Development of High Voltage Technology Demonstration Satellite, HORYU-2.

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Since five years ago, students of Kyushu Institute of Technology have been working on a satellite project. We have been developing a nano-satellite named "HORYU", a standard-size 10cm cube and finished PFM. In April, 2010, a new project to develop "HORYU-2" started. On October 6, 2010, it was officially announced that HORYU-2 will be launched as a secondary payload of H2A rocket which will launch GCOM-W1 in fiscal year 2011. In the present paper, the mission objectives and design of HORYU2 will be presented.

Keywords: Nanosatellite, High Voltage Solar Array, Spacecraft Charging, Cell Degradation, Debris Sensor

1. Introduction

Since five years ago, students of Kyushu Institute of Technology (KIT) have been working on a satellite project. We have been developing the nano-satellite named "HORYU", a standard-size 10cm cube and finished PFM. Currently, we are developing the HORYU-2 which inherits the technology and knowledge of HORYU. On October 6, 2010, it was officially announced that HORYU-2 will be launched as a secondary payload of H2A rocket. The purpose of the present paper is to give overview of HORYU-2, especially its mission objectives and development status.

2. Development Concept of HORYU-2

There are two major points in the development concept of HORYU-2. The first point is that the satellite development is carried as a part of official education program of KIT graduate school, (Training of Project Leader Type Doctor Engineers -ProST). The aim of the ProST is to train graduate students to be active as a leader through a project-based learning program. In the program, a group of student made of various majors forms a team to develop a system. In the system development, the student will experience the whole processes of system development from conceptual design, testing to operation. The students learn the project management, acquire systems engineering thinking and improve the communication skills through the projects by applying various systems engineering practices to their project. In HORYU-2 project, students make project documents such as Requirement Allocation Sheet(RAS), Work Breakdown Structure (WBS) and Integrated Master Plan (IMP). By setting schedule milestones such as technical reviews, risk management and others, they manage the schedule. Students also make Interface Control Document(ICD) to coordinate the interface and share the design information.

The second point is its mission, on-orbit demonstration of new technologies developed at KIT in the area of spacecraft environmental interaction study, which is the major feature of KIT space engineering research represented by the Laboratory of Spacecraft Environmental Interaction Engineering. A nanosatellite is suitable for timely demonstration of new technology in orbit that is difficult on a medium or large scale satellite. The main mission of HORYU-2, 300V power generation in space, is especially difficult to do on larger satellite as the risk of electrostatic discharge is feared by a satellite developer or other people who have their mission payloads on the same satellite.

3. Design of HORYU-2

Table 1. Specification of HORYU-2

Operational period	1year
Orbit / Altitude	Sun-Synchronous orbit （Orbit inclination : 98° ） / 680 km
Size（X×Y×Z）	350mm × 320mm × 296mm
Mass	6.8 kg

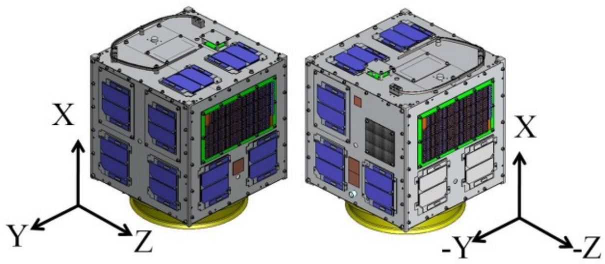

Fig 1. Conceptual view of HORYU-2

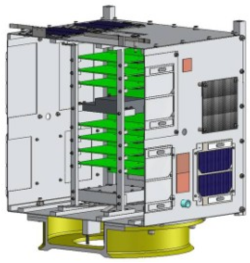

Fig 2. Internal structure of HORYU-2

3.1. Structure

Figure 1 shows an external view of HORYU-2 made by 3D CAD software. Table 1 list the basic specifications. HORYU-2 has a cubic shape of roughly 30cmx30cmx30cm. Its mass is approximately 6.8kg. It is a very light design for this size of nanosatellite. This is due to the requirement that the satellite must be de-orbited within 25 years after the launch. The satellite was designed so that an area to mass is sufficiently large, 0.0186 [m^2/kg]. The analysis shows the orbital lifetime of 20.7 years. The internal structure of HORYU-2 is shown in Fig. 2. The electronics boards of mission and bus systems are arranged in the center of a satellite. Each board is electrically connected by the bottom board arranged at －Z side.

At the present moment, we carried out vibration test of structure thermal model (STM). The STM went through a required set of vibration specified by H2A users manual. It was confirmed that the lowest natural frequencies of the structure satisfies the requirement. No structural damage was observed after the test nor any sign of chattering of the separation switches.

Due to its small mass, its thermal capacity of the satellite is very small, posing a risk of going to very low and high temperatures in orbit. Currently thermal analysis is underway to determine the best combination of the thermal finishes on the external panels. The analysis will be confirmed by the thermal equilibrium test.

3.2. Power

A double junction thin film solar cell is used for the satellite power. Two series connected cells make one string. Two strings are glued to one panel. Five panels except –X panel have the cells, making 10 strings in total. The maximum generating power is more than 4W, the average power is estimated to be 3.65W. There are four other types of solar cells on HORYU-2, 300V solar array, film solar array, semi-conductive coating solar array, and conventional design solar array. Those four solar cells are not used to provide the satellite power. They are separated from the bus power system and used only for the missions.

Nickel-Metal Hydride battery is used for HORYU-2 in order to supply the steady power. The rated voltage is 1.2V. We will connect three batteries in series and make 3 parallel circuits. The voltage rating is 3.6V and the stored power is 4200mAh. The specification is listed in Table 2. The battery is fixed to the structure using an aluminum battery case. The photograph of battery and the battery case are shown in Fig. 3 and Fig. 4.

Table2. Specification of battery

Battery type	Ni-MH
Rated voltage	1.2V
Rated amperage	1400mAh
Size	67×16×5mm
Mass	25g

Fig 3. Battery

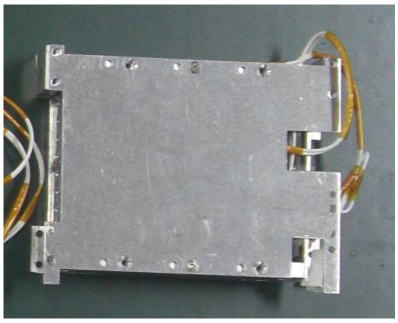

Fig 4. Conceptual of battery case

The battery has already gone through the environment tests. The tests include the high-temperature, low-temperature, and vibration. At this moment, we are carrying out charging and discharge cycle test by putting a battery in a thermal vacuum chamber, where the maximum and minimum temperature is applied to the battery, while simulating the power consumption at the satellite load.

3.3. On Board Computer

OBC consists of two H8 processors. Main-H8 is in charge of task management, such as operation of all the mission instruments, data conversion, time management, and COM-H8 is in charge of communication systems, such as CW transmission and FM reception. Main-H8 has an oscillator for RTC (Real Time Clock), and makes a clock by this pulse. The outline of an OBC system is shown in Fig. 5. The flash-main for data storage is connected to Main-H8 by SPI (Serial Peripheral Interface) transmission line. The mission data and sensor data are stored to Flash-main, and Flash-share is used to relay the downlink data to COM-H8. All of the operations of mission apparatus and FM transmission are performed by the command from the ground.

At the present moment, interfaces between the Main-H8 and other peripheral devices are being tested using electronics circuit boards of Engineering Model. HORYU-2 inherits many of the operational software from HORYU-1. In parallel to HORYU-2 development, a long duration operational test is underway using the flight model of HORYU-1 to single out the program bugs. Soon, a table satellite of HORYU-2 will be made using the EM electronics board and testing of operational software will begin.

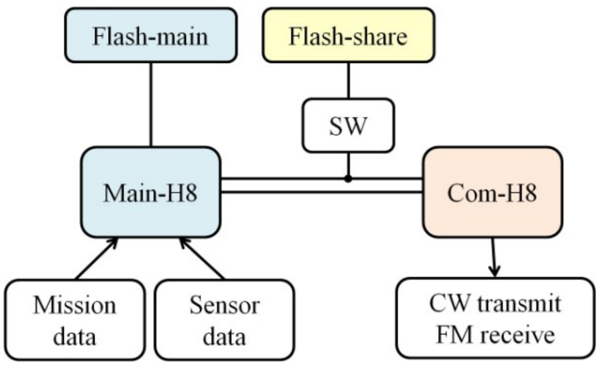

Fig5. OBC system

3.4. Communication

The radio transmission mode of HORYU-2 is CW transmission and FM transmission. The CW transmission mode send the sensor data of the satellite health monitoring, such as power, temperature, attitude to the ground station via Morse signal. The FM transmission mode send more detailed satellite information and mission data via FM packets. The communication design is summarized in Table 3.

Table 3. Communication design of HORYU-2

	CW transmit	FM Transmission and reception	
		Transmission	Reception
Communication speed	20wpm	1200bps	
Protocol	―	Ax.25	
Modulation	―	GMSK	
Frequency band	430MHz	430MHz	144MHz

The communication between the ground station and the satellite is made of two modes. One is the ordinary operation mode and the other FM transmission mode. Details of each mode are described below.

3.4.1. Ordinary operation mode

CW transmission and FM reception are performed in this mode. CW transmission is performed by both PIC and COM-H8. Regular data such as call signs is handled by PIC. The variable data such as housekeeping data are handled by H8 each. In addition, FM reception is also processed by the same H8 microcomputer. Because the CW transmission and FM reception cannot be done at the same time by the H8 microcomputer, the ordinary operation mode is done by the flow shown in Figure 6. PIC performs CW transmission of regular data and H8 performs FM reception. When PIC finishes the CW transmission of regular data, it gives the control of the transmitter radio to the COM-H8 and wait for a fixed time. After the standby time is completed, PIC resumes the Morse transmission and repeat the process until COM-H8 receives the FM uplink command from the ground. Once the processor receives the command from the ground, it sends the command to the main H8. If the command is the starting of FM transmission, H8 interrupt the CW transmission by PIC and shifts into the FM transmission mode.

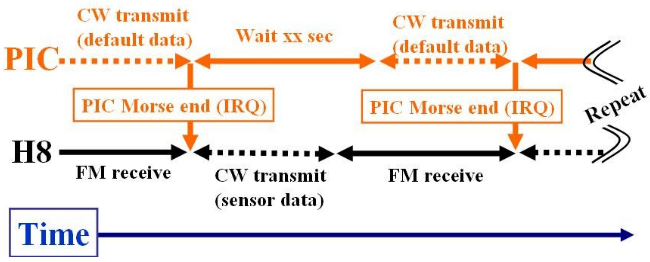

Fig 5. Flow chart of ordinary operation mode

3.4.2. FM transmission mode

This mode is the mode where the FM downlink is made to the ground station. Only when FM transmitting command from the ground is received, it shifts to the FM transmission mode. Because FM transmission and FM reception are processed with one H8 microcomputer, FM transmission and reception cannot be performed simultaneously. In addition, because the same frequency and the same antenna are used by the CW transmission and FM transmission, FM transmission and the CW transmission cannot be done at the same time. The flow chart in FM transmission mode is shown in Fig.6. When FM transmission command from the ground is received, COM-H8 sends an interrupt signal to PIC. After the interruption, H8 carries out Ax.25 protocol creation, performs data modulation with a modem, and starts FM transmission. Once the FM transmission is over, When interrupt servicing from H8 is received, PIC makes the CW transmitter a stand-by state, and fixed time stands by. When the FM transmission is finished, H8 sends another interruption signal to PIC to resume the ordinary operation mode.

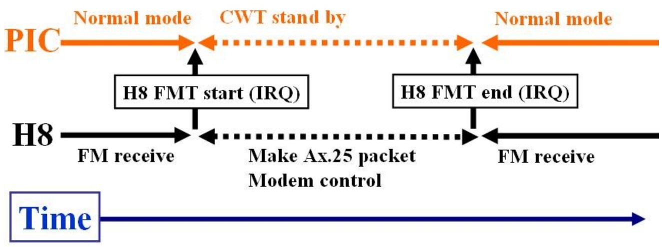

Fig 6. Flow chart of FM transmission mode

4. Missions of HORYU-2

In recent years, satellite size and power keep increasing. For large space platforms such as a space station, it is necessary to generate and transmit the power at a high voltage to minimize the Joule heating loss or the increase in the cable mass. It has been known that in LEO a solar array with a negative potential of 100 to 200V with respect to the plasma can suffer electrostatic discharge. Because of this, ISS power system was limited to 160V generation and 120V transmission. Generally speaking the transmission power is proportional to the square of the voltage. For a large space platform which requires 1MW-class power, such as a space hotel or a space factory, power generation at a voltage of 300 to 400V is required. The present HORYU-2 mission, 300V power generation in space without any discharge, is the first space environment test of the new technology that will be strongly demanded in near future. Also, as the satellite power employs higher voltage, there will be more demand for spacecraft charging mitigation or monitoring. The technologies that address those issues will be also tested on board HORYU-2. Table 4 summarizes the HORYU-2 missions. We now explain each mission in detail.

Table 4. The missions list of HORYU-2

300V power generation in LEO
Demonstration of new solar array design for electrostatic discharge mitigation
Measurement of solar cell electrical performance degradation due to cumulative electrostatic discharges
Demonstration of electron emitting Film (ELF) for spacecraft charging mitigation
Demonstration of COTS surface potential meter in space (Trek)
Demonstration of new debris sensor
Taking photographs of the Earth (SCAMP)

4.1 300V power generation in LEO

Special solar cell made by the KYO-SEMI Corporation is used to generate 300V power in space. Each solar cell is made of spherical shape. Although the generating current is very small due to its small size, one unit of solar cell shown in Fig.7 can generate a voltage of as high as 6volts.

By connecting more than 100 solar cells in series, we can generate a voltage beyond 300V. The solar cells are attached to the ±Z panel. In orbit, the voltage generated by these solar cells make the floating potential of the negative end of the solar cell string near -300V with respect to the space plasma. At the positive end of the circuit

Fig 7. Conceptual view of solar cell for generation 300V

4.2 Demonstration of electrostatic discharge mitigation

Two types of solar cell designs are tested. One is film type solar cell that covers the entire solar cell by thin transparent film to protect the solar cell coverglass from charging via ions.[1] Fig.9 shows a schematic view. By placing the film, the electric field build-up near triple-junction where metal, insulator and vacuum meet is prevented. The other is solar cell that has transparent semi-conductive coating over entire solar cell to relax the charge on the insulator. Fig.10 shows a schematic view. Both types of solar cell design were already tested in laboratory and the effectiveness to mitigate electrostatic discharge has been already demonstrated.

By connecting the solar cells at the negative end of the 300V solar array, the solar cells have a floating potential of near -300V with respect to the plasma. A solar cell with a conventional design that exposes the triple junction to the plasma usually suffer electrostatic discharge once its floating potential become more negative than -200V. The solar cells with the mitigation design will be made by modifying the conventionally designed GaAs multi-junction solar cells. Two solar cells are connected in series. One string is covered by film and the other string has the semi-conductive coating. The both strings are put on +Y panel.

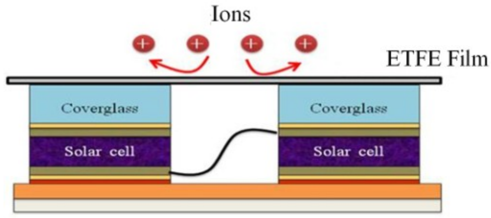

Fig 9. Electric discharge controlling processing using film

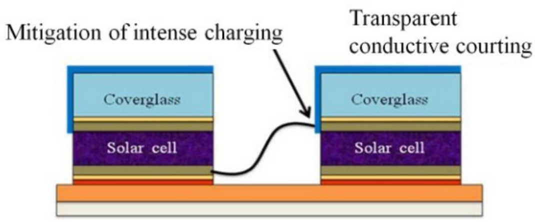

Fig 10. Electric discharge controlling processing using courting

4.3 Measurement of solar cell degradation due to discharges

It has been found that when an electrostatic discharge occurs at the edge of solar cell, it can damage the power generation capability of the solar cell[2] Although many experimental observations were made in the laboratory tests, there has been no effort to confirm the phenomenon in space.

Two solar cells are connected in series. This string is a typical conventional design of GaAs multi-junction solar cell without any discharge mitigation. This solar array is used to intentionally let electrostatic discharge occur. The VI characteristics of this string are measured routinely to observe how the solar cell electrical output degrades as solar cells suffer discharge in orbit. This solar array string is carried on the upper part of -Y panel.

4.4 Demonstration of Electron-emitting Film (ELF)

This mission carries out the demonstration of Electron Emitting Film (ELF). The ELF aims at mitigation of spacecraft charging, especially charging of a satellite body with respect to the surrounding plasma (absolute charging)[3]. ELF has been invented and studied at KIT for the past five years. The potential difference occurs between satellite chassis and the insulator of the ELF by energetic electrons, such as aurora electrons. A strong electric field is developed at the conductor surface of the ELF near its triple junction by this potential difference. The charging is mitigated because electrons are emitted from the conductor surface (Fig.11). When a satellite charged, the electrons are automatically emitted from ELF. On HORYU-2, the electron current is measured. At the same time, the insulator surface potential is measured by a Surface Charging Monitor (SCM)[4] to detect the change on the insulator potential due to the electron emission.

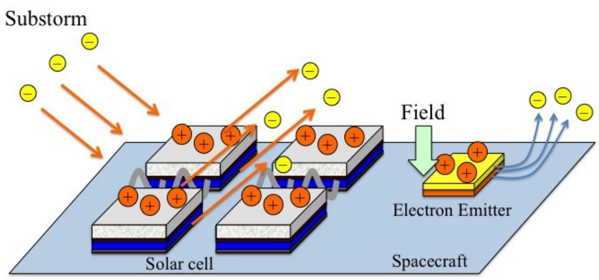

Fig.11 Principle of operation the ELF

4.5 Demonstration of COTS surface potential meter in space (Trek)

This mission demonstrates a surface potential meter in space. The potential meter has been developed by TREK, Inc. aiming for terrestrial commercial application. It is a contact type potential meter with extremely large input impedance so that the contact does not affect the charging state of the specimen. KIT is currently working with TREK, Inc. to convert the potential meter for extreme environments such as space or plasma processing chamber. The in-orbit demonstration is a part of the joint research program. To put the COTS device on HORYU-2, the electronics board and the consumed power have been reduced significantly.

When HORYU-2 passes through the aurora zone, differential charging may develop between the insulator surface and the satellite chassis. The potential meter will measure the potential of the insulator that is the same material to be used for SCM. The two measurements are compared to validate against each other.

The functionality in thermal vacuum environment has been checked. At the present time, charging of the insulator is being simulated by an electron beam in laboratory.

4.6 Debris observation with debris sensor

This mission aims at detecting the micro-debris impact on the surface of HORYU-2. Space debris has become a serious threat to satellites in orbit. Observation of micro debris less than 1mm has been very difficult. The debris sensor consists of many conductive thin wired laid down in parallel in the area of 8x8 cm. Upon impact, some of the lines are cut and the resistance becomes infinite. It has been verified in laboratory that the collision is detected once the lines are cut by impact of hyper-velocity projectiles.

4.7 Taking photographs of the Earth

This mission aims at taking the pictures of the Earth using a small CMOS camera. The camera called SCAMP (Surry Camera Payload) shown in Fig.12. It was developed by University of Surrey, a sister school of KIT. SCAMP takes a picture in a JPEG format of 640x480. From 700km altitude, one pixel corresponds to 1.6km. Fig.13 shows an expected image of Kyushu island with 1.6km resolution. The shutter of SCAMP is activated by a signal from OBC. In order to take the arbitrary places of the Earth, the ground station sends an uplink command that tells when HORYU-2 takes a photograph. When the time comes, HORYU-2 will judge the moment when the camera is facing the Earth from the readings of the current sensors attached to solar arrays on the five panels. Once it judges the camera facing the Earth, the shutter is opened.

Fig.12 conceptual view of SCAMP

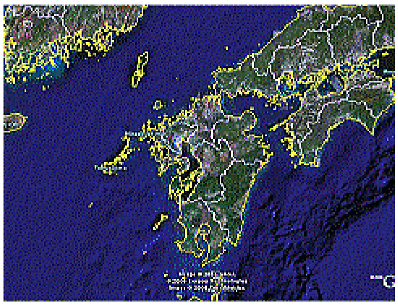

Fig.13 Image picture of SCAMP

6. Current development

Now, HORYU-2 is in the phase of EM (Engineering Model) development. We are performing system integration and evaluation. The tests we plan for the next few months are table satellite which tests an integrated software, the vibration test which evaluates the tolerance to launch vibration of H2-A rocket, the thermal equilibrium test which verify the accuracy of the thermal analysis, and the thermal-vacuum cycle test which verifies that the satellite can operate under the high and low temperatures in space. The mission instruments such as 300V solar array and discharge mitigation solar array will be also tested in a plasma vacuum chamber. Completion of EM development is judged by CDR (Critical Design Review) planned at the end of March. After that, the project shifts to FM (Flight Model) development. The flow of development of HORYU-2 is shown in Fig.14.

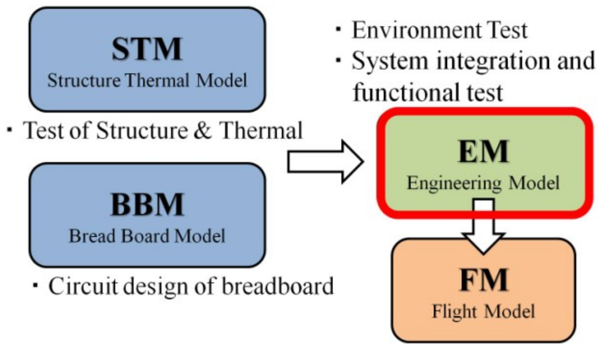

Fig 14. Flow of development of HORYU-2

7. Conclusion

HORYU-2 under development at Kyushu Institute of Technology currently was selected as an auxiliary payload of the H2-A rocket to be launched in the 2011 fiscal year.

The satellite development is in EM phase now. Aside the educational purpose of systems engineering study, the satellite will carry out technology demonstration of high voltage power generation that has been regarded too risky as an experimental payload on a medium or large satellite.
If successful, the experimental results will contribute to realization of large-scale high-power space platforms envisioned after the International Space Station.

Currently HORYU-2 is in EM development phase. The development project is carried out as an official education program of KIT. Students are responsible for every aspect of the satellite development from its conceptual design to operation from the ground station. Except a few items for the flight model, all the environment tests will be carried out inside KIT using the test facilities of recently inaugurated Center for Nanosatellite Testing. It will serve as an important test bed of the nanosatellite environment tests.

8. Reference

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