Space Physics Sensor on KOMPSAT-1

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Abstract. A small package of plasma instruments, Space Physics Sensor, will monitor the space environment and its effects on microelectronics in the low altitude region as it operates on board the KOMPSAT-1 from 1999 over the maximum of the solar cycle 23. The Space Physics Sensor (SPS) consists of two parts: the Ionospheric Measurement Sensor (IMS) and the High Energy Particle Detector (HEPD). IMS will make in situ measurements of the thermal electron density and temperature, and is expected to provide a global map of the thermal electron characteristics and the variability according to the solar and geomagnetic activity in the high altitude ionosphere of the KOMPSAT-1 orbit. HEPD will measure the fluxes of high energy protons and electrons, monitor the single event upsets caused by these energetic charged particles, and give the information of the total radiation dose received by the spacecraft. The continuous operation of these sensors, along with the ground measurements such as incoherent scatter radars, digital ionosondes and other spacecraft measurements, will enhance our understanding of this important region of practical use for the low earth orbit satellites.

1. Introduction

The effect of the space environment should be seriously considered in the development stage as well as during the operation of spacecrafts [Garrett and Pike, 1980]. For example, high energy particles are known to cause single event upsets and the total dose effects, while low energy plasma particles can accumulate on the spacecraft surface charging it sometimes to several kilovolts. In addition, solar ultraviolet radiation and X-rays can damage the spacecraft surface, and the atmospheric oxygen may also be an important environmental factor in the case of low earth orbit satellites. As the constituents of the space environment vary according to the location in space, the orbital element becomes a crucial input in determining its effects. Spacecrafts in the geosynchronous orbit can suffer charging effects from the plasma sheet particles, especially during the magnetic substorm, and the satellites of the GPS orbit are affected by the high energy electrons in the outer radiation belt. The single event upsets and the total dose effects are two of the most important damages to the low earth orbit satellites as they pass through the South Atlantic Anomaly where high energy protons are densely populated. Cosmic particles of ultra-high energy can penetrate the geomagnetic shielding in the polar region and cause damages to the polar orbiting satellites.

As it is evident that the continuous observation of the space environment is crucial to reliable spacecraft operations, it has become a general practice to include space environment monitoring systems composed of several detectors when meteorological satellites or satellites for the routine earth observation are developed. Geosynchronous and polar orbiting satellites operated by NOAA and the Japanese satellite GMS are such examples. The data obtained from these routine observations are combined with those from higher quality experiments on scientific satellites to be used for monitoring and forecasting the space environment. In Korea, the Radio Research Laboratory (RRL) has developed recently its own forecasting system using the domestic ground data such as the magnetograms, ionograms, and the solar radio spectrograms and the overseas data available through the internet. Hence, it will greatly enhance the capability of the space weather forecast in Korea if the space data available directly from the Korean satellites is incorporated into the system, and it is very fortunate that KOMPSAT-1 provides just that opportunity. Another notable aspect of the current KOMPSAT-1 opportunity is its timeliness in the observation of space environment as the 23rd solar cycle reaches its maximum in the year 2000.

2. Space Physics Sensor

2.1 Purpose of SPS Experiment

The KOMPSAT-1 orbit, a circular sunsynchronous orbit at 685 km altitude with the inclination angle 98 deg, resides in a relatively safe environment without a dense population of high energy particles compared to other orbits at higher altitudes. Nevertheless, there still exist high energy and ultrahigh energy particles in the South Atlantic Anomaly and in the polar cap region. Also at times, the spacecraft of this low altitude polar orbit is bombarded with a large amount of auroral electrons originating from the plasma sheet in the deep magnetosphere [Tascione, 1988]. The region of 685 km altitude is the upper part of the ionospheric F-layer, in which the low energy thermal electrons and ions are the main constituents [Hargreaves, 1992]. The Space Physics Sensor (SPS) will monitor this thermal electron environment by observing the electron density and temperature as it is affected by the solar and geomagnetic activity. SPS will also measure high energy proton and electron fluxes, and their effects on microelectronics by observing single event upsets caused by these particles and the total radiation dose deposited during the mission.

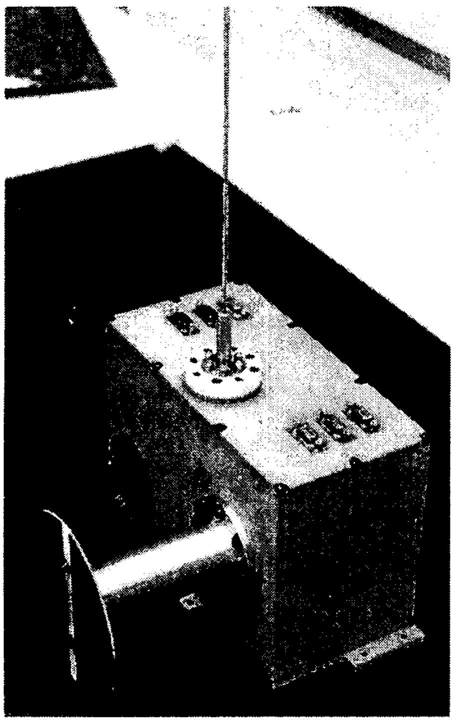

Figure 1. Integrated SPS package

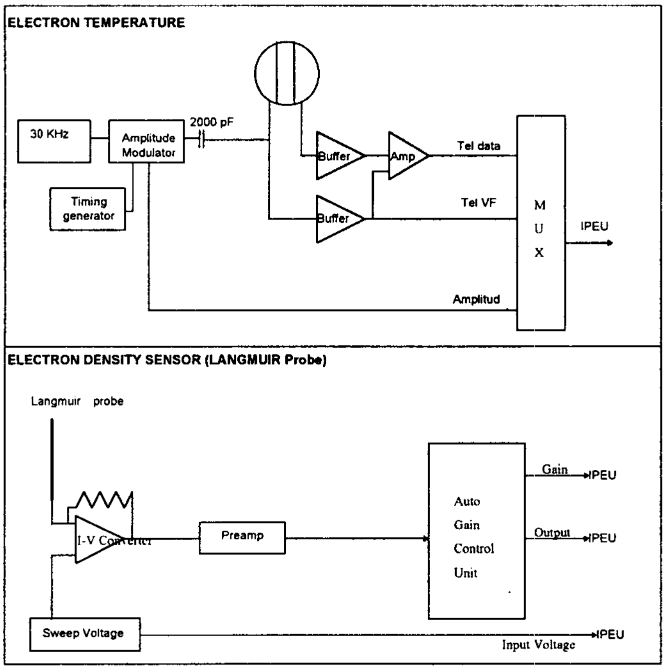

Figure 2. Functional diagram of ETS and LP

2.2 SPS Hardware Description

SPS is composed of two parts: IMS (Ionospheric Measurement Sensor) measures electron density and temperature, and the HEPD (High Energy Particle Detector) studies the high energy particle environment and its effects. These two instruments share the power and the mechanical structure, but have separate data interfaces. They will be operated at 100% duty cycle, which will then enable us to study the global characteristics and changes of the space environment at this altitude. Figure 1 shows the integrated SPS package.

IMS has two independent sensors, LP (Langmuir Probe) and ETS (Electron Temperature Sensor) to measure the electron density and temperature. The LP is a conventional Langmuir probe which measures the current drawn by the probe as a function of the voltage applied to the probe. As the ionic contribution to this current is negligible due to the large mass of ions, the electron density and temperature can be determined by fitting the observed I-V curve with a suitable mathematical function. The electron temperature can also be measured directly from the ETS, a modified Langmuir probe utilizing the voltage shift in the floating potential when a small amplitude sinusoidal wave is applied to the probe. The schematic block diagram of IMS is shown in Figure 2.

HEPD consists of four subsystems: the Proton and Electron Spectrometer (PES) and the Linear Energy Transfer (LET) which measure the fluxes as well as the energies of the incident high energy protons and electrons, the Total Dose Monitor (TDM) which measures the total accumulated radiation dose, and the Single Event Upset Monitor (SEM) which records the radiation induced errors in the RAMs (random access memories). The PES, as Figures 3 shows its schematic diagram, is made of four silicon surface barrier detectors and the blocking materials inserted between the two neighboring sensors. As the incident particle passes through the silicon detectors and the blocking materials, the energy of the particle is delivered to these detectors and materials. The particle species and its energy can be determined by measuring the energy transferred to the detector SSD1 (LET) and by comparing the signals produced by the detectors including SSD1 (PES). 64 channels are assigned to the LET, while PES detects protons in 3 channels, electrons in 3 channels, and discriminates the alpha particles. The design values of the IMS and PES are shown in Table 1.

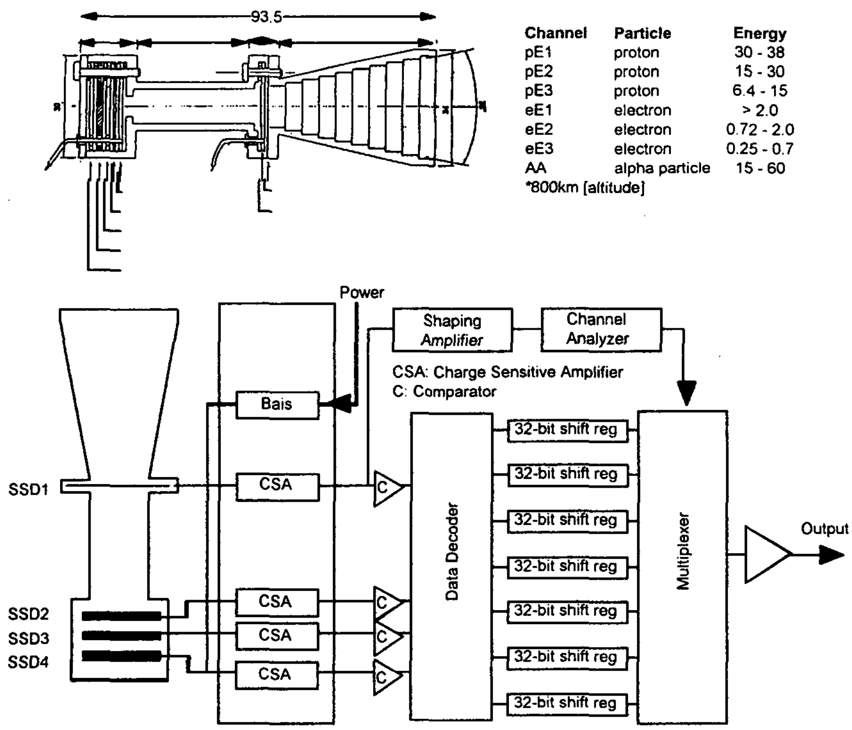

Figure 3. Functional block diagram of PES and LET

Table 1. SPS design specifications

power	16 W	
mass	7.6 kg	
size	25.9 cm X 11.4 cm X 16 cm	
IMS	ETS	< 1 eV electron temperature
	LP	10^3 - 10^6 cm^{-3} electron density
HEPD	PES	proton: 30-38 MeV, 15-30 MeV, 6.4-15 MeV
		electron: > 2MeV, 0.7-2 MeV, 0.25-0.7 MeV
		alpha particle: 15-60 MeV
	LET	16 - 40 $MeVcm^2/g$ (64 channels)
	TDM	0 - 40 kRad

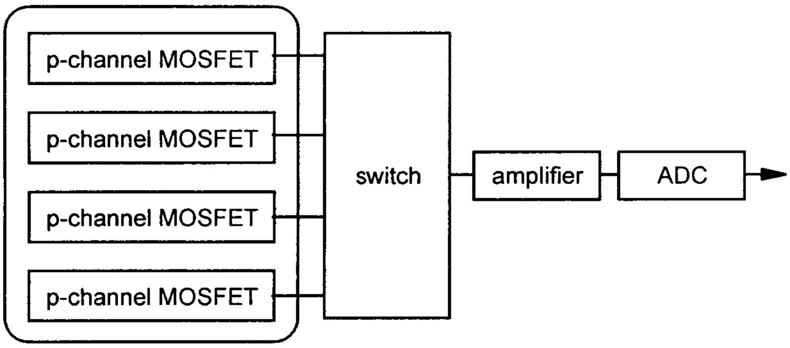

Figure 4. TDM block diagram

The Total Dose Monitor (TDM) measures the long term accumulated ionizing radiation dose in SiO_2 with 4 pairs of RADFET dosimeters. Each RADFET sensor consists of a matched pair of p-channel MOSFETs, one of which is biased during exposure (measure mode), while the other remains un-biased. Exposure to radiation causes the formation of trapped holes in the gate oxide, which gradually shifts the threshold voltage according to the accumulated dose. The electric field across the biased FET causes it to experience a greater dose effect than the un-biased FET [Adams and Holmes-Siedle, 1978]. A constant current is switched to each RADFET in the read mode and the threshold voltage is measured. The SEM utilizes commercial RAMs to monitor the software errors such as single event upsets as well as more serious hardware errors like single event latchups by writing and reading the data with a well defined pattern. The block diagrams of TDM and SEM are shown in Figure 4 and in Figure 5, respectively.

IMS produces 700 bytes/sec (600 bytes/sec from LP and 100 bytes/sec from ETS) which are equally distributed to 4 VCDUs (Virtual Channel Data Units) and transferred to the OBC (On Board Computer). HEPD produces 180 bytes/sec (28 bytes/sec from PES, 128 bytes/sec from LET, 8 bytes/sec from TDM, and 16 bytes/sec from SEM) which is contained in a single VCDU. These science data and the telemetry data will be down-linked through the S-band and pre-processed at the KARI's ground station. The science data and the necessary ancillary data will be transferred to SaTReC (Satellite Technology Research Center) for the analysis.

2.3 Data Analysis

The pre-processed SPS data will be tailored at SaTReC to be used for the routine analysis and for the detailed scientific analysis. The processed data will be sent to RRL and used for the space weather forecasting. Figure 6 shows one example of the routine plots in which the measured particle fluxes as well as the predicted values from the NASA model [Sawyer and Vette, 1976] are given along the satellite trajectory in the prescribed color code. The processed data will also be permanently stored for the future analysis.

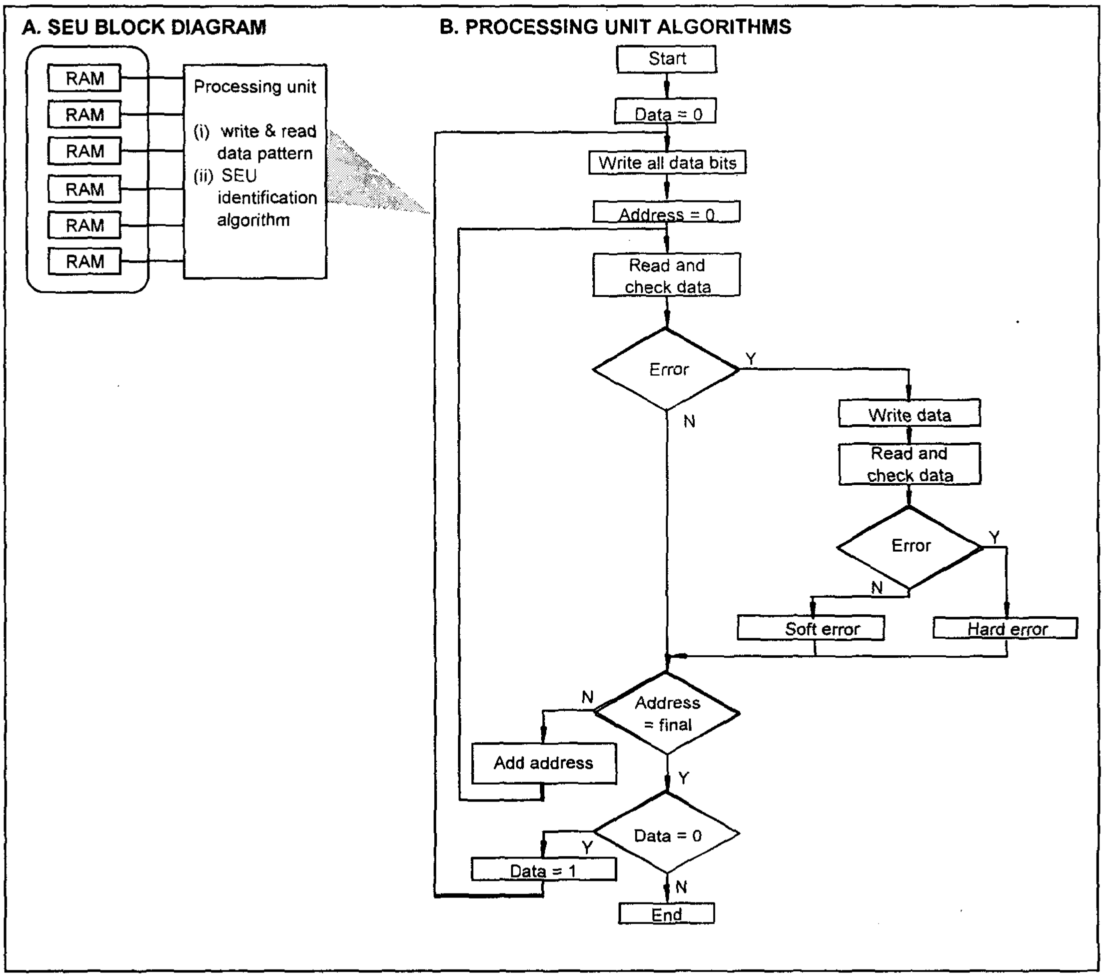

Figure 5. SEM block diagram and algorithm

3. Discussions

The flight model of SPS has passed all the necessary environmental test and is presently being integrated to the spacecraft platform. The sensors have been calibrated using the engineering model of the same design specifications. Initial steps for the development of the analysis software have been taken.

Space environment is not only harsh but also very dynamic. One observation in a certain spatial location at a particular time does not tell much about the global and time varying environment. It is very important to compare the data with other available space and ground observations done simultaneously with SPS. In addition, frequent flight opportunities should be provided to the space environment monitoring system for the continuous observation which is essential for the reliable satellite operations. The high energy particles and the low energy thermal electrons are not the only important environment constituents in space. The auroral particles in the keV energy range are also important, especially regarding the polar atmospheric heating, although SPS does not measure these particles. It is suggested that future experiments should include the detection of plasma particles in this energy range.

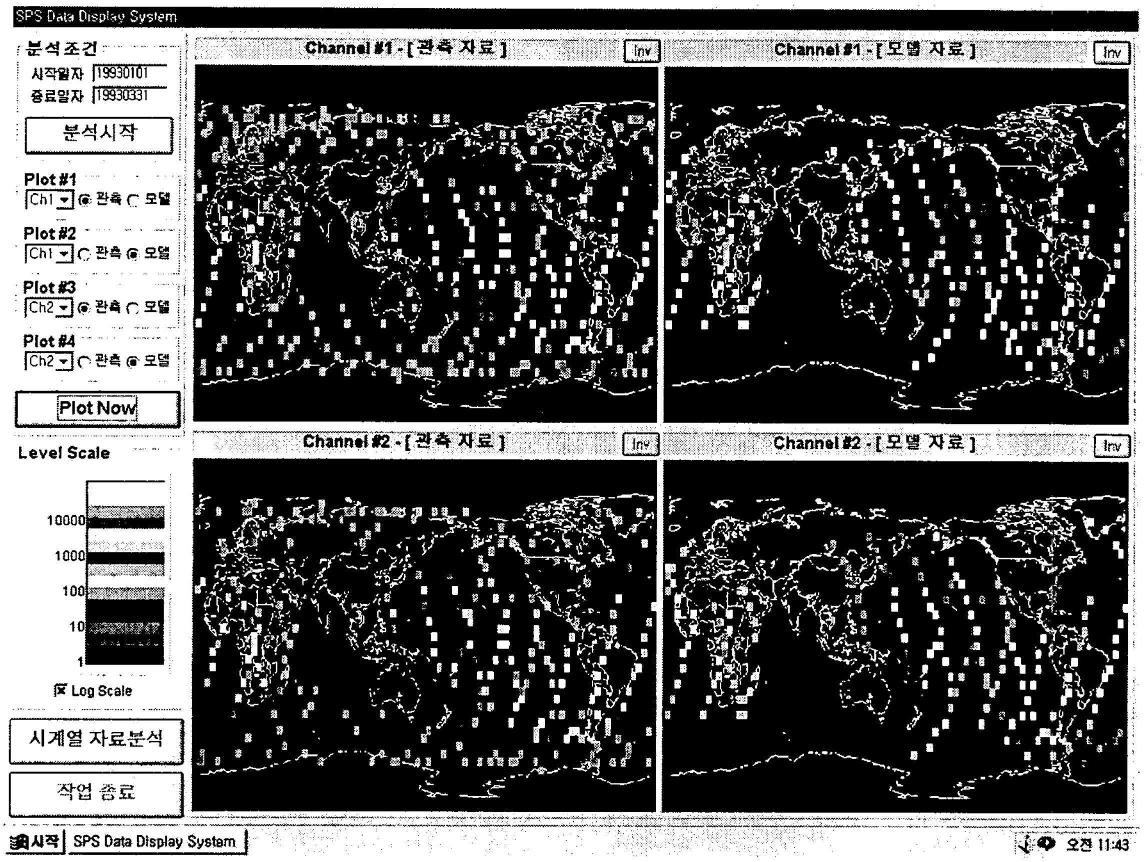

Figure 6. An example of the routine plots in which the measured particle fluxes as well as the predicted values from NASA model.

References

Adams, L. and A.G. Holmes-Siedle, The Development of an MOS Dosimetry Unit for Use in Space, IEEE Trans. Nucl. Sci., 25, 1657, 1978.

Garrett, H.B. and C.P. Pike, Space Systems and Their Interactions with Earth's Space Environment, AIAA, New York, 1980.

Hargreaves, J.K., The Solar Terrestrial Environment, Cambridge Univ. Press, New York, 1992.

Sawyer, D.W. and J.I. Vette, AP-8 Trapped Proton Environment for Solar Maximum and Minimum, NSSDC/WDC-A-R&S 76-06, 1976.

Tascione, T.F., Introduction to the Space Environment, Orbit Book Co., Florida, 1988.