

STEREO

SEP LET and SEP Central

Flight Software Requirements

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Andrew Davis, Caltech Space Radiation Laboratory

Document Revision Record

Rev.	Date	Description of Change	Approved By
A	2002-Feb-27	First Draft	-
B	2002-May 10	Incorporated comments from LET team, moved implementation details to an Appendix	-
C	2002-May 20	Various minor comments and updates from Caltech folks. Updates to LET and SEPT beacon data products. Add LET software task of dynamically adjusting thresholds during high-rate periods.	-
D	2002-Aug 21	HK and Beacon will be transferred to the IDPU as data blocks rather than CCSDS packets. Added requirement that SEP Central ensure time-synchronization of Beacon data from SEP sensors. Incorporated responses to RFAs generated during software requirements peer review: 1. Added requirement that SEP common needs to store and transfer flight software for HET and SIT. 2. Added requirement to allow modification of dynamic threshold algorithm on-orbit, and that there be a disable command. 3. Added requirements for on-orbit software RAM patch capability for LET and SEP Central, and EEPROM reload capability for SEP Central.	-
E	2002-Oct 02	Added more detailed requirements for dynamic threshold algorithm, and described schedule and verification/testing methods for this function. Added requirement that SEP Central buffer SEP command responses to conserve telemetry bandwidth. Added requirement that LET send at least one CCSDS packet to SEP Central in each of its allocated windows. Updated SEPT data processing section	
F	2002-Nov 13	Update event processing details	

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1. Introduction

The IMPACT SEP sensor suite consists of four sensors – LET, HET, SEPT and SIT. Four microprocessors are dedicated to controlling, interfacing, and acquiring data from these sensors. This document defines the requirements for the flight software that will reside in the LET and SEP Central microprocessors. A separate document defines the requirements for the flight software that will reside in the HET and SIT microprocessors.

SEP flight software will be developed at the Caltech Space Radiation Laboratory (SRL) and at the Laboratory for High Energy Astrophysics at GSFC. Caltech SRL will do the Software development for LET and SEP Central, and GSFC will do the development for HET and SIT. Previously, the Caltech group developed the flight software for the SIS and CRIS instruments on ACE, and for several balloon instruments. The GSFC group developed the flight software for the EPACT instrument suite on WIND.

1.1. *Document Conventions*

In this document, **TBD** (To Be Determined) means that no information currently exists. **TBR** (To Be Resolved) means that a statement is preliminary. In either case, the initials of the institutions/persons responsible for providing the information typically follow the acronym.

1.2. *Applicable Documents*

Some of these documents and drawings can be found on the Berkeley STEREO/IMPACT website: <http://sprg.ssl.berkeley.edu/impact/dwc/>
Others are currently available from Caltech SRL.

1. Phase A Report/PAIP (Performance Assurance Implementation Plan)
2. IMPACT Performance Specification
3. SEPT Operation Control and Data Processing requirements
4. LET and SEP Central Software Development Plan (STEREO-CIT-001.J)
5. P24 MISC processor manual (STEREO-CIT-005.A)
6. IMPACT Intra-Instrument Interface ICD
7. SEP Sensor Suite ICDs (STEREO-CIT-008.A, -009.A, -010.A, -011.A)
8. P24 MISC G-buss I/O Interface (**TBD-WRC**)
9. IMPACT/Spacecraft ICD
10. LET Science Data Frame Format Specification (STEREO-CIT-003.5-0)
11. SEP Commanding and Users Manual (STEREO-CIT-007.B)
12. IMPACT IDPU Software Requirements Document
13. SEPT FPGA Data Sheet
14. LET Functional Test Plan (STEREO-CIT-006.A)

1.3. *Acronyms*

ACE	Advanced Composition Explorer
ADC	Analog to Digital Converter
API	Application Programming Interface
APID	Application Process Identifier
ASIC	Application Specific Integrated Circuit
CCSDS	Consultative Committee for Space Data Systems
DPU	Data Processing Unit
EEPROM	Electrically Erasable Programmable Read Only Memory
FIFO	First In First Out
FPGA	Field Programmable Gate Array
HET	High Energy Telescope
HiZ	Particles with charge > 2
ICD	Interface Control Document
ID	Identity
IMPACT	In situ Measurements of Particles and CME Transients
LET	Low Energy Telescope
MISC	Minimal Instruction Set Computer
PDFE	Particle Detector Front End
RAM	Random Access Memory
SEP	Solar Energetic Particles
SIT	Suprathermal Ion Telescope
SEPT	Solar Electron Proton Telescope
SRAM	Static Random Access Memory
SRL	Space Radiation Laboratory

2. Host System

This section briefly describes the environment in which the software will function. More details about the host system and interfaces can be found in references 4 and 5.

The LET, HET, and SIT sensors each require a dedicated microprocessor for onboard data processing. The microprocessor used for LET and SEP Central will be the P24 MISC (Minimal Instruction Set Computer). The P24 MISC has a 24-bit CPU core with dual stack architecture intended to efficiently execute Forth-like instructions. The processor design is simple to allow implementation within field programmable gate arrays. For the LET and SEP Central applications, the MISC is implemented in the ACTEL 54SX72A FPGA. For LET, the MISC will be clocked at 8 MHz or less. See reference 5 for more details.

There will be two serial interfaces between the SEP sensors and the SEP Central MISC. The first interface will be bi-directional, for transferring boot-code, commands, and command responses. The second interface will be uni-directional, for transferring data from the instruments to the SEP Central MISC. The protocol for using these interfaces is defined in Reference 7. Details of memory, I/O, operating system, and other interfaces can be found in References 5 and 7.

Processed data from the microprocessors associated with the LET, HET, and SIT will be gathered by the SEP Central MISC, and formatted for transmission to the IMPACT DPU (per Reference 6 ICD). The two SEPT telescopes do not have a dedicated microprocessor, and data from SEPT will be gathered directly by the SEP Central MISC. Some compression of SEPT data will occur in the SEP Central MISC before the data are formatted and transmitted to the IMPACT DPU. Figure 2.1 shows a block diagram of the SEP Sensor Suite.

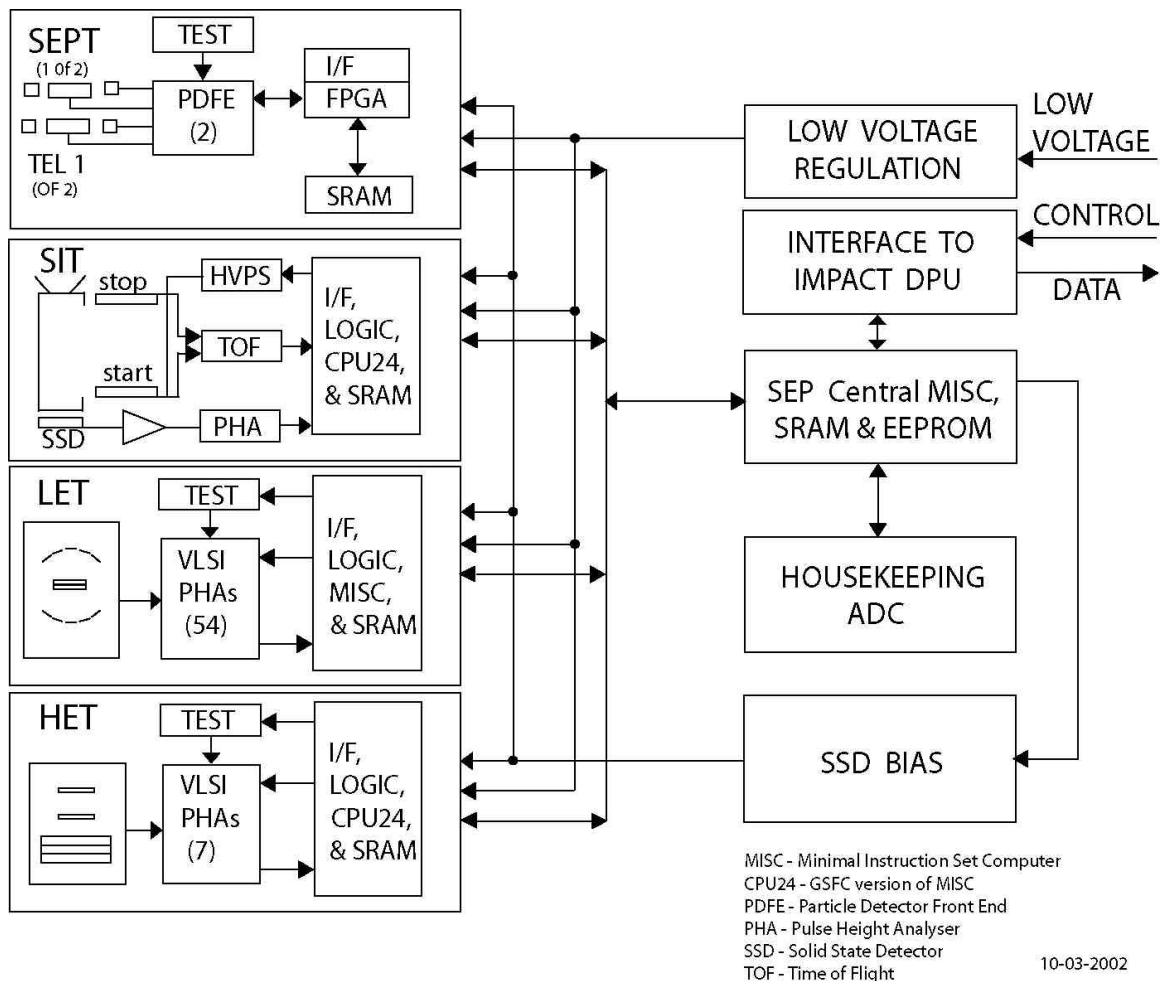


Figure 2.1: SEP Sensor Suite Block Diagram

3. Software Requirements

3.1. Overview

The Caltech Space Radiation Lab will develop two software packages for STEREO IMPACT:

1. SEP Central Software
2. LET Software

The SEP Central software package consists of the software routines unique to the SEP Central MISC, including the software dedicated to onboard processing of SEPT data. The LET software package consists of the software routines running on the LET MISC. In addition to the two software packages above, Caltech SRL will also provide and maintain a version of the Forth operating system for the LET and SEP Central MISCs that implements all standard Forth words necessary to implement flight software for LET and SEP Central. This Forth system will allow for the use of assembly-language subroutines where necessary for performance considerations. Associated with this Forth system, Caltech will provide an API that will enable access to the MISC hardware I/O interfaces. A round-robin software multi-tasking environment for the MISC will also be provided. All these items (the Forth operating system for the MISC, the I/O API, and the multitasking software) have been developed at Caltech for other missions and projects as well as STEREO. Therefore these items are not described in detail in this document.

3.2. *LET Software Requirements*

3.2.1. LET Power-On Initialization

In flight configuration, the LET MISC will boot via the bi-directional serial link from the SEP Central MISC. Thus, only the SEP Central MISC will need EEPROM during flight.

The LET MISC boot process will occur in multiple stages. First the Forth operating system will be transferred over the serial link and loaded. Once Forth is running on the LET MISC, loading of the LET flight software from the SEP Central MISC to the LET MISC will proceed. Protocols governing this process will be described in references 7 and 11. After the boot process, the LET MISC will configure the LET front-end electronics into a default state. The default state will be defined in tables loaded into SRAM during the boot process.

3.2.2. On-Orbit RAM Patches

The LET software will include the capability to implement software RAM patches uploaded by command during the mission.

3.2.3. Science Data Acquisition

The LET software will be responsible for acquiring science data from the LET front-end electronics. Event control logic on the ACTEL 54SX72 FPGA will interrupt the MISC

processor when event data is ready to be read into memory. Figure 3.1 illustrates the data flow logic.

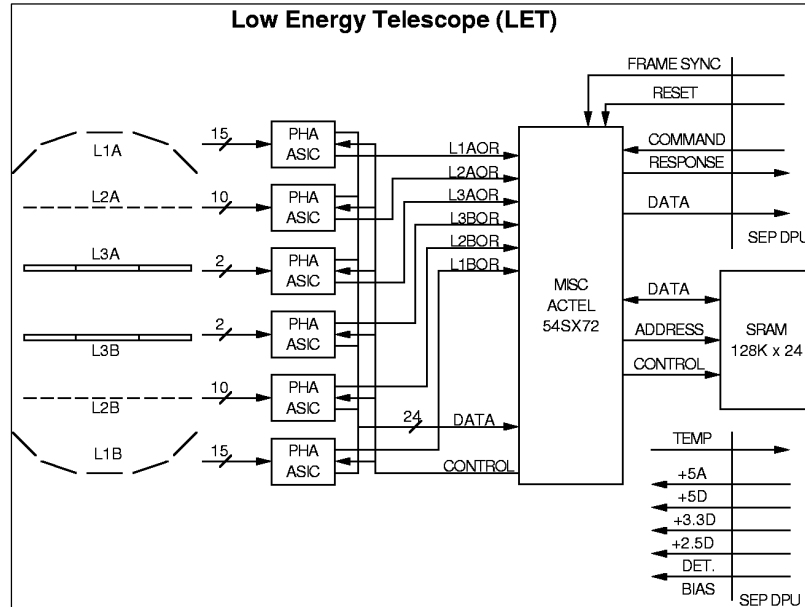


Figure 3.1: LET Logic/Data Flow

3.2.4. Science Data Processing

The telemetry bandwidth allocated to LET is adequate to telemeter only a fraction of the events recorded by the sensor. Although ~5 events will be telemetered per second, the LET software will process most events onboard. The objective of the onboard event processing will be to analyze the data gathered during each event and assign a species and energy to the particle that generated the event. For certain classes of events, look-direction information will also be assigned.

For each event acquired by the LET sensor, the onboard software will perform the following operations:

1. Sort the event into one of several streams: L1L2, L1L2L3, Penetrating, ADC cal and Invalid events. Invalid events are defined as those events not suitable for onboard processing. The sort criteria will be changeable by command. An example of an invalid event might be one for which the particle trajectory results in an ambiguity in deciding whether the particle is stopping or penetrating.
2. For valid events, determine the species and energy of the particle by mapping the event data into a 2-dimensional detector response matrix. Increment a matrix rate counter associated with the species and energy-range determined.
3. For selected classes of good events (class determined in step 2 above), determine look-direction and increment the appropriate look-direction counter.
4. Perform higher-resolution species identification for selected classes of events, e.g. to obtain isotope identification for helium events.
5. Select events for telemetry from both good and bad events based upon a priority scheme. The priority scheme will be changeable by command.

Implementation details of data-flow through the LET MISC and onboard processing algorithms are given in Appendix 1 of this document.

The LET science data accumulation cycle will be one minute in length. Each minute, the LET MISC will transfer the accumulated science data to SEP Central, per the protocols described in reference 7 and section 3.3.2 of this document. Format of the LET science data is described in section 3.2.6 below and reference 10.

3.2.5. Housekeeping and Status Data Acquisition

The LET MISC will be responsible for gathering LET housekeeping data (voltages, currents, temperatures, etc.) that are not more appropriately gathered by the SEP Central MISC. LET housekeeping data shall include the contents of key command, status and configuration tables maintained in RAM.

LET housekeeping data will be forwarded to the SEP Central MISC via the uni-directional data serial interface and combined with housekeeping data from the other SEP sensors, per protocol in reference 7 (LET-SEP_Central ICD).

3.2.6. Beacon Data Processing

LET beacon data are a subset of LET science data that will be used for real-time space weather operations. LET will generate a beacon data packet once per minute and transfer the packet to SEP Central, per the protocols described in reference 7 and section 3.3.3 of this document. The table below summarizes the species and energy ranges currently defined for inclusion in the LET beacon data.

<u>Species</u>	<u>(MeV or MeV/nuc)</u>		<u>Geom. Factor (cm²sr)</u>	<u>Number of Directions</u>	<u>bps</u>
	<u>E1</u>	<u>E2</u>			
Protons	1.4	3	2.25	2	0.53
	3	6	4.5	1	0.27
Helium	1.7	3	2.25	2	0.53
	3	6	4.5	1	0.27
	6	13	2.25	2	0.53
3He	1.7	3.3	4.5	1	0.27
	3.3	13	4.5	1	0.27
CNO	3	6	4.5	1	0.27
	6	13	4.5	1	0.27
	13	30	4.5	1	0.27
Fe	3	6	4.5	1	0.27
	6	13	4.5	1	0.27
	13	30	4.5	1	0.27
	30	50	4.5	1	0.27
Livetime					0.27
H/He-Effic					0.27
Z-Effic					0.27
L1A-th					0.27
L1B-th					0.27
L2L3th					0.27
Sum LET					6.13

3.2.7. Data Formatting

LET science data formatting is described in detail in reference 10.

The LET MISC will format LET science data (rates and events) into LET science frames, and transmit the frames to the SEP Central MISC via the uni-directional data serial interface. Each LET science frame will contain matrix rates and sampled raw events accumulated over one minute, along with **TBR LET team** status information.

The length of a LET science frame will be such that the data will fit exactly into 16 272-byte CCSDS packets (see reference 6). Each of these packets includes an 11-byte header that does not count towards the LET bit rate allocation.

The protocol for transfer of CCSDS packets from LET to SEP Central is described briefly in section 3.3.3 of this document, and in detail in reference 7.

3.2.8. Command Processing

LET will receive commands via the bi-directional command serial link to the SEP Central MISC. Command responses from LET will be sent via the bi-directional command serial interface to the SEP Central MISC, where they will be formatted for telemetry. Flags in the LET science frames will indicate error conditions.

3.2.9. Dynamic Detector Threshold adjustment during High-Rate Periods

During very high-rate periods (e.g., peak of Bastille Day 2000 event) the single-detector count rates, especially on the front detectors, can exceed $10^5/\text{sec}$, mostly due to out-of-geometry, wide-angle protons. LET is designed to provide measurements of both composition and energy spectra during these high-rate periods. Collimation and segmentation of the L1 detectors and shielding of the L2 and L3 detectors provide some protection, but the sensor will also respond dynamically to high rates by disabling the high-gain PHA response on a fraction of the L1, L2, and L3 detectors, such that these detectors will trigger only on heavy ions and not on the much more abundant H and He ions. The geometry factor for protons and helium will therefore be reduced, while the geometry factor for the more rare heavy ions will be preserved (heavy ions deposit more energy in the detectors, thus triggering the low-gain PHA chain).

The high-gain response will be disabled in steps, depending on the “OR” of count rates from detectors that are not adjusted (L1A3, L1B3, L2A5, L2A6, L2B5, L2B6, L3Ai, L3Bi), as follows:

1. All L1 outer segments (reduces H, He geometry by x5 and singles by x5).
2. All L2 detectors except L2A5, L2A6, L2B5, and L2B6. Also L3A outer, L3B outer (reduces H, He geometry by additional $\sim x5$ factor)
3. All L1 inner bulls-eye segments except L1A3, L1B3 (reduces H, He geometry & singles by additional $\sim x5$ factor).

Details of the implementation will depend on simulations based on Wind/ACE events and laboratory testing. Hysteresis and suitable time averaging will each play roles in the algorithm. The implementation of the algorithm will adhere to the following requirements:

- Parameters will be modifiable by ground command. In particular, the count rate trigger for re-enabling high-gain response shall be modifiable separately from the count rate trigger for disabling the response. The averaging periods for determining these count rates shall also be modifiable.
- It will be possible to turn off dynamic thresholding via ground command.
- Changes will occur on sensible time boundaries (e.g. on 1-minute LET science frame boundaries).

The dynamic threshold function will be tested on the bench before flight using pulsers and radioactive sources, and will also be tested during accelerator tests. The first version of the algorithm will be written and tested during LET software build 2 (ending 4/2003), and the final version will be written and tested during LET software build 3 (ending 9/2003).

3.2.10. **Periodic Functional Tests**

The LET software shall perform periodic in-flight functional tests of the LET electronics, as detailed in reference 14.

3.3. ***SEP Central MISC and SEPT Software Requirements***

3.3.1. **SEP Central Power-On Initialization**

The SEP Central MISC will boot via EEPROM. The Forth operating system and the flight software will both be loaded from EEPROM into SRAM and executed automatically.

Each of the SEP sensors will reboot or power-on whenever SEP Central reboots or powers-on. The LET, HET, and SIT processors will boot via the command serial link from SEP Central. Therefore, immediately after booting, the SEP Central MISC will begin the process of transferring boot code from EEPROM to each of the SEP sensors. The protocol for performing this transfer is described in references 7 and 11.

3.3.2. **On-Orbit RAM Patches and EEPROM reloads**

The SEP Central software will include the capability to implement software RAM patches uploaded by command during the mission. The SEP Central software will also include the capability to write program uploads to EEPROM during the mission.

3.3.3. **Science Data Acquisition**

The SEP Central MISC will acquire data from each of the SEP sensors via the uni-directional serial data link. The protocols for data transfer will be the same for LET, HET and SIT. These protocols are described in detail in reference 7. A brief description is given below. Since SEPT does not have its own processor, the data transfer protocol will be different for SEPT (see references 3 and 13).

Science data will be transferred from LET, HET, and SIT to SEP Central in CCSDS packets. The only part of the packet that will be filled-in by SEP Central is the UT time-

stamp in the header. Otherwise the science packets will be just passed on by SEP Central to the IMPACT IDPU.

Packet transfers from LET, HET, and SIT to SEP Central will be orchestrated by a once per second pulse (frame sync) generated by SEP Central. A double pulse will mark the beginning of a 1-minute interval. The sensors will use timers and interrupts tied to these frame syncs to schedule events. SEP Central will ensure that the 1-minute double-pulse marker is synced to UT minute intervals.

Frame sync pulses will be 1ms wide positive pulses, with 1 second period, with every 60th pulse followed, after a 1ms delay, by an extra 1ms wide pulse (the minute marker). The basic sensor data accumulation interval will be 1 minute, starting at the first frame sync following the minute-mark. Sensors will transmit their data to SEP Central during a 200ms window following each frame sync.

HET will send data packets following frame syncs 0, 3,..., 57

SIT will send data packets following frame syncs 1, 4, ..., 58

LET will send data packets following frame syncs 2, 5, ..., 59

Data acquisition from the two SEPT telescopes (electronic units) will be managed directly by SEP Central, per reference 3.

A sensor must send at least one packet during each window (for diagnostic testing purposes). More than one packet may be sent in the same window, but packets should be spread out roughly evenly over the 60-second cycle. Since LET, HET, and SIT are each allocated 20 windows per minute (more than they need), some packets will be zero-filled.

Data packets collected from the sensors during minute (N+1) by SEP Central will contain data collected during the prior minute (N) and will be transmitted to the IMPACT DPU during minute (N+2). SEP Central will fill in the UT portion of all packets received during minute (N) with the UT code associated with tic0 of minute (N-1). (i.e. the UT code of a packet will refer to the beginning of the minute during which it's data was accumulated.)

SEP sensors are free to define several different packet types if they wish. Packet types will be distinguished by packet APID codes. These APID codes are assigned to the SEP team by the Project. They are documented in references 7 and 11.

3.3.4. SEP Common Housekeeping and Status Data Acquisition

SEP Central will be responsible for acquiring SEP housekeeping data (voltages, currents, temperatures, etc.) that are not more sensibly acquired by the SEP sensors. SEP Central will combine these data with the housekeeping data received from the SEP sensors, and format the combined housekeeping data into a common SEP housekeeping data block for transfer to the IDPU.

3.3.5. Beacon Data and Sensor-specific Housekeeping Data Acquisition

Beacon and housekeeping data messages will be generated once per minute by the LET, HET and SIT sensors. These messages will be identified when received by SEP Central

via the uni-directional serial data link. They will be combined with SEPT beacon and housekeeping data into common SEP beacon and housekeeping data blocks. The SEP Central software shall ensure that SEPT, LET, HET and SIT beacon data are synchronized (not out-of step by 1 minute, for example).

The format of LET, HET, and SIT sensor beacon and housekeeping data messages is described in the SEP sensor-suite ICDs (reference 7 for LET), and reference 11.

3.3.6. SEPT Data Processing

The SEPT units (SEPT-NS and SEPT-E) produce science and housekeeping data, which need to be acquired and compressed by SEP Central before transmittal to the IMPACT IDPU. Details of the interface protocol between SEPT and SEP for command and telemetry can be found in references 3 and 13.

3.3.6.1 SEPT Data Acquisition

The SEPT FPGA control logic will be responsible for acquiring data from the SEPT Particle Detector Front End (PDFE) electronics. It provides particle event data collection, filtering and binning for science data acquisition. It provides ADC results of analogue channels and counting results of single detector channels for housekeeping data acquisition. The science and housekeeping data will be accumulated over one minute. SEP Central will acquire the science and housekeeping data from each of the SEPT units per the protocols described in reference 3.

3.3.6.2 SEPT Housekeeping and Status Data

To evaluate the detector health in SEPT-E and SEPT-NS, a total of 16 singles rate counters (8 center disks, 8 guard rings), 8 bias leakage currents, 2 temperatures and 80 status bits are monitored. These items shall be incorporated into the SEPT science packet and/or the SEP housekeeping message once per minute, per reference 3. In addition, SEPT lookup tables stored in SEP Central RAM shall be telemetered as part of the regular SEPT science packet.

3.3.6.3 SEPT Science Data Processing

The science data from the two telescopes SEPT-E and SEPT-NS are comprised of a total of eight histograms with 32 bins each. Four electron histograms cover the electron energy range from 20 keV to 400 keV with quasi-logarithmic binning in four directions, four proton histograms cover the proton energy range from 20 keV to 7 MeV with quasi-logarithmic binning, also in four directions.

Each histogram bin is implemented as a counter of 24 bit depth. The counter will not wrap around but will stop counting upon reaching FF FF FF (hex). In order to reduce the required bit rate, each counter shall be logarithmically compressed by SEP Central from 24 bits to 12 bits. The eight histograms constitute – after compression – the basic contents of the SEPT science packet.

The resulting SEPT science packet is summarized in the following table. The required telemetry bitrate is 58.9 bits/sec.

Data Item	Number of Channels	Bits per Channel	Total Number of Bits	Time Resolution
Histogram	8 x 32	12	3072	60 s
Singles Rates	2 (multiplexed)	23	46	60 s
Singles address	2	3	6	
Leakage Current	16	8	128	60 s
Temperature	2	8	16	60 s
Lookup Tables			184	60 s
Status	2	40	80	60 s
Total			3532	

3.3.6.4 SEPT Beacon Data Processing

SEPT provides four electron and four proton channels for continuous transmission of beacon mode data to the ground station with a time resolution of one minute. Each channel is a summation of several histogram channels.

<u>Species</u>	<u>(MeV or MeV/nuc)</u>		<u>Geom. Factor</u> <u>(cm²sr)</u>	<u>Number of</u> <u>Directions</u>	<u>bps</u>
	<u>E1</u>	<u>E2</u>			
Electrons	0.02	0.05	0.2	4 separate	1.07
	0.05	0.1	0.8	4 summed	0.27
	0.1	0.2	0.8	4 summed	0.27
	0.2	0.4	0.2	4 separate	1.07
Ions (mostly protons)	0.02	0.1	0.24	4 separate	1.07
	0.1	0.5	0.96	4 summed	0.27
	0.5	2.5	0.96	4 summed	0.27
	2.5	7	0.24	4 separate	1.07
SEPT Status (1 bit/channel; 20 channels + 12 spare)					0.53
Sum SEPT					5.87

SEP Central shall perform the summation according to the following data processing steps:

- Use eight uncompressed histograms as input. Sum up all four view-directions for the two middle energy-bands for electrons and protons, but preserve the look-direction information for the lowest and highest energies. Use 32 bit integers for summation. Set warning flag for overflow if one of input bins is FF FF FF (hex), 1 flag for protons, 1 flag for electrons. Set warning flag if SEPT status is not nominal.
- Sum up several bins (typically ten) of the electron histogram to form 4 electron channels, sum up several bins (typically ten) of the proton histogram to form 4 proton channels.
- Optional: compress the six channels using a suitable compression scheme (e.g. 32 bit to 16 bit).
- Incorporate rates and flags in beacon packet.

3.3.7. Data Formatting

SEP Central will be responsible for transferring SEP science, housekeeping, beacon and command response packets to the IMPACT IDPU per the protocol described in Reference 6, and references therein.

3.3.8. Command Processing

Commands destined for SEP will be formatted on the ground as variable-length CCSDS command packets. In flight, the IMPACT IDPU will pass these packets on to SEP Central as described in reference 6. The IMPACT IDPU will strip off the CCSDS header portion of these packets before passing them to SEP Central. SEP Central will pass on commands destined for LET, HET, or SIT via the bi-directional SEP serial command link. SEP Central will monitor the serial command link for command responses from the SEP sensors. SEP Central will incorporate these responses into 272-byte CCSDS SEP command response packets and transmit them to the IMPACT DPU. The format of these command response packets will be described in reference 11 (**TBD Caltech**).

Although command response messages do not count towards the SEP telemetry allocation, Section 8 of the IMPACT Intra-instrument Interface ICD (reference 6) specifies that SEP may not exceed its telemetry allocation by more than two CCSDS packets over any 1-minute interval. Therefore SEP Central must ensure that no more than two command response packets are transmitted to the IDPU each minute. SEP Central will achieve this by buffering command responses into a software FIFO. Software running in SEP Central will inspect this buffer at regular intervals and will construct command response packets from the contents at a rate of no more than two packets per minute. Thus, more than one command response may be packed into the same command response packet. The software will attempt to minimize latency for short command responses, while the command response FIFO will be sized to accommodate the largest command response generated by the SEP sensors.

3.3.9. Timing

The SEP Central MISC will receive time information from the IMPACT DPU. The IMPACT DPU will send two different kinds of time messages: UT time, and a sample clock. The format and delivery frequency of these messages are described in reference 6. The SEP Central MISC will use these time messages to control the frame-syncs and minute-markers distributed to the SEP sensors, and to fill in the UT time tag in all CCSDS packets forwarded to the IMPACT DPU.

3.4. Common Software Requirements

3.4.1. Safing

Safing refers to any autonomous function the system requires to put the sensor in a safe mode in the event of an off-nominal condition. No autonomous safing is needed for LET or SEP.

3.4.2. Reliability

The software must be robust in handling errors or failures. It is not expected that automatic onboard correction of error conditions will be implemented, but whenever possible (consistent with instrument safety) the system should remain in an operational state following an error. Error conditions will be flagged in the science telemetry and corrective action will be initiated from the ground.

The software will maintain a command table containing all variable settings (thresholds, gains, modes, etc. (**TBR-LET**)). This table will be used to refresh the settings periodically. Checksums will be calculated periodically on this table, and the other lookup tables. If a checksum changes, that fact will be reported in the science telemetry, and automatic refresh of the hardware command registers will halt.

The hardware watchdog timer shall be reset in the periodic timer interrupt handler. That module in turn shall keep track of the status of all other modules using a software watchdog scheme (**TBR-WRC**).

On reset the system shall start up automatically and begin operating in a default mode.

3.5. System Resource Requirements

Tables 1 and 2 list estimated microprocessor and RAM resource requirements for LET and SEP Central, extracted from software requirements and based on previous experience and analysis. The estimates assume a MISC running at 8 MHz in both cases.

Table 1: LET System Resource Requirements

Task	Processor Cycles, %	Code Size, kwords*	Buffer Memory, kwords*
Operating System	<1%	2	2
Data Acquisition	5%	2	3
Data Processing	35%	8	42
Data Formatting	5%	3	1
Command Processing	1%	2	1
Total	46%	17	49
Available	100%	128kwords	
% Usage	46%	52%	

*Note: for the MISC, one word = 3 bytes

Table 2: SEP Central System Resource Requirements

Task	Processor Cycles, %	Code Size, kwords*	Buffer Memory, kwords*
Operating System	<1%	2	2
Data Acquisition	10%	2	10
SEPT Data Processing	20%	4	4
Data Formatting	5%	3	1
Beacon Data Processing	5%	2	1

Command Processing	1%	2	1
Total	40%	15	19
Available	100%	128kwords	
% Usage	40%	27%	

*Note: for the MISC, one word = 3 bytes

Each MISC can accommodate up to 256kwords of EEPROM. In addition, the large matrix lookup tables can be compressed by a factor of three before they are written to EEPROM, so EEPROM requirements are not as large as RAM requirements. With 256 kwords of EEPROM in SEP Central, and given that LET, HET, and SIT will all boot via the serial link, we estimate a 50% EEPROM margin for the SEP sensor suite. If GSFC decides to implement EEPROMs for HET and SIT, the margin will be higher.

4. Appendix 1: LET Onboard Data Processing Details

The material in this appendix is provided to give context to the LET onboard software requirements. It is not intended to be a complete description of the LET onboard processing software. Some or all of this material may be moved to another document.

4.1. *Matrix rate Data Processing*

Figure 4.1, illustrates the flow of event data through the LET MISC software. When the MISC receives an event interrupt, an interrupt service routine will read the pulse-height data from the LET ASICs into a software FIFO. A fast-sort software routine will read events from this FIFO and sort them into several streams.:

- L1L2 events – stop in one of the L2 detectors
- L1L2L3 events – stop in one of the L3 detectors
- Pen events – penetrating events
- Invalid events

The sort criteria will include the number of hit detector elements, the IDs of the hit detectors, and possibly a preliminary analysis of the raw pulse-height-data. These criteria will be changeable via ground command. Invalid events are defined as those events not suitable for onboard processing. An example of an invalid event might be one for which the particle trajectory results in an ambiguity in deciding whether the particle is stopping or penetrating.

Valid events will be passed on to event processing routines. The sort criteria will be changeable by command.

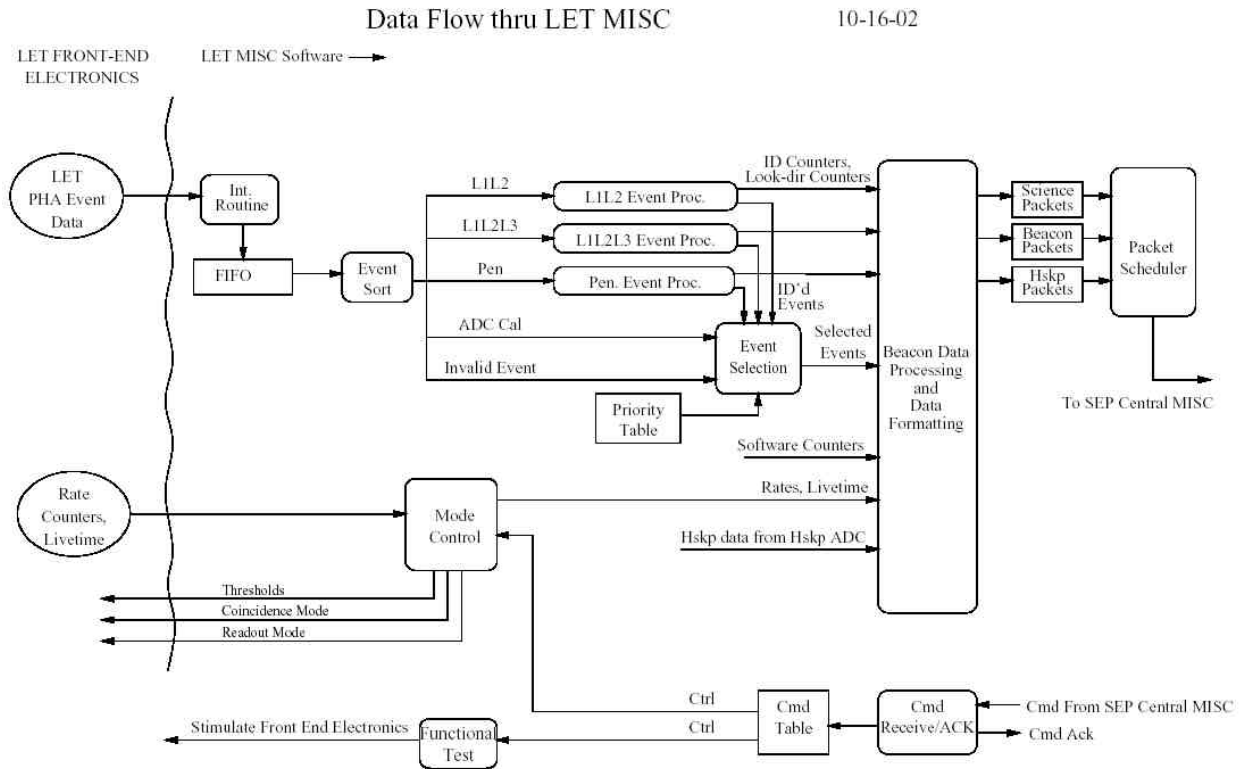
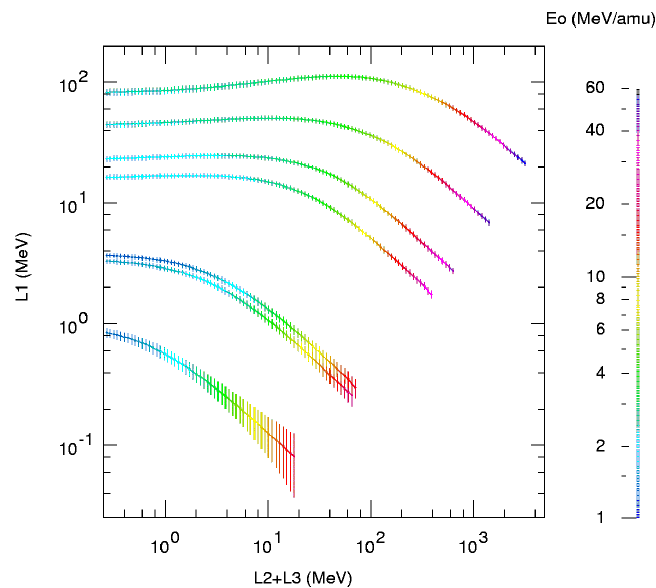


Figure 4.1: Data Flow through LET MISC

Figure 4.2: a scatter-plot of ∂E vs. E'

For each event processed onboard, species and energy will be determined by mapping the event data into a 2-dimensional detector response matrix. The detector response matrix can be thought of as a ∂E vs. E' matrix, where ∂E is the energy lost in the L1 detector, and E' is the energy lost by stopping particles in L2 + L3 (see figure 4.2). In a scatter-

plot of ∂E vs. E' , events fall on different tracks for different species. The energy of the particle determines the position on the track.

The dimensions of the detector response matrix for good events will be $\sim 128 \times 128$, and the L1 and L2+L3 signals will be logarithmically mapped into this matrix. Each cell of the matrix will contain the address of a particle ID counter. There will be a total of ~ 200 particle ID counters, each corresponding to a particular species and energy range. For example, one of the counters might count oxygen nuclei in the energy range 20-25 MeV/nucleon. Note that many cells of the response matrix will be associated with the same counter – the large number of response matrix cells relative to ID counters allows for flexibility in the assignment of a region of the response matrix to a particle ID. We will call a group of cells that all point to the same ID counter a “matrix rate box”. Tables loaded during the boot process will determine the mapping of matrix cells into particle ID counters. The mapping will be adjustable via command uploads. The ~ 200 particle ID counters will be read out every minute, and these data will be incorporated into the LET science data stream and telemetered to the ground.

Figure 4.3 illustrates the algorithm for basic matrix rate processing performed on all good events.

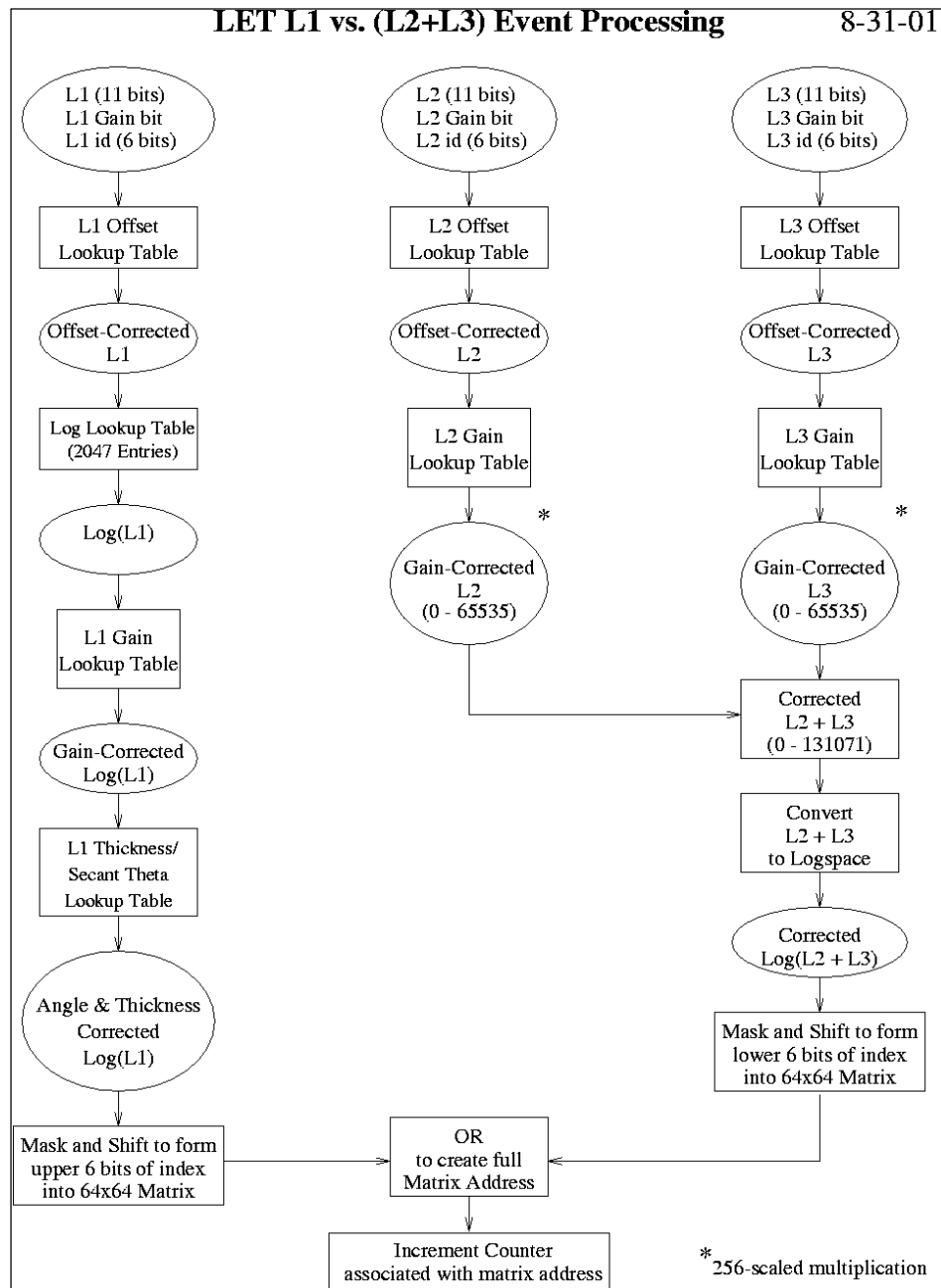


Figure 4.3: LET Basic Matrix Event Processing Algorithm

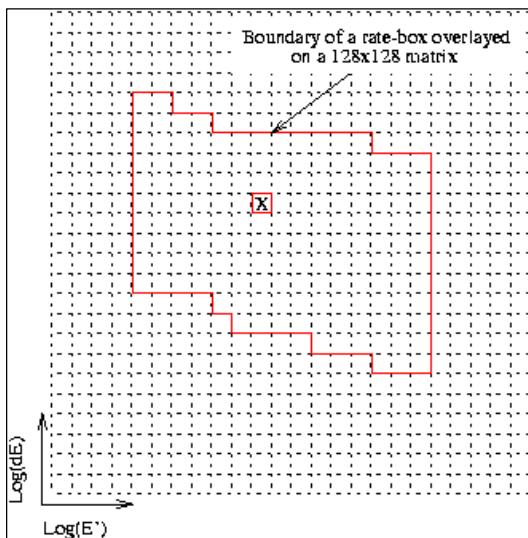
4.2. Look-direction Processing

Look-direction information will be preserved automatically for each event that is telemetered to the ground from LET. However, it will also be necessary to record some look-direction information from events that are processed onboard but not telemetered.

The following general requirements apply:

- Look-direction data will not consume more than ~5% of the LET telemetry allocation.
- Look-direction data is only required for certain ranges of species and energy covered by the LET matrix rate boxes., i.e. we will want to record look-direction data from sets of rate boxes. For instance, we might define a set of C, N, and O rate boxes and record look-direction data for that set.
- Eight forward look-directions and eight rear look-directions are required, for a total of 16 look-directions. Given this, and the requirement to keep the amount of telemetry used below 5%, we can define up to 10 16-element arrays of look-direction counters. If we telemeter them once per minute, they will occupy 4% of the LET telemetry allocation.
- The definition of matrix rate box subsets for look-direction purposes will be commandable.

For each event, the look-direction will be defined by combining the L1 and L2 detector IDs and consulting a lookup table. The lookup table will map the 300 possible detector combinations (150 front and 150 rear) into 16 look-directions.



During normal onboard processing, a LET pulse-height event will be mapped into a cell “X” in a 2-dimensional matrix. A portion of this matrix is illustrated in the figure on the left. In the figure, the boundary of a rate box is shown. The borders of the rate box define a certain species and energy range. Cell X contains the address “addr” of a counter. All the cells within this rate box contain the same address (they point to the same counter). The event is recorded by incrementing the counter pointed to by addr.

In order to accommodate the recording of look-direction information, the following algorithm will be used:

The contents of memory location $\text{addr}+1$ shall contain either

Zero, in which case no look-direction data will be recorded for events falling in this rate box,

or

The base address of a 16-element array of look-direction counters.

During onboard processing, after the rate box counter has been incremented, the contents of the next memory location after the counter will be examined. If the contents are a valid address, the appropriate element of the look-direction array pointed to by the address will be incremented.

Note that any number of rate boxes can be associated with a single array of look-direction counters. In this way, groups of rate boxes can be grouped together for look-direction purposes.

The LET onboard software will allow for the association of rate boxes with look-direction arrays to be changed via commands from the ground.