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

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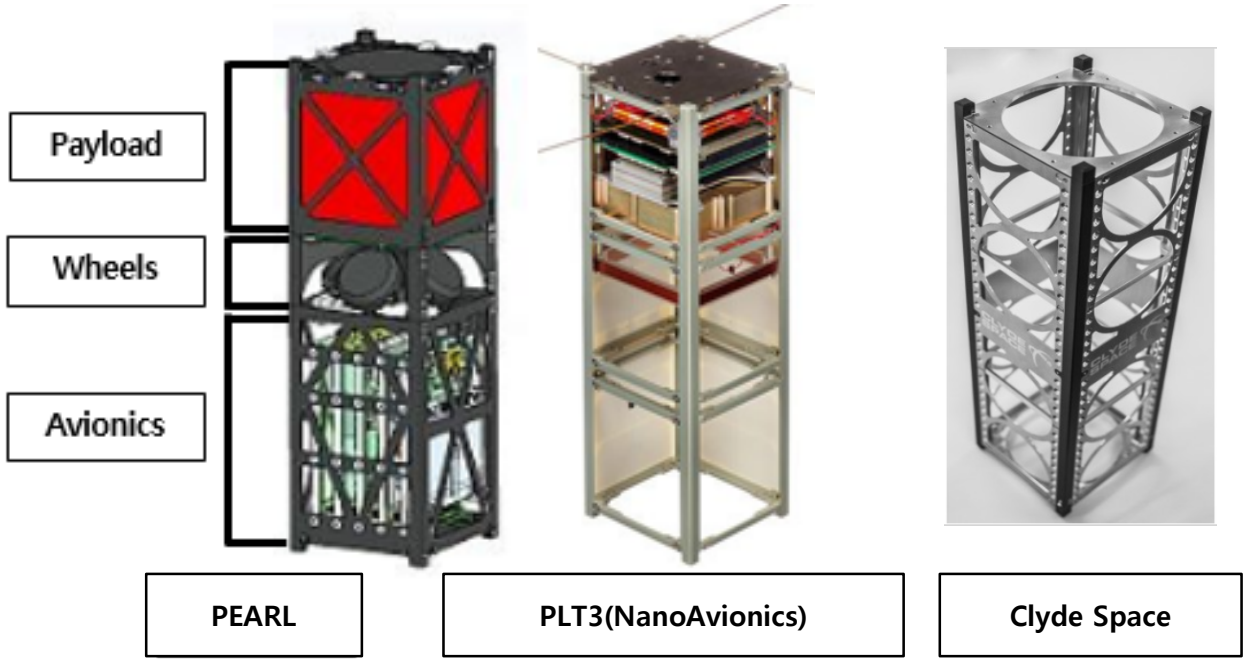
INTRODUCTION

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.



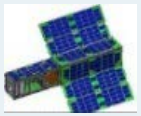
Introduction

3U CubeSat Platform and Configuration

- **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

3U CubeSat Platform and Configuration

- **The CubeSat configuration can be greatly changed depending on the mount and deployment configuration of the solar panels as followings;**

	CubeSat Name	Mission	Solar Panel Type	Similar Type of CubeSat
	Aalto 1	Tech. Demo EO imaging/ Radiation Detect.	Attached Type (1st Configuration)	Armadillo, RAX-1, CanX-2, GOMX-1, Etc.
	Dove 1	Low Cost, Observation satellite Development & Verification	Side Deployment Type(2nd Configuration)	Flock-1, Helio 4 ExoplanetSat
	Aeneas	Tracking location cargo Containers on a global scale	Upper Deployment Type (3rd Configuration)	Alice, Cadre Lightsail A, Delfi-n3xt
	All-Star /Theia	THEIA Verification	Diagonal Deployment Type (2nd Configuration)	Inspire A, Lemur-2 Delfi phi
	ISARA	Ka-band reflector array antenna verification	Etc.	ORS Tech. Mayflower-Caerus

[The Configuration of 3U CubeSat Depending on the Solar Panel Deployment]

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

3U CUBESAT STANDARD PLATFORM DESIGN

3U CubeSat Standard Platform Design

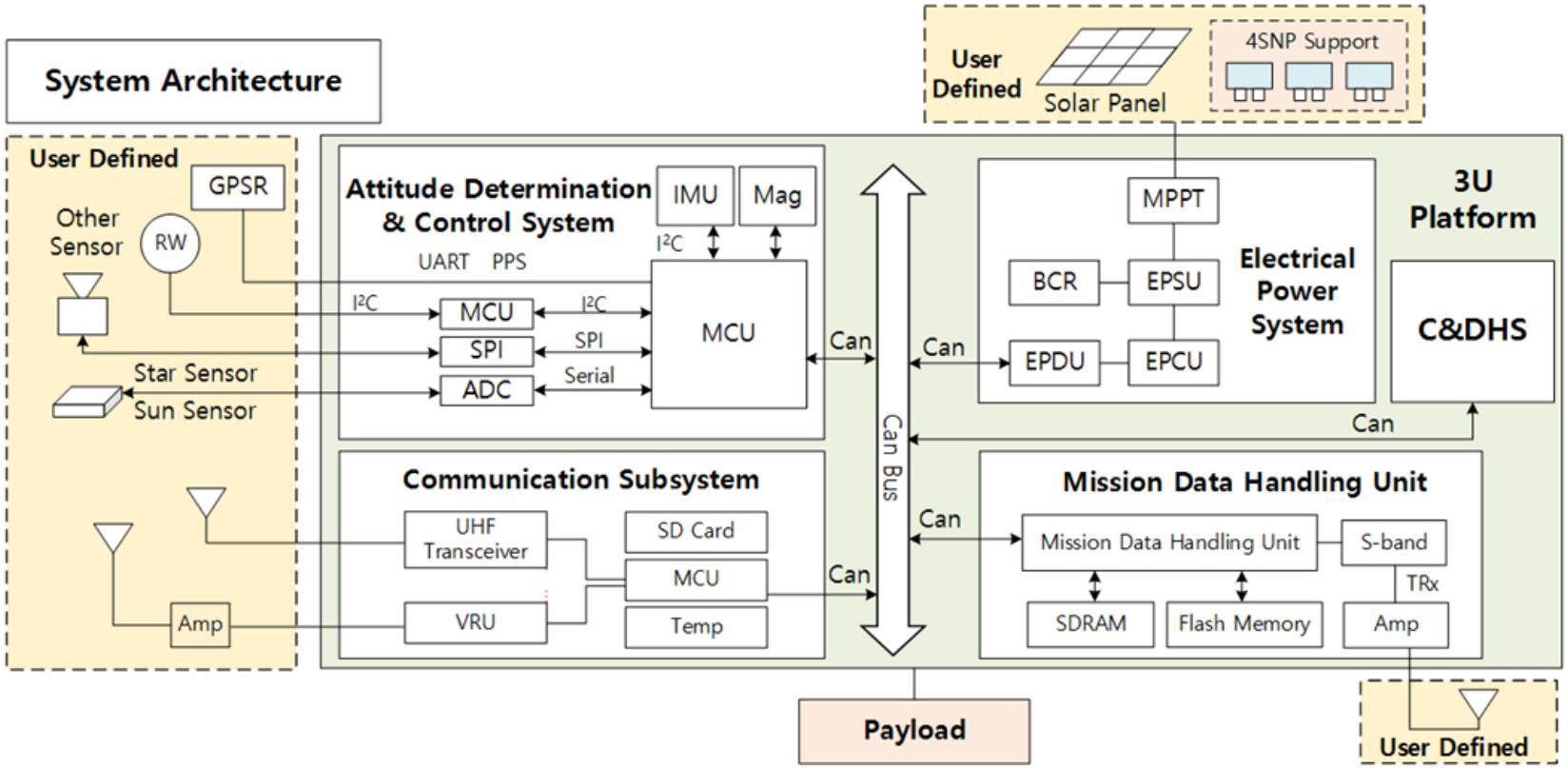
3U CubeSat Standard Platform Architecture

- **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

3U CubeSat Standard Platform Architecture

- System Architecture of the Standard Platform



3U CubeSat Standard Platform Design

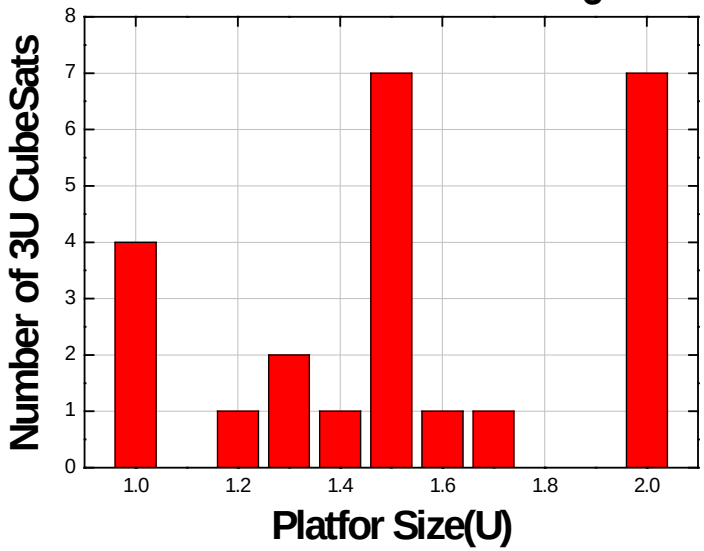
Baseline of 3U CubeSat Standard Platform Design

- **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

3U CubeSat Standard Platform Design

Configuration Selection for 3U Standard Platform

- **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 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)**



[Classification of 3U CubeSat Platform Size]

3U CubeSat Standard Platform Design

Specification Selection for Standard Platform

- 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

3U CubeSat Standard Platform Design

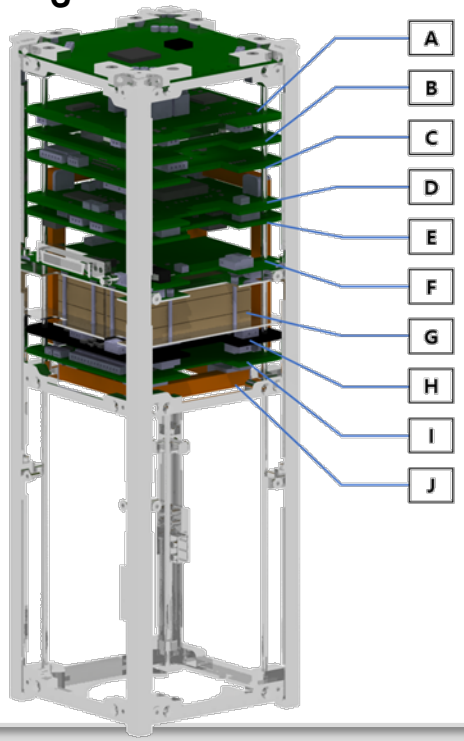
Basic Specification for 3U CubeSat Standard Platform

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

3U CubeSat Standard Platform Design

SMS(Structure and Mechanism Subsystem)

- **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



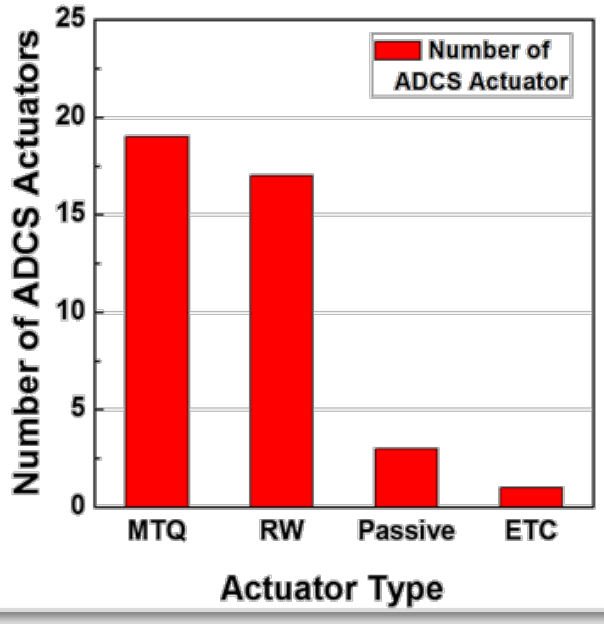
A	ADCS 1 Board
B	GPS
C	ADCS 2 Board
D	EPS 1 Board
E	C&DHS Board
F	GMRM & TCS
G	Battery
H	EPS 2 Board
I	CS Board
J	MTQ

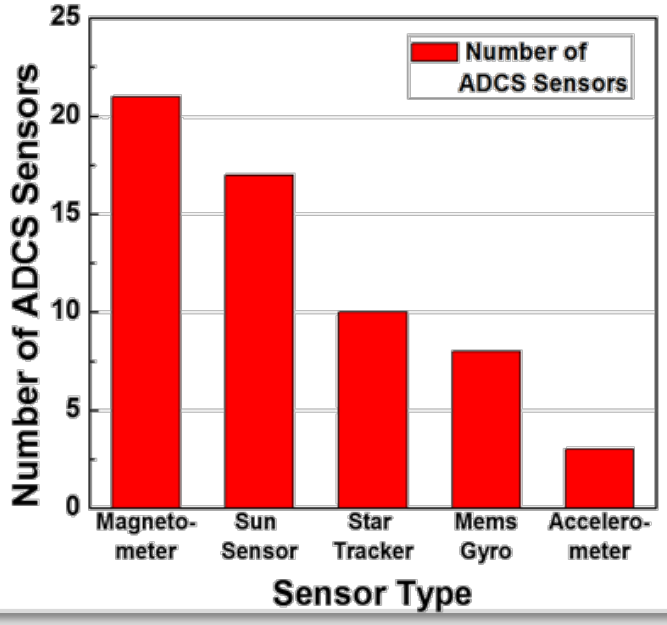
[Structure Configuration of Standard CubeSat Platform]

3U CubeSat Standard Platform Design

ADCS(Attitude Determination and Control Subsystem)

- **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

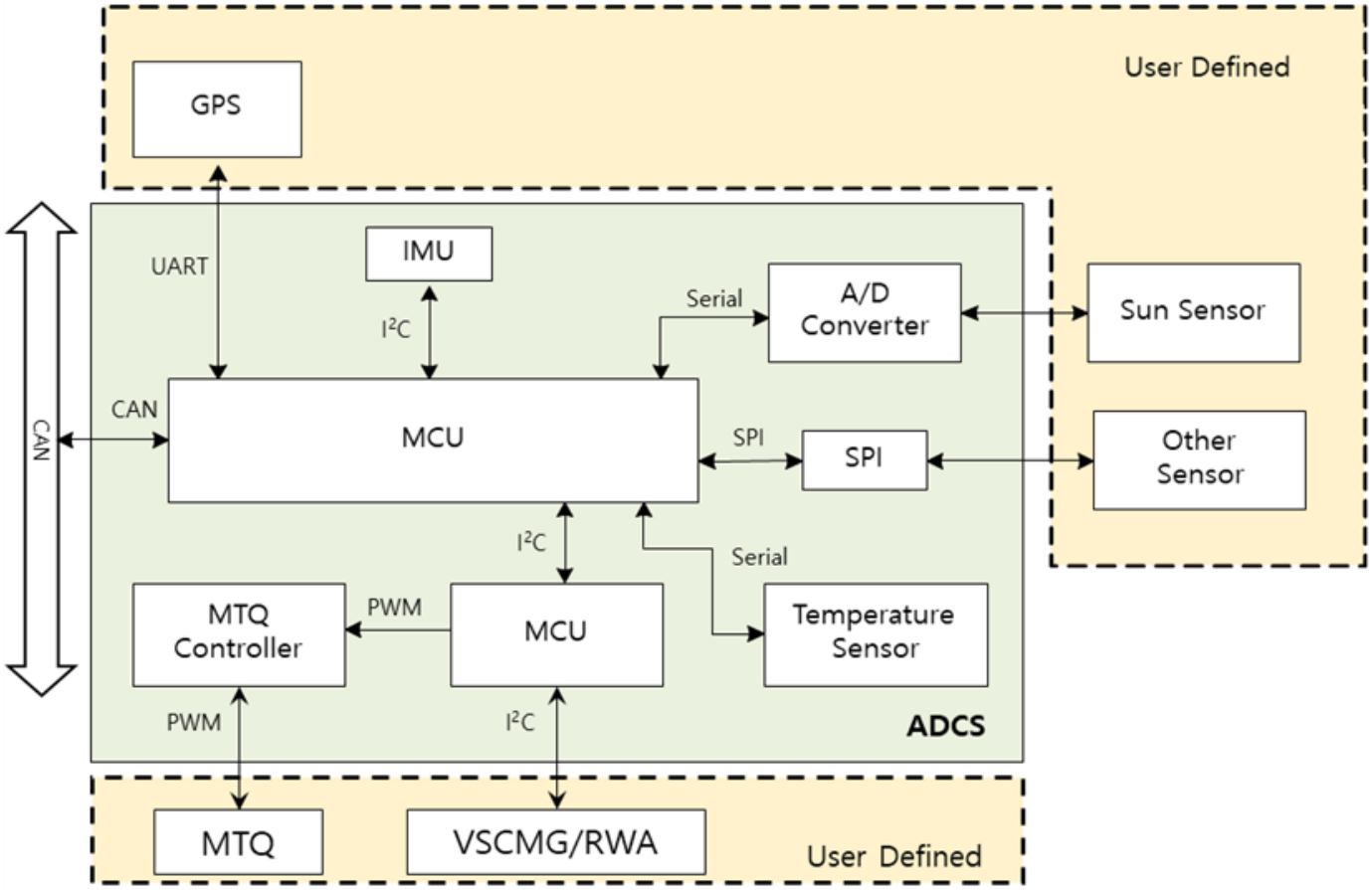




3U CubeSat Standard Platform Design

ADCS(Attitude Determination and Control Subsystem)

- The functional diagram of the ADCS is shown in the following figure



3U CubeSat Standard Platform Design

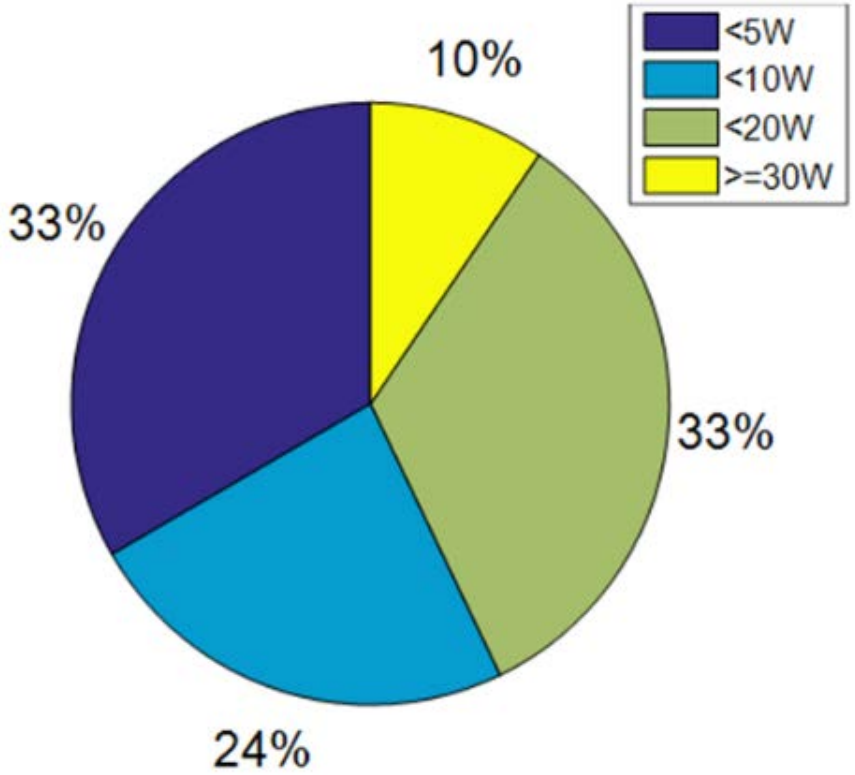
C&DHS(Command and Data Handling Subsystem)

- **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

3U CubeSat Standard Platform Design

EPS(Electrical Power Subsystem)

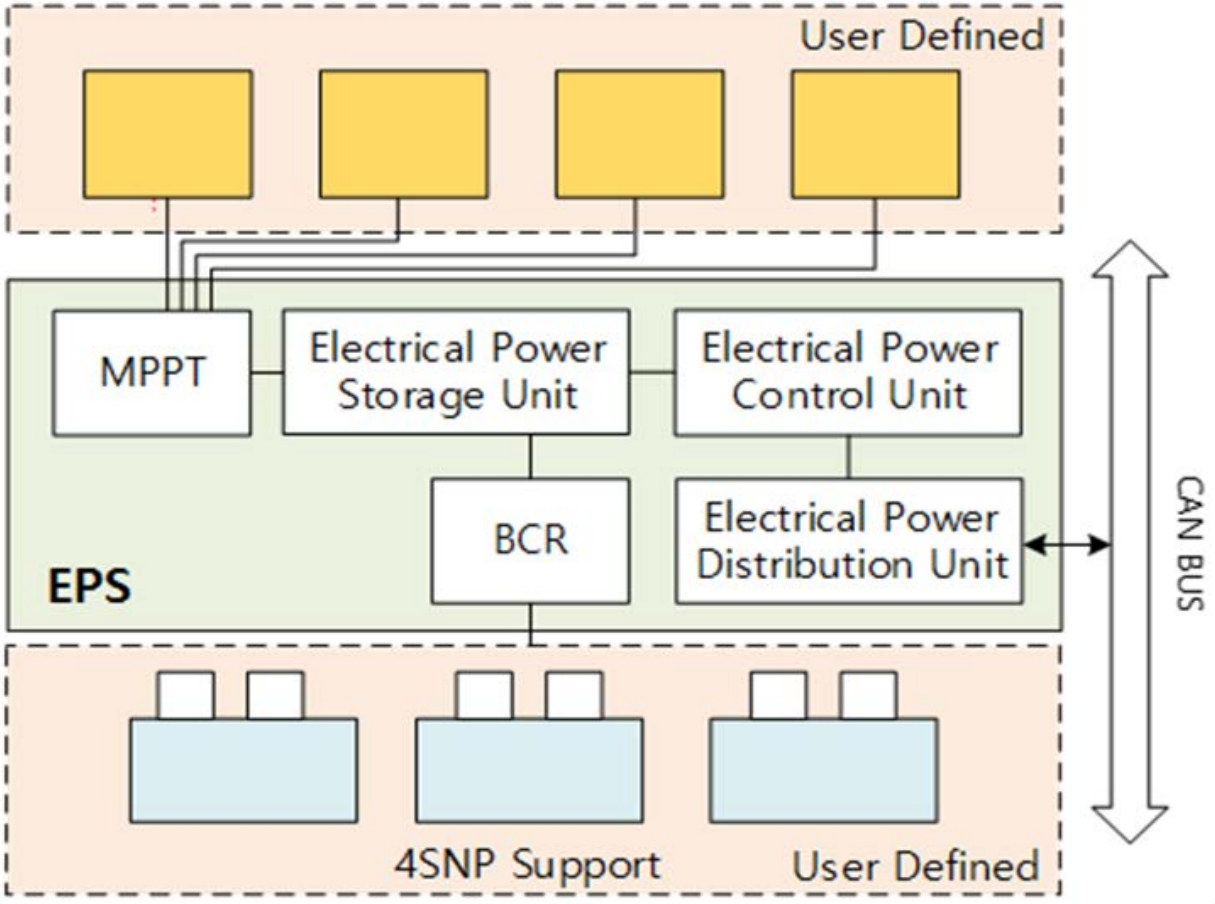
- The EPS of the standard platform shall supply enough power to the satellite payload and platform for a successful mission during the satellite´s mission
- The power generated by 3U CubeSat shows less than 30W
  - Maximum power generated by EPS is assumed to be 30W
  - Fuzzy Logic based MPPT is equipped with P&O (Perturb & Observe) and the MPPT algorithm can be changed by the user



[Distribution According to Electrical Power Generation]

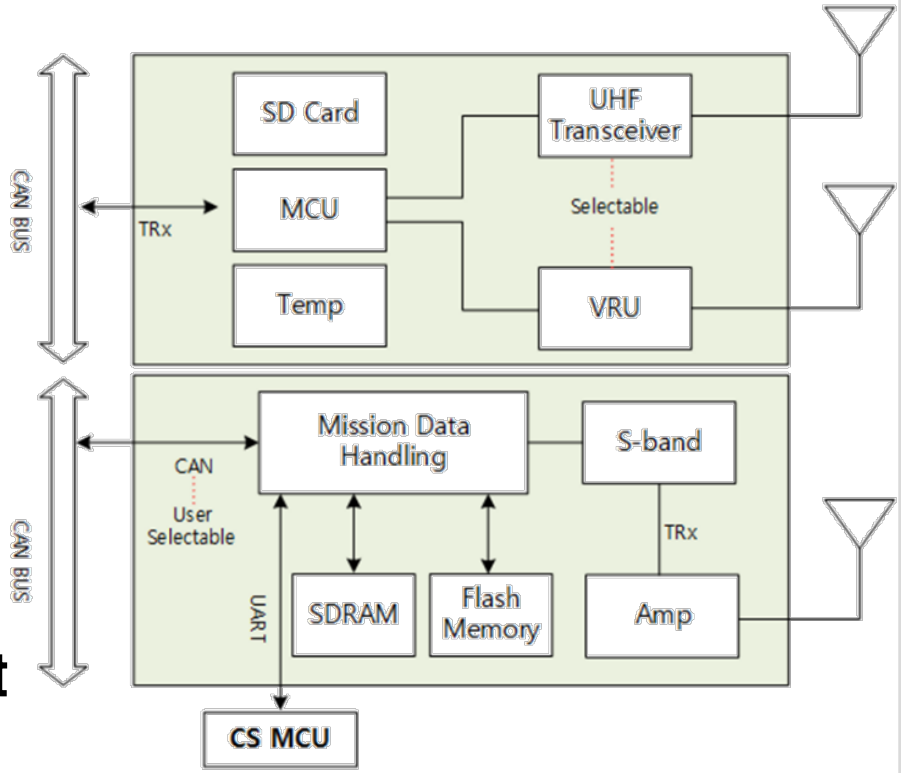
EPS(Electrical Power Subsystem)

- The functional diagram of the EPS is shown in the following figure



CS(Communication Subsystem) and MDHU(Mission Data Handling Unit)

- 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

Application of Standard Platform to KAUSAT-5

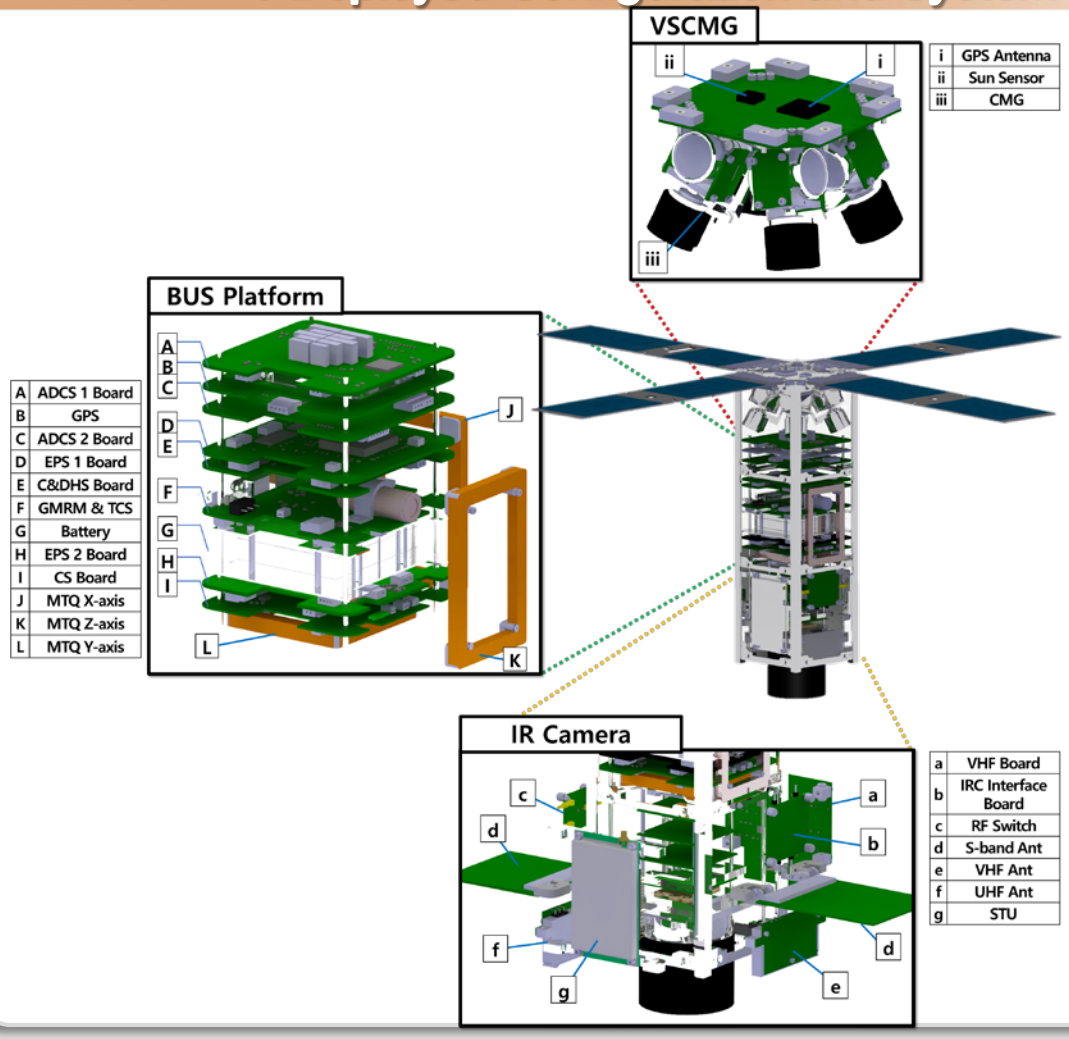
KAUSAT-5 Missions

- **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

	Subsystem	Components
Platform	SMS	Structure, Deployer (Solar Panel, Antenna)
	TCS	Heater, Temperature Sensor
	EPS	Solar Cell, Battery, MPPT, EPSU, EPCU, EPDU
	C&DHS	On-board Computer, MU (Memory Unit), SU (Sensor Unit), IU (Interface Unit)
	ADCS	Sun Sensor, Magnetic torquer, GPSRU (GPS Receiver Unit)
	CS	UTU, STU, VRU, Antenna
Payload	IRC	Lens, Detector, Shutter, IRC Temperature Control Unit
	GMRM	GMRM Tube, Transformer
	VSCMG	VSCMG, Interface Unit

Application of Standard Platform to KAUSAT-5

KAUSAT-5 Deployed Configuration and System Specification



[KAUSAT-5 System Specification]

Item	Description
Mission Orbit	Sun synchronous Orbit: 510km Inclination : 98°
Mission Life Time	> 1 year
Dimension	100×100×340mm^3
Payload	IR Camera, GMRM, VSCMG, FLCMPPT
Payload Accommodation	IRC Mass : 580 g GMRM Mass : 47 g
IR Camera Specification	Resolution : 320 x 240 (m) FOV : 13.5 deg.
GMRM Specification	Resolution : >18 CPS/mR/h Accuracy : <3 mR/h
Spacecraft Mass	< 4 kg
Satellite Power	< 6.4 W @ EOL (Nadir) < 13 W @ EOL (Sun Pointing)
Attitude Control Specification	3-Axis Stabilization Accuracy : < 0.88 deg. Knowledge : < 0.87 deg. Stability : < 0.42 deg/s
Link Margin	> 3 dB @ 10 deg. Elevation Angle
Data Rate	UHF Downlink : 9,600 bps VHF Uplink : 1,200 bps S-band Downlink : 115,200 bps

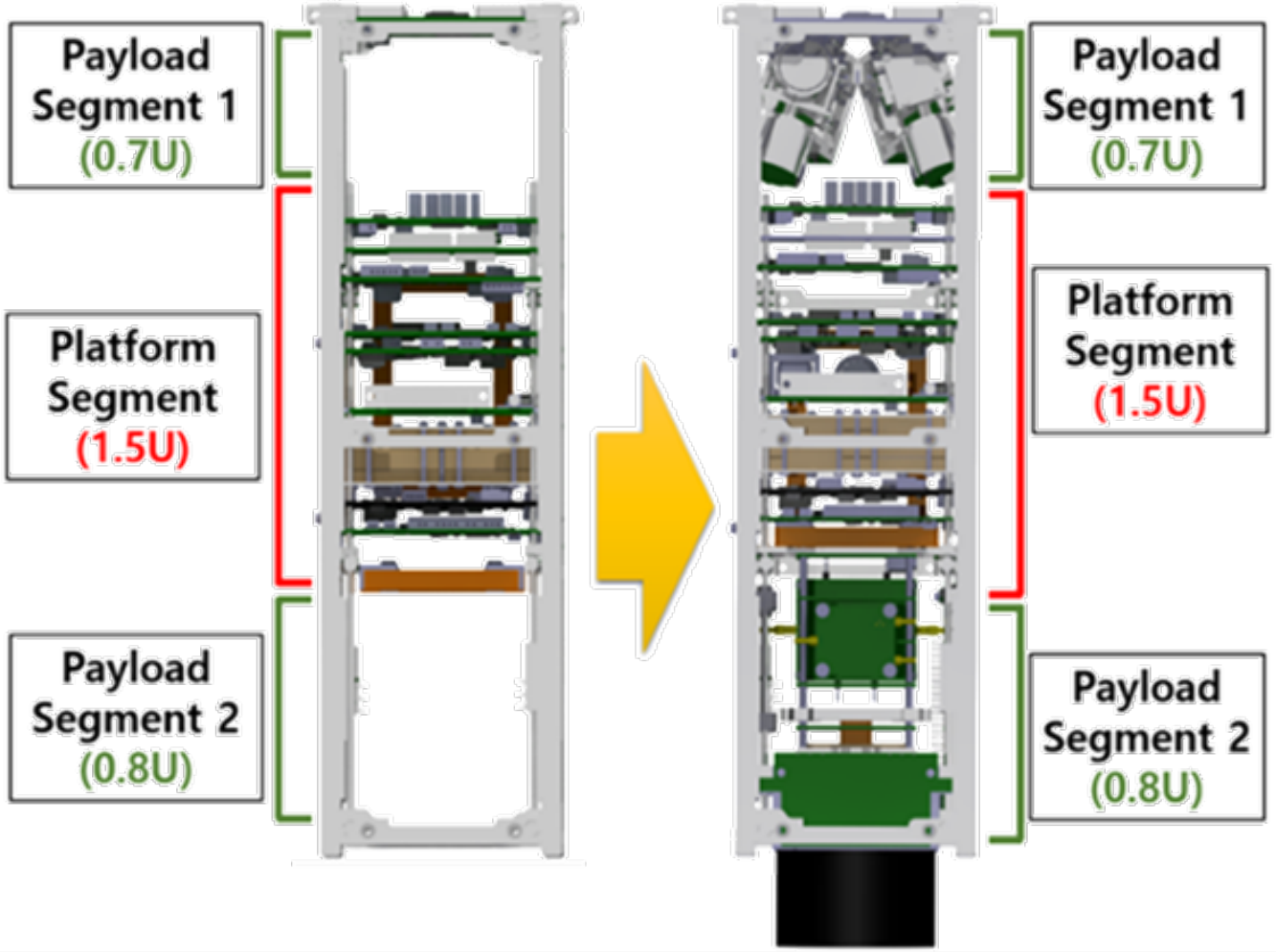
Application of Standard Platform to KAUSAT-5

Volumetric Occupation of KAUSAT-5 Payload and Platform

- **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



Application of Standard Platform to KAUSAT-5

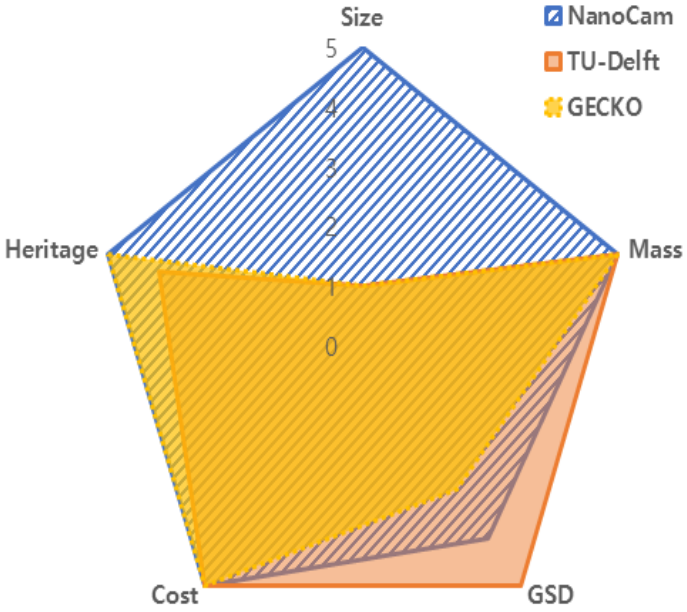
Development Time and Cost Reduction by 3U CubeSat Standard Platform

- 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

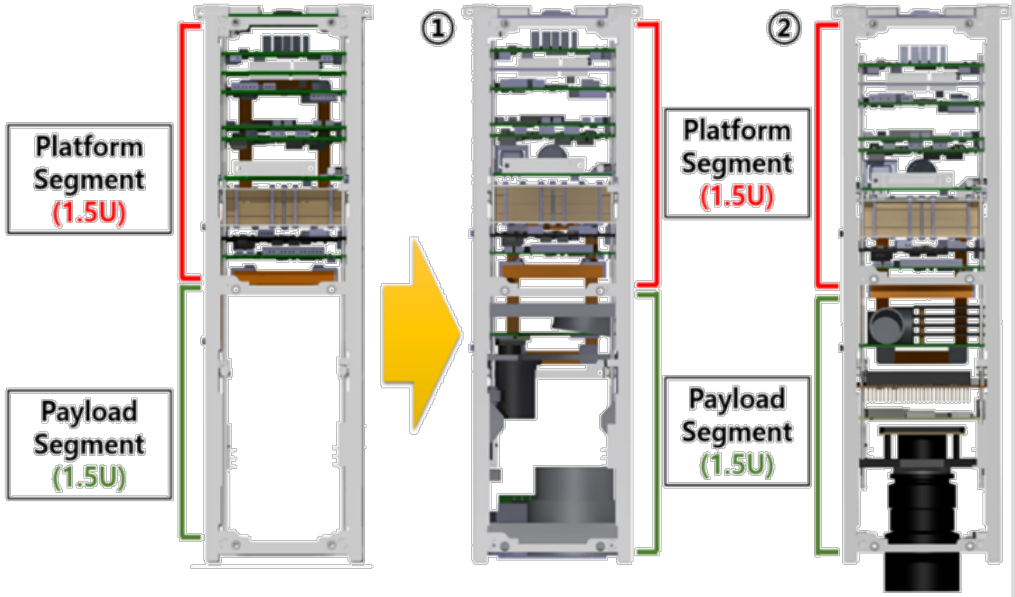
Application of Standard Platform to KAUSAT-5

Application of Standard Platform to Various Payloads

- **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]

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

KAUSAT-5 SYSTEM AIT AND VERIFICATION

KAUSAT-5 AIT and Verification

ETB Design, AIT (Assembly, Integration and Testing)

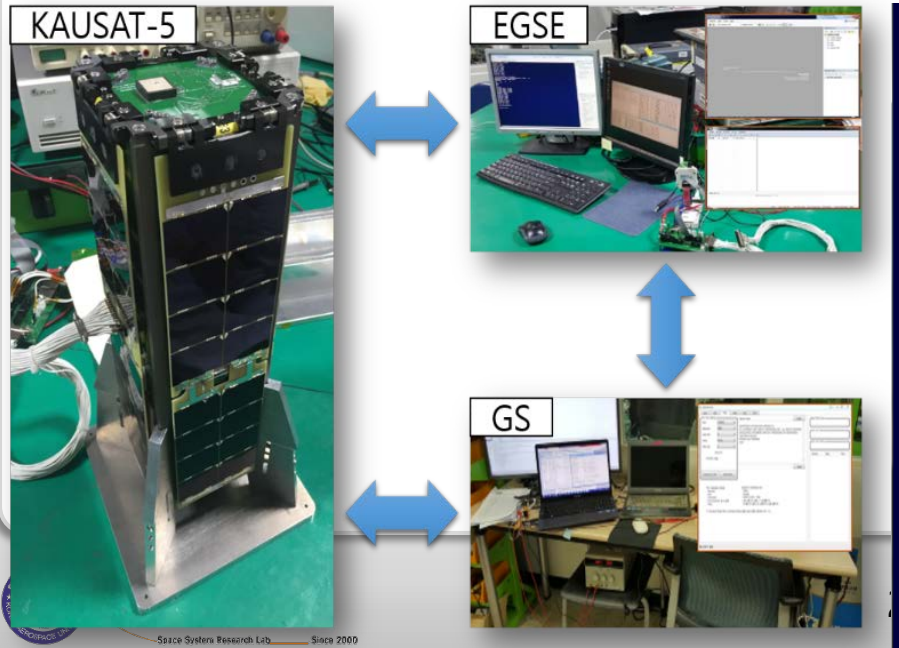
- **ETB (Electrical Test Bed) was developed and tested to verify the function of all payload and platform subsystem, flight software, and the electrical interface between modules as well as components**
  - The module and components that were implemented for ETB test are engineering model, and tested to verify the electrical functions

	✓ ETB Preparation ✓ Subsystem level Assembly
Level 1. C&DHS EM + EGSE (JTAG & CAN Analyzer)	✓ EGSE & C&DHS Integration Test ✓ Debugger Test
Level 2. C&DHS EM + EPS EM + EGSE (DC Power & Solar Simulator)	✓ EPS & C&DHS Integration Test ✓ Command Check ✓ Electrical Performance Check
Level 3. C&DHS + Payload + EGSE	✓ Payload & C&DHS Interface Check ✓ Payload & C&DHS Integration Test
Level 4. C&DHS + EPS + Payload + EGSE	✓ Electrical Performance Check ✓ Payload & C&DHS Integration Test
Level 5. C&DHS + EPS + Payload + ADCS + EGSE	✓ Electrical Performance Check ✓ S/S Integration Test
Level 6. C&DHS + EPS + Payload + ADCS + CS+ EGSE (+RF Performance Analyzer)	✓ Electrical Performance Check ✓ Total Integration Test ✓ Scenario Test
Level 7. Operation Demonstration (Operation Mode Simulation)	✓ Operation Test ✓ ADCS Simulator Operation
Level 8. Fault Management	✓ Safe Mode Test ✓ Fault Detection & Recovery

KAUSAT-5 AIT and Verification

Integrated System Test

- **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




```
adding dns 168.126.63.1
done.
Starting portmap daemon: portmap.
net.ipv4.conf.default.rp_filter = 1
net.ipv4.conf.all.rp_filter = 1
hwclock: RTC_RD_TIME: Invalid or incomplete multibyte or wide character
Wed Mar 10 00:30:00 UTC 2010
INIT: Entering runlevel: 5
Starting Dropbear SSH server: modprobe: FATAL: Could not load /lib/modules/3.10.0+/modules.dep: No
 such file or directory

modprobe: FATAL: Could not load /lib/modules/3.10.0+/modules.dep: No such file or directory

dropbear.
Starting system message bus: dbus.
Starting syslogd/klogd: done
Starting thttpd.
 * Starting Avahi mDNS/DNS-SD Daemon: avahi-daemon
[ ok ]

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The Angstrom Distribution at91sam9260ek ttyS0

Angstrom 2009.X-stable at91sam9260ek ttyS0

at91sam9260ek login: root
root@at91sam9260ek:~#
```

Environmental Test; Vibration 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

Environmental Test; Vibration Test

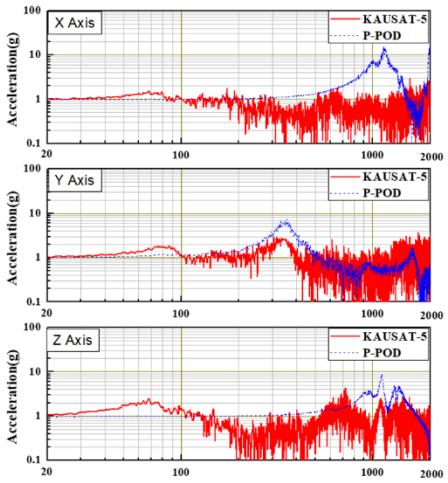
- **The system-level acceleration test** was performed only on the QM
  - Test condition of the acceleration test was carried out for 60 seconds at +18.75 g at a sine wave of 0.013 g2/Hz
- **The random vibration test was performed in both the qualification and the acceptance test**
  - The amplitude 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

		Qualification	Acceptance
Freq. Profile	**20 Hz**	0.013 g^2/Hz	0.013 g^2/Hz
	50 Hz	0.08 g^2/Hz	0.08 g^2/Hz
	800 Hz	0.08 g^2/Hz	0.08 g^2/Hz
	2000 Hz	0.013 g^2/Hz	0.013 g^2/Hz
RMS acceleration		14.1 g	10.0 g
Duration		180 sec/axis	60 sec/axis

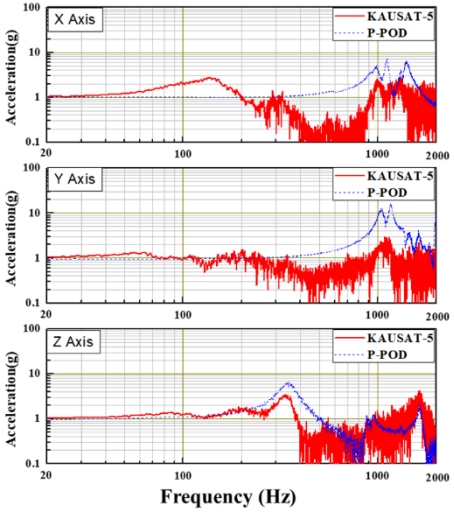
[Random Vibration Test Conditions]

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



[QM Vibration Test Results]



[FM Vibration Test Results]

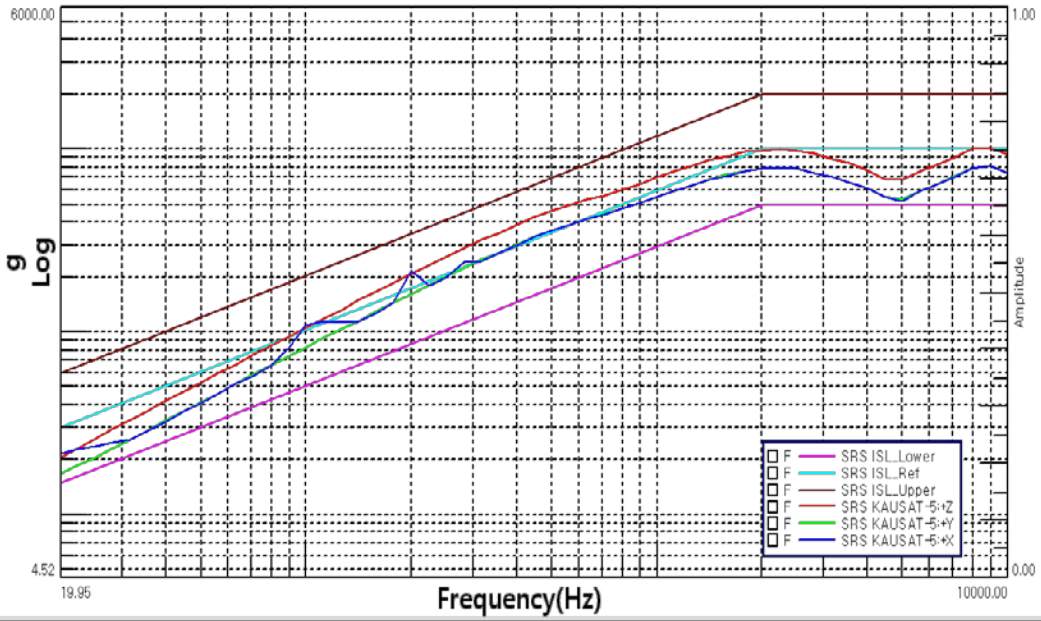
KAUSAT-5 AIT and Verification

Environmental Test; Shock Test

- 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

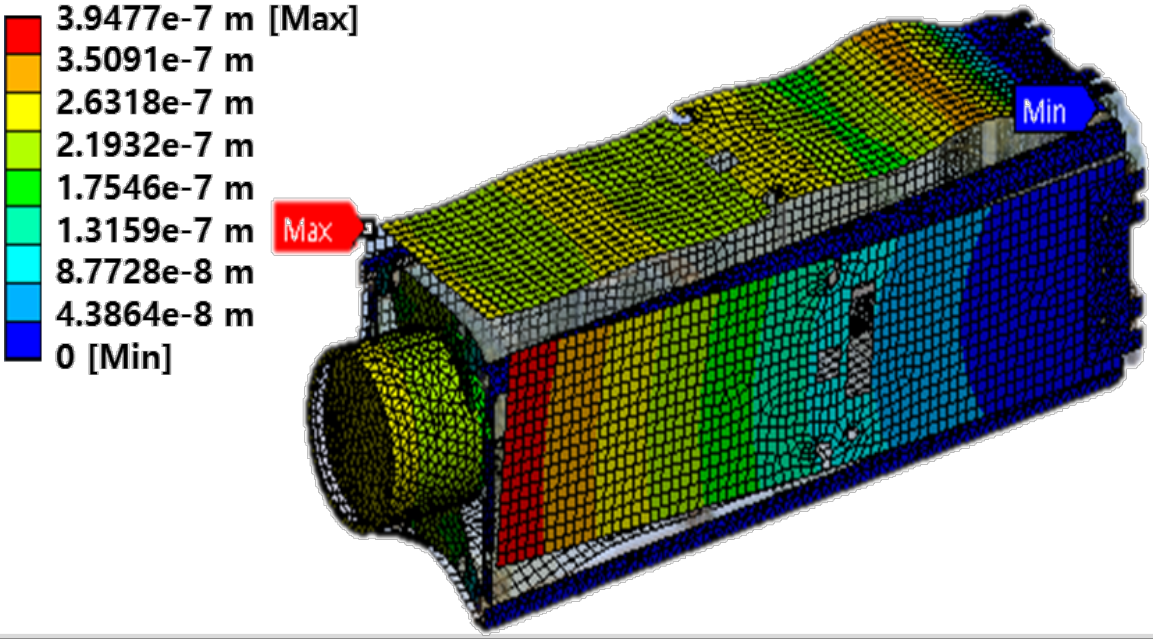
Environmental Test; Shock Test Results

- 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



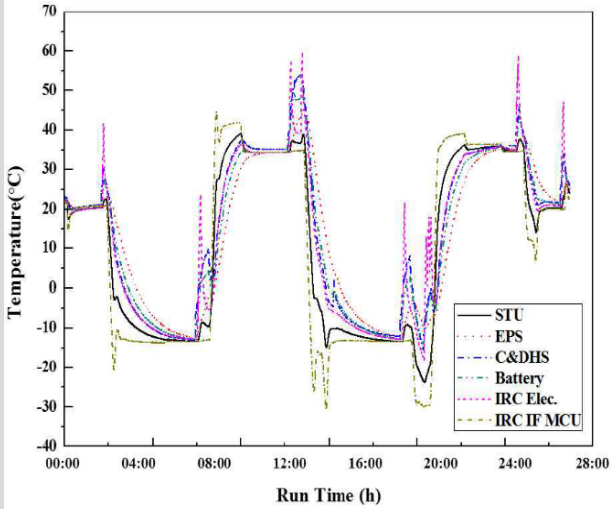
Environmental Test; Shock Analysis Results

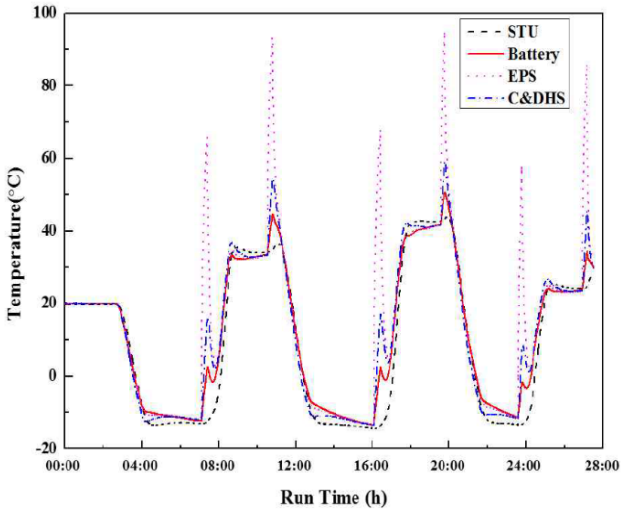
- The shock at the acceptance level of KAUSAT-5 FM was verified by analysis instead of shock test. The results of the shock analysis for the flight model are shown in figure below
  - The tendency of the overall SRS curve is similar to the results of the actual shock as a result of analyzing the damping effect in the P-POD



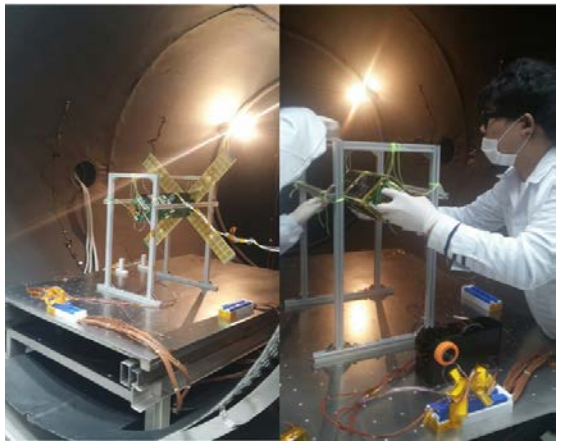
Environmental Test; Thermal Vacuum Test

- The thermal vacuum test of KAUSAT-5 was performed for both EQM and FM under vacuum condition of 1.0 × 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





[Thermal Vacuum Test Results for EQM(left) and FM(right) major Components]



[KAUSAT-5 in TV Chamber]

CONCLUSION

- **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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