Development of Modular 3U CubeSat Standard Platform and Its Application to KAUSAT-5

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Development of Modular 3U CubeSat Standard Platform and Its Application to KAUSAT-5

INTRODUCTION
Introduction

3U CubeSat Platform and Configuration

- 3U CubeSat is the most popular configuration in ultra-small satellite
- Many CubeSat venture companies (such as Pumpkin, Nano Avionics and Clyde Space) are developing and commercializing 3U CubeSat platform and subsystem modules.

![Diagram of 3U CubeSat components: Payload, Wheels, Avionics, PEARL, PLT3(NanoAvionics), Clyde Space]
The CubeSat configuration can be greatly changed depending on the mount and deployment configuration of the solar panels as followings;

- The first configuration is that the solar panels are directly attached on the satellite structure surface
  - No need to deploy the solar panel
  - Low power generation

- The second configuration is that the solar panels are deployed from the satellite side edge
  - High power generation due to its side edge solar panel
  - Possibility of failure upon solar panel deployment

- The third one is that the solar panel is deployed from upper edge
  - Structure is simple and stable in development
  - It has a relatively low failure rate
The CubeSat configuration can be greatly changed depending on the mount and deployment configuration of the solar panels as followings:

<table>
<thead>
<tr>
<th>CubeSat Name</th>
<th>Mission</th>
<th>Solar Panel Type</th>
<th>Similar Type of CubeSat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dove 1</td>
<td>Low Cost, Observation satellite Development &amp; Verification</td>
<td>Side Deployment Type (2nd Configuration)</td>
<td>Flock-1, Helio 4 ExoplanetSat</td>
</tr>
<tr>
<td>Aeneas</td>
<td>Tracking location cargo Containers on a global scale</td>
<td>Upper Deployment Type (3rd Configuration)</td>
<td>Alice, Cadre Lightsail A, Delfi-n3xt</td>
</tr>
<tr>
<td>All-Star /Theia</td>
<td>THEIA Verification</td>
<td>Diagonal Deployment Type (2nd Configuration)</td>
<td>Inspire A, Lemur-2 Delfi phi</td>
</tr>
<tr>
<td>ISARA</td>
<td>Ka-band reflector array antenna verification</td>
<td>Etc.</td>
<td>ORS Tech. Mayflower-Caerus</td>
</tr>
</tbody>
</table>

[The Configuration of 3U CubeSat Depending on the Solar Panel Deployment]
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3U CUBESAT STANDARD PLATFORM DESIGN
**3U CubeSat Standard Platform Design**

### Basic requirements of the standard platform design are;
- To optimize and design lightweight modules for reducing the cost and schedule of the 3U CubeSat development
- To develop and modify the modules related to specific payload and interface changes for various missions

### Architecture of the 3U CubeSat standard platform
- The major subsystems provided for the standard platform are as follows;
  - SMS (Structure and Mechanism Subsystem)
  - ADCS (Attitude Determination and Control Subsystem)
  - C&DHS (Command and Data Handling Subsystem)
  - EPS (Electrical Power Subsystem)
  - CS (Communication Subsystem)
  - MDHU (Mission Data Handling Subsystem);
  - TCS (Thermal Control Subsystem)
- Further extensibility of the platform subsystem is feasible depending on mission requirement
3U CubeSat Standard Platform Design

System Architecture of the Standard Platform
The Basic Communication Interface

- I2C and CAN, which are widely used in the existing miniature satellite, was selected as the basic communication interface considered for interworking with the currently COTS (Commercial-Off-The-Shelf) products.
- The interface supports M2M (Multi-to-Multi) communication and the number of components can be extended per the developer’s convenience.

Mission Data Processor for Payloads

- The interface between platform and payload can be minimized due to separate interface for data storage and S-band communication system for mission data transmission.

Actuators and Sensors for ADCS

- The developer can expand actuators and sensors for ADCS.

EPS (Electrical Power Subsystem)

- The solar panel, the battery, and the mechanism can be configured by the developer.
To select the platform configuration and size, 24 CubeSats being developed and operated among 3U CubeSats are analyzed.

- The platform includes various subsystems such as SMS, ADCS, EPS, CS, etc. The size of the surveyed platform varies depending on the mission of each satellite.
- The platform size of 1.5 U or 2 U is the most common among 3U CubeSats as shown in the right figure.

Based on this data, the 3U CubeSat standard platform developed for this study is occupying 1.5U, and the remaining 1.5U for the payload and ADCS actuators, such as CMG (Control Moment Gyro) or RWA (Reaction Wheel Assembly).
The main performance parameters are analyzed to select the standard specification by referring to the specification of the CubeSat currently being operated or the CubeSat kit that is available commercially.

The performance of C&DHS and ADCS have been remarkably improved:
- 8-bit, 8-MHz MCUs → More than a 32-bit, 200-MHz
- Passive control → Active control for ADCS implementing CMG or RWA

Frequency Band for CubeSat:
- Amateur radio frequency → S-band and/or X-band frequency band for high capacity mission data transmission
## Basic Specification for 3U CubeSat Standard Platform

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Generation</td>
<td>&lt; 30 W</td>
</tr>
<tr>
<td>BCR Function</td>
<td>Included</td>
</tr>
<tr>
<td>MPPT Function</td>
<td>Included (P&amp;O, Fuzzy)</td>
</tr>
<tr>
<td>Uplink</td>
<td>UHF or VHF, 1,200 or 9,600 bps</td>
</tr>
<tr>
<td>Downlink</td>
<td>UHF or VHF, 1,200 or 9,600 bps</td>
</tr>
<tr>
<td>Mission Data Downlink</td>
<td>S-band Up to 1 Mbps</td>
</tr>
<tr>
<td>Mission Data Handling Unit</td>
<td>Included</td>
</tr>
<tr>
<td>ADCS Board</td>
<td>462 MIPS, 215 MHz</td>
</tr>
<tr>
<td>D&amp;DHS Board</td>
<td>220 MIPS/ 200 MHz, NandFlash (&lt;256 MB) SDRAM (&lt;1 GB)</td>
</tr>
<tr>
<td>CMD/TLM Bus</td>
<td>CAN, I2C</td>
</tr>
<tr>
<td>ADCS Actuator Expansion</td>
<td>CAN, I2C</td>
</tr>
<tr>
<td>ADCS Sensor Expansion</td>
<td>I2C, SPI</td>
</tr>
<tr>
<td>GPS Expansion</td>
<td>UART, PPS</td>
</tr>
</tbody>
</table>
3U CubeSat Standard Platform Design

SMS of 3U CubeSat standard platform is basically designed according to the CDS (CubeSat Design Specification).

- The deployment mechanism of the solar panel is one of the main considerations to decide the configuration of 3U CubeSat structure.
- The solar panel deployment mechanism is a part that must be defined by the user.
- If the payload meets the required specifications, the payload can be housed mechanically within the platform using a pole for PCB connection, and if necessary, only by changing or modifying the electrical interface.

[Structure Configuration of Standard CubeSat Platform]
Basic ADCS of the 3U CubeSat standard platform is equipped with MTQ (Magnetic Torquer) as an actuator and magnetometers and sun sensor as sensors.

Depending on the mission requirement, other actuator like RWA (Reaction Wheel Assembly) or CMG (Control Moment Gyro) can be implemented for high torque actuation and high agility.
The functional diagram of the ADCS is shown in the following figure.
The C&DHS of the standard platform focuses on devices that are widely used by 3U CubeSat developers in various fields, and have flight heritage in space.

- AT91SAM926X CPU based on ARM-926EJ Core in the 3U CubeSat standard platform is selected.
- ARM-926EJ Core provides BSP (Board Support Package) in various RTOS such as uCLinux, Real-Time Executive for Multiprocessor Systems (RTEMS), uC/OS-III, FreeRTOS and VxWorks.

The C&DHS of the standard platform is designed to be composed of a microcontroller with flight software, an interface part for transmitting and receiving commands and data to CAN/I2C, which is a common communication interface between memory and subsystem.
The EPS of the standard platform shall supply enough power to the satellite payload and platform for a successful mission during the satellite’s mission.

The power generated by 3U CubeSat shows less than 30W.

- Maximum power generated by EPS is assumed to be 30W.
- Fuzzy Logic based MPPT is equipped with P&O (Perturb & Observe) and the MPPT algorithm can be changed by the user.

[Distribution According to Electrical Power Generation]
The functional diagram of the EPS is shown in the following figure.
In the standard platform, two communication bands (VHF and UHF) can be used as a baseline, and the communication protocol is AX.25.

The VHF receives the remote command of the ground station, and the UHF transmits the beacon transmission and the telemetry containing the status information of the satellite to the ground station.

The MDHU is a subsystem configured to process and store mission data and transmit to the ground in S-band.

[Functional diagram of the CS and MDHU]
Development of Modular 3U CubeSat Standard Platform and Its Application to KAUSAT-5

APPLICATION OF 3U CUBESAT STANDARD PLATFORM
**KAUSAT-5 Missions**

KAUSAT-5 is a 3U(100×100×340mm³) CubeSat that performs multiple science and technical verification missions.

- The primary mission is to observe the Earth through infrared camera
- The secondary mission is to verify the equipment(device) such as VSCMG(Variable Speed Control Moment Gyro) and fuzzy logic-based MPPT internally developed

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Platform</strong></td>
<td></td>
</tr>
<tr>
<td>SMS</td>
<td>Structure, Deployer (Solar Panel, Antenna)</td>
</tr>
<tr>
<td>TCS</td>
<td>Heater, Temperature Sensor</td>
</tr>
<tr>
<td>EPS</td>
<td>Solar Cell, Battery, MPPT, EPSU, EPCU, EPDU</td>
</tr>
<tr>
<td>C&amp;DHS</td>
<td>On-board Computer, MU (Memory Unit), SU (Sensor Unit), IU (Interface Unit)</td>
</tr>
<tr>
<td>ADCS</td>
<td>Sun Sensor, Magnetic torquer, GPSRU (GPS Receiver Unit)</td>
</tr>
<tr>
<td>CS</td>
<td>UTU, STU, VRU, Antenna</td>
</tr>
<tr>
<td><strong>Payload</strong></td>
<td></td>
</tr>
<tr>
<td>IRC</td>
<td>Lens, Detector, Shutter, IRC Temperature Control Unit</td>
</tr>
<tr>
<td>GMRM</td>
<td>GMRM Tube, Transformer</td>
</tr>
<tr>
<td>VSCMG</td>
<td>VSCMG, Interface Unit</td>
</tr>
</tbody>
</table>
### Application of Standard Platform to KAUSAT-5

#### KAUSAT-5 Deployed Configuration and System Specification

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mission Orbit</strong></td>
<td>Sun synchronous Orbit: 510km Inclination : 98°</td>
</tr>
<tr>
<td><strong>Mission Life Time</strong></td>
<td>&gt; 1 year</td>
</tr>
<tr>
<td><strong>Dimension</strong></td>
<td>100x100x340mm³</td>
</tr>
<tr>
<td><strong>Payload</strong></td>
<td>IR Camera, GMRM, VSCMG, FLCMPPT</td>
</tr>
<tr>
<td><strong>Payload Accommodation</strong></td>
<td>IRC Mass : 580 g GMRM Mass : 47 g</td>
</tr>
<tr>
<td><strong>IR Camera Specification</strong></td>
<td>Resolution : 320 x 240 (m) FOV : 13.5 deg.</td>
</tr>
<tr>
<td><strong>GMRM Specification</strong></td>
<td>Resolution : &gt;18 CPS/mR/h Accuracy : &lt;3 mR/h</td>
</tr>
<tr>
<td><strong>Spacecraft Mass</strong></td>
<td>&lt; 4 kg</td>
</tr>
<tr>
<td><strong>Satellite Power</strong></td>
<td>&lt; 6.4 W @ EOL (Nadir) &lt; 13 W @ EOL (Sun Pointing)</td>
</tr>
<tr>
<td><strong>Attitude Control Specification</strong></td>
<td>3-Axis Stabilization Accuracy : &lt; 0.88 deg. Knowledge : &lt; 0.87 deg. Stability : &lt; 0.42 deg/s</td>
</tr>
<tr>
<td><strong>Link Margin</strong></td>
<td>&gt; 3 dB @ 10 deg. Elevation Angle</td>
</tr>
<tr>
<td><strong>Data Rate</strong></td>
<td>UHF Downlink : 9,600 bps VHF Uplink : 1,200 bps S-band Downlink : 115,200 bps</td>
</tr>
</tbody>
</table>
Payload 1; VSCMG
- Occupies 0.7U on the top part of the platform
- It is designed considering the possibility of electromagnetic field due to noise of BLDC motor of VSCMG, the problem of deflection of the center of mass to the bottom, and convenience of assembling

Payload 2; Infrared Camera
- The infrared camera at the bottom part occupies 0.8U
- The lens diameter and barrel length are 66 and 67 mm, respectively

Platform; 3U CubeSat Standard Platform
- The platform on the KAUSAT-5 occupies the remaining 1.5U
Application of Standard Platform to KAUSAT-5

Sectional Views of KAUSAT-5 CubeSat

Payload Segment 1 (0.7U)
Platform Segment (1.5U)
Payload Segment 2 (0.8U)
Payload Segment 1 (0.7U)
Platform Segment (1.5U)
Payload Segment 2 (0.8U)
3U CubeSat standard platform has been verified by successfully performing system performance test, functional test and space environment test of KAUSAT-5.

The satellites adopting 3U CubeSat standard platform can reduce the development cost and schedule by avoiding repetitive test.

- No need to repeat the qualification test for the platform system and modules.
- The development and qualification of 3U CubeSat typically takes a year or more, and the total development time can be much longer depending on the complexity of the mission and the experience of the development personnel.
- If a standard platform is used, the development time can be minimized within one year depending on the preparation of the payload.
The 3U CubeSat standard platform can be applied to various payloads:

- Currently, our team is working on the design of 3U CubeSat equipped with Electro Optical Camera, followed by KAUSAT-5.
- It is necessary to mount RWA or CMG to increase pointing accuracy.

[Trade-Off of EO Camera Characteristics for 3U CubeSats]

[Application of Standard Platform to EO Mission]
KAUSAT-5 SYSTEM AIT AND VERIFICATION

Development of Modular 3U CubeSat Standard Platform and Its Application to KAUSAT-5
ETB (Electrical Test Bed) was developed and tested to verify the function of all payload and platform subsystem, flight software, and the electrical interface between modules as well as components. The module and components that were implemented for ETB test are engineering model, and tested to verify the electrical functions.
Functional and performance tests were performed to verify that the operations required by payload and standard platform to perform KAUSAT-5 actual missions are performed successfully.

- The hardware and software of the satellite are verified through functional and performance tests simultaneously.
- It also verifies the communication between the satellite and the ground station through an end-to-end test.
Vibration tests were completed for the KAUSAT-5 as follows;

- Acceleration test
- Random vibration test
- Shock test

The vibration tests on KAUSAT-5 QM (Qualification Model) and FM (Flight Model) were performed for qualification and acceptance, respectively, for 3-axes with satellite inserted in P-POD.

- The vibration test was first carried out to collect the natural frequency data of the satellite prior to perform the random vibration test.
- The results of modal analysis were compared to check whether the natural frequency of the satellite changes after the vibration test.
The system-level acceleration test was performed only on the QM. Test condition of the acceleration test was carried out for 60 seconds at +18.75 g at a sine wave of 0.013 g²/Hz.

The random vibration test was performed in both the qualification and the acceptance test. The amplitude of the qualification test is twice that of the acceptance test. The duration of the qualification test is three times longer than that of the acceptance test.

<table>
<thead>
<tr>
<th>Freq. Profile</th>
<th>Qualification</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Hz</td>
<td>0.013 g²/Hz</td>
<td>0.013 g²/Hz</td>
</tr>
<tr>
<td>50 Hz</td>
<td>0.08 g²/Hz</td>
<td>0.08 g²/Hz</td>
</tr>
<tr>
<td>800 Hz</td>
<td>0.08 g²/Hz</td>
<td>0.08 g²/Hz</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>0.013 g²/Hz</td>
<td>0.013 g²/Hz</td>
</tr>
</tbody>
</table>

RMS acceleration

<table>
<thead>
<tr>
<th>Duration</th>
<th>Qualification</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 sec/axis</td>
<td>14.1 g</td>
<td>10.0 g</td>
</tr>
<tr>
<td>60 sec/axis</td>
<td>60 sec/axis</td>
<td>10.0 g</td>
</tr>
</tbody>
</table>

[Random Vibration Test Conditions]
Environmental Test; Vibration Test Results

Random Vibration Qualification Test Results

- The random vibration test results of the KAUSAT-5 QM are shown in the right figure.
- Structural defects and functional failure of modules and components did not occur after the vibration test.
- It was confirmed through this test that KAUSAT-5 is structurally stable and has design margins.

Random Vibration Acceptance Test Results

- The random vibration test results for KAUSAT-5 FM are shown in the right figure.
- The natural frequencies of the X, Y, and Z axes were found to satisfy the predicted requirement of 90Hz or more.
- It was confirmed through this test that the satellite structure does not show any defect.
To verify the robustness against any shock environments caused by rocket stage separation, deployment of solar array, etc.

The pyro shock test method was applied to KAUSAT-5.

It was checked through visual inspection whether there was any damaged modules and components in the satellite, and in addition, a functional test was performed to make sure whether the satellite operates normally after shock test.

The shock test of KAUSAT-5 was only performed on QM at qualification level, and the deformation level after the shock was analyzed on FM under the same conditions as QM test.

The shock conditions were 30g at 20Hz and 1,000g at 1,000~10,000Hz.
The shock test results for X-axis of the qualification model are shown in figure below. After analyzing the results of SRS (Shock Response Spectrum) results, it was confirmed that there was no damage to the structure of KAUSAT-5 satellite before and after shock.
The shock at the acceptance level of KAUSAT5 FM was verified by analysis instead of shock test. The results of the shock analysis for the flight model are shown in figure below.

The tendency of the overall SRS curve is similar to the results of the actual shock as a result of analyzing the damping effect in the P-POD.

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.9477e-7 m</td>
<td>Max</td>
</tr>
<tr>
<td>3.5091e-7 m</td>
<td></td>
</tr>
<tr>
<td>2.6318e-7 m</td>
<td></td>
</tr>
<tr>
<td>2.1932e-7 m</td>
<td></td>
</tr>
<tr>
<td>1.7546e-7 m</td>
<td></td>
</tr>
<tr>
<td>1.3159e-7 m</td>
<td></td>
</tr>
<tr>
<td>8.7728e-8 m</td>
<td></td>
</tr>
<tr>
<td>4.3864e-8 m</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Min</td>
</tr>
</tbody>
</table>
The thermal vacuum test of KAUSAT-5 was performed for both EQM and FM under vacuum condition of $1.0 \times 10^{-6}$ torr. and thermal cycles.

The thermal vacuum test was carried out three cycles at a temperature range at -15℃ to 45℃ for QM and two cycles at -10℃ to 35℃ for FM.
A standard platform of 3U CubeSat has been developed and its function and performance have been verified by applying the standard platform to KAUSAT-5 CubeSat. Since the standard platform was developed as a modular concept, it was designed to be able to mount a variety of payload per the user’s mission.

The KAUSAT-5, adopting 3U CubeSat standard platform, was developed and tested for its verification. KAUSAT-5 QM and FM were built to verify the design margin and workmanship, respectively.

The 3U CubeSat can be easily and fast developed with the suitable payload on standard platform least modified. The standard platform will be validated in space after the launch in the first quarter, 2018. The 3U CubeSat newly developed does not need additional qualification test for the platform, thereby reducing the development cost and schedule.
Thank You!

KAUSAT-5
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