

Energetic Charged Particle Spectrometer for the Space Environment Reliability Verification Integrated System (SERVIS-1) Satellite

Gary E. Galica, B. David Green, Takashi Nakamura, Hiroshi Hasegawa, Tatsuya Itoh, and Yasutomo Sasaki, Hiroshi Kanai, Masatsuga Akiyama, and Kazumori Hama

Abstract

We present the design and results from a new radiation sensor, the Light Particle Detector, designed specifically to quantify the orbital environment responsible for microelectronics damage. It supports Japan's Space Environment Reliability Verification Integrated System.

Introduction

Physical Sciences Inc. (PSI) has developed a new, high-energy, charged particle spectrometer as part of the Space Environment Reliability Verification Integrated System-1 (SERVIS-1) satellite developed by the Institute for Unmanned Space Experiment Free Flyer (USEF) under contract from Japan's New Energy and Industrial Technology Development Organization (NEDO).¹ The LPD, or Light Particle Detector, characterizes the proton, electron and ion fluxes and energy distributions incident on the SERVIS-1 spacecraft. The LPD is one component of a comprehensive Environment Monitor System for Space (EMSS) being developed by the Mitsubishi Precision Co., Ltd., for USEF. The EMSS comprises the LPD energetic particle spectrometer, a Single Event Upset Monitor and several distributed FET dosimeters.

The purpose of the SERVIS project is to establish the parts evaluation and equipment design guidelines required to utilize commercial off-the-shelf (COTS) parts and technologies in space. As part of the SERVIS program, COTS components are subjected to various ground evaluation tests, including radiation tolerance tests. Those parts that survive the screening process will be verified in the space environment on a series of SERVIS satellites. Ground evaluation results will be compared with performance in space. Verification testing will be done at the part level as well as at the subsystem level. Advanced bus subsystems that use state-of-the-art COTS technologies are also being developed. The SERVIS-1 satellite was launched successfully on 30 October 2003 into a 1000 km, 99.5 deg orbit. The SERVIS-1 satellite has a 2 year planned mission. The system, including LPD, is designed for a >5 year mission life.

There are several reasons for validating COTS performance in space. Radiation damage is one of the primary factors that limit the life of spacecraft. At the same time that satellite launches are increasing, the availability of radiation-tolerant, high-reliability parts is decreasing. With decreasing availability comes increased price and longer delivery times. The use of space-validated COTS components will result in considerable cost reduction for future satellites. In addition, the satellite community can take advantage of the higher level of performance that COTS components offer compared to typical radiation tolerant parts. For example, in order to reduce hardware size, weight and power consumption, some functions of present hardware system must be shifted to software. This goal can be realized by using high performance COTS such as CPU's and memories.

LPD Sensor Configuration

The SERVIS LPD is designed to characterize the high-energy charged particle radiation environment that is primarily responsible for on-orbit electronics damage.² It detects, discriminates, and energy analyzes 1.2 to 150 MeV protons, 0.3 to 10 MeV electrons, > 7 MeV alpha particles and > 2 MeV/nucleon heavy ions. The SERVIS LPD detection system is based on SSD and inorganic scintillators coupled to state-of-the-art analog and digital electronics. The detection system comprises a single 500 μm thick, fully-depleted, solid-state silicon detector (SSD) backed by a 24 mm thick Yttrium Aluminum Perovskite (YAP) scintillator.³ YAP scintillators are relatively high-Z and have an excellent stopping power for electrons. They also exhibit an almost negligible temperature coefficient up to very high temperatures. Hamamatsu metal dynode photomultiplier tubes (PMT) detect the scintillator photons. These PMTs have been used previously for spaceborne scintillator detectors.^{4,5} A collimator defines the acceptance angle and an aluminum and gold plated kapton window rejects visible photons and low energy charged particles.

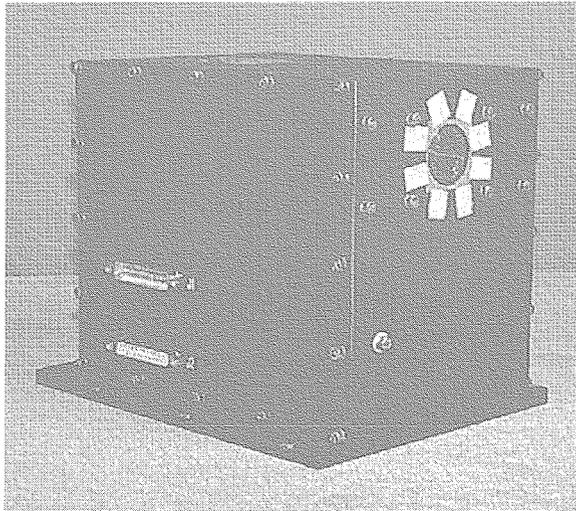


Figure 1. Exterior view of SERVIS-1 LPD.

Because the LPD is considered a component of the spacecraft bus and it is an integral part of the measurement of the on-orbit radiation environment central to the mission success, it has completely redundant systems. The LPD comprises two completely independent sets of electronics as well as two SSDs and two PMTs. Both PMTs are mounted on a single YAP crystal. The 2 SSDs are in a stacked configuration. With this configuration, the A-side and B-side performance is slightly different, but we obtain the benefit of full redundancy while minimizing weight and volume growth of the sensor.

Sensor Modeling and Calibration

We have calibrated the LPD extensively for both protons and electrons over much of its energy range. We have used two facilities for calibration: Harvard Cyclotron Laboratory (HCL), Cambridge, MA, the Indiana University Cyclotron Facility (IUCF), and the National Institute of Standards and Technology (NIST), Gaithersburg, MD. The HCL facility had a 160 MeV primary energy proton cyclotron. The energy was adjusted in steps from 29 MeV to 160 MeV by using a series of energy degraders. IUCF had a similar configuration except with a 200 MeV primary beam that was adjustable in steps from 50 MeV to 200 MeV. At NIST, we used both a van de Graaff generator (0.4 to 2.0 MeV) and a cascading rheostat accelerator (0.02 to 0.35 MeV) to provide nearly continuously tunable monoenergetic electrons from roughly 0.02 MeV to 2 MeV.

We developed a complete, three-dimensional sensor model based on the CERN GEometry ANalysis Tool (GEANT) Monte Carlo particle propagation code. The GEANT-based model incorporates all the geometry and material properties of the sensor with high fidelity. It tracks the trajectory of each particle and the energy deposited as the particle penetrates the detectors. Using the model, we predict the energy response, energy resolution and particle specificity. Once validated with calibration data, we use the physics-based sensor model with confidence to interpolate and extrapolate LPD performance to particle-energy regimes that we cannot calibrate on the ground. We are also using the model to interpret on-orbit results.^{6,7} Figure 2 shows example output from the sensor model. In Figure 2 we have plotted the energy deposited in SSD-A and in the scintillator for a distribution of electrons, protons, alphas, and representative ions.

During calibration, we have measured the LPD proton response to monoenergetic protons from 29 MeV to 200 MeV. From these data we determine the energy response and energy resolution of the system. Both the SSDs and the scintillator demonstrate linear responses. Those responses are in good agreement with the GEANT model

The SSD and PMT signals are amplified by high speed, ultra low noise charge sensitive preamps. The shaped preamp outputs are fed into a peak-hold hybrid circuit and digitized by a 12-bit ADC system. The digitized values are input to a radiation-tolerant Actel RT54SX32 field programmable gate array (FPGA) that handles all the on-board signal processing, health monitoring, and telemetry.

An ACTEL radiation-tolerant FPGA analyzes each particle event by simultaneously processing the SSD and PMT signals. The FPGA program identifies each particle as a proton, electron, alpha, heavy or other, and determines that particle's energy. The spectrum is stored as a histogram of twelve, roughly logarithmically spaced bins. Table 1 summarizes the performance parameters.

TABLE 1
SUMMARY OF SERVIS LPD PERFORMANCE PARAMETERS

Parameter	Value
Energy range	
Protons	1.2 – 150 MeV (6 bins)
Electrons	0.3 – 10 MeV (4 bins)
Alphas	7 – 640 MeV (1 bin)
Heavy ions	2 – 160 MeV/nucleon (1 bin)
Energy resolution	dE/E = 0.25 fwhm
Count rate	200,000 particles/sec
G-factor	0.2 cm ² sr
Weight	4.2 kg
Power	7.5 watts
Size	120 x 120 x 150 mm ³

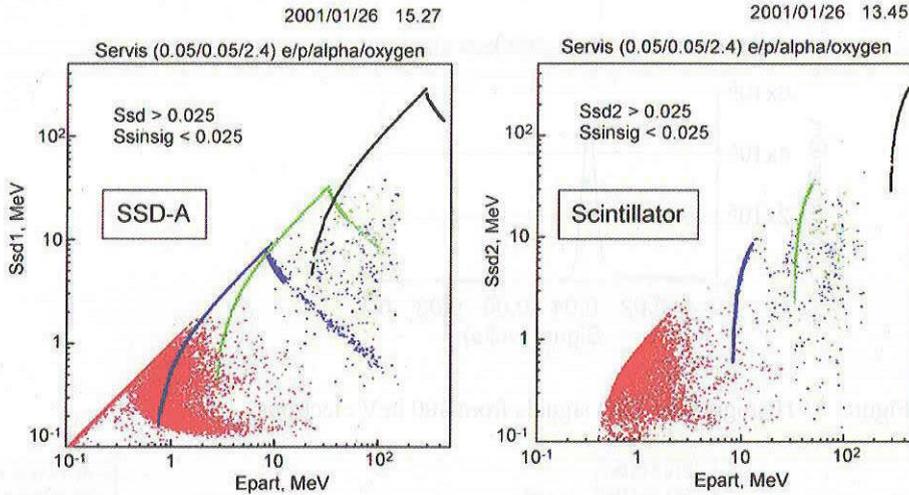


Figure 2. LPD sensor model output. We create a high-fidelity geometric model of the sensor and use the GEANT particle propagation code to predict the sensor response for electrons, protons, alphas, and a representative ion (O).

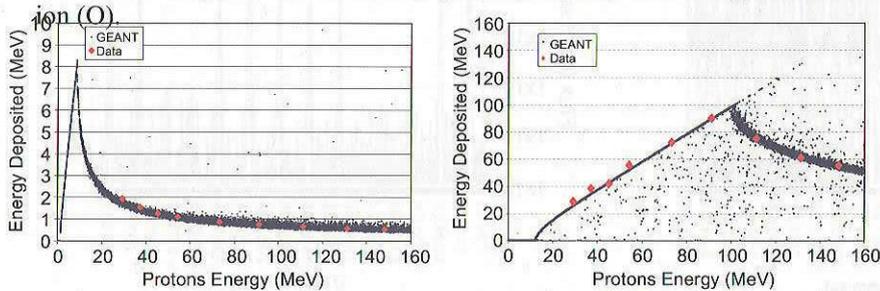


Figure 3. The GEANT predictions of the SSD (left) and scintillator (right) response are in good agreement with the calibration data.

predictions as shown in Figure 3. The scintillator resolution is the key determining factor in the overall sensor energy resolution. We determined that the inherent resolution is 0.15 dE/E fwhm.

The electron calibration was performed using the NIST van de Graaff generator. As with the proton calibrations, the electron response is in good agreement with the GEANT model predictions. Figure 4 shows the electron response of the SSDs as a function of energy deposited. Figure 5 shows a histogram of the SSD response to 300 keV electrons.

Preliminary Flight Data

LPD has been acquiring data since early November 2003. We present some data from 1 December 2003. Figure 6 shows electron and proton in-bin fluxes as a function of time over the period of 1 day on

1 Dec 2003. Figure 7 shows the AE-8 and AP-8 predictions of integral flux (electrons > 0.3 MeV and protons > 1 MeV) over the course of 1 day. The observed overall temporal profiles and flux rates agree with predictions quite well.

On 2 Dec 2003, SERVIS LPD detected a sudden, spatially distinct enhancement of low-energy protons. Low energy protons (1-12 MeV) were enhanced first, followed by an enhancement in higher energy protons (12-25MeV; 25-50 MeV). At the same time, there was no discernable change in the electron behavior. The SAA proton flux was also enhanced (see Figure 8) During this same period, a similar enhancement was observed by the GOES satellites (E>10 MeV, E>50 MeV) (Figure 9).

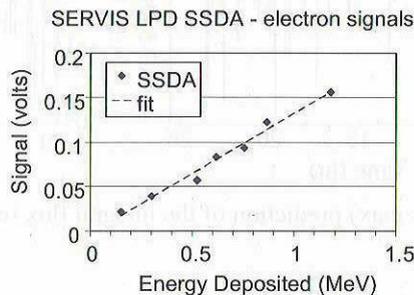


Figure 4. SSD response to electrons

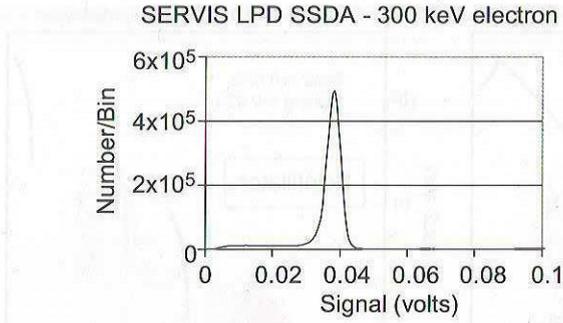


Figure. 5. Histogram of SSD signals from 300 keV electrons.

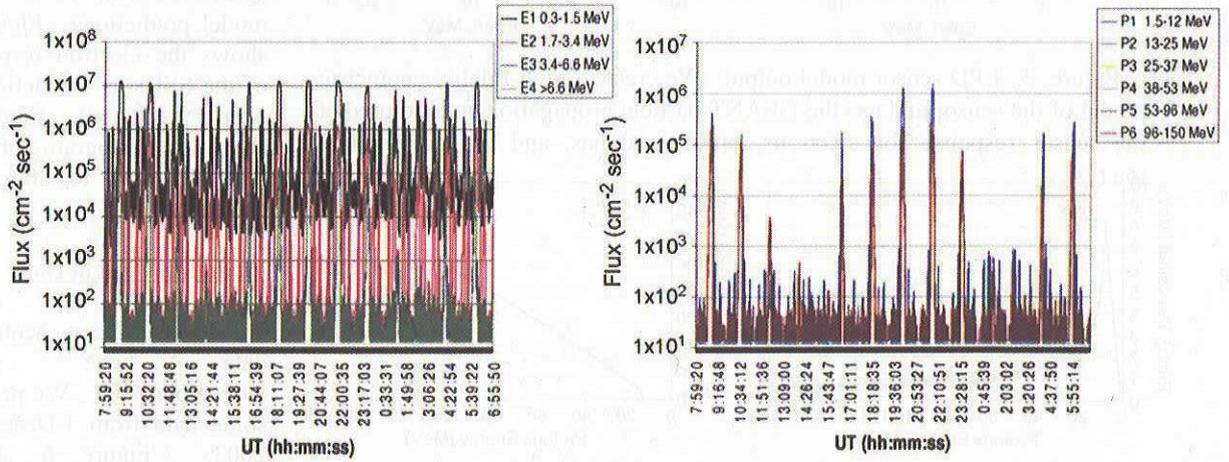


Figure. 6. LPD electron and proton fluxes as a function of time over the period of 1 day (1 Dec 2003).SSD response to electrons.

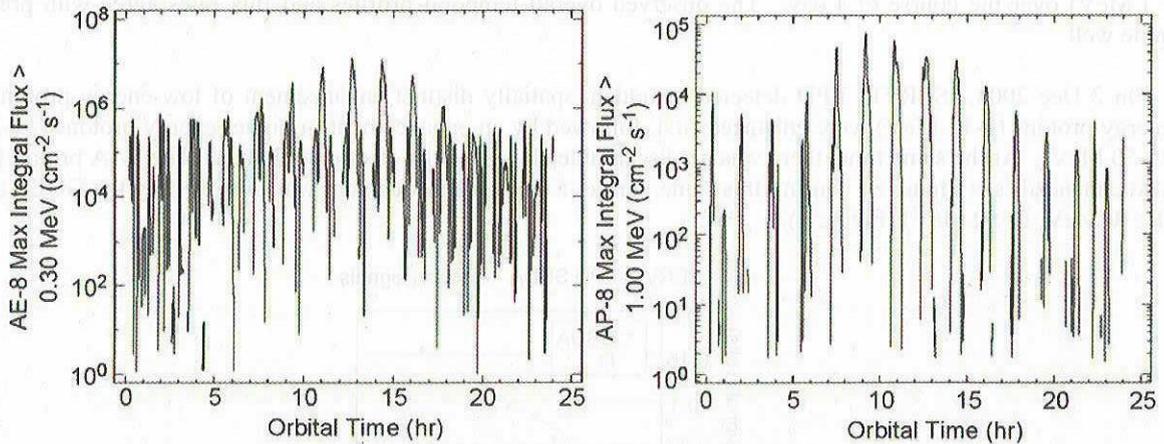


Figure. 7. AE-8 and SP-8 (solar max) prediction of the integral flux (electrons > 0.3 MeV, protons > 1 MeV) over the period of 1 day.

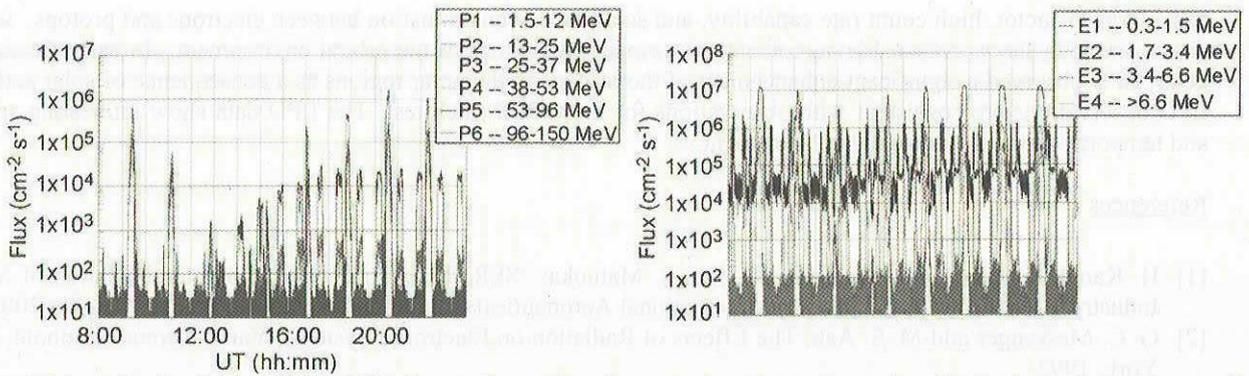


Figure 8. On 2 Dec 2003, LPD detected a sudden increase in proton flux primarily in the polar regions. The enhancement began around 1300 UT. No discernible activity was observed in the electrons.

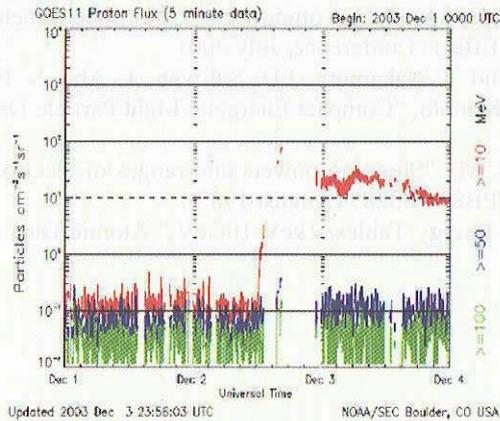


Figure 9. The GOES satellite proton detector response. It is consistent with the LPD observations.

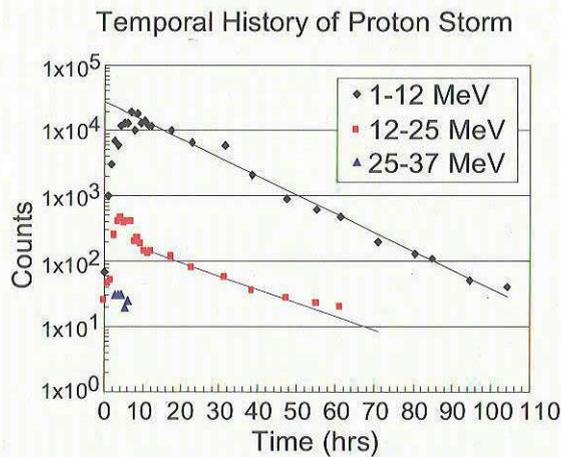


Figure 10. The temporal profile of the proton enhancement measured by LPD.

Conclusions

We have developed a new, high-energy, charged particle spectrometer as part of the Space Environment Reliability Verification Integrated System-1 (SERVIS-1) satellite developed by the Institute for Unmanned Space Experiment Free Flyer (USEF) under contract from Japan's New Energy and Industrial Technology Development Organization (NEDO). LPD has been operational and returning high-quality data since its turn-on in late 2003. LPD

has a large G-factor, high count rate capability, and small cross-contamination between electrons and protons. Initial data from LPD shows reasonable agreement with model predictions of the orbital environment. In early December 2003, LPD observed a significant enhancement of the protons in the polar regions as a consequence of solar activity. LPD observations are consistent with observations for the GOES satellites. The LPD data show interesting spatial and temporal structure during the enhancement.

References

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