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A PARTICLE AND PLASMA ANALYZER SYSTEM FOR THE PHOBOS MISSION

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The ESTER particle and plasma analyzer system for the Phobos Mission comprised a complex of three instruments (LET, SLED and HARP) serviced by a common Data Processing Unit. An account is provided of this complex, its objectives and excellent performance in space.

1. The Phobos Mission

Two similar three-axis stabilized spacecraft, separated in time by five days, were launched to Mars and its Phobos moon by the Soviet Union in July 1988. The Mission, which was named Phobos, was multi-objective in scope and featured interdisciplinary studies of Mars (its surface, atmosphere, ionosphere, magnetosphere) and of Phobos (its surface; inner structure; orbital motion) as well as Cruise Phase studies of the Sun (its corona; upper chromosphere; solar flares; solar oscillations) and of the interplanetary medium (solar wind; solar cosmic rays; interplanetary shocks; cosmic and solar gamma ray bursts).

2. The ESTER Complex

The spacecraft carried a special instrumentation segment for studying ambient particle and plasma environments during the Cruise Phase and at Mars Encounter. The present paper describes, in particular, the so called ESTER complex, which comprised a suite of instruments (HARP, SLED and LET) with the capability to concurrently monitor particle fluxes over a range extending from populations in the undisturbed solar wind to low energy cosmic rays. The hardware and software of the dedicated Data Processing Unit (codenamed DPU-B) servicing the ESTER instruments and providing their electrical interface with the spacecraft are also provided.

General reference is made in these accounts to the scientific objectives of individual instruments and to their successful performance in space. These matters are treated in detail in individual papers concerning HARP, SLED and LET in /1,2 and 3/, respectively.

The individual components of the ESTER complex HARP, SLED and LET, together with the LET rotating platform, see /3/, and a special LET interface unit (LIU) with the common Data Processor, were attached to a mounting frame, accommodated on the Phobos spacecraft. Identical ESTER setups were mounted on the two spacecraft Phobos-1 and Phobos-2.

3. The Mission Profile

Phobos-1 and Phobos-2 were respectively launched on July 7 and July 12, 1988 from the Baikonur Cosmodrome using Proton rockets. Following injection of the twin spacecraft into the Earth-Mars transfer trajectory, the ESTER instruments were, after a period of approximately 12 days to allow for outgassing, activated by command on July 19 at 00.30 UT (Phobos-1) and on July 25 at 05.59 UT (Phobos-2). Each of the three experiments on the two spacecraft performed nominally.

Ground-based contact with Phobos-1 was lost at the end of August 1988. Phobos-2, however, continued to transmit data to Earth and, after a 204-day flight, was transferred on February 01, 1989 into a series of highly eccentric orbits around Mars with a periareon of 860 km; subsequently it was transferred first to an elliptical orbit of high pericenter, then to a circular equatorial orbit with an altitude of about 6330 km, and finally,in March, to an orbit nearly synchronous with that of the Phobos moon. Ground-based communication with the probe was lost at the end of March.

The instruments of the ESTER complex functioned continuously from switch on to the end of the active life of both spacecraft with minor interruptions during special manoeuvres or for other operational reasons.

The component instruments of ESTER differed in their appearance and principle of operation. Short accounts of each of these measurement systems are provided below.

4. HARP

HARP was designed to study the characteristics of solar wind electrons during the Phobos Cruise Phase and to determine the directional distributions of low energy electrons and ions in the range 0.4 eV-750 eV in the Martian environment. On the basis of the extensive interplanetary measurements of solar wind electron spectra made by HARP, some conclusions can be drawn concerning transport mechanisms, acceleration processes and instabilities in the solar wind. More importantly,the data gathered during Planet Encounter provide the information concerning the bow shock,magnetosheath, magnetopause,and magnetospheric tail crossings.

The detector consisted of two hyperbolic electrostatic lenses arranged perpendicular to each other. The particles were imaged on two microchannel plates mounted so that one was located behind each lens. Angular coverage was provided by eight windows, each of $20^0 \times 10^0$ solid angle, arranged at 22.5^0 intervals in a fan-shaped geometry in the antisolar hemisphere. These channels were simultaneously sampled while E/Q was stepped over a maximum number of 75 logarithmically spaced channels.

5. SLED

SLED was designed to monitor both the interplanetary flux of low energy cosmic rays (30 keV-3.2 MeV) and the galactic background flux during the Cruise Phase and to study the plasma interaction at the boundary layers inside the Martian magnetosphere during Encounter. Since the Cruise Phase coincides with the transition phase between solar minimum and solar maximum, data secured en route to Mars can be used to support the International Solar Interplanetary Variability (SIV) Study Programme. At the planet, energetic particles in the range 30 keV - < 350 keV were detected deep in the Martian magnetosphere at an altitude of <1000km above the surface. Energy of related particles shadowing by the planet was also identified.

The SLED detector system comprised two semiconductor telescopes each incorporating two silicon surface barrier detectors mounted coaxially. Count rate differences between the telescopes which observed in the same direction but with foil covered and open apertures, allowed protons and electrons to be distinguished. The geometric factor of each telescope was 0.4 cm^2 ster and the field of view axis, with a 40^0 apex angle, was in the ecliptic plane at 55^0 to the sunward direction. Table 1 lists the energy channels covered by each telescope and provides information concerning the kinds of particle recorded.

Table 1

ESTER SLED data channels

Telescope without foil		Telescope with foil		
30- 50 keV	electrons+ions	30- 30 keV	electrons	(350-400 keV ions)
50-200 keV	electrons+ions	50-200 keV	electrons	(400-500 keV ions)
200-600 keV	electrons+ions	200-600 keV	electrons	(0.5- 1 MeV ions)
0.6-3.2 MeV	ions	0.8-3.2 MeV	ions	
E>3.2 MeV	ions	E>3.2 MeV	ions	
E> 30 MeV	background rate	E> 30 MeV	background rate	

6. LET

The LET instrument was designed to monitor the fluxes, spectra and elemental composition of nuclei from hydrogen up to iron in the energy $\gtrsim$1 Mev/N - $\lesssim$75 MeV/N using a double dE/dX vs E solid-state detector telescope, see Table 2. A rotatable platform, adjustable to five different angular positions in steps of 45^{o}, enabled coarse anisotropy measurements to be made.

Table 2

ESTER LET data channels

Species	Energy ranges	
protons	0.9-19 MeV,	5 channels
alphas	1-19 MeV/N,	4 channels
Li-Be-B	1.9-26 MeV/N,	2 channels
C-N-O	2.6-39 MeV/N,	2 channels
Nuclei, Z>10	3 -50 MeV/N,	2 channels
Nuclei, Z>10	12 -75 MeV/N,	1 channel
Electrons	0.35-1.5 MeV,	1 channel

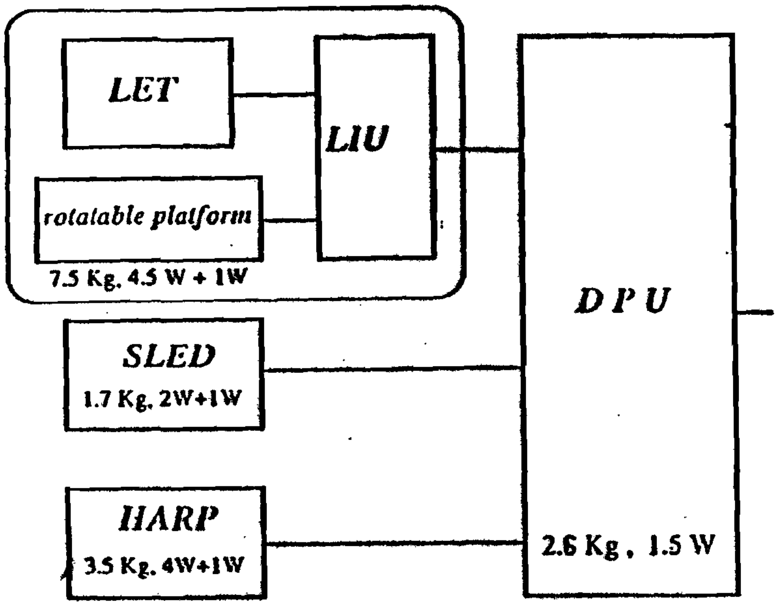
Data secured during the Cruise Phase show the clear separation of isotopes He-3 and He-4. Monitoring by LET of He,N,O and Ne nuclei (elements of the anomalous cosmic ray component, ACR) in the energy range 3-30 MeV/N within the 1988-89 time frame now allow critical comparisons to be made with ACR components recorded by earlier experimenters during the previous epoch.

7. The Data Processing Unit

The three instruments HARP, SLED, and LET were coupled together by their common Data Processing Unit, see Fig.1. A block diagram of the DPU is presented in Fig.2. Essentially it consisted of four main units, namely the Processing Unit; the Communication Unit; the Spacecraft Interface Unit and the Power Supply.

7.1. The Processing Unit

The Processing Unit was based on an NSC800 type microprocessor which has already proved it's suitability for space projects during the VEGA and GIOTTO missions. This microprocessor combined high computing capability with low power consumption, com-



Weight: 16.1 Power: 12W + 3W

Fig.1 Block diagram of the ESTER complex

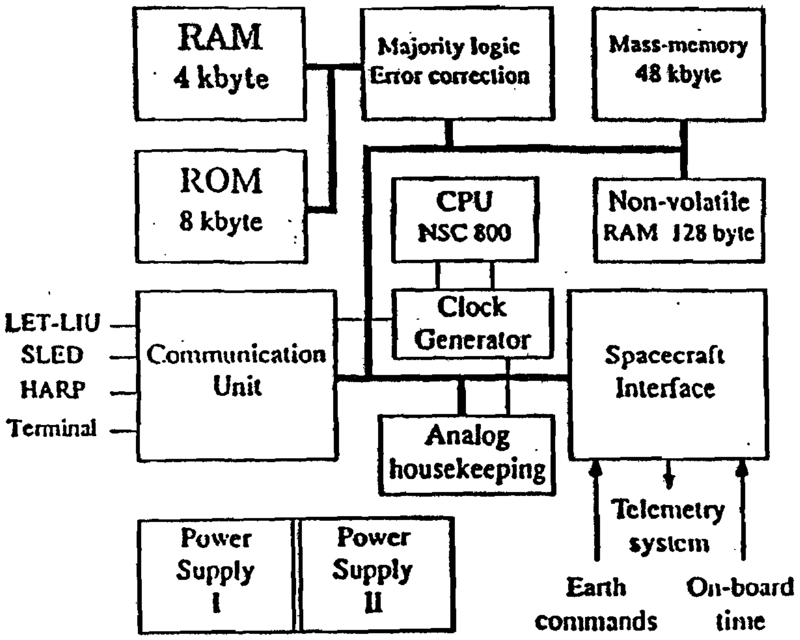


Fig.2 Block diagram of the ESTER dedicated DPU

plemented by an excellent software background due to its compatibility with the Z80 µP. The system memory had a capacity of 8 kbyte ROM and 4 kbyte RAM. Both were error corrected through the majority logic circuitry. Error correction was built in because the memories were expected to be sensitive to single event upsets produced by heavy particles.

The Processing Unit had a memory for temporary data storage offering a capacity of 48 kbyte (not error corrected) in the direct address space of the microprocessor. A non-volatile memory of 128 bytes (placed in the I/O address space of the µP) was provided for continuous storage of instrument command and status information. This memory was backed-up by a high reliability battery with the capability to operate over an extended temperature range.

The Clock Generator block provided all frequencies necessary for the system, including the µP clock (2.4576 MHz); the real-time interrupt (32Hz); the communication clock (2.4576 MHz) and the clock for the analog housekeeping system (614.4 kHz). The analog housekeeping unit utilized an 8 channel, 8 bit ADC, for the measurement of current consumption (4 values), voltages (3 values), and the temperature of the DPU box.

7.2. The Communication Unit

The Communication Unit provided interfacing with the detector units (SLED, LET-LIU, HARP) using serial links. The interfacing was performed using a current loop method (approximately 20 mA) to allow high bit rate communication (153.6 kBaud) through rather long interconnecting cables (about 5m). Another factor that stimulated the use of a current loop was the necessity to provide ground separation between the sensors and the DPU. This was achieved by utilising high speed optocouplers.

Communication was performed by generating interrupts of the µP. A decoupled digital line was provided for each sensor head to relay directly information of immediate importance to the DPU. These lines were also used to generate interrupts of the microprocessor to ensure short latency. An additional serial link was provided to permit communication with external terminals (suitably decoupled by means of optocouplers to avoid noise injection through electrical network ground loops). The so called "terminal task" used this link during the software development phase (see Section 8.5).

7.3. The Spacecraft Interface Unit

The Spacecraft Interface Unit performed the tasks of telecommand and onboard time reception, as well as the transmission of preprocessed data to the telemetry system of Phobos. Interfacing with the input signals coming from the spacecraft was carried out using majority logic devices.

The output of the DPU was able to transmit data to both (cold redundant) onboard telemetry systems. The data transmission cycle was either 1 minute or 20 minutes, depending on the mode of operation. The data transmission rate was 16 kbit/sec.

7.4. The Power Supply

The last unit was the Power Supply, which featured two identical, hot redundant blocks sharing the power requirement of the DPU. Each of them was able to supply the DPU separately to increase the overall reliability. The unit provided output voltages of +5V and +9V, with power handling capability of 3 W and 200 mW, respectively. The efficiency was about 70%. The actual power consumption of the DPU was only about 1.5 W, a large proportion of which was used by the current loops of the Communication Unit. The Power Supply also contained a relay-based switching network to switch on and off the power of the sensor heads and their heating elements under particular operational conditions.

8. The operating software

A real-time multitask operating system (called RTS-800) was developed for the DPU to solve the problem of simultaneously controlling three independent sensor heads, while synchronizing them with the spacecraft data transmission cycles and optimizing the temporary data storage memory size. In this system, the task repetition rate was 32 times per second. The eight tasks, in priority order, were the following.

8.1. Control Task (CT)

This task was always active. It handled the so called watchdog/ timing facilities (provided by software) which were used by seven other tasks (see below) for selection of the device utilization/allocation and for measurement timing appropriate to the task in question.

8.2. Command Decoder Task (CD)

The CD Task comprised the reception and interpretation of telecommands from the Earth; the immediate execution of hardware-oriented commands (e.g. turning instrument heaters on/ off) and the storing of software-oriented commands in an experiment-specific command buffer (to ensure their execution at a time suitable to the task controlling the instrument concerned).

8.3. Telemetry Task (TM)

The TM Task comprised preparing the measurement data and status information provided by the instruments, together with the status information of the DPU, for telemetry transmission. This transmission was performed using hardware circuitry (Direct Memory Access, DMA) rather than by the TM task itself, under the influence of a TM request flag. The end of the action was indicated for the TM task by means of an interrupt. The transmission duration was 20 minutes in the normal mode and 1 minute in the fast telemetry mode. In these intervals, the TM task formatted data frames of the instruments for the TM-DMA action. In each telemetry cycle, the ESTER complex transmitted 720 bytes, divided into 6 frames with 120 bytes each. In cases where one or more instruments happened to be switched off, the TM task re-allocated data frames, according to a pre-defined pattern, to the remaining instruments.

8.4. The Instrument Control Tasks of LET, SLED and HARP

The LET Task controlled the timing and gating of the LET counters, the periodic shift of the platform in steps of 45°,and the assembling of LET frames containing measured and housekeeping data.

The SLED instrument had four operation modes, namely: measurement, calibration, memory dump and test mode. In the measurement mode, the contents (16 bit) of 12 event counters were suitably stored, after a 12 bit logarithmic compression performed in the DPU, pending data transmission.

A 48 kbyte mass-memory was reserved in DPU for the HARP instrument. The HARP Task handled this memory as a temporary storage circular buffer. For details see /1/.

8.5. The Terminal Task (TE) and Test Task (TS)

The TE Task was used during the ESTER development phase for debugging and testing the software running in the DPU. It was not installed in flight units so as to save memory space.

The TS Task provided for testing the DPU memories and storing the test results in a "status table". The 48 kbyte mass-memory was divided into 192 blocks (256 bytes each), and the HARP task (see above) could store data only in those blocks, which were classified "error-free" in the status table. The status table, supplemented by the analog housekeeping data and the onboard time, constituted the basis of the DPU frame.

9. Conclusion

The ESTER complex, comprising the HARP, SLED and LET instruments with their common DPU, was designed to make simultaneous measurements of the solar wind, of suprathermal and energetic particle populations and of low energy cosmic rays from aboard the twin spacecraft Phobos Mission to Mars and its Moons. This complex functioned nominally during the operating life of both spacecraft and a wealth of scientific data obtained during the Cruise Phase to Mars and at the planet itself have been garnered.

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