DAQ data structure for the Muon g-2 experiment

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Abstract

This document outlines the DAQ data structure of the Muon g-2 experiment. A detailed list of the MIDAS data bank will be shown and their contents will described.

Contents

1 Introduction

1.1 Data unpacking in a nutshell

The basic idea of data unpacking is to convert compact DAQ information stored in MIDAS banks to well-structured data products, as depicted in Fig. 1. Several unpackers are used to decode the information stored in MIDAS banks and the outputs are stored in different data products which are basically structs in C++ language.

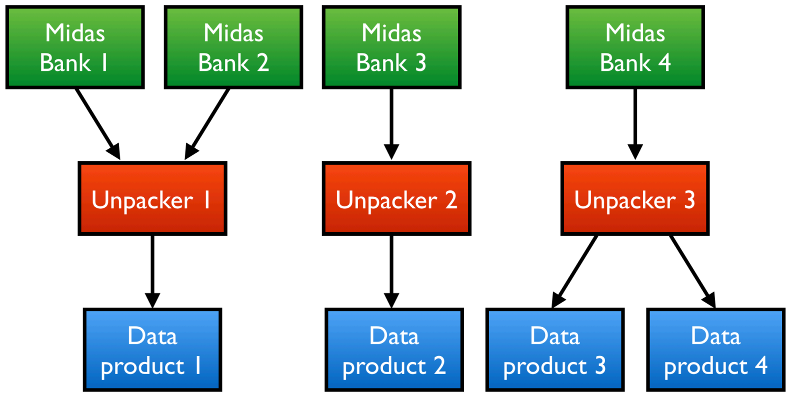


Figure 1: *Simplified diagram of the flow of the data unpacking.*

1.2 MIDAS DAQ output in a nutshell

The main DAQ framework for the Muon g-2 experiment is based on MIDAS [1]. MIDAS event structure is as depicted in Fig. 2.

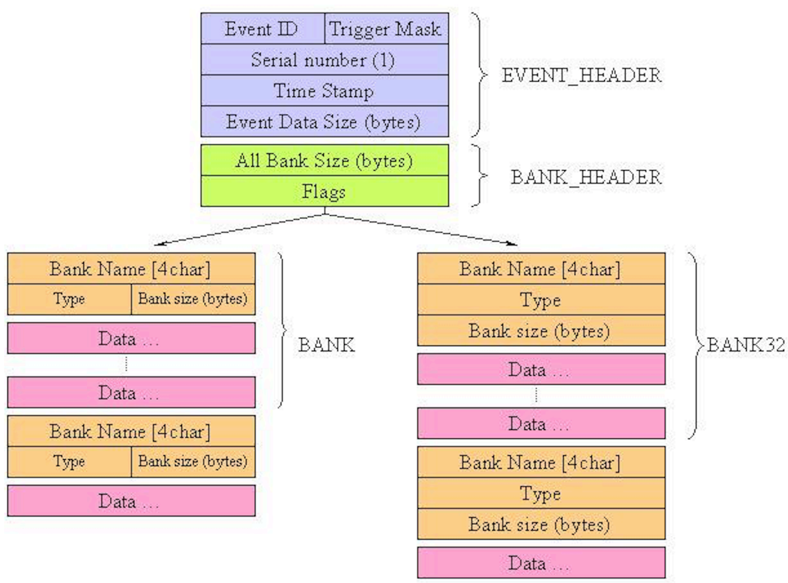


Figure 2: *MIDAS event structure. Each event has its header that is followed by the bank header. Then all the banks will appear according the defined order.*

2 MIDAS Bank list

Hundred of banks will be stored in each MIDAS event and it is very important to classify them properly. At the moment they can be grouped into 4 categories: calorimeter, auxiliary detector, CCC and magnetic field. Naming of these banks will be described in this section and their contents will be explained in the next section.

2.1 Calorimeter-related banks

There are 3 fill types for the calorimeter. `Muon` fill is the typical muon events, laser fill is event dedicated for laser calibration and monitoring events and pedestal fill is trivia from its name. Data from each fill type is identified from the bank name. The muon fill is denoted by "**C**", the laser fill is denoted by "**L**" and the pedestal fill is denoted by "**P**". A summary of the banks is listed in Tab. 1.

Table 1: *MIDAS bank list for the calorimetry data.*

muon fill	laser fill	pedestal fill	Description
Bank name			
CA	LA	PA	AMC13 Header
CB	LB	PB	WFD5 header
CC	LC	PC	GPU timing data
CF	LF	PF	GPU fitted data
CH	LH	PH	per-crystal Q-method data (N-th event, end of run)
CL	LL	PL	Clock data
CP	LP	PP	Pedestal
CQ	LQ	PQ	per-calo Q-method data (every event)
CR	LR	PR	WFD5 raw data
CT	LT	PT	T-method islands
CZ	LZ	PZ	AMC13 CDF trailers

Since each bank has to be named exactly four characters, the last 2 characters denoted the calorimeter number, e.g. **CT03** means the T-method bank from calorimeter number 3. Hence the number 01-24 are reserved for the calorimeters and 25 is reserved for the laser system.

2.2 Auxiliary detector-related banks

A separate T/Q-method is needed for auxiliary detectors. Their data banks are denoted with the initial "**K**". A list of these banks are summarized in Tab. 2.

Table 2: *MIDAS bank list for auxiliary T/Q data. This is mainly for the fiber harps, quads and kickers.*

Bank name	Description
KH	Per aux. detector channel Q-method data (N-th event, end of run)
KQ	Per aux. detector Q-method data (every event)
KT	T-method data

The last 2 characters of the bank name will be decided soon.

2.3 CCC related banks

This is the bank storing the information regarding the CCC system based on FC7. A list of these banks are summarized in Tab. 3.

Table 3: *MIDAS bank list for the CCC data.*

TTCA	AMC13 Header
TTCR	CCC AMC13 Payload
TTCZ	AMC13 Trailer

2.4 Field related banks

All field-team banks are filled once per event and the definition of an event is different from the one of the ω_a related banks. For many field-team banks, a c struct is defined in the `field_struct.hh` file, accessible for all frontends and unpackers. Programmers should able to cast the read-out bank (array of bytes) onto a pointer of the corresponding struct. A midas bank can be an entire struct (like **TLNP**, **ABPR**, etc) or a array of structs (like **GALI**). A list of these banks are summarized in Tab. 4.

Table 4: *MIDAS bank list for the magnetic field related data.*

System	Name	Description
Fixed probe	FXPR	Fixed probe, header + NMR waveforms
Trolley	TLNP	Trolley NMR Pulse, header + NMR waveforms
	TLBC	Trolley Barcode, header + Barcode waveforms
	TLMN	Trolley Monitors (temperatures, voltages and pressure), header + voltage waveforms
	GALI	Galil (trolley and garage) data, positions + velocities + control voltages + tensions
Absolute probes	ABPR	Absolute probe (spherical probe and plunging probe are using the same bank), header + NMR waveforms
Flux gate	FLUX	Flux gate, fluxgate waveforms
Surface coil	SFCL	Surface coil, current readouts

3 Bank contents

This section details contents of each MIDAS bank. All the banks are packed in 32-bit word integer regardless of the original format.

3.1 Calorimeter-related banks

CA (LA, PA) banks

This is the bank for the AMC13 to DAQ header information. The first 64-bit word is the CDF header and the next 64-bit word is the payload header as shown in Fig. 3.

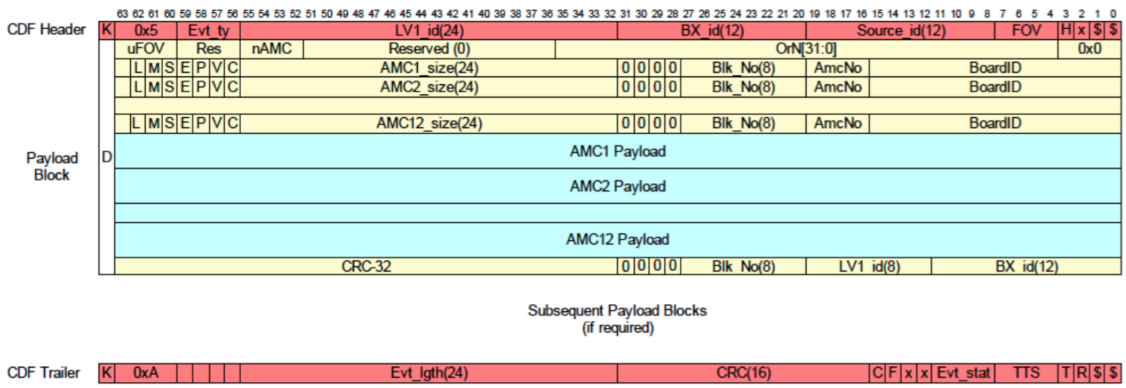


Figure 3: *Data structure for AMC13 to DAQ. The first 2 64-bit words are stored in the CA (LA, PA) bank.*

CZ (LZ, PZ) banks

This is the bank for the AMC13 to DAQ trailer information. The first 64-bit word is the last 64-bit word of the payload block and the next 64-bit word is the CDF trailer as shown in Fig. 3.

CB (LB, PB) banks

This is the bank for the WFD5 to AMC13 header information as shown in Fig. 4.

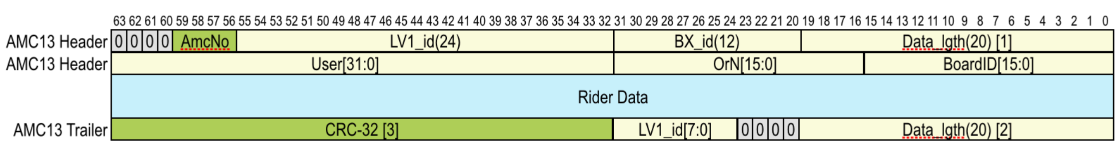


Figure 4: *Data structure for Rider to AMC13.*

CR (LR, PR) banks

This is the bank for the full WFD5 payload as shown in Fig. 5. Due to the huge data size of raw payload, a pre-scale of about 1000 event is usually being set in the MIDAS ODB.

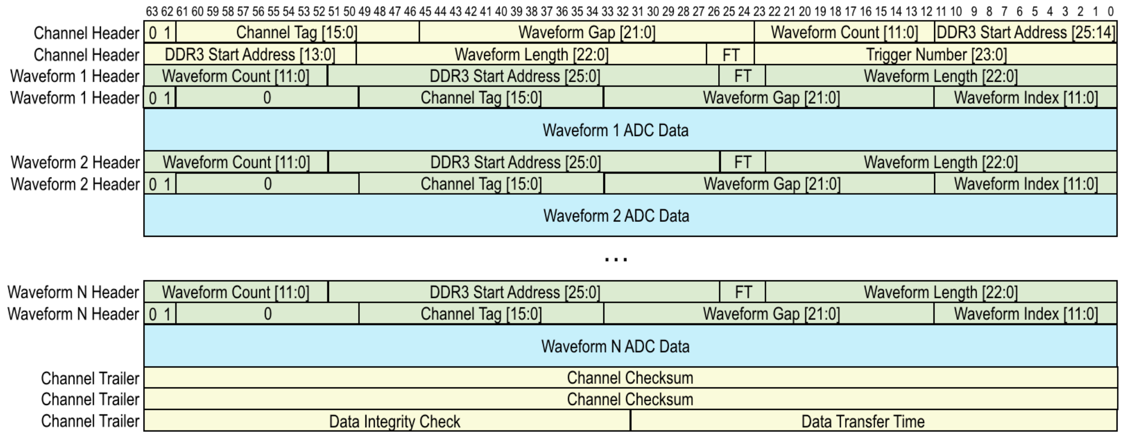


Figure 5: *Data structure for the WFD5 raw payload.*

CT (LT, PT) banks

This is the bank for calorimeter T-method chopped islands. A collection of 54 islands from 54 crystals/segments are extracted per trigger. The detailed structure is shown in Fig. 6.

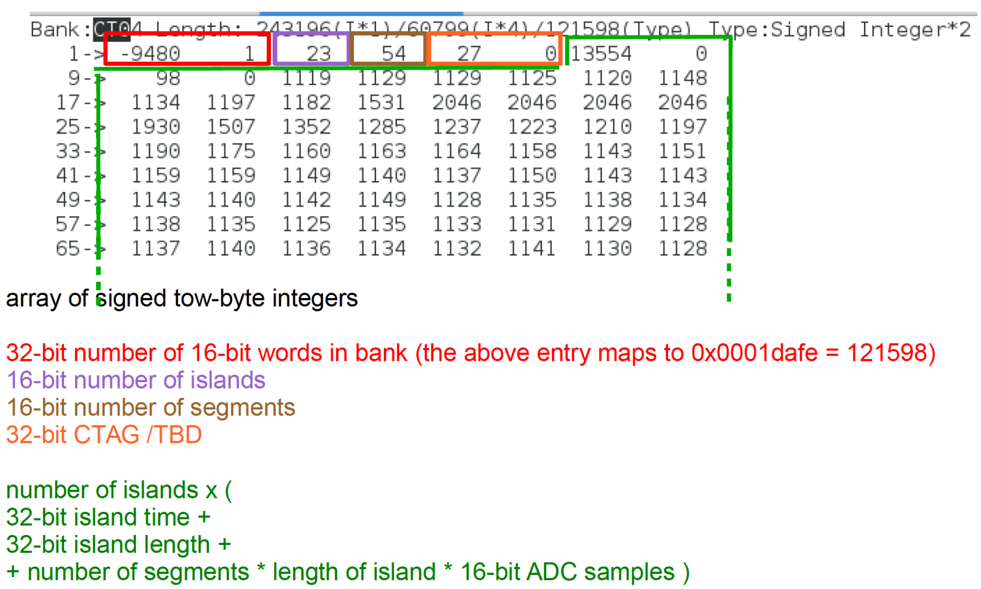


Figure 6: *Data structure for the CT bank (T-method chopped islands).*

CH (LH, PH) banks

This is the bank for calorimeter segment histograms. Histogram from each segment is being summed to itself each fill and is flushed out every N-th event. The detailed structure is shown in Fig. 7.

CQ (LQ, PQ) banks

This is the bank for calorimeter sum histograms. Histograms from all segments are summed together and decimated, and then are being flushed out every fill. The detailed structure is

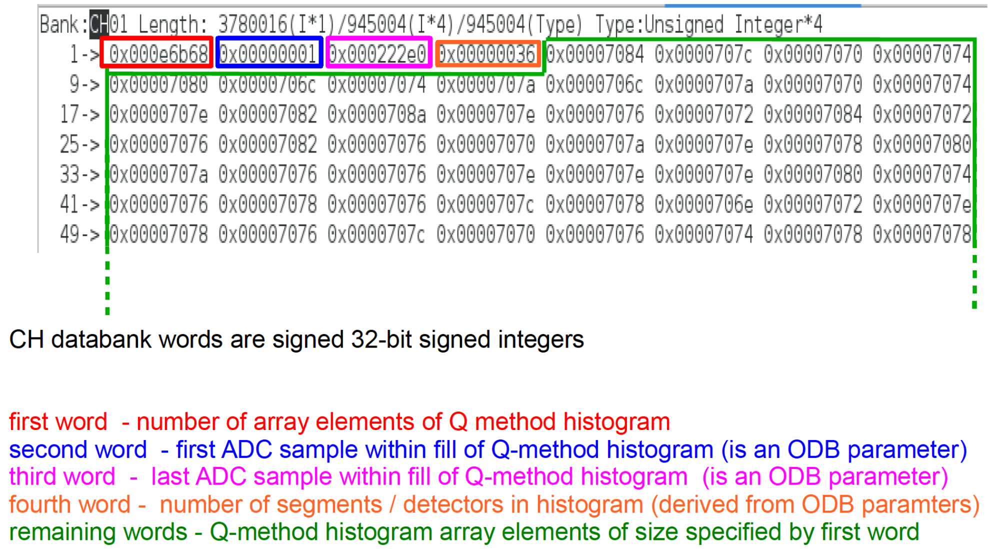


Figure 7: *Data structure for the CH bank (calo segment histograms).*

shown in Fig. 8.

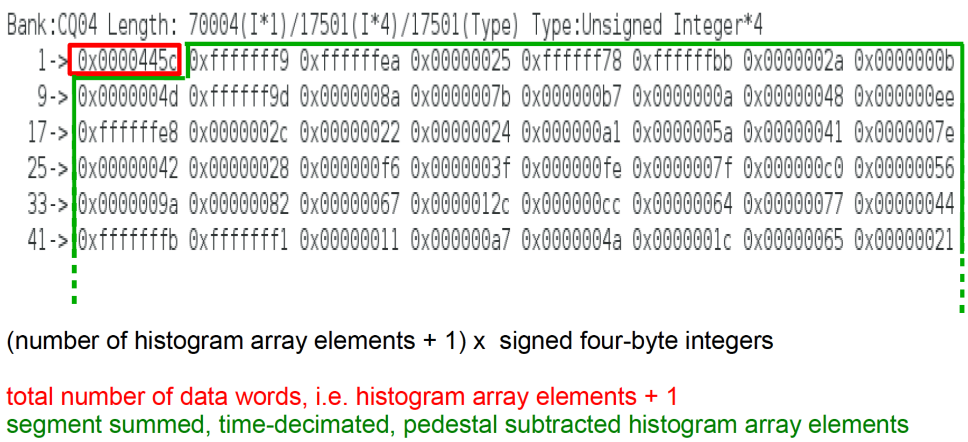


Figure 8: *Data structure for the CQ bank (calo sum histograms).*

CP (LP, PP) banks

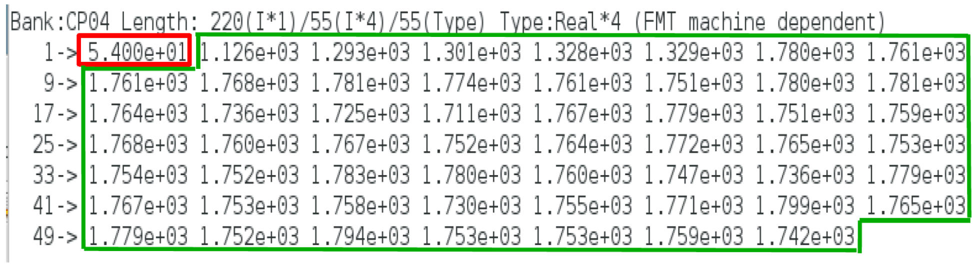
This is the bank for calorimeter pedestals. The detailed structure is shown in Fig. 9.

CC (LC, PC) banks

This is the bank for the calorimeter DAQ performance related information. It has information like tcp timing and gpu timing. The detailed structure is shown in Fig. 10.

CR (LR, PR) banks, asynchronous

This is the bank for the WFD5 payload in the asynchronous mode. The detailed structure is shown in Fig. 11.

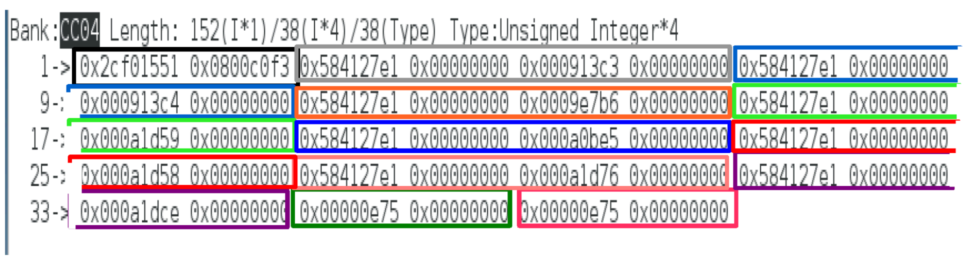


```
Bank:CP04 Length: 220(I*1)/55(I*4)/55(Type) Type:Real*4 (FMT machine dependent)
  1-> 5.400e+01 1.126e+03 1.293e+03 1.301e+03 1.328e+03 1.329e+03 1.780e+03 1.761e+03
  9-> 1.761e+03 1.768e+03 1.781e+03 1.774e+03 1.761e+03 1.751e+03 1.780e+03 1.781e+03
 17-> 1.764e+03 1.736e+03 1.725e+03 1.711e+03 1.767e+03 1.779e+03 1.751e+03 1.759e+03
 25-> 1.768e+03 1.760e+03 1.767e+03 1.752e+03 1.764e+03 1.772e+03 1.765e+03 1.753e+03
 33-> 1.754e+03 1.752e+03 1.783e+03 1.780e+03 1.760e+03 1.747e+03 1.736e+03 1.779e+03
 41-> 1.767e+03 1.753e+03 1.758e+03 1.730e+03 1.755e+03 1.771e+03 1.799e+03 1.765e+03
 49-> 1.779e+03 1.752e+03 1.794e+03 1.753e+03 1.753e+03 1.759e+03 1.742e+03
```

(number of segments + 1) x four bytes float format

number of segments
number of segments x pedestal values

Figure 9: *Data structure for the CP bank (T-method pedestals).*



```
Bank:CC04 Length: 152(I*1)/38(I*4)/38(Type) Type:Unsigned Integer*4
  1-> 0x2cf01551 0x0800c0f3 0x584127e1 0x00000000 0x000913c3 0x00000000 0x584127e1 0x00000000
  9-> 0x000913c4 0x00000000 0x584127e1 0x00000000 0x0009e7b6 0x00000000 0x584127e1 0x00000000
 17-> 0x000a1d59 0x00000000 0x584127e1 0x00000000 0x000a0be5 0x00000000 0x584127e1 0x00000000
 25-> 0x000a1d58 0x00000000 0x584127e1 0x00000000 0x000a1d76 0x00000000 0x584127e1 0x00000000
 33-> 0x000a1dce 0x00000000 0x00000e75 0x00000000 0x00000e75 0x00000000
```

array of 64-bit words (sec, usecs are obtained from gettimeofday() and struct timeval in sys/time.h

64-bit CDF header word
TCP proc unlocked / started, first 64-bit word is seconds, second 64-bit word is usecs
got TCP header word, first 64-bit word is seconds, second 64-bit word is usecs
got TCP header word, first 64-bit word is seconds, second 64-bit word is usecs
GPU proc unlocked / started , first 64-bit word is seconds, second 64-bit word is usecs
GPU copy done , first 64-bit word is seconds, second 64-bit word is usecs
GPU proc done , first 64-bit word is seconds, second 64-bit word is usecs
MFE proc unlocked, first 64-bit word is seconds, second 64-bit word is usecs
MFE banks made, first 64-bit word is seconds, second 64-bit word is usecs
current TCP fill number
current GPU fill number

Figure 10: *Data structure for the CC bank (calo performance).*

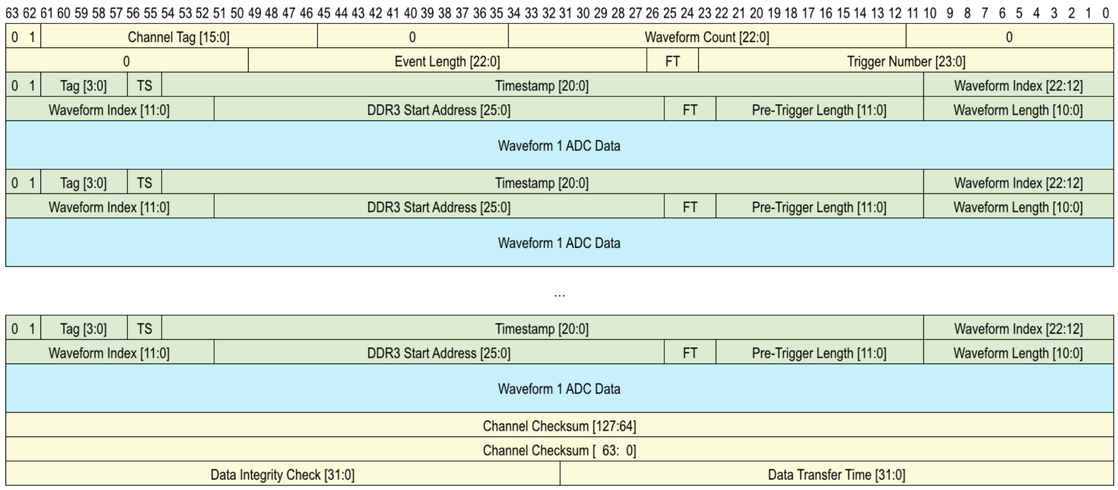


Figure 11: *Data structure for asynchronous mode for Rider.*

3.2 Auxiliary detector-related banks

KH and KQ banks

These two banks have the same format as the CH and CQ banks.

KT bank

This bank has the same format as the CT bank.

3.3 CCC related banks

TTCA, TTCR, TTCZ banks

TTCA bank will have the same format as the CA bank in the calorimeter-related data since the uTCA crate has the same data format. TTCZ on the other hand will have the same format as the CZ bank.

There are two types of TTCR banks for the FC7 - encoder and fanout. The data format of the encoder and fanout FC7 are shown in Fig. 12 and Fig. 13. respectively.

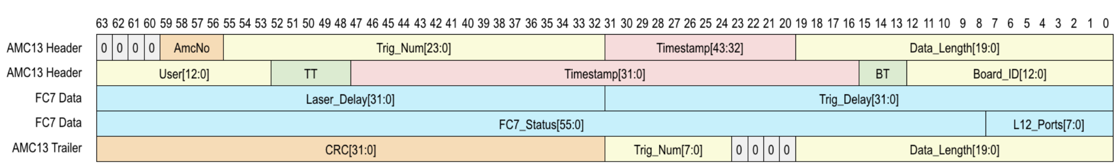


Figure 12: *Data structure for encoder FC7.*

3.4 Field related banks

FXPR bank

This is the bank for fixed probes. It consists of a header and NMR waveforms. Structure of the FXPR bank is summarized in Tab. 5 and its macros are summarized in Tab. 6.

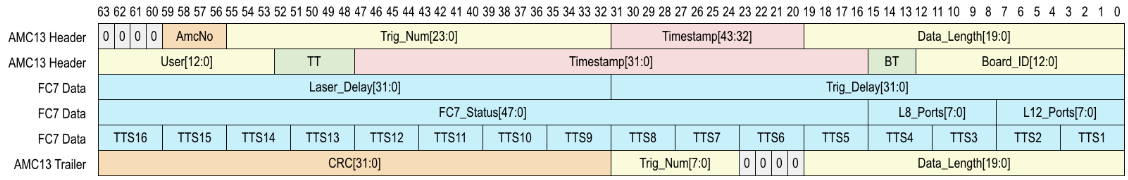


Figure 13: *Data structure for fanout FC7.*

Table 5: *MIDAS bank structure for the FXPR bank.*

start word index	type	array length	field name	content	struct name
0	Double_t	num_ch	sys_clock	system clock	fixed_t
4*num_ch	Double_t	num_ch	gps_clock	gps clock	
8*num_ch	Double_t	num_ch	dev_clock	device clock	
12*num_ch	Double_t	num_ch	snr	signal to noise ratio	
16*num_ch	Double_t	num_ch	len	length of each wave form	
20*num_ch	Double_t	num_ch	freq	frequency extracted	
24*num_ch	Double_t	num_ch	ferr	frequency error	
28*num_ch	Double_t	num_ch	freq_zc	frequency extracted, zero crossing	
32*num_ch	Double_t	num_ch	ferr_zc	frequency error, zero crossing	
36*num_ch	UShort_t	num_ch	health	health indicator of probes	
37*num_ch	UShort_t	num_ch	method	frequency extraction method	
38*num_ch	UShort_t	num_ch * rec_len	trace	NMR waveforms: Waveform_Ch1 + Waveform_Ch2 + ... + Waveform_Ch6	

Table 6: *Hard-coded macros in the FXPR bank.*

Name in the code	Name in this doc	Value
NMR_NUM_FIXED_PROBES	num_ch	378
NMR_FID_LENGTH_RECORD	rec_len	10000

TLNP bank

This is the bank for Trolley NMR pulses. It consists of a header and NMR waveforms. Structure of the TLNP bank is summarized in Tab. 7 and its macros are summarized in Tab. 8.

Table 7: *MIDAS bank structure for the TLNP bank.*

start word index	type	array length	field name	content	struct name
0	ULong64_t	1	gps_clock	Time stamp of the first NMR sample	trolley_nmr_t
4	UShort_t	1	probe_index	probe index	
5	UShort_t	1	length	length of the NMR waveform	
6	Short_t	nmr_len	trace	Trolley Probe NMR wavefrom	

Table 8: *Hard-coded macros in the TLNP bank.*

Name in the code	Name in this doc	Value
TRLY_NMR_LENGTH	nmr_len	24000

TLBC bank

This is the bank for Trolley barcode readers. It consists of a header and barcode waveforms. Structure of the TLBC bank is summarized in Tab. 9 and its macros are summarized in Tab. 10.

Table 9: *MIDAS bank structure for the TLBC bank.*

start word	index	type	array length	field name content	struct name
0	ULong64_t	1	gps_clock	Time stamp of the first barcode sample	trolley_barcode_t
4	UShort_t	1	length_per_ch	length of the barcode waveform per channel	
5	UShort_t	bc_ch*bc_len	traces	Barcode wavefroms: Waveform_Ch1 + Waveform_Ch2 + ... + Waveform_Ch6	

TLMN bank

This is the bank for Trolley monitors. It consists of information like temperatures, voltages and pressures. Structure of the TLMN bank is summarized in Tab. 11 and its macros are summarized in Tab. 12.

Table 10: *Hard-coded macros in the TLBC bank.*

Name in the code	Name in this doc	Value
TRLY_BARCODE_LENGTH	bc_len	3000
TRLY_BARCODE_CHANNELS	bc_ch	6

GALI bank

This is the bank for trolley and garage data. It has information like the trolley positions and velocities. Structure of the GALI bank is summarized in Tab. 13 and 14, and its macros are summarized in Tab. 15.

ABPR bank

This is the bank for absolute probe data. Both spherical probe and plunging probe are using the same bank. It has information like the header and NMR waveforms. Structure of the ABPR bank is summarized in Tab. 16.

FLUX bank

This is the bank for the fluxgate. It has information like the fluxgate waveforms. Structure of the FLUX bank is summarized in Tab. 17 and its macros are summarized in Tab. 18.

SFCL bank

This is the bank for the surface coil. It has the information like current readouts from the surface coils. Structure of the SFCL bank is summarized in Tab. 19 and its macros are summarized in Tab. 20.

[1]Note: the length of the NMR waveform is not fixed from event to event. For each event, its length is determined by the "length" field of the "absolute_nmr_info_t" struct in the header section.

Table 11: *MIDAS bank structure for the TLMN bank.*

start word index	type	array length	field name	content	struct name
0	ULong64_t	1	gps_clock_cycle_start	Time stamp of the measurement cycle	trolley_monitor_t
4	UInt_t	1	PMonitorVal	Pressure Monitor readout value	
6	Uint_t	1	PMonitorTemp	Pressure Monitor temperature	
8	Uint_t	1	RFPower1	RF Power monitor 1	
10	Uint_t	1	RFPower2	RF Power monitor 2	
12	Uint_t	1	NMRCheckSum	NMR waveform check sum, calculated by trolley inerface	
14	Uint_t	1	FrameCheckSum	Frame data check sum, calculated by trolley interface	
16	Uint_t	1	FrameSum	Frame data sum calculated by DAQ	
18	Uint_t	1	FrameIndex	Frame index	
20	UShort_t	1	StatusBits	(Bit 5-7)Reserved	
21	UShort_t	1	TMonitorIn	Temperature monitor, interia	
22	UShort_t	1	TMonitorExt1	Temperature monitor, exteria 1	
23	UShort_t	1	TMonitorExt2	Temperature monitor, exteria 2	
24	UShort_t	1	TMonitorExt3	Temperature monitor, exteria 3	
25	UShort_t	1	V1Min	Voltage Monitor 1, mininum	
26	UShort_t	1	V1Max	Voltage Monitor 1, maximum	
27	UShort_t	1	V2Min	Voltage Monitor 2, mininum	
28	UShort_t	1	V2Max	Voltage Monitor 2, maximum	
29	UShort_t	1	length_per_ch	waveform length per channel for the voltage monitors	
30	UShort_t	mn_len	trace_VMonitor1	waveform of voltage monitor 1	
30+mn_len	UShort_t	mn_len	trace_VMonitor2	waveform of voltage monitor 2	

Table 12: *Hard-coded macros in the TLMN bank.*

Name in the code	Name in this doc	Value
TRLY_MONITOR_LENGTH	mn_len	3000

Table 13: *MIDAS bank structure for the GALI bank.*

start word index	type	array length	field name	content	struct name
0	galil_data_t	group_size	-	Array of structs: galil_data_t	galil_data_t

Table 14: *Format of the struct galil_data_t.*

start word index	type	array length	field name	content
0	ULong64_t	1	TimeStamp	time stamp of the readout
4	Int_t	2	Tensions	Tensions of the fishing line and the signal cable
8	Int_t	3	Positions	Positions: Motor 1, Motor 2 and Garage
14	Int_t	3	Velocities	Velocities: Motor 1, Motor 2 and Garage
20	Int_t	3	OutputVs	Output voltages: Motor 1, Motor 2 and Garage

Table 15: *Hard-coded macros in the GALI bank.*

Name in the code	Name in this doc	Value
GALILREADGROUPSIZE	group_size	50

Table 16: *MIDAS bank structure for the ABPR bank.*

start word index	type	array length	field name	content	struct name
0	ULong64_t	1	time_stamp	Time stamp of the NMR sample	absolute_nmr_info_t
4	Uint_t	1	length	probe index	
6	Uint_t	4	position	length of the NMR waveform	
14	UShort_t	1	flay_run_number	Trolley Probe NMR wavefrom	
15	UShort_t	1	probe_index		
16	UShort_t	length	-	NMR waveform[1]	

Table 17: *MIDAS bank structure for the FLUX bank.*

start word index	type	array length	field name	content	struct name
0	float64	num_ch*period*rate	-	Flux gate wave forms for all channels: Waveform_ch1 + Waveform_ch2 + ...	

Table 18: *Hard-coded macros in the FLUX bank.*

Name in the code	Name in this doc	Value
FLUX_NUM_CHANNELS	num_ch	9
FLUX_TRACE_PERIOD	period	60
FLUX_RATE	rate	8000

Table 19: *MIDAS bank structure for the SFCL bank.*

start word index	type	array length	field name	content	struct name
0	Double_t	num_coil	sys_clock	system clock	surface_coil_t
4*num_coil	Double_t	num_coil	gps_clock	gps clock	
8*num_coil	Double_t	num_coil	top_board	top board currents	
12*num_coil	Double_t	num_coil	bot_board	bottom board currents	

Table 20: *Hard-coded macros in the SFCL bank.*

Name in the code	Name in this doc	Value
SC_NUM_COILS	num_coil	100

4 Parsers for MIDAS bank data

Muon g-2 offline analysis framework relies on parsers in the gm2parser namespace hosted under repository gm2unpackers to decode the data. To checkout the codes,

```
git clone ssh://p-gm2dqm@cdcvs.fnal.gov/cvs/projects/gm2unpackers
```

Alternatively, you can also use

```
mrb g gm2dqm
```

in our g-2 environment. These parsers are written in C++ and are being used in the *art* producer modules. They can also be used in your standalone C++ codes, if you wish to. The parsers are located at

```
gm2unpackers/calo/parsers
```

at the moment for both calorimeter and CCC related information. This document will be updated accordingly once they are reorganized.

References

[1] TRIUMF MIDAS homepage, accessed Jan 5, 2017. https://midas.triumf.ca/MidasWiki/index.php/Main_Page