Research of radiation testing method for Lean-satellites using Californium-252

I. BACK GROUND

In recent years, many lean-satellites are being developed in universities and private enterprises. Characteristics of these lean-satellites are low cost and short development period. Therefore, commercial off the selves (COTS) ICs are often used in lean-satellite manufacturing projects. However, COTS components are not designed for space usages. Therefore, the reliability of COTS component in the space environment is under questions and it will force the safety level of lean-satellite down directly. In order to raise the reliability in the space environment, the environmental test of COTS components is required.

This paper describes about radiation test. Since the conventional radiation tests use a particle accelerator, it requires time and cost as well as the test method is complicated. Therefore, It has been focused on Californium-252 (^{252}Cf) as an alternative radiation source similar to particle accelerator. ^{252}Cf is a radio isotope that continuously emits heavy ions. It also does not need a large-scale infrastructure, moreover, it is easy to handle.

II. OBJECTIVE

Single-Event-Latchup (SEL) is mentioned as one of the most fatal incidents occurs in radiation environment, which takes place in a satellite. SEL is the phenomenon that generates over-current in the IC, when a particle strikes a semiconductor surface followed by static charges generation that ultimately causes failure of IC. By using the radiation source of ^{252}Cf, on orbit SEL was simulated on H8/36057 microprocessor, which is on board Horyu-2. Horyu-2 is a lean-satellite developed by Kyushu Institute of Technology, Japan, launched on 18th May 2012. Up to now (March, 2015), 8 times SEL was observed on the H8/36057 on board Horyu-2.

^{252}Cf doesn't emit proton which is main cause to occur SEL on orbit but heavy ions. Therefore, it is difficult to compare the result of ^{252}Cf test with the on orbit environment easily. The purpose of this paper is to compare SEL occurrence probability between ^{252}Cf and orbit environment and lead the radiation test method suitable for lean-satellite.

Ⅲ. TESTING METHOD

Radiation test was in the Kyoto University Research Reactor Institute, Japan. Fig.3-1 shows the chamber for radiation test facility. The radiation source is movable. Flux of heavy ions can be controlled by setting the distance between target and radiation source.

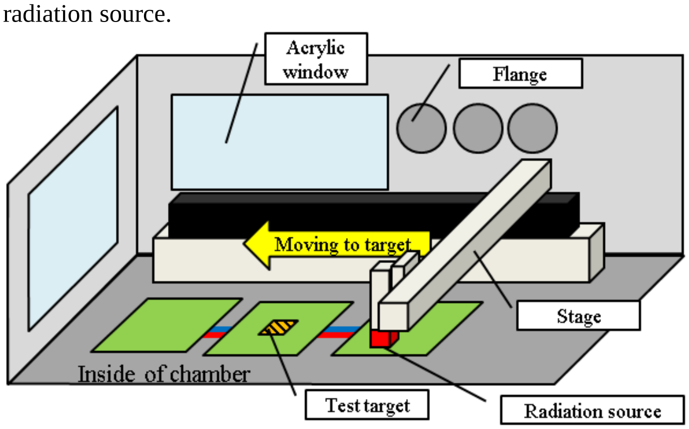

Fig.3-1 Arrangement inside of chamber (Schematic)

Ⅳ. TEST METHOD

Particle flux was changes day by day since ^{252}Cf was a radioisotope. In order to have a constant flux, distance between target and radiation source was controlled. When it was not controllable, test under various fluxes was also done. Fig.4-1 shows the schematic of sample arrangement with radiation source. At the beginning, current due to radiation was measured that helped calculating the flux. Then radiation source was placed on the sample followed by power on and time counting. As soon as SEL occurs, timer was stopped followed by recovery of H8/36057 by restating the power. These steps were repeated 100 times at different sample to source distances (1cm, 2cm and 3cm). Current consumption was measured from the voltage drop across a 1Ω resistor shown in Fig.4-1. Finally, these results were compared with the Horyu-2 on orbit data.

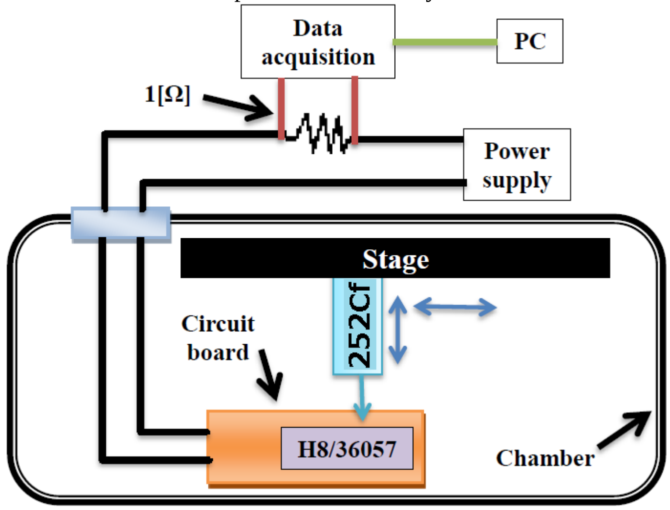

Fig.4-1 Experimental schematic

Ⅴ. TEST RESULTS

Ⅴ. Ⅰ .RESULT OF 252CF TEST

Current consumption when SEL occurred is shown in Fig.5-1.

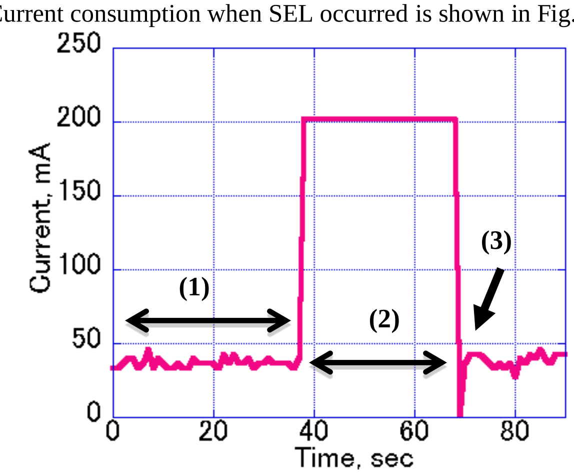

Fig5-1. Current consumption of H8/36057 during the SEL occurred.

During the section (1), the experimental board was working normally. In section (2), SEL occurred and duration was 38 seconds and the current was increased to 200mA. At section (3), the H8/36057 was rebooted and returned to normal mode.

Table.5-1 shows average occurrence time, total time and flux of ions for 100 number of SEL at three different distances. Then, the fluence of ions from radiation source was 786[ions/sec]. And area of microchip is 0.2cm^2.

Table.5-1 Result of SEL occurrence at three distances

	1[cm]	2[cm]	3[cm]
Average time [s]	19.3	42.2	86.3
Flux [ions /(sec・cm^2)]	6.2	2.5	1.2

Now, SEL occurrence probability cross-section can be measured as below

$$\text{Cross-section}=1/(\text{Ave.time}*\text{flux})\ [\text{cm}^2/\text{ions}] \quad [2]$$

Table.5-2 shows cross-section of each distance.

Table.5-2 Cross-section for three distances

	1[cm]	2[cm]	3[cm]
Cross-section [cm^2/ions]	8.4×10^{-3}	9.5×10^{-3}	9.7×10^{-3}

This evaluation method doesn't depend on the distance. However, result is different from each other. Therefore, it can be conferred that the cross-section of H8/36057 was 8.4~9.7x10^{-3}[cm^2/ions].

Ⅴ.Ⅱ.RESULT FROM HORYU-2

There are two microprocessors (H8/36057) on board Horyu-2. Until now (March, 2015), 8 SEL was observed. Table.5-3 shows SEL occurrence time on orbit. The average time of SEL occurrence is 155 days.

Table.5-3 SEL occurrence time on orbit

	H8①[days]	H8②[days]
First	18	43
Second	697	152
Third	162	11
fourth	2	19

By the Horyu-2's on orbit current consumption, it was confirmed that SEL occurred. Fig.5-2 shows current consumption of Horyu-2's DC/DC converter when Horyu-2 recovered from failure. Horyu-2 has two DC/DC converters. H8/36057 used 3.3V converter's voltage. This sampling rate is 10minutes.

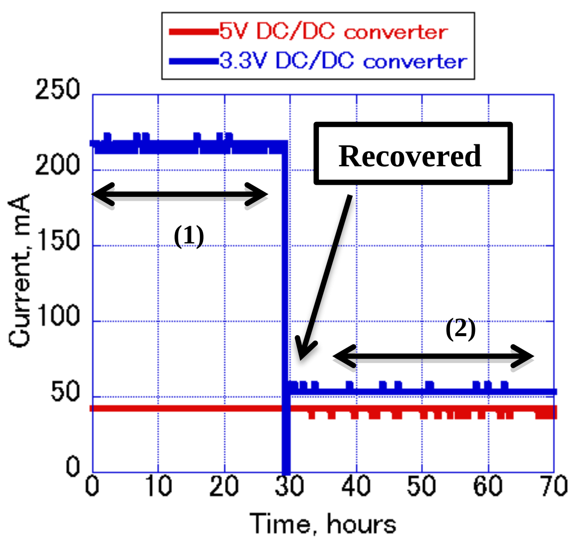

Fig.5-2 current consumption of Horyu-2's DC/DC converters (orbit data)

During the section (1) in Fig. 5-2, SEL occurred on second microprocessor, H8②. At 30 hours, H8②was recovered. This situation is similar to the simulation radiation test by ^{252}Cf test shown in Fig.5-1. Therefore, Horyu-2's power consumption became higher than power generation. So, supply current decrease and became 0mA. It means H8/36057 was in power off and recovered from SEL. At (2), H8/36057 was returned to normal mode. Therefore, it can be concluded that similar situation was simulated by ^{252}Cf radiation test and on board sudden current jump was due to SEL.

Ⅵ.CONSIDERATION

On orbit proton flux whose energy is higher than 20MeV has been calculated during the period from May, 2012 to December 2014 using by SPENVIS. SPENVIS is website of space environment information. Then, average flux is found 68.7[protons/(cm^2.sec)] and the cross-section on Horyu-2 orbit is 1.1x10^{-9}[cm^2/protons] using average time of 155days until SEL occurred. Therefore, the cross-section of 8.4~9.7x10^{-3}[cm^2/ions] in case of ^{252}Cf radiation testing system corresponds to 1.1x10^{-9}[cm^2/protons] on PEO.

Latter, probability distribution SEL is also investigated. First, it is analysed whether SEL is Poisson distribution. Fig.6-1 shows occurrence probability at each time of results of 1cm. Red line shows equation [3].

$$P(t)=\exp(-\lambda t) \quad [3]$$

This equation is Poisson distribution. λ means 1/(average time). t means horizontal value. Since it follows red line, it can be concluded that SEL distribution is Poisson type.

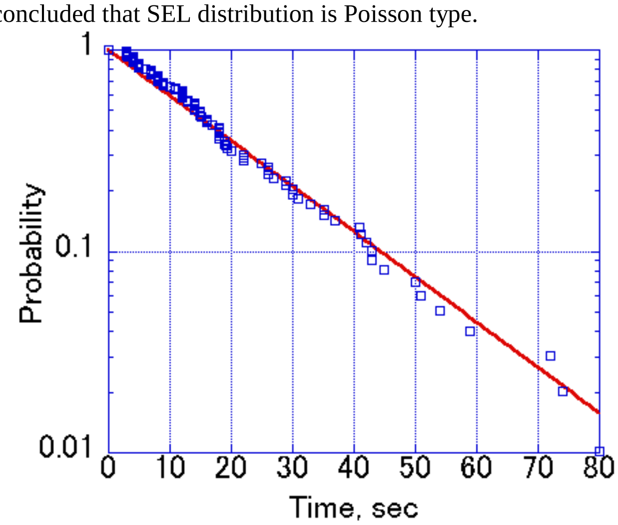

Fig.6-1. Occurrence probability at each time

Ⅷ.CONCLUSION

Single event latchup (SEL) test has been simulated by using ^{252}Cf as radiation source on a microprocessor (H8/36057). This H8/36057 IC is a COTS component used on Horyu-2, a 30cm cubic nan-satellite, made by Kyushu Institute of Technology, Japan. Through this ground result, cross-section was calculated 8.4~9.7x10^{-3}[cm^2/ions]. After investigating the on-orbit data of Horyu-2, cross-section was found 1.1x10^{-9}[cm^2/protons] in PEO. Therefore, it is concluded that cross section of 8.4~9.7x10^{-3}[cm^2/ions] is equivalent to the cross section of 1.1x10^{-9}[cm^2/protons] in LEO. Using these numbers as references, the first-order estimate of the SEL probability in orbit can be obtained by comparing the SEL cross-section to the H8/36057.

It is also concluded that SEL follows the Poisson distribution.