dRICH ePIC DAQ

Synchronization, protocols and data format

Modification History

Version	Date	Description	Author
0.1	2026/04/10	First version	P. Antonioli
0.2	2026/04/13	Corrected error about EoC status word	PA
0.3	2026/04/23	Fixed uplink-downlink definition	AL

1. Introduction

1.1. TO BE WRITTEN

2. EIC Clock and ALCOR clock

2.1. EIC clock is distributed from DAM to RDO at 98.6 MHz. Each period corresponds to an EIC bunch crossing (BC) every 10 ns

2.2. Recovered clock by RDO is multiplied by 4: a 394.4 MHz clock is the primary clock distributed to dRICH ALCOR ASIC (“ALCOR clock”)

2.3. The ALCOR clock feeds the coarse counter of ALCOR timestamps. The LSB is therefore 2.54 ns.

2.4. Every four ALCOR clock cycles a BC happens

2.5. The signal corresponding to a new orbit in the collider (RevTick) is distributed from GTU to DAM and in turn to RDO

3. ALCOR data format and EIC orbit

3.1. Words (32-bit words called A-word) out of ALCOR lanes are enclosed in frames (“ALCOR frames”).

3.2. A new ALCOR frame is started in two cases: when the ALCOR coarse counter expires (“rollover”) or when a soft reset signal is sent to the chip.

3.3. The structure of an ALCOR frame is the same for each ALCOR column (i.e. lane). Data are transmitted via 8b/10b encoding, and K codes are used to identify following special control words (with headers defining the meaning of the subsequent word(s)). K codes are repeated four times. A K code normally defines the meaning of just one subsequent word. K28.3 defines the 9 subsequent status words (8 pixel status words and 1 End Of Column Status word. The transmission of the 8 status words can be disabled. In that case the End Of Column is not preceded by K28.3 code.

	K code	HEX	# data words	32bit ALCOR data word
Frame header	K28.0	1C	1	Frame counter
Roll-Over/End of Frame	K28.2	5C	0	None
Status header	K28.3	7C	9/1	Status words (8) + End of Column
Checksum	K28.4	9C	1	CRC value

3.4. An orbit with zero hits (event words) can have therefore a payload of up to 12 additional special words plus the related K-code.

3.5. The ALCOR event word identifies the pixel firing, and its registered timestamp with the bit assignment described in Fig. 1.

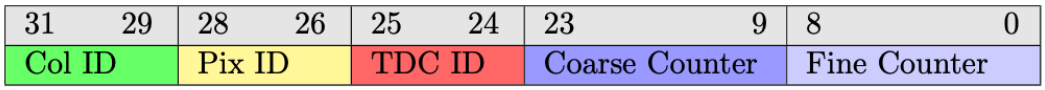

Fig. 1 ALCOR word (32 bit)

3.6. Coarse counter has 15 bits, expiring at 0x7FFF for a total of 83.2 μs, which is more than 4 EIC Orbits. Fine counter (resulting from TDC measurements via TAC inside ALCOR) has 9 bits. The coarse counter LSB (2.54 ns) can therefore be divided by 0x1FF, corresponding to a LSB of 4.97 ps. The 9-bit output of the fine counter must be calibrated and modified to provide a 9-bit representation of the phase of the coarse counter.

3.7. ALCOR can measure and provide hit timestamps of leading and trailing edges (TOT-mode), or timestamps at different thresholds (SLEW rate). For each hit (actual photon detection or dark current hits), therefore, two 32-bit words are timestamps provided.

3.8. ALCOR event words (timestamps) are transmitted by the lane following the frame counter and before the rollover/end of frame word. Data are therefore encapsulated with the following scheme.

```
K28.0
Frame counter
     Event word 0
     Event word 1
     ….
     Event word n
K28.2
K28.3
     [ Status word Pixel 0 ]
     …
     [ Status word Pixel 7 ]
     End Of Column Status word
K28.4
     CRC value
```

4. RDO data format

4.1. The RDO data format is designed to reduce payload on data transmission from RDO to DAM taking advantage of some EIC features.

4.2. At RevTick detection and before all data from ALCOR of a given orbit are sent to the DAM, the RDO sends a special RDO header. When all data from ALCOR of a given orbit are sent to the DAM, the RDO sends a special RDO trailer.

4.3. Data are decoded by RDO FPGA and leading and trailing edges of a given hit are matched and paired in a shorter unique word of 51 bits (R-word)

4.4. The R-word (shown in Fig. 2) doesn't repeat the geographical information identifying the pixel for both leading and trailing edges.

4.5. For the leading edge, the coarse counter has 13-bit dynamics (0x1FFF) which covers 20.7 usec, much larger than EIC orbit. The EIC BC is identified by bits 21-11.

4.6. For the trailing edge, the coarse counter is reduced to 7-bit dynamics (0x7F), which covers 321 ns, enough for any time-over-threshold or second threshold. It is not the timestamp of the hit, but it is the time interval relative to the leading edge. It is therefore directly a ToT (Time-over-Threshold) or TbT (Time-between-Thresholds) measurement

4.7. Need to specify format for orphans/missing TOT etc

50	49 48	47 45	44 42	41 40	39 33	32 24	23 22	21 9	8 0
0	FEB ID	Col ID	Pixel ID	TDC Id (trail)	Coarse (trailing)	Fine (trailing)	TDC Id (lead)	Coarse (leading)	Fine (leading)

Fig. 2: RDO event word (R-word) (51-bit)

4.8. For each ALCOR lane the following R-word are also defined (with bit 50 set) essentially encoding in the first 8 bits the hex equivalent of the corresponding K code used in 8b/10b encoding in ALCOR data encapsulation and in bits 8-39 the corresponding 32-bit ALCOR word

4.9. The RDO maintains independently an Orbit counter based on RevTick signals registered. ALCOR Frame Counter and RDO Counter are reported in the Frame header.

4.10. The potential total number of R-words to be passed in each orbit by the RDO to the DAM is therefore given by the number of event words (hits) + a fixed payload of 4 (FEB) * 8 (columns) * 12 R-words = 384 R-words. If Status words are suppressed this payload decreases to 96 R-words.

4.11. Given the data are reformatted by the RDO the CRC value shall be recomputed. RDO must provide verification of ALCOR CRC and report it. If an error is found - checking ALCOR CRC - bit 44 ("V") of the CRC R-word must be set. RDO shall provide

in the last R-word of the frame also the total value of R-words transmitted by the lane during the frame.

4.12. Additional slow control information might be added (introducing different pseudo -K code, i.e. 8 bit- pattern). Note the identification of special R-words using bits 0-7 (replicating the corresponding ALCOR K-code is probably too much): we have space for up to 255 different special words. We might use just 4 bits (16 different special words) and use the other four bits for other purposes.

Frame Header											K28.0								
50	49 48	47 45	44	43	42	41	40	39 24	23 8		7								0
1	FEB ID	Col ID	C	0	0	0	0	RDO Orbit Counter (16-bit)	ALCOR FRAME Counter (16-bit)		0	0	0	1	1	1	0	0

End of Frame / Roll Over												K28.2								
50	49 48	47 45	44	43	42	41	40	39 32	31 24	23 8		7								0
1	FEB ID	Col ID	0	0	0	0	0	OUT FIFO loss	IN FIFO loss	Frame length (coarse counter at RevTick)		0	1	0	1	1	1	0	0

Status word pixel [0-7]										K28.3								
50	49 48	47 45	44	43	42	41	40	39 8		7								0
1	FEB ID	Col ID	0	0	X	X	X	Status Word Pixel XXX=[0-7]		0	1	1	1	1	1	0	0

CRC / frame trailer										K28.4								
50	49 48	47 45	44	43	42	41	40	39 24	23 8	7								0
1	FEB ID	Col ID	E	0	0	0	0	Number of words in frame	CRC value	1	0	0	1	1	1	0	0

Fig. 3 Special control R-words written by RDO

4.13. Data encapsulation from RDO is therefore as follows:

```
Frame counter
     Event word 0
     Event word 1
     ….
     Event word n/2
End of Frame / frame length
[ Pixel Status word Pixel 0 ]
…
[ Pixel Status word Pixel 7 ]
Frame trailer/CRC
```

The event words with respect to ALCOR case are “n/2” meaning the n leading trailing edge 32-bit ALCOR event word are packed in n/2 R-words.

5. RDO: application of the fine time calibration

5.1. The fine counters of the ALCOR are not directly a 9-bit representation of the phase (i.e. the division of the LSB in 512 smallest bins). A correction, normally represented by a linear equation $T_{phase} = A*T_{raw} + B$ has to be applied.

5.2. The application of the calibration is not mandatory: it is requested at configuration of the readout. If the calibration is applied or not this is tracked in data: bit 44 of Frame Header (marked as "C") is set to 1 if calibration is applied.

5.3. The calibration constants A and B for each channel will be loaded to RDO memory at each start of run.

5.4. The RDO when receiving an ALCOR event word, from a given channel and TDC will transform the T_{raw}(fine) in T_{phase}. Such correction must be applied in such a way shifts in coarse counter are adjusted, if needed.

5.5. The time values in R-words are for the leading: 22-bit timestamp with bits 22-11 representing the EIC BC, and LSB=4.95 ps and for the trailing 16-bit timestamp with LSB=4.95 ps. This is beyond the time resolution of the TDC, but a 9-bit representation is kept ensuring correct data transmission when raw data (uncalibrated) are requested in output.

5.6. The leading value is absolute time in the orbit; the trailing value is the time difference between the arrival time of the trailing edge and the arrival time of the leading edge. If the data are uncalibrated, the fine value of the trailing edge is reported as it is from ALCOR, and the coarse value is the time difference between the coarse counter values between the trailing and leading edges.

6. RDO: time ordering

6.1. Timestamps (event words) from ALCOR lanes don't come necessarily time-ordered (meaning chronologically), due to delays in time conversions of TDCs and delays in data serialization at the end of the column.

6.2. The RDO shall provide within a given ALCOR frame the data to the DAM in a time ordered way.

6.3.

1 Data transmission from DAM to RDO (downlink)

6.4. Data link from DAM to RDO is defined as downlink. It operates at maximum speed of 5 Gbps.

6.5. The clock sent by DAM to RDO via uplink is the EIC clock received by the GTU. The recovered clock from downlink protocol must be 39.6 MHz and

6.6. Downlink protocol is GBT with 8b/10b encoding and 120-bit words (user field available are 82 bits).

6.7. Define format/commands

2 Data transmission from RDO to DAM (uplink)

6.8. Data link from RDO to DAM is defined as uplink. It operates at maximum speed of 10 Gbps.

6.9. Uplink protocol is FULL (8b/10b encoding and 256-bit words).

6.10. Data pushed by ALCOR and read by RDO are packed in 51-bit R-words. Up to four R-words are transmitted in 256-bit word. The format is described in Fig. 4.

255	254	253	252	251 … 204	203 … 153	152 … 102	101 … 51	50 … 0
DF3	DF2	DF1	DF0	DCS info (TBD)	RDO word 3	RDO word 2	RDO word 1	RDO word 0

Fig. 4: 256 bit data transmission on uplink while in readout mode

6.11. Data format over uplink while RDO is in configuration mode has to be defined

7. dRICH DAM data format

7.1. There are 1248 PDU in the dRICH. The RDO ID information is therefore encoded in 11 bits. Each DAM is link-aware i.e. shall know the RDOID corresponding to a given link.

7.2. Adding the RDOID information to each R-word, the DAM creates a 64-bit dRICH word that uniquely identify in space and time a dRICH hit in the run.

63	62	61	60 … 50	49 48	47 … 45	44 … 42	41 40	39 … 33	32 … 24	23 22	21 … 9	8 … 0
0			RDO ID	FEB ID	Col ID	Pixel ID	TDC Id (trail)	Coarse (trailing)	Fine (trailing)	TDC Id (lead)	Coarse (leading)	Fine (leading)

Fig. 5: final 64 bit dRICH-word as transmitted by DAM

7.3. All the RDO special R-words received from a given RDO by the DAM must be passed to the DAQ. The format of the dRICH special words is similar: bit 50 of the R-word (which is set to 1) is moved to bit 63, and in bits 60-50 is inserted the RDOID.

Frame Header — K28.0

63	62	61	60 … 50	49 48	47 … 45	44	43	42	41	40	39 … 24	23 … 8	7 … 0
1			RDO ID	FEB ID	Col ID	C	0	0	0	0	RDO Orbit Counter (16-bit)	ALCOR FRAME Counter (16-bit)	0 0 0 1 1 1 0 0

End of Frame / Roll Over — K28.2

63	62	61	60 … 50	49 48	47 … 45	44	43	42	41	40	39 … 32	31 … 24	23 … 8	7 … 0
1			RDO ID	FEB ID	Col ID	0	0	0	0	0	OUT FIFO loss	IN FIFO loss	Frame length (coarse counter at RevTick)	0 1 0 1 1 1 0 0

Status word pixel [0-7] — K28.3

63	62	61	60 … 50	49 48	47 … 45	44	43	42	41	40	39 … 8	7 … 0
1			RDO ID	FEB ID	Col ID	0	0	X	X	X	Status Word Pixel XXX=[0-7]	0 1 1 1 1 1 0 0

CRC / frame trailer — K28.4

63	62	61	60 … 50	49 48	47 … 45	44	43	42	41	40	39 … 24	23 … 8	7 … 0
1			RDO ID	FEB ID	Col ID	0	0	0	0	0	Number of words in frame	CRC value	1 0 0 1 1 1 0 0

8. dRICH DAM data reduction

8.1. Within each orbit the dRICH DAM analyse at each EIC bunch crossing the pattern of registered hit and, based on space and time pattern, takes a decision if the BC has to be evaluated as “good” event (keep BC), or “bad” (discard or flag as bad the BC)

8.2. If the DAM is configured to discard data belonging to a bad event all the corresponding R-words (hit timestamps) of all RDOs are not passed to the DAQ.

8.3. If the DAM is configured to “flag” BC, but not discard hits belonging to bad event, all the corresponding R-words of all RDSs are passed to the DAQ with bit 62 set to 1.

8.4. DAM output to ePIC DAQ

8.5. [ci servono specifiche su come li vogliono impachettati, ogni quanto mandiamo pagine .. ecc]

9. dRICH DAM: communication with GTU

10. dRICH DAM: communication to RDO (configuration)

11. dRICH DAM: communication from RDO (slow control)