The EPIC system onboard the ESA XMM mission

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ABSTRACT

The **E**uropean **P**hoton **I**maging **C**amera (EPIC) is one of the two main instruments onboard the ESA X-Ray Cornerstone mission XMM. It is devoted to performing imaging and spectroscopy of the X-Ray sky in the domain 0.1-10 keV with a peak sensitivity in 10^5 seconds of $2x10^{-15}$ erg/cm^{-2}. The X-ray instrumentation is complemented by a radiation monitor which will measure the particle background. The spectral resolution is approximately 140 eV @ 6.4 keV and 60 eV @ 1 keV. The instrumentation consists of three separate Focal Plane Cameras at the focus of the three XMM telescopes, containing CCDs passively cooled to typically -100° via radiators pointing toward the anti-Sun direction. The two cameras with the field of view partially occulted by the RGS Grating Boxes will have MOS technology CCDs while the third camera, with full field of view, will be based on p-n technology. The CCDs in the focal plane of the Cameras will cover the entire 30'x30' field of view of the telescope while the pixel size (40x40μ for the MOS camera and 150x150μ for the p-n) will be adequate to sample the ~20" PSF of the mirrors. In order to cope with a wide range of sky background and source luminosity in the visible/UV band, a filter wheel with six positions has been implemented in each Camera. The six positions correspond to: open position, closed position, one thin filter (1600 Å of plastic support and 400 Å of Al) , one medium filter (1600 Å of plastic support and 800 Å of Al) and one thick filter (~3000 Å of plastic support, ~1000 Å of Al and 300 Å of Sn). The final position will be a redundant filter of type still to be decided. A set of radioactive sources in each camera will allow the calibration of the CCDs in any of the operating modes and with any filter wheel position. Vacuum doors and valves operated will allow the operation of the Camera Heads on the ground, in a vacuum chamber and/or in a controlled atmosphere, and will protect the CCDs from contamination until the spacecraft is safely in orbit. The MOS camera will have 7 CCDs, each of 600 x 600 pixels arranged in a hexagonal pattern with one central and six peripheral. The p-n camera head will have 12 CCDs, each with 200x64 pixels, in a rectangular arrangement, 4 quadrants of 3 CCDs each. The Radiation Monitor is based on two separate detectors to monitor the Low (electrons > 30 keV) and the High (electrons >200 keV and protons >10 MeV) energy particles impinging on the telescope along its orbit.

1. INTRODUCTION

The European Photon Imaging Camera (EPIC) was selected in 1989 for the European Space Agency's (ESA) X-ray Multi-Mirror (XMM) Mission, one of the cornerstone missions of the Agency's Horizon 2000 plan. The EPIC System consists of three similar cameras mounted at the focus of the three mirror modules which comprise the XMM optics, and a separate Radiation Monitor instrument. The detecting elements of the three cameras are Charge Coupled Devices (CCDs) of two types, MOS and p-n, while the arrays of CCDs cover the entire field of view of the mirrors and the pixel sizes are adequate for the sampling of the mirrors' P.S.F.

The EPIC system is being developed by a collaboration of 10 Scientific Institutes in 4 European countries and the financial support is provided by the relative Space Agencies, ASI (Italy), CNES&CEA (France), SERC (U.K.) and DASA (Germany):

Italy has the overall responsibility of the program. The Principal Investigator, the only point of contact between EPIC and ESA, performs the management and the control of the collaboration through the EPIC System Team. On the hardware side, Italy has the responsibility for the EPIC MOS/p-n, Data Handling electronics (EMDH and EPDH), for the three electronic chains and of all the activities at system level.

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France is responsible for the EPIC MOS Control & Recognition electronics (EMCR), for the EPIC MOS Voltage Converter (EMVC), for the EPIC Calibration Facility at Orsay and finaliy for the EPIC Radiation Monitor System (ERMS).
The **U.K.** is responsible for the two EPIC MOS Camera Heads (EMCH) and for the two EPIC MOS Analogue Electronics (EMAE).
Germany is responsible for the overall p-n chain, apart from the EPIC p-n Data Handling electronics.

2. THE EPIC CONFIGURATION

The EPIC instrument consists of three similar focal plane cameras with their associated electronics and one Radiation Monitor. In Figs. 1a,b and c are shown the schematic layouts for each susbsystem. The EPIC cameras provide full coverage of the focal plane, 30 arcmin in diameter and using a combination of full field image, window and timing modes can cope with the full range of source brightness as detailed in Table 1.

Regime	**I(mCrab) pile-up limit**	**MOS max rate (kbit/s)**		**pn max rate (kbit/s)**	
default (very faint)	1	**2.6**	**Full Field**	**2.1**	**Full Field**
faint source	2	**5.2**	**Window mode**	**2.7**	" "
medium intensity	12	**10.3**	" "	**13.7**	**Window Mode**
medium-strong source, timing+spectroscopy	40	**11.4**	**Timing Mode**	**29.1**	" "
strong source spectroscopy	120	***5.0***	**Refresh Frame store**	***10.8***	**Burst Mode**
idcm, timing	120	**31.9**	**Timing no NDC**	***13.3***	**Timing mode**
		11.3	**Timing w/ NDC**		
very strong source	230	**20.4**	**Timing w/ NDC**	***20.9***	**Timing mode**
				18.2	**Burst Mode**
ultra-strong timing	800	not used		***51.0***	**Timing mode**
ultra-strong spectroscopy	1600	not used		***14.1***	**Burst Mode**
Low surface brilliance extended source (Tycho|Perseus)		**12.3**		**13.2**	
High surface brilliance small size extended source (Kepler)		**5.6 Window** (220 x 220)			

Tab.1: Each regime corresponds to a source intensity less than or equal to the pile-up limit for the corresponding selection of readout modes. The bit rate of the pileup limit considers the bit allocation per event (96 bitper event for MOS imaging ; 48 bit MOS timing ; 16 bit MOS timing with NDC-Non Destructive data Compression-; 32 bit for all p-n modes) plus all frame header and trailer overheads. Values in italics indicate that the data are undersampled or contain gaps.

Two of the cameras are situated after the Reflecting Grating Spectrometer (RGS), and each of these has a detection plane consisting of an array of 7 MOS CCDs with 600*600 square pixels of size 40 μm which corresponds, in the sky, to approximately 1.1 arcsec. The third camera, placed in the RGS-free telescope, has a single chip with 12 p-n CCDs, each of 64*200 pixels and a pixel size of 150 μm which corresponds to an angle of 4.1 arcsec. When the mission was planned, the mirrors' PSF was assumed to be 30 arcsec (this was used in the calculations of the pileup limit in Tab. 1), but now that the program is in the EQM phase it is almost certain that the PSF will be 20 arcsec or better but the CCDs pixel size is still more than adequate to allow sufficient sampling.

The Electronic chains perform the CCD readout, the digitalisation of the signals, the thresholding, the discrimination between good X-ray events and background, the organisation in packets of the data to be sent to the data Bus, the commanding and the housekeeping data generation and control.

3. SCIENTIFIC PERFORMANCE

The scientific performance of the EPIC instrument is detailed in Table 2, while in Figs. 2a and b the effective area for the MOS and p-n system (including the mirror response) are shown. It must be considered that while the p-n camera receives the full beam coming from its mirror module, the 2 MOS cameras receive only 40% of the flux each due to the absorption and deflection caused by the RGS box.

Parameter	pn CCD	MOS CCD
Pixel size	150 μm (4.1")	40 μm (1.1")
Full Focal Plane Frame time	48 ms	2.7 s
Timing Resolution	40 μs	1 ms
Energy Resolution	140 eV @ 6.4 keV 60 eV @ 1 keV	135 eV @ 6.4 keV 55 eV @ 1 keV
Quantum Efficiency (HE)	99% @ 6.4 keV 97% @ 8 keV	87% @ 6.4 keV 65% @ 8 keV
Quantum Efficiency (LE)	88% @ 0.5 keV	45% @ 0.5 keV
Compton Background	$5\ 10^{-4}\ cm^{-2}s^{-1}$	$2\ 10^{-4}\ cm^{-2}.s^{-1}$
Operating Temperature	-128 °C	-80 °C

Tab. 2: MOS and p-n scientific performances

4. THE CAMERA HEAD DETAILED DESIGN

The Camera Heads (CH) are the highly sophisticated mechanical devices which house the CCDs and provide all the subsystems which are necessary for their correct functionality. As can be seen in Figs. 3 and 4, the two types of cameras are very similar and some subsystems are identical.

If we follow a top-down approach, the first subsystem we find is the Radiator which, orientated away from the sun, provides the necessary cooling to the CCDs via a Cold Finger. The geometries of the MOS and p-n Radiators are quite different (the MOS is conical while the p-n is rectangular and flat) and while that for the MOS is defined as a quasi-three stage system, the p-n is a pure two stage design. Both systems are capable of cooling the CCDs down to -150° C and a set of heaters located in various positions and controlled by the EMCR perform the temperature control. The electronics which perform the temperature setting and control are located in the EMAE for the MOS and in the EPEA for the p-n chain. The operating temperature for the two systems will be set to the nominal value of -80° C at the beginning of the mission, and subsequently to lower values for the MOS as radiation damage increases.

The detecting elements, the MOS and p-n CCDs, which are attached to the cold fingers and are surrounded by a thick Al shield, are described in two separate papers presented at this conference. The shield will limit the amount of radiation impinging onto the CCDs to a level such that the degradation of performance during the ten years orbital life will be very limited. In case the damage is higher than expected and the degradation becomes important, it is possible to perform "annealing" of the CCDs by heating them up to ~ 150° C.

A set of two calibration sources, positioned via telecommand, will allow the calibration of the CCDs at any moment during both the on-ground operation and the flight. The low energy source will also allow the monitoring of the amount of contamination deposited on the CCDs surfaces.

A 6-position Filter Wheel, again operated via telecommand, is positioned in front of the CCDs and will allow observations of celestial targets in a wide range of Optical/UV contamination. Of the six positions, one is Open (no filter), one is closed by a 1.5mm thick Al disk and the other four will have a thick, medium and thin filters plus a redundant filter of a type still TBD. The thick filter (3000Å of plastic support and approx. 1000Å of Al and Sn) is manufactured by the M.P.I.- Garching, Germany and is presented in a separate paper at this conference; the medium and thin filters are manufactured by MOXTEK-Inc. Orem, Utah. The medium filter has a polyamide support of 1600Å, is coated on the two sides with 400 Å of Al, the thin one has again 1600 Å of support but only 200+200Å of Al.

On a PCB around the CCDs detectors is located the electronics to drive the CCDs and the preamplifiers. to send the signals down into the EMAE where they are digitised and transmitted downstream. The mechanical structure which contains the CCDs, can be kept closed with vacuum inside via a vacuum door operated via telecommand. The door during the operations on the ground can be commanded open and closed while in orbit it can only be commanded open. A vacuum valve, also operated via telecommand completes the CH subsystems. The vacuum valve will be used to slowly vent-out any residual atmosphere inside the CH before the vacuum door opening, preventing in this way a rush of air which could cause damage to the filters. The CH is bolted to the instrument bulkhead from where it will have a direct view of its Mirror Module. An Al shield on the other side of the bulkhead will limit the amount of radiation which could reach the CCDs.

5. THE MOS ELECTRONICS CHAIN

5.1 MOS Focal Camera Unit

Each focal camera unit contains 7 CCDs and 14 preamplifiers with heaters and thermistors for thermal control.

5.2 MOS Analogue Electronics Unit

The analogue electronics unit provides programmable bias voltages to the CCDs and clock drivers. Programmable sequences generate the CCDs clocking waveforms per pair of CCDs, except for the central CCD which is clocked by a single independent (with redundant) sequencer. Signals from the 14 preamplifiers inside the focal camera unit are fed into the control & recognition unit. The seven outputs of the 14 nodes from each focal camera unit are processed contemporaneously. The remaining seven outputs are provided for redundancy. The analogue electronics unit monitors all the CCD bias voltages, some internal temperatures and various digital registers. The analogue housekeeping values are digitised to 8 bits, and sent to the control & recognition unit as serial data. The unit controls the CCD temperature with an 8 bit command word giving a range of -150 °C to +50 °C.

5.3 MOS Control & Recognition Unit

The EPIC MOS Control and Recognition Unit (EMCR) provides an interface between the EPIC MOS Analogue Electronics Unit (EMAE) and the EPIC MOS Data handling Unit (EMDH). Its aim is to recognise and extract the few X ray events in the images of the 7 CCDs of the focal plane among mostly dark pixels with no direct physical interest, and cosmic-ray background (long traces on the CCDs). The recognition algorithm is able to reduce by about three orders of magnitude the data flow to cope with the limited telemetry rate towards the ground. To process in real time the high data flow coming from the CCD, an ASIC technology had to be used.

The EMCR receives commands from the EMDH, interprets and transmits them to the EMAE. It acquires Housekeeping data and transmits them to the EMDH. It uses two Low Bit Rate bi-directional asynchronous serial lines to process commands and housekeeping data to and from the EMAE and EMDH.

The EMCR receives raw data (pixels content) from the EMAE, processes them in the Event Detection Units (EDU) and sends the result of the X-ray event recognition algorithm to the EMDH. It uses High Bit Rate mono-directional synchronous serial lines to receive and transmit data from the EMAE and to the EMDH.

The EDU identifies X-rays in the raw CCD image by performing a proximity analysis in a 5x5 pixel matrix. It looks, for each centred pixel recognised as the brightest one in the central matrix, that the pattern formed by adjacent pixels above threshold belongs to a library of 32 pre-defined patterns (this library is re-programmable from ground). Once an X-ray event is recognised, its pattern code number, location, energy and quality parameters are sent to the EMDH.

Last, the EMCR co-ordinates and synchronises the four sequencers of the EMAE to perform the observation sequences as requested by the EMDH.

The EMCR program is stored in ROM and loaded in RAM at the start-up time of the micro-processor. Modification of the program if needed, and the configuration parameters to be transmitted to the EDU's or to the EMAE are up-linked from the ground.

5.4 MOS voltage Converter Unit

The voltage converter unit contains redundant DC/DC converters which supply power to the EMAE and EMCR. The unit is supplied with main and redundant 28 V power lines from the EMDH. A thermistor monitors its temperature.

5.5 MOS Data Handling Unit

The data handling unit performs an additional data reduction, and formats the data to the spacecraft. It has a dedicated DC-DC converter for its own purpose. The data handling units fulfil the following functions:

- Management and control of the electronic chain, for all the modes of operation;
- Acquisition of HK telemetry for the other units;
- Acquisition of scientific data from the other units; data processing according to the selected mode operation;
- Preparation of source packets and forwarding to the OBDH;
- Storage of scientific data in RAM, when necessary, for specific modes of operation;
- Telecommands reception from the OBDH and distribution to other units;
- Power conditioning for the instrument heaters and the mechanisms inside the focal camera units;

6. THE P-N ELECTRONICS CHAIN

6.1 FOCAL Camera Unit

The Focal camera contains 12 CCDs grouped in 4 quadrants. Each CCD has 64 output nodes with on-chip amplifiers, which are directly bonded to the inputs of a CMOS Amplifier and Multiplexing chip (CAMEX). All the necessary digital signals needed to control the CAMEX chip are provided by the TIMEX chip. The TIMEX converts a serial pulse pattern into a sequence of parallel control pulses for the CAMEX. The drives for the 3 phase line clock pulses and drives for the anode reset switches are mounted in enclosed boxes on the outside of the focal camera unit.

6.2 pn Control Electronics Unit

All the electronics needed to power the CCD detectors, to control their temperatures and to operate the filter wheel and the calibration source mechanism are mounted in the control electronics unit. This unit controls programmable voltages for the CCDs, controls the read-out sequence of the four quadrants and monitors all the CCD bias voltages, the CCD temperatures, the internal temperatures and various digital registers. The CCD temperature is controlled with a command word giving a range -150 °C to + 20 °C.

The filter wheel motor (with both main and redundant windings) is controlled from a motor drive board in the control electronics unit. The drive circuit can be commanded to move the motor one step in either direction. Position sensors on the filter wheel are read out in the housekeeping to verify its position but are not necessarily used in a feedback mode on-board. When the control electronics unit receives a command for the event analyser unit, it passes this command through a dedicated serial interface line. The control electronics unit collects from the focal camera unit all the housekeeping data, which are the formatted and sent to the data handling unit via a serial line.

6.3 pn Event Analyser Unit

Analogue data from the CCDs are processed in the event analyser unit which also provides the digital pulse sequences for the CCD readout. The event analyser unit consists of four identical modules. Each module manages the readout of the three CCDs from a one detector quadrant and processes the analogue event data from this detector quadrant.
A programmable sequencer generates the CCD clocking waveforms and the TIMEX and CAMEX control pulses. The pixel energy is converted into a 12 bit word by a fast flash ADC. The digital event filter and address encoder board (DEFA) performs a digital noise reduction and provides the positional information which is then added to the energy.
The numbers of good and rejected events will be counted. In order to determine the event times to better than 20 microseconds, at the beginning of each readout cycle a 31 bit time information from a clock which has a fixed offset relative to the spacecraft time is also transmitted to the data handling unit. The event analyser also contains circuits to stimulate the CCD anodes. This will enable testing and the electrical recalibration of the analogue signal processing chain.

6.4 pn Voltage Converter Unit

The voltage converter unit contains a thermistor and the redundant DC/DC converters which supply power to the control electronics unit, to the focal camera unit and to the event analyser unit. The voltage converter unit is supplied with main and redundant + 28V power line via the data handling unit.

6.5 pn Data Handling Unit

The data handling unit performs an additional data reduction, and formats the data to the spacecraft. It has a dedicated CD-CD converter for its own purpose. The data handling unit fulfils the following functions:

- Management and control chain, for all the modes of operation;
- Acquisition of HK telemetry from the other units;
- Acquisition of scientific data from the other units; data processing according to the selected mode of operation;
- Preparation of source packets and forwarding to the OBDH;
- Storage of scientific data in RAM, when necessary, for specific modes of operation;
- Telecommands reception from the OBDH and distribution to the other units;
- Power conditioning for the instrument heaters and the mechanisms inside the focal camera unit;

7. MOS/PN OPERATING MODES

7.1 MOS/ pn Camera Instrument Chain Modes

The mode transition diagrams for the MOS or pn instrument chain are shown in Figs. 5 and 6.

7.2 Observation Modes

MOS-PRIMARY, in which all 7 CCDs are read using imaging options (possibly with partial window, according to preset parameters)
MOS-FAST, in which one CCD is read using timing option and the other 6 CCDs using imaging option.
MOS-OFFSET/ VARIANCE, used for set-up of full frame imaging. All pixels of each CCD are transparently sent by the EMCR unit to the EMDH unit, which computes the row and column offset and the overall variance.

MOS-CCD DIAGNOSTIC, used for troubleshooting verification of the OFFSET/VARIANCE computation or replacement of it in conjunction with window imaging or timing read-out. All pixels of one CCD (one frame) are transparently sent by the EMCR unit to the EMDH unit, packetized and downlinked.

In all of the above modes all the data are available via TLM and no TLC is accepted, with the exception of "Enter EMCS IDLE or Safe Stand-By mode". In these modes, the shroud, annealing and HOP heaters are off and it is not allowed to remove the primary power.

Calibrations, using the built-in radioactive source or celestial sources will be done as normal observations, using any of the above modes.

pn-IMAGING, in which all CCDs in the 4 quadrants are read using imaging option (possibly with partial window, according to preset parameters)

pn-TIMING, in which one CCD of each quadrant is read using timing option.

pn-BURST, in which one CCD of each quadrant is read in a special manner (i.e. the duty cycle is less than 100% and thus there are time gaps)

pn-PIXEL CHARACTERISTICS, in which information can be selected between: offset/bad pixel map, pixel noise map, discarded line map.

pn-CCD DIAGNOSTIC, used troubleshooting. All pixels (for a programmable number of frames) are transparently sent by the EPEA unit to the EPDH unit, packetized and downlinked.

In all the above modes all the data are available via TLM and no TLC is accepted, with the exception of "Enter EPCS IDLE or Safe Stand-By mode". In these modes, the extraheating and HOP heaters are off and it is not allowed to remove the primary power.

Calibrations, using the built-in source or celestial sources will be done as normal observations, using any of the above modes.

7.3 Engineering Modes

INIT, in which primary power is applied to the instrument, all the units initialize themselves and the focal plane temperature control by the S/C is not active. Results of the initialization procedures will be transmitted via TLM.

SAFE STANDBY, in which the filter wheel is always in closed position, the thermal control of the focal plane is active with a default value of temperature, the heating devices controlled by the EMDH and EPDH units are off and the HK of the EMCH and EPCH units are available via TLM. In this mode only some specific TLCs from ground can be accepted.

IDLE, in which all the TLCs (with some exceptions) are accepted. Status of the filter wheel, the CCDs the thermal control temperature, the calibration source, the HOPs, etc. depend on instrument configuration, performed by TLC. In this mode shroud and annealing heaters (for EMCH) and extraheating heaters (for EPCH) are off and the HK of the EMCH and EPCH units are available via TLC. It is not allowed to remove primary power in this mode.

EXTRAHEATING, which comprises the following modes:

ANNEALING (only for EMCS): the temperature of the focal plane is maintained at + 130 C and the CCD and HOPs heaters are off.

SECONDARY SHROUD/DE-ICING: the temperature of the focal plane is maintained at - 70 C and the CCD and HOPs heaters are off.

DECONTAMINATION: the temperature of the focal plane is maintained at + 20 and the CCD, secondary shroud (only for EMCS) and HOP heaters are off.

In all the three above modes the door is open, the filter wheel is in the open position and the CCDs are off; HK of the EMCH and EPCH units are available via TLM, no TLC can be accepted (with the exception of "Enter EMCH/EPCH IDLE or Safe Stand-By mode") and it is not allowed to remove the primary power.

IN-FLIGHT TEST, which various tests can be performed, both using simulation sources and dedicated h/w and s/w functions. HK data are available via TLM and it is not allowed to remove the primary power. Only few TLCs can be accepted.

7.4 Non-operating Modes

LAUNCH, in which the instrument is not powered. All the mechanisms are in a closed position.

OFF, on which the instrument is not powered on and the door mechanism and the vents mechanism are opened under spacecraft control. Focal plane temperature is under S/C control. Filter wheels are in closed position.

8. ERMS OPERATING MODES

The ERMS operating modes are shown schematically in Figure 7.

START-UP: This mode is reached after an h/w reset or after power on. It is a temporary mode where the s/w computes the autotest and the equipment initialisation. In this mode there is no telemetry. After about 4 seconds, the radiation monitor instrument conducts an autonomous mode transition.
STANDBY: This mode is reached at the end of START-UP. The ERME processes the TC it receives, the 3 ASICs are stopped while any mode transition can be commanded. In this mode the telemetry is generated according to the SLOW mode format and the detector data are marked as invalid.
SLOW: On this mode the s/w collects the three spectra, computes them and sends the SLOW mode telemetry to the s/c. The radiation monitor instrument provides broad-band count rates every 4 sec, spectra every 512 sec and generates a warning flag every 4 sec.
FAST: In this mode, the s/w computes the spectra as in SLOW mode, but the accumulation is not done. The radiation monitor instrument provides broad band count rates and spectra every 4 sec and generates a warning flag every 4 sec.
STORAGE: In the event that the telemetry link is unavailable (perigee passage), the radiation monitor instrument is commanded in storage mode, where count rates and spectra are stored until a mode command is received.
The first full telemetry format, after a mode change to SLOW or FAST, contains the stored data. The timing of the format is according to the mode selected. Any mode change will become effective at the beginning of a 4 seconds cycle, after the decoding of a mode TC. The internal test generator can be set in any mode.

Non-operating Mode
OFF: In this mode the radiation monitor instrument is powered off. This mode can be entered from any other mode.

9. THE RESOURCES

The power, weight and telemetry resource budgets are detailed in Table 3.

	Allocated	EMCS	EPCS	ERMS	Total (including contingency)
Mass	242.0 kg	68.8 (x2) kg	78.6 kg	6.5kg	222.8 kg
Power	210 W (average) 260 W (peak)	81 W (x2)	72 W (BOL max) 59 W (BOL min) 71 W (EOL max) 57 W (EOL min)	7 W	241 W (BOL max) 228 W (BOL min) 240 W (EOL max) 226 W (EOL min)
Telemetry	48 kbits/sec	**allocation**	**according to**	**selectable**	**tables**

Tab. 3 - Allocated resources for EPIC

FIGURE CAPTIONS

Figure 1. Schematic Layout of the three types of EPIC instrumentation (clockwise from top left)
a) MOS chain (2 units onboard)
b) pn Chain (1 unit)
c) Radiation Monitor (1 unit)
Figure 2. The effective area of the MOS (upper) and pn CCD detection units including mirror response and medium filter.
Figure 3. The MOS camera head design
Figure 4. The pn camera head design
Figure 5. The operational mode transition diagram for the MOS instrument.
Figure 6. The operational mode transition diagram for the pn instrument.
Figure 7. The operational mode transition diagram for the radiation monitor.

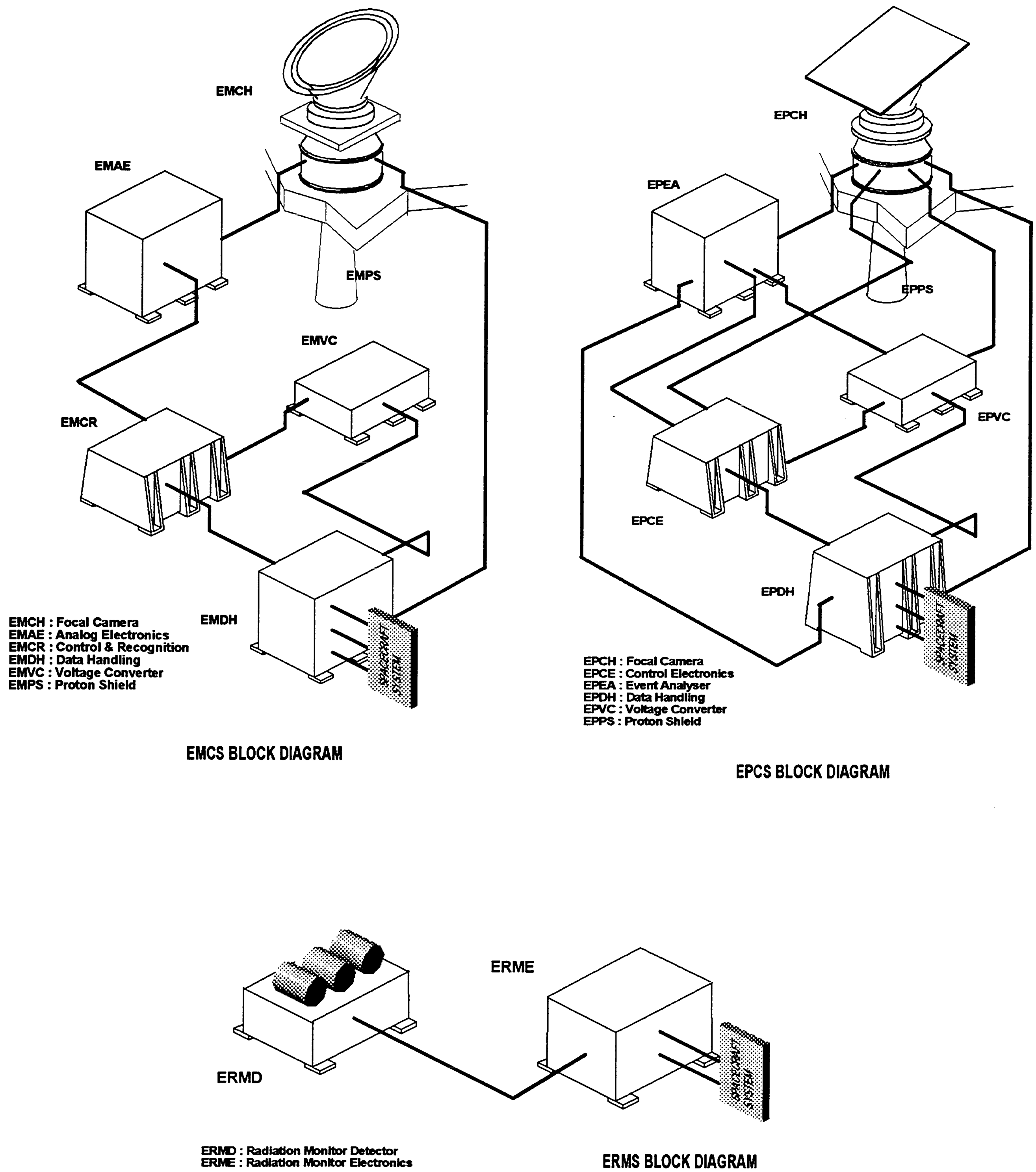
EMCH
EMAE
EMPS
EMVC
EMCR
EMDH
SPACECRAFT SYSTEM
EMCH : Focal Camera
EMAE : Analog Electronics
EMCR : Control & Recognition
EMDH : Data Handling
EMVC : Voltage Converter
EMPS : Proton Shield
EMCS BLOCK DIAGRAM
EPCH
EPEA
EPPS
EPVC
EPCE
EPDH
SPACECRAFT SYSTEM
EPCH : Focal Camera
EPCE : Control Electronics
EPEA : Event Analyser
EPDH : Data Handling
EPVC : Voltage Converter
EPPS : Proton Shield
EPCS BLOCK DIAGRAM
ERME
ERMD
SPACECRAFT SYSTEM
ERMD : Radiation Monitor Detector
ERME : Radiation Monitor Electronics
ERMS BLOCK DIAGRAM

FIG. 1

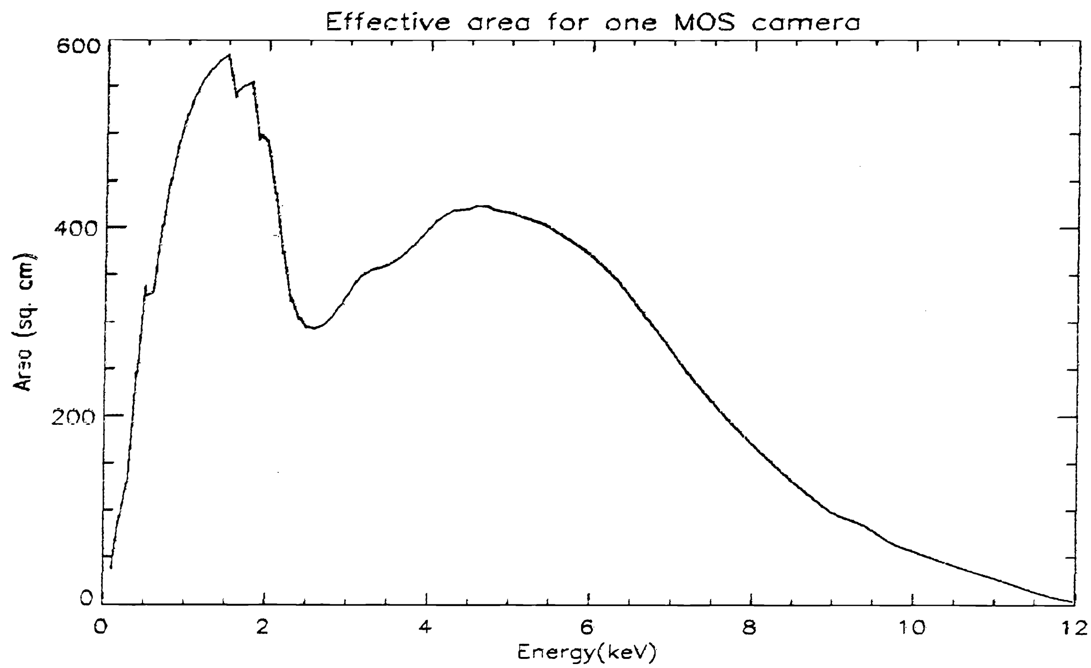
Effective area for one MOS camera
600
400
200
0
Area (sq. cm)
0
2
4
6
8
10
12
Energy(keV)

Fig.2a

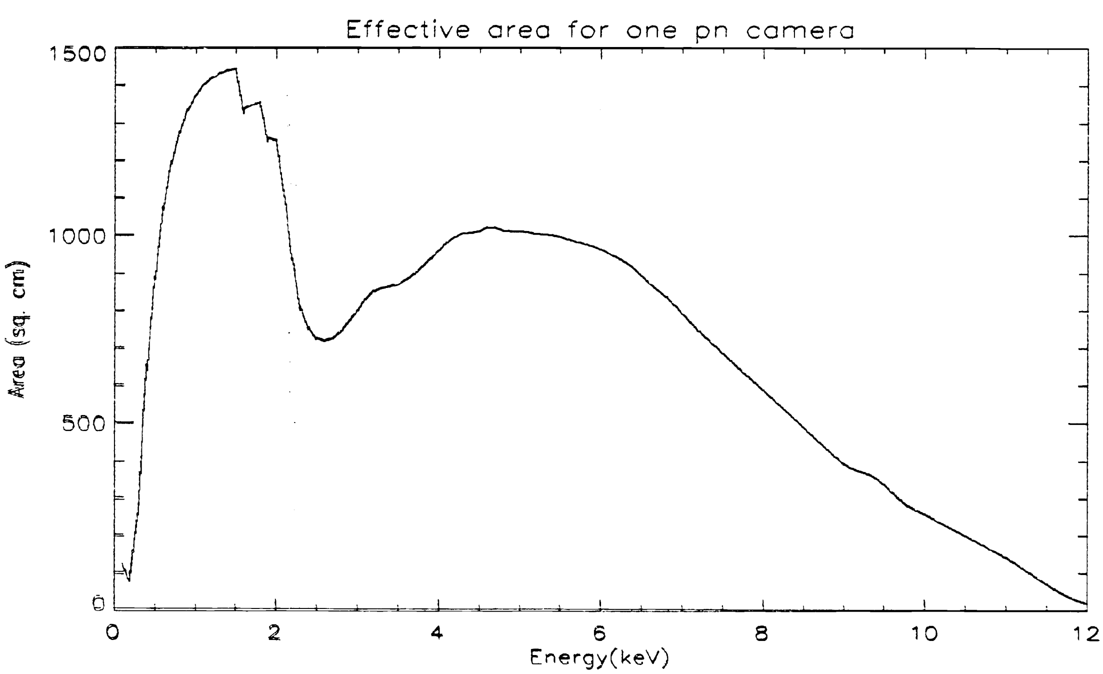
Effective area for one pn camera
1500
1000
500
0
Area (sq. cm)
0
2
4
6
8
10
12
Energy(keV)

Fig.2b

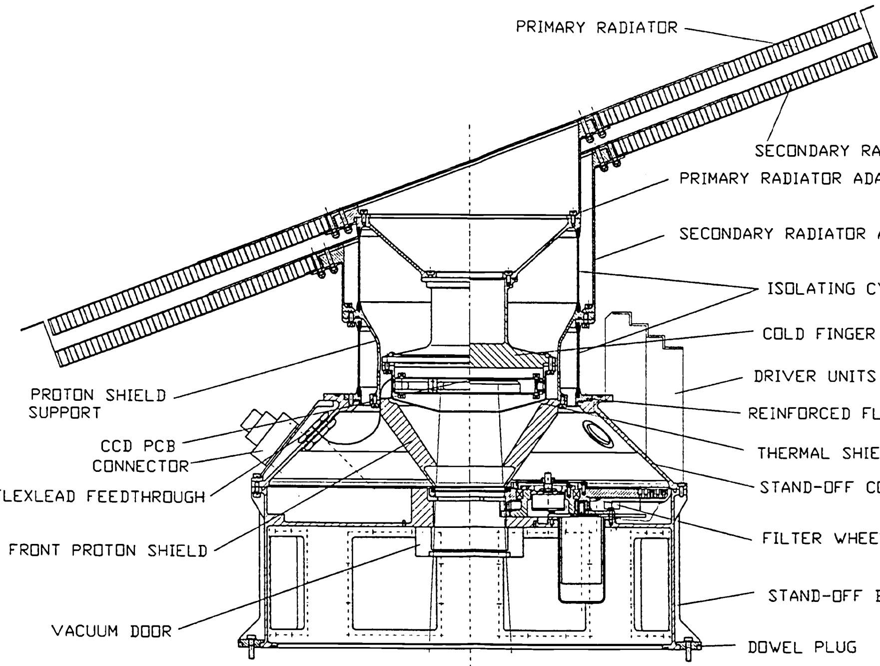
PRIMARY RADIATOR
SECONDARY RADIATOR
PRIMARY RADIATOR ADAPTER
SECONDARY RADIATOR ADAPTER
ISOLATING CYLINDER
COLD FINGER
DRIVER UNITS
PROTON SHIELD SUPPORT
REINFORCED FLANGE
CCD PCB CONNECTOR
THERMAL SHIELD
FLEXLEAD FEEDTHROUGH
STAND-OFF CONE
FRONT PROTON SHIELD
FILTER WHEEL
STAND-OFF BASE
VACUUM DOOR
DOWEL PLUG

Fig. 3

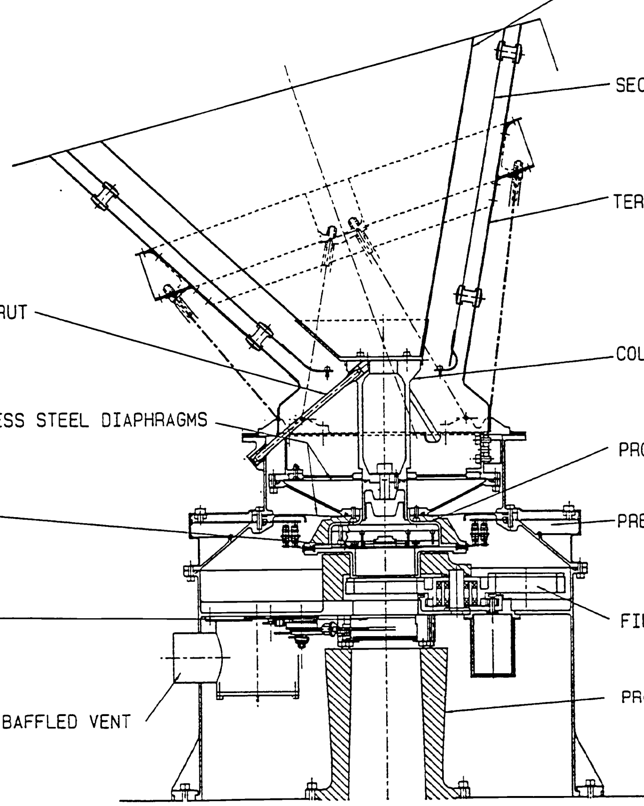
PRIMARY RADIATOR
SECONDARY RADIATOR
TERTIARY RADIATOR
GRP STRUT
COLD FINGER
STAINLESS STEEL DIAPHRAGMS
PROTON SHIELD
CCD
PRE-AMPLIFIERS
DOOR
FILTER WHEEL
LIGHT BAFFLED VENT
PROTON SHIELD

Fig.4

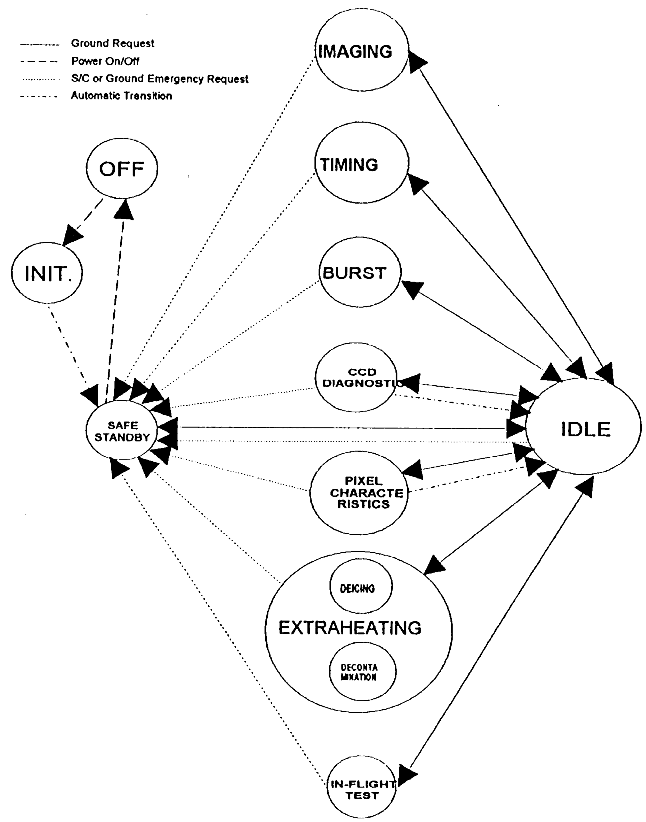

Figure 6

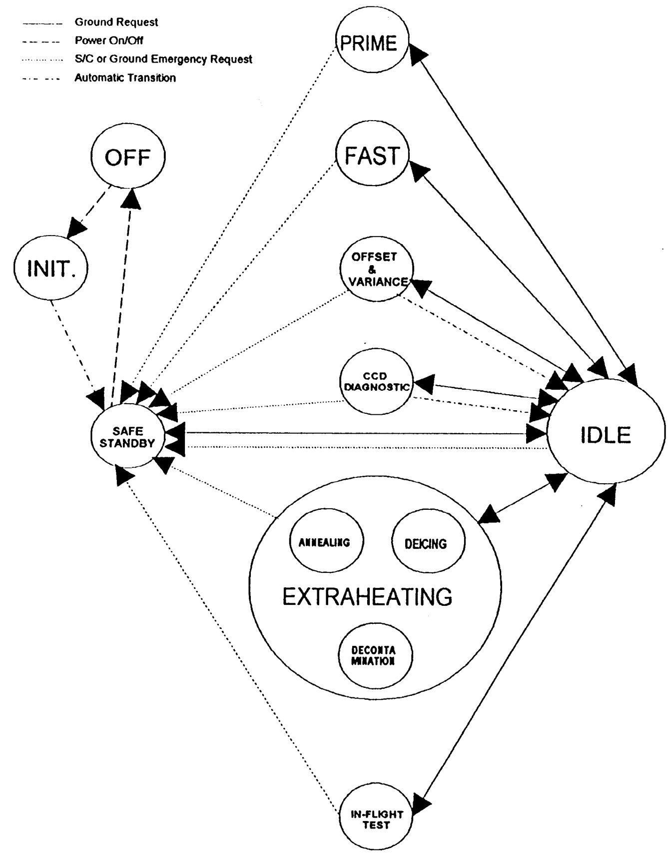

Figure 5

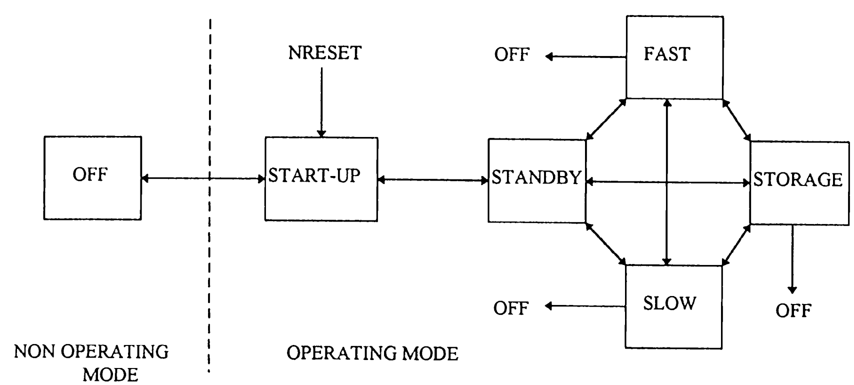

Fig. 7