Extremely High-Energy Plasma/Particle Sensor for Electrons onboard an ERG Satellite

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Electron radiation belts change dramatically over a period ranging from a few seconds to as long as years. It is well known that the energetic electron flux varies during geomagnetic disturbances and that relativistic electrons in the other radiation belt change with solar wind speed. However, electronic direct observation (10 eV-20 MeV) in the field of acceleration has not been realized to date. To investigate the radiation belt, a smallsat Energization and Radiation in Geospace (ERG) is planned. One purpose of the ERG mission is to reveal the acceleration mechanism of high energy particles in the radiation belt. To achieve this, the ERG will observe electrons directly, which are thought to be accelerated to high energy. In the present paper, we introduce the performance of Extremely High-Energy Plasma/Particle sensor for Electrons (XEP-e) and response result of the sensor by GEANT4 simulations.

Keywords: XEP-e, ERG, Electron Radiation Belts

1. Introduction

The radiation belt, which was discovered by Dr. Van Allen late in the 1950s, was initially thought to be stabilized. However, the radiation belt particles have since been observed by various satellites, and the dynamics of the outer radiation belt have become clear. To date, two or more theories explaining these dynamics have been proposed. It is crucial to clarify the acceleration mechanism of the radiation belt to enable the positive employment of an artificial satellite and to do so, the ERG satellite has been planned as a JAXA science mission. This satellite will carry out the "integrated observation" of particles, electromagnetic fields, and waves in an orbit which traverses the radiation belt. The ERG satellite is intended to answer the following three questions:

- (1) Under what kind of conditions do external supply and internal acceleration occur?
- (2) What kind of physical process is bearing particle acceleration?
- (3) Why does the disappearance mechanism of the radiation belt particle occur?

Currently, we are engaged in research and development in the eXtremely high-Energy Plasma/particle sensor for electron (XEP-e) for ERG. In the present paper, we introduce the principle of the XEP-e and show its current development status with regard to the ERG satellite.

2. ERG Project and XEP-e Sensor

2.1. Purpose of ERG

The high energy electrons of the radiation belt change dramatically in a magnetic storm. During the main phase of the latter, these high energy electrons disappear and it is well known that high energy electrons will swiftly increase in the recovery

phase. Now, as for this process when the radiation belt recovery phase commences, two processes, namely external supply (adiabatic) and internal acceleration (non-adiabatic), are advocated. An adiabatic process is one in which particles are conveyed to the strong magnetic field domain near the earth from the weak magnetic field in the plasma sheet. A non-adiabatic process, conversely, is one accelerated on that spot to relativistic energy by the interaction of a plasma wave motion and particles.

Although the adiabatic process was advocated from the second half of the 1990s, it cannot now be used to explain the rapid radiation belt change. Consequently, the potential increase in electrons from a non-adiabatic process has attracted increasing attention in recent years. This process is made possible by observing the time development of the phase space density. Particularly in the recovery phase of a magnetic storm, if the phase space density increases from outside, it will become adiabatic acceleration, and if increasing from the inside, it will become internal acceleration.

2.2. eXtremely high-Energy Plasma/particle sensor for electron (XEP-e)

The ERG satellite performs four kinds of observations simultaneously, namely plasma particles, a magnetic field, a plasma wave motion, and an electric field, in order to clarify the acceleration mechanism. The Plasma and Particle Experiment (PPE) consists of five observation devices (TSP-e, LEP-e, MEP-e, HEP-e, XEP-e), and observes the electrons over the entire 0.1 eV-20 MeV range.

The range of observations of each piece of equipment is as follows. XEP-e, which we are developing, measures peak energies in these pieces of equipment, and observes changes in the high energy electrons in the radiation belt particle generation

in a magnetic storm. Fig. 1 shows the PPE measuring range.

TSP-e (Thermal- and Suprathermal-energy Plasma/particle sensor for electrons): 0.1 - 10 eV

LEP-e (Low-Energy Plasma/particle sensor for electrons):
12 eV - 20 keV

MEP-e (Medium-Energy Plasma/particle sensor for electrons):
5 - 80 keV

HEP-e (High-Energy Plasma/particle sensor for electrons):
30 keV - 2 MeV

XEP-e (eXtremely high-Energy Plasma/particle sensor for electrons):
200 keV - 20 MeV

Fig. 1. PPE measuring range.

2.3. Development circumstances

Previously, JAXA has carried space environment measuring devices in many satellites [1] [2]. The first equipment was carried in the geostationary satellite ETS-5 (Kiku-5) launched in 1987. The LPT carried in the Jason-2, GOSAT, and QZS satellites is the latest version of such equipment.

The data acquired with this equipment is used in order to keep JAXA satellites from breaking down due to radiation. Moreover, some of the acquired data is exhibited on a WEB site (SEES: Space Environment & Effects System).

Based on the LPT result, the XEP-e equipment raises the resolution and processing speed of energy for ERG satellites.

3. Development Approach

3.1. Sensor head

The ERG satellite outline is shown in Table 1 and it will pass along the same orbit as MDS-1 (Tsubasa) launched in February, 2002. XEP-e was examined based on the predicted value of the AE8 mode, and the observational data of MDS-1. Electronic flux distribution on this orbit is shown in Fig. 2. XEP-e consisted of four solid-state silicon detectors (SSDs) and a high-Z scintillator (GSO). The scintillator adds mass complexity but permits the accurate energy determination of high-energy electrons, while the SSDs provide low-energy differential and total-energy detection, and the scintillator permits high-energy detection and discrimination. The SSD2-4 allow simplification of the circuit adjustment by using the same thickness.

Fig. 3 shows a cross-sectional view of a sensor. Ion-implanted fully depleted silicon detectors from Micron Semiconductor Ltd. are located in close proximity just behind the defining aperture. SSD1 revealed aluminum vapor deposition of 1 μm -thickness, which does not react to 1 solar sunlight. A Scintillator of 2-mm thickness GSO (Hitachi Chemical Co., Ltd.) placed behind the SSD stack resolved up to 20 MeV electrons. The signal from the scintillator is measured by a photomultiplier tube (PMT) (Hamamatsu R9722A), operated at approximately 1400 V and coupled to the scintillator via an optical gasket.

Table 1. ERG satellite outline.

Perigee altitude	350km
Apogee altitude	> 4Re (26000 km)
Orbit inclination	About 31 degrees
Mission period	1 year or more

(a) Electronic distribution of >200 keV

(b) Electronic distribution of >2 MeV

Fig. 2. Electronic flux distribution on this orbit.

Fig. 3. Cross-sectional view of a sensor.

The geometrical factor was designed to 0.006799 cm² sr, meaning the electrons of >300 keV in the outer radiation belt peak could measure $1 \times 10^3 - 1 \times 10^5$ cps. The geometric factor G is given by

$$G = \frac{\pi^2}{2.0} \times \left[r_1^2 + r_2^2 + h^2 - \sqrt{(r_1 - r_2)^2 + h^2} \sqrt{(r_1 + r_2)^2 + h^2} \right] \quad (1)$$

Where, r_1 is the collimator radius, r_2 is the semiconductor sensor radius, and h is the collimator length. To secure a viewing angle correctly, the collimator is made of tantalum, while the sidewall shield excludes penetrating protons up to about 60 MeV at normal incidence using copper. It is still expected that a high energy proton will result in scintillator incidence. We are examining surrounding GSO volumes using a 10-mm thick plastic anticorrelation scintillator (ACS). A photograph of BBM of XEP-e is shown in Fig. 4.

Fig. 4. Photograph of XEP-e BBM with the top cover removed.

3.2. Electric circuit

With the processing speed realized to date, when a magnetic storm occurs and the radiation flux increases, this may result in a saturation phenomenon. Consequently, with power consumption in mind, the circuit was changed, parts were reexamined and peak processing of 6×10^4 cps was enabled. Moreover, telemetry data has three patterns, a table mode, a list mode, and both combined. The table mode divides the measurement energy range into 18 ch, and outputs the count data of each channel, while the list mode outputs the pulse high price of each detector. Moreover, a count value can also be output at the average count for every 1/16 spin.

3.3. Evaluation of sensor performance

The sensor evaluation was performed using the GEometry ANalysi Tool4 (GEANT4) code. The collimated beam of the electron and proton was entered into the collimator, and the deposited energy of SSDs and the scintillator was evaluated. Figure 5 shows the result.

Fig. 5. XEP-e sensor model output.

The result verified the lack of proton contamination when using this system. The measurement started when the pulses were produced coincidentally in the SSD1 and SSD2 above lower threshold SSD1 (60 keV) and SSD2 (100 keV). However, when the pulse of SSD1 exceeded the upper threshold SSD1(300 keV) or SSD2(2 MeV), it was judged to be a proton. Even if the pulse of the scintillator similarly exceeded 20 MeV, it was judged to be a proton. When the pulse of GSO exceeded the lower threshold (250 keV), the particles were judged as having passed all SSD. When the particle stopped in SSD, the sum of the SSD pulse was assumed to be the incidence energy. When all SSD had passed, the total of all SSD pulses and the scintillator pulses were assumed to represent the incidence energy. The performance of the sensor is shown from these results in Figure 6. Figure 6(a) shows the relation between incidence energy and scintillator output. The linearity attains good results overall, though the characteristic declined around 5MeV. Figure 6(b) shows the energy resolutions taking the noise in the detector into consideration, whereupon they became 17, 17, 25 and 17% (10, 1, 7, and 10 MeV respectively). Figure 6(c) shows the detection efficiency of each energy. This time, SSD1 used one of 250 μ m thickness that had already been developed for the spending cut.

For a detector of 250 μm thickness, a detection efficiency of 400 keV or less is considered poor. We are examining measures including lowering the SSD2 signal threshold and reducing the SSD1 thickness.

(a)

(b)

(c)

Fig. 6. Sensor performance.

(a) Relation between incidence energy and scintillator output.

(b) Variation of scintillator output.

(c) Detection efficiency of electron.

While conducting an irradiation experiment with the JAXA accelerator and henceforth checking the sensor performance, the improvement of sensor composition and trigger conditions, etc. are added. The specification target of the final XEp-e is shown in Table 2.

Table 2. Specification of XEp-e.

Viewing angle	$> \pm 10^\circ$
Data out	Every 0.25 sec (1/16 spin)
Energy resolution	Table mode: 200 keV-2 MeV 9ch 2 MeV-20 MeV 9ch List mode: $\Delta E/E = 410 \text{ KeV}$
G-factor	$0.006799 \text{ cm}^2 \text{ sr}$
Size	$190\text{mm}\Phi \times 250\text{mm}$ (goal)
Power	5 W

4. Conclusion

We performed radiation measurements over many years in order to avoid the failure of the satellite used by the Japan Aerospace Exploration Agency (JAXA). We want to develop the XEp-e for the ERG satellite based on the developmental results for the current radiation measurement device, and thus help clarify the radiation belt particle acceleration mechanism.

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