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UNIFORM-1: First Micro-Satellite of Forest Fire Monitoring Constellation Project

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ABSTRACT

UNIFORM Project had started in November 2010 with its vision of constructing sustainable micro-satellite constellation system via cooperation with various countries. International collaboration and actual utilization of the system are the keys of the project for realizing sustainable space industry. Forest fire monitoring was selected as the first mission. UNIFORM-1 is the first micro-satellite, weighing 50kg with 50cm cubic size, in this project and launched on May 24th, 2014 by H-IIA rocket as a secondary payload. UNIFORM-1 carries two cameras of area sensor: uncooled microbolometer camera and visible light camera. Both have GSD of less than 200[m] and swath is about 100km. These two cameras are used for localization of heat anomaly spots. The acquired image will be overlaid on global map to generate a "forest fire map" which will be released so that local fire department of the concerning country can take action promptly and extinguish forest fire. Other key features of this satellite are

following: 3-axis control with reaction wheels, deployable solar array panel wings, lithium ion battery, and 10Mbps X-band transmitter for mission data. Design and test result of UNIFORM-1 flight model is explained in detail in this paper. As the result of initial operation of five days after launch, image of infrared camera was successfully acquired.

BACKGROUND AND PURPOSE

There have been some small-satellite-related education and/or constellation programs in the world. Many of them, however, do not really focus on actual use of data but on scientific research or technology demonstration. Advantage of miniaturized satellite is its low-cost and responsiveness for needs, but just a single satellite cannot do much. Therefore constellation of multiple satellites can expand its usability by its larger coverage, higher time resolution and redundancy. In fact, to realize such constellation system by a single organization or country is not easy task. Also, expecting customers would help to develop the system in some future but that would not happen from the beginning. UNIFORM (University International Formation Mission) program thus started with proposition that several countries work together to construct multiple satellites, components or even ground system and realize constellation system to share data within the community. There are many countries that are trying to develop or expand space industry; And UNIFORM project is aiming to collaborate with such countries and construct community to develop sustainable constellation system together.

INTRODUCTION OF UNIFORM PROGRAM

With the purpose stated above, UNIFORM program has started in Japan at November 2010, as a project of MEXT (Ministry of Education, Culture, Sports, Science and Technology) and of research and development of micro-satellite. This is in fact successor of Micro STAR program of JAXA, in which they had provided an opportunity of capacity building on some researchers from Asian pacific region, and done some conceptual design of earth observation micro satellite. UNIFORM program, on the other hand, involves many organizations such as Wakayama University, University of Tokyo, Next Generation Space System Technology Research Association, Tokyo University of Science, Hokkaido University, Keio University, Tohoku University and JAXA. And some researchers from Vietnam, Korea also contributed in conceptual design phase.

As a very first step towards construction of micro satellite constellation and community among some countries, forest fire monitoring is selected as the first mission; And UNIFORM-1 has been developed to demonstrate the feasibility of the mission. Not only UNIFORM-1 development, we have also been working on collaborating with other countries and actually researchers from Kazakhstan started to join after UNIFORM-1 was launched, and planning to involve some researchers from Brazil as well to work on development of UNIFORM-2 and 3. Moreover, micro satellite education program with Vietnam had also started as an achievement of this activity. Although it may take a while to achieve building forest fire monitoring constellation, the goal of UNIFORM program, as MEXT funding program, and which is five year program, had set as following: (1) Construct UNIFORM-1 for demonstrating feasibility of forest fire monitoring mission, (2) Develop micro satellite community with other countries through various ways of collaboration. The latter goal is somewhat achieved and been continued, as stated above. In this paper, therefore, UNIFORM-1, the very first satellite of this program, is focused on to discuss and result of the design, test and initial operation after launch is introduced in detail.

UNIFORM-1 SYSTEM

Mission Definition of UNIFORM-1 System

Mission of UNIFORM-1 is forest fire monitoring. Emission of CO_2 on the earth per year is 29 billion tons and 15 billion tons of them are emitted by forest fire.

Figure 1: Wildfire in California (From Wikimedia Commons)

Earth observation satellites can monitor the Earth globally, thus if there are some satellites sending images of grounds for forest fire monitoring steadily, those data can be used to help extinguishing those fires. That contributes not only for decreasing the amount of CO_2 emission but also saving people from disastrous fire. There exists such system that monitors forest fire globally by satellites already, but they are only for large-scale fire, which could not be controlled unless well-developed fire fighting system is ready. Such system should be limited in developed countries or some national parks. In this project, therefore, UNIFORM-1 system has been developed so that it can be utilized even for developing countries by informing forest fire information to local fire fighting group.

System Architecture of UNIFORM-1

UNIFORM-1 system is consisted of four segments: Flight segment (=satellite), ground segment, service segment and user segment. Data flow from satellite to end-user is shown on Figure 2.

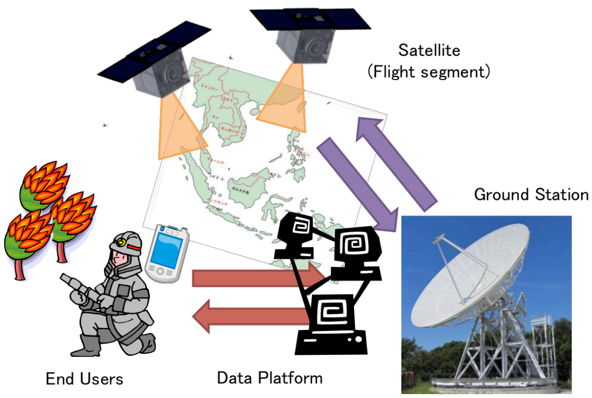

Figure 2: Data Flow from Satellite to End-User

It starts from user segment requesting where and when to monitor, and service segment generate operation plan based on the request. These two, as of now, have not been really developed yet as an automated system, but simply those who are interested in getting data request what to do and operation team discuss how to operate UNIFORM-1. From operation plan, such as "change attitude to point to the earth" and "take images of the ground at 2014 August 6th, 06:15:00 (JST), " operation team creates Satellite Operation Procedure (SOP), (somewhat automatically in the near future). Creating SOP from mission operation plan is part of ground segment. In the mean time, ground station, which is also part of ground segment, calculate antenna trajectory to track satellite; And now it is ready to operate satellite passing above the ground station. Telemetry data is received from satellite and demodulated so that operator can understand state of satellite; and, command sent from operator is modulated and sent to the satellite. These are through 3m-parabola-antenna. Mission data, on the other hand, is received through 12m-parabola-antenna; that is then demodulated and stored on the data server at the ground station. The data can be instantly processed for users to see them as pictures. Detailed diagram of ground system is shown in Figure 3.

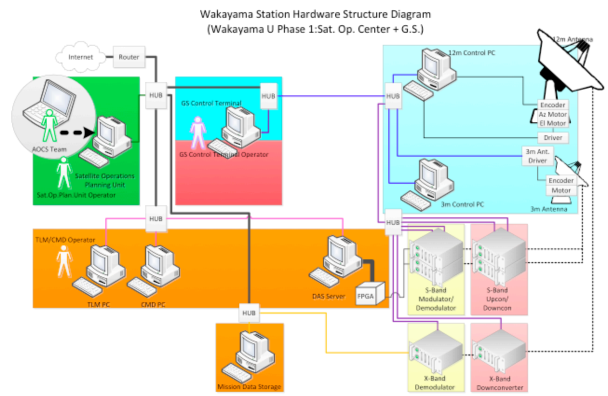

Figure 3: Ground System Diagram

Moreover, another software is ready to read the image data for luminance correction and overlay the corrected image on global map with ancillary data of satellite attitude and orbital position information. Once those processes are done, the final product, corrected image data on global map can be distributed through the Internet.

UNIFORM-1 SATELLITE SYSTEM DESIGN

Overview of UNIFORM-1 Satellite System

UNIFORM-1 satellite carries two cameras; one is microbolometer camera, which is uncooled thermal infrared camera for detecting heat anomaly spot on the ground, and the other is visible light camera, which supports position identification of the ground image. With these cameras and all other bus system included, it weighs about 50kg and size is about 50cm cube. In addition, it has deployable solar array wings to generate more power.

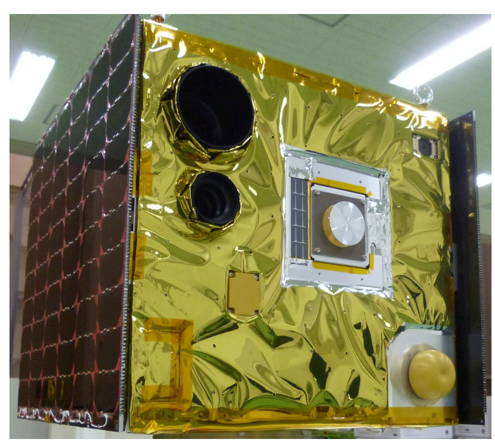

Figure 4: Flight Model of UNIFORM-1 (SAP Wings Closed)

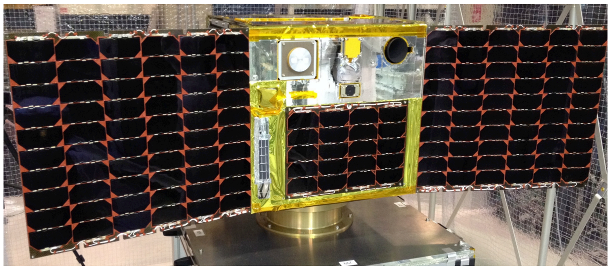

Figure 5: Flight Model of UNIFORM-1 (SAP Wings Opened)

UNIFORM-1 is a secondary payload launched by H-IIA, and the main payload is ALOS-2. The main satellite decides its orbit; and mechanical interface and safety regulation is based on JAXA's standards of piggyback launch.

Table 1: UNIFORM-1 Orbit (Same as ALOS-2's)

Type	Sun Synchronous
Altitude	628 km
Local Time at Descending Node	12:00 (Noon)
Inclination	97.9 deg

There are four phases of UNIFORM-1 satellite: launch phase, initial operation phase, nominal operation phase and disposal phase. First, in the launch phase, satellite is simply turned off and there is no electrical interface with rocket but mechanical interface. Second, in the initial operation phase, solar array wings are deployed by sending command from the ground; subsequently, it de-tumble and spin-up along with z-axis of satellite, which is perpendicular to the solar array panel plane, and move the spinning axis towards the Sun. This and any other type of transition are all executed manually. There are other types of attitude control modes such as sun pointing mode (3-axis controlled) and earth pointing mode. With all of those functions and components verified to work properly, it is ready to be utilized by users, meaning nominal operation phase. In nominal phase, UNIFORM-1 is used to correct images taken by bolometer camera and visible light camera. Again, this where and when to take is determined by users and they resister time-line commands to do so. Lastly, after mission is completed, although it is not specifically determined when to end, while design life is about two years, UNIFORM-1 is disposed into the atmosphere. Natural atmospheric drag simply pulls it down without satellite doing anything, and according to analysis it takes 18 years until it is gone down to be burn out.

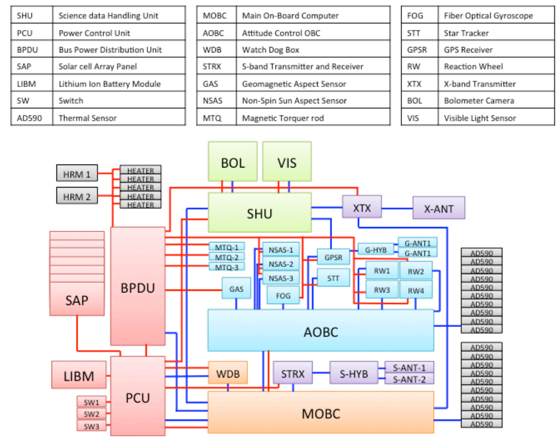

Figure 6: UNIFORM-1 System Diagram

UNIFORM-1 is designed to realize those operations introduced above. System diagram of UNIFORM-1 is shown in Figure 6. There are four reaction wheels and 3 magnetic torquers as attitude control actuators, and sun sensors, geomagnetic sensor, fiber optic gyro, star sensor and GPS receiver as sensors. There are three on-board computers: Main On-Board Computer (MOBC), Attitude control On-Board Computer (AOBC) and Science data Handling Unit (SHU). Battery is Li-Ion type battery. Communication between ground and satellite is through S-band and X-band RF signal. S-band is for telemetry and command with bitrate of 64kbps at maximum; and X-band is for mission data downlink with bitrate of 10Mbps at maximum. Overview of specification is summarized in Table 1. Detail of mission subsystem and other subsystem of bus system are explained in the following sections.

Table 2: Specifications Summary

Mass	49 kg (Approx.)
Size	50cm x 50cm x 50cm (Approx.)
Mission Payloads	Microbolometer Array Sensor Visible Light Camera
Onboard Computer	SOI-SOC OBC, SH-4 Processor RS422, Active/Passive Analog Interface
Communication	S-band Downlink (HK) 64kbps S-band Uplink (HK) 4kbps X-band Transmitter (Mission) 10Mbps CCSCS compliant
Power	SAP: MAX Generation 140W Li-Ion Battery: 23.0-33.2[V], 6200m[Ah]
Attitude Control Sensors	GPS Receiver, Sun sensors x3, Star Tracker, Fiber Optics Gyroscope, Magnetometer
Attitude Control Actuators	Magnetic Torquer Rods x3, Reaction Wheels x4

Mission Subsystem

Mission subsystem is consisted of a microbolometer (BOL) camera, which is a camera with uncooled 2D array thermal infrared sensor, and visible light camera (VIS) with CMOS sensor, and SHU. BOL is used to distinguish heat anomaly spot and other area on the ground; Forest fire identification, however, is not computed on-board but rather on the ground, after image of bolometer is taken and simply transmitted without any image correction. VIS, on the other hand, helps to identify the location of the heat anomaly spot. It is important for those who take action to extinguish forest fire to know exact location of that, but accuracy of ground location identification is not as high as it is needed. VIS and BOL, therefore, take image simultaneously, and VIS image is used to identify the location of image more precisely by comparing it with known terrain and landmark information and relative alignment of BOL and VIS. SHU handles command from the ground, control BOL and VIS, collect both house-keeping information and image data, and transmit them ether through X-TX or S-TX.

(a) BOL design

Scale of forest fire needs to be small enough for fire fighters to suppress with mobile extinguishing system, thus this UNIFORM-1 system is designed to find that size of fire. Forest fire expands elliptically, and intensity of the fire is defined as emitting energy per unit length of its “fire front.”

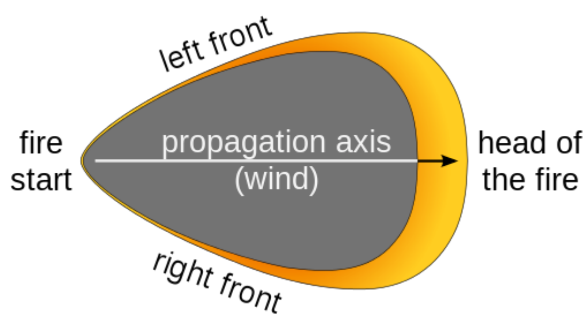

Figure 7: Propagation Model of Wildfire (From Wikimedia Commons)

Intensity of fire which fire fighters can suppress is about 500[kW/m] and the size would be 200[m] (length of fire line) X 10[m] (depth of fire front). 10um band of wavelength and 200[m] of spatial resolution are set as requirements for BOL. Table 2 is summary of BOL specification.

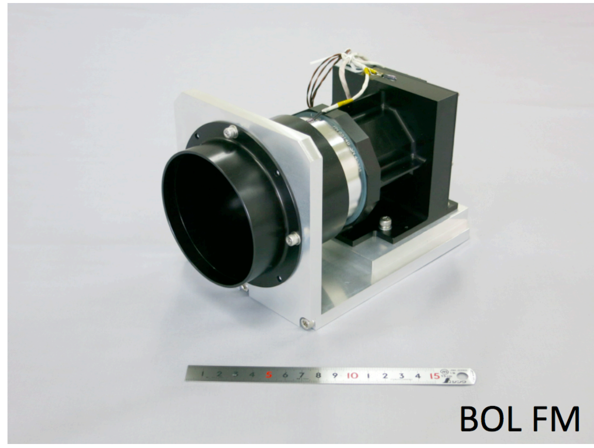

Figure 8: BOL Flight Model

Table 3: BOL Specifications

Detector	UL04171 (ULIS France)
Wave Length	8-14 [um]
Active Pixels	640(H) x 480 (V)
Pixel Size	25 [um]
Detector Size	16.0 x 12.0 [mm]
Data Size	614.4 [kB]
Frame rate	60 [Hz]
NETD	0.12K@300K, f/1
Absolute Temperature Accuracy	+/- 3 [K]
Spatial Resolution	0.0143 [deg/pixel] (157.0 [m/pixel]@628km)
FOV	9.17 deg(H) x 6.88 deg(V) (100.5 x 75.4 km)
Power	7.0 V, 1.8A
Size	100.0 x 100.0 x 123.0 [mm]
Weight	800 [g]
Ge Lens	Ophir65148 F=100 mm F/1.4

(b) VIS design

VIS is designed so that area of image is as large as BOL while its resolution is less than 100[m]. Table 3 is summary of VIS specification.

Figure 9: VIS Flight Model

Table 4: BOL Specifications

Detector	VITA1300 (ON Semiconductor)
Wave Length	400 - 1000[nm]
Active Pixels	1280(H) x 1024 (V)
Pixel Size	4.8 [um]
Detector Size	6.14 x 4.92 [mm]
Data Size	2.63 [MB]
Frame rate	150 [Hz]
Spatial Resolution	0.0079 [deg/pixel] (86.1 [m/pixel]@628km)
FOV	10.6 deg(H) x 8.05deg(V) (110.2 x 88.2 km)
Size	90.5 x 90.5 x 95.5 [mm]
Weight	580 [g]
Ge Lens	JHF50MK F=35 mm F/1.4

(c) SHU design

Role of SHU is to control BOL and VIS, store image data and send it through X-band transmitter. Figure 10 is the architecture of mission subsystem.

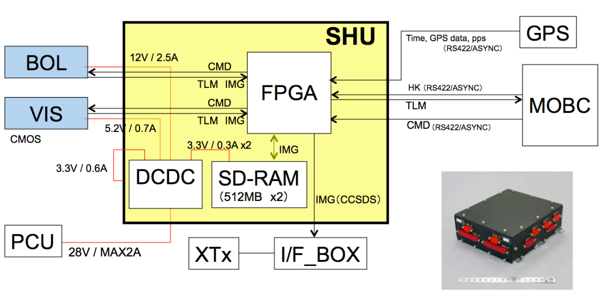

Figure 11: Mission Subsystem Architecture

SHU also has a function to provide power to cameras; the power is originally provided from Power Control Unit (PCU). Image data is stored on SD-RAM (512MB) without compression. SHU stores not only image data but also HK data of SHU and other computers.

UNIFORM-1 Bus System

(a) Attitude Determination and Control Subsystem (ADCS)

ADCS is consisted of sensors, actuators and an on-board computer. Sensors include three non-spin sun sensors (NSAS), geomagnetic sensor (GAS), fiber optic gyro (FOG), star tracker (STT) and GPS receiver (GPSR). Actuator includes four reaction wheels (RW) and three magnetic torquers (MTQ). There is an on-board computer, AOBC, dedicated to attitude determination and control. AOBC, in fact, is almost identical to MOBC, which manage whole satellite system. The only difference is power control board inside the box; MOBC provide power to AOBC. Table 5 is summary of specification of components.

Table 6: ADCS Components Specifications

Name	Weight &Size	Power	Specs
NSAS	46g, 31x50x22mm	5V, 150mW	RS422, ~1 deg accuracy
GAS	320g 95x95x45mm	5V, 30mA	Analog out +/- 100000nT range 4000nT/V
FOG	1kg 135x150x45mm	28V 120mA	RS422 and Analog +/- 5deg range 400mV/deg/s, <0.01de/s noise
STT	510g, 147x80x77mm	28V, 2.5W	RS422, 2Hz output Accuracy: 30 arcsec (Y, Z) 0.04 deg (X)
GPSR	400g 98x98x22mm	5V 180mA	RS422, 1Hz
RW	1.1kg 120x120x64mm	28V(motor), 5V(controller	RS422, >0.003Nm @4000rpm,
MTQ	375g 176x54x47mm	5V 70mA	5AM^2 +/- 20%

There are four ADCS modes in addition to a mode that does nothing for control but telemetry and command handling. They are (1) Spin Sun Pointing Mode, (2) Coarse Sun Pointing Mode, (3) Coarse Earth Pointing Mode, and (4) Fine Earth Pointing Mode. In the initial phase of operation, SSP mode is used at the beginning. In terms of power budget, it is planned to set nominal mode as CSP mode, and it transitions to upper modes to take image of the earth, in the nominal operation phase.

(1) Spin Sun Pointing Mode (SSP Mode):

List of sensors/actuators to be used are FOG, GAS, NSAS and MTQ. This is the most robust and reliable mode and can be used as safe mode; and total power consumption is the lowest among other control modes. First, it rotates along with z-axis of satellite body. The algorithm is rate control by FOG and MTQ. Second, move the rotating axis (z-axis) to direction of the Sun, based on the following algorithm.

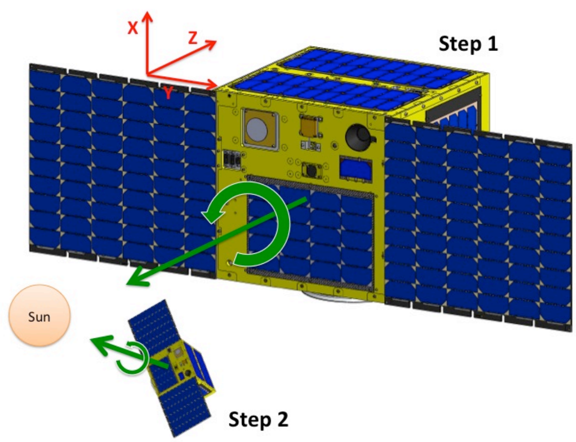

Figure 12: SSP Mode

(2) Coarse Sun Pointing Mode (CSP Mode):

List of sensors/actuators to be used are FOG, GAS, NSAS, GPSR, MTQ and RW. MTQ is just for unloading of RW. In this mode, satellite is 3-axis controlled and points the SAP face to the Sun without spinning.

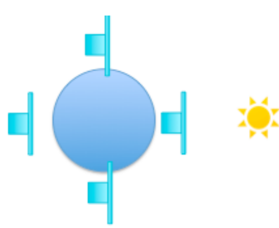

Figure 13: CSP Mode

AOBC calculate orbital position based on GPSR data, and determine the direction of the Sun in inertial frame. On the other hand, attitude of the body is determined based on FOG, GAS and NSAS data. Torque input is then calculated based on the attitude error and angular rate (i.e. PD control). Since input of actual reaction wheels used for this satellite is voltage input, the voltage is calculated from the required torque.

(3) Coarse Earth Pointing Mode (CEP Mode):

List of sensors/actuators to be used are FOG, GAS, NSAS, GPSR, MTQ and RW. Control algorithm is almost the same as CSP mode.

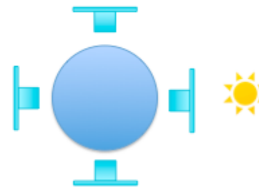

Figure 14: CEP and FEP Mode

Only difference is that the target direction is center of the Earth and +Z direction, which has cameras' lends, is pointed to that direction. Target direction is also calculated based on GPSR data.

(4) Fine Earth Pointing Mode (FEP Mode):

List of sensors/actuators to be used are FOG, STT, GPSR and RW. In this mode, current attitude is calculated based on STT and FOG output. Once current attitude and position are determined, control algorithms are same as CSP and CEP modes.

(b) Command and Data Handling Subsystem (C&DH)

C&DH is consisted of MOBC, Watch Dog timer Box (WDB) and part of AOBC. C&DH mainly has functions to handle command from the ground, to collect data from other components, to manage satellite mode, and under voltage control of battery. C&DH includes platform software of both MOBC and AOBC and tasks are managed by real-time operating system. Function of satellite management and attitude control is divided into those to OBCs for flexible and efficient software development by two or more groups. Communication between other components are through RS-422 interface, thus the network structure of OBC is designed as star connection. WDB is simply a box in which there is watchdog timer IC. It resets MOBC by turning it power off and on, when MOBC stops sending alive signal to OBC. Other specification of OBC is summarized below.

Figure 15: MOBC and AOBC Flight Model

Table 7: OBC Specifications

Common	Hardware: SOI-SOC SH-4 Processor, 500MIPS, 64MB SDRAM, 2MB SRAM, 4MB Flash Memory 153x156x100mm Software: TOPPERS real-time operating system
MOBC	1677[g], 8.1[W] Role: Satellite management, telemetry and command handling
AOBC	1144[g], 5.7[W] Role: Attitude determination and control

(c) Electrical Power Subsystem (EPS) [1]

Electrical power subsystem is consisted of Lithium-Ion Battery Module (LIBM), Power Control Unit (PCU), Bus Power Distribution Unit (BPDU) and Solar Array Panels. LIBM is consisted of 8series and 2 parallels of cells and inner circuit controls voltage balancing and protects cells to be over-charged. Voltage and capacity of LIBM is 23.0-33.2[V] and 6200m[Ah].

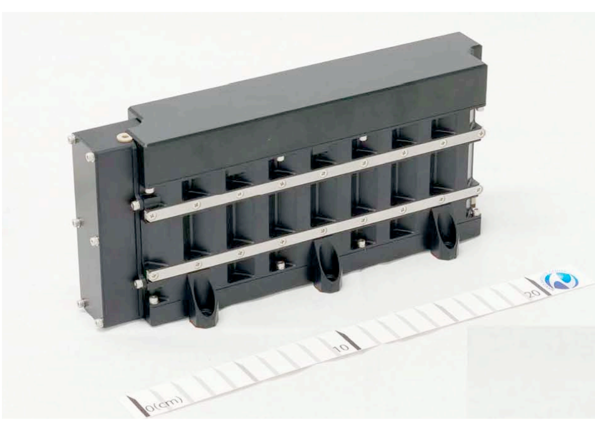

Figure 16: Li-Ion Battery Module

Solar cells are GaInP2/GaAs/Ge triple junction type; and the single cell size is 80 x 40[mm] weighing 2.6[g]. It generates 1W at 2.0V in 80[degC]. Number of cell series is decided as 20 so that they can charge the LIBM with 33.2[V] at maximum. Solar cells are attached on the satellite body and two wings. The roles of PCU are to balance power generation and consumption, to provide power to core components of system, to send basic EPS information to MOBC and to control under voltage of battery by cutting of power supply to some components. BPDU, on the other hand, distribute power to rest of components and drop bus voltage to stabilized 5V for some components. Summary of EPS components are displayed below.

Table 8: EPS Specifications

Battery	Li-Ion, 8 series x 2 parallel, 23.0~33.2V, 6200mAh 1306g
Solar Cell	GaInP2/GaAs/Ge triple junction type, 1W at 2.0V in 80[degC], 20 series 3 strings on each SAP wing 2 strings on +X panel 1 string on –X, +/-Y, and –Z panel
PCU	2852g (PCU and BPDU combined) Control to balance power generation and consumption, Under voltage control, Heater control for LIBM, Power supply to fundamental components
BPDU	Power distribution to components, Voltage conversion to 5V

(d) Communication Subsystem (COM)

COM is consisted of S-band transmitter and receiver (STRX), S-band antenna (S-ANT), X-band transmitter (XTX) and X-band antenna (X-ANT). STRX transmits HK data with 64kbps at maximum; there are two S-ANTs, patch-antennas, on the top and bottom of satellite body, so that satellite does not really need to point to the earth for telemetry and command communication. X-band, on the other hand, takes care of mission data, and transmits large data with 10Mbps bitrate at maximum. X-ANT, also called "Isoflux Antenna" is attached on the +Z surface, and it has higher gain to the peripheral direction by four line helical antenna for efficient transmission.

Figure 17: X-band Isoflux Antenna

Specification of COM components is summarized below.

Table 9: COM Specifications

STRX	Selectable bitrate: 4, 16, 32, 64kbps PCM (NRZ-L)-PSK-PM Demodulation BPSK Modulation, 0.2W Transmission power 2051.617 MHz (Command), 2228.0MHz (Telemetry) RS422, self-reset function, Emergency command reception to reset MOBC 736g, 4.6W @ 28V
S-ANT	2 antennas, 74deg beam width, 107g
XTX	Selectable bitrate: 1.25, 2.5, 5, 10Mbps MSK Modulation, 8055MHz, 2W Transmission power RS422 interface 1150g, <20W @ 28V
X-ANT	Max gain at +/- 60 deg, 151g

(e) Structure and Thermal Subsystem

Structure of UNIFORM-1 satellite is 50cm cube and T-shaped panel supports it structure mainly while keeping accessibility to all of components and ease of integration. It is designed to have natural frequency of more than 100[Hz] for vertical direction of rocket (X-axis of satellite), and more than 50[Hz] for lateral direction of rocket (Y and Z axis of satellite).

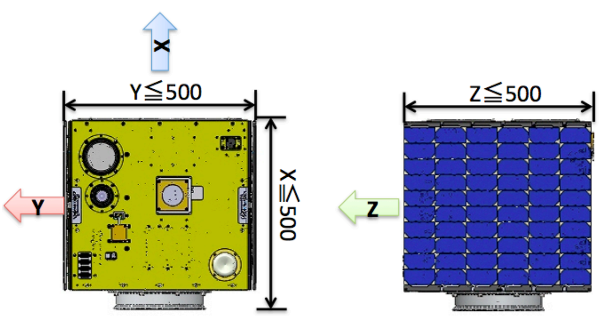

Figure 18: UNIFORM-1 Structure

There is no active thermal control function for whole satellite body although there are some heaters that locally controls components temperature. Instead, MLI is attached on +/- X and +/-Z panels to prevent satellite from over heated or cooled, while +/- Y panel is colored to black for releasing heat of body, heated by components power consumption inside.

Safety Review of H-IIA Rocket

Since UNIFORM-1 is secondary payload of H-IIA rocket, it needs to be compliant with safety standard of "piggy-back launch for small satellite for H-IIA." In addition to all kinds of mechanical interface, thermal interface, electro-magnetic compatibility and environmental condition, it is specifically required not to harm people and other satellites while launch preparation and launching. LIBM and Hold-Release Mechanism (HRM) of SAP wings are especially pointed out to secure its safety because both would cause so-called "catastrophic hazard." Therefore, LIBM and surrounding EPS components are designed to have three inhibits to prevent battery related hazard from being activated. And HRM is designed never to release SAP wings while launched, and tested through vibration test and thermal test.

RESULT OF FLIGHT MODEL TEST

System Integration

System integration of flight model was started with checking power and signal interface among components on a table. Once they were done, components necessary for system test is placed on the satellite structure first. For example, MOBC, STRX, are needed for communicating with ground (Data Acquisition System (DAS) as testing jig in this case). And PCU and BPDU are needed for supplying power for each component. Stabilized power supply is used for main power input for testing to prevent battery to be harmed by malfunction of other components. By using system harness, and those core components, interface of respective components are again tested one by one on satellite structure at this time. Once all components are fixed, operator sends command to it from DAS and check telemetry by turning all components on. Functions that heavily related to application software of OBCs are tested later, after every environmental test is conducted.

Heat Cycle Test

Heat cycle test is held in a thermostatic chamber to check if there is no workmanship error such as bad soldering in a component. Also, basic functions as a whole satellite system are checked at highest and lowest temperature. Range of temperature is set as -5 to 50 [degC]. Although some software related malfunction is detected, it is verified that all the components works properly in this heat cycle environment.

Electro-Magnetic Compatibility (EMC) Test

EMC test is held in radio anechoic chamber to check if noise from components affect on other components; especially communication between satellite and ground is checked if they do not affect on others nor are affected by others. In addition, this was the first opportunity to test it with aerial RF communication while system ground was not connected to earth.

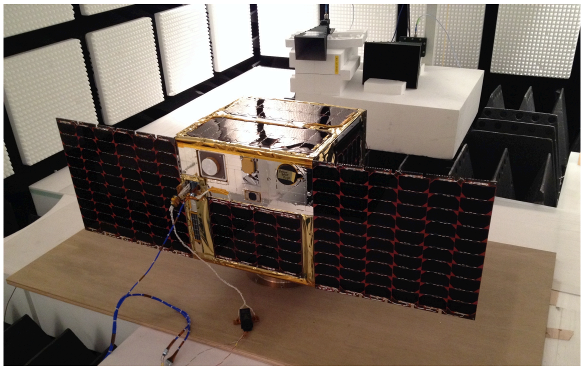

Figure 19: EMC Test in Radio Anechoic Chamber, Waseda University

It is confirmed, through this experiment, that effect to and from STRX and XTX are negligible for nominal operation.

Thermal Vacuum Test

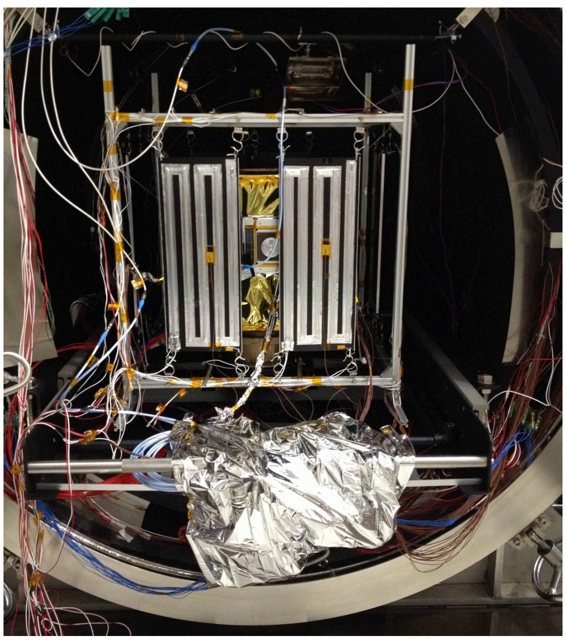

Figure 20: Second Thermal Vacuum Test at Center for NanoSatellite Testing, Kyushu Institute of Technology

Thermal vacuum test is conducted in a thermal vacuum chamber for following purposes: (1) to get reference data for tuning thermal analysis model, (2) to see if BOL controls its lens temperature properly and (3) to see if all basic functions of satellite works properly. In fact, thermal vacuum test was held twice because power to BOL heater control board was not properly provided, and this was regarded as severe malfunction. This was caused by low threshold of current limit of one of BPDU port to BOL heater. Then another port was decided to be used for this interface, and it is tested in the same environment again. After the second test, almost all of functions tested in the thermal vacuum environment worked properly. HRM, did not works as expected, thus some adjustment was applied on them after this test.

Separation Shock Test

When satellite is separated from rocket, shock is applied to bottom of the satellite. JAXA provides opportunity to conduct separation shock test with actual separation unit with explosive devices. Basic functions of satellite are tested before and after this shock test to see nothing is damaged because of the shock. Also it is confirmed that no mechanical damage, such as removal of bolts and structural deformation, is identified.

Vibration Test

Vibration test is held to verify followings: (1) natural frequency of satellite meets requirement of H-IIA piggy-back satellite standards, (2) no mechanical damage is occurred, (3) separation detection switches do not make chattering, and (4) SAP wings do not open. Random vibration, sine-wave vibration and sine-burst vibration are applied to the satellite for X,Y and Z axis. All the items above are successfully verified as a result.

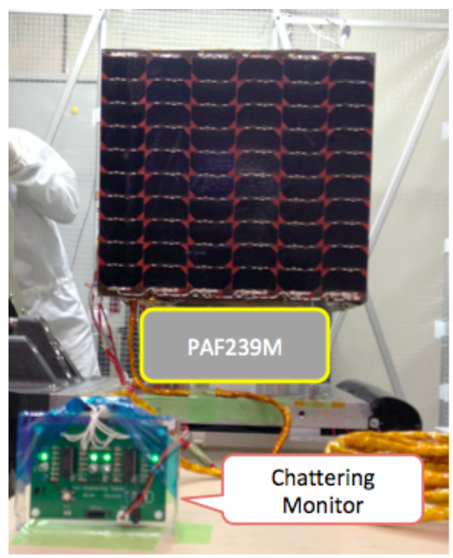

Figure 21: Vibration Test

Software Test

Software on MOBC and AOBC are developed somewhat independently from hardware integration and test. Fundamental function of the software such as function of telemetry and command data handling is necessary for the system test, thus it is developed in advance. However, functions of application layer such as time-line command, re-programming, under voltage control for MOBC and any kind of attitude control algorithm are developed independently since they are not directly related to the purpose of hardware test with or without specific environment. Most of basic functions are developed only with OBC and DAS but attitude control software is developed with dynamics simulator. There are three steps to verify attitude control software: Model in the Loop Simulation (MILS), Software in the Loop Simulation (SILS) and Hardware in the Loop Simulation (HILS). Detail of each step is explained below. See other reference[1] for more discussion.

(a) Model in the Loop Simulation (MILS)

Simulation environment of satellite orbit and attitude dynamics and are made of MATLAB/Simulink functions. In this step, attitude determination and control algorithms are modeled with MATLAB/Simulink as well to test its logic, thus this step can be regarded as part of design of software. Once all attitude control mode is modeled, stability and accuracy of determination and control is verified to meet requirements.

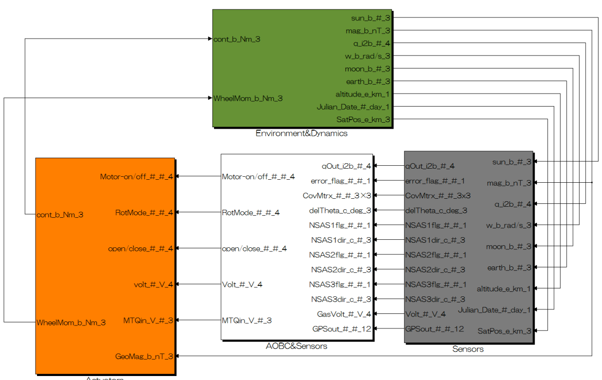

Figure 22: Simulator with MATLAB/Simulink

(b) Software in the Loop Simulation (SILS)

In this step, the attitude control logic modeled above is coded in C, which is used for on-board software. Simulation environment is consistent with MILS while interfacing C code and the environment is modified. It is important to use exactly same code both is this step and on actual OBC, thus driver layer is somewhat emulated by simulator. Although transition from MILS and SILS, meaning code in C based on the design by MATLAB/Simulink, is done manually in this project, it can be done by automatic code generation in the near future.

(c) Hardware in the Loop Simulation (HILS)

Once software in C is verified to work properly, it is installed on AOBC and tested with the same simulator. LabVIEW functions, such as Software Interface Toolkit are used to interface between simulator and AOBC.

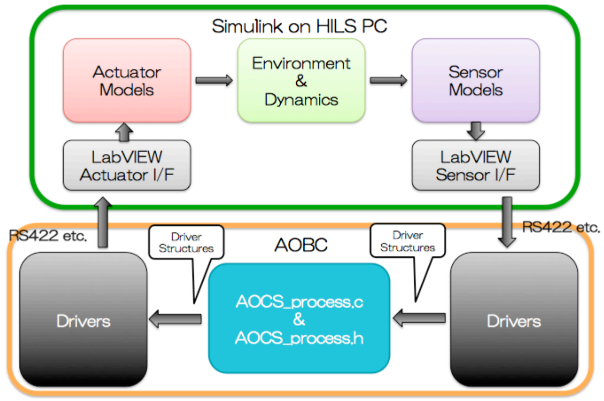

Figure 23: HILS Architecture

"Hardware" here includes AOBC and MOBC only and other components necessary for simulation of attitude control software are emulated Simulink (dynamical behavior) and LabVIEW (signal processing behavior).

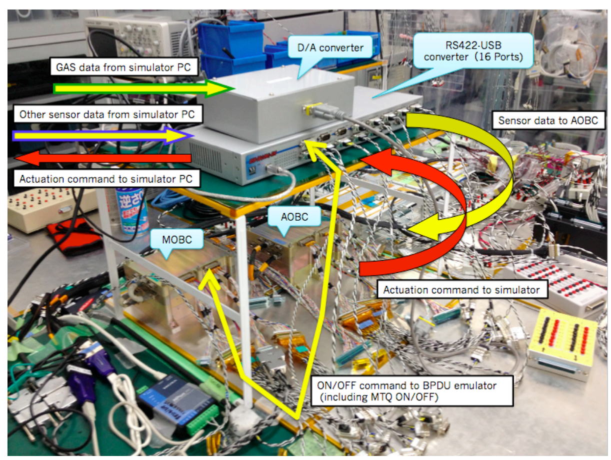

Figure 24: Picture of HILS

(d) Software Test on Flight Model System

MILS, SILS and HILS are important ways to verify attitude determination and control software step by step. Software of MOBC and AOBC as a whole, however still needed to be tested with flight model integrated. Software test conducted in this phase are following: all command check, inner parameter change test, software UVC function, telemetry mode change test, mode transition test, macro command test, reprogramming test and long run test. Software on MOBC and AOBC are easily re-written with out any struggle with hardware since there is accessible port to re write. Therefore, this final software test is more like iterative process of modify, test and debug. With all software is completed, UNIFORM-1 is shipped to Tsukuba Space Center, JAXA on early April 2014.

RESULT OF CRITICAL OPERATION

UNIFORM-1 was launched from Tanegashima Space Center at 12:05:14 JST May 24th 2014. Result of the first critical operation of five days is introduced in this section. First AOS at ground station at Wakayama University was 13:45:48 JST. Signal from satellite was successfully received and all of HK information was in a good state. From next passes, however, initial TLE was not accurate enough to keep tracking satellite. Correct TLE from several TLEs that NORAD provides was identified at the night of next day. SAP wings are deployed successfully by sending command to deploy on May 26th. Next, attitude control was activated by transitioning to SSP mode. Regardless of relatively high tumbling rate of more than 10 [deg/s], which is estimated value from telemetry and a video at separation provided by JAXA, attitude was successfully converged to the target spin rate of (0, 0, 3) [deg/s] and the spin-axis is faced to the sun within +/- 20[deg]. Third, first light of BOL was taken on the sunshine side since it could capture image of the ground on that side even in sun pointing mode. Finally, the image was transmitted at around 13:30 JST May 20th.

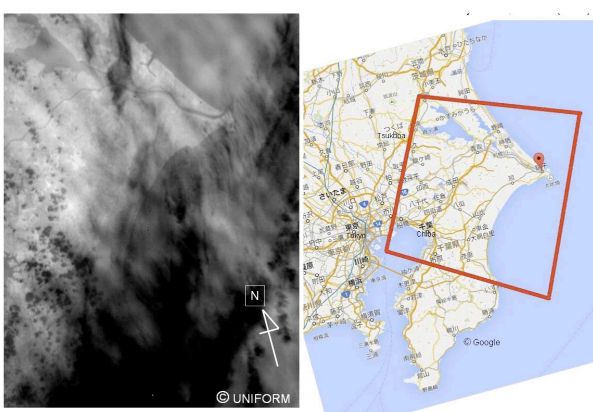

Figure 25: First Light of BOL Camera (Part of Chiba Prefecture, Japan)

After this successful critical operation, other control modes are being checked while some other images of BOL and VIS are taken from time to time.

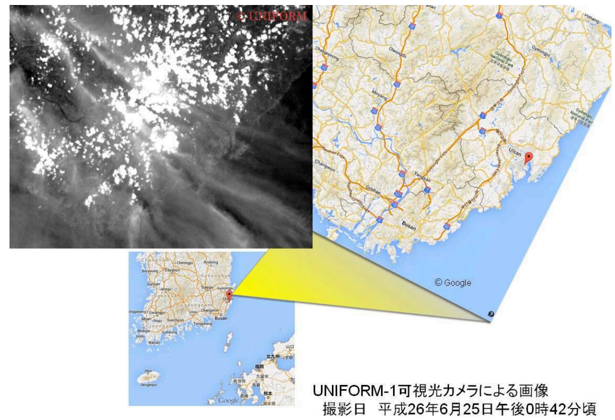

Figure 26: Image Taken by VIS Camera (Part of South Korea)

SUMMARY

Broad goal of UNIFORM project is to establish sustainable space industry in Japan and other countries by constructing small satellite constellation system together. Although funding from MEXT is only for five years and 2014 is the last year, this concept is inherited to various type of project. UNIFORM-1 is developed as the very first step of the project, with the mission of forest fire monitoring. Design, test result of the flight model and result of initial operation are focused on to be discussed in this paper. Operation of satellite is being continued as of now, to start providing forest fire information steadily.

ACKNOWLEDGEMENTS

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