram (Input Mode):

1

Disable 0

0

16

ADC Samples

PlayBack

ADC Samples

PlayBack

Sel PlayBack

Disable 16

0

To Read Out Path

To Trigger Path

Figure 2. Block Diagram (Read Out Path):

To Data Format

Mode 0 Raw Mode:

Samples in Window are read back

Mode 1 Pulse Raw Mode:

Samples in Window from NSB and NSA and Time **only** when Sample > Threshold (TET) are read back

Mode 2 Integral Mode:

SUM of samples in Window from NSB and NSA and Time **only** when Sample > Threshold (TET) are read back

Mode 3 TDC Mode:

Time when Vmid occurred, Vmin, Vmax are read back only when samples are greater then TET

Mode Supervisor:

Mode 0,1,2,3,6,7

(In Mode 7, Mode 0 runs then Mode 3 run). In Mode 6, Mode 2 run then Mode 3

Figure 3. Trigger Path: Sample Processing Code

SampleSN

SampleD

Delay

by NSB

SampleN

>

State

Machine

Sample

Counter

Rising

Edge

Detect

= NSB+NSA

= NSA

0

Threshold

To All Channel Sum

Pedestal

Figure 4. Example for Trigger Path Sample Processing Code:

**Input**

**SampleN**

Threshold

NSA

NSB=2

NSA

Output To

All Channel

Sum

**Reset:**

Hard Reset: Reset Everything except Time Stamp and ADC IC

Soft Reset: Reset Everything except Time Stamp, Registers, and ADC IC

Sync : Only reset Time Stamp.

ADC IC is reset through register bit.

**Trigger Path Processing:**

To implement FADC250 energy sum described in “Some specifications on the FADC250 and CTP trigger firmware for Hall D calorimeters” by A. Somov, this section of code has tow parts: Sample Processing Code and Summing Code.

Each ADC channel has Sample Processing Code that does the following:

1. When a sample is equaled or greater then a programmable threshold, it outputs a programmable (0 to 15) Number of Sample Before (NSAB) this sample and a programmable (0 to 63) Number of Sample After (NSA) this sample. NSA count includes this sample. The NSA + NSB has to be less than 63. The NSB count is one more then the value set.
2. If the pulse width is wider (greater) then NSA, NSA count will be repeated. This is repeated until at the end of NSA count, the sample is less then threshold. In other words, samples that are equaled or greater than threshold will be outputted.
3. If another pulse occurred while NSA count is in progressed, NSA count restarted. Another pulse occurred is defined as one sample less than threshold and another following sample is equaled or greater than threshold.

As shown in Figure 3, Sample Processing Code does the following:

1. Delay SampleN from ADC by NSB = 2 samples
	1. SampleD = SampleN delay by NSB.
2. Subtract 12-bits Pedestal from 12-bits ADC samples. Each ADC has its own pedestal.
	1. SampleSN = SampleD - Pedestal
3. When SampleN crosses 12-bits threshold (one 12-bit threshold for all 16 ADC):
	1. Input SampleSN to “All Channel Sum” code
	2. Start Sample Counter.
	3. When Sample Counter counts to NSB+NSA, input Zero to Sum code.
	4. If SampleN crosses 12-bits threshold again while Sample Counter is counting.
		1. Restart Sample Counter
		2. Continue inputting SampleSN to “All Channel Sum code”.
		3. When Sample Counter counts to NSA, input Zero to Sum code.
4. The output is NSB + NSA + 1. One extra sample after NSA is due to pipelining the code.
5. Figure 4 shows an example.

The outputs of all 16 , Sample Processing Code are added together and are transferred to the CTRL FPGA to be sent to the CTP on two full duplex gigabit transceiver ports. The transceivers are configured to operate at 2.5Gb/s per lane and will communicate directly to the VXS switch “A” slot.

**Programmable Pulse Generator (PPG)**:

 Input to Channel Data Processing can either come from ADC after pedestal subtraction or the Programmable Pulse Generator (PPG). Users can load simulated PMT data into the PPG via VME host. When a trigger occurs in test mode, the stored data is read and apply to Channel Data Processing. There are 16 PPG, one for each ADC channel and each PPG can hold 32 samples.

**1. Channel Data Processing:**

Overall View:

We briefly describe the current operating modes of the FADC250 and identify the data word types that each produces. Since several modes report pulse data, we begin by discussing how pulses are defined, and how times are assigned to pulses.

**Pulse Definition**

Several modes of operation of the FADC250 detect a pulse from the raw samples and report data associated with this pulse. We describe the pulse detection algorithm that is currently implemented in the firmware. Exceptions are noted below.

The trigger window consists of NW samples of the ADC. Samples are 4 ns apart in time. Samples within the trigger window are numbered from 1 to NW.

A pulse window width that would contain the entire expected detector pulse is specified by the user. The pulse window width (in number of samples) is defined from two programmed values (NSB, NSA): width is NSB + NSA.

Pulse identification is initiated if at least one sample in the trigger window is above the programmed threshold. The sample number of the first threshold crossing (TC) in the trigger window is determined. If the first sample of the trigger window is above threshold, a pulse is declared and TC = 1 for this pulse. Otherwise, the transition above threshold must be explicitly visible: at least one sample before TC must be at or below threshold.

The parameter NSB represents the number of samples before the threshold crossing sample (TC) that are included in the pulse data set. When TC is found and TC – NSB < 1, the expected pulse started before the trigger window. In this case, the first sample of the pulse data set is declared to be the first sample of the trigger window.

The parameter NSA represents the number of samples after the threshold crossing to include in the pulse data set. Sample number TC is included in this count. If the computed last sample number (TC + NSA – 1) of the pulse data set is greater than NW, the expected pulse extends past the trigger window. In this case, the last sample of the pulse data set is declared to be the last sample of the trigger window.

In summary, the pulse data set consists of sample numbers:

MAX( (TC – NSB), 1 ) to MIN( (TC + NSA – 1), NW ).

Up to three distinct pulses may be detected within the trigger window. The maximum number of pulses is programmable. The earliest pulses found, up to the programmable limit, are reported. Any additional activity in the trigger window is ignored.

After a pulse is detected, a search for a subsequent pulse begins at the sample number after the pulse (TC + NSA). Another pulse is identified only if there is a clear transition above threshold after the previous pulse: at least one sample before TC must be at or below threshold. Consecutive pulses may overlap (i.e. share samples). The magnitude of possible overlap is determined by NSB.

**Pulse Time**

When operating in a pulse finding mode, a time is assigned to each pulse found. The simplest reportable time is TC, the number of the first sample above threshold for the pulse. ADC modes 2 and 3 report TC as pulse time.

A procedure for calculating a high-resolution time has also been implemented in the firmware. The time reported represents the time on the pulse’s leading edge where half of its maximum sampled amplitude is reached. The algorithm for computing this time is described below. Exceptional cases where the algorithm cannot be applied are also discussed. Whenever the algorithm fails, the reported time is the threshold crossing time TC. Information is returned that identifies these cases to the user.

A baseline amplitude (VMIN) is determined for the entire trigger window by averaging the first 4 samples of the trigger window. A pulse with threshold crossing sample number TC is identified in the manner discussed in the section on pulse definition. The peak amplitude (VPEAK) is determined by finding a sample beyond TC for which the sample value first decreases. The algorithm will search for VPEAK beyond the expected end of the pulse (TC + NSA). Cases for which no VPEAK is detected are discussed below.

The half amplitude (VMID = (VPEAK + VMIN) / 2)) of the pulse is computed. The sample number N1 is found on the leading edge of the pulse that satisfies:

V(N1) ≤ VMID < V(N1+1)

where V(N1) and V(N+1) are the sample values of adjacent samples N1 and N1+1. N1 is reported as the coarse time.

The estimated time of occurrence of VMID between samples N1 and N1+1 is determined by a linear interpolation using their sample values V(N1) and V(N1+1). The time between samples (4 ns) is divided into 64 subsamples (62.5 ps each). In essence,

TF = 64\*(VMID – V(N1)) / (V(N1+1) – V(N1)).

TF is reported as the fine time with values from 0 to 63. In addition to the time data word (type 8) consisting of the coarse and fine times, a pulse parameter data word (type 10) reports the values of VMIN and VPEAK used in the computation of the high resolution time.

A problem in the computation of the high resolution time will occur when VMIN is greater than VPEAK. In the current implementation of the algorithm, the simplest way to protect against this situation is to require that all 4 samples that determine the VMIN must be at or below threshold for the high resolution timing algorithm to be used. If this condition is not satisfied, the reported pulse time is TC, and both VMIN and VPEAK are reported as 0 in the pulse parameter data word (type 10) to identify the condition.

A problem with the algorithm occurs if VPEAK is not found within the trigger window. In this case, the reported pulse time is TC. To identify this condition, the pulse parameter data word (type 10) reports VPEAK = 0 and VMIN as measured.

In the current implementation of the algorithm, a technical difficulty arises when TC is near the end of the trigger window. If (NW – TC) < 5, the reported pulse time is TC, and the pulse parameter data word (type 10) reports VPEAK = 0 and VMIN as measured.

To standardize reporting of the pulse time, a 15-bit time value is always formed. The coarse time is reported in bits 14 through 6, while the fine time is reported in bits 5 through 0. Each count represents 62.5 ps. In situations where only the threshold crossing TC is reported, TC is set to be the coarse time and the fine time is 0.

**ADC Modes**

ALL operating modes produce data types 0 (block header), 1 (block trailer), 2 (event header), 3 (trigger time), 12 (scaler – optional), 14 (data not valid), 15 (filler) (see **Appendix 1**).

1 – Raw ADC data samples. If any sample in the trigger window is above the programmed threshold, all samples of the trigger window are reported. (Data type 4).

2 – Pulse Raw ADC data samples. A pulse is identified in the manner described above. Raw samples that constitute a detected pulse are reported. If the programmed width (NSB + NSA) is odd, an extra sample is reported. The threshold crossing sample number (TC) is also reported so that the pulse samples can be referenced to the start of the trigger window. Up to 3 pulses can be identified within the trigger window. (Data type 6.)

3 – Pulse integral. A pulse is identified in the manner described above. The sum of raw samples that constitute the pulse data set is reported. The threshold crossing sample number TC is reported as the pulse time. Up to 3 pulses can be identified within the trigger window. (Data types 7, 8).

4 – High-resolution time. A high-resolution time for the pulse is reported. Parameters used to compute this time are also reported. Up to 3 pulses can be identified within the trigger window. (Data types 8, 10).

7 – Pulse integral + high-resolution time. Equivalent to the processes of mode 3 and 4. Note that the time in mode 3 is replaced by the high-resolution time of mode 4. (Data types 7, 8, 10).

8 – Raw ADC data samples + high-resolution time. Equivalent to the processes of mode 1 and 4. (Data types 4, 8, 10.) (This mode is used to validate the implementation of the high-resolution time algorithm.)

**Recommended modes of operation are 1, 2, 3, 7.**

**Firmware Implementation**

As in most complex projects, the FADC250 firmware was developed in stages. Pulse detection mode 3, reporting the pulse integral and threshold crossing time TC, was delivered early. The high resolution timing algorithm was developed later and added as an independent process so it would not disrupt the functioning modes of operation.

As a consequence of having separate processes for pulse identification and timing, we have observed rare occasions where there is a mismatch in the number of pulses identified (pulse integral) and the number of pulse times reported. To be safe, we suggest that the user eliminate this data from consideration.

A future version of the firmware is planned that combines the pulse finding and high resolution algorithms into a single process. This will eliminate the pulse and time mismatches described above, and soften some of the restrictions we have imposed on when the high resolution timing mode can be applied. It will also increase trigger rate capability of the module.

**Mode Illustrations:**

ADC Data Trigger Input

 Time Line |

 |

 |🡨Programmable Trigger Window🡪| |

 -------- 100nS to 2uS --------------- |

 |

 |🡨----------Programmable Latency (100nS to 8uS ------------------🡪 |

 Data from ADC are stored continuously in circular buffer until Trigger input becomes active (low). The data that was stored from the time that the Trigger occurs back to the time specified by Programmable Latency within the Programmable Trigger Window are processed.

 There are three main options to which these data are processed. The options are selectable by the user via VME register setting and two Trigger Inputs.

 While data are being processed, ADC FPGA will continue storing incoming ADC data with no loss of data.Programmable Trigger Window (PTW) and Programmable Latency(PL) are common to all 8 ADC channels.

**Mode 0 (Raw Mode):**

Data within the Programmable Trigger Window [PTW] is passed with no further processing to the VME Host.

**Option 1 Raw Mode Data to VME Host Illustration:**

Trigger Input

Time Line |

 |

 |🡨Programmable Trigger Window🡪| |

 |

 |🡨----------Programmable Latency -----------------------------------🡪 |

**Mode 1 (Pulse Mode) :**

When an ADC sample has a value that is greater than Programmable Trigger Energy Threshold (TET), the number of samples before (NSB) the Maximum value (Vp) and the number of samples after (NSA) Vp are sent to VME Host. NSB and NSA are programmable. T1 and T2 are Time at which the first sample is greater than TET.

TET is 12 bits and unique to each ADC channel.

NSB has a maximum value of 512

NSA has a maximum value of 512

**Mode 1 Pulse Mode Data to VME Host Illustration:**

Vp

Vp

T1

TET

T2

NSB

NSA

NSB

NSA

PL

PTW

**Mode 2 Integral Mode:**

Data within NSB and NSA of Option 2 Raw Mode are summed around T1 and T2. PNS defines the number of samples before and after T1 and T2 include in Sum 1 and Sum 2 respectively**.** Only Sum 1, T1, Sum 2, and T2are passed to VME FPGA. T1 and T2 are Time at which the first sample is greater than TET.

**Mode 2 Integral ModevData to VME Host Illustration:**

Sum2

Sum1

Vp

Vp

T1

TET

T2

NSB

NSA

NSB

NSA

PL

PTW

**Mode 3 TDC Algorithm:**

The TDC algorithm calculates time of the mid value (Va) of a pulse relative to the beginning of the look back window. Va is the value between the smallest and the peak value (Vp) of the pulse. The smallest value (Vm) is the beginning of the pulse. The time consists of coarse time and fine time. The coarse time is the number of clock the sample value before the mid value and the fine time is the interpolating value of mid value away from next sample. The coarse value is 10 bits and the fine value is 6 bit. The resolution of LSB is 1/(CLK \* 64). For a 250MHz the resolution is 62.5 pS. For example for a 20MHz clock, a pulse time (Ta) value of 110 means the mid-point of the pulse occurred at 6.875nS (62.5pS \* 110) from the beginning of look back window.

Vp

Vm

Va

Va

Vm

Vp

PTW

PL

Ta1

Ta2

**Requirements for TDC Algorithm:**

* + 1. There must be at least 4 samples (background) before pulse. Four of these samples are used to determine the pedestal (Vnoise) floor. The minimum value of the pulse is the first value that is greater than Vnoise.

 **Mode 6 Algorithm:**

Run Mode 2 follow by Mode 3 algorithms. Only the TDC time is reported back when the condition for TDC is met, else time from Mode 2 is reported back.

**Trigger Input Buffer:**

In the event that the Trigger Input rate is faster than the data processing time, the processing algorithm has to be able to process 100 consecutives triggers with no loss in time lines. If a trigger cannot be processed due to an overflow condition, the VME FPGA will be notified: “no data for trigger. If T1, T2, or T3 is less than 50 Ns, the trigger will not be recorded.

**Successive Trigger Input Illustration:**

T1

T2

T3

1

2

3

4

 **|🡨 Window 1 🡪 | | | |**

 **|🡨Latency 1 🡪| | | |**

 **| | |**

 **|🡨Window 2 🡪| | | |**

 **|🡨Latency 2 🡪 | | |**

 **🡨**T1**🡪 | | |**

 **|🡨Window 3 🡪| | |**

 **|🡨Latency 3 🡪| |**

 **🡨**T2 **🡪 | |**

 **|🡨 Window 4 🡪| |**

 **|🡨 Latency 4 🡪|**

 **🡨**T3 **🡪**

**Memory Model for Successive Trigger Input Illustration:**

Processing

OverHead

Spec.

8uS

**Trig 1**

PTW

**Trig 2**

PTW

**Trig 3**

**Trig 4**

PTW

PTW

**Fill**

**3. HITBITS:**

 When counts from an ADC channel are greater than threshold, the corresponding Hit Bit for that channel is high. The HitBits are processed by TRIG\_PROC\_TOP to form coincident trigger.

**HitBits Illustration:**

**ADC data**

TET

**Hit Bit**

**\_\_ \_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_**

 **| | | | | | || | | | |**

 **| | | | | | || | | | |**

 **----- --- -- -- ---- -------**

**Conceptual Architecture Diagram**

**Overview:**

15

VME FGPA IFACE

Control Bus

**EXT**

**FIFO**

CTRL

FPGA

**ADC PROC TOP**

ADC

250MHz

CLK

PROCESS

ALGO-

RITHMS

Trig

48 Bits

Time Stamp

DATA FORMAT

27 Bits Trigger Counter

DATA

BUFFER

Re

Sync

Dat

**ADC CH1**

**ADC CH16**

Re Sync Dat

From ADC CH0 to 15

HIT BITS

SUM

15

15

36

Sel

TRIG\_PROC\_TOP

>

-

PedSub Reg 0 to 15

0

Data from each ADC is resynchronized with FPGA main CLK. The outputs of the Resync are inputs of Data Buffer, Pedestal Substraction, and Hit Bits circuits. Each ADC Channel has Resync, Data Buffer and Processing Circuits. The Data Buffer stores Resync Data, Trigger Number, and Time Stamp. Processing Circuit processes data from Data Buffer. Format read results from each ADC channels (0-15) Processing Circuit and mux it to external FIFO. For each of the ADC, Pedestal Subtraction Circuit subtracts a programmable constant from ADC sample if the sample is greater than the constant. If the sample is smaller than the constant, zero is output. The output of the Pedestal Subtraction Circuit is fed to the Sum circuit. Sum circuit adds the pedestal-subtracted-samples from each Pedestal Subtraction Circuit on a clock by clock basis. Bit Bits circuit compare Resync data to TET and produce a low active signal when Resync data is above TET.

The architecture supports Processing Modularity. Processing algorithms are independent of the other functions.

Sel block was added on March 3, 2008 to accommodate both 10 bits and 12 bits FADC boards This feature also allows individual ADC Channel values (counts) to be set to zero (effectively disable the ADC). CONF register (see below) configures these options.

On March 15, Sel block is expanded to include Programmable Pulse Generator.

**Programmable Pulse Generator (PPG)**:

 The PPG generates pulses by reading out digitized values of pulses (samples) stored in a memory. The memory has 32 locations. Each location has 16 bits and can hold one sample. Thirteen of the bits simulated the 12 data and 1 overflow bits output of the ADC implemented on the FAD250 board. The 16th bit facilitates writing and reading the memory. Samples are written to the PPG memory when VME write to address (0x0211 and 0x0011) and bit 16th is a one. The address automatically incremented after a sample is written. The last two samples written are required to have bit 16 zeroed (Sample value = 0x0000). After the last samples (0x0000) the address reset to the location of the first sample. Bits 14 and 15 are don’t care bits. VME can verify the data is written by immediately read back the data (write follow by read).

Data are read out of PPG memory when Play-Back and Test-On are both logical one. The first location that will be read out is set by a register (Read-Out-Start-Address). Subsequent locations are read out at 4nS interval until Play-Back returns to logical zero. The read back cycles to Read-Out-Start-Address when bit 16th is a zero.

 AUX\_IO(1) is used as Play-Back.

 Bit 7 of CONFIG register is used as Test-On

 Bit 8-15 of CONFIG register is used as CHx-OFF

For the FADC250 Version 1 the PPG can only hold 16 samples. The last two samples have to be written with 0x8000.PPG Mode:

ADC 15 Samples

PPG

Memory

Play-Back

0

**Test-On**

**CH15-Off = 0**

To CH15 Processing

0

**Test-On**

**CH0-O ff = 0**

To CH0 Processing

ADC 0 Samples

**Test-On**

Test On is bit 6 of Configuration register. CHx-Off are bits 8-15 of configuration register.**Data Buffer:**

PTW Buffer Overrun

RAW Buffer Overrun

Number Of PTW Data Blocks

increment

Primary Buffer

Secondary Buffer

From

Resync

DP

RAM

Logic:

Cir.

Buf

Logic:

Secondary

Storage

TRIG

DP

RAM

48 BITS TIMER

26 BITS TRIG NUMBER

CLK2

Process

Algorithms

TRIG

FIFO

Counter

Decrement

Maximum PTW Data Blocks

1. Synchronize data from ADC to 250 MHz FPGA CLK
2. Store ADC data to Primary Buffer. Implement Primary Buffer as ring (circular) buffer.
3. When a Trigger occurs, the trigger is stored along with the values of the 48 Bits Timer and the Pointer of the Primary Buffer in a FIFO.
4. For each trigger, data within Programmable Trigger Window are copied from Primary Buffer to Secondary Buffer with time stamps and markers necessary for further processing. After the block is copied, Number of PTW Data Blocks increments by one.
5. After a block is read and process, Decrement should be pulsed to decrease th Number of PTW Data Blocks by one.
6. Each ADC channel has its own Data Buffer.
7. When the Trigger Rate is faster then the time needed to copy ADC Data from Primary Buffer to Secondary Buffer, RAW BUFFER OVERRUN is set and remain set until RESET\_N or SOFT\_RESET\_N goes low.
8. When Number of PTW Data Block is equaled Maximum PTW Data Blocks setted by the host, PTW Buffer Overrun sets and remains set until RESET\_N or SOFT\_RESET\_N goes low.
9. Utilized 700 LUT, six 18000-bits RAM blocks. Max Clock is 252 MHz.

**Process Algorithms:**

DATA FORMAT

VME FPGA IFACE

Secondary

FIFO

Option 1

Option 2,3

Logic:

Acceptance

Energy Sum

Option 4

HIT BITS

Dual

Port

Process

Memory

SUM

HIT SUM

FPGA

Process Block Counter

DECREMENT

1. Read data from Secondary Buffer.
2. Parse data to Processing Algorithms
3. Process all three options of Data Channel Processing.
4. Create Acceptance (Hit bit) pulse
5. Compute Energy Sum

**VME FPGA IFACE:**

Control Bus

CTRL

AD

ADDRESS DECODE

STATE

MACHINE

REGISTER FILES

TO: Data Buff, Process Algorithm,

Data Format

STATUS

**VHDL Hierarchy**

1. **ADC\_PROC\_TOP**
	1. SYNC\_ADC\_IN\_VER2
		1. IODELAY
	2. PlayBack\_WV\_Ver2
		1. DPRAM\_16\_1024 (UMEM)
	3. Data\_Buffer\_AllCh\_Ver2\_TOP
		1. Data\_Buffer\_Top (UADCx)
			1. DP\_RAM1\_TOP (2Kx13) (URAW\_BUFFER\_IN)
			2. FIFO\_1 (UTrigger\_Buffer)
			3. DP\_RAM2\_TOP(2Kx17) (UPTW\_DATA\_BUF)
			4. PTWCPSM
	4. TimeStamp\_TOP
		1. Time\_stamp (Xilinx core gen)
	5. Trigger\_Number\_TOP
		1. Trigger\_number
	6. Processing\_All\_Ver2\_Top
		1. PROCESSING\_TOP (CHx\_PROCESSING)
			1. DP\_RAM3\_TOP (2Kx18) (UPROCESS\_BUF)
			2. PROCESSM
			3. fifo\_12\_64 (UProcAdrHist)
			4. TDC\_TOP
				1. Linear\_Interpolation (ULI)

Divide\_18By12

DIVIDESM

* + - * 1. TDCSM
		1. PROALLSM
	1. DataFormat\_VER2\_TOP
		1. DATFORSM
	2. TriggerProcessing\_TOP
		1. TriggerProcessing
			1. Delay1\_To\_16
			2. Pedestal Sub
			3. TRPATHSM
		2. LVDS\_OUT\_16Bits
	3. Hit\_Bit\_All\_ver2\_Top (UHIT\_BITS\_ALL\_TOP)
		1. HIT\_BITS\_TOP (UHIT\_x)
		2. IOREG\_8bits
1. **HOST\_ADCFPGA\_VER2\_TOP**
	1. HSHOSTSM

**VHDL Block Diagram**

**ADC Input ReSync**

**HARD**

**RESET N**

**FPGACLK**

13

**ADC**

**CLK**

**ADC**

**DP**

**DN**

FIFO

15X13

WrEn

Empty RdEn

D Q

**IOB**

D Q

**TO**

**DATA**

**BUFFER**

D Q

Each ADC has 12 bits data, an overflow, and an ADCCLK. The ADC Input Resync captures ADC’s data and overflow bits with ADC’s output clock to a 15 deep (smallest allow by ISE) by 13 bits FIFO. The FIFO allows the FPGA main CLK to be independent of ADC clock. The FPGA main CLK clocks the data out of FIFO and send to the Data Buffer Block.

The advantage of using ADC’s own CLK to capture its data is the elimination of timing variations from ADC to ADC. Moreover, the FIFO Empty signal is used as FIFO Read Enable to allow variation in ADC start up time.

 **Data Buffer**

**Primary Memory Map**

|  |  |
| --- | --- |
| **Address Location** | **Content** |
| **0** | **ADC Data 0** |
| **1** | **ADC Data 1** |
| **2** | **ADC Data 2** |
| **3** | **ADC Data 3** |
| **4** | **ADC Data 4** |
| **:** | **:** |
| **:** | **:** |
| **:** | **:** |
| **4078** | **ADC Data 4078** |
| **4079** | **ADC Data 4079** |
| **4080** | **ADC Data 4080** |
| **0** | **ADC Data 4081** |
| **1** | **ADC Data 4082** |
| **2** | **ADC Data 4083** |
| **3** | **ADC Data 4084** |
| **:** | **:** |
| **:** | **:** |
| **:** | **:** |

**Primary Memory stores ADC data as it comes in. At the end of buffer, the storing re-circulates and overwrites previous data.**

 **Data Buffer**

**Secondary Memory Map**

|  |  |
| --- | --- |
| **Memory location from beginning of PTW** | **Content** |
| 0 | PTW **0** “10010” Trigger Number bits 26-16 |
| 1 | Trigger Number bits 15-0  |
| 2 | “10011000” Time Stamp bits 47-40 |
| 3 | Time Stamp bits 39-24 |
| 4 |  “00000000” Time Stamp bits 23-16 |
| 5 | Time Stamp bits 15-0 |
| 6 | PTW **0** data 0 |
| : | PTW **0** data 1 |
| : | : |
| N-4 | “111” PTW **0** data N-4. “111” indicate almost last data |
| N-3 | PTW **0** data N-3 |
| N-2 | PTW **0** data N-2 |
| N-1 | PTW **0** data N-1 |
| N | PTW **0** last data |
|  |  |
| N+1 | PTW **1** “10010” Trigger Number bits 26-16 |
| N+2 | Trigger Number bits 15-0  |
| N+3 | “10011000” Time Stamp bits 47-40 |
| N+4 | Time Stamp bits 39-24 |
| N+5 |  “00000000” Time Stamp bits 23-16 |
| N+6 | Time Stamp bits 15-0 |
| N+7 | PTW **1** data 0 |
|  | PTW **1** data 1 |
|  | : |
| M-4 | “111” PTW **1** data M-4. “111” indicate almost last data |
| M-3 | PTW **1** data M-3 |
| M-2 | PTW **1** data M-2 |
| M-1 | PTW **1** data M-1 |
| M | PTW **1** last data |
|  |  |
| M+1 | PTW **2** “10010” Trigger Number bits 26-16 |
| M+2 | Trigger Number bits 15-0  |
| M+3 | “10011000” Time Stamp bits 47-40 |
| M+4 | Time Stamp bits 39-24 |
| M+5 |  “00000000” Time Stamp bits 23-16 |
| M+6 | Time Stamp bits 15-0 |
| M+7 | PTW **2** data 0 |
|  | PTW **2** data 1 |
|  | : |
| O-4 | “111” PTW **1** data O-4. “111” indicate almost last data |
| O-3 | PTW **2** data O-3 |
| O-2 | PTW **2** data O-2 |
| O-1 | PTW **2** data O-1 |
| O | PTW **2** last data |

When a trigger occurs, a number of ADC data words (=PTW\*25MHz) is copied from Primary to Secondary Buffer. The time at which the trigger occurred and the Trigger Number of Bits is included. Since the Number of ADC data words effects where the buffer ended and to minimize gate count, the location of the end of the buffers is provided by the Host Interface block. The Secondary Buffer Size is 2040 to accommodate 4 successive triggers of 2uS PTW (500 locations per trigger).

**Trigger Buffer**

15-0

“10010” & 26-14

**TriggerNumber**

**Trigger**

Trigger address

Trig Fifo

Empty

Trigger

Raw Data Out PTR

Pending

“0000” & 12-0

15-0

“00000000” & 23-16

39-24

“10011000” & 47-40

TimeStamp

0

1

2

3

4

5

6

48

0

1

12

0

1

Enable

COUNTER

Set

Clr

= 3

D Q

FIFO(500 x16)

WE RE

 Empty

Trig Buf

Fifo Out

Trig Fifo

RDEN (sm)

When a trigger occurs, the time stamp and the pointer that points to beginning of Programmable Trigger Window (Raw Data Out PTR Pending) is store to 16 bit FIFO. The 48-bits time stamp is stored in 4 consecutive locations with LSB stored first. Bits 11-0 is padded with “1100” to signify the beginning of PTW window and Time Stamp Words. Bits 23-12, 35-24, and 47-36 are padded with “0100” to signify Time Stamp.

After the first word is stored, TrigFifoEmpty goes high and kick off the State Machine to copy time stamp from FIFO to Secondary Dual-Port memory. Data in the PTW stored in the Primary Buffer starting at Trigger Address are copied to Secondary Buffer.

**Data Buffer:**

**Primary and Secondary Buffer**

LastPtwWord

RAW\_DATIN\_PTR

**PTW\_DATA\_BLOCK\_CNT**

PTW\_COPY\_DONE

(sm)

PTW\_BUF\_DAT\_IN

PTW\_DPRAM WREN1 (sm)

PTW\_DPRAM WREN2 (sm)

12

16

Primary Buffer

SEL\_TS (sm)

Trig Buf

Fifo Out

“000”

13

RawBufRdEn (sm)

**0**

Ld Raw Out PTR

(sm)

Trig Buf Fifo Out

12

12

**SoftReset\_N**

**Reset\_N**

**ADC**

D

WEN AdrA AdrB

 DP RAM

 4090x13

 Q

Clear

COUNTER

1

0

1

0

1

0

**+**

=

4080

0

1

16

12

Secondary Buffer

D

WEN AdrA AdrB

 DP RAM

 2200x16

 Q

**PTW RAM ADDR**

**PTW RAM
DATA**

 Enable

COUNTER

Clear

**=**

**PTW DAT BUF LAST ADR (host)**

Enable

COUNTER

PTW\_BUF\_

DAT\_CNT\_EN (sm)

**PTW\_WORDS (host)**

**=**

Inc Dec

PTW

COUNTER

INC\_PTW\_CNT (sm)

**DEC\_PTW\_CNT**

0

1

“111”

LastPtwWord

**=**

**PtwWordMinus1 (host)**

After power up, data from ADC is stored in Ring Buffer continuously. When Trigger is in Trigger Buffer, the Time Stamp is copied from the Trigger Buffer to the Secondary Buffer. The Primary Address when the trigger occurred is retrieved from the Trigger Fifo to be used as the starting Primary address to copy ADC data over. A counter is keeping track of the number of ADC words copied. When the counter equaled the PTW words the copied process stop. Another counter that keeps track of the number of triggers that are in the Secondary Buffer ready for Process algorithm. When a block of trigger is process, this counter is decrement by the Process algorithm.

The Secondary Buffer storage is such that the starting address of each block of trigger data is determine by the PTW but it is fixed with PTW. For example, if PTW is 2uS, the starting address are 0, 504, 1008, 1512. The data formats from low to high address are

 “1000” “TS bits 47-36”

 “1000” “TS bits 35-24”

 “1000” “TS bits 23-12”

 “1000” “TS bits 11-0”

 “010” “ TriggerNumber bits 26-14”

 “01” “ TriggerNumber bits 13-0”

 “000” “ADC data”

 :

 :

 “001” “Last ADC data in PTW”

 PTW Counter is coded such that when decrement commands and increment commands occurs exactly at the same time, decrement occurs before increment.**Data Buffer:**

 **STATUS**

**Data Processing:**

**Memory Map**

**Data Processing Memory Assignment for Mode 0**

|  |  |
| --- | --- |
| **Memory location from beginning of PTW** | **Content (WITH EVENT)** |
| **0** | **“00” “10010” Trigger Number bits 26-16** |
| **1** |  **“00” Trigger Number bits 15-0** |
| **2** | **“00” “10011000” Time Stamp bits 47-40** |
| **3** | **“00” Time Stamp bits 39-24** |
| **4** | **“00” “00000000” Time Stamp bits 23-16** |
| **5** | **“00” Time Stamp bits 15-0** |
| **6** | **“00” PTW data 0** |
| **7** | **“00” PTW data 1** |
| **8** | **“00” PTW data 2** |
| **9** | **“00” PTW data 3** |
| **etc** | **etc** |
| **N+7** | **\*”11” “FFFF” : end of PTW** |
|  |  |
| **Memory location from beginning of PTW** | **Content (WITHOUT EVENT)** |
| **0** | **“00” “10010” Trigger Number bits 26-16** |
| **1** |  **“00” Trigger Number bits 15-0** |
| **2** | **“00” “10011000” Time Stamp bits 47-40** |
| **3** |  **“00” Time Stamp bits 39-24** |
| **4** | **“01 “00000000” Time Stamp bits 23-16** |
| **5** |  **“01” Time Stamp bits 15-0** |
| **6** |  **“01” “0000”**  |
| **7** | **“01” “0000”** |
| **:** | **:** |
| **:** | **:** |
| **N+6** | **N** |
| **N+7** | **“11” “0000” : end of PTW** |
|  |  |

**N = PTW**

**Data Processing Memory Assignment for Mode 1:**

|  |  |
| --- | --- |
| **Memory location from beginning of PTW** | **Content (WITH EVENT)** |
| **0** | **“00” “10010” Trigger Number bits 26-16** |
| **1** |  **“00” Trigger Number bits 15-0** |
| **2** | **“00” “10011000” Time Stamp bits 47-40** |
| **3** |  **“00” Time Stamp bits 39-24** |
| **4** | **“00” “00000000” Time Stamp bits 23-16** |
| **5** |  **“00” Time Stamp bits 15-0** |
| **6** | **“10” “0000” Pulse Number “00” SampleNumber from Thredhold bits 9-0** |
| **7** | **“00” PTW pulse 0 data 0** |
| **8** | **“00” PTW pulse 0 data 1** |
| **N** | **“00” PTW pulse 0 data last**  |
| **N+1** | **“10” “0000” Pulse Number “01” SampleNumber from Thredhold bits 9-0** |
| **N+2** | **PTW pulse 1 data 0** |
| **N+3** | **PTW pulse 1 data 1** |
| **M** | **PTW pulse 1 data last** |
| **M+1** | **“10” “0000” Pulse Number “10” SampleNumber from Thredhold bits 9-0** |
| **M+2** | **PTW pulse 2 data 0** |
| **M+3** | **PTW pulse 2 data 1** |
| **O** | **PTW pulse 2 data last** |
| **O+1** | **“10” “0000 Pulse Number “11” SampleNumber from Thredhold bits 9-0** |
| **O+2** | **PTW pulse 3 data 0** |
| **O+3** | **PTW pulse 3 data 1** |
| **P** | **PTW pulse 3 data last** |
| **P+1+7** | **“11” “0000” : end of PTW** |
|  |  |
|  |  |
| **Memory location from beginning of PTW** | **Content (WITHOUT EVENT)** |
| **0** | **“00” “10010” Trigger Number bits 26-16** |
| **1** |  **“00” Trigger Number bits 15-0** |
| **2** | **“00” “10011000” Time Stamp bits 47-40** |
| **3** |  **“00” Time Stamp bits 39-24** |
| **4** | **“01” “00000000” Time Stamp bits 23-16** |
| **5** |  **“01” Time Stamp bits 15-0** |
| **6** | **x”10000”** |
| **7** | **x”10000”** |
| **8** |  **“11” “0000” : end of PTW** |

**Data Processing Memory Assignment for Mode 2:**

|  |  |
| --- | --- |
| **Memory location from beginning of PTW** | **Content (WITH EVENT)** |
| **0** | **“00” “10010” Trigger Number bits 26-16** |
| **1** | **“00” Trigger Number bits 15-0** |
| **2** | **“00” “10011000” Time Stamp bits 47-40** |
| **3** | **“00” Time Stamp bits 39-24** |
| **4** | **“00” “00000000” Time Stamp bits 23-16** |
| **5** | **“00” Time Stamp bits 15-0** |
| **6** | **“10” “0000” Pulse Number “00” SampleNumber from Thredhold bits 9-0** |
| **7** | **“00” Pulse 0 Sum bits 18-3** |
| **8** | **“00” “0000000000000” Pulse 0 Sum bits 2-0** |
| **9** | **“10” “0000” Pulse Number “01” SampleNumber from Thredhold bits 9-0** |
| **10** | **“00” Pulse 1 Sum bits 18-3** |
| **11** | **“00” “0000000000000” Pulse 1 Sum bits 2-0** |
| **12** | **“10” “0000” Pulse Number “10” SampleNumber from Thredhold bits 9-0** |
| **13** | **“00” Pulse 2 Sum bits 18-3 20-5** |
| **14** | **“00” “0000000000000” Pulse 2 Sum bits 2-0 4-0** |
| **15** | **“10” “0000” Pulse Number “11” SampleNumber from Thredhold bits 9-0** |
| **16** | **“00” Pulse 3 Sum bits 18-3** |
| **17** | **“00” “0000000000000” Pulse 3 Sum bits 2-0** |
| **18** | **“11” “0000” : end of PTW** |
|  |  |
| **Memory location from beginning of PTW** | **Content (WITHOUT EVENT)** |
| **0** | **“00” “10010” Trigger Number bits 26-16** |
| **1** | **“00” Trigger Number bits 15-0** |
| **2** | **“00” “10011000” Time Stamp bits 47-40** |
| **3** | **“00” Time Stamp bits 39-24** |
| **4** | **“01” “00000000” Time Stamp bits 23-16** |
| **5** | **“01” Time Stamp bits 15-0** |
| **6** | **x”10000”** |
| **7** | **x”10000”** |
| **8** | **“11” “0000” : end of PTW** |

**Data Processing Memory Assignment for Mode 3:**

|  |  |
| --- | --- |
| **Memory location from beginning of PTW** | **Content (WITH EVENT)** |
| **0** | **“00” “10010” Trigger Number bits 26-16** |
| **1** | **“00” Trigger Number bits 15-0** |
| **2** | **“00” “10011000” Time Stamp bits 47-40** |
| **3** | **“00” Time Stamp bits 39-24** |
| **4** | **“00” “00000000” Time Stamp bits 23-16** |
| **5** | **“00” Time Stamp bits 15-0** |
| **6** | **“10” “0000” Pulse Number “00” SampleNumber from Thredhold bits 9-0** |
| **7** | **“00” Tfine(5..0) Vmin (11..4)**  |
| **8** | **Vmin(3..0) Vp (11..0)** |
| **9** | **“10” “0000” Pulse Number “01” SampleNumber from Thredhold bits 9-0** |
| **10** | **“00” Tfine(5..0) Vmin (11..4)**  |
| **11** | **“00” Vmin(3..0) Vp (11..0)** |
| **12** | **“10” “0000” Pulse Number “10” SampleNumber from Thredhold bits 9-0** |
| **13** | **“00” Tfine(5..0) Vmin (11..4)**  |
| **14** | **“00” Vmin(3..0) Vp (11..0)** |
| **15** | **“10” “0000” Pulse Number “11” SampleNumber from Thredhold bits 9-0** |
| **16** | **“00” Tfine(5..0) Vmin (11..4)**  |
| **17** | **“00” Vmin(3..0) Vp (11..0)** |
| **18** | **“11” “0000” : end of PTW** |
|  |  |
| **Memory location from beginning of PTW** | **Content (WITHOUT EVENT)** |
| **0** | **“00” “10010” Trigger Number bits 26-16** |
| **1** | **“00” Trigger Number bits 15-0** |
| **2** | **“00” “10011000” Time Stamp bits 47-40** |
| **3** | **“00” Time Stamp bits 39-24** |
| **4** | **“01” “00000000” Time Stamp bits 23-16** |
| **5** | **“01” Time Stamp bits 15-0** |
| **6** | **x”10000”** |
| **7** | **x”10000”** |
| **8** | **“11” “0000” : end of PTW** |

**Data Processing:**

Data Processing for all mode involves scanning the entire secondary buffer. If there is no pulses (data that cross thredshold), x”FFF0” is written to processing memory (PTW) data locations. Trigger Number and Time Stamp info are copied from secondary buffer to processing memory. X”FFF0” signal DataFormat block to prevent data from written to external FIFO. This feature only writes ADC channel that has data that cross thresdhold (TET).

Data Processing consists of 4 state machines, counters, and pointers. The 4 State Machines include Main and one for each of the 3 Processing Options. When there is ADC data to process, Main State Machine read Time Stamps and Trigger Number from Secondary Buffer and write to Data Processing Buffer. It then calls on one of the other three state machines to process the Option that is in effect.

The state machine for option 1 does the following:

1. Copies PTW \* 20MHz number of words from Secondary Data Buffer to Data Processing.
2. Increment number of process counter by one

The state machine for option 2 does the following:

1. Read ADC data from Secondary Data Buffer. Start PULSE\_TIMER to tick mark the data read.
2. If ADC data is above Trigger Threshold, it writes PULSE\_TIMER to Process Buffer. Then it copies NSB and NSA number of words from Secondary Data Buffer to Data Processing Buffer as follow:
	1. If the number of words read before threshold is greater than NSB load RD\_PTW\_PTR with address that is NSB before threshold. If the number of words read (WORD\_AFTER\_TS\_CNT) is less than NSB, load the RD\_PTW\_PTR with address of WORD\_AFTER\_TS\_CNT word back from threshold.
	2. Start NSB\_CNT.
	3. When NSB\_CNT = NSB if WORD\_AFTER\_TS\_CNT > NSB **or** NSB\_CNT = WORD\_AFTER\_TS\_CNT if WORD\_AFTER\_TS\_CNT < NSB start NSA\_CNT.
	4. When NSA\_CNT = NSA, it stop reading Secondary Buffers.
3. Repeat Step 1 and 2 until number (PTW \* 250MHz) numbers of words have been read.
4. Write “FFFF” to signal the end of PTW.
5. Increment number of process counter by one

The state machine for option 2 does the following:

1. Read ADC data from Secondary Data Buffer.
2. If ADC data is above Trigger Threshold, it unable accumulated sum circuit to add ADC value from NSB to NSA ADC words.
3. Write accumulated sum to Secondary Data Buffer
4. Repeat Step 1, 2, and 3 until number number PTW \* 20MHz numbers of words have been read.
5. Write “FFFF” to signal the end of PTW.
6. Increment number of process counter by one

In mode 2 and 3, when the number of words read before the ADC value exceeds the Trigger Threshold is less then NSB, only that many word are processed.

Each state machine is responsible to change and reset the counters that pertained to the option.

The counters and their functions are listed below.

1. WORD\_AFTER\_TS\_CNT: keep track of words read from beginning of PTW to the ADC sample that exceeds the Trigger Threshold. If WORD\_AFTER\_TS\_CNT is less then NSB when this Threshold exceeded occurs, the NSB\_PTR\_ENOUGH pointer is used as starting address. Only WORD\_AFTER\_TS\_CNT number of word before Threshold is processed.
2. TS\_CNT: keep track of the number of time stamp and trigger number words read from the Secondary Buffer. Main state machine uses this to stop copying time stamp and trigger number words.
3. PTW\_WORDS\_CNT: keep track of the number of word in PTW has been read out. It is cleared when it is equaled to number of “PTW words + 4 Time Stamp words + 2 Trigger Number words”.
4. NSB\_CNT: Keep track of the number of words before Threshold has read and process.
5. NSA\_CNT: Keep track of the number of words after Threshold has read and processed.
6. PULSE\_TIMER: Tick mark ADC data read from Secondary Buffer from beginning of PTW.
7. PULSE\_NUMBER: Keep track of the number of pulses in PTW.
8. HOST\_BLOCK\_CNT: Keep track of the number of PTW ready to transfer to host. The host decrement this counter after the host read one PTW.

The pointers and theirs functions are listed below:

1. NSB\_PTR\_ENOUGH: This pointer is used as starting address if the number of words read from PTW beginning to Threshold is greater than NSB value. A number of NSB words is processed.
2. NSB\_PTR\_NOT\_ENOUGH: This pointer is used as starting address if the number of words read from PTW beginning to Threshold is less than NSB value. Only WORD\_AFTER\_TS\_CNT number of word is processed.

Counters that also serve as pointers are listed below:

1. RD\_PTW\_PTR: This is the address to the Secondary Buffer. It is load with either NSB\_PTR\_ENOUGH or NSB\_PTR\_NOT\_ENOUGH and increment under state machine control. It is cleared (restart at address 0) when PTW\_WORDS\_CNT is equaled to “number of PTW words + 4 Time Stamp words + 2 Trigger Number words”.

**TDC Algorithm Overview:**

 The TDC algorithm calculates time of the mid value of a pulse relative to the beginning of the look back window. The mid value is the value between the smallest and the peak value of the pulse. The smallest value is the beginning of the pulse. The time consists of coarse time and fine time. The coarse time is the number of clock the sample value before the mid value and the fine time is the interpolating value of mid value away from next sample. The coarse value is 10 bits and the fine value is 6 bit. The resolution of LSB is 1/(CLK \* 64). For a 250MHz the resolution is 62.5 pS. For example for a 20MHz clock, a pulse time value of 110 means the mid-point of the pulse occurred at 6.875nS (62.5pS \* 110) from the beginning of look back window.

**Requirements for TDC Algorithm:**

* + 1. There must be at least 5 samples (background) before pulse. Four of these samples are used to determine the pedestal (Vnoise) floor. The minimum value of the pulse is the first value that is Vnoise.

**TDC Algorithm for Mode 3:**

1. Search for Vaverage
	1. Latch starting PTW\_RAM ADR
	2. Read four samples. Vnoise = Average of 4 samples. Increment sample count by 4.
	3. Vmin = Vnoise. Increment sample count.
	4. Read until Vram < Vram\_delay. Vpeak = Vram if Vram is greater than TET. Increment sample count.
	5. Store PTW\_RAM ADR for Vpeak.
	6. Vaverage = (Vpeak – Vmin) / 2
2. Search for sample before (Vba) and sample after (Vaa) Vaverage
	1. Restore starting PTW\_RAM ADR. Increment Pulse Timer whenever the address is incremented.
	2. Read until Vram > Vmin. Vba = Vram
	3. Read one more for Vaa
	4. Calculated Tfine
3. Write Pulse Number and Pulse Timer to Processing RAM.
4. Increment Pulse Number
5. Restore PTW\_RAM ADR for Vpeak. Load sample count to Pulse Timer.
6. Read until Vram < Vmin. End of first pulse. Increment Pulse Timer whenever the address is increment. End processing whenever PT\_RAM data is ended.
7. Go to step 1.**Data Format :**

Data format read data from Data Processing Memory, put the data in proper format as described in FADC Data Format, and write to external FIFO to host. The data format falls into 5 categories: Event\_Header, Time\_Stamp, Window\_Raw\_Word1, Pulse\_Raw\_Word1, Window\_Pulse\_Raw\_Words\_2\_to\_N, Pulse\_Integral and Event\_Trailer. The words are 36 bits wide.

Event\_Header indicates the start of an event and bits are assigned as follow:

(35-34) = 0

(33-32) = 1

(31) = 1

(30-27) = 2

(26-0) = trigger number

🡺 x”19 trigger number”

Trigger Time (Time\_Stamp) indicates time of trigger occurrence relative to the most recent global reset. The six bytes (48 bits) of trigger time Ta Tb Tc Td Te Tf are format in two 32-bits words:

Word1:

 (35-34) = 0

 (33-32) = 0

 (31) = 1

 (30-27) = 3

 (26-24) = 0

 (23-16) = Ta

 (15-8) = Tb

 (7-0) = Tc

 🡺 x”0980 time stamp hi

Word2:

 (35-34) = 0

 (33-32) = 0

 (31) = 0

 (30-24) = 0

 (23-16) = Td

 (15-8) = Te

 (7-0) = Tf

🡺 x”0000 time stamp lo

Window Raw Word1 indicates the beginning of Window Raw Data.

 (35-34) = 0

 (33-32) = 0

 (31) = 1

 (30-27) = 4

 (26-23) = Channel number (0-7)

 (22-12) = 0

 (11-0) = Window Width (PTW) (in number of samples).

🡺 x”0A ChannelNumber 00 numberOfSamples”

3322 2222 2222 1111 1111 1198 7654 3210

1098 7654 3210 9876 5432 10

------------------------------------------------------

1010 0Cha n000 0000 0000 Ptw- ---- ----

Pulse Raw Word1 indicates the beginning of Pulse Raw Data.

 (35-34) = 0

 (33-32) = 0

 (31) = 1

 (30-27) = 6

 (26-23) = Channel number (0-7)

 (22-21) = pulse number (0-3)

 (20-10) = 0

 (9-0) = time from beginning of PTW that the pulse crossed thredshold

🡺 x”0B ChannelNumber 00 TIME”

3322 2222 2222 1111 1111 1198 7654 3210

1098 7654 3210 9876 5432 10

------------------------------------------------------

1011 0Cha nP#0 0000 0000 00Ti me-- ----

Remaining words for Pulse Raw Data and Window Raw Data have the same format.

 (35-34) = 0

 (33-32) = 0

 (31) = 0

 (30) = 0

(29) = 1 indicates sample x not valid

 (28-16) = ADC sample x (includes overflow bit)

 (15-14) = 0

(13) = 1 indicates sample x+1 not valid.

 (12-0) = ADC sample x+1 (includes overflow bits).

3322 2222 2222 1111 1111 1198 7654 3210

1098 7654 3210 9876 5432 10

------------------------------------------------------

00xA dcSa mple ---- 00xA dcSa mple ----

**Pulse Time** (8) – time associated with an identified pulse within the trigger window.

 (31) = 1

 (30 – 27) = 8

 (26 – 23) = channel number (0 – 15)

 (22 – 21) = pulse number (0 – 3)

 (20 – 19) = measurement quality factor (0 – 3)

 (18 - 16) = reserved (read as 0)

 (15 – 6) = coarse pulse time

 (5 – 0) = fine pulse time

3322 2222 2222 1111 1111 1198 7654 3210

1098 7654 3210 9876 5432 10

------------------------------------------------------

1100 0Cha nP#0 0000 Puls eTim e

**Pulse Integral** (7) – integral of an identified pulse within the trigger window. The pulse integral may be a simple sum of raw data samples over the pulse duration, or the result of a complex fit to pulse shape. Pedestal subtraction may be included.

 (31) = 1

 (30 – 27) = 7

 (26 – 23) = channel number (0 – 15)

 (22 – 21) = pulse number (0 – 3)

 (20 – 19) = measurement quality factor (0 – 3)

 (18 – 0) = pulse integral

 (20-0) = pulse integral

3322 2222 2222 1111 1111 1198 7654 3210

1098 7654 3210 9876 5432 10

 ------------------------------------------------------

 1011 1Cha nP#0 0Pul seIn tegr al

**Pulse Vmin Vpeak** (10) – ADC count for minimum and peak value of a pulse. This is too be used off line to apply correction to Pulse Time in TDC mode.

 (31) = 1

 (30 – 27) = 10

 (26 – 23) = channel number (0 – 15)

 (22 – 21) = pulse number (0 – 3)

 (20 – 12) = Vmin

 (11 – 0) = Vpeak

3322 2222 2222 1111 1111 1198 7654 3210

1098 7654 3210 9876 5432 10

 ------------------------------------------------------

 1101 0Cha nP#v minn nnn vpea kkkk kkkk

 D

**Event Trailer:** Indicate the end of an event.

 EVENT\_TRAILER = "0010" & X"E8000000";

Example:

Raw Data (mode0) :

 x”19\_\_\_\_\_” Event Header

 x”98\_\_\_\_\_ “ Time Stamp upper 24 bits.

 x”\_\_\_\_\_\_\_” Time Stamp lower 24 bits.

 x”A\_\_\_\_\_” Channel Number, Window Width (PTW)

 x”\_\_\_\_\_\_” Raw Data

 x”2E8000000” End of Event

Pulse Data (mode 1):

 x”19\_\_\_\_\_” Event Header

 x”98\_\_\_\_\_ “ Time Stamp upper 24 bits.

 x”\_\_\_\_\_\_\_” Time Stamp lower 24 bits.

 x”B\_\_\_\_\_\_” ChanNum(26-23), PulseNumb(22-21),Time from beginning of PTW that the pulse crossed thredshold(9-0).

 x”\_\_\_\_\_\_\_” 2 pulses (12-0) (28-16) per 36 bits words.

 x”2E8000000” End of Event

Pulse Sum (mode 2):

 x”19\_\_\_\_\_” Event Header

 x”98\_\_\_\_\_ “ Time Stamp upper 24 bits.

 x”\_\_\_\_\_\_\_” Time Stamp lower 24 bits.

 x”C\_\_\_\_\_\_” Pulse time, ChanNum(26-23), PulseNumb(22-21),Time(15-0)

 x”B8\_\_\_\_\_” Channel Numbe(26-23)r, Pulse Number(22-21), Pulse Integral (18-0)

 x”2E8000000” End of Event

TDC (mode 3):

 x”19\_\_\_\_\_” Event Header

 x”98\_\_\_\_\_ “ Time Stamp upper 24 bits.

 x”\_\_\_\_\_\_\_” Time Stamp lower 24 bits.

 x”C\_\_\_\_\_\_” Pulse time, ChanNum(26-23), PulseNumb(22-21),Time(15-0)

 x”D\_\_\_\_\_\_” ChanNum(26-23), PulseNumb(22-21),Vm(20-12),Vp(11-0)

 x”2E8000000” End of Event

Raw Data and TDC (mode 7)

 x”19\_\_\_\_\_” Event Header

 x”98\_\_\_\_\_ “ Time Stamp upper 24 bits.

 x”\_\_\_\_\_\_\_” Time Stamp lower 24 bits.

 x”A\_\_\_\_\_” Channel Number, Window Width (PTW)

 x”\_\_\_\_\_\_” Raw Data

 x”C\_\_\_\_\_\_” Pulse time

 x”D\_\_\_\_\_\_” VminVpeak

 x”2E8000000” End of Event

**Data Format VHDL:**

The VHDL code read data streams from processing block, format them per document "FADC Data Format" by Ed Jastrzembski. When all HOST\_BLOCKx\_CNT is greater then one, DATFORSM begins the write out algorithm. The algorithm is as follow:

 1) Pop the starting and last address of the data in the processing buffer.

 2) Load the starting adddress of Channel 0 to Address counter. Start FIFO clock. Inc Address counter on rising edge of FIFO clock.

 Output Address to PROCx\_ADR

 3) Read data from PROCx\_OUTDAT. Assemble them into Event Header, TimeStamp1, and TimeStamp2 and writes to FIFO.

 4) In mode 0, the Address is stop after TimeStamp2 address (5) to allow time to insert Window Raw Data Word 1 which contains Channel Number and Window Width.

 5) In mode 1 and mode 2, the Address is stop after Pulse Number and SampleNumber from Threshold Address (6), to allow time to assemble Pulse Raw Data Word 1 which contains Channel Number and

 first sample number for pulse or Pulse Time which contains Channel Number and pulse time.

 6) The data are read and write in pairs until the Address counter equal last address of the processing buffer. The channel are incremnent and repeats step 1 through 6.

 7) After the last channel is finish, Event Trailer is written to FIFO.

 Because of the different in the data format between the modes: 0,1,and 2, each mode has its own state machine.

 In mode 2, there might be extra words (for some setting of NSA and NSB) in the processing buffer after the last integral, the statemachine does not write this to FIFO.

 In mode 0 and 1, for even number of data, the number of data written to FIFO is 2 more, for odd number of data, the number of data written to FIFO is one more.

Data Streams from Processing for diferent modes:

 In mode 0: EventHeader, TimeStamp1, TimeStamp2, WindowRaw(not from processing), Deven Dodd,..., TimeEnd

 In mode 1: EventHeader, TimeStamp1, TimeStamp2, PulseRaw(upper 16 from processing, not lower 16), Deven Dodd,..., TimeEnd

 In mode 1: EventHeader, TimeStamp1, TimeStamp2, PulseRaw(upper 16 from processing, not lower 16), Integral, TimeEnd **Data Format VHDL Diagram**

FirstChannel

FIFO

DATA

“0001”

“0000”

Load

Mode

Chx

ChxFirstLastProcAdr

Fifo Clk Gen

Edge Detect

First Last Process Address

Adr Gen

Channel

Count

=ProcBufSize

R

ProcX\_ADR

=ProcBufSize

ChX\_Done

FIFO

CLK

ProcX

OutDat

Chx

UpperWd Valid

Word Hi

Word LO

Format

Assembler

Chx

Pulse Wd 1

Pulse Time

Format

Assembler

WinPulse Wd 2

Pulse Int

Event Header

Time Stamp

Event

Trailer

Qualifier

FIFO\_WEN

SelEventHeader

SelTimeStamp

MODE

FirstChannel

FIFO

WEN

**Data Format State Machine Main**

****

Main State Machine does the following:

1. Call State Machine for Mode 0,1,or 2.

**Data Format State Machine For Mode 0**

****

**Data Format State Machine RD For Mode 1**

****

**Data Format State Machine RD For Mode 2**

** SUM**

Resync Data

0

0

0

0

 **+**

12

12

12

12

Resync Data

ADC 5

ADC 6

ADC 7

ADC 8

 **+**

12

12

12

12

 **+**

14

14

D Q

15

**IOB**

**HIT BITS**

 -**VME FPGA IFACE:**

ADC1

12

Everage

12

**>**

8

ADC8

12

Average

12

**>**

D Q

**IOB**

Control Bus Memory Map for FADC FPGA

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Name  | Width (Bits) | Quantity | Access | Primary Address(SecondaryAddress) | Function  |
| STATUS0 | 16 | 1 | R | 0x0000(---) | Bits 14 to 0: Code VersionBit 15: 1= Command can be sent to AD9230 |
| STATUS1 | 16 | 1 | R | 0x0001(---) | TRIGGER NUMBER BIT 15 to 0 |
| STATUS2 | 16 | 1 | R | 0x0002(---) | Monitor Data For Debugging Purpose  |
| CONFIG 1 | 16 | 1 | R/W | 0x0003(---) | Bit 0-2 (process mode): 000 🡪 Select Mode 0 001 🡪 Select Mode 1 010 🡪 Select Mode 2 011 🡪 Select Mode 3 111 🡪 Run Mode 0 then Mode 3 for each triggerBit 3: 1:RunBit 5-4 : Number of Pulses in Mode 1 and 2Bit 7: Test Mode (play Back). Bit 11 to 8: Select which ADC Data channel to be read at Status 2.  |
| CONFIG 2 |  |  | R/W | 0x0004(---) | When 1 ADC values = 0Bit 0 🡪 ADC 0 Bit 1 🡪 ADC 1 Bit 2 🡪 ADC 2 Bit 3 🡪 ADC 3 Bit 4 🡪 ADC 4 Bit 5 🡪 ADC 5 Bit 6 🡪 ADC 6 Bit 7 🡪 ADC 7 Bit 8 🡪 ADC 8 Bit 9 🡪 ADC 9 Bit 10🡪 ADC 10 Bit 11🡪 ADC 11Bit 12🡪 ADC 12Bit 13🡪 ADC 13Bit 14🡪 ADC 14Bit 15🡪 ADC 15 |
| CONFIG 4 | 16 | 1 |  | 0x0005 | 7 => rising edge write to AD9230 ADC6 => 1 write to all ADC5 => 0 write to AD9230 1 read from AD9230 4 => 1 Reset ADC3..0 => Select ADC to write to |
| CONFIG 5 | 16 | 1 |  | 0x0006 | 15..8 => Registers inside AD92307..0 => Data to write to register. |
| PTW | 9 | 1 | R/W | 0x0007(---) | Number of ADC sample to include in trigger window.PTW = Trigger Window (ns) \* 250 MHz.**Minimum is 6**.**Always report Even Number. For odd PTW number, discard the last sample reported.** |
| PL | 11 | 1 |  | 0x0008(---) | Number of sample back from trigger point.PL = Trigger Window(ns) \* 250MHz |
| NSB | 12 | 1 |  | 0x0009(---) | 8..0: Read Back Path NSBNumber of sample before trigger point to include in data processing. This include the trigger Point. **Minimum is 2 in all mode.**12..9: Trigger Path NSB |
| NSA | 13 | 1 |  | 0x000A(---) | 8..0: Read Back Path NSANumber of sample after trigger point to include in data processing. **Minimum is (6 in mode 2)and ( 3 in mode 0 and 1). Number of sample report is 1 more for odd and 2 more for even NSA number.**14..9: Trigger Path NSA |
| TET | 12 | 16 |  | 0x000B -0x001A | Trigger Energy Thredhold. |
| PTW DAT BUF LAST ADR | 12 | 1 |  | 0x001B | Last Address of the Secondary Buffer. See calculation below |
| PTW MAX BUF | 8 | 1 |  | 0x001C | The maximum number of unprocessed PTW blocks that can be stored in Secondary Buffer. See Calculation below. |
| Test Wave Form | 16 | 1 |  | 0x001D | Write to PPG. Read should immediately follow write. |
| ADC0 Pedestal Subtract  | 16 | 1 | R/W | 0x001E | Subtract from ADC0 Count before Summing  |
| ADC1 Pedestal Subtract  | 16 | 1 | R/W | 0x001F | Subtract from ADC1 Count before Summing  |
| ADC2 Pedestal Subtract  | 16 | 1 | R/W | 0x0020 | Subtract from ADC2 Count before Summing  |
| ADC3 Pedestal Subtract  | 16 | 1 | R/W | 0x0021 | Subtract from ADC3 Count before Summing  |
| ADC4 Pedestal Subtract  | 16 | 1 | R/W | 0x0022 | Subtract from ADC4 Count before Summing  |
| ADC5 Pedestal Subtract  | 16 | 1 | R/W | 0x0023 | Subtract from ADC5 Count before Summing  |
| ADC6 Pedestal Subtract  | 16 | 1 | R/W | 0x0024 | Subtract from ADC6 Count before Summing  |
| ADC7 Pedestal Subtract  | 16 | 1 | R/W | 0x0025 | Subtract from ADC7 Count before Summing  |
| ADC8 Pedestal Subtract  | 16 | 1 | R/W | 0x0026 | Subtract from ADC8 Count before Summing  |
| ADC9 Pedestal Subtract  | 16 | 1 | R/W | 0x0027 | Subtract from ADC9 Count before Summing  |
| ADC10 Pedestal Subtract  | 16 | 1 | R/W | 0x0028 | Subtract from ADC10 Count before Summing  |
| ADC11 Pedestal Subtract  | 16 | 1 | R/W | 0x0029 | Subtract from ADC11 Count before Summing  |
| ADC12 Pedestal Subtract  | 16 | 1 | R/W | 0x002A | Subtract from ADC12 Count before Summing  |
| ADC13 Pedestal Subtract  | 16 | 1 | R/W | 0x002B | Subtract from ADC13 Count before Summing  |
| ADC14 Pedestal Subtract  | 16 | 1 | R/W | 0x002C | Subtract from ADC14 Count before Summing  |
| ADC15 Pedestal Subtract  | 16 | 1 | R/W | 0x002D | Subtract from ADC15 Count before Summing  |
|  |  |  |  |  |  |
| Config 3 | 16 | 1 | R/W | 0x002E | (11..0) Trigger Path Processing Threshold |
| STATUS 3 | 16 | 1 | R | 0x002F | FPGA core temp (DieTemp) |
| STATUS 4 | 16 | 1 | R | 0x0030 | FPGA V Internal (Vint) |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

PTW MAX BUF = INT(2016 / (PTW + 8))

 Where:

 2016 🡪 Number of address of Secondary Buffer

 PTW 🡪 Trigger Window width in nano-second

PTW DAT BUF LAST ADR = PTW MAX BUF \* (PTW + 8)- 1;

DieTempDieTemp 6 🡪 4 address for Time Stamp and 2 address for Trigger Number

 NumberOfBytePerTrigger 🡪 PTW \* 250 MHz.

**TrIgger Path NSB + Trigger Path NSA has to be less then 63.**

 **Temperature\_C = ((float)(DieTemp >> 6) \* 503.975/1024) - 273.15;**

 **VCC\_INT (Volts) = ((Vint >> 6) / 1024) x 3V**