

1 The Solar Electron and Proton Telescope (SEPT)

1.1 System Description

A knowledge of the three-dimensional distribution of energetic electrons and protons is essential for characterizing the dynamic behaviour of CME associated and solar flare associated events. The Solar Electron and Proton Telescope (SEPT) consists of two dual double-ended magnet/foil particle telescopes which cleanly separate and measure electrons in the energy range from 20 - 400 keV and protons from 20 - 7000 keV and provide anisotropy information.

1.2 Approach

1.2.1 The Detector System

Each double-ended telescope has two solid state detectors (SSDs) of the Passivated Ion-implanted Planar Silicon (PIPS) type. Each SSD is 300 micrometer thick and 0.53 cm^2 in area, and closely stacked with its partner at 600 micrometer separation. Each SSD is surrounded by an active guard ring on the same Si wafer. To achieve low background, the output of each SSD is operated in anti-coincidence with its partner and its guard ring to reject penetrating particles. One SSD looks through a parylene foil and its partner through the air gap of a magnet system. The foil leaves the electron spectrum essentially unchanged but stops protons of energy up to the energy of electrons ($\sim 400 \text{ keV}$) which penetrate the SSD. The rare earth permanent magnet (NdFeB) is designed to sweep away electrons below 400 keV, but leaves ions unaffected. In the absence of $> 400 \text{ keV}$ ions, the foil SSD only detects electrons, and the magnet SSD only detects ions. Ions from 400 keV to 7 MeV will stop in the magnet SSD and their fluxes will be cleanly measured. The contribution of $> 400 \text{ keV}$ ions to the foil SSD can then be computed and subtracted to obtain the electron fluxes. The SEPT sensor schematics is shown in *Abbildung 1*. Some SEPT sensor characteristics are given in *Tabelle 1*.

As the spacecraft is not spinning, special efforts are made to acquire anisotropy information in four look directions: SEPT-E observes in the ecliptic plane along the nominal Parker spiral magnetic field direction both forward and backward, SEPT-N/S observes out of the ecliptic plane perpendicular to the magnetic field both North and South. Thus, SEPT partially complements the viewing directions for ions of the Low Energy Telescope (LET) whose multiple look directions are all in the ecliptic. To warrant unobstructed field of views, the full angle of the viewing cones is limited to 60 degrees and the boresight viewing directions are relaxed by 9 degrees in the ecliptic plane and 5 degrees out of the ecliptic plane. For the same reason, the telescopes are not collocated: while SEPT-E is mounted together with SIT, LET and HET, SEPT-N/S is mounted remotely on its own mounting bracket. This has consequences on the electronics design as sensitive analog signals should not be routed over longer distances. The geometric factor for each of the four magnet telescopes is $0.24 \text{ cm}^2 \text{ sr}$ and for each of the four foil telescopes $0.20 \text{ cm}^2 \text{ sr}$.

Tabelle 1: SEPT Sensor Characteristics

Channel	Species	Geometric Factor	View Cone	Boresight	Accum. time
D1 D2 G1 G2	electrons 20 – 400 keV	$\sim 0.2 \text{ cm}^2 \text{ sr}$	60°	ecliptic 315°	60 s
D2 D1 G1 G2	protons 20 – 7000 keV	$0.24 \text{ cm}^2 \text{ sr}$	60°	ecliptic 135°	60 s
D3 D4 G3 G4	protons 20 – 7000 keV	$0.24 \text{ cm}^2 \text{ sr}$	60°	ecliptic 315°	60 s
D4 D3 G3 G4	electrons 20 – 400 keV	$\sim 0.2 \text{ cm}^2 \text{ sr}$	60°	ecliptic 135°	60 s
D5 D6 G5 G6	electrons 20 – 400 keV	$\sim 0.2 \text{ cm}^2 \text{ sr}$	60°	north	60 s
D6 D5 G5 G6	protons 20 – 7000 keV	$0.24 \text{ cm}^2 \text{ sr}$	60°	south	60 s
D7 D8 G7 G8	protons 20 – 7000 keV	$0.24 \text{ cm}^2 \text{ sr}$	60°	north	60 s
D8 D7 G7 G8	electrons 20 – 400 keV	$\sim 0.2 \text{ cm}^2 \text{ sr}$	60°	south	60 s

Abbildung 1: SEPT Sensor Schematics (1 of 2)

1.2.2 The Magnet System

The magnet system consists of four rare-earth permanent magnets of type VACODYM VD745HR which offer highest remanence values and thus energy densities currently available. The excellent magnetic properties of this material group can be traced to the strongly magnetic matrix phase $\text{Nd}_2\text{Fe}_{14}\text{B}$ featuring very high saturation polarization and high magnetic anisotropy. Each two of the four magnets are facing each other leaving an air gap with the necessary magnetic induction to deflect the electrons. Two yokes, made of the iron-cobalt alloy VACOFLEX 50, combine the two sets intensifying the magnetic induction. The long-range field is attenuated by having two oppositely polarized magnetic dipoles at close distance. Thus, the two air gaps provided by the magnet system serve two sensor systems simultaneously with anti-parallel viewing directions at minimum weight penalty.

A number of design options were investigated for the (3a)-1612(w0in)-12. ped f-8.2(e)ou.9(p)-2(a)-12.315.9(o)-12.0015 T

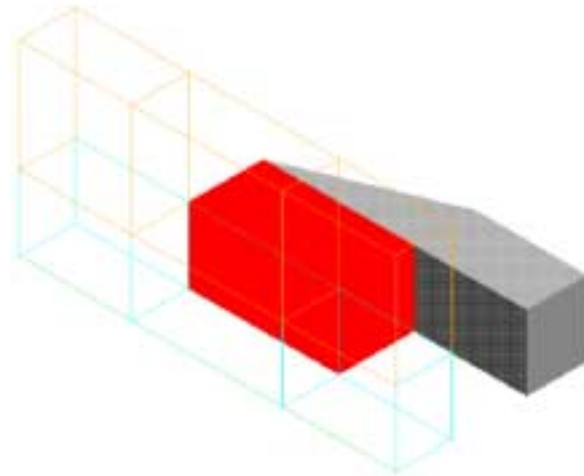


Abbildung 2: Magnet Geometry (x towards upper right, y towards upper left, z towards top of page)

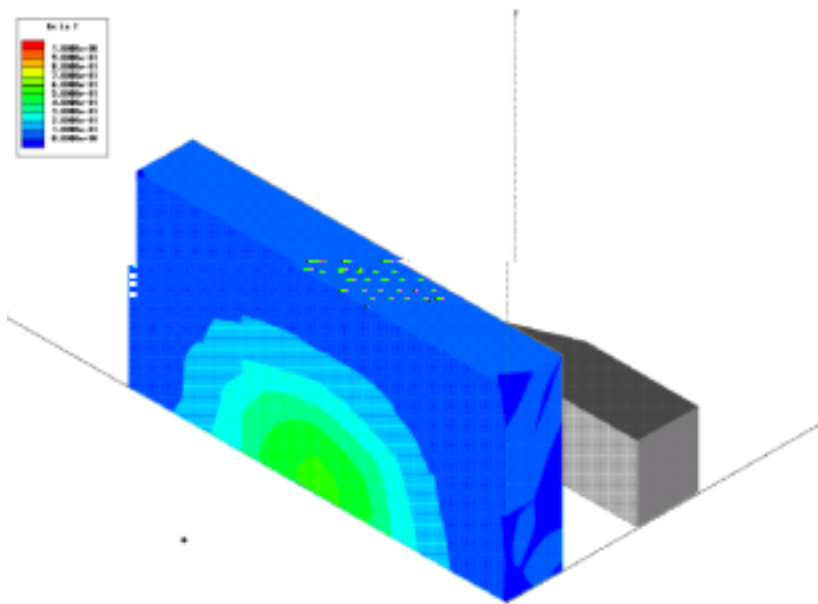


Abbildung 3: Magnetic Field Homogeneity (B_x component, colour coded: 0.1 T (blue), 1.0 T (red))

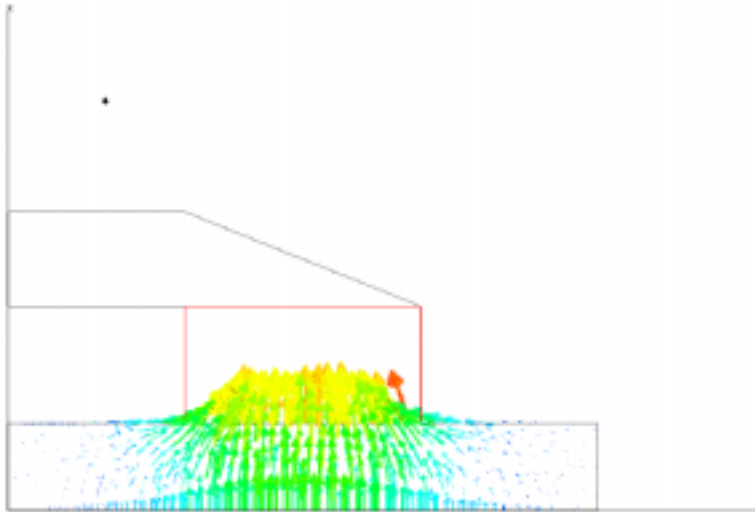


Abbildung 4: Magnetic Field Vector (in x-y plane, x towards top, y towards right of page)

1.2.3 Pointing Accuracy

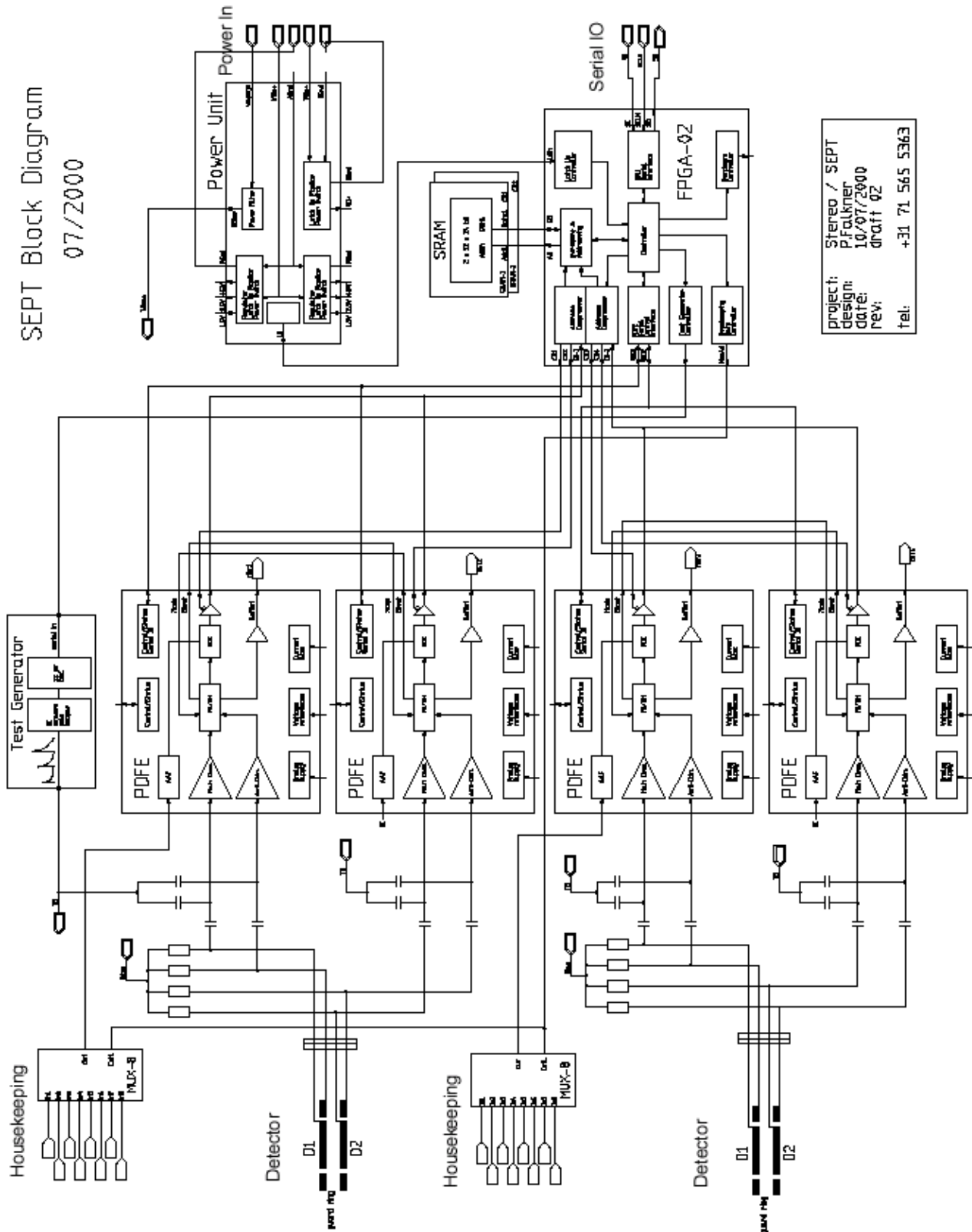
SEPT requires only after the fact knowledge of the pointing direction to an accuracy of $< 2^\circ$.

1.2.4 The Onboard Electronics

Two identical electronics units are mounted close to their respective telescopes. Each electronics unit analyses the signals of four SSDs and four associated guard rings. One Particle Detector Front End (PDFE) integrated circuit is used to analyze the signal from detector D1, using its guard ring in anti-coincidence. A second PDFE is used to analyze the signal from D2 in anti-coincidence with its guard ring. Furthermore, anti-coincidence signals between D1 and D2 ensure that an “exclusive OR” function is performed, i. e. only stopping particles are analyzed. In a special calibration mode, this exclusive OR is inhibited in order to use minimum ionizing particles for on-station calibration. The signals from the detector pairs D3/D4 through D7/D8 are treated in an identical fashion.

Additional 16 housekeeping signals are sampled, digitised, and transferred to the SEP-CPU to monitor SEPT health and status. A specific test pulse generator permits calibration of the instrument in flight and during ground testing. The low-level operation of SEPT electronics is controlled by a specific FPGA. The high level operation of SEPT is controlled by the SEP-CPU by way of commands sent on the serial interface. The same serial interface is used to transfer all scientific, calibration and housekeeping data from SEPT to the SEP-CPU. The block diagram in Abbildung 5 shows in some more detail the front-end electronics for one of the two SEPT telescopes, together with the accumulation logic.

SEPT Block Diagram
07/2000



project: Stereo / SEPT
design: P.Falkner
date: 10/07/2000
rev: draft 02
tel: +31 71 565 5363

Abbildung 5: SEPT Electronics Block Diagram (1 of 2)

1.2.4.1 PDFE

SEPT will use miniaturised electronics based on a Mixed Analogue/Digital Application Specific Integrated Circuit (ASIC) which has been developed for the Space Science Department of ESA by the European Space Agency under its GSTP programme. This circuit contains almost all of the circuitry required to process the signal coming from a solid state detector, and its use will not only enable a considerable amount of weight saving, but will, for a given weight allocation, allow a much more comprehensive measurement to be made. The ASIC is a follow-on from a CMOS Silicon-on-Sapphire Digital ASIC which was developed several years ago by ESA. This ASIC was developed primarily for the Space Science Dept.'s involvement in NASA's WIND 3DP experiment, and was marketed commercially by ABB-HAFO in Sweden. It is also in use in several other experiments on WIND, Polar, and SOHO.

The new ASIC, known as PDFE (Particle Detector Front End) weighs just a few grams, and will replace a circuit board with components weighing 10 - 100 times more. It contains two analog charge amplifying channels. The first channel is the main one, whereas the second channel is used for (anti-) coincidence or gating purposes. The coincidence detection can also be done externally. Eight-bit-programmable discriminators are provided for both channels. A peak detector holds the peak value of the main semi-gaussian pulse. An 8-bit analog to digital converter is implemented on chip to digitise that peak value. It can be cascaded together with more PDFE's to control a multiple detector telescope. The operation of the PDFE is controlled via pins and a serial interface, which permits also uploading of parameters. Several reference voltages and currents are requested to operate the PDFE. A 4 MHz crystal is used to clock the PDFE.

1.2.4.2 FPGA and SRAM

The Field Programmable Gate Array (FPGA) controls operations of the SEPT electronics. It steers the operation of the four PDFEs, reads their conversion results, applies logarithmic binning (selectable) to the data, reads, increments, and stores counter contents kept in the SRAM. It handles the communication interface with the SEP-CPU, i.e. data transmission, command receipt and command interpretation. It controls the test generator and housekeeping multiplexer.

Upon detection of a valid event, the PDFE notifies the FPGA which reads the parallel output of the PDFE. Dependent on mode selection the address compressor either does a quasi-logarithmic or linear binning. The result is used as an address in the SRAM where the corresponding 24-bit counter is incremented. A timing command from the SEP-CPU causes the FPGA to swap output buffer. While the new buffer is being filled, data from the old buffer are transferred to the SEP-CPU: either 8 histograms with 32 bins of 24-bit depth (logarithmic binning) or 8 histograms with 256 bins of 24-bit depth (linear binning). Linear binning is only used on unit level during ground checkout. After the transfer, the counters are reset.

On command the FPGA can start the test pulse generator (a 12 bit DAC and shaping filter) which feeds pulses of growing amplitudes to the 16 test inputs of the PDFEs. Upon completion the generator is automatically switched off returning SEPT into nominal operation mode. Also on command, the FPGA can transfer to the SEP-CPU the 10 housekeeping channels (temperatures and leakage currents), which were converted by the PDFE internal ADC.

1.2.4.3 Power Unit

As the PDFE may develop latch-ups, the supply lines for the PDFE need to be current limited and - in case of a latch-up trigger - to be power cycled. This is to remove the latch-up condition from the chip. The latch-up monitor within the power unit will perform this task and notify the FPGA about a contingent latch-up via the latch-up detector (LD). The FPGA may send some information about the latch-up to the SEP-CPU (TBC) and clear the contents of counters related to the PDFE which has latched up. When power is reapplied normal operation can be resumed. Within the power unit all necessary reference voltages and constant current sources for the PDFE's and the rest of the SEPT electronics will be generated.

1.2.4.4 Low and High Voltage Supply Requirements

Power supply for SEPT analog and digital rails will be provided by the Low Voltage Power Supply (LVPS) for the SEP instrument package under the responsibility of UCB. Detector bias will be provided through the

SSD Bias Supply for SEP. The SEPT power consumption and regulation requirements for the various rails are provided in Tabelle 2.

Tabelle 2: SEPT Power Specification

Voltage	Power (low rate)	Power (high rate)	Ripple	Spikes	Accuracy	Remark
[V]	[mW]	[mW]	[mV _{pp}]	[mV _{pp}]	[+ / - V]	
+ 5.0	605	605	15	50	0.1 / 0.15	analog rail
+ 5.0	334	347	30	90	0.1 / 0.15	digital rail
+ 3.5	10	110	30	90	0.1 / 0.15	SRAM
- 40	1	2	0.2	1	1.0 / 1.00	SSD bias
Total	950	1064				

1.2.5 The Interface with Common Electronics

1.2.5.1 Communication with SEP-CPU

Without a microprocessor of its own, the SEPT electronics relies on high level control from the SEP-CPU. A bi-directional link transfers commands from the SEP-CPU to SEPT and data packets from SEPT to the SEP-CPU. A serial link is proposed which is both simple and reliable. As an additional benefit, this interface lends itself easily to standard PC control during development, integration, ground testing, and calibration. A total of two independent serial lines are requested to serve the two units SEPT-E and SEPT-NS.

standard	RS-422
data lines	symmetrical
handshake signals	no CTS, no RTS
number of start bits	1
number of stop bits	2
parity	none

1.2.5.2 Data Processing Requirements

A simple logarithmic compression algorithm shall be used in order to meet the SEPT telemetry bitrate allocation of 57 bps. This task shall be performed by the SEP CPU. The following is a proposal how to compress a 24-bit counting result into a 12-bit representation: compute the logarithm dualis, represent the mantissa in 8 bits with 'Hidden One Notation', represent the exponent in 4 bits.

In order to reduce SEPT data for 'Beacon Mode Transfer', sum up four proton histograms, sum up four electron histograms, sum up the 32 bins of each histogram into 3 bins, transmit the 6 counting results with optional logarithmic compression.

1.2.6 Telemetry Products

1.2.6.1 Data Rates and Formats

The scientific data from the two telescopes SEPT-E and SEPT-NS are comprised in a total of 8 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 2 MeV with quasi-logarithmic binning and a single bin for ions from 2-7 MeV/n, also in four directions.

To evaluate the detector health, 16 single detector channels (8 center disks, 8 guard rings) and 8 bias leakage currents are monitored. Together with two telescope temperatures and digital status bits, they constitute the SEPT housekeeping data set.

Data Item	Number of Channels	Bits per Channel	Total Number of Bits	Time Resolution
Histogram	8 x 32	12	3072	60 s
Single Rate	16	12	192	60 s
Leakage Current	8	8	64	60 s
Temperature	2	8	16	60 s
Status	2	32	64	60 s
Total			3408	

The total SEPT bitrate requirement is 57 bits per second.

All histogram and rate data are logarithmically compressed. It is assumed that timing information and packaging overhead is covered within the SEP allocation.

1.2.6.2 Beacon Mode Data

SEPT will provide three electron and three proton channels for continuous transmission of beacon mode data to the ground station. As this data set results from a summation, at least 16 bit after compression should be used for transmission. With a time resolution of 60 seconds, the required bitrate is 1.6 bps.

Electrons 20 – 50 keV	Protons 20 – 150 keV
Electrons 50 – 150 keV	Protons 150 – 1000 keV
Electrons 150 – 400 keV	Protons 1000 – 7000 keV

1.2.6.3 Burst Mode Data

No SEPT contribution to the burst mode memory is foreseen.

1.3 Development Plan

1.3.1 New Technology

The PDFE ASIC described above is a miniaturised mixed analog/digital integrated circuit. First production samples of this device became available early in 1999, following a lengthy period of development, which included production of a preliminary evaluation device. In April 2000 an improved prototype became available which is currently undergoing testing. Although some element of risk is involved in the use of such a device, we believe that, given now the availability of the prototype, that suitable devices will be available in time to enable it to be flown as part of the experiment, and so benefit from the weight saving it gives.

1.3.2 Design of the Magnet System

The geometry of the magnetic system and of the magnetic field vector in the air gap needs to be optimized to secure a clean separation of electrons and protons. Both finite element methods for the determination of the vector field and Monte Carlo simulations for particle trajectories in this field geometry are in progress to warrant a satisfactory deflection of electrons. The challenge in this effort is to achieve a good separation while staying within the stringent weight allocation.

1.3.3 Open Issues

The design of the SEPT aperture is no yet finalized. During the transfer trajectory phase, there is the possibility that the SEPT apertures are viewing the Sun for a period of about 20 minutes. As the the magnet side of the telescopes view open space, the thermal input is a hazard to the solid state detectors. Although the silicon detectors of the PIPS type are able to tolerate temperatures up to 100 °C, the resulting temperatures may be higher necessitating the use of four protective covers. The final decision will be taken pending a detailed thermal analysis. Also, the use of a one-time opening cover versus a reopening cover will have to be discussed.

1.3.4 Model Philosophy

There will be an engineering model of SEPT for development and test within the SEP instrument suite. There will be two flight models as deliverables to the STEREO project. Spare parts will be procured and stored for swift refurbishment in case of a failure on ground.

1.3.5 Testing and Calibration

Prelaunch testing will be carried out as part of the SEP instrument suite, including vibration, thermal-vacuum, electromagnetic compatibility and interference, and magnetic cleanliness. Prior to integration of SEP, SEPT will be checked out on unit level and electronically calibrated in the operational temperature range as well as calibrated with radioactive sources, atmospheric μ -mesons, protons from a synchrotron and electrons from a linear accelerator. Postlaunch calibration is possible by way of an inflight test pulse generator and a special calibration mode where drifts in the onboard electronics can be detected using penetrating minimum ionizing particles. Should drifts occur the field programmable gate array in charge of binning can be modified by ground command.

1.3.6 Ground Support Equipment

Two sets of SEPT GSEs will be provided to operate the telescopes in the following configurations:

- SEPT electronics alone
- SEPT electronics integrated with SEPT sensor
- SEPT integrated with SEP
- SEPT integrated with IMPACT
- SEPT integrated with STEREO

The GSE will perform the following functions contingent upon the actual configuration:

- operate SEPT by way of sending commands
- display SEPT data by way of telemetry read-out
- store SEPT data for off-line analysis
- stimulate SEPT data through onboard test pulse generator and ground high precision pulse generator

The GSE will include all necessary auxiliary equipment (e.g. LVPS simulator) needed in the various configurations. The GSE will support SEPT activities during manufacturing, assembly, test, calibration, spacecraft integration, and environmental tests. Two sets will be provided to allow concurrent operation of the two flight units.

1.4 Operational Constraints

The eight viewing cones of SEPT shall be unobstructed during flight. Protective aperture covers are red tag items used on ground, but removed prior to launch. Owing to the low energy thresholds no aperture foils are built in for the proton telescopes. Hence, in space, direct sunlight as well as specular straylight must be avoided and diffuse straylight minimized to guarantee flawless detector performance. After initial turn-on, SEPT will operate autonomously without the need for ground intervention except for occasional (every few months) commanding into calibration mode.

First turn-on in space shall occur not before 24 hours after launch to allow for outgassing. Commissioning shall take place outside the radiation belts, i.e. at spacecraft altitudes above 30,000 km.

1.5 Management Processes

1.5.1 Roles and Responsibilities

1.5.1.1 University of Kiel

The University of Kiel will design and build the four telescopes with a total of sixteen detectors. These numbers reflect the fact that there are two STEREO spacecraft. The detector signals will be fed into electronics chains provided by ESA ESTEC Space Science Department. Low voltage and high voltage rails will be provided by the IMPACT collaboration. The University of Kiel will ensure that the respective interfaces meet the needs of the IMPACT investigation w.r.t. mechanical, thermal, electrical, magnetical, and cleanliness requirements.

The University of Kiel will perform modelling of the instrument performance using the GEANT Monte-Carlo-Simulation. The purpose of this model is to determine the detection efficiency of the sensor system and the capability of the magnet/foil technique to separate electrons and ions.

Finite element techniques are applied to perform thermal and mechanical modelling to assure compliance with the spacecraft design requirements.

The University of Kiel will perform or participate in qualification and acceptance testing on unit-level, integrated experiment level, or system level in compliance with the design verification program of the STEREO mission.

The University of Kiel will carry out functional checkout, electronical calibration in the operational temperature range as well as physical calibration using radioactive sources, atmospheric μ -mesons, protons at a synchrotron, and electrons at a linear accelerator.

The University of Kiel will participate in IMPACT team mission operations. This includes routine health checks, commanding, lookup-table uploads, and inflight calibration data analysis.

The University of Kiel will participate in IMPACT team science. This includes analysis of the IMPACT experiment results, comparison between the two STEREO spacecraft, and correlation with optical STEREO experiments, L1-based or Earth orbiting satellites, ground observing stations and theoretical model predictions. The University of Kiel will submit processed data to relevant public data archives and provide internet access.

1.5.1.2 ESTEC

The Solar System Division of the Space Science Department of ESA at Estec (SSD) will design and build the analogue and digital electronics as described above. This electronics contains the Particle Detector Front End integrated circuit which SSD will develop under ESA's GSTP Technology programme. SSD will ensure that the electronics meets the needs of the SEPT sensors and the SEP CPU interface requirements.

SSD will design and provide the bench level ground support equipment (GSE) interfacing directly with the SEPT as well as with higher level check-out equipment in the various test configurations. SSD will participate in testing and calibration.

SSD will prepare software based upon that developed for the ISEE-3 and WIND missions for the analysis of 3-dimensional anisotropy measurements from the SEPT telescopes. SSD will undertake analysis of the results and participate in IMPACT team science.

1.5.2 Heritage

The proposed SEPT design is based on techniques for which long-standing and continuously upgraded experience exists at the University of Kiel, ESTEC, and the University of Berkeley. Expertise with solid state detector telescopes at the University of Kiel stems from space missions Helios, ISEE, Galileo, Ulysses, and SOHO. On SOHO, also rare-earth magnets were successfully implemented. Extensive experience is also gathered in the collaborating institutions at ESTEC and University of Berkeley, which have successfully designed and built the Solid State Telescope (SST) onboard the WIND spacecraft which is still in operation. SST incorporates many elements of the proposed design. The Space Science Dept. of ESA has a long history of involvement in the development and production of space hardware, the analysis of space data, the dissemination of space data, and outreach activities.