4. Instrument Data Handling

4.5.3. Telecommands

The majority of the telecommands sent to EPIC from ground will be passed to the relevant EPIC 1-2-3 EDHU by the OBDH and be compliant with ESA Packet Telecommand standard (Ref. 4.4). A limited number of critical commands which are passed directly from the OBDH RTU to the relevant EPIC box via dedicated lines is listed in EID-B (Ref. 4.5 ?)

It will be a task of the EDHU to decode received telecommand packets, and either execute them locally, or pass them to downstreams units (controllers, analog electronic, filter wheel, camera heads etc.).

What follows is a non-exhaustive list of commands [Andy, for me you could stop at the previous two sentences]

- management and configuration commands handled locally at EDHU level
- Commands related to packing modes handled locally at EDHU level
- On-board s/w reload and/or patch (both locally in EDHU and in underlying processors (EPIC 1C, 3B))
- "hardware" commands to be passed by EDHU to downstream units for basic setup

commans to heaters under EPIC control
commands to position the filter wheel
CCD bias voltages, clock drivers and sequencer programmes
stimuli for in flight tests

- Commands related to CCD operating mode choice to be passed by EDHU to downstream units. This includes :

selection of CCD mode and chip selection for a given mode
number of readout nodes (FF, FS modes) and selection of relevant lines
pixel binning (FF, FS modes)
image integration time (FF, RFS modes) or integration factor (pn FF mode)
basic clock frequency (pn modes)
size and position of window (Window modes)
size of column set, first column, number of lines to be summed (FW mode)
Node to be used (MOS FW, T mode)
Clocking speed (FW only vertical; T)
Choice to read whole matrix or part of it (FW)

ECCE EDU lower energy threshold
EPCE lower energy threshold (per column, 64 per CCD chip)
EPCE upper energy threshold
ECCE pattern libraries and other correction tables

4.5.4. Inter-experiment data exchange

All data (if any) which one of the EPIC1-2-3 D EDHUs might need from other instruments (e.g. the EPIC Radiation Monitor) or XMM onboard subsystems (e.g. attitude data from AOCS) will be acquired from the OBDH Bus using the Packet Telemetry standard (Ref. 4.2 and 4.3).

4.6. EPIC data rate

4.6.1.processes contributing to the determination of the data rate

EPIC bit rates cannot simply be scaled from source count rates. This will be more apparent after a brief review of the main processes which affect the detection of photons in an EPIC chain.

1) an X-ray photon interacts with the CCD material giving rise to a charge cloud, with the total charge being proportional to the photon energy ($E = 0.00368\ q$, where E is in keV, and q is the number of electrons). However this charge diffuses in the CCD material, and may be subdivided among adjacent pixels. This effect is called splitting.
This means a single photon may give rise to more than one event at chip level.

2) Events (pixels) whose charge content is below a programmable lower threshold are however rejected and not passed any further.

3) The charge content of a pixel may be altered during the shifts necessary for readout. This effect is termed charge transfer inefficiency. This effect will be neglected here.

4) if more than one photon reach the same pixel before the current frame is read out, the charge deposited by the last photon adds to the charge already present. This alters the proportionality between energy and charge, hence the energy resolution. Therefore this effect shall be avoided as much as possible. This effect is called pile-up.

5) if a photon reaches the CCD while this is being read out, the photon might be detected at a wrong position. This effect is called smearing. Since this does not affect the event rate, it will be neglected here.

6) background charged particles also interact with the CCD material and deposit a lot of charge, in excess of the amount deposited by a photon having the highest energy possible in practice because of the optics efficiency. However the rejection of all pixels having a charge content above a programmable upper threshold is in general too rough. In fact also the charge deposited by a particle spreads among adjacent pixels, and may generate spurious events with charge below the upper threshold. The rejection should therefore take advantage of the geometry of the charged particle track (which in general is quite elongated, unless the particle is impinging perpendicularly to the CCD surface).

It is not immediately possible to quantify the above effects. One way would be to await data from experimental measurements, another to use some rough parametrization, and another to perform simulations of the detection in the CCD, and of the possible processing in the Controllers and EDHU. All of them may be (and were) used in some extent, but any result shall be regarded as highly preliminary due to the large number of free parameters.

4.6.2.limiting rates for CCD modes

Splitting and pileup are the main effects which may affect the data rate due to X-ray sources (at the level of the camera head to controller interface). Here we term count rate the number of photons incident on a chip in the unit of time, and event rate the number of non-null-charge pixels in the unit of time. Because of splitting, one photon may give rise to more than one event. Splitting depends both on the photon energy (hence on the chip physical parameters), and of the pixel size (therefore the pn camera, with its larger pixels, is less affected than the MOS camera). J

Both splitting and charged particle background act in the direction of increasing the data rate, however this increase may be counteracted upon in the controller, as described in the next section.

On the other hand the pile-up, which is purely due to the source intensity, has an effect of limiting the maximum practical rate which can be attained in a given mode. This is not because one event is generated instead of two, when two photons impinge on the same pixel, but because pile-up must be avoided because it may severely degrade the energy response, and irrecoverably spoil the scientific usage of the data. Therefore in each mode (essentially as a function of the mode integration time) there is a maximum source intensity above which pileup degrades the spectrum. Although the instrument may still operate, in practice it will never be used above the limiting rate, because data will be scientifically useless.

One may quantify the limiting rate in a coarse parametric way, saying that one shall not exceed a rate $r < 1/n$ photon/pixel/frame (where the value of n is debatable, but usually around 40), or simulations of the CCD detection may be performed, counting the number of pile-ups as a function of increasing count rate. Comparison of the source spectrum before and after the CCD detection show that above a percentage of 5% of piled events, the spectrum starts to be altered in a significant way.

This allows therefore to compute the following (provisional) count rate limits (these are based on simulations using a Crablike spectrum, where 10 mCrab (3x10-10 erg/cm2/s in the 0.1-10 keV band) are 187 counts/s incident on the chip.

Table 4.x Limiting source rates (maximum source intensity observable without significant pileup)

MOS operating mode	Rate (mCrab)	pn operating mode	Rate (mCrab)
Full Frame	0.37	Full Frame	10
Frame Store	3.7		
Refreshed FS	360		
Window	70	Small Window	90
Fast Window	100		
Timing	200	Timing	1900 (sic!)
		Burst	3000 (sic!)

The values given in the above table (and all values mentioned below) refer to the case of one EPIC unit receiving the full optics area. The EPIC units placed behind the grating will have their effective area halved, therefore the limiting rates can be twice as high as far as source intensities are concerned.However the event rate produced by a source twice as intense with half the area will be the same, and therefore the remainder of the discussion about data rates is unaffected.

4.6.3. controller rejection and reconstruction efficiency

The figures in the above table indicate the maximum source rate allowed in a given mode. The diffuse background rate shall be added to the source rate, but it is negligible (of the order of 1-2 counts/s/chip). Such photon rate gives rise to a higher event rate because of splitting, which might increase the nominal rate of a factor 30-50% (if one does not consider application of a low energy threshold; such a threshold at e.g. 0.1 keV will reject all pixels with a very small "residual" charge content, confining the increase to about 15-25 %).

The charged particle background is subject to a more severe splitting, and may give rise to a significant event rate. If one assumes e.g. as reference a medium solar activity background of 9 particle/s/chip in the MOS case, or 4.5 particle/s/chip in the pn case (the factor 2 is the geometrical area ratio of the MOS to pn chip; in both cases approximately 90% of the particles are protons and 10% alpha particles), this nominally gives an event rate of 150 event/s/chip for MOS, and 25 event/s/chip for pn.

Application of lower and upper energy threshold (e.g. at 0.1-10 keV) allow to reject only 50% of the MOS particle background, or 80% of the pn particle background.

Among the main tasks of the EPIC Controller units (1C and 3B) will be the rejection of charged particles, and the reconstruction of split events by mean of pattern analysis. This is described in sections 2.2.2 and 2.3.2 [ANDY, any more references in chapter 3 ??]

The event rate at the Controller to EDHU interface therefore depends essentially on the performance of the controller for background rejection and split event reconstruction. In particular the background rejection efficiency is critical : a change in the rejection efficiency from 99% to 90% can easily increase the background event rate by a factor 8 for a MOS camera.

4.6.4. Usage of direct and indirect modes

One can therefore generate a rough estimate of the bit rates in direct modes (neglecting any overhead due to the various headers described in 4.4.1 above) assuming for each mode a source at the limiting rate (or at one third of the Crab, whichever the smaller), an allocation of bit/event as given in table 4.6??, a split event reconstruction efficiency of 100%?????, a typical particle background, and a background rejection efficiency of 99%????.

This assumes in general a single point source located in a chip operated in the particular CCD mode, while all other chips are in the default CCD mode (with the exception of the pn timing modes, where the other chips are not read out) and look at the background.

Table 4.y Maximum data rates for an entire EPIC unit in direct modes
(these are based on the limiting rates in table 4.x, except for the pn timing and burst mode, which are based on an intensity of 360 mCrab, although those modes can in principle support stronger sources).

MOS operating mode	Rate (kbit/s)	pn operating mode	Rate (kbit/s)
Full Frame	1.5	Full Frame	6.1
Frame Store	5.1		
Refreshed FS	18.0		
Window	76.7	Small Window	49.0
Fast Window	66.8		
Timing	113.0	Timing	180.0 *
		Burst	182.0 *

(the data rate scales linearly with source intensity for intensities higher than approximately 1 mCrab, below which the data rate is essentially due to the background)

From this one can see that for a source stronger than 15-30 mCrab the nominal data rates from the windowing, fast windowing and timing modes (both for MOS and pn) exceed the typical telemetry rate available to one EPIC unit (assumed as 16 kbit/s per unit). Only the MOS RFS mode is marginally consistent with that, and allows stuidy of a stronger source (however with a small duty cycle, see tab. 4.1). Even if we consider 40 kbit/s allocated to one EPIC unit (with the other ones producing just HK data), it is not possible to observe sources stronger than 60-80 mCrab. For stronger sources usage of an indirect mode is necessary.

The data rate from an indirect mode is independent of the source intensity, but depends on the parameters of the accumulation, which will be freely programmable. Since typical settings for indirect modes have not yet been decided, there is no sense in giving excessive detail here, however it should always be possible to match the scientific goals and the available telemetry with a suitable choice of parameters.

Some extreme and less extreme case that may be considered are :

a spectral mode with a 4096 channel (nominal 12-bit ADC resolution, unlikely to be used) spectrum, 8

bit/channel, integration time of 10 s gives 3.2 kbit/s
The bit rate obviously scales with the number of channels and the inverse of the integration time (being this mode used mainly for strong objects, hence in "fast" CCD modes, the only constraint is that the integration time is a multiple of the frame time; since the latter is very small, the integration time can assume virtually any value).
a spectral mode with 1024 channels, 8 bit/channel, integration time of 1 s gives 8 kbit/s.

for timing studies an 8 band time profile, 8 bit/bin, bin size of 10 ms gives 6.4 kbit/s
Here too the bit rate scales in an obvious way with the number of bands and the inverse of the bin size.

4.7. Typical observation scenarios

The default operating mode for the observation of faint sources (faint point-like and extended objects, wide fields, surveys) will be : a) for the MOS camera the Frame Store (FS) mode in the central chips pointed on the target, and the Full Frame (FF) mode in the remaining chips, used in serendipity mode; b) for the pn camera the FF mode for all chips.
The default mode should be able to accomodate most extended sources except the brightest galactic supernova remnants or cluster cores.

In case of imaging at a vey low level of surface brightness (the extreme case will be imaging of the diffuse background) it has to be considered that the integration to readout ratio of 10:1 induces a 10% smearing. Therefore usage of the FS mode w.r.t. the FF mode might be preferred.

In the case of the MOS cameras the usage of the Refreshed Frame Store (RFS) mode will enable imaging with spectroscopy of sources stronger than allowed by the (more complex) windowing mode. However the RFS mode is inconvenient for timing studies. Therefore a possible scenario would be to observe with one EPIC unit in RFS mode, and another EPIC unit in Timing mode at the same time.

Windowing (W) mode could be used for point sources with fluxes higher than those allowed by the FF or FS modes (when millisecond timing is unimportant), as well as for bright knots and for relatively compact extended objects.

The Fast Window (FW) mode could enable timing studies for fainter sources, when the timing mode cannot be used due to low statistics. In addition this mode may be used for sources which are not isolated in the field of view, since it restrains the processing to a selected set of columns on the CCD chip.

Usage of windowing modes may require a preliminary "acquisition" exposure in the default mode in order to correctly position the window on the chip.

In the case of extended sources containing bright point-like sources (e.g. clusters with a strong central galaxy, or SNRs with bright knots) one may set up separate EPIC units, one in Windowing mode to image with spectroscopy the bright source, and the other one in default mode to observe the fainter parts of the source. This may occur using different modes in two units at the same time, or also in sequence with the same unit.

The timing modes (MOS Timing, pn Timing and eventually Burst) are particularly appropriate for compact binary objects with variability down to the millisecond timescale. These modes also allow the study of objects stronger than most other modes.

The FW and Timing modes might be combined for phase-resolved spectroscopy of bright X-ray pulsars. A typical sequence could consist of a short exposure in timing mode, in order to precisely measure the period, followed by a longer FW run, which will usually provide a uniform phase coverage of the source.

The transparent mode is liable to provide a high bit rate, since one has to transmit all pixels in a CCD frame (typically for an integration time equal to the standard mode if the diagnostic is run with an X-ray source in the field of view, while longer integration times might be used for estimates of the pixel-by-pixel dark current, the diagnosis of radiation damage, the effects of low level signals). However since this is used unfrequently, for dedicated diagnostic sessions, it is felt appropriate to consider that most of the entire XMM telemetry budget could be reserved to the instrument being diagnosed.