RAPID/CLUSTER

FLIGHT OPERATION

USER MANUAL

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1.0 Instrument Description

1.1 Overview

The RAPID spectrometer for the Cluster mission is an advanced particle detector for the analysis of suprathermal plasma distributions in the energy range from 20–400 keV and 2 keV/nuc–1500 keV for electrons and ions, respectively. Novel detector concepts in combination with pin-hole acceptance allow the measurement of angular distributions over a range of 180° in polar angle for either species. The detection principle for the ionic component is based on a two-dimensional analysis of the particle's velocity and energy. Electrons are identified by the well known energy-range relationship. The detection techniques are briefly described and selected areas in geospace highlight the scientific objectives of this investigation.

Keywords: Energetic particle spectrometer, plasma dynamics, reconnection field line

1.1.1 Scientific Objectives

Over many years of intense research the Earth magnetosphere has emerged as a highly structured and dynamic, magnetically contained body of plasma. At times or permanently parts of the magnetosphere seem to be connected with interplanetary field lines. The field topology in the outer regions of the magnetosphere and its time dependence is by a large a result of currents carried by the thermal plasma.The supra-thermal component,on the other hand, may be less important for most of the macroscopic plasma quantities but it plays an important role on its own rights due to peculiarities in the physics of energetic particles. Acceleration processes in the magnetosphere of still unknown nature energize particles elsewhere in the magnetosphere to hundreds of keV. The relatively fast motion of these particles can carry information about the energization process over significant distances to an observing platform. Studies of the intensity profile, the energy distribution, and the ionic mass and charge composition can provide important clues on the nature of the process. Furthermore, the kinetic properties of these particles can be used as a tool to trace out plasma structures over distances as large as an Earth radius by utilizing the particle's gyroradius. Information can even be transmitted over global distances by the rapid drift of energetic particles in field gradients or, even more important, by field-aligned swift electrons travelling with speeds comparable with the speed of light. In tail-like field configurations these particles can transmit over very large distances almost instant information on changes in the field topology.

The Cluster polar orbit (4×19 R_E), provides excellent opportunities for energetic particle studies. The physics at the magnetopause, the bow shock, and the near-earth magnetotail are key regions of interest for the RAPID investigation. The state-of-the-art detection techniques, the large energy range for nuclei and electrons, and the complete coverage of the unit sphere in velocity space lead to the following capabilities:

- Remote sensing of local density gradients over distances comparable with particle gyroradii. Species dependent structures in gradients can be studied, gradient motions can be resolved to one spin period (T = 4 sec).
- Determination of major ion species (H, He, CNO) in the energetic plasma component. A special operational mode allows the identification and analysis of energetic neutral atoms (ENA).
- Characterization of magnetic field line topologies using the fast motion of energetic electrons.

These observational features allow detailed studies in all regions of geospace visited by Cluster.

The RAPID instrument uses two different and independent detector systems for the detection of nuclei and electrons. The IIMS (imaging ion mass spectrometer) identifies the nuclear mass of incident ions or neutral atoms from the kinetic energy equation: A time-of-flight and energy measurement determines the particle mass. One-dimensional images of spatial intensity distributions result from the projection principle. The IES (imaging electron spectrometer) is dedicated to electron spectroscopy. The well known energy-range relationship is used to identify electrons over a limited energy range.

The RAPID Science Team, listed in Table 1.1, is the primary user of the RAPID data. Close collaboration with the other Cluster teams is essential to bring to bear the wealth of information expected from this multi-spacecraft mission which indeed offers an unprecedented scientific tool for studies of long-standing problems in the magnetosphere.

Table 1.1: The RAPID Science Team

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The following sections describe the detection techniques employed in IIMS and IES and expand on specific aspects of the signal processing and data generation in the two segments of RAPID.

1.2 Instrumentation

1.2.1 The RAPID Spectrometer

Outer envelopes of the RAPID spectrometer with some principal dimensions are shown in Fig. 1. The instrument is physically a single structure which contains all major elements shown in Fig. 2: the SCENIC and IES sensor systems, the front-end electronics (called SCU), and the digital processing unit (DPU) with the the low-voltage power-supply (LVPS) and the spacecraft interface in the back of the box. Fig. 3 is a photograph of the EM unit.

The sensor system for nuclei is composed of three identical SCENIC heads (the acronym will be explained in Section 1.2.1.1) The positions of the three systems S1, S2, and S3 in the instrument reference system are marked in Fig. 1. Each spectrometer head Sy (y = 1, 2, 3) is protected by a mechanical door. After insertion into the vacuum of space the individual door latches are released by bi-phenyl ($C_{12}H_{10}$) operated mechanisms and the doors are rotated into the open position by the action of a spring. An opened door and the orifice for the bi-phenyl evaporation is sketched in Fig. 1 for head S2. This rather straightforward scheme for an one-shot actuator is based on the vast difference in evaporation speed of large bi-phenyl molecules in air and in vacuum. However, the obvious simplicity of such a device is somewhat offset by the difficulty to predict with some reliability the accurate release time due to the uncertainties in the knowledge of the bi-phenyl temperature during the launch phase. Measurements in the laboratory suggest a delay time of about 30 to 40 hours for the doors to be released after launch.

The electron detector IES is composed of three identical sensor heads as well, however, the detection technique differs entirely from the principle used in SCENIC. Again the apertures are protected by bi-phenyl operated closures but in this case the "mechanism" is rather simplified: The tiny entry holes of the IES heads are closed by bi-phenyl "plugs" which leave the holes open after evaporation in space. The positions of the heads Sn are shown in Fig. 1 as well.

1.2.1.1 The Nuclei Detector SCENIC

The center piece of the IIMS sensor system is the so-called SCENIC detector head. The acronym stands for "spectroscopic camera for electrons, neutral and ion composition". In essence SCENIC is a miniature telescope composed of a time-of-flight (TOF) and energy (E) detection system. The novel aspect is the imaging of flux distributions and the capability to identify energetic neutral atoms (ENA) in a certain energy band.

The particle identifying function of the SCENIC spectrometer is obtained from a two-parameter measurement: The particle velocity (V) and the energy (E) are measured as independent quantities, the particle mass A is then uniquely determined either by computation ($A \sim E \cdot V^{-2}$) or by statistical analysis in two-dimensional (V, E) space with the mass A as the sorting parameter. Actually the velocity detector measures the flight-time (T) the particle needs to travel a known distance in the detector geometry.

Fig. 4 shows cross-sections of the SCENIC detector telescope drawn to scale. A particular feature is the triangular structure with a 60° opening angle. The energy measuring solid state detectors (SSD) are mounted in the apex at the rear of the system. A group of two SSDs (an energy detector ED and a back detector BD) is combined in an anti-coincidence condition for high energy electron detection. The flight-time (T) measuring system is the entry element of the telescope. It is essentially composed of a thin foil (see Table 1.2) and the front surface of detector ED. The distance between the foil and detector ED along the line of symmetry is the nominal flight path s for the T-measurement.

Particles passing through the telescope release “secondary electrons” (SE) from the entry foil. The SE are accelerated and directed to a microchannelplate (MCP) for detection. The MCP output signal constitutes the START signal for the T-measurement. Details of the isochronous SE transfer to the START-MCP are shown in the upper cross-section of Fig. 4. Upon impact of the particle on detector ED secondary electrons are ejected from its surface as well. These SE are transferred to the STOP-MCP by a technique similar to the start electrons. The STOP signal completes the T measurement.

The energy E of the incident particle, reduced by the loss in the START foil, is measured in detector ED. For sufficient high energies the particle is able to penetrate detector ED and to strike the back detector (BD). This leads to the elimination of the event from analysis as described in Section 2.2.

Fig. 4 shows the START foil as an elongated rectangle. The design of the START-system is such that the SE transfer to the MCP is not only isochronous but also position preserving: Four read-out anodes behind the START-MCP (not shown in Fig. 4) correspond to four contiguous segments on the entry foil and each of these forms a 12° by 15° viewing cone with the ED detector in the back of the system. In a sense this geometry can be considered a degenerated case of a “projection camera” with only one pixel in the back plane. In this special case the “virtual” image plane coincides with the entrance foil.

Incident particles are strongly collimated before they reach the T/E-telescope. Two microchannel collimators (COLL1 and COLL2 in Fig. 4) define a highly anisotropic field-of-view (FOV) with 12° lateral and 60° polar opening. A set of plates between the collimating elements with potentials 0 and +Udef forms a linear electrostatic deflector (DEFL). The primary purpose of DEFL is to protect the instrument from overloads due to large fluxes of low energy particles (e.g. solar wind plasma). Some selected technical parameter of the SCENIC head are listed in Table 1.2.

The relative high gain of the active collimator (approx. 10) allows efficient separation of energetic neutral atoms (ENA) from ions for energies up to 100 keV. This energy band is generally considered important for magnetospheric neutrals produced in the ring current region.

Table 1.2: Technical parameter of the SCENIC head

Flight path s (mean)	34 mm
Field-of-view (total)	$12° \times 60°$
Polar angles	$4 \times 15°$
E-Detector (ED)	
Area/Thickness	5×15 mm^2/300 μ
B-Detector (BD)	
Area/Thickness	5×15 mm^2/300 μ
START foil (nominal)	—
Al/Lexan/Al (μg/cm^2)	17/10/17
Deflection voltage	0 – 10 kV

The fraction in E-T space covered by the SCENIC head is shown in Fig. 5 together with calculated loci of major magnetospheric nuclei or groups of nuclei. The width of the particle traces reflects the effect of flight path variations over the 60° opening of the SCENIC head. The energy (E) scale from 0 keV up to 4000 keV is partitioned by discriminators A, B, and C which define a lower threshold for energy measurements at 30 keV, an upper limit of the linear range at 1500 keV, and an overflow limit at 4000 keV, respectively. The time (T) range extends essentially from 0 nsec to 80 nsec.

Particles (electrons or nuclei) with sufficient energy to penetrate the ED-detector create a veto signal in the BD-detector which results in the elimination of this event from subsequent analysis.

With reference to Fig. 5 the following definitions are used for particle identification:

Logic State in the E-Ch.	T-Range	Species	Remarks
$\overline{ABC}$	t0 - t1	Proton	Reduced resolution
	t1 - t2	Helium	Reduced resolution
$A\overline{BC}$	2 - 80 nsec	All nuclei	Nominal resolution
$AB\overline{C}$	T0 - T1	Proton	Unique identification
	T1 - T2	Helium	Unique identification
	T > T2	CNO and heavier	No mass resolution

As mentioned earlier the IIMS sensor system is composed of three identical SCENIC heads in a configuration such that contiguous coverage over 180° in the polar angle is achieved (the polar angle is defined with respect to the Cluster spin axis). The sectored rotation of the spacecraft provides the completing azimuthal coordinate. The design features of the SCENIC head combined with the specific lay-out of the electronic system lead to performance parameters summarized in Table 1.3.

Table 1.3: Characteristic parameter of the IIMS and IES sensor systems

	IIMS	**IES**
Energy Range		
Hydrogen	46 - 1500 (4000)	—
Helium	76 - 1500 (4000)	—
CNO	98 - 1500 (4000)	—
Electrons	—	20 - 400
ENA	46 - 100	—
Mass Classes (amu)	1, 4, 12 - 16, 28 - 56	—
Mass Resolution (A/dA)	4 (Oxygen)	—
Field-of-View	±6°x 180°	±17.5°x 180°
Angular Coverage		
Polar (Range/Intervals)	180°/12	180°/9
Azimuthal (Range/Sectors)	360°/16	360°/16
Deflection Voltage (kV)		
Range/ Steps	0 - 10 / 16	—
Geometric Factor (cm2 . sr)		
Total/Differential	$2.4 \cdot 10^{-1}$ / $2 \cdot 10^{-2}$	$1.2 \cdot 10^{-2}/1.4 \cdot 10^{-3}$

The response functions of the SCENIC head (and likewise of the IIMS sensor system) is generally described by a complex family of energy dependent functions parameterized by the particle mass A and the selected type of science data (science data (SD) are described e.g. in Annex A.1). The conversion from observed counting rates n (cts/sec) to particle flux j in physical units is therefore represented by functions of the form

$$j = [GF \cdot \varepsilon \, (E, A; SD)]^{-1} \cdot n$$

with GF denoting the geometric factor and ε describing the detection efficiency as a function of particle energy (E), particle mass (A), and selected Science Data channel (SD).

1.2.1.2 The Electron Detector IES

Electrons with energies from 20 keV to 400 keV are measured with the Imaging Electron Spectrometer (IES). Advanced microstrip solid state detectors having a 0.5 cm × 1.5 cm planar format with three individual elements form the image plane for three acceptance "pin-hole" systems. Each system divides a 60° segment into 3 angular intervals. A schematic cross-section of an IES pin-hole camera is presented in Fig. 6. Three of these detectors arranged in the configuration shown in Fig. 1 provide electron measurements over a 180° fan.

The 800 micron thick ion-implant solid state devices are covered with a 450 μg/cm^2 (Si eq) absorbing window which eliminates ions up to 350 keV through the mass dependent range-energy relationship. The principle energy range for IES is shown in Fig. 7.

The 9 individual strips on the three focal plane detectors are interrogated by a multi-channel switched-charge/voltage-converter (SCVC) in monolithic technology. The SCVC provides for each particle coded information on the strip number and particle energy. This primary information is transferred to the DPU for further evaluation.

1.2.2 Signal Conditioning Units (SCU)

The general lay-out of the RAPID instrument in Fig. 2 shows that either of the two sensor systems is followed by a dedicated circuitry called signal conditioning unit or SCU. The primary task of the SCU is to provide proper analog amplification and signal shaping, event definition logic, control functions for configuring the detector system, and to interface with the digital processing unit or DPU.

1.2.2.1 The IIMS Signal Conditioning Unit

Fig. 8 is a simplified representation of the SCU which is intended to amplify essential components and their role in the complex signal generation and signal processing on different levels. An important task of the SCU is to ensure that signals generated in the IIMS sensor system are indeed caused by a single incident particle. Within limits the SCU detects and excludes events which involve two or more particles arriving at the sensor system within a defined time window. The following is a description of major electronic SCU components and the sequential signal processing on different levels:

Level 0:

A particle passing through a SCENIC head Sy is analysed with respect to its flight-time T (or equivalently to its velocity), to its energy E, and to its direction of incidence DIR. Accordingly the SCENIC head generates a set of signals (analog and digital) in the energy (E) –, the time (T) – and the direction (DIR) channel with the following definitions:

CH	SIGNAL	DEFINITION
E	EAN	Analog signal from the energy detector ED.
	EDI, OVF	Digital pulses from the lowest (A) and highest (C) thresholds in the ED amplifier chain. Overflow indicator.
	BDI	Digital pulse from the back detector BD, BDI inhibits EDI and OVF.
T	STA, STO	START and STOP signals.
DIR	DD	One-out-of-four direction signals.

The signal multiple (EAN, EDI, OVF, BDI, STA, STO, DD)y obtained from the head Sy represents an event at level 0. The subset (EAN, EDI, STA, STO, DD)y is used for further processing in the SCU whereas the duple (BDI, OVF)y is transferred directly to scalers in the DPU.

Level 1:

The signals (EAN, EDI, STA, STO, DD)y are offered to the next stage in the SCU for a first evaluation. As sketched in Fig. 8 the analog signals EANy and the time signals (STA, STO)y are connected to so-called OR/MUX devices for selection. The DPU can specify the sensor operation by setting the E and T multiplexer to the OR or MUX mode. In the OR mode signals are accepted on a first-come-first-serve basis; in operational terms this mode is called Parallel Mode (PM). In the MUX mode sensors Sy are selected sequentially and only signals from a given sensor are accepted at a time; in operational terms this mode is called Serial Mode (SM).

An analog EANy signal in the E-channel is processed only if the digital EDIy meet some constraints. The EDIy signals are evaluated in the sE-TRIGGER LOGIC (sE stands for "single EAN") to ensure that a single Sy sensor was active. The peak detector PD in the analog path can operate on the EAN signal only if exactly one out of the three EDIy lines carries a pulse. If this condition is met sE-TRIGGER LOGIC creates an ENY pulse to indicate that the (EAN, EDI)y combination concurs with the mentioned requirements. In general: An EAN signal will not be accepted by the PD circuit if

- its amplitude was below the lower threshold A (no EDI created);
- the particle energy was sufficiently high to stimulate the back detector BD and the resulting BDI signal disabled the EDI pulse;
- more then one EDI pulse was detected by the sE-TRIGGER LOGIC.

The T-OR/MUX circuit in the T-channel selects a (STA,STO) pair in a similar manner as the EAN signal is selected in the E-channel. The time-to-amplitude converter (TAC) transforms the pair into an analog signal called TAN (T analog) with an amplitude proportional to the observed flight-time T, and issues a digital TAC pulse to indicate the detection of a valid TAN signal.

In the DIR-channel a device marked SEDILO (Fig. 8) converts the pulse pattern on the DDy lines (three times four lines) in signals and codes characterizing the status and contents of the direction measurement:

1. A sDIR-3S pulse is issued if only a single active x-direction was found in all three detector heads.
2. The sDIR-Sy pulse defines the stimulated detector head Sy (y = 1, 2, 3).
3. The DIR-x (x = 1, 2, 3, 4) code defines the four look-directions in Sy.

In summary the Level 1 processing leads to the following products: A new multiple of digital pulses (STA, STO, TAC, ENY) is established reflecting that START and STOP pulses are selected and a valid TAN signal is produced; an EAN signal from a single detector is received and the signal sampling in the S & H circuitry is initiated. As indicated in Fig. 5a ENY and TAC are combined to form a TCR pulse (functionally TCR is formed at this stage but the logic is actually located in the DPU). This pulse proves that valid analog energy (EAN) and time (TAN) signals are present. However, it is important to note that the compliance of the (EAN, TAN) pair with the trigger condition specified in the TRIGGER LOGIC has yet to be demonstrated in the Level 2 processing phase.

When the DIR-channel has found a single direction, a corresponding (sDIR-3S) signal is created and the direction is characterized by the duple (sDIR-Sy, DIR-x) with the ranges y = 1, 2, 3 and x = 1, 2, 3, 4.

As discussed above a particle's direction of incidence within 180° polar angle is defined by a coarse direction Sy (one of the three 60° SCENIC heads Sy) and a fine direction DIR-x (division of Sy in four 15° intervals). The coarse direction Sy can be obtained from three different channels: From the E-channel (EDI-Sy), from the DIR-channel (sDIR-Sy), and from the multiplexer system (E-, T-, DIR-MUX) by selecting a sensor head Sy. The fine direction DIR-x, on the other hand, is extracted only from the DIR-channels. Of particular interest is the susceptibility of this system to particle pile-up in the DIR-channel and its dependence on the sensor mode (parallel or serial):

Serial Mode

The DPU activates a single sensor head Sy at any given time and cycles through the sensor heads Sy (y = 1, 2, 3) in a preprogrammed sequence. A unique coarse direction y is therefore imposed for all events. A fine direction DIR-x will be issued by SEDILO only if the DDy code from the DIR-channel shows unambiguous direction information. Invalid DDy codes (two or more lines show high levels due to multiparticle interaction or charge splitting between read-out modes) disable SEDILO and the triple (sDIR-3S, sDIR-Sy, DIR-x) will not be generated. However, the DPU accepts the remaining digital signals for accumulation in COUNTER ARRAY but the classification is restricted to MTRX data as will be discussed in Annex A.1.

Parallel Mode

All three sensor heads are active and particles are accepted on a first-come-first serve basis. The direction of incidence (y, x) is obtained from measured quantities only. The unbiased sensitivity over 180° makes this mode attractive in low flux environments but this advantage is increasingly qualified by the susceptibility to multi-particle events if the flux exceeds a certain critical level.

The response to ambiguous directional measurements can be presented in a convenient form by using the definitions

- DDu(2): DIR-detector in sensor head Su shows two active anodes due to multi-particle interaction or charge splitting; the DIR-detectors from the other heads are assumed inactive,
- 2DD: DIR-detectors from two different heads, Su and Sv, show valid single directions; the third detector is assumed inactive,
- EDI-y: Single (s) or multiple (m) y-directions active, and by referring to the DPU description:

SENSOR		SEDILO			DPU	
EDI-y	DDy	sDIR-3S	sDIR-Sy	DIR-x	CLASSF.	CTR. ARRAY
s, m	DDu(2)	–	–	–	I-MTRX	Yes
s	valid	Yes	≠EDI-Sy	Yes	no	Yes
s, m	2DD	–	sDIR-Su;v	–	no	Yes

<u>Level 2</u>

The digitization of the EAN and TAN amplitudes in the analog-to-digital converters actually located in the DPU) depends on precise coincidence conditions. The circuitry TRIGGER LOGIC imposes commandable trigger modes and time windows on the event pattern (EAN, TAN, sDIR) with sDIR-3S abbreviated to sDIR:

Trigger Mode	Accepted Event Type
1. E + (T⋆ sDIR)	(E, T, sDIR), (0, T, sDIR)
2. E + T	(E, T), (E, 0), (0, T)
3. E ⋆ T ⋆ sDIR	(E, T, sDIR)
4. E ⋆ T	(E, T)
5. E	(E, T), (E, 0)
6. T	(E, T), (0, T)

The above trigger conditions lead obviously to a digital filter function with effects on the overall detection efficiency of the spectrometer. The following is a qualitative assessment of the filter effect:

- The coincidence conditions in Mode 1 and 3 lead generally to a rather low rate of occurrence. This is even amplified by the relatively low probability for creating a sDIR-3S pulse. As a result little practical value will be put on these modes.
- The coincidence condition in Mode 2 has a reasonable efficiency but the accepted event structures have clearly a mixed distribution.
- The double coincidence in Mode 4 is lower in occurrence rate than Mode 2 but it creates clean distributions with acceptable efficiency. This mode is therefore the preferred operational mode.
- Modes 5 and 6 are implemented merely for the case of drastic failures in either the energy or the time channel.

The E- and T-ADC in the DPU start the conversion in binary codes if the analog pair (EAN, TAN) meets the coincidence requirement set in TRIGGER LOGIC and the event, now represented in an all-digital form, is ready for the classification process in the DPU.

1.2.2.2 The IES Signal Conditioning Unit

Figure 8b shows the principal features of the IES signal conditioning unit. The initial amplifier stages for the nine energy channels and a multiplexer are implemented in monolithic technology. This chip (a development of the Rutherford Appleton Laboratory/Oxford, UK) is physically integrated into the sensor housing. The second part of the SCU accepts the serialized output signals from the chip for amplification in a single amplifier chain and subsequent digitization. This part of the SCU is designed with standard electronic components.

As mentioned above, the SCU utilizes an integrated multiplex chip denoted "switched charge/voltage converter" (SCVC) as the input stage for the analogue signal processing. The SCVC contains a total of 16 charge-sensitive preamplifiers with a noise at zero input capacitance of 700 electrons rms (= 6 keV FWHM). The total power consumed is about 10 mW; only nine preamplifier channels are actually used for IES. The essential functions of the SCVC chip are shown in the simplified circuit diagram presented in Figure 8b. The charge placed in an active strip of the solid-state detector by an incident particle is integrated a stored on the capacitor C2 following the preamp. This stored charge is compared with a background value stored on a companion capacitor C1. The difference between these two values of charge is then strobed out and fed into a comparator circuit. From the comparator, the signal is read into an 8-bit analogue-to-digital converter (ADC). The resultant digitized signal represents the "pulse height" or energy E of the incident particle.

The charge deposited by the incoming particle can be integrated for periods ranging from 2 to 50 microseconds via a DPU-controlled command. The use of the shorter time constant lengthens the dead time due to the finite time required to strobe all nine channels, but tends to reduce the system noise. Depending on counting rate, the DPU can optimize the integration time constant. The SCVC chip has an offset or "pedestal" value which is different for each channel. The pedestal values are stable over time and temperature, but must be handled correctly in analysis of the converted ADC value. The output of the IES/SCU is a set of nine ADC values corresponding to the signal-plus-pedestal recorded since the previous readout. As indicated in Figure 8b, each of the energy measurements is associated with a four-digit direction number D to form an (E,D) address pair for the information processing in the follow-on Electron Pre-Processor (EPP) in the DPU and accumulation by the microprocessor. This permits the DPU to handle the IES data at a sample time equivalent to strobing-out the SCVC channels.

As mentioned the IES is a very compact sensor system. Because of this compactness, it has not been possible to test the system in the standard manner of electronic pulse stimulation through a charge terminator. Instead, the full system can be stimulated with a set of radioactive sources which produce a series of gamma- or X-ray lines in the 20 keV to a few hundred keV region. When a set of spectra are recorded from these sources, it is possible to calibrate the IES system very accurately, demonstrate the linearity of the amplifier gains, and observe the effect of the pedestal variation from channel-to-channel.

1.2.3 The Digital Processing Unit (DPU)

The internal digital processing unit (RAPID-DPU) serves the SCUs and sensor systems (IIMS and IES), evaluates and compresses the primary event data rate to a level which is compatible with the telemetry capacity, and arranges the output data in the format of an experiment data block (EDB). The present description of the DPU and its functions is a rather brief extract with strong emphasis on the data manipulation and the final construction of "Science Data". A more comprehensive report of the DPU will be submitted as a separate publication.

The simplified DPU block diagram in Fig. 9 the following key elements:

- Interface to the IIMS SCU,
- Ion Pre-Processor (IPP),
- Electron Pre-Processor (EPP),
- Microprocessor system (80C86 based),
- Memory protection and latch-up detection safeguard electronics,
- Interface to the Cluster spacecraft,
- Inter-experiment-link (IEL) to the magnetometer instrument (FGM),
- Low voltage power converter.

1.2.3.1 IIMS Event Processing

A main task of the DPU is the compression of the enormous data rate received from the IIMS/SCU system. It was mentioned in the previous section that each fully defined particle event is described by 2 analog signals (EAN, TAN) and a set of 18 digital pulse channels. These data are processed in the DPU and eventually transformed into "Science Data" for nuclei. The various data types created in the SCU on the different levels of processing are transferred to the DPU as schematically shown in Fig. 10. The multitude of IIMS signal channels, shown on the left side of Fig. 10, is divided into three groups. The first group includes the 18 digital pulse channels. A subset (TAC, EDI-y, sDIR-Sy, DIR-x) is passed through a logic to expand the TAC and EDI-y pulses into channels with higher directional resolution. This process leads to pulse types of the form TAC-y, TAC-yx, and EDI-yx. These pulses and the set (STA, STO, BDI-y, OVF-y, ENY, sDIR-3S) are offered to COUNTER ARRAY (Fig. 10) to increment appropriate scalers.

The second group is essentially a duplication of direction relevant information from the DIR- and E-channels (sDIR-Sy, sDIR-3S, DIR-x, EDI-y) and the overflow indicator OVF-y. This subset is used for consistency checks in a precursing process before the analog signals EAN and TAN in the third group are accepted for digitization and classification. Events showing overflow in the energy channel (E $\geq$ 4 meV) and/or inconsistent direction information in EDI-y and sDIR-Sy are discarded. For all other events the two ADCs can be enabled by the trigger signals Es and Ts. At the same time the DPU processes the event-related direction information (sDIR-Sy, DIR-x) and synchronizes it with the digitized (E, T) pair to remove dynamic phase shifts. The DPU also converts the SCU direction code (y, x) into a serial number D = 0,. . . ,11 which defines twelve unique directions within the 180° polar range of the instrument with the counting convention specified in Fig. 13. In case the sDIR-3S pulse fails to indicate the presence of a high resolution directional measurement (positive identification of a single direction out of the 12 polar angular intervals) the DPU determines a coarse y direction from the EDI-y pattern and assigns to these the direction numbers D = 12, 13, 14 (inspect Fig. 13 for the counting convention).

The event (E, T, D) is now prepared for the classification process in the follow-on ion pre-processor or IPP in Fig. 11. The objective is to extract from the (E, T) pair the particle mass A and the energy per mass ratio E/A with high precision. In addition the A-E/A space is subdivided into a coarse bin field which is then combined with high resolution direction information. This leads to a substantial reduction in the required data rate without the necessity to reduce resolution in time and direction.

The DPU initiates the classification process upon the appearance of at least one of the trigger signals Es and Ts. The E/A ratio is established in a straightforward single table look-up technique since this quantity is obtained from the measured flight-time T directly. The particle mass A, on the other hand, depends on energy E and flight-time T. A 4-step successive approximation in an E = f(T,A)-table is applied to obtain the mass A. This process can handle a maximum event rate of roughly 50000 sec^{-1}.

The final product of the classification is the construction of high resolution (A, E/A) vectors which are used to address

(1) a (16 x 64) matrix counter field and

(2) a bin definition field.

The selected matrix counters are incremented, the contents of this counter field represents the IIMS part of the "Science Data" MTRX. The output of the bin definition field is a bin number B which defines 41 bins in the (A-E/A) plane. The bin number, combined with the direction number D, addresses the bin counter array and the respective bin counter is incremented. The contents of the bin counter array is the basis for the "Science Data" I-SPCT, I-PAD, and I-3DD. This process reduces the (A-E/A)-matrix from a total of 1024 to 41 elements which cover the same area in A-E/A space with a coarser resolution.

The above description of the classification process refers essentially to (E, T, D) events with valid values for all three parameters. Events with missing parameters are processed according to the following scheme (missing parameters are shown as 0):

E	T	D	Classification
0	T	D	yes
E	0	D	no
E	T	0	MTRX only
0	T	0	MTRX only

1.2.3.2 Electron Pre-Processor (EPP)

According to Fig. 10 signals from the IES /SCU are transferred to the electron pre-processor in the DPU. The EPP tasks are the provision of a serial command interface to IES and the pre-processing of IES event data. A simplified block diagram of the electron pre-processor is presented in Fig. 12. A valid electron event at the EPP input is described by a digital signal duple (E,D), with E (8 bit) and D (4 bit) denoting the electron's energy and direction of incidence, respectively. The (E,D) pair serves as an input vector for a bin definition look-up table (LUT) which defines a bin number B (8 bit). The bin number B and the current sector number SCT (SCT defines 16 azimuthal sectors) are concatenated to form an other vector pointing to a RAM SCALER field (a RAM based counter array) and the selected counter is then incremented. The contents of the RAM SCALER serves as the basis for the electron Science Data.

The bin definition LUT can be exchanged by telecommand thus allowing arbitrary schemes for binning the energy and direction ranges. A set of pre-defined LUTs is permanently available in the DPU for the generation of the electron Science Data (consult Table 1.4 for definitions):

(1) E-3DD, E-PAD,m
(2) Direct Events (DE)

Look-up tables are dedicated to either group (1) or group (2). This implies that, in contrast to IIMS, the two groups are mutually exclusive since only a single LUT is active at any given time. A set of about 16 different LUTs is required to cover the entire range in energy and direction for the high resolution direct events in group (2).

1.2.3.3 On-Board Pitch-Angle Computation

The RAPID spectrometer is connected to the magnetic field instrument FGM via an inter-experiment link (IEL). FGM sends 64 uncorrected magnetic field vectors (Bx,By,Bz) per spacecraft rotation (T =4 sec). Vector components are offered in digital form with a width of 12 bits each. The objective is to determine for each of the 16 azimuthal sectors which look direction in the IIMS and IES fan, respectively, is perpendicular to the current B-vector (the DPU uses the second B-vector received in a given sector as the reference vector).

The DPU implements this 90° pitch-angle determination by applying the following algorithm in each sector: Vectors $\mathbf{D}_\nu$, (ν = 0,..,11 for IIMS and ν = 0,..8 for IES) with normalized magnitude are introduced to describe the boresights of the detector look directions. A software routine calculates the 12 (9) vector products ($\mathbf{D}_\nu \bullet \mathbf{B}$) and determines the vector $\mathbf{D}_n$ for which the product assumes a minimum value, i.e. the direction $\mathbf{D}_n$ corresponds to 90° pitch angle. The number of events accumulated with the direction number D = n are part of the I-PAD (E-PAD) Science Data together with events from detectors with the fixed direction numbers D = 0 and D = 11 (D = 0 and D = 8 for IES).

1.2.4 The IIMS And IES Science Data

The final data products resulting from the DPU are called "Science Data". According to Fig. 10 the main body of the Science Data contains ion data (I-SPCT, I-PAD, I-3DD), electron data (E-PAD, E-3DD,m), and MTRX data. Each one of these data types is obtained from the classification process in IPP and the bin sorting in EPP. Two more types of Science Data are provided for IIMS:

- SGL-Data. The DPU samples the 45 accumulators in COUNTER ARRAY with specified frequencies and forms single parameter rates called SGL-Data.
- DE-Data. A fraction of unprocessed (E,T,D) events is selected to bypass the classification for transmission to the ground (so-called direct events DE). The selection of DE events is based on a four-step priority P which is assigned to the bin number B (this assignment can be changed by telecommand; default is P = const for all B of a given particle species). Priority P = 3 refers to high priority particles. With this definition priorities are assigned as follows:

Priority P	0	1	2	3
Species	e,p	He	CNO	Si-group

A maximum of 16 DEs per priority is accepted in each of the 16 azimuthal sectors on a first-come-first-serve basis and written into a (4 x 16 x 16) event buffer. Events are selected for addition to an EDB by applying the following prescription:

(a) At any given time the four least significant bits of the spin counter (INDEX) designate an azimuthal sector with the sector number SCT_n (SCT_n = INDEX MOD 16).

(b) The DPU starts the transmission in sector SCT_n by reading out the contents with decreasing priority Pμ (μ = 3,2,1,0); the DPU sequences through the sectors until the number of events equals the maximum number S allowed per EDB. More precisely this can be written as

$$\sum_{\nu=SCT_n}^{SCT_n+15} \sum_{\mu=3}^{0} P_\mu(\nu \bmod 16) \leq S$$

with Pμ designating the number of events per priority P and sector (P$\mu \leq 16$); the total number of DE events S per EDB is defined in Table 1.4.

A definition of the Science Data together with a brief description of the respective prime scientific value is given in Table 1.4.

Table 1.4: The RAPID Science Data

Data Type	Particle Species	No. of E-Ch.	Polar Intervals	Azimuthal Sectors	Scientific Objectiv
I-SPCT	H,He,CNO	8 d	i	i	E- spectrum
I-PAD	H	2 w	3x15°	16	Pitch-angle distr.
I-3DD	H,He,CNO,	8 d	12x15°	16	3-d distr.,high res.
MTRX	all	all	i	i	A-E/A distr.
E-PAD	Electrons	2 w	3x20°	16	Pitch-angle distr.
E-3DD	Electrons	12 d	9x20°	i	3-d distr.
m	Electrons	—	—	16	Detector index
DE	All	256	max 12x15°	16	High res. direct events
SGL	na	na	na	var.	Digital pulse rates

d = narrow differential energy channels, w = wide energy channels, i = integral

The DPU samples the above data types and constructs an "experiment data block" (EDB) as the basic unit for the data transmission to the ground. The EDB period T = 4 sec is defined by the spacecraft telemetry system, however, the data structure varies with the telemetry mode. Table 1.4 shows the distribution of the Science Data in an EDB for operation in the telemetry nominal mode (NM). The EDB structure is the ultimate definition of the science return from RAPID.

Finally it should be noted without details that SCU and DPU provide also valuable information in two other data fields which support the interpretation of the Science Data in a significant way. The first set comprises analog and digital housekeeping (HK) data which reflect the actual operational configuration of the instrument and the health of all subsystems in an engineering sense. These data are transmitted in a dedicated telemetry channel. The second data set comes from the IIMS built-in precision pulse generator used to monitor and characterize the performance of the IIMS/SCU and, to some extent, of the DPU as well. The calibrator system operates in two different modes:

- The In-Flight Particle Simulator (IFPS). A calibrating (E, T) pulse pair is injected into the front-end SCU electronics once per spin and with a fixed phase. The DPU varies the pulse amplitudes by cycling through a pre-programmed sequence which generates these simulated particle events such that an even coverage in A-E/A space is achieved. The IFPS is permanently active and cannot be switched off. A comparison of the simulated event pattern with the image obtained by the DPU reveals irregularities in the analog and digital signal processing. IFPS results are transmitted with full resolution in a dedicated area of the EDB (not included in Table 1.4), and contribute to science data I-SPCT, MTRX, and SGL rates.

- The In-Flight Functional Test (IFFT) . This routine must be initiated by telecommand and the instrument resumes the pre-test operational mode automatically after completing the test . The IFFT monitors threshold positions and amplifier linearity in the SCU. It should be noted that the transmission of science data is incomplete during operation of the test routine.

The distribution of the Science Data in an EDB is defined in the Instrument User Guide, Chapter 2 on Annex A.1.

1.3 On–Board Software

Instrument Software Tasks

- IIMS sensor handling procedures. A collection of small procedures to handle the interface hardware to the IIMS SCU and the stepping of high voltages.
- IIMS classification handling procedures. Procedures to calculate classification tables, control the classification state machine and readout the results. Furthermore a test program to verify that the hardware is working correctly.
- IIMS calibration. Software to stimulate the sensor electronics so that they generate test events that can be processed by the classification unit in the DPU. There are two calibration modes, the always running single shot calibration and the in flight functional test (IFFT) that is only executed on command.
- command handling. Administration of the command buffers and FIFO, checking of the commands and execution of them. Return codes of commands are sent to the HK frame generating software.
- save and restore of the instrument configuration. Automatically every spin the actual instrument configuration is stored in the NV-ram to get the ability to restore the instrument status after switching off because of a detected latchup. Additionally you have the chance to store the actual configuration at any time and reconfigure to this state later on.
- telemetry:

  1. HK formatting
  2. EDB formatting

1.3.1 Architecture

RAPID DPU software is completely written in 80C86 assembler. It consists of a short main program, the NMI procedure to control the watchdog functions and an event triggered task manager, called job manager.

The main program only initializes the DPU hardware and software variables on power up. Then it stays in an infinite 1 ms loop to determine free processor time, when no interrupt driven tasks, controlled by the job manager have to be performed.

The watchdog function is implemented by a hardware that generates a NMI every second. This NMI must be responded by the DPU within a given time by a port write command at a specific address with a fixed value (f1h) to prevent the hardware circuit from generating a RESET pulse for the processor system. This port write command will only be executed if the spin counter increases for at least 1 step in about 2 $\frac{1}{2}$ spins.

The real instrument handling is divided into two parts:

1. interrupt procedures to handle asynchronous events like telecommands, get timing information like the sun pulse or the sector clock and perform tasks that have to be done at exactly that time, as for example the starting of measurement periods.
2. tasks that are started from the job manager as soon as possible, depending on a fixed, given priority scheme.

1.3.1.1 Interrupt Procedures

NMI The NMI is the interrupt with the highest priority. It is used for watchdog purposes. Because there is no hardware-FIFO for received telecommands, which could arrive every 240 μs, the NMI first tests whether it interrupted the command interrupt. In this case it returns very quickly to the command interrupt to prevent data loss. Else it tests for incrementing of spin counters and telemetry requests to make sure that the system is still running properly. If the test result is negative the DPU program waits in an endless loop for the hardware reset from the watch dog unit.

INT0 The highest priority maskable interrupt is assigned to command receiving. Every time a complete 16 bit command word is received, the interrupt line goes active and the DPU has to read the data from the command latch of the spacecraft interface. Before leaving the interrupt it is made sure that the next word wasn't received meanwhile otherwise it is also read.

INT1 The next priority is given to timer 0 interrupt. This timer is used to generate an artificial sector clock in case of missing clock information from the spacecraft (SSC,SRP).

INT2 This interrupt appears every 256 ms. It is derived from the spacecrafts spin segment clock (SSC) and used to divide the whole spin measurement period into 16 equal fields. The numbering and position relative to the sun direction can be changed by two telecommands.

Within this interrupt procedure the measurement dead time timer is started to get the same dead time in all sectors, independent of the tasks to be performed here. There are spin and sector orientated tasks that must be performed within the interrupt procedure or at least during the dead time (before the measurement starts again!):

- increment of the sector number
- send sector information to the EPP
- readout of single counters
- readout of IIMS direct events
- readout of IIMS classification counters
- readout of IES classification counters

- increment spin counters
- copying of data to the scratch memory
- latchup detector measurement in sensitive mode in sector 5
- IIMS single shot calibration in sector 9

INT3 The IIMS classification parity error interrupt. This interrupt disables the classification and starts new table calculations if the tables are corrupted by SEUs.

INT4 Timer 1 interrupt is used for the dead time period and the switching of IIMS detector heads in serial operating mode.

INT5 This interrupt should become active if a latchup is detected by the instrument. Then the microprocessor has to read the latchup source from a register and write it into the permanently powered, latchup free Marconi RAM.

INT6 This interrupt serves all telemetry inputs. Such a low priority interrupt can be used because all signals are buffered by FIFOs or the time until the next event is very long:

1. spacecraft RESET pulse signifies a new acquisition frame. On that signal the HK-FIFO is cleared and a new HK-block of 40 bytes is written into the FIFO.
2. read complete FGM vector from the spacecraft interface (3 * 12 bit + 3 bit range code + 1 trigger bit for the scratch memory).
3. fill telemetry FIFO with next 512 bytes block.

INT7 Timer 2 is used to generate the timing of IFFT shots to the IIMS SCU.

1.3.1.2 Job Manager Tasks

The job manager is a program to manage event triggered software execution,that means: every time a special event has occurred, for example the begin of a sector or a spin, a signal is sent to the job manager. Then it looks whether there are procedures to be executed at this event and eventually starts them. There is always only one task active at a time but this task must be interrupted by a task which is more urgent. So it's easy to understand, that all sector related jobs must be completed before spin orientated jobs because the latter could be completed at any time during the 4 s spin period whilst sector jobs must end before the next sector starts (250 ms sector period). To solve this problem a fixed priority scheme is implemented. Furthermore, the job manager can handle two different types of tasks, those that have to be executed once, function pointers to these tasks are stored in *FIFOs*, and tasks to be performed every time the signal is received, stored in *tables*.

For RAPID there are 9 priority levels:

1. execution immediate (highest priority)
2. execution every sector
3. execution in next sector
4. execution after receiving a command byte
5. execution every spin
6. execution in next spin
7. execution every 64th spin
8. execution in next 64th spin
9. execution immediate with lowest priority

All normal measurement tasks are implemented as jobs in level 2 or 5. Command execution is done with level 4, stepping of high voltages is implemented as level 6 job, IIMS classification test is done with a level 9 job. Jobs could be added or deleted to these tables and FIFOs at any time by telecommand.

1.3.1.3 On–Board Software Modifications

During flight new program code or parameters for table calculations can be sent to the RAPID DPU (details on program patches and table patches are addressed in Section 7.1). For this purpose some commands are defined to select the physical memory address or for parameter loads a logical memory address where the the new bytes should be stored. Most likely this will be an address in the permanently powered ram area where the new bytes are kept available even in non operating periods of the instrument for the next power on situation. After transmitting of the target address to the DPU, the bytes themselves are sent. They are collected in a buffer until the complete block has arrived. Then CRC checking is performed and the result is echoed in the HK frame. If the CRC is ok than the block will be moved to the right location in the memory. To activate the patch code another telecommand is necessary to change a pointer in the non volatile ram to point to the new code instead of the old code in the PROM, or to store a job in one of the job managers levels to call the new code.

See also Section 3.5.

1.4 Instrument Physical Characteristics

1.4.1 Location on the Spacecraft

RAPID is mounted on the instrument platform, the viewing direction is radially outward. The instrument position and the angular range of the two sensor systems, IIMS and IES, is shown in Fig. 13.

1.4.2 Flight Covers

a. The three SCENIC heads in the IIMS sensor system are protected by flight covers which are released by an autonomous bi-phenyl actuator. Release time: Approximately 30 hours after launch.

b. The three IES detector heads are protected by non-flight covers containing desiccant for humidity control. These covers are removed shortly before launch leaving the small entrance holes unprotected during launch.

1.4.3 Physical Properties

Dimensions (mm) L x W x H	 351 x 200 x 208 (doors open)
Weight (kg)	5.615
Power (W)	4.500

1.5 Figures

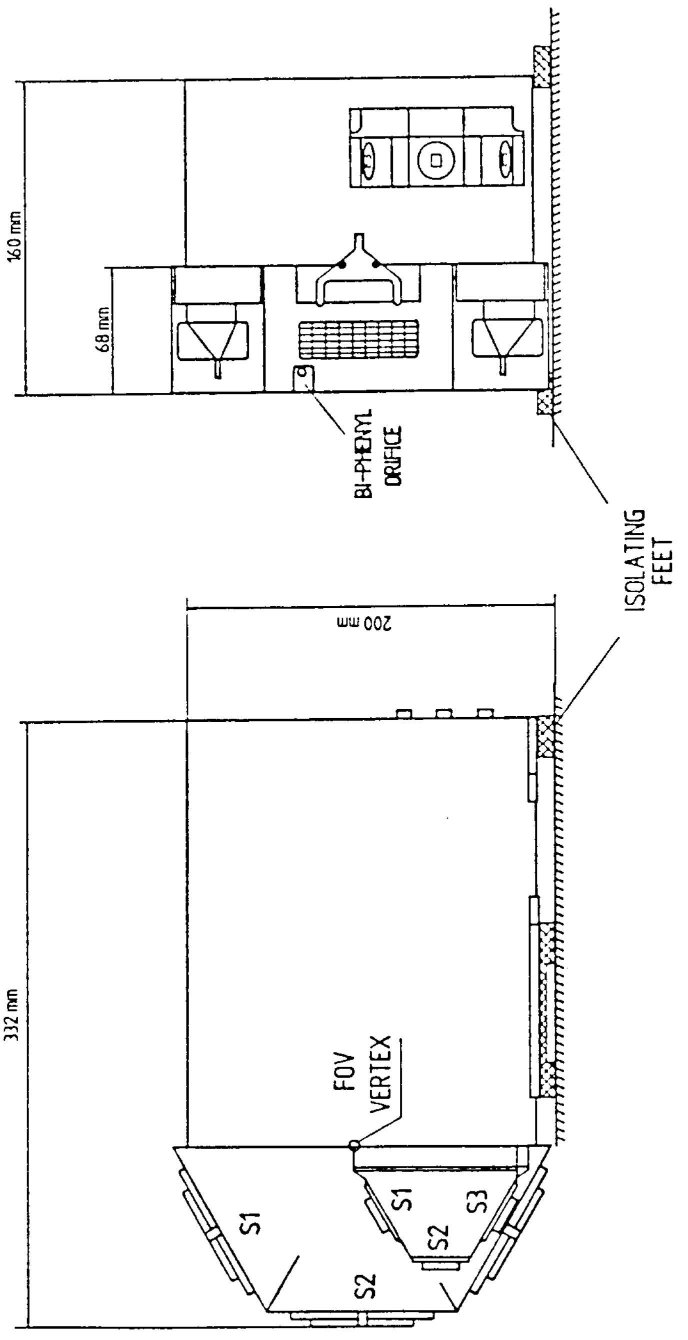

Figure 1: Mechanical configuration of the RAPID instrument showing the sensor system IIMS and IES. Individual detector heads are indicated by Sn (n = 1, 2, 3).

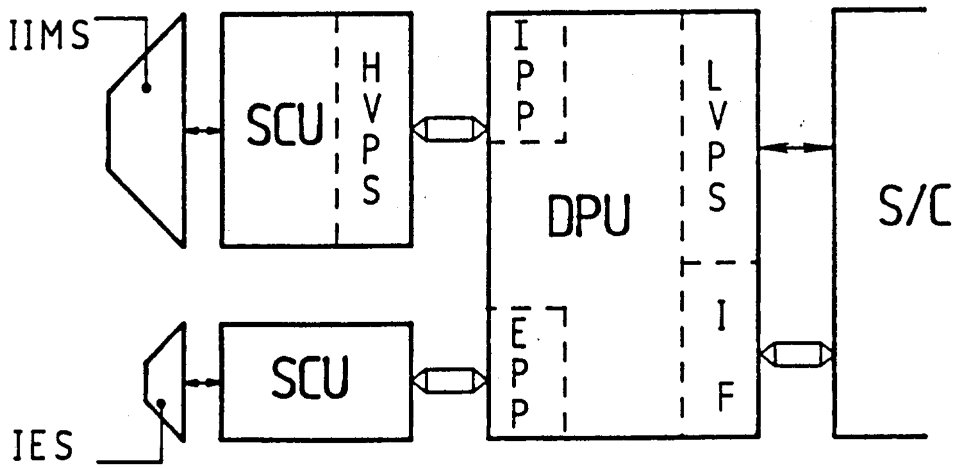

Figure 2: Key components of the dual sensor spectrometer integrated into the single RAPID boxstructure.

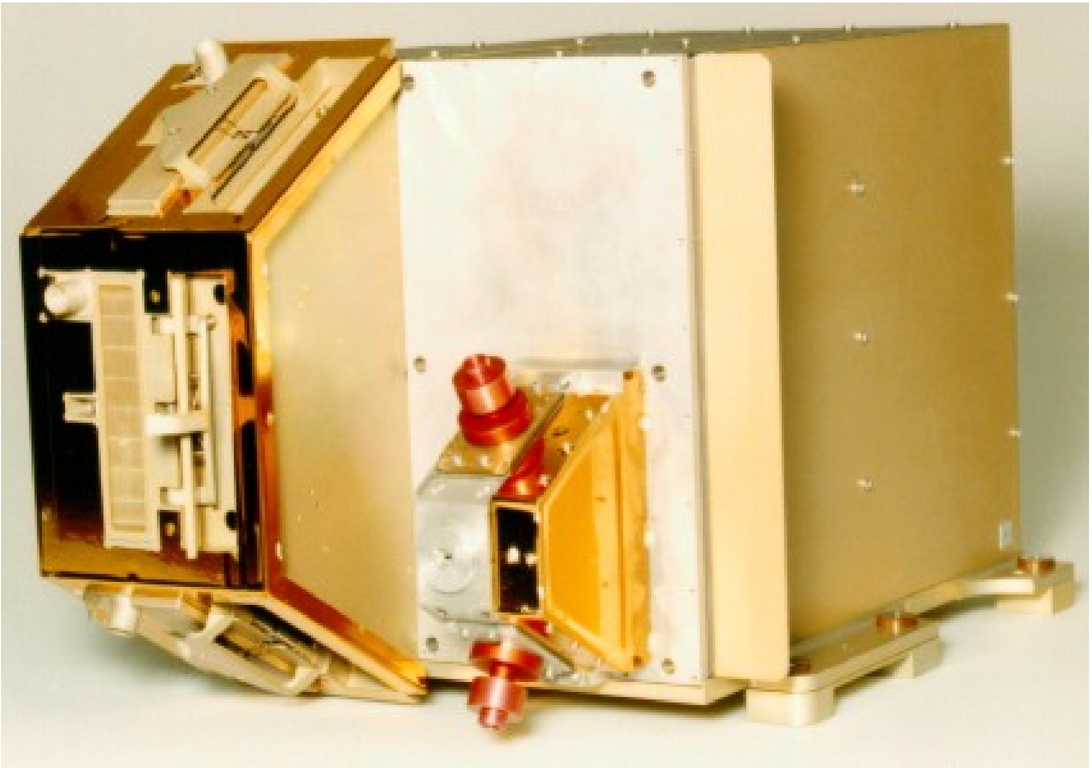

Figure 3: A photograph of the RAPID EM unit. The sensor system IIMS is on the left side.

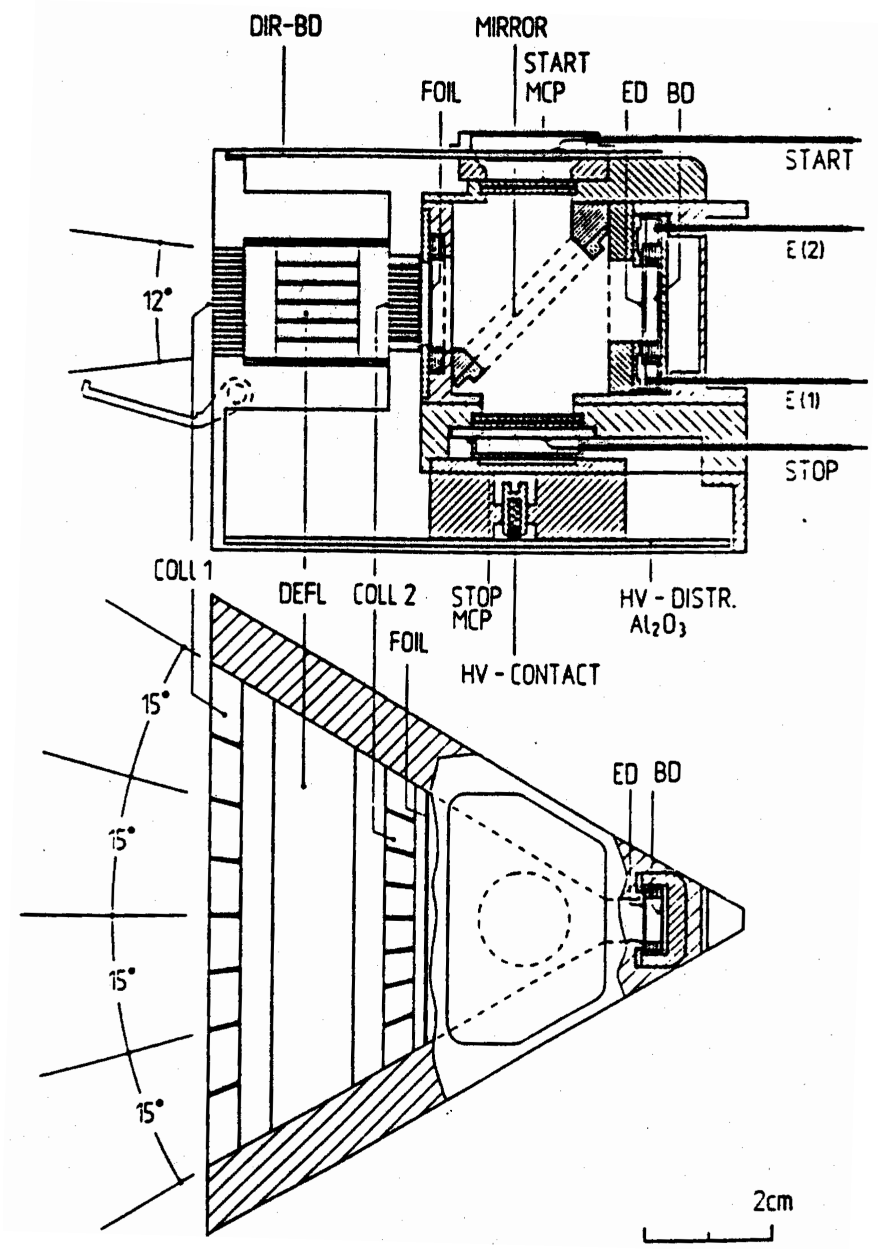

Figure 4: Cross-sections of the SCENIC head. Two narrow collimators (COLL1 and COLL2) and a set of deflection plates (DEFL) form the entry element. The foil (FOIL) and the solid state detector (ED) define the time-of-flight geometry. The detector BD is in anticoincidence to ED · Microchannelplates (MCP) detect "start" and "stop" secondary electrons.

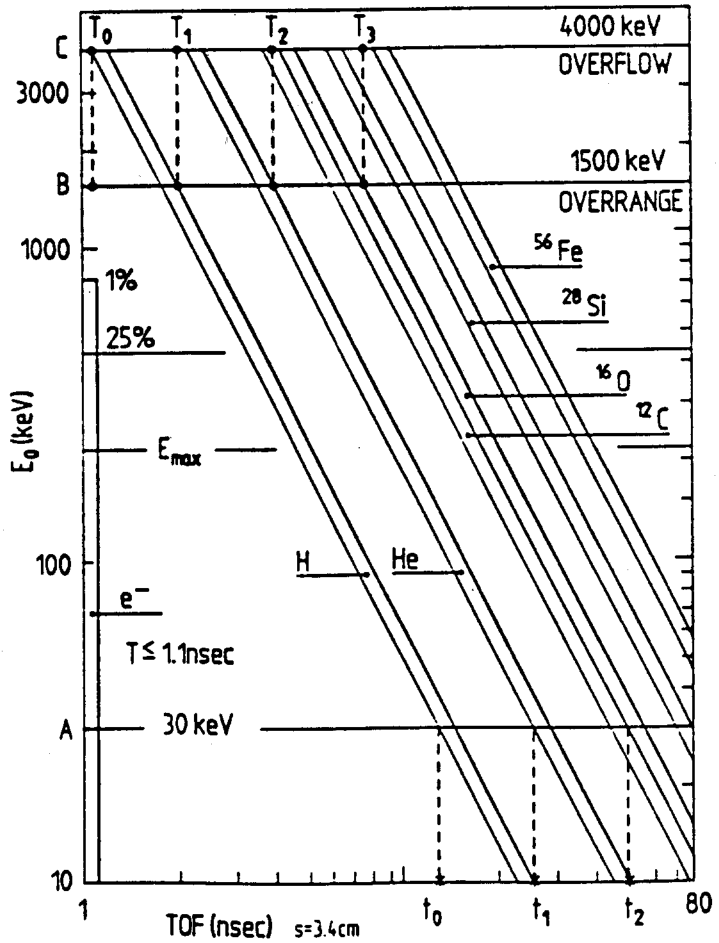

Figure 5: Fraction of the energy-time plane covered by the IIMS system. The width of the particle traces reflects the variation of the flight-path in the SCENIC geometry. Energy thresholds A, B, and C define the lowest energy value accepted, the upper limit for linear response, and overrange, respectively.

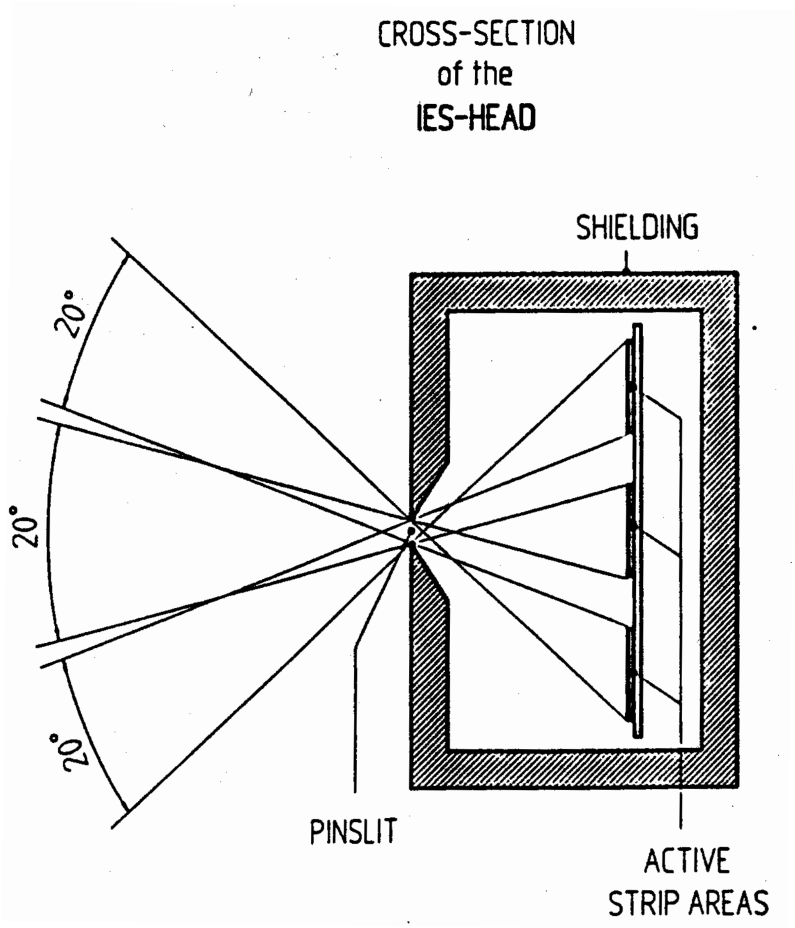

Figure 6: The IES Sensor Concept. Multiple look directions are achieved using a single detector with multiple elements place behind a pin slit.

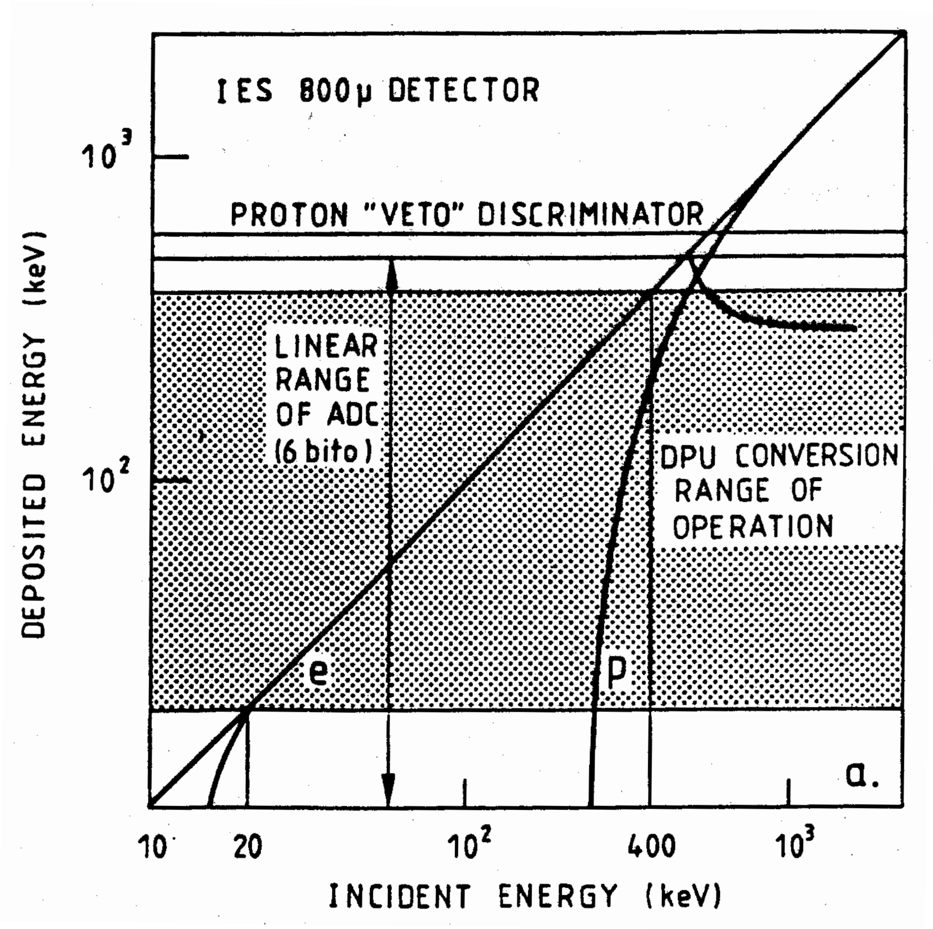

Figure 7: Energy range covered by the IES detector system. The shaded area indicates unique electron identification.

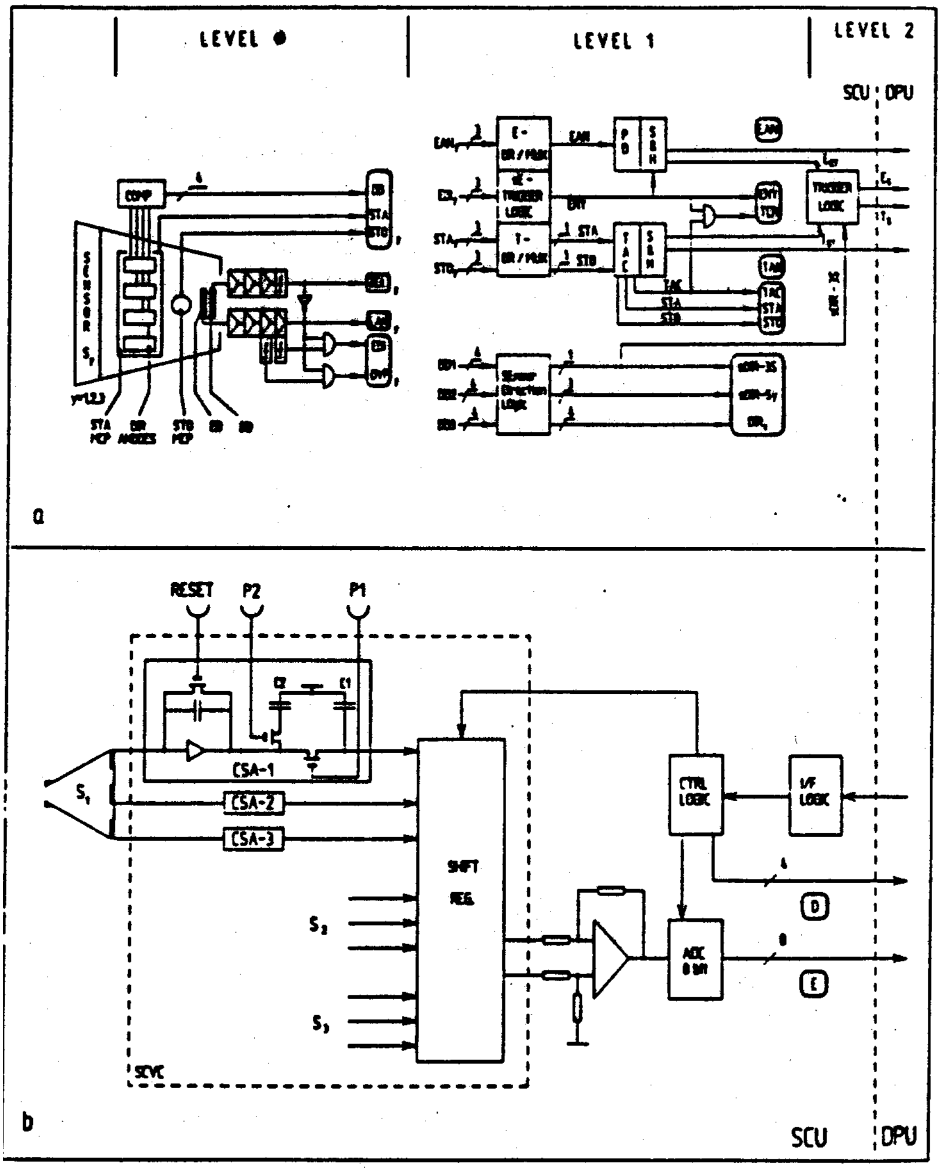

Figure 8: Simplified diagrams of a) the IIMS and b) IES signal conditioning units with emphasis on the signal and data formation (data are shown in heavy rounded rectangles).

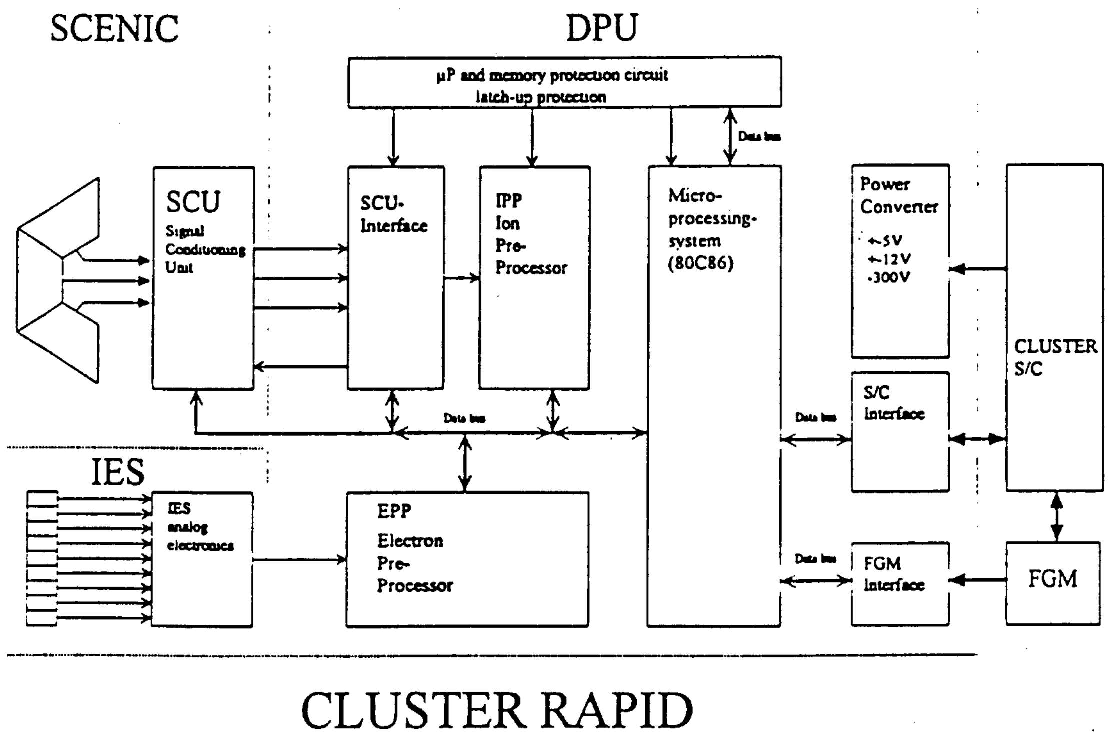

Figure 9: Block diagram of the RAPID digital processing unit and its interfaces to the sensors and to the spacecraft.

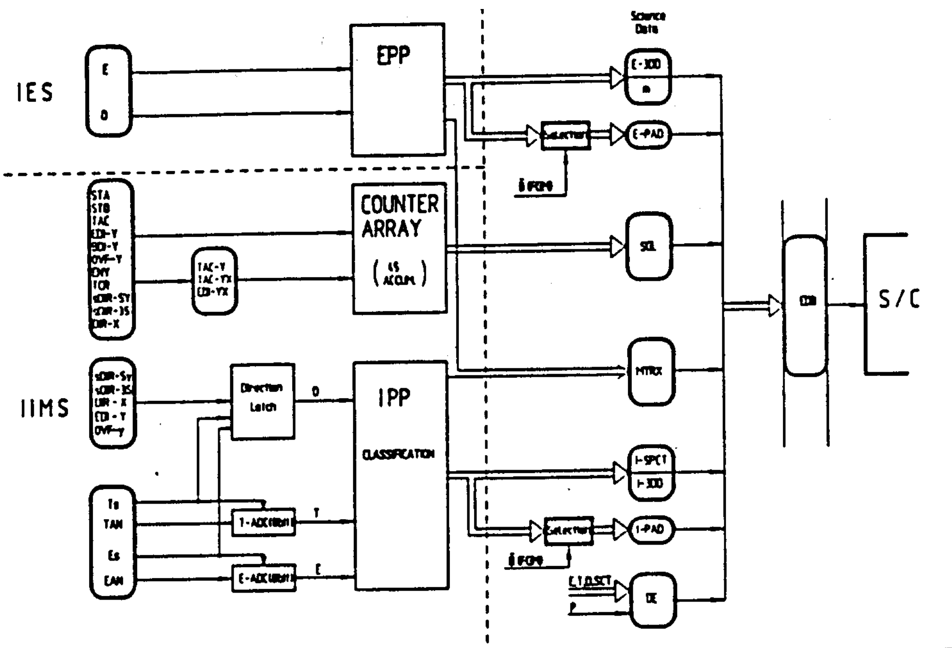

Figure 10: Schematic representation of the data processing in the DPU. Input data from the IIMS/SCU and IES/SCU are shown on the left (heavy rounded rectangles). The sorting and classification processes eventually result in Science Data which, in turn, are organised in Experiment Data Blocks (EDB) for transmission.

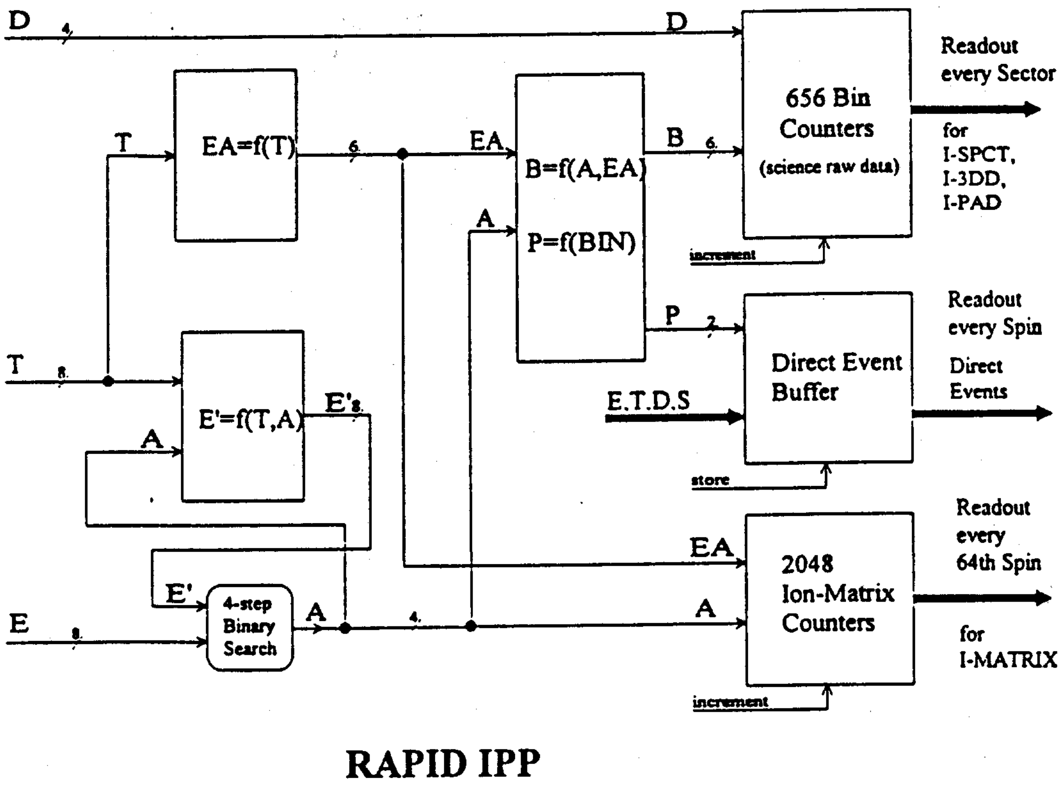

Figure 11: Diagram of the ion pre-processor IPP showing the data flow in the classification process.

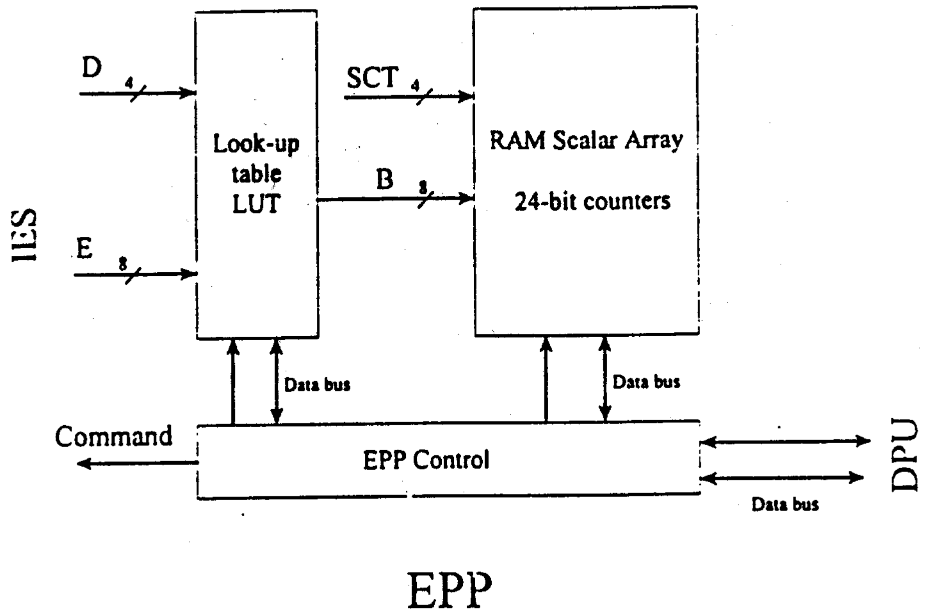

Figure 12: Schematic block diagramm of the electron pre-processor (EPP). Electron input data (energy E and direction number D) are passed through a sorting process to reduce the data volume.

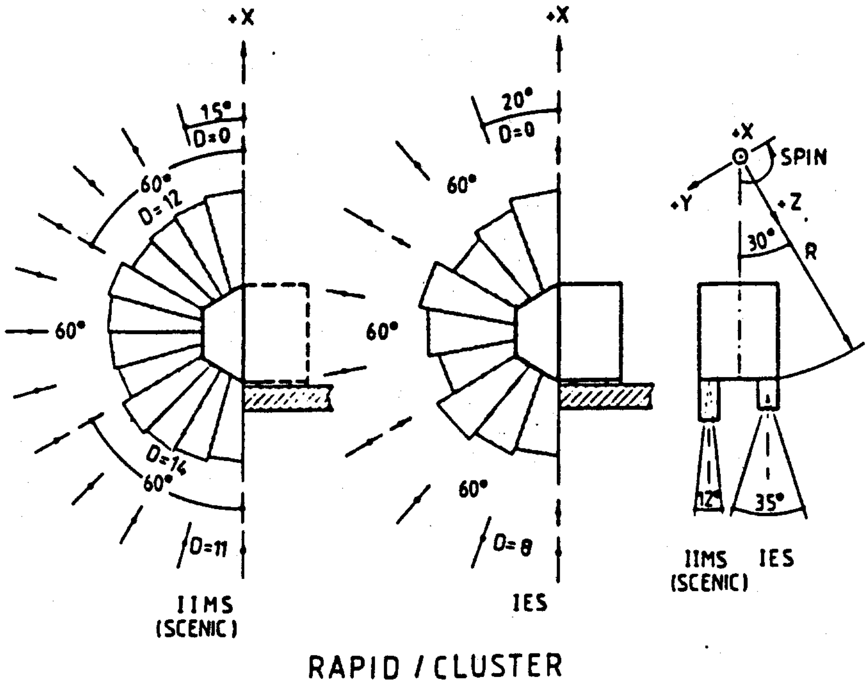

Figure 13: Orientation of RAPID on the Cluster spacecraft. The convention for the direction numbers D is shown for the two sensor systems.

2.0 Telemetry

The general structure/sequence for the downlink (TM words) and the uplink (TC words) telemetry is (compare also Annex A.1, chapter 2):

	Byte Length	Word Length	Bytes per S/C Sampling	Structure	Bit Sequence
TM	8 bit	8 bit	1	—-	MSB first
TC	8 bit	16 bit	High Byte	TC name	MSB first
			Low Byte	TC parameter	MSB first

Details on TC structure see Section 3.2

Down link telemetry modes/bitrates:

Telemetry Mode	Bitrate (bps) (adjusted)
NM-1 = NM-2 = NM-3	1024.80
BM-1	4620.92
BM-2	1155.23
BM-3	1925.38

NM-1 contains Science Nominal Data
BM-1 contains Science Burst Data
BM-2 contains same data format as NM-1
BM-3 contains same data format as BM-1 plus additional check bytes, compare also Section 6.1.1.1

2.1 Monitoring Philosophy

All monitoring is through the RAPID housekeeping telemetry (HK telemetry). The HK-TM contains data which monitor the technical status of the instrument (e.g. temperatures and voltages) and data which allow a quick judgement on the functional performance. The latter type of data has also significance for the interpretation of the information in the science telemetry.

OBDH monitoring: S/C thermistor in RAP

Position	Operational Range	RAP -Status	Out-of-Limit Actions	Parameter	Proc.
SCU	-30 ≤ T ≤ +45°	ON	T > + 45 °: RAP OFF T < − 30°: No action	ERAP_T	P8
		OFF	T > + 45°: No action T < − 30°: RAP ON if possible		P1

2.2 Housekeeping TM

The DPU Software Users Guide (Annex A.1) is the reference document for the RAPID HK parameters. A A.1 provides a detailed definition of the parameters and specifies the position in the HK telemetry frame (at interface to OBDH). The document A A.1 is the principle source for Annex A.2 which shows the same information in the context of the HK telemetry (down link telemetry). A A.2 provides also calibration curves for analogue parameters.

2.2.1 Introduction

Important information on the instrument health (engineering HK data) and information relevant for the instrument performance (science HK data) are transmitted in the HK telemetry (HK-TM). The type of HK data is listed in Table 2.1.

2.2.2 Voltage Monitors

a. *Low voltages (LV)* According to Table 2.1 the HK channels 1 to 6 monitor the ± 12 V and the ± 5 V lines for the electronic circuitry and the bias voltage (60 V) for the solid state detectors (three energy detectors and three back detectors). The LV lines are either ON or OFF.

Table 2.1:

Source	Ch-Nr.	Parameter	Type
IIMS / SCU	1	+ 12 V	A
	2	+5 V	A
	3	−5 V	A
	4	−12 V	A
	5	E − Bias	A
	6	BD − Bias	A
	7	STA − CHPS	A
	8	STO − CHPS	A
	9	DEF PS	A
	10	Door 1	A
	11	Door 2	A
	12	Door 3	A
	13	HV S/A	A
	14	Temp1 (Sensor)	A
	15	Temp2 (SCU)	A
	16	GND − Ref	A
DPU	17	Index	D
	18	Status	D
	19	Command Buffer	D
	20	latchup detect. status	D
	21	Internal counter	D
IIMS	22	Status	D
	23	Calibration data	D
	24	MCP and HV control	D
	25	HK data	D
	26	Single counts	D
IES	27	Rates	D

Parameter	HK-Name
+5 V	ERIP5VRF
−5 V	ERIM5VRF
+12 V	ERIP12RF
−12 V	ERIM12RF
+60 V (E)	ERDEBIAS
+60 V (B)	ERDBBIAS

Detailed definitions of the LV related HK parameters and calibration curves are given in Annex A 2.

b. *High Voltages (HV)* According to Table 2.1 the HK channels 7, 8 and 9 monitor the adjustable high voltages for the START channelplates (STA−CHPS), the STOP channelplates (STO−CHPS), and the deflection voltage (DEFPS):

Parameter	HK-Name	Range (kV)
STA−CHPS	ERISTAHV	0 – 4.5
STO−CHPS	ERISTOHV	0 – 4.5
DEFPS	ERIDEFHV	0 – 10.0

Detailed definitions of the HV related HK parameters and the calibration curves are given in Annex A.2.

Activation of the high voltage power supplies, setting a HV level or stepping the voltage requires special procedures (compare Annex A.3).

2.2.3 Temperature Monitors

Two instrument powered thermistors are used in RAPID:

ID	HK-Name	Location
T–1	ERISTREF	IIMS sensor
T–2	ERIHKTRF	HK–board

An additional S/C powered thermistor is not covered by this document.

Details of the temperature HK parameters and calibration curves are given in Annex A.2.

2.2.4 Instrument Status

The instrument configuration (status) is generally reflected in the status information of the control logic (DPU). All analogue parameters (Table 2.1) can be used for independent verification of commanded settings or configurations.

Accepted as well as rejected TCs are reflected in the HK telemetry.

2.2.5 Analogue Parameter Settings

With reference to Table 2.1 only HK parameters 7, 8, 9 are controlled by dedicated TC (all other analog HK-parameters are set by RAPID power ON/OFF TC).

2.2.6 IEL - Status and Data

The IEL status is monitored by the following parameters:

Parameter	HK-Name
IEL interface ON/OFF	ERDIELIE
Number of received FGM vectors	ERDFGMCR

Details are given in Annex A A.1.

2.2.7 List of all HK Parameters

Reference lists of all HK parameters are given in

- Annex A 1, chapter 4.1 and 4.2 (at RAPID OBDH interface)
- Annex A 2, A 2.1, A 2.2 (down link telemetry)

2.2.8 Parameter Short Description

Short parameter descriptions are part of reference lists specified in 2.2.7.

2.3 Initial Settings

2.3.1 Introduction

HK parameters are subcommutated with varying commutation depth. After a POWER ON command the following prescription shall be applied:

- Check HK-parameter ERDHKFCR (Frame counter or HK-set counter). This rotating 5 bit counter starts at value 0 and increments with every new frame (HK-set).
- The first 8 HK-sets shall be discarded since the values may not be consistent due to internal settling time.

2.3.2 Instrument Status

The POWER ON command causes the DPU to activate instructions stored in program memory which define the initial configuration of the instrument. Details of the initial parameter settings see Annex A.3 (Procedures), procedure P-1 and related default settings shown in Table A.4.1 in Annex A.4.

2.3.3 Analog Parameter

The POWER ON command configures the analogue parameters as follows:

Parameter	HK-Name	Raw Value
STA-CHPS	ERISTAHV	128
STO-CHPS	ERISTOHV	128
DEF-PS	ERIDEFHV	128

For all other parameters consult default settings listed in Annex A.4, Table A.4.1.

2.4 Important Parameters for Prime Instrument Modes

2.4.1 Introduction

The instrument can be operated in a large variety of modes or configurations. A small subset of these modes defines the so-called Operational Modes (OM) described in Section 6.0, all other potential modes are activated only in the case of unexpected malfunctions or functional flaws (these modes will not be described in this document).

2.4.2 Test and Commissioning Phase

Parameters will be checked in dependence on telecommand sequences (see Section 5.0); virtually any parameter can be considered relevant in this phase.

Consult Annex A.3 (Procedures), procedure P-3.

2.4.3 Technical Mode (Memory Dump Mode)

Required only on specific request by experimenter (requested only if data indicate unexplained peculiarities). In such a case selected RAM fields will be checked. The required command sequence is described in Annex A.3 (Procedures), procedure P-4. HK-parameters to be monitored:

HK-Name	Value
ERDRCHKL	Lower RAM address
ERDRCHKU	Upper RAM address
ERDRAMCK	Memory Dump ON/OFF

2.4.4 Standby Mode

In this mode the instrument is configured in any of the Operational Modes (OM) described in Section 6.0 with the high voltage power supplies TURNED OFF.

Required parameter settings: See Section 2.4.5.

2.4.5 Hot Standby Mode

In this mode the instrument is configured in any of the Operational Modes (OM) described in Section 6.0 but the high voltages (STA–CHPS, STO–CHPS and DEFPS) are set to the lowest level (U = 0 V). Required command sequence is described in Annex A.3, procedure P-5. HK-parameters to be monitored:

Mode	Parameter	HK-Name	Value
Hot Stand-by	1 (Relays ON)	ERDRELS2	1 (ON)
Stand-by	0 (Relays OFF)	ERDRELS2	0 (OFF)

2.4.6 Nominal Mode

Routine operational modes are called Nominal Modes (NM) with defined HV settings and sensor configurations. For all Nominal Modes the following parameters are considered most important:

Parameter	HK-Parameter	Value
STA-CHPS	ERISTAHV	see Section 6.0
STO-CHPS	ERISTOHV	”
DEFPS	ERIDEFHV	”

3.0 Control

3.1 Control Philosophy

3.1.1 Introduction

Most instrument functions are controlled by telecommand, i.e. the instrument is configured by a set of TCs which are stored in registers. Among others, these TCs define the nominal Operational Modes (OM) and all emergency modes (e.g. deactivating a noisy detector).

In standard operations the instrument will be configured in steps:

- POWER ON: Instrument in a safe (without high voltages) but scientifically meaningful (e.g. all solid state detectors active) configuration. Full operational capacity can be achieved by a small number of TCs (typically 10–20).
- TURN ON HV relays.
- Set HV levels.
- In case of emergency a POWER-OFF/POWER-ON cycle resets the instrument to the default mode (POWER-ON mode). Emergency situation is defined as an unintended deviation from normal performance. We distinguish two categories:
  - Serious emergency (a):
    HV discharge, failure in TC section etc; requires immediate action.
  - Soft emergency (b):
    Noisy detector etc; situation must be considered, however, action, not time critical.
- Functional integrity will be checked continuously with the built-in test calibrator IFPS.
- Internal over-current detectors (latch-up detector) will switch parts of the instrument automatically OFF and ON in case of excessive currents in the DPU (seen on ground, no action required but inform PI).
- General approach for instrument control during unattended periods: Automatic monitoring of a minimum number of parameters (e.g. S/C powered thermistor in RAP).

(a) = Critical for instrument health
(b) = Critical for scientific quality

Execution of an external TC is generally delayed until the beginning of the next spin rotation although some TCs are associated with longer delay times (consult Annex A.1, chapter 3.3).

3.1.2 Parameters

Parameters may be changed at any time by single TCs or by sequence of TCs. For example, changing a high voltage level requires typically 4 TCs. Operational Modes (OM) are defined with nominal settings of the high voltages but, without changing the OM, other HV levels may become desirable to adjust for gain changes. Similarly, selected detector heads can be omitted from the measurements or the TAC slope can be changed to compensate for changes in the electronic system. After sending a POWER ON command the DPU configures the instrument according to information stored in a PROM.

A multitude of configurational parameters (variables) can be stored in the non-volatile RAM (keep-alive line powered). Two storage modes are implemented:

a. The current instrument configuration can be frozen in the RAM by TC (ZERCFGSS, parameter: 0). This set of parameters can be loaded into the volatile main RAM at any later time by TC (ZERCFGSS, parameter: 1).

b. Configuration back-up of the configuration segment in the main RAM. Cycle time is 1 spin. This back-up is automatically retrieved after a latch-up was detected or a watchdog reset has occurred.

3.1.3 Modes

Operational Modes (OM) can be changed with no restrictions except for changes in the high voltage levels (see Section 6.0). Routine OMs are associated with a certain HV setting obtained from pre-flight calibrations. However, test and/or commissioning phases require different HV settings as part of the check-out procedure. The term “test” refers to unexpected instrument response which requires detailed examinations with specific adopted test sequences controlled by ground commands.

Safe operation of the high voltage system requires the following steps if a high voltage level is to be increased:

- Set a new limit value (higher or equal to the intended target value).
- Enable changing of HV level.
- Set desired target value.
- Disable changing of HV level

A decrease of the HV value can be achieved by simply stepping down to the new value.

3.2 External Telecommands

According to EID-A, chapter 3.3.3.2 telecommands are divided into

- Memory Load Commands (MLC) and
- ON/OFF Commands (OOC).

3.2.1 Memory Load Commands (MLC)

A MLC is constructed as a 16 bit word (compare details in Annex A.1, chapter 3.3 and EID-A, chapter 3.3.3.2.1). MLCs can be organized as single word commands (discrete commands or DC) or as multiple word commands (block command or BC). MLCs are listed and defined in Annex A.1, chapter 3.3). RAPID DC commands are coded ZER. . . , BC commands are coded BER. . . .

3.2.2 Command Execution Delay

DC commands are executed after a pre-defined time delay. Delay times are specified in Annex A.1, chapter 3. BC commands have no defined delay time, activation requires a separate DC.

3.2.3 ON/OFF Commands

The instrument has no internal ON/OFF commands.

3.2.4 High Voltage Control/Critical Commands

DC and BC commands which control high voltages or sensitive instrument functions are considered critical. Commands of this nature are:

Telecommand	Function	Criticallity
ZERALEVS	Set STA-CHPS voltage level	Potential danger of discharges
ZERPLEVS	Set STO-CHPS voltage level	”
ZERDLEVS	Set DEFPS voltage level	”
BERIOWRS	Write into hardware port	Extreme care required

3.2.5 Parameter Commands

All DC Commands are Parameter Commands; see Section 3.2.1.

3.2.6 Alphabetic List of DC and BC Commands

Annex A.1 contains listings for both BC commands (chapter 3.3.3) and DC commands (chapter 3.3.4).

3.3 Reflection of TCs on TM

Section 3.4 in Annex A.1 provides a detailed description for each external telecommand (in alphabetic order). Effects of TCs are reflected in the "Returns" section of each command description (Annex A.1, chapter 3.4; consult also chapter 3.2).

3.3.1 Direct Commands/Block Commands

Compare Section 3.3.

3.3.2 High Voltage Control

Compare Section 3.3.

3.3.3 Parameter Commands

Compare Sections 3.2.5 and 3.3.

3.4 On-board Calibration Tables Modification

On-board calibration tables cannot (!) be modified by TCs.

3.5 On-board Software Modification

Commands for patching S/W are included in Annex A.1. To include patchcode into the running software involves the following commands:

Telecommand	Function
BERPLADS	Set program load address
BERMLDCS	Memory load
ZERPDISE	Enable patches
BERJOBS	Store job in job manager

Patching procedures will be provided when needed.
Generic procedure for changing on-board software (e.g. changing values in look-up tables): See Procedures P 26 in Annex A.3.

3.6 Internal Control and Commands

The following internal control functions are available:

- POWER ON commands:
  - In the first 120 sec following POWER ON the instrument is in an idle state and is exclusively responding to telecommands as a safeguard for unforeseen deadlock effects.
  - The DPU configures the instrument automatically in the POWER ON RESET mode characterized by the default values listed in Table A.4.1 in Annex A.4.
- Pre-set upper limits for the high voltage power supplies CHPS and DEFPS ensure that neither a specified target value nor the actual value can exceed the respective limit.
- Loss of S/C provided sector clock causes the DPU to switch automatically to internal (artificial) sector clock.
- Other features: Consult Section 3.1.1.
- Internal/external source for the sector clock is flagged in the HK-parameter ERDSSINT (see Annex A.1). A source change for the sector clock has no effect on the Operational Mode (OM) of the instrument ("no mode change"). This is particularly important for operations in short eclipses (compare Section 7.1; for operation in long eclipses compare Section 7.2).

3.7 Constraints and Applicability of Telecommands

Constraints and criteria for the applicability of telecommands are addressed in Annex A.1, chapter 3.4 for each TC.

4.0 Environment

4.1 Thermal

4.1.1 Conditions

No particular requirements for any Operating Mode (OM) other than: the temperatures shall have to be within nominal range for platform mounted units.

4.1.2 Monitoring

Two instrument powered thermistors (described in Section 2.2.3).

The HK-parameters are defined in Annex A.1, chapter 4. Telemetry specifications (location etc), limits and calibration curves are given in Annex A.2.

Reaction in response to deviations in POWER ON condition:

Limits and required action is described in Annex A.2 (HK parameter ERIHKTRF and ERISTRF).

4.1.3 Control

The instrument has no active thermal control hardware. The only means for temperature control by TC is to turn the instrument power ON or OFF.

4.1.4 Procedures

Condition	RCP	Function / Action
T-1 > + 40∘C	P8	power turned-off/ inform experimenter
T-2 < - 40∘C	P1	power turned-on / inform experimenter

Procedures (RCP) are to be executed by ground operations only!
Procedures see Annex A.3.

4.2 Power

4.2.1 Profiles

The power for the DPU, the SCU, and the high voltage power supplies is taken from the ± 12 V and the ± 5 V lines. Typical values are given in the following table (reference line: 28.3 V, 80% efficiency). The power is not mode (OM) dependent. Variation between units: +8%, − 5%.

Condition (F-1)	**CM**	**Raw Power** (mW) No particles	**Raw Power** (mW) 1000 particles / sec
Power ON HV Relay OFF	Stand-by Mode	3962	3990
HV Relay ON	Hot Stand-by	3990	4018
HV ON [1)]	Operational Mode	4160 4216	4188 4216
All HV on max. Level	EoL Operational Mode	4302	4302

[1)] STA-CHPS on step 8 (3,5 kV)
STO-CHPS on step 8 (3,5 kV)
DEFPS on step 7 (4.2 kV)

Comments:
– Temperature T = +20○C
– EoL refers to end-of-life conditions for the Micro Channel Plates (MCP)
– CM = Configuration Mode

4.2.2 High Voltages

The instrument has three different high voltage power supplies (powered from the internal low voltage power supply LVPS). All three HV supplies are independently controlled by TC:

Power supply	Function	Range (V)	Steps
STA-CHPS	START Microchannel plate	0 - 4000	16
STO-CHPS	STOP Microchannel plate	0 - 4000	16
DEFPS	Deflection voltage	0 -10000	16

All high voltages are completely contained in the instrument, i.e. field lines do not extend into free space. In-flight software safety precautions are taken: Limit control, stepping control.

4.2.3 Conditions

The power consumption has a quasi-hard relationship with the operational modes (OM):

a. In Stand-by Modes the power dissipation is within 1 or 2% constant (IES creates a minute rate dependence).

b. In all other modes the power consumption can vary by no more than +10% due to the particle flux in IIMS.

Consult also Section 4.2.1

4.2.4 Monitoring

The low voltages ± 12 V, ± 5 V and the high voltages STA-CHPS, STO-CHPS, and the DEFPS are monitored by the respective analogue value in the analogue HK-parameters, the setting of the high voltage levels is reflected in the HK-telemetry:

Function	HK-Parameter (A)	TC	HK-Parameter (D)
+ 12 V	ERIP12RF	—	—
− 12 V	ERIM12RF	—	—
+ 5 V	ERIP5VRF	—	—
− 5 V	ERIM5VRF	—	—
STA-CHPS	ERISTAHV	ZERALEVS	ERDSTMHC
STO-CHPS	ERISTOHV	ZERPLEVS	ERDSPMHC
DEFPS	ERIDEFPS	ZERDLEVS	ERDDPHCL

Definitions of HK-parameters and telecommands are provided in Annex A.1. Location in the HK-telemetry, limits, required action, and calibration curves are given in Annex A.2

Note: For monitoring of the above HK-parameters some delay time for the respective parameter has to be taken into account. Delay times in the order of a few seconds correspond to time constants in the HV system.

4.2.5 Control

The power consumption of the instrument is determined by the operational mode (OM) activated by TC. Power consumption for Stand-by and Hot Stand-by is shown in Section 4.2.1.

Excessive power consumption due to latch-up leads to an automatic partial power OFF/ON cycle.

Instrument reaction on latch-up/recovery:

- DPU powered down for 2 sec (except control circuitry).
- Automatic power up for DPU.
- Resuming pre-event instrument configuration (i.e. operational mode including HV settings remain unchanged by latch-up event).
- Event is flagged in HK parameter ERDLRES.

Nominal instrument is monitored in HK-parameter ERDDPUCU (see Annex A.1, chapter 4.2).

4.2.6 Procedures

Condition:	Power consumption exceeds 100% for more than 5 min (HK parameter ERDDPUCU)
Action:	Inform PI

Limit checking see Table 8.1, Section 8.3.

4.3 Communications

4.3.1 Bit Rates Associated to Each TM And Each Instrument Mode

The instrument has four different bit rates (bps) defined by the telemetry. The relationship between TM, bps and operational mode (OM) is as follows

TM-mode	Bitrate (bps) (adjusted)	OM
NM-1	1024.80	a.m.
NM-2	1024.80	a.m.
NM-3	1024.80	a.m.
BM-1	4620.92	a.m.
BM-2	1155.23	a.m.
BM-3	1925.38	a.m.

a.m. = all modes

4.3.2 Conditions

No constraints provided S/C operates under nominal conditions.

4.3.3 Monitoring

The instrument has no provision for monitoring the TM.

4.3.4 Control

No constraints

4.3.5 Procedures

N.a.

4.4 Timing

4.4.1 Conditions

RAPID is time critical but the required time accuracies remain well within the Cluster specifications. No specific requirements.

4.4.1.1 Command Timing

The timing of commanded changes in the instrument is entirely an internal process:

- Direct Commands (DC): Execution delayed as specified in Annex A.1, chapter 3.3.
- Memory Load Commands (MLC): No specific time delay.

4.4.1.2 IEL Timing

No requirements beyond existing specifications.

4.4.1.3 Sector Timing

Sector timing is critical for the science data; it is derived from the Sun Reference Pulse and the Sector Reference Clock (SRC). In case SRC is not available the instrument switches over to an internal artificial sector clock. See also Section 3.6.

4.4.2 Monitoring

No requirements.

4.4.3 Control

No requirements

4.4.4 Procedures

None

4.5 Interface to Other Experiments

4.5.1 Conditions

RAPID has a single IEL interface to FGM. The magnetic field data are used for on-board pitch angle calculations. In case the data on the IEL are not usable or corrupted by interference the DPU can be commanded to disable the IEL interface.

4.5.2 Monitoring

The status of the IEL interface in the instrument is monitored by the following HK-Parameter:

HK-parameter	Function
ERDIELIE	IEL enabled/disabled
ERDIELCS	IEL clock 1 kHz/16 kHz
ERDFGMCR	Number of FGM vectors received in the last spin
ERIPITCH	Quality of pitch angle distribution

Proper functioning of the IEL can only be assessed by inspecting science data. There is no immediate action required.

4.5.3 Control

The IEL interface is controlled by TC:

TC	Function
ZERFCLKS	Sets clock (1 kHz/16 kHz), enables/disables FGM interface.

Baseline: 1 kHz

Reference: Annex A.1.

4.5.4 Procedures

In case analysis shows inadequate quality of obtained pitch angle data, the RAPID team will decide whether or not to disable the FGM interface.

- When FGM is in calibration mode (typically 5 min per orbit) the RAP IEL shall be disabled by TC issued by JSOC. Procedure P27 (Annex A.3) describes the IEL disable/enable cycle.

5.0 Commissioning

5.1 Initialization of the Instrument

- Initialization/Commissioning will be executed by RAPID team
- For the patch codes that are to be uploaded, consult Annex A.1, sect 5.3.
- For the commissioning RAPID requests data from the on-board Tape Recorder in addition to real time data acquisition.
  - Perigee passage
  - Magnetosheet crossing
  - Solar Wind part of the orbit (Magnetosheath and undisturbed SW).

Note:

- The maximum stepping speed for MCPHV is 1 step/Tspin.
- The maximum stepping speed for DEFHV is 1 step/2 · Tspin
- During the commissioning phase lower stepping speeds will be used.

5.1.1 Timeline

Table 5.1: Commissioning Plan and Timeline

Step	Description	Proc.	Time (min)	Conditions
1	Bi-phenyl actuators release doors	none		T_O + 35 hours Steps 2–6 on first day of session
2	POWER ON – Default Mode (10,11)	P1	∼ 2	Final orbit reached Payload: No constraints
3	Patch Code upload	P31	30	
4	Set IES int. time 5 µs	P32	1	
5	IIMS Commissioning (A) – IFFT – TAC slope variation – IFFT	P20	35	As for step 2
6	Data Evaluation		> 15	WHISPER: OFF FGM: No constraints Other: No constraints
7	Set IES int. time 15 µs	P33	1	

continued...

Table 5.1: Commissioning Plan and Timeline, *continued*

Step	Description	Proc.	Time (min)	Conditions
8	HV-Commissioning (IIMS) – HV-relays ON (Mode: 19,11) – Increment MCPHV to step 3 – Increment MCPHV to step 7 – Hold step 7 (operational level) —(Note: S/C2 different!) – Step DEFHV to HV step 6 and hold – Step DEFHV to HV step 15 (10 kV) – Hold DEFHV step 15 – IFFT – Step DEFHV to step 0	P17	460	
9	Set IES int. time 2 μs	P28	1	
10	Data Evaluation		30	As for step 6
11	Set IES int. time 50 μs	P29	1	
12	IIMS Commissioning (B) – Variations of configurations – IFFT – Step DEFHV to step 10 and hold – Data evaluation – IFFT – Step DEFHV to step 0	P22	100	As for step 6
13	IES Commissioning – Variation of integration time – Histogram mode, vary int. time – Int. time to 2μs – IFC ON – Data evaluation – IFC OFF	P21	80	
14	Modification of Default Setting – Rephasing of SRP-pulse – Store new configuration	P23	30	As for step 6
15	FGM–IEL Test – IEL ON (default) – IEL OFF – IEL ON	P27 P24	5	FGM: ON FGM avail. on ground WHISPER: OFF Other: No constraints Region: M-Sheet, Inner MSPH
16	Listening Mode (CM 14.011)		30	FGM: ON WHISPER: ON Other: No constraints
17	IES test, 2μs	P16, 40h	5	As for step 16

continued...

Table 5.1: Commissioning Plan and Timeline, *continued*

Step	Description	Proc.	Time (min)	Conditions
18	IIMS in CM 24.011 (Listening Mode for IIMS)	P14	30	As for step 16
19	Resetting to CM 14.011	P13		Payload: No constraints
20	–			
21	–			
22	Setting as step 19			Data to be recorded for rest of orbit.
23	Final adjustments		60	1 week later
	End of Commissioning			

Note:

- All data collected during times with no real-time contact should be recorded to improve knowledge about the functional integrity in as many different regions of geospace as possible.
- Definition of procedures see Annex A.3.
- Following POWER ON the instrument assumes full functionality after a delay time of 120 sec. In this interval no HK data are produced (see also Section 3.6).

5.1.2 Operational Constraints

Only one instrument at a time. Real-time HK-telemetry must be available.
High voltage turn-on: Door position not critical,
no restriction for HV operation!

5.1.3 Constraints

Regional constraints in GEOSPACE for the commissioning:

HV turn-on:	Low flux environment preferred.
IES check-out:	Region not critical but not close to perigee
FGM interface:	Inside magnetosphere
WHISPER interference:	All regions (high and low plasma density).

5.1.4 Resources

On the spacecraft:	Nominal power and bitrate.
At ESOC:	Experiment EGSE and 1 ESOC workstation per spacecraft.

5.1.5 Procedures

A description of procedures is given in Annex A.3. The procedure used for the commissioning phase is P3.

5.2 Mechanisms

5.2.1 Under Experiment Control

The IIMS doors are opened by bi-phenyl actuators (no TC required). Timing/Temperature: The doors will be released about 35 hours after lift-off if the spacecraft temperature is about +20°C. Higher temperatures will accelerate the opening process whereas lower temperatures lead to delays. It is a single-shot release mechanism.

5.2.2 Active Covers

None

5.2.3 Environmental Control

None (compare comments in Section 5.2.1).

5.2.4 High Voltages ON

See initialization procedure in Sections 5.1 and 5.1.5 After successful completion of the commissioning phase the high voltages are routinely turned-on and off by applying procedures P2 and P7 (described in Annex A.3).

6.0 Nominal Operations

6.1 Operational Scenario

(a) Routine operations of the instrument along the orbit involve a number of different configuration modes (CM, see definitions below) to cope with drastically different flux levels encountered in the various regions of geospace. The following typical scenarios are ordered by the apogee position; the intention is to provide a baseline for planning, some further fine-tuning is probably required when in-orbit experience is available.

Configuration Modes CM describe the internal settings of the instrument (sensor systems, in-flight calibrator, integration time etc.). A detailed description of CMs is given in Section 6.1.1. For the present purpose the code CM-n illustrates simply the amount of mode switching expected:

A: Apogee in the magnetotail inside the magnetopause

Region in geospace	Configuration Mode (CM)
Magnetosheet	CM-1
Magnetopause (skimming)	CM-1
Lobe/Polar cap	CM-2 (+ CM-3)
Cusp	CM-2
Inner Magnetosphere (inside 5 R_E)	CM-4

B: Apogee in the magnetosheath between magnetopause and bow shock

Region in geospace	Configuration Mode (CM)
Magnetosheath	CM-2
Magnetopause (crossing)	CM-1
Lobe/Polar cap	CM-2 (+ CM-3)
Cusp (if crossed)	CM-2
Inner Magnetosphere (inside 5 R_E)	CM-4

C: Apogee in the solar wind (outside the bow shock)

Region in geospace	Configuration Mode (CM)
Solar Wind	CM-2
Bow Shock	CM-1
Magnetosheath	CM-2
Magnetopause (crossing)	CM-1
Cusp	CM-2
Polar cap/Lobe	CM-2 (+ CM-3)
Inner Magnetosphere (inside 5 R_E)	CM-4

Typical number of TC per mode change: 5

(b) Monitor and Housekeeping Box: N.A.

(c) Once per orbit the in-flight calibration (CM-3) will be activated in a low-flux environment (lobes). After completion of the IFFT cycle (about 240 sec) the instrument returns to the pre-test configuration.

6.1.1 Mode Structure

(Telemetry -, Configuration - and Operational Modes)

Operational Modes (OM)

The RAPID operational modes (OM) are formed by the telemetry mode (TM- normal and high bitrate, see Section 2.0) and the internal instrument configuration mode (CM):

OM = TM + CM.

6.1.1.1 Telemetry Modes

The RAPID telemetry modes and bitrates are shown in Sections 2.0 and 4.3.1.

a. Science Nominal Mode NM

For RAPID all NM are equal: NM-1 = NM-2 = NM-3

The instrument will operate more than 90% of the time in an unattended telemetry mode NM-1. Energetic ions and electrons are analysed and processed on-board by look-up tables contained in EPROM devices or by LUTs generated from uploaded TCs. In the POWER OFF mode, stand-by power is required from KAL at all times. Lack of stand-by power results in the loss of memory and will require extensive memory loading procedures following each POWER ON command.

b. Science Burst Mode BM

RAPID can operate under three burst modes with different accelerated bit rates:

BM-1: Nominal telemetry mode for high speed data taking.
BM-2: Identical to NM-1
BM-3: Read-out of RAPID scratch memory
(BM-1 EDB format plus check bytes).
Compare also Section 2.0.

6.1.1.2 Configuration Modes

IIMS and IES are largely independent subsystems of RAPID with different internal set-up structures called Configuration Modes (CM). Configuration modes (emergency modes are not considered) are conveniently represented by Mode Matrices:

a. IIMS Configuration Modes (AB)

1. Definition of A, B

The configuration parameter A and B refer to two independent functional levels in the internal control system of the instrument. The parameter A defines sensor and/or DPU operations, parameter B defines the HV conditions in the instrument.

A	B			
0 = OFF	0 = HV OFF	(relay OFF)		
1 = S	1 = HV ON	STA = 0V	STO = 0V	DEF = 0V
2 = P	2 = HV ON	STA = r	STO = s	DEF = t
3 = SWG	3 = HV ON	STA = R	STO = S	DEF = T
4 = IFFT ON	4 = HV ON	STA = R	STO = S	DEF = 0V
5 = DPU Test	5 = HV ON	STA = R	STO = S	DEF = 10 kV

Comments:

DPU Test = RAM/ROM dump
HV step r, s, t = arbitrary step numbers between 1 and 16
HV step R, S, T = fixed step numbers defined by ground calibration

2. Two-dimensional Mode Matrix **AB** for IIMS

A	B	0	1	2	3	4	5
0		00	-	-	-	-	-
1		10	11	12	13	14	15
2		20	21	22	23	24	25
3		30	31	32	33	34	35
4		40	41	42	43	44	45
5		50	51	52	53	54	55

3. Principal IIMS Modes

- CM (00):
  POWER OFF
- CM (1B):
  SERIAL Mode, the 3 SCENIC heads are activated in a standard 1-2-3 sequence (only 1 SCENIC head is active at a time).
- CM (2B):
  PARALLEL Mode, the 3 SCENIC heads are all active at the same time Particles will be processed on a first come - first serve basis.
- CM (3B):
  SWG Mode (SWITCHING Mode), the 3 SCENIC heads are sequenced in a prescribed pattern selected by TC. As in SERIAL Mode only 1 SCENIC head is active at a given time.
- CM (4B):
  IFFT, inflight calibrator ON.
  Activated by TC, upon completion of test sequence instrument returns to the pretest configuration automatically.
- CM (5B):
  DPU Test Mode (DTM)
  Verifies stored coefficients for particle mass determination.

b. IES Configuration Modes (LMN)

1. Definition of L, M, N

The operation of the IES subsystem requires three parameters L, M, and N which refer to three independent functional levels:

L: In-flight calibration.
This function can be activated in parallel to the current operational mode of the instrument.

M: Energy binning parameter.
This parameter transforms the 8 bit primary accuracy of energy signals into an output signal with lower or equal accuracy. The transformations are performed by look-up tables (LUTs) which are different for each unit and which need to be uploaded by patches when the instruments are first turned on, or when the power (KAL) has been lost. (See Annex A.1, Section 5.3.3.)

1. LUT-1
   Binning from 256 to 12 (burst mode) or 8 (normal mode) bins.
2. —
   Not used (for Cluster I, this was a 2nd LUT for a different temperature).
3. LUT-3
   Histogram mode, 1 to 1 binning (8 bit output).
   This LUT is called if full energy resolution is required.

N: Integration time parameter.
This parameter defines the integration time t in the detector read-out system. Selection of an integration time t is dictated by the particle flux.

In autoswitching mode, the integration time is not fixed but changes automatically with count rate.

2. Three-dimensional Mode Matrix LMN for IES

L		M		N	
0	measuring			0	Autoswitching
1	In-flight calibration	1	LUT (12 or 8 binning)	1	t = 2μs
		2	not used	2	t = 5μs
		3	256 bins (histogram)	3	t = 15μs
				4	t = 50μs
		5	Memory dump mode		

3. Major Configuration Modes (LMN)

Principle IES CMs

- CM L,10: Autoswitching mode
- CM L,11: High flux mode (fixed integration time 2μs)
- CM L,14: Low flux mode (fixed integration time 50μs)
- CM L,3N: High resolution mode
- CM L,5N: Memory dump mode, verifies stored pedestal values

6.1.1.3 Operational Modes (OP Modes)

RAPID operational modes are constructed from IIMS and IES configuration modes. Operational Modes are coded OP (AB.LMN). The OP modes will be used for normal (NM) and burst (BM) telemetry:

Short Description of Major Configuration Modes

Mode	AB (IIMS)	LMN (IES)
POWER ON (default mode)	10	014
Stand-by	10	0MN
Hot stand-by	11	0MN
Nominal operation		
Low flux mode:		
Fixed int. time	24	014
Autoswitching†	24	010
High flux mode		
Fixed int. time	14	011
Autoswitching†	14	010
In-flight Cal	4B (64 sec)	1MN
ENA*	15 or 25	LMN

*ENA: Energetic neutral atoms.

†Autoswitching or fixed times to be decided at commissioning.

I. Routine Operations

1. Routine Operations for each Orbit
   Routine operations of RAPID are largely driven by the ambient particle flux (i.e. the region in geospace). Ordering the orbits by the apogee position as in section 6.1 the following routine operations along an orbit can be expected:

   A: Apogee in the magnetotail inside the magnetopause

Region in geospace	Configuration Mode (CM)
Plasmasheet	14.011 or 14.010
Magnetopause (skimming)	14.011 or 14.010
Lobe/Polar cap	24.014 or 24.010
Cusp	24.014 or 24.010
Inner Magnetosphere (inside 5 R_E)	11.011 or 11.010

   B: Apogee in the magnetosheath between magnetopause and bow shock

Region in geospace	Configuration Mode (CM)
Magnetosheath	24.014 or 24.010
Magnetopause (crossing)	14.011 or 14.010
Lobe/Polar cap	24.014 or 24.010
Cusp (if crossed)	24.014 or 24.010
Inner Magnetosphere (inside 5 R_E)	11.011 or 11.010

   C: Apogee in the solar wind (outside the bow shock)

Region in geospace	Configuration Mode (CM)
Solar Wind	24.014 or 24.010
Bow Shock	24.014 or 24.010
Magnetosheath	24.014 or 24.010
Magnetopause (crossing)	14.011 or 14.010
Cusp	24.014 or 24.010
Polar cap/Lobe	24.014 or 24.010
Inner Magnetosphere (inside 5 R_E)	11.011 or 11.010

   Typical number of TC per mode change: 5

   It is anticipated that the autoswitching mode (AB.010) for IES will be applied as much as possible unless commissioning or later experience reveals problems with this feature; in which case, fixed integration times will be used.

2. Routine Operations for 1 Orbit per Month
   Radial distance R > 40 000 km: CM (24.034)
   At Apogee: CM (55.05N) to completion
   CM (4B.114) for 10 min
   Radial distance R < 40 000 km: CM (10.011) or CM (10.010)

The assumption is that mode switching is based on model predictions.

II. Special Operations

For 1st month (Pedestal Monitoring)

- even orbits and R > 40 000 km: CM (24.031)
  or CM (24.034)
- odd orbits and R > 40 000 km: CM (25.014)
- all orbits and R < 40 000 km: CM (10.011)

III. Special CM on Demand

The detection of energetic neutral atoms (ENA) requires to configure the RAPID unit on one spacecraft in the ENA mode (IIMS CM 15 or 25, in Section 6.1.1.2). The orbital segment in the lobes/polar cap is ideal for this purpose (low background from ions or penetrating particles).

6.2 Operational Procedures

Procedures for the change of operational modes (OP) are given in Annex A.3.

6.3 Planning

The planning of the operational modes and the transitions between these modes is in agreement with the Cluster science operations as recommended to the SWT.

In practice, this means interfacing with JSOC to define the operational modes and the transition procedures that switch between them. For the sake of simplification, the JSOC modes are given descriptive names which translate into the more precise modes defined in Section 6.1.1.2. The JSOC input is given in Section 6.4.

6.4 Modes and Transitions for JSOC

The following is the input supplied to JSOC to define the operation modes and the transition commands.

Expected Operating Modes

We presently expect to switch both instruments between high and low fluxes together; the neutral mode will be considered to be low.

The electrons will be high or low as the ions are high or low. If IES is run in autoswitching, then its mode is independent of IIMS

Thus

	IES Fixed	Autoswitching
Low flux mode:	24.014	24.010
High flux mode:	14.011	14.010
ENA mode:	25.014	25.010

Standby Modes

Cold standby:	10.011	Voltage turned off
Hot standby:	11.011	Voltage on but set to 0V
Red Hot standby:	12.011	Voltage on but set to non-zero value

Test Modes

In-flight test modes are 4B.LMN and AB.1MN which switch automatically back to the original mode when finished

FGM Calibration

When FGM is calibrating, it is necessary to switch off the IEL (Inter-Experiment Link). This is not a mode change, but only a flag change.

High Level Mode Names

Since the above modes are difficult to remember, we define some with English names. These are the modes that are used with JSOC commanding and the input to the Master Science Plan.

JSOC Mode	Description	AB.LMN
OFF	RAPID is switch off, no power	00.000
HIGH	High flux rates, reduced sensitivity	14.011 or 14.010
LOW	Low flux rates, full sensitivity	24.014 or 24.010
NLOW	Neutral particle mode for ions, low flux	25.014 or 25.010
HIGHXIEL	Same as HIGH but with IEL turned off	
LOWXIEL	Same as LOW but with IEL turned off	
NLOWXIEL	Same as NLOW but with IEL turned off	
STANDBY0	Cold standby: power on but HV off	10.01N
STANDBY1	Hot standby: power on and HV on	11.01N

The procedures referred to in the 2nd column of Table 6.1 are those defined in Annex A.3.

Mode switching

Table 6.1: JSOC Modes and Procedures

Initial_Mode	Procedures	Final_Mode	IBMD Procedure
Any	P8	OFF	p8
OFF	P6	Previous	p6
OFF	P1	STANDBY0	p1
STANDBY0	P8	OFF	p8
STANDBY0	P2+P34,ies_hi	HIGH	cld_hi
STANDBY0	P2+P34,ies_lo	LOW	cld_lo
STANDBY1	P8	OFF	p8
STANDBY1	P18+P34,ies_hi	HIGH	hot_hi
STANDBY1	P18+P34,ies_lo	LOW	hot_lo
HIGH	P14+P34,ies_lo	LOW	hi_lo
HIGH	P14+P25+P34,ies_lo	NLOW	hi_nlo
HIGH	P8	OFF	p8
HIGH	P7	STANDBY0	p7
HIGH	P5	STANDBY1	p5

. . .

Table 6.1: JSOC Modes and Procedures, *continued*

Initial_Mode	Procedures	Final_Mode	IBMD Procedure
LOW	P13+P34,ies_hi	HIGH	lo_hi
LOW	P27	LOWXIEL	p27
LOW	P25	NLOW	p25
LOW	P8	OFF	p8
LOW	P7	STANDBY0	p7
LOW	P5	STANDBY1	p5
NLOW	P26	LOW	p26
NLOW	P26+P13+P34,ies_hi	HIGH	nlo_hi
NLOW	P27	NLOWXIEL	p27
NLOW	P8	OFF	p8
NLOW	P7	STANDBY0	p7
NLOW	P5	STANDBY1	p5
HIGHXIEL	P24	HIGH	p24
HIGHXIEL	P8	OFF	p8
HIGHXIEL	P7	STANDBY0	p7
HIGHXIEL	P5	STANDBY1	p5
LOWXIEL	P24	LOW	p24
LOWXIEL	P8	OFF	p8
LOWXIEL	P7	STANDBY0	p7
LOWXIEL	P5	STANDBY1	p5
NLOWXIEL	P24	NLOW	p24
NLOWXIEL	P8	OFF	p8
NLOWXIEL	P7	STANDBY0	p7
NLOWXIEL	P5	STANDBY1	p5

7.0 Critical Operations

7.1 Short Eclipse

7.1.1 General Approach

During short eclipses (perigee eclipse, t $\approx$ 50 min) RAPID will be operated in "Stand-by" mode (see Section 2.4.6) i.e. the HV generators are turned OFF, the pre-eclipse operational mode remains unchanged (reference: EID-A, Section 3.3.3.3.2 and Section 10.2.6).

7.1.2 Preparation of the Instrument

Two cases are distinguished:

a) Payload remains ON in Eclipse.
No change in the RAPID pre-eclipse configuration mode (CM). In order to monitor the temperature effects on the IES performance the instrument will be set to the IES histogram-mode shortly prior and after the eclipse:

P#	Name	Description	Set-up Time
P16	IES Test	Histogram	few minutes

Objective

- IES test at pre-eclipse temperature. Actual test-time before entry into shadow is not critical (typically 5 min).
- IES test at post-eclipse temperatures. Actual test-time after the S/C emerged from shadow must be as short as possible in order to reflect end-of-shadow temperature effects.
- IES test after temperature recovery to pre-eclipse value:
Test at t = 50 min after eclipse.

b) Payload has to be turned OFF in Eclipse.

The following procedures apply:

P#	Name	Description	Set-up Time
P8	POWER DOWN	Power off sequence	few minutes
P6	POWER UP	Power on sequence to pre-eclipse CM	$\approx$ 10 minutes

The required procedures are given in Annex A.3

7.1.3 Monitoring or Activities During the Eclipse

The instrument status and behaviour is monitored by the normal HK channels; no special activities are foreseen.

7.1.4 Conditioning after the Eclipse

See Section 7.1.2 a) and b).

7.1.5 Constraints

None

7.1.6 Resources

It is assumed that nominal power for the instrument can be provided.

7.1.7 Procedures

See Section 7.1.2.

7.2 Long Eclipses

7.2.1 General Approach

See specifications in EID-A, Sections 3.3.3.3.2 and 10.2.6.

7.2.2 Preparation of the Instrument Before the Eclipse

Same as Section 7.1.2.

7.2.3 Monitoring or Activities During the Eclipse

During long eclipses no activities are planned, monitoring is not required.

7.2.4 Conditioning after Eclipse

See Section 7.1.2.

7.2.5 Constraints

None

7.2.6 Resources

Nominal spacecraft power and bitrate must be available before the instrument is configured after the eclipse.

7.2.7 Procedures

See Section 7.1.2.

7.3 Perigee Passages

7.3.1 General Approach

It is expected that the ion sensor (IIMS) in RAPID will be exposed to rather high counting rates due to both high forward fluxes and penetrating particles when the spacecrafts travel through the inner parts of the ring current region. As a result, the scientific value of the data may be reduced by background contamination, furthermore, the high rates may present a lifetime problem for the microchannel plates (MCP). As a precaution RAPID will be put into the Hot Stand-by mode:

- STA-PS, STO-PS and DEFHV are set to 0 V (the power supplies remain ON!)
- The IES sensor remains fully active, the integration time constant for IES will be optimized for a high flux environment, the solid state detectors in IIMS are active but no TOF measurement.

Criterion for switching into the Hot Stand-by Mode: Geocentric radial distance below 5 R_E (geocentric).

Note: The commissioning/test phase will be used to establish actual counting rates for perigee passes. This data base will be used to assess the actual hazard for MCPs and the optimum settings for IES operations. A modification of predefined perigee procedures may result.

7.3.2 Preparation of the Instrument Before Perigee

Before perigee the instrument will be configured in Hot Stand-by Mode:

P#	Name	Description
P7	StandBy	HV down (HV relays OFF)

7.3.3 Monitoring or Activities During Perigee Passage

No specific activities are planned for perigee passes. The Monitoring is accomplished via nominal telemetry channels (on-line or off-line), no special precautions are required.

7.3.4 Conditioning after Perigee

After perigee (geocentric radial distance larger than specified in 7.1.1) the instrument will be brought back to the pre-perigee configuration.

P#	Name	Description
P18	HVUp	HV increase to nominal level

Procedure is defined in Annex A.3.2.

7.3.5 Constraints

Time tagged TCs are acceptable after verification of instrument health during commissioning. Availability of "normal telemetry link" is acceptable.

7.3.6 Resources

Normal telemetry link required for preparation of instrument functions before and after perigee.

7.3.7 Procedures

As described in Section 7.3.2 the instrument will be commanded into "Hot Stand-by" mode and after perigee pass the instrument will be reconfigured in pre-perigee mode (see Sections 7.3.2 and 7.3.4 for procedure).

7.4 Manoeuvers

7.4.1 General Approach

For manoeuvers with engine burns the instrument is to be turned OFF.

7.4.2 Preparation of the Instrument Before the Manoeuver

Normal POWER OFF procedure:

P#	Name	Description
P8	PowerDown	Power OFF sequence

7.4.3 Monitoring or activities during Manoeuver

N.a. since instrument is not powered.

7.4.4 Conditioning after the Manoeuver

Configuration procedure for normal operation:

P#	Name	Description
P6	PowerUp	Standard Power-ON sequence (boot sequence IES) (T = 2 μsec/ autoswitching ON)

7.4.5 Constraints

None

7.4.6 Resources

Full telemetry link for instrument commanding.

7.4.7 Procedures

Instrument operations before and after manoeuvers involve procedures defined in Sections 7.4.2 and 7.4.4; definitions are given in Annex 3.2.

7.5 Boundary Crossings

7.5.1 General Approach

The in-orbit operations for RAPID are based on the principle "minimal mode changes". Along trajectory the instrument modes are driven by the particle flux encountered. Final decisions on routine mode changes can only be taken after the commissioning phase. Potential mode sequences and switching criterion see Section 6.1.1.3, I.

Mode changes along an orbit are subject to a critical review after the commissioning phase. The intention is to minimize the number of routine mode changes.

Crossings of boundaries (such as the magnetopause, bow shock etc.) may require mode changes (6.1.1.3). Experience gained during the Commissioning Phase will establish a baseline for routine mode switching at boundaries and may result in a modification of the CM-table in 6.1.1.3. Special campaigns may require special mode settings.

7.6 Patching SW

7.6.1 General Approach

There are two possibilities for patching software:

- Up-loaded subroutines are included into the running s/w by the embedded "job manager".
- Software "hooks" can be used to include up-loaded program codes.

Details and procedures will be provided by the experimenter when needed.

Consult also Annex A.1, sect. 5.3.

7.6.2 Loading the Patch

General procedure:

- Definition of a target address (see command BERPLADS in Annex A.1)
- Uploading Patch Code using command BERMLDCS (see Annex A.1)
  Comment:
  The actual amount of commands is defined by the required patch code (driven by the detected anomaly).

7.6.3 Validation and Verification

General approach:

- Acceptance of the commands (defined in Section 7.6.2) verified as described in Annex A.1.
- RAM-check to verify positioning and contents of the uploaded code. Definition of the RAM-check start address uses command BERRCADS (Annex A.1). Switching ON/OFF RAM-check is done by command ZERIRCKS (Annex A.1).
- Chaining of the patch (selection of the chain procedure depends on details of the detected anomaly).

7.6.4 Configuration Control of Patching

To the extend it is possible (e.g. a constraint may result from limited telemetry rates) the patch will be checked by

- special flags in the HK-Data (functionality),
- special flags in the Science Data (assignment of EDB pattern).

7.6.5 Reload of Software after e.g. Power OFF

Patch codes are stored in non-volatile RAM (keep-alive power), thus reloading patch codes after POWER OFF is not necessary (except patch codes require memory space in the main RAM (volatile)). However, after POWER ON, chaining may be required.

7.6.6 Constraints

Uploading/chaining of patch codes is generally a critical operation (the instrument may end up in an undefined status). Specifically we request that all HV-voltages be turned OFF during uploading/chaining of patches.

7.6.6 Resources

Reasonable patch code operations are limited by the size of free space in the non-volatile RAM (max 2 KByte).

7.6.7 Procedures

Can only be defined with an exact knowledge of the problem to be addressed (e.g. new scientific modes, work-arounds for software bugs, improved content of look-up tables (LUT), or correcting anomalies).

7.6.8 Note on the RAP-F1 (Phoenix), F6, F7, and F8 embedded S/W

1.) A minor inconsistency in module 14.3 of the RAP F1 (PHOENIX) unit's embedded S/W (see attached S/W list) was corrected for RAP F6, F7, and F8. RAP F1 requires uploading of Patch Code A (see Instrument User's Guide (Annex A.3) p.5-4) to update Module 14.3 to version 2.01.

2.) In order to improve the counting statistics for the data type I-3DD the duty cycle for RAP-F6, F7, and F8 was increased to 8/16 spins (compared to 1/16 spin for F1 (Phoenix). See also Instrument User's Guide (Annex A.3) p.2-1 and p.2-3.

RAPID embedded S/W Modules

Version	Module	Description	Function
1.0	1.0	task manager	tool for organization of management
1.0	2.0	interrupt procedures:	
1.0	2.1	- command interrupt	process telecommands
1.0	2.2	- sector interrupt	spin synchronization
1.0	2.3	- artificial sector clock	
1.0	2.4	- latchup interrupt	stores LU source
2.0	2.5	- watchdog	
1.0	3.0	IIMS sensor handling procedures	
1.5	4.0	IIMS classification handling procedures	
1.0	5.0	IIMS calibration	single calibration shot once/spin
1.0	6.0	IIMS IFFT	in flight functional test
1.2	7.0	command handling	execution of TCs
1.0	8.0	telemetry	data transfer procedures
1.2	9.0	HK formatting	generation of HK frames
	10.0	EDB formatting	generation of science data frames
2.1	10.1	IIMS data	
3.0	10.2	IES data	new beginning scheme implementation (Jan. 97)
2.0	11.0	IIMS classification test	procedure to test IIMS classification H/W and data formatting
	12.0	Instrument conf. image	save/restore intr. config.
	13.0	latchup detector serving	fine strobing of LU circuits
2.0	14.0	EPP handling	
1.0	14.1	table calculation	calc. and load classification tables into EPP
1.0	14.2	test procedures	procedures to test EPP H/W and data formatting
2.01	14.3	IES automatic mode change	

8.0 Contingency Operations

8.1 Failure Analysis (FMECA)

8.1.1 General Failures

Failures in the "low voltage" area of the electronics (DPU, SCU) are possible but not very likely. Procedures for a failure analysis will be provided in case the principle function of the instrument is in question (the large variety of possibilities does not warrant any effort at this stage).

8.1.2 High Voltage System

The high voltage system of the instrument comprises the high voltage generators STA-PS, STO-PS and DEFHV, the high voltage distribution and the interior of the sensor systems. The HV generators demonstrated "short proof" capabilities, in addition they are protected by internal current limiters. In case of a catastrophic failure in one of the three HV generators the unit in question can be disabled without effecting the functions of the remaining generators. Impact on instrument operation: Consult Section 8.2.

8.1.3 Detectors (MCP, SSD)

The detectors used in the instrument are

- Microchannel plates (MCP) for the START and STOP systems in IIMS,
- Solid State Detectors (SSD), ion implant - single active volume detectors (IIMS),
- Solid State Detectors (SSD), ion implant- microstrip detectors (IES).

All detectors are very delicate objects with some sensitivity to particle flux (SSD) or extracted total charge (MCP). Detectors are usually bottlenecks, i.e. loss of a detector leads to the loss of an entire data channel; there is no redundancy in the detector system but the degradation of instrument functions is reasonably weakly dependent on detector failures due to the number of systems used. Impact of detector loss is detailed in Section 8.2.

8.2 Instrument Failure Recovery

8.2.1 General Recovery Procedure

In case a catastrophic failure is detected in either the HV-system or in a detector (MCP or SSD) the instrument will be commanded into an operational mode which eliminates the use of the suspected detector or component. A certain loss of data is an inevitable result of this recovery process, however, in most cases the remaining science data are not expected to show degradation in quality.

8.2.2 Redundancy Concept

As already mentioned above, RAPID has no redundancy in the detector or HV-system but a few precautionary steps were taken to reduce the science loss due to a single failure in this area:

DEFHV:
Single unit, failure can result in loss of deflection voltage, the instrument works perfectly well with no deflection voltage in the collimator.

MCPHV:
The high voltage bias for channel plates is provided by two independent power supplies. The START plates are driven by the STAPS and the STOP plates are drive by the STOPS. Loss of one system results in the loss of atomic mass information from all three IIMS sensor heads; the sensor heads continue to function as particle counters without mass identification.

300 V:
The low voltage power supply provides also the 300 V bias for the three microstrip SSD in the IES heads. The 300 V line has no independent control but is current limited in case of a short. The total loss of IES can result if the 300 V is lost or pulled down significantly.

START-MCP:
Substantial increase of dark current in one START channel plate can be tolerated by the STAPS, the sensor system in question can be totaly disabled should crosstalk lead to unacceptable interference.

STOP-MCP:
Same as for START-MCP.

E-DET:
Energy detectors in IIMS (E-Det(n), n=1,2,3). Any noisy detector can be eliminated by TC. Result: Loss of atomic mass information from one sensor head.

B-DET:
Back detectors in IIMS (B-det(n), n=1,2,3). Any noisy detector can be disabled by TC. Result: Loss of high energy response in the affected sensor head.

IES-Det:
If one of the three microstrip detectors in the IES detector heads develops excessive noise no recovery action is possible. Dependant on the noise level the system either tolerates the malfunction or the data are corrupted to a point which makes them unusable; IES cannot be powered down separately.

8.2.3 TM Parameters Monitored

No special arrangement required, all functions will be monitored through the normal HK-channels (by instrument and technical HK checks by ESOC), compare Annex A.2.2.

8.2.4 Troubleshooting Chart

The nature of a failure dictates the amount of troubleshooting required to identify the kind of failure and to develop means to recover instrument functions. Most of the conceivable failure modes described in Section 8.2.2 are likely to be discovered in the HK-data or in the science data. A need for additional troubleshooting may or may not arise.

8.3 Contingency Recovery Procedures

Table 8.1 summarizes all analog/digital HK parameters for which a specified action is required in case the parameter exceeds/deviates from prescribed ranges/values. The column "Action" describes steps to be taken by the ground operator in proportion to the severity of the deviation observed.

Table 8.1:

HK-Parameter Identifier	Analog range / Digital Value	Action
ERDSSINT ERDBBIAS	1	Inform PI

A.1 CLUSTER RAPID

Instrument Users Guide

(IDA)

Please click here for
Issue 2 Revision 7
from Feb. 15, 2000

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A.2 TM Parameters (Dornier Database)

The TM parameters are not provided in this electronic version since they are not readily available in electronic form. However the same information is to be found in the following text files:

S/C 1 `rapid_f1.tm`
S/C 2 `rapid_f2.tm`
S/C 3 `rapid_f3.tm`
S/C 4 `rapid_f4.tm`

A.3 RAPID Command Language (RCL)

Please click here for
Issue 4 Revision 1
from June 19, 2000

A.4 Default Settings Following POWER–ON TC

Table A.4.1: Default Settings Following POWER–ON TC

Ch-No	Parameter	HK-Name	Initial Value	Function	Remark
17	Index	ERDHKFCR	0	Frame counter	counting
18	Status	ERDTMMOD	00	TM-NM	static
		ERDSSINT	0	Int. sectorclock OFF	static
		ERDIELIE	1	IEL interf. ON	static
		ERDRAMCK	0	RAM check OFF	static
		ERDSCMXS	n.a.	S/C MUX	n.a.
		ERDSCMEM	0	Scratch mem off	static
		ERDSPPOS	7F (HEX)	Sun pos in Sun sector	static
		ERDPATAC	0	Patch OFF	static
		ERDSPSEC	0	Sun sector	static
		ERDDEADT	0	Deadtime	static
		ERDWATEN	1	Watchdog ON	always 1
		ERDCMDER	0	TC error	static
		ERDCMDIV	0	Invalid TC	static
		ERDCMDVD	0	Valid TC	static
19	Command Buffer	ERDECODE	0000	Errorcode	static
		ERDLVCMD	(FF)[1])44(hex)[2])	Last valid TC	static
		ERDSVCMD	(FF)[1])45(hex)[2])	Second last valid TC	static
		ERDLICMD	FF	Last invalid TC	static
20	Latch-up Detector	ERDLUSEN	0	Sensitive mode OFF	changes to 1 (ON) after 32 spins
		ERDLUDE1	0	LUD MPB OFF	
		ERDLUDE2	0	LUD MPB MEM OFF	change to 1 (ON)
		ERDLUDE3	0	LUD Counter OFF	after 32 spins
		ERDLUDE4	0	LUD CLASMEM OFF	
		ERDLUMS1	0	LUD MPB Sensitive OFF	
		ERDLUMS2	0	LUD MPB Sensitive OFF	change to 1 (ON)
		ERDLUMS3	0	LUD MPB Sensitive OFF	after 32 spins
		ERDLUMS4	0	LUD MPB Sensitive OFF	

[1]) Value without any memory uploading before

[2]) The value effect when Patch b is loaded

Ch-No	Parameter	HK-Name	Initial Value	Function	Remark
21	Interval Counter	ERDLEDBC	≈ 3	EDB counter	24 bits length every 32 spins
		ERDSPINC	≈ 0E(hex)	Spin counter	24 bits length sampled every 32 spins
		ERDEDBCR	0	EDB counter for IFPS	6 bit length
		ERDFGMCR	0	FGM counter	7 bit length Received number of vectors in last spin Read-out value: ≈ 62 FGM ON (0 FGM OFF
		ERDICCNT	0	Invalid TC counter	8 bit length
		ERDVLCNT	(0)[1]) 2[2])	Valid TC counter	8 bit length
		ERDCECNT	0	TC error counter	8 bit length
		ERDTOERC	≈ 5	Time out error counter	16 bit length can happen during initialisation
		ERDFRPRT	not predictable	MP free time	16 bit length
22	IIMS Status	ERDTRIGM	0	Trigger Mode (E+T)	Default setting
		ERDIFIND	0	Serial Mode	Default setting
		ERDEDET1	0	Energy Det S1	Default ON
		ERDEDET2	0	Energy Det S2	Default ON
		ERDEDET3	0	Energy Det S3	Default ON
		ERDBDET1	0	Back Det S1	Default ON
		ERDBDET2	0	Back Det S2	Default ON
		ERDBDET3	0	Back Det S3	Default ON
		ERDDMUX1	0	DIR MUX S1	Default ON
		ERDDMUX2	0	DIR MUX S2	Default ON
		ERDDMUX3	0	DIR MUX S3	Default ON
		ERDTMUX1	0	T-MUX S1	Default ON
		ERDTMUX2	0	T-MUX S2	Default ON
		ERDTMUX3	0	T-MUX S3	Default ON

[1]) Value without any memory uploading before
[2]) The value effect when Patch b is loaded

Ch-No	Parameter	HK-Name	Initial Value	Function	Remark
(22)		ERDDWISP	6	Dir window STP	5 bits, static
		ERDDWIST	3	Dir window STA	5 bits, static
		ERDEWISP	14	Energy window STP	5 bits, static
		ERDEWIST	6	Energy window STA	5 bits, static
		ERDFLAP1	0	Flap 1 status	0 closed, 1 open
		ERDFLAP2	0	Flap 2 status	0 closed, 1 open
		ERDFLAP3	0	Flap 3 status	0 closed, 1 open
		ERDHMASK	7	Head selection	default
		ERDTCFAC	00	TAC slope	default 0 %
		ERIPITCH	66 (HEX)	Look direction for I-PAD data formatting	FGM OFF 66 HEX, FGM ON Value unpredictable
23	Calibration	ERICALEN	n.a.	Cal energy value	varying values
		ERICALTF	n.a.	Cal. TOF value	varying values
24	MCP/HV Control	ERISAREF	n.a.	HV-disable	Reading depends on S/C control disable connector
		ERDRELS2	0	HV-relay OFF	default value (all HV voltages OFF)
25	HK Data	n.a.			
26	Single Counter	ERIENYCP	not predictable	Counting rate SSD	8 bit length compressed Counting rate, depends on particle flux
		ERIENYLB	not predictable	Counting rate SSD	Low Byte (8 bit)
		ERISTACP	≤ 10	IFC counts	HV OFF, IFC counts
		ERISTALB	≤ 10	IFC counts	HV OFF, IFC counts
		ERISTOCP	≤ 10	IFC counts	HV OFF, IFC counts
		ERISTOLB	≤ 10	IFC counts	HV OFF, IFC counts
27	Rates	ERERATE1	unpredictable	IES noise level	Det quality
		ERERATE2	before	IES noise level	Det quality
		ERERATE3	ZERELUTS....	IES noise level	Det quality
		ERERATE4	commands	IES noise level	Det quality
		ERERATE5		IES noise level	Det quality
		ERERATE6		IES noise level	Det quality
		ERERATE7		IES noise level	Det quality
		ERERATE8		IES noise level	Det quality
		ERERATE9		IES noise level	Det quality
		ERDIESIE	1	IES interface ON	default value
		ERIPADTS	0	IES pitch angle format	default EPAD formatting method
		ERECMDRT	0	IES TC answer	default setting (2 μs)
				LUT 1, t = 2 μsec	LUT 1 = binning integration time = 2 μsec default value
		EREFXLUT	0	Autoswitching fix - bit	Default: Autoswitching ON