Mission Results and Anomaly Investigation of HORYU-II

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ABSTRACT

HORYU-II is a 30cm-cubic nano-satellite weighing 7.1kg developed by Kyushu Institute of Technology. HORYU-II was launched to 680km Sun-synchronous orbit as a piggy-back satellite onboard a H-IIA rocket of JAXA on May 18, 2012 (Japan standard time). Its main mission is to demonstrate high voltage photovoltaic power generation technology. HORYU-II succeeded in generating high voltage photovoltaic power, up to 350V, which is the world record as power generation voltage in orbit. The past record was 160V held by the International Space Station. HORYU-II also carried out other technology demonstration missions related to electrostatic discharge mitigation solar array designs, a spacecraft charging monitor, a passive spacecraft charging mitigation device, and a debris impact sensor. Three weeks after the launch, HOYRU-II suffered a serious anomaly for one month, and the satellite was not able to communicate with the ground station. Based on the anomaly investigation including various ground tests, the authors judged that a single event latch-up (SEL) due to radiation was the most probable cause. SEL occurred on two microprocessors. When the second SEL occurred, the battery was depleted due to the increased current consumption. The battery's depletion reset HORYU-II, and the satellite could be restored to its original condition. The lessons of HORYU-II suggest the needs of environmental testing standard to improve the satellite reliability, especially at the early phase of operation in orbit.

INTRODUCTION

Thanks to the rapid development of small satellites and the increase of launch opportunities, universities and private companies can nowadays access space more easily. Small satellites are developed at lower cost in a shorter term than big satellites. Moreover, the Japan Aerospace Exploration Agency (JAXA) offers piggy-back launch opportunities. Therefore, many universities in Japan are developing small satellites for new space technology demonstrations as a part of the education for the purpose of learning systems engineering and project management.

The Kyushu Institute of Technology (KIT) satellite development project has been working to develop nano-satellites since 2006. HORYU-I, a 10cm-cubic nano-satellite, was developed for the 100th anniversary of KIT as a memorial satellite. However, the launch was postponed indefinitely due to some issues with the launcher. From April 2010, the high voltage technology demonstration satellite HORYU-II was developed based on the bus system of HORYU-I. On May 18, 2012, HORYU-II was launched by a H-IIA rocket as a piggy-back satellite. Three weeks after the launch, HOYRU-II suffered a serious anomaly for one month. However, the satellite was restored to its original condition. In the first half of this paper, the mission results of HORYU-II will be presented. In the second half of this paper, the anomaly investigation and the lessons learned will be presented.

THE SPECIFICATION OF HORYU-II

Satellite Overview

Specifications of HORYU-II are shown in Table 1. The purpose of HORYU-II is demonstration of high voltage photovoltaic power generation technology. When a satellite generates a high voltage in space, especially in the low earth orbit (LEO) where plasma density is high, the probability of discharge occurrence becomes high because the satellite is charged to the same voltage than its generation voltage. In the worst case, all functions of a satellite may be lost due to discharges on solar panels, making difficult to have the adequate power supply for the missions. For instance, the Earth observation satellite ADEOS-II developed by the JAXA lost 80% of its power capacity after an electric discharge accident, which led to the end of its operations. The negative impact of electric discharge accidents on spacecraft is thus non negligible. Before HORYU-II, the International Space Station (ISS, 100kW-class) was the spacecraft able to generate the highest voltage in LEO with 160V. A future 1MW-class spacecraft will require high voltage of 300 to 400V. However, when the voltage exceeds 200V in LEO, the probability of arcing increases dramatically, which was the reason to limit the voltage of the ISS to 160V. In the future, larger space systems such as space hotel, space factory, and technology demonstration satellites will require the high voltage technology to operate at a voltage higher than 160V. Since high voltage photovoltaic power generation was demanded, KIT decided to develop HORYU-II to demonstrate the feasibility of achieving 300V in LEO without creating arcing. Solar arrays with arcing mitigation technologies were intentionally kept to a highly negative potential with respect to the ambient plasma by a solar array generating more than 300V. Under this condition, the mitigation technologies and the tolerance against LEO environment were evaluated. HORYU-II also carried out other technology demonstration missions such as a spacecraft charging monitor, a passive spacecraft charging mitigation device, and a debris impact sensor. The overview of HORYU-II is shown in Figure 1.

Table 1: The specification of HORYU-II

Size	350×310×315mm
Mass	7.1kg
Design Life Time	1 year
Orbit	Sun-synchronous polar orbit
Altitude	670km

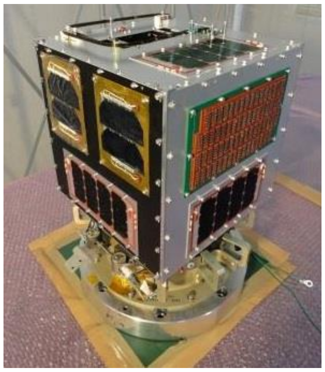

Figure 1: Overview of HORYU-II

Past High Voltage Experiments on Orbit

In the past, several high voltage experiments on orbit were performed as shown in Table 2. However, solar cells were mainly biased to a highly negative potential by a DC/DC converter. This biasing method had several disadvantages. For example, the DC/DC converter broke down easily, and the arcing current path along with the response to the ambient plasma were different from the actual conditions.

In 1996, the Space Flyer Unit (SFU), launched by Japan, was planned to perform high voltage experiments by using a solar array (maximum expected voltage: 260V). This project, however, resulted in failure due to harness disruption. Therefore, the high voltage power generation above 200V has not yet been tested in LEO. For the first time, HORYU-II demonstrated the feasibility of high voltage photovoltaic power generation in LEO. The greatest feature of HORYU-II mission is to perform the high voltage experiments via a specially designed high voltage solar array instead of using DC/DC converter.

Table 2: Past high voltage experiments on orbit and HORYU-II

Age	Country	Satellite/Mission	Bias method
1980s	USA	PIX I, II	DC/DC converter
1990s	USA	SAMPIE, PASP	DC/DC converter
1996	JAPAN	SFU	Solar array
2011	JAPAN/USA	MISSE-8	DC/DC converter
2012	JAPAN	HORYU-II	Solar array

SPECIFICATIONS OF MISSION PAYLOADS

In this paper, only the 300V generation which is the main mission of HORYU-II is described.

High Voltage (300V) Array

The high voltage array is not used for orbital demonstration nor as a power supply to the satellite bus system, but is used to create an environment prone to discharges. Figure 2 shows an overview of the high voltage (300V) array. The size is 122×214mm and the mass is 186g. Conductive surfaces of the 300V high voltage array are covered with RTV adhesive to prevent arcing.

The high voltage solar array consists of spherical solar cells made by Sphelar Power Co., Ltd. The generation voltage per spherical solar cell F12 module (spherical cell module) is approximately 7V (open circuit voltage, room temperature). Two high voltage solar arrays connected in series are mounted on HORYU-II. The high voltage solar arrays are mounted on each panel in a symmetrical manner as shown in Figure 2. Each high voltage solar array consists of 66 spherical cell modules in series. If all modules generate at the open circuit voltage, the maximum generation voltage is approximately 900V. The high voltage solar arrays were designed to have sufficient margin against partial breakages at launch, degradation due to thermal cycle, and other environmental factors. Therefore, the generation voltage of the high voltage solar array was limited to 350V by zener diodes.

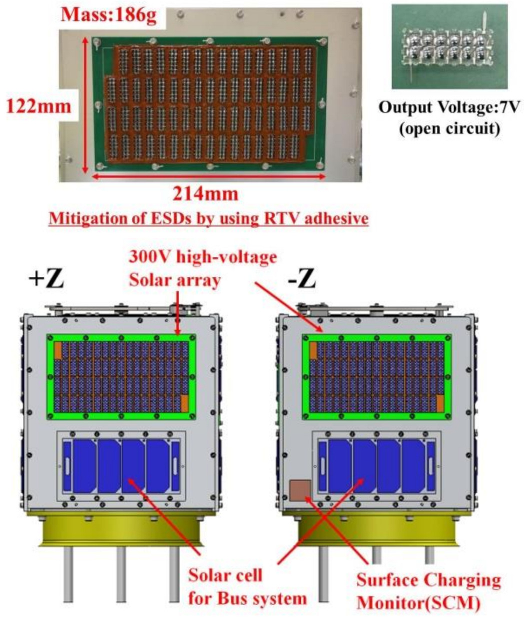

Figure 2: 300V high voltage solar array

Electronic Circuit Board of 300V System

The board is very small and light. All parts of the electronic circuit are inexpensive commercial off-the-shelf (COTS) parts, which can be easily purchased in a short time.

Circuit Design

The electric circuit of 300V system is shown Figure 3. The mission payloads related to high voltage and discharge are completely insulated from the bus system for safety reason. An insulated DC/DC converter is used as the power supply and magnetic couplers are inserted in the control signal transmission line.

After receiving test commands from the onboard computer of the bus system, 300V system CPU turns on the short-circuited switch connected parallel to the high voltage solar array. Then, the high voltage solar array starts generating as they are illuminated by the sunlight. During the test, the AD converters of 300V system CPU measure the photovoltaic generation voltage, the potential of 300V system, and the board's temperature.

For the measurement of the potential, surface charging monitor (SCM), which has been flight proven in the past, will be used. SCM is composed of flour-polymer resin over a copper substrate. SCM measures the voltage across the flour-polymer resin and the ground (300V system ground) via division of capacitances. Since both the surface of the flour-polymer resin and the electron collector are almost equal to the plasma potential, the potential of 300V system is acquired by the measurement of the voltage between the surface and the ground.

To evaluate the tolerance against space environment of state-of-the-art arcing mitigation methods, we put three types of solar arrays as test specimen as shown Figure 4. Each solar array consists of two series-connected conventional GaAs/InGaP/Ge multi-junction solar cells. One of the solar arrays (nominal TJ array) is used as a reference and free of arcing mitigation method. Two of the solar arrays (film TJ array and coating TJ array), are arranged for each arcing mitigation. The TJ arrays are connected via the switches (MOSFET, for biasing) to the negative end of the high voltage solar array, where arcs tend to occur. Discharge test will be performed on each TJ array when the biasing switch is activated.

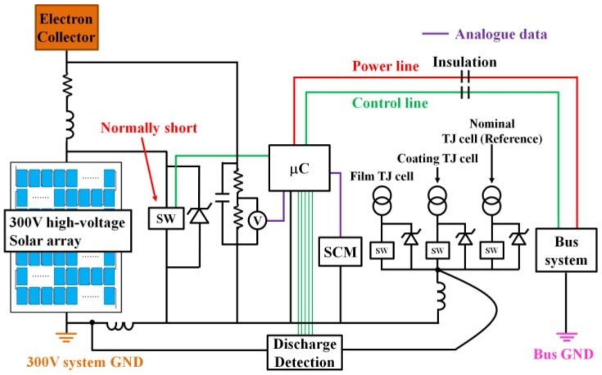

Figure 3: Electric circuit of 300V system

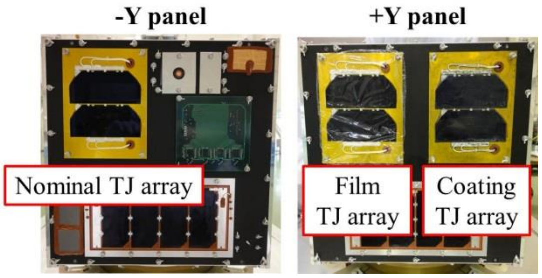

Figure 4: Three types of TJ array as test specimen

TEST PLAN ON ORBIT

The mission success criteria is whether the high voltage solar arrays stably generate over 300V with no arcing. To fulfill the criteria, the generation voltage of the high voltage solar array and the potential of 300V system are measured. The measurements are performed every one minute and before an arcing event. In addition, arc detection is performed every second. Note that arcing data is saved only when an arcing event is detected.

There are five test modes as listed in Table 3. In the mode1, the measurement of temperature and the potential is performed in 25 seconds to check the soundness of the circuit board. In the other mode, the test time is one hour for each test mode so that HORYU-II is illuminated by the sunlight whenever the test starts. For the evaluation of the tolerance against LEO environment of arcing mitigation, each TJ array is biased in turn, and then the numbers of arcing are compared among three TJ arrays.

Table 3: Test mode

Test Mode		Biased array	Test time
1	Initial operation check	-	25sec
2	300V generation mode	-	60min
3	Nominal TJ array mode	Nominal TJ array	60min
4	Film TJ array mode	Film TJ array	60min
5	Coating TJ array mode	Coating TJ array	60min

ON-ORBIT MISSION RESULT

The result of 300V photovoltaic power generation during one-hour operation is shown in Figure 5.The generation voltage is above 300V. And the potential measured by SCM is also above 300V. Therefore, it is confirmed that HORYU-II successfully generated the highest photovoltaic voltage in space, for the first time in the world. Moreover, because the potential is above 300V, HORYU-II also successfully created an environment prone to electric discharges.

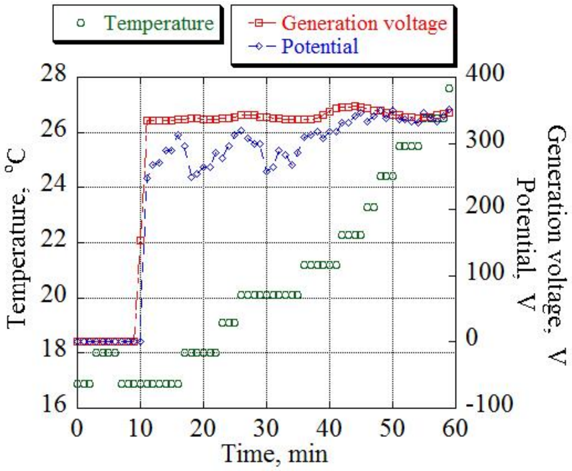

Figure 5: Result of 300V generation

The arc detection circuit also worked well in space. As shown in Table 4, HORYU-II could detect discharges on TJ solar arrays.

Table 4: The number of Arc detection

	Mode 2	Mode 3	Mode 4	Mode 5
TJ discharge	0	34	6	0
Momentary stop of PIC	12	8	9	5
Total test time [min]	790	680	620	620

"Momentary stop of PIC" represents the PIC of the 300V system that stopped working for an instant. This phenomenon is confirmed with the discharge test on the ground and the on orbit 300V generation (Mode2). It is, however, not sure that the momentary stop of PIC is related with a discharge.

From the obtained data, compared with three types of TJ array, the number of discharge on the film and the coating TJ array is less than that of discharge on the nominal TJ array. Therefore, the authors could confirm the effect of electrostatic discharge (ESD) mitigation solar array designs.

SPECIFICATIONS OF BUS SYSTEMS

The block diagram of the on-board computer (OBC) is shown in Figure 6. OBC has two identical microprocessors, which are industrial microprocessors for automobiles usually called H8. MAIN carries out acquisition and preservation of housekeeping (HK) data and a part of mission data. MAIN also turns on and off each mission instrument. COM sends transmission data to the ground, interprets the signal sent from the ground, and hands the data to MAIN. MAIN and COM watch each other. If one side does not send a return signal within a certain time, the other side forces the reset.

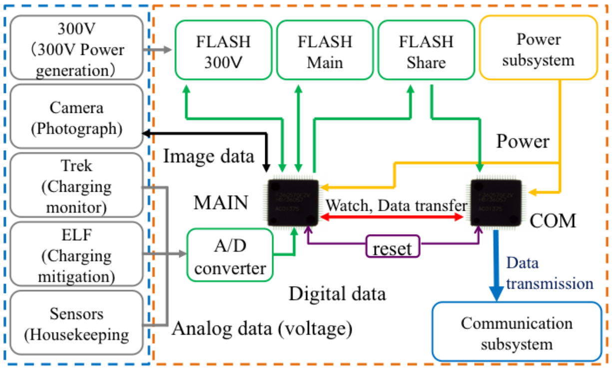

Figure 6: Block diagram of OBC

The authors inherited the design of OBC made of two microprocessors from HORYU-I. Originally HORYU-I project selected H8 mainly because other university satellites used it. Radiation test to select the electronic parts was not performed because it would have increased development time and cost. Instead, the following mitigation against radiation were selected: (1)

periodic reset every 3 hours, (2) mutual watching by two microprocessors, (3) spot shield by 3mm thick tungsten sheet, (4) over current protection circuit in the power line to OBC that will activate when the current exceeds 0.5A.

Figure 7 shows the operational sequence of HORYU-II. As the nominal operation mode, the satellite repeats the call sign, JG6YBW HORYU and the real-time housekeeping (RTHK) data made of 15 characters (4bits per each character) via Morse code. This transmission lasts 20 seconds. Then the satellite waits for 30 seconds to receive uplink command from the ground. If the command does not come, the satellite resumes the call sign and the RTHK data. This sequence of about 1 minute is repeated except during the mission or when the satellite is transmitting packet data.

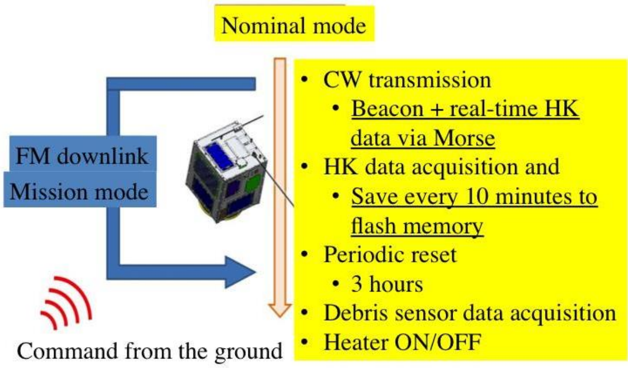

Figure 7: Operational sequence of HORYU-II

During the nominal operation mode, the MAIN microprocessor collects data from various sensors inside the satellite every 10 minutes and stores the data in a flash memory. The satellite sends this sensor data as packets once it receives the command from the ground to downlink the sensor data. Once the ground station sends a command to the satellite, COM microprocessor receives the command and sends back the acknowledgement to the ground. The COM hands the command data to MAIN. If the commands are sensor data to downlink, MAIN retrieves the specified data from the flash memory and transfers it to another flash memory shared with COM. MAIN gives the address on the shared flash memory to COM. COM retrieves the data from the shared flash memory and sends it to the ground.

Figure 8 shows the block diagram of communication subsystem. PIC microprocessor generates the call sign and sends it to continuous wave (CW) transmitter. After the call sign is sent, PIC controls the multiplexer so that COM and the CW transmitter are connected. COM converts the RTHK data given by MAIN to Morse code and sends them to the CW transmitter. The CW transmitter is shared by COM and PIC. The multiplexer is governed by PIC, which means we trusted PIC over COM (H8). PIC is used for the call sign for the case anomaly occurs on OBC. Even if something goes wrong with OBC, the satellite keeps sending the call sign so that the satellite will not be lost. During the anomaly in orbit, this contingency mode worked and the satellite could be tracked. The reason why PIC microprocessor was chosen is that it was a different type from the microprocessor used for OBC and many university cubsats had used PIC.

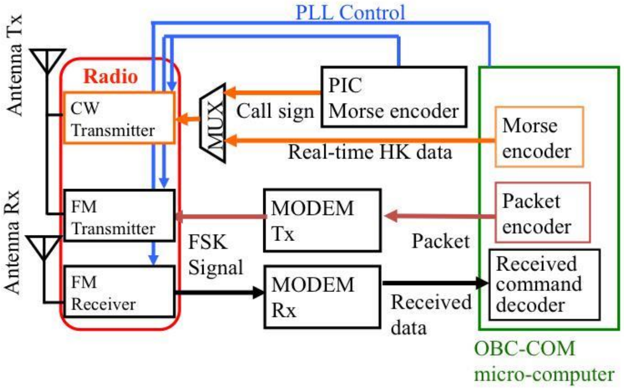

Figure 8: Block diagram of communication subsystem

ON ORBIT ANOMALY

Since its launch on May 18, 2012, the condition of HORYU-II was very healthy. There was no anomaly in RTHK or detailed sensor data sent every 10 minutes. The satellite bus system was functioning normally. On June 5, 2012, however, a serious anomaly occurred. The phenomena observed were as follows:

1. The content of RTHK data is not renewed.
2. The status of one kill-switch in RTHK indicated ON.
3. When we send a command to downlink the sensor data, the satellite returns only acknowledgement but no sensor data.
4. Even if reset command was sent from the ground, no change was observed.

From these phenomena, we identified either MAIN microprocessor or the parts to reset MAIN as possible anomaly cause. The location where the anomaly occurred was inferred as 10 to 20 minutes past the end of eclipse from the fixed RTHK data (the battery current and the transmitter temperature). The inferred location matched South Atlantic Anomaly (SAA) at the south-east off the shore of Brazil. The remaining causes left after fault tree analysis were the following,

1. Soldering of electronic parts damaged by thermal cycle.
2. Discharge on OBC circuit board due to internal charging.
3. Foreign particles caused short-circuit on the circuit board.
4. Reset parts damaged by radiation.
5. Microprocessor went out of control due to single event effect (SEE).

For the cause 1, we carried out thermal cycle test using the spare board in nitrogen environment. From the telemetry data before the anomaly, the circuit board was within -5 to +25°C, mostly 0 to +20°C. 600 cycles were carried out, twice the actual cycle before the anomaly in orbit. One cycle was 15 minutes. The temperature range was -10 to +40°C. No defect on the circuit board was found. The electrical functions were quite normal after the test. This circuit board was soldered by a manufacturer whom we ordered via the Internet. The soldering method was no different from ordinary soldering for COTS products. Even such circuit boards can endure this level of thermal cycles.

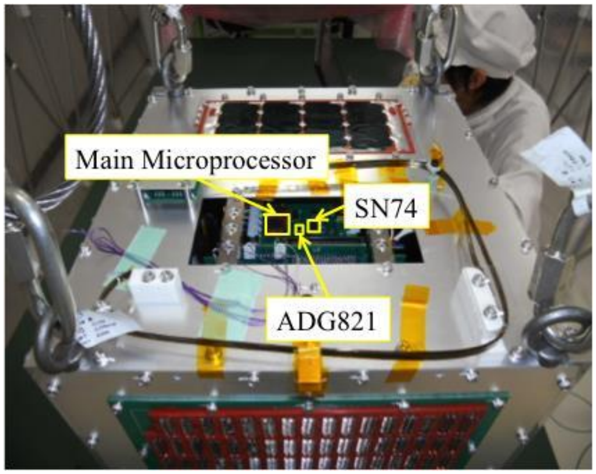

Figure 9: OBC circuit board

OBC circuit board is located near the satellite external panel (1mm thick aluminum) as shown in Figure 9. During the ground works, the access port was facing upward. Therefore, there is a possibility that foreign particles entered through the opening. As a lesson, we learned that the access port should not be upward. Electrons with energy higher than 500keV can penetrate the 1mm thick aluminum plate. Assuming the circuit board has a thickness of several millimeters, including the electronic parts, we can assume that electrons, whose energy ranges from 500keV to 2MeV, charge the circuit board. There are many grounded metals in the circuit board. Therefore, the charge can relax with time. However, if the relaxation process is slow, the charge accumulates with time.

The authors investigated by a ground test how soon the charge relaxes. A spare circuit board was set up in a vacuum chamber and irradiated by an electron beam of several keV. Measurements on how the charge decayed were performed. Figure 10 shows the test result. We can see that the charge did not relax even after several hours. As increased the charging potential was increased, discharge at -3.5kV could be confirmed. The electron flux data from 500keV to 1.6MeV, measured by Low Particle Telescope (LPT) onboard GOSAT that flew onto a similar orbit as HORYU-II, were analyzed. From May 18 to June 5, the average current density to the OBC board was approximately $1x10^{-10}$A/m^2. From the ground test result, if a capacitance of $4.4x10^{-7}$F/m^2 is assumed, the electron current density is short by one order of magnitude to charge the OBC board to -3.5kV. The internal charging can thus be dismissed from the possible cause of the anomaly for this case. Nano-satellites, however, whose internal circuit boards are separated from the outer space by just one single aluminum panel, have a larger risk of internal charging compared to conventional satellites. In future, the issue of internal charging needs to be further investigated.

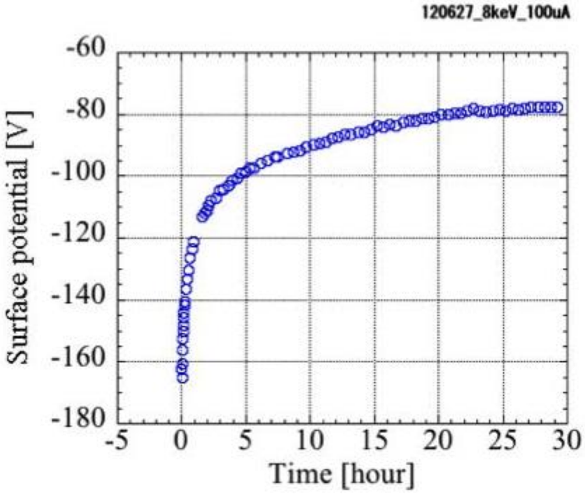

Figure 10: Charge relaxation process on the OBC circuit board

While we were preparing for SEE test scheduled in August to confirm the causes 4 or 5, the anomaly condition got worse on June 30. Among the CW signal, only the beacon could be received. COM also went out of control and only PIC was operating. Although it was a very critical situation, on July 3 the satellite conditions went back to normal. We confirmed that RTHK signal was renewed. The detailed sensor data were downloaded and it was found that the battery was almost depleted. Later, the battery was charged to the normal state. From the fact that the satellite recovered, we can say that the anomaly was not a permanent one.

Therefore, even it was due to radiation, we could exclude total ionization dose (TID) as the cause.

SEE test was carried out at Nuclear Reactor Experiment Facility of Kyoto University, using a californium irradiation facility. MAIN and COM microprocessors and reset-related electronic parts on the OBC board were tested after removing the plastic packages. The OBC board was put in the facility along with the spare board of power and communication board and the radio transmitter. The same microprocessors as the one onboard HORYU-II, HD64F3605FZJV, were already out of production. Therefore, we used a similar one, HD64F36057FZV, which had a different temperature range and better yield rate. Californium produces heavy ions as fission fragment of ^{252}Cf in addition to neutrons. The latter are only 3% of the fission fragment, but centered at 102.5 and 78.7MeV with a mass of 106.2 and 142.2 AMU. The average LET for silicon is 43.0MeVcm^2/mg. The purpose of the test was to investigate whether SEE, especially latch-up, really occurs or not and whether we can reset the microprocessors if the latch-up occurs. SEE on the electronic parts related to reset could not be observed, but SEE could be easily observed on the microprocessors.

Figure 11 shows the SEE test result. The ^{252}Cf source was placed 2cm above MAIN and turned on the microprocessor. Within one minute, SEE occurred and the consumption current (we measure the power line from the external power supply) increased by a step of 0.1A. The MAIN went out of control. While MAIN was out of control, we moved ^{252}Cf over COM. Then COM went out of control too and the current increased by 0.1A. Once a microprocessor went out of control, the reset command sent from the external PC could not reset the processor. To return the microprocessors to the normal state, we had to turn off the power once.

During the test, the current to OBC was supplied through the power circuit of HORYU-II. When SEE shown in Figure 10 occurred, however, the over current protection circuit on the power board did not activate itself. We inferred that the current flew was just below the threshold current, 0.5A, of the circuit breaker.

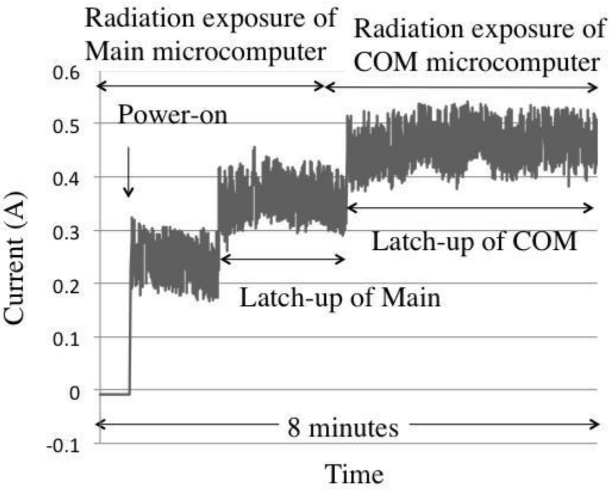

Figure 11: Current supplied by external power supply during irradiation by californium

Based on the SEE test result, we can conclude the cause of anomaly as the following:

1. On June 5, a microprocessor suffered latch-up due to radiation. It went out of control and could not respond to even a reset signal.
2. On June 30, the second microprocessor suffered latch-up.
3. The power consumption increased and the battery could not be charged fast enough.
4. On July 3, the battery voltage dropped below the maximum voltage to active the DC/DC converter. The power to OBC board was shut down once and the microprocessors were hard reset.

The anomaly could be reproduced by SEE. Yet, there is still one open issue in the anomaly investigations, the anomaly location. At the beginning, we inferred that the location was over SAA from the frozen RTHK data. After the recovery, the sensor data remaining on the flash memory were analyzed. The last point when the normal sensor data were written was 30 minutes before SAA, near the equator, over New Guinea. The two data points at two different locations. From the limited amount of data, we could not narrow the location further.

LESSONS LEARNED FROM OPERATIONS OF HORYU-II

We have described the mission results and the anomaly investigation. HORYU-II could establish an electric discharge test method on the orbit by simulating electric discharge environment intentionally because of high voltage power generation. In addition, because not enough data were collected to confirm ESD mitigation solar array designs, we want to carry out further experiments on orbit.

In the development stage, the influence of radiation was not seriously considered because the orbit of HORYU-II was LEO and the design life time was only 1 year. However, HORYU-II suffered a serious anomaly during one month only three weeks after the launch due to radiations. To take measure of single event latch-up, we inserted over current protection circuit in the power line to OBC that will activate itself when the current exceeds 0.5A. However, the validity of the threshold current was not confirmed because we were too optimistic about the estimate of the radiation effects. When a single event latch-up occurred, the over current protection circuit did not activate itself because the current flew was just below the threshold current. Moreover, we thought HORYU-II recovered from a single event latch-up because of periodic reset every 3 hours. However, this reset was only the measure for soft abnormalities, and HORYU-II did not take measures for hard abnormalities.

Not many nano-satellites do SEE test. However, the authors recommend to do SEE test at least at circuit board level to know how the satellite system behaves when a single event occurs and confirm that the mitigation method actually works.

The advantages of nano-satellite are their low-cost and fast-delivery. These advantages are gained by the extensive use of COTS components and pats. Because COTS components are not meant for use in space, tests must be performed to confirm that they are resistant to space environment. Many tests increase cost and may kill the advantages of the nano-satellite. In the case of HORYU-II, many verification tests were performed by using test facilities at KIT. Table 5 and 6 show the order of the test and the time required for examination. We have worked to develop a reliable satellite through tests. However, HORYU-II suffered an anomaly because of a radiation. If the test standard had existed, and SEE test had been performed on HORYU-II, the nano-satellite may not have suffered an anomaly and we could carry out many missions. Therefore, environmental test standard which is suitable for nano-satellites seems to be a necessity because of the further development of nano-satellite and the efficient use of a valuable launch opportunity.

Table 5: Tests done for HORYU-II (the number is the order of the test)

Tests	Total numbers	STM	EM	EM Ver.2	FM
Antenna pattern	1	1			
Vibration	7	2,3	8,11	16.18	27
Electrical interface	3		4	13	20
Communication	3		5	17	23
Thermal balance	1		6		
Shock	6	7	10	15,19	28,29
Thermal vacuum	4		9	14	22,24
Function	3		12		26
Baking	1				30
End-to-end	1				31
Inspection	2				21,25

Table 6: Time required for each testing of HORYU-II (the number is in man * day)

Tests	Total	STM	EM	EM Ver.2	FM
Antenna pattern	90	90			
Vibration	294	110	90	63	31
Electrical interface	45		5	26	14
Communication	124		89	23	12
Thermal balance	120		120		
Shock	185	9	60	50	66
Thermal vacuum	492		74	169	249
Function	31		8		23
Baking	59				59
End-to-end	81				81
Inspection	51				51
Mission payload	577				
Components	78				
Ground station Operation rehearsal	62				
Total	2289	209	446	331	586

NETS PROJECT

Since September 2011, a new project called Nano-satellite Environment Test Standardization (NETS) project, has started under the support of Japanese government funding to improve the reliability of nano-satellites. The project will be promoted by four organizations: (1) Kyushu Institute of Technology, (2) International Standard Innovation Technology Research Association (INOTEK), (3) the Society of Japanese Aerospace Industries (SJAC), and (4) Astrex with participation of domestic and international stakeholders. The goal of the project is to establish an ISO standard including the following points;

1. Environment tests of nano-satellite system.
2. Documentation of nano-satellite environment tests.
3. Environment tests of nano-satellite components.

The standardization is suitable for qualification test and acceptance test and is mainly environment tests such as vibration and vacuum. Functional testing is also partially included.

Figure 12 shows the approach of NETS project. There are already various environment test standards both domestic and international. As an international standard, ISO-15864 (Space systems-General test methods for spacecraft, subsystems and units) was established in 2004. As domestic standard, JERG-2-002 of JAXA and ECSS-E-ST-10-03C of Europe exist. Those standards were based on 50 years' experience and were suitable for large satellites. They are therefore meant for very expensive satellites. At the same time, they are meant to be highly reliable. Therefore, we take advantage of the existing standards by tailoring the requirements written there. To do tailoring, a certain rationale based on scientific knowledge is needed. To obtain the rationale, basic researches will be carried out in this project. The basic research will also produce new innovations that are suitable for the nano-satellite environment.

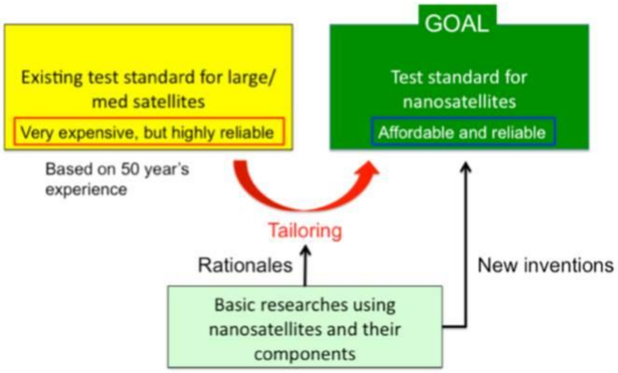

Figure 12: Approach of NETS project

As of May 2013, the standard draft titled, "Space systems —Design Qualification and Acceptance Tests of Small-scale Satellite and Units Seeking Low-cost and Fast-Delivery" is under discussion at ISO/TC20/SC14. There have been already two international workshops, where the experts from all over the world participated. The next workshop will be held on November 19, 2013, in Tokyo. Those who want to participate in the project are encouraged to take contact through the following link:

http://cent.ele.kyutech.ac.jp/nets_web/nets_web.html

CONCLUSION

The authors realized the harshness of the space environment through the operation of HORYU-II, and we felt the necessity to investigate further reliable satellite design techniques. It is necessary to share the information in many universities and companies because there are still many unknowns in space and there is a growing interest in nano-satellites development and applications in the world.

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