Development and integration of the high-speed current detection circuits in particle sensors dedicated to Wave-Particle Interaction Analyzer

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In outer space near the earth, many high-energy electrons are captured in the radiation belt. Since these electrons cause charging of satellites and interfere with their operations, it is important to predict a fluctuation of electron flux in the radiation belt. When a geomagnetic storm occurs, electron flux in the radiation belt decreases greatly, but after a while, the flux recovers to an original level. We assume that there are some kinds of accelerating mechanisms that produce relativistic energy electrons in space. One of the accelerating mechanisms is "wave-particle interaction." Therefore, observing it from satellites is indispensable for understanding space electromagnetic environments.

Wave-particle interaction is described by the following equation:

$$\frac{\mathrm{d}\{m_0 c^2(\gamma-1)\}}{\mathrm{d}t} = q\boldsymbol{E}\cdot\boldsymbol{v}. \tag{1}$$

m_0 is the rest mass of the particle, c is the speed of light, and γ is the Lorentz factor. According to this equation (1), the phase difference between the electric field vectors and the velocity vectors determines the direction of energy flows between plasma waves and particles. A conventional observation method of wave-particle interaction has a problem that the phase difference information is lost. For this reason, it is impossible to calculate the amount of energy conversion quantitatively. WPIA (Wave-Particle Interaction Analyzer) is a new method of observing wave-particle interaction [1]. It calculates inner product of plasma wave vectors and particle velocity vectors of each particle on a satellite and determines the amount of energy conversion directly. The high relative time precision for detecting vectors of plasma waves and particles is essential in the WPIA. This requires a synchronous performance of plasma wave receivers and particle detectors. We introduce a system that feeds feeble current pulses of particle detectors into plasma wave receivers to achieve the synchronization. Our developed chip consists of two stages. The first stage is the current-voltage conversion circuit. It picks up each current pulse and converts into voltage signals with enough amplitude to drive the second stage. The second stage contains a comparator and a peak-hold circuit. They ensure picking up real signals by setting a threshold level. In this study, we designed the circuits that it operates within several nanoseconds from the arrival of a particle to the rise of the detection signal. Conventional circuits are made of discrete electronic parts. That leads to the increase of their sizes and weights. We integrate detection circuits using ASIC (Application Specific Integrated Circuit) technology. For this reason, the developed chip is highly small and light-weight.

In this study, we develop the circuit which can output detection signals within 30ns after the arrival of particles and can be reset within 12ns on inputting the reset command. The size of one channel of the developed circuit is $210\mu\mathrm{m} \times 570\mu\mathrm{m}$. It is assumed that 16 circuits will be connected in parallel when they are mounted on a satellite, but we can load them into one chip of 5mm square.

In this session, we show the details of the chip designed for the particle detection including experimental results.

References

[1] H. Fukuhara, H. Kojima, Y. Ueda, Y. Omura, Y. Kato, and H. Yamakawa, "A new instrument for the study of wave-particle interactions in space: One-chip Wave-Particle Interaction Analyzer," Earth Planets Space, 61, 2009, pp.765-778.