BIRDS Bus Open-Source Webinar # 11

KITSUNE Satellite Bus System Overview

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Project Overview (1)

KITSUNE satellite has been developed as a collaboration between international academic institutions and private sector in Japan.

- Kyushu Institute of Technology (Kyutech)
- Harada Seiki Co. Ltd. (HSK)
- Addnics Corp.
- Nanyang Technological University (NTU)
- Arthur C. Clarke Institute for Modern Technologies (ACCIMT)

KITSUNE satellite

The name of KITSUNE stands for the mission objectives as building **K**yutech standardized bus, **I**maging **T**echnology **S**ystem, **U**tilization of **N**etworking and **E**lectron content measurements.

Project Overview (2): KITSUNE Collaboration

Amateur radio frequency controlled segment

Non-amateur radio frequency controlled segment

2U Main Bus System
3U Camera Mission

1U SPATIUM 2

ADDNICS | Harada Seiki | KYUTECH | NTU | ACCIMT | BIRDS Countries

Kyutech 2U standardized bus development

3U camera payload development

C-band communication demonstration from main and mobile GS / Amateur radio service

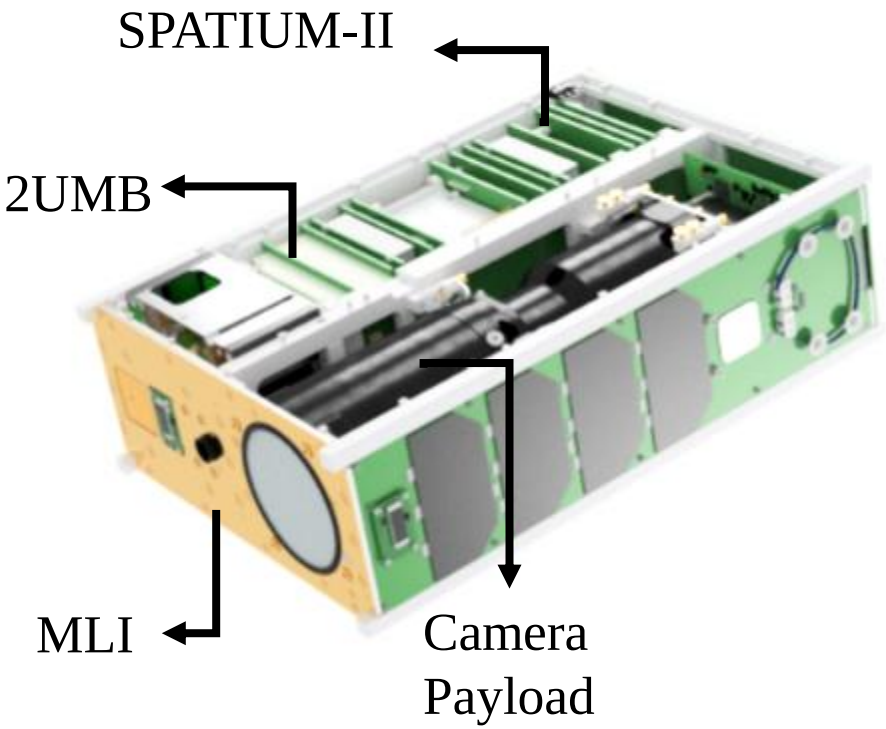
Total electron content measurements in ionosphere / CSAC demonstration

Store and forward mission / LoRa demonstration

GST capacity building in developing countries

Satellite configuration (1)

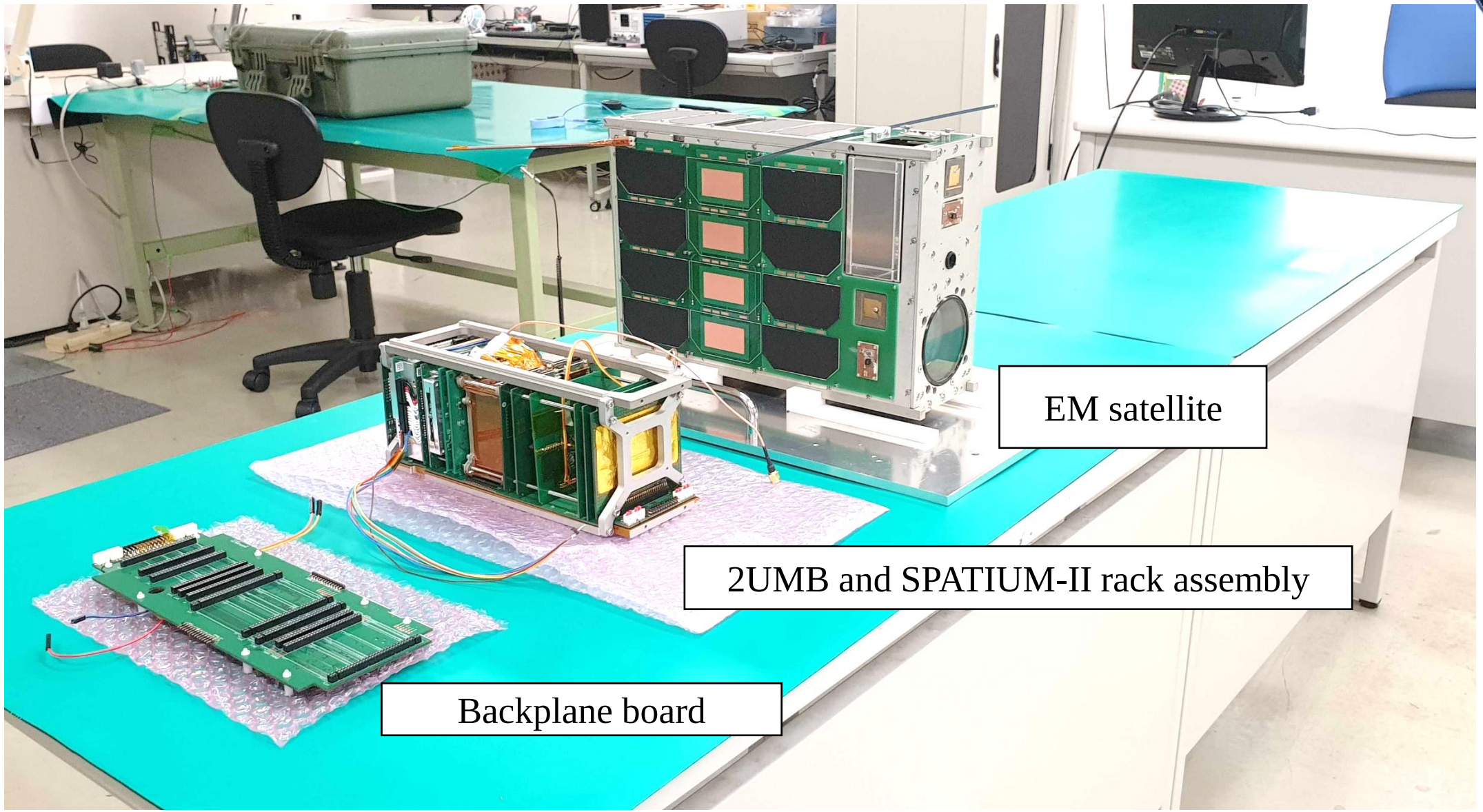
Utilizing backplane design to connect subsystems to minimize harness usage.



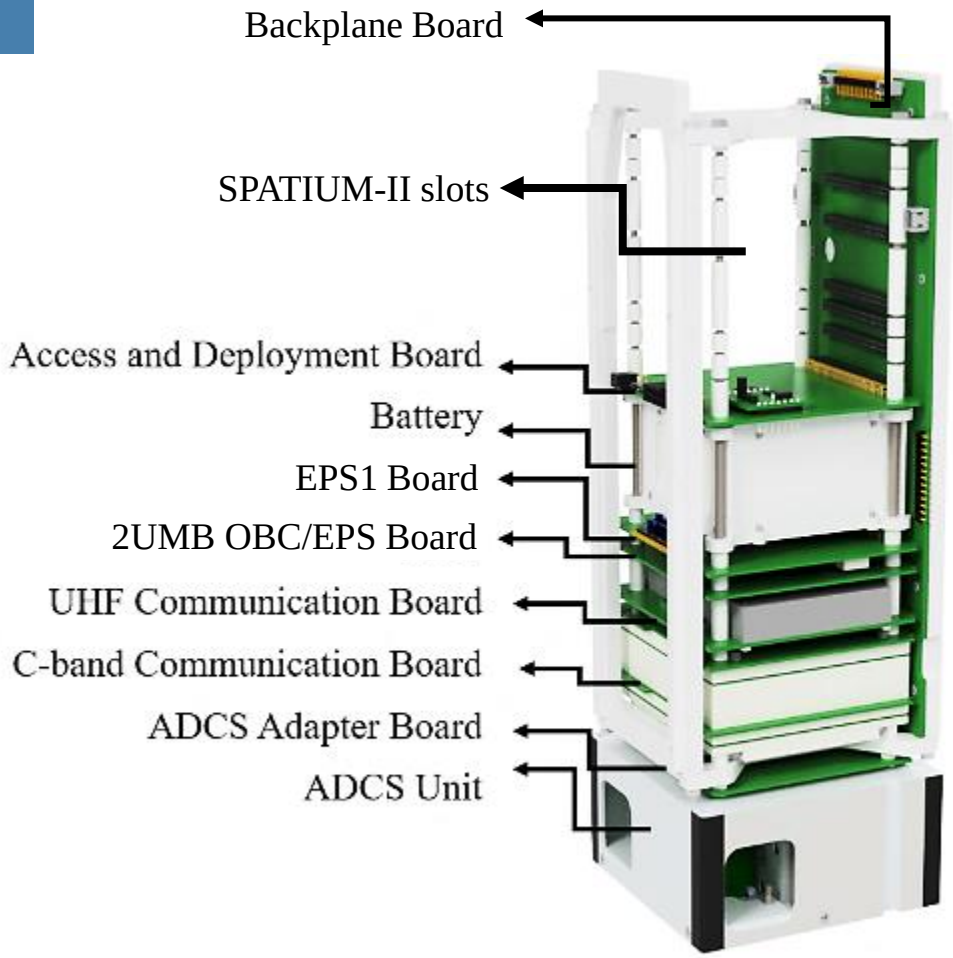
2U Main Bus (2UMB)

KITSUNE is the first multi-layer insulation equipped CubeSat to be deployed from International Space Station (ISS).

Satellite Configuration (2)

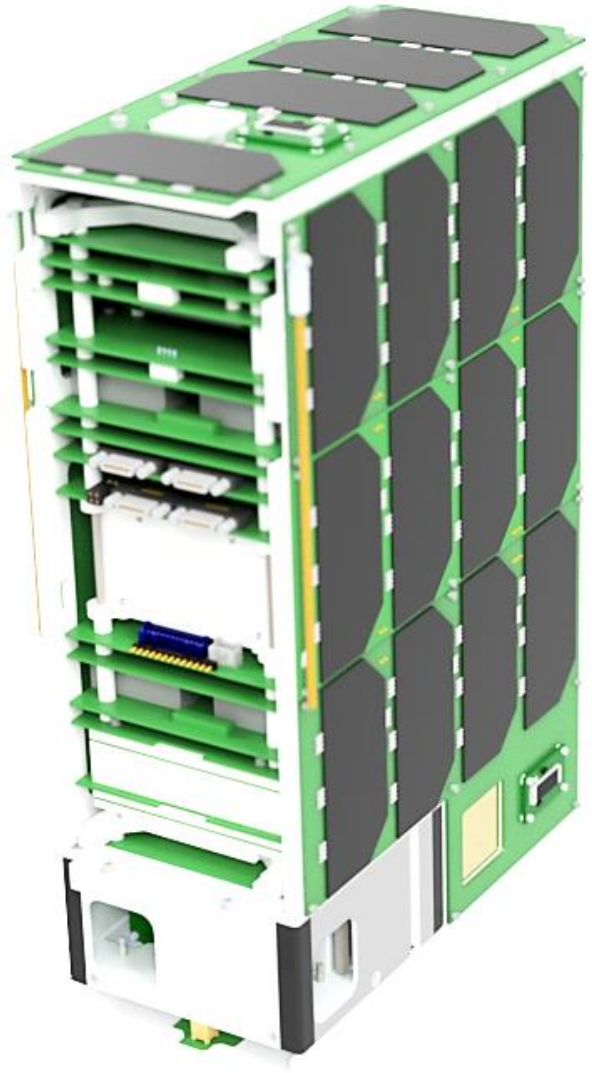


KITSUNE 2-Unit Main Bus System



Rack assembly

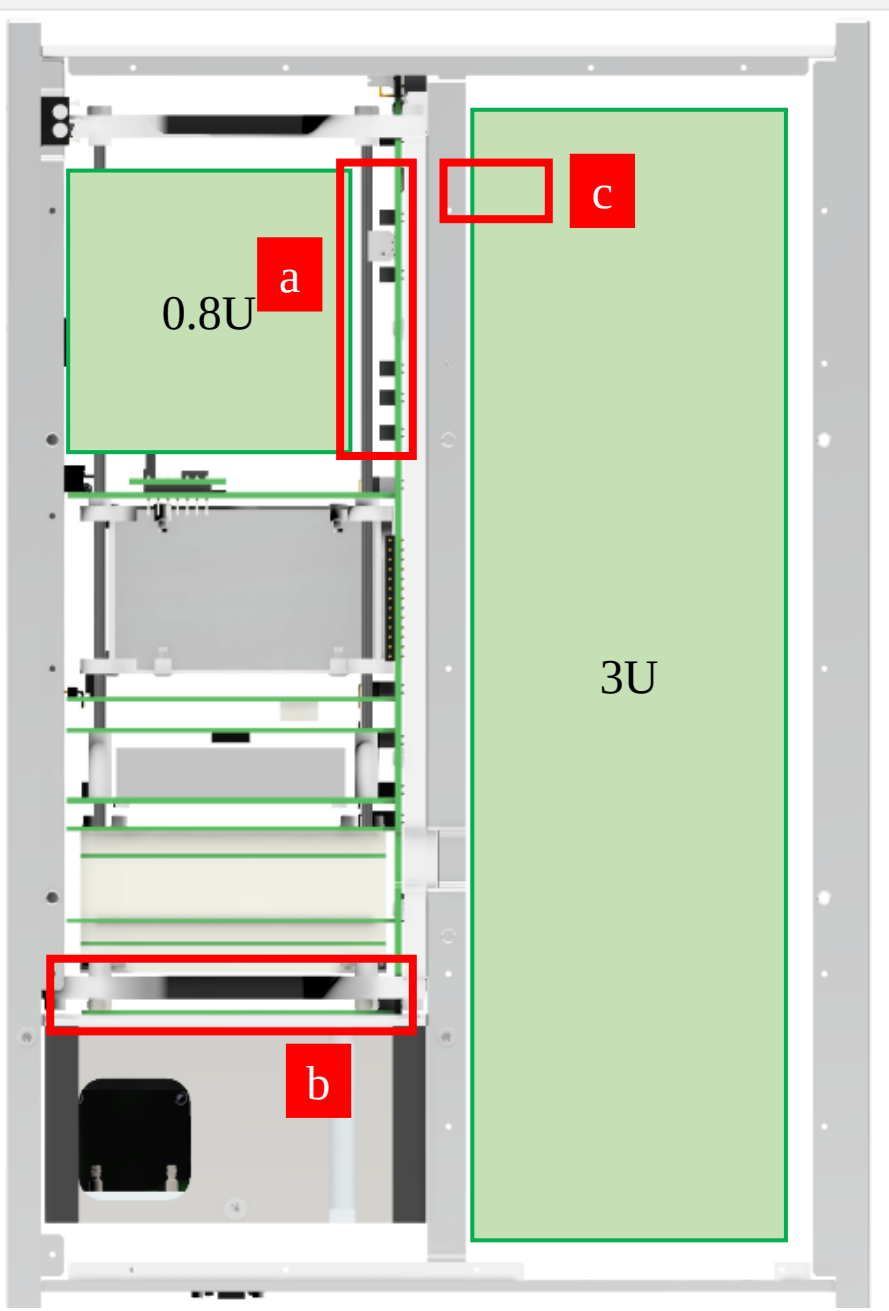
Structure assembly with rack



Satellite assembly without only +Y solar panel

Interface with the bus system

- There are three types of connection with the bus system
  a. Using 50-pin connector standard to interface with backplane board (used by SPATIUM-2).
  b. Using an adapter board with 50-pin connector standard to interface with backplane board (used by **ADCS MAI401** with connectors at the center).
  c. Using harness between subsystem and backplane board (used by 3U camera system).



Interface with the bus system

- Electrical bus
  - Unregulated line (+7.4V nominal, +8.4V maximum) with maximum 4A current.
  - +5V line with maximum 2A current
  - +12V line with maximum 2 A current
  - Raw power line from battery (SPATIUM-II)
    - This is not preferred for regular payloads since SPATIUM-II is unique with its own power distributions and OCP settings.
- Data interface
  - The most common interface:
    - UART for command/data transfer
    - SPI for shared flash memory access
  - PCIB (payload control/interface board) design from another satellite project in Kyutech could be implemented to include Ethernet, USB, SPI, I2C, camera serial interface (CSI-2); however, it will increase the bus system power consumption with RPi CM3.

Available power for the payload

ADCS mode	Power generation	Bus system consumption	Margin for payload	Maximum Payload power consumption estimation	Remarks
Tumbling (without ADCS subsystem)	7.0 - 7.5 Wh	2.8 Wh	3.2 Wh	10.7 W (20% duty cycle) 4.3 W (50% duty cycle) 2.8 W (75% duty cycle) 2.1 W (Always-on)	Tumbling mode without any ADCS subsystem or with passive control. Battery heater is off.
Tumbling (with ADCS MAI401)	7.0 - 7.5 Wh	4.0 Wh	2 Wh	6.7 W (20% duty cycle) 2.7 W (50% duty cycle) 1.8 W (75% duty cycle) 1.3 W (Always-on)	Detumbling mode is similar at the moment, it will be added after satellite rotation is decreased. Battery heater is off.
Sun-tracking	10 - 10.5 Wh	6.3 Wh	2.1 Wh	7 W (20% duty cycle) 2.8 W (50% duty cycle) 1.8 W (75% duty cycle) 1.4 W (Always-on)	ADCS power consumption is slightly less than 3.5 Wh. It is significantly higher than the ground measurements. Battery heater is off.

Margin for payload is calculated based on the estimation of full recovery of battery after shadow.

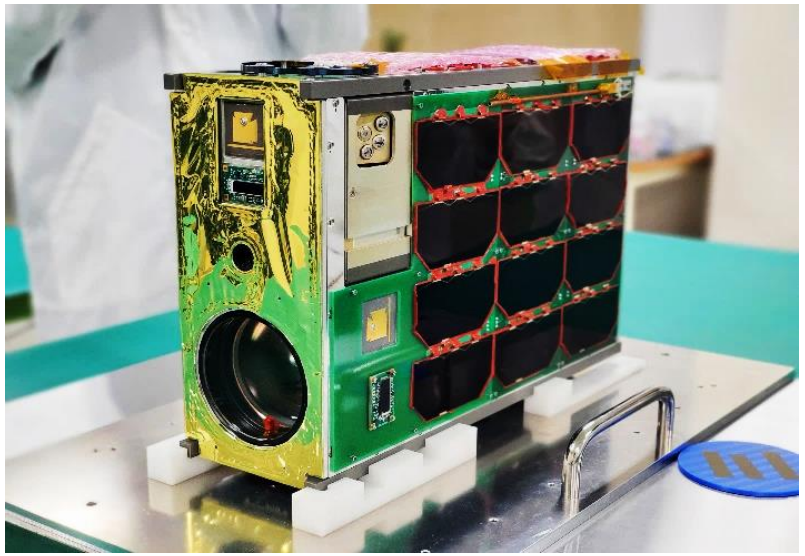
Data downlink capability

- UHF downlink: 100-450 packets per day (approximately 8 - 32 kB)
  - The satellite can downlink more data; however, some of the ground pass time is used for uplink commands. (max. 726 packets during operation)
- C-band downlink: 128 Mbit in one pass
  - This value depends on ADCS mode, satellite attitude, and the uplink window when C-band Rx mode is activated every 4 minutes.

Mission Objectives: Amateur radio frequency controlled segment

2U main bus (2UMB) and 3-unit camera payload

- Earth observation with 5-m class resolution color images.
- Demonstration of C-band communication from the main and mobile ground stations.
- Development and demonstration of Kyutech standard bus system as 2UMB for future missions.
- Downlink of low-resolution images from a secondary camera by C-band uplink commands and amateur radio service.



Mission Success Criteria: Amateur radio frequency controlled segment

Main camera mission	Criteria
Minimum Success	Image is downloaded to the ground station (with or without focus).
Full Success	Capturing any letters or characters done by group of people within 100m x100m.
Extra Success	Capturing images with 5-m class resolution (< 6 m/pixel).

C-band demonstration	Criteria
Minimum Success	Achieving 1 Mbps downlink speed.
Full Success	Achieving 20 Mbps and being able to decode data clearly.
Extra Success	Achieving 20 Mbps with 10^{-5} BER.

C-band mobile GS	Criteria
Minimum Success	Achieving 100 kbps downlink speed.
Full Success	Achieving 1 Mbps and being able to decode data clearly.
Extra Success	Achieving 1 Mbps with 10^{-5} BER.

Mission Objectives: Non-amateur radio frequency controlled segment

SPATIUM-II

- Total electron content (TEC) measurements of the ionosphere.
- On-orbit demonstration of LoRa communication board.
- S&F mission from the ground sensor terminals of BIRDS countries.
- Monitoring chip-scale atomic clock (CSAC) board on-orbit performance (resuming one of the SPATIUM-I objectives (Aheieva et al., 2017; 2018)).
- Development of mobile and fixed ground sensor terminals (GSTs).

1) Aheieva, K., Rahmatillah, R., Ninagawa, R., Adebolu, I.O., Kim, S., Kakimoto, Y., Yamauchi, T., Masui, H., Cho, M., Lap, C.C. and Ying, Z.: Project Overview of SPATIUM-I: A Technology Demonstration Mission Toward Global Three-Dimensional Ionosphere Mapping via CubeSat Constellation Equipped with an Atomic Clock, 69th International Astronautical Congress (IAC), Bermen, Germany, IAC-18-B4 (Vol. 7), 2018.
2) Aheieva, K., Rahmatillah, R., Ninagawa, R., Adebolu, I.O., Masui, H., Yamauchi, T., Kim, S., Cho, M., Chow, C.L., Tse, M.S. and Li, K.H.H.: CubeSat mission for ionosphere mapping and weather forecasting using chip-scale atomic clock, IEEE Progress in Electromagnetics Research Symposium-Fall (PIERS-FALL), 2017, pp. 761-766.

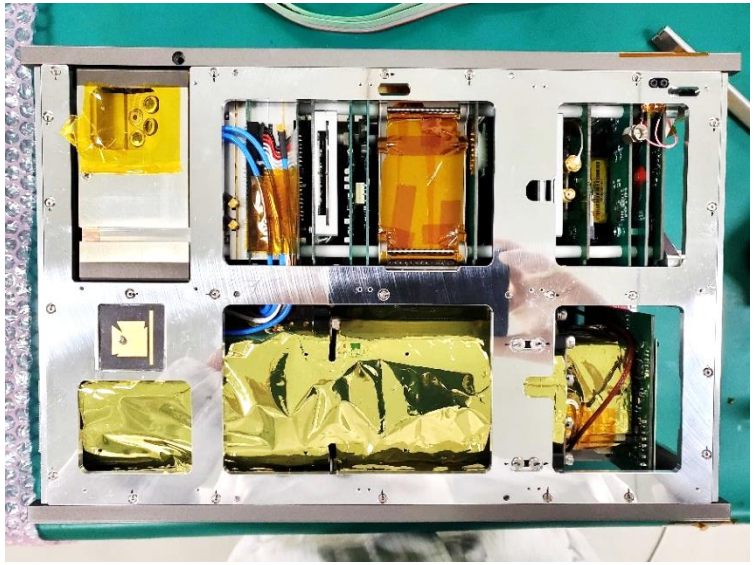
Mission Success Criteria: Non-amateur radio frequency controlled segment

TEC mission	Criteria
Minimum Success	SS signal is demodulated onboard.
Full Success	Time-delay is derived by onboard processing.
Extra Success	Electron content measurement is performed.

Store and Forward	Criteria
Minimum Success	Any data uplink is forwarded to the ground station.
Full Success	Data is stored and forwarded from multiple countries' GST (at least 2), and it is distributed to the related countries.
Extra Success	1 week of continuous operation is achieved.

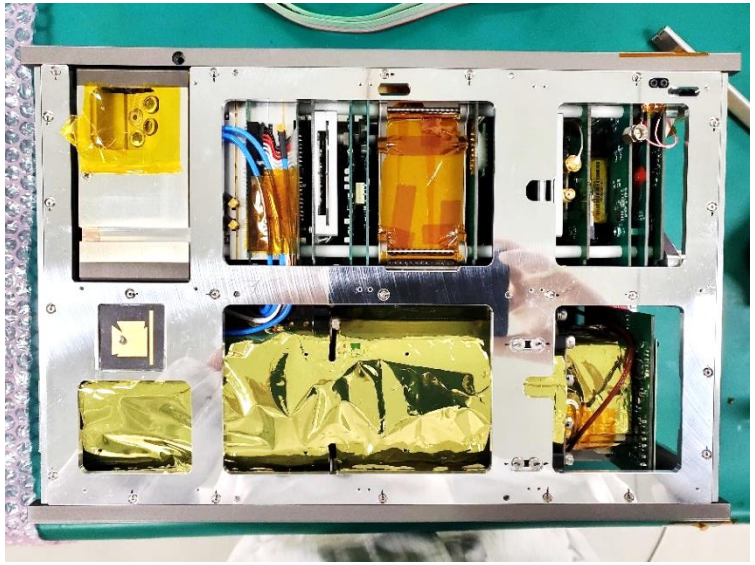
Satellite Design Overview (1)

Specification	Information
Mechanical Properties	
Dimensions	340.5 x 226.3 x 100 mm
Total weight	7544 g
Power Storage	
Battery Type	Li-ion
Cell connectivity	2S3P (2 in series, 3 in parallel)
Battery capacity/nominal voltage	74.5 Wh/7.2 V
Power Generation per Orbit	
Sun tracking mode	7.5 Wh – 10.0 Wh
Nadir pointing mode	5.7 Wh – 7.4 Wh
Detumbling mode	5.2 Wh – 7.3 Wh



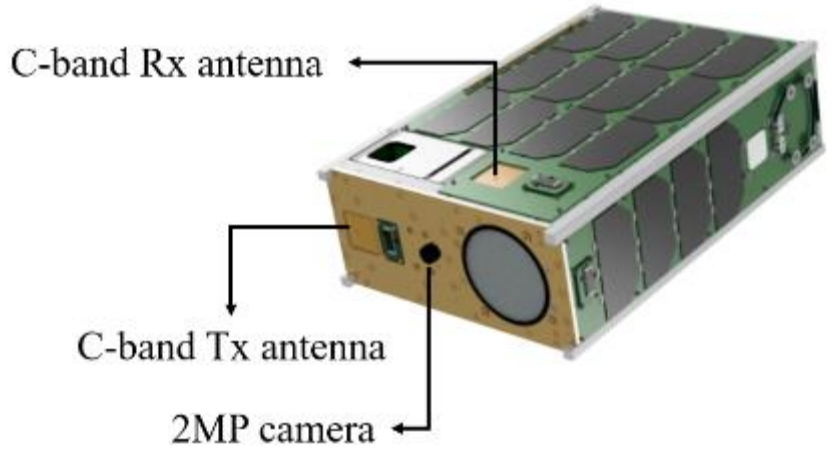
Satellite Design Overview (2)

EPS Bus Voltage	
2UMB	(3x) Unregulated line (2x) +3.3 V line (1x) +5.0 V line (1x) +12.0 V line
SPATIUM-II system	(2x) Unregulated line (1x) +3.5 V line (1x) +4.5 V line (1x) +5.0 V line
Nominal Power Consumption	
2UMB	~6.0 Wh
SPATIUM-II	~1.5 Wh
ADCS Modes	
Nominal mode	Sun-tracking
EO mission mode	Nadir or Target pointing
SPATIUM-II mission mode	No requirement
Deployment mode	De-tumbling

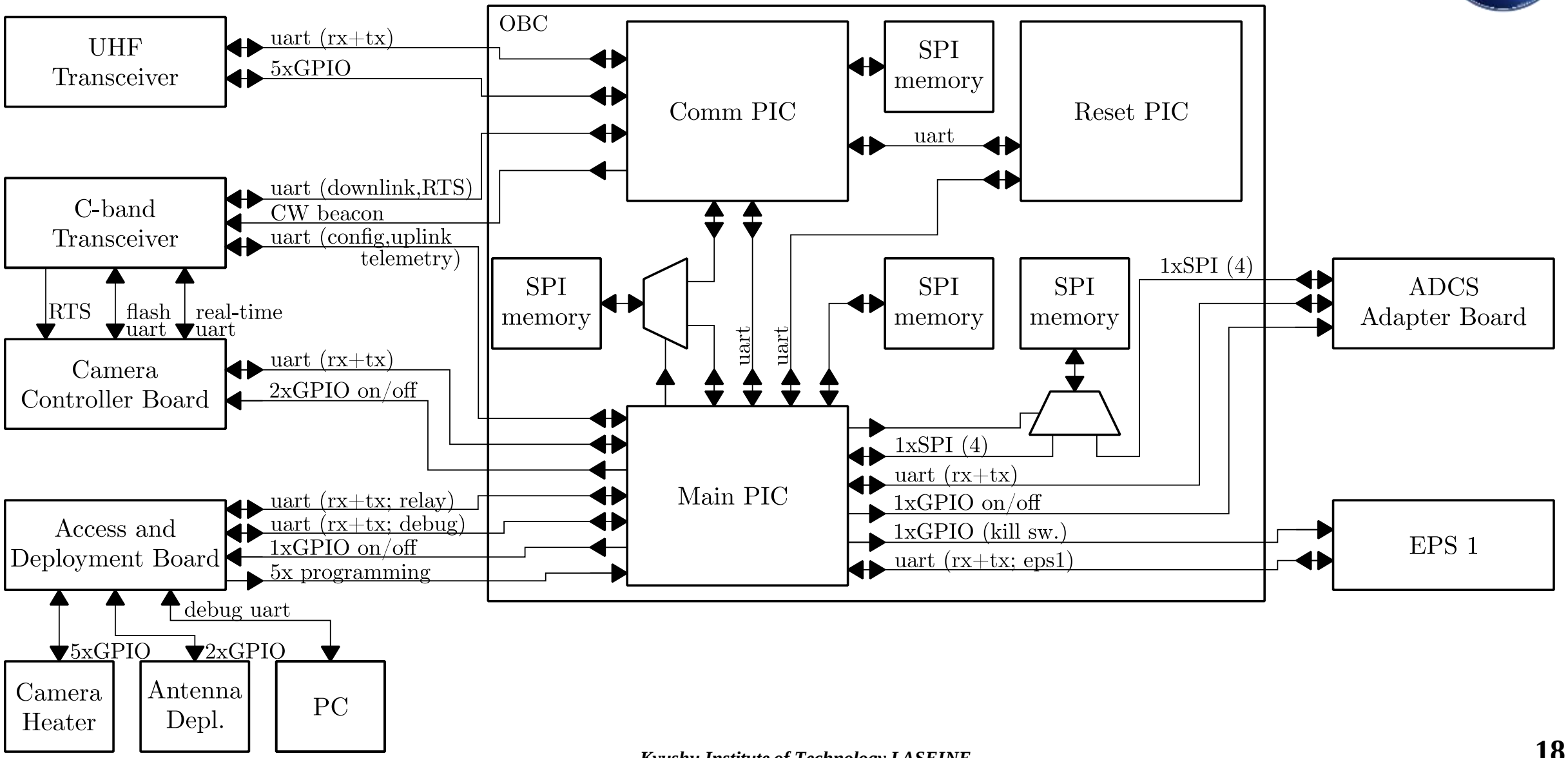


Satellite Design Overview (3)

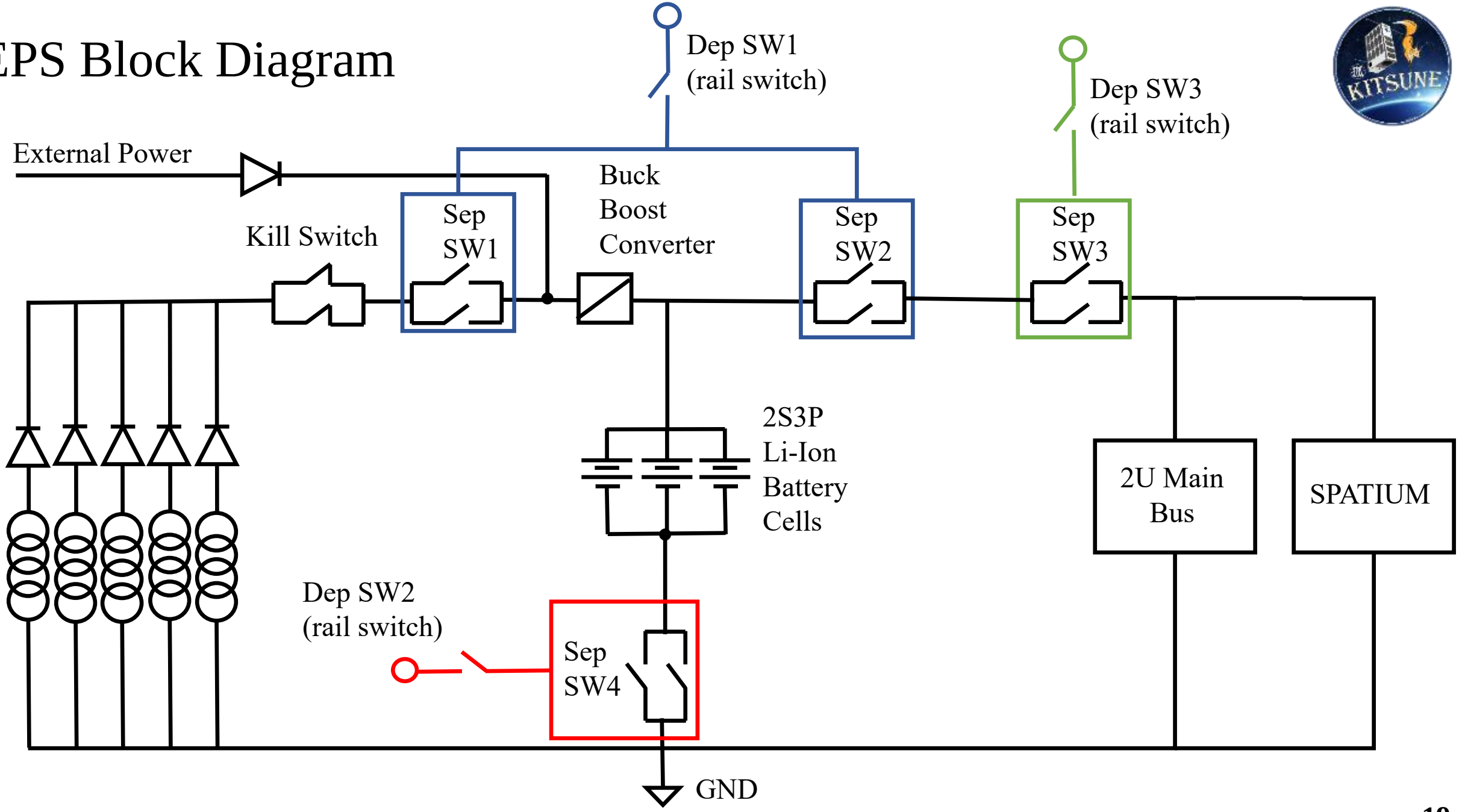
Antenna System	
2UMB	(1x) C-band Tx patch antenna (2x) C-band Rx patch antenna (1x) UHF dipole antenna
SPATIUM-II	(1x) UHF dipole antenna (2x) UHF monopole antenna
Communication System	
2UMB (Amateur Frequencies)	
C-band Tx/Rx speed	100 kbps – 20 Mbps 250 bps – 4 kbps
C-band Tx/Rx frequency	5.65 – 5.67 GHz 5.83 – 5.85 GHz
UHF Tx/Rx speed	4.8 kbps/4.8 kbps
UHF Tx/Rx frequency	435 MHz/437 MHz
SPATIUM-II (Non-amateur Frequencies)	
UHF Tx/Rx speed	4.8 kbps/4.8 kbps
UHF Tx/Rx frequency	401 MHz/450 MHz
LORA Rx speed	488 bps – 855 bps
LORA Rx frequency	400 MHz and 433 MHz
SS Rx speed	250 bps
SS Rx frequency	449 MHz



Subsystem – OBC Block Diagram



EPS Block Diagram



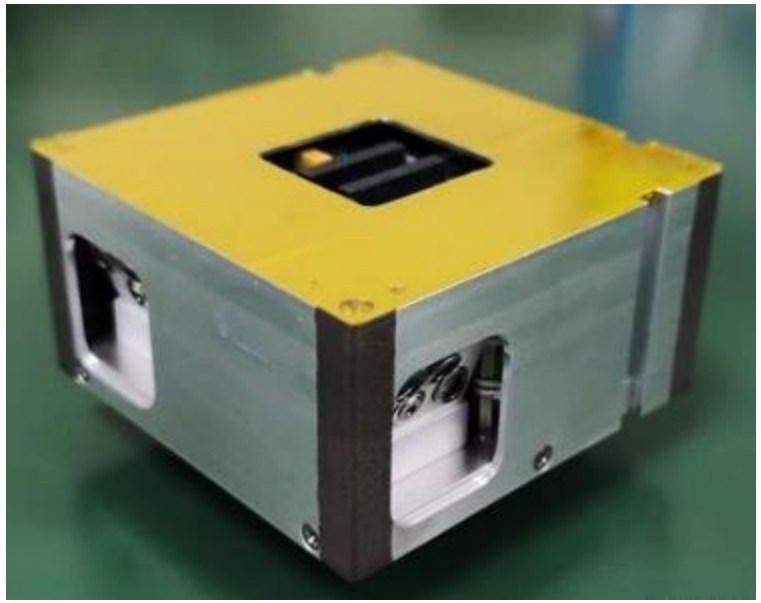
ADCS overview

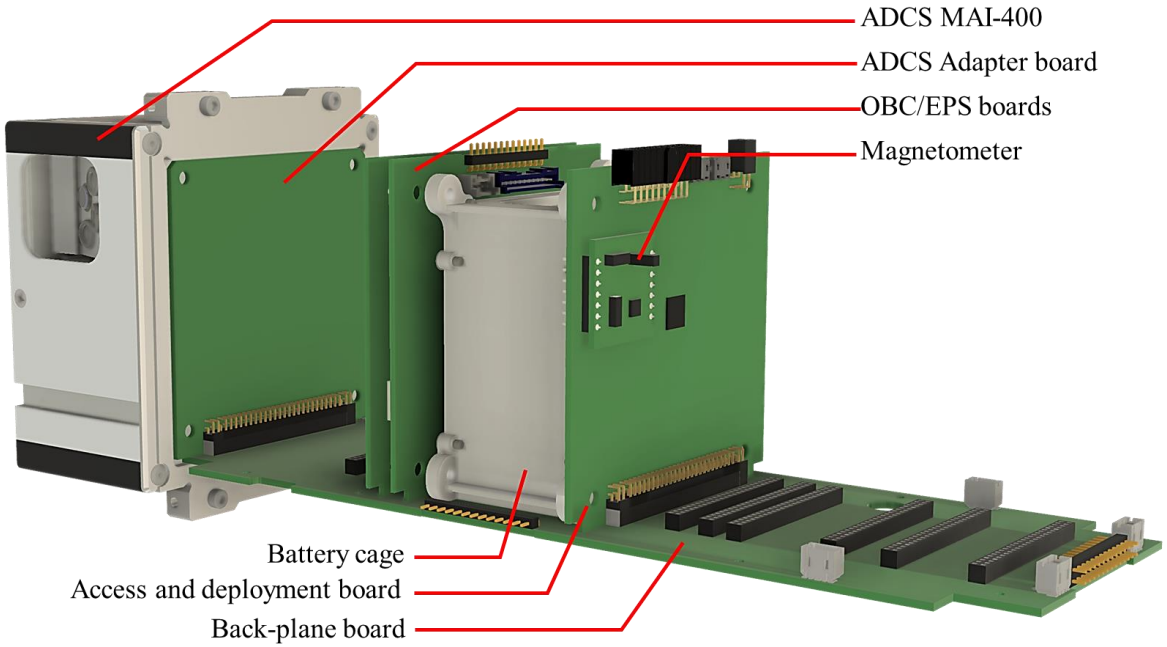
Modes of Operation

- Detumbling mode
- Sun-tracking mode
- Nadir pointing mode
- Target pointing mode
- Tumbling mode

Hardware

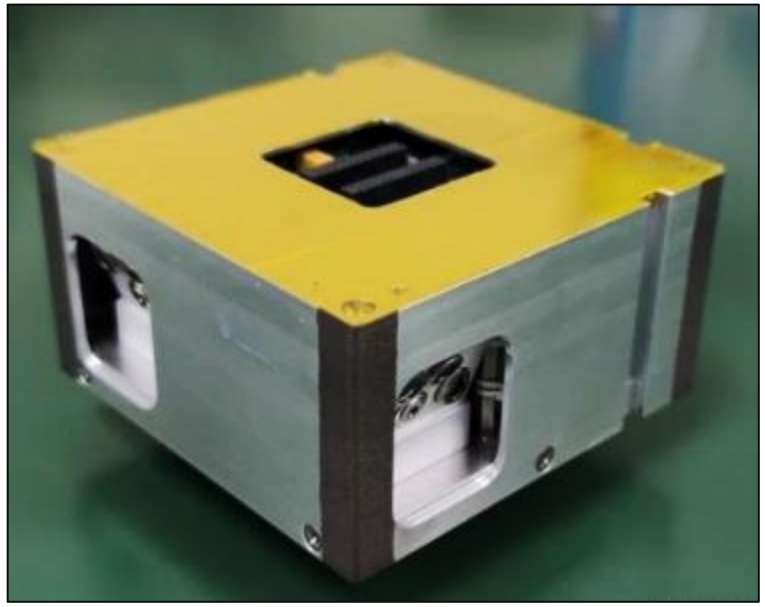
- Adcole Space MAI-401 (Control unit, 3 RW, 3 Magnetorquers, gyroscope, 2 Earth horizon sensors)
- ADCS adapter board
- External Magnetometer
- External 6 sun sensors
- External GPS

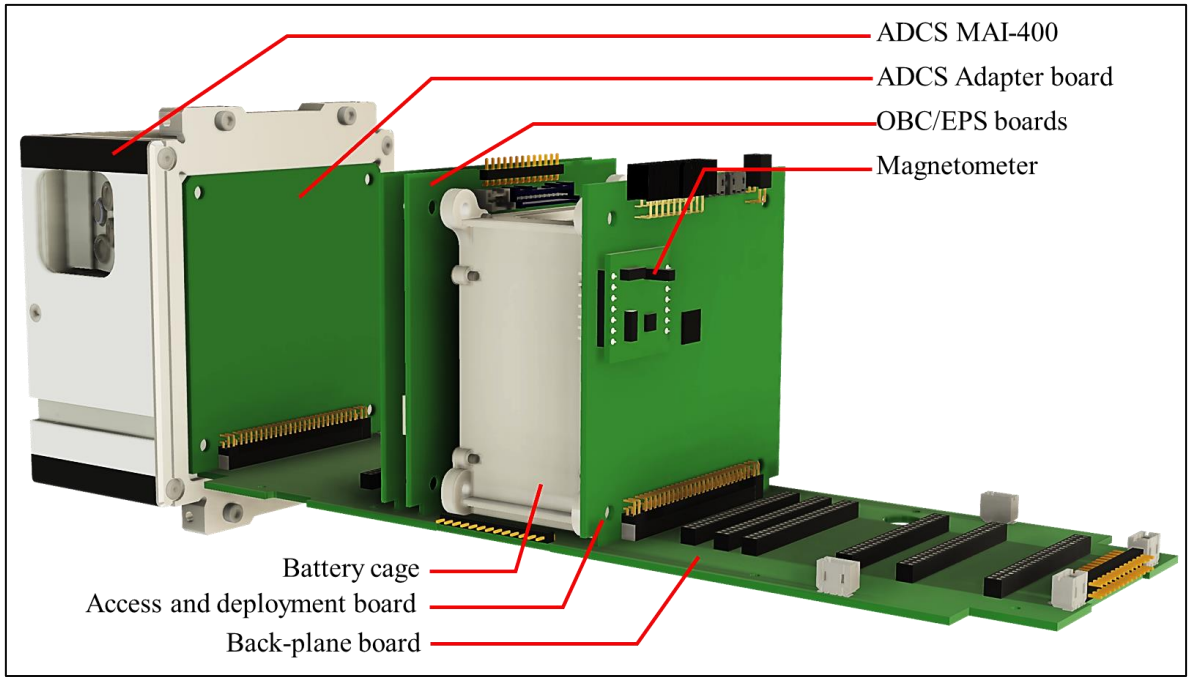




ADCS overview

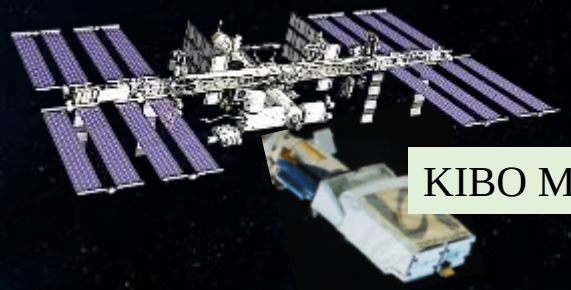
Attitude hardware	Manufacturer / Provider	Main features
Sun sensor	Adcole Space	6 units distributed along satellite sides, analog output (maximum 0.5V). Attitude knowledge error is <5deg
Magnetometer	PNI / Adcole Space	SPI interface, operation voltage 3.3V, Magnetometer Measurement Range -900 to +900 nT.
Earth sensors	Adcole Space	Earth limb detector, 3 narrow and 1 wide FOV thermopiles (7 and 60 deg respectively). Attitude knowledge error is <0.3deg.
Gyroscope	Adcole Space	MEMS, operation voltage 3.3V, measurement range 250deg/s.
Accelerometer	Adcole Space	MEMS, operation voltage 3.3V, measurement range 16g.
Reaction wheels	Adcole Space	3-axis RWs, operation voltage 5V, 10000 RPMs maximum speed, moment of inertia 8.93 [kg·m^2].
Magnetorquers	Adcole Space	3-axis magnetorquer, operation voltage 5V, duty cycle 72%, maximum magnetic dipole 0.108 A·m^2.
GPS receiver	Chubu University	GPS signal receiver, NMEA format compatible

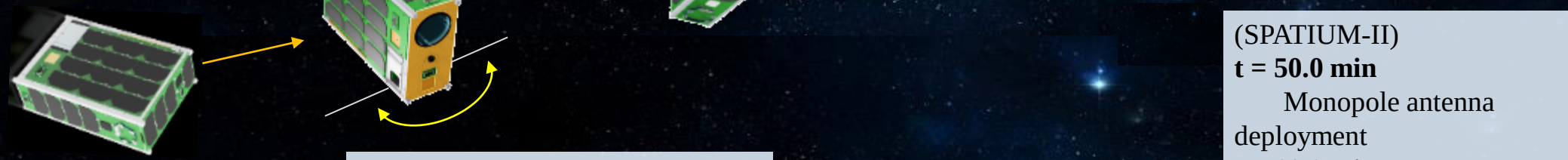




Deployment Timeline

Deployment date: March 24, 2022





KITSUNE Deployment (t = 0)

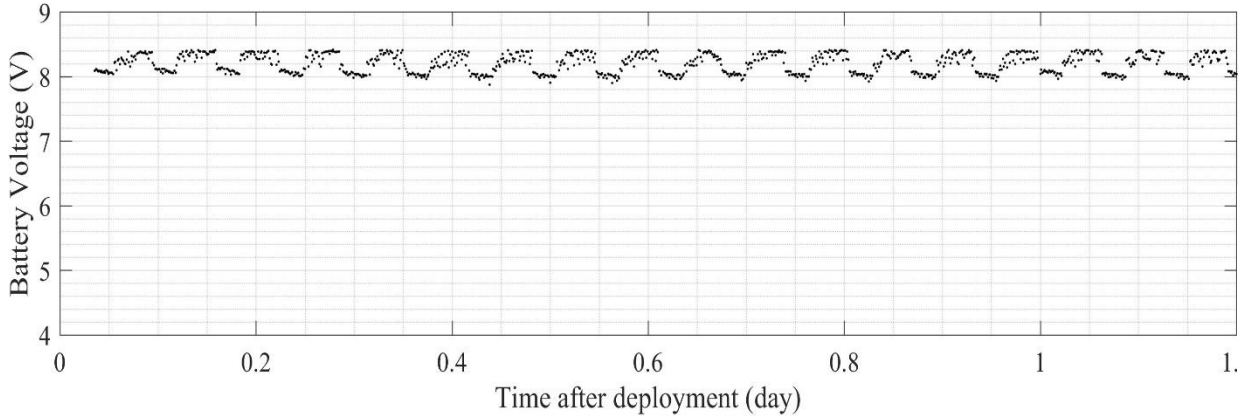
- Deployment switches are closed
- EPS is engaged and charging starts
- OBC turns on
- Telemetry collection
- Detumbling mode

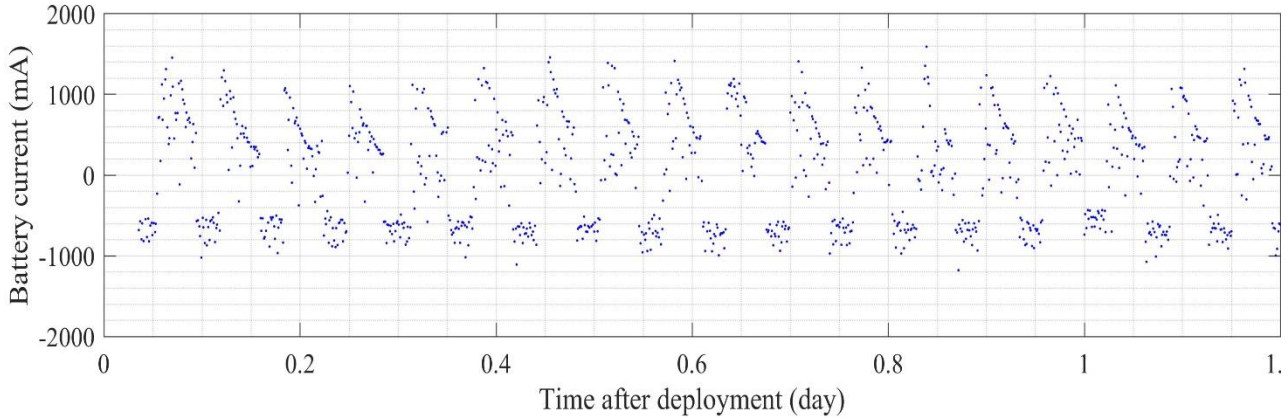
(2U MAIN BUS)
t = 30.0 min
Sun tracking mode
t = 30.5 min
Dipole antenna deployment
t = 31.0 min
UHF board turns on
C-band board turns on
t = 31.0+ min
CW transmission starts

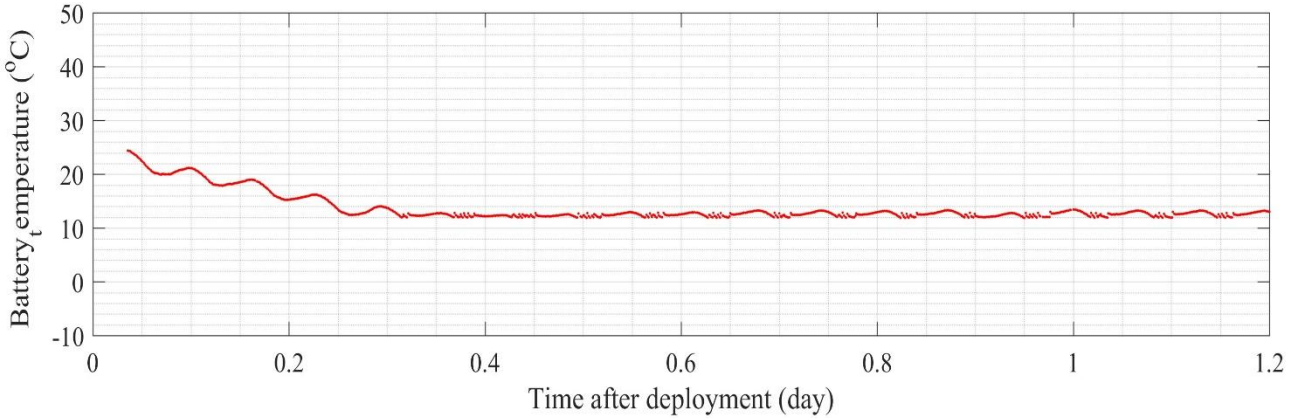
(SPATIUM-II)
t = 31.0 min
UHF board turns on
t = 31.0+ min
CW transmission starts
t = 40.0 min
Monopole antenna deployment

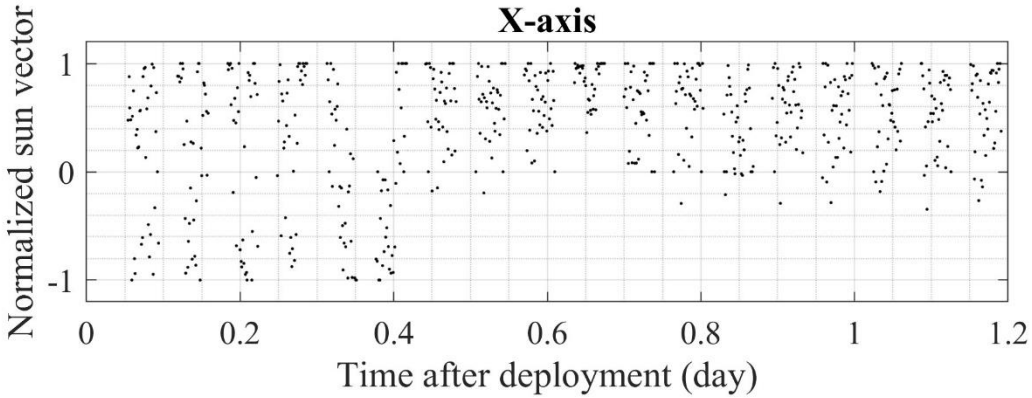
(SPATIUM-II)
t = 50.0 min
Monopole antenna deployment
t = 60.0 min
Dipole antenna deployment

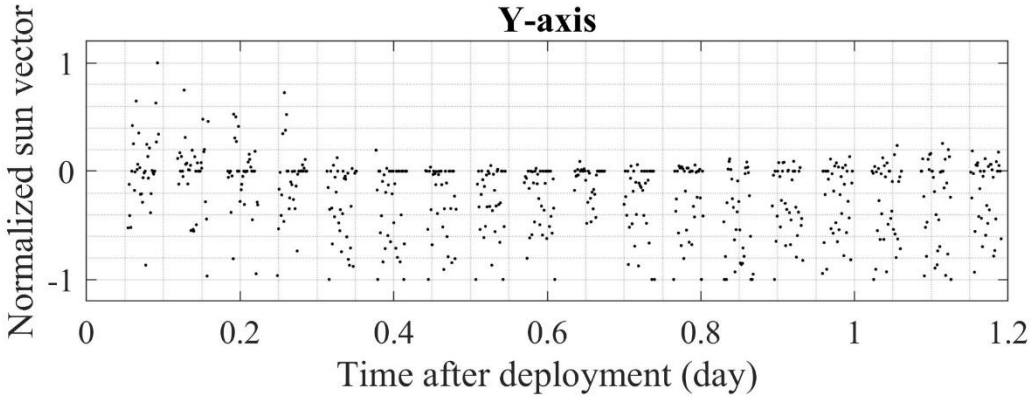
Sun-tracking (1st day operation)



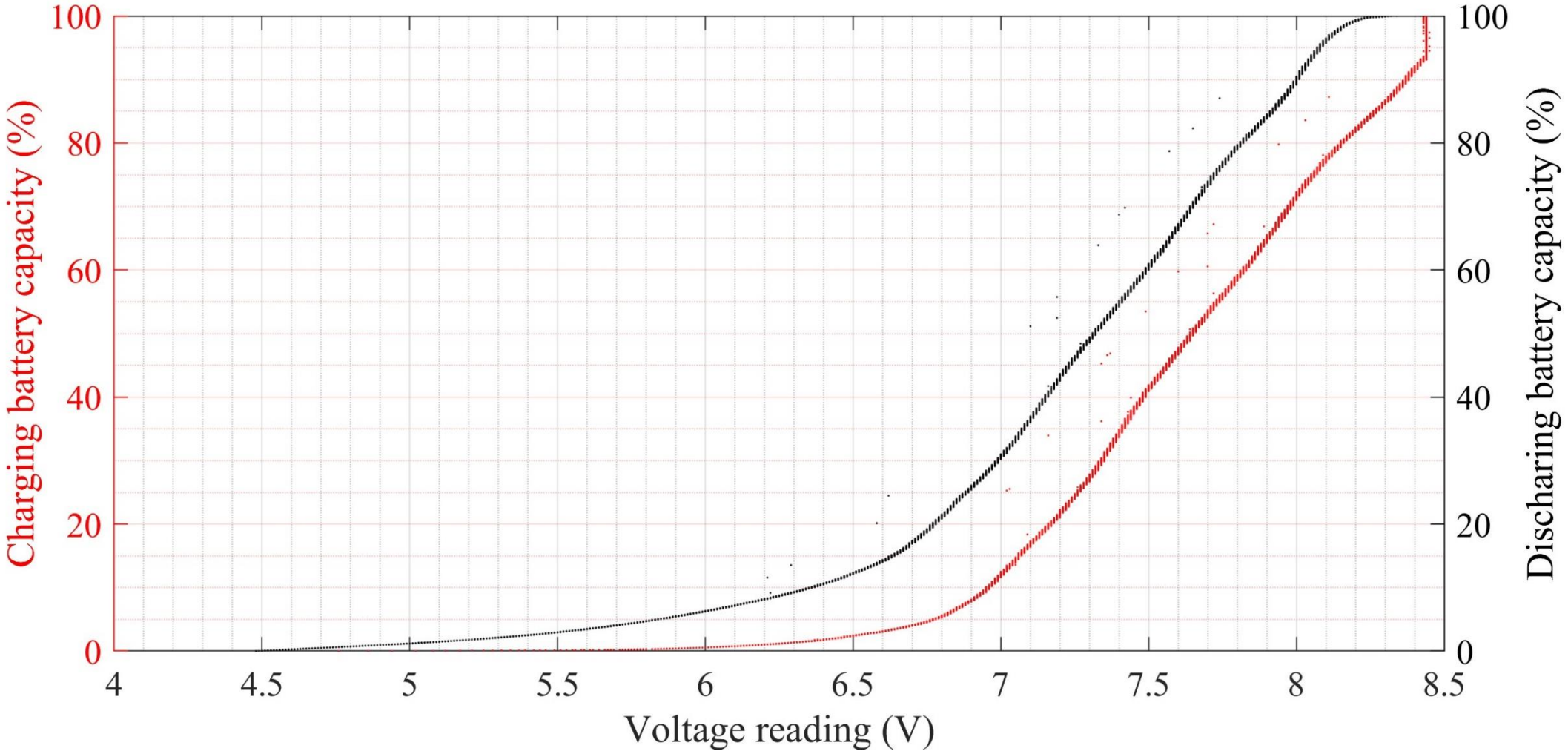




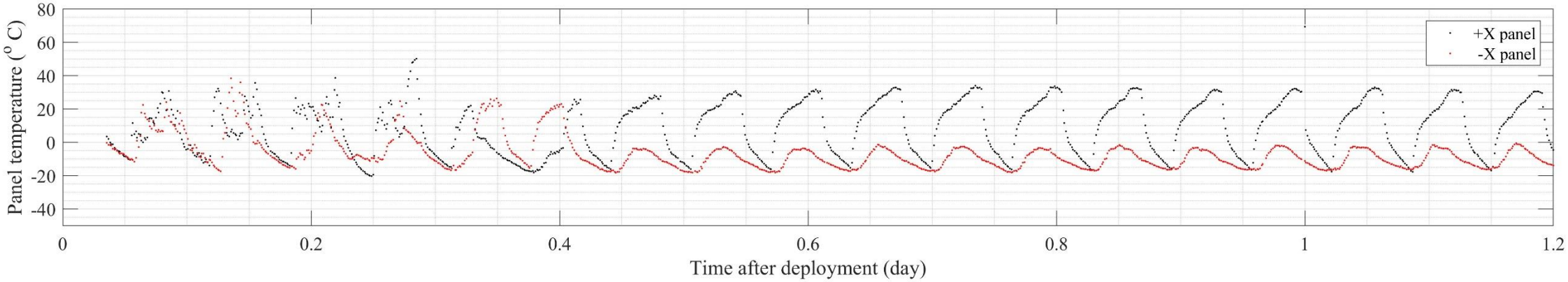


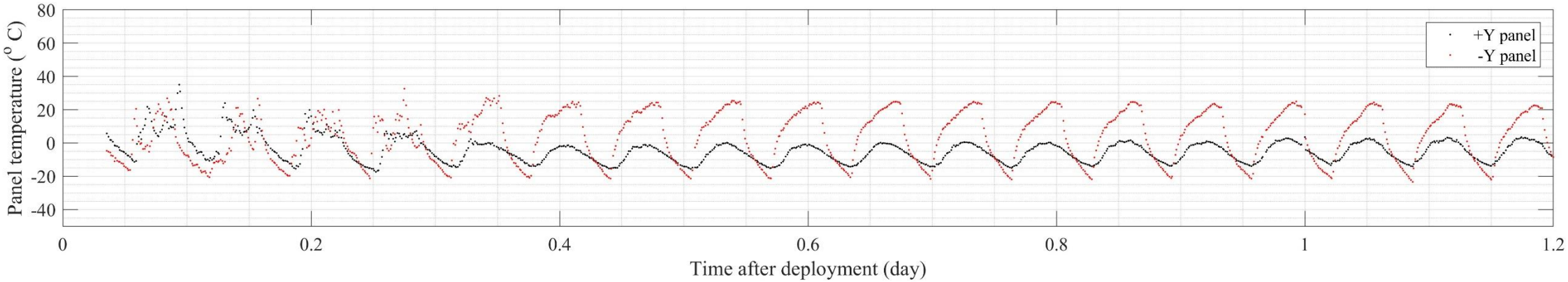


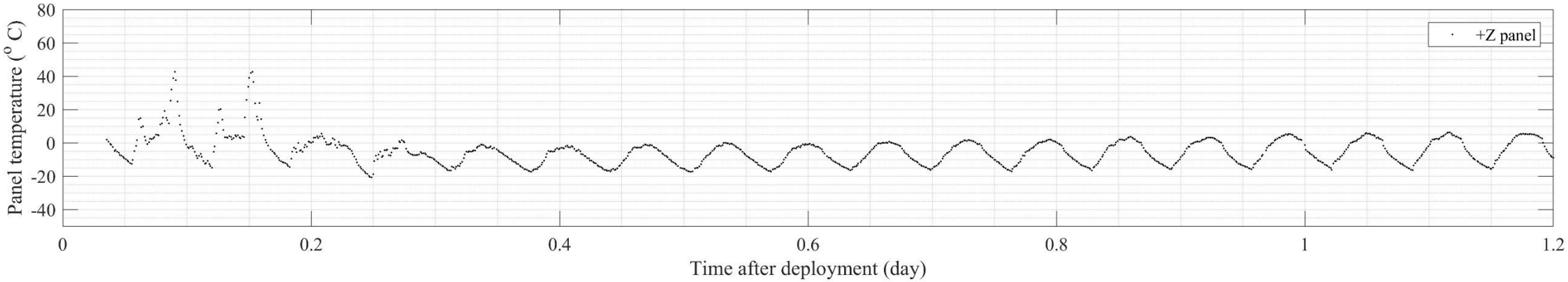
Battery capacity with charge and discharge condition



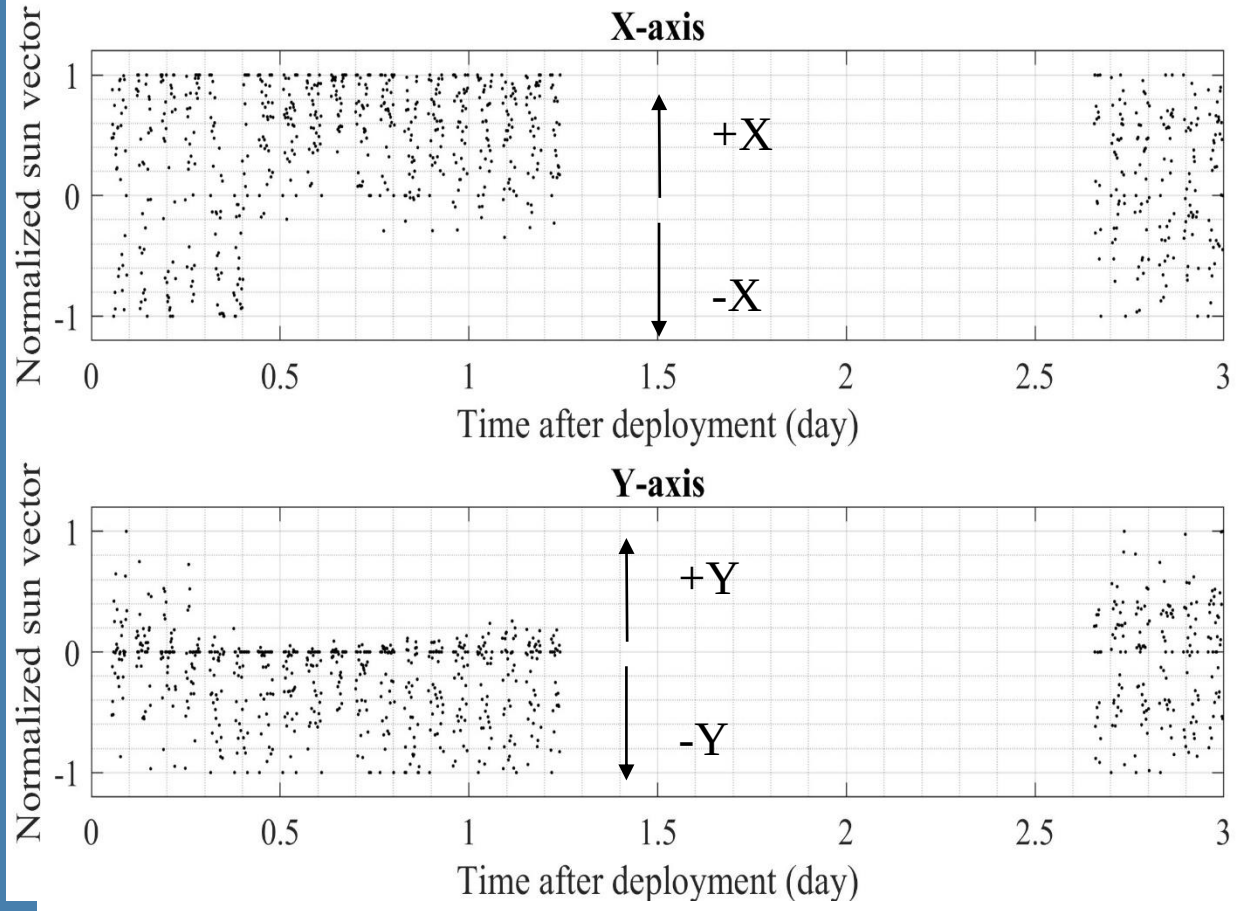
Sun-tracking (1st day operation)

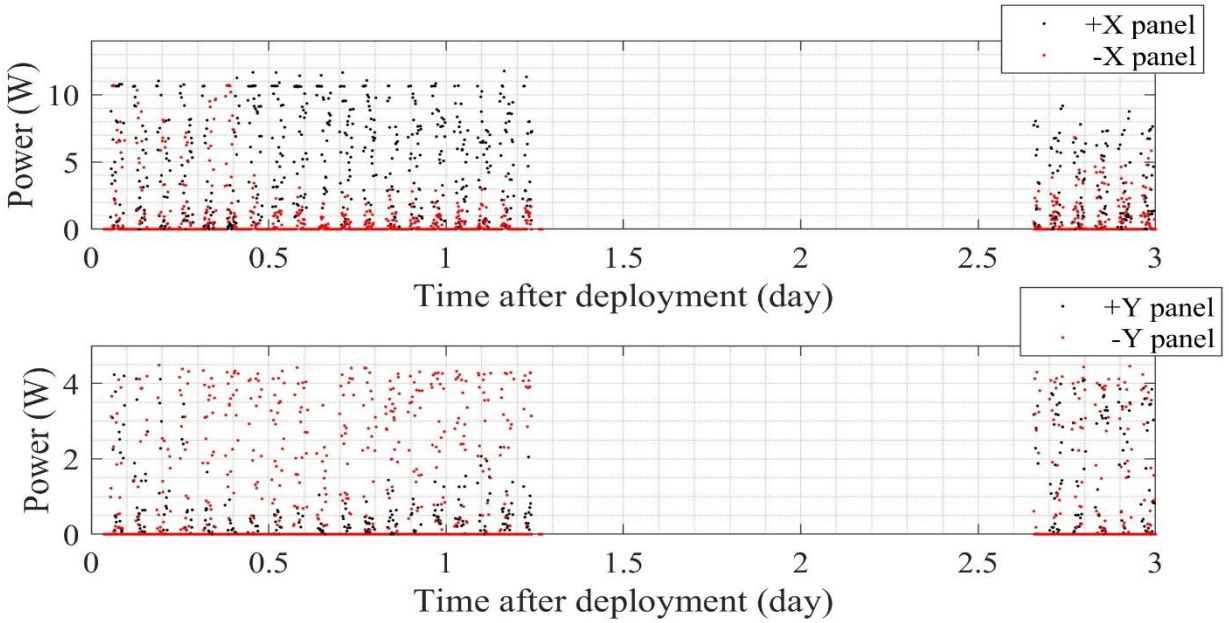






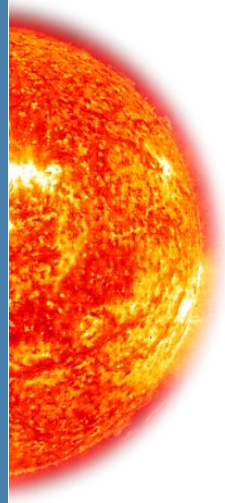
Loss of sun-tracking



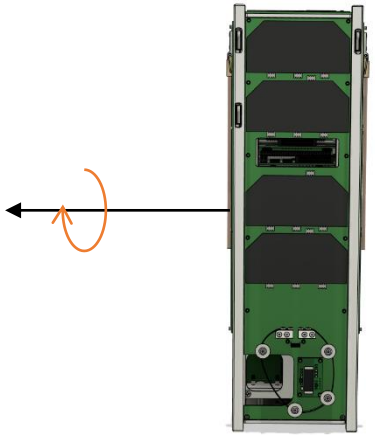


Telemetry downlink is in progress.
ADCS lost sun-tracking with 3-axis stabilization within 2nd day of the operation.

Satellite sun vector variation



Satellite temperature
is decreasing



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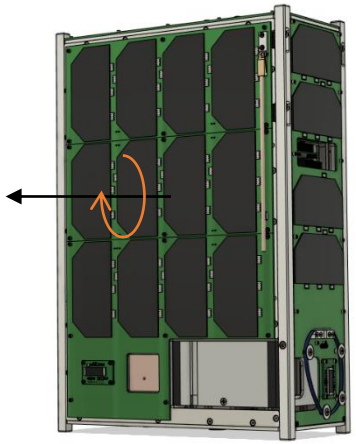

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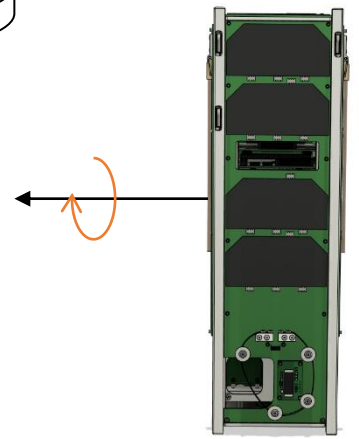
Satellite temperature
is increasing



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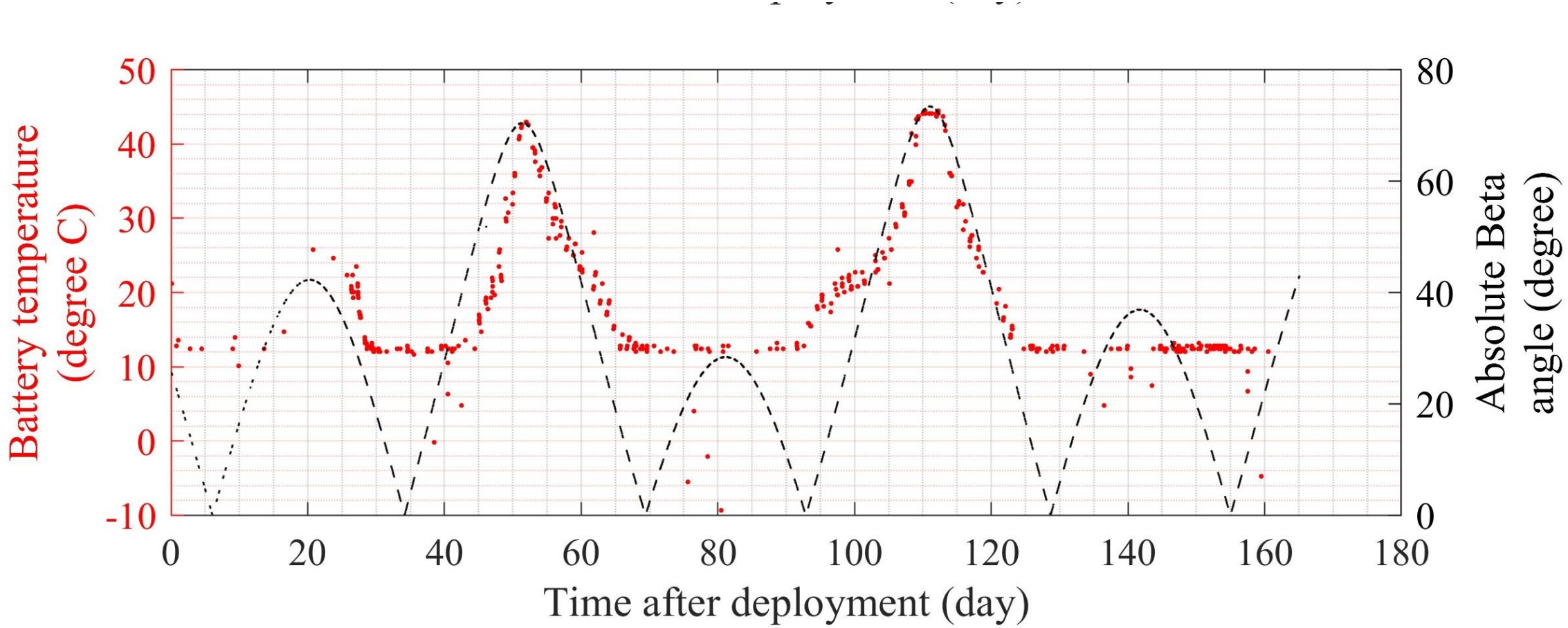
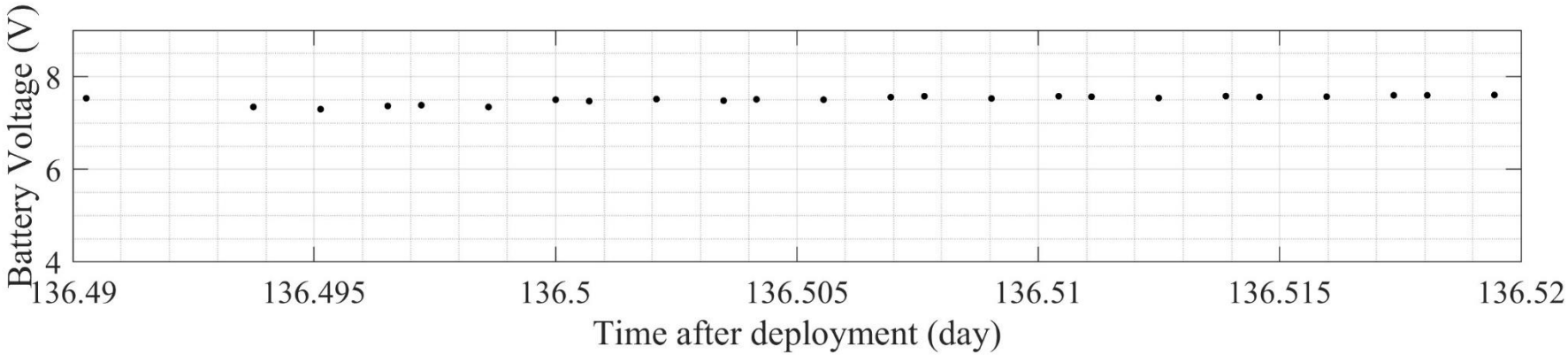
Power budget highly depends on the satellite temperature.

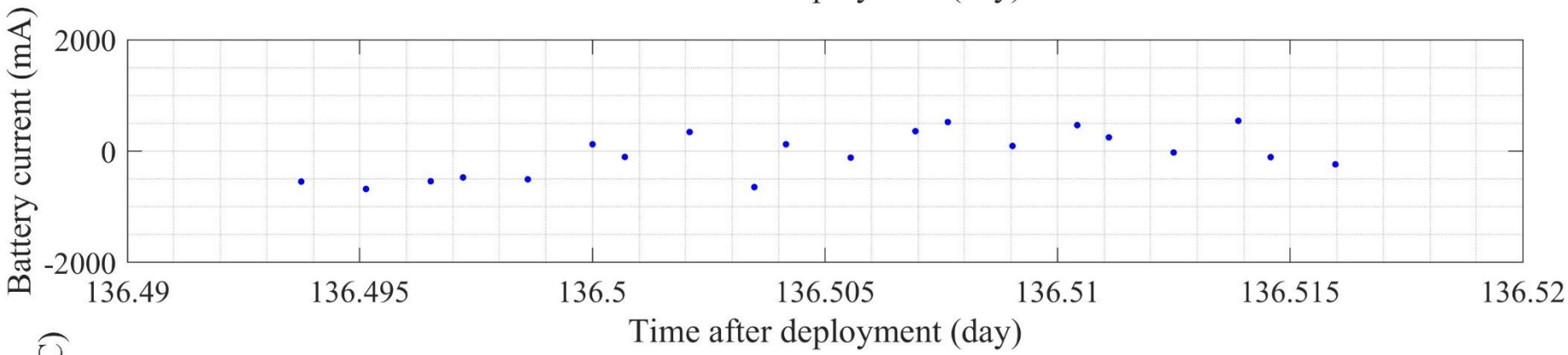
- Attitude mode effect > beta angle effect

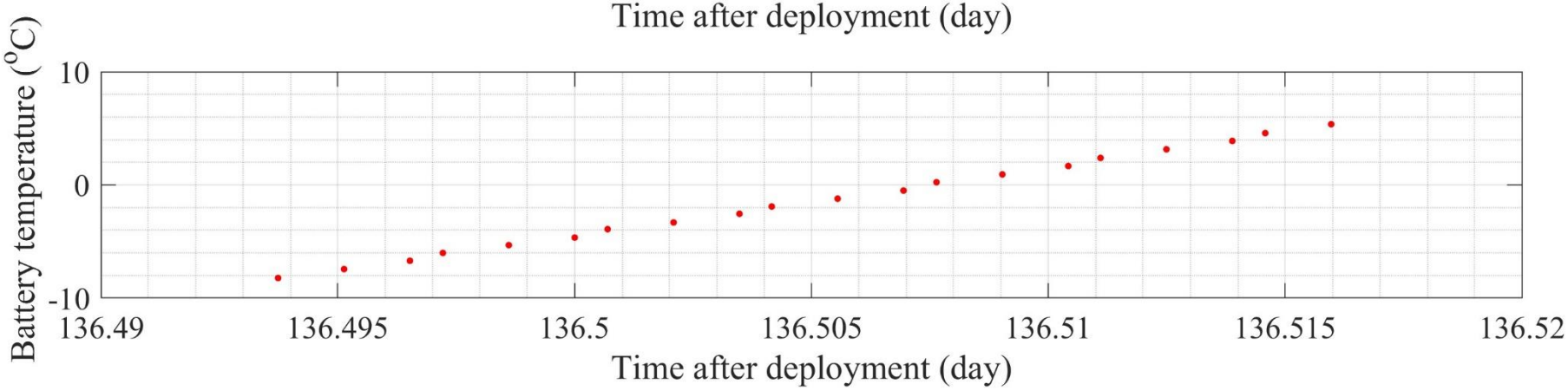
Battery temperature from CW beacon



Battery temperature recovery with heater







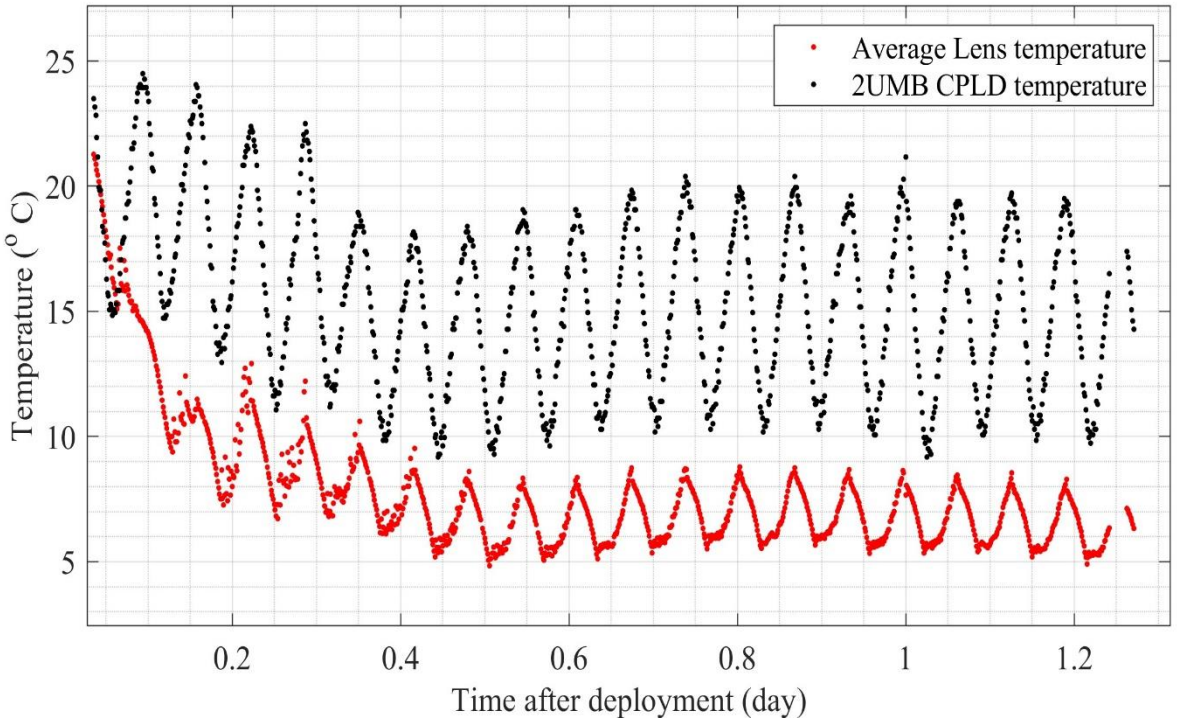
The battery heater increases the battery temperature:

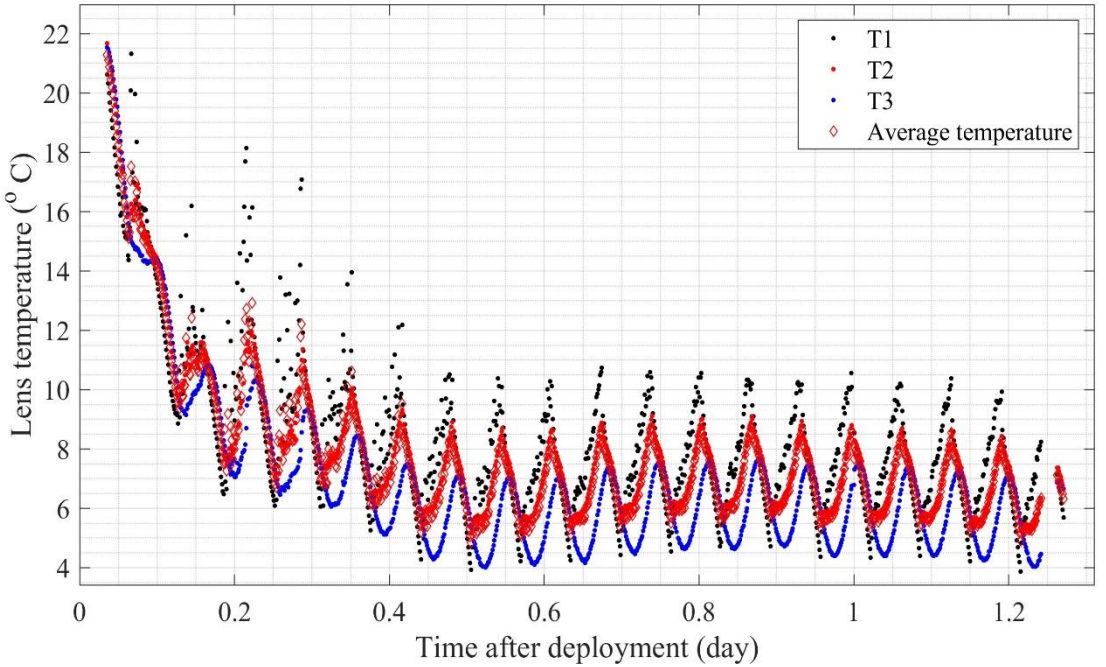
- ~25.74 degree C/hour
- ~0.43 degree C/minute

Telemetry (March 24-25, 2022)

- Beta angle = 22.0 - 25.5 degree
- ADCS mode: Deployment condition
  - Sun-tracking on +X panel
  - Detumbling mode
- Rotation speed: ~0 – 23.5 degree per second

	Min temperature (degree C)	Max temperature (degree C)
CPLD temperature	9.2	24.5
Lens sensor T1	3.9	20.6
Lens sensor T2	5.2	21.7
Lens sensor T3	4.0	21.5
Average lens temperature	4.9	21.3
Temperature difference (CPLD – average lens temp)	-2.0	11.8

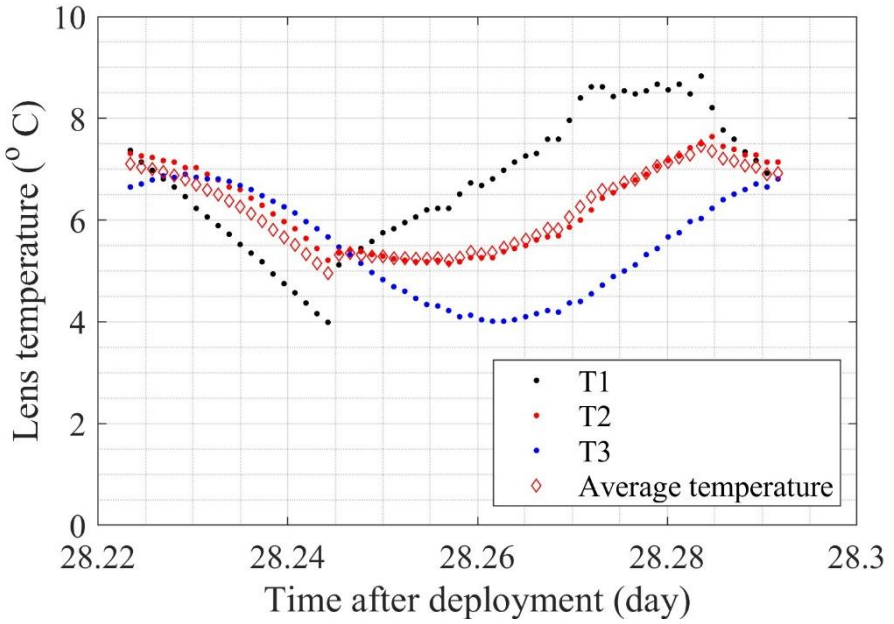


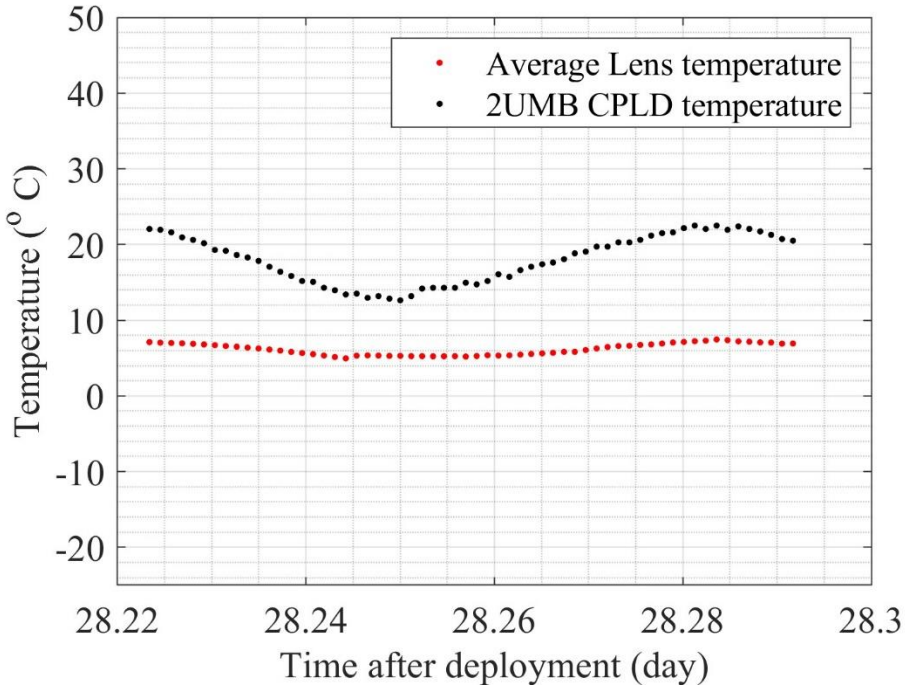


Telemetry (April 22, 2022)

- Beta angle = 25.0 degree
  - ADCS mode: Sun-tracking on +X panel
- Rotation speed: ~60 degree per second

	Min temperature (degree C)	Max temperature (degree C)
CPLD temperature	12.6	22.5
Lens sensor T1	4.0	8.8
Lens sensor T2	5.1	7.6
Lens sensor T3	4.0	6.9
Average lens temperature	5.0	7.5
Temperature difference (CPLD – average lens temp)	7.3	15.3





Mission: Main camera mission (1/4)

Sun-tracking mode

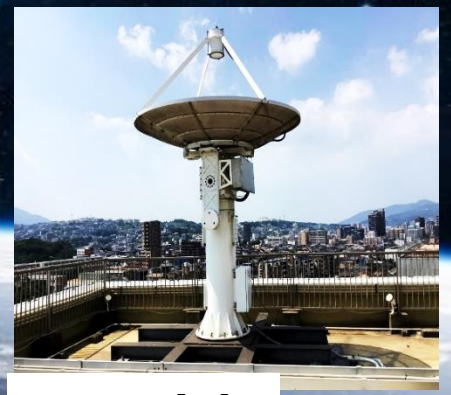
Nadir pointing

UHF uplink from amateur GS

Target pointing or nadir pointing

Amateur UHF downlink

Amateur C-band downlink



2.4 m dish

Camera Payload

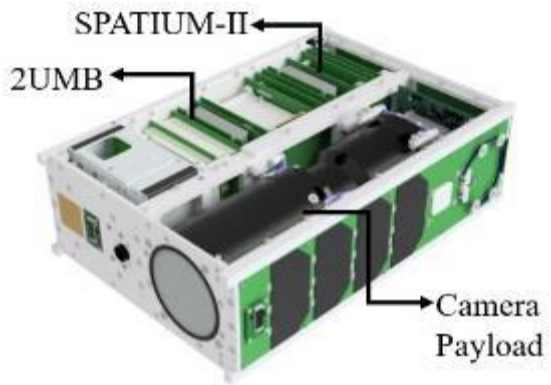
Sensor	Information
Number of pixels	31.4 million pixels
Sensor type	CMOS
Shutter method	Global shutter
Shutter speed	30 μs to 10.0 s
Interface	Ethernet
Data transmission speed	10 Mbps
Power supply	+12 V

Camera controller board	Information
Model	Customized board with Raspberry Pi compute module 3+
Operating system	GNU/Linux Ubuntu distribution version 18.04
CPU	ARMv8, 1.2GHz
Memory	32 GB (Flash), 1 GB (RAM)
Image capturing speed	**0.42** - 1.2 frames per second
Interface	Ethernet, USB, UART
Optics	
Focal length	300 mm
Temperature control	Active control and multi-layer insulator

Pattern test

Color check with various gains

Long distance target from clean room

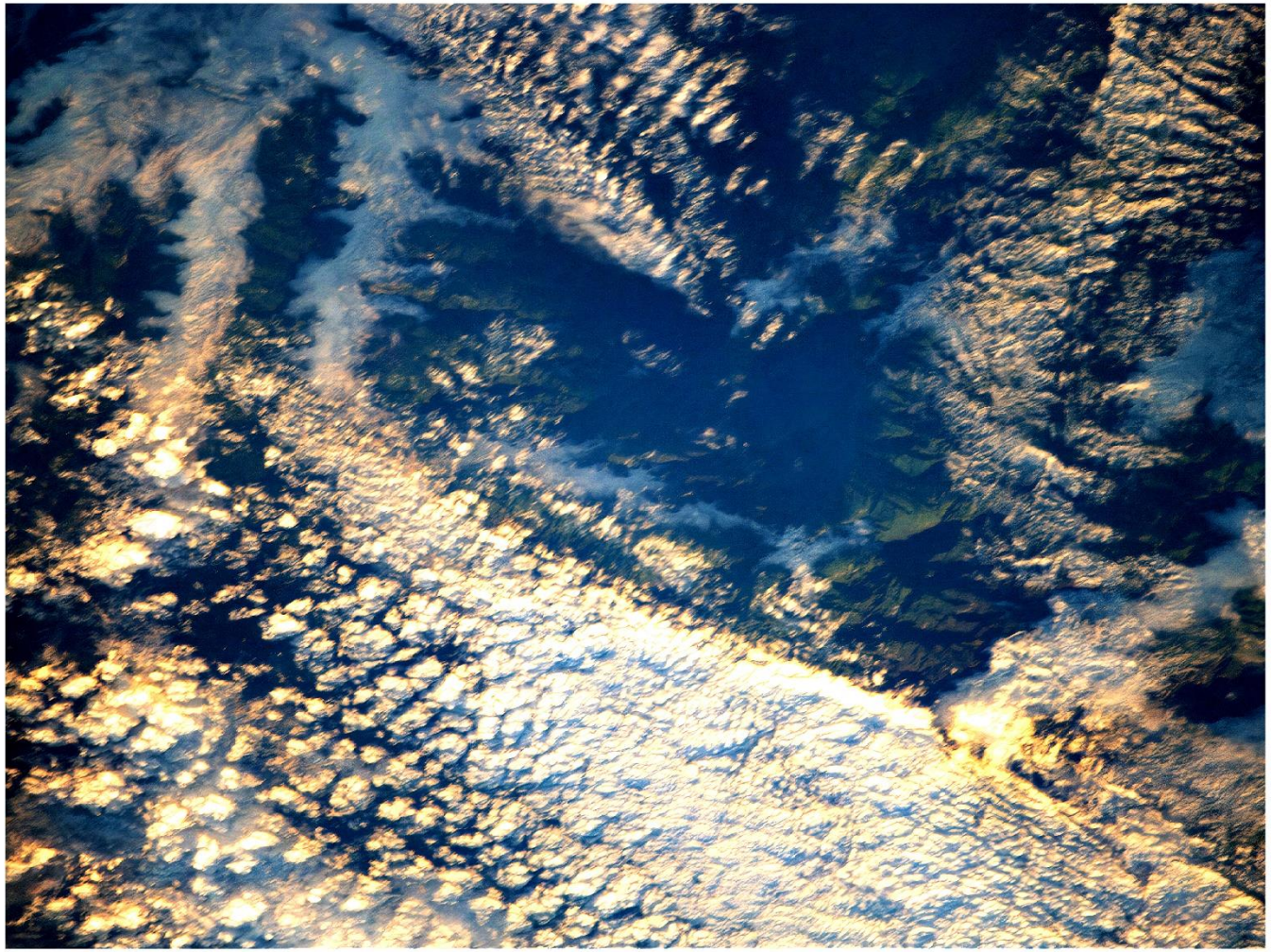


Camera Image

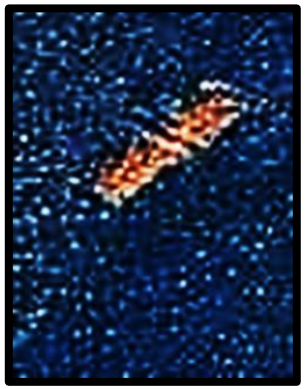
Image source: Google Maps

- The image is taken from the clean room window.
- Google maps shows approximately 4.7 km distance to the buildings in the image.

The first image downlink



Google maps



Google maps

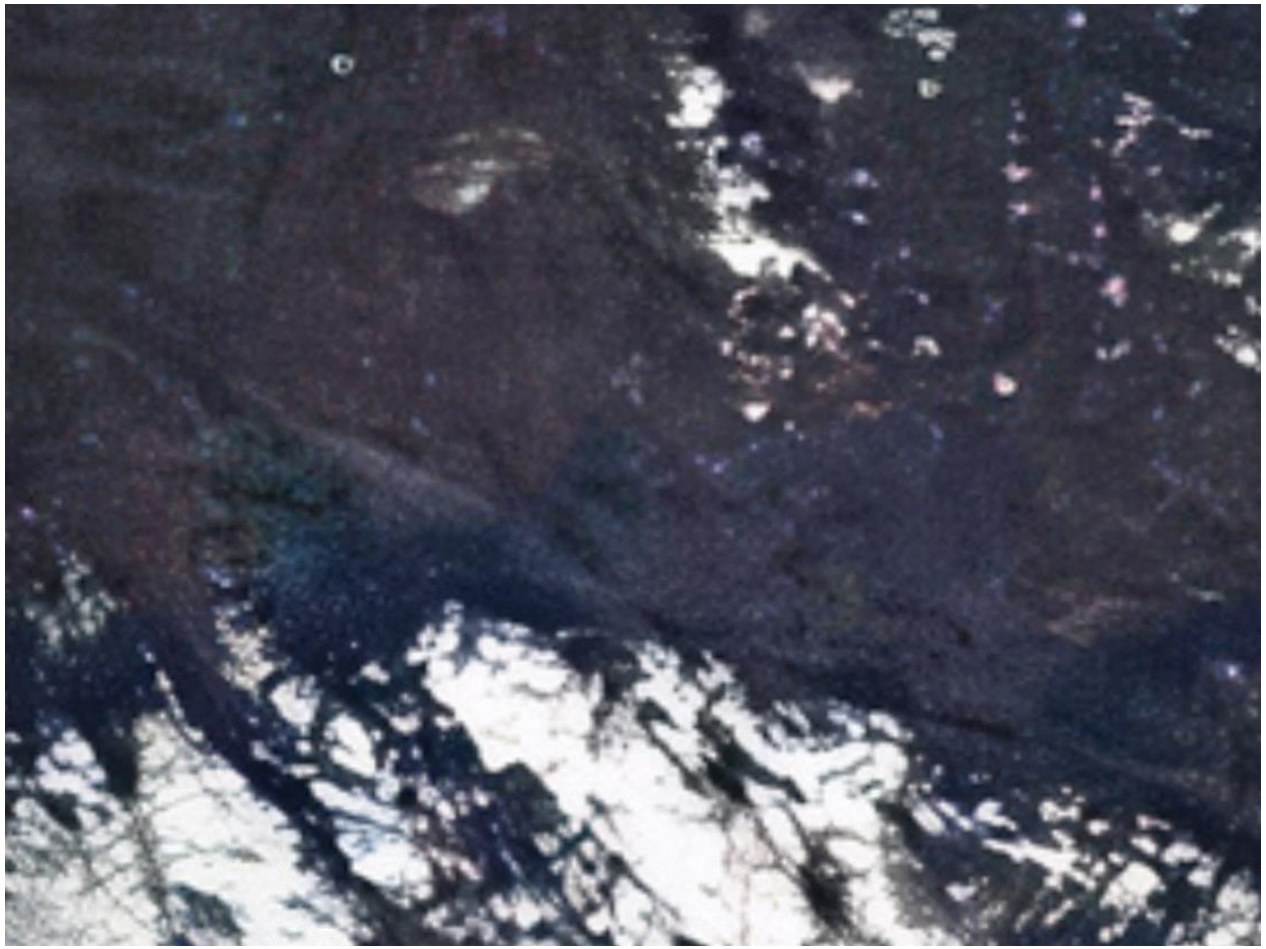
The location is still being investigated.

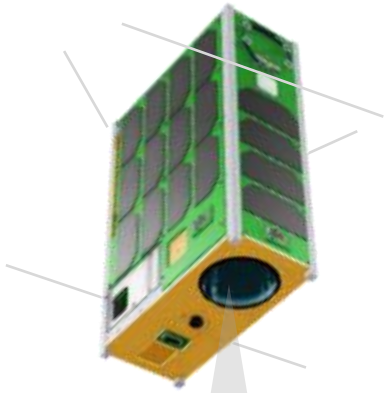
2022/6/24 20:06:23 (JST)
Daytime (13:06:23 Spain time)
39.2887, -0.5489 at Valencia (Spain)

CPLD temperature: 12.4 degree C
Lens temperature: ~0.0 degree C (estimation)

Some parts of the image look sharper.

Camera Pointing (October 2022)





Continuous nadir pointing

Capturing 6 images in a sequence

Mission: Small camera mission (2/4)

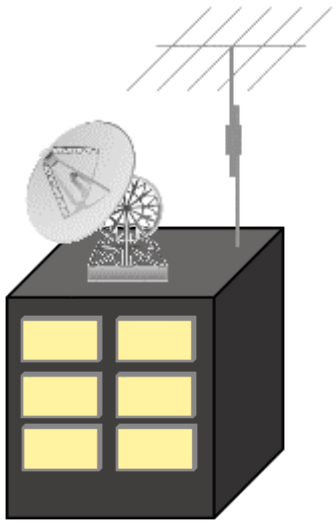
A small camera image downlinked after C-band uplink command during TVT

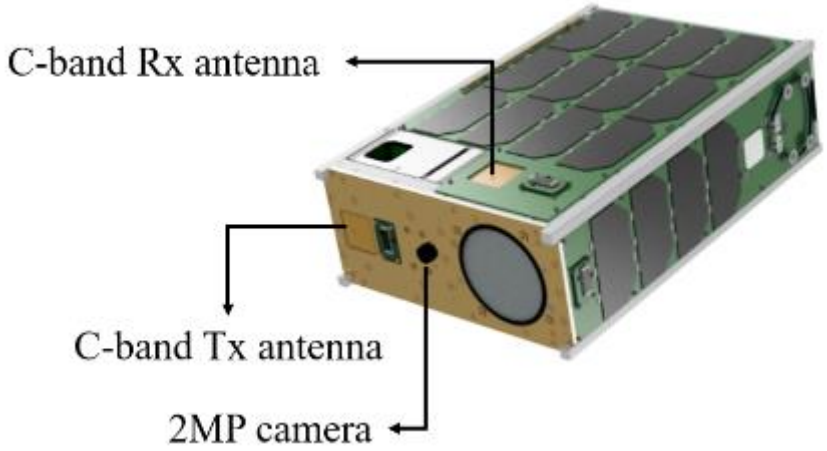
C-band Rx mode

UHF uplink from amateur GS

C-band uplink

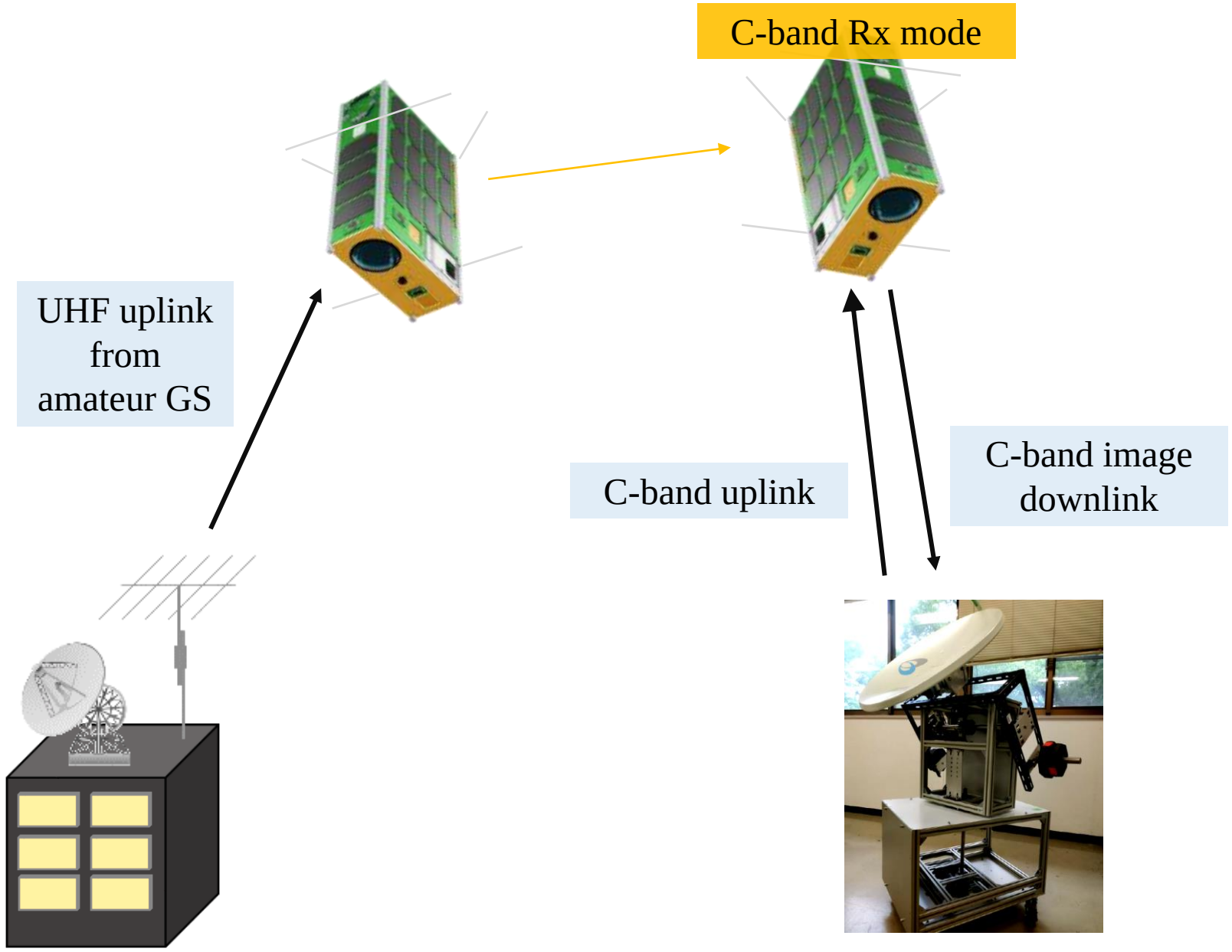
C-band image downlink

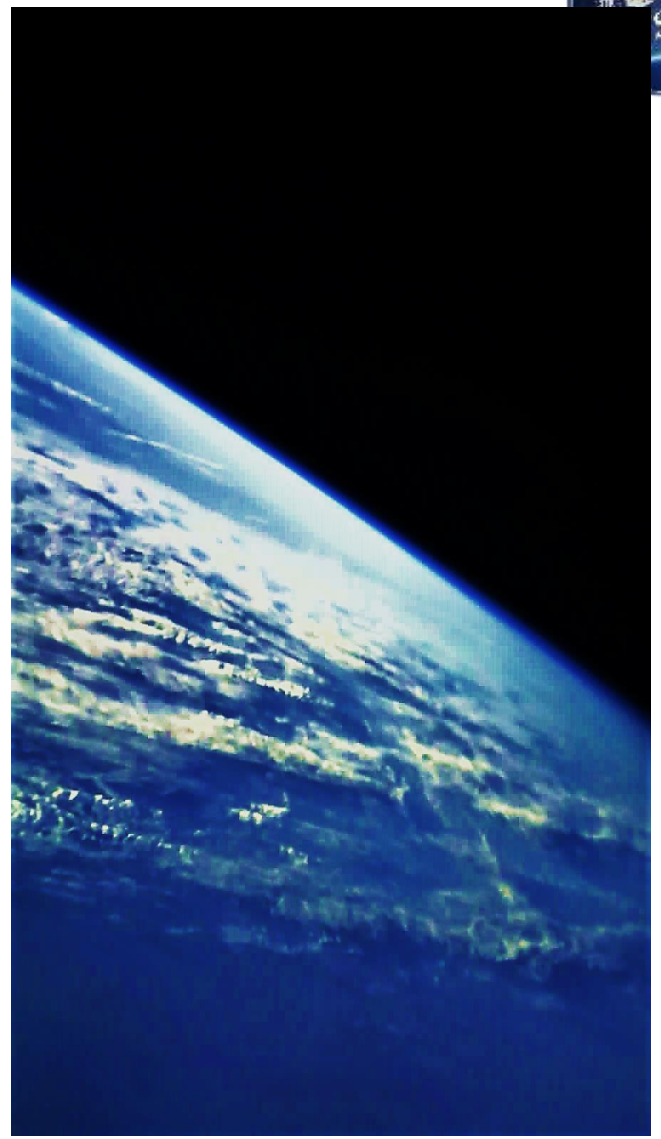




<u>Amateur radio service:</u>
Recognizing an uplink command for capturing images with the small camera and transmit to the uplink command sender.

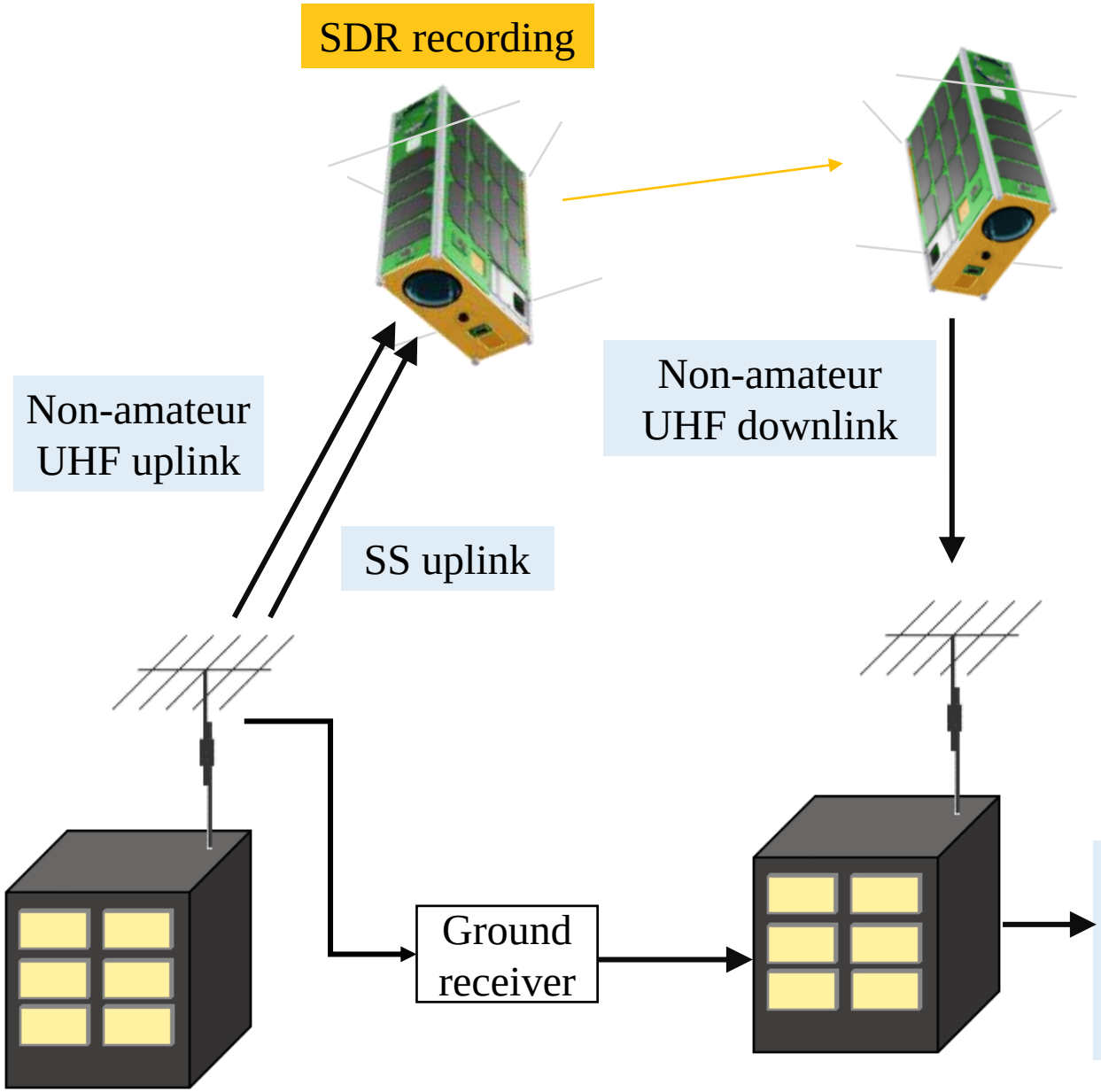
Mission: Small camera mission (2/4)

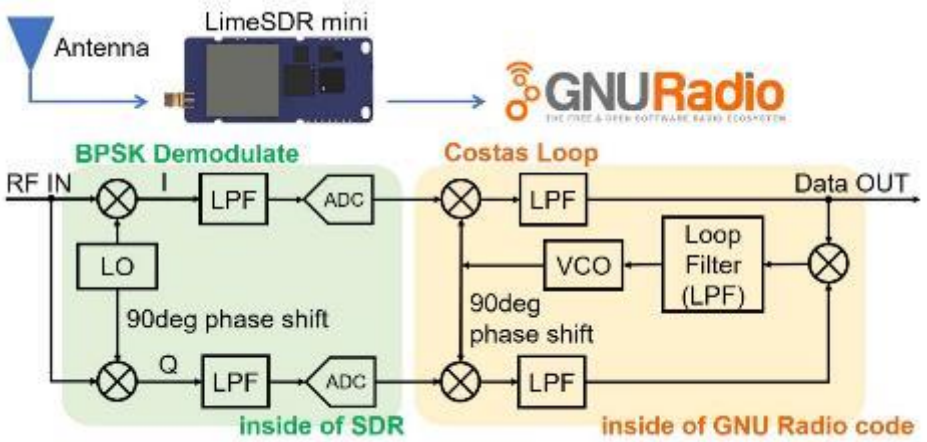




A small camera image downlinked with C-band operation

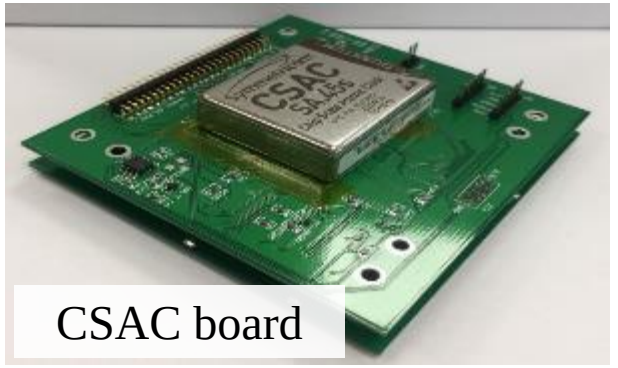
Mission: Total electron content mission (3/4)



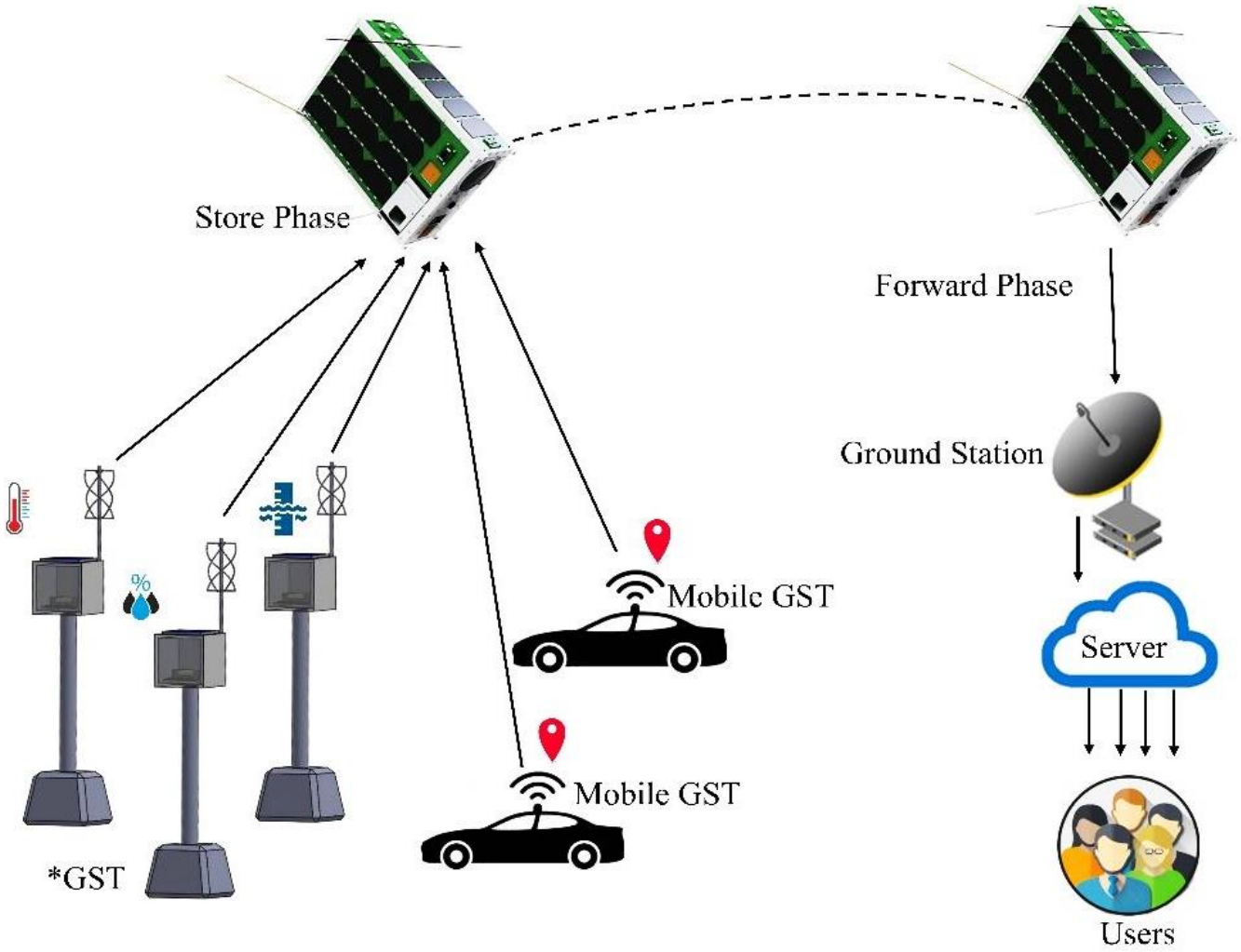


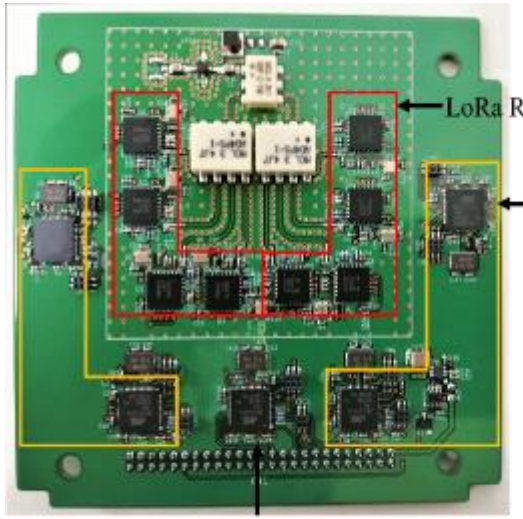
BPSK Demodulate Process at SDR and GNU Radio code

Fireant GPS receiver



Mission: Store-and-Forward (4/4)





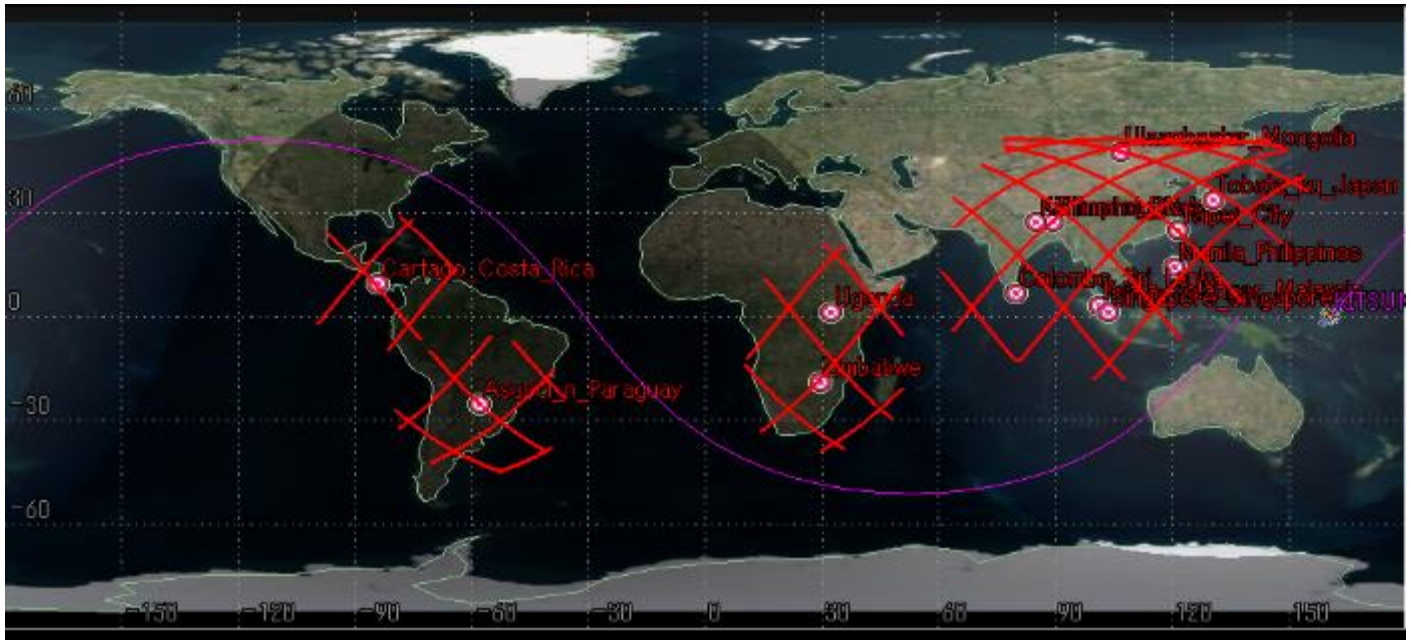
Onboard Payload design

Parameters	Values
Dimensions	90 mm x 86 mm
Power consumption	240 mA at 3.5V
Frequency range	400 MHz – 440 MHz
Receiving data rate	11 bps – 9.3 kbps
Reconfigurable spreading factor	6 – 12
Bandwidth	7.8 kHz – 125 kHz
Coding Rate	4/5 – 4/8
Number of receivers	8
Antenna type	Monopole
Maximum gain	0.3 – 0.4 dBi
Antenna return loss	-15.4 – -14.9 dB

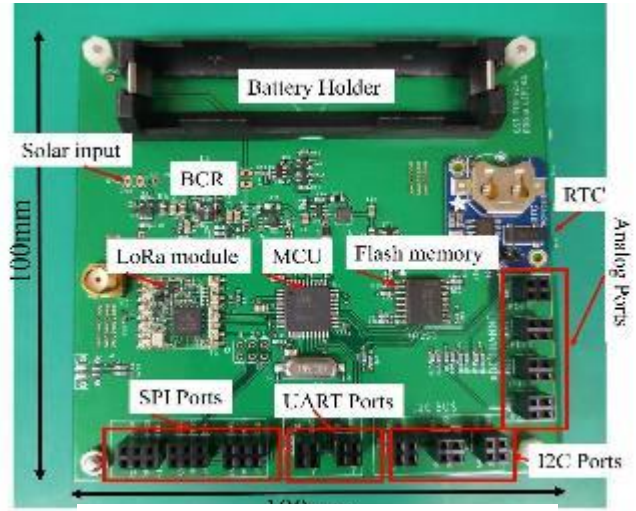
Mission: Store-and-Forward (4/4)

GST in Kyutech during field test (no RF transmission)

GSTs developed in various developing countries based on Kyutech design



Store and forward mission coverage



GST board design

Parameters	Values
Frequency range	400MHz - 440MHz
Transmit power	Up to 100mW (20dBm)
Data rate	46bps-781bps
Bandwidth	7.8kHz to 125kHz
Communication ports	I2C, SPI, UART, Analog

Approximately up to 43 KB data will be forwarded over Kyutech database daily.

Project Timeline

- Satellite hardware/software development and testing: approximately 15 months. (MDR-FRR)
- MDR date coincides with Covid-19 start.
- PDR - ΔCDR period was most influenced by campus lock-downs and state-of-emergencies.
- Frequency coordination took longer than expected.

Present Status:

- KITSUNE was launched on 19 February 2022.
- It was deployed on 24 March 2022.
- 2UMB design is already being employed in other Kyutech satellites.

Kyutech Team

Acknowledgement

- I would like to thank the KISTUNE development members and ground station operators. Without their contribution, the satellite could never be built. In addition, I would like to acknowledge the support provided by Prof. Mohammad Tariqul Islam on C-band patch antennas. The part of KITSUNE development work, especially 2UMB, C-band and camera payload was supported by Ministry of Economy, Trade and Industry. The part of SPATIUM-II TEC mission development was supported by MEXT Coordination Funds for Promoting AeroSpace Utilization; Grant Number JP000959.

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- Jose Rodrigo Cordova Alarcon
- Tharindu Lakmal Dayarathna Malmadayalage
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- Masui Hirokazu
- Mariko Teramoto
- Kentaro Kitamura
- Mengu Cho
- Dmytro Faizullin
- Kateryna Aheieva

Kyushu Institute of Technology LASEINE

QUESTIONS?