Inputs about ExDH and EPIC system requirements

L.Chiappetti - IFCTR & F.Battini - Laben
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a. scope

This note (originally issued in draft form as an internal memo) tries to give a comprehensive view of the overall **data flow** of EPIC in the form of **requirement** items. However it must be noted that in a number of cases reference is made to design decisions already taken, therefore the item is not a requirement but purely a *statement* of an *a posteriori* justification and explanation of such decisions.
Complete reference to other preliminary documents, or to e-mail correspondence are reported in Appendix A and recalled in text as "Ref. [n]". In addition we acknowledge also inputs obtained during meetings of the EDH WG.
A detailed justification of all numbers contained in this note, and based on simulations, is contained in a separate report, EPIC-IFC-TN-005, issued contextually to the present one (Ref. [12]).

This note attempts to give a system-wise impression of the overall data flow. We stress that, in most cases, my worry has been to have a complete list of actions to be done (even if indicated as TBS) and not to define which device has to do it.

Bars on the margin mark statements changed since previous draft issues, for convenience of the recipients of such drafts. This first official issue of document supersedes any previous draft and any provisional definition and shall be considered as unique reference.

Author's comment: Paragraphs entirely in italics like this one identify author's comments and additional explanations (which are not part of a requirement).

b. conventions used

For easy reference statements are labelled as E*cnnnn*, where: *c*=X indicates a statement/requirement applicable to the whole of EPIC or anyhow to both EPIC chains; *c*=M indicates a statement/requirement appicable to or specific of the MOS chain; *c*=P similarly for the pn chain. *nnnn* is a sequential number : I left ample gaps in the numbering to allow insertion of new statements without renumbering. Statements with a similar scope are assigned consecutive numbers. It is also possible to have a set of EX, EM and EP statements with the same nnnn in the case that the EMnnnn and EPnnnn are the MOS or pn specific application of the generic EXnnnn.

1 General requirements

1.1 purpose

EX0001 : the purpose of EPIC is to detect, using CCDs as detectors, **individual X-ray photons**, measuring their **position** in the focal plane with the best spatial resolution given by optics and measuring their **energy** (do spectroscopy) with the best **energy resolution** allowed by the physical conversion process in the Silicon.

EX0002 : a secondary purpose (i.e. this applies to a limited number of observations only) is to allow **timing studies** measuring the photon arrival time with a time resolution up to TBD ms.

1.2 Operating modes

Note that the integration-and-readout way of operation typical of CCDs is apparently in contrast both with the photon counting and with the high time resolution requirements, therefore requires the development of specific modes of operation.

EX0003: The CCD operation modes are given below. For tracing the evolution of their definition please refer to Appendix B.

EM0003: The MOS CCD operation modes are defined as follows :

Mode	Parameters	Parameter range
Transparent		
Imaging	Readout nodes Window size Window position Integration time	1 or 2 TBD-600 (XY) 0-600 (XY) TBD see text
Timing	Column window size and position	TBD

EP0003: The pn CCD operation modes are defined as follows :

Acronym	Mode	Parameters	Parameter range
Transp	Transparent		
FF	Full Frame	see Ref. [8]	
LW	Large Window	Window size and position	TBD
W (SW)	Small Window	Window size and position	TBD
T	Timing	Chip selection	1-12
B	Burst (*)	Chip selection	1-12

<u>Author's comment</u>: *although the basic readout procedures are a limited number, different values of the parameters of the modes allow some variability in derived numerical values, like the frame time, and ultimately the data rate. The representative values used in the simulations supporting this document are explained in detail in Ref. [12].*

EM0004: For the MOS CCD in Imaging mode, a set of different readout *sequences* or *procedures*, based on the common Frame Store technique (see Ref. [5]) can be constructed according to the values assumed by the 5 parameters (window size and position and integration time). In addition also the number of readout nodes controls the frame duration, and ultimately affects the bit rate. Such procedures are called below for brevity with the name of *options*.

Option	Acronym	Description
Frame Store	FS (*)	the window size and position are set to cover the entire chip integration time is equal to readout time
Window	W	the window covers only a region of the chip integration time is equal to readout time
Refreshed Frame Store	RFS	the integration time is lower than the readout time any window size and position (usually all chip)

(*) FS1 and FS2 refer to the case of 1 or 2 readout nodes, when the distinction is relevant.

`EM0005`: The MOS Timing mode (identified by the acronym T) has no options.

1.2.1 Basic imaging modes

`EX0011` : the measurement of position is satisfied at CCD level by the usage of the currently defined **Imaging mode** (and eventual options, see `EX003`)

`EX0012` : the CCD frame readout may give **smearing** (the position of photons coming while reading are detected in the wrong place). The effects or smearing shall be minimized.

`EM0012`: for MOS this is achieved by use of the **Frame Store** technique

`EP0012`: for pn this is achieved by the use of **larger pixels** and hence faster readout in the standard Full Frame mode

`EX0013`: in normal operation only the pixels whose charge content is above a given low threshold (25 TBV e^-) are to be considered "full" and processed beyond the ExCE level.

`EX0014:` only for diagnostic purposes the content of all the pixels have to be transmitted to the ground. This is the so-called **Transparent mode**. In this mode no operation at ExCE or ExDH level is foreseen but packing.

`EX0015`: the pixel energy content is assumed to have a 12-bit significant value.

1.2.2 Timing mode requirements

`EM0031`: the timing requirement `EX0002` is otherwise satisfied for MOS using the **Timing mode** (T).
Author's comment: what is now called Timing mode was called Fast Window mode in former documentation. Refer to Appendix B for the evolution of operating modes.

`EP0031`: similarly for pn using the **Timing mode** (T)

`EX0032`: the pixel energy content is a 12-bit value (same as `EX0015`).

2 Processing requirements

2.1 Pileup effects

EX0021: The fact that CCD readout occurs in frames and is relatively slow, when observing strong sources causes **pileup** (more than one photon falls in same pixel), therefore altering the measured energy value (proportional to charge deposited). The effects of pileup shall be avoided without impairing the possibility of studying strong sources.

EM0021: for MOS this is achieved by an effective reduction of the frame time using the **W or RFS options** of the imaging mode.

EP0021: for pn this is achieved using the **W or B modes**

Note that increasing the readout speed (as done by the above modes) may also partially satisfy the timing requirement EX0002.

2.2 Cosmic ray rejection

EX0041: also **cosmic rays** (and not only X-rays) impinge on CCDs and since they deposit charge in many pixels, give rise to a large number of spurious events, which **shall be rejected**.

EM0041: The following table gives representative cosmic ray rates for the MOS case, and the related event rates. These rates are to be assumed as the number of c.r. events in output from the camera head. Note that the values refer to a single chip section and no charge thresholds are used !

Solar activity	MOS Image section		MOS Store section	
	particle/s/chip	event/s/chip	particle/s/chip	event/s/chip
Low	6.9	122	2.1	65
Medium	**9.3**	**167**	**2.8**	**97**
High	13	236	3.9	125

EP0041 : The following table gives representative cosmic ray rates for the pn case, and the related event rates. These rates are to be assumed as the number of c.r. events in output from the camera head. Note that the values refer to a single chip and no charge thresholds are used !

Solar activity	pn	
	particle/s/chip	event/s/chip
Low	3.5	1.9
Medium	**4.6**	**23**
High	6.5	31

Note: in both cases the "Medium" solar activity case (indicated in **boldface** and corrsponding to ~ 1.6 particle/cm2/s) is assumed as typical case in what follows.

EM0042: MOS in Imaging mode achieves a first degree of cosmic ray rejection thru the EDU **5x5 pattern analysis** (ref. [1]).

EM0043: the EDU rejection rate is not sufficient to get rid of all cosmic rays, although it has a very high efficiency (99 % TBV). The number of **residual c.r. events/s after 5x5 pattern analysis** in imaging mode is given by about 1.3 event/s/chip for the medium solar activity case (image and store section together). These rates are to be assumed *in input* to EMDH.

Note that in the W and RFS options of the Imaging mode the rates have to be scaled down by the fraction *f* of chip area used, or the duty cycle *c* respectively.
Typical values may be assumed as *f*=.028 for a 100x100 pixel window (which gives 4.6 event/s/chip before rejection in input to EDU, 0.04 event/s/chip after rejection in input to EMDH)or *c*=5.8% for an exposure of 60 ms in RFS option over full chip.
Authors' comment: The fraction f is (100x100)/(600x600) i.e. only in the image section, and the result match my simulations, but I am not sure this is handling realistically the store section in W mode. Or even for the image section one should consider a stripe (100x600)/(600x600) ?

`EM0044`: further c.r. rejection may be achieved by **applying an high energy threshold** on the total event charge (see `EM0108` below) (this has to be done in EMDH). The rejected events have to be counted, and the counter made available to telemetry.

`EM0045`: The number of **residual c.r. events after EMDH** thresholding in imaging mode is given by about 0.01 event/s/chip (for the case considered in `EM0043`).

`EM0046`: a **further rejection** of residual cosmic rays (which are generally located at the chip borders) may be done by an analysis of data across two chips. Given the rates under consideration it is felt appropriate to defer this to ground analysis.
Note that for MOS chip borders include "node borders" as defined in `EM0105`.

`EM0051`: MOS in Timing mode also requires cosmic ray rejection. The rates given in `EM0041` have to be scaled down for the **geometric factor** *f=column_width/600*.
Typical values may be assumed as *f*=.09 for a 54-pixel wide window.
Author's comment: I am unsure what geometric factor one shall use, is it a linear ratio 54/600 or a surface ratio (54/600 squared ?) or shall one consider 1200 pixels ? The ratio I get from simulations is 0.03 corresponding to 5-7 event/s/chip to be handled on board. See `EM0053`.

`EM0052`: a **1-d version of 5x5 pattern analysis** (projecting the 2-d patterns along one axis one has just 1 monopixel, 2 bipixel and 1 tripixel patterns) may be assumed as an effective way of achieving a good rejection rate.

`EM0053`: The number of events in input to the pattern analysis is of the order 5 event/chip/s. The number of events after the pattern analysis is 0.8 event/chip/s.

`EM0054`: further c.r. rejection may be achieved by **applying an high energy threshold** on the total event charge (see `EM0104/0108` below) (this has to be done in EMDH). The rejected events have to be counted, and the counter made available to telemetry.

`EM0055`: The number of residual c.r. events after EMDH thresholding in timing mode is given by about 0.06 event/s/chip (for the case considered in `EM0053`).

`EM0056`: a further rejection of **residual "border" cosmic ray events** (in this case borders refer to the *geometric vertical borders* of the column where data are taken, as well as to the smeared events across the *horizontal border between consecutive "frames"* : see also `EM0104)`. Given the rates under consideration it is felt appropriate to defer this to ground analysis.

`EP0042`: (ref. [2]) pn in FF and multichip window modes may reject at event analyser (EVA) level all 64-pixel rows where a single pixel is saturated, plus a guard region of two adjacent rows.
It is required to keep a line deadtime map (200 words) per chip.
The deadtime map shall be telemetered with frequency TBD (synchronous with n frames ?)

`EP0043`: (ref. [2]) pn in small W mode may entirely reject at EVA level all frames where a single pixel is saturated.
It is required to keep a deadtime counter.
The deadtime counter shall be telemetered with frequency TBD (synchronous with n frames ?)

EP0046: (ref. [2]) a further rejection of cosmic rays across quadrant borders could be done by dedicated analysis (not in EVA since there is no talk between quadrants, hence in EPDH or on ground). Given the rates under consideration it is felt appropriate to defer this to ground analysis.

EP0051: (ref. [2]) no c.r rejection performed in Timing mode

EP0052: c.r. rejection requirement for Burst mode TBD (*assumed* no rejection as in Timing mode)

EP0060: in all cases the EVA shall apply programmable (by column) low and high thresholds and reject events outside them.

2.3 Considerations about split events

EX0100: the charge of an X-ray event may be split in adjacent pixels: in order to measure the true energy the splitting shall be recoverable (adding up the content of pixels coming from one event) in the worst case by ground processing. Nevertheless some preliminary processing of split events may be performed by normal processing stages on board.

EM0100: the energy dependency of the splitting in the MOS case is such that the percentage of monopixel events decreases from 90% at 0.3 keV to 30% at 8 keV and the percentage of events split in more than 4 pixels increases from 0% at 0.3 keV to 20% at 8 keV (Ref. [3]).
Author's comment: These values match my simulations if one measures splitting with no lower charge threshold. Assuming a threshold of 25 e- (i.e. neglecting pixels with residual charge only) one has 99% monopixel at 0.3 keV, and 47% at 8 keV; 0% in more than 4 pixels at 0.3 keV and 8% at 8 keV.

EM0101: MOS in imaging mode may achieve a first degree of split event reconstruction thru the EDU **5x5 pattern analysis**, referred to in EM0042.

EM0102: MOS in timing mode may partially achieve split event reconstruction at CCD level, as events **split in the vertical direction** are summed in the output register.

EM0103: Split event reconstruction in timing mode **along the horizontal direction** may be achieved via 1-d pattern analysis, i.e. the same algorithm responsible of cosmic ray rejection (see EM0052-53).

EM0104: In timing mode it is possible that, because of smearing, a split event is divided between two consecutive frames. The effect may be corrected for (at EMDH or EDU level) by appropriate measures in the 1-d pattern analysis, e.g. use a "2-frame-high window". The effect can be quantified as 0.06 % i.e. can be deferred to ground.

EM0105: in all cases where the readout occurs via 2-nodes, the on board EDU processing cannot properly analyse (X-ray and cosmic ray) events split across the 2-node boundary (vertical line at chip middle), therefore this effect has to be recoveredin EMDH (Ref. [1]) or in EMCE (ref. [4]) on the ground. The requirement in Ref. [1] to do it on board is cancelled.
Author's comment : the operation shall therefore be performed by ESA (SOC) during the construction of the ODF. However the relevant algorithm may require tuning during early mission phases. It is suggested that, according to standard astronomical practices, the ODF includes both a raw data file and a reconstructed data file (leaving to the observer the possibility of re-doing the correction with variants of the algorithm).

EM0106: as consequence of the EDU pattern analysis, in imaging mode the energy information produced consists of four energy words E1 E2 E3 E4 (Ref. [1]).

EM0107: transmission of the entire raw energy information E1 E2 E3 E4 to the ground is foreseen only for diagnostic purposes . This is TBV since apparently the telemetry rate might allow transmission of entire information at all times.

EM0108: otherwise it is mandatory for EMDH to reconstruct on board the event total energy by summing E1+E2. This sum is the energy to be sent to the ground.

EM0109: the energy values E4 or E3+E4 shall be monitored to estimate charge leakage (Ref. [1]). The relevant procedure (accumulate histograms ?) is to be clarified.

EM0111: in Timing mode photons shall be tagged with time (Ref. [1]).
Note: It has to be resolved (at EDU or EMDH level) the fact that in this mode a photon reaches the output node 600 row-readout cycles after the time the relevant window has been added up to the first line of the store section (ref. [5]).

EP0100: the energy dependency of the splitting in the pn case is such that, irrespective of energy, the percentage of monopixel events is 50-60%, and the percentage of mono- or bipixel events is about 95%, while there are no events split in more than 4 pixels. If one ignores events with less than 25 e-, one has 90% (0.3 keV) to 75% (8 keV) of monopixel events, and 100% of events in less than 2 pixels.

EP0101: If pn split event reconstruction is not done on board, the telemetry rate increases by 20-40% w.r.t. the case it is done on board with an algorithm similar to the MOS one. It is therefore acceptable to defer this operation to the ground.
Author's comment : the operation shall therefore be performed by ESA (SOC) during the construction of the ODF. However the relevant algorithm may require tuning during early mission phases. It is suggested that, according to standard astronomical practices, the ODF includes both a raw data file and a reconstructed data file (leaving to the observer the possibility of re-doing the correction with variants of the algorithm).

2.4 Pileup limiting rates

EX0201: for each CCD operating mode setup (i.e. choice of mode *and* related parameters, like window sizes, integration times ...) a **"hard" pileup limit** on the source count rate will exist. **Sources stronger than this limit will not be observed**, because the energy information will be irrecoverably corrupted by pile-up (both the case of the charge from two or more photons falling into same pixel, or in adjacent pixels typically in horizontal or vertical direction).

EX0202: Best effort shall be made to recover pileup effects (e.g. geometrical) between a "soft" and a "hard" limit, e.g. via on-board actions (see EM0202) or in the ground analysis (e.g. at response matrix level).
Author's comment: I am not sure it makes sense to distinguish hard and soft, what is reported below is 'soft'. This is subject to further analysis (in progress).

Note: in all the computations below it has been assumed (using the XMM mirror effective area supplied by C.Erd and B.Aschenbach, and a grating obscuration factor of 43% independent of energy) that :

1 mCrab = 27 photon/s incident before the mirrors on 3000 cm^2
1 mCrab = 13 photon/s after a full mirror unit
1 mCrab = 5.6 photon/s after a grating-obscured mirror

EM0201: The limiting rates given by pileup for each MOS mode are reported in the table below. The values indicated "with grating" are obtained conservatively, scaling the values "with full mirrors" by a factor 2.32=1/0.43 (the higher values in square brackets refer to a direct simulation).

Mode	Limit (mCrab) full mirror	Limit (mCrab) mirror+grating
FS 1 node	0.5	1.2 [2]
FS 2 node	1	2.3
Window	7	16
RFS	50	116
Timing	100	232 [300]

EP0201: The limiting rates given by pileup for each pn mode are reported in the table below. The values indicated "with grating" are obtained by a conservative scaling by 2.32.

Mode	Limit (mCrab) full mirror	Limit (mCrab) mirror+grating
FF	2	4.6
Large Window	---	---
Small Window	40	93
Timing	800	1856 sic!
Burst	>1600 sic!	3712 sic!

EM0202: The MOS imaging mode pattern analysis (ref. EM0042, EM0101) allows recover of geometrical "diagonal" pileup events aliased to splitting (Ref. [1]). This action can be done at EMDH level, assigning E1 and E2 as energy to two separate events, whose position can be derived from the EDU provided position (for the event with E1), and from the pattern number (for the event with E2, add ±1 to X,Y according to pattern).

EM0203: the effect of the implicit recovery of split events (in terms of EM0101) on the data rates (input rates to EMDH), combined with the limiting rates, allow to tabulate the maximum rates as indicated in the following table. Note that, because of the split event reconstruction implicit in the pattern analysis algorithm, the number of resulting event/s are actually "reconstructed photon/s".

Mode/option	Limit (event/s) full mirror	Limit (event/s) mirror+grating
Imaging FS 1 node	6.2	idem
Imaging FS 2 node	12.4	idem
Imaging Window	87.0	idem
Imaging RFS	30.6	idem
Timing	(*) 1220	idem

(*) in the case of the timing mode the value given is "reconstructed photon/s" if one assumes split event reconstruction to occur on board in EDU as described in EM0103 (remember also that summation in the output register during readout already corrects partially for splitting). If this is not done the event rate in input to EMDH is about 1.2 times higher.

Note also that the presence of grating has no effect on event rates since the limiting source intensity will be higher by 2.32=1/0.43 but the number of events associated with such intensity will be lower by 0.43.

EP0203 : The pn maximum rates (derived from the limiting rates) are reported in the following table. For reference also indicate the effect of doing or not doing split event reconstruction.
The column labelled "event/s full mirror" gives the rates for in output from EPCE (which does a plain thresholding and no split event reconstruction). In the case EPDH (TBV) performs split event reconstruction on-board, the output rate from EPDH Considering split event reconstruction, the data rate will be reduced as indicated in the column labelled "photon/s split ev. recons.", which indicates that reconstruction may be deferred to ground. Therefore the previous column has been used below.

Mode	Limit (event/s) full mirror	Limit (photon/s) split ev. recons.	Limit (event/s) mirror+grating
FF	33.1	24.7	idem
Large Window	---	---	---
Small Window	607	429	idem
Timing	11690	9938	idem
Burst	2100	1512	idem

Note also that the presence of grating has no effect on event rates since the limiting source intensity will be higher by 2.32=1/0.43 but the number of events associated with such intensity will be lower by 0.43.

2.5 Bad pixel rejection

EX0301: it is possible that a number of pixels in a chip be flagged as bad (dead pixels, hot pixels). It is required to keep a map of permanent bad pixels, in order to avoid transmitting the relevant spurious information to the ground, and to correct the energy measurements of them, and their neighbours, when a true event falls there.

EM0301: MOS requires permanent bright pixel subtraction to be done on boardat EMDH level, keeping there a map sized to at least 228 positions and energy content per chip (for contingency this number should be multiplied by a factor n TBD). The rationale is explained in Ref. [6]. It is not required to correct for flickering pixels. The correcting action for bright pixels will be the subtraction of the stored content from the content measured at the relevant position.
Author's comment: The algorithm to avoid redundant processing of the list of bad pixels is TBD but appropriate sorting by position may make it faster.

EM0302: An entire bright column may be set to zero by EDU using the "offset line" mechanism (Ref. [1])

EP0301: (Ref. [2]) pn will store a bad pixel map for three chips in each quadrant EVA, and perform rejection of bad pixels at this level.
Author's comment: Is is TBV whether the algorithm is event rejection or event charge correction.

EX0401: For the measurement or correction of optical light background (Ref. [7]) one shall use the E3 and E4 information (charge in outer pixels of the 5x5 matrix) to keep a running mean value. This value could either be telemetered to ground (e.g. as an image accumulated over a long TBD interval of time) or subtracted on board from the reconstructed photon energy (with the exception of the events with an excess charge, i.e. "extended" geometrical pileups similar to the ones described in EM0202. This requirement is TBC by dedicated simulations.

2.6 Camera head readout sequences

EM0501: requirements on interconnections of the two nodes of the central chip to 4 TBV EDUs are specified in fig. 1/2 in Annex to the minutes of 2nd EDHWG meeting. Usage of 2 node operation at all times is foreseen.

EM0502: the central chip can operate in any mode (Imaging or Timing) and option

EM0504: requirements on failure recovery of nodes or EDUs for central chip are TBS

EM0511: requirements on interconnections of two nodes of a couple of outer chips to 2 TBV EDUs are specified in fig. 1/2 in Annex to 2nd EDHWG meeting.

EM0512: outer chips will be operated as baseline only in imaging mode (FS option over the full chip) with readout from one node

EM0513: outer chips may be readout from two nodes as a fallback in case CTE is degraded.

EM0514: requirement on failure recovery of nodes or EDUs for outer chips are TBS

EM0515: consequences on the number of FSI active at any one time on EMDH are TBS

EM0520: MOS chips can be read in a totally asynchronous way

EP0501: requirements on interconnections of 3 chips to one EVA in quadrant arrangement are TBS

EP0502: the readout of the 12 chips in FF mode will be synchronous, i.e. there is a cycle in which one chip at a time is read out for 1/12th of the cycle time, and exposed for 11/12th. The chips are read out in a fixed sequence (see Ref. [8])

Note: "synchronous" has to be interpreted in a limited sense, as there might be a delay for FIFOs to empty.

EP0503: there will be a modified synchronous readout of 1 chip in small W mode and 11 chips in FF mode (the exposure time of the chip in W mode is slightly different and drives the duration of the cycle, see ref. [8])

EP0504: there will be a special readout sequence (involving some chips only) in multi-chip W mode (see ref. [8])

EP0505: T and B mode will be operating only on a single chip, and the other chips will not be read out at all.

EP0506: requirements on failure of nodes or EVAs are TBS

EP0515: (ref. [2]) The number of FSI from EPEA to EPDH is 4. Under normal operating conditions only one FSI at the time will be sending data. However it shall be possible EPDH should be able to handle all 4 FSI in parallel, provided the overall data rate does not exceed TBD.

EM0532: the table gives typical frame duration and maximum number of source event/frame (with reference to limit rate values in EM0203)

Mode/option	Integration	Frame time	event/frame
Imaging FS 600x600	1 node 2.1612 s 2 node 1.0812 s	2.1630 s 1.0827 s	13.4 13.4 (*)
Imaging window 100x100	0.1102 s	0.1125 s	9.8
Imaging RFS 600x600	2 node 0.060 s	0.0624 s frame 1.0827 s cycle	33.1 (*)
Timing window 54 pix	0.00087 s	0.00087 s (n/a)	1.06

(*) these figures refer to the readout of the whole chip. Since it occurs via two nodes, the quoted number of event/frames will be distributed somehow among the two nodes (half and half in the case the source is located exactly across the dividing line).

Note that for the timing mode the concept of frame is ill-defined. It is likely that some suitable multiple of the integration time will be used. The choice may depend on the design of the telemetry system (e.g. frame overheads).

EP0532: the table gives typical frame duration and maximum number of source event/frame (with reference to limit rate values in EM0203). The highest value in the event/frame column assumes no split event reconstruction is done on board and is the value to be used (for reference we show in square brackets the value including split event reconstruction).

Mode/option	Integration	Frame time	event/frame
FF	0.044 s	0.048 s	1.6 [1.2]
Small window 48x30	0.004005 s	0.004625 s	2.8 [2.0]
Large window (192x200 6 chip)	0.011 s	0.0132 s	---
Timing	0.000039 s	0.00039 s (10x)	4.6 [3.9]
Burst	0.0002 s	0.004 s	8.4 [6.0]

In the case of the timing mode the frame time is defined as the time needed to read the entire chip, whose height is divided into 10 20-pixel high windows.

2.7 Data modelling

EX0600: photon times must be tagged, at least with the time of the "frame" in which they were detected (in some modes a finer tagging of individual photons is possible). See note in Appendix A for details.

EX0601: it is required at ExDH level to separate data by chip id (or node id TBC for MOS) and process them separately .

EX0602: there is no on board requirements on the normalization of XY node coordinates to chip coordinates and/or to a common frame of reference in flight (see enclosed figures) (to be verified).
Author's comment: Note that this (with a straightforward algorithm) has to be done by ESA (SOC) prior to building the ODF on the ground !!

EM0610: EDU will A count of the number of events above threshold per frame (Ref. [1]). EMDH has to acquire this information shall be acquired and attached to the telemetry (it is TBD how to keep synchronism with science data)
EM0611: requirement for EMDH to generate or transmit from ground a test image to EMCE is TBS.

EM0612: requirement on additional spatial windows to be applied in EMDH (Ref. [1]), to be confirmed or cancelled.

EM0613: requirement on node-dependent gain normalization on energy in EMDH (Ref. [1]) is TBC.

EM0614: Some MSB to time information in timing mode may be added by EMDH (Ref. [1]), TBC.

EM0615: The X-coordinate (from node-window relative to absolute) in timing mode may be normalized by EMDH (Ref. [1]), TBC.

EM0616: X-position might be compensated for spacecraft drift (in timing mode) by EMDH. To be confirmed or cancelled.

EM0617: Resynchronizing the timing counter used within EDU in timing mode shall be supplie by EMDH.

EX0690: counters must be provided (and downlinked) for any class of events rejected at any level.

EX0691: Synchronization of HK and Science data must be kept

2.8 Operational context

EX0700: packet telemetry should be compliant with Ref, [10] and references therein.

EX0701: the basic telemetry constraint is 48 kbit/s available to whole EPIC (Radiation Monitor excluded ?) as explained in Ref. [9].

EX0702: the baseline apportionment is 16 kbit/s to each EPIC chain
Author's comment : (does this make sense with the grating obstruction on 2 telescopes ? most likely yes, simulations show we are almost always below this rate)

EX0703: the minimum bit rate for an alive EPIC chain is given by the HK rate i.e. TBD kbit/s

EX0704 : the maximum bit rate for a single EPIC chain used alone in science mode is therefore given by 48 - 2*HK rate

EX0705: the maximum bit rate may be allocated only in transparent mode, and during particular science observations (e.g. for strong sources which can be observed by the pn camera only or calibrations).

EX0706: other possible bit rate combinations are contained in Ref. [9].
Author's comment: I regard these as representative values subject to revision (otherwise said, an open point).

2.9 Processing flow

EM0711: the data rate in transparent mode can be computed considering : 16 bit/event of which 12 bits only are valid; 600x600 pixels in a frame; frames are read out with normal CCD mode rates.
Data from one frame shall be buffered in EMDH and transmitted as soon as possible, suspending further data taking during transmission.
For the sake of brevity this transmission option is identified within this document as "direct 0" or "D0".

EM0712: If, in imaging mode, one sends to ground the complete allocation of bit/event used by EDU after pattern analysis, one has the full combination transmission option (*identified below as "direct 1" or "D1"*): currently this is 80 bit per event of which 72 are valid (TBV after ongoing redefinition). It has to be specified what to do with frame headers and trailers. Note also that node id information is redundant if data are sorted by chip (per EX0601).
Author's comment: In principle one can legitimately presume that this combination will not be used routinely, but mainly for diagnostics. However pure bit rate considerations do not forbid its use at all times.

EM0713: The essential combination transmission in imaging mode (*identified below as "direct 2" or "D2"*) shall somewhat reduce the bit/event allocation : only one energy information need to be transmitted (E1+E2 per EM0108), also chip id may be dropped, and a reclassified pattern id (3 bit instead of 5) may be used.
Author's comment: This might be considered as the normal transmission option if a reduction of the bit rate w.r.t. D1 is felt desirable.

EM0714: alternate combinations and allocation of bit/event are possible in imaging mode ("alternate direct modes"), details (e.g. resample energy or position with less bits ?) are possible but at the moment not foreseen.

EM0715: The basic allocation of bit/event in timing mode (as passed from EDU to EMDH) is 32 bit per event, which can be sent to ground (*this transmission option identified below as "direct 3" or "D3"*) .
Open point: It has to be specified what to do with headers and trailers : the relevant overheads are **NOT NEGLIGIBLE** for all cases in which the number of event/frame (see Ex0532) is less than 1, because one **adds the overhead once per event !!!** This has impact on the design of the actual telemetry content.

EM0716: An alternate combination (*identified below as "direct 4" or "D4"*) in timing mode might drop the 10-bit X-information (mean X has to be saved somehow and telemetered)

EM0717: A cross reference table can be produced using limiting rates and bit/event allocation, in order to derive maximum nominal bit rates (due *only* to the strongest source which can be observed in a given mode, and considering *event data only*, i.e. no headers or trailers).

CCD Mode/opt	Packing mode & bit/event	Limit (kbit/s) full mirror
Transparent	D0 [16 bit TBV]	5625/ΔT (*)
Imag. FS 1 node	D1 [80 bit TBV] D2 [40 bit TBV]	0.5 0.25
Imag. FS 2 node	D1 [80 bit TBV] D2 [40 bit TBV]	1.0 0.5

Imag. Window	D1 [80 bit TBV] D2 [40 bit TBV]	7.0 3.5
Imag. RFS	D1 [80 bit TBV] D2 [40 bit TBV]	2.4 1.2
Timing	D3 [32 bit] D4 [22 bit TBV]	38. 26.

(*) for transparent mode, the bit rate depends on the time ΔT allocated to downlink one frame (e.g. 19 kbit/s for 5 minutes).

EM0720: the need for indirect modes (on board spectra or time profiles) exists only for the timing mode (in all other cases the bit rate for a source below the limiting rate is always within the limits)., for sources stronger than 40-55 mCrab (93-127 mCrab with grating).
The interest of studying such sources has been discussed (see ref. [11]) and has been confirmed by the PI.

Note: the requirement mentioned in the past that spectra be accumulated by pattern classes has no longer sense if spectra accumulation is limited to the timing mode.

EM0721: the need or not for direct modes with selection, e.g. on pattern range (transmit only single events, or otherwise a subset, and count the rest) , or on position ("software window"), is to be verified (but it looks like there is no reason on a pure telemetry reduction ground).

EP0711: data rate in transparent mode can be computed considering : 16 bit/event of which 12 bits only are valid; 64x200 pixels in a frame; frames are read out with normal CCD mode rates. It is required for EPDH to extract the 16 (12) energy bits from the 32-bit data format available (the rest being unused) received from EPCE.
It is TBS if data from one frame are to be be buffered in EPDH, or if only some columns in the chip are read in a frame (as suggested in ref. [8]).
For the sake of brevity this transmission option is identified within this document as "direct 0" or "D0".

EP0712: As a baseline in imaging modes, the normal combination transmission will send the basic 32-bit data format received from EPCE. Note also that chip id information is redundant if data are sorted by chip (per EX0601). *This is identified below as "direct 1" or "D1".*

EP0714: alternate combinations and allocation of bit/event are possible in imaging mode ("alternate direct modes") are possible but at the moment not foreseen.

EP0715: Requirements for timing modes are TBS, either use "direct 1", or do additional time tagging (different for T and B modes)

EP0716: A cross reference table can be produced using limiting rates and bit/event allocation, in order to derive maximum nominal bit rates (due *only* to the strongest source which can be observed in a given mode, and considering *event data only*, i.e. no headers or trailers).
The effect of the frame header overhead (see also EM0715) is **NOT NEGLIGIBLE** and has noteworthy design impacts for all cases in which the number of event/frame (see Ex0532) is less than 1, because one **adds the overhead once per event !!!**

Mode	Packing mode & bit/event	Limit (kbit/s) full mirror	Limit (kbit/s) on board recons.
Transparent	D0 [16 bit TBV]	200/ΔT (*)	n/a
FF	D1 [32 bit]	1.0	0.8
Large Window	D1 [32 bit]	---	---
Small Window	D1 [32 bit]	19.0	13.4
Timing	D1 [32 bit]	365.	311.
Burst	D1 [32 bit]	65.6	47.3

(*) for transparent mode, the bit rate depends on the time ΔT allocated to downlink one frame (e.g. 3.3 kbit/s for 1 minutes).

EP0720: the need for indirect modes (on board spectra or time profiles) exists only for the timing mode for sources stronger than 75 mCrab.
See also EM0720 for further considerations on indirect modes.

EX0730: *Author's consideration: note that a range of source intensities exists, which cannot be observed by the MOS camera, but can be observed by the pn camera. In such case one may conceive to assign to the pn camera a high bit rate allocation, and to the MOS cameras either the HK rate (science mode inactive), or a limited "background" rate (which requires the MOS cameras to be put in a "serendipity mode" in which events from the pn target are masked out and not transmitted, while the rest of the field of view is transmitted).*

Appendix A: References

Section A.1 lists the documents used to compile this note, which are referred to in the text with the abbreviation Ref. [n]. Whenever a given requirement item makes reference to a specific page or table of a document, this is indicated in section A.2.

A.1 Reference documents

[1] A.Bouere, C.Cara, M.Lortholary, C.Pigot, Description of the EDU architecture and operation, Issue 0.1 - Nov 1993
[2] E.Kendziorra, e-mail of 31 Jan 1994 (on cosmic ray rejection etc.)
[3] A.Holland, Status of the Open Electrode MOS CCDs, 25 Nov 1993
[4] EST Letter to Laben, prot. GV/LC/09, Apr 1994
[5] C.Pigot "Some comments on operating modes" Nov 1993
[6] A.Holland's fax "Analysis of bright spots in Bulk EEV CCDs" 5 Jan 1994.
[7] A.Holland, "Requirement for image normalization in EDH" 16 Jan 1994.
[8] L.Chiappetti (ed.), EPIC Operating Modes. Report of the OMWG. Issue 1.A - 31 May 1993 - EPIC-IFC-TN-001
[9] Experiment Interface Document - part A, RS-PX-0016 Issue 3
[10] Packet Structure Definition, RS-PX-0032
[11] C.Pigot's fax, "Do we need indirect modes", 27 Jan 1994
[12] L.Chiappetti, A re-assessment of EPIC telemetry rates, Issue 1 - 26 Apr 1994 - EPIC-IFC-TN-005
[13] E.Kendziorra, fax on "pn burst mode", 16 Sep 1993
[14] E.Kendziorra, e-mail of 4 Oct 1993 (exchange of correspondence with L.Chiappetti, 29 Sep and 8 Oct 1993).

A.2 Punctual references by requirement item

EM0042: Ref. [1], all
EM0100: Ref. [3], section 3.6
EM0105: Ref. [1], pag. 19
EM0106: Ref. [1], pag.13
EM0109: Ref. [1], pag. 13 and 21
EM0111: Ref. [1], pag. 16; ibidem, note: Ref. [5], figure labelled "Timing mode operation"
EM0202: "diagonal" pileup events are patterns 15/16/19/20 in fig. at pag. 15 of Ref. [1]
EM0302: Ref. [1], pag. 10
EM0502: Ref. [8] fig. 2.3
EM0503: Ref. [8] fig. 2.8a
EM0504: Ref. [8] fig. 2.8b
EX0600: see note below.
EM0610: Ref. [1], pag. 17
EM0612: Ref. [1], pag. 20
EM0613: Ref. [1], pag. 21
EM0614: Ref. [1], pag. 23
EM0615: Ref. [1], pag. 23
EX0701 and EX0706: Ref. [9], pag. 62, tab. 5.8.4.2.1
EM0711-17 : see note below.
EP0711-16 : see note below.
EP0711: Ref. [8], pag. 2-41

Note:
The current references for the EDU-EMDH Fast Serial Interface protocol are EPIC-SAP-TN-310 and EPIC-IFC-TN-001, but the actual details of the protocol are under revision (see also minutes of EDH Working Group meetings for proposed changes).
The current references for the EVA-EPDH Fast Serial Interface protocol are MAXIBIT1.TXT 25 Jan 93 and EPIC-IFC-TN-001, but the actual details of the protocol are under revision (see also minutes of EDH Working Group meetings for proposed changes).

Appendix B : evolution of mode definitions

The main reference for operating modes in the past (before ISVR) has been ref. [8]. However since its issue there have been a number of changes, which, in absence of a comprehensive document, are summarized in the following table :

MOS

~~Full Frame~~	deleted
Frame Store	Imaging
Window	
Refresh FS	
Fast Window	Timing
~~Timing~~	deleted

pn

Full Frame	
Large Window	
Small Window	
Burst (old)	Burst (redefined)
Timing	

Ex0003 and following requirements gives sketchy definitions of the modes. For further details on the evolution of modes, see the references listed here below :

Evolution	**Reference**
MOS Full Frame mode has been deleted	[8] [5]
MOS FS, W and RFS are absorbed in an unique Imaging mode with a new readout procedure which exploits the new focal plane frame store arrangement; see EM0004 .	[8] modified as in [5]
The former MOS Fast Window mode is now called Timing mode; with a modified readout procedure	[8] modified as in [5]
The pn imaging modes (FF, LW, SW) are confirmed	[8]
The pn Burst mode has been redefined	[13]
The pn Timing mode is confirmed, but fig. 2.10 in ref. [8] is wrong and misleading (text is correct).	[14]

Appendix C

The following table gives the valid combination of modes for one MOS chip at CCD, event handling and transmission level, and identifies the main configurations. The event handling cases are specified by `EM0042` and `EM0052`. The transmission options are specified by `EM0711-20`.

# config	A	B1	B2	B...	C1	C2	C...	CI...
CCD	any	Imaging (any option)			Timing			
Ev. H.	Transp	Imaging			Timing			
Trans.	D0	D1	D2	Other	D3	D4	Other	Indir.
Usage	Diag	Diag	**Main ?**	Aux	**Main**	Aux	Aux	Aux

The following table gives the valid combination of modes for one chip at CCD, event handling (Ev.H) and transmission (Trans.) level, and identifies the main modes. The event handling cosmic ray rejection procedures are specified by `EP0042-60`. The transmission options are specified by `EP0711-20`.

# config	A	B1	B...	C1	C...	D1	D...	D...	DI..
CCD	any	FF or large W		small W		T or B	T	B	T
Ev. H.	Transp	3-row rejection		window rejection		plain thresholding			
Trans.	D0	D1	Other	D1	Other	D1	Other	Other	Indir.
Usage	Diag	**Main**	Aux	**Main**	Aux	**Main**	Aux	Aux	Aux

Author's comment: The "Usage" row gives a preliminary indication of how a given setup can be used. "Main" identifies primary modes likely to be used often. "Diag" identifies modes used for diagnostics. "Aux" identifies secondary modes likely to be used only for a few observations (or - in the case of the "Other" transmission options - to be confirmed or cancelled).

The combination of modes across chips may be derived from requirements `EM0502`, `EM0512`, `EP0502`, `EP0503`, `EP0504`, `EP0505`.