

HORYU-4: Miniaturised Laboratory for In-Orbit High Voltage Technology Demonstration

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Abstract: Currently, we are finalising development of a new satellite “HORYU-4” (30cm cuboid, around 10kg) to be launched in early 2016 as a piggy bag satellite of H-IIA rocket. This is the succession spacecraft to HORYU-2, and the main mission of these satellites is demonstration of high voltage solar array technologies in real space environments. The key concept of HORYU-4 is performing same testing as on ground, but with real space environments. In fact, this spacecraft carries standard laboratory equipment such as an oscilloscope and video cameras. These flight data will not only be used for confirmation of the new high voltage technology to evaluate and improve present ground testing methods. In addition, such challenges have not yet been succeeded in orbit, and therefore it might discover new arcing phenomena.

1. Introduction

Electrostatic discharges on spacecraft have been known as a harmful incident, which leads to reductions in the spacecraft lifetime¹⁻⁵. Higher array voltage increases susceptibility to such arcs, and 200V is the upper limit at this moment¹. However, such voltage has become inadequate for recent high performance space products/missions require multi-kilo-watts. To tackle this dilemma, many investigations have been conducted such as physical experiments (i.e. ground testing) and computer simulations. In addition, in-orbit solar array charge/discharge experiments have been performed since 1970s to validate new solar array technologies and these ground testing methods in real space environments.

HORYU-2 (low Earth orbiting nano-satellite launched in 2012) is one of these solar array technology experimental satellites. It carries 300V (high voltage with low current cells stacked in series) solar array as a DC bias source and in-house developed high voltage proofed sample solar arrays⁶. These high voltage proofed solar arrays had perfectly demonstrated its performance in primary arc mitigation during ground testis, but several arcs have been detected on one of these arrays in-orbit. Unfortunately, data provided by the sensor on-board HORYU-2 (i.e. just occurrence of discharge) are insufficient for further analysis.

Therefore, we repeat the same in-orbit experiment with more measurement instruments on HORYU-4. HORYU-3 (3U cube-sat) was the sister satellite of HORYU-4⁷, and both project started at similar time, but it was indefinitely postponed in order to focus on HORYU-4 development. Nanosatellites are ideal for such risky missions, in addition it allows rapid repeat cycle for example HORYU-2 to HORYU-4.

This paper presents an overview of this satellite and the main missions.

2. Overview of the Spacecraft

Currently, the HORYU-4 development is in the final phased to deliver and will be launched in 2016 first quarter. Figure 1 shows the satellite exterior of the Structure-Thermal Model (STM) in early development phase to the Final Flight Model (FM). The size of spacecraft is 33x33x33 cm, and its mass is around 10.3kg. It will be launched by H-IIA 30th flight as a piggyback satellite of the ASTRO-H, and the expected orbit and its inclination are 580km and 31 degrees, respectively. The missions of this spacecraft are as follows:

- Comparison of ground testing results with in-orbit (new mission)⁸
- Imaging arc flash lights to support measurement data (new mission)⁸
- Technology demonstration of a high voltage proofed solar array (continue from HORYU-2)⁹
- Technology demonstration of a direct drive vacuum arc thruster (new mission)¹⁰
- Long-term measurement of exposed materials degradation (new mission)
- Plasma measurement using double Langmuir probes (new mission)
- Measurement of polyimide films' photoelectron current (new mission)
- Earth imaging (continue from HORYU-2) with attitude/orbit synchronised shutter (new mission)
- Transmit music from space using VOCALOID™ voice synthesiser on-board (new mission)¹¹

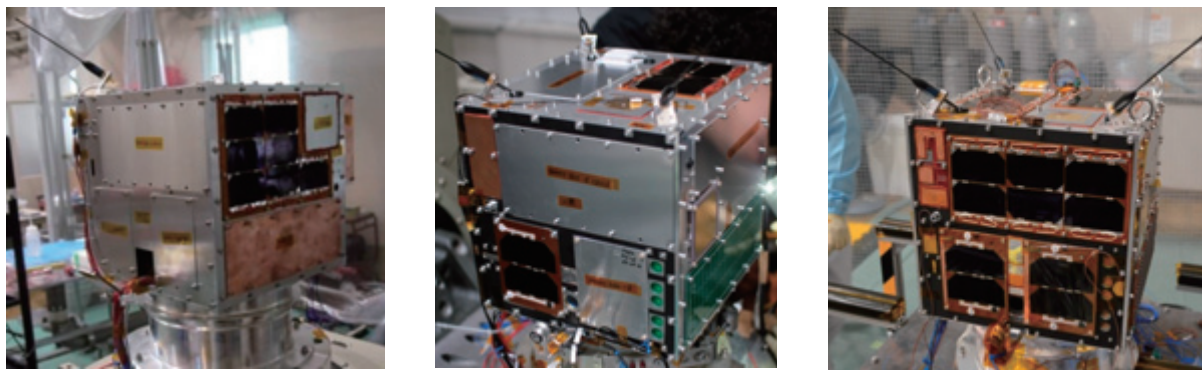


Figure 1: HORYU-4 Structures (Left: STM, Middle: EM, Right: FM)

In order to accommodate solar arrays for the experiment -i.e. Normal Triple Junction Array (nTJA), Filmed Tripped Junction Array (fTJA) and High Voltage Solar Array (HVSA), only half of the $\pm Y$ and $\pm Z$ panels are available for bus solar arrays as shown in Figure 2. Hence, the available power on this satellite is tighter than typical nanosatellites, and this has become the main design constraint on-board electronics design.

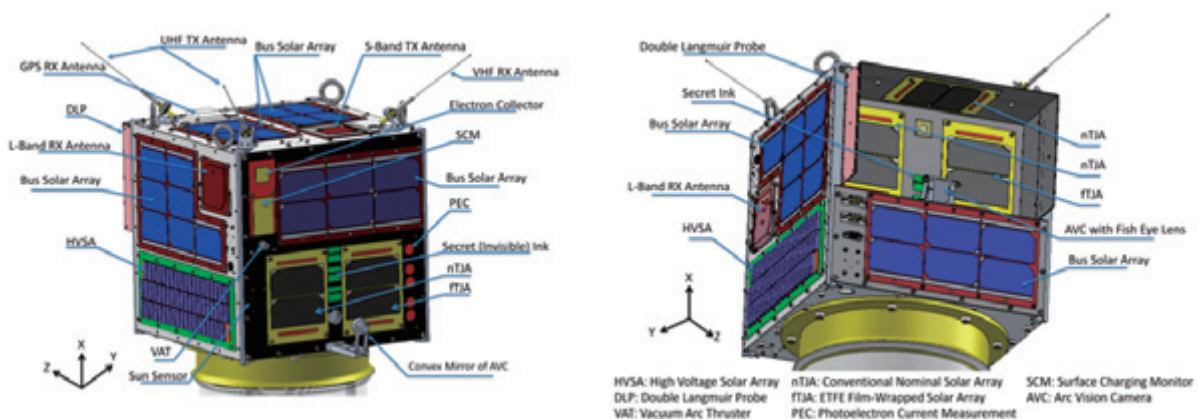


Figure 2: HORYU-4 Exterior Configuration (Right: +X+Y+Z panels, Left: -X-Y-Z panels)⁸

The main subsystems of the HORYU-4 have been inherited from HORYU-2, including the power system, the OBC and the VHF/UHF communications. On the other hand, two major learned lessons from HORYU-2 are applied to the system design of HORYU-4, for instance:

- complete power reset (satellite re-boot) against single event latch up
- complete measurement system (similar equipment to ground testing) for better understanding

Figure 3 is a block diagram shows overview of the satellite. New watchdog micro-processor and L-band uplink are the upgrade from the previous satellite, and these are dedicated for the satellite reset. The communication is consisted of two uplinks (i.e. VHF main and L-band back up), and two downlinks (UHF 1200bps and S-band 100kbps). The new S-band transmitter will mainly be used for sending captured arc images.

This satellite has two power systems, which are the ordinal power system for satellite operation and the high voltage power source (High Voltage Solar Array - HVSA) for the experiments. HVSA is in charge of high voltage generation and its distribution to experimental equipment (i.e. sample solar arrays, a vacuum arc thruster and a Langmuir probe).

In order to provide equivalent facility to ground, this satellite carries the oscilloscope (On-Board Oscilloscope - OBO). This instrument will provide complete discharge waveform captured in space first in the world. In addition, a picture of each arc flash light will also be captured by the Arc Vision Camera -AVC, and this also will be the world premiere result.

Big-Apple board conducts rest of the scientific missions, which are Photoelectron Current (PEC) measurement, Double Langmuir Probe (DLP) and Vacuum Arc Thruster (VAT).

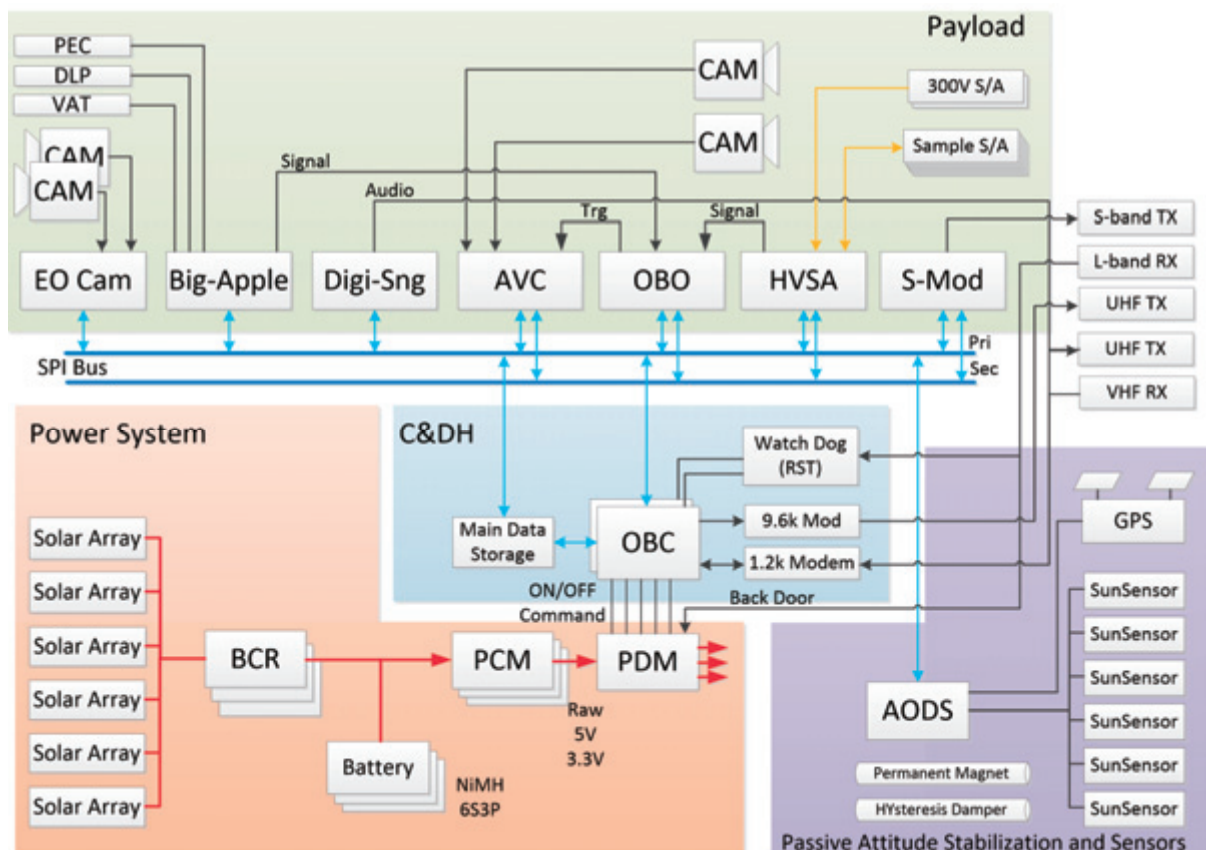


Figure 3: General Block Diagram of the Satellite

3. Main Mission Payload

Figure 4 shows circuit diagram of the on-board high voltage experiment system. This experiment system and the satellite main system are electrically isolated including control and measurement signals. The HVSA controller board distributes high voltage from HVSA (i.e. 350V) to sample solar arrays. The generated high voltage also distributed to the DLP and VAT for surface cleaning and drive, respectively.

The electrical potential of this circuit is sunk toward negative with respect to the spacecraft body as the generation voltage of the HVSA. When an arc is occurred on one of sample solar arrays, electrons move from the solar array to the electron collector through plasma. The oscilloscope captures this discharge current transition. Here, the main objective of this satellite is to compare these current transitions measured in-orbit and on ground. In addition, the AVC captures the arc flash light synchronised with the discharge current transition. This configuration is the same as typical ground test setup. Figure 5 shows the FM version of AVC camera for +Z panel monitoring and an image taken by this camera during assembly.

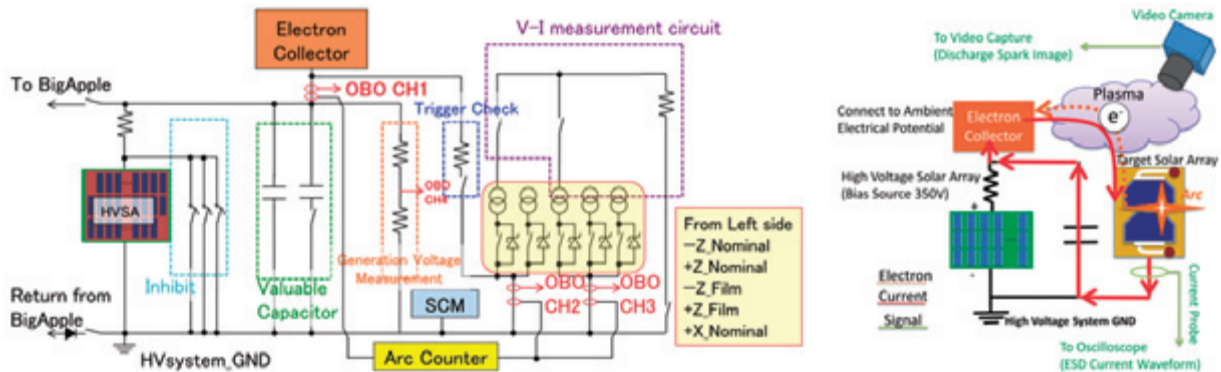


Figure 4: High Voltage Experiment System ⁸

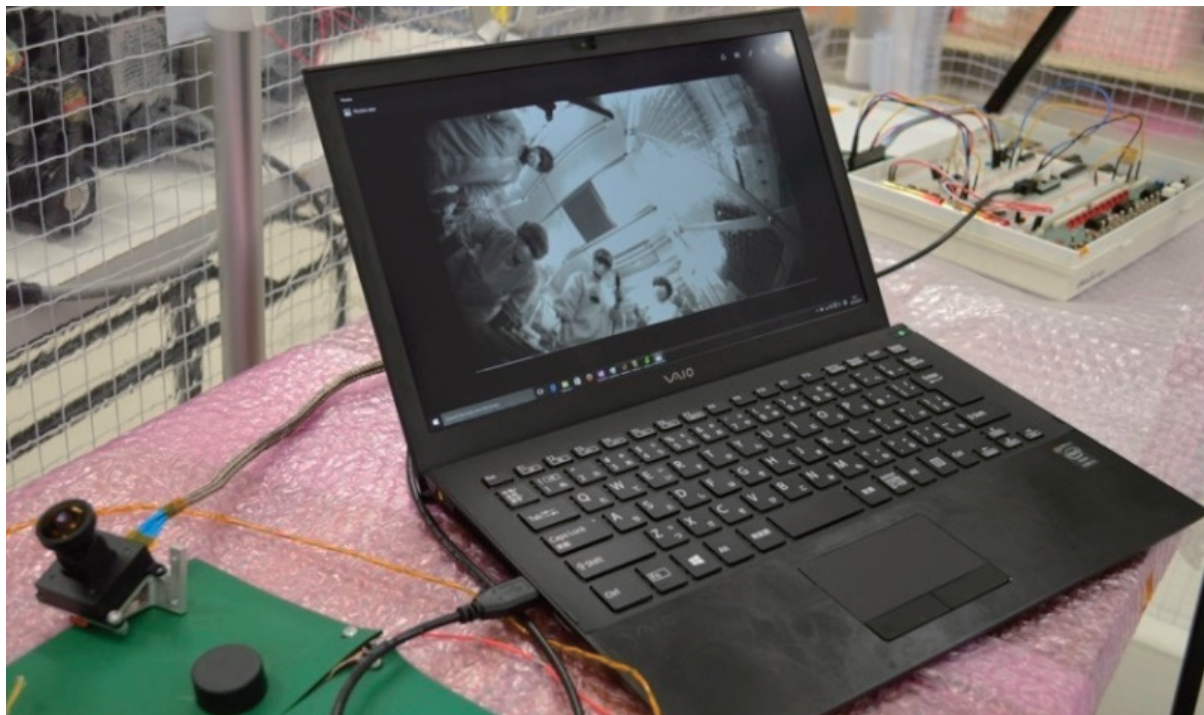


Figure 5: +Z AVC during FM assembly

6. Conclusions

This mission will be the first measurement of arc current waveforms and flash lights in-orbit. Therefore, it might discover new arcing phenomena. These results will be compared with ground testing results to evaluate and improve the present ground testing methods (e.g. ISO-11221), and it will contribute to the increase to the increasing solar array voltage. We wish HORYU-4 good luck with its missions in space!

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