

FADC125 OPERATION AND DATA FORMAT REQUIREMENT V4.1

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1. INTRODUCTION

This document specifies the data format produced by the JLab 125 MHz Flash ADC module (fADC125) and those of its operating modes which differ from the Flash 250 MHz ADC module (fADC250) [2]. All data produced by the fADC125 will be in the form of 32-bit words. The module will adhere to the overall format standard described in the document [1] produced and maintained by the JLab Data Acquisition group¹.

The fADC125 operating modes and data format follow those of the fADC250 [2] as closely as possible, modified where necessary for the drift chambers. The main differences are in the pulse data formats (types 7 to 9), which permit output of pulse time, pulse amplitude or integral and some quality factors in one pair of data words, the addition of a combined data format (types 10 and 11), which combines output of calculated pulse time and integral data with raw ADC data, and in the methods used to calculate the pulse time and integral. These are detailed later in this document. Common data types are listed for completeness.

2. DATA WORD CATEGORIES

Data words from the module are divided into two categories: Data Type Defining (bit 31 = 1) and Data Type Continuation (bit 31=0). Data Type Defining words contain a 4-bit data type tag (bits 30-27) along with a type dependent payload (bits 26-0). Data Type Continuation words provide additional data payload (bits 30-0) for the *last defined data type*. Continuation words permit data payloads to span multiple words and allow for efficient packing of raw ADC samples. Any number of Data Type Continuation words may follow a Data Type Defining word.

¹At the time of writing, an early form of the document [1] can be found online as GlueX-doc-2365 and a later draft can be found online at <https://halldweb1.jlab.org/wiki/images/5/58/JlabModuleDataFormat.pdf>. Much of the critical information has been reproduced in this document. Contact a member of the JLab DAQ group to obtain the most recent copy.

3. DATA TYPE TAGS

Data types 7 to 10 are specifically for the fADC125.

- 0:** block header
- 1:** block trailer
- 2:** event header
- 3:** trigger time
- 4:** window raw data (samples)
- 5:** – unused –
- 6:** pulse raw data (samples)
- 7:** pulse data (integral and time, CDC format)
- 8:** pulse data (integral and time, FDC format)
- 9:** pulse data (peak amplitude and time, FDC format)
- 10:** pulse data and pulse samples, CDC format
- 11:** pulse data and pulse samples, FDC format
- 12:** scaler data
- 13:** event trailer (debug only)
- 14:** data not valid (empty module)
- 15:** filler (non-data) word

4. DATA TYPES

Descriptions of the data types produced by the FADC125 follow:

Block Header (0): indicates the beginning of a block of events (High speed readout of the board or set of boards is done in blocks of events.)

- (31) = 1
- (30 - 27) = 0
- (26 - 22) = slot number (set by VME64x backplane)
- (21 - 18) = module ID (=2 for FADC125)
- (17 - 15) = data format (for future use in format specification)
- (14 - 8) = block number (incrementing scalar counting completed blocks)
- (7 - 0) = number of events in block (1-255)

Block Trailer (1): indicates the end of a block of events. The data words in a block are bracketed by the block header and trailer.

- (31) = 1
- (30 - 27) = 1
- (26 - 22) = slot number (set by VME64x backplane)
- (21 - 0) = total number of events in event block

Event Header (2): indicates the start of event specific data. The included event number is useful to ensure the proper alignment of event fragments when building

events. The 22-bit trigger number will roll over, but (4 M count) is not a limitation as it will be used to distinguish events within blocks, or among other events that are currently being built or transported.

- (31) = 1
- (30 - 27) = 2
- (26 - 22) = slot number (set by VME64x backplane)
- (21 - 0) = event number (trigger number)

Trigger Time (3): Time of trigger occurrence relative to the most recent global reset. Time is measured by a local counter/scaler that is clocked by the system clock or by a local module clock that may or may not have been synchronized with the system clock. In principle, a global reset signal is distributed to every module. The assertion of the global reset will clear the counters and inhibits counting. The de-assertion of the global reset enables counting and thus, sets $t=0$ for the module. The trigger time is necessary to ensure system synchronization and is useful for aligning event fragments when building events. For example, in the FADC250 there is a 48 bit counter (1 count = 4ns). The six bytes of the trigger time:

$$\text{Time} = T_A T_B T_C T_D T_E T_F$$

are reported in two words (Type Defining + Type Continuation). However, the module may be configured to *only* emit the first word (Type Defining) which contains the lower 24 bits of the trigger time. This should be sufficient for most cases and reduces the overall data size slightly.

Word 1:

- (31) = 1
- (30 - 27) = 3
- (26 - 24) = reserved (read as 0)
- (23 - 16) = T_D
- (15 - 8) = T_E
- (7 - 0) = T_F

Word 2:

- (31) = 0
- (30 - 24) = reserved (read as 0)
- (23 - 16) = T_A
- (15 - 8) = T_B
- (7 - 0) = T_C

Window Raw Data (4): raw ADC data samples of the whole trigger window are reported if at least one value is above the threshold TH for the particular channel. The first word indicates the channel and slot number and number of samples in the trigger window. Multiple continuation words contain two raw samples each. The

earlier sample is stored in the most significant half of the continuation word. Strict time ordering is maintained in the order of the continuation words. A *sample not valid* flag may be set for any sample; for example the last reported sample is tagged *not valid* when the pulse interval consists of an odd number of samples.

Word 1:

- (31) = 1
- (30 - 27) = 4
- (26 - 20) = channel number (0-71)
- (19 - 15) = slot number (set by VME64x backplane)
- (14 - 12) = reserved (read as 0)
- (11 - 0) = window width (in number of samples)

Word 2-N:

- (31) = 0
- (30) = reserved (read as 0)
- (29) = sample x not valid
- (28 - 16) = ADC sample x (includes overflow bit)
- (15 - 14) = reserved (read as 0)
- (13) = sample x+1 not valid
- (12 - 0) = ADC sample x+1 (includes overflow bit)

Pulse Raw Data (6): All the raw ADC data samples for an identified pulse are reported. The first word contains the channel number, the slot number and the sample number of threshold crossing (first sample above the threshold). For the rest of the words the same rules apply as for the Window Raw Data (4).

Word 1:

- (31) = 1
- (30 - 27) = 6
- (26 - 20) = channel number (0-71)
- (19 - 15) = slot number (set by VME64x backplane)
- (14 - 12) = reserved (read as 0)
- (11 - 0) = sample number of threshold crossing

Word 2-N:

- (31) = 0
- (30) = reserved (read as 0)
- (29) = sample x not valid
- (28 - 16) = ADC sample x (includes overflow bit)
- (15 - 14) = reserved (read as 0)
- (13) = sample x+1 not valid
- (12 - 0) = ADC sample x+1 (includes overflow bit)

Pulse Data (integral and time in CDC format) (7): Integral and time of an identified pulse within the trigger window.

Word 1:

- (31) = 1
- (30 - 27) = 9
- (26 - 20) = channel number (0-71)
- (19 - 15) = slot number (set by VME64x backplane)
- (14 - 4) = leading edge time
- (3) = time quality bit
- (2 - 0) = overflow count

Word 2:

- (31) = 0
- (30 - 23) = pedestal
- (22 - 9) = integral
- (8 - 0) = first max amplitude

Pulse Data (integral and time in FDC format) (8): Integral and time of an identified pulse within the trigger window.

Word 1:

- (31) = 1
- (30 - 27) = 7
- (26 - 20) = channel number (0-71)
- (19 - 15) = slot number (set by VME64x backplane)
- (14 - 12) = overflows
- (11 - 0) = integral

Word 2:

- (31) = 0
- (30 - 19) = leading edge time (in 800 ps time units)
- (18 - 11) = peak time (in samples)
- (10 - 0) = pedestal

Pulse Data (peak amplitude and time in FDC format) (9): The only difference compared to the previous type is that we have the peak amplitude instead of the integral.

Word 1:

- (31) = 1
- (30 - 27) = 8
- (26 - 20) = channel number (0-71)
- (19 - 15) = slot number (set by VME64x backplane)
- (14 - 12) = overflows
- (11 - 0) = peak amplitude

Word 2:

- (31) = 0
- (30 - 19) = leading edge time (in 800 ps time units)
- (18 - 11) = peak time (in samples)
- (10 - 0) = pedestal

Pulse Data and Pulse Samples, CDC format (10): The integral and time of an identified pulse are reported, followed by all the samples within the pulse window. This essentially combines the data from types 6 and 7 by appending the samples as continuation words to the extracted pulse parameters. The one difference is that the first sample number (identifying the threshold crossing) is not recorded here as it is for data type 6. However, one can use the extracted pulse time and peak time to find where the pulse lies within the window. See notes for data types 6 and 7 for details. This data type is needed only for diagnostics.

Word 1:

- (31) = 1
- (30 - 27) = 10
- (26 - 20) = channel number (0-71)
- (19 - 15) = slot number (set by VME64x backplane)
- (14 - 4) = leading edge time
- (3) = time quality bit
- (2 - 0) = overflow count

Word 2:

- (31) = 0
- (30 - 23) = pedestal
- (22 - 9) = integral
- (8 - 0) = first max amplitude

Word 3-N:

- (31) = 0
- (30) = reserved (read as 0)
- (29) = sample x not valid
- (28 - 16) = ADC sample x (includes overflow bit)
- (15 - 14) = reserved (read as 0)
- (13) = sample x+1 not valid
- (12 - 0) = ADC sample x+1 (includes overflow bit)

Pulse Data and Pulse Samples, FDC format (11): The integral and time of an identified pulse are reported, followed by all the samples within the pulse window. This essentially combines the data from types 6 and 7 by appending the samples as continuation words to the extracted pulse parameters. The one difference is that the first sample number (identifying the threshold crossing) is not recorded here as it is for data type 6. However, one can use the extracted pulse time and peak time to find where the pulse lies within the window. See notes for data types 6 and 7 for details. This data type is needed only for diagnostics.

Word 1:

- (31) = 1
- (30 - 27) = 10
- (26 - 20) = channel number (0-71)
- (19 - 15) = slot number (set by VME64x backplane)
- (14 - 12) = overflows
- (11 - 0) = integral

Word 2:

- (31) = 0
- (30 - 19) = leading edge time (in 800 ps time units)
- (18 - 11) = peak time (in samples)
- (10 - 0) = pedestal

Word 3-N:

- (31) = 0
- (30) = reserved (read as 0)
- (29) = sample x not valid
- (28 - 16) = ADC sample x (includes overflow bit)
- (15 - 14) = reserved (read as 0)
- (13) = sample x+1 not valid
- (12 - 0) = ADC sample x+1 (includes overflow bit)

Scaler Header (12): Indicates the beginning of a block of scaler data words. The number of scaler words to follow is given in the header.

(31) = 1
 (30 - 27) = 12
 (26 - 10) = reserved (read as 0)
 (9 - 0) = number of scaler words to follow

Word 2-N:

(31) = 0
 (30 - 0) = scaler counts

Event Trailer (13): (suppressed for normal readout - debug mode only) last word from ADC processing chip for event

(31) = 1
 (30 - 27) = 13
 (26 - 22) = slot number (set by VME64x backplane)
 (21 - 0) = undefined

Data Not Valid (14): module has no data available for read out, or there is an error condition in the module that will not allow it to transfer data.

(31) = 1
 (30 - 27) = 14
 (26 - 22) = slot number (set by VME64x backplane)
 (21 - 0) = undefined

Filler Word (15): non-data word appended to the block of events. Forces the total number of 32-bit words read out of the module to be a multiple of 2 or 4 when 64-bit or 2e VME block transfers are used.

(31) = 1
 (30 - 27) = 15
 (26 - 22) = slot number (set by VME64x backplane)
 (21 - 0) = undefined

5. CONFIGURATION CONSTANTS FOR THE CDC

The configuration constants are described in Table 1. These will be programmable through the VME backplane. Unless otherwise noted, they are common for all channels. Note that the sample period is 8 ns and the ADC units are 12 bits, 0-4095.

TABLE 1. List of configuration constants, CDC

Name	Description	Units	Default
WS	Hit search window start relative to the trigger arrival time	samples	0
WE	Hit search window end relative to the trigger arrival time	samples	100
NP	Number of samples to be used for pedestal ending with sample WS-1	samples	4
H 0-71	Hit threshold for each channel	ADC units	80
TH 0-71	High timing threshold for each channel	ADC units	64
TL 0-71	Low timing threshold for each channel	ADC units	16
IS	Integration start offset Integration starts IS samples before the hit threshold crossing	samples	3
IE?	Integration end? The CDC has a variable integration period ending at WE. I think the FDC might have a fixed integration period. We could use one rule for both if the integration stops at the earlier of (hit-threshold crossing + IE) and WE If this doesn't work then we don't need IE here, just use WE for CDC.	samples	WE

6. TIMING ALGORITHM CONFIGURATION CONSTANTS

The configuration constants for the timing algorithm are described in Table 2. These will be programmable through the VME backplane. They are common for all channels.

TABLE 2. List of configuration constants, CDC

Name	Description	Units	Default
NS	Number of samples (subset) to send to the time-finding module	samples	14
TS	Position in subset of first sample above hit-threshold H	samples	8
LP	Position in subset of sample to be used as local pedestal	samples	4
RT	If ADC values do not exceed high threshold TH _n return hit time of TS - RT	sample/10	20

TABLE 3. List of extra configuration constants which might be workable for both CDC and FDC, if the FDC format had the time (12 bits) and overflow (3 bits) moved into the first word. For the CDC these would be fixed.

Name	Description	Default for CDC (bits)
IBIT	2^{IBIT} scale factor for integral	4
ABIT	2^{ABIT} scale factor for first signal amplitude	3
PBIT	2^{PBIT} scale factor for pedestal	0
IW	width of field for integral	14
AW	width of field for signal amplitude	9
PW	width of field for pedestal	9
IPOS	start position in word 2 for integral	30
APOS	start position in word 2 for amplitude	22
PPOS	start position in word 2 for pedestal	8

7. CDC PULSE ANALYSIS

Pulse analysis is activated by the trigger signal and performs a search through the raw sample data buffered in the fADC to identify a hit signal. It uses several thresholds which can be related to the pedestal standard deviation, σ . These are determined during calibration and uploaded into the fADC firmware as constants. Values optimized using the small prototype are available as a starting point: hit identification threshold $H \sim 5\sigma$, high timing threshold $TH \sim 4\sigma$, low timing threshold $TL \sim \sigma$ and local pedestal lead time $LP \sim 4$ for σ of 15.

The hit search window, WS to WE , specifies the range of samples to be searched for a hit, relative to the trigger signal. Following the trigger arrival, analysis proceeds as follows:

- (1) The event pedestal, P_{evt} , is found, as the mean of NP samples ending at sample $WS - 1$. This is implemented by summing the samples and right-shifting, so NP must be a power of 2.
- (2) The samples within the hit search window are searched for a hit, which is found if the data exceed a high threshold $P_{evt} + H$ at point x . If no hit is found, no further action is taken.
- (3) The local pedestal, P_{loc} , is obtained as the ADC value at LP samples before x .
- (4) A small number NS of consecutive samples surrounding sample x are sent to the time-finding module, described later.
- (5) The integrated signal is calculated, starting with sample $x - IS$ and subtracting P_{loc} from each sample, and ending with the earlier of WE and $x + IE$.
- (6) A count of the number of samples during the integration period is made, until the count exceeds 6.
- (7) The signal is scanned starting with sample x for the first maximum in value.

If a pulse is found, the following quantities are returned:

- (1) **Time** Leading edge time in units of sample/10
- (2) **Time Quality Factor** Set to 0 if time is good, 1 if time is a rough estimate
- (3) **Overflow count** Count of number of overflows between start of pulse and WE, set to 7 if more than 6 are found
- (4) **Pedestal** Pedestal immediately before the start of pulse, right-shifted $IBIT$ bits (CDC: no right-shift), all bits set if $> 2^{PW} - 1$
- (5) **Integral** Signal integral from start of pulse to WE, right-shifted $IBIT$ bits, all bits set if the integral exceeds $2^{IBIT} - 1$
- (6) **First maximum amplitude** First maximum in signal between start of pulse and WE, right-shifted $ABIT$ bits

8. LEADING EDGE TIME ALGORITHM

- (1) A small subset NS of consecutive samples surrounding the threshold crossing sample are sent to the time-finding module, with the threshold crossing sample in place TS (starting with sample 0).
- (2) The algorithm searches through the samples starting from sample $LP + 1$ to find sample x_h , where the ADC value first exceeds or equals the high timing threshold, $P_{loc} + TH$. If this is not found, the algorithm returns an error code and the value of $10(x_h - RT)$. The value of RT is set in configuration parameters.
- (3) It then searches the samples from x_h back toward LP to find sample x_l , where the ADC value is less than or equal to the low timing threshold, $P_{loc} + TL$.
- (4) The ADC data are upsampled by a factor of 5 to calculate values at $1.6 ns$ intervals, from $x_l - 0.2$ to $x_l + 1.2$.
- (5) The upsampled values are searched from $x_l + 1.2$ down to $x_l - 0.2$ to find the point where the values fall equal to or below $P_{loc} + TL$, and then interpolated to find the threshold crossing to the nearest tenth of a sample. This quantity is returned by the algorithm as an integer.

9. PROGRAMMABLE PARAMETERS, FDC

The programmable parameters are described in Table 4. We assume they will be accessible through the VME backplane.

TABLE 4. List of Programmable parameters, FDC

Name	Description	Units
BW	trigger window beginning	8 ns samples
NW	trigger window width	8 ns samples
TH1-TH72	72 thresholds for each channel	12-bit ADC units
NSB	beginning of pulse window w.r.t. threshold crossing	8 ns samples
NSA	end of pulse window w.r.t. threshold crossing	8 ns samples
NSE	absolute end of pulse window	8 ns samples
IBIT	2^{IBIT} scale factor for integral	bits
PBIT	2^{PBIT} scale factor for pedestal	bits

All the quantities in the text abbreviated with capital letters are assumed to be programmable parameters. Unless otherwise noted, these parameters are common for all the channels.

10. PULSE ANALYSIS, FDC

The pulse detection is very similar to the algorithm described in [2]. Important difference is that we require identification only of the first pulse, as defined below.

The trigger window is defined by its beginning, BW, backwards with respect to the trigger time and width, NW, both in 8 ns samples. The samples within the window are numbered from 1 to NW.

The pulse identification is initiated if within the trigger window, there's at least one sample above the threshold, TH, programmed individually for each channel. The pulse window starts NSB samples before the threshold crossing and ends at NSA samples after the threshold crossing, so that the total width is NSB+NSA samples. In case of the CDC mode of operation, the end of the pulse window is fixed, at the NSE sample number within the trigger window. As in case of fADC250, if these limits are outside of the trigger window, the corresponding trigger window limit defines the pulse window.

We specify the extraction of the pulse parameters as follows:

Integral: sum over the pulse window shifted right by IBIT bits (i.e. divided by 2^{IBIT}).

Overflows: number of samples with overflowed values within the pulse window, or 7 if bigger than 7.

Peak amplitude: absolute maximum within the pulse window.

Peak time: sample number of the maximum.

Leading edge time: see the algorithm described below.

Pedestal: calculated by summing PS samples starting from sample number PB within the trigger window. The sum is shifted right by PBIT bits and reported as a pedestal.

REFERENCES

- [1] "VME Data Format Standards for JLab Modules" GlueX-doc-2365 <http://argus.phys.uregina.ca/cgi-bin/public/DocDB/ShowDocument?docid=2365> and also a more recent version at <https://halldweb1.jlab.org/wiki/images/5/58/JlabModuleDataFormat.pdf>
- [2] E.Jastrzembki, H.Dong "Summary of the FADC250 Operating Modes" 2/18/2014